UNITED NATIONS GLOBAL GEODETIC CENTRE OF EXCELLENCE

MODERNISING GEOSPATIAL REFERENCE SYSTEM CAPACITY DEVELOPMENT WORKSHOP

Introduction to data standardisation, tools and registers

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HOW

Day 2, Session 2 [2_2_1]

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Summary

- Geodetic data needs to be Findable, Accessible, Interoperable and Reusable (FAIR) so that is can be applied by emerging user base including location-based services.
- Despite many geospatial and geodetic standards existing, geodetic data is not FAIR.
- Member States are encouraged to update the ISO Geodetic Register with metadata about their datums and transformation parameters as this is the authoritative source for a country's information.

Standards

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Introduction

- Geodetic services (like IGS) provide data for an increasingly diverse community
- In the past, the user community was predominantly those from the geodesy and surveying industry, governments and academia
- More recently there has been widespread uptake across society of accurate and reliable positioning information in new markets

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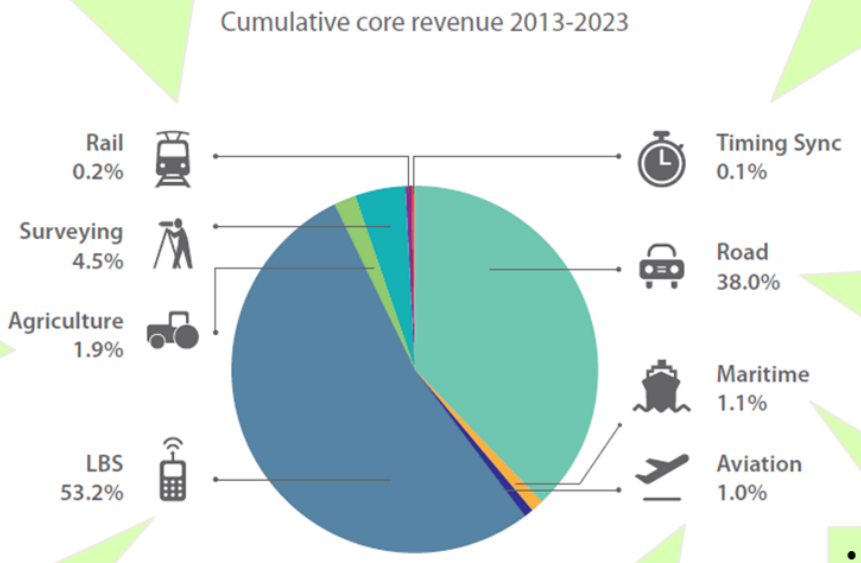
Changing world …

Growing need for real-time data and interoperability

- Automated Train Management Systems
- Accurate Rail Centreline & Curvature Data
- Autonomous Trains (e.g. Mines and Ports)
- Reduced Maintenance Costs

- Time Synchronisation (e.g. Energy, Finance, Telecommunications, Transport Networks)
- Time-Stamping (e.g. Financial Transactions and Network Issues)

- Consistent Spatial Data
- Higher Productivity
- Lower Equipment Costs



- Autonomous Vehicles
- Reduced Fatalities
- Congestion Avoidance
- Reduced Emissions
- Reduced Road damage
- Incident Detection
- Dynamic Navigation
- Situational Awareness

- Increased Yield
- Improved Safety
- Reduced Water Run-off, Soil Compaction, Soil Erosion & Fuel Usage
- Lower Emissions
- Preserved Water Quality

- Accurate Location Awareness
- Emergency Services
- Augmented Reality
- Value-Added Applications

- Safety-of-Life Services
- Integrity Monitoring
- Fuel Efficiency
- Internationally Standardised

- Higher Tonnage
- Public Safety
- Environmental Protection
- Fuel Efficiency
- Internationally Standardised

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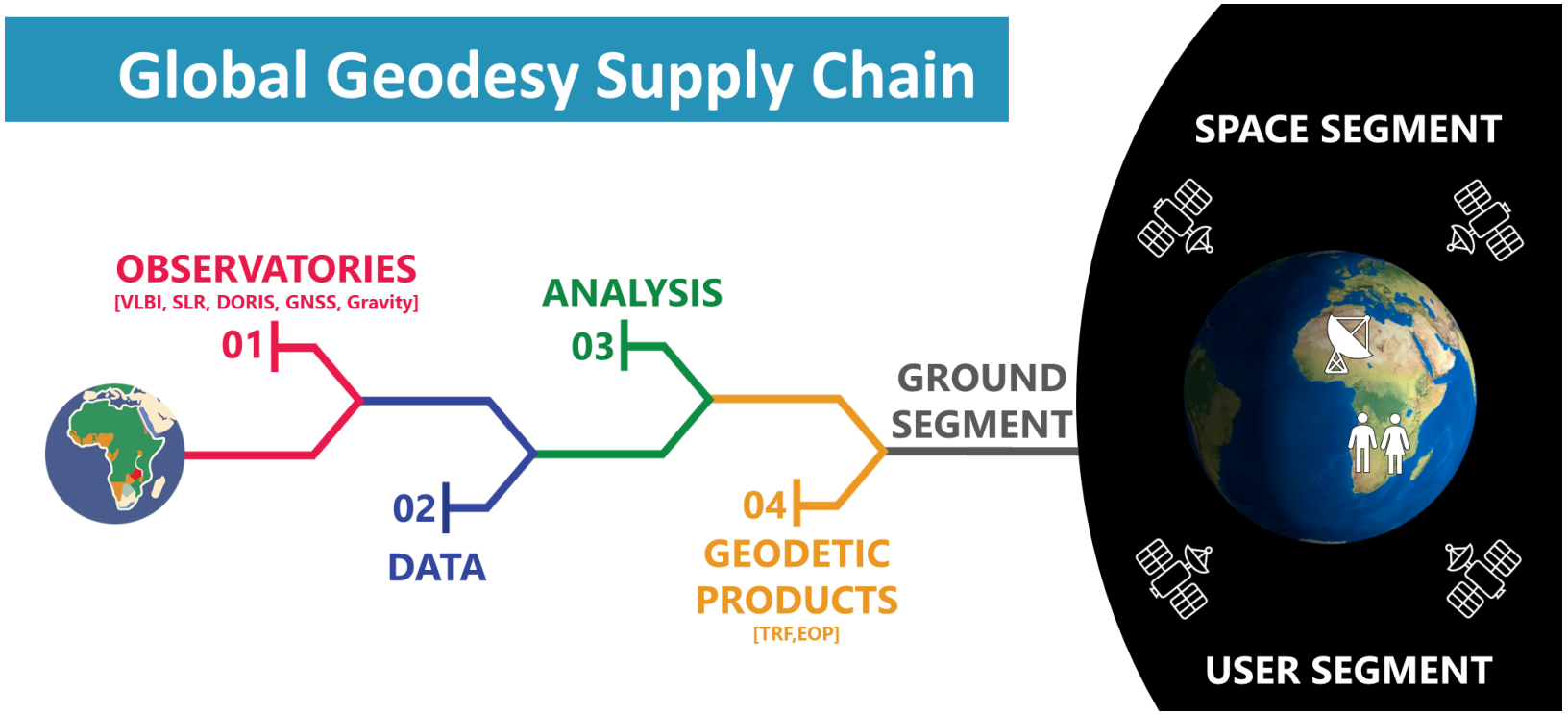
Why do we need standards in geodesy?



- **Consistency** of raw observations from various ground and space-based stations
- **Consistency** of analysed data and geodetic products
- Observations and data **quality assurance**
- **Interoperability** of different geodetic techniques
- **Compatibility** of geodetic data with another geospatial information systems
- **Seamless access** to geodetic products for users

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What do users expect from geodetic data?

- **Users** want to determine whether **data fits their purpose**
- **Users** aren't native geodesists but **have expectations on the quality of geodetic data**, and they learned to use standard geodetic language for that.

