Assessing Stewardship Maturity of the Global Historical Climatology Network-Monthly (GHCN-M) Dataset: Use Case Study and Lessons Learned

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Abstract

Assessing stewardship maturity— the current state of how datasets are documented, preserved, stewarded, and made accessible publicly—is a critical step towards meeting U.S. federal regulations, organizational requirements, and user needs.

The scientific data stewardship maturity matrix (DSMM), developed in partnership with NOAA's National Centers of Environmental Information (NCEI) and the Cooperative Institute for Climate and Satellites–North Carolina (CICS-NC), provides a consistent framework for assessing stewardship maturity of individual Earth Science datasets and capturing justifications for transparency. The consolidated stewardship maturity information will allow users and decision-makers to make informed use decisions based on their unique data needs.

This DSMM was applied to a widely utilized monthly-land-surface-temperature dataset derived from the Global Historical Climatology Network (GHCN-M). This paper describes the stewardship maturity ratings of GHCN-M version 3 and provides actionable recommendations for improving the maturity of the dataset.

The results from the use case study show that an application of DSMM like this one is useful to people who produce or care for digital environmental datasets. Assessments can identify the strengths and weaknesses of an individual dataset or organization's preservation and stewardship practices, including how information about the dataset is integrated into different systems.

Keywords: Scientific Data Stewardship, Data Management and Preservation, Stewardship Maturity Matrix, Transparency, GHCN-M

1. Introduction

Digital environmental and geospatial data products are increasingly treated as important assets to both scientific and business communities. Information derived from environmental data is considered a valuable resource to the U.S. Federal Government (OMB, 2013; OSTP, 2013). As a result, there is greater scrutiny placed on organizations to ensure data quality, to convey data quality information, to provide easy and timely data access, and to promote data transparency and traceability (OMB, 2002; NOAA, 2011; see Peng et al. (2016) for an overview of U.S. Federal Government policies and some of the agencies' requirements on ensuring data quality and improving data sharing).

The National Oceanic and Atmospheric Administration (NOAA) is responsible for providing environmental intelligence to American citizens, businesses, and governments to enable informed decisions (Sullivan, 2013). NOAA collects and cares for geophysical measurements of more than two thousand diverse parameters. Data come from a broad range of platforms, including (but not limited to) satellites, fixed and mobile radars, research aircraft, buoys, ships, land-based in situ surface and upper air networks, and weather and climate models, each of which presents its own data management issues (NRC, 2007). Therefore, NOAA is facing a serious challenge to provide a wide breadth of trustworthy data in a timely and user-friendly manner in a rapidly changing and resource-limited environment.

The National Centers for Environmental Information (NCEI) fulfills NOAA's responsibility by ensuring and improving data quality, discoverability, and accessibility. As NOAA's designated national data center, NCEI is responsible for collecting, stewarding, and providing access to

atmospheric, oceanic, coastal, terrestrial, and solar observations. In recent years, environmental data volume at NCEI has grown at an astounding rate and is projected to grow even faster in the next decade and beyond (Fig. 1).

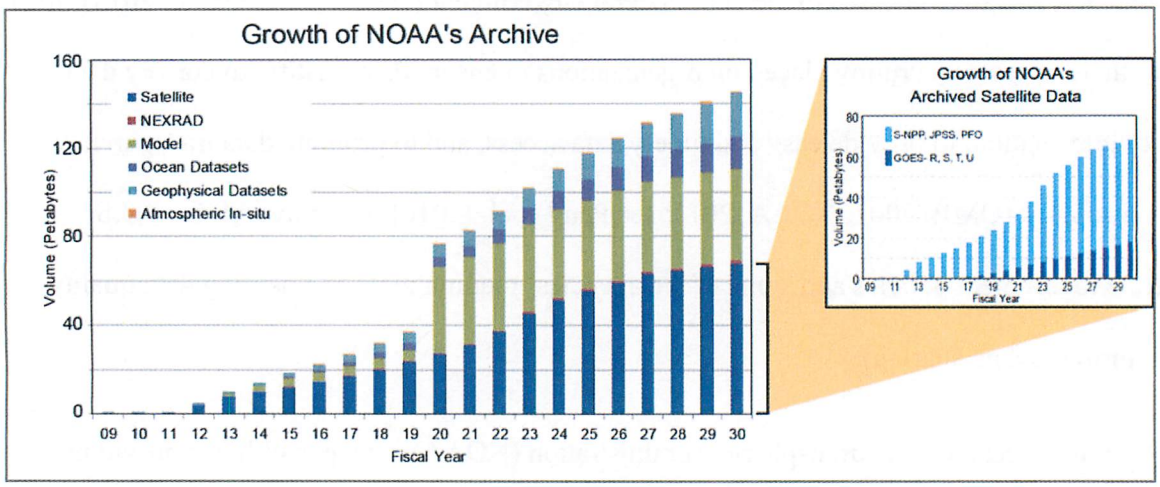

Figure 1: Environmental data archive volume at the NOAA's National Centers for Environmental Information (NCEI) since year 2009 and its projected data archive volume to year 2030.

Digital datasets of diverse data types with massive volume have become increasingly challenging to manage. This is especially true in the context of ensuring data and information quality while also meeting requirements to reduce latency and improve discoverability, accessibility, and traceability. But by systematically utilizing standardized reference frameworks for assessing quality of individual datasets, it is possible to capture, curate, and provide consistent, content-rich, quality information to users, thereby streamlining and simplifying data understanding and improving usability.

Several maturity assessment models have been developed and utilized for measuring the maturity of organizational capabilities and processes in the area of data preservation (see Peng et al., 2015

for an overview.) As the first work to focus on individual datasets, Bates and Privette (2012) introduced a reference framework for measuring the maturity of data products in a form of a matrix. In contrast to scientific quality of a data product, which is defined in terms of accuracy, precision, uncertainty, validity and suitability for use (Ramapriyan et al., 2016), product maturity addresses how well the scientific quality is assessed and documented, how complete the metadata and documentation are.

