WIGOS Measurement Unit Standard

Status of this Memo

This RFC document describes the WIGOS metadata representation code for measurement units as a proposal for standardizing unit notations.

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Abstract

Units are essential to interpret the physical quantities obtained from measurements and model outputs, which are often used to quantitatively characterize physical processes or phenomena. Although appropriate units are generally given in NASA Earth Science data products, the notation used to represent units lacks standardization. It is quite common to see different data producers use different notation to represent the same unit, e.g., µg/m3, ug/m3, ug.m-3, and ug m^-3. To facilitate data usability and interoperability, unit notations should be standardized, and should be clear to anyone using the data, including both humans and machines. Interdisciplinary researchers, for example, may not be familiar with the specific measurement techniques of disciplines outside of their own. To ensure these researchers can properly interpret data, units should be precisely defined and traceable to the International System of Units (Système international d'unités, SI), when applicable. Inconsistent notation also limits machine actionability and therefore data interoperability. The use of certain "extended ASCII" characters, e.g., Greek characters, hinders broad interoperability of data with tools and services. For example, some systems incorrectly convert "µ" to "m", causing substantial data errors.

This RFC proposes adoption of the WIGOS (World Meteorological Organization (WMO) Integrated Global Observing System) Metadata Representation code list for measurement units (https://codes.wmo.int/wmdr/unit) by the NASA Earth Science community for standardizing unit

notations. The current version of the WIGOS measurement unit code list offers comprehensive coverage for the majority of units commonly used to measure Earth Science variables. WIGOS units are comprised of SI base units, SI derived units, and non-SI units that are widely used in research. Definitions for derived units and non-SI units include the SI base unit equivalent when applicable. The measurement unit code list is maintained by the WMO Expert Team on Metadata (ET-Metadata) under an established governance process managed by the WIGOS SC-IMT (Standing Committee on Information Management and Technology). ET-Metadata recently updated the WIGOS measurement unit code list to ensure that every unit was properly and clearly defined, and that every definition includes the SI base unit equivalent, when applicable. The notation for each unit in the WIGOS code list is also included in WIGOS documentation. The notation uses a subset of ASCII characters that are used in SI to ensure that data products encoded with WIGOS units are broadly interoperable. While this means that WIGOS notation deviates from SI notation, mainly by eliminating the use of some special characters, this restriction is designed to reduce data errors caused by misinterpretation.

Adopting the WIGOS measurement unit code will help improve interoperability and (re)usability of NASA Earth Science data, which is an important step to support NASA's Open-Source Science initiative.

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1. Introduction

This document introduces the WIGOS (World Meteorological Organization (WMO) Integrated Global Observing System) Metadata Representation (WMDR) code list for units [1] as the standard unit notation for NASA Earth Science data. The WMDR unit code list is an International System of Units (Système international d'unités, SI) [2] based unit system with a

set of standardized notations that is comprehensive enough to support NASA Earth Science research activities in both the satellite and field campaign communities, covering observations and modeling analyses. WIGOS measurement units are readily adaptable to binary (e.g., NetCDF and HDF) and ASCII formats, and suitable to construct URIs (Uniform Resource Identifier), which are necessary to enhance data product interoperability and (re)usability. This document is intended to support NASA data centers and scientists who generate observational and modeling data as well as data users. Data representing measurements of Earth system phenomena would be incomplete and incomprehensible if they were not properly associated with units of measurement. Additionally, if the notation used to represent the units is not generally understood by data users, including non-human users such as software applications, the usability of data products will be fundamentally impaired. While the inclusion of units in NASA Earth Science research data products is a requirement, standardized notation has not been implemented. This has created issues related to data usability, which have hindered attempts at automating data services.

It is not uncommon to see different data producers use different notations for the same unit. For example, the unit “micrograms per cubic meter” can be found in data files as “ug/m3”, “ug m-3” or “ug m^-3”. Similarly, the unit “molecules per square centimeter” has appeared as “molec/cm^2”, “molecules/cm^2”, “mol/cm2”, “mol.cm-2” or “mol cm-2". In other cases, units have been introduced for certain measurements to highlight the difference between them and other similar types of measurements. For example, certain particulate organic carbon compound measurements, e.g., water soluble carbon (WSOC) measurements, are reported in micrograms of carbon per cubic meter (ugC/m3). Aerosol composition measurement units, on the other hand, are usually stated by the instrument scientists as micrograms per cubic meter (ug/m3). Often, however, this unit has the added notation “s” or “std” (ug/sm3 or ug/stdm3), to indicate that the measurements are reported at standard temperature and pressure. This ensures they can be readily compared with measurements of the same quantity from other locations or times without the effect of temperature and pressure changes. Neither of these notations are typically defined in the data files; hence some researchers are likely to be unfamiliar with them. Unitless variables also contain a wide range of notation, including none, fraction, N/A, or the SI standard of “1”. These self-introduced units can be substituted with standardized units and an appropriate variable description. Implementing this standardization will promote data (re)usability and interoperability.