Agriculture	Rail	Road	Maritime	Aviation	Location-Based Services	Time & Synchronisation	Surveying
Accuracy Availability Integrity Coverage Reliability	Accuracy Availability Integrity Coverage Reliability Robustness Continuity Authentication	Accuracy Availability Integrity Continuity Reliability Authentication Interoperability	Accuracy Availability Integrity Coverage Reliability Coverage	Accuracy Availability Integrity Continuity	Accuracy Availability Integrity Authentication	Accuracy Authentication	Accuracy Availability

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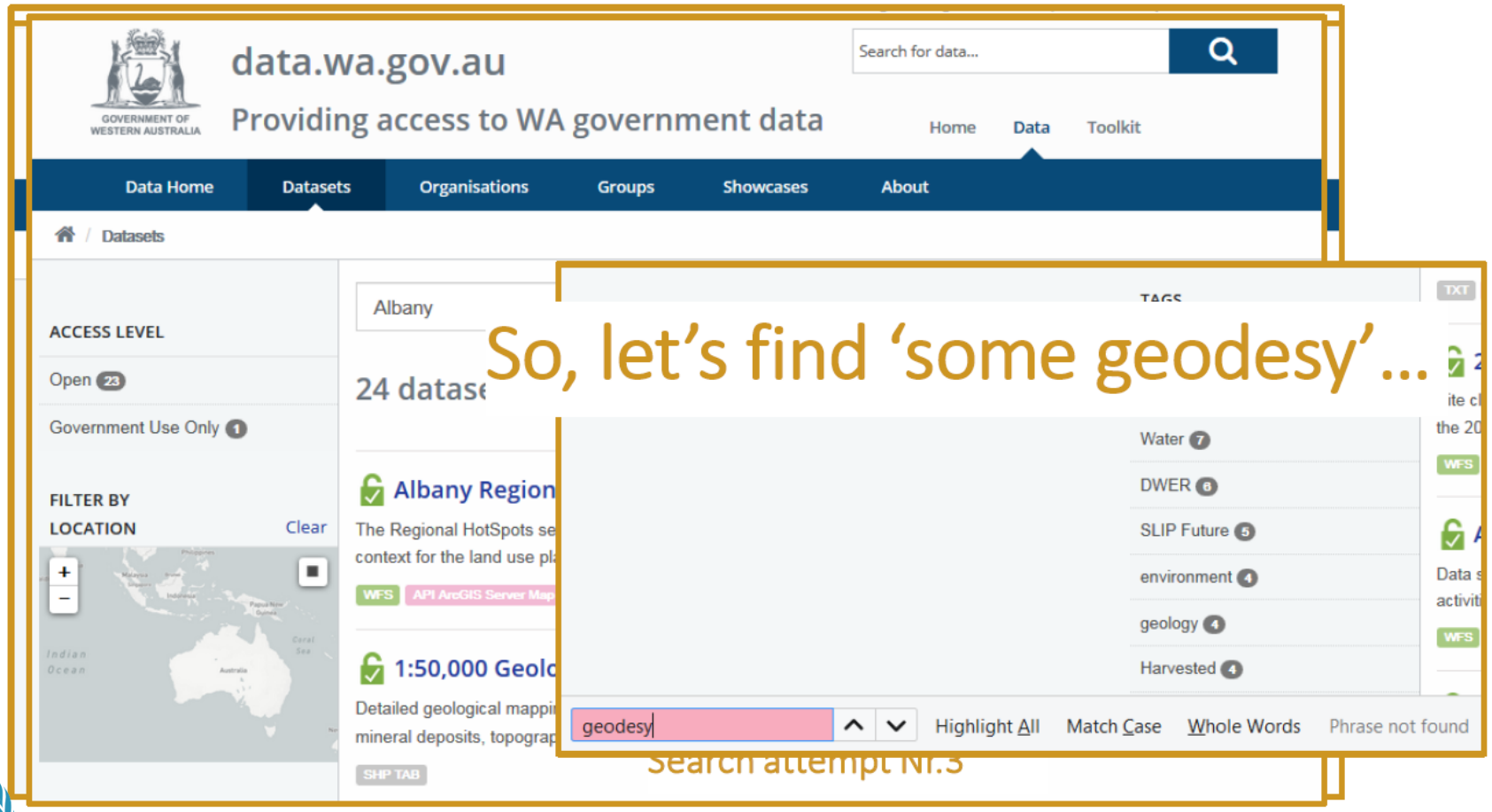
What are users getting today?

I want GNSS data from Albany station from 6 June 2019, **where are the data?**



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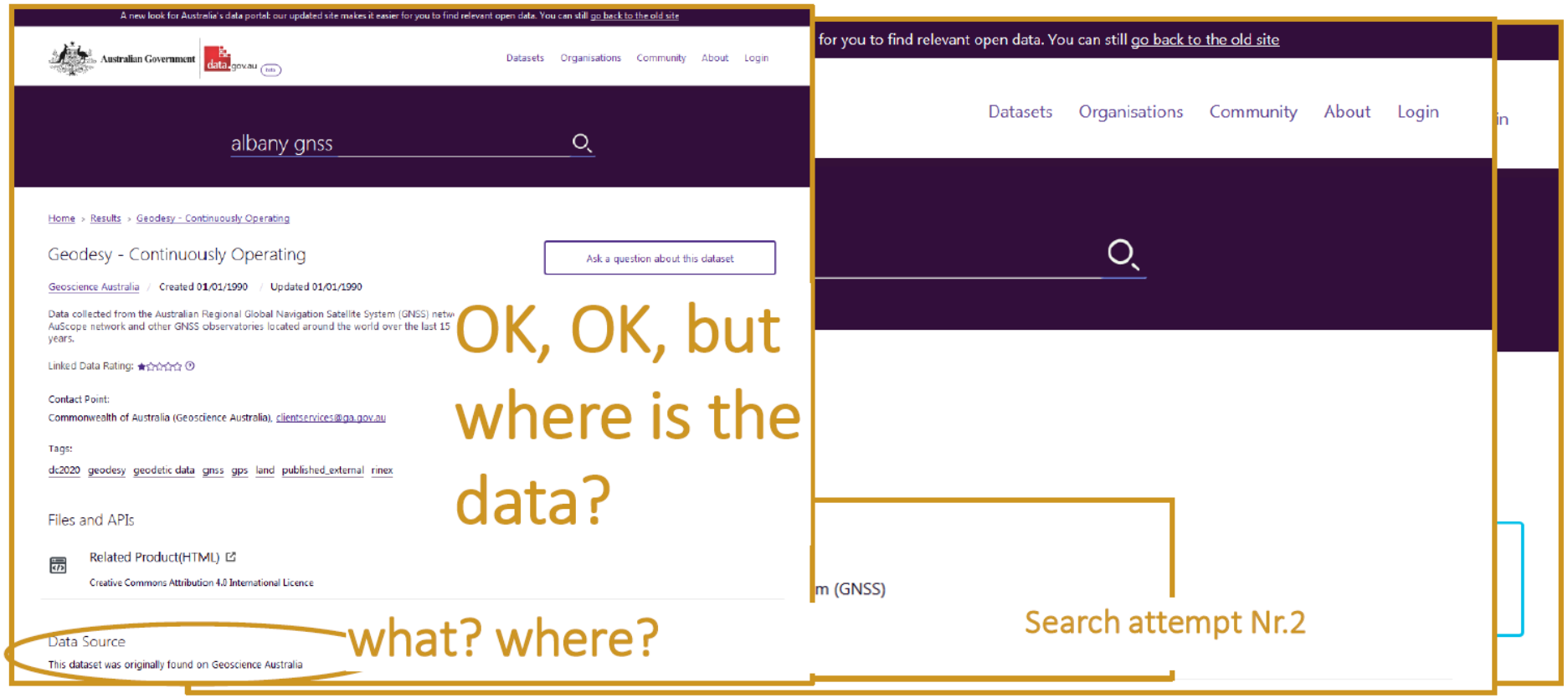
What are the data?

Oh, I know now, this is part of national network, so must be somewhere within the national data portal...



