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P6.1 CLIMATE DATA RECORDS FROM ENVIRONMENTAL SATELLITES

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1. INTRODUCTION

At the dawn of the twenty-first century, NOAA's mission includes a bold new mandate to "understand climate variability and change to enhance society's ability to plan and respond." An integral component of NOAA's emphasis on climate involves creating a stewardship plan to generate, analyze, and archive long-term satellite climate data records (CDRs) that assess the state of the environment. Although the concept of a "climate data record" has surfaced numerous times in recent literature, the climate community has yet to agree on a consistent definition. For this report, a climate data record is defined as "**a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.**" We further segment satellite-based CDRs into two types: The first, fundamental CDRs (FCDRs), are calibrated and quality-controlled sensor data that have been improved over time, and the second, thematic CDRs (TCDRs), are geophysical variables derived from the FCDRs, such as sea surface temperature and cloud fraction.

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2. STUDY PROCESS

To generate the best possible plan for creating climate-quality data, NOAA asked the National Academies to assist in developing a plan for creating CDRs using satellites that monitor environmental conditions. The National Academies formed the Committee on Creating Climate Data Records from NOAA Operational Satellites and charged it with providing a comprehensive and practical evaluation of the NOAA CDR plan, including conclusions and recommendations. This paper is a summary of the first phase of a two-phase process (the full report is available at http://books.nap.edu/catalog/10944.html). It provides NOAA with general advice on the elements needed in a successful CDR generation process. NOAA will then use these recommendations to develop a plan to guide generation of satellite-based CDRs. In the second phase, the committee will review the NOAA CDR plan and make specific comments.

The committee met four times in generating this report. The first meeting was a large community workshop, attended by over 40 scientists familiar with CDRs. The committee also solicited community input by distributing a short questionnaire. In creating this report the committee relied upon the expertise of its members and the opinions of the community as discussed in the workshop and the surveys.

3. STUDY RESULTS

NOAA's new climate mandate is fundamentally different from the traditional weather forecasting mandate and poses a new set of challenges because of the many uses of climate data, the complexities of data generation, and difficulties in sustaining the program indefinitely. More commitment and changes at various levels within the agency are needed to institute and fund the various components of CDR stewardship. NOAA will not however be the first entity to generate climate-quality data and will take away many lessons from previous efforts. By looking back on historical programs, some commonalities for success have included science advisory panels, regular calibration and validation of data, adequate resources for reprocessing, user workshops to solicit advice on the future of the program, clear data storage and dissemination policies, and a willingness to form partnerships. To that end, 14 key elements for creating a climate data record program based mainly on satellites were created (Table 1). Adherence to these elements would help NOAA create CDRs that are accepted as community standards, while ensuring they remain responsive to user needs. A key to success is early attention to data stewardship, management, access, and dissemination policies, and implementing actual practices. Since a successful CDR program will ultimately require reprocessing, datasets and information used in their creation (e.g. metadata) should be preserved indefinitely in formats promoting easy access. Since the ultimate legacy of long-term CDR programs is the data left to the next generation, the cost of data management and archiving must be considered an integral part of every CDR program.

The new emphasis and importance of climate within NOAA's mission requires increased focus on partnerships and new approaches as it relates to supporting extramural research. Many agencies and groups are involved in creating, analyzing, and storing CDRs. By partnering with other government agencies, academia, and the private sector in development, analysis, and reprocessing of CDRs, NOAA can create and sustain a successful CDR effort. Interagency coordination on the requirements, definition, and implementation of CDRs is important for satisfying the broad user communities of today and providing climate data stewardship for the next generation.

OVERARCHING RECOMMENDATION: NOAA should embrace its new mandate to understand climate variability and change by asserting national leadership for satellite-based Climate Data Record generation. This includes applying new approaches to generate and manage satellite Climate Data Records, developing new community relationships, and ensuring long-term consistency and continuity for a satellite Climate Data Record generation program.

NOAA is recognized as a leader in weather information, including the management of a weather satellite program and creation of weather products. To that end, success in establishing and sustaining a CDR program requires a long-term commitment and a level of effort that goes beyond NOAA's current weather program. A key component of NOAA's success will be in defining steps for creating FCDRs and TCDRs. The plan should also account for all of the data and stored metadata in an easily accessible, self-describing format. By enhancing and expanding community involvement in the CDR program, NOAA can help ensure community acceptance and creation of high-quality CDRs.