The most widely adopted system of units in the world nowadays is the International system of units, SI (from French Système international d'unités), which was first published in 1960 [2]. The SI system extends the metric system and, especially in the recent years, has been extensively used in scientific communities and adopted as the official unit system in many cases. Two issues, however, are driving our recommendation of WMDR rather than SI: backward compatibility to existing literature and data records, and the required use of some of the extended ASCII characters, including Greek characters, superscripts, and exponents, in SI unit symbols. The SI system is founded on base units and includes derived units in terms of base units that can be recursively constructed from base units or other derived units. However, there are some units

ubiquitous within Earth Science data products and literature which are not represented in SI and have no SI equivalent (e.g., parts per million by volume (ppmv)) or which predate the SI standard (e.g., the Dobson unit (DU) and pH unit). Strictly enforcing the use of SI units could hinder machine actionability and backward compatibility of a large volume of NASA Earth Science data. If existing data files and literature refer to units that have no equivalent in the adopted standard, then systems programmed to only recognize standard terms will struggle to interoperate with those existing data files and literature. WMDR, in contrast to SI, is more inclusive with respect to the types of units that can be used, thereby reducing the likelihood of backward incompatibility. Moreover, WMDR provides a mapping between non-SI units and SI units, when applicable. This allows user communities to continue using their own units, while providing a well-maintained and up-to-date resource for translating to SI units as necessary, thereby improving interoperability with communities adhering to the SI standard.

The second issue that is driving our recommendation of WMDR over SI is the use of some extended ASCII characters, including Greek characters. These characters can be problematic for ASCII file format standards still widely used in the Earth Science community, e.g., ICARTT [3]. Translations across platforms and operating systems are sometimes inaccurate, introducing errors in the data. For example, “µg” can sometimes become “mg” after a file exchange between PC, Mac, and Linux servers. Some of these characters are also not suitable for use in URIs or URLs, hindering the transition of SI terms into web resources. On the other hand, WMDR notation (equivalent to SI unit symbol) relies exclusively on a set of ASCII characters that are suitable for most data formats used within the Earth Science research community, and to construct URIs and URLs.

Programmatic handling of units expressed using, e.g., Greek characters - as the CF (Climate and Forecast (CF) Metadata Convention) Standard [4] currently used within NASA permits - is problematic as such characters are not suitable for tools and services developed for use with the ICARTT format, which is also a NASA standard. We propose, therefore, standardizing unit notation within EOSDIS by adopting the WMDR notation. We also recommend that the CF Convention constrain the allowable notation for expressing CF standard units to that used by WMDR, and that the Unidata UDUNITS package be extended to include WMDR notation.

The CF units convention allows multiple notations. According to the CF guidelines, “The value of the units attribute is a string that can be recognized by Unidata’s UDUNITS package, with a few exceptions” [4]. The strings that are recognizable by Unidata’s UDUNITS package are found in the UDUNITS-2 database [5], which is comprised of SI units, units accepted for use with SI, and non-SI units. A unit such as “kilograms per square meter per second”, for example, can be written as kg/m^2/s, or kg m-2 s-1, or kg m^-2 s^-1. Units may be multiplied together, indicated by a space or a dot ‘.’; taken to an integral power, denoted using ‘^n’ or ‘**n’; or divided by a quotient using either ‘per’ or ‘/’ or a negative number [6].

Not only does this flexibility hinder machine readability, but as mentioned above, many of the permitted symbols and/or characters are unsuitable for ASCII-based data formats, and for

constructing URIs or URLs. URI's are composed from an allowed set of ASCII characters. The reason this is important is because some of the characters currently used in SI are not part of the allowed set of characters (e.g., the mid-dot), and others (e.g., "/") have special meanings in a URL string. WMDR units have URLs that are conveniently constructed by concatenating the WMDR code to URL and the actual notation used to express the unit. For example, the WMDR unit "kg.m-2.s-1" has this url: https://codes.wmo.int/wmdr/unit/kg.m-2.s-1. If this URL were written as https://codes.wmo.int/wmdr/unit/kg/m^2/s, however, it would be parsed and interpreted incorrectly.