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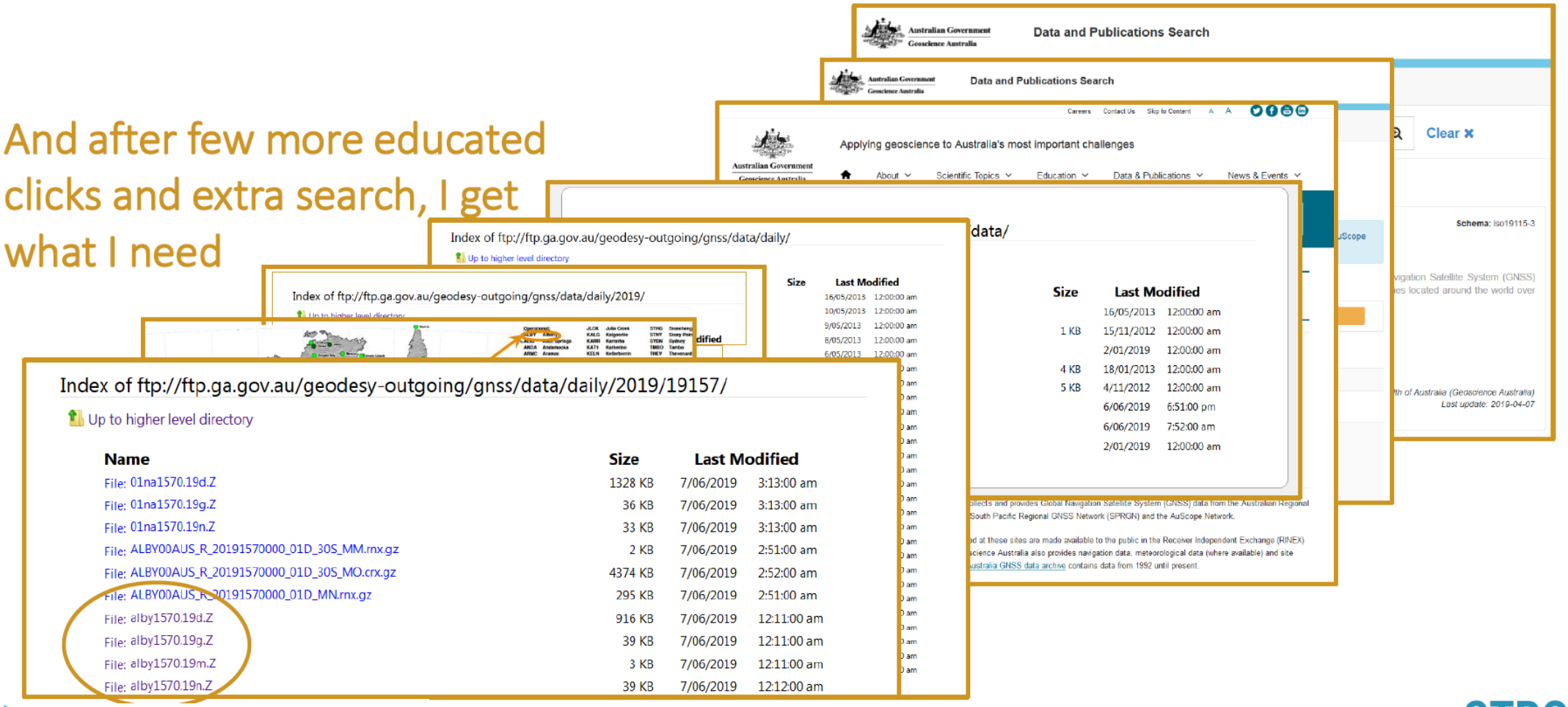
What are the data?

And after few more educated clicks and extra search, I get what I need



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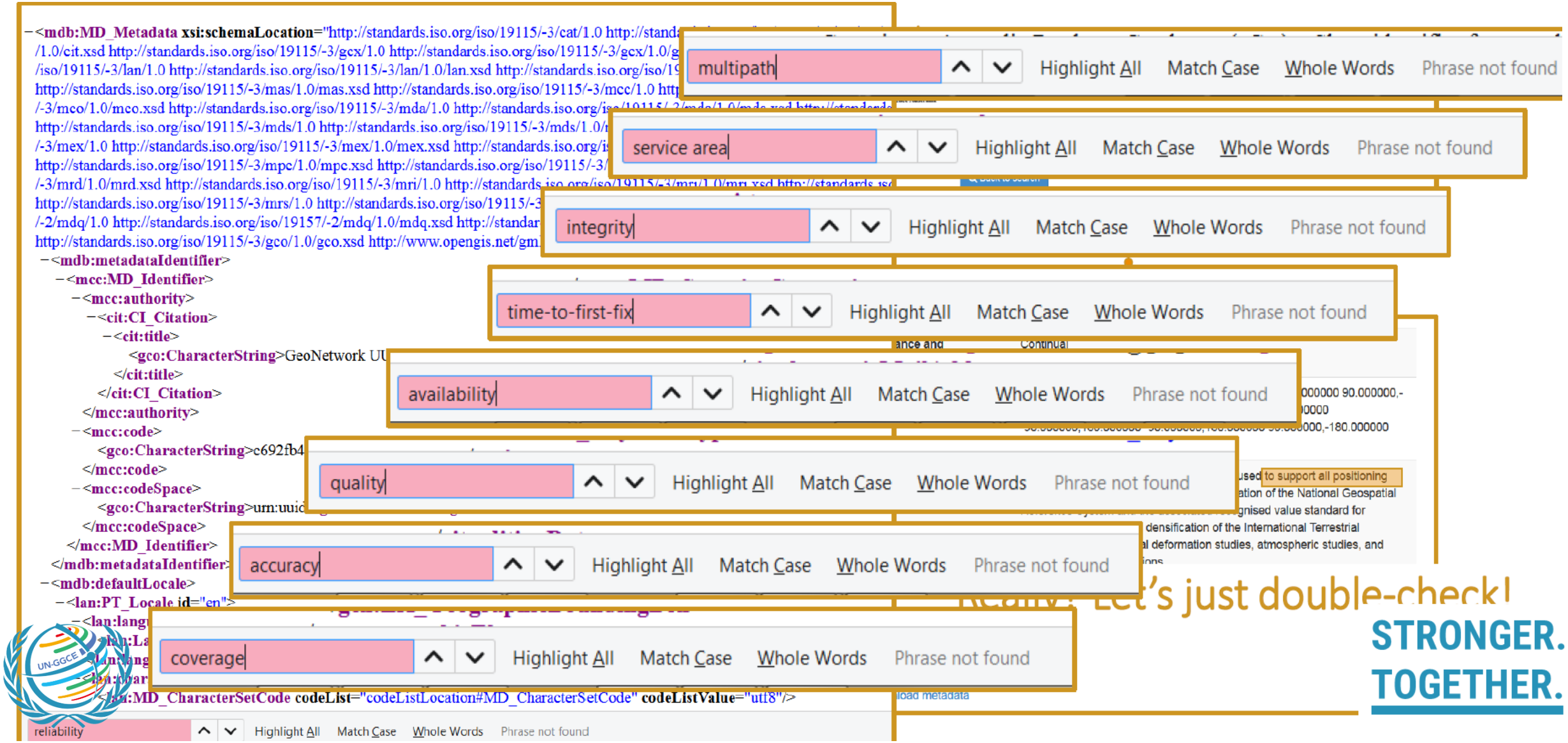
But how fit for purpose is the data?



User requirements

- To satisfy the user demands, our geodetic data and the associated metadata need to be standardized, discoverable, interoperable and authoritative
- Current standards for delivering geodetic data will not adequately serve the needs of new (non-geodetic) users, who will emerge on account of the rapid growth in precise positioning services.
- Broad, multi-domain, standards are important for combining geodetic data with data from other domains.

The need for modern standards

- Well known standards are available for encoding fundamental geodetic data (e.g., SINEX, RINEX, ANTEX, SP3 etc.)
- But not all users know where or how to look for information (e.g., coordinates in a SINEX file) to fit their requirements
- Users need to be able to query, access and retrieve data in near real-time without knowing how (e.g., format) or where (e.g., data center) the information is stored
- No international standard is available which makes geodetic data and metadata openly accessible, machine-to-machine readable and interoperable for these emerging markets
- **There is a need to modernize standards to encode and exchange geodetic data and metadata**

