Assessment of **National Oceanic and Atmospheric Administration** Scientific Integrity Policies and Procedures

As Applied to the 2015 Dr. Thomas Karl, et al., Science Paper: "Possible Artifacts of Data Biases in the Recent Global Surface Warming Hiatus"

July 2018

MITRE

MTR180173V1

MITRE TECHNICAL REPORT

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As Applied to the 2015 Dr. Thomas Karl, et al. *Science* Paper: "Possible Artifacts of Data Biases in the Recent Global Surface Warming Hiatus"

July 2018

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Sponsor: Department of Commerce
Dept. No.: P181
Contract No.: SS133017CN0002
Project No.: 19178600-AA

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Executive Summary

On June 26, 2015, scientists from the National Oceanic and Atmospheric Administration (NOAA) published a manuscript in *Science* Magazine, "Possible Artifacts of Data Biases in the Recent Global Surface Warming Hiatus," addressing the perceived decrease in the upward trend of global surface temperatures. Based on a revised interpretation of the observational data for the ocean, Karl, et al. (2015) (hereafter referred to as "the Karl Study") concluded that "the rate of warming during the first 15 years of the 21st century is at least as great as the last half of the 20th century." The paper was critiqued in a February 2017 blog posting written by former NOAA employee, Dr. John Bates.

The Department of Commerce (DOC) engaged MITRE as an independent not-for-profit entity to objectively assess the processes used to develop and publish the Karl Study. MITRE, which operates federally funded research and development centers, has a 60-year history of leveraging independent expertise in science and systems engineering to inform government decision making. MITRE assembled a team of leading scientists from prestigious institutions to collaborate with MITRE personnel to provide an objective analysis of all available information relevant to this assessment. The teaming between MITRE and the assembled scientists will be referred to as "the MITRE Committee."

This report addresses the following tasks in the MITRE Statement of Work from the DOC:

- **Task A**: Assess NOAA's scientific review process for assurance of unbiased decision making when completing and publishing the Karl Study
- **Task B**: Assess the merits to Dr. John Bates' complaints regarding the data and conclusions made in the Karl Study

To perform Task B, the MITRE Committee examined the questions, criticisms, and concerns regarding the Karl Study that were raised by Bates in a blog post dated February 4, 2017.

The MITRE Committee was also tasked with examining the adequacy of the following protocols and whether they were followed adequately in the Karl Study:

- Procedures in place at NOAA to ensure the scientific integrity of work by its staff
- Mechanisms for internal review of manuscripts projected for external release
- Procedures for the classification of papers judged as "policy relevant" requiring either appropriate disclaimers or stringent NOAA internal peer reviews
- Methods for selecting and applying the data used in the Karl Study
- Procedures to distinguish between the treatment and use of data developed for immediate scientific release and data destined for inclusion in more-permanent archives

Sections 2 and 3 of this report are devoted to the MITRE Committee's analysis and findings regarding Tasks A and B and the additional assessment topics above tasked by the DOC. Section 4 summarizes the MITRE Committee's findings. The MITRE Committee was tasked to provide recommendations, as appropriate, for changes in existing NOAA policies and procedures to address its findings. Section 5 provides the MITRE Committee's recommendations.

Finally, this report includes an Afterword, which is a projection of the prospects for future advances in observational systems and analytical procedures. It is the MITRE Committee's belief that these future advances may be expected to markedly enhance the climate science community's ability to diagnose and contextualize the relative importance of the multiple factors, both natural and human related, that combine to determine the function and properties of data used to assess the climate system.

The findings and recommendations are summarized below. The MITRE Committee determined that no recommendations were necessary for Findings 1, 2, and 7-10.

Finding 1: After carefully reviewing internal NOAA email correspondence, the MITRE Committee found no evidence that the Karl Study falsified, or intentionally distorted climate data. The Karl Study data were subsequently used in multiple peer-reviewed scientific publications.

Finding 2: Under the Office of Management and Budget (OMB) Guidelines and the 2013 NOAA and Department of Commerce procedure documents for internal review and approval of fundamental research communications (FRCs), research submitted for outside peer review may be exempt from the agency review requirements of the Information Quality Act (IQA) if certain requirements are met. Because the authors published the Karl Study in *Science* Magazine, and not through NOAA, the OMB exemption was applied. However, the MITRE Committee determined that the 2013 NOAA guidelines were ambiguous and not clear on when the more stringent agency IQA review requirements should apply. In 2016, NOAA updated the Framework for Internal Review and Approval to reference the OMB exemption. While this new language is an improvement over the 2013 NOAA guidance, it should be written more clearly and presented more prominently in the guidance.

Finding 3: Because the NOAA officials knew in advance of publication that the paper would be influential, impactful, and controversial, the authors of the Karl Study should have included a disclaimer in the paper to indicate that the views expressed in the paper represented the opinions of the authors and, as indicated with the guideline suggested in the NOAA Framework for Internal Review and Approval, that it "did not necessarily reflect the views of NOAA or the Department of Commerce."

> **Recommendation**: Develop a new NOAA policy document for the production of fundamental research communications (FRCs).

Finding 4: NOAA policies and procedures for climate data management do not provide clear direction and requirements for distinguishing research and operational data and for determining when and how to archive climate data and make it publicly available.

> **Recommendation**: Update current NOAA policies, and develop and implement new procedures for environmental data management.

Finding 5: The NOAA internal review, which was conducted by one NOAA scientist during a five-day period, was not considered by the MITRE Committee to be a sufficient internal review, given the anticipated importance and controversy of the paper.

> **Recommendation**: Develop and widely disseminate a new NOAA Peer Review Handbook for FRCs.

Finding 6: The Karl Study was submitted to *Science* one day before written confirmation of the completion of the internal NOAA review process, which was not compliant with NOAA public release procedures.

> **Recommendation**: Develop and widely disseminate a new NOAA Peer Review Handbook for FRCs.

Finding 7: At the time of publication, the Karl Study data were available to the public and were in full compliance with *Science* and community standards.

Finding 8: The *Science* peer review was thorough, not expedited, and exceeded the average *Science* review time.

Finding 9: After review of the evidence, the MITRE Committee found the Administration did not apply pressure on the Karl Study team, or on NOAA, to influence national and international deliberations on climate policy.

Finding 10: Use of 90-percent confidence intervals was warranted and appropriate because that was the standard used by the Intergovernmental Panel Climate Change (IPCC) Fifth Assessment Report (AR5).

Acknowledgments

MITRE would like to thank Dr. Thomas R. Karl and Dr. John J. Bates, both retired from NOAA, for their cooperation in this assessment.

We would also like to thank the MITRE Committee, who authored this assessment with MITRE and contributed much thoughtful review and commentary:

MITRE Committee:

- Dr. Arthur B. Baggeroer (Massachusetts Institute of Technology)
- Dr. Cindy Lee Van Dover (Duke University)
- Dr. Robert B. Gagosian (Woods Hole Oceanographic Institution)
- Dr. Domenico Grasso (University of Michigan)
- Dr. Michael B. McElroy (Harvard University) [Co-chair]
- Dr. Jay J. Schnitzer (MITRE) [Co-chair]
- Dr. Steven C. Wofsy (Harvard University)
- Dr. Linda Zall (Central Intelligence Agency, Retired)

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1 Introduction

On June 26, 2015, scientists from the National Oceanic and Atmospheric Administration (NOAA) published a manuscript in *Science*, "Possible Artifacts of Data Biases in the Recent Global Surface Warming Hiatus" [1] (hereafter referred to as "the Karl Study"), addressing the previously reported decrease in the upward trend of global surface temperatures in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) [2]. The Karl Study was met with many questions from the scientific community, in the form of numerous letters [3] [4], publications [5] [6], blogs [7] [8], and congressional inquiries [9] [10], regarding the quality of the scientific research processes used to conduct and publish the Karl Study. One critic of the Karl Study was Dr. John Bates, a NOAA scientist and former colleague of Karl who, in a February 4, 2017 blog posting, documented several concerns, criticisms, and issues [7].

To explore these assertions and ensure that NOAA scientific processes remain beyond reproach, the Department of Commerce (DOC) proactively engaged an independent entity to objectively assess the processes used to develop and publish the Karl Study. The DOC engaged MITRE, which operates seven federally funded research and development centers (FFRDCs) chartered in the public interest. An FFRDC is a unique organization that serves as a long-term strategic partner to the government by channeling independent expertise to advance government missions. FFRDCs provide objective guidance in an environment free of conflicts of interest, and assist with a range of critical needs, including independent study and analysis.

This report addresses the following tasks that the DOC contracted with The MITRE Corporation[1] (for details, see Appendix A):

- **Task A**: Assess whether NOAA followed a proper scientific review process for assurance of unbiased decision making when completing and publishing the Karl Study [1]
- **Task B**: Determine whether there were merits to Dr. John Bates' complaints regarding the data and conclusions made in the Karl Study [7]

The DOC also gave MITRE nine specific directions related to assessing NOAA's scientific integrity policies and procedures as applied to the Karl Study, and directed MITRE to provide recommendations as needed.

To create expert responses to these tasks, MITRE assembled a committee of leading scientists from prestigious institutions to team with MITRE to provide an objective analysis of all available information relevant to this assessment (see Section 1.4.1 and Appendix C for details). Hereafter, the work of MITRE and the MITRE Committee will be referred to jointly as the MITRE Committee.

To provide the context for the Karl Study, and the questions that followed, this section begins with a concise account of the role played in climate assessments by analyses of trends in global average surface temperatures.

1.1 Background

The concept of the trend in global average surface temperatures is a tool for detecting and tracking changes in the Earth's energy budget—how much sunlight Earth absorbs minus how much it radiates to space as heat—over time. Scientists use four major data sets to study global

[1] www.mitre.org.

temperature. The United Kingdom (UK) Met Office Hadley Centre and the University of East Anglia's Climatic Research Unit jointly produce the Hadley Center/Climate Research Unit (HadCRUT4).[2] In the United States (U.S.), the Goddard Institute for Space Studies Surface Temperature Analysis (GISTEMP) series comes via the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Sciences (GISS),[3] and NOAA creates the Merged Land-Ocean Surface Temperature Analysis (MLOST) record.[4] The Japan Meteorological Agency (JMA) produces a fourth data set.[5]

AR5 of the IPCC [2] made note of an apparent slowdown in the trend of global average surface temperatures over the period of 1998 to 2012—the so-called "hiatus."

The climate models for IPCC AR5 were provided through the Coupled Model Intercomparison Project Phase 5 (CMIP5),[6] an international initiative coordinated through the World Climate Research Program (WCRP).[7] The IPCC report noted that 111 of the 114 simulations conducted under CMIP5 projected global-mean-surface-temperature trends over the period of 1998 to 2012 that were significantly warmer (a mean of 0.21°C per decade) than the observational results from HadCRUT4 (0.05°C per decade), despite generally satisfactory agreement between models and inferred observational trends during earlier periods.

The records of trends in global average surface temperatures reported in HadCRUT4 are in excellent agreement, as noted by IPCC AR5, with independent results reported by the two other groups conducting such studies at that time, NASA GISS (GISTEMP) and NOAA (MLOST) (see Section 2). The suggestion that the impact on climate of increasing emissions of greenhouse gases may have been overestimated in the climate models set the scene, and was a motivation for, the Karl Study, as was a question of residual data biases in global-surface-temperature data.

1.2 Purpose

The purpose of this report is to present assessment results compiled by the MITRE Committee to address the two tasks, nine directions, and the request for recommendations for the future contained in the DOC Statement of Work (SOW) (see Section 1.1 and Appendix A).