Adopting a similar approach, the Data Stewardship Maturity Matrix (DSMM) has been developed jointly by NCEI and NOAA's Cooperative Institute for Climate and Satellites - North Carolina (CICS-NC) (Peng et al., 2015). The stewardship maturity measures the current state of how datasets are documented, preserved, stewarded, and made accessible publicly (Peng et al., 2015; Ramapriyan et al., 2016).

DSMM aims for a consistent evaluation of the maturity of stewardship practices applied to individual datasets and captures justifications for transparency. For each of nine quasi-independent key components (Fig. 2), DSMM defines criteria based on measureable stewardship practices that can be used to apply a progressive, five-level rating to an individual dataset, representing maturity stages rated as Ad Hoc, Minimum, Good, Advanced, and Optimal (Fig. 2; see Peng et al., 2015 for the rationale and detailed definitions for each key component).

Maturity Scale / Key Component	Level 1 - Ad Hoc Not Managed	Level 2 - Minimal Managed Limited	Level 3 - Intermediate Managed Defined, Partially Implemented	Level 4 - Advanced Managed Well-Defined, Fully Implemented	Level 5 - Optimal Level 4 + Measured , Controlled , Audit
Preservability	*The state of being preservable*				
Accessibility	*The state of being publicly searchable and accessible*				
Usability	*The state of data product being easy to understand and use*				
Production Sustainability	*The state of data production being sustainable and extendable*				
Data Quality Assurance	*The state of data product quality being assured/screened*				
Data Quality Control / Monitoring	*The state of data product quality being controlled and monitored*				
Data Quality Assessment	*The state of data product quality being assessed*				
Transparency / Traceability	*The state of being transparent, trackable, and traceable*				
Data Integrity	*The state of data integrity being verifiable*				

Figure 2: Conceptual diagram showing the nine DSMM key components, 5-level scale structure, and high-level descriptions of what each key component measures.

(In the following, DSMM key components will be denoted using capitalization.)

For operational datasets managed by designated NOAA data centers such as NCEI (see NOAA, 2008 for the classification of NOAA data centers), Level 3 is the recommended minimum maturity rating for all nine key components (Peng et al., 2015).

A pilot use case study to apply DSMM to various NCEI data types (Table I) has been underway by NCEI's Data Stewardship Division (DSD), in collaboration with NCEI's Center for Weather and Climate (CWC) and NOAA's Climate Data Record Program (CDRP).

Table I: Selected NCEI Core Datasets for the NCEI Pilot DSMM Use Case Study Project

Data Type	**Dataset**
Satellite – polar ocean	NOAA/NSIDC Sea Ice Concentration Climate Data Record (CDR)
GIS – regional	Digital Elevation Models (DEM)
Station – global land	Global Historical Climatology Network-Monthly (GHCN-M)
Station – gridded – U.S. land	National Climate Division (nClimDiv)
Satellite – global ocean	NOAA Optimal Interpolation Sea Surface Temperature (OI SST) CDR
Physical Records – in situ - global land	Local Climatology Monthly Summaries
Paleoclimatology – global land	International Tree – Ring Data Bank (ITRDB)

The purposes of this pilot use case study are to:

1) demonstrate the utility of DSMM and evaluate its appropriateness and completeness over various NCEI data types;
2) establish a stewardship maturity baseline for selected NCEI high-utility datasets;
3) identify the area(s) of strength and weakness of stewardship practices applied to the datasets for decision-making support;
4) provide product users with a consolidated and consistent document for content-rich stewardship practice quality information and provide DSMM users, including data managers, with examples of maturity ratings and justifications of stewardship practices information;

5) assess the roles and knowledge required of the Integrated Product Team (IPT) members for effective stewardship maturity evaluation of individual datasets;
6) identify standards used for different data types, assess the need for defining a set of core data types, and define core data types, if needed, for consistent and scalable implementation; and
7) explore requirements for tool(s) to assess and display the current maturity rating, including how to define and display a roadmap for improvement in a systematic and easy-to-understand way.

In this paper, we describe results from a case study of applying the DSMM to the version 3 monthly land surface temperature data product derived from the Global Historical Climatology Network (hereinafter referred to as GHCN-M). This dataset was selected because of its importance to national and international climate monitoring and assessment activities. This paper will touch on the first five of the aforementioned seven goals of the pilot NCEI DSMM use case study project.

2. Why do we start with GHCN-M?

GHCN is an integrated database of climate summaries from land surface stations across the globe. Since the GHCN-M dataset was first released in the 1990s (Vose et al., 1992), it has been widely utilized and has provided the foundation for understanding trends and variability in global and regional temperatures. It provides data for ongoing monitoring of the global climate and makes it possible to place current conditions in historical perspective (e.g., most recent State of the Climate report by NCEI, see Blunden and Arndt, 2016). It is used in national and

international climate assessments (e.g., Karl et al., 2009; IPCC, 2013; Melillo et al., 2014) to understand how rapidly the Earth's climate is varying and changing in association with natural and anthropogenic influences. It also is a source of information for users in the private sector for understanding local and regional climate conditions.

GHCN-M version 3 has gone through the NCEI managed archival process and has been available to the general public since April 2011 (Lawrimore et al., 2011), with some modifications (Gleason et al., 2015). Enhancements to the dataset continue to be made, with version 4 currently under development and expected to be released in 2016. This makes the GHCN-M product an ideal candidate for assessing the maturity of stewardship practices applied to the data, thereby establishing a baseline of the maturity ratings of the current version and identifying potential areas of improvement for future versions of the product.

3. What we have found

a. Stewardship maturity ratings

The maturity of GHCN-M v3 has been assessed utilizing the DSMM assessment template (Peng, 2015; which can be freely downloaded from: http://dx.doi.org/10.6084/m9.figshare.1211954.) Results are displayed in Figs. 3 and 4, namely, stewardship maturity ratings diagram and scoreboard, respectively. (They are developed as a standard set of DSMM graphics. Although both diagrams present essentially the same maturity information, rating diagram (e.g., Fig. 3) provides a simple and clear view of the current ratings while the DSMM scoreboard (e.g., Fig.4) provides a high-level overview but potentially allowing users to dive in for more in-depth DSMM definitions. After carried out a maturity assessment of individual dataset utilizing the

DSMM assessment template, it is recommended to create a DSMM report, consisting of DSMM assessment metadata, maturity ratings, and justifications (e.g., Appendix A) and DSMM graphics (e.g., as shown in Figs. 3 and 4). Effort is underway as a part of the NOAA OneStop Project to systematically and automatically generate DSMM reports, publish those reports and integrate DSMM assessment information including stewardship maturity ratings into ISO collection-level metadata records.)