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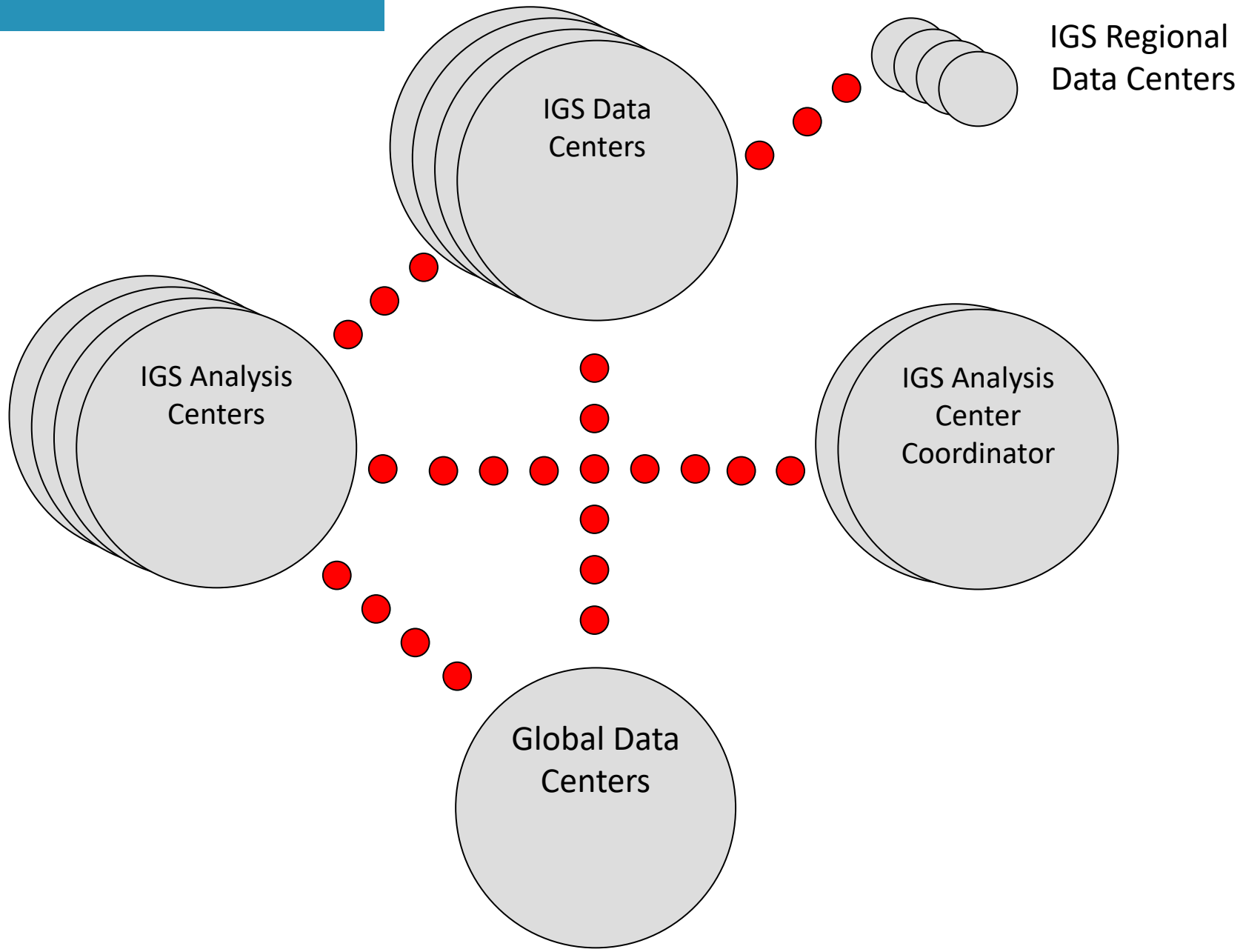
Imagine …



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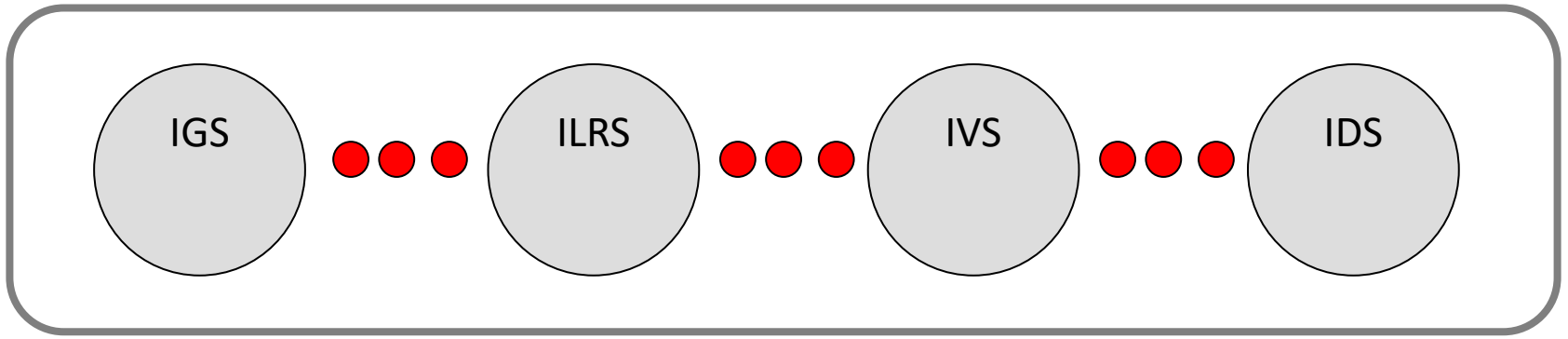
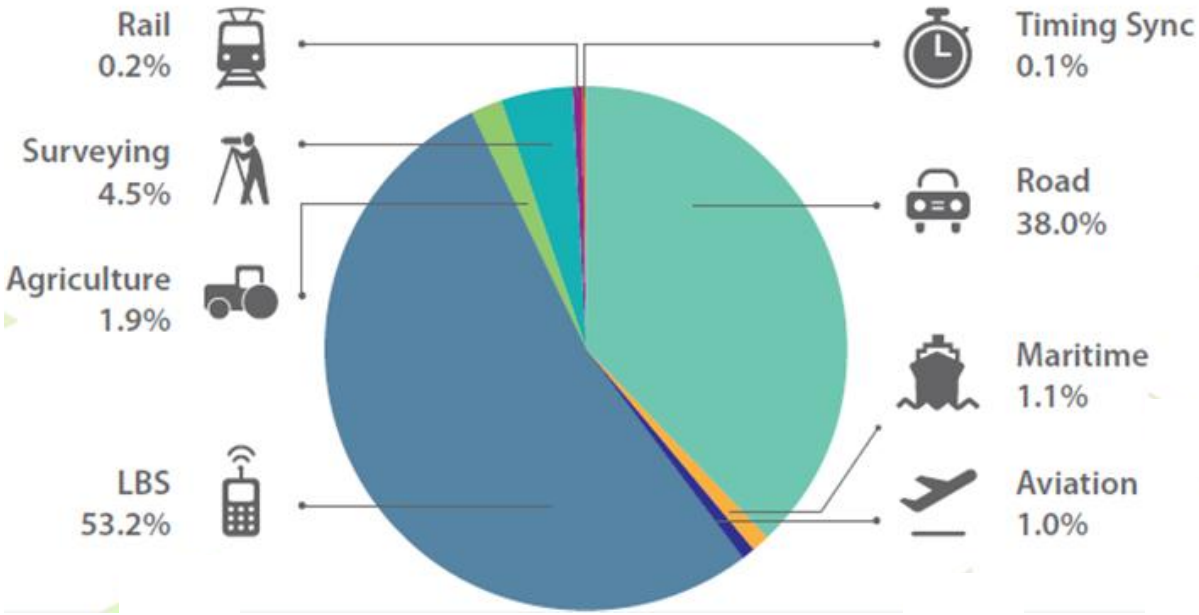
Reference Frame



Discover **Share** **Combine** **Display**



+ government
+ academia

GeodesyML

GeodesyML

is **a** solution for efficient positioning data (and metadata) delivery

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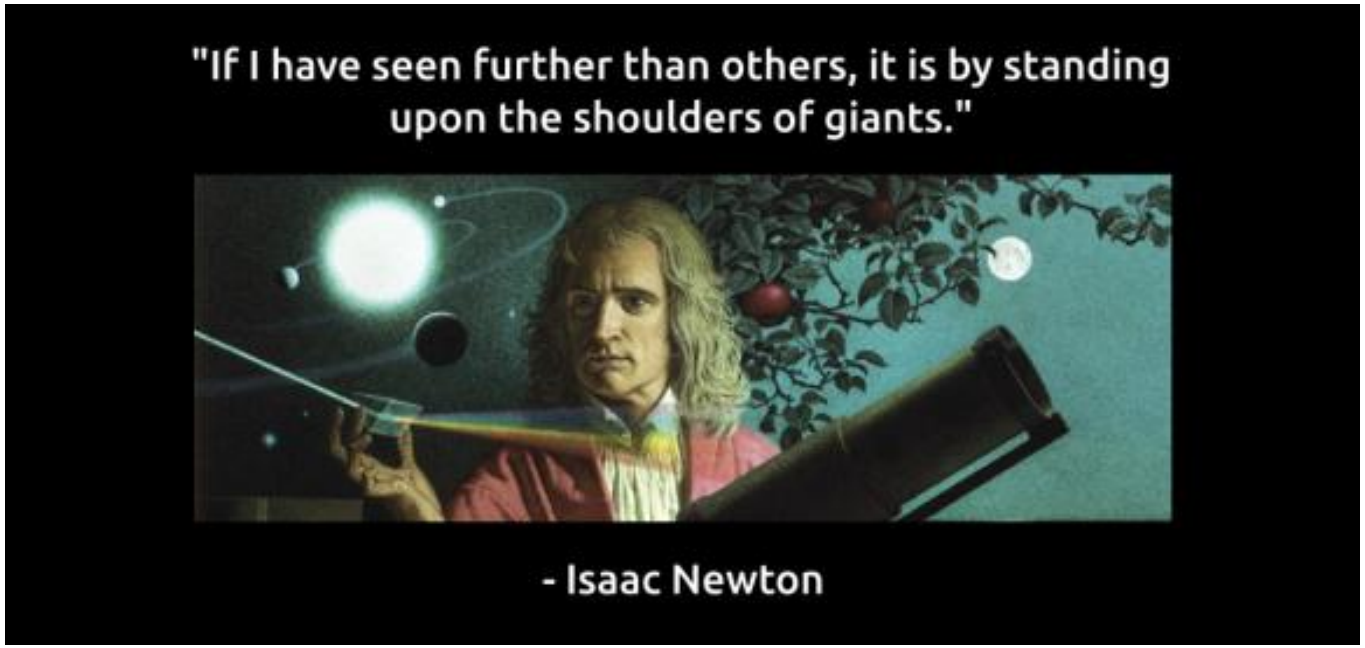
Extending Geography Markup Language (GML)