1.3 Scope

This report addresses the two tasks in the DOC SOW (see Appendix A), the nine directions, and the request for recommendations. The MITRE Committee made no attempt to analyze or validate the results of the Karl Study [2] or those of AR5 of the IPCC [11]. Also, this report is not an additional scientific peer review of the Karl Study. Finally, it does not address the underlying causes of global surface temperature change, whether natural or from humans. These matters lie outside the charge to the MITRE Committee.

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[2] https://crudata.uea.ac.uk/cru/data/temperature/.
[3] https://data.giss.nasa.gov/gistemp/.
[4] https://www.ncdc.noaa.gov/data-access/marineocean-data/mlost.
[5] https://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/ann_wld.html.
[6] https://cmip.llnl.gov/cmip5/.
[7] https://www.wcrp-climate.org/.

1.4 Methodology

This section summarizes the phases and activities of this assessment. Figure 1 depicts a high-level overview of the assessment activities from October 2017 through March 2018.

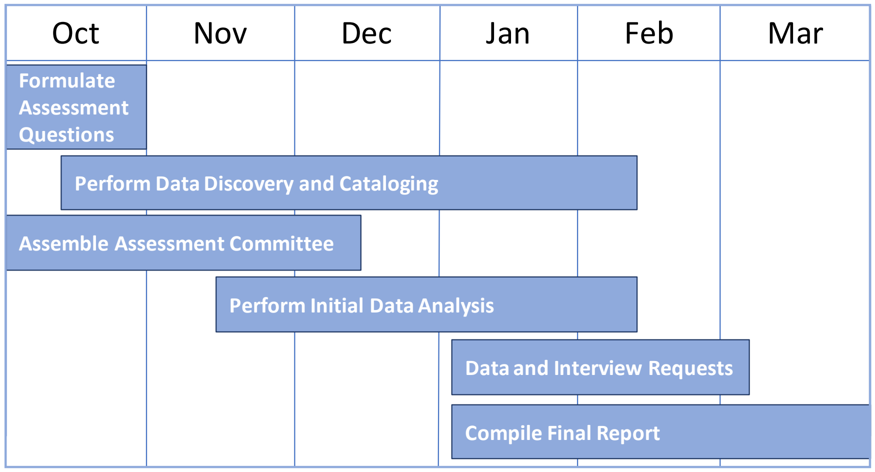

Figure 1. Assessment Method

1.4.1 Assemble MITRE Committee

In parallel with the data discovery and analysis in Sections 1.4.4 and 1.4.6, MITRE assembled leading scientists from prestigious institutions to team with MITRE to provide an objective analysis of all available information relevant to this assessment, applying the following criteria in the selection process:

- Qualifications:
  - From a prestigious institution/organization
  - Prominent/world-class in their field
  - Published in peer-reviewed journals in their field and cited widely
  - Climate/atmospheric/oceanographic/environment scholars included, but not exclusively
  - Expertise in scientific integrity policies and procedures, acquisition, production, and preservation of data

- Potential biases to be balanced across the MITRE Committee:
  - Climate-related publications
  - Social-media activity relatively clean of strong opinions on climate change
  - Recently worked for or contracted with NOAA (since 2014)
- Disqualifiers:
  - Currently work for or contracted with NOAA
  - Were involved in the contested study in any way
  - Have published rebuttals of any of the study authors' work

- Have been found in violation of scientific integrity standards

MITRE performed checks of publicly available information (e.g., publications, biographies, citations, social-media activity) for initial background, and followed up, in most cases, with a conversation. MITRE considered 50 individuals. Nine of the individuals declined, while 17 individuals consented to serve if asked. For due diligence, the DOC performed a formal legal background check on the leading candidates (there were no issues). MITRE selected the final set of eight experts based on its criteria above (listed alphabetically by last name):

- Dr. Arthur B. Baggeroer (Massachusetts Institute of Technology)
- Dr. Cindy Lee Van Dover (Duke University)
- Dr. Robert B. Gagosian (Woods Hole Oceanographic Institution)
- Dr. Domenico Grasso (University of Michigan)
- Dr. Michael B. McElroy (Harvard University) [Co-chair]
- Dr. Jay J. Schnitzer (MITRE) [Co-chair]
- Dr. Steven C. Wofsy (Harvard University)
- Dr. Linda Zall (Central Intelligence Agency, Retired)

The selected Committee members bring expertise not only in climate-related scientific areas, but in other areas as well, such as engineering and mathematical sciences, medical research, physics, electrical engineering, and strategic technology assessments.

Sub-contracted to MITRE, the MITRE Committee members were formally notified of their selection on November 30, 2017. MITRE gave the MITRE Committee access to all of the information gathered to date. The first formal meeting of the MITRE Committee occurred on December 18, 2017.

1.4.2 Data and Interview Requests

During MITRE's data gathering and analysis, questions arose that required either additional, non-publicly available information, or clarification by speaking to an individual within NOAA with the specific knowledge required. MITRE sent all such requests through the DOC to expedite responses. Once contact was made with the right experts within NOAA, email and phone conversations increased the efficiency of data gathering.

In addition to "principals" in this review (Dr. Karl and Dr. Bates), the MITRE Committee received information from, or otherwise corresponded with, the following individuals at NOAA:

- Mike Tanner, Director of the Center for Weather & Climate
- Julie Kay Roberts, Director of Communications
- Cynthia Decker, Executive Director of the NOAA Science Advisory Board and NOAA Scientific Integrity Officer
- David Bedell, Office of the Chief Information Officer
- Tom Gleason, NOAA Office of the General Counsel
- Patricia Geets Hathaway, NOAA Scientific Integrity Office

1.4.3 Formulate Assessment Questions

To guide and organize its initial research efforts, MITRE developed a set of basic "assessment questions" to collect information to support the MITRE Committee's work to be responsive to the SOW directions. Four topic areas are addressed in the SOW: (a) NOAA scientific integrity policy and procedures, (b) NOAA climate data management practices, (c) NOAA publication policy and procedures, and (d) NOAA protocols addressing scientific concerns. For each of the four topic areas, the MITRE Committee addressed three questions:

1. What were NOAA-applicable policies/procedures at the time of the Karl Study?
2. Were these policies/procedures consistent with best practices, in the opinion of the MITRE Committee?
3. Were these policies/procedures applied to the Karl Study?

1.4.4 Data Discovery and Cataloging

After scoping the assessment questions, MITRE gathered the necessary, supporting, publicly available information; identified the information to be requested from DOC or NOAA; and planned interview candidates for follow-on questions. Data were gathered in the following areas:

- NOAA policies, procedures, and guidelines (publicly available)
- *Science* publication policies
- Relevant "best practices," if available—including those from other federal agencies, industry, and the National Academy of Sciences[8]
- Related published information, including the Karl Study [2] and supplemental material [11], all of the paper's cited works, and other related publications
- The collection of media (press, blogs, etc.) discussing the controversy around this study and the subsequent Bates blog post
- Climate data used in the Karl Study[9]
- Additional artifacts and correspondence related to the ongoing House Committee on Science, Space, and Technology review

1.4.5 Related Internal NOAA Correspondence (Emails)

Across the study, email correspondence provided a resource for understanding the application of the NOAA processes and procedures, and for determining the specific activities related to the Karl Study. The NOAA email corpus used for this project was obtained via a request through the DOC Office of General Counsel (OGC). The resultant email corpus was approximately 135 gigabytes (GB) in size and included approximately 606,000 emails and related attachments.

Specific searches within the email corpus were conducted in several ways. In all cases, the search queries were tightly related to the assessment topics and questions. While it is possible that not all appropriate emails were identified, as discovery was ultimately limited by the fidelity of the searches, the MITRE Committee is confident the search was thorough and provided sufficient information for an objective assessment. Care was taken by all researchers to limit the

[8] https://www.nas.org/.
[9] ftp://ftp.ncdc.noaa.gov/pub/data/scpub201506.

review to study-related queries. The privacy of NOAA and other federal staff was respected at all times during the review.

1.4.6 Initial Data Analysis

MITRE analyzed the gathered data to organize the varied sources for the MITRE Committee's analysis and to identify and investigate additional, potentially relevant sources. More specifically, MITRE performed the following actions:

- Catalogued and researched all relevant policies, procedures, media pieces, and emails for leads to other relevant information (approximately 200 artifacts)
- Performed initial statistical analysis of the data used in the Karl Study publication, for the following purposes:
    - Develop comparisons between various publicly available data sets (Hadley Centre Sea Ice and Sea Surface Temperature [HadISST v3.2.2,[10] Extended Reconstructed Sea Surface Temperature [ERSST] v4,[11] etc.) as a point of comparison for the MITRE Committee
    - Confirm the availability and archiving of the Karl Study data
- Developed summaries and timelines to aid in the MITRE Committee's research

During the MITRE Committee's research and analysis, questions arose that required either additional, non-publicly available information, or clarification by speaking to an individual within NOAA with the specific knowledge required. MITRE sent all such requests through the DOC to expedite responses. Once contact was made with the right experts within NOAA, email and phone conversations increased the efficiency of data gathering (see Section 1.4.2 for a list of the NOAA leadership and staff consulted).

1.4.7 Develop Findings and Recommendations

The MITRE Committee met (either electronically or in person) several times between December 2017 and February 2018. Before each meeting, the members reviewed written materials, including the Karl Study, the Bates blog posting, and the NOAA policies and procedures, and then discussed these and other documents (including emails) to formulate findings and recommendations. There was a healthy diversity of scientific background, climate science expertise, and expert opinion about the evidence reviewed, as well as very robust and healthy moderated discussions over several meetings. These discussions led to consensus regarding 10 findings and three recommendations, all of which were evidence-based and resulted from an objective analysis by the MITRE Committee.

1.4.8 Compile Final Report

This document is the culmination of the phases described above. MITRE compiled the discovered supporting data, along with the MITRE Committee's observations, findings, and recommendations, into this final report.

[10] https://www.metoffice.gov.uk/hadobs/hadisst/.
[11] https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v4.

1.5 Report Organization

Figure 2 illustrates the organization of this report, which is structured to directly respond to the issues of most interest to the DOC.

Section 2 addresses SOW Task A, including the primary concerns with the application of NOAA policies and practices to the Karl Study before, during, and after publication. Specifically, Section 2 addresses NOAA policies and practices for scientific integrity policies, climate data management, publication and peer review, and addressing scientific concerns. Section 2 also assesses whether NOAA policies and practices are consistent with best practices, as determined by the independent MITRE Committee of experts. It then includes a description of the Karl Study analysis of sea and land surface temperature data.

Section 3 addresses SOW Task B, which covers the specific concerns raised by Dr. John Bates in February 2017 [7].

Section 4 summarizes significant findings of the MITRE Committee. Section 5 provides specific recommendations from the MITRE Committee based on the findings, best practices, and the expert scientific views of the MITRE Committee. Section 6 discusses future sources of data that might provide more-reliable and more-targeted tests to improve the accuracy of climate models. Section 7 lists the references used during the course of this assessment.

Finally, the appendices contain supporting information and are referenced throughout the main body of this report.

