CF Metadata Conventions

Status of this Memo

This is a description of an ESDS Community Standard.

Distribution of this memo is unlimited.

Change Explanation

This is the first draft

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Abstract

This document nominates the Climate and Forecast (CF) Metadata Conventions [1] for adoption as a NASA ESDSWG community standard. The CF Metadata Conventions are intended to promote interoperability among data providers, data users, and data services by providing a clear and unambiguous standard for representing geolocations and times of earth-science data, physical quantities that the data represent, and other ancillary information useful in interpreting the data or comparing it with data from other sources.

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1 Introduction

Metadata conventions are agreements restricting metadata representations to limit the number of equivalent possibilities with which software must deal, and thus to foster interoperability. Conventions are needed in addition to standard scientific data formats, primarily because such formats support multiple equivalent ways to represent the same metadata.

Equivalent variations include ways to name things, ways to represent relationships, and ways to locate data in space and time. Although a human may be able to ignore gratuitous differences and recognize a variety of metadata representations as equivalent, it is difficult to write software that handles such differences. Conventions that select a single way to represent metadata make it practical to write software that "understands" the metadata. The resulting uniformity of access supports the development of applications with powerful extraction, regridding, analysis, visualization, and processing capabilities.

Conventions also document specific recommended ways to make good use of the abstractions supported by general data models to represent data semantics. Conventions embody the experience of practitioners who have discovered or invented ways that work well to capture the meaning in data and to make data semantics accessible to humans as well as programs.

Conventions may also add value to scientific formats by providing higher-level abstractions such as coordinate systems, and by supporting capabilities needed by specific communities, such as standard names for physical quantities to determine whether data from different sources are comparable and to distinguish variables in archives.

At this time, no standard for the CF conventions exists that is endorsed by a recognized standards organization and that provides sufficient detail for confident use in scientific archives intended to preserve the scientific integrity and usefulness of datasets over the long term. Making CF an ESDS standard provides a reference that describes the meaning of CF-compliance for data stored in a multitude of archives. A published reference standard increases confidence that data in CF-compliant archives will continue to be useful, because it transcends issues concerning the future availability of specific hardware and software. Such a standard may also encourage increased interoperability of data services, scientific analysis software, and data management software, as researchers, data providers, and developers learn of the existence and usefulness of the CF Conventions.

Adding to the value of a standard for the CF conventions are the availability of two technologies associated with the growing popularity of CF metadata, netCDF-Java and the NetCDF Markup Language (NcML). The netCDF-Java software can access data stored in more than 20 formats through a Common Data Model interface which adds CF conventions for coordinate systems "on-the-fly" as the data is accessed. For example, a properly configured server can serve files in GRIB format as if they were CF-compliant netCDF data. This permits applications written for CF-compliant data to handle many other kinds of data from such servers. The second technology is NcML, a dialect of XML that can be used to create virtual datasets that aggregate existing datasets or add metadata to achieve CF-compliance, again without modifying the referenced datasets. A collection of existing data can frequently be made to appear to be CF-compliant by writing a small NcML "wrapper" that provides the necessary additional metadata for files in the collection, when accessed through the NcML virtual dataset.

2 References

Normative References

[1] Climate and Forecast (CF) Metadata Conventions, R. Rew, Attached as Appendix to ESDS-RFC-021v0.02

3 Authors' Addresses

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4 Appendix A - Glossary of terms and acronyms

Acronym	Description
CF:	Climate and Forecast (CF) Metadata Convention
GRIB:	Gridded Binary Format
NCAR:	National Center for Atmospheric Research
NcML:	NetCDF Markup Language
netCDF:	network Common Data Form
XML:	eXtensible Markup Language

5 Appendix B – CF Metadata Conventions

CF Metadata Conventions

1 Status of this Memo

This is a description and formal specification of the Climate and Forecast Metadata conventions, provided in enough detail to support independent implementations of software to promote interoperability among data providers, data users, and data services.

Distribution of this memo is unlimited.

2 Change Explanation

This is a first draft.