The current maturity ratings of GHCN-M v3 are at Level 2 or higher for all nine key components. Specifically, there are three Level 2, four Level 3, and two Level 4 key components.

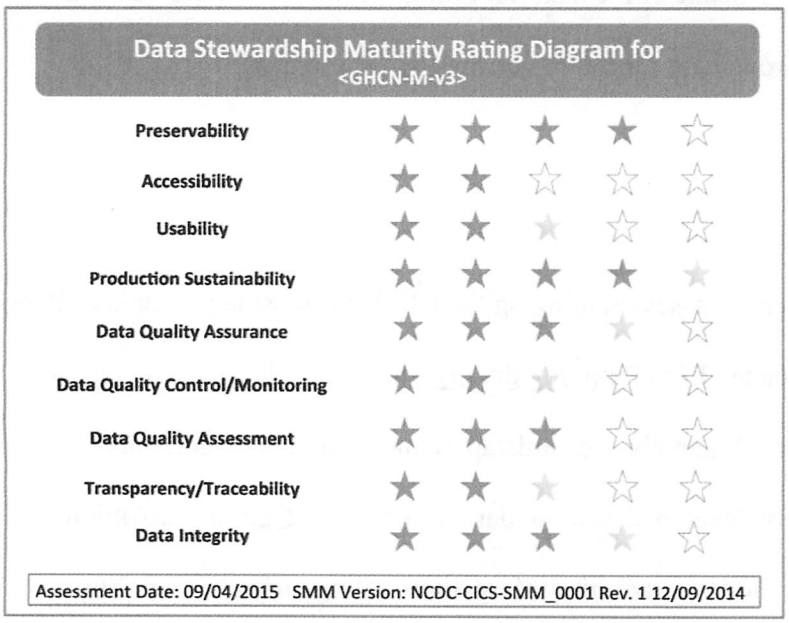

Figure 3: Data stewardship maturity rating diagram of GHCN-Monthly, v3. The dark filled stars indicate that all the practices are completely satisfied. The light filled ones indicated that not all the practices are satisfied. And the non-filled ones indicated that the practices are not satisfied.

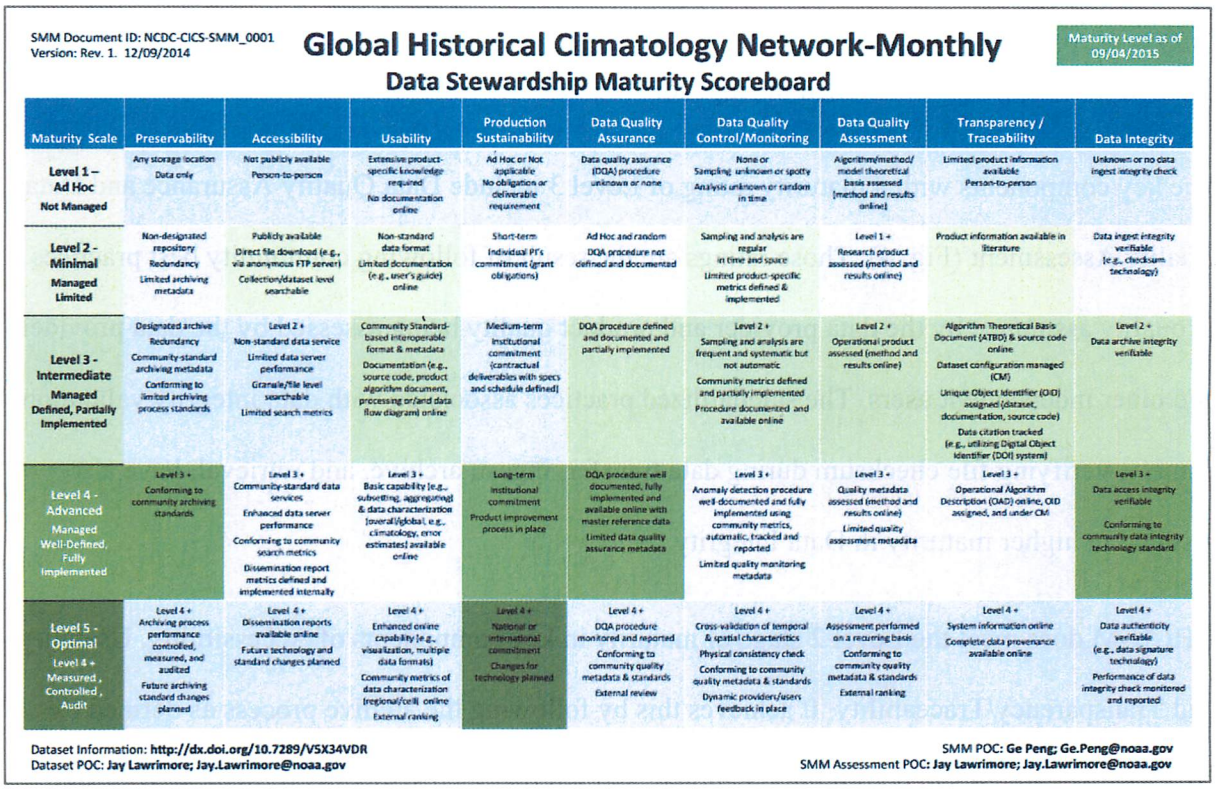

Figure 4: Data stewardship maturity scoreboard of GHCN-Monthly, v3. If two cells in the same column are filled, it is an indication that only a partial maturity rating at the higher level is satisfied. The scoreboard is only intended to provide a high-level overview of ratings.