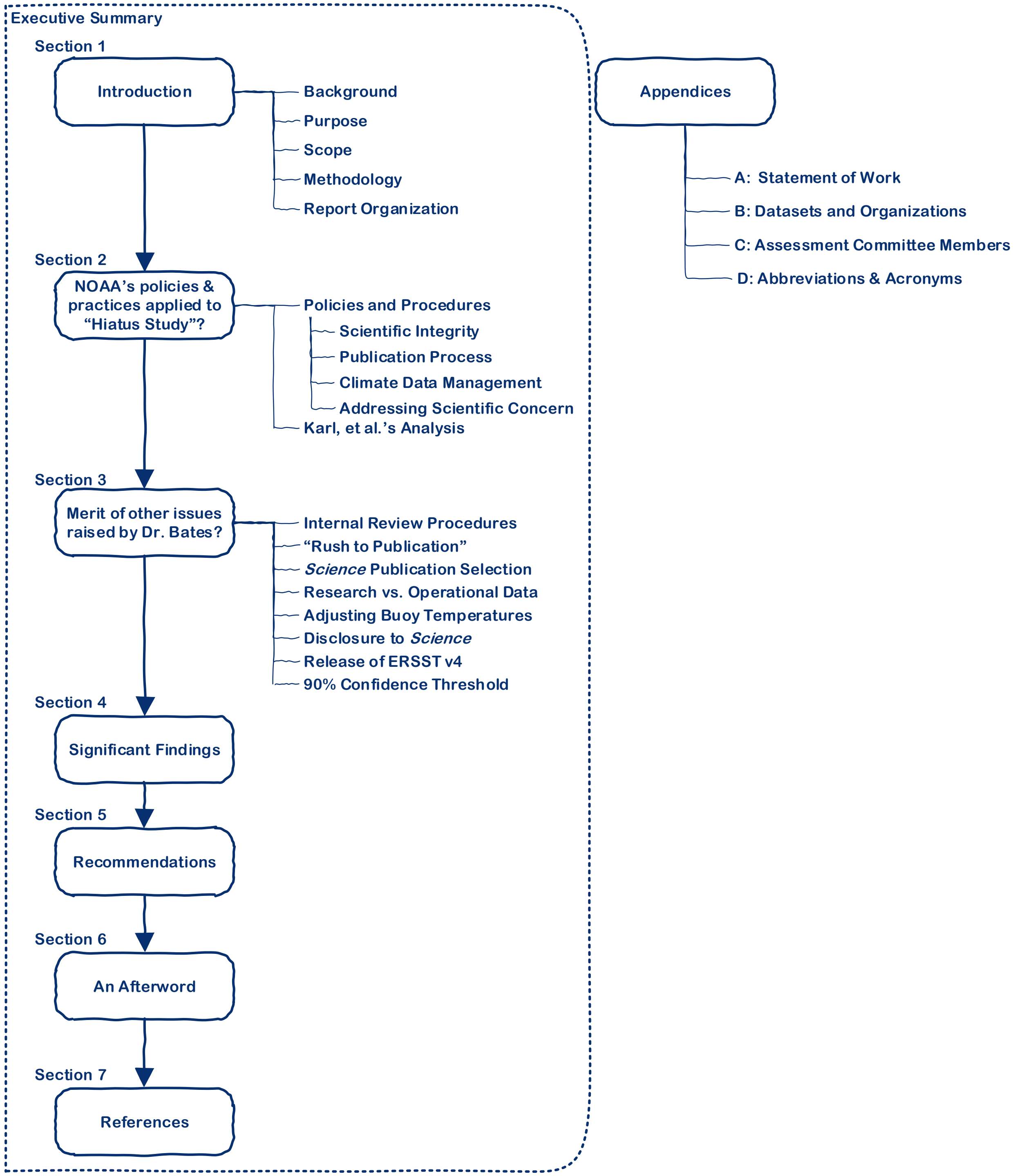

Figure 2. Report Organization

2 Task A: Assessment of NOAA Scientific Review Process and Application to the Karl Study Publication

This section presents the assessment of NOAA's scientific review process that was applied to the Karl Study. Section 2.1 compares NOAA's scientific integrity policy and procedures (relevant to the Karl Study) with standards and best practices. Section 2.2 is a summary of the Karl Study analysis of sea and land surface temperature data, which sets the context for the detailed analysis presented in Section 3.

2.1 NOAA Scientific Integrity Policies and Procedures

The MITRE Committee was tasked with assessing how NOAA scientific integrity policies and procedures compare with standards and best practices. The MITRE Committee assessed NOAA policies and procedures in the following areas:

- Scientific integrity
- Publications and peer review
- Climate data and records management
- Addressing scientific integrity concerns

2.1.1 Scientific Integrity

NOAA scientific integrity policy (NOAA Administrative Order [NAO] 202-735D [12], dated December 7, 2011) defines terms relevant to scientific integrity in the type of work performed by NOAA. This policy also describes principles, code of conduct, code of ethics, and scientific and research misconduct. NOAA scientific integrity policy compares well to best practices in government, academia, and industry. The following two NOAA scientific integrity principles are highly relevant to this NOAA assessment effort: (1) publications by NOAA scientists and NOAA peer review policies and procedures and (2) the requirement for each NOAA Line Office to develop peer review procedures consistent with an overall NOAA framework.

> *NOAA scientists are encouraged to publish data and findings in ways that contribute to the effective transparency and dissemination of NOAA science and that enhance NOAA reputation for reliable science, including online in open formats and through peer-reviewed, professional, or scholarly journals. Development and dissemination of scientific and technical products must be consistent with NOAA policies and procedures related to peer review, the Open Government Initiative, NOAA Information Quality Guidelines, and other legislative and policy mandates.* [12]
>
> *Each line office will develop and document procedures for review and approval consistent with the Research Council framework. The procedures must include time limits for review and approval and procedures for redress if time limits are not met. The framework and procedures will be posted on the NOAA Scientific Integrity Commons website.* [13]

2.1.2 Publications and Peer Review

Information Quality Act Applicability

Federal (OMB) directives on information quality, stemming from the 2001 Information Quality Act (IQA)[12], are the basis of the NOAA Information Quality Guidelines [14] dated October 30, 2014. These NOAA guidelines are complete and comprehensive. The NOAA guidelines repeat the definitions of terms from the OMB Information Quality Guidelines [15], such as quality, utility, objectivity, integrity, dissemination, influential, scientific information, scientific assessment, reproducibility, and transparency.

The NOAA Information Quality Guidelines also reference the OMB Information Quality Bulletin for Peer Review [16] and identify the need for more stringent peer review of publications that are in influential categories (i.e., influential scientific information [ISI] and highly influential scientific assessments [HISA]) as defined in the OMB bulletin. However, the OMB guidelines make a specific exemption for scientific research published by agency scientists:

> *By contrast, an agency does not "initiate" the dissemination of information when a Federally employed scientist or Federal grantee or contractor publishes and communicates his or her research findings in the same manner as his or her academic colleagues, even if the Federal agency retains ownership or other intellectual property rights because the Federal government paid for the research. To avoid confusion regarding whether the agency agrees with the information (and is therefore disseminating it through the employee or grantee), the researcher* ***should*** *include an appropriate disclaimer in the publication or speech to the effect that the ''views are mine, and do not necessarily reflect the view'' of the agency. [15]*

The NOAA Framework for Internal Review and Approval [17] dated April 4, 2013, which was in effect when the Karl Study was conducted and published, did not reference the OMB Peer Review Bulletin and did not mention ISI and HISA categories of publications.

However, the internal NOAA review of the Karl Study was conducted under the above-mentioned exemption in the OMB Bulletin for Peer Review. Email exchanges among MITRE, Patricia Geets Hathaway of the NOAA Scientific Integrity Office, and Tom Gleason of the NOAA Office of General Counsel confirmed that this exemption to the OMB review procedures is normally applied to internal reviews of papers to be submitted to peer-reviewed scientific journals.

[12] https://www.gpo.gov/fdsys/pkg/PLAW-106publ554/html/PLAW-106publ554.htm.

Under the Office of Management and Budget (OMB) Guidelines [16] and the 2013 NOAA and Department of Commerce procedure documents for internal review and approval of fundamental research communications (FRCs) [17], research submitted for outside peer review may be exempt from the agency review requirements of the Information Quality Act (IQA) if certain requirements are met. Because the authors published the Karl Study in *Science* Magazine, and not through NOAA, the OMB exemption was applied. However, the MITRE Committee determined that the 2013 NOAA guidelines were ambiguous and not clear on when the more stringent agency IQA review requirements should apply. In 2016, NOAA updated the Framework for Internal Review and Approval to reference the OMB exemption. While this new language is an improvement over the 2013 NOAA guidance, it should be written more clearly and presented more prominently in the guidance (see Finding #2 in Section 4).

NOAA Internal Review

According to email correspondence (dated December 23–24, 2014), corroborated by the internal review management tool used by NOAA (ScholarOne Manuscript Central), the Karl Study was submitted for internal NOAA review on December 19, 2014. The standard NOAA internal review process was followed, and the manuscript received internal written approval on December 24, 2014.

However, the paper was submitted to *Science* on December 23, 2014, the day before it was approved. This timing deviates from the NOAA internal review guidelines (see Section 3.1 for further discussion of this topic). There is no way of knowing if there was any sort of verbal approval communicated prior to the written approval on December 24, 2014.

There was one internal scientific reviewer of the Karl Study. According to the NOAA Manuscript Central logs, on average, there are three internal reviewers for NOAA papers. The one internal scientific reviewer submitted comments directly to the author. While the MITRE Committee did not see those comments, it discerned no significant differences between the manuscript submitted for review and the version ultimately submitted to *Science* for publication.

Applying the IQA "Disclaimer"

As discussed above, NOAA reviewed the Karl Study in compliance with the applicable Office of Management and Budget (OMB) and NOAA guidelines. Under these guidelines, most research submitted for outside peer review is exempt from the review requirements of the Information Quality Act (see Finding #2 in Section 4). However:

Because the NOAA officials knew in advance of publication that the paper would be influential, impactful, and controversial, the authors of the Karl Study should have included a disclaimer in the paper to indicate that the views expressed in the paper represented the opinions of the authors and, as indicated with the guideline suggested in the NOAA Framework for Internal Review and Approval [17], that it "did not necessarily reflect the views of NOAA or the Department of Commerce." (see Finding #3 in Section 4).

The MITRE Committee believes the authors should have included this disclaimer in the paper, particularly projecting the publicity that the paper was likely to receive as a function of challenging the "hiatus" hypothesis. With appropriate foresight, this reaction should have been anticipated by Dr. Karl and Dr. Bates, and indeed was anticipated in Bates' approval of the paper (see Section 3.1). As the NOAA Approving Officer, Bates could have requested that the disclaimer be applied before his approval of the paper, but he did not.

2016 Update to NOAA Procedures

The NOAA Framework for Internal Review and Approval document was updated on November 8, 2016 (after the Karl Study was published), and added references to the OMB Peer Review Bulletin as well as the requirements for more-stringent peer reviews of ISI and HISA publications, including the exemption for information that is not disseminated by the agency. The 2016 NOAA Framework for Internal Review and Approval also added the following statement: "High profile and potentially controversial papers intended for external peer reviewed journals may require a more detailed internal technical review" [18].

The 2016 updated NOAA Framework for Internal Review and Approval references the OMB exemption above in a new Appendix 2 added to the document, and further states:

> *From this exemption, publications in peer reviewed journals and presentations at scientific conferences are not subject to IQA review if they include a disclaimer. ISI and HISA do not qualify for this exemption. However, it is important to note that* [Department Administrative Order] (*DAO) 219-1* [i.e. the Department of Commence Policy on Public Communications] *requires an internal review of all fundamental research communications. So even though they are exempt from IQA review, these publications are still subject to review under the DAO.* [18]

2.1.3 Climate Data and Records Management

NOAA climate data and records management policies and procedures reflect multiple inconsistent approaches to managing climate data, and there are no cross references to the various approaches in the documents associated with the different approaches. The NOAA Environmental Data Management (EDM) Framework [19], dated March 27, 2013, describes a modern data management framework and high-level architecture, and this is the only NOAA document found in this assessment that addresses the full data management life cycle and reflects data management best practices. However, no documentation was found that described the current state of this EDM Framework and associated implementation plans.