- GML provides a rich set of primitive objects like, geometry, coordinate reference system, time etc.
- But not detailed / specific standards. For example, GML can not be used to describe everything about a GNSS, VLBI, SLR, DORIS sites.
- The geodetic standard needs objects like antenna, receiver, cable, adjustments etc.
- GML Application Schemas extend GML to meet the needs of a specific community of interest (e.g. SensorML, GeoSciML, GeodesyML)

GML Application Schemas



- Coordinate Reference System, Time, Unit of measures
- Many proprietary and open-source software vendors and database technology providers support GML

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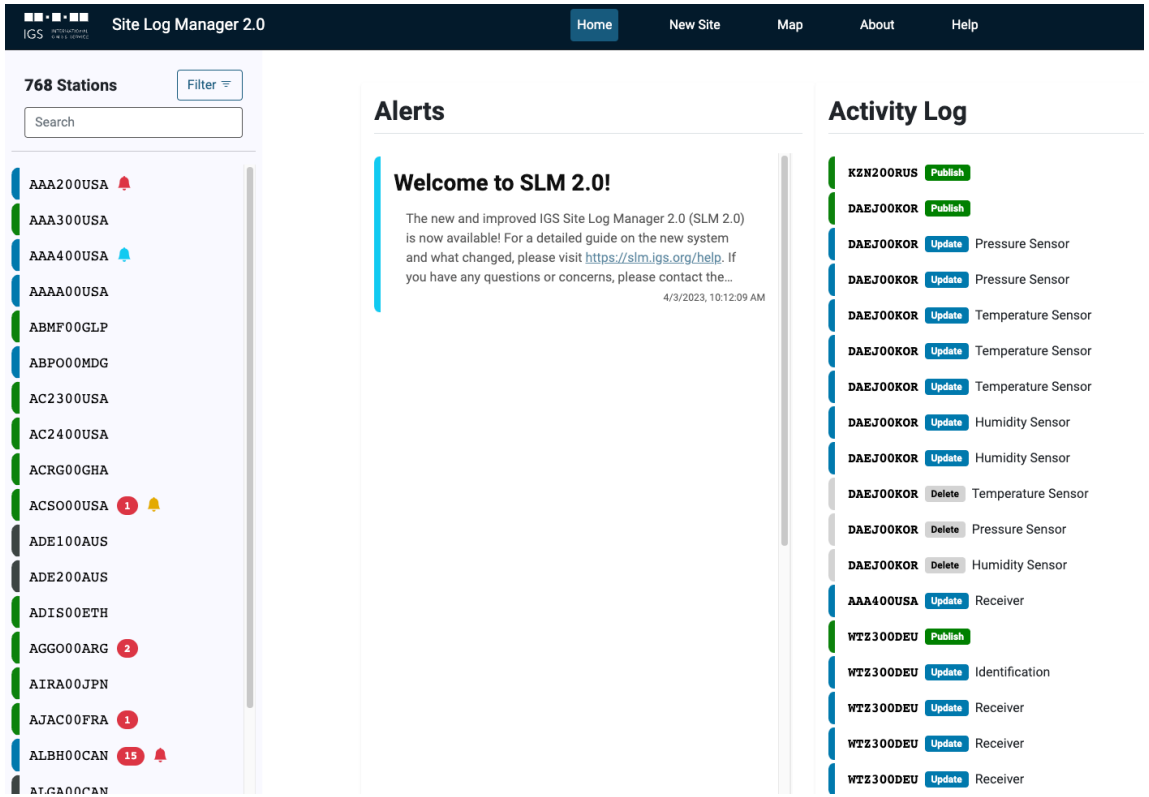
GeodesyML

- **GeodesyML** enables machine-readable access via the internet, i.e. for more than dedicated (geodetic) equipment.

- Australia and New Zealand have created the **Geodesy Markup Language (GeodesyML)**
- **GeodesyML** is a standard way of describing (encoding) and sharing geodetic data and metadata in XML format
- **GeodesyML** harmonizes language of geodesy – allows mapping of geodetic database into a common language to exchange data with others.
- **GeodesyML** is proposed Application Schema of the Geography Markup Language (ISO Standard)

IGS Site Log Manager

- https://github.com/International-GNSS-Service/SLM
- The Site Log Manager (SLM) is a web framework for managing GNSS ground station meta data. SLM is maintained by the International GNSS Service and is freely licensed for general use under the MIT License. The SLM is implemented in Python and JavaScript using the Django web framework.



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TOGETHER.

OUTLINE

1. Introduction and key definitions

2. ISO standards

3. OGC standards
4. Other standardisation practices
5. Summary and conclusions

2.1 What is ISO?

2.2 Geographic locations and coordinates (ISO 6709, ISO 19111, ISO 19161)

2.4 Metadata (ISO 19115)

2.5 Data registry (ISO 19127, ISO 19135)

What is ISO?

- **International Organization for Standardization** (ISO) is an independent, non-governmental international organization founded in 1947, which now links 169 national standards bodies (as of 2023)[1]
- **ISO standards** are internationally recognised guidelines and specifications developed by ISO. They are "the formula that describes the best way of doing something"[1]
- **ISO Technical Committee 211** (ISO/TC 211)[2]
  - Develops standards for geographic information and geomatics
  - Specifies methods, tools, and services for data management, including acquisition, processing, analysis, access, publishing and transferring of data between different users and systems
  - Links to appropriate standards for information technology and data
  - Provides a framework for the development of sector-specific applications using geographic data
  - Under the direct responsibility of ISO/TC 211[3] [4]
    - 100 standards published[5]
    - 28 are under development[5]

1. International Organization for Standardization. "ISO - International Organization for Standardization." ISO, https://www.iso.org/home.html. Accessed 9 January 2025.
2. ISO/TC 211. "ISO/TC 211 Geographic information/Geomatics" ISO, https://committee.iso.org/home/tc211. Accessed 9 January 2025.
3. ISO/TC 211. "ISO/TC 211 Geographic Information/Geomatics. Projects" ISO, https://committee.iso.org/sites/tc211/home/projects.html. Accessed 21 January 2025.
4. International Organization for Standardization. "ISO/TC 211 Geographic Information/Geomatics." ISO, https://www.iso.org/committee/54904.html. Accessed 21 January 2025.
5. International Organization for Standardization. "Standards by ISO/TC 211 Geographic information/Geomatics. Catalogue." ISO, https://www.iso.org/committee/54904/x/catalogue/p/1/u/0/w/0/d/0. Accessed 21 January 2025.

ISO19111 for coordinate referencing

ISO 19111:2019 "Geographic information – Referencing by coordinates", https://www.iso.org/standard/74039.html.
This standard includes conceptual schema (i.e., a structured framework or a technical drawing) to describe referencing by coordinates. It defines the elements necessary to determine coordinate reference systems (CRS)[1], including a datum[2] and a coordinate system and provides description of operations, such as transformation or conversion, between two different CRSs.