The Level 4 key components are Preservability and Production Sustainability. The high rating in Preservability stems from multiple facets. NCEI has a well-defined and managed archival process that follows the ISO Open Archival Information System Reference Model (OAIS RM) (CCSDS, 2012). NCEI also complies with archive standards set by the National Archives and Records Administration (NARA).

Level 4 Production Sustainability is the result of long-term institutional and international commitment, along with the product improvement process that is in place (Fig. 4; the DSMM

document for GHCN-M, containing stewardship maturity assessment metadata, ratings and detailed justifications, is included in Appendix A).

The key components with a maturity rating of Level 3 include Data Quality Assurance and Data Quality Assessment (Fig. 4). Those ratings are the result of following community best practices in quality assurance by the data provider and product quality being assessed by the data provider and other independent users. The standardized practices associated with data integrity validation, namely, verifying file checksum during data transfer, ingest, archive, and retrieval, have also resulted in higher maturity in Data Integrity.

GHCN-M does meet the Level 2 stage of maturity in key components of Accessibility, Usability, and Transparency/Traceability. It achieves this by following the archive process as defined by NCEI, which adheres to community, national, and international standards for data stewardship. For example, an identifier unique to NCEI has been assigned and a digital object identifier (DOI) has been minted with a corresponding landing page (http://dx.doi.org/10.7289/V5X34VDR). In addition, the dataset has been documented with ISO collection-level metadata. However, the ratings for those components fall short of the recommended Level 3 maturity ratings for the NCEI operational digital datasets, largely due to a lack of publicly accessible information that meets the standard for Level 3. Details regarding methods for improving these three areas are provided in the following section.

b. Recommendations for Improvement

Fig. 5 summarizes actionable steps for a roadmap forward in achieving Level 3 ratings in all nine key components, based on DSMM. They are described in details below.

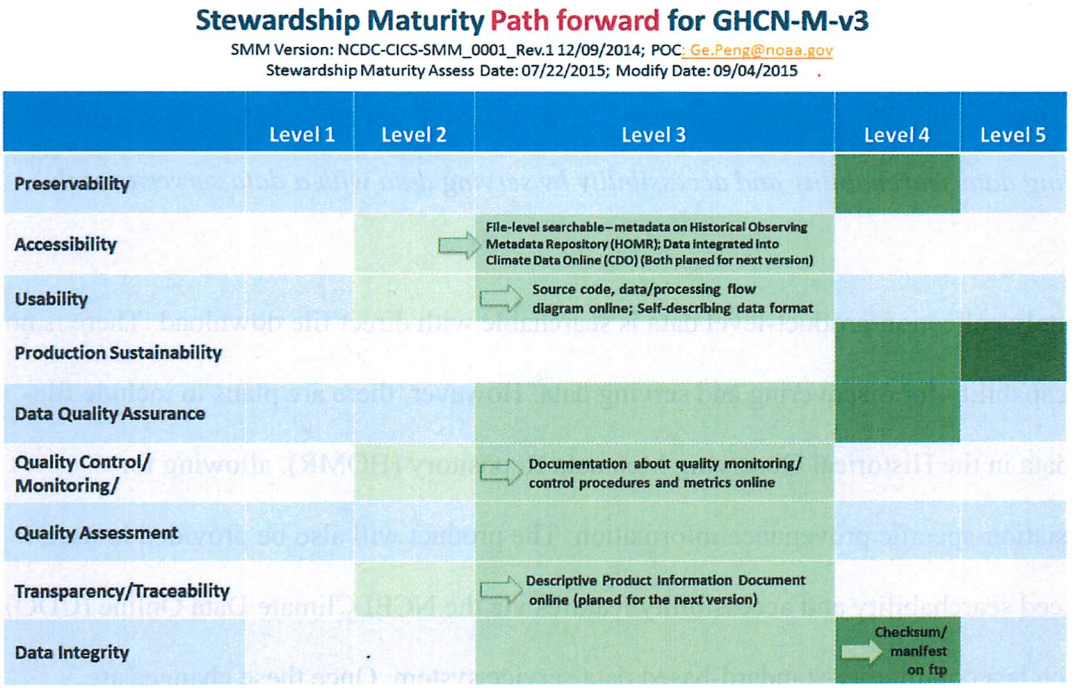

Figure 5: Diagram of path forward for improving the stewardship maturity of GHCN Monthly data product to Level 3 or higher, recommended ratings for NOAA's high-utility and high-impact digital environmental and geospatial datasets.

i. *Documenting data quality monitoring practices and making them available to users online*

The product quality is monitored regularly with flags and metrics online at the product site (http://www.ncdc.noaa.gov/ghcnm/v3.php). Quality monitoring metrics are consistent with the in situ community. Manual reviews of automatically generated plots or statistics are conducted regularly on a monthly basis. However, the procedure is not documented. Recommendation is to document the data quality monitoring procedure and practices and make them available online, which will be adopted for the next version and captured in the descriptive product information

document. Making this document publicly available will also improve the maturity rating of Transparency/Traceability.

ii. *Improving data searchability and accessibility by serving data with a data server or web service*

Currently, only collection/product-level data is searchable with direct file download. There is no additional capability for discovering and serving data. However, there are plans to include file-level metadata in the Historical Observing Metadata Repository (HOMR), allowing for additional station-specific provenance information. The product will also be provided to users with enhanced searchability and accessibility features via the NCEI Climate Data Online (CDO) portal, which is a community-standard-based data service system. Once these changes are implemented, it will improve the maturity rating in Accessibility to Level 3. This should allow users to effectively and efficiently find and use data based on their unique needs.

iii. *Making the checksum available for each of data file on the ftp server*

A checksum is a character string that represents the sum of the correct digits in a data file. It is used to ensure the integrity of a file, especially during transmission or storage. Upon reviewing the best practices defined for Data Integrity, the Access Specialist pointed out that it would require only a minimal effort to make the checksum available for each GHCN-M data file on the ftp server, because the checksums are already retrieved when data files are pulled from the archive and staged for access. Therefore, although not required for the minimum stewardship maturity requirement for Data Integrity, by making the checksum file available, the user can

verify the integrity of the downloaded data file. By doing this the Data Integrity rating will reach Level 4.