3 Copyright Notice

4 Abstract

This is a description of the specification for a community standard for metadata used for Earth science datasets. The CF Metadata Conventions are intended to promote interoperability among data providers, data users, and data services by providing a clear and unambiguous standard for representing geolocations and times of earth-science data, physical quantities that the data represent, and other ancillary information useful in interpreting the data or comparing it with data from other sources.

This document provides references to authoritative documents at the cfconventions.org web site that describe how to create CF-compliant datasets, how to develop software that interprets CF-compliant data, how to propose additions to CF, and how such additions might become part of the evolving CF metadata standard. It also generalizes the applicability of the concept of CF-compliance by explaining the sense in which CF metadata conventions are independent from the specific data format in terms of which they are expressed.

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5 Introduction

The goals of this document are to:

- Overview the development of the CF Conventions
- List the principles that have guided the development of the CF Conventions
- Provide authoritative references to the three primary CF standards documents
- Clarify the meaning of CF-compliance
- Explain the sense in which CF Conventions are independent of data format
- Reference descriptions of the process for continued development and maintenance of the CF Conventions

5.1 Development of the CF Metadata Conventions

The 1993 version of the NetCDF User's Guide documented a small set of attribute conventions for netCDF files, including a handful of conventional names for variable attributes that included `long_name`, `missing_value`, and `units`. In 1995, the "Cooperative Ocean/Atmosphere Research Data Service (COARDS)", a NOAA/university cooperative led by Steve Hankin (NOAA PMEL) for sharing and distributing global atmospheric and oceanographic research data sets, published the COARDS Conventions [I3], an extension to the earlier User's Guide Conventions. Two independent extensions of the COARDS Conventions were developed subsequently, the GDT Conventions with authors Jonathan Gregory (Hadley Centre, UK Met

Office), Bob Drach (PCMDI, LLNL), and Karl Taylor (PCMDI, LLNL), and the NCAR-CSM metadata conventions authored by Brian Eaton (NCAR). In December, 1999 an effort to merge the GDT and NCAR-CSM conventions into a new CF Metadata Conventions was begun. The initial version was developed by Eaton, Gregory, Drach, Taylor, and Hankin, and was released in October 2003, following two years of community discussions of earlier drafts.

As reflected in the name, the original purpose of the Climate and Forecast Metadata Conventions was to provide a clear and unambiguous standard for representing metadata for climate and forecast model output encoded in the netCDF binary format, specifically spatiotemporal locations of grid output and other information needed to facilitate model output comparisons.

Further development has resulted in broadening the scope of CF metadata to include descriptions of observational data and derived products, while remaining focused on issues of common and frequent concern in the design of metadata representations for the earth sciences.

Examples of such issues include:

- Provenance
- Data description
- Uniform identification of physical quantities
- Specification of coordinates
- Methods for packing and compression
- Grid cell properties and interpretation

After the initial release of CF-1.0 in 2003, discussions continued on the community CF email list that resulted in suggestions for various additions. As often occurs in such email discussions of proposed changes, new issues surfaced without always resolving previous issues or coordinating discussion to reach consensus. The need for a more formal process for deciding what suggestions and proposals deserved adoption became apparent to most participants. The activity of refining and approving proposals for new standard names for physical quantities was an additional but mostly independent effort that occasionally resulted in delays from lack of adequate time and funded staff resources. Ultimately discussions held at the BADC in 2005 resulted in the white paper "Maintaining and Advancing the CF Standard for Earth Science Community Data" [I4] outlining proposals for maintaining the scientific integrity of the CF conventions while transitioning to a community governance structure from informal maintenance by the original authors. Community processes that have since evolved are summarized below.

The subsequent success of the CF Conventions, evidenced by their widespread use in climate and ocean modeling communities, has demonstrated the soundness of this approach to developing a community metadata standard. The CF Conventions web site lists more than 30 groups, projects, and institutions [I5] that have adopted or encourage use of CF conventions for their metadata. Use of CF Conventions was mandated for archiving model output in the PCMDI archives associated with the IPCC Fourth Assessment, and open access to the resulting WCRP CMIP3 multi-model datasets has resulted in over 530 scientific publications as of this writing.