The overall process for making the decision to archive specific NOAA scientific records is outlined in the NOAA Appraisal and Archive Approval Process [20], dated September 2008. This process is complicated and manually intensive, and does not specify information on where NOAA scientific records will be archived, who in NOAA is responsible for physically archiving scientific records, and the physical procedures for archiving records.

Considerable documentation exists on the NOAA Climate Data Record (CDR) Program,[13] which began in 2004 with a focus on satellite data, but is expanding to include *in situ* data and blended sets of satellite and *in situ* data. Both the CDR Program and NOAA Policy on Research and Development Transition to Operations (R2O) [21] encompass complex concepts around six data and process maturity levels that are based on Technology Readiness Levels[14] (used mainly by NASA and the Department of Defense) and on the Carnegie Mellon Software Engineering Institute's Capability Maturity Model Integration (CMMI) levels (used mainly in software and systems engineering) [22]. The two documents, Transitioning NOAA CDRs from Research to Operations [23], dated March 13, 2014, and Transitioning NOAA CDRs from IOC to FOC [24], dated July 5, 2011, are based on these six maturity levels and describe complex processes that some NOAA scientists either do not understand or do not accept as necessary.

Dr. John Bates was a strong proponent and leader of the CDR Program, and, in September 2016, he co-authored a journal article titled, "Sustained Production of Multidecadal Climate Records: Lessons from the NOAA CDR Program." This article states that the average time for CDRs to progress from the initial research grant to initial operational capability (IOC) was approximately 60 months and that the average time to achieve full operational capability (FOC) was 84 months. This is a long timeline and reflects the complicated nature of the processes.

2.1.4 Addressing Scientific Integrity Concerns

The NOAA Procedural Handbook for NAO 202-735D, Scientific Integrity [25], which was originally dated December 7, 2011 and was updated on May 11, 2012 and September 2017, describes a clear and comprehensive process for NOAA to respond to allegations of scientific misconduct or a loss of scientific integrity by a NOAA employee, contractor, or recipient of NOAA financial assistance. This process requires that allegations of scientific misconduct or a loss of scientific integrity be submitted in writing to the NOAA Scientific Integrity Officer within 90 calendar days of discovery of the alleged misconduct. No formal allegation of misconduct was submitted related to the Karl Study, neither during conduct of the study nor after the manuscript was completed. Hence, the process for officially and formally addressing scientific integrity concerns was not exercised by anyone.

2.2 The Karl Study's Analysis of Sea and Land Surface Temperature Data

> After carefully reviewing internal NOAA email correspondence, the MITRE Committee found no evidence that the Karl Study falsified, or intentionally distorted climate data. The Karl Study data were subsequently used in multiple peer-reviewed scientific publications (see Finding #1 in Section 4).

As stated in Section 1.1, the Karl Study was motivated to a significant extent by discussion in AR5 [2] of the IPCC, suggesting a slowdown in the rate of increase of global average surface temperatures over the period of 1998 to 2012, compared to the trend observed over the prior 50 years. The IPCC referred to this slowdown as a "hiatus." AR5 also drew attention to a discrepancy between the observational record for this 15-year period and the projections from models over the same time scale intended to simulate the influence of both natural and human-induced influences on the climate system. The models applied in this case were developed under the CMIP5 [26] organized by the WCRP [27]. Of the 114 simulations

[13] https://www.ncdc.noaa.gov/cdr.

[14] https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html.

conducted under CMIP5, 111 simulations projected rates of increase of temperature over the period of 1998 to 2012 that were significantly higher than the trend implied by the observational data recorded and analyzed by the HadCRUT4. The models predicted an average of 0.21°C per decade, compared to 0.05°C per decade for the observational data.

Results from the HadCRUT4 analysis were consistent with trends derived independently by groups at NASA (GISTEMP) and NOAA (MLOST). AR5 raised the possibility that the discrepancy could be attributed to a deficiency in the ability of the models to account for the impact of human activity on the global climate system, and that these models might have seriously overstated this impact.

The Karl Study offered a re-analysis of the observational record, questioning the "hiatus" hypothesis. The authors signaled their concern pointedly with the choice of title for their paper: "Possible Artifacts of Data Biases in the Recent Global Surface Warming Hiatus." The paper drew major attention when it appeared online in *Science Express* on June 4, 2015, and then in the printed version of *Science* on June 26, 2015 [1], prompting the extensive criticisms leveled at the study subsequently by former NOAA employee, Dr. John J. Bates [7].

The Karl Study was built on reconstructions of trends in global average surface temperatures, based on records from more than 30,000 land-based stations extending back to the year 1850 (in some cases, earlier), complemented, for the ocean, primarily by measurements from ships and, more recently, drifting surface buoys.

Rennie, et al. [67] described the complex process that is involved in developing a credible database that can be deployed to study changes in land surface temperatures (LSTs). The Karl Study, in the LST portion of their study, used records of monthly mean temperatures available through a database referred to as the Global Historical Climatology Network – Monthly (GHCN-M) developed initially in 1992 as a collaboration between NOAA and the Carbon Dioxide Information Analysis Center (CDIAC) of the Department of Energy.

For the "old analysis," the Karl Study used Version 3 of GHCN-M released in 2011. The more-recent measurements made available through the International Surface Temperature Initiative (ISTI) data set Version 1.1 were used for the "new analysis." The Karl Study commented that the same methods for quality control of these data were applied that had been applied in the earlier release of GHCN-M Version 3. Table 1, which is the same as Table S1 in the supplementary material for the Karl Study [11], summarizes the differences between GHCN-M Version 3 and ISTI Version 1.1, in terms of the trends in LST inferred for different time intervals. In the timeframe identified for the alleged "hiatus" (1998–2012, highlighted in green in Table 1), the LST difference (°C per decade) between the two database versions is relatively minor: 0.117 ± 0.119 with ISTI Version 1.1, compared to 0.112 ± 0.119 with Version 3.[15] A much greater change is inferred for the ocean temperature during that same time period.

There are three sources of data that entered into the Karl Study's analysis of the trends in sea surface temperature (SST):

1. Temperature measurements of water drawn on board ships in buckets
2. Temperature measurements of engine room intake (ERI) water employed to cool ship engines

[15] The criteria employed to define the indicated uncertainty ranges are discussed in Section 3.8 of this report.

3. In situ temperature measurements from free-floating buoys deployed specifically to measure water temperature

The SST data set employed by the Karl Study for the "new analysis" is identified as monthly ERSST v4 [1].

Table 1. Karl Study Comparisons of Old and New Temperature Analyses (in °C per decade)

Timeframe	Analysis	Global	Land	Ocean
1880–2014	New	**0.068** ± 0.017 (0.017)	**0.106** ± 0.017 (0.017)	**0.055** ± 0.017 (0.017)
1880–2014	Old	**0.065** ± 0.015 (0.015)	**0.096** ± 0.016 (0.017)	**0.055** ± 0.015 (0.015)
1950–1999	New	**0.113** ± 0.027 (0.030)	**0.169** ± 0.037 (0.038)	**0.091** ± 0.025 (0.029)
1950–1999	Old	**0.101** ± 0.026 (0.027)	**0.159** ± 0.038 (0.039)	**0.079** ± 0.022 (0.022)
1951–2012	New	**0.129** ± 0.020 (0.022)	**0.207** ± 0.031 (0.032)	**0.100** ± 0.017 (0.020)
1951–2012	Old	**0.117** ± 0.021 (0.021)	**0.194** ± 0.031 (0.032)	**0.088** ± 0.017 (0.017)
1998–2012	New	**0.086** ± 0.075 (0.100)	0.117 ± 0.119 (0.153)	0.075 ± 0.075 (0.097)
1998–2012	Old	0.039 ± 0.082 (0.094)	0.112 ± 0.119 (0.150)	0.014 ± 0.090 (0.092)
1998–2014	New	**0.106** ± 0.058 (0.079)	**0.134** ± 0.092 (0.122)	**0.097** ± 0.059 (0.076)
1998–2014	Old	0.059 ± 0.063 (0.074)	**0.119** ± 0.091 (0.118)	0.038 ± 0.071 (0.073)
2000–2014	New	**0.116** ± 0.067 (0.093)	**0.164** ± 0.109 (0.148)	**0.099** ± 0.078 (0.097)
2000–2014	Old	0.066 ± 0.076 (0.090)	**0.150** ± 0.111 (0.146)	0.036 ± 0.097 (0.099)

The challenge in constructing a credible record of the long-term variation of SST relates to the difficulty involved in reconciling biases intrinsic in the different sources of data. Buoy data are expected to provide the most accurate measure of SSTs. Temperatures derived from bucket measurements are likely to be biased to the low side, when compared to ERI, with the difference varying depending on factors, such as the insulating properties of the bucket material, and on the time elapsed between acquisition and measurements of the samples. In contrast, measurements from the ship's ERI method are likely to be biased on the high side.

Compounding the problem, there has been a significant change over time in: (a) the nature of the ship fleets involved in acquiring these measurements; (b) the relative contribution of ship-based measurements by buckets relative to ERI (greater prevalence of the latter); and (c) a change in the relative importance over time of ships versus buoys (a greater role due to more numerous buoys in more-recent years for the latter). These issues were addressed in detail by Huang, et al.

[28] and resulted in a significant difference in the trends inferred using ERSST v4, compared to ERSST v3b.

Ocean entries included in Table 1 that were identified as "old" were derived using ERSST v3b. Entries identified as "new" used ERSST v4. The ERRST v4 data set was developed by a group of scientists at NOAA led by Dr. Boyin Huang. The approach that they used, including differences from the earlier version of ERSST, was described in a paper published in the Journal of Climate [28] in February 2015. Several co-authors of this paper (J.H. Lawrimore, T.C. Peterson, and H. Zhang), including lead author B. Huang, were also co-authors on the Karl Study.

As indicated in Table 1, trends inferred using ERSST v4 are generally higher than the trends derived using ERSST v3b. The difference (in °C per decade) is notable for the so-called "hiatus" period (1998 to 2012): 0.075 ± 0.075, compared to 0.014 ± 0.092. In neither case, though, can the positive values for these trends be taken as statistically significant (using the 90-percent significance criterion employed by the Karl Study, which is consistent with the criterion used by IPCC, as discussed in Section 3.8). Combining SSTs and LSTs with the new data sets for each, Table 1 indicates an overall trend of 0.086 ± 0.075°C per decade, compared to 0.039 ± 0.094°C per decade using the old data.

Assuming the IPCC 90-percent confidence threshold, the Karl Study's analysis suggests that the positive trend for global average temperatures obtained using the "new" analysis should be interpreted as positive and statistically significant. The Karl Study concluded that the trends inferred for just the period of 1998 to 2012 were not statistically significant. Extending the analysis to cover intervals between 1998 and 2014, and for 2000 and 2014 separately, the Karl Study concludes that the trends in global average temperatures were positive and statistically significant in these cases, even based on the more stringent criterion for significance. The overall conclusion, highlighted in the abstract of the paper, is that "the central estimate for the rate of warming during the first 15 years of the 21st century is at least as great as the last half of the 20th century." The Karl Study concludes that the statement by IPCC that global surface temperature "has shown a much smaller increasing linear trend over the past 15 years than over the past 30 to 60 years" (i.e., the "hiatus") is "no longer valid." This conclusion by the Karl Study set the stage for the questions, critiques, and comments that followed. These are reviewed and assessed in Section 3.