Coordinate set
collection of single-point positions

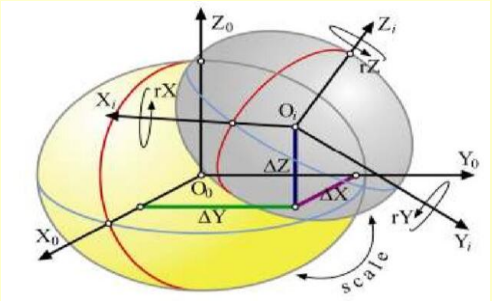
referenced to

"Source" CRS

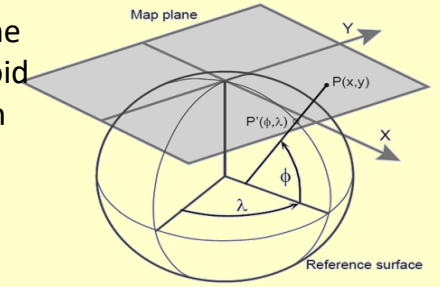
- **known** datum XX
- **known** coordinate system XX

Coordinate operations

- **Transformation** operates on CRS through translation ΔX, ΔY, ΔZ, rotation rX, rY, rZ, and a scale factor[1]



- **Conversion** changes coordinates remaining the same datum (e.g., ellipsoid axes). Conversion example: mapping of ellipsoidal to Cartesian coordinates using a map projection



Coordinate set
collection of single-point positions

referenced to

"Derived" CRS

- Transformation: **new (derived)** datum, **known** coordinate system YY
- Conversion: **inherited** datum XX, **known** coordinate system YY

1. Coordinate reference system (CRS) is a coordinate system that is related to an object (e.g., the Earth) by a datum or a reference frame. In other words, it is a framework for mapping Earth's geographic locations and vice versa, for relating maps to real-world locations on the Earth's surface. It encompasses a coordinate system, datum or a reference frame, units, and coordinate operations. References: "Introduction to Coordinate Reference Systems", https://www.earthdatascience.org/courses/earth-analytics/spatial-data-r/intro-to-coordinate-reference-systems/; ISO 19111:2019 "Geographic information – Referencing by coordinates", https://www.iso.org/standard/74039.html.
2. Datum and reference frame is used interchangeably according to the modern ISO notations. For details see ISO 19111:2019 "Geographic information – Referencing by coordinates", https://www.iso.org/standard/74039.html.

Other references used

1. The schematic is adopted from: National Geospatial-Intelligence Agency. "Department of Defense, World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems." National Geospatial-Intelligence Agency, https://earth-info.nga.mil/php/download.php?file=coord-wgs84. Accessed 25 January 2025.
2. GIS Coordinate Reference Systems, https://www.youtube.com/watch?v=WWp1k0SIMUU, Accessed 31 January 2025.
3. Nedeljković Z. and Sekulić A.: Concept of spatial coordinate systems, their defining and implementation as a precondition in geospatial applications. Glasnik Srpskog geografskog drustva, 95(4), pp.77-102, https://doi.org/10.2298/GSGD1504077N, 2015.
4. ITC. "Map Projections." Geometric Aspects of Mapping, https://kartoweb.itc.nl/geometrics/Map%20projections/body.htm. Accessed January 26, 2025.

ISO 19161-1, 19161-2 for ITRS and ground stations identification

ISO 19161-1:2020 "Geographic information – Geodetic references – Part 1: International terrestrial reference system (ITRS)", https://www.iso.org/standard/70655.html.

- Sets standards on how to "realise" the ITRS according to different categories (e.g., general, primary, secondary) and intended purposes.

(under development, approved)
ISO 19161-2 "Geographic information – Geodetic references – Part 2: Unique identification of geodetic ground stations", https://www.iso.org/standard/89134.html#lifecycle.

- Modernises the method for unique identification of ground geodetic stations by replacing the existing Directory Of MERIT[1] Sites (DOMES) numbering system.
- Contributes to interoperability among various Global Navigation Satellite Systems (GNSS).
- Supports the United Nations Global Geospatial Information Management (UN-GGIM) actions on global geodetic reference frame.

DOMES number[2]: **10002M006**

- The first 3 digits indicate the area, usually the country **100=France**
- The next 2 digits indicate the site number within the country **02=Grasse**
- The next letter indicates the tracking point **"M" for monuments**
- the last 3 digits represent a sequential point number **006 is GPS Pillar/brass mark**

1. MERIT – an international program to Monitor Earth Rotation and Intercompare the Techniques (MERIT) of observation and analysis. For further details see
   - Wilkins, G. A., and I. I. Mueller (1986), Rotation of the Earth and the Terrestrial Reference System, Eos Trans. AGU, 67(31), 601-605, doi:10.1029/EO067i031p00601.
   - Wilkins, G.A., Mueller, I.I. (1986), On the rotation of the Earth and the terrestrial reference system. Bull. Géodésique 60, 85-100, https://doi.org/10.1007/BF02519356.
2. ITRF. "Description of the DOMES Numbering System." ITRF Network, https://itrf.ign.fr/en/network/domes/description. Accessed January 26, 2025.

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ISO Geodetic Registry (ISOGR)

https://geodetic.isotc211.org

- Maintained by the ISO Technical Committee on geographic information/ geomatics (ISO/TC 211)
- Main purpose is to serve as the authoritative source for reference frames and transformation parameters
  - Information in the ISOGR has been either directly entered or approved by the agencies responsible for defining and maintaining the reference systems and transformations
  - Serves as an authoritative source for other registers (e.g., EPSG)
  - Not meant to compete with other registries but complement them

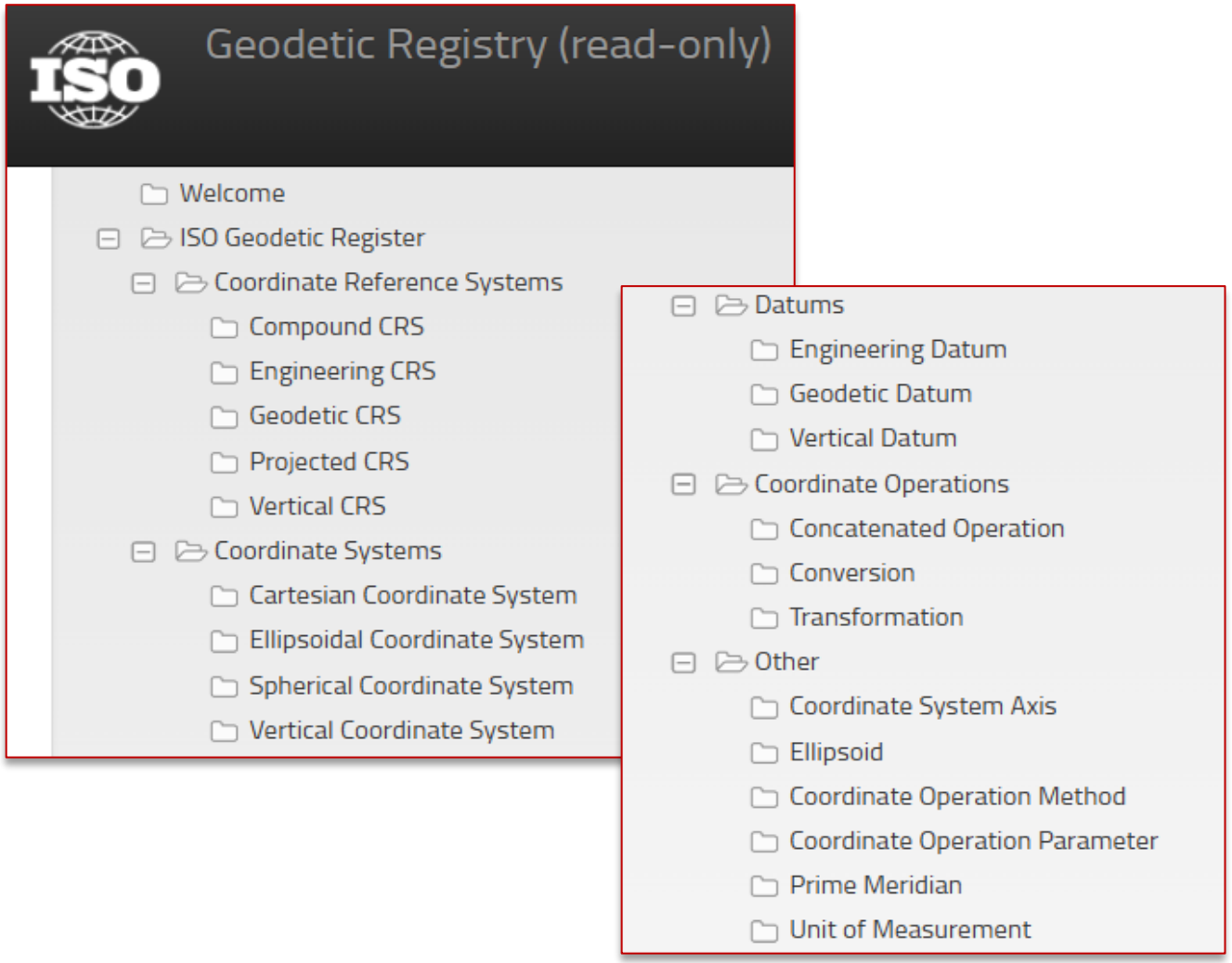
ISO 19127 Geodetic Register

ISO 19127:2019 "Geographic information – Geodetic register", https://www.iso.org/standard/67252.html

- Specifying the data elements required within the geodetic register, in accordance with ISO 19111:2007 "Spatial referencing by coordinates" and ISO 19135-1:2015 "Procedures for item registration".
- Defines the management and operations of the ISO geodetic register, including roles, responsibilities, rules, and procedures.