Current development efforts include community agreement on how to specify metadata conventions for common kinds of observations, remote sensing data, and derived satellite products. Although continued evolution of the CF conventions has been largely through volunteer efforts from the community, modest funding has supported stewardship of a CF Conventions web site at LLNL for maintaining authoritative versions of the conventions documents, scientific support at the UK Met Office to vet proposals for additions to the CF

Standard Names table, and resources at NOAA NESDIS to develop conventions for satellite data products and to coordinate resolution of conventions issues raised by proposed additions. Originally framed as a netCDF-based standard, efforts to establish CF as format independent are also under way and discussed below.

The CF Conventions by design do not attempt to anticipate all future needs for metadata in the earth sciences. Instead they are growing and evolving to incorporate solutions to newly identified needs as agreed to by a community of modelers, data providers, software developers, and users. As the need for new metadata conventions is clarified, new additions to CF result in new versions of the three authoritative CF documents. The standard embodies a community commitment to preserve backward compatibility for CF-compliant data and software, so that previously existing data archives and application programs will not have to be rewritten due to additions to the standard.

Although this RFC is associated with specific versions of the three CF documents, it also lists the principles that preserve the integrity of new versions with respect to previous versions, specifies how to access current versions of the authoritative documents, and describes the process under which the standard evolves.

5.2 Guiding Principles

Five general principles, first articulated by Jonathan Gregory [I6], continue to guide development of the CF Conventions:

- Data should be self-describing, without external tables needed for interpretation.
- Conventions should only be developed for known issues, when the need is apparent and not before.
- Conventions should be easy to use for both data writers and data readers.
- Metadata should be understandable to humans as well as easily interpretable by programs.
- Redundancy should be minimized to avoid inconsistencies when writing data.

The desire to avoid the need for consulting external tables maintained at centralized registries makes the CF conventions relatively self-contained and independent of changes adopted in other standards. Developing conventions on an as-needed basis, without trying to anticipate more general needs in the indefinite future, keeps the conventions concise and grounded with immediate feedback helping to avoid mistakes. The conventions could be designed to favor data readers at the cost of being more onerous for data providers, but this is likely to result in data providers ignoring use of the conventions, defeating the goal of fostering data sharing and interoperability. Using binary forms incomprehensible to humans could more concisely represent metadata, but this defeats the goals of ease of use for readers and data self-description. When redundancy in representations is permitted, extra care is needed to guard against or deal with the possibility of resulting inconsistencies.

In addition to general principles, various informal guidelines have kept the use of CF conventions coherent and consistent with the underlying data model, which represents information using *dimensions*, *variables*, and *attributes*. Briefly, a variable is a value or multidimensional array of values of the same type, which has associated attributes that hold metadata about the variable, such as units. Dimensions are used to specify variable shapes, grids, and coordinate systems, and may be shared among variables, indicating common axes or grids. The CF Conventions document includes a more comprehensive description of the data model, which is the netCDF "classic" model [I7].

Some specific guidelines for CF conventions include the following:

- Conventions are implemented by agreements about the names and values of attributes, not variables.
- CF-specific attribute names follow a specified conventional style and spelling.
- Specific units of measurement are not specified, allowing use of physically equivalent units of measure to be specified in a *units* attribute.
- Aliases may be used to support superseded standard names and to correct mistakes.
- Limited redundancy is tolerated if it supports the independence of variables from each other, so that extraction, copying, and merging of separate variables is more practical.

The CF Metadata Conventions document includes many examples that further illustrate both mandatory and recommended ways to represent metadata following the CF principles and guidelines.

6 Standard documents

There are three CF documents for which a standards endorsement is sought:

1. CF Metadata Conventions, version 1.4
2. CF Standard Names, version 13
3. CF Requirements and Recommendations, version 1.4

The CF Standard Names table has a different version than the other documents, because it is subject to more frequent additions and thus evolves independently and more rapidly than the other CF conventions documents.

