Applying WIGOS Metadata Standards to Improve FAIRness of NASA Field Campaign Data

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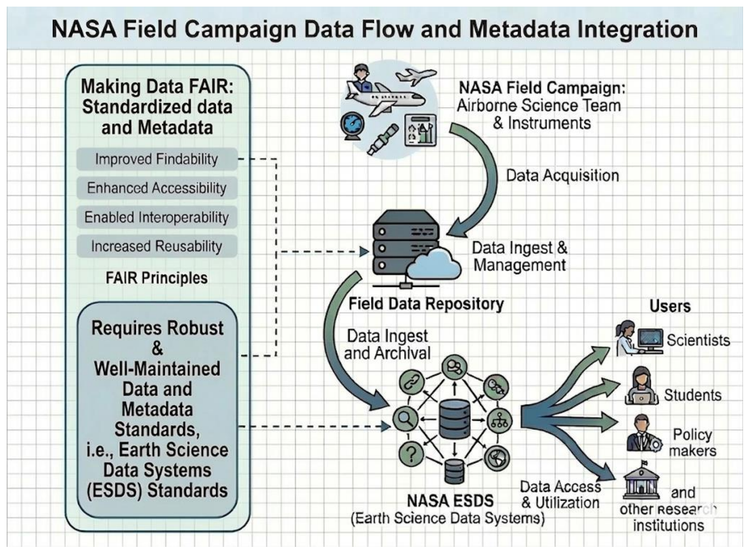
Abstract

NASA's atmospheric composition field campaigns have generated data products with a proven record of advancing atmospheric science; yet realizing their full research potential depends on reaching a wider user base. Adherence to FAIR principles, which prescribe the use of rich, standardized metadata to improve **F**indability, **A**ccessibility, **I**nteroperability, and **R**eusability, is key to maximizing the research value of the data generated by atmospheric composition field campaigns. The WMO WIGOS metadata standard offers a comprehensive framework for describing atmospheric composition measurements, especially in situ observations. Leveraging this established, well maintained, and robustly supported international standard is more efficient than developing new metadata frameworks—an undertaking that requires substantial resources and expertise from both data science and atmospheric science domains. WIGOS presents an opportunity to enhance NASA field campaign data discoverability and integration with global observing systems. As a first step, the WIGOS measurement unit code list was adopted as a NASA Earth Science Data Systems standard for unit notation, addressing long-standing inconsistencies in unit representation across NASA datasets. This work demonstrates the applicability of WIGOS metadata standards to NASA atmospheric composition field campaigns. Beyond the immediate benefits of making NASA data more FAIR, and therefore increasing the potential research value of the data, this effort offers mutual value to both NASA and the WMO: expanding the application of the WIGOS metadata standard to more research-grade measurements and incorporating NASA's operational perspectives can help identify further improvements to the standard. For example, applying the unit code list to recent radar measurements led to the addition of units to the WIGOS code. We present our methodology for applying WIGOS standards, lessons learned from the unit code list adaptation, challenges encountered, and recommendations for future applications to support NASA's effort to develop a FAIR variable level metadata standard.

Motivation



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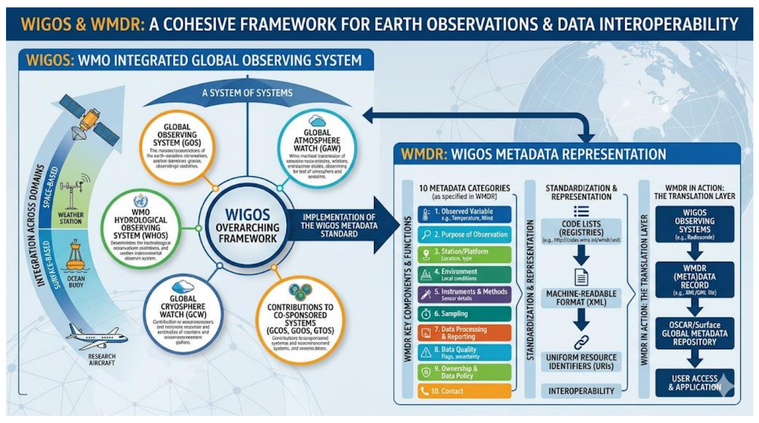
The NASA Practical Guide for Open, Free & FAIR NASA Earth Science Data Products ([1]Peng et al., 2025) details a systematic, albeit subjective, assessment of NASA's Earth science data stewardship. The manuscript identifies several limitations in the current NASA Earth Science Data System metadata standards, specifically noting that achieving metadata completeness at the variable level and maintaining controlled vocabularies across diverse scientific domains remains labor-intensive and technically challenging.