Example of a geodetic registry: ISO Geodetic Registry (ISOGR), https://geodetic-v1.isotc211.org

- Structured database of coordinate reference systems (CRS) and their transformations



Source: https://geodetic-v1.isotc211.org

EPSG registry

https://epsg.org/

- **E**uropean **P**etroleum **S**urvey **G**roup (EPSG)
  - Online registry
  - Holds data, has a graphic user interface (GUI) and application programming interface (API)
  - Data is stored in a data model which implements ISO 19111

- **EPSG Database**
  - EPSG Geodetic Parameter Dataset – the data in the EPSG registry
  - The Dataset contains definitions of coordinate reference systems and coordinate transformations which may be global, regional, national or local
  - One of the Dataset export options, MS Access used as carrier
  - Dataset export also available as MySQL, Oracle or PostgreSQL scripts
  - The Dataset is maintained by the Geodesy Subcommittee of the IOGP Geomatics Committee

Overview of ISO standardisation

Benefits

- Globally recognised
- Compliant with legal regulatory requirements
- Enhances operational efficiency
- Reduces risks and operational cost
- Improves geodetic product and service quality
- Enhances system compatibility with other sectors
- Improves data discoverability
- Enhances system sustainability

Deficits

- High implementation and maintenance cost
- Time-consuming implementation process
- Heavy bureaucracy
- Requires special expertise
- Requires continuous commitment to sustain the standards

OUTLINE

1. Introduction and key definitions
2. ISO standards

3. OGC standards

3.1 What is OGC?
3.2 Types of OGC standards
3.3 OGC and ISO standards compatibility

4. Other standardisation practices
5. Summary and conclusions

What is OGC?

Open Geospatial Consortium

- **Open Geospatial Consortium** (OGC) is a non-profit international voluntary open-membership consensus standards organisation founded in 1994
- **OGC mission** is to develop open **free of charge** standards that "enable interoperability[1] and seamless integration of geospatial information, geoprocessing software, and geospatial services"[2]
- **OGC standards** are internationally recognized technical documents, developed by OGC, that describe specifications and protocols to ensure optimal interoperability of different geospatial systems[2]
- **OGC** has
  - **500+ members** including vendors, government agencies, universities and research institutions (as of 2017)[3]
  - **50+ standards**[4 5]
- **OGC** closely cooperates with **ISO** and other standards developing organisations

1. Interoperability is the ability of two or more components or services to exchange and mutually utilize information without affecting their functionality or performance. Interoperability implies the integration and compatibility of those components or services (e.g., geodetic devices, data formats, standards). Source: International Organization for Standardization. "ISO/IEC TR 15944-14:2020 Information technology — Business operational view — Part 14: Open-edi reference model and cloud computing architecture." 1st ed., https://www.iso.org/standard/73177.html. Accessed 4 February 2025.
2. Open Geospatial Consortium. "OGC - Open Geospatial Consortium.", https://www.ogc.org/. Accessed 9 January 2025.
3. Bermudez, L. "New frontiers on open standards for geo-spatial science.", Geo-Spatial Information Science, 20(2), 126-133. https://doi.org/10.1080/10095020.2017.1325613, 2017.
4. Simmons, S. "OGC and the Relevance of Standards for Environmental Matters." Open Geospatial Consortium. https://www.landcareresearch.co.nz/assets/Events/Link-series/OGC_relevance_standards_environmental_matters.pdf, 2017.
5. Open Geospatial Consortium. "Progress of Official OGC Standards", https://portal.ogc.org/public_ogc/standards/standards_workflow.php?bg=1. Accessed February 7, 2025.

OUTLINE

1. Introduction and key definitions
2. ISO standards
3. OGC standards

4. Other standardisation practices

4.1 Geodetic Formats
4.2 INSPIRE
4.3 SI and physical constants
4.4 FAIR principles for data management
4.5 Resolutions and conventions

5. Summary and conclusions

Selection of GNSS Data and Metadata Formats

Format/Standard	Information
SSR v1.0	The IGS State Space Representation (SSR) format is an open standard for dissemination of real-time products to support the IGS Real-Time Service and the wider community. The messages support multi-GNSS and include corrections for orbits, clocks, DCBs, phase-biases and ionospheric delays.
RINEX v. 4.02	RINEX 4.02 (2024) is an upgrade of the format document that introduces the pico-second resolution to the observations time tagging, as well as new navigation messages for NavIC L1 and GLONASS L1 and L3 CDMA. In addition, navigation messages subtypes have been introduced, to support dual ION models available for the QZSS and NavIC systems. Additional editorial changes have been introduced to improve clarity.
SINEX	station position and velocity solutions
sp3 version d	GNSS and SBAS orbit solutions
sp3 version c	GPS and GLONASS orbit solutions
erp	Earth rotation parameter files
clock RINEX 3.04	station and satellite clock solutions
Bias-SINEX V1.00	GNSS code and phase biases for satellites and stations
IONEX V1.00	ionospheric TEC grid products
Tropo SINEX v2.00	Solution (Software/Technique) Independent Exchange (SINEX) format for TROpospheric and meteorological parameters
Tropo SINEX	Zenith path delay products
site log v2.0	History of site installation
ANTEX Format	ANTEX: The Antenna Exchange Format, Version 1.4

https://igs.org/formats-and-standards

INSPIRE

- The European INSPIRE (Infrastructure for Spatial Information in Europe) program is an initiative aimed at creating a unified spatial data infrastructure across Europe. This program is designed to facilitate the sharing of environmental spatial information among public sector organizations and improve public access to spatial information across Europe. The INSPIRE Directive, which was established in 2007, sets the legal framework for this initiative.

- The main objectives of the INSPIRE program include:
  - **Interoperability:** Ensuring that spatial data from different sources across Europe can be combined and used seamlessly.
  - **Accessibility:** Making spatial data more accessible to the public and various stakeholders.
  - **Harmonization:** Standardizing spatial data to ensure consistency and compatibility across different regions and sectors.
  - **Support for Environmental Policies:** Providing reliable spatial data to support environmental policies and decision-making processes.
  - The INSPIRE program covers a wide range of spatial data themes, including land use, transportation networks, hydrography, and protected sites, among others. It aims to create a more efficient and effective way of managing and using spatial data to address environmental and societal challeng

Content of the INSPIRE directive

INSPIRE Directive

The INSPIRE Directive establishes an **infrastructure for spatial information in Europe** to support Community **environmental policies, and policies or activities which may have an impact on the environment**.

