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Open Geospatial Consortium

OGC TESTBED-21: DATA QUALITY FOR INTEGRITY, PROVENANCE AND TRUST REPORT

ENGINEERING REPORT

PUBLISHED

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I EXECUTIVE SUMMARY

This Report summarizes the OGC Testbed-21 Data Quality for Integrity, Provenance, and Trust (DQ4IPT) activity, which evaluated and implemented ISO 19157-1:2023 as the primary framework for standardized data quality (DQ) reporting in Earth Observation (EO) systems. As EO data increasingly supports automated analytics and AI-driven decision-making, structured quality assessment, traceable provenance, and verifiable integrity are essential to establishing trust. Indeed, integrity, provenance, and trust (IPT) considerations are increasingly becoming a necessity in data ecosystems.

The report analyzes interoperability between ISO 19157, ISO 19115/19115-4, W3C PROV, NASA Unified Metadata Model (UMM), OGC Training Data Markup Language for AI (TrainingDML-AI) standard, and the SpatioTemporal Asset Catalog (STAC) community standard. Two DQ-enabled IPT server prototypes demonstrate delivery of satellite products metadata with embedded ISO 19157 quality reports and PROV-based lineage. The server prototypes are based on the OGC API — Processes and OGC API — Records standards respectively. A supporting software library enables metadata conversion, provenance transformation, and validation.

Results show that ISO 19157-1:2023 provides a stronger foundation for trust-enabled EO infrastructures than ISO 19115 alone, particularly through standardized measures, meta-quality, and Geospatial Data Interpretability Index (GDII) assessment, while maintaining backwards compatibility and cross-standard interoperability.

I.A. Key Achievements

- Implementation of ISO 19157-1:2023 data quality metadata in IPT frameworks
- Successful integration with NASA UMM and OGC TrainingDML-AI metadata standards
- Development of metadata conversion library supporting multiple quality standards
- Integration of ISO 19115 and ISO 19157 standards in a proposed STAC extension for liability and claims
- Integration of W3C PROV in the above mentioned STAC extension
- STAC extension liability and claims submitted as OGC Building Block to manage Data Quality, Identity, Provenance and Trust as a service
- DQ_ prefix used as an alias to non prefixed concepts.

I.B. Document and Components Delivered

- **D001**: DQ-enabled IPT Server Architecture and Requirements (this document)
- **D101**: IPT Server that implements the OGC API – Processes standard
- **D102**: IPT Server that implements the OGC API – Records standard and supports ISO 19115-4 conformant metadata
- **D103**: Metadata Conversion Software Library

I.C. Value Proposition

This work enables:

- **Data Producers**: Comprehensive quality reporting following international standards
- **Data Consumers**: Machine-readable quality metadata for fitness-for-purpose assessment
- **ML Developers**: Quality-aware training data selection via TrainingDML-AI integration
- **Achieves**: Interoperable quality metadata across NASA, ESA, and CEOS systems

II KEYWORDS

The following are keywords to be used by search engines and document catalogues.

Data quality, Identity Provenance Trust, ISO 19157, ISO 19115-4, NASA UMM, Training ML, QA4EO CEOS

III SUBMITTING ORGANIZATIONS

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- 4113 Engineering (L. Colaiacomo)
- Geoknoesis LLC (S. Fellah)
- KurrawongAI (J. Feiss)
- Secure Dimensions GmbH (A. Matheus)
- Spacebel s.a. (Y. Coene)

1 INTRODUCTION

1 INTRODUCTION

The incorporation and prioritization of the principles of **Integrity, Provenance, and Trust (IPT)** are critical for maintaining the availability, reliability, and credibility of data across various endpoints and operators. As defined in OGC Testbed-20, these principles are mutually reinforcing: **Integrity** ensures data remains unaltered and fit for purpose; **Provenance** provides the chain of custody to verify that integrity; and **Trust** is the confidence established by these assurances.

However, a prerequisite for achieving trust is the effective documentation and communication of **Data Quality**. As noted by Bugbee et al., "Incorrect or missing information may impede a user from determining the dataset's fitness for a particular engineering research question or new application."[34] This Report documents the results of the DQ4IPT task, which explored how standardized data quality reporting can be integrated into IPT frameworks to provide this essential assurance for Earth Observation (EO) data.

The integration of data quality metadata into Integrity, Provenance, and Trust (IPT) frameworks for Earth observation data requires careful selection and implementation of appropriate international standards. This Report documents the development and evaluation of data quality-enabled IPT servers based on comprehensive analysis of available data quality standards, including ISO 19157-1:2023, ISO 19115/19115-4, W3C PROV, and their interoperability with NASA UMM and OGC TrainingDML-AI.

1.1. Background

1.1.1. The Transition to Analysis Ready Data

Over the last three decades, the Earth Observation (EO) industry has undergone a fundamental paradigm shift, moving from a scarcity-driven scientific discipline to a massive-scale data utility. This evolution has been driven by the convergence of open data policies, commercial "New Space" agility, and the explosion of Artificial Intelligence. These forces collectively necessitated the creation of Analysis Ready Data (ARD), a concept for a standard that transforms satellite imagery from simple "pictures" into reliable, machine-readable measurements.

This transformation occurred in distinct phases:

- The Data Deluge: The opening of government archives (Landsat, Sentinel) and the rise of high-cadence commercial monitoring (e.g., Planet) created data volumes that manual processing could no longer handle; and
- The AI Convergence: The rise of Geospatial Foundation Models means data is now consumed primarily by algorithms rather than human analysts. These models require

"tensor-ready" consistency, necessitating strict ARD standards to ensure pixels are physically accurate and comparable over time.

1.1.2. The Challenge of Trust in Automated Systems

As EO data becomes the input for automated decision-making from algorithmic trading to defense systems, it becomes a high-value vector for "Data Poisoning" attacks. Unlike traditional vandalism, these attacks aim to weaponize the credibility of the data. For example, an adversary might subtly alter spectral signatures in ARD to hide environmental non-compliance or introduce mathematical noise to blind computer vision models (Adversarial AI).

In this context, **Integrity** is not just about error checking; it is a security control against adversarial modification. **Provenance** is the defense against "Deepfake Geography," ensuring that the chain of custody can be audited back to a trusted sensor. Consequently, Earth observation data users require confidence in the **quality**, **provenance**, and **trustworthiness** of satellite imagery and derived products

1.1.3. Implementation Gaps

Despite these emerging threats, current implementations lack standardized mechanisms for comprehensive data quality reporting that integrate with modern provenance tracking frameworks. While ARD standards address the scientific Geospatial Data Interpretability Index (GDII) of the data, The GDII is an ordinal quality index defined over a scale of 1 to 9 (or 1 to 5 for lower-resolution applications), where each level is associated with: A normative level description specifying the analytical tasks the data objectively supports at that level (analogous to NIIRS criterion text) A minimum threshold for each contributing ISO 19157 quality element they do not inherently solve the trust and security requirements of distributed systems.

Organizations implementing Integrity, Provenance, and Trust (IPT) capabilities currently face multiple specific challenges.

- Quality Standard Selection: Multiple overlapping standards exist (ISO 19115, ISO 19157, ISO 19115-4) with varying levels of comprehensiveness and adoption.
- Metadata Interoperability: There is a critical need to support NASA UMM, TrainingDML-AI, and other domain-specific metadata models alongside international standards.
- Provenance Integration: Systems face conflicting requirements for both geospatial (ISO) and semantic web (W3C PROV) provenance representations.
- Measure Standardization: There is a lack of consistent quality measure definitions across organizations, leading to ambiguity in automated reporting.
- Trust Assessment: There is a growing need for "metaquality" (quality of the quality report itself) and Geospatial Data Interpretability Index (GDII) evaluations to determine if data is fit for purpose.

This Testbed addressed these challenges by implementing and evaluating ISO 19157-1:2023 as the primary data quality framework, with full interoperability support for existing standards.

1.1.4. Foundations from OGC Testbed-20

The OGC Testbed-20 IPT activity established the initial architectural building blocks for resilient data services, demonstrating how to maintain data reliability in distributed systems where access points fluctuate. Two primary IPT server implementations were developed to secure the data lifecycle: a Federated Agile Collaborative Trusted System (FACTS) by Secure Dimensions, which utilized Smart Certificates to manage data reliability through trusted processes like "Trusted Teapot" and "Trusted Watermarking"; and a server by Spacebel that leveraged Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs) to verify the authenticity of Earth Observation (EO) data sources. These architectures were validated through nine Technology Integration Experiments (TIEs) and applied to critical scenarios, including an EO Data Supply Chain use case for verifying data origin, an EO Traceability Service for tracking product lineage, and a Situation Report use case that merged vector and raster data into validated outputs. Collectively, these efforts demonstrated how IPT principles can support cross-organizational trust without altering legacy data formats, providing the technical baseline upon which this testbed expands.

1.2. Aims

The aim of the DQ4IPT task was to develop and demonstrate a comprehensive data quality framework for IPT that:

1. **Standardizes Quality Reporting**: Implements ISO 19157-1:2023 for comprehensive, interoperable quality metadata;
2. **Enables Provenance Integration**: Maintains full compatibility with W3C PROV for semantic web applications;
3. **Supports Metadata Interoperability**: Demonstrates conversion between ISO 19157, ISO 19115, NASA UMM, and TrainingDML-AI;
4. **Provides Trust Assessment**: Implements metaquality and Geospatial Data Interpretability Index (GDII) evaluation frameworks; and
5. **Delivers Practical Implementation**: Creates reusable server components and software libraries.

1.3. Objectives

OGC Testbed-21 is a collaborative effort to rapidly prototype, design, develop, and test solutions to location-related challenges. OGC Testbed-21 is exploring the following tasks:

- Data Quality for Integrity, Provenance, and Trust (DQ4IPT);
- GEOINT Imagery Media for Intelligence, Surveillance, and Reconnaissance for OGC Testbed-21 (GIMI-T21); and
- Conformance Testing Tool Development (CTTG).

While working on the aforementioned tasks, participants collaborated to create mechanisms that improve the representation of Data Quality in Integrity, Provenance, and Trust (IPT) frameworks; facilitate the development of the GEOINT Imagery Media for Intelligence, Surveillance, and Reconnaissance (GIMI) specification; and advance the development of conformance testing tools for GIMI. The aim of the DQ4IPT task was to explore the integration of data quality considerations into IPT frameworks in such a way that users of Earth Observation data can have confidence in the data they use for analysis. The objectives of the task were therefore to:

- develop a reference architecture that integrates data quality considerations into IPT frameworks,
- demonstrate how the reference architecture can improve confidence in Earth Observation data, and
- identify the challenges likely to be encountered when adapting existing platforms to the approach proposed by the reference architecture.

The deliverables of the task include the following.

- D101 DQ-enabled IPT Server 1: An OGC API – Processes implementation, along with supporting software components, that together implement IPT capabilities. At least one of the processes offered by the API must offer outputs that include a processed image (originally collected by a satellite) and JSON-encoded ISO 19115 metadata that includes data quality reports that reference definitions of quality measures from OGC RAINBOW.[1]

Key features of the DQ-enabled IPT Server 1 include the following.

[1]OGC RAINBOW is an OGC research initiative to design an online registry providing persistent HTTP identifiers for geospatial definitions, vocabularies, and standards. It acts as a machine-readable, linked-data registry to ensure interoperability and semantic alignment across different geospatial datasets. While we use the term “OGC RAINBOW” or “RAINBOW” in this report, the initiative is in transition to a new name and focus based upon OGC member inputs. We will continue to refer to it as “OGC RAINBOW” throughout this report to avoid confusion.

- D102 DQ-enabled IPT Server 2: An OGC API – Records implementation, along with supporting software components, that together implement IPT capabilities. The metadata served by the OGC API – Records implementation must include links to JSON-encoded ISO 19115 metadata that includes data quality reports that reference definitions of quality measures from OGC RAINBOW.
- D103 DQ-enabled software library: A software library capable of accessing metadata and data quality reports from the servers implemented by Components D101 and D102, and then retrieving data from the servers. The software library must be able to convert metadata from ISO 19115-3 conformant XML documents to ISO 19115-4 (draft) conformant JSON documents. The software library must also support conversion of metadata from NASA UMM conformant JSON documents to ISO 19115-4 (draft) conformant JSON documents. Furthermore, the software library must demonstrate conversion of metadata from TrainingDML-AI JSON documents to ISO 19115-4 (draft) conformant JSON documents.
- D001 Data Quality for Integrity, Provenance and Trust Report: A report that captures all results and lessons learned.

1.3.1. Primary Objectives

The objectives of the DQ4IPT task were as follows.

1. **Implement ISO 19157-1:2023 Framework**: Develop server components using ISO 19157-1:2023 as the primary data quality standard, including:
    - All quality categories (completeness, logical consistency, positional accuracy, temporal quality, thematic quality, metaquality, Geospatial Data Interpretability Index (GDII))
    - Standardized quality measures from ISO 19157 register (https://iso19157.quality.fgi.fi/)
    - Structured evaluation methods (directInternal, directExternal, indirect)
    - Multiple result types (quantitative, conformance, descriptive, coverage)
2. **Ensure Standards Interoperability**: Demonstrate conversion and compatibility between:
    - ISO 19157-1:2023 ↔ ISO 19115/19115-4 (backward compatibility)
    - ISO 19157 ↔ NASA UMM (5/5 compatibility via ISO 19115 alignment)
    - ISO 19157 ↔ OGC TrainingDML-AI (4/5 compatibility for ML training data)
    - ISO 19157 ↔ W3C PROV (full provenance integration)

3. **Integrate Provenance and Trust**: Maintain identity and provenance compatibility across all quality frameworks:
    - W3C PROV for semantic web provenance graphs
    - ISO 19115/19157 lineage for geospatial workflows
    - Metaquality assessment for trust evaluation
4. **Validate with OGC RAINBOW**: Reference ISO 19157 registered quality measures from OGC RAINBOW catalog
5. **Develop Practical Implementations**: Create reusable server components and libraries

1.3.1.1. Deliverables

The deliverables of the task include the following.

1. **D101 DQ-enabled IPT Server 1**: An OGC API – Processes implementation, along with supporting software components, that together implement IPT capabilities. At least one of the processes offered by the API must offer outputs that include a processed image (originally collected by a satellite) and JSON-encoded ISO 19115 metadata that includes data quality reports that reference definitions of quality measures from OGC RAINBOW. Key features include:
    - Processed satellite imagery outputs
    - JSON-encoded ISO 19157-1:2023 data quality reports (RECOMMENDED)
    - Backward compatible ISO 19115/19115-4 quality reports
    - Quality measures referencing ISO 19157 register and OGC RAINBOW definitions
    - W3C PROV provenance graphs with full identity preservation
2. **D102 DQ-enabled IPT Server 2**: An OGC API – Records implementation, along with supporting software components, that together implement IPT capabilities. The metadata served by the OGC API – Records implementation must include links to JSON-encoded ISO 19115 metadata that includes data quality reports that reference definitions of quality measures from OGC RAINBOW. Key features include:
    - Metadata records with JSON-encoded ISO 19115 quality reports
    - Metadata including data quality reports

- Data quality reports that reference definitions of quality measures from OGC RAINBOW.

3. **D103 DQ-enabled software library**: A software library capable of accessing metadata and data quality reports from the servers implemented by Components D101 and D102, and then retrieving data from the servers. The software library must be able to convert metadata from ISO 19115-3 conformant XML documents to ISO 19115-4 (draft) conformant JSON documents. The software library must also support conversion of metadata from NASA UMM conformant JSON documents to ISO 19115-4 (draft) conformant JSON documents. Furthermore, the software library must demonstrate conversion of metadata from TrainingDML-AI JSON documents to ISO 19115-4 (draft) conformant JSON documents. Capabilities include:

    - Accessing ISO 19157-1:2023 and ISO 19115/19115-4 quality reports
    - Converting between ISO 19115-3 XML ↔ ISO 19157 JSON
    - Converting NASA UMM JSON → ISO 19157/ISO 19115-4 JSON
    - Converting TrainingDML-AI JSON → ISO 19157/ISO 19115-4 JSON
    - Maintaining provenance across all conversions using W3C PROV
    - Validating quality reports using JSON Schema and SHACL

4. **D001 Data Quality for Integrity, Provenance and Trust Report**: A report that captures all results and lessons learned, documenting:

    - ISO 19157-1:2023 implementation approach and results
    - Standards comparison and interoperability analysis
    - Best practices for quality-enabled IPT frameworks
    - Lessons learned and recommendations for future work

2 TOPICS

2 TOPICS

2.1. Review of Implemented Standards: Significance and Challenges

This section provides a critical evaluation of the key standards selected for the DQ4IPT architecture. It analyzes their strategic significance for Integrity, Provenance, and Trust (IPT) and documents specific implementation challenges encountered during the Testbed.

2.1.1. ISO 19157 (Geographic Information — Data Quality)

The standardization of geospatial data quality has evolved from fragmented regional efforts in the 1980s to a consolidated international framework. Initially, ISO managed data quality through three separate and interdependent specifications (ISO 19113, 19114, and 19138), but this complexity led to the 2013 unification of principles, evaluation procedures, and measures into a single document, ISO 19157:2013. This consolidation provided a unified conceptual model but remained a static document, which proved difficult to update at the pace required by modern technologies like Big Data and Artificial Intelligence.

To address these challenges, the standard was recently restructured into the modular **ISO 19157-n** series (where n is a part number), dividing the framework into specialized parts to enhance flexibility and machine readability.

- **Part 1 (General Requirements)** defines the core conceptual model and evaluation procedures, notably replacing the legacy "Geospatial Data Interpretability Index (GDII)" element with a robust extensibility mechanism.
- **Part 2 (XML Schema Implementation)** provides the technical encoding rules for machine-readable reporting.
- **Part 3 (Data Quality Measures Register)** establishes the governance for a dynamic online register, allowing new quality measures to be added and maintained without requiring a revision of the entire standard.
- **Usage in Testbed**: Utilized as the primary framework for structuring data quality reports, defining measures, and encoding results within the IPT Servers.
- **Significance for IPT**: Unlike ISO 19115, which treats quality as a metadata field, ISO 19157-1 elevates quality to a standalone model. Its introduction of **Metaquality** (the quality of the quality report itself) and **completeness** (measures the presence and absence of features, their attributes, and relationships in a dataset compared to what should be

present according to specifications) is critical for establishing *Trust*, as it allows users to quantitatively assess the reliability of the quality claims.

- **Limitations & Challenges**
  - **Lack of JSON Schema**: The standard officially supports XML. Developing a robust, non-normative JSON schema for modern REST APIs was a primary engineering hurdle for this Testbed.
  - **ML Gap**: The standard lacks native measure codes for Machine Learning concepts (e.g., Class Imbalance, Label Noise), requiring custom extensions.
  - **Complexity**: The nested structure of evaluations (Direct/Indirect) and result types creates a high barrier to entry for developers compared to simpler models.

2.2. ISO 19115 Series (Geographic Information — Metadata)

The standardization of geospatial metadata began with the ISO 19115 series, which established the core conceptual models for describing geographic information. While the conceptual fundamentals were refined in ISO 19115-1:2014, the industry historically relied on the ISO/TS 19139 Technical Specification to provide the concrete XML encoding needed for actual data exchange. This "ISO XML" format became the backbone of global interoperability, eventually evolving into ISO 19115-3 to support newer data models, yet legacy 19139 implementations remain dominant in many operational archives.

Today, the industry is transitioning from these monolithic XML encodings toward lighter, web-friendly formats to align with modern architectural patterns. The emerging ISO 19115-4 standard addresses this shift by defining a standardized JSON encoding for the ISO 19115-1 conceptual model, bridging the gap between rigorous geospatial semantics and modern REST APIs. This evolution is critical for ensuring that high-fidelity metadata can be seamlessly consumed by cloud-native systems and OGC API implementations without the overhead of traditional XML parsing.

The series currently consists of the following key parts relevant to Data Quality integration.

- **ISO 19115-1:2014**: Geographic information — Metadata — Part 1: Fundamentals (Conceptual Model)
- **ISO 19115-2:2019**: Geographic information — Metadata — Part 2: Extensions for acquisition and processing (Critical for EO imagery lineage)
- **ISO 19115-3:2016**: Geographic information — Metadata — Part 3: XML schema implementation for fundamental concepts

- **ISO 19115-4 (Draft)**: Geographic information — Metadata — Part 4: JSON schema implementation of metadata fundamentals
- **Usage in Testbed**: Utilized as the primary "host" structure for embedding data quality reports. The Testbed demonstrated backward compatibility by mapping modern ISO 19157-1 quality elements into legacy ISO 19115-1 metadata records, ensuring older catalogs can still serve trust-enabled data.
- **Significance for IPT**: ISO 19115 provides the **Provenance Context** (Lineage). While ISO 19157 defines **quality**, ISO 19115's `LI_Lineage` class defines the processing history (steps and sources) that led to that quality state. Without this lineage, a user cannot verify **why** a dataset has a specific quality level, making it essential for the "Provenance" pillar of IPT.
- **Limitations & Challenges**:
  - **Complexity vs. Agility**: The full ISO 19115 model is massive and deeply nested, often leading to "profile fatigue" where different organizations implement incompatible subsets.
  - **Encoding Lag**: The industry is shifting rapidly to JSON, but the normative XML encoding (ISO 19115-3) remains dominant in legacy systems. The Testbed highlighted the urgent need for a stable ISO 19115-4 JSON schema to bridge this gap for modern REST APIs.

2.2.1. OGC SpatioTemporal Asset Catalog (STAC)

The SpatioTemporal Asset Catalog (STAC) specification originated in October 2017 at a collaborative code sprint in Boulder, Colorado, convened by the Radiant Earth Foundation to address the fragmentation of geospatial data discovery. Bringing together developers from 14 major organizations—including Planet, Development Seed, Google, and Element84, the initiative aimed to replace the bespoke API structures used by different satellite providers with a unified standard. This collaborative effort was driven by the need to make geospatial assets easily indexable and searchable across different platforms without requiring developers to write custom code for every dataset.

Central to the standard's design was a "static first" and "cloud-native" philosophy, which allowed catalogs to exist as simple, crawlable linked JSON files on cloud storage. Crucially, the dynamic STAC API was architected as a compliant implementation of **OGC API — Features,** ensuring that every STAC Item is accessible as a standard OGC Feature . This alignment allows standard geospatial clients (like QGIS) to consume STAC catalogs out of the box. Following a series of iterative development sprints, STAC Version 1.0.0 was released in May 2021, and the standard is now formally transitioning its intellectual property to the Open Geospatial Consortium (OGC) to ensure long-term stability and deep integration with the OGC API ecosystem.

- **Usage in Testbed**: Implemented as the primary delivery mechanism for the IPT Servers. The Testbed utilized the STAC Liability and Claims Extension to embed ISO 19157-1 quality reports and W3C PROV lineage directly into STAC Items, making trust data immediately accessible to cloud-native clients.

- **Significance for IPT**: STAC enables accessibility for trust data. By placing quality and provenance metadata directly in the JSON file alongside the data links (assets), STAC ensures that a user or algorithm cannot access the data without also seeing its "Trust Scorecard." This tight coupling prevents the "detached metadata" problem common in older XML-based systems.

- **Alignment with CEOS-ARD (Incomplete)**: A critical emerging area is the alignment with **CEOS Analysis Ready Data (ARD)** standards. While STAC provides the structure for discovery, CEOS-ARD defines the rigorous processing and quality thresholds required for scientific analysis. Work is currently underway to develop a dedicated **STAC CEOS-ARD Extension** that maps these quality parameters (such as geometric accuracy and radiometric calibration) directly into STAC Items. This extension remains a work in progress, representing a significant gap in the current ecosystem: until it is finalized, identifying truly "Analysis Ready" data via standard STAC queries relies on ad-hoc metadata fields rather than a certified, interoperable standard

- **Limitations & Challenges**:

    - **Extension Maturity**: While the core STAC specification is stable, complex IPT features rely on extensions (like the Liability and Claims Extension) that are still evolving, requiring careful version management.

    - **Granularity Management**: Applying rigorous cryptographic signatures (Integrity) to highly dynamic STAC catalogs can introduce latency, requiring a balance between real-time indexing and static verification.

2.2.2. OGC Immutable SpatioTemporal Asset Catalog (STAC)

The **Immutable** SpatioTemporal Asset Catalog (STAC) is a compliant implementation where the metadata records (STAC Items) are stored on a public permissioned blockchain (Hyperledger Fabric). The Testbed-21 implementation supports the regular STAC API and data format which ensures interoperability with existing implementations. To create a STAC Item onto the blockchain, aka into the Immutable Catalog, a RESTful API was implemented. The API interacts with the immutable catalog Hyperledger Fabric chaincode which ensures immutability by only allowing a get (HTTP GET), create (HTTP PUT/POST) , and delete (HTTP DELETE) of STAC Items. The API supports the creation of a single STAC Item via HTTP PUT and a bulk creation by POSTing an array of STAC Items. The API is asynchronous to ensure optimal performance when interacting with the blockchain. This asynchronous behavior introduces a latency between the actual create request and the availability on the Immutable Catalog.

By introducing a metadata storage on the blockchain, there is no need to store Verifiable Credentials, as the blockchain entries are immutable by definition and can always be verified to be trustworthy. However, to achieve a local storage of an immutable STAC Item, one export mechanism could be based on using W3C Verifiable Credentials.

- **Usage in Testbed**: The Immutable SpatioTemporal Asset Catalog is used by the IPT-Server 1 for storing the data quality and provenance enriched metadata. A STAC Browser is deployed to visualize the STAC API in a common way.

- **Performance**: In order to understand the performance implications of a blockchain-anchored catalog, approximately. 4.8 Million records from the ESA Sentinel-2 catalog were cloned. The `Immutable Catalog with ESA Sentinel-2 records` can also be searched via spatio-temporal queries.

The following results were measured on a Virtual Server environment with 8 vCPU, 16GB RAM and SSD:

- fetch 1000 items with 10 parallel queries: 150ms
- fetch 1000 items with BBOX filter and 10 parallel queries: 150ms
- fetch 1000 items with TEMPORAL filter and 10 parallel queries: 2000ms
- fetch 1000 items with BBOX and TEMPORAL filter and 10 parallel queries: 1700ms

2.2.3. W3C Verifiable Credentials (VC)

The **Verifiable Credentials (VC)** standard is a core component of the W3C's decentralized identity stack, designed to express credentials on the web in a way that is cryptographically secure, privacy-respecting, and machine-verifiable. Analogous to a digital version of a physical passport or university degree, a VC allows an **Issuer** to assert claims about a **Subject**, which a **Holder** can then present to a **Verifier**. This model decouples the verification process from the issuer's direct involvement, enabling scalable, offline-capable trust architectures.

- **Usage in Testbed**: Used as the cryptographic "wrapper" to package ISO 19157 quality reports and EO products, ensuring tamper-evidence during transport.
- **Significance for IPT**: VCs provide the **Integrity** layer that scientific formats (like GeoTIFF or JSON) lack. They allow data to be digitally signed by an Issuer (e.g., ESA, USGS) so that any modification by an intermediary invalidates the credential, preventing "Man-in-the-Middle" or "Data Poisoning" attacks.
- **Limitations & Challenges**
  - **Payload Overhead**: Wrapping granular granule-level metadata in VCs significantly increases file sizes and processing latency.
  - **Resolver Maturity**: The ecosystem of DID Resolvers is fragmented. Universal Resolvers often failed to handle specific DID methods (e.g., `did:web` vs `did:indy`) consistently during interoperability experiments.

2.2.4. W3C PROV-O / PROV-JSON

The **W3C PROV** family of specifications provides a generic, cross-domain foundation for provenance interchange on the Web. Developed to enable the interoperable exchange of provenance information in heterogeneous environments, PROV defines a core data model built around **Entities** (physical, digital, or conceptual things), **Activities** (dynamic processes

that generate or use entities), and **Agents** (parties responsible for activities). This model allows systems to capture the "who, what, where, when, and how" of data generation in a way that transcends specific application domains.

- **Usage in Testbed**: Implemented to map ISO 19115 `LI_Lineage` steps into a semantic graph format that tracks the processing history of data.
- **Significance for IPT**: PROV provides **Provenance** interoperability beyond the geospatial domain. By using PROV, the lineage of a satellite image becomes queryable by general-purpose semantic web tools (via SPARQL), allowing non-geospatial systems to audit the "chain of custody".
- **Limitations & Challenges**
  - **Granularity Mismatch**: Mapping the rigid, step-by-step structure of ISO `LI_ProcessStep` to the flexible graph structure of PROV `Activity` requires careful semantic alignment to avoid losing detail.
  - **Verbosity**: PROV-JSON representations can become extremely verbose for complex processing chains, impacting API performance.

2.2.5. OGC TrainingDML-AI

As Artificial Intelligence (AI) becomes central to Earth Observation, the quality of the training data itself—not just the imagery—has become a critical concern. The OGC Training Data Markup Language for Artificial Intelligence **TrainingDML-AI** is an OGC Standard designed to address this gap by defining a conceptual model and encoding for documenting high-quality training datasets. It standardizes how to describe the provenance, quality, and characteristics of training samples, ensuring that Machine Learning models are trained on reliable, well-understood data.

- **Usage in Testbed**: Used to describe the quality of training datasets for Machine Learning models, specifically for the AI/ML use cases.
- **Significance for IPT**: As automated systems increasingly rely on AI, the quality of *training data* becomes a security issue. TrainingDML-AI provides the specific metrics (IoU, F1 Score) needed to trust an AI model's output.
- **Limitations & Challenges**
  - **ISO Interoperability**: There is a "semantic friction" between TrainingDML-AI and ISO 19157. While 4/5 of concepts map cleanly, AI-specific statistical metrics do not have direct equivalents in the ISO measure registry, necessitating the use of generic `DescriptiveResult` fields which reduces machine-interpretability.

2.2.6. W3C Decentralized Identifiers (DID)

Decentralized Identifiers (DIDs) are a new type of globally unique identifier standardized by the W3C. Unlike traditional identifiers (like URLs or email addresses) that are controlled by a central

registry, DIDs are designed to be decoupled from centralized authorities, allowing the owner to prove control over the identifier using cryptographic proofs. A DID resolves to a **DID Document**, which contains the public keys and service endpoints necessary to initiate trusted interactions, forming the foundational identity layer for Self-Sovereign Identity (SSI) architectures.

- **Usage in Testbed**: Employed to assign persistent, cryptographically verifiable identifiers to two distinct classes of entities: **Organizations** (e.g., Data Providers, Catalogs) and **Resources** (e.g., EO Collections and individual Granules). The testbed primarily utilized the `did:web` method for ease of deployment, while also experimenting with ledger-based methods like `did:indy`.
- **Significance for IPT**: DIDs are the foundational **Trust Anchor** of the architecture. By decoupling identity from physical location (server URL), DIDs allow users to verify the *origin* of a dataset regardless of where it is currently stored. This enables a "Self-Sovereign Identity" (SSI) model where data providers control their own verification keys, preventing "vendor lock-in" for trust services.
- **Limitations & Challenges**
  - **Method Fragmentation**: The lack of a truly universal resolver was a significant hurdle. Interoperability experiments (TIEs) revealed friction between different DID methods (e.g., `did:web` vs. `did:indy`) and key formats. For instance, the FACTS ecosystem could process keys in `publicKeyBase58` format but failed with `publicKeyJwk`, limiting cross-component verification.
  - **Resolver Maturity**: To be highlighted that "none of the available DID resolvers offer the level of universality… expected from a production-grade solution," creating a fragility in the verification chain.
  - **Granularity vs. Scale**: Assigning a unique DID to every single satellite image granule (product) creates a massive management overhead for DID Documents, raising questions about the scalability of this approach for petabyte-scale archives.

2.3. Data Quality Standards for Integrity, Provenance, and Trust

Implementing trustworthy IPT frameworks for Earth observation data requires selecting and properly integrating international data quality standards. This section analyzes the available standards and recommends an implementation approach based on comprehensive testing and interoperability analysis.

2.3.1. ISO 19157-1:2023 vs ISO 19115/19115-4: Standards Comparison

Two primary ISO standards address data quality for geographic information.

ISO 19115-1:2014 / ISO 19115-4 (draft): Metadata standards that include basic quality elements as part of general metadata structures. ISO 19115-4 provides a JSON encoding for the ISO 19115-1 metadata model, thus offering a JSON alternative to the ISO 19115-3 and ISO 19157-1 XML schemas.

ISO 19157-1:2023: Dedicated data quality standard providing comprehensive framework specifically designed for quality assessment and reporting.

The following table compares the two standards based on implementation testing in STAC liability claims extension:

Table 1 — ISO 19157-1:2023 vs ISO 19115/19115-4 Comparison

FEATURE	ISO 19115/19115-4	ISO 19157-1:2023
Quality Categories	5 basic categories (completeness, consistency, positional accuracy, temporal accuracy, thematic accuracy)	7 comprehensive categories including **metaquality** (confidence, representativity, homogeneity) and **completeness**
Quality Measures	Generic measure descriptions, no standardization	**Standardized measures** with persistent codes (e.g., Measure 28 = "Mean value of positional uncertainties")
Evaluation Methods	Limited method specification	Explicit method types: **directInternal**, **directExternal**, **indirect**
Result Types	Basic conformance/quantitative	4 comprehensive result types: **quantitative**, **conformance**, **descriptive**, **coverage**
Lineage	Basic processStep elements	Enhanced lineage with **LE_ProcessStep**, **LE_Source**, LE_ProcessSteps with LE_Processing, LE_ProcessStepReport and LE_ProcessParameter and LE_Source from ISO 19115-2:2019
Trust Assessment	None	**Metaquality** for quality-of-quality assessment, **confidence** levels
Measure Registry	No registry	ISO 19157 registry at https://schemas.isotc211.org/19157/-/dqm/1.2.0/
completeness	Not addressed	ISO 19157-1:2023 now defines a proper extensibility mechanism in compliance with ISO 19115-1:2014, which ensures addition of new quality elements.

FEATURE	ISO 19115/19115-4	ISO 19157-1:2023
Backward Compatibility	N/A	**100% compatible** — all ISO 19115 quality can map to ISO 19157

Recommendation: Implement **ISO 19157-1:2023 as primary standard** while maintaining ISO 19115/19115-4 backward compatibility through conversion libraries. ISO 19157 provides superior capabilities for IPT frameworks requiring trust assessment through metaquality and persistent measure codes for consistent cross-organization reporting.

2.3.2. W3C PROV Provenance Integration

Both ISO standards require integration with W3C PROV for semantic web provenance tracking. Testing demonstrates **full compatibility** between ISO 19157/19115 lineage and W3C PROV:

Table 2 — ISO Lineage to W3C PROV Mapping

ISO CONCEPT	W3C PROV CONCEPT	ALIGNMENT
`LI_Lineage`	`prov:Activity` graph	Lineage encompasses provenance activities
`LI_ProcessStep`	`prov:Activity`	Direct 1:1 mapping
`LI_Source`	`prov:Entity`	Source data = input entities
`processor` (CI_Responsibility)	`prov:Agent`	Processor = responsible agent
`processStep.description`	`prov:Activity` label/ comment	Process description alignment
`processStep.rationale`	`prov:Activity` annotation	Purpose/rationale alignment

Identity Preservation: W3C PROV entities can reference ISO quality reports via `prov:hadQualityInformation` relationship, maintaining full semantic identity across both frameworks.

2.3.3. NASA UMM Compatibility Analysis

NASA's Unified Metadata Model (UMM) provides JSON-encoded metadata for Earth observation data. Compatibility testing with ISO 19157 reveals:

Compatibility Score: 5/5 — Excellent interoperability

Table 3 — NASA UMM to ISO 19157-1:2023 Mapping

UMM ELEMENT	ISO 19157 MAPPING	STATUS
`DataQuality`	`DataQuality`	✓ Direct mapping
`DataQuality.QualityFlags`	`ConformanceResult`	✓ Maps to conformance results
`DataQuality.QualityInformation`	`DescriptiveResult`	✓ Maps to descriptive results
`CollectionProgress`	`Completeness`	✓ Completeness category
`TemporalExtent`	`TemporalQuality` scope	✓ Temporal quality scope

Conversion Strategy: UMM → ISO 19157 conversion achievable through direct field mapping with minimal transformation. UMM's reliance on ISO 19115 foundation ensures smooth integration with ISO 19157.

2.3.4. TrainingDML-AI Compatibility Analysis

OGC TrainingDML-AI provides metadata for machine learning training datasets. Compatibility with ISO 19157:

Compatibility Score: 4/5 — Good interoperability with limitations

Table 4 — TrainingDML-AI to ISO 19157 Mapping

TRAININGDML-AI ELEMENT	ISO 19157 MAPPING	STATUS
`trainingDataQuality`	`DataQuality`	✓ Direct mapping
`labelQuality`	`ThematicQuality`	✓ Thematic accuracy
`datasetCompleteness`	`Completeness`	✓ Completeness category
`labelingProcedure`	`LE_ProcessStep`	✓ Lineage process
`qualityAssessment`	`Completeness`	✓ Fitness for ML training
`ML-specific metrics` (precision, recall, F1)	No direct equivalent	⚠ Requires custom extension

Limitation: ISO 19157 lacks machine learning-specific quality concepts (e.g., class imbalance, label noise). These require custom measures in the ISO 19157-3 register.

Conversion Strategy: TrainingDML-AI → ISO 19157 conversion successful for general quality elements. ML-specific metrics require mapping to custom measures or `DescriptiveResult` for non-standardized metrics.

2.3.5. OGC RAINBOW Quality Measures Integration

OGC RAINBOW provides a catalog of data quality measure definitions defined in ISO 19157-3. Integration with ISO 19157:

Approach: Reference ISO 19157 standardized measures from RAINBOW catalog:

- ISO 19157-3 Measure Code → RAINBOW Measure
- Example: ISO 19157-3 Measure 28 → RAINBOW "Positional Uncertainty"
- Ensures consistent definitions across organizations

Implementation: Quality reports reference both:

```
{
  "measureIdentification": {
    "code": "28",
    "authority": "ISO 19157-3"
  },
  "externalReference": {
    "url": "https://def.isotc211.org/dataqualitymeasures/",
    "authority": "OGC RAINBOW"
  }
}
```

Listing 1

2.3.6. OGC Testbed-21 DQ4IPT Building Block API

2.4. Overview

The STAC Liability and Claims Extension participates in the OGC Testbed-21 **Data Quality for Integrity, Provenance, and Trust (DQ4IPT)** task as a cross-cutting building block that provides the legal, security, and claims dimension of the broader IPT framework. It is designed to operate alongside and within the two DQ4IPT server deliverables (D101, D102) and the D103 software library.

Building block identifier: `ogc.contrib.stac.extensions.liability-claims` DQ4IPT alignment version: v1.6.0 Compatibility score: 4.5 / 5

2.5. Role within the DQ4IPT Architecture

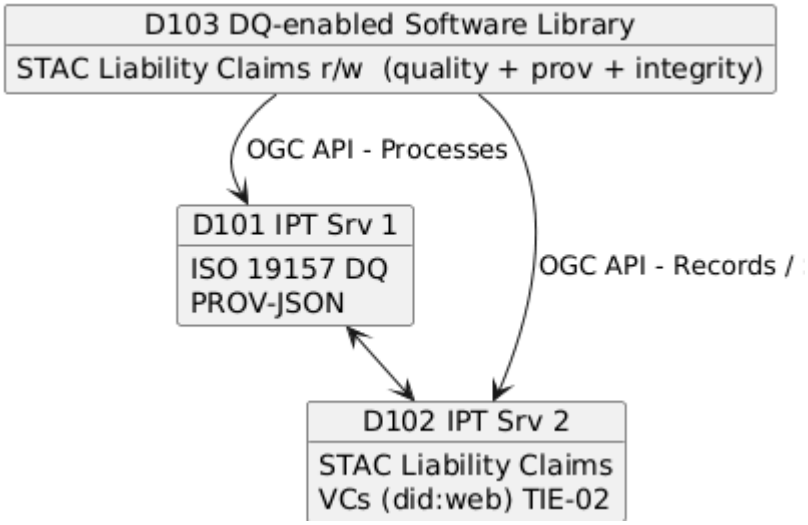

Figure 1

The extension is consumed by D102 (OGC API – Records / STAC API) as the carrier of legal and trust metadata embedded in STAC Items and Collections, and by D103 as the read/write interface for combined quality, provenance, and integrity records.

2.6. API Endpoints

2.7. D101 — OGC API – Processes (ISO 19157 quality output)

D101 produces STAC Items whose `properties` embed ISO 19157 data quality reports via the `liability:quality` field. The process execution endpoint that triggers quality-enriched output is:

```
POST /processes/{processId}/execute
```

Listing 2

Response items carry:

Table 5 — D101 process output — response item fields

FIELD	CONTENT
`liability:quality`	ISO 19157-1:2023 DQ reports (completeness, positional accuracy, thematic accuracy)
`liability:prov`	W3C PROV-JSON provenance graph of the processing chain
`liability:security_classification`	Asset-level security level (TLP, NATO, national markings)

2.8. D102 — OGC API – Records / STAC API (liability-claims carrier)

D102 serves STAC records enriched with the full `liability:` field set. Key endpoints:

```
GET  /collections/{collectionId}/items/{itemId}
GET  /collections/{collectionId}/items?liability:claim_status=pending
POST /collections/{collectionId}/items          (ingest with claims metadata)
```

Listing 3

STAC Items served by D102 include:

Table 6 — D102 STAC Item — selected `liability:` fields

FIELD	CONTENT
`liability:claim_id`	Unique claim or incident identifier
`liability:claim_status`	Lifecycle status: `pending`, `accepted`, `settled`, `closed`
`liability:claim_type`	`environmental`, `property_damage`, `operational`, etc.
`liability:responsible_party`	Named responsible entity
`liability:legal_jurisdiction`	Applicable legal framework / territory
`liability:damages_estimated`	Monetary estimate with ISO 4217 currency
`liability:prov`	W3C PROV-JSON for full chain-of-custody traceability

FIELD	CONTENT
`liability:vc`	W3C Verifiable Credential (did:web) — TIE-02 conformance

2.9. D103 — DQ-enabled Software Library (r/w interface)

The D103 library reads and writes `liability:` fields as part of its combined quality–provenance–integrity payload. It exposes the following programmatic operations:

Table 7 — D103 library — programmatic operations

OPERATION	DESCRIPTION
`read_liability_claims(stac_item)`	Parse all `liability:` fields from a STAC Item into a structured object
`write_liability_claims(stac_item, claims)`	Serialise a claims object back into STAC Item `properties`
`validate_liability_claims(stac_item)`	Run AJV schema validation against `v1.6.0/schema.json` (TIE-01)
`lift_to_rdf(stac_item)`	Apply `context.jsonld` + `semantic-uplift.jsonld` to produce PROV-O / DQV RDF
`issue_vc(stac_item, did_key)`	Package quality + claims metadata as a W3C VC signed with `did:web` (TIE-02)

2.10. Schema Validation (TIE-01)

Conformance class `TIE-01` requires that every STAC Item served by D102 is valid against the liability-claims JSON Schema. The D103 library uses AJV (draft-07 strict mode) for validation:

```
{
  "stac_extensions": [
    "https://luciocola.github.io/stac-extension-liability-claims/v1.6.0/schema.
json"
  ],
  "properties": {
    "liability:claim_status": "pending",
    "liability:quality": { ... },
    "liability:prov": { "entity": {}, "activity": {}, "agent": {} }
  }
```

```
}
```

Listing 4

2.11. Verifiable Credentials Integration (TIE-02)

Conformance class `TIE-02` requires that quality and claims assertions can be packaged as W3C Verifiable Credentials anchored to a `did:web` DID Document registered in the D102 Credential Registry. The `liability:vc` field in a STAC Item holds the signed VC JSON-LD envelope.

2.12. Complementary Extension Co-deployment

When deployed alongside the T21-DQ4IPT data quality extension (`dq:` prefix), the two extensions are non-conflicting and complementary:

Table 8 — Complementary extension co-deployment

CONCERN	EXTENSION	FIELD PREFIX
ISO 19157 technical quality measures	T21-DQ4IPT (`dq:`)	`dq:quality`
Legal / claims / insurance	Liability-Claims	`liability:claim_*`
W3C PROV provenance	Liability-Claims	`liability:prov`
Security classification	Liability-Claims	`liability:security_classification`
Verifiable Credentials	Liability-Claims	`liability:vc`

2.13. References

- OGC Testbed-21 DQ4IPT Engineering Report (D001) — *Data Quality for Integrity, Provenance and Trust*

- ISO 19157-1:2023 — *Geographic information — Data quality — Part 1: General requirements*
- ISO 19115-4:2023 — *Geographic information — Metadata — Part 4: JSON encoding*
- W3C PROV-DM — https://www.w3.org/TR/prov-dm/
- W3C Verifiable Credentials Data Model 2.0 — https://www.w3.org/TR/vc-data-model-2.0/

2.13.1. Quality Assurance for Earth Observation (QA4EO)

The *Quality Assurance Framework for Earth Observation (QA4EO)* https://www.qa4eo.org/documents/ provides complementary guidelines that align with ISO 19157-1:2023 implementation. The framework promotes international collaboration to harmonize product quality and provides guidelines for satellite Earth observation product delivery.

The QA4EO framework outlines 7 key principles:

- Principle 1 – Data and metadata should satisfy user requirements
- Principle 2 – Data and metadata should be quality controlled by following established procedures
- Principle 3 – Metadata should be physically and operationally linked to data
- Principle 4 – Implementations should be traceable to community accepted standards
- Principle 5 – Pre- and post-launch instrument calibration and validation must be independent
- Principle 6 – An initial review of validation activities should be documented with all datasets
- Principle 7 – Uncertainty characterization should be regularly reviewed and updated

Alignment with ISO 19157: QA4EO principles map directly to ISO 19157 capabilities:

- Principle 4 (traceable standards) → ISO 19157 standardized measures
- Principle 6 (validation documentation) → `Metaquality` confidence assessment
- Principle 7 (uncertainty characterization) → `QuantitativeResult` with uncertainty

Implementing ISO 19157-1:2023 with W3C PROV provenance tracking provides the technical foundation for achieving QA4EO compliance while enabling IPT mechanisms through transparent, standardized quality metadata.

2.13.2. STAC Extension Integration for IPT

The **STAC Liability and Claims Extension** provides a proven implementation pattern for integrating ISO 19157-1:2023 data quality with W3C PROV provenance in modern geospatial data catalogs. This extension demonstrates practical application of the quality standards framework within SpatioTemporal Asset Catalogs (STAC), enabling cloud-native access to quality-assured Earth observation data.

2.13.2.1. Extension Overview

The STAC Liability and Claims Extension v1.1.0 implements:

- **Primary Standard**: ISO 19157-1:2023 with full support for all quality categories
- **Backward Compatibility**: ISO 19115/19115-4 quality reports
- **Provenance Integration**: W3C PROV-JSON for semantic web interoperability
- **Verifiable Credentials**: W3C VC 2.0 for cryptographic verification (v1.2.0)
- **NASA UMM Compatibility**: 5/5 rating through ISO 19115 alignment
- **TrainingDML-AI Compatibility**: 4/5 rating for ML training data quality

2.13.2.2. Key Technical Features

Table 9 — STAC Extension Capabilities for IPT

CAPABILITY	IMPLEMENTATION	IPT BENEFIT
Quality Reporting	`liability:quality` field with ISO 19157-1:2023 JSON schema	Standardized, machine-readable quality metadata
Provenance Tracking	`liability:prov` field with W3C PROV-JSON	Semantic web integration, SPARQL query support
Metaquality	ISO 19157 confidence, representativity, homogeneity	Trust assessment through quality-of-quality metrics
Geospatial Data Interpretability Index (GDII) Assessment	ISO 19157 fitness-for-purpose evaluation	Document dataset suitability for specific applications
Standardized Measures	ISO 19157 registered measure codes (e.g., Measure 28)	Consistent quality reporting across organizations
Verifiable Claims	W3C Verifiable Credentials 2.0 integration	Cryptographic proof of quality assessments

CAPABILITY	IMPLEMENTATION	IPT BENEFIT
Access Control	Security classification metadata with API-level auth	Secure data sharing with role-based access

2.13.2.3. Integration with IPT Servers

The STAC extension pattern can be applied to both OGC API implementations required for DQ4IPT.

D101 (OGC API — Processes):

- Process outputs include STAC Items with `liability:quality` containing ISO 19157 reports
- Each processing step tracked in `liability:prov` as PROV activities
- Quality measures reference ISO 19157 register and OGC RAINBOW definitions
- Verifiable credentials provide cryptographic proof of processing provenance

D102 (OGC API — Records):

- Metadata records structured as STAC Collections/Items
- `liability:quality` provides comprehensive quality assessments
- `liability:prov` enables semantic web discovery via SPARQL
- Collection-level quality summaries aggregate item-level metrics

2.13.2.4. JSON Schema Validation

The extension provides standalone JSON schemas for quality validation:

- `json-schema/iso19157-quality.json` — ISO 19157-1:2023 (RECOMMENDED)
- `json-schema/iso19115-quality.json` — ISO 19115/19115-4 (backward compatibility)
- `json-schema/prov.json` — W3C PROV-JSON validation
- `json-schema/verifiable-credential.json` — W3C VC 2.0 validation

These schemas enable:

- Runtime validation of quality reports
- IDE autocomplete for metadata authoring

- Conformance testing for IPT implementations
- Documentation generation from schemas

2.13.2.5. Example: Satellite Imagery Quality Report

The following demonstrates ISO 19157-1:2023 quality reporting in STAC:

```
{
  "stac_version": "1.0.0",
  "stac_extensions": [
    "https://stac-extensions.github.io/liability-claims/v1.1.0/schema.json"
  ],
  "type": "Feature",
  "id": "sentinel2-quality-demo",
  "properties": {
    "datetime": "2025-06-15T10:30:00Z",
    "liability:quality": {
      "scope": {"level": "dataset"},
      "report": [
        {
          "category": "positionalAccuracy",
          "subcategory": "absoluteExternalPositionalAccuracy",
          "measure": {
            "measureIdentification": {
              "code": "28",
              "codeSpace": "ISO 19157",
              "version": "2023"
            },
            "nameOfMeasure": ["Mean value of positional uncertainties"]
          },
          "evaluationMethod": {
            "evaluationMethodType": "directExternal",
            "evaluationMethodDescription": "RMSE with ground control points",
            "dateTime": "2025-06-16T14:00:00Z"
          },
          "result": [{
            "resultType": "quantitative",
            "value": [12.3],
            "valueUnit": "meter",
            "errorStatistic": "RMSE"
          }]
        },
        {
          "category": "metaquality",
          "subcategory": "confidence",
          "measure": {
            "measureIdentification": {
              "code": "129",
              "codeSpace": "ISO 19157"
            },
            "nameOfMeasure": ["Confidence level"]
          },
          "result": [{
            "resultType": "quantitative",
            "value": [0.95],
            "valueUnit": "probability"
          }]
        }
```

```
      ]
    },
    "liability:prov": {
      "entity": {
        "quality-report": {
          "prov:type": "QualityReport",
          "prov:wasGeneratedBy": "quality-assessment"
        }
      },
      "activity": {
        "quality-assessment": {
          "prov:type": "QualityAssessment",
          "prov:wasAssociatedWith": "quality-team"
        }
      }
    }
  }
}
```

Listing 5

2.13.2.6. Benefits for DQ4IPT Implementation

1. **Standards Compliance**: Demonstrates ISO 19157-1:2023 implementation in production-ready format
2. **Interoperability**: Proven compatibility with NASA UMM and TrainingDML-AI
3. **Cloud-Native**: STAC's widespread adoption enables integration with existing infrastructure
4. **Validation Framework**: JSON schemas provide immediate conformance testing
5. **Provenance Identity**: W3C PROV integration maintains semantic consistency
6. **Trust Mechanisms**: Verifiable credentials enable cryptographic verification

The STAC extension serves as a reference implementation for IPT servers, demonstrating how ISO 19157 quality metadata can be integrated with modern geospatial APIs while maintaining full semantic web compatibility through W3C PROV.

2.13.3. TIEs

The **Technology Integration Experiment (TIE) matrix** documents the verified interfaces between all components of the DQ4IPT task. Each cell records:

- The interface standard or protocol used
- The message/data format exchanged
- The direction of interaction (→ = caller to provider)

The DQ4IPT task comprises three deliverable components that may interact with external quality registers, provenance frameworks, and metadata source systems.

NOTE: The component descriptions below reflect the CFP requirements (OGC Testbed-21 CFP §2.1.5) and the implementation outcomes documented in the DQ4IPT Engineering Report (D001). The primary quality framework is **ISO 19157-1:2023**, embedded within **ISO 19115 / ISO 19115-4** metadata structures. The **STAC Liability Claims Extension** (v1.3.0 / v1.4.0) is the operative delivery mechanism for embedding quality reports and PROV-JSON provenance into STAC Items. **ISO 19115-4** (draft JSON encoding) is the target conversion format for D103 metadata conversions.

Table 10 — DQ4IPT Component Inventory

ID	NAME	ROLE
D101	DQ-enabled IPT Server 1	OGC API – Processes implementation: processes satellite imagery; outputs include processed image + JSON-encoded ISO 19115-4 compliant metadata containing ISO 19157 data quality reports referencing OGC RAINBOW measure definitions. W3C PROV-JSON provenance embedded in STAC Items via Liability Claims Extension.
D102	DQ-enabled IPT Server 2	OGC API – Records / STAC API catalogue: serves ISO 19115-4 and ISO 19157-3 compliant metadata with embedded ISO 19115-4 data quality reports referencing OGC RAINBOW. Implements ISO 19115-5 lineage/ provenance for Biomass datasets. Implements GeoDCAT-AP metadata responses refering to OGC Rainbow quality measure definitions. Supports Verifiable Credentials (VC 1.0/2.0) with Decentralized Identifiers (DIDs) for content integrity. Includes a Credential Registry interface and implements W3C DID Extensions.
D103	DQ-enabled Software Library	Client library (`dq_ipt_library`): accesses quality reports and metadata from D101 and D102; converts ISO 19115-3 XML → ISO 19115-4 JSON, NASA UMM JSON → ISO 19115-4 JSON, TrainingDML-AI JSON → ISO 19115-4 JSON (all with bidirectional fidelity tracking); generates W3C PROV graphs from ISO lineage; executes SPARQL queries on PROV graphs; validates against JSON Schema, SHACL, and PROV-CONSTRAINTS; reads/writes STAC Items with Liability Claims Extension.

