P2.11 A MATURITY MODEL FOR SATELLITE-DERIVED CLIMATE DATA RECORDS

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ABSTRACT

Considerable confusion exists in the scientific community, and in the general public, about how to define a climate data record (CDR) produced from satellite remote sensing data. We have defined a set of metrics for such CDRs in an attempt to: 1) reduce difficulty and confusion in the community, 2) produce an easily understood way of identifying maturity of CDRs, and 3) help identify areas needing improvement. There is a wide diversity of views in the scientific community regarding maturity of CDRs including differences in vocabulary, experience, and background. We define the maturity in three dimensions; scientific maturity, preservation maturity, and societal impact. Within each of these dimensions we then define key attributes and rate each on a scale of 1-5.

1. INTRODUCTION

The last 15 years have been marked by the rapid expansion in the use of satellite remote sensing for climate applications. As this field of climate applications has matured, there is increasing emphasis on use of these satellite products for making decisions that have important societal effects. Several of the most widely used satellite climate data record products have generated controversy and have required repeated revisions as we have learned more about the satellite characteristics that effect the quality of the CDR (e.g., Mears and Wentz, 2005; Trenberth et al., 2002). It is not surprising or unusual that data sets and results are updated when new information is uncovered. Indeed, this is the essence of science. These controversies in the use of satellite climate data records, however, have garnered wide interest due to the public interest and controversy over global warming.

Various attempts have been made to define the concept of a climate data record, the most recent by a National Academies panel in their report, 'Climate Data Records from Environmental Satellites' (NRC, 2004). That committee defined a climate data record as a 'time series of sufficient length, consistency, and continuity to determine climate variability and change'. They further recommended definitions for satellite-based climate data records (CDRs) into fundamental CDRs (FCDRs), which are calibrated and quality-controlled sensor data that have been improved over time, and thematic CRDs (TCDRs), which are geophysical variables derived from the FCDRs, such as sea surface temperature and cloud fraction.

In addition, this committee also defined key elements of successful CDR generation programs based upon past experience (Table 1). These elements are divided into organizational, generation, and sustaining. While these elements are helpful to organizing future efforts for CDR generation, they do not capture the detailed levels of maturity and capability needed to distinguish between initial efforts and those that are well developed.

CDR Organizational Elements	CDR Generation Elements	Sustaining CDR Elements
• High-level leadership council	• High accuracy and stability of FCDRs	• Available resources for reprocessing CDRs as new information becomes available
• Advisory council to represent climate research community and other stakeholders	• Pre-launch characterization of sensors and lifetime monitoring	• Provisions for feedback from scientific community
• Fundamental Climate Data Record (FCDR) Teams	• Thorough calibration of sensors	• Long-term commitment of resources for generation and archiving of CDRs and associated data
• Thematic Climate Data Record (TCDR) Teams	• Well-defined criteria for TCDR selection	
	• Stakeholder involvement and feedback for TCDRs	
	• Well-defined criteria for TCDR validation	
	• Use of *in-situ* data for validation	

Table 1. Key elements of successful CDR generation programs

In order to better assess the effectiveness of CDRs for use in societal applications, we are attempting to construct a scientific stewardship maturity index that combines features of scientific classification, or taxonomic, systems with maturity assessment approaches from the software engineering world. Scientific classification has a long and productive history that enhances collaboration by establishing a common framework balanced by the need to accommodate a wide diversity of scientific vocabulary, experience, and background. Perhaps the best know classification system occurs in the biological sciences and is attributed to Carolus Linneaus. This system uses a hierarchy to classify living things into kingdom, phylum,

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class, order, family, genus, and species. For the purposes of defining climate data records, we offer the hierarchy of dimensions, attributes, and key assessment areas.

From the software engineering world, we borrow the concept of a maturity model. The Capability Maturity Model Integration (CMMI) is a process improvement approach developed to apply across an organization. CMMI helps integrate traditionally separate organizational functions, helps set the process improvement goals and priorities, provides guidance for quality processes, and provides a point of reference for appraising current processes. CMMI uses a numerical scale from one to five to assess maturity levels from the initial to the optimal.