Implementing Rules (IR) are adopted in a number of specific areas:

- Metadata,
- Data Specifications,
- Network Services,
- Data and Service Sharing
- Monitoring and Reporting

The Directive addresses 34 spatial data themes

ANNEX: 1

- Addresses
- Cadastral parcels
- Geographical grid systems
- Hydrography
- Transport networks
- Administrative units
- Coordinate reference systems
- Geographical names
- Protected sites

ANNEX: 2

- Elevation
- Land cover
- Geology
- Orthoimagery

ANNEX: 3

- Agricultural and aquaculture facilities
- Atmospheric conditions
- Buildings
- Environmental monitoring Facilities
- Human health and safety
- Meteorological geographical features
- Natural risk zones
- Population distribution and demography
- Sea regions
- Species distribution
- Utility and governmental services
- Area management / restriction / regulation zones & reporting units
- Bio-geographical regions
- Energy Resources
- Habitats and biotopes
- Land use
- Mineral Resources
- Oceanographic geographical features
- Production and industrial facilities
- Soil
- Statistical units

FAIR[1,2] principles for data management

Concise and measurable set of principles to increase reusability of digital assets

Findability

- (Meta)data are assigned a globally unique and persistent identifier
- Data are described with rich metadata (see “Reusable”)
- Metadata clearly and explicitly include the identifier of the data they describe
- (Meta)data are registered or indexed in a searchable resource

Accessibility

- (Meta)data are retrievable by their identifier using a standardised communications protocol
- The protocol is open, free, and universally implementable
- The protocol allows for an authentication and authorisation procedure, where necessary
- Metadata are accessible, even when the data are no longer available

Interoperability

- (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
- (Meta)data use vocabularies that follow FAIR principles
- (Meta)data include qualified references to other (meta)data

Reuse

- (Meta)data are richly described with a plurality of accurate and relevant attributes
- (Meta)data are released with a clear and accessible data usage license
- (Meta)data are associated with detailed provenance
- (Meta)data meet domain-relevant community standards

1. GO FAIR. “FAIR Principles”, https://www.go-fair.org/fair-principles. Accessed February 13, 2025.
2. Wilkinson, M., Dumontier, M., Aalbersberg, I. J., et al. (2016). The FAIR guiding principles for scientific data and stewardship. Scientific Data, 3, 160018. https://doi.org/10.1038/sdata.2016.18.

Summary

Explored standardisation practices throughout the data lifecycle in geodesy

- **ISO standards** (ISO 6709, ISO 19111, ISO 19115, ISO 19161, ISO 19127, ISO 19135)
- **Types of OGC standards**
- **ISO and OGC compatibility**
- **International System of Unites (SI) and fundamental physical constants**
- **Resolutions and conventions**
- **FAIR principles for data management**

Learnt definitions

- **Standard**
- **Standardisation**
- **Metadata**
- **Identifier**
- **Register**
- **Registry**
- **Registration**

Additional resources

1. ArcGIS Pro: Create ISO 19115-1 and ISO 19115-3 metadata, https://pro.arcgis.com/en/pro-app/latest/help/metadata/create-iso-19115-1-and-iso-19115-3-metadata.htm.
2. ISO TC 211: ISO Geodetic Registry (ISOGR), https://geodetic-v1.isotc211.org/.
3. ISO TC 211: Good practice, https://committee.iso.org/sites/tc211/home/resolutions/isotc-211-good-practices.html.
4. ISO TC 211: ISO/TC 211 Multi-Lingual Glossary of Terms (MLGT), https://isotc211.geolexica.org/.
5. ISO TC 211: ISO/TC 211 Resources, https://www.isotc211.org/.
6. ISO TC 211: XML schema representations of geographic technology standards, https://schemas.isotc211.org.
7. ISO/TC 211: Support for United Nations activities, https://committee.iso.org/sites/tc211/home/standards-in-action/united-nations.html.
8. ISO/TC 211/WG 9: Geographic information – Geodetic register user guide, https://iso-tc211.github.io/iso-geodetic-register-docs/documents/user-guide.html
9. ISO/TC 211: GitHub Repository, https://github.com/ISO-TC211.
10. NOAA National Coastal Data Development Center. (2012). ISO 19115 Geographic information – Metadata Workbook: Guide to Implementing ISO 19115:2003(E), the North American Profile (NAP), and ISO 19110 Feature Catalogue. Silver Spring, MD, NOAA National Coastal Data Development Center, 248pp. http://dx.doi.org/10.25607/OBP-770.

Additional resources

1. Duque, J. P., Pugliese, A. D. J., and Brovelli, M. A. (2024). A standardised approach for serving environmental monitoring data compliant with OGC APIs, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-4/W12-2024, 51–58, https://doi.org/10.5194/isprs-archives-XLVIII-4-W12-2024-51-2024.
2. Huang, M., Fan, X., Jian, H., Zhang, H., Guo, L., & Di, L. (2022). Bibliometric Analysis of OGC Specifications between 1994 and 2020 Based on Web of Science (WoS). ISPRS International Journal of Geo-Information, 11(4), 251. https://doi.org/10.3390/ijgi11040251.
3. Open Geospatial Consortium (2021). OGC Testbed-17: UML Modeling Best Practice Engineering Report, https://docs.ogc.org/per/21-031.pdf.
4. Open Geospatial Consortium. GitHub, https://github.com/opengeospatial.
5. Open Geospatial Consortium: Glossary of Terms, https://defs.opengis.net/vocprez/object?uri=http%3A//www.opengis.net/def/glossary.
6. Open Geospatial Consortium: List of Best Practices, https://www.ogc.org/best-practice/.
7. Open Geospatial Consortium: List of Community Practices, https://www.ogc.org/community-practices/.
8. Open Geospatial Consortium: List of Discussion Papers, https://www.ogc.org/discussion-papers/.
9. Open Geospatial Consortium: List of Technical Papers, https://www.ogc.org/technical-papers/.
10. Open Geospatial Consortium: OGC Schema Repository, https://schemas.opengis.net/.
11. Open Geospatial Consortium: OGC's Registry for Accessible Identifiers of Names and Basic Ontologies for the Web (OGC Rainbow), https://defs.opengis.net/vocprez/.
12. Open Geospatial Consortium: Standards, https://www.ogc.org/publications/.

Additional resources

1. Angermann, D., Gruber, T., Gerstl, M., Heinkelmann, R., Hugentobler, U., Sánchez, L., & Steigenberger, P. (2020). *Inventory of standards and conventions used for the generation of IAG products*. International Association of Geodesy. Retrieved from https://iag-aig.org/doc/GH2020/402_Inventory.pdf
2. Bermudez, L. (2017). New frontiers on open standards for geo-spatial science. Geo-Spatial Information Science, 20 (2), 126–133. https://doi.org/10.1080/10095020.2017.1325613.
3. GGOS Bureau of Products and Standards, https://www.dgfi.tum.de/en/international-services/ggos-bureau-of-products-and-standards/
4. Guide to Coordinate Reference System (CRS) Resources. (2022). Joint ISO/TC 211, OGC, IOGP text. Retrieved from https://committee.iso.org/files/live/sites/tc211/files/Resources/GuideToCRSRegistries3.pdf.
5. INSPIRE Knowledge Base: Infrastructure for Spatial Information in Europe, https://knowledge-base.inspire.ec.europa.eu.
6. Ivanova, I., Brown, N., Rubinov, E., Fraser, R., and Tengku N. (2020). Ensuring fair access to precise positioning by improving geodetic data interchange standards. Retrieved from https://frontiersi.com.au/wp-content/uploads/2020/11/P1003-Geodetic-Standards-Final-Report.pdf.
7. United Nations Committee of Experts on Global Geospatial Information Management. (2022). A Guide to the Role of Standards in Geospatial Information Management, Ed. 3.0.0:2022-01-01, 80 pp. Retrieved from https://standards.unggim.ogc.org/index.php
8. United Nations Committee of Experts on Global Geospatial Information Management. A Guide to the Role of Standards in Geospatial Information Management, Appendix 1:Standards Inventory, https://standards.unggim.ogc.org/Appendix1.html
9. United Nations Committee of Experts on Global Geospatial Information Management. A Guide to the Role of Standards in Geospatial Information Management, Appendix 7: Communities of Practice, https://standards.unggim.ogc.org/Appendix7.html.

Additional resources

1. Bradke, M.: Update from the GeodesyML Working Group, International GNSS Service (IGS) Workshop 2022 – Splinter Session. Retrieved January 20, 2025, from https://files.igs.org/pub/resource/pubs/workshop/2022/IGSWS2022_S10_04_Bradke.pdf.

2. Donnelly, N., Fraser, R.W., Haasdyk, J., and Tarbit, S.: GeodesyML – A GML Application Schema for Geodetic Data Transfer in Australia and New Zealand, 2013. Retrieved January 28, 2025, from https://api.semanticscholar.org/CorpusID:130458997.

3. Intergovernmental Committee on Surveying and Mapping (ICSM): The Use of GeodesyML to Encode IGS Site Log Data. Retrieved January 15, 2025, from https://lists.igs.org/pipermail/igs-dcwg/attachments/20150604/e32d991f/attachment.pdf

4. International GNSS Service. GeodesyML [Software]. GitHub. Available from https://github.com/International-GNSS-Service/GeodesyML.

5. Open Geospatial Consortium: Geography Markup Language (GML). Retrieved January 25, 2025, from https://www.ogc.org/publications/standard/gml/.