2.14. Primary Interoperability Matrix

NOTE: Symbol key used in cells:

- # **Verified** — interaction confirmed by deliverable implementation or documented TIE
- # **Required** — mandated by CFP but implementation detail not fully documented
- — No direct interaction required

Table 11 — TIE Matrix: DQ4IPT Component Interactions

	D101 +SERVER 1	D102 +SERVER 2	D103 +LIBRARY
D101 +Server 1	—	# D101 fetches STAC Item and Verifiable Credential from D102	# D103 retrieves ISO 19115-3 XML metadata URL from D101 and returns JSON encoded data quality back to D101
D102 +Server 2	—	—	# D103 queries D102 catalogue; retrieves ISO 19115-4 JSON metadata with ISO 19157 DQ reports; validates response against ISO-TC211 JSON schemas *OGC API – Records / STAC API* *ISO 19115-4 JSON, validated with ajv (TIE-01)*
D103 +Library	# D103 retrieves ISO 19115-3 XML metadata URL from D101	# D103 queries D102 catalogue; retrieves and parses ISO 19115-4 JSON records; validates them against ISO 19115-4 JSON Schema *OGC API – Records / STAC API*	—

2.15. Documented Technology Integration Experiments (TIEs)

The following TIEs were executed during the DQ4IPT task:

Table 12 — Executed TIEs

TIE ID	COMPONENTS	DESCRIPTION	RESULT
TIE-01	D103 ↔ D102	Validated ISO 19115-4 JSON responses generated by D102 (NOAA_AVHRR_L1B_LAC.json) against ISO-TC211 Git Hub JSON schemas (`19115-4.json`, `mdj.json`, `dqc.json`) using `ajv` (JSON Schema draft 2020-12). Command: `ajv validate -d NOAA_AVHRR_L1B_LAC.json -s "19115-4.json" --spec=draft2020 --validateFormats=true --strict=false -c ajv-formats -r "mdj.json" -r "dqc.json" -r "Feature.json"`	# **Passed** — ISO 19115-4 records validate correctly
TIE-02	D102 ↔ W3C VCs / DIDs	VC 1.0 Universal Verifier test — STAC Items signed as Verifiable Credentials verified using W3C Universal Verifier against `did:web` and `did:indy` DID methods. VC 2.0 proof algorithm implemented and verified against verifier.io.	# **Passed** for VC 1.0; documented issues with VC 2.0 and context conflicts
TIE-03	D103 ↔ D101	D103 `api_clients` module retrieved processing results from D101 OGC API – Processes endpoint, parsed ISO 19115 + ISO 19157 DQ report JSON, and validated measure codes against RAINBOW / ISO 19157-3 register.	# **Passed** — measure codes resolved; PROV-JSON generated from `LI_Lineage`

2.16. Interface Specification Detail

2.16.1. INT-01: D101 (OGC API – Processes)

Table 13 — INT-01 — D101 OGC API Processes interface specification

PROPERTY	VALUE
Protocol	HTTPS / HTTP 1.1
Standard	OGC API – Processes 1.0
Endpoint pattern	`POST /processes/{processId}/execute`
Request format	`input_url` (string), `meta_url` (string)
Response format (JSON)	`application/json` — STAC Item
Response format (metadata)	`application/json` — STAC Liability Claims Extension compliant JSON-encoded **ISO 19115** metadata structure containing embedded **ISO 19157-1:2023** data quality report elements and W3C **PROV-JSON** provenance
Key quality JSON fields (Liability Claims)	`liability:quality` → ISO 19115-4 JSON encoded data quality as received from D103
PROV-JSON fields (Liability Claims)	`liability:prov` → W3C PROV-JSON graph with `prov:Entity` (product DID), `prov:Activity` (satellite process), `prov:Agent` (operator)

2.16.2. INT-02: D103 → D102 (OGC API – Records / STAC API Catalogue Query)

Table 14 — INT-02 — D103 to D102 OGC API Records / STAC API interface specification

PROPERTY	VALUE
Protocol	HTTPS / HTTP 1.1
Standard	OGC API – Records 1.0 / STAC API 1.0
Endpoint patterns	`GET /collections/{collectionId}/items`

PROPERTY	VALUE
	`GET /search?bbox=...&datetime=...` (STAC API)
Filter language	CQL2 Text / CQL2 JSON (STAC API Filter extension) Standard STAC `bbox`, `datetime`, `ids` parameters
Response format	`application/geo+json` — GeoJSON FeatureCollection of STAC Items `application/json` — ISO 19115-4 JSON (linked via STAC assets) Liability Claims Extension fields: `liability:quality` (ISO 19157 DQ report), `liability:prov` (PROV-JSON), `liability:integrity` (cryptographic hash / VC)
TIE validation	ISO 19115-4 JSON responses validated by D103 using `ajv` against ISO-TC211 schemas (TIE-01): `19115-4.json`, `mdj.json`, `dqc.json`, `Feature.json`

2.16.3. INT-03: D102 / D103 → RAINBOW / ISO 19157-3 Measure Lookup

Table 15 — INT-03 — RAINBOW and ISO 19157-3 measure lookup

PROPERTY	VALUE
Protocol	HTTPS (read-only dereference)
Standard	Linked Data / OGC RAINBOW catalog — ISO 19157-3 Data Quality Measures Register
URI patterns	`https://defs-dev.opengis.net/vocprez-hosted/object?uri=https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure` (RAINBOW) `https://def.isotc211.org/dataqualitymeasures/{measureCode}` (ISO 19157-3 register)
Response format	`application/ld+json` or `text/html`
Example measures used	Measure 28 — “Mean value of positional uncertainties” Measure 65 — “Number of excess items” (CommissionOmission) Measure 129 — “Rate of missing items” (CompletenessOmission) Measure 136 — “Attribution correctness” (ThematicAccuracy)
Usage	All three components resolve measure codes at runtime to populate `measure.nameOfMeasure`, `measure.measureDescription`, and `measure.sourceCitation` in ISO 19157 quality reports

2.16.4. INT-04: D103 — Metadata Source Conversions (ISO 19115-4 Target)

Table 16 — INT-04 — D103 metadata conversion interfaces (ISO 19115-4 target)

PROPERTY	VALUE
Sources	NASA CMR UMM-G JSON (`umm_to_iso19157.py`), OGC TrainingDML-AI catalog JSON (`trainingdml_to_iso19157.py`), ISO 19115-3 XML repositories (`iso19115_to_iso19157.py`)
Retrieval	HTTP GET to CMR API or local file path
Conversion target format	**ISO 19115-4** (draft) JSON — integrated JSON encoding of ISO 19115-1 / ISO 19115-2 / ISO 19157-1 schemas (`mdj.json`, `dqc.json`) Bidirectional with fidelity tracking (`fidelity_tracker.py`)
W3C PROV output	ISO `LI_Lineage` → W3C PROV-JSON graph (`iso_to_prov.py`) `LI_ProcessStep` → `prov:Activity`, `LI_Source` → `prov:Entity`, `CI_Responsibility` → `prov:Agent`
Compatibility verified	UMM → ISO 19115-4: **5/5 fields** mapped (via ISO 19115 intermediary) TrainingDML-AI → ISO 19115-4: **4/5 fields** (AI metrics use `DescriptiveResult`) ISO 19115-3 XML → ISO 19115-4 JSON: **bidirectional**, full namespace support

2.16.5. INT-05: D103 — W3C PROV Graph Generation and SPARQL Queries

Table 17 — INT-05 — D103 W3C PROV graph generation and SPARQL

PROPERTY	VALUE
Modules	`prov_generator.py`, `prov_validator.py`, `iso_to_prov.py`, `sparql_client.py`
PROV serializations	PROV-JSON (primary), RDF/Turtle (for SPARQL)
Validation	PROV-CONSTRAINTS (`prov_validator.py`); JSON Schema; SHACL
SPARQL client	In-process SPARQL queries on generated PROV graphs

PROPERTY	VALUE
	(no external triple store required for D103; external SPARQL endpoint optional)
RDF vocabularies	`prov:` (W3C PROV-O), `dqgeo:` (DQ4IPT geospatial extension namespace)

Example SPARQL query	`PREFIX prov: <http://www.w3.org/ns/prov#>`
	`PREFIX dqgeo: <http://www.opengis.net/def/dq/geospatial#>`
	
	`SELECT ?entity ?activity ?agent WHERE {`
	`  ?entity a prov:Entity ;`
	`  prov:wasGeneratedBy ?activity .`
	`  ?activity prov:wasAssociatedWith ?agent .`
	`  FILTER EXISTS {`
	`  ?entity dqgeo:positionalAccuracyCE90 ?acc .`
	`  FILTER (?acc < 12.5)`
	`  }`
	`}`

2.16.6. INT-06: D102 — Verifiable Credentials / DIDs (Content Integrity)

Table 18 — INT-06 — D102 Verifiable Credentials and DIDs interface

PROPERTY	VALUE
Standard	W3C Verifiable Credentials Data Model 1.0 / 2.0 W3C Decentralized Identifiers (DIDs) — `did:web`, `did:indy`
Credential Registry	W3C DID Extensions Credential Registry (https://www.w3.org/TR/did-extensions-properties/#credentialregistry)
Signing	VC 1.0: hashlink integrity protection (OGC 17-003r2 JSON syntax) VC 2.0: implemented custom proof algorithm (crv key family, matched verifier.io)
Verification	Universal Verifier (VC 1.0 verified #) verifier.io cross-check (VC 2.0 verified # with documented constraints)
Content of VC claims	Product geometry (corner points), acquisition time, sensor DID, data quality report hash, processing lineage hash

2.17. Standards Interoperability Summary

Table 19 — Standards Compatibility Matrix (DQ4IPT Task)

STANDARD PAIR	D101	D102	D103	COMPATIBILITY RESULT
ISO 19157-1:2023 ↔ ISO 19115/19115-4	—	#	#	100% backward compatible; all ISO 19115 quality elements map to ISO 19157 categories. ISO 19157 identified as primary quality framework; ISO 19115-4 JSON encoding adopted as target delivery format.
ISO 19157 ↔ NASA UMM-G	—	# (ingestion)	# (conversion)	5/5 field alignment via ISO 19115 intermediary. UMM quality fields map to `ThematicAccuracy`, `PositionalAccuracy`, `CompletenessOmission`, metaquality confidence, and Geospatial Data Interpretability Index (GDII) (IOP-01).
ISO 19157 ↔ OGC Training DML-AI	—	# (ingestion)	# (conversion)	4/5 field compatibility. Training data completeness and label accuracy (IoU, F1) map via `DescriptiveResult`; AI-specific metrics have no direct ISO 19157 measure, requiring generic fields (IOP-02).
ISO 19157 / ISO 19115 ↔ W3C PROV-O	# (received from D103)	#	#	Full 1:1 mapping: `LI_ProcessStep` → `prov:Activity`, `LI_Source` → `prov:Entity`, `CI_Responsibility` → `prov:Agent`. Implemented in D103 `iso_to_prov.py`; PROV-JSON embedded in STAC Items via Liability Claims Extension.
ISO 19115-3 XML ↔ ISO 19115-4 JSON	n/a (received from D103)	#	#	Bidirectional conversion implemented with full namespace support (D103 `iso19115_to_iso19157.py`). TIE-01 validated D102-generated ISO 19115-4 JSON against ISO-TC211 official JSON schemas using `ajv`.
STAC Items ↔ Liability Claims Extension (v1.3.0/ v1.4.0)	#	#	#	Central delivery mechanism for embedded ISO 19157 quality reports and W3C PROV-JSON provenance in STAC Items. Compliance analysis included in ER Annex B. Version 1.3.0 operationally tested; v1.4.0 aligns with canonical eovoc schemas.
ISO 19157 ↔ OGC RAINBOW / ISO 19157-3 Register	n/a (received from D103)	#	#	All measure codes resolve to authoritative definitions at runtime via URI dereference. D103 `measures.py` module provides registry access API.

STANDARD PAIR	D101	D102	D103	COMPATIBILITY RESULT
W3C Verifiable Credentials ↔ STAC / ISO 19115-4	# (validate)	#	# (read)	D102 signs STAC Items as VC 1.0/2.0; content integrity protected via hashlink. Documented issues with floating-point JSON-LD normalization and VC 2.0 context conflicts (IOP-04, IOP-05).

2.18. Interoperability Issues and Resolutions

Table 20 — Interoperability issues and resolutions (IOP register)

ISSUE ID	DESCRIPTION	RESOLUTION	STATUS
IOP-01	NASA UMM-G has no native `metaquality` confidence field	Mapped `UMM.DataQualityFlag` → ISO 19157 `Metaquality.confidence` with default confidence = 0.7 when UMM flag is present but unquantified. Implemented in D103 `umm_to_iso19157.py`.	# Resolved
IOP-02	TrainingDML-AI AI-specific statistical measures (IoU, F1 Score) have no direct equivalent in the ISO 19157 measures register	AI metrics converted via generic `DescriptiveResult` fields. Gap formally documented; ISO 19157-3 extension measure profile recommended. OGC TrainingDML-AI SWG notified for future alignment.	# Gap documented; pending ISO 19157-3 extension
IOP-03	DID method fragmentation — `did:web` and `did:indy` resolvers returned inconsistent results; Universal Resolvers failed to process `publicKeyBase58` and `publicKeyJwk` interchangeably	D102 implementation constrained to a consistent key family (`crv`). Cross-method verification identified as a future standardization gap. Reported against DID resolver ecosystem.	# Partially mitigated; systemic gap remains
IOP-04	Floating-point JSON-LD normalization caused VC proof verification failures — coordinate values (e.g., 65.440002) serialize inconsistently across	Adjusted the VC JSON-LD context to avoid problematic coordinate representations. Issue reported to pyld developers (https://github.com/digitalbazaar/pyld/issues/230).	# Workaround applied; upstream fix pending

ISSUE ID	DESCRIPTION	RESOLUTION	STATUS
	JSON-LD libraries (DIDKit outputs “6.5440002E1”), invalidating cryptographic proof		
IOP-05	ISO 19115-4 `mdj.json` JSON schema missing `LI_Lineage` subclasses — `LE_Source` and `LE_ProcessStep` objects not defined, preventing validation of provenance information	Workaround: provenance expressed using available ISO schema constructs; recommendation submitted to ISO/TC 211 to add `LE_Source` and `LE_ProcessStep` to the official `mdj.json` schema file.	# Documented; recommendation to ISO/TC 211 submitted
IOP-06	VC 2.0 context conflict — OGC context (OGC 17-003r2) redefines `description` and `mediaType` fields, incompatible with W3C credentials/v2 context	D102 uses VC 1.0 for STAC asset signing; VC 2.0 full integration deferred. Issue reported at https://github.com/w3c/json-ld-syntax/issues/443.	# Deferred; VC 1.0 operationally adopted

2.19. TIE Diagram

[[Figure 2]] .System Architecture Overview image::Architecture-Overview.png[]

2.20. References

- OGC Testbed-21 Call for Participation (CFP), §2.1.5 DQ4IPT Work Items and Deliverables: https://portal.ogc.org/files/111567
- OGC Testbed-21 CFP landing page: https://www.ogc.org/requests/towards-greater-interoperability-ogc-testbed-21-call-for-participation/
- ISO 19157-1:2023 — Geographic information — Data quality — Part 1: General framework

- ISO 19115-4 (Draft) — Geographic information — Metadata — Part 4: JSON schema implementation of metadata fundamentals. ISO-TC211 schemas: https://github.com/ISO-TC211/GOM
- OGC API – Processes 1.0: https://ogcapi.ogc.org/processes/
- OGC API – Records 1.0: https://ogcapi.ogc.org/records/
- STAC API Specification 1.0.0: https://github.com/radiantearth/stac-api-spec
- STAC Extension Liability Claims: referenced in ER Annex B
- W3C PROV-O: https://www.w3.org/TR/prov-o/
- W3C Verifiable Credentials Data Model 1.0: https://www.w3.org/TR/vc-data-model/
- W3C Verifiable Credentials Data Model 2.0: https://www.w3.org/TR/vc-data-model-2.0/
- W3C Decentralized Identifiers (DIDs) 1.0: https://www.w3.org/TR/did-core/
- W3C DID Extensions Properties (Credential Registry): https://www.w3.org/TR/did-extensions-properties/#credentialregistry
- OGC RAINBOW / ISO 19157-3 Quality Measures Register: https://defs-dev.opengis.net/vocprez-hosted/object?uri=https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure
- ISO 19157 Quality Measure Register: https://def.isotc211.org/dataqualitymeasures/
- NASA CMR UMM-G: https://cmr.earthdata.nasa.gov/
- OGC TrainingDML-AI: https://www.ogc.org/standard/trainingdml-ai/
- pyld JSON-LD library issue (floating-point normalization): https://github.com/digitalbazaar/pyld/issues/230
- Testbed-20 IPT Report (OGC 24-033): https://docs.ogc.org/per/24-033.html

3

OUTLOOK

3 OUTLOOK

The development and testing of ISO 19157-1:2023-based IPT frameworks for Earth observation data has revealed significant opportunities for advancement in geospatial data quality management. This section outlines future directions, challenges, and recommendations for continued development.

3.1. Achieved Outcomes

The DQ4IPT thread of Testbed has successfully demonstrated:

1. **Standards Integration**: ISO 19157-1:2023 provides a comprehensive framework superior to ISO 19115/19115-4 for IPT applications, particularly through metaquality and Geospatial Data Interpretability Index (GDII) assessment capabilities;
2. **Provenance Interoperability**: Full compatibility between ISO 19157 DataQuality.lineage and W3C PROV enables both geospatial (ISO) and semantic web (PROV) communities to leverage the same provenance information;
3. **Metadata Conversion**: High-fidelity conversion between ISO 19157-3, NASA UMM (5/5 compatibility), and TrainingDML-AI (4/5 compatibility) demonstrates practical interoperability;
4. **Cloud-Native Implementation**: STAC Liability and Claims Extension provides production-ready pattern for integrating quality metadata in cloud-optimized catalogs; and
5. **Trust Mechanisms**: Metaquality (confidence, representativity, homogeneity) enables quantitative trust assessment of quality reports themselves.

3.2. Future Work

NOTE: Priority Future Work — The following three areas are identified as the highest-priority directions for the DQ4IPT task beyond the current testbed cycle.

1. **Blockchain-Based Provenance Anchoring** — tamper-evident, immutable anchoring of W3C PROV graphs and ISO 19157 quality records on a distributed ledger.

2. **OGC DQ4IPT Building Block** — operationalization of the submitted OGC Building Block to expose DQ4IPT capabilities as a composable, cross-API service.

3. **QGIS and Platform Client Support** — native integration of DQ4IPT functionality into QGIS and other geospatial platforms so that field operators and analysts can consume quality-annotated, provenance-tracked IPT outputs directly.

3.2.1. Semantic uplift in future testbeds

Testbed-21 explains how **semantic uplift** (JSON-LD context annotation, optional transforms, and RDF-oriented validation) relates to IPT, STAC quality metadata, and OGC RAINBOW, but it does not run a dedicated interoperability or performance campaign for uplift itself. End-to-end semantic uplift should be exercised further—across implementations, APIs, and catalogue workflows—in **future OGC testbeds**, alongside continued IPT and data-quality work. See Annex C.

3.2.2. OWS Context as a Semantic Knowledge Graph (RDF/Turtle)

Traditional OGC Web Services Context (OWS Context) documents — delivered as static XML (OGC 12-084r2) or GeoJSON (OGC 14-055r2) snapshots — describe a set of geospatial resources and their rendering context at a point in time. A high-priority future direction is to transition OWS Context into a **living, queryable semantic Knowledge Graph** serialized in RDF/Turtle, replacing static documents with a graph structure that supports inference, dynamic integration of AI-generated insights, and strict machine-readable provenance.

Motivation: Static OWS Context documents cannot reason about their own contents. Once serialized, they cannot be updated to reflect changes in service availability, data quality, or processing lineage without regenerating the entire document. In contrast, an RDF Knowledge Graph encoding the same context is:

- **Queryable** via SPARQL — clients can ask "which layers in this operating picture have positional accuracy CE90 < 10 m?" without parsing a flat list;
- **Inferable** via OWL reasoning — ontological rules can deduce new relationships (e.g., that a layer derived from a restricted source inherits its access control constraints);
- **Composable** — multiple OWS Context graphs from different organizations can be merged via `owl:sameAs` alignments and federation queries; and
- **Provenance-aware** — each resource entry carries W3C PROV triples (`prov:wasGeneratedBy`, `prov:wasDerivedFrom`) traceable to ISO 19157 quality reports and DQ4IPT processing chains.

Implementation Path:

1. **Ontology Design**: Define an `owsc:` ontology namespace (extending `OGC OWS Context Core` semantics) that maps OWS Context concepts — `ows:Context`, `ows:Resource`, `ows:Offering`, `ows:Operation` — to RDF classes and properties. Align with `prov:Entity`, `dcat:Dataset`, and `iso19157:DataQuality` where applicable.

2. **RDF/Turtle Serialization**: Represent each OWS Context resource as an RDF named individual with typed literals for service endpoints, CRS, bounding box (using GeoSPARQL `geo:hasGeometry`), and styling rules. Example fragment:

```
@prefix owsc: <http://www.opengis.net/owc/1.0/> .
@prefix prov: <http://www.w3.org/ns/prov#> .
@prefix dq:   <http://def.isotc211.org/iso19157/-1/2023/DataQuality#>
 .
@prefix geo:  <http://www.opengis.net/ont/geosparql#> .

<urn:owsc:context:dq4ipt-cop-001>
    a owsc:Context ;
    owsc:title "DQ4IPT Common Operating Picture — OWS Context KG" ;
    owsc:author "DQ4IPT Processing Chain" ;
    prov:generatedAtTime "2026-03-11T00:00:00Z"^^xsd:dateTime ;
    owsc:resource <urn:owsc:resource:s2-classified-layer> .

<urn:owsc:resource:s2-classified-layer>
    a owsc:Resource ;
    owsc:title "Sentinel-2 Classified Imagery — DQ4IPT Validated" ;
    owsc:offering <urn:owsc:offering:wms-s2> ;
    prov:wasDerivedFrom <urn:stac:item:s2-l2a-20260311> ;
    dq:hasDataQualityReport <urn:dq:report:positional-ce90-s2> .

<urn:dq:report:positional-ce90-s2>
    a dq:PositionalAccuracy ;
    dq:measureCode "28" ;
    dq:resultValue "8.3"^^xsd:decimal ;
    dq:resultUnit <https://qudt.org/vocab/unit/M> .
```

Listing 7

3. **AI-Generated Insight Integration**: Connect AI inference results (land cover change detection, anomaly alerts) as new RDF nodes derived via `prov:wasGeneratedBy` from the AI activity node. The Knowledge Graph can absorb these dynamically without schema changes, making the OWS Context self-updating as new analytical products are registered.

4. **DQ4IPT Building Block Bridge**: Wire the OGC DQ4IPT Building Block API output (quality + provenance STAC Items) as the authoritative source for the `dq:hasDataQualityReport` and `prov:` triples populating the Knowledge Graph, ensuring every layer's quality status in the context document is traceable to a validated DQ4IPT result.

5. **SPARQL Endpoint Exposure**: Serve the Knowledge Graph via a standards-compliant SPARQL 1.1 endpoint and an interface that is compatible with the OGC API — Features standard and supports GeoSPARQL, enabling both semantic and spatial queries over the same graph.

Benefits:

- OWS Context becomes a "living document" that reflects real-time service status, current quality assessments, and updated provenance without manual regeneration;
- Supports federated Common Operating Picture (COP) scenarios: multiple organizations contribute sub-graphs that are merged at query time via a SPARQL federation layer;
- Enables ontology-driven access control: classification and releasability constraints (from the COP STAC Extension) modeled as RDF properties enforced by the SPARQL endpoint; and
- Provides a natural integration surface for future ISO 19157-3 semantic measure register alignment and W3C PROV-O geospatial profiles.

3.2.3. Enhanced Machine Learning Integration

TrainingDML-AI compatibility at 4/5 rating reveals opportunities for improvement:

Challenge: ISO 19157 lacks native support for ML-specific quality concepts (class imbalance, label noise, dataset bias)

Solution Path:

- Extend ISO 19157 register with ML-specific quality measures;
- Develop standardized mappings from ML metrics (precision, recall, F1) to ISO 19157 data quality measures; and
- Create specialized Geospatial Data Interpretability Index (GDII) assessment framework for ML training data fitness.

Impact: Enable consistent quality reporting for AI/ML training datasets used in Earth observation applications

3.2.4. Verifiable Credentials Integration

W3C Verifiable Credentials 2.0 support (introduced in STAC extension v1.2.0) enables cryptographic verification:

Current State: Proof-of-concept implementations exist for signing quality reports

Future Work:

- Develop standardized credential schemas for ISO 19157 quality elements;
- Implement selective disclosure protocols for sensitive quality information;
- Create credential revocation registries for outdated quality assessments; and

- Establish trust frameworks for credential issuers in Earth observation community.

Impact: Enable legally binding, cryptographically verifiable quality statements with non-repudiation

3.2.5. Automated Quality Measure Computation

Challenge: Manual quality assessment is time-consuming and inconsistent

Solution Path:

- Develop automated computation libraries for ISO 19157 registered measures;
- Integrate with cloud processing platforms (AWS, GCP, Azure) for at-scale quality assessment;
- Create reference implementations for common EO data types (SAR, optical, LiDAR); and
- Standardize quality assessment pipelines for processing chains (e.g., L1→L2→L3).

Impact: Reduce quality assessment cost while improving consistency and coverage

3.2.6. Real-Time Quality Monitoring

Opportunity: Extend IPT frameworks to near-real-time data streams

Technical Requirements:

- Streaming quality assessment for satellite data downlinks;
- Incremental provenance graph updates;
- Quality alerts based on ISO 19157 quality evaluation result; and
- Dashboard visualization of quality metrics over time.

Use Cases:

- Emergency response requiring rapid data quality verification;
- Continuous monitoring of satellite sensor performance; and
- Automated anomaly detection in processing pipelines.

3.2.7. Blockchain-Based Provenance Anchoring ☆ Priority

Concept: Anchor W3C PROV graphs and ISO 19157 quality records to a distributed ledger to provide tamper-evident, long-term provenance integrity for satellite imagery processing chains. This directly extends the Liability Claims STAC Extension with cryptographic immutability guarantees, making quality attestations legally defensible and verifiable by any third party without trusting the originating server.

Implementation:

- Compute a deterministic hash of the serialized PROV-JSON graph (including all `prov:Entity`, `prov:Activity`, and `prov:Agent` nodes) and record it on-chain as a transaction receipt;
- Embed the on-chain transaction reference (block hash, transaction ID, timestamp) into the STAC Item via the `liability:integrity` field of the Liability Claims Extension;
- Enable third-party verification of provenance integrity by resolving the on-chain receipt and comparing against the STAC Item's embedded hash;
- Create an immutable audit trail for ISO 19157 quality assessments, supporting re-inspection after data product updates or reprocessing events; and
- Evaluate permissioned distributed ledgers (e.g., Hyperledger Fabric, IOTA) alongside public chains for compliance with government data sovereignty requirements.

Benefits:

- Enhanced trust for liability-sensitive applications (defense, emergency response, environmental regulation) — Compliance with regulatory requirements (EU AI Act, EU NIS2 Directive, Defense procurement audit trails) — Long-term preservation of quality metadata independent of the originating service's availability — Non-repudiation: processing agents cannot disown quality attestations once anchored;
- Compliance with regulatory requirements (EU AI Act, NIS2, Defence procurement audit trails);
- Long-term preservation of quality metadata independent of the originating service's availability; and
- Non-repudiation: processing agents cannot disown quality attestations once anchored.

3.2.8. OGC DQ4IPT Building Block and OGC API Implementation ☆ Priority

Concept: Operationalize the DQ4IPT outcomes as a reusable **OGC Building Block** — as per the Building Block submitted during this testbed — to expose DQ4IPT capabilities as a composable, cross-API service accessible to any OGC API-conformant system.

Implementation:

- Package the DQ4IPT quality assessment and provenance pipeline as a formally described OGC Building Block with a machine-readable API definition, executable schema, and conformance class;
- Enable satellite sensor outputs, vector datasets, and Common Operating Picture (COP) layers to be submitted to the building block for DQ4IPT compliance validation, returning a structured response (JSON, RDF/Turtle, or STAC Item) with verified conformance status;
- Expose the building block as an OGC API – Processes endpoint (`POST /processes/dq4ipt-validate/jobs`) accepting input data references and returning quality + provenance annotations conformant with the Liability Claims STAC Extension;
- Require that validated outputs be referenced in an immutable catalogue (STAC, OGC API – Records) to preserve the chain of quality evidence; and
- Publish the Building Block to the OGC Building Blocks Register to enable discovery and reuse across testbed participants and production deployments.

Benefits:

- Simplifies DQ4IPT adoption across organizations by providing a single, well-documented integration surface rather than requiring per-system integration of multiple standards;
- Creates a transversal quality service applicable to all OGC API families (Processes, Records, Features, Maps);
- Enables automated DQ4IPT validity checks for any incoming digital information before storage or dissemination; and
- Supports federated quality governance: organizations can run their own building block instances while cross-validating against a shared OGC registry.

3.2.9. QGIS and Platform Client Support for IPT Functionality ☆ Priority

Concept: Develop native client-side support for DQ4IPT functionality within **QGIS** and other mainstream geospatial platforms (ArcGIS Pro, OpenLayers, GDAL/OGR toolchain), enabling field operators, analysts, and data managers to consume quality-annotated, provenance-tracked IPT outputs without requiring specialist technical knowledge of the underlying standards.

Implementation:

- Develop a **QGIS plugin** that connects to DQ4IPT-compliant services (OGC API – Records / Processes, STAC API with Liability Claims Extension) and renders quality and provenance metadata directly in the layer properties panel and map canvas;
- Expose ISO 19157 quality report elements (completeness, positional accuracy, thematic accuracy) as queryable layer attributes, filterable in QGIS expressions and symbology rules;
- Visualize W3C PROV graphs as an interactive lineage diagram within QGIS, navigable per feature or per raster tile;
- Provide a one-click "Verify Provenance" action that resolves the blockchain anchor (where present) and displays the tamper-evidence status alongside the layer metadata;
- Implement equivalent read/display support in web clients (OpenLayers / Leaflet plugin) and the GDAL metadata domain for command-line and scripting workflows; and
- Integrate with the **OGC DQ4IPT Building Block** API so that QGIS can submit layers for remote DQ4IPT validation and receive annotated STAC Items in return.

Benefits:

- Lowers the barrier to adoption by making quality and provenance information accessible within the tools already used by end-users (emergency responders, defense analysts, environmental agencies);
- Enables spatially-aware quality filtering: users can select only features or tiles meeting a defined quality threshold before analysis or dissemination;
- Bridges the gap between backend standards compliance (ISO 19157, W3C PROV, Liability Claims Extension) and frontline operational decision-making; and
- Supports the **Common Operating Picture (COP)** use case by surfacing classification, releasability, and provenance trust indicators directly in the map view.

3.3. Standardization Activities

3.3.1. OGC Standards Development

Recommendations for OGC

1. **Formalize STAC Quality Extension**: Submit Liability and Claims Extension to OGC for standardization as community standard;

2. **Develop OGC API — Quality**: Create dedicated API for querying and managing ISO 19157 quality metadata;
3. **Enhance RAINBOW Catalog**: Expand OGC RAINBOW quality measure catalog with:
    - ML/AI quality measures;
    - Real-time/streaming data quality measures;
    - Crowdsourced data quality measures; and
4. **Create Best Practices Guide**: Document recommended ISO 19157 implementation patterns for EO data.

3.3.2. ISO Standards Evolution

Recommendations for ISO/TC 211

1. **ISO 19157**: Develop domain-specific extensions for:
    - Machine learning training data;
    - Real-time/streaming data;
    - Crowdsourced data or Volunteered Geographic Information (VGI);
    - Synthetic/simulated data;
2. **Automated Quality Assessment**: Develop standard procedures for automated measure computation; and
3. **Metaquality Framework**: Expand metaquality concepts with operational guidelines.

3.3.3. W3C Coordination

Recommendations for W3C Integration

1. **PROV-GEO**: Create geospatial profile of PROV specifically for EO data processing;
2. **PROV-Quality**: Develop formal ontology linking PROV provenance to ISO 19157 quality; and
3. **Credential Schemas**: Standardize Verifiable Credential templates for quality assertions.

3.4. Community Adoption Challenges

3.4.1. Training and Education

Challenge: ISO 19157-1:2023 complexity creates adoption barrier

Mitigation Strategies: - Develop comprehensive training materials and workshops; - Create simplified "starter" profiles for common use cases; - Provide reference implementations and code examples; and - Establish certification programs for quality assessment practitioners.

3.4.2. Tool Ecosystem Development

Current Gap: Limited commercial tool support for ISO 19157-1:2023

Required Developments: - Desktop GIS integration (QGIS, ArcGIS Pro); - Web-based quality authoring tools; - Validation services (SaaS offerings); and - Migration tools for legacy ISO 19115 metadata.

3.4.3. Performance Optimization

Challenge: Comprehensive quality metadata increases payload sizes

Solutions: - Develop compression strategies for quality reports; - Implement lazy loading for quality metadata in APIs; - Create summary/aggregation patterns for collection-level quality; and - Optimize JSON-LD contexts for compact representation.

3.5. Research Directions

3.5.1. Quality Propagation Modeling

Research Question: How does quality propagate through processing chains?

Approach: - Develop mathematical models for quality uncertainty propagation; - Implement error propagation frameworks for multi-stage processing; and - Create simulation tools for quality prediction.

Application: Enable users to predict output quality before processing

3.5.2. User-Driven Quality Assessment

Research Question: How to integrate domain expert knowledge into quality frameworks?

Approach: - Develop crowd-sourced quality validation platforms; - Create reputation systems for quality assessors; and - Design user interfaces for Geospatial Data Interpretability Index (GDII) assessment capture.

Application: Supplement automated quality measures with expert judgment

3.5.3. AI-Assisted Quality Evaluation

Research Question: Can machine learning improve quality assessment efficiency?

Approach: - Training ML models to predict quality metrics from data characteristics; - Develop anomaly detection for quality outliers; and - Create recommender systems for fitness-for-purpose evaluation.

Application: Reduce manual quality assessment workload

3.6. Implementation Recommendations

For organizations implementing ISO 19157-based IPT frameworks:

1. **Start with Core Categories**: Begin with positional accuracy, completeness, and logical consistency before expanding to metaquality and Geospatial Data Interpretability Index (GDII);
2. **Leverage Existing Standards**: Build on ISO 19115 lineage and NASA UMM compatibility for smooth migration;
3. **Adopt STAC Extensions**: Use proven STAC Liability and Claims Extension pattern for cloud-native implementations;
4. **Validate Early and Often**: Implement JSON Schema validation in development pipelines;
5. **Document Measures**: Reference ISO 19157 register and OGC RAINBOW definitions for all measures;
6. **Maintain Provenance**: Generate W3C PROV graphs alongside ISO lineage for maximum interoperability; and

7. **Plan for Evolution**: Design systems to accommodate future enhancements (Verifiable Credentials, blockchain anchoring).

3.7. Conclusion

The harmonization of ISO 19115/19115 and ISO 19157 for Earth observation data quality represents a significant advancement in capabilities, particularly for IPT applications requiring trust assessment and fitness-for-purpose evaluation. The demonstrated interoperability with NASA UMM, TrainingDML-AI, and W3C PROV, combined with the practical implementation pattern provided by the STAC Liability and Claims Extension, creates a solid foundation for widespread adoption.

Key success factors for continued development include:

- **Standardization coordination** across OGC, ISO, and W3C;
- **Tool ecosystem development** to lower adoption barriers;
- **Community training** to build expertise in ISO 19157 implementation; and
- **Research investment** in quality propagation, ML integration, and automated assessment.

Organizations implementing IPT frameworks should adopt ISO 19157-1:2023 as their primary quality standard while maintaining backward compatibility with ISO 19115/19115-4 through the proven conversion patterns demonstrated in this testbed. The combination of standardized quality measures, metaquality assessment, and W3C PROV provenance provides the technical foundation for establishing trust in Earth observation data products.

4

SECURITY, PRIVACY AND ETHICAL CONSIDERATIONS

4 SECURITY, PRIVACY AND ETHICAL CONSIDERATIONS

Integrity, Provenance, and Trust (IPT) can be implemented in different ways. During previous OGC Testbeds, options under the Data Centric Security (DCS) were introduced. During this OGC Testbed the options to implement IPT as a separate ecosystem were introduced. Which is the best fitting approach depends on the use cases. Because DCS ties the security requirements with the data itself, the use cases must be clearly defined before a security scheme is designed and added to the data. Considering the High Efficiency Imagery Format (HEIF) as an example, one potential implementation of DCS for HEIF files is the C2PA Content Credentials Specification. When implementing IPT based on a separate ecosystem, the support for different use cases is more agile as demonstrated by the Testbed-21 IPT ecosystems (FACTS) that supports the IPT-Server 1.

Security in the context of IPT must not only consider the typical requirements like data integrity, confidentiality, and accessibility but also authenticity of processing actors (users or processes) that process data. With DCS, the implementation of these security requirements can easily be implemented for any newly generated data. But it is extremely difficult if not impossible to apply DCS to existing data. All existing data would have to exist in at least two different formats: the old unprotected format and the new DCS format. One could easily imagine that perhaps more than one DCS format will evolve over time. Therefore, the implementation of DCS for EO and other data that is used in international collaboration is not recommended.

The approach in the OGC Testbed-21 is based on establishing an IPT supporting ecosystem that allows for the keeping of data as is! The FACTS ecosystem that supports the IPT-Server 1 component introduces an immutable SpatioTemporal Asset Catalog (iSTAC) that stores metadata records for data assets on a blockchain. This ensures tamper resistance for the metadata records themselves. The metadata record (a STAC feature) is linked to the actual data asset via the data's hash. This allows to link data assets with trusted metadata records stored on an immutable catalog.

With this approach, any data asset can be associated to a metadata record for verifying genuineness. It does not matter where the data is stored, i.e. in the cloud, on the edge, on local drives, on USB stick, etc. as long as it is possible to calculate the data hash. With the data hash, a genuine check can be performed via the iSTAC API or via the Smart Contract on the blockchain itself. A genuine check verifies the data integrity and authenticity to establish trust into the data asset.

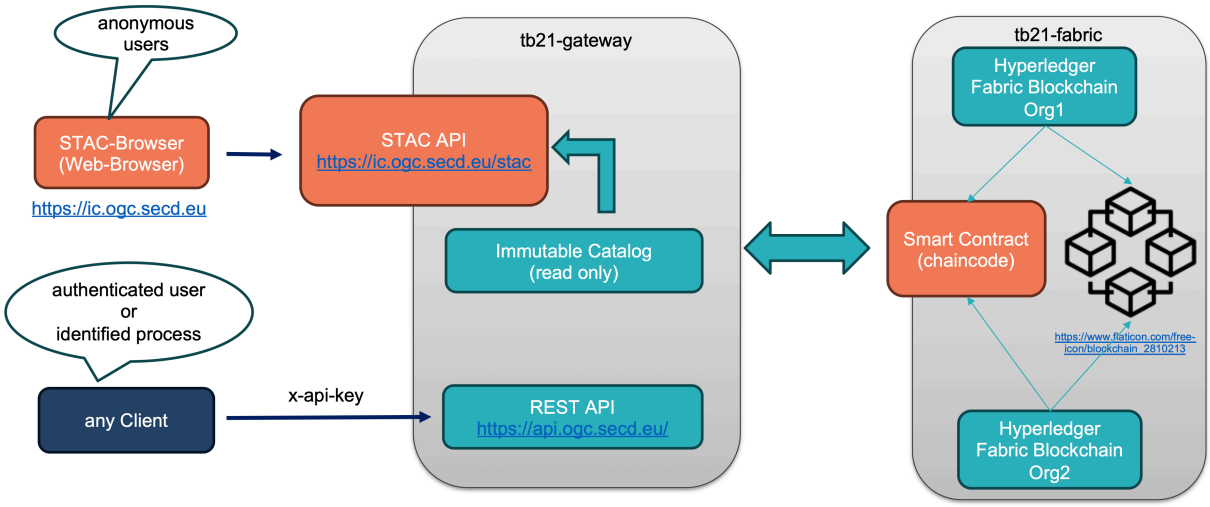

Figure 2 — Testbed-21 Secure Dimensions Immutable Catalog Components

Privacy in the context of IPT is concerned with the user and not with the data. In other words, privacy is about the user's information required to implement IPT. In simplified terms, the EU GDPR describes the conditions for the collection, storage and processing of user personal and personal identifiable information. For example, an email address must be considered user personal information and a geo location from GPS must be considered personal identifiable information. Regarding the implementation of IPT, it is important that collected user data by organization "A" cannot simply be pushed to other organizations unless the user has authorized that personal information forwarding. The rule of thumb to be considered when implementing IPT is that the user must be the acting entity that has full sovereignty over their personal data. For OGC Testbed-21 the FACTS ecosystem introduces the use of SSI (Self Sovereign Identifiers) combined with blockchain based certificates that guarantee that users stay on top of their personal data and can decide for which transaction a particular personal attribute shall be used. In a system of trusted processes, the use of certificates stored in user wallets paired with ZKP (Zero Knowledge Proof) ensures GDPR compliance.

Ethics in the context of IPT address the freedom of an acting user to be able to decline that personal information is being collected or processed without an harm. In other words, it is not ethical to push (force) the user into actions that they do not want. So, for example, the automated collection and processing of personal data without the user's approval must be considered non ethical. Therefore, when designing IPT the ethical considerations should be incorporated into the design. The Testbed-21 FACTS ecosystem can be considered ethical as it introduces SSI (Self Sovereign Identifiers) for users and ZKP (Zero Knowledge Proof) which allows the user to withhold non required personal information in a proof process. Furthermore, ZKP allows the user to proof being in possession of a particular personal attribute without releasing the attribute value.

5

DQ ENABLED IPT SERVER 1: OGC API – PROCESSES IMPLEMENTATION

5 DQ ENABLED IPT SERVER 1: OGC API — PROCESSES IMPLEMENTATION

This component implements an OGC API — Processes server that provides satellite imagery processing with comprehensive ISO 19115-4 JSON encoded data quality reporting and W3C PROV provenance tracking. The server demonstrates integration of quality metadata into Integrity, Provenance, and Trust frameworks through standardized API outputs.

5.1. Architecture Overview

The DQ-enabled IPT Server 1 implements the following architecture:

Table 21 — Server 1 Architecture Components

COMPONENT	DESCRIPTION
OGC API — Processes	RESTful API following OGC API — Processes 1.0 specification
Processing Engine	Satellite imagery processing pipeline
Quality Assessment Module	ISO 19115-4 quality metadata
Provenance Tracker	W3C PROV-JSON provenance graph generation for all processing steps
Metadata Generator	STAC-compliant metadata with `liability:quality` and `liability:prov` fields
Quality Data Integration	Quality measures from DQ4IPT Enabled Software Library
Output	STAC-compliant metadata uploaded to immutable STAC and processed imagery uploaded to IPFS

5.2. Aims

The aims of the DQ-enabled IPT Server 1 were to:

1. **Demonstrate ISO 19115-4 Integration**: Provide prototype implementation of comprehensive data quality reporting;
2. **Enable Provenance Tracking**: Generate W3C PROV graphs documenting complete processing lineage;
3. **Standardize Quality Measures**: Reference ISO 19157 registered measures as received from DQ4IPT Enabled Software Library; and
4. **Support Immutable STAC**: Upload STAC Items with quality metadata to Immutable Catalog via REST API.

5.3. Objectives

5.3.1. Primary Objectives

The primary objectives of the server were to:

1. **Implement OGC API — Processes**: Deploy conformant API offering satellite imagery processing;
2. **Quality Reports**: Import ISO 19115-4 JSON encoded quality assessments for all outputs from DQ4IPT Enabled Software Library;
3. **Track Provenance**: Document processing workflows using W3C PROV;
4. **Deliver STAC Outputs**: Format results as STAC Items with embedded quality metadata; and
5. **Store Processed Results**: Use IPFS to upload processed imagery and store content identifier (CID) in STAC metadata.

5.3.2. Technical Implementation

5.3.2.1. Process Definition

The server implements a satellite imagery processing workflow:

Process ID: `gs:trusted-watermarking`

Inputs:

- `image_url`: Satellite imagery thumbnail
- `meta_url`: STAC Item metadata for `image_url`

Outputs:

- STAC Item with quality and provenance metadata

Indirect Outputs:

- Processed image uploaded to IPFS
- STAC Item uploaded to Immutable STAC (FACTS blockchain)

5.3.2.2. Quality Assessment Implementation

The quality assessment module uses the ISO 19115-3 XML URL from the STAC Item referenced by the `meta_url` to call the DQ4IPT Enabled Software Library. The `dataQualityInfo` element from the response is integrated into the STAC Item.

5.3.2.3. Provenance Graph Structure

The W3C PROV provenance graph documents:

Entities:

- Source imagery (input imagery);
- Source metadata (input metadata);
- Intermediate product VC for input image;
- Intermediate product watermarked image;
- Intermediate product STAC Item based on liability and claims STAC extension;

Activities:

- Watermarking;
- Integrating quality assessment;
- Integrating provenance assessment;

Agents:

- Processing software (GeoServer 3.0.0 SNAPSHOT — Trusted Watermarking Process); and

- Responsible organization.


```
{
  "liability:prov": {
    "prefix": {
      "prov": "http://www.w3.org/ns/prov#",
      "ex": "http://ogc.org/testbed-21/dq4ipt#"
    },
    "entity": {
      "ex:source-imagery": {
        "prov:type": "prov:Entity",
        "prov:label": "Input Imagery (Sentinel-2 L1C)",
        "ex:role": "InputImagery"
      },
      "ex:source-metadata": {
        "prov:type": "prov:Entity",
        "prov:label": "Input Metadata (ISO 19115 / ISO 19157)",
        "ex:role": "InputMetadata"
      },
      "ex:vc-input-image": {
        "prov:type": "prov:Entity",
        "prov:label": "Verifiable Credential for Input Image",
        "ex:role": "IntermediateProductVC",
        "prov:wasDerivedFrom": "ex:source-imagery",
        "prov:wasGeneratedBy": "ex:watermarking"
      },
      "ex:watermarked-image": {
        "prov:type": "prov:Entity",
        "prov:label": "Watermarked Image (Trusted Watermark Applied)",
        "ex:role": "IntermediateProductWatermarkedImage",
        "prov:wasDerivedFrom": "ex:source-imagery",
        "prov:wasGeneratedBy": "ex:watermarking"
      },
      "ex:stac-item-liability": {
        "prov:type": "prov:Entity",
        "prov:label": "STAC Item (Liability Claims Extension)",
        "ex:role": "IntermediateProductSTACItem",
        "prov:wasDerivedFrom": ["ex:watermarked-image", "ex:source-metadata"],
        "prov:wasGeneratedBy": "ex:integrating-provenance-assessment"
      }
    },
    "activity": {
      "ex:watermarking": {
        "prov:type": "ex:Watermarking",
        "prov:label": "Trusted Watermarking Process",
        "prov:used": ["ex:source-imagery", "ex:source-metadata"],
        "prov:startTime": "2025-06-15T10:00:00Z",
        "prov:endTime": "2025-06-15T10:05:00Z",
        "prov:wasAssociatedWith": "ex:geoserver-software"
      },
      "ex:integrating-quality-assessment": {
        "prov:type": "ex:QualityAssessmentIntegration",
        "prov:label": "Integrating Quality Assessment (ISO 19157 DQ Report)",
        "prov:used": ["ex:watermarked-image", "ex:source-metadata"],
        "prov:wasInformedBy": "ex:watermarking",
        "prov:wasAssociatedWith": ["ex:geoserver-software", "ex:responsible-
organization"]
      },
      "ex:integrating-provenance-assessment": {
        "prov:type": "ex:ProvenanceAssessmentIntegration",
        "prov:label": "Integrating Provenance Assessment (W3C PROV-JSON into
STAC Item)",
```

```
        "prov:used": ["ex:watermarked-image", "ex:vc-input-image", "ex:source-
metadata"],
        "prov:wasInformedBy": "ex:integrating-quality-assessment",
        "prov:wasAssociatedWith": ["ex:geoserver-software", "ex:responsible-
organization"]
      }
    },
    "agent": {
      "ex:geoserver-software": {
        "prov:type": "prov:SoftwareAgent",
        "prov:label": "GeoServer 3.0.0-SNAPSHOT — Trusted Watermarking Process"
      },
      "ex:responsible-organization": {
        "prov:type": "prov:Organization",
        "prov:label": "Responsible Organization",
        "prov:actedOnBehalfOf": "ex:geoserver-software"
      }
    }
  }
}
```

Listing 8 — Example PROV structure

5.3.2.4. STAC Output

All processing outputs are delivered as STAC Items with embedded quality and provenance metadata:

```
{
    "stac_version": "1.0.0",
    "assets": {
        "PRODUCT": {
            "file:checksum": "1e2095c5b784a1ed6d616a009b43e088a7a3f73649a530bafb8
ebc76b1956ff84695",
            "alternate": {
                "FACTS_Browser_Cookie": {
                    "description": "In order to download the asset via a Web
Browser, you first need to establish a connection with your wallet via https://
assets.ogc.secd.eu/link so that the Asset Controller can request proof for FACTS
Certificates via that secure and private connection when you try to fetch the
Asset. Once you have a connection established, you can use the Download link
above to fetch the GeoPackage.",
                    "href": "https://assets.ogc.secd.eu/files/6b5614108583449cf0e
1ea3fb2c405139cf31be2fd2033f5bf79818ea42f83f1",
                    "title": "Download Asset via Web Browser session cookie",
                    "type": "image/jpeg"
                },
                "FACTS_API_Key": {
                    "auth": {
                        "refs": [
                            "apiKey"
                        ],
                        "roles": [
                            "download"
                        ],
                        "schemes": {
                            "flows": {
                                "authorizationCode": {
                                    "authorizationApi": "https://wallet.ogc.secd.
eu/user/x-facts-key",
```

```
                                    "method": "get",
                                    "responseField": "x-facts-key",
                                    "parameters": {
                                        "expires_in": {
                                            "schema": {
                                                "examples": "300",
                                                "type": "string"
                                            },
                                            "in": "query",
                                            "description": "the validity of the
token in seconds",
                                            "required": "true"
                                        }
                                    }
                                }
                            },
                            "in": "header",
                            "name": "X-FACTS-Key",
                            "description": "X-FACTS-Key represents the
connection between your Wallet and the Asset Controller to request proof of
required FACTS Certificates.",
                            "type": "apiKey",
                            "required": "true"
                        }
                    },
                    "description": "In order to download the asset via the API,
you first need to fetch an API-Key token (X-FACTS-Key) via https://wallet.ogc.
secd.eu/connections/select which must be submitted as HTTP Header `X-FACTS-Key`
with the asset URL from `Copy URL`. ",
                    "href": "https://assets.ogc.secd.eu/files/6b5614108583449cf0e
1ea3fb2c405139cf31be2fd2033f5bf79818ea42f83f1",
                    "title": "Download Asset via X-FACTS-Key",
                    "type": "image/jpeg"
                }
            },
            "href": "https://ipfs.ogc.secd.eu/files/6b5614108583449cf0e1ea3fb2c40
5139cf31be2fd2033f5bf79818ea42f83f1",
            "title": "Product",
            "type": "image/jpeg"
        }
    },
    "bbox": [
        95.91153308,
        25.92713265,
        96.09259599,
        26.08689352
    ],
    "geometry": {
        "coordinates": [
            [
                [
                    95.91153308,
                    26.08689352
                ],
                [
                    95.91153308,
                    25.92713265
                ],
                [
                    96.09259599,
                    25.92713265
                ],
                [
```

```
                    96.09259599,
                    26.08689352
                ],
                [
                    95.91153308,
                    26.08689352
                ]
            ]
        ],
        "type": "Polygon"
    },
    "links": [
        {
            "rel": "derived_from",
            "href": "https://emc.spacebel.be/collections/TropForest/items/KO2_
OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?httpAccept=appli
cation%2Fgeo%2Bjson%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org",
            "type": "application/geo+json",
            "title": "Source metadata"
        },
        {
            "rel": "self",
            "href": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt/items/
asset_1773241644929",
            "type": "application/geo+json",
            "title": "asset_1773241644929"
        },
        {
            "rel": "collection",
            "href": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt",
            "type": "application/json",
            "title": "test_dq4ipt"
        }
    ],
    "collection": "test_dq4ipt",
    "id": "asset_1773241644929",
    "type": "Feature",
    "stac_extensions": [
        "https://stac-extensions.github.io/file/v2.1.0/schema.json",
        "https://stac-extensions.github.io/alternate-assets/v1.1.0/schema.json",
        "https://stac-extensions.github.io/processing/v1.2.0/schema.json",
        "https://luciocola.github.io/stac-extension-liability-claims/json-schema/
schema.json"
    ],
    "properties": {
        "output": {
            "image_height": 92,
            "file:checksum": "1e2095c5b784a1ed6d616a009b43e088a7a3f73649a530bafb8
ebc76b1956ff84695",
            "metadata_url": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt/
items/asset_1773241644929",
            "image_url": "https://assets.ogc.secd.eu/files/6b5614108583449cf0e1ea
3fb2c405139cf31be2fd2033f5bf79818ea42f83f1",
            "image_width": 100,
            "image_type": "image/jpeg"
        },
        "liability:prov": {
            "agent": {
                "ex:responsible-organization": {
                    "prov:type": "prov:Organization",
                    "prov:label": "Responsible Organization",
                    "prov:actedOnBehalfOf": "ex:geoserver-software"
                },
```

```
                "ex:geoserver-software": {
                    "prov:type": "prov:SoftwareAgent",
                    "prov:label": "GeoServer 3.0.0-SNAPSHOT u2014 Trusted
Watermarking Process"
                }
            },
            "activity": {
                "ex:watermarking": {
                    "prov:used": [
                        "ex:source-imagery",
                        "ex:source-metadata"
                    ],
                    "prov:startTime": "2026-03-11T15:07:24Z",
                    "prov:wasAssociatedWith": "ex:geoserver-software",
                    "prov:type": "ex:Watermarking",
                    "prov:label": "Trusted Watermarking Process",
                    "prov:endTime": "2026-03-11T15:07:24Z"
                },
                "ex:integrating-provenance-assessment": {
                    "prov:used": [
                        "ex:watermarked-image",
                        "ex:vc-input-image",
                        "ex:source-metadata"
                    ],
                    "prov:wasAssociatedWith": [
                        "ex:geoserver-software",
                        "ex:responsible-organization"
                    ],
                    "prov:type": "ex:ProvenanceAssessmentIntegration",
                    "prov:label": "Integrating Provenance Assessment (W3C PROV-
JSON into STAC Item)",
                    "prov:wasInformedBy": "ex:integrating-quality-assessment"
                },
                "ex:integrating-quality-assessment": {
                    "prov:used": [
                        "ex:watermarked-image",
                        "ex:source-metadata"
                    ],
                    "prov:wasAssociatedWith": [
                        "ex:geoserver-software",
                        "ex:responsible-organization"
                    ],
                    "prov:type": "ex:QualityAssessmentIntegration",
                    "prov:label": "Integrating Quality Assessment (ISO 19157 DQ
Report)",
                    "prov:wasInformedBy": "ex:watermarking"
                }
            },
            "prefix": {
                "ex": "http://ogc.org/testbed-21/dq4ipt#",
                "prov": "http://www.w3.org/ns/prov#"
            },
            "entity": {
                "ex:source-imagery": {
                    "prov:type": "prov:Entity",
                    "prov:label": "Input Imagery (Sentinel-2 L1C)",
                    "ex:role": "InputImagery"
                },
                "ex:watermarked-image": {
                    "prov:wasDerivedFrom": "ex:source-imagery",
                    "prov:wasGeneratedBy": "ex:watermarking",
                    "prov:type": "prov:Entity",
```

```
                    "prov:label": "Watermarked Image (Trusted Watermark
Applied)",
                    "ex:role": "IntermediateProductWatermarkedImage"
                },
                "ex:vc-input-image": {
                    "prov:wasDerivedFrom": "ex:source-imagery",
                    "prov:wasGeneratedBy": "ex:watermarking",
                    "prov:type": "prov:Entity",
                    "prov:label": "Verifiable Credential for Input Image",
                    "ex:role": "IntermediateProductVC"
                },
                "ex:stac-item-liability": {
                    "prov:wasDerivedFrom": [
                        "ex:watermarked-image",
                        "ex:source-metadata"
                    ],
                    "prov:wasGeneratedBy": "ex:integrating-provenance-
assessment",
                    "prov:type": "prov:Entity",
                    "prov:label": "STAC Item (Liability Claims Extension)",
                    "ex:role": "IntermediateProductSTACItem"
                },
                "ex:source-metadata": {
                    "prov:type": "prov:Entity",
                    "prov:label": "Input Metadata (ISO 19115 / ISO 19157)",
                    "ex:role": "InputMetadata"
                }
            }
        },
        "processing:level": "L1",
        "input": {
            "image": {
                "image_height": 92,
                "file:checksum": "1220e76930f8123c4fc42abd0f6c9d22cd5daa24785b6fc
bf43891f6e76263be43dd",
                "image_url": "https://tpm-ds.eo.esa.int/oads/meta/Tropforest/
thumbnail/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.
ZIP_TIMG.jpg",
                "image_width": 100,
                "image_type": "image/jpeg;charset=UTF-8"
            },
            "metadata": {
                "metadata_url": "https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application%2Fgeo%2Bjson%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org",
                "vc_url": "https://emc.spacebel.be/collections/TropForest/items/
KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?httpAccept=
application/vc%2Bld%2Bjson",
                "VC_verification": true,
                "VC": {
                    "relatedResource": [
                        {
                            "digestMultibase": "zQmYRMC8UMw4ipWvivUKvzvTWrjbKk1oy
wH1QpoY6w3tCQX",
                            "id": "https://schemas.opengis.net/eo-geojson/1.0/eo-
geojson.jsonld"
                        },
                        {
                            "digestMultibase": "zQmXqCSMRKhzJm6JnhLAVL7seE13dZG7u
JscvTXANw4jmJr",
                            "id": "http://tpm-ds.eo.esa.int/oads/meta/Tropforest/
browse/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.ZIP_
BID.JPG"
```

```
                        },
                        {
                            "digestMultibase": "zQmduyvHCpCQTv51KqbuQih8vs4cRcS9D
dKnUYeuNnzfosr",
                            "id": "http://tpm-ds.eo.esa.int/oads/meta/Tropforest/
thumbnail/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.
ZIP_TIMG.jpg"
                        }
                    ],
                    "credentialSubject": {
                        "date": "2009-11-21T03:27:23Z/2009-11-21T03:27:23Z",
                        "bbox": [
                            95.91153308,
                            25.92713265,
                            96.09259599,
                            26.08689352
                        ],
                        "geometry": {
                            "coordinates": [
                                [
                                    [
                                        95.91153308,
                                        26.08689352
                                    ],
                                    [
                                        95.91153308,
                                        25.92713265
                                    ],
                                    [
                                        96.09259599,
                                        25.92713265
                                    ],
                                    [
                                        96.09259599,
                                        26.08689352
                                    ],
                                    [
                                        95.91153308,
                                        26.08689352
                                    ]
                                ]
                            ],
                            "type": "Polygon"
                        },
                        "links": {
                            "data": [
                                {
                                    "href": "https://tpm-ds.eo.esa.int/oads/data/
Tropforest/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.
ZIP",
                                    "title": "Download",
                                    "type": "application/x-binary"
                                }
                            ],
                            "previews": [
                                {
                                    "href": "http://tpm-ds.eo.esa.int/oads/meta/
Tropforest/browse/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026.ZIP_BID.JPG",
                                    "title": "QUICKLOOK",
                                    "type": "image/jpeg"
                                },
                                {
```

```
                                    "href": "http://tpm-ds.eo.esa.int/oads/meta/
Tropforest/thumbnail/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026.ZIP_TIMG.jpg",
                                    "title": "THUMBNAIL",
                                    "type": "image/jpeg"
                                }
                            ]
                        },
                        "id": "did:web:emc.spacebel.be:collections:TropForest:
items:KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026",
                        "title": "KO2_OTPF_KO2_MSC_2F_20091121T032723_
20091121T032723_017702_E096_N026",
                        "updated": "2024-04-30T11:32:32Z"
                    },
                    "issuanceDate": "2026-03-11T15:07:22Z",
                    "id": "did:web:emc.spacebel.be:collections:TropForest:items:
KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026",
                    "proof": {
                        "created": "2026-03-11T15:07:22.696Z",
                        "jws": "eyJhbGciOiJFUzI1NksiLCJraWQiOiJiQnpXOHlHeEt1RUNMa
l9JeFNyTkN1eVJKOUppZ2ptTU9DeDJGZHpDcnFBIiwiY3JpdCI6WyJiNjQiXSwiYjY0IjpmYWxzZX0..o
pXmcXQlUvxz9q6Bbyn7BPLmHm3U1x4pxJsOmqB197RM77L2oRz38cCYOKzAxVHzIIrYBZIj3Ygfap36e3
OqDQ",
                        "proofPurpose": "assertionMethod",
                        "type": "EcdsaSecp256k1Signature2019",
                        "verificationMethod": "did:web:emc.spacebel.be:
organisations:esa_esrin#owner"
                    },
                    "type": [
                        "VerifiableCredential",
                        "Feature"
                    ],
                    "@context": [
                        "https://www.w3.org/2018/credentials/v1",
                        "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.
jsonld",
                        {
                            "digestMultibase": {
                                "@type": "https://w3id.org/security#multibase",
                                "@id": "https://w3id.org/
security#digestMultibase"
                            },
                            "relatedResource": {
                                "@type": "@id",
                                "@id": "https://www.w3.org/2018/
credentials#relatedResource"
                            }
                        }
                    ],
                    "issuer": "did:web:emc.spacebel.be:organisations:esa_esrin"
                }
            },
            "image_hash_verified": true
        },
        "datetime": "2026-03-11T15:07:24Z",
        "start_datetime": "2009-11-21T03:27:23Z",
        "end_datetime": "2009-11-21T03:27:23Z",
        "processing:facility": "Secure Dimensions Processes",
        "processing:lineage": "Watermarking Process",
        "processing:datetime": "2026-03-11T15:07:24Z",
        "liability:quality": {
            "scope": {
                "level": "dataset"
```

```
            },
            "report": [
                {
                    "result": [
                        {
                            "valueRecordType": "decimal",
                            "type": "QuantitativeResult",
                            "value": [
                                4.0
                            ]
                        }
                    ],
                    "measure": {
                        "measureIdentification": {
                            "code": "7",
                            "codeSpace": "https://standards.isotc211.org/19157/-
3/1/dqc/content/qualityMeasure/"
                        },
                        "measureDescription": "Cloud cover",
                        "nameOfMeasure": [
                            "Percentage of image obscured by cloud"
                        ]
                    },
                    "evaluationMethod": [
                        {
                            "evaluationMethodType": "directInternal",
                            "type": "FullInspection"
                        }
                    ],
                    "type": "CompletenessOmission"
                }
            ]
        },
        "processing:software": {
            "name": "Geoserver",
            "version": "3.0-SNAPSHOT"
        }
    }
}
```


Listing 9 — STAC Item Example

5.3.3. Validation and Testing

5.3.3.1. Conformance Testing

The server undergoes conformance testing for:

- **OGC API — Processes**: Compliance with OGC API — Processes 1.0 specification; and
- **STAC Specification**: Conformance with STAC 1.0.0 and liability-claims extension.