The MITRE Committee was also tasked to "consider the data selected for use in the study, [and] the methods by which it was selected and applied…" (see SOW in Appendix A). To do so, it is helpful to view this issue with a broader perspective provided by the longer-term record of the changes in global average surface temperatures dating back to 1850. A summary of results from independent analyses by five groups—one at NOAA, the second at NASA, the third at HadCRUT (Figure 3, Panel A), the fourth from Berkeley-Earth (Figure 3, Panel B), and the fifth from the Japan Meteorological Agency (JMA) (Figure 3, Panel C)—is shown in Figure 3.[16] The shaded area in Panel A of Figure 3 defines the 95-percent confidence limits assigned in the HadCRUT reconstruction. Note that the y-axis scales on the three panels are different.

The data provide evidence for a continuing long-term increase in global average surface temperatures. As indicated, the increase did not proceed uniformly across the time span included in the graphs. Although there are differences, including which period was chosen as a baseline

[16] Met Office Hadley Centre and Climatic Research Unit (https://www.metoffice.gov.uk/research/monitoring/climate/surface-temperature); Berkeley Earth (http://berkeleyearth.org/global-temperatures-2017/); Japan Meteorological Society (https://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/ann_wld.html).

and how the calculations were performed, all five graphs show a similar pattern and trend. Temperatures were relatively constant from 1850 to about 1920. The temperatures increased by about 0.5ºC between 1920 and 1940. This was followed by an approximately 40-year interval over which temperatures changed little and might have even decreased. The modern increase began in about 1980 and has persisted to the present. The increase since 1980 amounts to about 0.7ºC, and the increase since 1850 amounts to a little more than 1ºC.

There are time intervals since 1850 over which temperatures changed little. The interval from 1920 to 1940, for example, shows minimal change. It is important to recognize that the global average surface temperature integrates the composite influence of a variety of factors—some natural, and others arguably reflecting the impact of human activity.

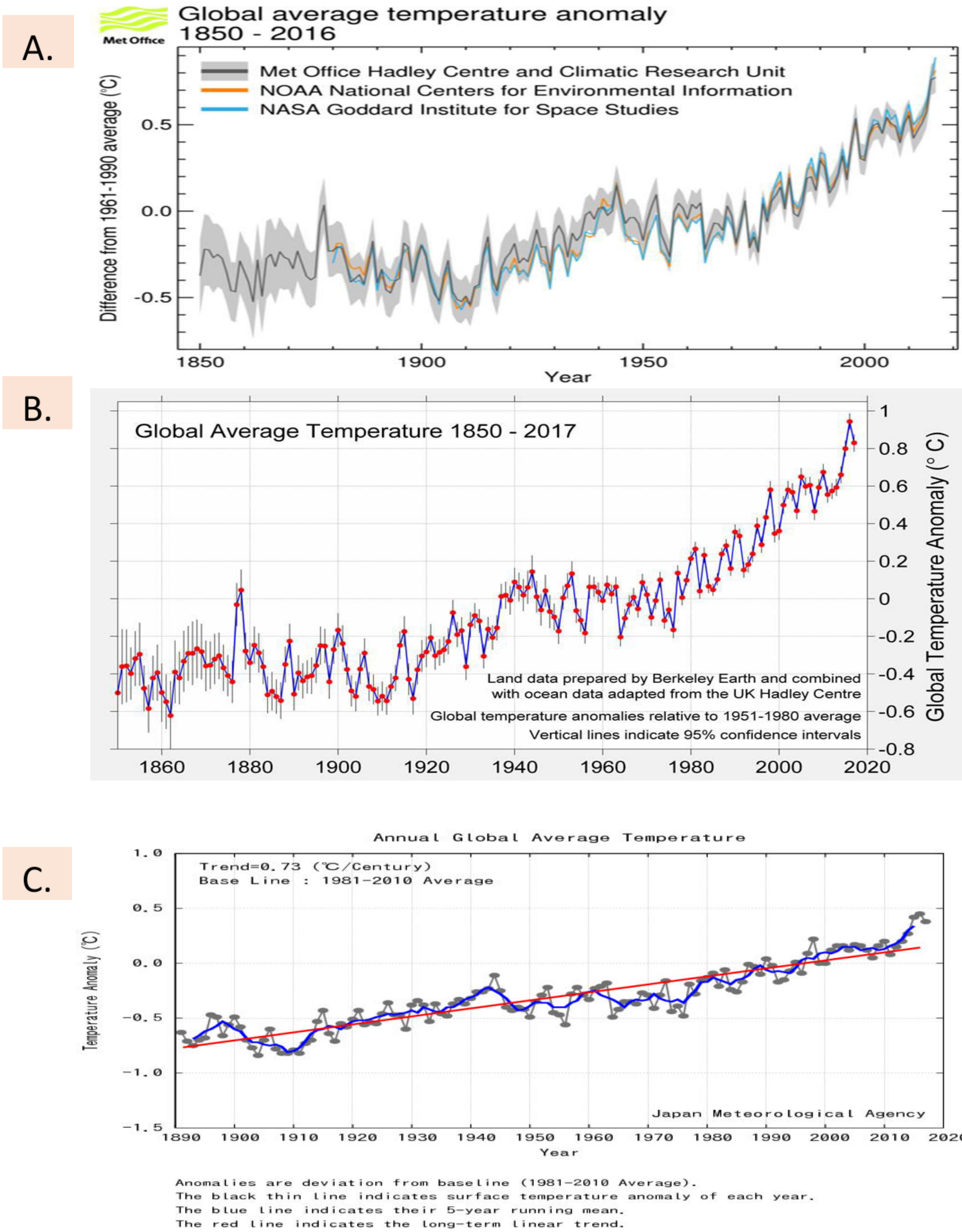

Figure 3. Global Average Temperature Anomaly Charts: (A) Met Office, NOAA, and NASA, (B) Berkeley Earth, and (C) JMA

3 Task B: Assessment of Dr. John Bates' Critiques of the Karl Study Publication

This section outlines and responds to some of the issues raised concerning the Karl Study. The following sub-sections will refer to individuals initially with titles, dropping the titles subsequently in the interests of brevity. For the most part, this section addresses criticisms contained in the blog by Dr. John J. Bates posted on Dr. Judith Curry's website [29] on February 4, 2017 [7]. Additionally, this section will draw on elaborations of these criticisms included in Bates' response to the questions forwarded to him by the MITRE Committee co-chairs, Drs. Schnitzer and McElroy. Materials from the blog will be referred to as "Bates blog." Materials from the exchange with Schnitzer and McElroy will be referred to as "Bates email." The order selected for treatment of the specific issues covered in this section is not intended to reflect a judgment as to either their relative importance or priority.

In the blog entry of February 4, 2017, Dr. Bates raised the questions, criticisms, and concerns covered in the following subsections. Each subsection here includes a statement of the issue, a description of the evidence reviewed as part of this assessment, and the email inputs from both Dr. Bates and Dr. Karl, as appropriate. Any associated finding, as appropriate, is presented in a text box in the corresponding subsection, and all findings are listed in Section 4.

3.1 Criticism Concerning the Procedures Followed in the Internal Review of the Karl Study (Bates Blog Posting and Email)

In his email response (dated February 26, 2018), Bates criticized the internal review of the Karl Study on four counts:

1. The paper should have been designated as an HISA, and should have been reviewed internally according to the stringent requirements of the OMB Guidelines based on the IQA applicable to HISAs.
2. A NOAA contractor submitted the paper for internal review, rather than Karl himself.
3. The quality of the NOAA internal review.
4. Criticisms of a draft version of the Karl Study paper by J. Meehl were ignored.

The MITRE Committee devoted significant attention to the circumstances attending the internal treatment of the Karl Study. It appears that an internal review was chaired by Dr. John Bates and took place in a largely *pro forma* manner. The review involved one internal scientific reviewer, Tim Owen, after which authorization to proceed with submission to *Science* was granted by the Approving Officer, John Bates, on December 24, 2014, based on the following written confirmation from Mara Sprain:

> *All required reviews have been returned by the reviewers for Manuscript ID 2014-12-OA-DOXX-OTHER-0029 entitled "The Recent Global Surface Warming Hiatus: Fact or Artifact?" with James McMahon as contact author. The First & Second Line Supervisors' recommendations have also been received.*

> The Karl Study was submitted to *Science* one day before written confirmation of the completion of the internal NOAA review process, which was not compliant with NOAA public release procedures (see Finding #6 in Section 4).

The MITRE Committee learned that the internal review, later criticized by Bates, was conducted and approved under his own authority. The MITRE Committee found no evidence that Bates ever mentioned this fact in his blog, email, or anywhere else in his discussion of the matter in public.

According to email correspondence (dated December 23–24, 2014) corroborated by the internal review management tool used by NOAA (ScholarOne Manuscripts), the Karl Study was submitted for NOAA internal review on December 19, 2014. It was forwarded by James McMahon, a co-author of the paper, who was a NOAA contractor and was authorized to submit the manuscript for internal review on behalf of his co-authors. As stated in Sections 2.02 and 2.03 of NAO 202-735D [12], the NOAA Scientific Integrity policy applies to all individuals receiving funding from NOAA, whether they are federal employees, Cooperative Institute employees, contractors, or grantees. Moreover, as stated in the NOAA FRC Framework document [17], "this guidance applies to all NOAA Line and Staff Offices and to all NOAA (Federal) authors and co- authors, as well as NOAA contractors to whom NAO 202-735D applies, regardless of order of authorship."

The 2013 framework document identifies the "head of the unit" as the "approving officer" for the review. As Karl notes in his response to the question posed by Schnitzer and McElroy:

> *Bates was one of two Principal Scientists employed by the NCEI* [National Centers for Environmental Information]. *The other Principal Scientist, Thomas Peterson, normally had the responsibility for the internal scientific review of all scientific manuscripts…Because Peterson was one of the authors of the Karl, et al. Science article, he was recused from his usual responsibility as Approving Officer as part of the normal course of NOAA conflict of interest procedures. Instead, Bates was given full responsibility for the internal review.*

In the email communicating his approval on December 24, 2014, Bates clearly recognized the high impact potential of the paper. He wrote, "It will be highly controversial and so the roll out and support for follow up should be carefully planned and fully staffed." The paper was submitted to *Science* on December 23, 2014, the day before it received written approval. This timing deviates from the NOAA internal review guidelines.

The published version [1] acknowledges "constructive comments" from J. Meehl, a distinguished scientist at the National Center for Atmospheric Research (NCAR),[17] and P. Duffy, who was, at the time, a Senior Advisor to the U.S. Global Change Research Program[18] for the National Science and Technology Council.[19] Internal correspondence shows that Karl and co-authors took the comments by Meehl and Duffy seriously, and that they made some changes in the paper as a result. The paper was subjected to comprehensive reviews from five subject matter experts, at the request of *Science*. Karl and his colleagues responded in detail to those reviews in advance of the decision by *Science* to proceed with publication.

[17] https://ncar.ucar.edu/.
[18] https://www.globalchange.gov/.
[19] https://www.whitehouse.gov/ostp/nstc/.

Under the Office of Management and Budget (OMB) Guidelines [16] and the 2013 NOAA and Department of Commerce procedure documents for internal review and approval of fundamental research communications (FRCs) [17], research submitted for outside peer review may be exempt from the agency review requirements of the Information Quality Act (IQA) if certain requirements are met. Because the authors published the Karl Study in *Science* Magazine, and not through NOAA, the OMB exemption was applied. However, the MITRE Committee determined that the 2013 NOAA guidelines were ambiguous and not clear on when the more stringent agency IQA review requirements should apply. In 2016, NOAA updated the Framework for Internal Review and Approval to reference the OMB exemption. While this new language is an improvement over the 2013 NOAA guidance, it should be written more clearly and presented more prominently in the guidance (see Finding #2 in Section 4).