6.1 CF Metadata Conventions

The first of the three authoritative standard CF documents, "NetCDF Climate and Forecast (CF) Metadata Conventions," [N1] is maintained in HTML and PDF forms accessible from links on the web page http://www.cfconventions.org/documents/. It provides an overview of the conventions and underlying data model, followed by descriptions of CF attributes for variables, coordinate types, coordinate systems, labels, multidimensional cells, and methods for dataset size reduction. The document is color-coded to identify provisionally accepted additions to the conventions.

In version 1.4, the conventions are specified in terms of 36 CF-specific attributes, 21 grid mapping attributes, and short lists of special values for particular attributes, such as the four Standard Name Modifiers. Two summary appendices list and define all these CF-specific attributes and modifiers. Depending on data complexity, individual datasets may require specification of only a few of these attributes for CF compliance, or many if multiple coordinate systems are represented in the same dataset, for example. Some CF attributes are optional for reasons of backward compatibility, but recommended when compatibility with earlier archives or applications is not a significant issue.

As will be explained below, only the values of CF attributes are considered in determining CF compliance. The presence of additional attributes from other conventions or standards has no effect on whether a dataset is CF-compliant. Similarly, whether an application is CF-compliant depends only on how it interprets CF-specific attributes, and not on what it does with other attributes not mentioned in the CF Conventions.

6.2 CF Standard Names

The second of the three authoritative standard CF documents, "The CF Standard Name Table," [N2] is maintained in synchronized XML and HTML forms that are accessible from links on the web page http://www.cfconventions.org/documents/. The HTML document provides search and subsetting services to assist in displaying all the standard names within a field and determining whether a standard name is already available to identify a specific physical quantity.

CF standard names specify an agreed upon way to identify physical quantities, independent of unit or measuring method. They are not variable names, but carefully constructed noun-phrases in a controlled vocabulary intended to be used as values of the variable-specific attribute `standard_name`. (Variable names, on the other hand, are not standardized by the CF Conventions, so can be chosen for convenience, may be in languages other than English, and may use UTF-8 encoded characters not in the US ASCII character set.)

As clarifying examples, some of the shorter names from the CF Standard Names table include `air_temperature`, `plant_respiration_carbon_flux`, `divergence_of_wind`, and `ocean_vertical_diffusivity`. Each name has an associated "Meaning" entry in the Standard Name Table that offers explanatory details such as

> … In accordance with common usage in geophysical disciplines, "flux" implies per unit area, called "flux density" in physics.

A "Canonical units" field is also provided for each entry in the table, but any equivalent units may be used for data values, as specified by the `units` attribute.

When a standard identification of a quantity or field is needed for which no acceptable standard name is available, the CF document "Guidelines for Construction of CF Standard Names" [I8] provides details about constructing new standard names, including conventional ways to specify surface, component, medium, process, and condition within a standard name. Rules are also provided for the character set, spelling, acceptable qualifying phrases, and transformations to derive new standard names from existing standard names.

Because the standard name table is a controlled vocabulary arrived at by community agreement using an open process governed by agreed upon rules, it has been widely adopted in earth-science contexts as a format-independent standard for precisely specifying physical quantities in the categories that include atmospheric chemistry, atmospheric dynamics, carbon cycle, clouds, hydrology, ocean dynamics, radiation, sea ice, and surface.

The standard names table is maintained independently from revisions to the CF Metadata Conventions document, so it has a different version number. Once entered, names are not removed, but they may later become aliases for revised names that improve existing names or correct errors.

6.3 Compliance: CF Requirements and Recommendations

The last of the three authoritative standard CF documents is "CF Requirements and

Recommendations," [N3] and it is maintained in HTML form accessible from a link on the web page http://www.cfconventions.org/conformance/. This is a versioned document intended to provide a concise summary of all rules and recommendations for conformance in the corresponding version of the CF Metadata Conventions document. If there are any discrepancies between the two documents, the longer Conventions document is the ultimate authority.

Many of the conventions are described as optional, either because they describe features added since an earlier version of the CF conventions, or because the conventions were originally written to be backwards compatible with the earlier and simpler COARDS conventions [I3].