5.3.3.2. Quality Measure Validation

Quality measures are validated against:

- **STAC Liability and Claims extension**: https://luciocola.github.io/stac-extension-liability-claims/json-schema/schema.json

5.3.4. Deployment Considerations

5.3.4.1. Infrastructure Requirements

- **Runtime**: GeoServer 3.0 SNAPSHOT (Java + Tomcat)
- **Dependencies**: Java libraries see below
- **Storage**: IPFS
- **Database**: PostgreSQL with PostGIS for metadata storage
- **Blockchain** Hyperledger Fabric

```
import com.danubetech.dataintegrity.verifier.LdVerifier;
import com.danubetech.dataintegrity.verifier.LdVerifierRegistry;
import com.danubetech.keyformats.crypto.ByteVerifier;
import com.danubetech.keyformats.crypto.PublicKeyVerifier;
import com.danubetech.keyformats.crypto.PublicKeyVerifierFactory;
import com.danubetech.keyformats.jose.JWK;
import com.danubetech.keyformats.jose.KeyTypeName;
import com.danubetech.verifiablecredentials.VerifiableCredential;
import com.google.gson.Gson;
import foundation.identity.jsonld.ConfigurableDocumentLoader;
import foundation.identity.jsonld.JsonLDException;
import io.grpc.ChannelCredentials;
import io.grpc.Grpc;
import io.grpc.ManagedChannel;
import io.grpc.TlsChannelCredentials;
import io.ipfs.multibase.Multibase;
import io.ipfs.multihash.Multihash;
import org.apache.commons.io.IOUtils;
import org.geoserver.wps.gs.GeoServerProcess;
import org.geotools.process.factory.DescribeParameter;
import org.geotools.process.factory.DescribeProcess;
import org.geotools.process.factory.DescribeResult;
import org.hyperledger.fabric.client.*;
import org.hyperledger.fabric.client.identity.*;
import org.hyperledger.fabric.client.identity.Identity;
import org.hyperledger.fabric.client.identity.Signer;
import org.json.simple.JSONArray;
import org.json.simple.JSONObject;
import org.json.simple.parser.JSONParser;
import org.json.simple.parser.ParseException;
```

```
import javax.imageio.ImageIO;
import javax.net.ssl.HttpsURLConnection;
import java.awt.*;
import java.awt.image.BufferedImage;
import java.io.*;
import java.lang.reflect.InvocationTargetException;
import java.net.*;
import java.net.http.HttpClient;
import java.net.http.HttpRequest;
import java.net.http.HttpResponse;
import java.nio.file.Files;
import java.nio.file.Path;
import java.nio.file.Paths;
import java.security.*;
import java.security.cert.CertificateException;
import java.security.cert.X509Certificate;
import java.text.DateFormat;
import java.text.SimpleDateFormat;
import java.time.Instant;
import java.util.*;
import java.util.List;
import java.util.concurrent.TimeUnit;
```

Listing 10 — Java library dependencies

5.3.4.2. API Endpoints

Key endpoints following OGC API — Processes (https://geoserver.ogc.secd.eu/geoserver/ogc/processes/v1/processes):

- `GET /processes` — List available processes;
- `GET /processes/gs:TrustedWatermarking` — Process description; and
- `POST /processes/gs:TrustedWatermarking/execution` — Execute process.

No `job` endpoints are required as the execution is synchronous.

5.3.5. Integration with IPT Framework

The server demonstrates IPT principles through:

1. **Integrity**: Cryptographic hashing of outputs (IPFS CID);; and
2. **Trust**: Verifiable quality assessments via STAC metadata on blockchain.

All outputs reference standardized quality measures ensuring consistent interpretation across organizations implementing IPT frameworks.

6

DQ ENABLED IPT SERVER 2: OGC API – RECORDS IMPLEMENTATION

6 DQ ENABLED IPT SERVER 2: OGC API — RECORDS IMPLEMENTATION

This component implements an OGC API-Records and STAC-API compliant catalogue server that provides access to satellite imagery metadata with embedded ISO 19115-4 data quality reports and ISO19115-4 compliant provenance information when available. The server demonstrates discovery and retrieval of quality-assured Earth observation data through standardized catalog interfaces it is integrated with an IPT-enabled framework based on W3C DID and Verifiable Credentials.

6.1. Architecture Overview

The DQ-enabled IPT Server 2 implements the following architecture:

Table 22 — Server 2 Architecture Components

COMPONENT	DESCRIPTION
OGC API-Records Catalogue Server	Multi-organization catalogue with RESTful API following OGC API-Records 1.0 and STAC API specifications. Supports content-negotiation to return ISO19115-4 or other metadata flavours (e.g. STAC, OGC 17-003r2, etc.).
Verifiable Data Registry	Registry providing access to W3C DID documents for resources and W3C Verifiable Credentials for EO products. The Registry implements an API as defined in DID Document Property Extensions.
STAC API-Extensions	Implements STAC API extensions: Filter, Fields, Sort, Collection Search, CQL2-JSON, CQL2-Text, etc.
DIF Universal Resolver	Online resolver at https://dev.uniresolver.io/ that can be used to resolve public DID.
Universal Verifier	Online verifier at https://univerifier.io/ that can be used to verify W3C Verifiable Credentials and Presentations.
STACBrowser	Open-source STAC Catalogue client that can access the OGC API-Records Catalogue Server https://radiantearth.github.io/stac-browser/#/external/emc.spacebel.be/?.language=en.
Jupyter Notebook	Notebook acting as Catalogue Client demonstrating the various interfaces and metadata responses implemented by the DQ-enabled IPT Server.

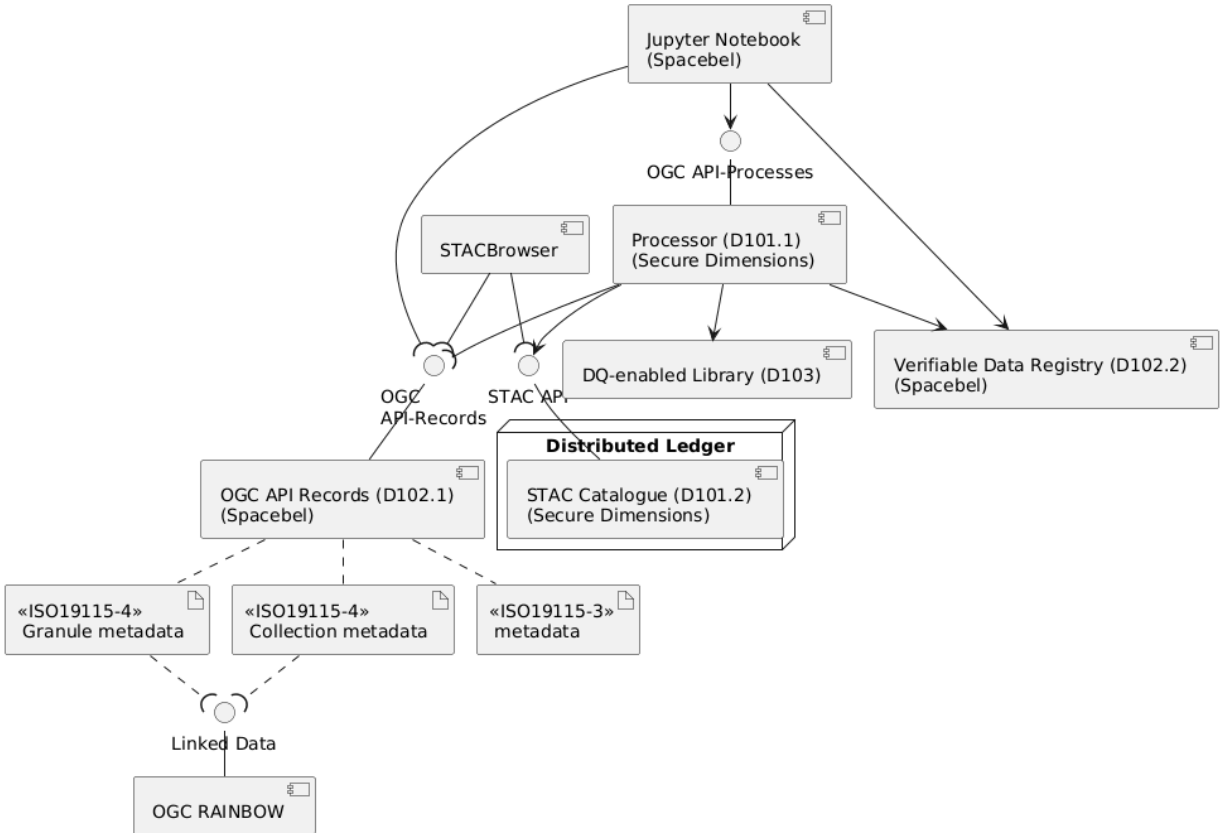

Figure 3 — Component Diagram

6.2. Objectives

The objectives of the DQ-enabled IPT Server 2 are to:

1. **Enable Discovery**: Provide search and filtering capabilities;
2. **Standardized Metadata Encoding**: Support STAC metadata encoding and implement ISO19115-4 JSON metadata encoding for collections and granules (products);
3. **Quality Reports** : Provide examples of Quality Reports in the EO domain encoded with ISO19115-4 referencing ISO19157 quality measures available in RAINBOW;
4. **Provenance Metadata** : Provide examples of Provenance metadata in the EO domain encoded with ISO19115-4 complementing the provenance information inherent to the use of DID and related crypographical proof verification;
5. **Standardized Catalog Access**: Implement OGC API-Records and STAC API specifications; and

6. **Support Trust and Integrity Assessment**: Publish resolvable W3C DID for EO resources and organizations and W3C Verifiable Credentials for EO products allowing cryptographical proof verification of origin of the metadata and integrity of metadata claims, including integrity of referenced external resources.

6.3. Technical Implementation

6.3.1. Catalog Organization

The catalogue is based on the CEOS FedEO and ESA MAAP Catalogue server implementations. The server organizes metadata as STAC Collections and Items. Collections may be "local" or obtained from federated catalogues. Items from external catalogues are accessed via distributed search and the server performs metadata format conversions as needed.

Collections (top-level groupings):

- Collections from multiple agencies (ISO19139-2, ISO19115-3, ISO19115-4, OGC 17-084r1, STAC, etc.);
- Each collection represented as STAC Collection;
- ISO 19157 metadata with quality reports/measures (if available) accessible as STAC asset;
- DID representing the collection included in the metadata (ISO19115-4, STAC Collection);
- Organization (e.g., agency) identified with a DID identifier/document; and
- ISO19115-4 encoding of CEOS ARD quality information used as examples of quality reports.

Items (individual products):

- Each product represented as STAC Item;
- DID representing the product included in the metadata (ISO19115-4, STAC Item);
- Product components including quicklooks represented as STAC assets;
- ISO 19157, ISO 19115-3 and ISO 19157-2 metadata with quality reports/measures accessible as STAC asset;
- Quality measure identifiers referring (i.e. identical to) to measure identifiers registered on OGC RAINBOW;
- W3C Verifiable Credential for the product represented as STAC asset;

- Provenance information (if available) via STAC Processing Extension, ISO19115-4 lineage complemented with `issuer/holder` DID (Document) information; and
- ISO19115-4 encoding of OGC17-003r2 quality information used as examples for quality reports (e.g., Biomass).

W3C DID (Decentralized Identifiers):

- Data Provider organizations represented by DID identifier (issuer/holder/verifier). Organizations are assumed to self-identify by having created a DID; In these cases, the DID subject is also the DID controller;
- Data Provider DID resolves to DID Document with public key information for integrity checks;
- EO Collection represented by DID identifier;
- EO Product represented by DID identifier;
- DID resolve to DID documents; and
- DID documents reference service to obtain Verifiable Credentials (Data Model v1.0 or 2.0) .

6.3.2. OGC API-Records Catalogue Server

The catalogue interfaces include but are not limited to OGC API-Records and STAC API. The diagram below shows the resources corresponding to the RESTful interface covering these two interfaces.

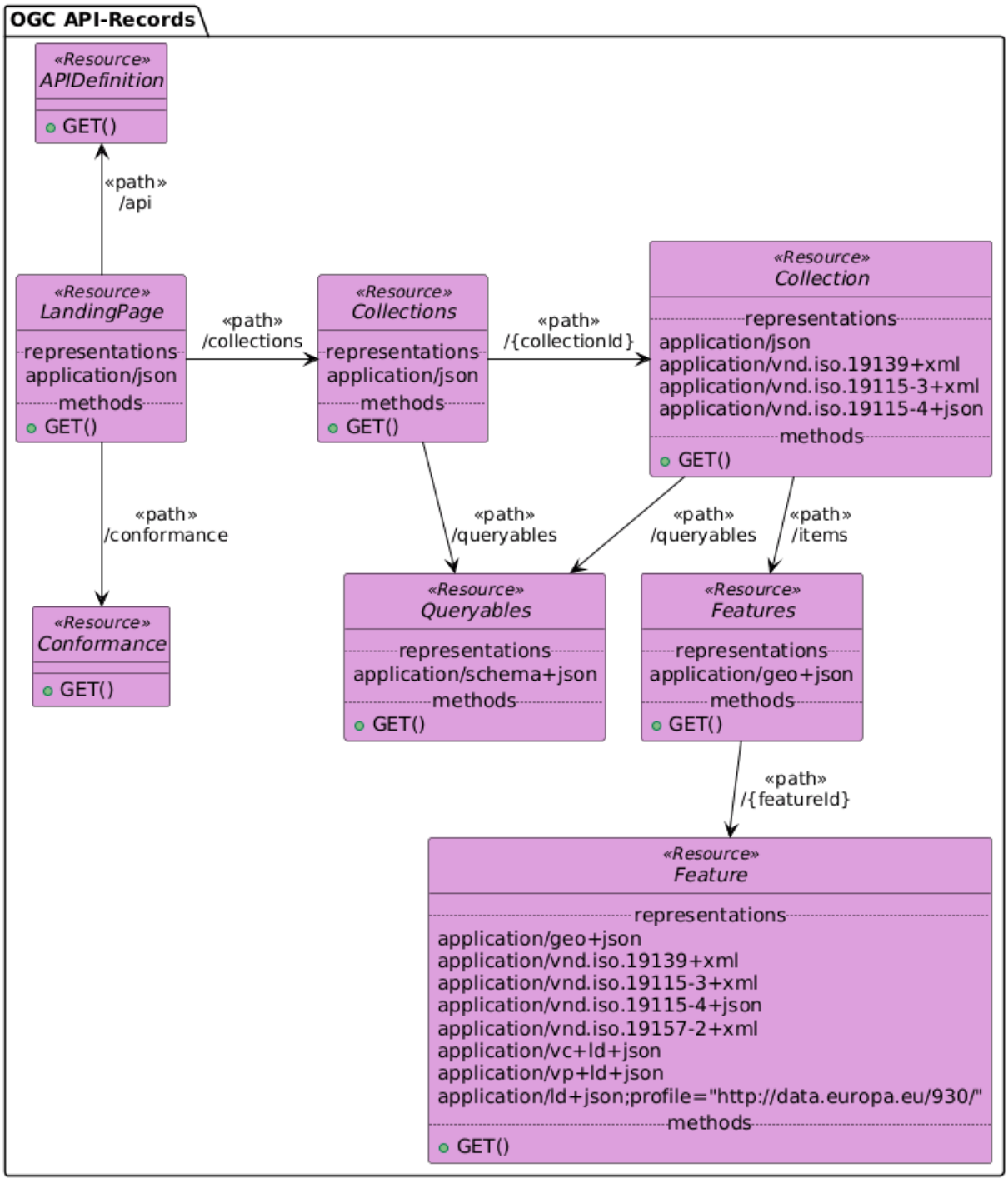

Figure 4 — Resource Diagram

6.3.3. Verifiable Data Registry

The DIF (Decentralized Identity Foundation) Linked Verifiable Presentation specification defines how to share, discover and retrieve Verifiable Credentials publicly via a service entry in a "DID Document". The W3C DID Property Extensions furthermore defines how to refer to

the Credential Registry where the Verifiable Credentials for a subject can be retrieved. Both extensions are used in the prototype implementation and the above example.

The following shows how the `vp` service can be used through a Universal Resolver:

https://api.godiddy.com/0.1.0/universal-resolver/identifiers/did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001?service=vp

An example of a call to the Credential Registry (VC 1.0):

- https://emc.spacebel.be/registry/vcs/did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001

Example calls to the Credential Registry for subjects with multiple VCs (VC 1.0 and VC 2.0):

- https://emc.spacebel.be/registry/vcs/did:web:emc.spacebel.be:collections:b673f41b-d934-49e4-af6b-44bbdf164367:items:urn%3Aeop%3ADLR%3AEOWEB%3ANOAA.AVHRR.LST_D%3A@dims_op_pl_dfd_XXXXB000000027082961040 4@dims_op_pl_dfd_@@NOAA.AVHRR.LST_D

- https://emc.spacebel.be/registry/vcs/did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:items:A2GL10301010301310_PNW000B000M0002100000

Example calls to the Credential Registry to get DID documents:

- https://emc.spacebel.be/registry/did/did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km

- https://emc.spacebel.be/registry/did/did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001

The interface to the Credential Registry was implemented using a part of the interface proposed in https://www.w3.org/TR/did-extensions-properties/#credentialregistry and partly represented below.

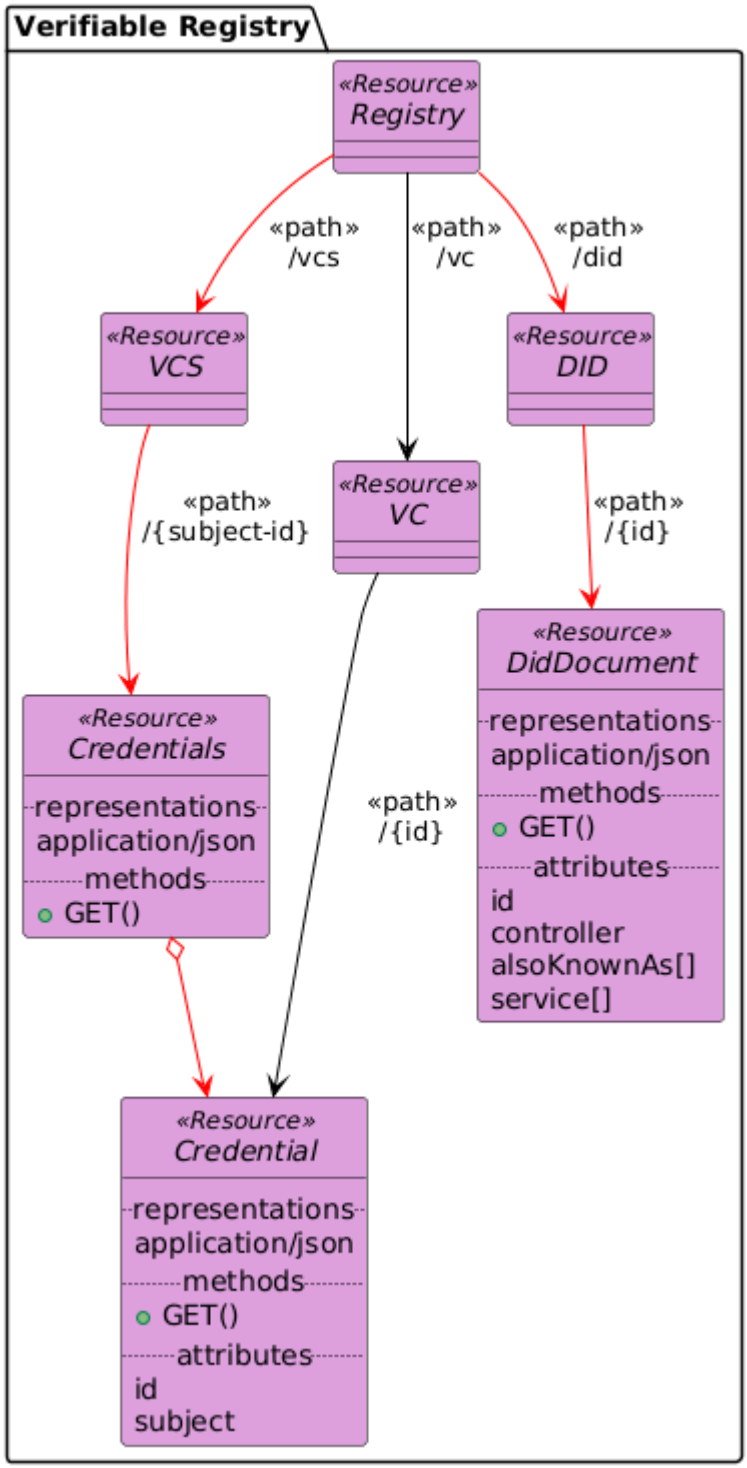

Figure 5 — Resource Diagram

The DIDs can also be resolved using the Universal Resolver endpoint https://dev.uniresolver.io/1.0/identifiers/<did> using content negotiation (application/json).

The various DID are recorded in the `Verifiable Data Registry` which supports returning data necessary to produce the corresponding DID documents. Although the DID use the `Web` method for simplicity, other DID methods might be applied as well.

6.3.4. Metadata

6.3.4.1. STAC Item

The digital identifiers of the resources described in the catalogue are included in the metadata (e.g. ISO19115-4 or STAC) in the catalogue as shown below. In the below collection example, a DOI and DID are both available.

```
{
    "date": {
        "creation": "2019-05-23"
    },
    "identifier": [
        {
            "code": "10.5270/esa-qoe849q",
            "codeSpace": "https://doi.org"
        },
        {
            "code": "did:web:emc.spacebel.be:collections:TropForest",
            "codeSpace": "https://www.w3.org/ns/did/v1"
        }
    ],
    "title": "TropForest"
}
```

Listing 11

In STAC Items and Collections, the DID identifier is encoded with the STAC Additional Identifiers Extension.

```
{
  "stac_version": "1.0.0",
  "type": "Feature",
  "stac_extensions": [
    "https://stac-extensions.github.io/external-ids/v1.0.0/schema.json"
  ],
  "properties": {
    "externalIds": [{
      "scheme": "https://www.w3.org/ns/did/v1",
      "value": "did:web:emc.spacebel.be:collections:TropForest:items:KO2_OTPF_
KO2_MSC_2F_20090813T143026_20090813T143026_016247_W060_S022"
    }]
  }
}
```

Listing 12

6.3.4.2. ISO19115-4

The catalogue served through the OGC API-Records instance provides access to metadata records of EO collections and EO products.

The following quality-related metadata is provided in the ISO19115-4 format:

- Encoding of Analysis Ready Data quality information (See Example 1.3 in the Notebook (Annex E)); and
- Encoding of Data Management and Stewardship Maturity Matrix quality information (Example 1.5 in the Notebook (Annex E))

Furthermore, the Quality Information available in the OGC 17-003r2 metadata is transformed into ISO19115-4 conformant metadata according to the following mapping and a default quality information is provided if this information is missing in the source format. An extract of the returned ISO19115-4 encoding is included in Example 2.1 in the Notebook (Annex E).

The product metadata in the ESA Catalogue is encoded as OGC 17-003r2 metadata. Quality information may be available in the `QualityInformation` and the `qualityStatus` flag. This flag can be `DEGRADED` or `NOMINAL` and thus be encoded using the ISO19157-3 measure at https://defs-hosted.opengis.net/prez-hosted/catalogs/hosted:iso-19157-3/collections/ns10:qualityMeasure/items/qualitymeasure:101

```
"productInformation": {
    "qualityInformation": {
        "qualityDegradationQuotationMode": "MANUAL",
        "qualityStatus": "DEGRADED",
        "qualityDegradationTag": "RADIOMETRY",
        "qualityDegradation": 10.0
    }
}
```

Listing 13

```
"productInformation": {
    "cloudCover": 4,
    "qualityInformation": {
        "qualityDegradationQuotationMode": "AUTOMATIC",
        "qualityStatus": "NOMINAL",
        "qualityDegradation": 0.0
    }
}
```

Listing 14

Table 23 — Mapping from OGC 17-003r2 quality fields to ISO 19157-3 and ISO 19115-4

OGC 17-003R2	ISO19157/ISO19115-4	OGC RAINBOW
qualityDegradationQuotationMode	evaluationMethod	

OGC 17-003R2	ISO19157/ISO19115-4	OGC RAINBOW
qualityStatus	measure “data product specification passed” (ConceptualConsistency)	https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/101
qualityDegradation	measure “rate of imperfect coverage” (Omission)	https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/211
cloudCover	measure “rate of missing items” (Omission)	https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/7
snowCover	measure “rate of missing items” (Omission)	https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/7

The table below shows the mapping that was implemented to encode the provenance information available for products from OGC 17-003r2 format to STAC and ISO19115-4. The `processing:lineage` property in the STAC Processing Extension is limited to a single string. The same STAC Extension recommends using the `derived_from` relation in a STAC link to refer to the STAC metadata of the item(s) that are used for producing the STAC Item.

Table 24 — Mapping from OGC 17-003r2 processing metadata to ISO 19115-3/4 and STAC

OGC17-003R2	ISO19115-3/4	STAC	EXAMPLE
processingCenter	processStep[].processor[]. party (organisation)	processing:facility	“Biomass CPF”
processingLevel	identificationInfo. processingLevel.code	processing:level	“1A”
processorName	processStep[].processing Information[]. software Reference.title	processing:software	“Biomass L1 Processor”
processorVersion	processStep[].processing Information[]. software Reference.edition	processing:software	“3.3.3”
processingDate	processStep[].stepDate Time	processing:datetime	“2025-07-03T03:45:31Z”

A sample of the `BiomassLevel1aIOC` collection from ESA MAAP is available at https://radiantearth.github.io/stac-browser/#/external/emc.spacebel.be/collections/BiomassLevel1aIOC The STAC Items of this collection have `assets` with ISO19115-4 metadata. This metadata includes quality information and provenance information produced from the source OGC 17-003r2 metadata as explained above.

The Provenance (lineage) Information available in the OGC 17-003r2 metadata is transformed by the catalogue into ISO19115-4 as shown in Example 2.6. Unfortunately, the available ISO19115-4 JSON schemas in the ISO Guthub repository contain an incomplete definition of `LI_Lineage` without `processStep`. The original mdj.json JSON schema was extended based on the ISO19115-3 Metadata for Resource Lineage (MRL) with the following types to be able to express the detailed provenance information:

- LE_Source
- LE_ProcessStep
- LE_ProcessStepReport
- LE_Algorithm
- LE_Processing
- LE_NominalResolution

The Example 2.6 in the Notebook (Annex E) can actually be produced from the corresponding BiomassLevel1aIOC OGC 17-003r2 metadata in ESA MAAP.

6.3.4.3. DIDs and DID Documents

The Testbed participants propose to identify `products` with a W3C DID identifier, these `products` may be single-file products or directory products. The directory products may correspond to unpacked `EO-SIP` (EO Submission Information Package) packages from a long-term archive. The original product corresponds to the assets in the red dashed line in the diagram above. As these product files (assets) may be in public S3 bucket for dissemination purposes, a way to be able to verify the provenance and authenticity of the `product` is of interest.

While many organizations now make available their EO Products in on-line object storage (S3), the product metadata format accompanying the data may vary.

The simulated environment consists of various organizations that self-identify by having created a DID. In these cases, the DID subject is also the DID controller (See B.9.1 of https://www.w3.org/TR/did-1.0/#data-model).

- did:web:emc.spacebel.be:organisations:esa_esrin
- did:web:emc.spacebel.be:organisations:csiro
- did:web:emc.spacebel.be:organisations:br_inpe
- did:web:emc.spacebel.be:organisations:ceos
- did:web:emc.spacebel.be:organisations:de_dlr

Also the different EO collections and EO products/granules are identified by DID. In this case, the DID controller differs from the DID subject.

Table 25 — DID subject types, examples, and controllers (Server 2)

DID SUBJECT TYPE	DID SUBJECT EXAMPLE	DID CONTROLLER
Organisation	did:web:emc.spacebel.be:organisations:esa_esrin	did:web:emc.spacebel.be:organisations:esa_esrin
EO Collection	did:web:emc.spacebel.be:collections: PROBA.HRC.1A	did:web:emc.spacebel.be:organisations:esa_esrin
EO Product	did:web:emc.spacebel.be:collections: PROBA.HRC.1A:items: PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001	did:web:emc.spacebel.be:organisations:esa_esrin

The DID resolve to DID documents.

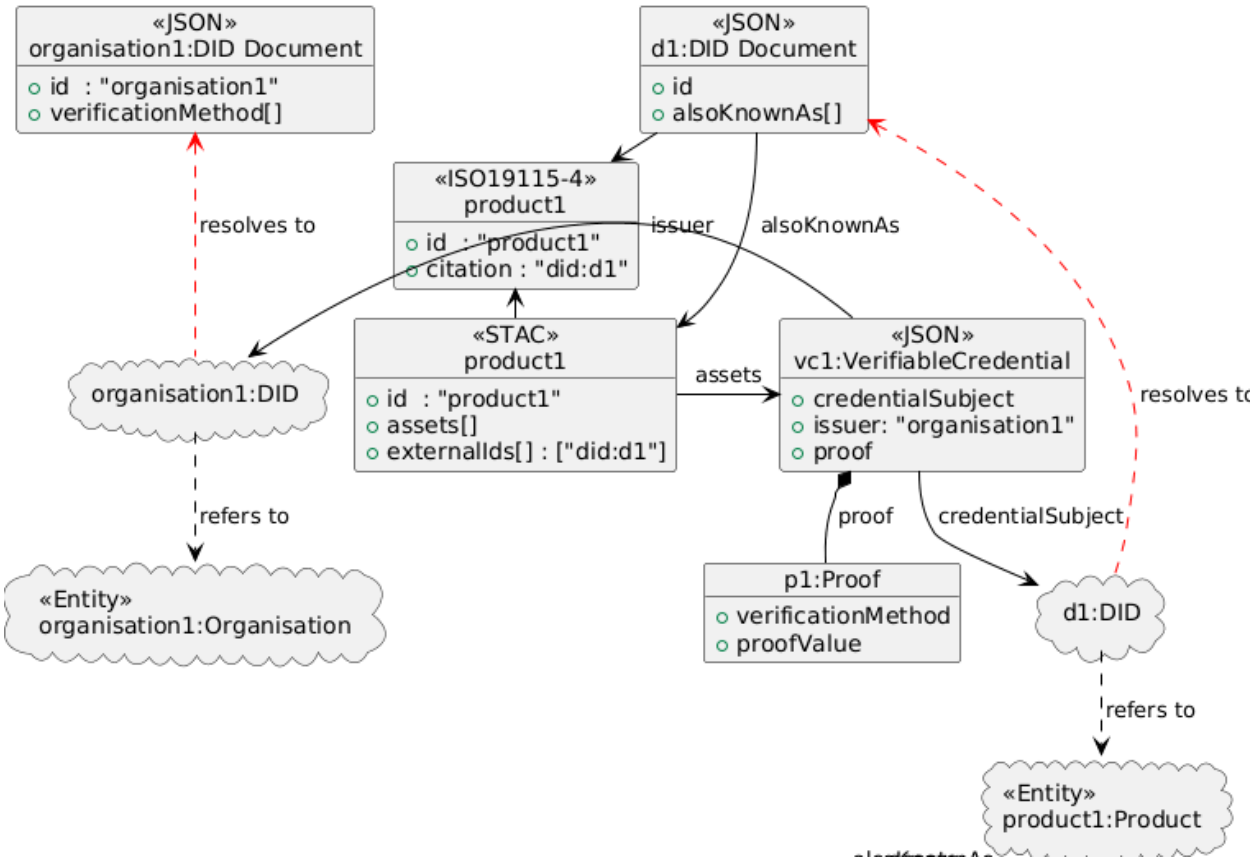

Figure 6 — Object Diagram

6.3.4.4. Verifiable Credential

Metadata for EO products contains information (claims or statements) about the actual EO product. By using a single format based on W3C Verifiable Credentials (VC), the Testbed participants aimed to make these `claims` verifiable and in addition offer a homogeneous solution. The VC can be considered the identity card of the product. Typical claims relate to where the actual product was acquired (i.e. the geometry), also the time it has been acquired. The Testbed participants aimed to avoid that incorrect geometry information and/or incorrect date of observation or other metadata properties may lead to wrong decisions.

The claim representation in the Verifiable Credentials is based on the following design drivers:

- Adoption of the W3C Verifiable Credential (VC) representation
- Avoid definition of yet another EO metadata format for expressing claims/verifiable statements about an EO product.

This can be achieved by adopting JSON-LD EO metadata representations such as the following.

- OGC 17-003r2 which allows interpretation as JSON-LD and for which the JSON encoding is widely adopted for ESA Earth Explorer, Heritage and Third Party missions.
- GeoDCAT-AP based on W3C DCAT and work at OGC Incubator.
- Schema.org as proposed in the eo-on-schema.org guidelines which are the outcome of an ESA project.

The IPT Engineering Report https://docs.ogc.org/per/24-033.html in addition mentions current work on a JSON-LD compatible representation for the popular STAC metadata format.

For any external resource referenced by a link from inside the VC, appropriate Content Integrity Protection is to be applied as explained in The OGC Testbed-20 IPT Engineering Report sections D.8, D.8.1. based on VC Data Model 1.1 and D.8.2. based on VC Data Model 2.0.

E.g., the VC 1.1 Data Model proposes a multibase multihash value e.g. provided as value of a hl query parameter using https://datatracker.ietf.org/doc/html/draft-sporny-hashlink-07. See https://w3c-ccg.github.io/ hashlink/#hl-url-params. The advantage of this is that the original (OGC 17-003r2 JSON) syntax of the claims can remain unchanged (as the href remain href properties, with an `hl` query parameter appended carrying the multihash value) and the original JSON schema is still respected.

The VC is accessible from the STAC Item in the API-Records/STAC Catalogue via a link. The EBSI media type for a VC and VP in the link allows to identify the VC. For VC 2.0, `version=2.0` is appended to the media type to distinguish both versions.

The prototype supports: - VC 1.0 for all collections (The open-source software DIDKit is used to sign these VCs); and - VC 2.0 for a subset of the collections (due to an implementation limitation

related to the key type (crv or cryptographic curve) associated with the key of the organization in its DID document), i.e. DLR and JAXA organizations.

Table 26 — Verifiable Credential versions supported by DID key type (crv) in prototype

KEY TYPE (CRV)	COLLECTIONS/ ORGANISATION	SUPPORTED VC VERSIONS IN PROTOTYPE
Ed25519	DLR, JAXA, CEOS	VC 1.0, VC 2.0
secp256k1	others, e.g. ESA, INPE	VC 1.0

Note that the above choice of key types was done in an arbitrary way in Testbed-20 to test multiple variations and remained unchanged for Testbed-21.

The current prototype uses the relatedResource property from the VC 2.0 Data Model applied to Version 1.0 Verifiable Credentials for content integrity protection. The missing VC 2.0 properties were included in the @context (in case of a VC 1.0) as shown below. The resulting VC can be validated using the Universal Verifier.

The VC is accessible from the STAC Item in the API-Records/STAC Catalogue via a link. The EBSI media type for a VC and VP in the link allows to identify the VC.

6.3.4.5. References to OGC RAINBOW

In the ISO19115-4 encoding, measurements are identified using their ISO19157-3 URI which are described in OGC RAINBOW. The Catalogue is also able to return GeoDCAT-AP responses containing the same quality information using the W3C PROV specification as depicted below.

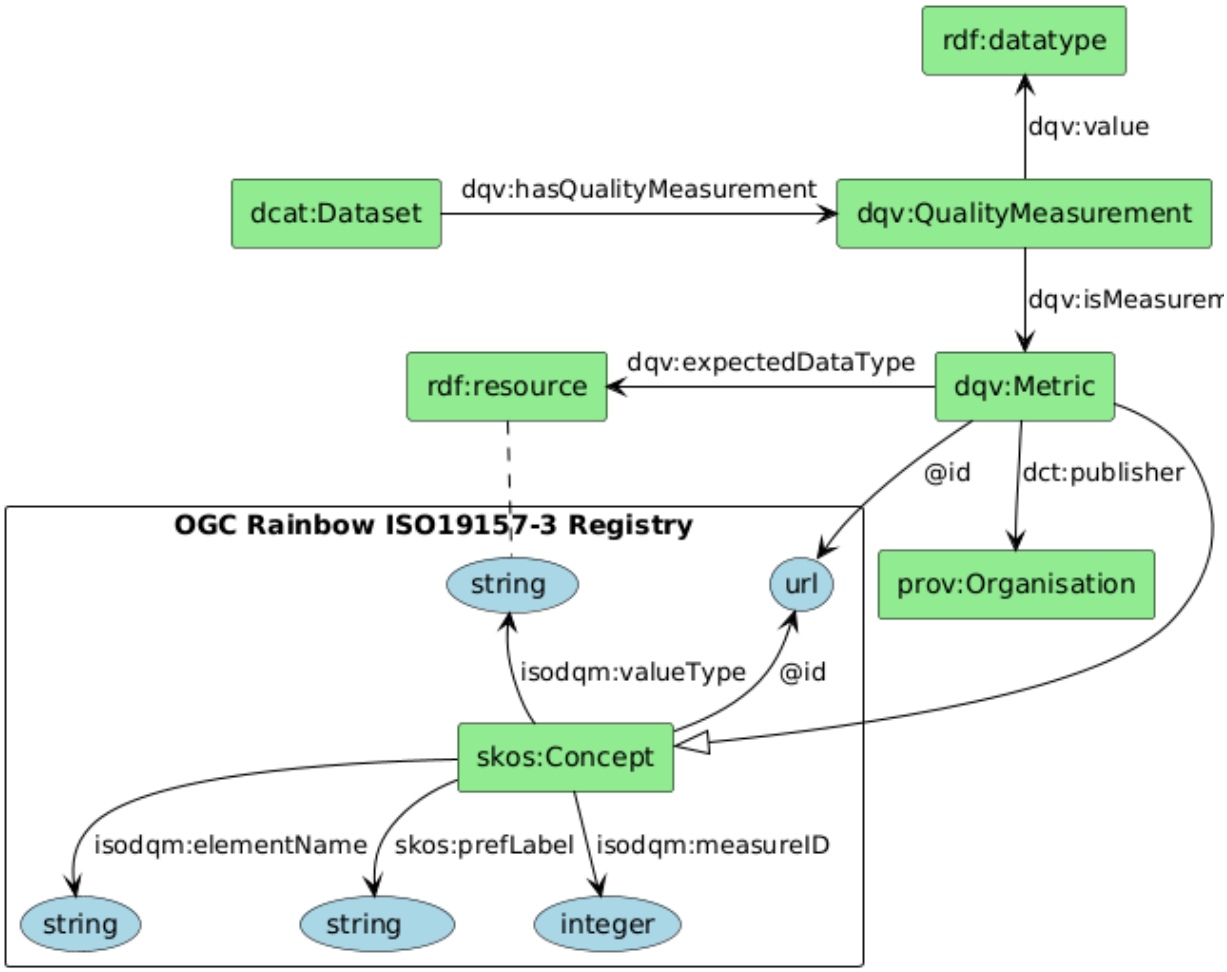

Figure 7 — Class Diagram

Example 2.2.4 in the Notebook (Annex E) shows the GeoDCAT-AP response.

Also, conformance results w.r.t. to a Specification can be expressed in GeoDCAT-AP using the PROV-O vocabulary as depicted below.

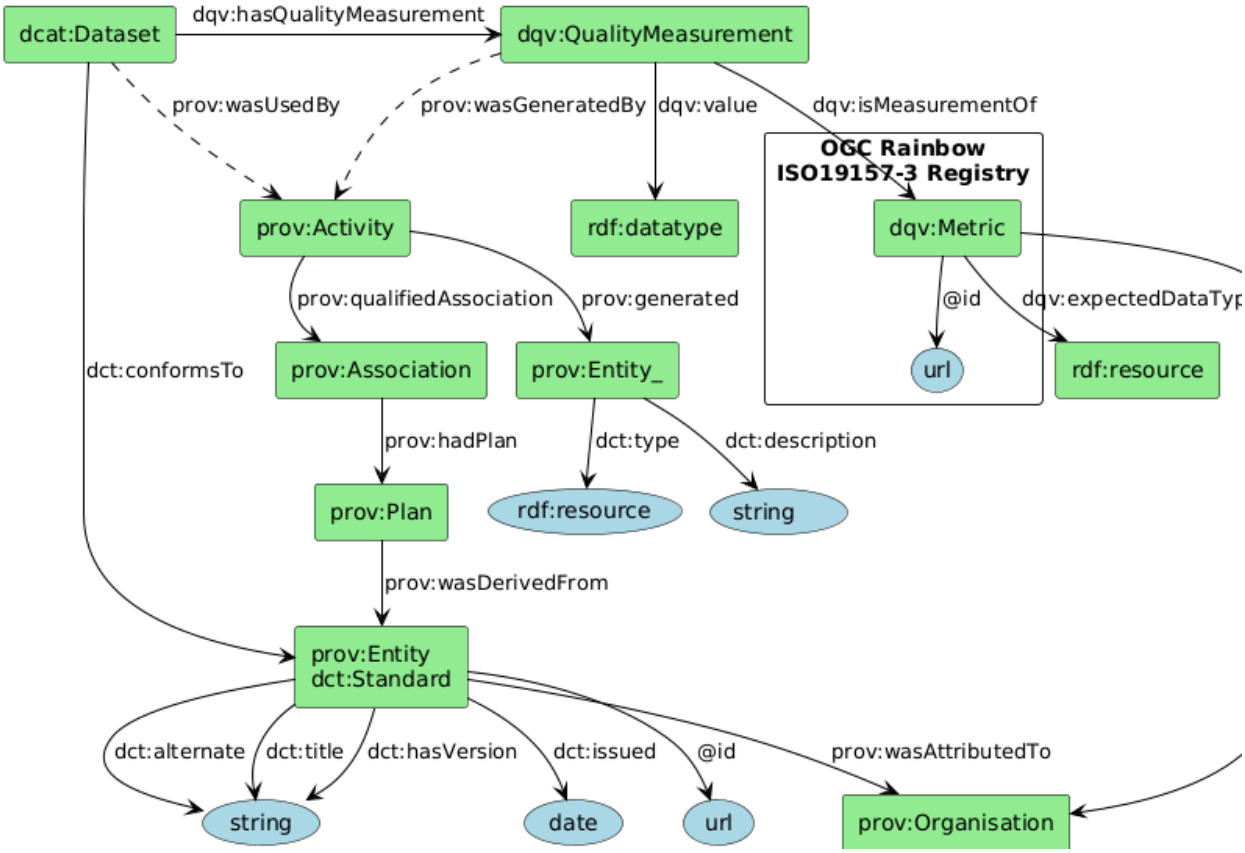

Figure 8 — Class Diagram

6.3.5. Validation and Conformance

The rows in the table below refer to a component invoking/using another component in the corresponding column. The Examples in the table refer to the corresponding part in the Jupyter Notebook available as Annex E in this Report.

Table 27 — Validation and conformance — component interactions and notebook references

FROM/TO	DID REPOSITORY (D102.2)	CATALOGUE (D102.1)	WATERMARKING PROCESS (D101.1)	IMMUTABLE CATALOGUE (D101.2)
Notebook	Notebook §3	Notebook §1-§2	Notebook §4.1-§4.3	Notebook §4.4
DIF Universal DID Resolver	Example	-	-	-
STACBrowser	-	Notebook Examples 1.6, 2.5	-	Notebook §4.5
Watermarking Process	Notebook §4.1-§4.3	Notebook §4.1-§4.3	-	Notebook §4.1-§4.3

FROM/TO	DID REPOSITORY (D102.2)	CATALOGUE (D102.1)	WATERMARKING PROCESS (D101.1)	IMMUTABLE CATALOGUE (D101.2)
VC Universal Verifier	See VC 1.0 and VC 2.0 examples below		-	-
ISO19115-4 Validator	-	See `ajv` example below	-	-

In addition, a TIE test has been performed to confirm that the ISO19115-4 response generated by the Catalogue (D102.1) — published as STAC assets — can be validated with the JSON schemas available in the ISO-TC211 GitHub repository.

Example of ISO19115-4 validation:

```
ajv validate -d NOAA_AVHRR_L1B_LAC.json -s "19115-4.json" --spec=draft2020 --validateFormats=true --strict=false -c ajv-formats -r "mdj.json" -r "dqc.json" -r "Feature.json"
```

Listing 15

Example of a VC 1.0 verification with Universal Verifier:

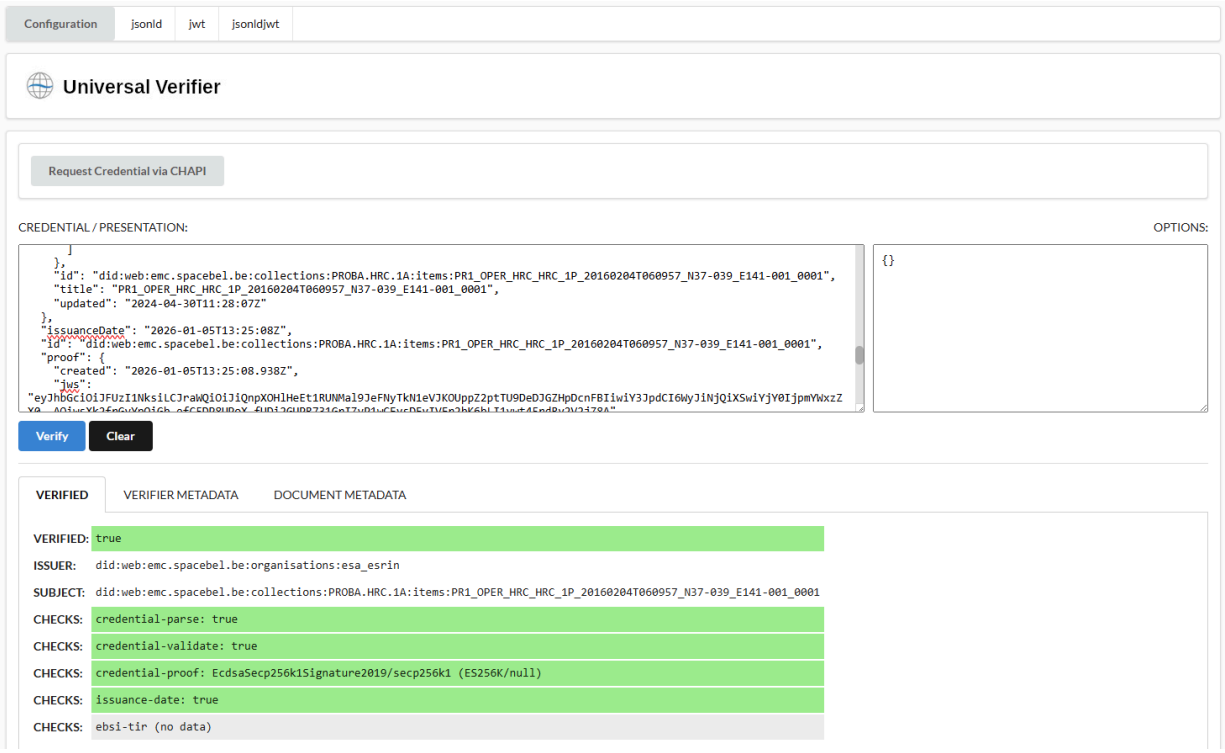

Figure 9 — Universal Verifier Example (VC)

6.3.5.1. Issues encountered

- No existing library for VC 2.0 signing and verification was identified. Therefore, the Testbed participants implemented the VC 2.0 proof algorithm. The implementation matches the verifier.io implementation for a specific key family (crv).
- The Testbed participants experienced different results after normalization of numerical values (coordinates) by different implementations which caused proof verification to fail. This is due to some of the coordinates in the metadata, e.g. 65.440002 . Such numbers cannot be represented accurately bitwise, and when serialized to exponential notation (as mandated by the RDF canonization algorithm), the result was 6.5440002000000001E1 . Here is a simple reproduction of the problem : https://json-ld.org/playground/#startTab=tab-canonized&json-ld=%7B%22%40context%22%3A%5B%7B%22bbox%22%3A%22ogc%3Abbox%22%7D%5D%2C%22bbox%22%3A%5B65.440002%5D%7D With DIDKit, we got “6.5440002E1” for the same input.
- the Testbed participants identified an issue with JSON-LD context expansion by a JSON-LD library our implementation is using. The issue was reported to the developers and is at https://github.com/digitalbazaar/pyld/issues/230. As work-around, we adjusted the context used in the VC.
- While we could include the external OGC context document for OGC 17-003r2 encoding in VC 1.0 and obtain valid VC, the same is not possible in VC 2.0. it is due to a conflict with the credentials/v2 context. More specifically, the OGC context redefines the “description” and “mediaType” fields, which are defined as protected in the VC context. It could be solved by putting the OGC context first in the list (letting the VC context override it), but the VC spec mandates that the VC context is first. See also https://github.com/w3c/json-ld-syntax/issues/443 and https://github.com/w3c/json-ld-syntax/issues/424.
- The `mdj.json` JSON schema in the ISO 19115-4 repository contains an `LI_Lineage` object definition without the `LE_Source` and `LE_ProcessStep` which are needed to express the provenance information. We recommend to add these objects in the official ISO `mdj.json` JSON schema file.