The MITRE Committee found that the internal NOAA review of the Karl Study was conducted under the exemption to OMB's Guidelines for implementing the IQA (as outlined in the OMB Bulletin for Peer Review [16] discussed above in Section 2.1.2). The 2013 NOAA Framework for Internal Review and Approval of FRCs [17] is consistent with this interpretation of the OMB guidance and was applied to the conduct of the Karl Study. Email exchanges among MITRE, Patricia Geets Hathaway of the NOAA Scientific Integrity Office, and Tom Gleason of the NOAA Office of General Counsel confirmed that this exemption to the OMB review procedures is normally applied to internal reviews of papers to be submitted to peer-reviewed scientific journals. Hence, Bates' objection regarding internal review of the paper under ISI or HISA procedures was incorrect.

3.2 Concern That There Was a "Rush to Time the Publication of the Paper to Influence National and International Deliberations on Climate Policy"

The *Science* peer review was thorough, not expedited, and exceeded the average *Science* review time (see Finding #8 in Section 4).

The MITRE Committee could find no evidence of a rush to publication on the part of *Science*. The manuscript was submitted to *Science* on December 23, 2014.[20] After a thorough review, it was accepted for publication on May 21, 2015, published online on June 4, 2015, and in print on June 26, 2015, 185 days after submission. There were five external scientific peer reviewers, who were, and remain, anonymous. According to the editor-in-chief of *Science* (Jeremy Berg), the typical review time for a manuscript is 109 days. The *Science* Senior Editor with whom Karl corresponded apologized to Dr. Karl in a May 22, 2015 email commenting (with respect to the *Science* publishing process for the Karl Study), "the process was far too full of delays and took much too long."

The NOAA internal review, which was conducted by one NOAA scientist during a five-day period, was not considered by the MITRE Committee to be a sufficient internal review, given the anticipated importance and controversy of the paper (see Finding #5 in Section 4).

[20] http://science.sciencemag.org/content/348/6242/1469/tab-article-info.

According to log entries from the internal NOAA manuscript tracking tool, in 2014, an original accepted article from NOAA authors took an average of 31 days to review, and had, on average, three reviewers. The Karl Study took five days and had one reviewer. Out of the 27 papers accepted in 2014 (including the Karl Study), only six papers took five days or less to review. The Karl Study was the only paper from NOAA in 2014 to receive just one review before approval. The MITRE Committee considered the NOAA internal review of the Karl Study to be less rigorous than most original articles submitted for approval, and insufficient given the anticipated importance and controversy of the paper.

> After review of the evidence, the MITRE Committee found the Administration did not apply pressure on the Karl Study team, or on NOAA, to influence national and international deliberations on climate policy (see Finding #9 in Section 4).

The MITRE Committee found no correspondence or other evidence related to the Karl Study, between the Administration and article authors or NOAA staff, that attempted to inappropriately influence the outcome of the study to support the government's climate policy. Furthermore, there was no evidence of effort to time the release of the paper to influence international climate change talks or agreements.

While there were communications between Karl and the President's Science Advisor, they were of a scientific and informative nature.

On January 7, 2015, the Science Advisor requested NOAA's "analysis of 2014 temperatures for the United States" and confirmation of when that report would be released. On January 17, 2015, Karl replied with "a set of slides related to the Global Temperature Announcement" and a link to a longer discussion ("http://www.ncdc.noaa.gov/sotc/global/").

Karl also replied to the Science Advisor later that same day to introduce him to the already submitted *Science* paper (i.e., the Karl Study):

> *…as we discussed back in November, I also attach* [sic] *a paper with supplementary material we have submitted (Dec 24) to* Science *that shows for the next upgrade of our data sets and analysis (to be implemented in 2015) the NOAA analyses of global temperatures will be even warmer temperatures* in *recent years than we report in our current operational version. As you will see in the article, this is attributed to correction of the cool bias introduced by buoys in recent decades and more land surface reporting stations enabling us to better monitor regions that were previously unavailable. The ocean correction is by the* [sic] *most important.*

In a third email on January 17, 2015, Karl informed the Science Advisor that Karl's team would be implementing:

> *…a process so I can send to you all pertinent information related to our Press Releases (including the release) at the same time we send up the Press Release for NOAA approval. I can tell you in advance, now that Science is reviewing our hiatus paper, (assuming it is accepted) this will cause a lot of raised eyebrows because we have been under reporting the rate of warming over the last few decades byt* [sic] *a significant degree.*
>
> *We will start the whole process of including you early and often in Jan for both the US and Global reports and other Press Releases.*

In an email message dated June 4, 2015, the President's Science Advisor informed colleagues that "in this week's issue of SCIENCE, a peer reviewed paper by NOAA scientists (led by Thomas Karl) arguing that the famous 'hiatus' in the pace of global warming in the first part of the century is illusory." The Science Advisor proceeded to provide a note of caution with: "…if the paper stands up to further peer scrutiny, it will certainly have a strong effect on the domestic and international discussion about the urgency of action." He also included a draft of the press release for their information. This communication, occurring the day of the release of the *Science* article, does not imply White House pressure or influence.

There were also communications between Karl and a White House Senior Advisor to the U.S Global Change Research Program (USGCRP).

The communication began on November 22, 2014, as a brief exchange between colleagues that started with the Senior Advisor to the USGCRP seeking information: "Tom [sic] at this point what's your guess as to the likelihood that 2014 will be the warmest year on record? I am getting tired of responding to questions about 'the hiatus!'"

On November 27, 2014, Karl attached a copy of his *Science* manuscript and asked the Senior Advisor to the USGCRP for comments.

On November 30, 2014, the Senior Advisor provided Karl with some comments:

> *…be careful suggesting that there is no hiatus (although I appreciate your point that the data are consistent with that finding) …the revised land temperatures still show a strong slowdown…other datasets (e.g. CRU) also show a slowdown.*
>
> *So my feeling is that the best approach scientifically…is to argue that there has been much less of a slowdown than previously thought- i.e. any hiatus is much less prominent than previously believed-and of course point out that the new data are consistent with no change in trends after 1998.*
>
> *Another substantive issue is the choice of start date for measuring short term trends…it would be best for an analysis that wants to be fair and objective to use a different start date* [than 1998]. *For this reason I suggest focusing primarily on trends starting in 2000, not 1998. Therefore it would be important to compare the trend for 1951-2014 to that for 2000-2014. Presumably the choice of 2000 as a start date would lend even stronger support to your contention that any "hiatus" is more muted than previously thought.*
>
> [Regarding] *the statement "there is no longer a statistically significant difference between the rates of global warming in the two periods."…the difference between the two periods now appears much smaller, but even in the previous analysis the trends during the two periods were not significantly different…What *is* new and perhaps noteworthy is that the trend for 1998-2012 is no longer consistent with zero.*

As noted above for Karl's exchanges with the President's Science Advisor, none of these comments suggested political pressure or influence, but just the normal give-and-take discussions that transpire with scientific discourse.

3.3 *Science* Publication Selection

The Karl Study team originally considered submitting the paper to *Eos*, a newsletter of the American Geophysical Union.[21] *Eos* publishes news about earth and space sciences, but does not publish original research and only publishes very short articles. The Karl Study authors determined that the paper would not fit these criteria for *Eos*, so shifted publication to *Science*.[22]

Science is considered a premier journal for the publication of major scientific research of broad interest to the general population, and is highly cited. In 2016, *Science* had an impact factor (a measure of the importance of the journal by assessing how often articles are cited) of 37.205 [30]. (Only 2 percent of the journals have an impact factor greater than 10.) *Science* utilizes a review and approval process that employs a knowledgeable staff editor and a Board of Reviewing Editors [31]. In addition, all articles will have at least two, and up to five, outside peer reviews. Once the reviews have been received, they encourage cross-review collaboration, further strengthening the review process. The selection of the publication venue was agreed upon by the authors of the paper, and appears to have been based on the journal's coverage, reputation and prestige, extensive peer review procedures, and acceptable article length.

3.4 The Use of Research Data Rather Than Operational Data

Based on NOAA email during the period January 2015 to June 2015 and continuing through Calendar Year 2015, there were considerable internal NOAA discussions revealing differences in opinion about whether the Karl Study data used research or operational data and whether the data had been archived. Bates had led a team in conducting an operational readiness review (ORR) for the SST data set (ERSST v4[23]) based on the ORR process developed for the NOAA CDR Program [32]. On January 15, 2015, the ORR for ERSST v4 was complete [33], and Bates, per his subsequent email discussion (on the same day) with Russell Vose, chair of the NOAA Science Council, recommended archiving the data and making it publicly available right away. However, Karl wanted to delay public release of ERSST v4 until differences between ERSST v3b[24] and ERSST v4 had been documented, understood, and described in three peer-reviewed scientific papers: [28], [34], and [1]. The MITRE Committee could not find a separate archiving Submission Agreement for ERSST v4.

> At the time of publication, the Karl Study data were available to the public and were in full compliance with *Science* and community standards (see Finding #7 in Section 4).

In June 2015, when the Karl Study was published in *Science* [1], all data sets used in the Karl Study were made publicly available via file transfer protocol (FTP) from a NOAA file server, as identified in the Supplementary Material for the *Science* article.[25] On February 23, 2016, Jay Lawrimore at NOAA initiated the process for archiving the Karl Study data sets, and this process was completed on May 17, 2016. This procedure created a permanent archive of the data specific to the Karl Study, which had been previously released via the FTP site on May 26, 2015.[26]

[21] https://eos.org/.
[22] http://www.sciencemag.org/.
[23] https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v4.
[24] https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v3b.
[25] ftp://ftp.ncdc.noaa.gov/pub/data/cmb/ersst/v4 and http://www.surfacetemperatures.org/databank.
[26] ftp://ftp.ncdc.noaa.gov/pub/data/scpub201506.

> NOAA policies and procedures for climate data management do not provide clear direction and requirements for distinguishing research and operational data and for determining when and how to archive climate data and make it publicly available (see Finding #4 in Section 4).

The lack of correlation and integration of multiple NOAA policy and procedure documents that discuss different aspects of climate data management may have led to multiple interpretations of, or a lack of understanding by, NOAA staff regarding the formal NOAA meaning of the terms CDR, ORR, IOC, FOC, and archive. NOAA has published several policy and procedure documents that pertain to climate data management. Those documents are summarized in the following paragraphs. Each of the documents is clear and comprehensible in isolation; however, all of these documents pertain to the same overall climate data management process, but are not correlated or integrated in any way. For example, the documents do not consistently reference each other or describe the components of the climate data management that are described in other related documents. Most of the documents describe a part of the current overall climate data management process. One document (NOAA EDM Framework [19]) describes an improved enterprise-wide end-to-end climate data management process, but does not state when or how that process will be implemented and which current documents will be replaced by this new improved climate data management process.

3.4.1 NOAA Environmental Data Management

The stated purpose of NOAA policy for Management of Environmental and Geospatial Data and Information, NAO 212-15, which was most recently updated on November 4, 2010 [35], is to guide procedures, decisions, and actions regarding EDM throughout NOAA. The policy states that it will be implemented via procedural directives that address the end-to-end data management life cycle for all NOAA environmental information records. The NOAA EDM Framework, dated March 27, 2013 [19], builds on NAO 212-15 and states that it incorporates both data access and data archiving. This framework was developed in response to a 2012 recommendation from the NOAA Science Advisory Board to establish a NOAA-wide process to integrate disparate EDM initiatives. The framework states that the NOAA National Data Centers, such as the National Climatic Data Center (NCDC), should have policies and procedures for long-term preservation of NOAA environmental data. However, the framework does not describe the current state of its implementation and does not provide references or connections to the current official NOAA archiving that identifies NOAA data to be preserved and placed under data management controls.