WMO Integrated Global Observing System (WIGOS)



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- WIGOS metadata has a comprehensive schema that supports "rich" metadata to make data FAIR
- WIGOS metadata standards have successfully supported a wide range of Earth Science measurements
- WIGOS metadata is adequately maintained and supported for implementation

A Use Case

WIGOS WMDS Code for Measurement Unit:

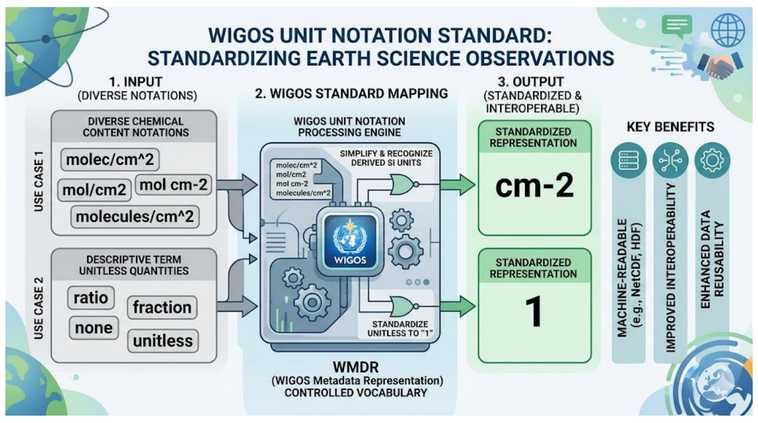
https://codes.wmo.int/wmdr/unit

- Based on SI: SI base units, SI derived units, Non-SI units accepted for SI use, domain-specific conventional units (e.g., DU, pH unit)
- Clear definition and traceable to SI when applicable
- Comprehensive coverage for Earth Science observations
- Broad applicability for both ASCII based and binary file formats by avoiding special characters in unit notation as well as space, middot…
- Non-static list maintained by the WMO Expert Team on Metadata (ET-Metadata) under an established governance process managed by the SC-IMT (Standing Committee on Information Management and Technology)

Adopting WIGOS WMDS Code Measurement Code

The WMDS measurement unit code list was approved for use in NASA Earth Science Data Systems in July 2025: ESDS-RFC-058 WIGOS Measurement Unit Standard[2]. This effort filled a gap in NASA ESDS variable level metadata standard.

Designed Outcome



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NASA ESCO Review Process

The NASA Earth Science Data and Information Systems (ESDIS) Project Standards Coordination Office (ESCO) organized community review for Request for Comments document to adapt WIGOS WMDS Measurement.

Strengths:

- Comprehensive and SI-aligned
- Simple notation enabling machine-actionability
- Enhancing data (re)usability and interoperability

Weakness:

- Untested alignment with UDUnits
- No testing code readily available
- Governance outside of NASA

Applicability:

Applicable to and suitable for Earth science data produced by both remote sensing and in-situ measurements.

Limitation:

The WIGOS standard does not recommend how units are written (notation) if not on the list.

Feedback to ET-Metadata

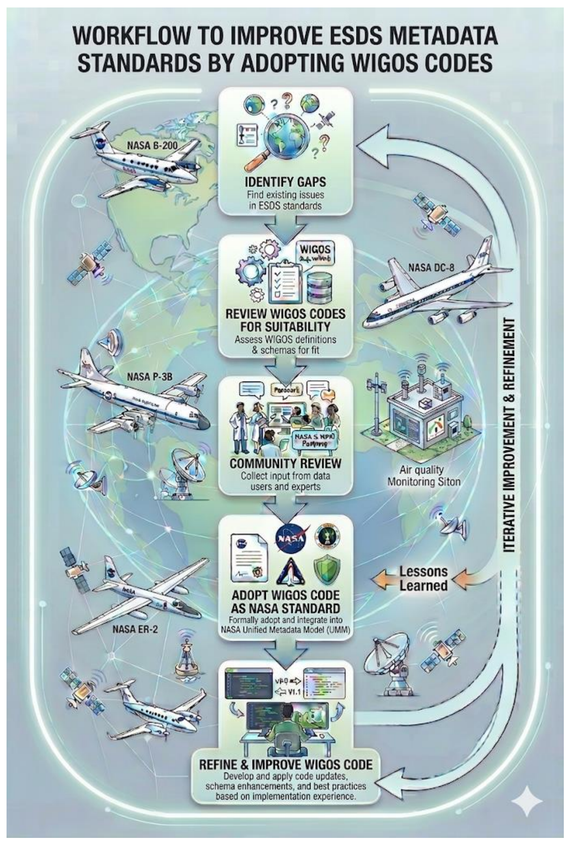
After applying the WIGOS WMDS measurement unit code to several NASA field campaign data products, gaps in the standard units were identified. A format request was submitted to the WMDS GitHub to add PVU (potential vorticity unit) and dBz (Radar reflectivity in decibel) units. Both are currently under fast track review for inclusion in the international standard.