7

DQ-ENABLED SOFTWARE LIBRARY

7 DQ-ENABLED SOFTWARE LIBRARY

This component provides a comprehensive software library for accessing, converting, and validating data quality metadata across multiple international standards. The library enables developers to integrate ISO 19157-1:2023 quality reporting and W3C PROV provenance tracking into their applications.

7.1. Library Overview

The DQ-enabled software library implements the following capabilities:

Table 28 — Library Capabilities

MODULE	FUNCTIONALITY
Quality Metadata Access	Read and parse ISO 19157-1:2023 and ISO 19115/19115-4 quality reports
Metadata Conversion	Bidirectional conversion between ISO 19157, ISO 19115, NASA UMM, and TrainingDML-AI
Provenance Processing	W3C PROV graph generation, validation, and SPARQL queries
Schema Validation	JSON Schema and SHACL validation for quality reports
STAC Integration	Read/write STAC Items with liability-claims extension
API Clients	Client libraries for OGC API — Processes and OGC API — Records
Quality Assessment Tools	Compute ISO 19157 registered measures from geospatial datasets
Measure Registry	Access ISO 19157 and OGC RAINBOW measure definitions

7.2. Aims

The aims of the DQ-enabled software library are to:

1. **Simplify Quality Metadata Access**: Provide high-level APIs for reading and writing ISO 19157 quality reports;
2. **Enable Standards Interoperability**: Demonstrate conversion between ISO 19157, NASA UMM, and TrainingDML-AI;
3. **Support Provenance Tracking**: Generate and validate W3C PROV graphs from processing workflows;
4. **Facilitate Integration**: Provide client libraries for accessing IPT servers; and
5. **Validate Compliance**: Implement comprehensive validation for quality metadata.

7.3. Objectives

7.3.1. Primary Objectives

1. **Implement Metadata Parsers**: Support ISO 19157, ISO 19115, NASA UMM, TrainingDML-AI;
2. **Provide Conversion Functions**: Bidirectional format transformation with fidelity tracking;
3. **Enable PROV Generation**: Create W3C PROV graphs from ISO 19115 lineage;
4. **Support Validation**: JSON Schema, SHACL, and PROV-CONSTRAINTS validation; and
5. **Deliver API Clients**: Python clients for OGC API — Processes and OGC API — Records.

7.3.2. Library Architecture

7.3.2.1. Module Structure

The library is organized into the following modules:

```
dq_ipt_library/
├── quality/
│   ├── iso19157.py          # ISO 19157-1:2023 parser and generator
│   ├── iso19115.py          # ISO 19115/19115-4 support
│   ├── nasa_umm.py          # NASA UMM metadata
│   ├── trainingdml.py       # TrainingDML-AI metadata
│   └── measures.py          # ISO 19157 measure registry access
```

```
├── provenance/
│   ├── prov_generator.py    # W3C PROV graph generation
│   ├── prov_validator.py    # PROV-CONSTRAINTS validation
│   ├── iso_to_prov.py       # ISO lineage → PROV conversion
│   └── sparql_client.py     # SPARQL query interface
├── conversion/
│   ├── converters.py        # Master conversion framework
│   ├── iso19157_to_iso19115.py
│   ├── iso19115_to_iso19157.py
│   ├── umm_to_iso19157.py
│   ├── iso19157_to_umm.py
│   ├── trainingdml_to_iso19157.py
│   └── fidelity_tracker.py  # Conversion quality assessment
├── validation/
│   ├── json_schema.py       # JSON Schema validation
│   ├── shacl_validator.py   # SHACL validation for RDF
│   └── conformance.py       # OGC conformance testing
├── stac/
│   ├── item_reader.py       # Read STAC Items with quality
│   ├── item_writer.py       # Write STAC Items with quality
│   └── collection_manager.py
├── api_clients/
│   ├── processes_client.py  # OGC API - Processes client
│   ├── records_client.py    # OGC API - Records client
│   └── stac_client.py       # STAC API client
└── utils/
    ├── measure_registry.py  # Access ISO 19157 + RAINBOW
    └── quality_metrics.py   # Compute quality measures
```

Listing 16

7.3.2.2. Core API Examples

Reading ISO 19157 Quality Reports:

```python
from dq_ipt_library.quality import ISO19157QualityReport

# Parse from JSON
with open('quality_report.json') as f:
    report = ISO19157QualityReport.from_json(f.read())

# Access quality elements
for element in report.quality_elements:
    print(f"Category: {element.category}")
    print(f"Measure: {element.measure.name}")
    print(f"Value: {element.result.value}")
    print(f"Confidence: {element.metaquality.confidence}")

# Filter by category
positional = report.get_elements_by_category('positionalAccuracy')
for elem in positional:
    if elem.result.value[0] <= 15.0:
        print(f"High accuracy: {elem.result.value[0]}m")
```

Listing 17

Converting Between Standards:

```python
from dq_ipt_library.conversion import MetadataConverter

# Initialize converter
```

```
converter = MetadataConverter()

# Convert NASA UMM → ISO 19157
umm_metadata = load_umm_metadata('umm_dataset.json')
iso19157, fidelity = converter.convert(
    source_format='nasa_umm',
    target_format='iso19157',
    metadata=umm_metadata
)

print(f"Conversion fidelity: {fidelity.score}/100")
print(f"Unmapped fields: {fidelity.unmapped_fields}")

# Convert ISO 19157 → TrainingDML-AI
trainingdml, fidelity = converter.convert(
    source_format='iso19157',
    target_format='trainingdml_ai',
    metadata=iso19157
)

# Save converted metadata
with open('trainingdml_output.json', 'w') as f:
    f.write(trainingdml.to_json())
```

Listing 18

Generating W3C PROV from ISO Lineage:

```
from dq_ipt_library.provenance import ISOToPROVConverter

# Read ISO 19115 lineage
iso_lineage = quality_report.lineage

# Convert to W3C PROV
converter = ISOToPROVConverter()
prov_document = converter.convert_lineage(iso_lineage)

# Serialize as PROV-JSON
prov_json = prov_document.serialize(format='json')

# Export as RDF for SPARQL
prov_rdf = prov_document.serialize(format='turtle')
with open('provenance.ttl', 'w') as f:
    f.write(prov_rdf)

# Query with SPARQL
from dq_ipt_library.provenance import SPARQLClient

client = SPARQLClient('http://localhost:3030/provenance')
results = client.query("""
    PREFIX prov: <http://www.w3.org/ns/prov#>
    SELECT ?activity ?agent
    WHERE {
        ?activity a prov:Activity ;
                  prov:wasAssociatedWith ?agent .
    }
""")
```

Listing 19

Validating Quality Metadata:

```
from dq_ipt_library.validation import QualityValidator
```

```
validator = QualityValidator()

# Validate against JSON Schema
is_valid, errors = validator.validate_json_schema(
    quality_report,
    schema_type='iso19157'
)

if not is_valid:
    for error in errors:
        print(f"Validation error: {error.message} at {error.path}")

# Validate W3C PROV using SHACL
prov_valid, violations = validator.validate_shacl(
    prov_document,
    shapes_file='shacl/liability-claims-shapes.ttl'
)

# Validate measure codes against registry
from dq_ipt_library.utils import MeasureRegistry

registry = MeasureRegistry()
for element in quality_report.quality_elements:
    measure_code = element.measure.identification.code
    if not registry.is_valid_measure(measure_code):
        print(f"Invalid measure code: {measure_code}")
    else:
        definition = registry.get_measure(measure_code)
        print(f"Measure: {definition.name}")
        print(f"Definition: {definition.description}")
```

Listing 20

Accessing IPT Servers:

```
from dq_ipt_library.api_clients import ProcessesClient, RecordsClient

# Access DQ-enabled IPT Server 1 (OGC API - Processes)
processes = ProcessesClient('https://processes.example.org')

# Execute satellite processing with quality assessment
job = processes.execute(
    process_id='satellite-imagery-quality-processor',
    inputs={
        'source_imagery': 'https://data.example.org/l1c.tif',
        'processing_level': 'L2A',
        'quality_assessment': True
    }
)

# Wait for completion
result = job.wait_for_completion()

# Access STAC Item with quality metadata
stac_item = result.get_stac_item()
quality_report = stac_item.properties['liability:quality']

# Access DQ-enabled IPT Server 2 (OGC API - Records)
records = RecordsClient('https://catalog.example.org')

# Search with quality filtering
items = records.search(
```

```
    bbox=[-122.5, 37.5, -122.0, 38.0],
    datetime='2025-06-01/2025-06-30',
    filter={
        'quality_threshold': {'positionalAccuracy': 15.0},
        'confidence_level': 0.90
    }
)

for item in items:
    print(f"Item: {item.id}")
    quality = item.properties['liability:quality']
    print(f"Positional accuracy: {quality.get_metric('positionalAccuracy')}m")
    print(f"Confidence: {quality.get_metaquality('confidence')}")
```

Listing 21

Computing Quality Measures:

```
from dq_ipt_library.utils import QualityMetrics
from osgeo import gdal

# Load geospatial dataset
dataset = gdal.Open('satellite_image.tif')

# Compute ISO 19157 measures
metrics = QualityMetrics()

# Measure 28: Mean positional uncertainty (requires GCPs)
ground_control_points = load_gcps('gcps.json')
positional_accuracy = metrics.compute_positional_uncertainty(
    dataset,
    ground_control_points,
    method='rmse'
)

# Measure 7: Number of missing items (completeness)
missing_pixels = metrics.compute_completeness(
    dataset,
    nodata_value=-9999
)

# Create ISO 19157 quality element
quality_element = ISO19157QualityElement(
    category='positionalAccuracy',
    subcategory='absoluteExternalPositionalAccuracy',
    measure=ISO19157Measure(
        identification={'code': '28', 'codeSpace': 'ISO 19157'},
        name='Mean value of positional uncertainties'
    ),
    evaluation_method=EvaluationMethod(
        method_type='directExternal',
        description='RMSE with ground control points',
        datetime=datetime.now(timezone.utc)
    ),
    result=QuantitativeResult(
        value=[positional_accuracy],
        unit='meter',
        error_statistic='RMSE'
    )
)
```

Listing 22

7.3.3. Conversion Fidelity Framework

The library tracks conversion quality between metadata standards:

Table 29 — Conversion Fidelity Metrics

METRIC	DESCRIPTION	RANGE
Field Coverage	Percentage of source fields mapped to target	0-100%
Semantic Preservation	Degree to which meaning is preserved	0-100%
Reversibility	Ability to round-trip without loss	0-100%
Overall Fidelity	Weighted average of above metrics	0-100%

Example fidelity report:

```
fidelity_report = converter.get_fidelity_report()

print(f"""
Conversion: NASA UMM → ISO 19157-1:2023
---
Field Coverage: {fidelity_report.field_coverage}%
Semantic Preservation: {fidelity_report.semantic_preservation}%
Reversibility: {fidelity_report.reversibility}%
Overall Fidelity: {fidelity_report.overall_score}%

Unmapped Source Fields:
{', '.join(fidelity_report.unmapped_source_fields)}

Unmapped Target Fields:
{', '.join(fidelity_report.unmapped_target_fields)}

Notes:
{fidelity_report.notes}
""")
```

Listing 23

7.3.4. Installation and Dependencies

Installation:

```
pip install dq-ipt-library

# Optional: Install SPARQL support
pip install dq-ipt-library[sparql]

# Optional: Install full validation suite
```

```
pip install dq-ipt-library[validation]
```

Listing 24

Dependencies:

- Python 3.11+
- `jsonschema` — JSON Schema validation
- `prov` — W3C PROV library
- `rdflib` — RDF processing
- `pyshacl` — SHACL validation
- `requests` — HTTP client for API access
- `pystac` — STAC library
- `osgeo/gdal` — Geospatial data processing (optional)

7.3.5. Testing and Validation

The library includes comprehensive test suites:

Unit Tests:

```
pytest tests/unit/

# Test quality report parsing
pytest tests/unit/test_iso19157.py

# Test conversions
pytest tests/unit/test_conversion.py

# Test PROV generation
pytest tests/unit/test_provenance.py
```

Listing 25

Integration Tests (require running servers):

```
# Set server URLs
export IPT_SERVER1_URL=https://processes.example.org
export IPT_SERVER2_URL=https://catalog.example.org

pytest tests/integration/

# Test full workflow: process → catalog → retrieve
pytest tests/integration/test_workflow.py
```

Listing 26

Conversion Fidelity Tests:

```
# Test round-trip conversions
```

```
pytest tests/fidelity/test_roundtrip.py

# Measure conversion quality
pytest tests/fidelity/test_conversion_scores.py --verbose
```

Listing 27

7.3.6. Documentation and Examples

The library provides comprehensive documentation:

- **API Reference**: Auto-generated from docstrings (Sphinx);
- **User Guide**: Tutorial-style documentation;
- **Example Gallery**: Jupyter notebooks demonstrating common workflows; and
- **Conversion Cookbook**: Recipes for specific metadata transformations.

Example notebooks included:

1. `01_reading_quality_metadata.ipynb` — Parse ISO 19157 and ISO 19115 reports;
2. `02_nasa_umm_conversion.ipynb` — Convert UMM ↔ ISO 19157;
3. `03_prov_generation.ipynb` — Generate W3C PROV from lineage;
4. `04_stac_integration.ipynb` — Work with STAC Items;
5. `05_api_clients.ipynb` — Access IPT servers; and
6. `06_quality_computation.ipynb` — Compute ISO 19157 measures from data.

7.3.7. Integration with IPT Framework

The library enables developers to:

1. **Build IPT-aware Applications**: Integrate quality and provenance into custom tools;
2. **Validate Metadata**: Ensure conformance with ISO 19157 and W3C PROV;
3. **Convert Legacy Metadata**: Migrate from ISO 19115 to ISO 19157-1:2023;
4. **Query Provenance**: Execute SPARQL queries on W3C PROV graphs; and
5. **Access IPT Servers**: Programmatic access to quality-assured data catalogs.

All library components maintain full compatibility with the STAC Liability and Claims Extension, ensuring consistent implementation across server and client applications.

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A

ANNEX A (NORMATIVE) ABBREVIATIONS/ACRONYMS

A ANNEX A (NORMATIVE) ABBREVIATIONS/ACRONYMS

API	Application Programming Interface
ARA	Agile Reference Architecture
ARD	Analysis Ready Data
BB	Building Block
CEOS	Committee on Earth Observation Satellites
CO	Collaborative Object
DCS	Data Centric Security
DID	Decentralized Identifier
DIF	Decentralized Identity Foundation
EBSI	European Blockchain Service Infrastructure
EO	Earth Observation
ESA	European Space Agency
FACTS	Federated Agile Collaborating Trusted Systems
FAIR	Findable Accessible Interoperable and Reusable
GDAL	Geospatial Data Abstraction Library
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
INPE	National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais)
IPFS	InterPlanetary File System
IPT	Integrity Provenance Trust
IRI	Internationalized Resource Identifier
ISO	International Organization for Standardization

JSON	JavaScript Object Notation
JWK	JSON Web Key
JWS	JSON Web Signature
JWT	JSON Web Token
OGC	Open Geospatial Consortium
RDF	Resource Description Framework
REST	Representational State Transfer
SaaS	Software as a Service
SatCen	European Union Satellite Centre
SC	Smart Certificate
SSI	Self-Sovereign Identity
STAC	SpatioTemporal Asset Catalog
TIE	Technology Integration Experiment
UMM	Unified Metadata Model
URL	Uniform Resource Locator
VA	Verifiable Attestation
VC	Verifiable Credentials
VP	Verifiable Presentations
W3C	World Wide Web Consortium
XML	eXtensible Markup Language
ZKP	Zero Knowledge Proof

B

ANNEX B (INFORMATIVE) STAC EXTENSION LIABILITY CLAIMS V1.3.0 – COMPLIANCE ANALYSIS

ANNEX B (INFORMATIVE) STAC EXTENSION LIABILITY CLAIMS V1.3.0 — COMPLIANCE ANALYSIS

B.1. Abstract of Annex

This document analyzes the compliance of STAC Extension Liability Claims v1.3.0 with canonical EOVOC schemas for ISO 19157 and ISO 19115 standards. It identifies structural differences, provides compliance assessment, and recommends implementation strategies for full interoperability.

B.2. Summary

The v1.3.0 directory contains `dqc.json` and `mdj.json` files that are **structurally similar** to the canonical eovoc schemas but **NOT fully compliant** due to:

1. **Different $id URIs** — Your schemas use `luciocola.github.io` instead of `eovoc.github.io`
2. **Cross-references point to local domain** — Internal `$ref` links use your URLs
3. **Anchor usage** — 1.2.0 schemas use `$anchor` while eovoc uses `$comment`
4. **Reference format differences** — Some internal refs use different patterns

B.3. Detailed Compliance Issues

B.3.1. old schemas use

```
"definitions": {
  "AbsolutePositionalAccuracy": {
    "$anchor": "AbsolutePositionalAccuracy",
    "type": "object",
    ...
  }
}
```

Listing B.1

B.3.2. eovoc schemas use

```
"definitions": {
  "AbsolutePositionalAccuracy": {
    "$comment": "AbsolutePositionalAccuracy",
    "type": "object",
    ...
  }
}
```

Listing B.2

B.4. Internal Reference Patterns

```
"$ref": "#MD_Constraints"
```

Listing B.3

B.4.1. vs eovoc

```
"$ref": "#/definitions/MD_Constraints"
```

Listing B.4

B.5. Compliance

B.5.1. Full Canonical Compliance, suggested approach

Use the official eovoc schemas directly by referencing them as external schemas.

B.5.1.1. Advantages

- Guaranteed compatibility with ISO 19115/19157 tools
- Automatic updates when eovoc updates their schemas
- Interoperability with other STAC extensions using eovoc
- Smaller extension package size (no duplicate schemas)
- Clear separation of concerns
- Follows STAC extension best practices

B.5.1.2. Implementation

In `schema.json`, replace local schema definitions with:

```
{
  "liability:iso19157_quality": {
    "description": "ISO 19157-1:2023 data quality information",
    "$ref": "https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/dqc.json#/
definitions/DataQuality"
  },
  "liability:iso19115_metadata": {
    "description": "ISO 19115-1:2014 metadata information",
    "$ref": "https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/mdj.json#/
definitions/MD_Metadata"
  }
}
```

Listing B.5

B.6. Recommended Action Plan for v1.3.0

B.6.1. Update schema.json to Reference Canonical Schemas

Update the quality-related field definitions to reference eovoc:

```
"liability:iso19157_quality": {
  "title": "ISO 19157 Data Quality",
  "description": "Data quality information compliant with ISO 19157-1:2023",
  "$ref": "https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/dqc.json#/
definitions/DataQuality"
},
"liability:iso19115_metadata": {
  "title": "ISO 19115 Metadata",
  "description": "Metadata information compliant with ISO 19115-1:2014",
  "$ref": "https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/mdj.json#/
definitions/MD_Metadata"
}
```

Listing B.6

B.6.2. Update iso19157-quality.json (Wrapper)

Replace internal definitions with canonical reference:

```
{
  "$schema": "http://json-schema.org/draft-07/schema#",
  "$id": "https://luciocola.github.io/stac-extension-liability-claims/v1.3.0/
iso19157-quality.json#",
  "title": "ISO 19157-1:2023 Data Quality (Canonical Integration)",
  "description": "Integration wrapper for eovoc canonical ISO 19157 schemas",
  "$ref": "https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/dqc.json#/
definitions/DataQuality"
}
```

Listing B.7

B.6.3. Update iso19115-quality.json (Wrapper)

```
{
  "$schema": "http://json-schema.org/draft-07/schema#",
  "$id": "https://luciocola.github.io/stac-extension-liability-claims/v1.3.0/
iso19115-quality.json#",
  "title": "ISO 19115 Metadata (Canonical Integration)",
  "description": "Integration wrapper for eovoc canonical ISO 19115 schemas",
  "$ref": "https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/mdj.json#/
definitions/MD_Metadata"
}
```

Listing B.8

B.7. Dependencies

This extension uses canonical ISO 19115/19157 schemas from the eovoc project:

- **Data Quality (ISO 19157)**: https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/dqc.json
- **Metadata (ISO 19115)**: https://eovoc.github.io/eof-eos-stac-extension/v0.0.1/mdj.json

These schemas are maintained by the Earth Observation Vocabulary project and ensure compatibility with ISO standards.

B.8. Structural Differences Summary

B.8.1. dqc.json Comparison

Table B.1 — dqc.json — structural comparison (v1.3.0 vs eovoc canonical)

ASPECT	YOUR V1.3.0	EOVOC CANONICAL	COMPLIANT?
$id domain	luciocola.github.io	eovoc.github.io	# No
$id trailing #	Yes (`dqc.json#`)	No (`dqc.json`)	# No
Uses $anchor	Yes	No (uses $comment)	⚠# Minor
Cross-refs to mdj.json	Point to luciocola	Point to eovoc	# No
Definition structure	Same	Same	# Yes
Property schemas	Same	Same	# Yes

B.8.2. mdj.json Comparison

Table B.2 — mdj.json — structural comparison (v1.3.0 vs eovoc canonical)

ASPECT	YOUR V1.3.0	EOVOC CANONICAL	COMPLIANT?
$id domain	luciocola.github.io	eovoc.github.io	# No
$id trailing #	Yes (`mdj.json#`)	No (`mdj.json`)	# No
Uses $anchor	Yes	No (uses $comment)	⚠# Minor
Internal $ref format	`#Name`	`#/definitions/Name`	# No
Cross-refs to dqc.json	Point to luciocola	Point to eovoc	# No
Definition structure	Same	Same	# Yes
Property schemas	Same	Same	# Yes

B.9. Content Verification

Table B.3 — Schema content verification summary

#	**Definitions are structurally identical** — Both define the same ISO 19157/19115 classes
#	**Property schemas match** — Field types and requirements are the same
#	**Required fields match** — Mandatory properties are identical
⚠#	**Reference mechanisms differ** — Format and targets of $ref links vary
#	**Schema identifiers differ** — URLs don't match canonical sources

B.10. STAC extension liability claims v1.3.0

The v1.3.0 schemas are **content-compatible but reference-incompatible** with the canonical eovoc schemas, this has been achieved with STAC extension liability claims v1.4.0

B.11. ISO standard lineage (DQ_ evolution)

This document covers:

- Structural differences in DataQuality class across three standard versions
- Quality category evolution from flat to hierarchical organization
- Lineage location changes and separation from quality reporting
- Metaquality formalization and fitness-for-purpose assessment mechanisms
- Migration strategies for implementers transitioning between versions

B.11.1. Referenced documents

The following documents are referred to in this document:

- ISO 19157:2013, *Geographic information — Data quality* (Withdrawn)
- ISO 19157-1:2023, *Geographic information — Data quality — Part 1: Framework*
- ISO 19157-2:2023, *Geographic information — Data quality — Part 2: Data quality measures*
- ISO 19157-3:2026, *Geographic information — Data quality — Part 3: Geospatial Data Interpretability Index (GDII) elements* (PROPOSED — Not yet published)
- ISO 19115-1:2014, *Geographic information — Metadata — Part 1: Fundamentals*
- ISO 19115-2:2019, *Geographic information — Metadata — Part 2: Extensions for acquisition and processing*
- **ISO 19157:2013**: Original monolithic standard
- **ISO 19157-1:2023**: Part 1 — Framework (fundamental restructuring)
- **ISO 19157-3:2026**: Part 3 — Geospatial Data Interpretability Index (GDII) elements (proposed reintroduction)

B.11.2. Key findings

Table B.4 — Comparison of key aspects across ISO 19157 versions

ASPECT	2013	2023	2026 (PART 3)
Geospatial Data Interpretability Index (GDII) support	# Included (15th element)	# Removed	# Reintroduced (separate part)
Quality Categories	15 flat elements	6 hierarchical categories	6 + Geospatial Data Interpretability Index (GDII) (optional)
Lineage Location	Inside DataQuality	ISO 19115-1:2014	ISO 19115-1:2014
Metaquality	Poorly defined	# Formalized (3 subcategories)	Enhanced
Measure Register	Informal (Annex D)	# URI-based register	Extended register
Part Structure	Single document	Multi-part (1-4)	Part 3 adds Geospatial Data Interpretability Index (GDII)

B.12. DataQuality class structure

B.12.1. ISO 19157:2013 — Original structure

```
DataQuality
├── scope: Scope [1..1]
│   ├── level: MD_ScopeCode (dataset, series, feature, etc.)
│   └── extent: EX_Extent [0..*]
│
├── report: Element [0..*]  ← Concrete class, 15 specific subtypes
│   ├── CompletenessCommission
│   ├── CompletenessOmission
│   ├── ConceptualConsistency
│   ├── DomainConsistency
│   ├── FormatConsistency
│   ├── TopologicalConsistency
│   ├── AbsoluteExternalPositionalAccuracy
│   ├── RelativeInternalPositionalAccuracy
│   ├── GriddedDataPositionalAccuracy
│   ├── TemporalConsistency
│   ├── TemporalValidity
│   ├── AccuracyOfATimeMeasurement
│   ├── ThematicClassificationCorrectness
│   ├── NonQuantitativeAttributeCorrectness
│   ├── QuantitativeAttributeAccuracy
│   └── Geospatial Data Interpretability Index (GDII)Element ← Removed in 2023,
reintroduced in 2026
│
└── lineage: LI_Lineage [0..*]  ← Moved to ISO 19115-1:2014 in 2023
```

```
    ├── statement: CharacterString [0..1]
    ├── processStep: LI_ProcessStep [0..*]
    └── source: LI_Source [0..*]
```

Listing B.9

B.12.2. Characteristics

- **Flat hierarchy**: 15 quality elements at same level
- **Lineage embedded**: LI_Lineage part of DataQuality
- **No abstraction**: Element is concrete class
- **Geospatial Data Interpretability Index (GDII) included**: As 15th element (later found to be incorrect interpretation)

B.12.3. ISO 19157-1:2023 — Framework restructuring

```
DataQuality
├── scope: Scope [1..1]
│   ├── level: MD_ScopeCode (enhanced list)
│   └── extent: EX_Extent [0..*]
│
├── report: AbstractDQ_Element [0..*]  ← Abstract class, hierarchical
│   │
│   ├── Completeness (Category)
│   │   ├── commission (Subcategory)
│   │   └── omission (Subcategory)
│   │
│   ├── LogicalConsistency (Category)
│   │   ├── conceptualConsistency
│   │   ├── domainConsistency
│   │   ├── formatConsistency
│   │   └── topologicalConsistency
│   │
│   ├── PositionalAccuracy (Category)
│   │   ├── absoluteExternalPositionalAccuracy
│   │   ├── relativeInternalPositionalAccuracy
│   │   └── griddedDataPositionalAccuracy
│   │
│   ├── TemporalQuality (Category)
│   │   ├── accuracyOfATimeMeasurement
│   │   ├── temporalConsistency
│   │   └── temporalValidity
│   │
│   ├── ThematicQuality (Category)
│   │   ├── thematicClassificationCorrectness
│   │   ├── nonQuantitativeAttributeCorrectness
│   │   └── quantitativeAttributeAccuracy
│   │
│   └── Metaquality (Category – ENHANCED)
│       ├── confidence (NEW distinct subcategory)
│       ├── homogeneity (NEW distinct subcategory)
│       └── representativity (NEW distinct subcategory)
│
└── standaloneQualityReportDetails: CharacterString [0..1]  ← NEW
```

```
    (URL to external quality report document)
```

Listing B.10

B.12.4. Lineage removed from DataQuality

Lineage is now defined in ISO 19115-1:2014:

```
MD_Metadata
└── dataQualityInfo: MD_DataQuality [0..*]
    └── lineage: LI_Lineage [0..1]
        ├── statement: CharacterString [0..1]
        ├── scope: MD_Scope [0..1]
        ├── processStep: LI_ProcessStep [0..*]
        ├── source: LI_Source [0..*]
        └── additionalDocumentation: CI_Citation [0..*]
```

Listing B.11

B.12.5. Characteristics

- **Hierarchical structure**: 6 categories → subcategories → measures
- **Abstract base class**: AbstractDQ_Element allows extension
- **Geospatial Data Interpretability Index (GDII) REMOVED**: Confirmed by ISO experts as incorrect
- **Lineage separated**: Moved to metadata standard (ISO 19115-1:2014)
- **Metaquality formalized**: 3 distinct subcategories with clear semantics
- **External reports**: standaloneQualityReportDetails for linked documentation

B.12.6. Critical changes

- # **Geospatial Data Interpretability Index (GDII)Element deleted** — "did not belong in quality standard"
- # **Metaquality now handles fitness-for-purpose** via confidence subcategory
- # **Conformance results** are primary fitness-for-purpose mechanism

B.12.7. ISO 19157-3:2026 — Geospatial Data Interpretability Index (GDII) elements (proposed)

B.12.8. Standard structure

```
ISO 19157 Multi-part Standard (2023-2026)
├── ISO 19157-1:2023 - Part 1: Framework (published)
├── ISO 19157-2:2023 - Part 2: Data quality measures (published)
├── ISO 19157-3:2026 - Part 3: Geospatial Data Interpretability Index (GDII)
elements (PROPOSED) ← NEW
└── ISO 19157-4:TBD - Part 4: Domain-specific quality measures (future)
```

Listing B.12

B.12.9. DataQuality extension

```
DataQuality (from ISO 19157-1:2023)
├── scope: Scope [1..1]
├── report: AbstractDQ_Element [0..*]
│   ├── [All ISO 19157-1:2023 categories: completeness, logicalConsistency,
│   │    positionalAccuracy, temporalQuality, thematicQuality, metaquality]
│   │
│   └── Geospatial Data Interpretability Index (GDII) (Category - REINTRODUCED
in Part 3) ← NEW/RESTORED
│       ├── fitnessForPurpose (Subcategory)
│       ├── accessibilityAndUsageConstraints (Subcategory)
│       ├── userExperienceAndInterfaceQuality (Subcategory - NEW)
│       └── fitnessForIntendedUse (Subcategory)
│
└── standaloneQualityReportDetails: CharacterString [0..1]
```

Listing B.13

B.12.10. Key features

B.12.11. Geospatial Data Interpretability Index (GDII) reintroduced as optional extension

- Not mandatory for ISO 19157-1:2023 compliance
- Separate conformance class: “Geospatial Data Interpretability Index (GDII) Quality Extension”
- Explicitly domain-specific (not universal quality requirement)

B.12.12. Clear separation from metaquality

Table B.5 — Metaquality vs Geospatial Data Interpretability Index (GDII)

METAQUALITY (ISO 19157-1:2023)	GEOSPATIAL DATA INTERPRETABILITY INDEX (GDII) (ISO 19157-3:2026)
confidence (trust in quality data)	fitnessForPurpose (meets user needs)
homogeneity (consistency)	accessibility (can user access?)
representativity (sample coverage)	userExperience (how easy to use?)

B.12.13. Fitness-for-purpose refinement

- **ISO 19157-1:2023**: Use metaquality confidence + conformance results
- **ISO 19157-3:2026**: Use Geospatial Data Interpretability Index (GDII).fitnessForPurpose when application-specific
- **Guidance**: Prefer conformance to specifications (CEOS-ARD, INSPIRE, etc.) over subjective fitness

B.12.14. New Geospatial Data Interpretability Index (GDII) measures (Part 3 register additions)

- Measure 501: Application domain suitability score
- Measure 502: User requirements compliance percentage
- Measure 503: API Geospatial Data Interpretability Index (GDII) rating (Nielsen heuristics)
- Measure 504: Visualization quality assessment
- Measure 505: Accessibility compliance (WCAG, Section 508)

B.12.15. Conformance classes

```
ISO 19157-3:2026 Conformance Classes
├── Core Geospatial Data Interpretability Index (GDII): Geospatial Data
Interpretability Index (GDII).fitnessForPurpose (mandatory if using Part 3)
├── Accessibility: Geospatial Data Interpretability Index (GDII).accessibilityAnd
UsageConstraints (optional)
```

```
├── User Experience: Geospatial Data Interpretability Index (GDII).userExperience
AndInterfaceQuality (optional)
└── Application Fitness: Geospatial Data Interpretability Index (GDII).
fitnessForIntendedUse (optional)
```

Listing B.14

B.12.16. Implementation guidance

Example 1 — Example: When to use Geospatial Data Interpretability Index (GDII) (Part 3) vs Metaquality (Part 1): Scenario 1: Cloud coverage limits confidence in classification

- **Correct approach**: ISO 19157-1:2023 metaquality confidence

```
{
  "category": "metaquality",
  "subcategory": "confidence",
  "result": [{
    "resultType": "quantitative",
    "value": 0.845,
    "valueUnit": "percentage clear pixels"
  }]
}
```

Example 2: Scenario 2: Product meets CEOS-ARD Surface Reflectance specification

- **Correct approach**: ISO 19157-1:2023 conformance result

```
{
  "category": "completeness",
  "result": [{
    "resultType": "conformance",
    "pass": true,
    "specification": {
      "title": "CEOS-ARD Surface Reflectance v5.0.1",
      "date": "2021-06-15"
    }
  }]
}
```

Example 3: Scenario 3: Dataset specifically designed for precision agriculture

- **Correct approach**: ISO 19157-3:2026 Geospatial Data Interpretability Index (GDII) fitnessForPurpose

```
{
  "category": "Geospatial Data Interpretability Index (GDII)",
  "subcategory": "fitnessForPurpose",
  "measure": {
    "nameOfMeasure": ["Suitability for precision agriculture"],
    "measureIdentifier": "https://def.isotc211.org/dataqualitymeasures/501"
  },
  "result": [{
    "resultType": "conformance",
    "pass": true,
    "specification": {
```

```
      "title": "Precision Agriculture Data Requirements v2.1",
      "date": "2025-03-01"
    },
    "explanation": "10m spatial resolution, 5-day revisit, NDVI accuracy ±0.02
meets precision agriculture requirements"
  }]
}
```

B.13. Comparative analysis

B.13.1. Quality categories evolution

Table B.6 — Comparison of quality categories across versions

CATEGORY	ISO 19157:2013	ISO 19157-1:2023	ISO 19157-3:2026
Completeness	2 elements (commission, omission)	# Category with 2 subcategories	Same as 2023
Logical Consistency	4 elements	# Category with 4 subcategories	Same as 2023
Positional Accuracy	3 elements	# Category with 3 subcategories	Same as 2023
Temporal Quality	3 elements	# Category with 3 subcategories	Same as 2023
Thematic Quality	3 elements	# Category with 3 subcategories	Same as 2023
Metaquality	1 element (poorly defined)	# Category with 3 formalized subcategories	Same as 2023
Geospatial Data Interpretability Index (GDII)	1 element (15th element)	# Removed (“did not belong”)	# Reintroduced as optional Part 3
Total	**15 flat elements**	**6 hierarchical categories**	**7 categories (6 core + 1 optional)**

B.13.2. Fitness-for-purpose assessment

Table B.7 — Fitness-for-purpose mechanisms across versions

VERSION	MECHANISM	EXAMPLE
ISO 19157:2013	`Geospatial Data Interpretability Index (GDII)Element` with descriptive result	"Suitable for 1:50,000 mapping" (unstructured)
ISO 19157-1:2023	`Metaquality.confidence` + `ConformanceResult`	Conformance to CEOS-ARD spec (structured)
ISO 19157-3:2026	`Geospatial Data Interpretability Index (GDII).fitnessForPurpose` + conformance	Conformance to application-specific requirements

NOTE: Evolution: From unstructured Geospatial Data Interpretability Index (GDII) statements → structured conformance → domain-specific fitness

B.13.3. Lineage location

Table B.8 — Lineage location across versions

VERSION	LINEAGE LOCATION	RATIONALE
ISO 19157:2013	Inside `DataQuality.lineage`	Lineage seen as quality aspect
ISO 19157-1:2023	**Moved to** `MD_Metadata` (ISO 19115-1:2014)	Lineage is metadata, not quality measure
ISO 19157-3:2026	Remains in ISO 19115-1:2014	No change — separation maintained

IMPORTANT

Lineage and quality are now cleanly separated. STAC Extension correctly implements this as separate `dq:lineage` and `dq:quality` fields.

B.13.4. Result types evolution

Table B.9 — Result types availability across versions

RESULT TYPE	2013	2023	2026
ConformanceResult	# Basic (pass/fail)	# Enhanced (specification citation)	# Same + domain specs
QuantitativeResult	# Value + unit	# Value + UOM + record type	# Same
DescriptiveResult	# Text statement	# Structured statement	# Same
CoverageResult	# Not available	# New (raster quality masks)	# Same

B.13.5. Measure registration system

Table B.10 — Measure identifier systems across versions

VERSION	MEASURE IDENTIFIER	REGISTRY TYPE	EXAMPLE
ISO 19157:2013	Informal reference	Annex D (static list)	"Measure 28" (no URI)
ISO 19157-1:2023	URI-based	Dynamic register	`https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/28`
ISO 19157-3:2026	URI-based (extended)	Dynamic + Part 3 measures	`https://def.isotc211.org/dataqualitymeasures/501` (permanent URI)

B.13.6. Permanent URI (effective April 2026)

- Core measures (1-XXX): `https://def.isotc211.org/dataqualitymeasures/{id}`
- Geospatial Data Interpretability Index (GDII) measures (501-5XX): `https://def.isotc211.org/Geospatial Data Interpretability Index (GDII)Measures/{id}`

B.14. Proposed migration strategies

B.15. ISO 19157:2013 → ISO 19157-1:2023

B.15.1. Breaking changes

1. # Remove `Geospatial Data Interpretability Index (GDII)Element` usage
2. # Migrate to `Metaquality.confidence` or conformance results
3. # Move lineage to separate field (outside DataQuality)
4. # Update measure identifiers to URIs

B.15.2. Example migration

```
{
  "dataQuality": {
    "scope": { "level": "dataset" },
    "report": [
      {
        "element": "Geospatial Data Interpretability Index (GDII)",
        "nameOfMeasure": ["Fitness for urban planning"],
        "result": {
          "type": "descriptive",
          "statement": "Suitable for 1:10,000 urban planning applications"
        }
      }
    ],
    "lineage": {
      "statement": "Derived from Sentinel-2 Level-2A"
    }
  }
}
```

Listing B.15 — ISO 19157:2013 (DEPRECATED)

```
{
  "dq:quality": [
    {
      "scope": { "level": "dataset" },
      "report": [
        {
          "category": "completeness",
          "measure": {
            "nameOfMeasure": ["Fitness for urban planning"],
            "measureIdentifier": "https://standards.isotc211.org/19157/-3/1/dqc/
content/qualityMeasure/7"
          },
          "result": {
            "resultType": "conformance",
            "pass": true,
            "specification": {
              "title": "Urban Planning Data Specification v3.2",
              "date": "2024-01-15"
```

```
            },
            "explanation": "Positional accuracy ≤5m, completeness ≥95% meets
urban planning requirements for 1:10,000 scale"
          }
        }
      ]
    }
  ],
  "dq:lineage": [
    {
      "type": "lineage",
      "statement": "Derived from Sentinel-2 Level-2A",
      "processStep": []
    }
  ]
}
```

Listing B.16 — ISO 19157-1:2023 (CURRENT)

B.16. ISO 19157-1:2023 → ISO 19157-3:2026 (optional upgrade)

B.16.1. When to adopt ISO 19157-3:2026

- # Your data serves specific application domains (agriculture, urban planning, emergency response)
- # You need to document API Geospatial Data Interpretability Index (GDII) or user experience metrics
- # You want to report accessibility compliance (WCAG, Section 508)
- # General-purpose datasets (use ISO 19157-1:2023 conformance instead)

B.16.2. Example: Adding Geospatial Data Interpretability Index (GDII) (Part 3)

```
{
  "dq:quality": [
    {
      "scope": { "level": "dataset" },
      "report": [
        {
          "$comment": "ISO 19157-1:2023 - Core quality (always include)",
          "category": "positionalAccuracy",
          "subcategory": "absoluteExternalPositionalAccuracy",
          "measure": {
            "nameOfMeasure": ["Mean positional uncertainty"],
```

```
            "measureIdentifier": "https://def.isotc211.org/dataqualitymeasures/
28"
          },
          "result": {
            "resultType": "quantitative",
            "value": 2.3,
            "valueUnit": "meters",
            "valueRecordType": "Real"
          }
        },
        {
          "$comment": "ISO 19157-3:2026 - Geospatial Data Interpretability Index
(GDII) extension (optional)",
          "category": "Geospatial Data Interpretability Index (GDII)",
          "subcategory": "fitnessForPurpose",
          "stac_extensions": [
            "https://def.isotc211.org/iso19157-3/v1.0.0/schema.json"
          ],
          "measure": {
            "nameOfMeasure": ["Suitability for precision agriculture"],
            "measureIdentifier": "https://def.isotc211.org/Geospatial Data
Interpretability Index (GDII)Measures/501"
          },
          "result": {
            "resultType": "conformance",
            "pass": true,
            "specification": {
              "title": "Precision Agriculture Data Requirements - ASABE S612.1",
              "date": "2024-11-01",
              "url": "https://elibrary.asabe.org/abstract.asp?aid=53684"
            }
          }
        }
      ]
    }
  ]
}
```


Listing B.17

B.17. Impact on STAC Extension Liability Claims

B.17.1. Current implementation (ISO 19157-1:2023)

Status: # COMPLIANT

The STAC Extension Liability Claims correctly implements ISO 19157-1:2023:

1. # **Geospatial Data Interpretability Index (GDII) removed** from v1.3.0, v1.4.0, v1.5.0
2. # **Lineage separated** via `dq:lineage` field (ISO 19115-1:2014)

3. # **Extended lineage** via `dq:extendedLineage` field (ISO 19115-2:2019)
4. # **Metaquality confidence** recommended for fitness assessments
5. # **Conformance results** for specification compliance

B.18. ISO 19157-3:2026 adoption considerations

B.18.1. Arguments for adoption

- # Remote sensing imagery has specific application fitness requirements
- # NIIRS ratings (already in v1.5.0) align with Geospatial Data Interpretability Index (GDII) assessment
- # Users need to document fitness for emergency response, agriculture, urban planning
- # Optional conformance class maintains backward compatibility

B.18.2. Arguments against adoption

- # ISO 19157-3:2026 is not yet published (still in draft/proposal stage)
- # ISO 19157-1:2023 conformance + metaquality already sufficient
- # Adds complexity — users may misuse Geospatial Data Interpretability Index (GDII) instead of conformance
- # Migration guide just removed Geospatial Data Interpretability Index (GDII); reintroducing may confuse users

B.18.3. Recommendations

WAIT until ISO 19157-3:2026 is officially published, then:

1. **Monitor adoption** by OGC, CEOS, ESA, NASA
2. **Add as optional extension** (new conformance class)
3. **Provide clear guidance** on when to use Geospatial Data Interpretability Index (GDII) vs metaquality

4. **Version as v1.6.0** or v2.0.0 with ISO 19157-3:2026 support

B.18.4. For current users (ISO 19157-1:2023)

1. # **Continue using metaquality confidence** for fitness limitations (cloud coverage, sensor quality)
2. # **Continue using conformance results** for specification compliance (CEOS-ARD, INSPIRE)
3. # **Keep lineage separated** in `dq:lineage` field
4. # **Use extended lineage** (`dq:extendedLineage`) for detailed algorithm documentation
5. # **Do NOT reintroduce Geospatial Data Interpretability Index (GDII)** until ISO 19157-3:2026 is published

B.18.5. For future planning (ISO 19157-3:2026)

1. # **Monitor ISO TC211 publication schedule** for ISO 19157-3:2026 release
2. # **Evaluate community adoption** by OGC, CEOS, Copernicus before implementation
3. # **Assess user demand** for domain-specific fitness assessments
4. ⚠# **Provide clear migration guidance** to avoid confusion with removed Geospatial Data Interpretability Index (GDII) from v1.3.0-v1.5.0
5. # **Create testbed examples** demonstrating correct Geospatial Data Interpretability Index (GDII) vs metaquality usage

B.19. ISO 19115 Family vs ISO 19157 vs STAC Liability & Claims Extension — Comprehensive Comparison

---

B.19.1. 1. Standards Overview

Table B.11 — Standards overview — ISO 19115, ISO 19157, and STAC Liability & Claims

STANDARD SERIES		FULL TITLE	PRIMARY ROLE	CURRENT STATUS
ISO 19115-1	ISO 19115	Geographic information — Metadata — Part 1: Fundamentals	Core metadata model for geographic resources	Published (2014, Amd.1:2018)
ISO 19115-2	ISO 19115	Geographic information — Metadata — Part 2: Extensions for acquisition and processing	Metadata extensions for imagery and gridded data acquisition	Published (2019)
ISO 19115-3	ISO 19115	Geographic information — Metadata — Part 3: XML schema implementation for fundamental concepts	XML encoding of ISO 19115-1/2	Published (2016)
ISO 19115-4	ISO 19115	Geographic information — Metadata — Part 4: Imagery and gridded data	Imagery-specific metadata quality elements	Published
ISO 19157-1	ISO 19157	Geographic information — Data quality — Part 1: General requirements	Data quality framework and principles	Published (2023 revision)
ISO 19157-3	ISO 19157	Geographic information — Data quality — Part 3: Data quality measures register	Standardized quality measures catalog with unique numeric codes	Expected April 2026
STAC Liability & Claims	STAC Extensions	STAC Extension for Liability Claims, Data Quality, Provenance, and Data Space fields	JSON-based STAC encoding of claims, quality, provenance, and ISO 20151 data sovereignty	v1.6.0 (April 2026)

B.19.2. 2. Conceptual Scope Comparison

Table B.12 — Conceptual scope comparison across standards

CONCEPT DOMAIN	ISO 19115 FAMILY	ISO 19157	STAC LIABILITY & CLAIMS
Metadata model	# Core focus (ISO 19115-1)	# Out of scope	⚠# Subset via `liability:*` fields
Data quality reporting	⚠# Via `dataQualityInfo` element (references ISO 19157)	# Core focus	# Via `liability:quality` → ISO 19157 DataQuality
Quality measures registry	# No standardized codes	# Core focus in ISO 19157-3 (numeric codes)	# References ISO 19157-3 measure codes

CONCEPT DOMAIN	ISO 19115 FAMILY	ISO 19157	STAC LIABILITY & CLAIMS
Imagery acquisition metadata	# ISO 19115-2 / ISO 19115-4	# Out of scope	⚠# NIIRS via `liability:niirs`
Lineage & provenance	# `LI_Lineage` in ISO 19115-1	# `DataQuality.lineage`	# W3C PROV-JSON via `liability:prov` + ISO 19115 LI_Source
Legal/liability claims	# Not addressed	# Not addressed	# Core focus (`liability:claim_*`, `liability:responsible_party`)
Insurance & financial damages	# Not addressed	# Not addressed	# `liability:damages_estimated`, `liability:insurance_provider`
Data sovereignty / data spaces	# Not addressed	# Not addressed	# ISO 20151 fields (usage policy, data contracts)
XML encoding	# ISO 19115-3 (XML/XSD)	# XML (`mdq:` namespace)	# JSON-LD / JSON Schema (STAC-native)
JSON Schema	⚠# ISO TC211 provides JSON schemas	⚠# via eovoc/dqc.json	# Native JSON Schema Draft-07
Semantic uplift / RDF	# Limited	# Limited	# `context.jsonld` with CEOS-ARD and ISO 19157-3 ontology namespaces
NIIRS interpretability	# Not addressed	# Not addressed	# `liability:niirs` (NIIRS 0–9 per sensor type)
Fitness for purpose	⚠# Informal in ISO 19115	# Geospatial Data Interpretability Index (GDII) category removed in ISO 19157-1:2023	# `dq:quality` descriptive results
Metaquality	# Not addressed	# ISO 19157-1:2023 (confidence, representativity, homogeneity)	# Supported in `liability:quality`

B.19.3. 3. Structural Architecture

B.19.3.1. ISO 19115 Family — Metadata-Centric Architecture

```
MD_Metadata (ISO 19115-1)
├── identificationInfo        → Resource description, keywords, spatial extent
```

```
├── contentInfo                → ISO 19115-2/4: Sensor, bands, acquisition
parameters
├── dataQualityInfo            → Integration point: contains DataQuality (ISO
19157)
├── resourceLineage            → LI_Lineage (source data, process steps)
├── metadataScope              → Scope level (dataset, series, tile, feature)
└── contact / dateInfo / ...   → Administrative metadata
```

Listing B.18

B.19.3.2. ISO 19157 — Quality-Centric Architecture

```
DataQuality (ISO 19157-1)
├── scope                      → MD_Scope (level: dataset, series, feature,
attribute...)
├── report[]                   → Array of Element subclasses:
│   ├── CompletenessOmission / CompletenessCommission
│   ├── AbsoluteExternalPositionalAccuracy
│   ├── ThematicClassificationCorrectness
│   ├── QuantitativeAttributeAccuracy
│   ├── ConceptualConsistency / DomainConsistency / ...
│   └── Metaquality (confidence, representativity, homogeneity)
│       ├── measureIdentification → ISO 19157-3 numeric code (e.g., Measure 28,
47, 129)
│       ├── evaluationMethod      → directInternal | directExternal | indirect
│       └── result[]              → QuantitativeResult | ConformanceResult |
DescriptiveResult
└── lineage                    → LI_Lineage reference
```

Listing B.19

B.19.3.3. STAC Liability & Claims — STAC-Native JSON Architecture

```
STAC Item / Collection
└── properties
    ├── liability:responsible_party     → Responsible party identifier
    ├── liability:claim_id              → Unique claim identifier
    ├── liability:claim_status          → pending | accepted | settled | closed
| ...
    ├── liability:claim_type            → environmental | property_damage |
financial | ...
    ├── liability:claim_date            → RFC 3339 datetime
    ├── liability:incident_date         → RFC 3339 datetime
    ├── liability:resolution_date       → RFC 3339 datetime
    ├── liability:resolution_status     → in_favor | against | partial_
settlement | ...
    ├── liability:coverage_area         → GeoJSON geometry
    ├── liability:affected_parties[]    → name, role, contact
    ├── liability:damages_estimated     → Numeric (minimum: 0)
    ├── liability:damages_currency      → ISO 4217 code (USD, EUR, ...)
    ├── liability:legal_jurisdiction    → Legal jurisdiction string
    ├── liability:insurance_provider    → Insurance entity name
    ├── liability:policy_number         → Policy identifier
    ├── liability:evidence_refs[]       → URI list (supporting materials)
    ├── liability:origin                → Source organization
    ├── liability:notes                 → Free text
    ├── liability:quality               → ISO 19157 DataQuality (via eovoc dqc.
json)
```

```
     │                                        OR ISO 19115 quality report (backward
compat.)
     ├── liability:prov                     → W3C PROV-JSON (entities, activities,
agents)
     ├── liability:niirs                    → NIIRS (overall + per-sensor variants)
     ├── dq:quality                         → Standalone DataQuality (ISO 19157-1)
     ├── dq:lineage                         → Standalone LI_Lineage (ISO 19115)
     ├── dq:extendedLineage                 → Extended LE_ProcessStep lineage
     └── ard:*                              → Flattened ARD queryable fields (CQL2-
compatible)
         ├── ard:geometric_accuracy      → Copies AbsoluteExternalPositionalAccura
cy value
         ├── ard:radiometric_accuracy    → Copies QuantitativeAttributeAccuracy
value
         ├── ard:cloud_coverage          → Cloud coverage % (optical)
         ├── ard:data_mask_coverage      → Data mask % (radar)
         └── ard:specification_compliance → CEOS-ARD PFS compliance status
```

Listing B.20

B.19.4. 4. Quality Category Mapping

Table B.13 — Quality category mapping — ISO 19115-4, ISO 19157-1, and STAC Liability & Claims

ISO 19115-1 ELEMENT	ISO 19115-4 ELEMENT	ISO 19157-1 CATEGORY	ISO 19157-3 MEASURE CODES	STAC LIABILITY FIELD	NOTES
`completeness`	`completeness`	`completeness.omission` / `completeness.commission`	3 (rate of missing items), 4 (rate of excess items), 6 (# missing items)	`liability:quality.report[].category: "completeness"`	Direct mapping; ISO 19157 adds subcategories
`logicalConsiste`	`logicalConsiste`	`logicalConsiste` `conceptual` / `.domain` / `.format` / `.topological`	7–15 (various consistency measures)	`liability:quality.report[].category: "logicalConsist`	ISO 19157 splits into 4 subcategories
`positionalAccur`	`positionalAccur`	`positionalAccur` `absoluteExterna` / `.relativeInterna` / `.gridded`	28 (mean positional uncertainty), 47 (RMSE), 48 (CEP), 50 (LEP)	`liability:quality.report[].category: "positionalAccu` + `ard:geometric_accuracy`	RMSE preferred; ISO 19157-3 adds gridded accuracy
`thematicAccurac`	`thematicAccurac`	`thematicQuality` `classification`	60–67 (attribute accuracy), 117	`liability:quality.`	Renamed in ISO 19157

ISO 19115-1 ELEMENT	ISO 19115-4 ELEMENT	ISO 19157-1 CATEGORY	ISO 19157-3 MEASURE CODES	STAC LIABILITY FIELD	NOTES
		/.quantitative /.nonquantitative	(value domain conformance)	report[].category: "thematicQualit + ard:radiometric_accuracy	
temporalAccurac	temporalAccurac	temporalQuality accuracy /.consistency /.validity	68–72 (temporal accuracy measures)	liability:quality.report[].category: "temporalQualit	ISO 19157 adds temporal consistency and validity
attributeAccura	—	Merged into thematicQuality	60–67	liability:quality.report[].category: "thematicQualit	Subcategory of thematic quality
topologicalCons	—	logicalConsiste topological	13–15	liability:quality.report[].category: "logicalConsist	Subcategory of logical consistency
lineage	lineage	lineage (LI_Lineage reference)	—	liability:prov + dq:lineage	PROV-JSON enriches ISO lineage
—	radiometricAccu (19115-4)	thematicQuality quantitativeAtt	60, 63	ard:radiometric_accuracy	No direct ISO 19157 category; maps to thematic quality
—	sensorQuality (19115-4)	metaquality.confidence	129 (confidence in DQ result)	liability:quality.report[].category: "metaquality"	Maps calibration status to metaquality confidence
—	cloudCoverage (19115-4)	metaquality.confidence (descriptive)	—	ard:cloud_coverage	No standardized ISO 19157-3 measure; use descriptive result
—	snowCoverage (19115-4)	metaquality.confidence (descriptive)	—	No direct field — descriptive result	No standardized ISO 19157-3 measure

ISO 19115-1 ELEMENT	ISO 19115-4 ELEMENT	ISO 19157-1 CATEGORY	ISO 19157-3 MEASURE CODES	STAC LIABILITY FIELD	NOTES
—	processingLevel (19115-4)	lineage. processStep	—	dq: extendedLineage processStep[]	Document as LE_ ProcessStep in lineage
—	Geospatial Data Interpretabilit Index (GDII)Assessmer (19115-4)	# Removed in ISO 19157-1:2023	—	liability: quality. result[]. resultType: "descriptive"	Use descriptive result for fitness-for-purpose
—	—	metaquality (NEW in ISO 19157-1:2023)	128–132	liability: quality. report[]. category: "metaquality"	No ISO 19115 equivalent; high value for geospatial claims
—	—	—	—	liability: niirs	NIIRS interpretability — no ISO standard equivalent

B.19.5. 5. Lineage and Provenance Comparison

Table B.14 — Lineage and provenance comparison

ASPECT	ISO 19115-1 LI_ LINEAGE	ISO 19157-1 LINEAGE	STAC LIABILITY `liability:prov`	STAC `dq:lineage`
Model	ISO 19115-1 metadata model	References ISO 19115 LI_Lineage	W3C PROV-DM (entities, activities, agents)	ISO 19115-1 LI_ Lineage (JSON encoding)
Process steps	LI_ProcessStep	LI_ProcessStep reference	prov:Activity with time intervals	LE_ProcessStep (ISO 19115-2)
Source data	LI_Source	LI_Source reference	prov:Entity with derivation relations	LI_Source (ISO 19115-2 via mdj.json)
Agents/actors	CI_ ResponsibleParty	CI_ ResponsibleParty	prov:Agent with prov: actedOnBehalfOf	CI_ ResponsibleParty via CI_Citation
Granularity	Medium (process steps, sources)	Medium (references 19115)	High (entity-activity-agent graph)	High (LE_ProcessStep with CI_Date)

ASPECT	ISO 19115-1 LI_LINEAGE	ISO 19157-1 LINEAGE	STAC LIABILITY `liability:prov`	STAC `dq:lineage`
Interoperability	XML/XSD only	XML + JSON (TC211)	W3C PROV-JSON (universal)	JSON-LD via STAC
Traceability	Dataset-level to source	Dataset-level	Item-level, fine-grained graph	Item-level, hierarchical
Legal admissibility	# Not designed for legal use	# Not designed for legal use	⚠# Partial (agent/activity trails)	# Not designed for legal use
Claim evidence support	#	#	# `prov:wasDerivedFrom`, `prov:wasGeneratedBy`	#
Blockchain / distributed	#	#	# Compatible with anchoring	#

B.19.6. 6. Evaluation Method Comparison

Table B.15 — Evaluation method comparison

METHOD TYPE	ISO 19115-1	ISO 19157-1	STAC LIABILITY ENCODING
Direct internal	Generic description	`evaluationMethodType: "directInternal"`	`evaluationMethod.evaluationMethodType: "directInternal"` in Element
Direct external	Generic description	`evaluationMethodType: "directExternal"`	`evaluationMethod.evaluationMethodType: "directExternal"`
Indirect	Generic description	`evaluationMethodType: "indirect"`	`evaluationMethod.evaluationMethodType: "indirect"`
Evaluation procedure citation	`LI_ProcessStep.description`	`evaluationProcedure: CI_Citation`	Full `CI_Citation` with responsible parties, identifiers, URLs
Evaluation date	`LI_ProcessStep.dateTime`	`evaluationMethod.dateTime`	`evaluationMethod.dateTime` (RFC 3339)

METHOD TYPE	ISO 19115-1	ISO 19157-1	STAC LIABILITY ENCODING
Measure identification	# No standardized codes	# ISO 19157-3 numeric codes (e.g., “28”)	`measureIdentification.code` + `codeSpace: "ISO 19157"`

B.19.7. 7. Result Types Comparison

Table B.16 — Result types comparison

RESULT TYPE	ISO 19115-1	ISO 19157-1	STAC LIABILITY ENCODING
Quantitative value	Simple number + unit	`QuantitativeResult` with `value[]`, `valueUnit`	`resultType: "quantitative"` + `value: [number]` (array since v1.3.0)
Multi-value (per band)	# Single value only	# Array of values	`value: [v1, v2, v3]` (v1.3.0+ breaking change from scalar)
Conformance (pass/fail)	Pass/fail description	`ConformanceResult` with `pass`, `specification`	`resultType: "conformance"` + `pass: true/false` + `specification: CI_Citation`
Descriptive statement	Free text description	`DescriptiveResult` with `statement`	`resultType: "descriptive"` + `statement: "..."`
Coverage result	# Not supported	`CoverageResult`	⚠# Partial support
Error statistic	# Not formalized	`errorStatistic` field	`errorStatistic: "RMSE"` / `"CEP"` / etc.