For users of the CF conventions not concerned with COARDS compatibility or compatibility with earlier versions, relevant optional conventions should be treated as strongly recommended.

The CF Conventions are intended to promote interoperability among data providers, data users, and data services. Software and services that support CF Conventions should be able to access metadata and data from CF-compliant datasets or to provide CF-complaint data.

A file is compliant if it follows all the requirements of the CF Conventions document, which are the same requirements listed in the CF conformance document. These include obligations, prohibitions, and recommendations. A CF-compliant file must conform to the obligations and prohibitions, but need not implement the recommendations. The presence of extra attributes not mentioned in the CF conventions in otherwise CF-compliant data preserves CF-compliance. CF-compliance checkers for data are available from the cfconventions.org web site.

An application or service that provides data is CF-compliant with regard to output if the output is a CF-compliant file, or would be CF-compliant if stored as a file. As an example, a server that provides specified subsets of data from an aggregation of GRIB files made to appear as a single virtual dataset that is accessed through an interface as if it were a CF-compliant file is CF-compliant.

An application that reads data is CF-compliant if it properly interprets all required CF metadata. Determining whether an application that reads data is CF-compliant is difficult, because no comprehensive collection of test data currently exists that can be used for ascertaining compliance. Even if such a collection of data were available, specifying a set of tests for the proper behavior for visualization and analysis applications (for example, "calculate the zonal mean of surface temperatures") would still be difficult. An application that ignored all optional metadata could be compliant without being very useful.

Versioning adds some nuances to the concept of CF-compliance. A file that is compliant to CF-1.0 is also compliant to CF-1.4, because the process of evolving new versions of the CF conventions preserves backwards compatibility. However, a file that is compliant to CF-1.4 may have CF metadata that cannot be properly interpreted by a CF-1.0 compliant application.

Data providers should not necessarily be constrained by the state of CF-compliance for current applications that analyze, visualize, or process data. To provide comprehensive metadata for archives intended for future use, it is wise to include optional but recommended conventions even if the metadata they represent cannot yet be properly interpreted by existing software.

6.4 Format Independence of CF

As a standard for naming physical quantities, the CF table of standard names is independent of the netCDF data format or data model. CF standard names are already being employed with non-netCDF formats and in other ontology projects, for example MarineXML [I9] uses a GML encoding of CF standard names in support of a framework for improving the interoperability of data for the marine community.

In contrast, the CF Conventions are currently written as a way to encode metadata in netCDF classic format files, represented using the netCDF classic data model [I7]. Furthermore, netCDF and CF are sometimes used in combination to specify a single standard for binary encoding, for example the netCDF-CF extension proposed for the OGC Web Coverage Service [I10]. It is also useful to consider whether CF is applicable to metadata representations for other data models and formats. In the following discussion, the netCDF classic data model on which the CF conventions are based will be referred to as the *CF data model* to emphasize its format independence.

Because of its simplicity and generality, other file formats can be modeled using the CF data model. Thus the concepts and relationships specified in CF may be applied to other formats by mapping the *variable*, *dimension*, and *attribute* abstractions in the CF data model to analogous concepts in the other formats, in a way that preserves the essential characteristics of the data model needed by the CF conventions.

For example, with suitable mappings, HDF5 [N6] is capable of representing metadata conforming to the CF Conventions in this more general sense, as demonstrated by the implementation of the netCDF-3 API on top of the HDF5 library. Where the CF Conventions documents refer to a *variable*, substitute the corresponding HDF5 concept of a *dataset*, and similarly for CF *attributes* and HDF5 *attributes*. The CF abstraction of a named dimension shared by multiple variables has no exact analogue in HDF5, but can be modeled by HDF5 *dimension scales* [I11], as used in the netCDF-4 software package to represent shared dimensions in HDF5. The fact that HDF5 dimension scales are more complex than CF dimensions is not relevant for the purpose of encoding CF metadata in the HDF5 format, because the extra complexity is not used.