To develop a maturity model for climate data records, we propose to identify the attributes of maturity in each of three dimensions, scientific maturity, preservation maturity, and societal applications (Figure 1). We propose to develop a maturity ranking for each attribute on a scale of one to five. Initially, the total maturity ranking then would simply be the sum from each dimension equally weighted. In the future, differential weighting may need to be developed to capture different aspects of the total maturity.

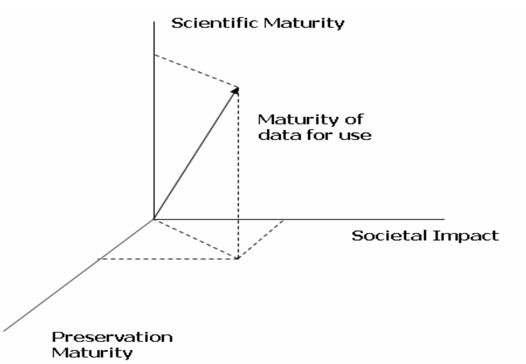

Figure 1. The three dimensions, scientific maturity, preservation maturity, and societal applications

2. DEFINING LEVELS AND ATTRIBUTES OF THE CLIMATE DATA RECORD MATURITY MODEL

First, we must define the overall numerical levels to characterize the numerical ranking for the total maturity of climate data records.

- Level 1 (Initial Research) – Results are based on environmental data records or a research satellite mission. Time series is short (usually less than 10 years). Validation is not yet complete.
- Level 2 (Managed Development) – Initial validation complete, peer-reviewed journal paper(s) published, etc.
- Level 3 (Validated) – Continuous validation for greater than 10 years, multiple investigators with understood differences in results. Provisionally used in assessments and societal benefit areas with positive impact demonstrated.
- Level 4 (Certified Validated; a preponderance of the evidence) – full provenance demonstrated; fully compliant with national and international standards; regularly used for identified societal benefit areas.
- Level 5 (Benchmark; beyond a reasonable doubt) – Variable critical to defining long-term climate change that is observed on the global scale; A measurement that is tied to irrefutable standards, usually with a broad laboratory base; Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation; Limited number of carefully selected observables, with highly confined objectives defining (a) climate forcings, (b) climate response.

Level 3 is minimally acceptable level for observing seasonal to inter-annual variations. Level 4 is the minimally acceptable level for decadal variability. Level 5 is required for observation of centennial variability. The technology needed to reach level 5 currently does not exist, but is the subject of a proposed NASA mission.

For each of the dimensions of the maturity model, we need to define a set of attributes that describe the priority critical areas in each dimension. For the first dimension of scientific maturity, we define the following set of attributes:

- Physical Understanding of Measurement Process
  - Forward Radiative Transfer Modeling Errors
  - Inverse Radiative Transfer Modeling Errors
  - Precision & Long term Stability (Bias error)
  - Coverage & Sampling
- Measurement of Key Instrument Characteristics
  - Pre launch characterization
  - On Orbit Characterization
  - Performance versus specifications
  - Performance relative to series
  - Instrument sensitivity to target geophysical parameter
- Public Accessibility of Data Processing
  - Reducing Model Uncertainties: Forcings/Feedbacks/Validation
  - Number of Analysis Teams/CDR
  - Number of Independent Observing Systems/CDR
  - Availability of technique and computer code
- Rigorous Validation
  - Climate regime [spatial] sampling
  - Temporal distribution of in situ
  - Length of in situ record
  - Accuracy of validation network

Within each of these attribute areas, we then define the key assess areas and, within each assessment area, the criteria for rating that assessment on a scale of 1-5.

For the dimension of preservation maturity, we have defined the attributes:

- Systematic Approach to Guaranteeing Preservation of Data Understanding
- Systematic Reduction of Threats to Preservation
- Assurance of Preservation Cost Effectiveness

Societal benefits are more difficult to quantify and it is likely that more subjective measures will be needed but a listing of those attributes include:

- Bibliometric Metrics
  - Publications and Citations
- Scientific Community Knowledge
  - Data use, including interdisciplinary data fusion and statistical studies
- Economic and Policy Utility
  - Market valuation increase
  - Reduction in time to influence policy
  - Benefit/Hazard Reduction resulting from data use

Although this approach sounds easy, implementation is not. The use of a maturity model for attempting to capture the maturity of climate data records will be exploratory and iterative. We have no expectation that we will get it ‘right’ the first time through the process. The stakes in the debate over climate change and global warming are high and our science will suffer in its credibility if we do not take the lead in quantifying our science. As scientists, we make judgments like this all the time in the peer review system.