iv. Improving data usability by adopting a more scalable data format

Although it can be argued that the ASCII data format is well-utilized and accepted by the in situ data community, extra steps are recommended to improve data usability:

1) self-describing by adding additional station and product information to the ASCII data files, or convert to the JSON (JavaScript Object Notation) data format. JSON is an open standard and language-independent format that uses human-readable text to transmit data objects consisting of attribute–value pairs (Crockford, 2009).
2) using a standard-based machine-independent and scalable format, such as Network Common Data Form (NetCDF) compliant with CF (Climate and Forecast) metadata conventions.

c. Roles and required knowledge

As a part of this use case study, we have examined the appropriateness of the current roles for stewardship maturity assessment of a data product. For this particular purpose, initial self-assessments of the GHCN-M stewardship maturity were separately carried out by each member of the team—Archive Specialist, Data Manager, Dataset Subject Matter Expert (SME), and Access Specialist (see Table II for roles and their NCEI affiliation).

Table II: Attributes of GHCN-M Stewardship Maturity Assessment Team

Role	**NCEI Affiliation**
Archive Specialist	DSD/Archive Branch (AB)

Data Manager	DSD/AB
Dataset SME	CWC/Climate Science Branch (CSB)
Access Specialist	DSD/Data Access Branch (DAB)
DSMM SME/Co-Lead	CWC/CSB
Project Lead/Key Sponsor	DSD/AB

The self-assessment results and underlying knowledge base of each team member are observed by the DSMM SME and recapped below:

- The Archive Specialist is very familiar with the NCEI data archiving process, including metadata/documentation standards and procedures, but is not clear about where to get information for Usability and three data quality related key components,
- The Data Manager has a general knowledge of the data archiving process and the dataset, and is willing, and knows where or who to go to, to get additional information if not readily available,
- The Dataset SME has extensive knowledge of data quality (DQ) assurance, control/monitoring, and assessment, of how the dataset is being served to users, and some knowledge of the data archive process.
- The Access Specialist has extensive knowledge in how the data files are staged and integrated to (or lack of) a data server or web service, has first-hand experience in integrating the collection-level metadata into the NCEI geoportal (http://gis.ncdc.noaa.gov/geoportal/catalog/search/resource/details.jsp?id=gov.noaa.ncdc:C00839) , and knows the NCEI collection-level metadata ID.

Rating assessment input from different team members and primary information sources are summarized in Fig. 6a while rating spread for each key component is shown in Fig. 6b.

Unlike many Dataset SMEs, the GHCN-M Dataset SME was very familiar with NCEI data stewardship practices. With the knowledge gained going through the NCEI archive process for GHCN-M, and some basic training with the NCEI metadata creation tool, the Dataset SME was able to provide input for all key components, including Preservability. A large portion of product-specific information, such as data quality assurance and control related practices, are available at the NCEI product web site (http://www.ncdc.noaa.gov/ghcnm/v3.php) and in the literature, and the Dataset SME was well aware of them. The Data Manager was also able to provide input for all but one of the key components, leveraging personal knowledge on NCEI archival process and on the product, as well from information available online. Product-specific data quality information was considered as not readily available or known to both the Archive and Access Specialists.

(a) Rating Input & Knowledge Sources

	Archive Specialist	Access Specialist	Dataset SME	Data Manager	Primary Knowledge Source
Preservability	X		X	X	Preservation-specific knowledge; Document/standard Associated with defined & managed process
Accessibility		X	X	X	Product website; Search/access-specific technology knowledge – integration to existing systems; Web search
Usability		X	X	X	Product website/community-specific best practices and standard
Production Sustainability			X	X	Product-specific knowledge
Data Quality Assurance			X	X	Product website/domain-specific best practices; Literature
Data Quality Control/ Monitoring			X		Product website & product-specific knowledge
Data Quality Assessment			X	X	Product website; Literature
Transparency/ Traceability			X	X	Product website; Literature; practices associated with defined process
Data Integrity	X	X	X	X	Preservation/access-specific practices with defined & managed process

(b) Rating Input Spread

	1	2	3	4	5	Min	Max	# Entry
Preservability				4		3	4	3
Accessibility		2				2	3	3
Usability			3.5			2	3.5	3
Production Sustainability				4.5		4	4.5	2
Data Quality Assurance			3.5			3	3.5	2
Data Quality Control/Monitoring		2.5				2.5	2.5	1
Data Quality Assessment			3			2	4	2
Transparency/Traceability		2.5				2.5	4	2
Data Integrity			3.5			3.5	4	4

Figure 6: Diagram showing (a) GHCN-M stewardship maturity rating input from the team members and primary knowledge sources and (b) rating input spread.

It is easy to see that the stewardship maturity evaluation of individual datasets requires knowledge from multiple disciplines. Currently product-specific data quality information is not always publicly available. If they are, they are not always defined and captured in a consistent way. Therefore, product-specific quality information often need to be inferred or derived from literature or online sources, which is clearly beyond the task scope of the Archive and Access Specialists. As in the most of cases the Archive Specialist should be the person carrying out the DSMM assessment of individual datasets, it would be beneficial to document the data quality practices in a consistent way and make them readily available and easy for an Archive Specialist to understand. Until then, a team approach is the most effective way to carry out stewardship maturity assessment. Additional description and discussions can be found in Section 4b.

During this case study, a number of gaps in knowledge and systems were uncovered, and some of them will be described in the next section within the context of improved GHCN-M stewardship maturity. Although it pertains to this use case only, it could be beneficial to others who plan to apply DSMM to their dataset or to define system requirements for a consistent way of assessing any publicly available digital environmental and geospatial datasets.