Table 1

Key Elements of Successful Climate Data Records Generation Programs

CDR Organizational Elements

1. A high-level leadership council within NOAA is needed to oversee the process of creating climate data records from satellite data.

2. An advisory council is needed to provide input to the process on behalf of the climate research community and other stakeholders.

3. Each fundamental CDR (FCDR) should be created by a specifically appointed team of CDR experts.

4. Science teams should be formed within broad disciplinary theme areas to prescribe algorithms for the thematic CDRs (TCDRs) and oversee their generation.

Table 1 continued

CDR Generation Elements

5. FCDRs must be generated with the highest possible accuracy and stability.

6. Sensors must be thoroughly characterized before and after launch, and their performance should be continuously monitored throughout their lifetime.

7. Sensors should be thoroughly calibrated, including nominal calibration of sensors in-orbit, vicarious calibration with in situ data, and satellite-to-satellite cross-calibration.

8. TCDRs should be selected based on well-defined criteria established by the Advisory Council.

9. A mechanism should be established whereby scientists, decision makers, and other stakeholders can propose TCDRs and provide feedback that is considered in the selection of TCDRs.

10. Validated TCDRs must have well-defined levels of uncertainty.

11. An ongoing program of correlative in situ measurements is required to validate TCDRs.

Sustaining CDR Elements

12. Resources should be made available for reprocessing the CDRs as new information and improved algorithms are available, while also maintaining the forward processing of data in near real time.

13. Provisions should be included to receive feedback from the scientific community.

14. A long-term commitment of resources should be made to the generation and archival of CDRs and associated documentation and metadata.

Supporting Recommendation 1: NOAA should implement an organizational structure where high-level leadership within NOAA receives advice from an advisory council that provides input to the process on behalf of the climate research community and other stakeholders. The advisory council should be supported by instrument and science teams responsible for overseeing the generation of Climate Data Records.

An important step in maintaining a successful program is developing an appropriate organizational framework incorporating feedback and advice from user communities. NOAA will help ensure its success if it includes scientists interested in CDRs, assigns committed people to generate the CDRs, develops technical and science support for users, and creates science teams that are renewed regularly. In particular, NOAA should utilize an advisory council of internationally recognized climate experts with the mission of:

1. Recommending and prioritizing variables that are developed into TCDRs.
2. Overseeing the calibration and validation of FCDRs and TCDRs.
3. Evaluating proposed new TCDRs as measurement capabilities improve or scientific insights change over time.
4. Reviewing the utility and acceptance of TCDRs and recommending the elimination of those that are not successful.
5. Reviewing and overseeing NOAA's stewardship of the CDR program.

The actual creation of FCDRs should be carried out by a team of engineers and scientists, who should monitor satellite characteristics and document their findings so future generations can assess and understand their work. Additionally, TCDR science teams with broad interdisciplinary representation should define algorithms for TCDR development and oversee TCDR generation. They should include research scientists funded by or employed by NOAA and scientists from other agencies, academia, or private industry who use the data, and they should be competitively selected, with limited (but renewable) terms.

Supporting Recommendation 2: NOAA should base its satellite-based Climate Data Record generation program on lessons learned from previous attempts; pointing out several unique characteristics of satellite Climate Data Records. This includes the need for continuing calibration, validation, and algorithm refinements, leading to periodic reprocessing and reanalysis to improve error quantification, thus reducing uncertainties.

Most of NOAA's operational satellites were created as weather rather than climate platforms, so NOAA should include nominal calibration, vicarious calibration monitoring, and satellite-to-satellite cross-calibration as part of the operational satellite system. Because orbital drift, sensor degradation, and instrument biases affect the creation of consistent CDRs, these steps become even more important. Nominal calibration involves determining the calibration of a single sensor on a single platform, and while this is considered standard prelaunch practice, it is important to calibrate the sensor in orbit as well. Vicarious calibration monitoring involves measuring a known target or comparing the satellite signal with simultaneous in situ, balloon, radiosonde, or aircraft measurements. These instruments should undergo vicarious calibration monitoring at regular intervals, regardless of on-board nominal calibration, to prevent drifting of the data over time due to orbital drift and drift in the observation time, which aliases the diurnal cycle onto the record. Satellite-to-satellite cross-

calibration involves adjusting several same-generation instruments to a common baseline, and this is particularly important for long-term studies, as each sensor will have slightly different baselines even if they are built to the same specifications.