2. WIGOS Measurement Unit

WIGOS is the regulatory framework that guides the implementation of a multi-component Earth observing system managed by WMO members and partner organizations. WIGOS is comprised of a wide array of Earth system measurements, involving both in-situ and remote sensing instruments related to atmospheric composition, hydrology, terrestrial and outer space disciplines. The WIGOS Metadata Standard (WMO-No.1192) [7] is designed to ensure "maximum usefulness" of WIGOS observational and modeled data. Metadata is expressed using the WIGOS Metadata Representation (WMDR), a set of codes covering ten categories: Observed variables, Purpose of observation, Station/platform, Environment, Instruments and methods of observation, Sampling, Data processing and reporting, Data quality, Ownership and data policy, and Contact. Using the WMDR codes (https://codes.wmo.int/wmdr) from all 10 categories can provide a comprehensive description of measurements enabling proper interpretation of the data in WIGOS data products.

The WMDR category, *Observed variable*, includes a code list for "Measurement unit" [1]. This list provides standardized unit notations and descriptions. Both aspects are fundamental to make data (re)usable and interoperable. The WMDR measurement unit code list leverages SI base units (e.g., m for meter and s for second), SI derived units (e.g., m s^{-1}), and units accepted for use with SI (e.g., h for hour). Each WMDR unit is clearly defined and is designated as a SI base unit, SI derived unit, or unit accepted for use with SI. Equivalency to SI base units is also provided for SI derived units, units accepted for use, SI, and conventional units when applicable. Individual URIs are provided for each measurement unit in the code list.

The WMDR measurement unit notation takes the same format as the SI unit symbol with several modifications to ensure the notation can be readily used in URLs. The mid dot, "·", was replaced with a period "." to represent a multiplication relationship. Superscripts, used by SI to indicate power functions (e.g., $m{\cdot}s^{-1}$ (meter per second)) are denoted by positive and negative numbers (for example, "m2" or "m.s-1") in WMDR measurement unit notation. The WMDR measurement unit notation only uses the twenty-six letters used in English version of the Roman alphabet, replacing Greek letters with Roman letters (e.g., "u" instead of "μ" or °C to degC). The Roman letters in the current version of the notation may be case sensitive in a few cases, e.g., "A" for Ampere and "a" for year. These changes enabled the WMDR measurement unit notation

to be readily used in ASCII data file format, e.g., ICARTT format [3], without concerns of being converted to illegible characters.

The WMDR measurement unit code list was recently updated to maximize compatibility with the SI unit system and to standardize conventional units that are widely used by the community and literature publications. This is not to say that units used within literature publications are or will be standardized with the WMDR unit code list, but that the WMDR unit code list is compatible with the nomenclature that is commonly used. For example, the Dobson Unit was included, which has been used to report ozone column measurements made for over a century. Similarly, units used to express volumetric mixing ratios, e.g., ppmv, ppbv, and pptv, were also adopted, reflecting their use in measurements and literature for well over five decades.

Since the same or similar measurement technologies are being used by NASA and the WMO, the WMDR unit code should provide adequate support to the NASA Earth Science observation and modeling activities. Applying the WMDR measurement unit broadly across NASA Earth Science data products would enhance data (re)usability and interoperability, which supports the implementation of the open-source science initiative.

3. Maintenance

The WMDR Measurement unit codes, along with the other WMDR codes, are maintained and supported by the WMO SC-IMT (Standing Committee on Information Management and Technology) expert team on metadata (ET-Metadata). The WIGOS codes GitHub repository (https://github.com/wmo-im/wmds) is used to document issues which are submitted by a wide range of users (e.g., data centers, data providers, and data users) for issues encountered in application of the current code and/or the need to add new codes. The git repository is constantly monitored by the Task Team on WIGOS Metadata (TT-WIGOSMD). Submitted issues are reviewed during task team meetings and assigned to a team member to moderate further discussion among the team members and outside experts, aiming to develop a resolution. The addition of new codes, e.g., units, or modification to the existing codes can become official in as little as six months by going through the WMO Fast-Track procedure.

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Normative References

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Appendix A - Glossary

Acronym	Description
ASCII	American Standard Code for Information Interchange
CF	Climate and Forecast (CF) Metadata Conventions

ESCO	ESDIS Standards Coordination Office
ESDIS	Earth Science Data and Information Systems Project
HDF	Hierarchical Data Format
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
LARC	Langley Research Center
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
RFC	Request For Comment
URI	Universal Resource Identifier
URL	Universal Resource Locator
SI	International System of Units
WIGOS	WMO Integrated Global Observing System
WMDR	WIGOS Metadata Representation
WMO	World Meteorology Organization