4. Lessons learned

a. *Easy does not mean simple*

Providing a consistent framework is only the first step in providing a consistent stewardship maturity measure to users, which is also confirmed by the DSMM use case study carried out by the Data Stewardship Committee of the Federation of Earth Science Information Partners (ESIP) (Hou et al., 2015). A consistent and scalable way of applying the DSMM is still required, and

additional steps or adjustments may be needed to systematically assess maturity of individual datasets.

b. Effective stewardship maturity assessment requires the knowledge of practices in multiple disciplines

Peng et al. (2016) pointed out that effective long-term scientific data stewardship requires knowledge and oversight from multiple domains. This is also true for effective evaluation of stewardship maturity. Descriptions of individual knowledge domains and practices required for stewardship maturity assessment are provided below:

- Data preservation - Archive and metadata standards and data management practices, including those for data integrity and transparency.
- Scientific stewardship and documentation - data quality management practices (e.g., data quality assurance practices, data quality control/monitoring practices), product usability (e.g., data characteristics - climatology and variability; uncertainty estimates, etc.), and traceability.
- Tools and systems - Data access, data integrity, and data interoperability (technology)

c. Well-defined processes and documents are beneficial

Well-defined processes and documentation, along with general knowledge of the existence of those documents and the information they capture, help facilitate the stewardship assessment process. Examples include the NCEI-defined and implemented archiving process, the NCEI-defined Submission Agreement (SA) template, and a consistent web-based user interface for

collecting information about data collection (e.g., ATRAC (Advanced Tracking and Resource tool for Archive Collections) tool).

d. Other potential improvement areas

One of the potential improvement areas uncovered during this use case study, which pertains to NCEI processes, is that integration of cross-center processes and procedures in various parts of OAIS RM (and NCEI) can be improved. An example regarding the DOI landing page and product web page is provided below.

- A DOI for the data product is assigned and its landing page is created by the Archive Branch (archive) (http://dx.doi.org/10.7289/V5X34VDR) but not discoverable by performing a Google search. This DOI landing page is based on an ISO 19115-2 compliant collection-level metadata record, with a layout that is defined for all NCEI managed datasets. It provides dataset citation. However, there are three different dataset identifiers listed at the landing page without any description of what they are. (They are in fact, the DOI with the link to the landing page, NCEI dataset Identifier (9100_03), and the collection-level metadata Identifier (C00839).)
- The Archive Specialist is aware that a DOI is assigned and minted and knows how to get to the DOI landing page.
- The Data SME is not sure if a DOI is issued. The Data Manager believes that it is issued but could not find the landing page online.
- The NCEI product web site is created and overseen by the Access Branch (access) (http://www.ncdc.noaa.gov/ghcnm/v3.php). It provides valuable information on quality

assurance and homogeneity adjustment. It includes the "Data Access" tab that takes user to the ftp sites for the GHCN-M data files and additional station-specific information and plots.

- The DOI landing page provides a link to the product web site under the "Access" tab. However, there is no link from the product page to the DOI landing page. Furthermore, there is no "Metadata" tab in the current NCEI GHCN-Monthly product web page.
- The Access Specialist knows the NCEI collection-level metadata ID and its integration to geoportal (dissemination) (http://gis.ncdc.noaa.gov/geoportal/catalog/search/resource/details.jsp?id=gov.noaa.ncdc:C00839) which leads to the DOI landing page.

Under the current NCEI data archiving process, a DOI is assigned and minted after the dataset has gone through the archiving process and has passed the archive readiness review. The GHCN-M DOI landing page is not currently discoverable by search engines like Google. Since a DOI is a persistent, resolvable, and trackable identifier, it would be better for users to use this as a primary gateway to the product. Therefore, we recommend to improve discoverability of the DOI landing page. As information at the NCEI DOI landing page is based on the ISO standard-based collection-level metadata and contains information about the dataset such as spatial and temporal coverage, data access, etc., we recommended adding a "Metadata" tab at the product web page. This "Metadata" tab should be linked to the DOI landing page to provide users with a direct entry to consistent and standard-based product metadata and also to provide the data producer with a way of estimating data usage and impact by having a persistent and trackable product citation.

6. Summary

The stewardship maturity of a highly-utilized NCEI data product, GHCN-M, is assessed based on a reference stewardship maturity framework. The current maturity ratings of GHCN-M v3 are at Level 2 or higher for all nine key components with three Level 2, four Level 3, and two Level 4 key components (Fig. 3).

Well-defined and managed processes following OAIS RM are found to be beneficial, as expected, in ensuring consistency in maturity of all managed data holdings. It has contributed to Level 3 stewardship maturity ratings for GHCN-M in both Preservability and Data Integrity. Consistent metadata and documentation are not only beneficial for system integration but also good resources for the IPT members, although even more beneficial would be additional training or communication about processes and resultant metadata and documentation.

The web-based tool for creating collection-level metadata has improved accessibility by making it easy to integrate this information with other NOAA resources, such as NCEI Geoportal and the NOAA catalog, thereby enhancing searchability of the product. However, better integration between information about the dataset, namely, the collection-level metadata via the DOI landing page (http://dx.doi.org/10.7289/V5X34VDR), and information about the product via the product web page (http://www.ncdc.noaa.gov/ghcnm/v3.php) will provide characterization and quality information about the dataset to users in a seamless and integrated way, which will in turn enhance the usability of the dataset.

Potential improvement is identified in the areas of Accessibility, Usability, and Data Quality Control/Monitoring. Recommendations for actionable stewardship practices based on the DSMM

are outlined to improve the stewardship maturity of the product. For example, currently, the data files are created with and served in the ASCII format, which is still the commonly accepted file exchange format for the in situ data community. However, we have recommended providing self-describing ASCII data files. In addition, we encourage providing end-users with a more scalable, machine-independent, and self-describing data format such as NetCDF.

One unexpected benefit of this use case study is that all participants have gained a better understanding of the strengths and weaknesses of the dataset and the organizational capabilities. This knowledge will empower them not only to better carry out their current responsibilities but also to help promote the stewardship best practices going forward.

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Disclaimer: Any opinions or recommendations expressed in this manuscript are those of the author(s) and do not necessarily reflect the views of NCEI or CICS-NC.

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Appendix A

The stewardship maturity ratings and detailed justifications for the GHCN-M version 3 dataset are shown below.