B.19.8. 8. Legal and Claims Domains

NOTE: This is the unique differentiator of the STAC Liability & Claims Extension — ISO standards do not address these concepts at all.

Table B.17 — Legal and claims domain comparison

CONCEPT	ISO 19115	ISO 19157	STAC LIABILITY & CLAIMS
Responsible party for claim	`CI_ResponsibleParty` (metadata contact only)	#	`liability: responsible_party`
Claim status lifecycle	#	#	`liability:claim_status`: pending → settled → closed
Claim type classification	#	#	`liability:claim_type`: environmental, property_damage, personal_injury, financial, operational
Affected parties	#	#	`liability:affected_parties[]` (name, role, contact)
Financial damages	#	#	`liability:damages_estimated` + `liability: damages_currency` (ISO 4217)
Insurance coverage	#	#	`liability:insurance_provider` + `liability: policy_number`
Legal jurisdiction	#	#	`liability:legal_jurisdiction`
Incident vs. claim date	#	#	`liability:incident_date` vs `liability: claim_date`
Resolution outcome	#	#	`liability:resolution_status`: in_favor, against, partial_settlement, dismissed, withdrawn
Evidence references	#	#	`liability:evidence_refs[]` (URI list to documents, images, STAC assets)
Geographic claim area	#	#	`liability:coverage_area` (GeoJSON geometry)
Data sovereignty	#	#	ISO 20151 fields (usage policy, data contracts, sovereignty constraints)

B.19.9. 9. Data Space and Sovereignty (ISO 20151)

NOTE: The STAC Liability & Claims Extension v1.5.0+ incorporates ISO 20151 data space interoperability fields. Neither ISO 19115 nor ISO 19157 address this domain.

Table B.18 — Data space and sovereignty comparison (ISO 20151)

CONCEPT	ISO 19115	ISO 19157	STAC LIABILITY & CLAIMS
Usage policy	⚠# Partial (`MD_Constraints`)	#	# ISO 20151 usage policy fields
Data contracts	#	#	# Data contract references
Sovereignty constraints	#	#	# Data sovereignty encoding
Access control	⚠# `MD_SecurityConstraints`	#	# Integrated with claims status

B.19.10. 10. Encoding and Interoperability

Table B.19 — Encoding and interoperability comparison

CHARACTERISTIC	ISO 19115-3 (XML)	ISO 19157 (XML/JSON)	STAC LIABILITY & CLAIMS (JSON)
Primary encoding	XML Schema (XSD)	XML + JSON (ISO TC211)	JSON Schema Draft-07
Namespace	`mdb:`, `mdq:`, `mrl:`	`mdq:`, `mdq:DQ_*`	`liability:`, `dq:`, `ard:`
Schema location	ISO TC211 XSD repository	TC211 + eovoc canonical	`luciocola.github.io/stac-extension-liability-claims/vX.Y.Z/schema.json`
JSON-LD context	# Limited	# Limited	# `context.jsonld` with CEOS-ARD + ISO 19157-3 ontologies
Semantic web (RDF)	#	#	# `ard:*` mapped to ISO 19157-3 and CEOS-ARD ontology concepts

CHARACTERISTIC	ISO 19115-3 (XML)	ISO 19157 (XML/JSON)	STAC LIABILITY & CLAIMS (JSON)
OGC API compliance	⚠# Via OGC Metadata API	⚠# Via OGC Features API	# STAC API + CQL2 queryable `ard:*` fields
STAC Item/Collection	#	#	# Native
W3C PROV	#	#	# `liability:prov` (PROV-JSON model)
Backward compatibility	# ISO 19115-1 → 19115-3	# ISO 19157-1:2013 → 2023	# v1.1.0 items valid in v1.6.0
Validation tooling	XML validators (Saxon, Schematron)	XML/JSON validators	Python (`validate.py`), JSON Schema validators

---

B.19.11. 11. Quality Framework Integration in STAC

The STAC Liability & Claims Extension integrates ISO 19157 quality into STAC through three complementary paths.

B.19.11.1. Path A — Full ISO 19157 Quality (Recommended, v1.3.0+)

```
{
  "liability:quality": {
    "scope": { "level": "dataset" },
    "report": [{
      "type": "AbsolutePositionalAccuracy",
      "category": "positionalAccuracy",
      "measure": {
        "measureIdentification": { "code": "47", "codeSpace": "ISO 19157",
"version": "2023" },
        "nameOfMeasure": ["Root mean square error"]
      },
      "evaluationMethod": {
        "evaluationMethodType": "directExternal",
        "dateTime": "2026-03-15T12:00:00Z"
      },
      "result": [{ "resultType": "quantitative", "value": [8.5], "valueUnit":
"meter", "errorStatistic": "RMSE" }]
    }]
  }
}
```

Listing B.21

References canonical eovoc `dqc.json` (ISO 19157).

B.19.11.2. Path B — ISO 19115 Quality (Backward Compatibility)

```
{
  "liability:quality": {
    "type": "iso19115_quality_report",
    "qualityElements": [...]
  }
}
```

Listing B.22

References local `iso19115-quality.json` (deprecated from v2.0.0).

B.19.11.3. Path C — ARD Flattened Fields (CQL2 Queryable)

```
{
  "ard:geometric_accuracy": 8.5,
  "ard:geometric_accuracy_unit": "meter",
  "ard:geometric_accuracy_type": "RMSE",
  "ard:cloud_coverage": 12.3,
  "ard:specification_compliance": "CEOS-ARD NRB v1.2"
}
```

Listing B.23

Enables CQL2 queries such as: `ard:geometric_accuracy <= 10 AND ard:cloud_coverage < 20`

B.19.12. 12. Standards Evolution Timeline

```
ISO 19115-1:2014 ──────────────────────────────────────────── Core metadata
model
ISO 19115-2:2019 ──────────────────────────────────────────── Imagery
acquisition
ISO 19115-3:2016 ──────────────────────────────────────────── XML
implementation
ISO 19115-4      ──────────────────────────────────────────── Imagery
quality metadata

ISO 19157-1:2013 ──▶ ISO 19157-1:2023 (revised) ──────────── DQ framework
ISO 19157-3:2026 (expected April 2026) ──────────────────── Measures
register

STAC Liability & Claims Extension:
  v1.1.0 (2025)      — Core claims + ISO 19157 quality + W3C PROV
  v1.2.0 (Feb 2026)  — ISO TC211 alignment + ARD queryable fields + semantic
uplift
  v1.3.0 (Feb 2026)  — Canonical eovoc schemas + MD_Scope objects + CI_Citation
  v1.4.0 (Feb 2026)  — EOVOC v0.0.2 alignment + CI_Date in LE_ProcessStep
  v1.5.0 (2026)      — ISO 20151 data space interoperability
```

```
v1.6.0 (Apr 2026)  — Current (NIIRS + full schema consolidation)
```

Listing B.24

B.19.13. 13. Decision Guide — Which Standard to Use When

Table B.20 — Decision guide — standard selection by requirement

REQUIREMENT	RECOMMENDED STANDARD
Archive geospatial metadata for cataloguing	ISO 19115-1 + ISO 19115-3 (XML)
Document imagery acquisition parameters (sensor, bands, orbit)	ISO 19115-2 / ISO 19115-4
Report standardized data quality with numeric measure codes	ISO 19157-1 + ISO 19157-3 measures
Publish geospatial data on the web with quality filters	STAC Liability & Claims (`ard:*` + `liability:quality`)
Track legal/insurance claims related to geospatial events	STAC Liability & Claims (`liability:claim_*`)
Document data provenance for legal/audit purposes	STAC `liability:prov` (W3C PROV-JSON)
Query imagery by positional accuracy or cloud coverage	STAC `ard:geometric_accuracy`, `ard:cloud_coverage`
Assess imagery interpretability (NIIRS)	STAC `liability:niirs`
Encode data contracts and sovereignty constraints	STAC `liability:*` (ISO 20151 fields)
Cross-validate against official ISO TC211 tooling	`liability:quality` → eovoc canonical dqc.json

B.19.14. 14. Key Gaps and Bridging Strategies

Table B.21 — Key gaps and bridging strategies

GAP	UPSTREAM STANDARDS	STAC LIABILITY & CLAIMS SOLUTION
ISO 19115 imagery elements (`cloudCoverage`, `snowCoverage`) have no ISO 19157-3 measure codes	ISO 19115-4 ↔ ISO 19157-3	Use `metaquality.confidence` with descriptive result + `ard:cloud_coverage` queryable field

GAP	UPSTREAM STANDARDS	STAC LIABILITY & CLAIMS SOLUTION
ISO 19157-1:2023 removed Geospatial Data Interpretability Index (GDII) category	ISO 19115 `Geospatial Data Interpretability Index (GDII)Assessment`	Use descriptive result with fitness-for-purpose statement
No legal/claims domain in either ISO 19115 or ISO 19157	Both ISO families	Full `liability:claim_*` fields + `liability:evidence_refs` + `liability:coverage_area`
No standardized NIIRS encoding in any ISO standard	Both ISO families	`liability:niirs` with per-sensor type variants (visible, radar, infrared, MSI, SAR)
XML-first ISO standards poorly suited for REST APIs	ISO 19115-3, ISO 19157	STAC JSON + CQL2-queryable `ard:*` fields
No W3C PROV link from ISO quality reports	ISO 19115 lineage	`liability:prov` PROV-JSON complementing `dq:lineage`
Data space/sovereignty not covered by ISO TC211	Both ISO families	ISO 20151 fields in v1.5.0+

B.19.14.1. Bibliography

[1] International Organization for Standardization (committee): ISO 19115-1:2014, *Geographic information — Metadata — Part 1: Fundamentals*. International Organization for Standardization, Geneva (2014). https://www.iso.org/standard/53798.html.

[2] International Organization for Standardization (committee): ISO 19115-2:2019, *Geographic information — Metadata — Part 2: Extensions for acquisition and processing*. International Organization for Standardization, Geneva (2019). https://www.iso.org/standard/67039.html.

[3] International Organization for Standardization (committee): ISO 19157:2013, *Geographic information — Data quality*. International Organization for Standardization, Geneva (2013). https://www.iso.org/standard/32575.html.

[4] International Organization for Standardization (committee): ISO 19157-1:2023, *Geographic information — Data quality — Part 1: General requirements*. International Organization for Standardization, Geneva (2023). https://www.iso.org/standard/78900.html.

[5] ISO: ISO 19157-2:2023, *Geographic information — Data quality — Part 2: Data quality measures*. ISO (2023).

[6] ISO: ISO 19157-3:2026, *Geographic information — Data quality — Part 3: Geospatial Data Interpretability Index (GDII) elements (PROPOSED — Not yet published)*. ISO (2026).

B.19.14.2. Measure registers

- Current: https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/
- Permanent (April 2026): https://def.isotc211.org/dataqualitymeasures/
- Geospatial Data Interpretability Index (GDII) measures (proposed): https://def.isotc211.org/Geospatial Data Interpretability Index (GDII)Measures/

C

ANNEX C (INFORMATIVE) SEMANTIC LIFTING

ANNEX C (INFORMATIVE) SEMANTIC LIFTING

C.1. Overview

This annex summarizes **semantic lifting**: transforming data from syntactic or application-specific formats into semantically annotated, machine-interpretable representations aligned with global vocabularies and knowledge models such as RDF and Linked Data. For the Data Quality for Integrity, Provenance, and Trust (DQ4IPT) work documented in this Report, that capability matters because quality metadata, provenance, and trust assertions increasingly travel as JSON alongside STAC and OGC API payloads—yet **trust** and **interoperability** require those payloads to mean the same thing to catalogues, validators, and policy engines across organizations. Semantic lifting is the bridge from application-specific JSON to **shared IRIs**, registered definitions (including ISO 19157 quality measures registered in OGC RAINBOW), and graph-friendly representations compatible with W3C PROV and semantic validation. The annex describes JSON-LD context annotation, optional pre- and post-processing, deterministic RDF generation, and the role of the OGC Naming Authority tooling that supports published vocabularies and registers.

Semantic lifting is the process of transforming data from syntactic or application-specific formats into **semantically annotated, machine-interpretable representations** aligned with global vocabularies and knowledge models such as RDF and Linked Data.

Within the **OGC ecosystem**, semantic lifting enables geospatial and related datasets, commonly expressed in JSON, XML, or other structured formats, to transition into **semantically grounded graph representations** that support interoperability, validation, reasoning, and cross-domain integration.

C.2. Relevance to DQ4IPT

The DQ4IPT activity in Testbed-21 ties **data quality** to **integrity, provenance, and trust** in Earth Observation (EO) services. That problem is not only syntactic—whether a document is valid JSON—but **semantic**: different systems must agree on what a quality result, measure reference, or lineage link **denotes**, and must be able to combine those facts with PROV, catalogues, and machine-learning pipelines without hand-coded one-off mappings.

Semantic lifting supports this Report's goals in several concrete ways:

- **Registered quality semantics** — Deliverables reference ISO 19157 quality reporting and definitions associated with OGC RAINBOW. Lifting connects instance data to stable IRIs and registers, so "the same" measure or scope is not reinvented per API or per project.
- **JSON-first EO metadata** — ISO 19115-4-oriented JSON, STAC Items, and API responses are the exchange surface for D101/D102 and the conversion library (D103). Semantic lifting explains how those encodings can be annotated so they remain aligned with ISO and W3C models when taken beyond a single vendor's parser.
- **STAC and API metadata** — DQ4IPT implementations surface quality and IPT-related fields in STAC Items and OGC API JSON. When those payloads are annotated with JSON-LD semantics, the same quality report can be validated, linked to PROV, and checked against registers without ad hoc field interpretation.
- **Provenance and trust tooling** — W3C PROV and semantic policies (for example SHACL) expect graphs with explicit identities and relationships. Lifting is what makes JSON-embedded quality and lineage participate in that ecosystem instead of staying trapped in siloed structures.
- **Conversion and meta-quality** — The report stresses interoperability among ISO 19157, ISO 19115, NASA UMM, and TrainingDML-AI. Lifting does not replace those conversions, but it clarifies how **target** models can be published with machine-readable semantics so conversions and "metaquality" checks are auditable and repeatable.

In short, semantic lifting is part of the **infrastructure story** for trustworthy, machine-actionable data quality metadata in IPT—not an optional academic step, but a practical way to keep JSON-centric APIs and graph-centric trust machinery aligned.

For DQ4IPT-style pipelines, semantic lifting is achieved primarily through:

- **Semantic annotation of schemas** using JSON-LD contexts (so ISO 19115-4 / ISO 19157 quality structures and identifiers have stable IRIs)
- **Optional transformation steps** before and after lifting (for example normalizing STAC or API JSON before uplift, or reshaping RDF afterward for catalogues)
- **Deterministic generation of RDF graphs** from JSON instances (so IPT and quality assertions can be audited and reasoned over consistently)

This approach ensures that semantics are declared **explicitly, transparently, and reusably**, rather than embedded implicitly in application logic.

C.3. Semantic lifting in OGC

Semantic lifting in OGC focuses on **schema-driven semantics**, not ad hoc data conversion. The core principle is:

> If the schema is semantically annotated, any conforming instance can be lifted consistently and repeatably.

Key characteristics of semantic lifting in OGC:

- Semantics are expressed using **JSON-LD contexts** mapping terms to IRIs
- Identifiers, classes, and relationships are made explicit
- Output graphs are compatible with RDF, SPARQL, SHACL, and GeoSPARQL
- Lifting workflows are **tool-independent and inspectable**

Semantic lifting enables:

- Explicit semantics for entities, properties, and relationships
- Integration with Linked Data ecosystems and domain ontologies
- Validation and reasoning using SHACL and rule engines
- Reuse of geospatial information across heterogeneous systems

Semantic lifting is therefore foundational to **semantic interoperability** across OGC APIs, datasets, catalogs, and digital infrastructures.

C.4. Role of the OGC Naming Authority

The **OGC Naming Authority (NA)** provides tooling and workflows for registering and publishing semantic assets such as vocabularies, schemas, and mappings used across OGC and partner communities OGC Naming Authority tools.

For DQ4IPT, those assets matter because data quality reports need **globally meaningful** identifiers for measures and scopes—exactly what registers such as OGC RAINBOW are intended to support [47]. Semantic lifting connects JSON instance fields (for example quality measure references inside ISO 19115-4-oriented metadata) to those IRIs so that validators, catalogues, and PROV-aware tools interpret them uniformly.

Semantic lifting is realized through **annotation and processing pipelines** (schema plus context, optional transforms, RDF output), not a single monolithic tool. Typical steps include:

- Annotating schemas with JSON-LD contexts
- Applying optional transformation steps before or after context application
- Producing JSON-LD and RDF in a reproducible manner for testing, publication, or downstream integration

---

C.5. Core mechanism: JSON-LD context annotation

C.5.1. Semantic annotation of JSON schemas

The primary mechanism for schema-driven semantic lifting is the **annotation of JSON Schemas with JSON-LD contexts**.

This can be achieved by:

- Shipping a `context.jsonld` file alongside the schema in a repository or component package; or
- Referencing a context via an `x-jsonld-context` property on the schema (URL or relative path to a JSON-LD context document)

This Report's STAC examples attach ISO 19157–oriented data quality metadata under `properties.liability:quality` (with `scope` and `report`), and reference the STAC **Liability and Claims** extension JSON Schema used in the IPT server sections—for example `https://luciocola.github.io/stac-extension-liability-claims/json-schema/schema.json` as listed in the `stac_extensions` arrays in Annex D and in the clause on DQ-enabled IPT Server 1. Semantic lifting does not introduce a different instance JSON shape: it associates a JSON-LD **context** with the **schema** that validates that JSON (for example via a root-level `x-jsonld-context` property on the JSON Schema document, or a `context.jsonld` file published alongside it), so that conforming STAC Items lift to RDF with stable IRIs for quality measures and scopes (including URIs aligned with OGC RAINBOW and ISO 19157-3 registers where applicable).

The fragment below reproduces the `properties` object from the STAC Item template already shown in this report (same structure as in Annex D); it is **instance** JSON, not a schema definition.

```
{
  "properties": {
    "datetime": "",
    "start_datetime": "",
    "end_datetime": "",
```

```
    "liability:quality": {
      "scope": {
        "level": "series"
      },
      "report": []
    }
  }
}
```

Listing C.1

These contexts define:

- Mappings from JSON property names to IRIs
- RDF classes (`@type`) associated with schema objects
- Base IRIs for identifier minting
- Linkages to external vocabularies and ontologies

Once annotated, the schema itself becomes a **semantic contract** that governs how instance data is interpreted as RDF.

C.5.2. Context modularity and composition

In complex specifications, schemas frequently reuse sub-schemas or nested components. Semantic lifting must therefore support **modular and composable contexts**.

Composable context design enables:

- Context fragments associated with individual schema components (for example separate fragments for STAC core, extensions, and quality blocks)
- Composition when sub-schemas are reused across services
- Avoidance of large, monolithic context documents

This supports scalable semantic annotation for large API or metadata stacks such as STAC plus multiple extensions.

C.6. Semantic uplift manifests and additional steps

C.6.1. Semantic uplift manifest (`semantic-uplift.yaml`)

For cases where direct JSON-LD annotation is insufficient, some toolchains support **additional uplift steps** defined in a `semantic-uplift.yaml` file (name and placement depend on the toolchain in use).

This manifest allows declarative specification of:

- **Pre-processing steps** (before JSON-LD context application)
- **Post-processing steps** (after RDF generation)

C.6.2. Pre-processing steps

Pre-processing steps typically reshape or normalize source JSON to make it suitable for semantic interpretation.

Examples include:

- JQ transformations
- ID normalization or minting
- Structural flattening or restructuring

These steps operate on JSON **before** semantic annotation is applied.

C.6.3. Post-processing steps

Post-processing steps operate on the RDF graph produced from JSON-LD.

Supported patterns include:

- SPARQL CONSTRUCT for graph reshaping
- SPARQL UPDATE for enrichment
- SHACL or SHACL-AF rules for inference and validation

These steps enable semantic patterns that cannot be expressed using JSON-LD context alone.

C.7. End-to-end semantic lifting workflow

A recommended semantic lifting workflow for DQ4IPT-style metadata is:

1. **Annotate schema**
   - Define JSON-LD contexts for schema terms
   - Associate classes, properties, and IRIs
2. **(Optional) Pre-processing**
   - Apply JSON transforms (for example, jq)
   - Normalize identifiers and structure
3. **Generate JSON-LD**
   - Apply context mappings to instance data
   - Produce semantically annotated JSON
4. **Convert to RDF**
   - Parse JSON-LD into RDF serializations (Turtle, N-Quads)
5. **(Optional) Post-processing**
   - Apply SPARQL or SHACL rules
   - Enrich or reshape the RDF graph
6. **Validate and reason**
   - Validate using SHACL shapes
   - Apply entailment or inference rules
7. **Publish**
   - Expose RDF via APIs or catalogs
   - Register datasets using DCAT or similar vocabularies

C.8. Runtime versus publication-time lifting

Semantic lifting for specification and catalogue assets is often performed:

- At **build time**, when generating examples, validation artifacts, or static RDF views
- At **publication time**, when datasets or metadata collections are prepared for dissemination

Runtime semantic lifting in live IPT or catalogue services is possible but depends on:

- Availability of reusable, documented uplift definitions
- Stability of transformation logic
- Performance and operational constraints

Support for reusable runtime uplift varies by implementation; DQ4IPT server and library components may perform conversion and validation without full RDF uplift unless that is an explicit requirement.

C.9. Semantic uplift in future testbeds

Testbed-21 DQ4IPT documents how semantic lifting relates to IPT, STAC-oriented quality metadata, and OGC RAINBOW, but it does not constitute a full interoperability exercise or conformance campaign for **semantic uplift** itself. End-to-end uplift (JSON-LD contexts, optional transforms, RDF generation, SHACL or SPARQL-based checks) should be tested further—under realistic loads, with multiple implementations, and across catalogue and API workflows—in **future OGC testbeds**, so that uplift definitions, tooling, and operational guidance can mature alongside IPT and data-quality deliverables.

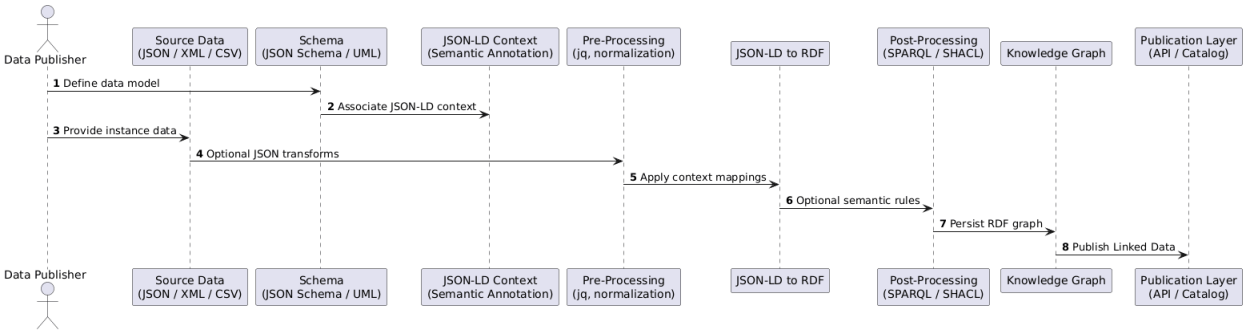

Figure C.1 — Semantic lifting end-to-end flow (conceptual sequence)

C.10. Sources and further reading

- OGC Naming Authority tools
- Tutorials — OGC Naming Authority tools
- OGC RAINBOW registry

D

ANNEX D (INFORMATIVE) IPT SERVER 1

ANNEX D (INFORMATIVE) IPT SERVER 1

The IPT-Server-1 for the Testbed-21 and the supporting infrastructure, the FACTS ecosystem, is contributed by Secure Dimensions.

D.1. FACTS Ecosystem Introduction

The FACTS ecosystem consists of two main components: (i) Smart Certificates and (ii) Immutable Catalog. The first component `Smart Certification` is outlined in the OGC Testbed-20 Engineering Report Testbed-20: Integrity, Provenance, and Trust (IPT) Report — Annex B. The second component `Immutable Catalog` is introduced in the following sub-sections.

The `iSTAC` component of the FACTS ecosystem is a SpatioTemporal Asset Catalog (STAC) where the STAC features (the metadata records) are stored on a provenance blockchain. For Testbed-21, a Hyperledger Fabric blockchain is used. To support Testbed-21, the deployment of a test instance was favored over using an existing provenance blockchain simply because an existing blockchain charges per transaction. For Testbed-21, one blockchain with different iSTAC was deployed. On iSTAC for performance testing of a blockchain-based STAC was loaded with approx. 4 million records from the ESA EO Sentinel-2 catalog. Would an existing blockchain have been used, the creation of 4M records would have a cost transaction fee. Also, we do not have the authority to establish an iSTAC on an existing blockchain that contains metadata records from ESA.

Any STAC feature, uploaded to the iSTAC must include the hash value for the actual data asset that is associated to the metadata record. This ensures that any data asset can easily be associated with its metadata record stored on the blockchain. For an immutable catalog, as deployed for Testbed-21, the responsible chaincode does allow the creation of new STAC feature for authorized users and allows bulk read via the STAC API.

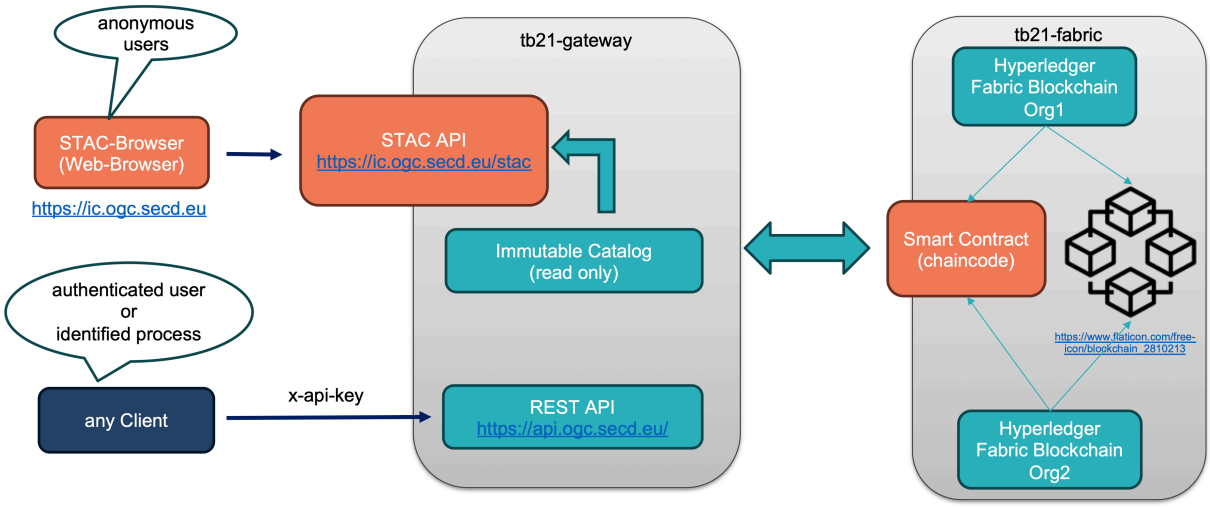

Figure D.1 — Testbed-21 Secure Dimensions Immutable Catalog Components

The component diagram illustrates the two main usages: (i) anonymous access to blockchain assets via the STAC API and (ii) authorized processes or users from basically any client component. Any STAC asset uploaded must follow a minimal structure:

```
{
  "assets": {
    "PRODUCT": {
      "href": "",
      "title": "Product",
      "type": "",
      "file:checksum": ""
    }
  },
  "bbox": [],
  "collection": "",
  "geometry": {},
  "id": "",
  "properties": {
    "datetime": "",
    "start_datetime": "",
    "end_datetime": "",
    "liability:quality": {
      "scope": {
        "level": "series"
      },
      "report": []
    }
  },
  "stac_extensions": [
    "https://stac-extensions.github.io/file/v2.1.0/schema.json",
    "https://stac-extensions.github.io/alternate-assets/v1.1.0/schema.json",
    "https://stac-extensions.github.io/processing/v1.2.0/schema.json",
    "https://luciocola.github.io/stac-extension-liability-claims/json-schema/
schema.json"
  ],
  "stac_version": "1.0.0",
  "type": "Feature",
  "links": [
    {
      "rel": "derived_from",
```

```
      "href": "",
      "type": "application/geo+json",
      "title": "Source metadata"
    },
    {
      "rel": "self",
      "href": "",
      "type": "application/geo+json"
    },
    {
      "rel": "collection",
      "href": "",
      "type": "application/json",
      "title": ""
    }
  ]
}
```

Listing D.1

The `file:checksum` is the most important element in the JSON template. This links the data asset with the STAC feature. Values are according to the `https://stac-extensions.github.io/file/v2.1.0/schema.json` described as multihash values. So for example the Blake3 hash with value `67f6f2beaa4fe9bb0082980dc2d1bbb14ffb7335914025e1dc5070be29748486` is encoded as `1e2067f6f2beaa4fe9bb0082980dc2d1bbb14ffb7335914025e1dc5070be29748486`.

The following image illustrates an iSTAC feature that documents the first computer bug:

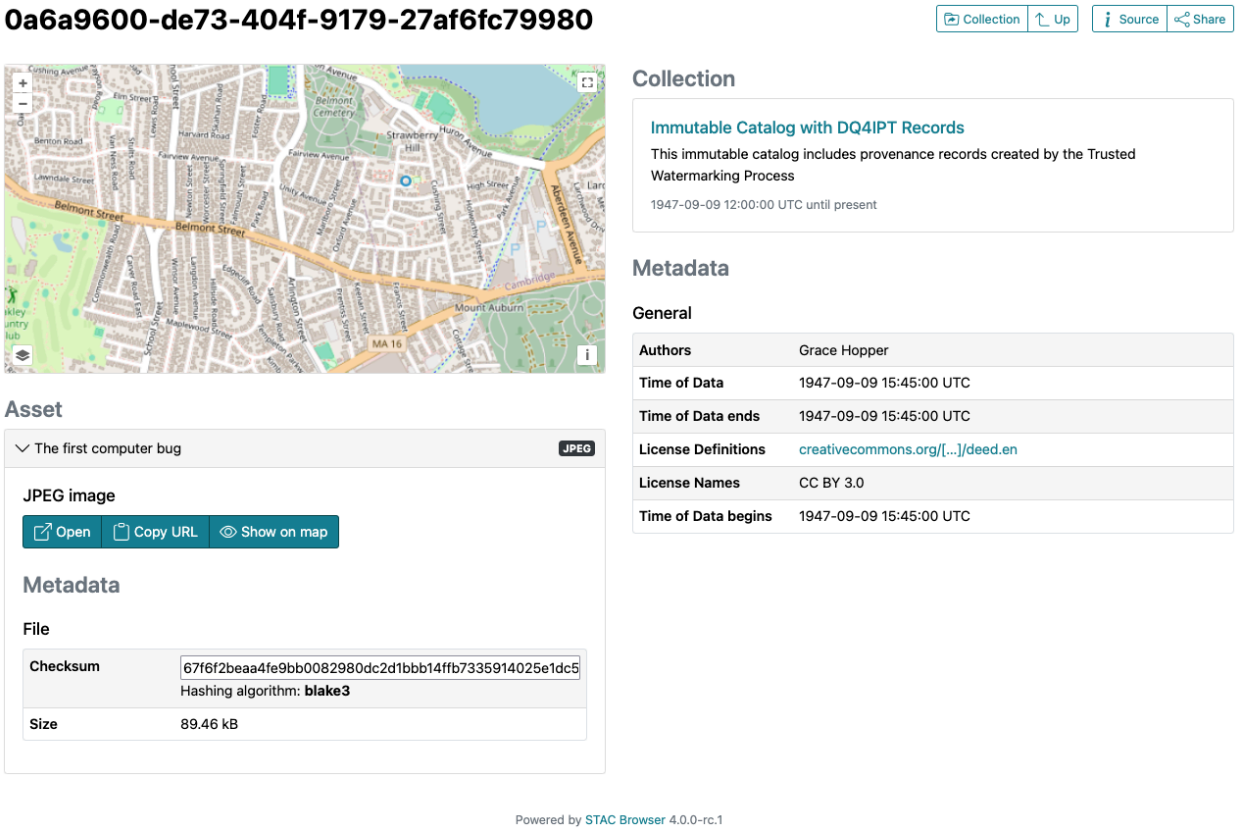

Figure D.2 — Testbed-21 Secure Dimensions Immutable Catalog
STAC Feature linked to the documentation of the first computer bug

The data asset links to the actual image showing the reporting of the first computer bug (the image itself is stored on IPFS):

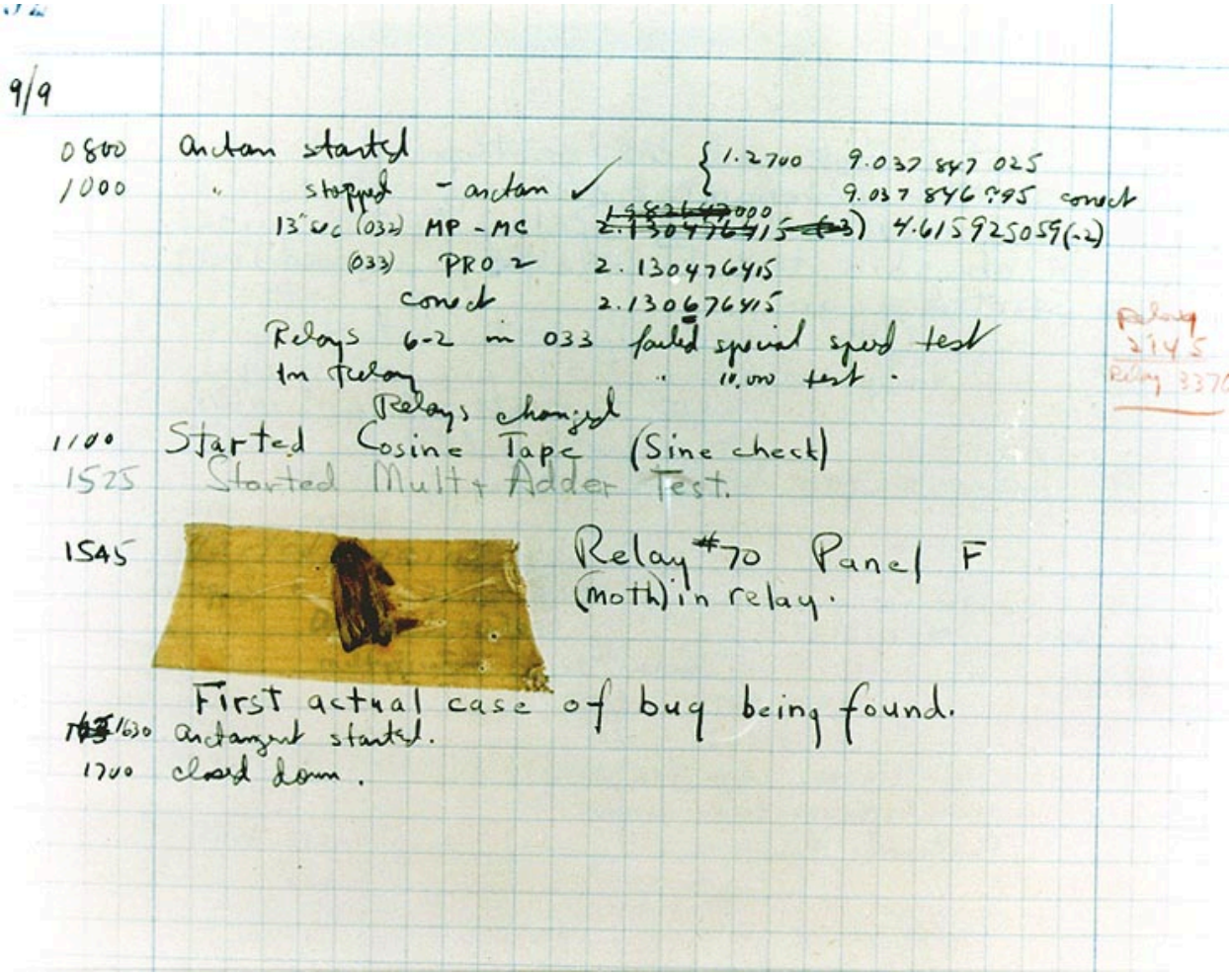

Figure D.3 — Testbed-21 Secure Dimensions IPFS documentation of the first computer bug

This data asset's Blake3 hash can easily be computed on the command line `b3sum FirstBug.jpg` with results in the value `67f6f2beaa4fe9bb0082980dc2d1bbb14ffb7335914025e1dc5070be29748486`. This documents that the image is genuine and the above metadata belongs to the image.

The genuine check can also be done via the iSTAC Browser as search via data asset hash is implemented as an additional search.

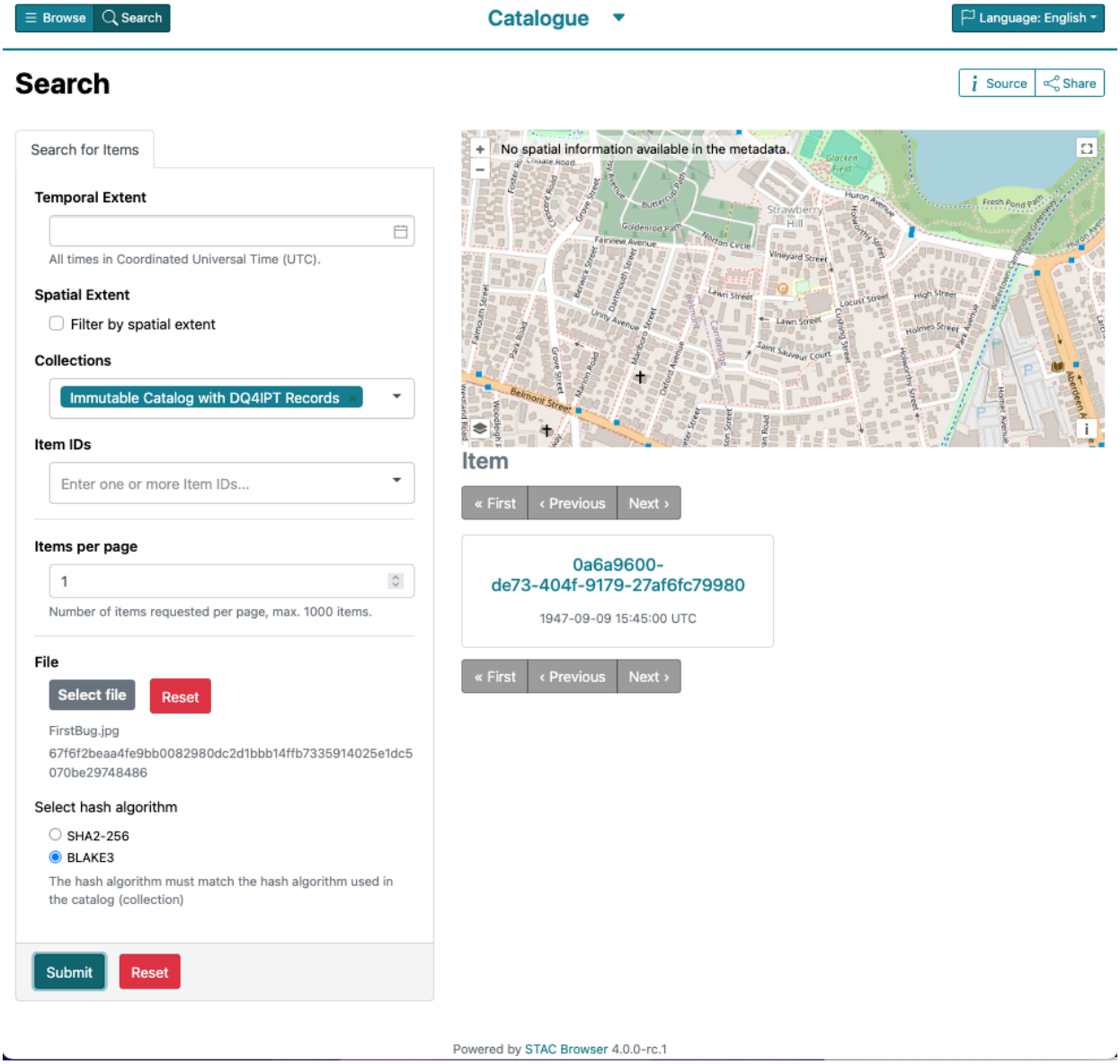

Figure D.4 — Testbed-21 Secure Dimensions Immutable Catalog STAC Browser Genuine Check

D.2. IPT-Server-1

D.2.1. Introduction

The IPT-Server-1 is implemented in Java as a Geoserver plugin for OGC API Processes named `TrustedWatermarking`. The plugin source code is available from the Github repository Geoserver Trusted Watermarking Plugin. The implementation creates a watermark to the input image and verifies the integrity of the input image based on a STAC record from a STAC catalog.

For each execution, the process generates IPT relevant metadata as defined in this Report that is uploaded to the FACTS iSTAC (immutable SpatialTemporal Asset Catalog). This STAC feature can be visualized via a regular STAC API. For demonstration purposes, the Testbed-21 ISTAC Browser can be used. The `Immutable Catalog with DQ4IPT Records` catalog contains the metadata records for the `TrustedWatermarking` process.

D.2.2. API

The IPT-Server-1 offers a regular OGC API Processes interface. The input and output parameters are defined here.