* Disclaimer: The diagrams were created with assistance from Google Gemini for better visual effect. The diagrams have been reviewed and edited by Gao Chen.

Moving Forward

Adopting the WIGOS WMDS measurement unit code demonstrated an effective and efficient way to enhance NASA Earth Science Data Systems (ESDS) metadata standards to support "rich" metadata for measurement variables. The WIGOS WMDS measurement unit code helps resolve long-standing unit notation inconsistency at NASA. The large number of research grade measurements at NASA also broadens the WIGOS measurement coverage. Similarly, this approach will likely work well on the development of the controlled vocabulary, which is labor intensive and technically challenging as identified by Peng et al (2025). It should be noted that the WMO ET-metadata team incorporates both research and data science expertise to develop these codes. The ESDS vocabulary development may involve these steps:

- Review established WIGOS WMDS established codes and definitions, e.g., Observed variable - measurand (atmosphere)
- Map to the ESDS requirement for variable level metadata
- Identify strategies to leverage or adapt the WIGOS codes
- Conduct a community review
- Implement the improved vocabulary



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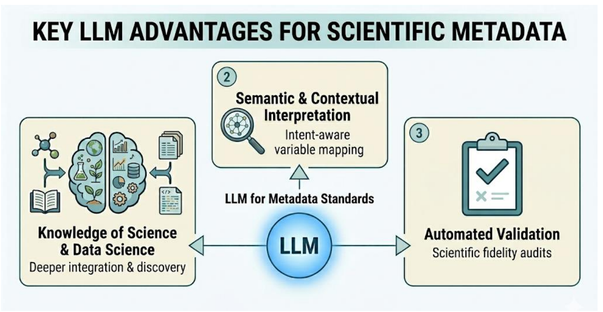
LLM-Driven Metadata Framework for Earth Science

- Identifying the "Scientific Minimum": Parse information from literature, documentation, and file headers to sufficiently describe data to make a dataset discoverable and (re)usable
- Meaning-Based Mapping: Move beyond syntactic (i.e., text-matching) mapping to semantic integration - ensure that physical variables map correctly into established standards, like WIGOS, based on their scientific context
- Strategic Unification: Identify commonalities across diverse data types (e.g., gases vs. aerosols, in-situ vs. remote sensing) to develop unified standards that simplify data access without sacrificing the unique physics of each measurement
- Standard Validation via Real-World Data: Audit existing data repositories against new standards to assess if the standards are practical or if current data reporting needs improvement
- Building a Use Case Library: Develop specific use cases to demonstrate how LLMs solve these metadata challenges and guide future applications



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[1] Peng, Ge, Downs, Robert R., Ramapriyan, Hampapuram K., Wei, Yaxing, Ramachandran, Bhaskar, Parsons, Mark A., Liu, Zhong, & NASA ESDSWG OFAIR Working Group. (2025). *A Practical Guide for Open, Free and FAIR NASA Earth Science Data Products*. NASA Earth Science Data and Information System Standards Coordination Office. https://doi.org/10.5067/DOC/ESCO/ESDS-RFC-057V1

[2] Silverman, M.L., Chen, G., Huffer, E.B., Buzanowicz, M.E., Collister, B., & Shook, M.A. (2025). WIGOS Measurement Unit Standard RFC. NASA Earth Science Data and Information Systems Standards Coordination Office. https://doi.org/10.5067/DOC/ESCO/ESDS-RFC-058v1