Stewardship Maturity Matrix (SMM) as of <09/04/2015>
for <GHCN-M-v3>

Dataset Title	Global Historical Climatology Network-Monthly, Version 3
Dataset Information URL	http://www.ncdc.noaa.gov/ghcnm/v3.php; http://dx.doi.org/10.7289/V5X34VDR
Data Provider POC (Name; E-mail; Affiliation)	Jay Lawrimore; Jay.Lawrimore@noaa.gov; NCEI/CWC/CSD/DSB
Dataset POC (Name; E-mail; Affiliation)	Jay Lawrimore; Jay.Lawrimore@noaa.gov; NCEI/CWC/CSD/DSB
SMM Version (Document ID and Version Number)	NCDC-CICS-SMM_0001_Rev.1 12/09/2014
SMM POC (Name; E-mail; Affiliation)	Ge Peng; Ge.Peng@noaa.gov; Cooperative Institute for Climate and Satellites, North Carolina (CICS-NC), North Carolina State University (NCSU) & NOAA's National Centers for Environmental Information (NCEI) [1]
SMM Template Version (Document ID and Version Numbers)	NCDC-CICS-SMM_0001_Rev.1 v4.0 06/23/2015
SMM Template POC (Name; E-mail; Affiliation)	Ge Peng; Ge.Peng@noaa.gov; Cooperative Institute for Climate and Satellites, North Carolina (CICS-NC), North Carolina State University (NCSU) & NOAA's National Centers for Environmental Information (NCEI)
SMM Assessment Version (v<nn>r<mm>, e.g., v01r00)	v01r03
SMM Assessment Date (MM/DD/YYYY)	09/04/2015
SMM Assessment POC (Name; E-mail; Affiliation)	Jay Lawrimore; Jay.Lawrimore@noaa.gov; NCEI/CWC/CSD/DSB; Valerie Toner; valerie.toner@noaa.gov; NCEI/DSD/AB; Christina Lief; Christina.Lief@noaa.gov; NCEI/DSD/AB; Ge Peng; Ge.Peng@noaa.gov; NCEI/CWC/CSD/PRB & CICS-NC; Rich Baldwin; Rich.Baldwin@noaa.gov; NCEI/DSD/DAB

Stewardship Maturity Ratings (kc1/kc2/kc3/kc4/kc5/kc6/kc7/kc8/kc9)	4.0/2.0/2.5/4.5/3.5/2.5/3.0/2.5/3.5
SMM Original Assessment Date (MM/DD/YYYY)	06/08/2015
SMM Original Assessment POC (Name; E-mail; Affiliation)	Valerie Toner; valerie.toner@noaa.gov; Archive Specialist, Contractor with Team ERT/STG, an affiliate of NOAA's National Centers for Environmental Information (NCEI)
SMM Last Modified Date (MM/DD/YYYY)	09/04/2015
SMM Last Modification POC (Name; E-mail; Affiliation)	Rich Baldwin; Rich.Baldwin@noaa.gov; NCEI/DSD/DAB
SMM Modified Date (MM/DD/YYYY)	07/22/2015
SMM Modification POC (Name; E-mail; Affiliation)	Ge Peng; Ge.Peng@noaa.gov; NCEI/CWC/CSD/PRB & CICS-NC; Jay Lawrimore; Jay.Lawrimore@noaa.gov; NCEI/CWC/CSD/DSB; Christina Lief; Christina.Lief@noaa.gov; NCEI/DSD/AB; Valerie Toner; valerie.toner@noaa.gov; NCEI/DSD/AB
SMM Modified Date (MM/DD/YYYY)	07/06/2015
SMM Modification POC (Name; E-mail; Affiliation)	Jay Lawrimore; Jay.Lawrimore@noaa.gov; NCEI/CWC/CSD/DSB
SMM Modified Date (MM/DD/YYYY)	06/25/2015
SMM Modification POC (Name; E-mail; Affiliation)	Christina Lief; Christina.Lief@noaa.gov; NCEI/DSD/AB
[1] NCEI includes the organizations previously referred to as National Climatic Data Center (NCDC), National Geophysical Data Center (NGDC), and National Oceanographic Data Center (NODC).	

Maturity Scale (across) Key Component (below)	Level 1 Ad Hoc Not Managed	Level 2 Minimal Managed Limited	Level 3 Intermediate Managed Defined, Partially Implemented	Level 4 Advanced Managed Well-Defined, Fully Implemented	Level 5 Optimal Level 4 + Measured, Controlled, Audit	Stewardship Maturity Rating And Justification or Evidence	Comments
Preservability *(The state of being preservable)*	Any storage location Data only	Non-designated repository Redundancy Limited archiving metadata	Designated archive Redundancy Community-standard archiving metadata Conforming to limited archiving standards	Level 3 + Conforming to community archiving standards	Level 4 + Archiving process performance controlled, measured, and audited Future archiving standard changes planned	❖ ***Level 4*** - Archived at NCEI-NC (Designated NOAA data center that is compliant to NARA archive standards.) - Conforming to the NCEI-NC archiving process and guideline that are following OAIS RM - Compliant to NCEI-NC defined archive procedure and requirement set forth by Submission Agreement (SA) - Offsite backup copy available - Collection level Metadata conforming to ISO 19115 metadata standards: (http://gis.ncdc.noaa.gov/geoportal/catalog/search/resource/details.jsp?id=gov.noaa.ncdc:C00839) –	
Accessibility *(The state of being searchable and accessible publicly)*	Not publicly available Person-to-person	Publicly available Direct file download (e.g., via anonymous FTP server) Collection/dataset level searchable online	Level 2 + Non-standard data service Limited data server performance Granule/file level searchable Limited search metrics	Level 3 + Community-standard data service Enhanced data server performance Conforming to community search metrics Dissemination report metrics defined and implemented internally	Level 4 + Dissemination reports available online Future technology and standard changes planned	❖ **Level 2** - direct file download via ftp server (http://www.ncdc.noaa.gov/ ghcnm/v3.php) - data and metadata are ASCII files, space delimited, in gzip'd tar files. (1 file containing all station data and 1 file containing all station metadata) - Collection-level searchable (Google, NCEI, NOAA Catalog, Geoportal) but not searchable at file-level - **Info needed on if dissemination report available internally**	Next version will be at level 3 (metadata will be in the Historical Observing Metadata Repository (HOMR) and data will be provided via Climate Data Online (CDO) portal)
Usability *(The state of being easy to use)*	Extensive product-specific knowledge	Non-standard data format Limited documentation	Community standard-based interoperable format & metadata Documentation (e.g., source	Level 3 + Basic capability (e.g., subsetting, aggregating) & data characterization	Level 4 + Enhanced online capability (e.g., visualization, multiple data formats)	❖ **Level 2.5** - README file online - Product algorithm reference list is online - Some source code online	Next version will be at level 3 (with all source code, data flow and process flow diagrams) with self-describing data format.