Community diversity must also be incorporated into the maturity model. The diverse nature of the U.S. climate program is both a strength and a weakness. To some, the climate program has diffuse objectives and the lack of priorities that have left it "marginalized and politically expendable”. On the other hand, it is the interconnected nature and resulting effect on everyday lives that makes progress in this field so critical. Within the use of observations to create climate data records, we have different views of data processing, calibration, validation, and the need for knowledge preservation. In addition, we often use different similar words to mean different things. A maturity model can help with defining our shared vocabulary, similar to the way classification systems help scientists in other disciplines reach common ground.

3. A COST ESTIMATION MODEL FOR REACHING MATURITY LEVELS

In order for the climate data record maturity model to be used for strategic planning purposes, we must begin to develop an objective cost estimation model for planning and execution of climate data record production. Similar to the maturity model, there are a series of steps that need to be planned and evaluated in order to construct such a model. These include:

- Designing the Data Products and Production Instances
- Estimating the Data Producer's Software Development Costs
- Specifying the Validation and Production Schedule
- Planning for Operational Production Problems
- Choosing Technology for Operational Production
- Calculating Capacity Profiles
- Calculating Investment Metrics
- Determining Performance Measures

Production costs can then be estimated using a forward model, where rates and volumes are used to estimate total cost for a particular CDR, or an inverse model, where cost is estimated from historical president or regression. Currently, both methods of cost estimation have considerable levels of uncertainty, but we illustrate the general behavior of such a cost model in the following example. Figure 2 illustrated the cumulative cost for achieving a level 5 maturity for a given CDR.

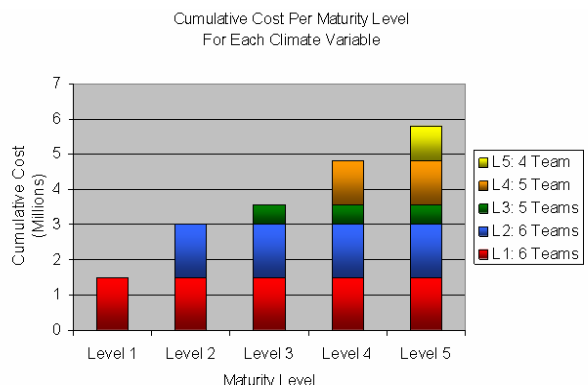

Figure 2. Cumulative Cost Per Maturity Level For Each Climate Variable

At the initial research stage (maturity level 1), there need to be several instrument teams a couple of science teams. In practice, there may be fewer teams but they would need several years of iteration to graduate to maturity level 2. Maturity level 2 has similar needs but increasingly supports more science teams. Promotion to level 3 requires that the shift to supporting science teams continues, there is now also a need to support additional preservation maturity here and at the higher levels, and the emphasis on instrument teams reaches a steady state at 1-2 teams. Level 3 uses the cumulative work of instrument teams from level 1 and 2 and so the total cost for achieving and maintaining level 3 is less than wither level 1 or 2. Achieving level 4, however, requires an additional boost in work by all teams. Level 5, which is not achievable with current observational technology, would capitalize on all the past investment, but still require significant ongoing support for instrument, science, and preservation teams.

4. CONCLUSIONS

We have outlined a straw man for the concept of a maturity model for the production of climate data records. The model represents an attempt at quantifying the collective best practices and lessons learned over the past 10-15 years of the relatively young science of using satellite remote sensing with in situ observations to produce a suite of essential climate variables. We believe that the iterative development of such a model would serve several important ends including: 1) clarifying the nomenclature associated with climate data records, 2) quantifying best practices for current and future CDRs, and 3) serve as a strategic planning tool. We have also suggested how the maturity model could be further tied into a cost production model to provide an objective means for planning.

We invite the scientific community to comment and apply this maturity model. This work is preliminary, but essential to improve communication and understanding within the scientific community, but also between the scientific community and public we serve.

5. REFERENCES

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