3.4.2 NOAA Scientific Records Appraisal and Archive Approval

The NOAA Procedure for Scientific Records Appraisal and Archive Approval, dated September 2008 [36], defines the procedure by which NOAA decides which scientific records will be preserved in, or removed from, a NOAA archive. This process complies with National Archives and Records Administration (NARA) records management directives [37] and with OMB Circular A-130 [38], which requires federal agencies to collect or create information needed for proper performance of agency functions. However, the NOAA process for data records appraisal and archive approval is complex, manually intensive, and generally requires several weeks to complete. Further, this process does not include a determination of where NOAA records will be archived, who is responsible for archiving scientific records, or the physical procedures for archiving records.

3.4.3 NOAA CDR Program

In 2004, the National Research Council defined CDRs as "a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change" [39]. The NOAA CDR Program was initially focused on satellite data, but it was recognized, as early as 2005, that the program should also include *in situ* data. An April 2013 NOAA fact sheet on their CDR Program states that CDRs are created by merging data from surface, atmospheric, and space-based systems across decades. An earlier (April 26, 2011) NOAA briefing by Jeffrey Privette, Acting CDR Program Manager at NCDC, has a slide that shows ERSST as one of the available CDR data sets. However, ERSST's absence from a more recent (October 26, 2015), peer-reviewed list of NOAA CDRs in the *Bulletin of the American Meteorological Society (BAMS)* [40] indicates a refinement in what NOAA treats as a CDR.

3.4.4 NOAA Policy on Research and Development Transition to Operations

The NOAA Policy on Research and Development Transitions to Operations (R2O), NAO 216-105B, issued on October 17, 2016 [21], supersedes NAO 216-105A, dated December 3, 2015. This policy establishes processes for identifying, transitioning, and coordinating research and development output to operation, application, and commercialization. NAO 216-105B defines CDRs in terms of six maturity levels, like the software Capability Maturity Model Integration defined by Carnegie Mellon in 2005. These maturity levels are used to distinguish research data from data that has reached IOC—a development state in which a CDR is scientifically defensible and is archived, maintained, and made publicly available by NOAA—and from data that has reached FOC. These six maturity levels are broken down as follows:

- Levels 1 and 2 = research
- Levels 3 and 4 = IOC
- Levels 5 and 6 = FOC

3.4.5 Transitioning NOAA CDRs from Research to Operations

The NOAA document, Transitioning CDRs from Research to Operations (R2O), dated March 13, 2014 [23], provides guidelines for transitioning CDRs from research to IOC at NCDC. A CDR is considered "operational" at IOC or FOC. A CDR achieves IOC when the following four conditions are true:

1. The CDR has met all of the source code, documentation, and data requirements.
2. This information is preserved in the NCDC archive.
3. The CDR passes an ORR.
4. The CDR is made publicly accessible.

3.4.6 Transitioning NOAA CDRs from IOC to FOC

The NOAA CDR Program IOC to FOC Transition Process document, dated July 5, 2011 [24], explains the steps and procedures for transitioning a CDR from IOC to FOC. This document states that, at IOC, a CDR is not regularly maintained or necessarily extended as new data becomes available. Moving a CDR from IOC to FOC provides continuous CDRs. To move from IOC to FOC, the CDR package must be further processed through numerous complicated and detailed steps organized in two phases, transition and production, which are like systems engineering verification and validation (transition) and periodic reevaluation of operational performance and possible upgrade (production).

In summary, there appears to be no official document describing the actual process for storing, accessing, monitoring, maintaining, and updating NOAA environmental data and its associated software code and documentation in the NOAA data centers. Also, there is currently no clear description of when and how research and operational data, including data that is associated with all types of NOAA fundamental research communications, should be made publicly accessible. These types of information are essential components of the end-to-end EDM life cycle.

3.5 Concern About Adjusting the Buoy Temperature Data Rather Than the Ship Data

Concerns were also raised regarding corrections for using ship versus buoy temperature data to correct differences in the two types of data. Buoy data provides a more accurate measure of SST than ship-based temperatures; a systematic adjustment to one measure or the other is required if both types of data are to be used in climate analyses. The Karl Study made use of the necessary correction that had been published by B. Huang, et al. (2015) [28] by adjusting buoy data upward, rather than adjusting ship data downward. This approach, the MITRE Committee presumes, was made to assume continuity of the long-term record of trends in SSTs, dominated for most of the record by data from the ship-based sources. The key adjustment was a relative one, and, in the final analysis, the evaluation of the trend did not depend on whether ship-based sources were adjusted downward or buoy-based sources were adjusted upward. The reason is that the trend is based on relative measurements, not absolute ones. The MITRE Committee observed that if the Karl Study had used a method that adjusted the ship data, rather than the buoy data, then the overall conclusions of the study would have been the same.

3.6 Failure to Disclose Critical Information to *Science* Regarding Data Set Archival and Documentation

In compliance with the requirements of *Science,* the Karl Study provides direct links to the data used in the paper.[27] The data can be downloaded by any standard FTP download program. The files are available in a standard digital format known as NetCDF [41]. Instructions for reading these files were previously posted on a NOAA website,[28] which states that these files can be read by many software packages, both free and commercial, including FERRET,[29] Grid Analysis and Display System,[30] NCAR[31] Command Language,[32] MATLAB,[33] Microsoft Excel, R,[34] and Interactive Data Language.[35]

This data access capability was subsequently, and successfully, used by two scientific groups for their peer-review publications: Fyfe in *Nature Climate Change* [42] and Hausfather in *Science*

[27] ftp://ftp.ncdc.noaa.gov/pub/data/cmb/ersst/v4 and http://www.surfacetemperatures.org/databank.
[28] https://www.esrl.noaa.gov/psd/data/gridded/read-our-files.html.
[29] http://ferret.pmel.noaa.gov/Ferret/.
[30] http://cola.gmu.edu/grads/grads.php.
[31] https://ncar.ucar.edu/.
[32] http://www.ncl.ucar.edu/Applications/.
[33] https://www.mathworks.com/products/matlab.html.
[34] https://www.r-project.org/about.html.
[35] http://www.ittvis.com/ProductServices/IDL.aspx.

Advances [43]. Thus, the MITRE Committee found no evidence to suggest that there was a failure to disclose critical information to *Science* regarding data set archival and documentation.

3.7 Timing of the Release of ERSST v4

In his February 4, 2017 blog post, John Bates contended that Tom Karl intentionally withheld the release of the operational ERSST v4 data to coincide with the publication of the Karl Study.

The MITRE Committee asked Tom Karl why ERSST v4 was not released operationally until May 26, 2015, when it had been approved for release by NOAA leadership on January 15, 2015 [33]. Karl detailed in his written response that, in his view, "…ERSST V4 was a major update to ERSST v3, and it had significant differences both in global and regional ocean temperature trends." He further stated that "…prudence dictated that the new data not replace the existing operational data set until the differences between them were more thoroughly explained and understood." He noted that there were to be three papers published (Huang, et al. [2015] [28]; Liu, et al. [2015] [34]; and the Karl Study), which, in his words, presented a "powerful set of methods and analysis for users to help interpret the new ERSST v4," and, thus, he was a proponent to wait for these scientific articles to be published so that NCEI would have confidence that it could respond to the implications of this new operational data set.

The MITRE Committee did not find evidence in the extensive government emails and documents that contradict Karl's explanation. However, the emails did corroborate that John Bates complained about the delay of the release of ERSST v4 to the chair of the Science Council, Russell Vose. In a January 15, 2015 email to Russell Vose, Bates wrote:

> *I am disappointed that Tom Karl has requested we do not release this important update, which we all agreed today is ready to go operational, until the release of his paper applying the data to analysis of the recent record…I wanted to be sure that the recommendation of the Science Council is to recommend release according to the time table originally proposed and not to be held up until after the Karl paper is out. I wanted to be sure this is the case and is in the record. Our duty is to get the data out when it is ready for operations as this is the public's data, not any individuals data.*

In a January 15, 2015 email reply to John Bates, Russell Vose agreed with Bates about the release of ERSST v4. He wrote, "Thanks, John. I did make a note to myself that Science Council recommends a release consistent with the original schedule (vs. waiting for the *Science* paper)."

Finally, in a May 22, 2015 email from Tom Karl to Katy Vincent, Karl agreed to ask *Science* to publish the paper the week of June 1, 2015 or soon thereafter, preferably before June 18, 2015 (before the May global climate report was published, which included ERSST v4[36]), so that NOAA could release ERSST v4 operationally *before* the Karl Study came out. ERSST v4 was subsequently released to the FTP site on May 26, 2015.[37]

The ERRST v4 beta version had been publicly available since October 3, 2014.[38] The rationale for the delay of the operational version until the changes had been assessed in the scientific literature—as apparently requested by Karl—appears to be reasonable. However, it would also have been reasonable to release the operational version of ERSST v4 four months earlier, as

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[36] Per email from Jay Lawrimore to Thomas Karl, Fri, May 22, 2015 at 8:07 AM.
[37] ftp://ftp.ncdc.noaa.gov/pub/data/cmb/ersst/v4/.
[38] https://www1.ncdc.noaa.gov/pub/data/cmb/ersst/v4/Readme.Status.Changes.

recommended by Bates. The MITRE Committee believes that the delay in the operational release of the ERSST v4 data did not affect the integrity of the data or its interpretation. Therefore, the MITRE Committee does not attach significance to this disagreement between Bates and Karl.

3.8 Use of 90-Percent Confidence Threshold for Evaluating the Statistical Significance of Surface Temperature Trends

> Use of 90-percent confidence intervals was warranted and appropriate, as that was the standard used by IPCC AR5 (see Finding #10 in Section 4).

The terms "confidence threshold," "confidence interval," and "confidence limit" are intended to convey the likelihood that the result quoted for a quantity is likely to lie within specific stated uncertainty limits. A confidence limit of 9 percent would imply that if additional (potentially more accurate) measurements of the item under question were to become available, then 90 percent of these measurements would be expected to lie within the stated error limits. To make it easier for non-specialists to interpret their results, IPCC [2] elected to avoid using technical terms such as confidence intervals or standard deviations. Instead, they devised ordinary language substitutes. If a result is quoted with error bars defined according to a 90-percent confidence interval, then the IPCC translation would state that it is "very likely" that the real result should lie within these limits. If a result is quoted with error bars defined according to a 95-percent confidence interval, then the IPCC translation would imply that it was "extremely likely" that the real result should lie between these limits. A 99-percent confidence limit would imply that it was "virtually certain" that the result would lie between the stated limits. A 68-percent confidence limit would imply simply that it was "likely" that the result would lie between these limits.

The takeoff point for the Karl Study was the revision developed by Huang, et al. [28] for the historical global average SST record (i.e., ERSST v4). The Karl Study specifically focused on how ERSST v4 seemed to point to the possibility of a faster rate of increase of temperature over the period of 1998 to 2012, compared to the results included in AR5 (the "hiatus"). In presenting the records relevant to this topic, AR5 elected to present the data using a 90-percent confidence threshold. Therefore, it was entirely appropriate under the circumstances then for Karl to use the same standard of statistical significance.