	required No documentation online	(e.g., user's guide) online	code, product algorithm document, processing or/and data flow diagram) online	(overall/global, e.g., climatology, error estimates) available online	Community metrics of data characterization (regional/cell) online External ranking	- All source code/data flow/process flow diagram not online - Data and file-level metadata are in ASCII format which is in situ community supported format - The current ASCII files are not self-describing	
Production Sustainability *(The state of data production being sustainable and extendable)*	Ad Hoc or Not applicable No obligation or deliverable requirement	Short-term Individual PI's commitment (grant obligations)	Medium-term Institutional commitment (contractual deliverables with specs and schedule defined)	Long-term Institutional commitment Product improvement process in place	Level 4 + National or international commitment Changes for technology planned	❖ **Level 4.5** - Long-term institutional and international commitment - Data are being updated regularly - Product improvement in place - Product under version control	
Data Quality Assurance *(The state of data quality being assured)*	Data quality assurance (DQA) procedure unknown or none	Ad Hoc and random DQA procedure not defined and documented	DQA procedure defined and documented and partially implemented	DQA procedure well documented, fully implemented and available online with master reference data Limited data quality assurance metadata	Level 4 + DQA procedure monitored and reported Conforming to community quality metadata & standards External review	❖ **Level 3.5** - DQA procedure defined in JGR-Atmospheres journal article (http://onlinelibrary.wiley.com/doi/10.1029/2011JD016187/abstract) and also described online (https://www.ncdc.noaa.gov/ghcnm/v3.php under "Data Assurance" tab) - Quality assurance procedures fully implemented - Community metrics are produced and made available online (ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/products/) - No data quality assurance metadata	
Data Quality Control/Monitoring *(The state of data quality being controlled and monitored)*	None or Sampling unknown or spotty Analysis unknown or random in time	Sampling and analysis are regular in time and space Limited product-specific metrics defined & implemented	Level 2+ Sampling and analysis are frequent and systematic but not automatic Community metrics defined and partially implemented Procedure documented and available online	Level 3 + Anomaly detection procedure well-documented and fully implemented using community metrics, automatic, tracked and reported Limited quality monitoring metadata	Level 4 + Cross-validation of temporal & spatial characteristics Physical consistency check Conforming to community quality metadata & standards Dynamic providers/users feedback in place	❖ **Level 2.5** - Quality flagged and statistics metrics are online at: http://www.ncdc.noaa.gov/ghcnm/v3.php - Regular monthly manual reviews of automatically generated plots or statistics are conducted. - Quality monitoring metrics are consistent with in situ community - Procedure is not documented and available online - No data quality control/monitoring metadata	For next version, documentation on the procedure(s) will be online – level 3

Data Quality Assessment *(The state of data quality being assessed)*	Algorithm/method/model theoretical basis assessed (methods and results online)	Level 1 + Research product assessed (methods and results online)	Level 2 + Operational product assessed (methods and results online)	Level 3 + Quality metadata assessed Limited quality assessment metadata	Level 4 + Assessment performed on a recurring basis Conforming to community quality metadata & standards External ranking	❖ **Level 3** - Information on the product algorithm and data quality assessment procedures is available in the JGR-Atmospheres article (http://onlinelibrary.wiley.com/doi/10.1029/2011JD016187/abstract) and online at http://www.ncdc.noaa.gov/ghcnm/v3.php. - Assessment of the operational product, i.e., GHCN-Monthly version 3.x, was done comparing with other datasets and included in the latest IPCC report (http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter02_FINAL.pdf) - No data quality assessment metadata	
Transparency /Traceability *(The state of being transparent, trackable, and traceable)*	Limited product information available Person-to-person	Product information available in literature	Algorithm Theoretical Basis Document (ATBD) & source code online Dataset configuration managed (CM) Unique Object Identifier (OID) assigned (dataset, documentation, source code) Data citation tracked (e.g., utilizing Digital Object Identifier (DOI) system)	Level 3 + Operational Algorithm Description (OAD) online, OID assigned, and under CM	Level 4 + System information online Complete data provenance online	❖ **Level 2.5** - Product information in the literature (http://onlinelibrary.wiley.com/doi/10.1029/2011JD016187/abstract) - Dataset ID is assigned (NCDC DSI 9100_03) and under CM - dataset doi is assigned and tracked (http://dx.doi.org/10.7289/V5X34VDR) - Detailed summary of each software modification and the resulting impacts to global temperatures is available at: ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/techreports/Technical Report NCDC No112_02_3.2.0-29Aug12.pdf; ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/techreports/Technical Report GHCNM No15-01.pdf - The Pairwise Homogeneity Adjustment algorithm software is available online at ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/software/	Descriptive Product Information Document will be generated and available for next version – Level 3
Data Integrity *(The state of data integrity being verifiable)*	Unknown or no data ingest integrity check	Data ingest integrity verifiable (e.g., checksum technology)	Level 2 + Data archive integrity verifiable	Level 3 + Data access integrity verifiable Conforming to community data integrity technology standard	Level 4 + Data authenticity verifiable (e.g., data signature technology) Performance of data integrity check monitored and reported	❖ **Level 3.5** - Data integrity is checked at ingest, archive, and dissemination using the check-sum technology - No check-sum available online for users to verify data files at access	Recommend including checksum/MANIFEST on ftp when staging the data files