Mapping the CF data model concepts into NcML [I12], netCDF-4 [I13], OPeNDAP [N5], or the Unidata Common Data Model [I2] is even more straightforward than for HDF5, because in each case the simpler CF data model is already embedded in the extended data model that includes it.

Employing such mappings of CF concepts into other data models and associated formats makes the CF standard more generally useful. Encoding CF metadata into other formats would be facilitated by agreement on standard mappings between the netCDF data model and the data models associated with the other formats. Taking this perspective is important for the evolution of CF, to ensure that extensions to the current CF data model can be faithfully mapped to other data models associated with formats in use for CF-compliant data, where here a more general sense of format-independent compliance is intended than in the previous section, where a specific binary encoding is required by concrete software applications.

7 CF Process for Evolution of Document Versions

7.1 Rules for Changes to the Standard Documents

The documents “Rules for making changes to the CF Conventions” [I14] and “Rules for correcting errors in the CF documents” [I15] are maintained at the CF conventions web site from links at http://www.cfconventions.org/governance The processes described there were agreed upon after open discussions on the CF email list, and archives of those discussions are also openly available at the same site.

An important aspect of these rules are the provisions that changes can be proposed and marked as provisional until implemented by multiple applications. This serves the needs of data providers for rapid incorporation of needed additions as well as the needs of developers for stability.

7.2 Working Committees

When it became clear, as a result of an expanding community of users and variety of applications, that the original small group of volunteer authors were no longer able to continue developing and maintaining the CF Conventions and CF Standard Names Table, governance arrangements were designed for the community to continue to guide the evolution of CF [I4]. Two committees of experts were constituted for conventions and standard names, respectively. The membership of each committee is open to those with significant interest and time to commit to taking CF forward.

The Conventions Committee is charged with overseeing changes to the CF standard, except for the standard name table and other controlled vocabulary. Their role is to develop, consider, and debate proposals for change, bearing in mind the needs of data-providers and data-users, consistency with CF as a whole, and backward compatibility. Membership of the Conventions Committee includes (but is not limited to) representatives of those who have reference implementations, who can provide feedback on the practicality of CF initiatives, and wish to validate tools as "CF-compliant".

The Standard Names Committee is charged with overseeing additions to the Standard Name table, considering and debating proposals for new standard names and for changes to existing standard names, and working towards interoperability with other vocabulary maintainers, bearing in mind the needs of data-providers and data-users, consistency with CF as a whole, and backward compatibility.

Although CF advancement is designed to be community-driven, a CF Governance Panel has also been formally established to be responsive to community needs. The Governance Panel, established under the auspices of relevant major international programs, has the ultimate responsibility for the maintenance and development of CF metadata conventions.

A list of the current membership of the two working committees and the Governance Panel is maintained at the CF conventions web site from links at http://www.cfconventions.org/governance.

8 References

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10 Appendix A - Glossary of terms and acronyms

Acronym	Description
ASCII:	American Standard Code for Information Interchange
BADC:	British Atmospheric Data Centre
CF:	Climate and Forecast (CF) Metadata Convention
CMIP3:	Coupled Model Intercomparison Project phase 3
COARDS:	Cooperative Ocean/Atmosphere Research Data Service
GML:	Geography Markup Language
HDF5:	Hierarchical Data Format, version 5
IPCC:	Intergovernmental Panel on Climate Change
LLNL:	Lawrence Livermore National Laboratory
MarineXML:	Marine extensible Markup Language
NCAR:	National Center for Atmospheric Research
NESDIS:	National Environmental Satellite, Data, and Information Service
netCDF:	network Common Data Form
NOAA:	National Oceanic and Atmospheric Administration
NcML:	NetCDF Markup Language
netCDF:	network Common Data Form
OPeNDAP:	Open-source Project for a Network Data Access Protocol
PCMDI:	Program for Climate Model Diagnosis and Intercomparison
PMEL:	Pacific Marine Environmental Laboratory

UCAR: University Corporation for Atmospheric Research

UTF-8: Unicode Transfer Format, 8 bit

WCRP: World Climate Research Programme

XML: eXtensible Markup Language