An ongoing program of validation should also be carried out to determine the uncertainty associated with TCDRs. This is based on establishing rigorously derived uncertainties for the TCDR using independent correlative measurements conducted throughout the data record and over global scales, which determines whether a trend can be detected. NOAA should establish a two-track generation program, including an upgradeable baseline CDR track and a second (mostly extramural) funded research program to validate, analyze, assess, and reduce uncertainties in future base versions. The two-track approach encourages a culture where scientists and users know that future improvements will be available over time.

Supporting Recommendation 3: NOAA should define satellite Climate Data Record stewardship policies and procedures to ensure that data records and documentation are inexpensive and easily accessible for the current generation and permanently preserved for future generations.

History reveals that programs are more successful when the data management system provides free and open access to data, facilitates reprocessing of CDRs, allows for new satellite TCDRs to be created, and has easy problem-reporting procedures. A clear data policy can ensure continuity in the data record, including the ancillary data used to reprocess CDRs, project and dataset documentation, and science production software. NOAA should ensure that the data management infrastructure can accommodate user requests and provide different data formats, given the large satellite data volumes that a CDR program will create. This system should include the capability for temporal searches and subsetting. The CDR program will be more robust if data is available in self-describing formats appropriate for a variety of uses, including geospatial and socio-economic applications. A process for scientifically assessing the long-term potential of data and data products should also be developed. Scientific assessments of the data can help NOAA organize its archive so that data dissemination is efficient and cost-effective.

Supporting Recommendation 4: NOAA should develop new community relationships by engaging a broader academic community, other government agencies, and the private sector in the development and continuing stewardship of satellite Climate Data Records.

One of the best methods NOAA can institute for gathering community input is to convene regular open science meetings where users share research and discuss limitations and recommendations for improving the CDRs. These meetings should be held regularly because research will improve data quality over time and regular dialogue will help to foster community support. They could be held in conjunction with conferences organized by the American Meteorological Society or the American Geophysical Union, which would be cost effective and reach a broader audience. NOAA should actively encourage other agencies and user communities to assist in development, analysis, and reprocessing of CDRs because expertise for CDRs lies within many sectors. Development of these partnerships would help NOAA create a more successful CDR program.

Supporting Recommendation 5: NOAA should consider existing U.S. multi-agency organizations for implementation of the Climate Data Record program, rather than devising a new structure. The most appropriate organization is the Climate Change Science Program.

Stewardship of CDRs is complex, costly, and demanding and NOAA should aggressively seek partnerships to help to ensure a successful program. NOAA does not need to invent and implement a new management structure for generating, analyzing, and archiving CDRs. The goals and management structure of the Climate Change Science Program (CCSP) are similar to NOAA's climate goals, and NOAA may therefore be able to implement part of the CDR program under the CCSP. If they were to volunteer to be the lead or executive agency (or delegate leadership to a partner) responsible for satellite CDRs under the CCSP umbrella, NOAA would advance its climate mandate and assert national leadership. Because the CCSP structure already has built-in interagency interactions, NOAA could also leverage them for the CDR program.

Supporting Recommendation 6: NOAA should pursue appropriate financial and human resources to sustain a multidecadal program focused on satellite Climate Data Records.

Developing a CDR program is fundamentally important to the nation, and it is imperative that the effort not be hindered by a lack of human or financial resources. Even if NOAA leverages funds and personnel from other agencies, academia, and private industry, and even if it integrates the CDR program into CCSP, it will still have to be aggressive in seeking additional funds. This program requires a long-term vision and commitment, and it is important to account for inflationary increases when outlining the human and infrastructure needs for achieving success in generating, analyzing, reprocessing, storing, and disseminating CDRs.

4. REFERENCES

National Research Council (NRC), 2004: Climate Data Records from Environmental Satellites. National Academies Press, Washington, DC. 116 pp.