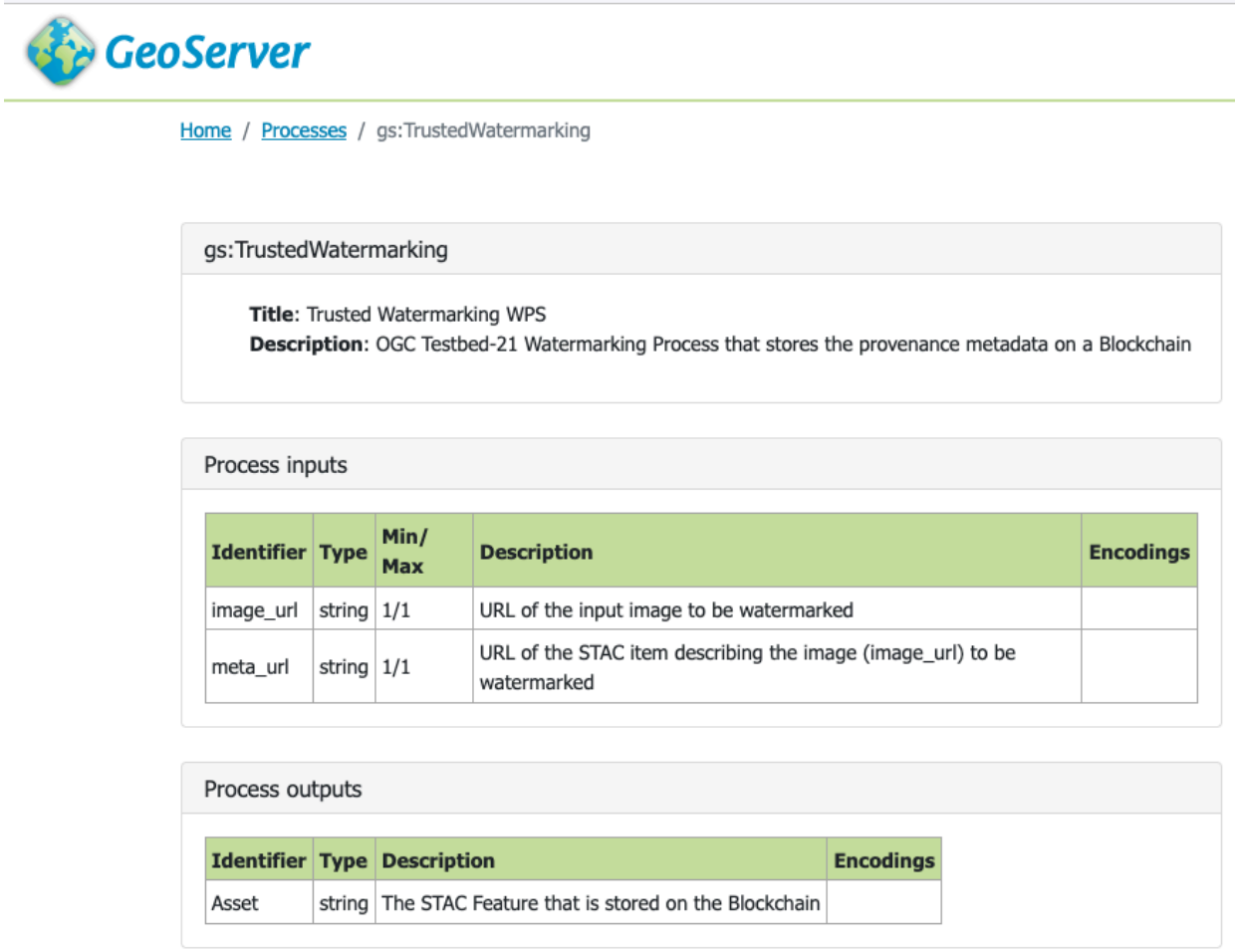

Figure D.5 — Testbed-21 Secure Dimensions Trusted Watermarking Process

The OGC API Records conformant execution of the process can be triggered via the Processes OpenAPI document with the following example input:

```
{ "inputs": {
            "image_url": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.PNG" ,
            "meta_url": "https://emc.spacebel.be/collections/PROBA.HRC.1A/items/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=application/
geo%2Bjson;profile=https://stacspec.org"
            }
```

}

Listing D.2

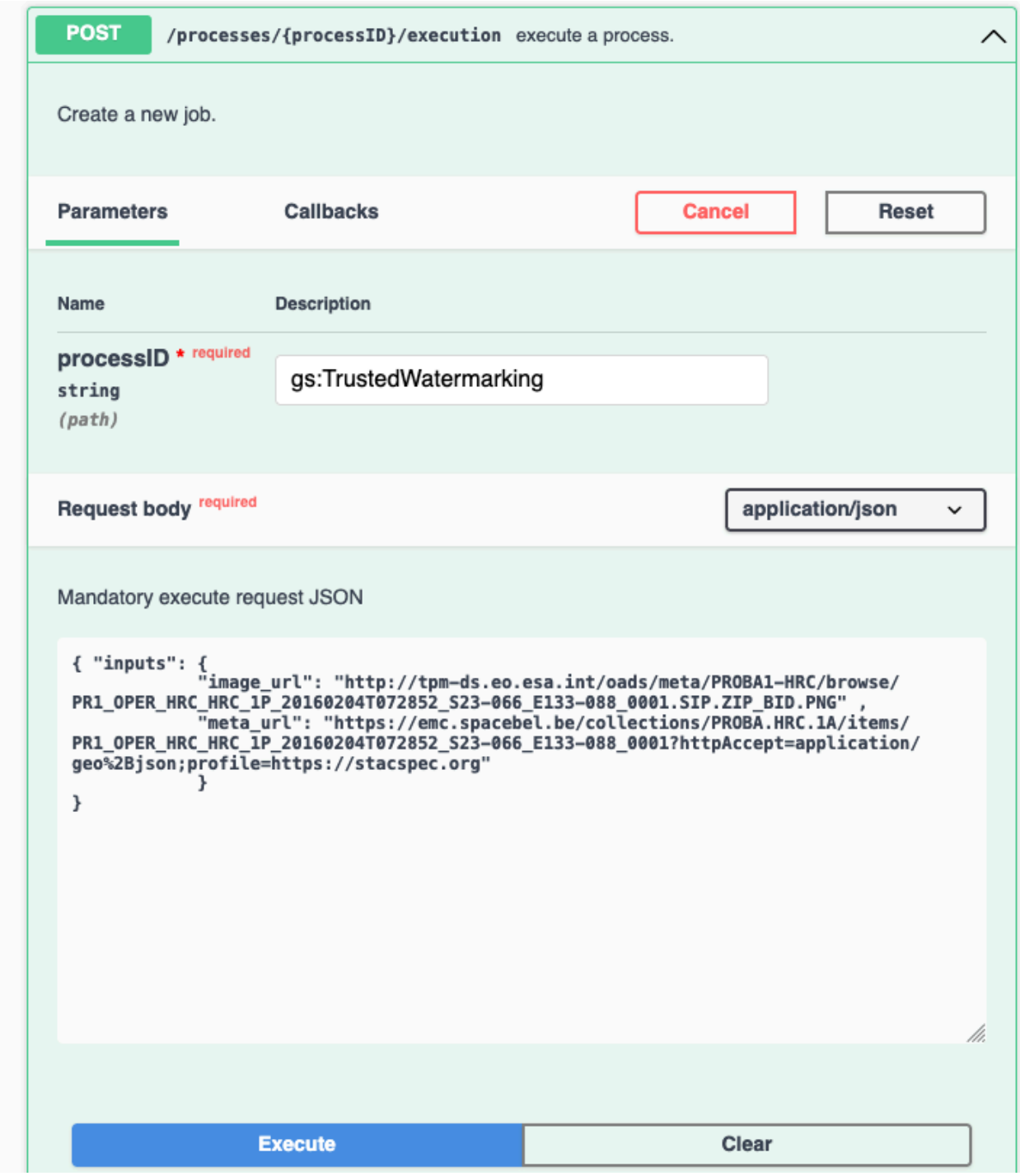

Figure D.6 — Testbed-21 Secure Dimensions IPT-Server-1 Execution

The response is the STAC Feature which is uploaded to the iSTAC (the blockchain). For the execution example above, the following STAC Feature (metadata record) was created:

```
{
    "stac_version": "1.0.0",
```

```
    "assets": {
        "PRODUCT": {
            "file:checksum": "1e20df9923d5d018df07f07ab9de843f46618329c2c3acace60
05b994795e51f8937",
            "alternate": {
                "FACTS_Browser_Cookie": {
                    "description": "In order to download the asset via a Web
Browser, you first need to establish a connection with your wallet via https://
assets.ogc.secd.eu/link so that the Asset Controller can request proof for FACTS
Certificates via that secure and private connection when you try to fetch the
Asset. Once you have a connection established, you can use the Download link
above to fetch the GeoPackage.",
                    "href": "https://assets.ogc.secd.eu/files/fa6271befa565099085
6528bf34e647dcbaa9e133d03447199ecc50df71dd4a0",
                    "title": "Download Asset via Web Browser session cookie",
                    "type": "image/jpeg"
                },
                "FACTS_API_Key": {
                    "auth": {
                        "refs": [
                            "apiKey"
                        ],
                        "roles": [
                            "download"
                        ],
                        "schemes": {
                            "flows": {
                                "authorizationCode": {
                                    "authorizationApi": "https://wallet.ogc.secd.
eu/user/x-facts-key",
                                    "method": "get",
                                    "responseField": "x-facts-key",
                                    "parameters": {
                                        "expires_in": {
                                            "schema": {
                                                "examples": "300",
                                                "type": "string"
                                            },
                                            "in": "query",
                                            "description": "the validity of the
token in seconds",
                                            "required": "true"
                                        }
                                    }
                                }
                            },
                            "in": "header",
                            "name": "X-FACTS-Key",
                            "description": "X-FACTS-Key represents the
connection between your Wallet and the Asset Controller to request proof of
required FACTS Certificates.",
                            "type": "apiKey",
                            "required": "true"
                        }
                    },
                    "description": "In order to download the asset via the API,
you first need to fetch an API-Key token (X-FACTS-Key) via https://wallet.ogc.
secd.eu/connections/select which must be submitted as HTTP Header `X-FACTS-Key`
with the asset URL from `Copy URL`. ",
                    "href": "https://assets.ogc.secd.eu/files/fa6271befa565099085
6528bf34e647dcbaa9e133d03447199ecc50df71dd4a0",
                    "title": "Download Asset via X-FACTS-Key",
                    "type": "image/jpeg"
```

```
                }
            },
            "href": "https://ipfs.ogc.secd.eu/files/fa6271befa5650990856528bf34e6
47dcbaa9e133d03447199ecc50df71dd4a0",
            "title": "Product",
            "type": "image/jpeg"
        }
    },
    "bbox": [
        133.87,
        -23.68,
        133.9,
        -23.64
    ],
    "geometry": {
        "coordinates": [
            [
                [
                    133.9,
                    -23.68
                ],
                [
                    133.9,
                    -23.64
                ],
                [
                    133.87,
                    -23.64
                ],
                [
                    133.87,
                    -23.68
                ],
                [
                    133.9,
                    -23.68
                ]
            ]
        ],
        "type": "Polygon"
    },
    "links": [
        {
            "rel": "derived_from",
            "href": "https://emc.spacebel.be/collections/PROBA.HRC.1A/items/PR1_
OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=application/geo
%2Bjson;profile=https://stacspec.org",
            "type": "application/geo+json",
            "title": "Source metadata"
        },
        {
            "rel": "self",
            "href": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt/items/
asset_1770644376054",
            "type": "application/geo+json",
            "title": "asset_1770644376054"
        },
        {
            "rel": "collection",
            "href": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt",
            "type": "application/json",
            "title": "test_dq4ipt"
        }
```

```
    ],
    "collection": "test_dq4ipt",
    "id": "asset_1770644376054",
    "type": "Feature",
    "stac_extensions": [
        "https://stac-extensions.github.io/file/v2.1.0/schema.json",
        "https://stac-extensions.github.io/alternate-assets/v1.1.0/schema.json",
        "https://stac-extensions.github.io/processing/v1.2.0/schema.json",
        "https://luciocola.github.io/stac-extension-liability-claims/json-schema/
schema.json"
    ],
    "properties": {
        "processing:level": "L1",
        "datetime": "2026-02-09T13:39:35Z",
        "start_datetime": "2016-02-04T07:28:52Z",
        "end_datetime": "2016-02-04T07:28:52Z",
        "processing:facility": "Secure Dimensions Processes",
        "processing:lineage": "Watermarking Process",
        "processing:datetime": "2026-02-09T13:39:35Z",
        "liability:quality": {
            "scope": {
                "level": "series"
            },
            "report": [
                {
                    "result": [
                        {
                            "pass": true,
                            "specification": {
                                "date": "2021-10-14T00:00:00Z",
                                "identifier": "https://ceos.org/spec/ard/conf",
                                "title": "CEOS ARD Normalised Radar Backscatter
(CARD4L-NRB)"
                            },
                            "type": "ConformanceResult",
                            "resultType": "conformance"
                        }
                    ],
                    "measure": {
                        "measureIdentification": {
                            "code": "101",
                            "authority": {
                                "alternateTitle": [
                                    "ISO"
                                ],
                                "title": "International Organization for
Standardization"
                            },
                            "codeSpace": "https://standards.isotc211.org/19157/-
3/1/dqc/content/qualityMeasure/"
                        },
                        "measureDescription": "The measure will take the value
true if all the requirements in the referred data product specification are
fulfilled.",
                        "nameOfMeasure": [
                            "Data product specification passed"
                        ]
                    },
                    "completeness": {
                        "category": "completeness"
                    },
                    "type": "ConceptualConsistency",
                    "category": "completeness"
```

```
                }
            ]
        },
        "processing:software": {
            "name": "Geoserver",
            "version": "3.0-SNAPSHOT"
        },
        "ipt": {
            "output": {
                "image_height": 1026,
                "file:checksum": "1e20df9923d5d018df07f07ab9de843f46618329c2c3aca
ce6005b994795e51f8937",
                "metadata_url": "https://ic.ogc.secd.eu/stac/collections/test_
dq4ipt/items/asset_1770644376054",
                "image_url": "https://assets.ogc.secd.eu/files/fa6271befa56509908
56528bf34e647dcbaa9e133d03447199ecc50df71dd4a0",
                "image_width": 1026,
                "image_type": "image/jpeg"
            },
            "input": {
                "image": {
                    "image_height": 1026,
                    "file:checksum": "1220ecff1a367594707fe3603f73fdd6091b039b8e0
b98c48d92643f84bc229cc471",
                    "image_url": "https://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
browse/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.
PNG",
                    "image_width": 1026,
                    "image_type": "image/png;charset=UTF-8"
                },
                "metadata": {
                    "metadata_url": "https://emc.spacebel.be/collections/
PROBA.HRC.1A/items/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?
httpAccept=application/geo%2Bjson;profile=https://stacspec.org",
                    "vc_url": "https://emc.spacebel.be/collections/PROBA.HRC.1A/
items/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=
application/vc%2Bld%2Bjson",
                    "VC_verification": true,
                    "VC": {
                        "relatedResource": [
                            {
                                "digestMultibase": "zQmYRMC8UMw4ipWvivUKvzvTWrjbK
k1oywH1QpoY6w3tCQX",
                                "id": "https://schemas.opengis.net/eo-geojson/
1.0/eo-geojson.jsonld"
                            },
                            {
                                "digestMultibase": "zQmeHnYH1jaUefpeAbARzC46rJSzS
te8uWn52GGcQWXMcmn",
                                "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-
HRC/browse/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.
PNG"
                            },
                            {
                                "digestMultibase": "zQmPFZfx6KoEAgPpFosgJEKQ17K7s
JpsSZWtyNo7vwBHXyr",
                                "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-
HRC/thumbnail/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_
TIMG.jpg"
                            }
                        ],
                        "credentialSubject": {
                            "date": "2016-02-04T07:28:52Z/2016-02-04T07:28:52Z",
```

```
                            "bbox": [
                                133.87,
                                -23.68,
                                133.9,
                                -23.64
                            ],
                            "links": {
                                "data": [
                                    {
                                        "href": "https://tpm-ds.eo.esa.int/oads/
data/PROBA1-HRC/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.
ZIP",
                                        "title": "Download",
                                        "type": "application/x-binary"
                                    }
                                ],
                                "previews": [
                                    {
                                        "href": "http://tpm-ds.eo.esa.int/oads/
meta/PROBA1-HRC/browse/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.
SIP.ZIP_BID.PNG",
                                        "title": "QUICKLOOK",
                                        "type": "image/png"
                                    },
                                    {
                                        "href": "http://tpm-ds.eo.esa.int/oads/
meta/PROBA1-HRC/thumbnail/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_
0001.SIP.ZIP_TIMG.jpg",
                                        "title": "THUMBNAIL",
                                        "type": "image/jpeg"
                                    }
                                ]
                            },
                            "geometry": {
                                "coordinates": [
                                    [
                                        [
                                            133.9,
                                            -23.68
                                        ],
                                        [
                                            133.9,
                                            -23.64
                                        ],
                                        [
                                            133.87,
                                            -23.64
                                        ],
                                        [
                                            133.87,
                                            -23.68
                                        ],
                                        [
                                            133.9,
                                            -23.68
                                        ]
                                    ]
                                ],
                                "type": "Polygon"
                            },
                            "id": "did:web:emc.spacebel.be:collections:PROBA.
HRC.1A:items:PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001",
```

```
                            "title": "PR1_OPER_HRC_HRC_1P_20160204T072852_S23-
066_E133-088_0001",
                            "updated": "2024-04-30T11:28:07Z"
                        },
                        "issuanceDate": "2026-02-09T13:39:33Z",
                        "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:
items:PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001",
                        "proof": {
                            "created": "2026-02-09T13:39:33.336Z",
                            "jws": "eyJhbGciOiJFUzI1NksiLCJraWQiOiJiQnpXOH
lHeEt1RUNMal9JeFNyTkN1eVJKOUppZ2ptTU9DeDJGZHpDcnFBIiwiY3JpdCI6WyJiNjQiXSwi
YjY0IjpmYWxzZX0..ww0HqgGaA8-WQV2-yO0GbK5JnisW9dXkkXD_DwUIzsg9TdG_yo2nC-mS1-
fcoCl0BTxHfwUX60MaXBOib39nCQ",
                            "proofPurpose": "assertionMethod",
                            "type": "EcdsaSecp256k1Signature2019",
                            "verificationMethod": "did:web:emc.spacebel.be:
organisations:esa_esrin#owner"
                        },
                        "type": [
                            "VerifiableCredential",
                            "Feature"
                        ],
                        "@context": [
                            "https://www.w3.org/2018/credentials/v1",
                            "https://schemas.opengis.net/eo-geojson/1.0/eo-
geojson.jsonld",
                            {
                                "digestMultibase": {
                                    "@type": "https://w3id.org/
security#multibase",
                                    "@id": "https://w3id.org/
security#digestMultibase"
                                },
                                "relatedResource": {
                                    "@type": "@id",
                                    "@id": "https://www.w3.org/2018/
credentials#relatedResource"
                                }
                            }
                        ],
                        "issuer": "did:web:emc.spacebel.be:organisations:esa_
esrin"
                    }
                },
                "image_hash_verified": true
            }
        }
    }
}
```


Listing D.3

NOTE: The above response is incomplete as the provenance recording is not included. More details about the STAC Feature are presented in another annex.

D.2.3. Processing Step Details

The following sequence diagram illustrates the different processing step of the `TrustedWatermarking` process.

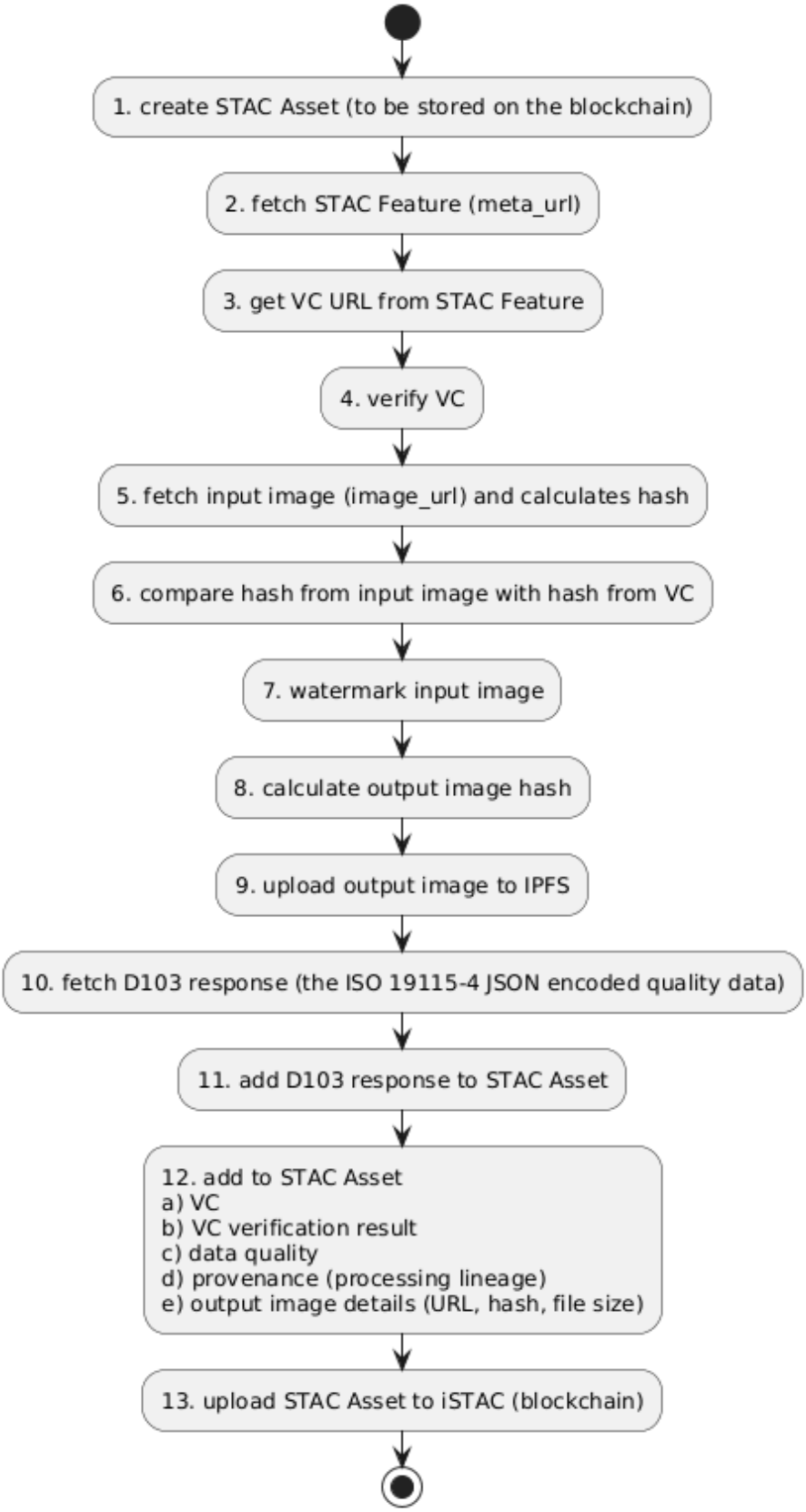

Figure D.7 — TrustedWatermarking Process Execution and Interaction Diagram

The following introduces the processing steps in more detail. The steps are simplified as the outcome of boolean tests is not captured for clarity. Also, the input verification (the tests whether the `image_url` and `meta_url` input parameters are present in the API call) are not shown.

Example:

1. creates a STAC Asset from the template that will capture all IPT related metadata. To capture the IPT and Data Quality metadata, the STAC Asset uses the [IPT Liability and Claims extension]() which was developed during Testbed-21.

2. fetches the input metadata as a STAC Feature from any STAC catalog. The Spacebel STAC Catalog has been used throughout Testbed-21 as their STAC features include the relevant link for establishing trusted processing: VC including asset hash and ISO metadata URL.

3. fetches the VC following the link with type `application/vc+ld+json`

4. verifies the VC using the Java Library `com.danubetech.dataintegrity.verifier.LdVerifier`. The result of the verification (true / false) is captured in the STAC Asset.

5. fetches the input image and calculates the input hash using the hash algorithm from the VC. The image hash is calculated only if the VC contains a hash for the `image_url`.

6. if the VC contains the `image_url`, the hash from the `image_url` and the hash from the VC are compared. The result is captured in the STAC Asset.

7. creates the output image with the watermark `SECD <date time now in ISO8601 format>` on the input image in the right bottom corner.

8. Calculates the Blake3 hash for the watermarked (output) image

9. uploads the watermarked image to the IPFS service

10. from the `meta_url` STAC feature get the ISO 19115-3 XML encoded metadata URL for asset of type `application/vnd.iso.19115-3+xml`. With that URL fetch the ISO 19115-4 JSON encoded quality metadata from D103

11. The response from D103 is the JSON encoded quality metadata that the `Trusted Watermarking` process can directly include into the `DataQualityInfo` element of the STAC Asset

12. adds all processing results to the STAC Asset

13. uploads the final STAC Asset to the iSTAC. As the iSTAC is read-only, the process uses a direct connection to the blockchain using the java library `org.hyperledger.fabric.client`.

E

ANNEX E (INFORMATIVE) D102 NOTEBOOK

ANNEX E (INFORMATIVE) D102 NOTEBOOK

E.1. Overview

The notebook shows how to obtain quality and provenance (lineage) information from the Spacebel D102 OGC API-Records / STAC Catalogue for:

- collections
- granules (products)

Examples of the following collection-level quality information (§1):

- CEOS-ARD compliant collection
- INSPIRE implementing rules compliant collection
- Collection with CEOS Data Management and Stewardship Maturity Matrix (DSMM) (NOAA_AVHRR_L1B_LAC)

Examples of granule-level information (§2):

- Quality measures incl. cloud cover, snow cover, ..
- Quality metadata in ISO19115-4, ISO19115-3 and ISO19157-2 encodings as STAC items.
- Lineage information (processing)

Resolution of W3C DID identifiers of resources (§3)

Invocation of the Processing service for watermarking (§4)

```
import json, requests, xml

from IPython.display import Markdown as md
from IPython.display import Image

from xml.dom import minidom
from xml.etree import ElementTree

# OGC API - Records endpoint
URL_LANDING_PAGE =  'https://emc.spacebel.be/'
```

```
# Immutable Catalogue STAC endpoint

URL_IMMUTABLE_CAT_LANDING_PAGE = 'https://ic.ogc.secd.eu/stac/'
STAC_BROWSER_URL = 'https://radiantearth.github.io/stac-browser/#/external/'

# First resolver is publicly accessible but cannot handle query parameters.
DID_RESOLVER_1 = "https://dev.uniresolver.io/1.0/identifiers/"

# The second DID resolver requires an access token and has access constraints
(calls per hour).
DID_RESOLVER_2 = "https://api.godiddy.com/0.1.0/universal-resolver/identifiers/"

DID_RESOLVER = DID_RESOLVER_1
```

Listing E.1

The Catalogue client can be accessed at https://radiantearth.github.io/stac-browser/#/external/emc.spacebel.be/?.language=en

E.2. Collections

E.2.1. Quality information / CEOS-ARD

E.2.2. GET /collections/{collection-id}

Example: 1.1
> Access a collection with CEOS-ARD Quality Information (GeoJSON). ISO19115-4 record is an asset of this collection. > More about CEOS-ARD at https://ceos.org/ard/. > See also recommendations DATA#1 to DATA#4 at https://github.com/ceos-org/interoperability-handbook/blob/main/Architecture.md.

```
response = requests.get(URL_LANDING_PAGE + 'collections/novasar_l2ard_hh_hv')

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.2


```
{
   "extent": {
      "spatial": {
         "bbox": [
            [
               -62.87262834116111,
               -55.94470669421993,
               173.246741777445,
               38.42053289934906
            ]
         ]
```

```
      },
      "temporal": {
         "interval": [
            [
               "2019-11-02T00:00:00.000Z",
               "2025-10-08T23:59:59.999Z"
            ]
         ]
      }
   },
   "stac_version": "1.0.0",
   "keywords": [
      "Normalised Radar Backscatter"
   ],
   "created": "2025-10-20T00:00:00.00Z",
   "externalIds": [
      {
         "scheme": "https://www.w3.org/ns/did/v1",
         "value": "did:web:emc.spacebel.be:collections:novasar_l2ard_hh_hv"
      }
   ],
   "description": "NovaSAR-1 CEOS-ARD (level 2) HH,HV polarizations",
   "type": "Collection",
   "title": "novasar_l2ard_hh_hv",
   "license": "various",
   "assets": {
      "metadata_ogc_17_069r3": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv",
         "type": "application/geo+json;profile=\"http://www.opengis.net/spec/
ogcapi-features-1/1.0\"",
         "title": "OGC 17-069r3 metadata"
      },
      "metadata_iso_19115_4": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/vnd.iso.19115-4%2Bjson",
         "title": "ISO19115-4",
         "type": "application/vnd.iso.19115-4+json"
      },
      "metadata_iso_19139": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/vnd.iso.19139%2Bxml",
         "title": "ISO 19139 metadata",
         "type": "application/vnd.iso.19139+xml"
      },
      "metadata_iso_19139_2": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/vnd.iso.19139-2%2Bxml",
         "title": "ISO 19139-2 metadata",
         "type": "application/vnd.iso.19139-2+xml"
      },
      "metadata_dif_10": {
```

```
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/dif10%2Bxml",
            "title": "DIF-10 metadata",
            "type": "application/dif10+xml"
         },
         "metadata_iso_19115_3": {
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/vnd.iso.19115-3%2Bxml",
            "title": "ISO 19115-3 metadata",
            "type": "application/vnd.iso.19115-3+xml"
         },
         "metadata_ogc_17_084r1": {
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?mode=
owc",
            "title": "OGC 17-084r1 metadata",
            "type": "application/geo+json;profile=\"http://www.opengis.net/spec/eoc-
geojson/1.0\""
         },
         "metadata_html": {
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=text/html",
            "title": "HTML",
            "type": "text/html"
         },
         "quicklook": {
            "roles": [
               "overview"
            ],
            "href": "https://eo-data.csiro.au/projects/easi-thumbnails/novasar_
l2ard_hh_hv/2019/11/CEOS-ARD_NRB_v5_5_NovaSAR_01_7940_scd_29_191102_023255_HH_HV_
A_R-ql.png",
            "type": "image/png",
            "title": "graphic overview"
         }
      },
      "links": [
         {
            "rel": "canonical",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv",
            "type": "application/json",
            "title": "novasar_l2ard_hh_hv"
         },
         {
            "rel": "self",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv",
            "type": "application/json"
         },
         {
            "rel": "root",
            "href": "https://emc.spacebel.be",
            "type": "application/json",
```

```
            "title": "FedEO Clearinghouse"
         },
         {
            "rel": "parent",
            "href": "https://emc.spacebel.be",
            "title": "collections",
            "type": "application/json"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/atom%2Bxml",
            "type": "application/atom+xml",
            "title": "Atom format"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/xml",
            "type": "application/xml",
            "title": "Dublin Core metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/json",
            "type": "application/json",
            "title": "STAC metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/ld%2Bjson;profile=https://schema.org",
            "type": "application/ld+json;profile=\"https://schema.org\"",
            "title": "JSON-LD (schema.org) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/ld%2Bjson;profile=http://data.europa.eu/930/",
            "type": "application/ld+json;profile=\"http://data.europa.eu/930/\"",
            "title": "JSON-LD (GeoDCAT-AP) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/rdf%2Bxml",
            "type": "application/rdf+xml",
            "title": "RDF/XML metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/rdf%2Bxml;profile=https://schema.org",
            "type": "application/rdf+xml;profile=\"https://schema.org\"",
            "title": "RDF/XML (schema.org) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/rdf%2Bxml;profile=http://data.europa.eu/930/",
            "type": "application/rdf+xml;profile=\"http://data.europa.eu/930/\"",
            "title": "RDF/XML (GeoDCAT-AP) metadata"
```

```
      },
      {
         "rel": "alternate",
         "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=text/turtle;profile=https://schema.org",
         "type": "text/turtle;profile=\"https://schema.org\"",
         "title": "Turtle (schema.org) metadata"
      },
      {
         "rel": "alternate",
         "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=text/turtle;profile=http://data.europa.eu/930/",
         "type": "text/turtle;profile=\"http://data.europa.eu/930/\"",
         "title": "Turtle (GeoDCAT-AP) metadata"
      },
      {
         "rel": "related",
         "href": "https://emc.spacebel.be/series/eo:organisationName/CSIRO",
         "title": "More collections for CSIRO"
      }
   ],
   "id": "novasar_l2ard_hh_hv",
   "stac_extensions": [
      "https://stac-extensions.github.io/external-ids/v1.0.0/schema.json",
      "https://stac-extensions.github.io/processing/v1.2.0/schema.json"
   ],
   "updated": "2025-10-20T00:00:00.00Z",
   "providers": [
      {
         "roles": [
            "producer"
         ],
         "name": "CSIRO",
         "url": "www.csiro.au"
      },
      {
         "roles": [
            "host"
         ],
         "name": "FedEO Clearinghouse",
         "url": "https://emc.spacebel.be/readme.html"
      }
   ],
   "summaries": {
      "processing:lineage": [
         "No info available."
      ]
   }
}
```


Listing E.3

The collection metadata is available in alternative metadata encodings which are included as STAC `assets`. One of the assets provides an ISO19115-4 metadata encoding. advertizes identifiers which may include a DOI and/or A DID.

```
jstr = json.dumps(data['assets']['metadata_iso_19115_4'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.4


```
{
```

```
   "roles": [
      "metadata"
   ],
   "href": "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?httpAccept=
application/vnd.iso.19115-4%2Bjson",
   "title": "ISO19115-4",
   "type": "application/vnd.iso.19115-4+json"
}
```


Listing E.5

```
data['assets']['metadata_iso_19115_4']['href']
```

Listing E.6

```
'https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?
httpAccept=application/vnd.iso.19115-4%2Bjson'
```

Figure E.1

```
response = requests.get(data['assets']['metadata_iso_19115_4']['href'])

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.7


```
{
   "bbox": [
      -62.87262834116111,
      -55.94470669421993,
      173.246741777445,
      38.42053289934906
   ],
   "geometry": {
      "coordinates": [
         [
            [
               -62.87262834116111,
               -55.94470669421993
            ],
            [
               173.246741777445,
               -55.94470669421993
            ],
            [
               173.246741777445,
               38.42053289934906
            ],
            [
               -62.87262834116111,
               38.42053289934906
            ],
            [
               -62.87262834116111,
               -55.94470669421993
            ]
         ]
      ],
      "type": "Polygon"
   },
   "id": "novasar_l2ard_hh_hv",
```

```
   "conformsTo": [
      "https://standards.iso.org/iso/19115/-4/0.1/core",
      "https://standards.iso.org/iso/19115/-4/0.1/data-quality-core",
      "https://standards.iso.org/iso/19115/-4/0.1/no-ref"
   ],
   "type": "Feature",
   "properties": {
      "defaultLocale": {
         "language": "eng",
         "characterEncoding": "utf8"
      },
      "identificationInfo": {
         "defaultLocale": {
            "language": "eng",
            "characterEncoding": "utf8"
         },
         "extent": [
            {
               "geographicElement": [
                  {
                     "northBoundLatitude": 38.42053289934906,
                     "southBoundLatitude": -55.94470669421993,
                     "type": "EX_GeographicBoundingBox",
                     "westBoundLongitude": -62.87262834116111,
                     "eastBoundLongitude": 173.246741777445
                  }
               ]
            }
         ],
         "descriptiveKeywords": [
            {
               "thesaurusName": {
                  "title": "CEOS-ARD Product Family Specification"
               },
               "keyword": [
                  "Normalised Radar Backscatter"
               ]
            }
         ],
         "citation": {
            "date": {
               "creation": "2025-10-20"
            },
            "identifier": [
               {
                  "code": "did:web:emc.spacebel.be:collections:novasar_l2ard_hh_
hv",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "novasar_l2ard_hh_hv"
         },
         "abstract": "NovaSAR-1 CEOS-ARD (level 2) HH,HV polarizations"
      },
      "metadataStandard": [
         {
            "title": "ISO 19115-1:2014"
         },
         {
            "title": "ISO 19115-4"
         }
      ],
      "contact": [
```

```
            {
               "role": "pointOfContact",
               "party": [
                  {
                     "contactInfo": [
                        {
                           "address": [
                              {
                                 "deliveryPoint": [
                                    "Building 101, Clunies Ross Street"
                                 ],
                                 "country": "Australia",
                                 "city": "Black Mountain",
                                 "postalCode": "ACT 2601"
                              }
                           ],
                           "phone": {
                              "voice": "tel:+61395452176"
                           }
                        }
                     ],
                     "name": "CSIRO",
                     "type": "CI_Organisation"
                  }
               ]
            }
         ],
         "dataQualityInfo": [
            {
               "scope": {
                  "level": "series"
               },
               "report": [
                  {
                     "result": [
                        {
                           "pass": true,
                           "specification": {
                              "date": {
                                 "publication": "2021-10-14"
                              },
                              "identifier": [
                                 {
                                    "code": "https://ceos.org/ard/files/PFS/NRB/
v5.5",
                                    "codeSpace": "https://ceos.org/ard"
                                 }
                              ],
                              "edition": "5.5",
                              "title": "CEOS-ARD Product Family Specification:
Normalised Radar Backscatter"
                           },
                           "type": "ConformanceResult",
                           "explanation": "See the referenced specification"
                        }
                     ],
                     "measure": {
                        "measureIdentification": {
                           "code": "101",
                           "authority": {
                              "alternateTitle": [
                                 "ISO"
                              ],
```

```
                           "title": "International Organization for
Standardization"
                        },
                        "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                     },
                     "measureDescription": "Indication that all requirements in
the referred data product specification are fulfilled.",
                     "nameOfMeasure": [
                        "Data product specification passed"
                     ]
                  },
                  "evaluationMethod": [
                     {
                        "referenceDoc": [],
                        "evaluationProcedure": {
                           "editionDate": "2021-10-14",
                           "edition": "5.5",
                           "onlineResource": [
                              {
                                 "linkage": "https://ceos.org/ard/files/PFS/NRB/
v5.5/CARD4L-PFS_NRB_v5.5.pdf"
                              },
                              {
                                 "linkage": "https://ceos.org/ard/files/Self
%20Assessments/NRB/v5.5/Opera%20RTC%20Sentinel-1%20self-assessment.zip"
                              },
                              {
                                 "linkage": "https://ceos.org/ard/files/Peer
%20Reviews/NRB/v5.5/NovaSAR_WGCVEval.zip"
                              }
                           ],
                           "title": "CEOS-ARD Product Family Specification:
Normalised Radar Backscatter"
                        },
                        "type": "FullInspection",
                        "evaluationMethodDescription": "This collection is
conformant with the CEOS-ARD NRB Specification"
                     }
                  ],
                  "type": "DomainConsistency"
               }
            ]
         }
      ],
      "dateInfo": {
         "revision": "2025-10-20"
      },
      "metadataScope": [
         {
            "resourceScope": "series",
            "name": "series"
         }
      ]
   }
}
```


Listing E.8

The ISO metadata includes Identification Information with a Citation. In this section, its identifiers such as an optional DOI and/or DID may be included. The DID resolves to a DID document.

```
jstr = json.dumps(data['properties']['identificationInfo']['citation'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.9

```
{
   "date": {
      "creation": "2025-10-20"
   },
   "identifier": [
      {
         "code": "did:web:emc.spacebel.be:collections:novasar_l2ard_hh_hv",
         "codeSpace": "https://www.w3.org/ns/did/v1"
      }
   ],
   "title": "novasar_l2ard_hh_hv"
}
```

Listing E.10

```
did = data['properties']['identificationInfo']['citation']['identifier'][0]
['code']
did
```

Listing E.11

```
'did:web:emc.spacebel.be:collections:novasar_l2ard_hh_hv'
```

Figure E.2

```
# resolve DID
print(did)
response = requests.get( DID_RESOLVER + did,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.12

```
did:web:emc.spacebel.be:collections:novasar_l2ard_hh_hv
```

Figure E.3

```
{
   "controller": "did:web:emc.spacebel.be:organisations:csiro",
   "id": "did:web:emc.spacebel.be:collections:novasar_l2ard_hh_hv",
   "@context": [
      "https://www.w3.org/ns/did/v1",
      "https://w3id.org/security/suites/jws-2020/v1"
   ],
   "alsoKnownAs": [
      "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv",
      "https://emc.spacebel.be/collections/novasar_l2ard_hh_hv?httpAccept=
application/vnd.iso.19115-4%2Bjson"
   ]
```

```
}
```

Listing E.13

Example: 1.2

> Access a collection with CEOS-ARD Quality Information (ISO19115-4) using content negotiation.

```
response = requests.get(URL_LANDING_PAGE + 'collections/novasar_l2ard_hh_hv',
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.14


```
{
   "bbox": [
      -62.87262834116111,
      -55.94470669421993,
      173.246741777445,
      38.42053289934906
   ],
   "geometry": {
      "coordinates": [
         [
            [
               -62.87262834116111,
               -55.94470669421993
            ],
            [
               173.246741777445,
               -55.94470669421993
            ],
            [
               173.246741777445,
               38.42053289934906
            ],
            [
               -62.87262834116111,
               38.42053289934906
            ],
            [
               -62.87262834116111,
               -55.94470669421993
            ]
         ]
      ],
      "type": "Polygon"
   },
   "id": "novasar_l2ard_hh_hv",
   "conformsTo": [
      "https://standards.iso.org/iso/19115/-4/0.1/core",
      "https://standards.iso.org/iso/19115/-4/0.1/data-quality-core",
      "https://standards.iso.org/iso/19115/-4/0.1/no-ref"
   ],
   "type": "Feature",
   "properties": {
      "defaultLocale": {
         "language": "eng",
         "characterEncoding": "utf8"
```

```
      },
      "identificationInfo": {
         "defaultLocale": {
            "language": "eng",
            "characterEncoding": "utf8"
         },
         "extent": [
            {
               "geographicElement": [
                  {
                     "northBoundLatitude": 38.42053289934906,
                     "southBoundLatitude": -55.94470669421993,
                     "type": "EX_GeographicBoundingBox",
                     "westBoundLongitude": -62.87262834116111,
                     "eastBoundLongitude": 173.246741777445
                  }
               ]
            }
         ],
         "descriptiveKeywords": [
            {
               "thesaurusName": {
                  "title": "CEOS-ARD Product Family Specification"
               },
               "keyword": [
                  "Normalised Radar Backscatter"
               ]
            }
         ],
         "citation": {
            "date": {
               "creation": "2025-10-20"
            },
            "identifier": [
               {
                  "code": "did:web:emc.spacebel.be:collections:novasar_l2ard_hh_
hv",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "novasar_l2ard_hh_hv"
         },
         "abstract": "NovaSAR-1 CEOS-ARD (level 2) HH,HV polarizations"
      },
      "metadataStandard": [
         {
            "title": "ISO 19115-1:2014"
         },
         {
            "title": "ISO 19115-4"
         }
      ],
      "contact": [
         {
            "role": "pointOfContact",
            "party": [
               {
                  "contactInfo": [
                     {
                        "address": [
                           {
                              "deliveryPoint": [
                                 "Building 101, Clunies Ross Street"
```

```
                                ],
                                "country": "Australia",
                                "city": "Black Mountain",
                                "postalCode": "ACT 2601"
                             }
                          ],
                          "phone": {
                             "voice": "tel:+61395452176"
                          }
                       }
                    ],
                    "name": "CSIRO",
                    "type": "CI_Organisation"
                 }
              ]
           }
        ],
        "dataQualityInfo": [
           {
              "scope": {
                 "level": "series"
              },
              "report": [
                 {
                    "result": [
                       {
                          "pass": true,
                          "specification": {
                             "date": {
                                "publication": "2021-10-14"
                             },
                             "identifier": [
                                {
                                   "code": "https://ceos.org/ard/files/PFS/NRB/
v5.5",
                                   "codeSpace": "https://ceos.org/ard"
                                }
                             ],
                             "edition": "5.5",
                             "title": "CEOS-ARD Product Family Specification:
Normalised Radar Backscatter"
                          },
                          "type": "ConformanceResult",
                          "explanation": "See the referenced specification"
                       }
                    ],
                    "measure": {
                       "measureIdentification": {
                          "code": "101",
                          "authority": {
                             "alternateTitle": [
                                "ISO"
                             ],
                             "title": "International Organization for
Standardization"
                          },
                          "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                       },
                       "measureDescription": "Indication that all requirements in
the referred data product specification are fulfilled.",
                       "nameOfMeasure": [
                          "Data product specification passed"
```

```
                     ]
                  },
                  "evaluationMethod": [
                     {
                        "referenceDoc": [],
                        "evaluationProcedure": {
                           "editionDate": "2021-10-14",
                           "edition": "5.5",
                           "onlineResource": [
                              {
                                 "linkage": "https://ceos.org/ard/files/PFS/NRB/
v5.5/CARD4L-PFS_NRB_v5.5.pdf"
                              },
                              {
                                 "linkage": "https://ceos.org/ard/files/Self
%20Assessments/NRB/v5.5/Opera%20RTC%20Sentinel-1%20self-assessment.zip"
                              },
                              {
                                 "linkage": "https://ceos.org/ard/files/Peer
%20Reviews/NRB/v5.5/NovaSAR_WGCVEval.zip"
                              }
                           ],
                           "title": "CEOS-ARD Product Family Specification:
Normalised Radar Backscatter"
                        },
                        "type": "FullInspection",
                        "evaluationMethodDescription": "This collection is
conformant with the CEOS-ARD NRB Specification"
                     }
                  ],
                  "type": "DomainConsistency"
               }
            ]
         }
      ],
      "dateInfo": {
         "revision": "2025-10-20"
      },
      "metadataScope": [
         {
            "resourceScope": "series",
            "name": "series"
         }
      ]
   }
}
```


Listing E.15

Example: 1.3

> Extract the CEOS-ARD quality information.

```
jstr = json.dumps(data['properties']['dataQualityInfo'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.16


```
[
   {
      "scope": {
         "level": "series"
      },
      "report": [
```

```
{
   "result": [
      {
         "pass": true,
         "specification": {
            "date": {
               "publication": "2021-10-14"
            },
            "identifier": [
               {
                  "code": "https://ceos.org/ard/files/PFS/NRB/v5.5",
                  "codeSpace": "https://ceos.org/ard"
               }
            ],
            "edition": "5.5",
            "title": "CEOS-ARD Product Family Specification: Normalised
Radar Backscatter"
         },
         "type": "ConformanceResult",
         "explanation": "See the referenced specification"
      }
   ],
   "measure": {
      "measureIdentification": {
         "code": "101",
         "authority": {
            "alternateTitle": [
               "ISO"
            ],
            "title": "International Organization for Standardization"
         },
         "codeSpace": "https://standards.isotc211.org/19157/-3/1/dqc/
content/qualityMeasure/"
      },
      "measureDescription": "Indication that all requirements in the
referred data product specification are fulfilled.",
      "nameOfMeasure": [
         "Data product specification passed"
      ]
   },
   "evaluationMethod": [
      {
         "referenceDoc": [],
         "evaluationProcedure": {
            "editionDate": "2021-10-14",
            "edition": "5.5",
            "onlineResource": [
               {
                  "linkage": "https://ceos.org/ard/files/PFS/NRB/v5.5/
CARD4L-PFS_NRB_v5.5.pdf"
               },
               {
                  "linkage": "https://ceos.org/ard/files/Self
%20Assessments/NRB/v5.5/Opera%20RTC%20Sentinel-1%20self-assessment.zip"
               },
               {
                  "linkage": "https://ceos.org/ard/files/Peer%20Reviews/
NRB/v5.5/NovaSAR_WGCVEval.zip"
               }
            ],
            "title": "CEOS-ARD Product Family Specification: Normalised
Radar Backscatter"
         },
```

```
                  "type": "FullInspection",
                  "evaluationMethodDescription": "This collection is conformant
with the CEOS-ARD NRB Specification"
               }
            ],
            "type": "DomainConsistency"
         }
      ]
   }
]
```

Listing E.17

E.2.3. Quality information / INSPIRE

See https://radiantearth.github.io/stac-browser/#/external/emc.spacebel.be/collections/PROBA.HRC.1A

Example: 1.4
> Access a collection with INSPIRE Quality Information (ISO19115-4) using content negotiation.

```
response = requests.get(URL_LANDING_PAGE + 'collections/PROBA.HRC.1A',
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data['properties']['dataQualityInfo'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.18

```
[
   {
      "scope": {
         "level": "series"
      },
      "report": [
         {
            "result": [
               {
                  "pass": false,
                  "specification": {
                     "date": {
                        "publication": "2010-12-08"
                     },
                     "title": "COMMISSION REGULATION (EU) No 1089/2010 of 23
November 2010 implementing Directive 2007/2/EC of the European Parliament and of
the Council as regards interoperability of spatial data sets and services"
                  },
                  "type": "ConformanceResult",
                  "explanation": "This data set is conformant with the INSPIRE
Implementing Rules for the interoperability of spatial data sets and services"
               }
            ],
            "type": "DomainConsistency"
         }
      ]
   }
```

```
]
```

Listing E.19

E.2.4. Quality information / CEOS DSMM

Example: 1.5
> Access a collection with CEOS Management and Stewardship Maturity Matrix (DSMM).

```
collection_url = URL_LANDING_PAGE + 'collections/NOAA_AVHRR_L1B_LAC'
```

Listing E.20

```
response = requests.get(collection_url,
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data['properties']['dataQualityInfo'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.21

```
[
   {
      "scope": {
         "level": "series"
      },
      "report": [
         {
            "result": [
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_1_MetadataForDiscovery"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "PartiallyManaged"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_2_OnlineAccess"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "FullyManaged"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_3_DataEncoding"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "Managed"
                  ]
               },
               {
```

```
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_4_DataDocumentation"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "Managed"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_5_DataTraceability"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "Managed"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_6_DataValidation"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "FullyManaged"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_7_DataUncertainty"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "PartiallyManaged"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_8_DataQualityControl"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "FullyManaged"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_9_DataPreservation"
                  },
                  "type": "QuantitativeResult",
                  "value": [
                     "FullyManaged"
                  ]
               },
               {
                  "resultScope": {
                     "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_10_DataMetadataVerification"
```

```
                    },
                    "type": "QuantitativeResult",
                    "value": [
                       "FullyManaged"
                    ]
                 },
                 {
                    "resultScope": {
                       "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_11_DataProcessingReprocessing"
                    },
                    "type": "QuantitativeResult",
                    "value": [
                       "Managed"
                    ]
                 },
                 {
                    "resultScope": {
                       "level": "https://ceos.org/resources/Codelist/DSMM_
Codelists.xml#MMP_12_PersistentResolvableIdentifiers"
                    },
                    "type": "QuantitativeResult",
                    "value": [
                       "FullyManaged"
                    ]
                 }
              ],
              "measure": {
                 "measureIdentification": {
                    "code": "CEOS.WGISS.DSIG.DSMM",
                    "authority": {
                       "edition": "1.3",
                       "alternateTitle": [
                          "CEOS"
                       ],
                       "title": "Committee on Earth Observation Satellites"
                    }
                 },
                 "measureDescription": "The Data Management and Stewardship
Maturity Matrix (DSMM) is a unified framework that defines criteria for each
of nine components based on measurable practices, which can be used to apply a
progressive, 4-level rating to an individual dataset, representing stewardship
maturity stages rated as Not Assessed or Not Managed (Level 0), Partially
Managed (Level 1), Managed (Level 2), Fully Managed (Level 3).",
                 "nameOfMeasure": [
                    "Data Management and Stewardship Maturity Assessment"
                 ]
              },
              "evaluationMethod": [
                 {
                    "referenceDoc": [],
                    "evaluationProcedure": {
                       "editionDate": "2024-10",
                       "edition": "1.1",
                       "onlineResource": [
                          {
                             "linkage": "https://ceos.org/document_management/
Working_Groups/WGISS/Interest_Groups/Data_Stewardship/White_Papers/WGISS%20Data%2
0Management%20and%20Stewardship%20Maturity%20Matrix.pdf"
                          }
                       ],
                       "title": "WGISS Data Management and Stewardship Maturity
Matrix"
```

```
                    },
                    "type": "FullInspection",
                    "evaluationMethodDescription": "Data Stewardship Maturity
Assessment was evaluated by the metadata content editor using the Scientific
Data Stewardship Maturity Assessment Model v1.3."
                 }
              ],
              "type": "ConceptualConsistency"
           },
           {
              "result": [
                 {
                    "pass": false,
                    "specification": {
                       "date": {
                          "publication": "2010-12-08"
                       },
                       "title": "COMMISSION REGULATION (EU) No 1089/2010 of 23
November 2010 implementing Directive 2007/2/EC of the European Parliament and of
the Council as regards interoperability of spatial data sets and services"
                    },
                    "type": "ConformanceResult",
                    "explanation": "This data set is conformant with the INSPIRE
Implementing Rules for the interoperability of spatial data sets and services"
                 }
              ],
              "type": "DomainConsistency"
           }
        ]
     }
]
```


Listing E.22

Example: 1.6

> Access a collection with CEOS Management and Stewardship Maturity Matrix (DSMM) from STACBrowser. ISO19115-4 metadata is available as an `asset`.

```
# remove https:// in item_url
browser_url = STAC_BROWSER_URL + collection_url.replace("https://","")
browser_url
```

Listing E.23

```
'https://radiantearth.github.io/stac-browser/#/external/
emc.spacebel.be/collections/NOAA_AVHRR_L1B_LAC'
```

Figure E.4

E.3. Products

E.3.1. 2.1 Quality information

The product metadata in the ESA Catalogue is encoded as OGC 17-003r2 metadata. Quality information may be available in the `qualityInformation` and the `qualityStatus` flag. This flag can be `DEGRADED'' or` NOMINAL" and thus be encoded using the ISO19157-3 measure at https://defs-hosted.opengis.net/prez-hosted/catalogs/hosted:iso-19157-3/collections/ns10:qualityMeasure/items/qualitymeasure:101 Also the `cloudCover` and `snowCover` properties can be considered quaity measures as they indicate the percentage of pixels that cannot be used.

```
"productInformation": {
      "qualityInformation": {
        "qualityDegradationQuotationMode": "MANUAL",
        "qualityStatus": "DEGRADED",
        "qualityDegradationTag": "RADIOMETRY"
      }
```

Listing E.24

```
"qualityInformation": {
        "qualityDegradationQuotationMode": "AUTOMATIC",
        "qualityStatus": "NOMINAL",
        "qualityDegradation": 0.0
}
```

Listing E.25

Table E.1

OGC 17-003R2	ISO19157/ISO19115-4	OGC RAINBOW
qualityDegradationQuotationMode	evaluationMethod	
qualityStatus	measure	https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/ MD101
qualityDegradation	measure	https://standards.isotc211.org/19157/-3/1/dqc/content/qualityMeasure/ MD211
snowCover	measure	https://standards.isotc211.org/19157/-3/1/dqc/content/ MD7
cloudCover	measure	https://standards.isotc211.org/19157/-3/1/dqc/content/ MD7

Example: 2.1

> Get ISO19115-4 metadata for a product (with quality information) using content negotiation

```
# https://emc.spacebel.be/collections/novasar_l2ard_hh_hv/items/PR1_OPER_HRC_HRC_
1P_20160505T083637_S28-078_E114-061_0001
# https://emc.spacebel.be/collections/PROBA.HRC.1A/items/PR1_OPER_HRC_HRC_1P_
20160505T083637_S28-078_E114-061_0001

# item_url = URL_LANDING_PAGE + 'collections/PROBA.HRC.1A/items/PR1_OPER_HRC_HRC_
1P_20160505T083637_S28-078_E114-061_0001'
item_url = URL_LANDING_PAGE + 'collections/TropForest/items/KO2_OTPF_KO2_MSC_2F_
20091121T032723_20091121T032723_017702_E096_N026'

response = requests.get( item_url,
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.26


```
{
   "bbox": [
      95.91153308,
      25.92713265,
      96.09259599,
      26.08689352
   ],
   "geometry": {
      "coordinates": [
         [
            [
               95.91153308,
               26.08689352
            ],
            [
               95.91153308,
               25.92713265
            ],
            [
               96.09259599,
               25.92713265
            ],
            [
               96.09259599,
               26.08689352
            ],
            [
               95.91153308,
               26.08689352
            ]
         ]
      ],
      "type": "Polygon"
   },
   "conformsTo": [
      "https://standards.iso.org/iso/19115/-4/0.1/core",
      "https://standards.iso.org/iso/19115/-4/0.1/data-quality-core",
      "https://standards.iso.org/iso/19115/-4/0.1/no-ref"
   ],
   "id": "KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026",
   "type": "Feature",
   "properties": {
```

```
      "defaultLocale": {
         "language": "eng",
         "characterEncoding": "utf8"
      },
      "identificationInfo": {
         "defaultLocale": {
            "language": "eng",
            "characterEncoding": "utf8"
         },
         "extent": [
            {
               "geographicElement": [
                  {
                     "northBoundLatitude": 26.08689352,
                     "southBoundLatitude": 25.92713265,
                     "type": "EX_GeographicBoundingBox",
                     "westBoundLongitude": 95.91153308,
                     "eastBoundLongitude": 96.09259599
                  }
               ]
            }
         ],
         "parentMetadata": {
            "identifier": [
               {
                  "code": "TropForest"
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:TropForest",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "TropForest"
         },
         "citation": {
            "identifier": [
               {
                  "code": "KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_
017702_E096_N026"
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:TropForest:items:
KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026"
         },
         "abstract": "KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026"
      },
      "metadataStandard": [
         {
            "title": "ISO 19115-1:2014"
         },
         {
            "title": "ISO 19115-4"
         }
      ],
      "contact": [
         {
            "role": "pointOfContact",
```

```
            "party": [
               {
                  "contactInfo": [
                     {
                        "address": [
                           {
                              "deliveryPoint": [
                                 "Largo Galileo Galilei 1"
                              ],
                              "country": "Italy",
                              "city": "Frascati (Roma)",
                              "postalCode": "00044",
                              "electronicMailAddress": [
                                 "eohelp@esa.int"
                              ]
                           }
                        ],
                        "phone": {
                           "voice": "tel:+3906941801"
                        }
                     }
                  ],
                  "name": "ESA/ESRIN",
                  "type": "CI_Organisation"
               }
            ]
         }
      ],
      "dataQualityInfo": [
         {
            "scope": {
               "level": "dataset"
            },
            "report": [
               {
                  "result": [
                     {
                        "type": "QuantitativeResult",
                        "value": [
                           "true"
                        ]
                     }
                  ],
                  "measure": {
                     "measureIdentification": {
                        "code": "101",
                        "authority": {
                           "alternateTitle": [
                              "ISO"
                           ],
                           "title": "International Organization for
Standardization"
                        },
                        "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                     },
                     "measureDescription": "The measure will take the value true
if all the requirements in the referred data product specification are fulfilled.
",
                     "nameOfMeasure": [
                        "MD101"
                     ]
                  },
```

```
                    "type": "ConceptualConsistency"
                },
                {
                    "result": [
                        {
                            "valueUnit": "%",
                            "type": "QuantitativeResult",
                            "value": [
                                0
                            ]
                        }
                    ],
                    "measure": {
                        "measureIdentification": {
                            "code": "211",
                            "authority": {
                                "alternateTitle": [
                                    "ISO"
                                ],
                                "title": "International Organization for
Standardization"
                            },
                            "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                        },
                        "measureDescription": "Quality degradation - rate of
imperfect coverage.",
                        "nameOfMeasure": [
                            "MD211"
                        ]
                    },
                    "evaluationMethod": [
                        {
                            "type": "FullInspection",
                            "evaluationMethodDescription": "Automatic quality
degradation check."
                        }
                    ],
                    "type": "Omission"
                },
                {
                    "measure": {
                        "measureIdentification": {
                            "code": "7",
                            "authority": {
                                "alternateTitle": [
                                    "ISO"
                                ],
                                "title": "International Organization for
Standardization"
                            },
                            "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                        },
                        "measureDescription": "Cloud cover",
                        "nameOfMeasure": [
                            "Percentage of image obscured by cloud"
                        ]
                    },
                    "evaluationMethod": [
                        {
                            "evaluationMethodType": "directInternal",
                            "type": "FullInspection",
```

```
                        "evaluationMethodDescription": "N/A."
                     }
                  ],
                  "type": "Omission",
                  "results": [
                     {
                        "valueUnit": "%",
                        "type": "QuantitativeResult",
                        "value": [
                           4
                        ]
                     }
                  ]
               }
            ]
         }
      ],
      "resourceLineage": [
         {
            "processStep": [
               {
                  "output": [
                     {
                        "source": [
                           {
                              "sourceCitation": {
                                 "code": "did:web:emc.spacebel.be:collections:
TropForest:items:KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_
N026",
                                 "title": "KO2_OTPF_KO2_MSC_2F_20091121T032723_
20091121T032723_017702_E096_N026"
                              }
                           }
                        ]
                     }
                  ],
                  "processingInformation": {},
                  "stepDateTime": {
                     "created": "2012-01-04T00:00:00Z"
                  },
                  "processor": [
                     {
                        "role": "processor",
                        "party": [
                           {
                              "name": "Astrium Services",
                              "type": "CI_Organisation"
                           }
                        ]
                     }
                  ]
               }
            ]
         }
      ],
      "dateInfo": {
         "revision": "2024-04-30T11:32:32Z"
      },
      "distributionInfo": [
         {
            "distributor": [],
            "transferOptions": [
               {
```

```
                  "onLine": [
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download",
                        "linkage": "https://tpm-ds.eo.esa.int/oads/data/
Tropforest/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.
ZIP"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "previews",
                        "description": "QUICKLOOK",
                        "linkage": "http://tpm-ds.eo.esa.int/oads/meta/
Tropforest/browse/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026.ZIP_BID.JPG"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "previews",
                        "description": "THUMBNAIL",
                        "linkage": "http://tpm-ds.eo.esa.int/oads/meta/
Tropforest/thumbnail/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026.ZIP_TIMG.jpg"
                     }
                  ]
               }
            ]
         }
      ],
      "metadataScope": [
         {
            "resourceScope": "dataset",
            "name": "dataset"
         }
      ]
   }
}
```


Listing E.27

Example: 2.2.1

> Extract ISO19115-4 quality information for the product.

```
# response = requests.get(URL_LANDING_PAGE + 'collections/PROBA.HRC.1A',
#    headers={'Accept': 'application/vnd.iso.19115-4+json'})

# data = json.loads(response.text)
jstr = json.dumps(data['properties']['dataQualityInfo'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.28


```
[
   {
      "scope": {
         "level": "dataset"
      },
      "report": [
         {
            "result": [
               {
                  "type": "QuantitativeResult",
```

```
                  "value": [
                     "true"
                  ]
               }
            ],
            "measure": {
               "measureIdentification": {
                  "code": "101",
                  "authority": {
                     "alternateTitle": [
                        "ISO"
                     ],
                     "title": "International Organization for Standardization"
                  },
                  "codeSpace": "https://standards.isotc211.org/19157/-3/1/dqc/
content/qualityMeasure/"
               },
               "measureDescription": "The measure will take the value true if
all the requirements in the referred data product specification are fulfilled.",
               "nameOfMeasure": [
                  "MD101"
               ]
            },
            "type": "ConceptualConsistency"
         },
         {
            "result": [
               {
                  "valueUnit": "%",
                  "type": "QuantitativeResult",
                  "value": [
                     0
                  ]
               }
            ],
            "measure": {
               "measureIdentification": {
                  "code": "211",
                  "authority": {
                     "alternateTitle": [
                        "ISO"
                     ],
                     "title": "International Organization for Standardization"
                  },
                  "codeSpace": "https://standards.isotc211.org/19157/-3/1/dqc/
content/qualityMeasure/"
               },
               "measureDescription": "Quality degradation - rate of imperfect
coverage.",
               "nameOfMeasure": [
                  "MD211"
               ]
            },
            "evaluationMethod": [
               {
                  "type": "FullInspection",
                  "evaluationMethodDescription": "Automatic quality degradation
check."
               }
            ],
            "type": "Omission"
         },
         {
```

```
            "measure": {
               "measureIdentification": {
                  "code": "7",
                  "authority": {
                     "alternateTitle": [
                        "ISO"
                     ],
                     "title": "International Organization for Standardization"
                  },
                  "codeSpace": "https://standards.isotc211.org/19157/-3/1/dqc/
content/qualityMeasure/"
               },
               "measureDescription": "Cloud cover",
               "nameOfMeasure": [
                  "Percentage of image obscured by cloud"
               ]
            },
            "evaluationMethod": [
               {
                  "evaluationMethodType": "directInternal",
                  "type": "FullInspection",
                  "evaluationMethodDescription": "N/A."
               }
            ],
            "type": "Omission",
            "results": [
               {
                  "valueUnit": "%",
                  "type": "QuantitativeResult",
                  "value": [
                     4
                  ]
               }
            ]
         }
      ]
   }
]
```


Listing E.29

Example: 2.2.2

> Extract ISO19157-2 quality information for the product.

```
response = requests.get( item_url,
    headers={'Accept': 'application/vnd.iso.19157-2+xml'})

xmlstr = minidom.parseString(response.text).toprettyxml(indent='  ',newl='')
md("```xml\n" + xmlstr + "\n```\n")
```

Listing E.30


```
<?xml version="1.0" ?><mdq:DQ_DataQuality xmlns:mdq="http://standards.iso.org/
iso/19157/-2/mdq/1.0" xmlns:gco="http://standards.iso.org/iso/19115/-3/gco/1.0"
 xmlns:mcc="http://standards.iso.org/iso/19115/-3/mcc/1.0" xmlns:xlink="http://
www.w3.org/1999/xlink" xmlns:xsd="http://www.w3.org/2001/XMLSchema#">
  <mdq:scope>
    <mcc:MD_Scope>
      <mcc:level>
        <mcc:MD_ScopeCode codeList="http://standards.iso.org/ittf/
PubliclyAvailableStandards/ISO_19139_Schemas/resources/codelist/gmxCodelists.
xml#MD_ScopeCode" codeListValue="dataset"/>
      </mcc:level>
```

```
    </mcc:MD_Scope>
  </mdq:scope>
  <mdq:report>
    <mdq:DQ_CompletenessOmission>
      <mdq:measure>
        <mdq:DQ_MeasureReference>
          <mdq:measureIdentification>
            <mcc:MD_Identifier>
              <mcc:authority xlink:href="https://www.iso.org/"/>
              <mcc:code>
                <gco:CharacterString>7</gco:CharacterString>
              </mcc:code>
              <mcc:codeSpace>
                <gco:CharacterString>https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/</gco:CharacterString>
              </mcc:codeSpace>
            </mcc:MD_Identifier>
          </mdq:measureIdentification>
          <mdq:nameOfMeasure>
            <gco:CharacterString>Percentage of image obscured by cloud</gco:
CharacterString>
          </mdq:nameOfMeasure>
          <mdq:measureDescription>
            <gco:CharacterString>Cloud cover</gco:CharacterString>
          </mdq:measureDescription>
        </mdq:DQ_MeasureReference>
      </mdq:measure>
      <mdq:evaluationMethod>
        <mdq:DQ_FullInspection>
          <mdq:evaluationMethodType>
            <mdq:DQ_EvaluationMethodTypeCode codeList="http://standards.iso.org/
iso/19157/-2/mdq/1.0/codelists.xml#DQ_EvaluationMethodTypeCode" codeListValue=
"directInternal"/>
          </mdq:evaluationMethodType>
        </mdq:DQ_FullInspection>
      </mdq:evaluationMethod>
      <mdq:result>
        <mdq:DQ_QuantitativeResult>
          <mdq:value>
            <gco:Record>
              <xsd:decimal>4.0</xsd:decimal>
            </gco:Record>
          </mdq:value>
          <mdq:valueUnit xlink:href="urn:ogc:def:uom:OGC:1.0:percent"/>
          <mdq:valueRecordType>
            <gco:RecordType>decimal</gco:RecordType>
          </mdq:valueRecordType>
        </mdq:DQ_QuantitativeResult>
      </mdq:result>
    </mdq:DQ_CompletenessOmission>
  </mdq:report>
</mdq:DQ_DataQuality>
```

Listing E.31

Example: 2.2.3

> Extract ISO19115-3 quality information for the product.

```
response = requests.get( item_url,
    headers={'Accept': 'application/vnd.iso.19115-3+xml'})

# xmlstr = minidom.parseString(response.text).toprettyxml(indent='  ',newl='')
```

```
# md("```xml\n" + xmlstr + "\n```\n")
```

Listing E.32

```
root = ElementTree.fromstring(response.text)

ns = {'mdb': 'http://standards.iso.org/iso/19115/-3/mdb/1.0'}
el = root.find('mdb:dataQualityInfo', ns)

xmltxt = ElementTree.tostring(el, encoding='unicode', method='xml')
# md("```xml\n" + xmltxt + "\n```\n")
xmlstr = minidom.parseString(xmltxt).toprettyxml(indent='  ',newl='')
md("```xml\n" + xmlstr + "\n```\n")
```

Listing E.33

```
<?xml version="1.0" ?><ns0:dataQualityInfo xmlns:ns0="http://standards.iso.org/
iso/19115/-3/mdb/1.0" xmlns:ns1="http://standards.iso.org/iso/19157/-2/mdq/1.0"
xmlns:ns2="http://standards.iso.org/iso/19115/-3/mcc/1.0" xmlns:ns3="http://www.
w3.org/1999/xlink" xmlns:ns4="http://standards.iso.org/iso/19115/-3/gco/1.0"
xmlns:ns5="http://www.w3.org/2001/XMLSchema#">
  <ns1:DQ_DataQuality>
    <ns1:scope>
      <ns2:MD_Scope>
        <ns2:level>
          <ns2:MD_ScopeCode codeList="http://standards.iso.org/ittf/
PubliclyAvailableStandards/ISO_19139_Schemas/resources/codelist/gmxCodelists.
xml#MD_ScopeCode" codeListValue="dataset"/>
        </ns2:level>
      </ns2:MD_Scope>
    </ns1:scope>
    <ns1:report>
      <ns1:DQ_CompletenessOmission>
        <ns1:measure>
          <ns1:DQ_MeasureReference>
            <ns1:measureIdentification>
              <ns2:MD_Identifier>
                <ns2:authority ns3:href="https://www.iso.org/"/>
                <ns2:code>
                  <ns4:CharacterString>7</ns4:CharacterString>
                </ns2:code>
                <ns2:codeSpace>
                  <ns4:CharacterString>https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/</ns4:CharacterString>
                </ns2:codeSpace>
              </ns2:MD_Identifier>
            </ns1:measureIdentification>
            <ns1:nameOfMeasure>
              <ns4:CharacterString>Percentage of image obscured by cloud</ns4:
CharacterString>
            </ns1:nameOfMeasure>
            <ns1:measureDescription>
              <ns4:CharacterString>Cloud cover</ns4:CharacterString>
            </ns1:measureDescription>
          </ns1:DQ_MeasureReference>
        </ns1:measure>
        <ns1:evaluationMethod>
          <ns1:DQ_FullInspection>
            <ns1:evaluationMethodType>
              <ns1:DQ_EvaluationMethodTypeCode codeList="http://standards.
iso.org/iso/19157/-2/mdq/1.0/codelists.xml#DQ_EvaluationMethodTypeCode"
codeListValue="directInternal"/>
            </ns1:evaluationMethodType>
```

```
          </ns1:DQ_FullInspection>
        </ns1:evaluationMethod>
        <ns1:result>
          <ns1:DQ_QuantitativeResult>
            <ns1:value>
              <ns4:Record>
                <ns5:decimal>4.0</ns5:decimal>
              </ns4:Record>
            </ns1:value>
            <ns1:valueUnit ns3:href="urn:ogc:def:uom:OGC:1.0:percent"/>
            <ns1:valueRecordType>
              <ns4:RecordType>decimal</ns4:RecordType>
            </ns1:valueRecordType>
          </ns1:DQ_QuantitativeResult>
        </ns1:result>
      </ns1:DQ_CompletenessOmission>
    </ns1:report>
  </ns1:DQ_DataQuality>
</ns0:dataQualityInfo>
```

Listing E.34

Example: 2.2.4

> Request GeoDCAT-AP encoding (RDF/XML) with quality information for the product.

```
response = requests.get( item_url,
    headers={'Accept': 'application/rdf+xml;profile="http://data.europa.eu/930/
"'})

xmlstr = minidom.parseString(response.text).toprettyxml(indent='  ',newl='')
md("```xml\n" + xmlstr + "\n```\n")
```

Listing E.35

```
<?xml version="1.0" ?><rdf:RDF xmlns:ldp="http://www.w3.org/ns/ldp#" xmlns:geo=
"http://a9.com/-/opensearch/extensions/geo/1.0/" xmlns:locn="http://www.w3.org/
ns/locn#" xmlns:dct="http://purl.org/dc/terms/" xmlns:dc="http://purl.org/dc/
elements/1.1/" xmlns:dqv="http://www.w3.org/ns/dqv#" xmlns:adms="http://www.w3.
org/ns/adms#" xmlns:prov="http://www.w3.org/ns/prov#" xmlns:skos="http://www.w3.
org/2004/02/skos/core#" xmlns:owc="http://www.opengis.net/ont/owc/1.0/" xmlns:
xsd="http://www.w3.org/2001/XMLSchema#" xmlns:rdf="http://www.w3.org/1999/02/
22-rdf-syntax-ns#" xmlns:eo="http://a9.com/-/opensearch/extensions/eo/1.0/"
xmlns:iana="http://www.iana.org/assignments/relation/" xmlns:rdfs="http://www.w3.
org/2000/01/rdf-schema#" xmlns:os="http://a9.com/-/spec/opensearch/1.1/" xmlns:
isodqm="http://www.opengis.net/def/metamodel/isodqm/" xmlns:void="http://rdfs.
org/ns/void#" xmlns:time="http://a9.com/-/opensearch/extensions/time/1.0/" xmlns:
owl="http://www.w3.org/2002/07/owl#" xmlns:vcard="http://www.w3.org/2006/vcard/
ns#" xmlns:gsp="http://www.opengis.net/ont/geosparql#" xmlns:dcat="http://www.w3.
org/ns/dcat#" xmlns:atom="http://www.w3.org/2005/Atom/" xmlns:foaf="http://xmlns.
com/foaf/0.1/">
    <dcat:Dataset rdf:about="https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026">
        <foaf:depiction>http://tpm-ds.eo.esa.int/oads/meta/Tropforest/browse/KO2_
OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.ZIP_BID.JPG</
foaf:depiction>
        <dct:conformsTo rdf:resource="http://www.opengis.net/def/serviceType/ogc/
wcs"/>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/previews</
dcat:hadRole>
                <dct:title>THUMBNAIL</dct:title>
```

```
                <dct:relation>http://tpm-ds.eo.esa.int/oads/meta/Tropforest/
thumbnail/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.
ZIP_TIMG.jpg</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>image/jpeg</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>ISO19115-4</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vnd.iso.19115-4%2Bjson</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/vnd.iso.19115-4+json</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dct:description>Dataset KO2_OTPF_KO2_MSC_2F_20091121T032723_
20091121T032723_017702_E096_N026 from TropForest acquired 2009-11-21T03:27:23Z</
dct:description>
        <foaf:isPrimaryTopicOf>
            <dcat:CatalogRecord>
                <dct:source>
                    <dcat:CatalogRecord rdf:about="https://emc.spacebel.be/
collections/TropForest/items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_
017702_E096_N026?httpAccept=application/gml%2Bxml&amp;recordSchema=om">
                        <dct:conformsTo>
                            <dct:Standard>
                                <dct:title>OGC10-157r4</dct:title>
                            </dct:Standard>
                        </dct:conformsTo>
                    </dcat:CatalogRecord>
                </dct:source>
                <dct:modified>2024-04-30T11:32:32Z</dct:modified>
                <dct:identifier>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026</dct:
identifier>
                <dct:conformsTo>https://joinup.ec.europa.eu/release/geodcat-ap/20
</dct:conformsTo>
            </dcat:CatalogRecord>
        </foaf:isPrimaryTopicOf>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>OGC 10-157r3 metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/gml%2Bxml&amp;recordSchema=om10</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/gml+xml;profile=&quot;http://www.
opengis.net/spec/EOMPOM/1.0&quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
```

```
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>JSON-LD (schema.org) metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/ld%2Bjson;profile=https://schema.org</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/ld+json;profile=&amp;quot;https://
schema.org&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>RDF/XML metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/rdf%2Bxml</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/rdf+xml</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:distribution>
            <dcat:Distribution>
                <dcat:mediaType>application/zip</dcat:mediaType>
                <dcat:downloadURL>https://tpm-ds.eo.esa.int/oads/data/Tropforest/
KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.ZIP</dcat:
downloadURL>
            </dcat:Distribution>
        </dcat:distribution>
        <dcat:endpointDescription>
            <owc:Offering>
                <owc:operations>
                    <owc:Operation>
                        <owc:type>image/tif</owc:type>
                        <owc:method>GET</owc:method>
                        <owc:href>https://wcs.maap.eo.esa.int/wcs?
service=WCS&amp;Request=GetCoverage&amp;coverageId=TROPFOREST&amp;subset=
Lat(25.92713265,26.08689352)&amp;subset=Long(95.91153308,96.09259599)&amp;subset=
time(2009-11-21T03:27:23Z,2009-11-21T03:27:23Z)</owc:href>
                        <owc:code>GetCoverage</owc:code>
                    </owc:Operation>
                </owc:operations>
                <owc:operations>
                    <owc:Operation>
                        <owc:type>text/xml</owc:type>
                        <owc:method>GET</owc:method>
                        <owc:href>https://wcs.maap.eo.esa.int/wcs?service=
WCS&amp;Request=DescribeCoverage&amp;coverageId=TROPFOREST</owc:href>
                        <owc:code>DescribeCoverage</owc:code>
                    </owc:Operation>
                </owc:operations>
```

```
                <owc:operations>
                    <owc:Operation>
                        <owc:type>text/xml</owc:type>
                        <owc:method>GET</owc:method>
                        <owc:href>https://wcs.maap.eo.esa.int/wcs?service=
WCS&amp;request=GetCapabilities</owc:href>
                        <owc:code>GetCapabilities</owc:code>
                    </owc:Operation>
                </owc:operations>
                <owc:code rdf:resource="http://www.opengis.net/spec/owc-geojson/
1.0/req/wcs"/>
            </owc:Offering>
        </dcat:endpointDescription>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/previews</
dcat:hadRole>
                <dct:title>QUICKLOOK</dct:title>
                <dct:relation>http://tpm-ds.eo.esa.int/oads/meta/Tropforest/
browse/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.ZIP_
BID.JPG</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>image/jpeg</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Atom format</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/atom%2Bxml</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/atom+xml</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>STAC metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/geo%2Bjson;profile=&amp;quot;https://stacspec.org&amp;quot;</dct:
relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/geo+json;profile=&amp;quot;https://
stacspec.org&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
```

```
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Verifiable Presentation</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vp%2Bld%2Bjson</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/vp+ld+json</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dct:type>http://inspire.ec.europa.eu/metadata-codelist/ResourceType/
dataset</dct:type>
        <dct:identifier>KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_
017702_E096_N026</dct:identifier>
        <dct:title>KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026</dct:title>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>OGC 10-157r4 metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/gml%2Bxml&amp;recordSchema=om</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/gml+xml;profile=&quot;http://www.
opengis.net/spec/EOMPOM/1.1&quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:distribution>
            <dcat:Distribution>
                <dcat:mediaType>image/jpeg</dcat:mediaType>
                <dcat:downloadURL>http://tpm-ds.eo.esa.int/oads/meta/Tropforest/
thumbnail/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.
ZIP_TIMG.jpg</dcat:downloadURL>
            </dcat:Distribution>
        </dcat:distribution>
        <prov:wasGeneratedBy>
            <prov:Activity>
                <prov:used>
                    <prov:Entity>
                        <dct:title>KOMPSAT</dct:title>
                    </prov:Entity>
                </prov:used>
                <prov:used>
                    <prov:Entity>
                        <dct:title>MSC</dct:title>
                    </prov:Entity>
                </prov:used>
                <prov:startedAtTime>2009-11-21T03:27:23Z</prov:startedAtTime>
                <prov:endedAtTime>2009-11-21T03:27:23Z</prov:endedAtTime>
            </prov:Activity>
        </prov:wasGeneratedBy>
        <dct:language rdf:resource="http://publications.europa.eu/resource/
authority/language/ENG"/>
        <dct:modified>2024-04-30T11:32:32Z</dct:modified>
        <dcat:qualifiedRelation>
```

```
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/up</dcat:
hadRole>
                <dct:title>OGC 17-084r1 metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest?
mode=owc</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/geo+json</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>JSON-LD (GeoDCAT-AP) metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/ld%2Bjson;profile=http://data.europa.eu/930/</dct:
relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/ld+json;profile=&amp;quot;http://
data.europa.eu/930/&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>ISO 19115-3 metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vnd.iso.19115-3%2Bxml</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/vnd.iso.19115-3+xml</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Turtle (GeoDCAT-AP) metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=text/turtle;profile=http://data.europa.eu/930/</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>text/turtle;profile=&amp;quot;http://data.europa.
eu/930/&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dqv:hasQualityMeasurement>
            <dqv:QualityMeasurement>
```

```
                <dqv:value rdf:datatype="http://www.w3.org/2001/
XMLSchema#decimal">4</dqv:value>
                <dqv:isMeasurementOf>
                    <dqv:Metric rdf:about="https://standards.isotc211.org/19157/-
3/1/dqc/content/qualityMeasure/7">
                        <dqv:expectedDataType rdf:resource="http://www.w3.org/
2001/XMLSchema#decimal"/>
                        <skos:prefLabel>7 - rate of missing items</skos:
prefLabel>
                        <skos:definition>Indication that all requirements in the
referred data product specification are fulfilled.</skos:definition>
                        <rdfs:label>Percentage of image obscured by cloud</rdfs:
label>
                        <isodqm:measureID>7</isodqm:measureID>
                        <isodqm:elementName>omission</isodqm:elementName>
                        <dct:publisher rdf:resource="http://dbpedia.org/resource/
International_Organization_for_Standardization"/>
                    </dqv:Metric>
                </dqv:isMeasurementOf>
            </dqv:QualityMeasurement>
        </dqv:hasQualityMeasurement>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>RDF/XML (schema.org) metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/rdf%2Bxml;profile=https://schema.org</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/rdf+xml;profile=&amp;quot;https://
schema.org&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>OGC 17-003r2 metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?mode=
owc</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/geo+json;profile=&amp;quot;http://
www.opengis.net/spec/eo-geojson/1.0&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>HTML</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=text/html</dct:relation>
                <dct:format>
                    <dct:MediaType>
```

```
                        <rdfs:label>text/html</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Turtle metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=text/turtle</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>text/turtle</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Verifiable Credential</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vc%2Bld%2Bjson</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/vc+ld+json</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:distribution>
            <dcat:Distribution>
                <dcat:mediaType>image/jpeg</dcat:mediaType>
                <dcat:downloadURL>http://tpm-ds.eo.esa.int/oads/meta/Tropforest/
browse/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026.ZIP_
BID.JPG</dcat:downloadURL>
            </dcat:Distribution>
        </dcat:distribution>
        <dct:isPartOf rdf:resource="https://emc.spacebel.be/collections/
TropForest"/>
        <dct:spatial>
            <dct:Location>
                <locn:geometry rdf:datatype="http://www.opengis.net/ont/
geosparql#gmlLiteral">&lt;gml:Envelope srsName=&quot;http://www.opengis.net/def/
crs/OGC/1.3/CRS84&quot;&gt;&lt;gml:lowerCorner&gt;95.91153308 25.92713265&lt;
/gml:lowerCorner&gt;&lt;gml:upperCorner&gt;96.09259599 26.08689352&lt;/gml:
upperCorner&gt;&lt;/gml:Envelope&gt;</locn:geometry>
                <locn:geometry rdf:datatype="http://www.opengis.net/
ont/geosparql#wktLiteral">POLYGON((95.91153308 26.08689352,95.91153308
25.92713265,96.09259599 25.92713265,96.09259599 26.08689352,95.91153308
26.08689352))</locn:geometry>
                <locn:geometry rdf:datatype="http://www.opengis.net/ont/
geosparql#geoJSONLiteral">{&quot;type&quot;:&quot;Polygon&quot;,&quot;
coordinates&quot;:[[[95.91153308,26.08689352],[95.91153308,25.92713265],
[96.09259599,25.92713265],[96.09259599,26.08689352],[95.91153308,26.08689352]]] }
</locn:geometry>
            </dct:Location>
        </dct:spatial>
```

```
        <dcat:endpointDescription>
            <owc:Offering>
                <owc:operations>
                    <owc:Operation>
                        <owc:type>image/png</owc:type>
                        <owc:method>GET</owc:method>
                        <owc:href>https://wms.maap.eo.esa.int/wmts?service=
WMS&amp;Request=GetMap&amp;layers=TROPFOREST:RGB&amp;transparent=TRUE&amp;styles=
default&amp;format=image/png&amp;width={width}&amp;height={height}&amp;time=2009-
11-21T03:27:23Z,2009-11-21T03:27:23Z</owc:href>
                        <owc:code>GetMap</owc:code>
                    </owc:Operation>
                </owc:operations>
                <owc:operations>
                    <owc:Operation>
                        <owc:type>application/xml</owc:type>
                        <owc:method>GET</owc:method>
                        <owc:href>https://wms.maap.eo.esa.int/wmts?service=
WMS&amp;request=GetCapabilities</owc:href>
                        <owc:code>GetCapabilities</owc:code>
                    </owc:Operation>
                </owc:operations>
                <owc:code rdf:resource="http://www.opengis.net/spec/owc-geojson/
1.0/req/wms"/>
            </owc:Offering>
        </dcat:endpointDescription>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Turtle (schema.org) metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=text/turtle;profile=https://schema.org</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>text/turtle;profile=&amp;quot;https://schema.
org&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>Verifiable Credential 2.0</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vc%2Bld%2Bjson;version=2.0</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/vc+ld+json;version=2.0</rdfs:
label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>ISO 19139 metadata</dct:title>
```

```
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vnd.iso.19139%2Bxml</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/vnd.iso.19139+xml</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dct:temporal>
            <dct:PeriodOfTime>
                <dcat:startDate rdf:datatype="http://www.w3.org/2001/
XMLSchema#date">2009-11-21T03:27:23Z</dcat:startDate>
                <dcat:endDate rdf:datatype="http://www.w3.org/2001/
XMLSchema#date">2009-11-21T03:27:23Z</dcat:endDate>
            </dct:PeriodOfTime>
        </dct:temporal>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>OGC 17-069r3 metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026</dct:
relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/geo+json;profile=&amp;quot;http://
www.opengis.net/spec/ogcapi-features-1/1.0&amp;quot;</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
        <dcat:qualifiedRelation>
            <dcat:Relationship>
                <dcat:hadRole>http://www.iana.org/assignments/relation/alternate
</dcat:hadRole>
                <dct:title>JSON-LD metadata</dct:title>
                <dct:relation>https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/ld%2Bjson</dct:relation>
                <dct:format>
                    <dct:MediaType>
                        <rdfs:label>application/ld+json</rdfs:label>
                    </dct:MediaType>
                </dct:format>
            </dcat:Relationship>
        </dcat:qualifiedRelation>
    </dcat:Dataset>
</rdf:RDF>
```

Listing E.36

Example: 2.3

> Extract the Citation with the DID identifier from the ISO19115-4 metadata of a product

```
jstr = json.dumps(data['properties']['identificationInfo']['citation'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.37

```
{
```

```
   "identifier": [
      {
         "code": "KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_
E096_N026"
      },
      {
         "code": "did:web:emc.spacebel.be:collections:TropForest:items:KO2_OTPF_
KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026",
         "codeSpace": "https://www.w3.org/ns/did/v1"
      }
   ],
   "title": "KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_
N026"
}
```


Listing E.38

```
# Extract the DID (shortcut assuming it is the 2nd id for simplicity)
did = data['properties']['identificationInfo']['citation']['identifier'][1]
['code']
did
```

Listing E.39

```
'did:web:emc.spacebel.be:collections:TropForest:items:KO2_OTPF_KO2_MSC_2F_2009
```

Figure E.5

Example: 2.4

> Obtain the DID document for the product. The DID document advertizes the existence of a service to obtain the corresponding Verifiable Presentation (#vp) and the DID Registry endpoint to obtain the Verifiable Credential(s). These services definitions are according to the W3C specifications https://www.w3.org/TR/did-extensions-properties/#linkedverifiablepresentation and https://www.w3.org/TR/did-extensions-properties/#credentialregistry and refer to the DIF specification https://identity.foundation/linked-vp/.

```
# resolve DID
# The controller property in DID document for a collection should be the issuer
print(did)
response = requests.get( DID_RESOLVER + did,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.40

```
did:web:emc.spacebel.be:collections:TropForest:items:KO2_OTPF_KO2_MSC_2F_20091
```

Figure E.6


```
{
   "controller": "did:web:emc.spacebel.be:organisations:esa_esrin",
   "service": [
      {
         "id": "#vp",
         "serviceEndpoint": "https://emc.spacebel.be/collections/TropForest/
items/KO2_OTPF_KO2_MSC_2F_20091121T032723_20091121T032723_017702_E096_N026?
httpAccept=application/vp%2Bld%2Bjson",
         "type": "LinkedVerifiablePresentation"
```

```
      },
      {
         "id": "#vc",
         "serviceEndpoint": {
            "registries": [
               "https://emc.spacebel.be/registry/vcs/{credentialSubject.id}"
            ]
         },
         "type": "CredentialRegistry"
      }
   ],
   "id": "did:web:emc.spacebel.be:collections:TropForest:items:KO2_OTPF_KO2_MSC_
2F_20091121T032723_20091121T032723_017702_E096_N026",
   "@context": [
      "https://www.w3.org/ns/did/v1",
      "https://w3id.org/security/suites/jws-2020/v1",
      "https://identity.foundation/linked-vp/contexts/v1"
   ],
   "alsoKnownAs": [
      "https://emc.spacebel.be/collections/TropForest/items/KO2_OTPF_KO2_MSC_2F_
20091121T032723_20091121T032723_017702_E096_N026",
      "https://emc.spacebel.be/collections/TropForest/items/KO2_OTPF_KO2_MSC_
2F_20091121T032723_20091121T032723_017702_E096_N026?httpAccept=application/vnd.
iso.19115-4%2Bjson"
   ]
}
```


Listing E.41

E.3.2. 2.2 Provenance information OGC 17-003r2, OGC 10-157r4

Example: 2.6
> Get ISO19115-4 metadata for a Biomass product (with provenance/lineage information) using content negotiation

```
item_url = URL_LANDING_PAGE + 'collections/BiomassLevel1aIOC/items/BIO_S1_SCS__
1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_D9M4O4'

response = requests.get( item_url,
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
# jstr = json.dumps(data['properties']['dataQualityInfo'], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.42


```
{
   "bbox": [
      -70.52321,
      -42.22084,
      -69.409775,
      -40.855946
   ],
   "geometry": {
      "coordinates": [
         [
            [
               -70.52321,
```

```
                -42.104725
            ],
            [
                -69.75153,
                -42.22084
            ],
            [
                -69.409775,
                -40.96954
            ],
            [
                -70.1544,
                -40.855946
            ],
            [
                -70.52321,
                -42.104725
            ]
        ]
    ],
    "type": "Polygon"
},
"conformsTo": [
    "https://standards.iso.org/iso/19115/-4/0.1/core",
    "https://standards.iso.org/iso/19115/-4/0.1/data-quality-core",
    "https://standards.iso.org/iso/19115/-4/0.1/no-ref"
],
"id": "BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_
01_D9M4O4",
"type": "Feature",
"properties": {
    "defaultLocale": {
        "language": "eng",
        "characterEncoding": "utf8"
    },
    "identificationInfo": {
        "defaultLocale": {
            "language": "eng",
            "characterEncoding": "utf8"
        },
        "extent": [
            {
                "geographicElement": [
                    {
                        "northBoundLatitude": -40.855946,
                        "southBoundLatitude": -42.22084,
                        "type": "EX_GeographicBoundingBox",
                        "westBoundLongitude": -70.52321,
                        "eastBoundLongitude": -69.409775
                    }
                ]
            }
        ],
        "processingLevel": {
            "code": "1A"
        },
        "parentMetadata": {
            "identifier": [
                {
                    "code": "BiomassLevel1aIOC"
                },
                {
```

```
                  "code": "did:web:emc.spacebel.be:collections:
BiomassLevel1aIOC",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "BiomassLevel1aIOC"
         },
         "citation": {
            "identifier": [
               {
                  "code": "BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___
M___C___T____F191_01_D9M4O4"
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:BiomassLevel1aIOC:
items:BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C_
__T____F191_01_D9M4O4"
         },
         "abstract": "BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C_
__T____F191_01_D9M4O4"
      },
      "metadataStandard": [
         {
            "title": "ISO 19115-1:2014"
         },
         {
            "title": "ISO 19115-4"
         }
      ],
      "contact": [
         {
            "role": "pointOfContact",
            "party": [
               {
                  "contactInfo": [
                     {
                        "address": [
                           {
                              "deliveryPoint": [
                                 "Largo Galileo Galilei 1"
                              ],
                              "country": "Italy",
                              "city": "Frascati (Roma)",
                              "postalCode": "00044",
                              "electronicMailAddress": [
                                 "contactesrin@esa.int"
                              ]
                           }
                        ],
                        "phone": {
                           "voice": "tel:+3906941801"
                        }
                     }
                  ],
                  "name": "ESA/ESRIN",
                  "type": "CI_Organisation"
               }
            ]
```

```
            }
         ],
         "dataQualityInfo": [
            {
               "scope": {
                  "level": "dataset"
               },
               "report": [
                  {
                     "result": [
                        {
                           "type": "QuantitativeResult",
                           "value": [
                              "true"
                           ]
                        }
                     ],
                     "measure": {
                        "measureIdentification": {
                           "code": "101",
                           "authority": {
                              "alternateTitle": [
                                 "ISO"
                              ],
                              "title": "International Organization for
Standardization"
                           },
                           "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                        },
                        "measureDescription": "The measure will take the value true
if all the requirements in the referred data product specification are fulfilled.
",
                        "nameOfMeasure": [
                           "MD101"
                        ]
                     },
                     "type": "ConceptualConsistency"
                  },
                  {
                     "result": [
                        {
                           "valueUnit": "%",
                           "type": "QuantitativeResult",
                           "value": [
                              0
                           ]
                        }
                     ],
                     "measure": {
                        "measureIdentification": {
                           "code": "211",
                           "authority": {
                              "alternateTitle": [
                                 "ISO"
                              ],
                              "title": "International Organization for
Standardization"
                           },
                           "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                        },
```

```
                     "measureDescription": "Quality degradation - rate of
imperfect coverage.",
                     "nameOfMeasure": [
                        "MD211"
                     ]
                  },
                  "evaluationMethod": [
                     {
                        "type": "FullInspection",
                        "evaluationMethodDescription": "Automatic quality
degradation check."
                     }
                  ],
                  "type": "Omission"
               }
            ]
         }
      ],
      "resourceLineage": [
         {
            "statement": "Biomass L1 Processor",
            "processStep": [
               {
                  "reference": [
                     {
                        "title": "BIOMASS L1a/b/c Products Format Specification
(BPS_L1_PFD) V1.2.9"
                     },
                     {
                        "title": "BIOMASS Product Performance Description (BPS_
PPD) V3.1.3"
                     }
                  ],
                  "output": [
                     {
                        "source": [
                           {
                              "sourceCitation": {
                                 "code": "did:web:emc.spacebel.be:collections:
BiomassLevel1aIOC:items:BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___
C___T____F191_01_D9M4O4",
                                 "title": "BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4"
                              }
                           }
                        ]
                     }
                  ],
                  "processingInformation": {
                     "softwareReference": {
                        "edition": "3.1.3",
                        "title": "Biomass L1 Processor"
                     }
                  },
                  "description": "Biomass L1 Processor",
                  "stepDateTime": {
                     "created": "2025-06-02T19:55:16Z"
                  },
                  "source": [
                     {
                        "sourceCitation": {
                           "title": "BIO_S1_RAW__0S_20250531T222451_
20250531T222648_C_G___M___C___T____F039_01_D9M2OX"
```

```
                        }
                     },
                     {
                        "sourceCitation": {
                           "title": "BIO_S1_RAW__0M_20250531T221052_
20250531T222854_C_G___M___C___T____F____01_D9M42F"
                        }
                     }
                  ],
                  "processor": [
                     {
                        "role": "processor",
                        "party": [
                           {
                              "name": "Biomass CPF",
                              "type": "CI_Organisation"
                           }
                        ]
                     }
                  ]
               }
            ]
         }
      ],
      "dateInfo": {
         "revision": "2025-07-26T10:13:47Z"
      },
      "distributionInfo": [
         {
            "distributor": [],
            "transferOptions": [
               {
                  "onLine": [
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_orb.xml",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/annotation/navigation/bio_s1_
scs__1s_20250531t222456_20250531t222517_c_g___m___c___t____f191_orb.xml"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_att.xml",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/annotation/navigation/bio_s1_
scs__1s_20250531t222456_20250531t222517_c_g___m___c___t____f191_att.xml"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_lut.nc",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
```

```
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/annotation/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_lut.nc"
                    },
                    {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_annot.xml",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/annotation/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_annot.xml"
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annotation.xsd"
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
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                    {
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
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xsd"
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
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                    },
                    {
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```

```
                        "name": "data",
                        "description": "bio-aux-orbit.xsd",
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/schema/bio-aux-orbit.xsd"
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/schema/bio-aux-attitude.xsd"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio-l1-vrt.xsd",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/schema/bio-l1-vrt.xsd"
                     },
                     {
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                        "name": "data",
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                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/measurement/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_i_abs.tiff"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_i_phase.tiff",
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/measurement/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_i_phase.tiff"
                     },
                     {
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                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
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                        "linkage": "https://catalog.maap.eo.esa.int/data/
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20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/measurement/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_i.vrt"
                     },
                     {
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                        "name": "data",
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```

```
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/annotation/navigation/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g__
_m___c___t____f191_orb.xml"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_att.xml",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
05/31/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/annotation/navigation/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g__
_m___c___t____f191_att.xml"
                     },
                     {
                        "function": "download",
                        "name": "data",
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/annotation/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g___m___c___t_
___f191_lut.nc"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_annot.xml",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/annotation/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g___m___c___t_
___f191_annot.xml"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio-l1ab-main-annotation.xsd",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/schema/bio-l1ab-main-annotation.xsd"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio-l1-annotations.xsd",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/schema/bio-l1-annotations.xsd"
                     },
                     {
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                        "name": "data",
                        "description": "bio-l1-overlay.xsd",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
05/31/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
```

```
D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
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                    },
                    {
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
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                    },
                    {
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                        "name": "data",
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                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
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                    },
                    {
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                        "name": "data",
                        "description": "bio-aux-attitude.xsd",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/schema/bio-aux-attitude.xsd"
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/schema/bio-l1-vrt.xsd"
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                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/measurement/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g___m___c___
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                    },
                    {
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                        "name": "data",
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```
                        "description": "bio_s1_scs__1s_20250531t222456_
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D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/measurement/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g___m___c___
t____f191_i_phase.tiff"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_i.vrt",
                        "linkage": "s3://biomass-pdgs-01/BiomassLevel1aIOC/2025/
05/31/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4/measurement/bio_s1_scs__1s_20250531t222456_20250531t222517_c_g___m___c___
t____f191_i.vrt"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "previews",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_ql.png",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/preview/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_ql.png"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "previews",
                        "description": "bio_s1_scs__1s_20250531t222456_
20250531t222517_c_g___m___c___t____f191_map.kmz",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/preview/bio_s1_scs__1s_
20250531t222456_20250531t222517_c_g___m___c___t____f191_map.kmz"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "icon",
                        "description": "BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4.BI.PNG",
                        "linkage": "https://catalog.maap.eo.esa.int/data/
biomass-pdgs-01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4/public/BIO_S1_SCS__1S_
20250531T222456_20250531T222517_C_G___M___C___T____F191_01_D9M4O4.BI.PNG"
                     }
                  ]
               }
            ]
         }
      ],
      "metadataScope": [
         {
            "resourceScope": "dataset",
            "name": "dataset"
         }
      ]
   }
```

```
}
```

Listing E.43

E.4. W3C DID Identifiers

This section gives examples of DID documents. The actual DID identifiers can be found in the corresponding metadata records. An interactive DID resolver is available at https://dev.uniresolver.io/. In practice, the DID of different data providers can be of different types and are not expected to have a systematic naming convention as in this Demonstrator.

We assume that the following entities are identified via a DID:

- Organisation
- EO Collection
- EO Product/Granule

E.4.1. 3.1 DID Identifiers for Organisations

- did:web:emc.spacebel.be:organisations:esa_esrin
- did:web:emc.spacebel.be:organisations:csiro
- did:web:emc.spacebel.be:organisations:br_inpe
- did:web:emc.spacebel.be:organisations:ceos
- did:web:emc.spacebel.be:organisations:spacebel_sa
- did:web:emc.spacebel.be:organisations:de_dlr

Example DID document

```
# resolve DID
did = DID_ISSUERS[0]
print(did)
response = requests.get( DID_RESOLVER + did,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.44

```
did:web:emc.spacebel.be:organisations:esa_esrin
```

Figure E.7

```
{
   "@context": [
      "https://www.w3.org/ns/did/v1",
      "https://w3id.org/security/suites/jws-2020/v1"
   ],
   "id": "did:web:emc.spacebel.be:organisations:esa_esrin",
   "alsoKnownAs": [
      "https://gcmd.earthdata.nasa.gov/kms/concept/c56b4a86-82f8-4f15-98ba-
c5f7abe8ee5a",
      "https://yago-knowledge.org/resource/European_Space_Agency",
      "https://dbpedia.org/resource/European_Space_Agency",
      "https://ror.org/03wd9za21"
   ],
   "verificationMethod": [
      {
         "id": "did:web:emc.spacebel.be:organisations:esa_esrin#owner",
         "type": "JsonWebKey2020",
         "controller": "did:web:emc.spacebel.be:organisations:esa_esrin",
         "publicKeyJwk": {
            "kty": "EC",
            "crv": "secp256k1",
            "x": "yKemFmBtShtFrYfZHj9D3h83FntzLcCbLm8n1O4VOyI",
            "y": "ssJjEkBMsd4OFejeKNiCZRhJYuTaITyEGz93Ti0gfqw"
         }
      }
   ],
   "assertionMethod": [
      "did:web:emc.spacebel.be:organisations:esa_esrin#owner"
   ]
}
```

Listing E.45

E.4.2. 3.2 DID Identifiers for Collections

List a number of examples of DID for EO collections from various providers.

- did:web:emc.spacebel.be:collections:PROBA.HRC.1A
- did:web:emc.spacebel.be:collections:novasar_l2ard_hh_hv
- did:web:emc.spacebel.be:collections:AMZ1-WFI-L4-SR-1

Example DID document

```
# resolve DID
did = DID_COLLECTIONS[2]
print(did)
response = requests.get( DID_RESOLVER + did,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
```

```
md("```json\n" + jstr + "\n```\n")
```

Listing E.46

```
did:web:emc.spacebel.be:collections:AMZ1-WFI-L4-SR-1
```

Figure E.8

```
{
   "controller": "did:web:emc.spacebel.be:organisations:br_inpe",
   "id": "did:web:emc.spacebel.be:collections:AMZ1-WFI-L4-SR-1",
   "@context": [
      "https://www.w3.org/ns/did/v1",
      "https://w3id.org/security/suites/jws-2020/v1"
   ],
   "alsoKnownAs": [
      "https://emc.spacebel.be/collections/AMZ1-WFI-L4-SR-1",
      "https://emc.spacebel.be/collections/AMZ1-WFI-L4-SR-1?httpAccept=
application/vnd.iso.19115-4%2Bjson"
   ]
}
```

Listing E.47

E.4.3. 3.3 DID Identifiers for Products

```
did = DID_COLLECTIONS[INDEX_ESA] + ":items:" + "PR1_OPER_HRC_HRC_1P_
20160505T083637_S28-078_E114-061_0001"
print(did)
```

Listing E.48

```
did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_201
```

Figure E.9

```
# resolve DID
response = requests.get( DID_RESOLVER + did,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.49

```
{
   "controller": "did:web:emc.spacebel.be:organisations:esa_esrin",
   "service": [
      {
         "id": "#vp",
         "serviceEndpoint": "https://emc.spacebel.be/collections/PROBA.HRC.1A/
items/PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001?httpAccept=
application/vp%2Bld%2Bjson",
         "type": "LinkedVerifiablePresentation"
      },
      {
         "id": "#vc",
         "serviceEndpoint": {
            "registries": [
               "https://emc.spacebel.be/registry/vcs/{credentialSubject.id}"
```

```
            ]
         },
         "type": "CredentialRegistry"
      }
   ],
   "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_
HRC_1P_20160505T083637_S28-078_E114-061_0001",
   "@context": [
      "https://www.w3.org/ns/did/v1",
      "https://w3id.org/security/suites/jws-2020/v1",
      "https://identity.foundation/linked-vp/contexts/v1"
   ],
   "alsoKnownAs": [
      "https://emc.spacebel.be/collections/PROBA.HRC.1A/items/PR1_OPER_HRC_HRC_
1P_20160505T083637_S28-078_E114-061_0001",
      "https://emc.spacebel.be/collections/PROBA.HRC.1A/items/PR1_OPER_HRC_HRC_
1P_20160505T083637_S28-078_E114-061_0001?httpAccept=application/vnd.iso.19115-
4%2Bjson"
   ]
}
```


Listing E.50

Obtain the corresponding VC via the VP which is directly accessible via the DID Document. See https://www.w3.org/TR/did-extensions-properties/#linkedverifiablepresentation.

```
href = data["service"][0]['serviceEndpoint']

response = requests.get( href,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data["verifiableCredential"], indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.51


```
[
   {
      "relatedResource": [
         {
            "digestMultibase": "zQmYRMC8UMw4ipWvivUKvzvTWrjbKk1oywH1QpoY6w3tCQX",
            "id": "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld"
         },
         {
            "digestMultibase": "zQmbyT7S2G7FS8N3asZsYSqSc3hCGepLkgSxvxYQUddGACD",
            "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/PR1_OPER_
HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_BID.PNG"
         },
         {
            "digestMultibase": "zQmeuPEJqShU5NvJvxejNqpH8WnTM1h4RrQz1YtxCXvBEtR",
            "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/thumbnail/PR1_
OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_TIMG.jpg"
         }
      ],
      "credentialSubject": {
         "date": "2016-05-05T08:36:37Z/2016-05-05T08:36:37Z",
         "bbox": [
            114.6,
            -28.8,
            114.62,
            -28.76
         ],
```

```
         "geometry": {
            "coordinates": [
               [
                  [
                     114.62,
                     -28.8
                  ],
                  [
                     114.62,
                     -28.76
                  ],
                  [
                     114.6,
                     -28.76
                  ],
                  [
                     114.6,
                     -28.8
                  ],
                  [
                     114.62,
                     -28.8
                  ]
               ]
            ],
            "type": "Polygon"
         },
         "links": {
            "data": [
               {
                  "href": "https://tpm-ds.eo.esa.int/oads/data/PROBA1-HRC/PR1_
OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP",
                  "title": "Download",
                  "type": "application/x-binary"
               }
            ],
            "previews": [
               {
                  "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_BID.PNG",
                  "title": "QUICKLOOK",
                  "type": "image/png"
               },
               {
                  "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
thumbnail/PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_TIMG.
jpg",
                  "title": "THUMBNAIL",
                  "type": "image/jpeg"
               }
            ]
         },
         "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_
HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001",
         "title": "PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001",
         "updated": "2024-04-30T11:28:07Z"
      },
      "issuanceDate": "2026-02-12T12:41:28Z",
      "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_
HRC_1P_20160505T083637_S28-078_E114-061_0001",
      "proof": {
         "created": "2026-02-12T12:41:28.575Z",
```

```
         "jws": "eyJhbGciOiJFUzI1NksiLCJraWQiOiJiQnpXOHlHeEt1RUNMal9JeFN
yTkN1eVJKOUppZ2ptTU9DeDJGZHpDcnFBIiwiY3JpdCI6WyJiNjQiXSwiYjY0IjpmYWxzZX0.
.xbgj6l8B22jUvhFwXjV9i-VJFlJDk1pwA42NlQ0NLjh3DsCO_1oicOKyflAlrcmC9LI1s39u4Y2hfAgk
aH5cEA",
         "proofPurpose": "assertionMethod",
         "type": "EcdsaSecp256k1Signature2019",
         "verificationMethod": "did:web:emc.spacebel.be:organisations:esa_
esrin#owner"
      },
      "type": [
         "VerifiableCredential",
         "Feature"
      ],
      "@context": [
         "https://www.w3.org/2018/credentials/v1",
         "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld",
         {
            "digestMultibase": {
               "@type": "https://w3id.org/security#multibase",
               "@id": "https://w3id.org/security#digestMultibase"
            },
            "relatedResource": {
               "@type": "@id",
               "@id": "https://www.w3.org/2018/credentials#relatedResource"
            }
         }
      ],
      "issuer": "did:web:emc.spacebel.be:organisations:esa_esrin"
   }
]
```


Listing E.52

Obtain the VC via the registry endpoint provided in the DID Document. See https://www.w3.org/TR/did-extensions-properties/#credentialregistry

```
# resolve DID
response = requests.get( DID_RESOLVER + did,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
```

Listing E.53

```
href = data["service"][1]['serviceEndpoint']['registries'][0]
href
```

Listing E.54

```
'https://emc.spacebel.be/registry/vcs/{credentialSubject.id}'
```

Figure E.10

```
did
```

Listing E.55

```
'did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_20
```

Figure E.11

```
# Replace the id with the DID of the subject for which the VC is requested.
```

```
url = href.replace('{credentialSubject.id}',did)
url
```

Listing E.56

```
'https://emc.spacebel.be/registry/vcs/
did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_201
```

Figure E.12

```
# Get the VCS from the registry
response = requests.get( url,
    headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.57


```
[
   {
      "relatedResource": [
         {
            "digestMultibase": "zQmYRMC8UMw4ipWvivUKvzvTWrjbKk1oywH1QpoY6w3tCQX",
            "id": "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld"
         },
         {
            "digestMultibase": "zQmbyT7S2G7FS8N3asZsYSqSc3hCGepLkgSxvxYQUddGACD",
            "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/PR1_OPER_
HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_BID.PNG"
         },
         {
            "digestMultibase": "zQmeuPEJqShU5NvJvxejNqpH8WnTM1h4RrQz1YtxCXvBEtR",
            "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/thumbnail/PR1_
OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_TIMG.jpg"
         }
      ],
      "credentialSubject": {
         "date": "2016-05-05T08:36:37Z/2016-05-05T08:36:37Z",
         "bbox": [
            114.6,
            -28.8,
            114.62,
            -28.76
         ],
         "geometry": {
            "coordinates": [
               [
                  [
                     114.62,
                     -28.8
                  ],
                  [
                     114.62,
                     -28.76
                  ],
                  [
                     114.6,
                     -28.76
                  ],
                  [
                     114.6,
```

```
                    -28.8
                ],
                [
                    114.62,
                    -28.8
                ]
            ]
         ],
         "type": "Polygon"
      },
      "links": {
         "data": [
            {
               "href": "https://tpm-ds.eo.esa.int/oads/data/PROBA1-HRC/PR1_
OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP",
               "title": "Download",
               "type": "application/x-binary"
            }
         ],
         "previews": [
            {
               "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_BID.PNG",
               "title": "QUICKLOOK",
               "type": "image/png"
            },
            {
               "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
thumbnail/PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001.SIP.ZIP_TIMG.
jpg",
               "title": "THUMBNAIL",
               "type": "image/jpeg"
            }
         ]
      },
      "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_
HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001",
      "title": "PR1_OPER_HRC_HRC_1P_20160505T083637_S28-078_E114-061_0001",
      "updated": "2024-04-30T11:28:07Z"
   },
   "issuanceDate": "2026-02-12T12:41:30Z",
   "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_
HRC_1P_20160505T083637_S28-078_E114-061_0001",
   "proof": {
      "created": "2026-02-12T12:41:30.489Z",
      "jws": "eyJhbGciOiJFUzI1NksiLCJraWQiOiJiQnpXOHlHeEt1RUNMal9JeFNyTkN1eV
JKOUppZ2ptTU9DeDJGZHpDcnFBIiwiY3JpdCI6WyJiNjQiXSwiYjY0IjpmYWxzZX0..2n6N-X0_dmO-
2jJBkvN1_RsIkyjfNgqscsSCCaJ0owxpwKhmWl7s6YiBhLr21bhMop6aM8_ETc6tUU_0IHU02Q",
      "proofPurpose": "assertionMethod",
      "type": "EcdsaSecp256k1Signature2019",
      "verificationMethod": "did:web:emc.spacebel.be:organisations:esa_
esrin#owner"
   },
   "type": [
      "VerifiableCredential",
      "Feature"
   ],
   "@context": [
      "https://www.w3.org/2018/credentials/v1",
      "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld",
      {
         "digestMultibase": {
            "@type": "https://w3id.org/security#multibase",
```

```
                "@id": "https://w3id.org/security#digestMultibase"
            },
            "relatedResource": {
                "@type": "@id",
                "@id": "https://www.w3.org/2018/credentials#relatedResource"
            }
        }
    ],
    "issuer": "did:web:emc.spacebel.be:organisations:esa_esrin"
  }
]
```

Listing E.58

E.5. Interaction with OGC API Processes

E.5.1. 4.1 Get available processes

```
OGC_API_PROCESSES = 'https://geoserver.ogc.secd.eu/geoserver/ogc/processes/v1'

url = OGC_API_PROCESSES + '/processes'
response = requests.get(url, headers={ 'Accept': 'application/json' })


# data = json.loads(response.text)
# jstr = json.dumps(data['processes'], indent=3)
# md("```json\n" + jstr + "\n```\n")
```

Listing E.59

E.5.2. 4.2 Describe Trusted Watermarking Process

```
url =  OGC_API_PROCESSES  + '/processes/gs:TrustedWatermarking'

response = requests.get(url, headers={ 'Accept': 'application/json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.60

```
{
   "id": "gs:TrustedWatermarking",
   "links": [
      {
         "href": "https://geoserver.ogc.secd.eu/geoserver/ogc/processes/v1/
processes/gs:TrustedWatermarking?f=application%2Fjson",
         "rel": "self",
         "type": "application/json",
         "title": "This document"
      },
      {
```

```
            "href": "https://geoserver.ogc.secd.eu/geoserver/ogc/processes/v1/
processes/gs:TrustedWatermarking?f=application%2Fyaml",
            "rel": "alternate",
            "type": "application/yaml",
            "title": "This document as application/yaml"
         },
         {
            "href": "https://geoserver.ogc.secd.eu/geoserver/ogc/processes/v1/
processes/gs:TrustedWatermarking?f=text%2Fhtml",
            "rel": "alternate",
            "type": "text/html",
            "title": "This document as text/html"
         }
      ],
      "version": "1.0.0",
      "title": "Trusted Watermarking WPS",
      "description": "OGC Testbed-21 Watermarking Process that stores the
provenance metadata on a Blockchain",
      "jobControlOptions": [
         "sync-execute",
         "async-execute"
      ],
      "inputs": {
         "image_url": {
            "title": "image_url",
            "description": "URL of the input image to be watermarked",
            "schema": {
               "title": "string",
               "type": "string"
            },
            "minOccurs": 1,
            "maxOccurs": 1
         },
         "meta_url": {
            "title": "meta_url",
            "description": "URL of the STAC item describing the image (image_url)
to be watermarked",
            "schema": {
               "title": "string",
               "type": "string"
            },
            "minOccurs": 1,
            "maxOccurs": 1
         }
      },
      "outputs": {
         "Asset": {
            "title": "Asset",
            "description": "The STAC Feature that is stored on the Blockchain",
            "schema": {
               "title": "string",
               "type": "string"
            }
         }
      }
   }
```


Listing E.61

E.5.3. 4.3 Execute Trusted Watermarking Process

The Watermarking Process does not use the VC as a direct input, so we cannot force in the request that it should use the VC 2.0 (if supported)

```
url =  OGC_API_PROCESSES  + '/processes/gs:TrustedWatermarking/execution'

# CITE Tests, last execution - 08/01/2026 9h00 CET.

# OK - catalogue supports VC 1.0 (context compacted)
#    - https://univerifier.io - OK
payload_1_proba = { 'inputs': {  \
            'image_url': 'http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.PNG' ,  \
            'meta_url': 'https://emc.spacebel.be/collections/PROBA.HRC.1A/items/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=application/
geo%2Bjson;profile=https://stacspec.org' } }

# OK - catalogue supports VC 1.0 (context not compacted)
#       - https://univerifier.io - OK
payload_2_oceansat = { 'inputs': {  \
            'image_url': 'http://tpm-ds.eo.esa.int/oads/meta/OceanSat2/browse/
OC2_OPER_OCM2_LA_2C_20160601T115359_20160601T115728_035428_0003_0010_0141.ZIP_
BID.PNG' ,  \
            'meta_url': 'https://emc.spacebel.be/collections/OceanSat-2.NRT.data/
items/OC2_OPER_OCM2_LA_2C_20160601T115359_20160601T115728_035428_0003_0010_0141?
httpAccept=application/geo%2Bjson;profile=https://stacspec.org' } }

# OK - catalogue supports VC 1.0 (context not compacted)
#    - https://univerifier.io - OK
payload_3_inpe = { 'inputs': {  \
            'image_url': 'https://data.inpe.br/bdc/data/s2-16d/v2/003/011/2025/
11/01/S2-16D_V2_003011_20251101.png' ,  \
            'meta_url': 'https://emc.spacebel.be/collections/S2-16D-2/items/
S2-16D_V2_003011_20251101?httpAccept=application/geo%2Bjson;profile=https://
stacspec.org' } }


# OK - catalogue supports VC 1.0 and VC 2.0 (context not compacted)
#    - https://univerifier.io - OK
payload_4_dlr = { 'inputs': {  \
            'image_url': 'https://eoweb.dlr.de/hma/browse/dims_op_pl_eoweb1_
XXXXB000000002281529141O6/1/anonymous/2025-12-04-09-05-28' , \
            'meta_url': 'https://emc.spacebel.be/collections/376e342e-3fb8-4d98-
bd1e-51a204e1268b/items/urn:eop:DLR:EOWEB:Water_Parameter_Baltic_Sea_MERIS_
seasonal_maps:%40dims_nz_pl_dfd_XXXXB000000000001139414390%40dims_nz_pl_dfd_
%40%40ENVISAT.MERIS.VA.L3.RWC_PCI?httpAccept=application/geo%2Bjson;profile=
https://stacspec.org' } }

# fails - catalogue supports VC 1.0 and VC 2.0 (context not compacted)
#       - https://univerifier.io - OK
payload_5_jaxa = { 'inputs': {  \
            'image_url': 'https://gportal.jaxa.jp/gpr/img/br/P1AME020600A_
P3SSW000700E0/P1AME020600A_P3SSW000700E0.jpg' , \
            'meta_url': 'https://emc.spacebel.be/collections/Aqua_AMSR-E_L3_SSW_
1month_0.25deg/items/P1AME020600A_P3SSW000700E0?httpAccept=application%2Fgeo%2Bjs
on%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org' } }

# OK - catalogue supports VC 1.0 (context not compacted)
```

```
#    - https://univerifier.io - OK
payload_6_biomass = { 'inputs': {  \
            'image_url': 'https://catalog.maap.eo.esa.int/data/biomass-pdgs-
01/BiomassLevel1aIOC/2025/05/31/BIO_S1_SCS__1S_20250531T222456_20250531T222517_
C_G___M___C___T____F191_01_D9M4O4/public/BIO_S1_SCS__1S_20250531T222456_
20250531T222517_C_G___M___C___T____F191_01_D9M4O4.BI.PNG' ,  \
            'meta_url': 'https://emc.spacebel.be/collections/BiomassLevel1aIOC/
items/BIO_S1_SCS__1S_20250531T222456_20250531T222517_C_G___M___C___T____F191_01_
D9M4O4?httpAccept=application/geo%2Bjson;profile=https://stacspec.org' } }

# OK - 22/01/2026 - catalogue supports VC 1.0 (context compacted)
#    - https://univerifier.io - OK
payload_7_proba_chris = { 'inputs': {  \
            'image_url': 'http://tpm-ds.eo.esa.int/oads/meta/PROBA1-CHRIS/browse/
PR1_OPER_CHR_MO1_1P_20020618T084000_N30-058_E034-008_0001.SIP.ZIP_BID.PNG' ,  \
            'meta_url': 'https://emc.spacebel.be/collections/PROBA.CHRIS.1A/
items/PR1_OPER_CHR_MO1_1P_20020618T084000_N30-058_E034-008_0001?httpAccept=applic
ation%2Fgeo%2Bjson%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org' } }

payload = payload_1_proba

response = requests.post(url, json = payload, headers={ 'Accept': 'application/
json' })

print(response.text)

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.62


```
{"stac_version":"1.0.0","assets":{"PRODUCT":
{"file:checksum":"1e20cbe790d1f9193bb7ce70e7197f760c2b9188c19dabe2db8583abaa99
{"FACTS_Browser_Cookie":{"description":"In order to download the
asset via a Web Browser, you first need to establish a connection
with your wallet via https://assets.ogc.secd.eu/link so that the
Asset Controller can request proof for FACTS Certificates via that
secure and private connection when you try to fetch the Asset. Once
you have a connection established, you can use the Download link
above to fetch the GeoPackage.","href":"https://assets.ogc.secd.eu/
files/683f5aa56037d688241e54cc004bc14fe3067d1c1f51c67133571efc29c6e3da","title
Asset via Web Browser session cookie","type":"image/
jpeg"},"FACTS_API_Key":{"auth":{"refs":["apiKey"],"roles":
["download"],"schemes":{"flows":{"authorizationCode":
{"authorizationApi":"https://wallet.ogc.secd.eu/
user/x-facts-key","method":"get","responseField":"x-
facts-key","parameters":{"expires_in":{"schema":
{"examples":"300","type":"string"},"in":"query","description":"the
validity of the token in
seconds","required":"true"}}}},"in":"header","name":"X-FACTS-
Key","description":"X-FACTS-Key represents the connection between your
Wallet and the Asset Controller to request proof of required FACTS
Certificates.","type":"apiKey","required":"true"}},"description":"In
order to download the asset via the API, you first need
to fetch an API-Key token (X-FACTS-Key) via https://
wallet.ogc.secd.eu/connections/select which must be
submitted as HTTP Header `X-FACTS-Key` with the asset URL
from `Copy URL`. ","href":"https://assets.ogc.secd.eu/
```

files/683f5aa56037d688241e54cc004bc14fe3067d1c1f51c67133571efc29c6e3da","title
Asset via X-FACTS-Key","type":"image/jpeg"}},"href":"https://
ipfs.ogc.secd.eu/
files/683f5aa56037d688241e54cc004bc14fe3067d1c1f51c67133571efc29c6e3da","title
jpeg"}},"bbox":[133.87,-23.68,133.9,-23.64],"geometry":
{"coordinates":[[[133.9,-23.68],[133.9,-23.64],[133.87,-23.64],
[133.87,-23.68],[133.9,-23.68]]],"type":"Polygon"},"links":
[{"rel":"derived_from","href":"https://emc.spacebel.be/collections/
PROBA.HRC.1A/items/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?
httpAccept=application/geo%2Bjson;profile=https://
stacspec.org","type":"application/geo+json","title":"Source
metadata"},{"rel":"self","href":"https://
ic.ogc.secd.eu/stac/collections/test_dq4ipt/
items/asset_1770900095005","type":"application/
geo+json","title":"asset_1770900095005"},
{"rel":"collection","href":"https://ic.ogc.secd.eu/
stac/collections/test_dq4ipt","type":"application/
json","title":"test_dq4ipt"}],"collection":"test_dq4ipt","id":"asset_177090009
["https://stac-extensions.github.io/file/v2.1.0/schema.json","https://
stac-extensions.github.io/alternate-assets/v1.1.0/
schema.json","https://stac-extensions.github.io/processing/
v1.2.0/schema.json","https://luciocola.github.io/stac-extension-
liability-claims/json-schema/schema.json"],"properties":
{"processing:level":"L1","datetime":"2026-02-12T12:41:35Z","start_datetime":"2
Dimensions Processes","processing:lineage":"Watermarking
Process","processing:datetime":"2026-02-12T12:41:35Z","liability:quality":
{"scope":{"level":"series"},"report":[{"result":
[{"pass":true,"specification":
{"date":"2021-10-14T00:00:00Z","identifier":"https://ceos.org/spec/
ard/conf","title":"CEOS ARD Normalised Radar Backscatter (CARD4L-
NRB)"},"type":"ConformanceResult","resultType":"conformance"}],"measure":
{"measureIdentification":{"code":"101","authority":
{"alternateTitle":["ISO"],"title":"International
Organization for Standardization"},"codeSpace":"https://
standards.isotc211.org/19157/-3/1/dqc/content/
qualityMeasure/"},"measureDescription":"The measure will
take the value true if all the requirements in the referred
data product specification are fulfilled.","nameOfMeasure":
["Data product specification passed"]},"completeness":
{"category":"completeness"},"type":"ConceptualConsistency","category":"complet
{"name":"Geoserver","version":"3.0-SNAPSHOT"},"ipt":{"output":
{"image_height":1026,"file:checksum":"1e20cbe790d1f9193bb7ce70e7197f760c2b9188
ic.ogc.secd.eu/stac/collections/test_dq4ipt/items/
asset_1770900095005","image_url":"https://assets.ogc.secd.eu/
files/683f5aa56037d688241e54cc004bc14fe3067d1c1f51c67133571efc29c6e3da","image
jpeg"},"input":{"image":
{"image_height":1026,"file:checksum":"1220ecff1a367594707fe3603f73fdd6091b039b
tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.PNG","im
png;charset=UTF-8"},"metadata":{"metadata_url":"https://
emc.spacebel.be/collections/PROBA.HRC.1A/items/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?
httpAccept=application/geo%2Bjson;profile=https://

```
stacspec.org","vc_url":"https://emc.spacebel.be/collections/
PROBA.HRC.1A/items/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?
httpAccept=application/vc%2Bld%2Bjson","VC_verification":true,"VC":
{"relatedResource":
[{"digestMultibase":"zQmYRMC8UMw4ipWvivUKvzvTWrjbKk1oywH1QpoY6w3tCQX","id":"ht
schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld"},
{"digestMultibase":"zQmeHnYH1jaUefpeAbARzC46rJSzSte8uWn52GGcQWXMcmn","id":"htt
tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.PNG"},
{"digestMultibase":"zQmPFZfx6KoEAgPpFosgJEKQ17K7sJpsSZWtyNo7vwBHXyr","id":"htt
tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/thumbnail/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_TIMG.jpg"}],
{"date":"2016-02-04T07:28:52Z/2016-02-04T07:28:52Z","bbox":
[133.87,-23.68,133.9,-23.64],"links":{"data":
[{"href":"https://tpm-ds.eo.esa.int/oads/data/PROBA1-HRC/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP","title":"Do
x-binary"}],"previews":[{"href":"http://tpm-
ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.PNG","ti
png"},{"href":"http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
thumbnail/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_TIMG.jpg","t
jpeg"}]},"geometry":{"coordinates":[[[133.9,-23.68],
[133.9,-23.64],[133.87,-23.64],[133.87,-23.68],
[133.9,-23.68]]],"type":"Polygon"},"id":"did:web:emc.spacebel.be:collections:P
{"created":"2026-02-12T12:41:33.485Z","jws":"eyJhbGciOiJFUzI1NksiLCJraWQiOiJiC
dvafyfezz2y3nUEKg1DVQWY0noAt5n-8KzA","proofPurpose":"assertionMethod","type":"
["VerifiableCredential","Feature"],"@context":["https://
www.w3.org/2018/credentials/v1","https://schemas.opengis.net/
eo-geojson/1.0/eo-geojson.jsonld",{"digestMultibase":
{"@type":"https://w3id.org/security#multibase","@id":"https://
w3id.org/security#digestMultibase"},"relatedResource":
{"@type":"@id","@id":"https://www.w3.org/2018/
credentials#relatedResource"}}],"issuer":"did:web:emc.spacebel.be:organisation
```


Figure E.13


```
{
   "stac_version": "1.0.0",
   "assets": {
      "PRODUCT": {
         "file:checksum": "1e20cbe790d1f9193bb7ce70e7197f760c2b9188c19dabe2db8583
abaa99e2b58c96",
         "alternate": {
            "FACTS_Browser_Cookie": {
               "description": "In order to download the asset via a Web Browser,
you first need to establish a connection with your wallet via https://assets.
ogc.secd.eu/link so that the Asset Controller can request proof for FACTS
Certificates via that secure and private connection when you try to fetch the
Asset. Once you have a connection established, you can use the Download link
above to fetch the GeoPackage.",
               "href": "https://assets.ogc.secd.eu/files/683f5aa56037d688241e54cc
004bc14fe3067d1c1f51c67133571efc29c6e3da",
               "title": "Download Asset via Web Browser session cookie",
               "type": "image/jpeg"
            },
            "FACTS_API_Key": {
```

```
                "auth": {
                   "refs": [
                      "apiKey"
                   ],
                   "roles": [
                      "download"
                   ],
                   "schemes": {
                      "flows": {
                         "authorizationCode": {
                            "authorizationApi": "https://wallet.ogc.secd.eu/user/
x-facts-key",
                            "method": "get",
                            "responseField": "x-facts-key",
                            "parameters": {
                               "expires_in": {
                                  "schema": {
                                     "examples": "300",
                                     "type": "string"
                                  },
                                  "in": "query",
                                  "description": "the validity of the token in
seconds",
                                  "required": "true"
                               }
                            }
                         }
                      },
                      "in": "header",
                      "name": "X-FACTS-Key",
                      "description": "X-FACTS-Key represents the connection
between your Wallet and the Asset Controller to request proof of required FACTS
Certificates.",
                      "type": "apiKey",
                      "required": "true"
                   }
                },
                "description": "In order to download the asset via the API, you
first need to fetch an API-Key token (X-FACTS-Key) via https://wallet.ogc.secd.
eu/connections/select which must be submitted as HTTP Header `X-FACTS-Key` with
the asset URL from `Copy URL`. ",
                "href": "https://assets.ogc.secd.eu/files/683f5aa56037d688241e54cc
004bc14fe3067d1c1f51c67133571efc29c6e3da",
                "title": "Download Asset via X-FACTS-Key",
                "type": "image/jpeg"
             }
          },
          "href": "https://ipfs.ogc.secd.eu/files/683f5aa56037d688241e54cc004bc14f
e3067d1c1f51c67133571efc29c6e3da",
          "title": "Product",
          "type": "image/jpeg"
       }
    },
    "bbox": [
       133.87,
       -23.68,
       133.9,
       -23.64
    ],
    "geometry": {
       "coordinates": [
          [
             [
```

```
                  133.9,
                  -23.68
               ],
               [
                  133.9,
                  -23.64
               ],
               [
                  133.87,
                  -23.64
               ],
               [
                  133.87,
                  -23.68
               ],
               [
                  133.9,
                  -23.68
               ]
            ]
         ],
         "type": "Polygon"
      },
      "links": [
         {
            "rel": "derived_from",
            "href": "https://emc.spacebel.be/collections/PROBA.HRC.1A/items/PR1_
OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=application/geo
%2Bjson;profile=https://stacspec.org",
            "type": "application/geo+json",
            "title": "Source metadata"
         },
         {
            "rel": "self",
            "href": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt/items/
asset_1770900095005",
            "type": "application/geo+json",
            "title": "asset_1770900095005"
         },
         {
            "rel": "collection",
            "href": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt",
            "type": "application/json",
            "title": "test_dq4ipt"
         }
      ],
      "collection": "test_dq4ipt",
      "id": "asset_1770900095005",
      "type": "Feature",
      "stac_extensions": [
         "https://stac-extensions.github.io/file/v2.1.0/schema.json",
         "https://stac-extensions.github.io/alternate-assets/v1.1.0/schema.json",
         "https://stac-extensions.github.io/processing/v1.2.0/schema.json",
         "https://luciocola.github.io/stac-extension-liability-claims/json-schema/
schema.json"
      ],
      "properties": {
         "processing:level": "L1",
         "datetime": "2026-02-12T12:41:35Z",
         "start_datetime": "2016-02-04T07:28:52Z",
         "end_datetime": "2016-02-04T07:28:52Z",
         "processing:facility": "Secure Dimensions Processes",
         "processing:lineage": "Watermarking Process",
```

```
      "processing:datetime": "2026-02-12T12:41:35Z",
      "liability:quality": {
         "scope": {
            "level": "series"
         },
         "report": [
            {
               "result": [
                  {
                     "pass": true,
                     "specification": {
                        "date": "2021-10-14T00:00:00Z",
                        "identifier": "https://ceos.org/spec/ard/conf",
                        "title": "CEOS ARD Normalised Radar Backscatter (CARD4L-
NRB)"
                     },
                     "type": "ConformanceResult",
                     "resultType": "conformance"
                  }
               ],
               "measure": {
                  "measureIdentification": {
                     "code": "101",
                     "authority": {
                        "alternateTitle": [
                           "ISO"
                        ],
                        "title": "International Organization for Standardization"
                     },
                     "codeSpace": "https://standards.isotc211.org/19157/-3/1/dqc/
content/qualityMeasure/"
                  },
                  "measureDescription": "The measure will take the value true if
all the requirements in the referred data product specification are fulfilled.",
                  "nameOfMeasure": [
                     "Data product specification passed"
                  ]
               },
               "completeness": {
                  "category": "completeness"
               },
               "type": "ConceptualConsistency",
               "category": "completeness"
            }
         ]
      },
      "processing:software": {
         "name": "Geoserver",
         "version": "3.0-SNAPSHOT"
      },
      "ipt": {
         "output": {
            "image_height": 1026,
            "file:checksum": "1e20cbe790d1f9193bb7ce70e7197f760c2b9188c19dabe2db8
583abaa99e2b58c96",
            "metadata_url": "https://ic.ogc.secd.eu/stac/collections/test_dq4ipt/
items/asset_1770900095005",
            "image_url": "https://assets.ogc.secd.eu/files/683f5aa56037d688241e54
cc004bc14fe3067d1c1f51c67133571efc29c6e3da",
            "image_width": 1026,
            "image_type": "image/jpeg"
         },
         "input": {
```

```
            "image": {
               "image_height": 1026,
               "file:checksum": "1220ecff1a367594707fe3603f73fdd6091b039b8e0b98c4
8d92643f84bc229cc471",
               "image_url": "https://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
browse/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.
PNG",
               "image_width": 1026,
               "image_type": "image/png;charset=UTF-8"
            },
            "metadata": {
               "metadata_url": "https://emc.spacebel.be/collections/PROBA.HRC.1A/
items/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=
application/geo%2Bjson;profile=https://stacspec.org",
               "vc_url": "https://emc.spacebel.be/collections/PROBA.HRC.1A/items/
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001?httpAccept=application/
vc%2Bld%2Bjson",
               "VC_verification": true,
               "VC": {
                  "relatedResource": [
                     {
                        "digestMultibase": "zQmYRMC8UMw4ipWvivUKvzvTWrjbKk1oywH1Q
poY6w3tCQX",
                        "id": "https://schemas.opengis.net/eo-geojson/1.0/eo-
geojson.jsonld"
                     },
                     {
                        "digestMultibase": "zQmeHnYH1jaUefpeAbARzC46rJSzSte8uWn52
GGcQWXMcmn",
                        "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
browse/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.PNG"
                     },
                     {
                        "digestMultibase": "zQmPFZfx6KoEAgPpFosgJEKQ17K7sJpsSZWty
No7vwBHXyr",
                        "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
thumbnail/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_TIMG.
jpg"
                     }
                  ],
                  "credentialSubject": {
                     "date": "2016-02-04T07:28:52Z/2016-02-04T07:28:52Z",
                     "bbox": [
                        133.87,
                        -23.68,
                        133.9,
                        -23.64
                     ],
                     "links": {
                        "data": [
                           {
                              "href": "https://tpm-ds.eo.esa.int/oads/data/
PROBA1-HRC/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP",
                              "title": "Download",
                              "type": "application/x-binary"
                           }
                        ],
                        "previews": [
                           {
                              "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-
HRC/browse/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_BID.
PNG",
                              "title": "QUICKLOOK",
```

```
                              "type": "image/png"
                           },
                           {
                              "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-
HRC/thumbnail/PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001.SIP.ZIP_
TIMG.jpg",
                              "title": "THUMBNAIL",
                              "type": "image/jpeg"
                           }
                        ]
                     },
                     "geometry": {
                        "coordinates": [
                           [
                              [
                                 133.9,
                                 -23.68
                              ],
                              [
                                 133.9,
                                 -23.64
                              ],
                              [
                                 133.87,
                                 -23.64
                              ],
                              [
                                 133.87,
                                 -23.68
                              ],
                              [
                                 133.9,
                                 -23.68
                              ]
                           ]
                        ],
                        "type": "Polygon"
                     },
                     "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:
items:PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001",
                     "title": "PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-
088_0001",
                     "updated": "2024-04-30T11:28:07Z"
                  },
                  "issuanceDate": "2026-02-12T12:41:33Z",
                  "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:
PR1_OPER_HRC_HRC_1P_20160204T072852_S23-066_E133-088_0001",
                  "proof": {
                     "created": "2026-02-12T12:41:33.485Z",
                     "jws": "eyJhbGciOiJFUzI1NksiLCJraWQiOiJiQnpXOHlHeEt1RUNMal9J
eFNyTkN1eVJKOUppZ2ptTU9DeDJGZHpDcnFBIiwiY3JpdCI6WyJiNjQiXSwiYjY0IjpmYWxzZX0..CYU_
nbMuB08KuOMfv_oAgLmpgDFs8iC5aoXDQ0jqEHFuPjgpzR-dvafyfezz2y3nUEKg1DVQWY0noAt5n-
8KzA",
                     "proofPurpose": "assertionMethod",
                     "type": "EcdsaSecp256k1Signature2019",
                     "verificationMethod": "did:web:emc.spacebel.be:
organisations:esa_esrin#owner"
                  },
                  "type": [
                     "VerifiableCredential",
                     "Feature"
                  ],
                  "@context": [
```

```
                    "https://www.w3.org/2018/credentials/v1",
                    "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.
jsonld",
                    {
                       "digestMultibase": {
                          "@type": "https://w3id.org/security#multibase",
                          "@id": "https://w3id.org/security#digestMultibase"
                       },
                       "relatedResource": {
                          "@type": "@id",
                          "@id": "https://www.w3.org/2018/
credentials#relatedResource"
                       }
                    }
                 ],
                 "issuer": "did:web:emc.spacebel.be:organisations:esa_esrin"
              }
           },
           "image_hash_verified": true
        }
     }
  }
}
```


Listing E.63

E.5.4. 4.4 Access the Immutable Catalogue with the result

https://ic.ogc.secd.eu/stac/collections/test_dq4ipt/items/asset_1764089807154

The Processing server stores the results of the processing in the Immutable Catalogue. The `collection` and `id` can be found in the Execute response.

```
data['id']
```

Listing E.64


```
'asset_1770900095005'
```


Figure E.14

```
data['collection']
```

Listing E.65


```
'test_dq4ipt'
```


Figure E.15

```
item_url = URL_IMMUTABLE_CAT_LANDING_PAGE + '/collections/' + data['collection']
+ '/items/' + data['id']
item_url
```

Listing E.66


```
'https://ic.ogc.secd.eu/stac//collections/test_dq4ipt/items/
asset_1770900095005'
```


Figure E.16

```
# Retrieve metadata of Processing result from Immutable Catalogue

response = requests.get(item_url, headers={ 'Accept': 'application/geo+json' })

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.67

```
{
   "code": 404,
   "description": "missing"
}
```

Listing E.68

E.6. NASA Examples

E.6.1. 5.1 NASA CMR Collection

Note that the metadata shown contains (fixed) quality information that was added for the purpose of examples and do not originate from the original metadata. Additional work is needed to extract this from the NASA catalogue endpoint.

Example: 5.1
> Access a NASA CMR collection.

```
# response = requests.get(URL_LANDING_PAGE + 'collections/C2734289572-ORNL_CLOUD?
parentIdentifier=EOP%3ANASA%3ACMR')

# C3246892554-LPCLOUD (Landsat)
# C2734289572-ORNL_CLOUD (Gedi)
response = requests.get(URL_LANDING_PAGE + 'collections/C3246892554-LPCLOUD?
parentIdentifier=EOP:NASA:CMR', \
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.69

```
{
   "geometry": {
      "coordinates": [
         [
            [
               -180,
               -90
            ],
            [
               180,
               -90
```

```
            ],
            [
               180,
               90
            ],
            [
               -180,
               90
            ],
            [
               -180,
               -90
            ]
         ]
      ],
      "type": "Polygon"
   },
   "conformsTo": [
      "https://standards.iso.org/iso/19115/-4/0.1/core",
      "https://standards.iso.org/iso/19115/-4/0.1/data-quality-core",
      "https://standards.iso.org/iso/19115/-4/0.1/no-ref"
   ],
   "id": "C3246892554-LPCLOUD",
   "type": "Feature",
   "properties": {
      "defaultLocale": {
         "language": "eng",
         "characterEncoding": "utf8"
      },
      "identificationInfo": {
         "defaultLocale": {
            "language": "eng",
            "characterEncoding": "utf8"
         },
         "parentMetadata": {
            "identifier": [
               {
                  "code": ""
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": ""
         },
         "citation": {
            "identifier": [
               {
                  "code": "C3246892554-LPCLOUD"
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:C3246892554-
LPCLOUD",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "HLS Operational Land Imager Vegetation Indices Daily
Global 30 m V2.0"
         },
         "abstract": "C3246892554-LPCLOUD"
      },
      "metadataStandard": [
```

```
            {
               "title": "ISO 19115-1:2014"
            },
            {
               "title": "ISO 19115-4"
            }
         ],
         "contact": [
            {
               "role": "pointOfContact",
               "party": [
                  {
                     "contactInfo": [
                        {
                           "address": [
                              {
                                 "deliveryPoint": [
                                    "Largo Galileo Galilei 1"
                                 ],
                                 "country": "Italy",
                                 "city": "Frascati (Roma)",
                                 "postalCode": "00044",
                                 "electronicMailAddress": [
                                    "eohelp@esa.int"
                                 ]
                              }
                           ],
                           "phone": {
                              "voice": "tel:+3906941801"
                           }
                        }
                     ],
                     "name": "ESA/ESRIN",
                     "type": "CI_Organisation"
                  }
               ]
            }
         ],
         "dataQualityInfo": [
            {
               "scope": {
                  "level": "dataset"
               },
               "report": [
                  {
                     "result": [
                        {
                           "type": "QuantitativeResult",
                           "value": [
                              "true"
                           ]
                        }
                     ],
                     "measure": {
                        "measureIdentification": {
                           "code": "101",
                           "authority": {
                              "alternateTitle": [
                                 "ISO"
                              ],
                              "title": "International Organization for
Standardization"
                           },
```

```
                        "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                     },
                     "measureDescription": "The measure will take the value true
if all the requirements in the referred data product specification are fulfilled.
",
                     "nameOfMeasure": [
                        "MD101"
                     ]
                  },
                  "type": "ConceptualConsistency"
               },
               {
                  "result": [
                     {
                        "valueUnit": "%",
                        "type": "QuantitativeResult",
                        "value": [
                           0
                        ]
                     }
                  ],
                  "measure": {
                     "measureIdentification": {
                        "code": "211",
                        "authority": {
                           "alternateTitle": [
                              "ISO"
                           ],
                           "title": "International Organization for
Standardization"
                        },
                        "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                     },
                     "measureDescription": "Quality degradation - rate of
imperfect coverage.",
                     "nameOfMeasure": [
                        "MD211"
                     ]
                  },
                  "evaluationMethod": [
                     {
                        "type": "FullInspection",
                        "evaluationMethodDescription": "Automatic quality
degradation check."
                     }
                  ],
                  "type": "Omission"
               }
            ]
         }
      ],
      "dateInfo": {
         "revision": "2025-02-18T00:00:00.000Z"
      },
      "distributionInfo": [
         {
            "distributor": [],
            "transferOptions": [
               {
                  "onLine": [
                     {
```

```
                        "function": "download",
                        "name": "data",
                        "description": "Download",
                        "linkage": "https://search.earthdata.nasa.gov/search/
granules?p=C3246892554-LPCLOUD"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download",
                        "linkage": "https://appeears.earthdatacloud.nasa.gov/"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "icon",
                        "description": "QUICKLOOK",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-public/HLSL30_VI.020/HLS-VI.L30.T10TFR.2025042T185002.v2.0/HLS-VI.L30.
T10TFR.2025042T185002.v2.0.jpg"
                     }
                  ]
               }
            ]
         }
      ],
      "metadataScope": [
         {
            "resourceScope": "dataset",
            "name": "dataset"
         }
      ]
   }
}
```

Listing E.70

E.6.2. 5.2 NASA CMR Product

Example: 5.3
> Access a NASA CMR Product (STAC).

```
# https://radiantearth.github.io/stac-browser/#/external/emc.spacebel.be/
# collections/EOP:NASA:CMR:GEDI_L4A_AGB_Density_GW_2028/items/G2734290436-ORNL_
CLOUD?httpAccept=application%2Fgeo%2Bjson%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org

# GEDI
# response = requests.get(URL_LANDING_PAGE + 'collections/EOP:NASA:CMR:GEDI_L4A_
AGB_Density_GW_2028/items/G2734290436-ORNL_CLOUD?httpAccept=application%2Fgeo%2Bj
son%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org')

# https://radiantearth.github.io/stac-browser/#/external/emc.spacebel.be/
collections/EOP:NASA:CMR:HLSL30_VI/items/G3680032246-LPCLOUD?httpAccept=applicati
on%2Fgeo%2Bjson%3Bprofile%3Dhttps%3A%2F%2Fstacspec.org

# Landsat
response = requests.get(URL_LANDING_PAGE + 'collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application%2Fgeo%2Bjson%3Bprofile%3Dhttps%3
A%2F%2Fstacspec.org')
```

```
data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.71


```
{
   "stac_version": "1.0.0",
   "assets": {
      "enclosure_10": {
         "roles": [
            "data"
         ],
         "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.TVI.tif",
         "type": "image/tiff",
         "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.TVI.tif"
      },
      "thumbnail": {
         "roles": [
            "thumbnail"
         ],
         "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
public/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.jpg",
         "type": "image/jpeg",
         "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.jpg"
      },
      "metadata_iso_19139": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vnd.iso.19139%2Bxml",
         "title": "ISO 19139 metadata",
         "type": "application/vnd.iso.19139+xml"
      },
      "enclosure_3": {
         "roles": [
            "data"
         ],
         "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.MSAVI.tif",
         "type": "image/tiff",
         "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.MSAVI.tif"
      },
      "enclosure_4": {
         "roles": [
            "data"
         ],
         "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NBR.tif",
         "type": "image/tiff",
         "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.NBR.tif"
      },
      "enclosure_1": {
         "roles": [
            "data"
         ],
```

```
         "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/
HLSL30.020/HLS.L30.T59WNT.2013101T001445.v2.0/HLS.L30.T59WNT.2013101T001445.v2.0.
Fmask.tif",
         "type": "image/tiff",
         "title": "Download Fmask quality layer HLS.L30.T59WNT.2013101T001445.
v2.0.Fmask.tif"
      },
      "enclosure_2": {
         "roles": [
            "data"
         ],
         "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.EVI.tif",
         "type": "image/tiff",
         "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.EVI.tif"
      },
      "metadata_ogc_10_157r3": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/gml%2Bxml&recordSchema=om10",
         "title": "OGC 10-157r3 metadata",
         "type": "application/gml+xml;profile=\"http://www.opengis.net/spec/
EOMPOM/1.0\""
      },
      "metadata_ogc_10_157r4": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/gml%2Bxml&recordSchema=om",
         "title": "OGC 10-157r4 metadata",
         "type": "application/gml+xml;profile=\"http://www.opengis.net/spec/
EOMPOM/1.1\""
      },
      "metadata_ogc_17_069r3": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD",
         "type": "application/geo+json;profile=\"http://www.opengis.net/spec/
ogcapi-features-1/1.0\"",
         "title": "OGC 17-069r3 metadata"
      },
      "metadata_iso_19115_4": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vnd.iso.19115-4%2Bjson",
         "title": "ISO19115-4",
         "type": "application/vnd.iso.19115-4+json"
      },
      "metadata_ogc_17_003r2": {
         "roles": [
            "metadata"
         ],
         "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?mode=owc",
         "title": "OGC 17-003r2 metadata",
```

```
            "type": "application/geo+json;profile=\"http://www.opengis.net/spec/eo-
geojson/1.0\""
         },
         "enclosure_9": {
            "roles": [
               "data"
            ],
            "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.SAVI.tif",
            "type": "image/tiff",
            "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.SAVI.tif"
         },
         "metadata_iso_19115_3": {
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vnd.iso.19115-3%2Bxml",
            "title": "ISO 19115-3 metadata",
            "type": "application/vnd.iso.19115-3+xml"
         },
         "metadata_iso_19157_2": {
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vnd.iso.19157-2%2Bxml",
            "title": "ISO 19157-2 metadata",
            "type": "application/vnd.iso.19157-2+xml"
         },
         "enclosure_7": {
            "roles": [
               "data"
            ],
            "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDVI.tif",
            "type": "image/tiff",
            "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.NDVI.tif"
         },
         "enclosure_8": {
            "roles": [
               "data"
            ],
            "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDWI.tif",
            "type": "image/tiff",
            "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.NDWI.tif"
         },
         "metadata_html": {
            "roles": [
               "metadata"
            ],
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=text/html",
            "title": "HTML",
            "type": "text/html"
         },
         "enclosure_5": {
            "roles": [
               "data"
```

```
            ],
            "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NBR2.tif",
            "type": "image/tiff",
            "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.NBR2.tif"
         },
         "enclosure_6": {
            "roles": [
               "data"
            ],
            "href": "https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-
protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDMI.tif",
            "type": "image/tiff",
            "title": "Download HLS-VI.L30.T59WNT.2013101T001445.v2.0.NDMI.tif"
         }
      },
      "bbox": [
         170.9994682,
         69.2990206,
         173.9164473,
         70.3060175
      ],
      "geometry": {
         "coordinates": [
            [
               [
                  173.7835564,
                  69.2990206
               ],
               [
                  173.9164473,
                  70.2824267
               ],
               [
                  170.9994682,
                  70.3060175
               ],
               [
                  170.9994925,
                  69.3213967
               ],
               [
                  173.7835564,
                  69.2990206
               ]
            ]
         ],
         "type": "Polygon"
      },
      "links": [
         {
            "rel": "self",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/geo%2Bjson;profile=https://
stacspec.org",
            "type": "application/geo+json;profile=\"https://stacspec.org\""
         },
         {
            "rel": "icon",
            "href": "s3://lp-prod-public/HLSL30_VI.020/HLS-VI.L30.
T59WNT.2013101T001445.v2.0/HLS-VI.L30.T59WNT.2013101T001445.v2.0.jpg",
```

```
            "type": "image/jpeg",
            "title": "This link provides direct download access via S3 to the
granule"
         },
         {
            "rel": "collection",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI?
parentIdentifier=EOP:NASA:CMR&httpAccept=application/json",
            "type": "application/json",
            "title": "EOP:NASA:CMR:HLSL30_VI"
         },
         {
            "rel": "parent",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI?
parentIdentifier=EOP:NASA:CMR&httpAccept=application/json",
            "type": "application/json",
            "title": "EOP:NASA:CMR:HLSL30_VI"
         },
         {
            "rel": "up",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI?
parentIdentifier=EOP:NASA:CMR&mode=owc",
            "type": "application/geo+json",
            "title": "OGC 17-084r1 metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/atom%2Bxml",
            "type": "application/atom+xml",
            "title": "Atom format"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/ld%2Bjson",
            "type": "application/ld+json",
            "title": "JSON-LD metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/ld%2Bjson;profile=https://
schema.org",
            "type": "application/ld+json;profile=\"https://schema.org\"",
            "title": "JSON-LD (schema.org) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/ld%2Bjson;profile=http://data.
europa.eu/930/",
            "type": "application/ld+json;profile=\"http://data.europa.eu/930/\"",
            "title": "JSON-LD (GeoDCAT-AP) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/rdf%2Bxml",
            "type": "application/rdf+xml",
            "title": "RDF/XML metadata"
         },
         {
```

```
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/rdf%2Bxml;profile=https://
schema.org",
            "type": "application/rdf+xml;profile=\"https://schema.org\"",
            "title": "RDF/XML (schema.org) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/rdf%2Bxml;profile=http://data.
europa.eu/930/",
            "type": "application/rdf+xml;profile=\"http://data.europa.eu/930/\"",
            "title": "RDF/XML (GeoDCAT-AP) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=text/turtle",
            "type": "text/turtle",
            "title": "Turtle metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=text/turtle;profile=https://schema.org",
            "type": "text/turtle;profile=\"https://schema.org\"",
            "title": "Turtle (schema.org) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=text/turtle;profile=http://data.europa.eu/
930/",
            "type": "text/turtle;profile=\"http://data.europa.eu/930/\"",
            "title": "Turtle (GeoDCAT-AP) metadata"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vc%2Bld%2Bjson",
            "type": "application/vc+ld+json",
            "title": "Verifiable Credential"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vp%2Bld%2Bjson",
            "type": "application/vp+ld+json",
            "title": "Verifiable Presentation"
         },
         {
            "rel": "alternate",
            "href": "https://emc.spacebel.be/collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD?httpAccept=application/vc%2Bld%2Bjson;version=2.0",
            "type": "application/vc+ld+json;version=2.0",
            "title": "Verifiable Credential 2.0"
         }
      ],
      "id": "G3680032246-LPCLOUD",
      "collection": "EOP:NASA:CMR:HLSL30_VI",
      "type": "Feature",
      "stac_extensions": [
```

```
      "https://stac-extensions.github.io/projection/v2.0.0/schema.json",
      "https://stac-extensions.github.io/external-ids/v1.0.0/schema.json"
   ],
   "properties": {
      "proj:epsg": 4326,
      "externalIds": [
         {
            "scheme": "https://www.w3.org/ns/did/v1",
            "value": "did:web:emc.spacebel.be:collections:EOP%3ANASA%3ACMR
%3AHLSL30_VI:items:G3680032246-LPCLOUD"
         }
      ],
      "title": "G3680032246-LPCLOUD",
      "updated": "2026-02-12T12:41:40Z"
   }
}
```


Listing E.72

Example: 5.4

> Access a NASA CMR Product (ISO19115-4).

```
# GEDI
# response = requests.get( URL_LANDING_PAGE + 'collections/EOP:NASA:CMR:GEDI_L4A_
AGB_Density_GW_2028/items/G2734290436-ORNL_CLOUD', \
#  headers={'Accept': 'application/vnd.iso.19115-4+json'})

# Landsat
response = requests.get( URL_LANDING_PAGE + 'collections/EOP:NASA:CMR:HLSL30_VI/
items/G3680032246-LPCLOUD', \
    headers={'Accept': 'application/vnd.iso.19115-4+json'})

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.73


```
{
   "bbox": [
      170.9994682,
      69.2990206,
      173.9164473,
      70.3060175
   ],
   "geometry": {
      "coordinates": [
         [
            [
               173.7835564,
               69.2990206
            ],
            [
               173.9164473,
               70.2824267
            ],
            [
               170.9994682,
               70.3060175
            ],
            [
               170.9994925,
               69.3213967
```

```
            ],
            [
               173.7835564,
               69.2990206
            ]
         ]
      ],
      "type": "Polygon"
   },
   "conformsTo": [
      "https://standards.iso.org/iso/19115/-4/0.1/core",
      "https://standards.iso.org/iso/19115/-4/0.1/data-quality-core",
      "https://standards.iso.org/iso/19115/-4/0.1/no-ref"
   ],
   "id": "G3680032246-LPCLOUD",
   "type": "Feature",
   "properties": {
      "defaultLocale": {
         "language": "eng",
         "characterEncoding": "utf8"
      },
      "identificationInfo": {
         "defaultLocale": {
            "language": "eng",
            "characterEncoding": "utf8"
         },
         "extent": [
            {
               "geographicElement": [
                  {
                     "northBoundLatitude": 70.3060175,
                     "southBoundLatitude": 69.2990206,
                     "type": "EX_GeographicBoundingBox",
                     "westBoundLongitude": 170.9994682,
                     "eastBoundLongitude": 173.9164473
                  }
               ]
            }
         ],
         "parentMetadata": {
            "identifier": [
               {
                  "code": "EOP:NASA:CMR:HLSL30_VI"
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:EOP%3ANASA%3ACMR
%3AHLSL30_VI",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
            "title": "EOP:NASA:CMR:HLSL30_VI"
         },
         "citation": {
            "identifier": [
               {
                  "code": "G3680032246-LPCLOUD"
               },
               {
                  "code": "did:web:emc.spacebel.be:collections:EOP%3ANASA%3ACMR
%3AHLSL30_VI:items:G3680032246-LPCLOUD",
                  "codeSpace": "https://www.w3.org/ns/did/v1"
               }
            ],
```

```
            "title": "G3680032246-LPCLOUD"
         },
         "abstract": "G3680032246-LPCLOUD"
      },
      "metadataStandard": [
         {
            "title": "ISO 19115-1:2014"
         },
         {
            "title": "ISO 19115-4"
         }
      ],
      "contact": [],
      "dataQualityInfo": [
         {
            "scope": {
               "level": "dataset"
            },
            "report": [
               {
                  "result": [
                     {
                        "type": "QuantitativeResult",
                        "value": [
                           "true"
                        ]
                     }
                  ],
                  "measure": {
                     "measureIdentification": {
                        "code": "101",
                        "authority": {
                           "alternateTitle": [
                              "ISO"
                           ],
                           "title": "International Organization for
Standardization"
                        },
                        "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                     },
                     "measureDescription": "The measure will take the value true
if all the requirements in the referred data product specification are fulfilled.
",
                     "nameOfMeasure": [
                        "MD101"
                     ]
                  },
                  "type": "ConceptualConsistency"
               },
               {
                  "result": [
                     {
                        "valueUnit": "%",
                        "type": "QuantitativeResult",
                        "value": [
                           0
                        ]
                     }
                  ],
                  "measure": {
                     "measureIdentification": {
                        "code": "211",
```

```
                        "authority": {
                           "alternateTitle": [
                              "ISO"
                           ],
                           "title": "International Organization for
Standardization"
                        },
                        "codeSpace": "https://standards.isotc211.org/19157/-3/1/
dqc/content/qualityMeasure/"
                     },
                     "measureDescription": "Quality degradation - rate of
imperfect coverage.",
                     "nameOfMeasure": [
                        "MD211"
                     ]
                  },
                  "evaluationMethod": [
                     {
                        "type": "FullInspection",
                        "evaluationMethodDescription": "Automatic quality
degradation check."
                     }
                  ],
                  "type": "Omission"
               }
            ]
         }
      ],
      "resourceLineage": [
         {
            "processStep": [
               {
                  "output": [
                     {
                        "source": [
                           {
                              "sourceCitation": {
                                 "code": "did:web:emc.spacebel.be:collections:EOP
%3ANASA%3ACMR%3AHLSL30_VI:items:G3680032246-LPCLOUD",
                                 "title": "G3680032246-LPCLOUD"
                              }
                           }
                        ]
                     }
                  ],
                  "processingInformation": {}
               }
            ]
         }
      ],
      "dateInfo": {
         "revision": "2026-02-12T12:41:42Z"
      },
      "distributionInfo": [
         {
            "distributor": [],
            "transferOptions": [
               {
                  "onLine": [
                     {
                        "function": "download",
                        "name": "data",
```

```
                        "description": "Download Fmask quality layer HLS.L30.
T59WNT.2013101T001445.v2.0.Fmask.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.
gov/lp-prod-protected/HLSL30.020/HLS.L30.T59WNT.2013101T001445.v2.0/HLS.L30.
T59WNT.2013101T001445.v2.0.Fmask.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.EVI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.EVI.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.MSAVI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.MSAVI.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NBR.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NBR.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NBR2.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NBR2.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDMI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDMI.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDVI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDVI.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
```

```
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDWI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.NDWI.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.SAVI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.SAVI.tif"
                     },
                     {
                        "function": "download",
                        "name": "data",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.TVI.tif",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-protected/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.TVI.tif"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "icon",
                        "description": "Download HLS-VI.L30.
T59WNT.2013101T001445.v2.0.jpg",
                        "linkage": "https://data.lpdaac.earthdatacloud.nasa.gov/
lp-prod-public/HLSL30_VI.020/HLS-VI.L30.T59WNT.2013101T001445.v2.0/HLS-VI.L30.
T59WNT.2013101T001445.v2.0.jpg"
                     },
                     {
                        "function": "browseGraphic",
                        "name": "icon",
                        "description": "This link provides direct download
access via S3 to the granule",
                        "linkage": "s3://lp-prod-public/HLSL30_VI.020/HLS-VI.L30.
T59WNT.2013101T001445.v2.0/HLS-VI.L30.T59WNT.2013101T001445.v2.0.jpg"
                     }
                  ]
               }
            ]
         }
      ],
      "metadataScope": [
         {
            "resourceScope": "dataset",
            "name": "dataset"
         }
      ]
   }
}
```


Listing E.74

E.7. Registry Interface

E.7.1. 6.1 Get VCs for a subject supporting 1 VC version.

```
URL_REGISTRY = URL_LANDING_PAGE + 'registry/'

subject_did = 'did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_
HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001'

response = requests.get(URL_REGISTRY + 'vcs/' + subject_did)

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.75


```
[
   {
      "relatedResource": [
         {
            "digestMultibase": "zQmYRMC8UMw4ipWvivUKvzvTWrjbKk1oywH1QpoY6w3tCQX",
            "id": "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld"
         },
         {
            "digestMultibase": "zQmXuxqvw6ZdkXvG7Tb6WQP2kkNuHrtkCZR7LtsAqBmum8i",
            "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/PR1_OPER_
HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001.SIP.ZIP_BID.PNG"
         },
         {
            "digestMultibase": "zQmTKNSFeikcQ1Kp75vfCRNiPkWjjEYmjws8X8Zv1qRAcw1",
            "id": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/thumbnail/PR1_
OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001.SIP.ZIP_TIMG.jpg"
         }
      ],
      "credentialSubject": {
         "date": "2016-02-04T06:09:57Z/2016-02-04T06:09:57Z",
         "bbox": [
            140.98,
            37.37,
            141.05,
            37.41
         ],
         "links": {
            "data": [
               {
                  "href": "https://tpm-ds.eo.esa.int/oads/data/PROBA1-HRC/PR1_
OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001.SIP.ZIP",
                  "title": "Download",
                  "type": "application/x-binary"
               }
            ],
            "previews": [
               {
                  "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/browse/
PR1_OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001.SIP.ZIP_BID.PNG",
                  "title": "QUICKLOOK",
```

```
                  "type": "image/png"
               },
               {
                  "href": "http://tpm-ds.eo.esa.int/oads/meta/PROBA1-HRC/
thumbnail/PR1_OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001.SIP.ZIP_TIMG.
jpg",
                  "title": "THUMBNAIL",
                  "type": "image/jpeg"
               }
            ]
         },
         "geometry": {
            "coordinates": [
               [
                  [
                     141.05,
                     37.37
                  ],
                  [
                     141.05,
                     37.41
                  ],
                  [
                     140.98,
                     37.41
                  ],
                  [
                     140.98,
                     37.37
                  ],
                  [
                     141.05,
                     37.37
                  ]
               ]
            ],
            "type": "Polygon"
         },
         "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_
HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001",
         "title": "PR1_OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001",
         "updated": "2024-04-30T11:28:07Z"
      },
      "issuanceDate": "2026-02-12T12:41:43Z",
      "id": "did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_
HRC_1P_20160204T060957_N37-039_E141-001_0001",
      "proof": {
         "created": "2026-02-12T12:41:43.190Z",
         "jws": "eyJhbGciOiJFUzI1NksiLCJraWQiOiJiQnpXOHlHeEt1RUNMal9JeFNyTkN1eVJK
OUppZ2ptTU9DeDJGZHpDcnFBIiwiY3JpdCI6WyJiNjQiXSwiYjY0IjpmYWxzZX0..9VVDezJvc3o65Vv_
8jnMXGPlkhDjJQmbns1cllC5vLYQhHxS4f7GXq8w-LdyHOaeHqWMOTH5L6QgxTpa-SygtA",
         "proofPurpose": "assertionMethod",
         "type": "EcdsaSecp256k1Signature2019",
         "verificationMethod": "did:web:emc.spacebel.be:organisations:esa_
esrin#owner"
      },
      "type": [
         "VerifiableCredential",
         "Feature"
      ],
      "@context": [
         "https://www.w3.org/2018/credentials/v1",
         "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld",
```

```
            {
               "digestMultibase": {
                  "@type": "https://w3id.org/security#multibase",
                  "@id": "https://w3id.org/security#digestMultibase"
               },
               "relatedResource": {
                  "@type": "@id",
                  "@id": "https://www.w3.org/2018/credentials#relatedResource"
               }
            }
         ],
         "issuer": "did:web:emc.spacebel.be:organisations:esa_esrin"
      }
]
```


Listing E.76

E.7.2. 6.2 Get VCs for a subject supporting 2 VC versions.

```
subject_did = 'did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:
items:A2GL10301010301310_PNW000B000M0002100000'

response = requests.get(URL_REGISTRY + 'vcs/' + subject_did)

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.77


```
[
   {
      "credentialSubject": {
         "date": "2003-01-25T00:42:22.14Z/2003-01-25T14:09:02.61Z",
         "hasGeometry": {
            "asWKT": "POLYGON((-179.999 90.0,-179.999 -90.0,180.0 -90.0,180.0
90.0,-179.999 90.0))"
         },
         "bbox": [
            -179.999,
            -90,
            180,
            90
         ],
         "links": {
            "data": [
               {
                  "href": "https://gportal.jaxa.jp/download/standard/
ADEOS-2/ADEOS-2.GLI-1km/L3B.NW000/210/2003/01/A2GL10301010301310_
PNW000B000M0002100000.01",
                  "title": "Download",
                  "type": "application/x-binary"
               }
            ]
         },
         "id": "did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:
items:A2GL10301010301310_PNW000B000M0002100000",
         "title": "A2GL10301010301310_PNW000B000M0002100000",
         "updated": "2005-06-05T02:25:07.00Z"
      },
      "issuanceDate": "2026-02-12T12:41:45Z",
```

```
      "id": "did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:
items:A2GL10301010301310_PNW000B000M0002100000",
      "proof": {
         "created": "2026-02-12T12:41:46.103Z",
         "jws": "eyJhbGciOiJFZERTQSIsImNyaXQiOlsiYjY0Il0sImI2NCI6ZmFsc2V9.
.E3XJCsONV3W9okldMTvviPPf_W8mF3pvCXqPR8CxBNivDAUy47uj-gIkg3RbW3GADYw3KdEOjBCH2i83
XSSxCw",
         "proofPurpose": "assertionMethod",
         "type": "Ed25519Signature2018",
         "verificationMethod": "did:web:emc.spacebel.be:organisations:jp_jaxa_
saoc#owner"
      },
      "type": [
         "VerifiableCredential",
         "Feature"
      ],
      "@context": [
         "https://www.w3.org/2018/credentials/v1",
         "https://schemas.opengis.net/eo-geojson/1.0/eo-geojson.jsonld",
         {
            "digestMultibase": {
               "@type": "https://w3id.org/security#multibase",
               "@id": "https://w3id.org/security#digestMultibase"
            },
            "relatedResource": {
               "@type": "@id",
               "@id": "https://www.w3.org/2018/credentials#relatedResource"
            }
         }
      ],
      "issuer": "did:web:emc.spacebel.be:organisations:jp_jaxa_saoc"
   },
   {
      "credentialSubject": {
         "hasGeometry": {
            "asWKT": "POLYGON((-179.999 90.0,-179.999 -90.0,180.0 -90.0,180.0
90.0,-179.999 90.0))"
         },
         "date": "2003-01-25T00:42:22.14Z/2003-01-25T14:09:02.61Z",
         "bbox": [
            -179.999,
            -90,
            180,
            90
         ],
         "links": {
            "data": [
               {
                  "href": "https://gportal.jaxa.jp/download/standard/
ADEOS-2/ADEOS-2.GLI-1km/L3B.NW000/210/2003/01/A2GL10301010301310_
PNW000B000M0002100000.01",
                  "type": "application/x-binary",
                  "title": "Download"
               }
            ]
         },
         "id": "did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:
items:A2GL10301010301310_PNW000B000M0002100000",
         "title": "A2GL10301010301310_PNW000B000M0002100000",
         "updated": "2005-06-05T02:25:07.00Z"
      },
      "id": "did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:
items:A2GL10301010301310_PNW000B000M0002100000",
```

```
      "validFrom": "2026-02-12T12:41:47Z",
      "proof": {
         "proofValue": "z5cbr79ZL7t83RgX3W55EXrd3YFtmh3rZdtmKMwNDGFrGLfwCPqqAfrS9
j74GQwr37aHgatXU4e41d4gLmL59UjvX",
         "created": "2026-02-12T12:41:47.872105",
         "proofPurpose": "assertionMethod",
         "type": "Ed25519Signature2020",
         "verificationMethod": "did:web:emc.spacebel.be:organisations:jp_jaxa_
saoc#owner"
      },
      "type": [
         "VerifiableCredential",
         "Feature"
      ],
      "@context": [
         "https://www.w3.org/ns/credentials/v2",
         "https://w3id.org/security/suites/ed25519-2020/v1",
         {
            "date": "dct:date",
            "asWKT": "gsp:asWKT",
            "gj": "https://purl.org/geojson/vocab#",
            "data": "iana:enclosure",
            "gsp": "http://www.opengis.net/ont/geosparql#",
            "bbox": {
               "@id": "gj:bbox",
               "@container": "@list"
            },
            "coordinates": "gj:coordinates",
            "icon": "iana:icon",
            "title": "dct:title",
            "Feature": "gj:Feature",
            "hasGeometry": "gsp:hasGeometry",
            "dct": "http://purl.org/dc/terms/",
            "previews": "iana:icon",
            "owc": "http://www.opengis.net/ont/owc/1.0/",
            "iana": "http://www.iana.org/assignments/relation/",
            "geometry": "gj:geometry",
            "links": {
               "@id": "owc:links",
               "@context": {
                  "@vocab": "http://www.iana.org/assignments/relation/",
                  "href": "@id",
                  "type": "http://www.w3.org/2005/Atom/type"
               }
            },
            "href": "@id",
            "id": "@id",
            "atom": "http://www.w3.org/2005/Atom/",
            "Polygon": "gj:Polygon",
            "updated": "dct:modified"
         }
      ],
      "issuer": "did:web:emc.spacebel.be:organisations:jp_jaxa_saoc"
   }
]
```


Listing E.78

E.7.3. 6.3 Get DID document

Example: https://emc.spacebel.be/registry/vcs/did:web:emc.spacebel.be:collections:PROBA.HRC.1A:items:PR1_OPER_HRC_HRC_1P_20160204T060957_N37-039_E141-001_0001

```
did = 'did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:items:
A2GL10301010301310_PNW000B000M0002100000'

response = requests.get(URL_REGISTRY + 'did/' + did)

data = json.loads(response.text)
jstr = json.dumps(data, indent=3)
md("```json\n" + jstr + "\n```\n")
```

Listing E.79


```
{
   "controller": "did:web:emc.spacebel.be:organisations:jp_jaxa_saoc",
   "service": [
      {
         "id": "#vp",
         "serviceEndpoint": "https://emc.spacebel.be/collections/ADEOS-II_
GLI_L3B_NW_1day_9km/items/A2GL10301010301310_PNW000B000M0002100000?httpAccept=
application/vp%2Bld%2Bjson",
         "type": "LinkedVerifiablePresentation"
      },
      {
         "id": "#vc",
         "serviceEndpoint": {
            "registries": [
               "https://emc.spacebel.be/registry/vcs/{credentialSubject.id}"
            ]
         },
         "type": "CredentialRegistry"
      }
   ],
   "id": "did:web:emc.spacebel.be:collections:ADEOS-II_GLI_L3B_NW_1day_9km:items:
A2GL10301010301310_PNW000B000M0002100000",
   "@context": [
      "https://www.w3.org/ns/did/v1",
      "https://w3id.org/security/suites/jws-2020/v1",
      "https://identity.foundation/linked-vp/contexts/v1"
   ],
   "alsoKnownAs": [
      "https://emc.spacebel.be/collections/ADEOS-II_GLI_L3B_NW_1day_9km/items/
A2GL10301010301310_PNW000B000M0002100000",
      "https://emc.spacebel.be/collections/ADEOS-II_GLI_L3B_NW_1day_9km/items/
A2GL10301010301310_PNW000B000M0002100000?httpAccept=application/vnd.iso.19115-
4%2Bjson"
   ]
}
```


Listing E.80