4 Significant Findings

The MITRE Committee uncovered 10 significant findings during its work, which are listed below in a summary form. The facts and evidence supporting these findings (i.e., the "details") and the related recommendations (in Section 5), where appropriate, are included in the report section noted in parentheses at the end of each item listed below.

1. After carefully reviewing internal NOAA email correspondence, the MITRE Committee found no evidence that the Karl Study falsified, or intentionally distorted climate data. The Karl Study data were subsequently used in multiple peer-reviewed scientific publications (details in Section 2.2).
2. Under the Office of Management and Budget (OMB) Guidelines [16] and the 2013 NOAA and Department of Commerce procedure documents for internal review and approval of fundamental research communications (FRCs) [17], research submitted for outside peer review may be exempt from the agency review requirements of the Information Quality Act (IQA) if certain requirements are met. Because the authors published the Karl Study in *Science* Magazine, and not through NOAA, the OMB exemption was applied. However, the MITRE Committee determined that the 2013 NOAA guidelines were ambiguous and not clear on when the more stringent agency IQA review requirements should apply. In 2016, NOAA updated the Framework for Internal Review and Approval to reference the OMB exemption. While this new language is an improvement over the 2013 NOAA guidance, it should be written more clearly and presented more prominently in the guidance (details in Section 3.1).
3. Because the NOAA officials knew in advance of publication that the paper would be influential, impactful, and controversial, the authors of the Karl Study should have included a disclaimer in the paper to indicate that the views expressed in the paper represented the opinions of the authors and, as indicated with the guideline suggested in the NOAA Framework for Internal Review and Approval [17], that it "did not necessarily reflect the views of NOAA or the Department of Commerce." (details in Section 2.1.2; recommendations in Sections 5.1 and 5.2).
4. NOAA policies and procedures for climate data management do not provide clear direction and requirements for distinguishing research and operational data and for determining when and how to archive climate data and make it publicly available (details in Section 3.4; recommendation in Section 5.3).
5. The NOAA internal review, which was conducted by one NOAA scientist during a five-day period, was not considered by the MITRE Committee to be a sufficient internal review, given the anticipated importance and controversy of the paper (details in Section 3.2; recommendation in Section 5.1).
6. The Karl Study was submitted to Science one day before written confirmation of the completion of the internal NOAA review process, which is not compliant with NOAA public release procedures (details in Section 3.1; recommendations in Sections 5.1 and 5.2).
7. At the time of publication, the Karl Study data were available to the public and were in full compliance with Science and community standards (details in Section 3.4).
8. The Science peer review was thorough, not expedited, and exceeded the average Science review time (details in Section 3.2).

9. After review of the evidence, the MITRE Committee found the Administration did not apply pressure on the Karl Study team, or on NOAA, to influence national and international deliberations on climate policy (details in Section 3.2).
10. Use of 90-percent confidence intervals was warranted and appropriate, as that was the standard used by IPCC AR5 (details in Section 3.8).

5 Recommendations

The MITRE Committee recommends the following new and updated NOAA policies and procedures based on the findings presented in this report. As a guiding principle for recommendations, the MITRE Committee recognizes that the goal of NOAA and the DOC, regarding communications, is to promote a broad, public understanding of the work of NOAA. As stated in DOC Directive DAO 219-1 [13], "Scientific progress relies on the broad and open dissemination of research results. An open exchange of scientific ideas, information, and research achieves the Department's vision for an informed society that uses objective and factual information to make the best decisions."

It is the goal of these recommendations to balance those guiding principles with the need for adequate scientific review. Overly prescriptive review requirements could have a chilling or dampening effect on scientific research by making it difficult to disseminate information. With that in mind, the MITRE Committee recommends that the DOC and NOAA remain committed to peer review. The following recommendations are intended to clarify any ambiguities that currently exist and to streamline current policy documents.

5.1 New NOAA Policy for Fundamental Research Communications

To address findings associated with the development of NOAA FRCs, Findings #4, #5, and #6 in Section 4, the MITRE Committee recommends that NOAA produce a new document titled, "NOAA Policy for Development of Fundamental Research Communications" to replace the relevant information in the Framework for Internal Review and Approval of Fundamental Research Communications, dated November 8, 2016 [17].

The MITRE Committee also recommends that the current NOAA Scientific Integrity Policy, NAO 202-735D, dated December 7, 2011 [12], be updated to reference this new document and to delete the reference(s) to the NOAA Framework for Internal Review and Approval of Fundamental Research Communications.

This new policy document will identify NOAA Scientific Integrity policy (NAO 202-735D) definitions, principles, scientific activities, code of conduct, and code of ethics, and the DOC policy on Public Communications (DAO 219-1) direction, that apply to the development of NOAA FRCs. This new NOAA policy document will reference the following documents:

1. NOAA Information Quality Guidelines, dated October 30, 2014, for information quality standards to be applied to FRCs [14]
2. OMB Information Quality Guidelines, dated February 22, 2002, for the definition of ISI and the additional quality standards that must be applied to ISI [15]
3. OMB Information Quality Bulletin for Peer Review, dated December 16, 2004, for the definition of HISA, which is a subset of ISI and requires even more-rigorous quality standards than ISI [16]

NAO 202-735D, Section 2, defines NOAA FRCs (based on the original definition of FRCs in DAO 219-1) as "public communications prepared as part of the employee's official work regarding products of basic or applied research in science and engineering, the results of which are published and shared broadly within the scientific community." The new NOAA policy document for the development of FRCs will inherit and strengthen relevant information in the

NOAA Framework for Internal Review and Approval of Fundamental Research Communications, but will not address peer review of FRCs.

The new NOAA document will strengthen and clarify the criteria for distinguishing a "NOAA initiated" FRC from an FRC that presents a NOAA staff member's "personal viewpoint or opinions." To supplement the OMB Guideline exemption, the MITRE Committee recommends that an FRC reflecting an employee's personal viewpoint that is not endorsed by NOAA require a specific disclaimer to be specified in this NOAA policy document (the disclaimer can be inherited from the NOAA Framework document). This requirement must be clear, and consistent with NOAA practice. An FRC representing an official NOAA position on a scientific topic produced by a NOAA employee, during official working hours (at the direction of a supervisor) and using government resources, would not require such a disclaimer.

This new document will also strengthen and clarify the standard notation for identifying and distinguishing the use of "research" versus "operational" data in FRCs, and the implications of using research or operational data in specific NOAA products (see Section 5.3.1).

To remedy some of the uncertainty with respect to the information quality requirements, the MITRE Committee recommends that OMB consider clarifying its language in its 2002 Guidelines document and 2004 Bulletin.

5.2 New NOAA Peer Review Handbook for Fundamental Research Communications

To address findings associated with the peer review of NOAA fundamental research communications (Findings #3, #5, and #6 in Section 4), the MITRE Committee recommends that NOAA produce and disseminate a new document titled, "NOAA Peer Review Handbook for Fundamental Research Communications." The two new documents, identified in Section 5.1 and in this subsection, will completely replace the existing Framework for Internal Review and Approval of Fundamental Research Communications, dated November 8, 2016 [18].

This new NOAA Peer Review Handbook will identify NOAA Scientific Integrity policy (NAO 202-735D) definitions, principles, scientific activities, code of conduct, and code of ethics that apply to peer review of NOAA FRCs. The handbook will also reference and comply with the OMB Information Quality Bulletin for Peer Review. In addition, and as appropriate, this new NOAA handbook will significantly strengthen the peer-review-related information in the 2016 NOAA Framework for Internal Review and Approval of Fundamental Research Communications.

In addition, this new NOAA Peer Review Handbook will:

- Explain when and how to determine whether an FRC meets the criteria for one of the influential categories (ISI or HISA), and who makes the decision
- Outline roles and responsibilities for all steps in the peer review processes for ISI, HISA, and other FRCs
- Provide a detailed description of the NOAA overall peer review processes for FRCs, including the more-structured peer review process for FRCs that can be classified as ISI, and the stringent and formal peer review process for ISI documents that can be classified as HISA (see Figure 4)

- Describe the plans for peer review of ISI and HISA communications required by OMB to be published on the NOAA Chief Information Officer's *Peer Review Plans* website[39] in advance of the peer review process

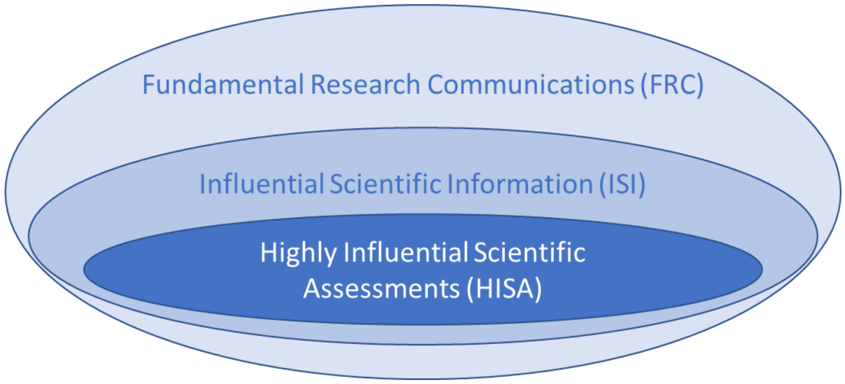

Figure 4. Relationship of FRCs, ISI, and HISAs

A good example of a government agency's detailed peer review handbook is the Environmental Protection Agency (EPA) Peer Review Handbook, dated October 2015 [44].

5.3 Updated Policies and New Procedures for Environmental Data Management

To address findings associated with managing climate data (see Section 3.4, and Finding #4 in Section 4), the MITRE Committee recommends that NOAA update its policies for EDM, and revise and integrate its current procedural documents for implementing these policies into a new single procedural document.

5.3.1 Update Current Policy for NOAA Environmental Data Management

The MITRE Committee recommends that NOAA update NAO 212-15, Management of Environmental and Geospatial Data and Information, dated November 4, 2010 [35], to include clear and authoritative definitions and explanations for the following items:

- Definitions of research and operational data, including definitions of those terms for climate data and its associated software code and documentation
- Methods for identifying and referencing research and operational data in all NOAA fundamental research communications, including peer-reviewed journals, less formal publications, public briefings, press releases, etc.

5.3.2 Update Current Policy for NOAA Research and Development Transitions

The MITRE Committee recommends that NOAA update NAO 216-105B, NOAA Policy on Research and Development Transitions, dated October 17, 2016 [21], for the following purposes:

- Simplify concepts and processes for transitioning research and development output to operations, application, and commercialization

[39] http://www.cio.noaa.gov/services_programs/prplans/PRsummaries.html.

- Clarify the definition of CDR, and specify the types of climate data that are included (or not included) in this definition, such as data from surface, atmospheric, and space-based systems
- Simplify the current definitions and concepts pertaining to the six levels of maturity for CDRs, with the goal of defining two levels of maturity: research and operational

5.3.3 New Procedural Document for NOAA Environmental Data Management

The MITRE Committee recommends that NOAA develop a new single procedural document that consolidates, integrates, simplifies, and describes NOAA-approved official processes for the end-to-end EDM life cycle. This new document will explain the following NOAA data management concepts:

- When and how CDRs are transitioned from research to operations, with the goal of consolidating IOC and FOC into a single operational stage
- When and how operational data is archived in the NOAA data centers
- When and how operational data and its associated software code and documentation are monitored, maintained, and updated
- When and how both research and operational data are made publicly accessible, with clear indications of their nature as either research or operational and the associated implications

Current NOAA documents that describe part of the end-to-end life cycle for data management should be replaced by the new Procedural Document for NOAA Environmental Data Management. These documents include those listed below:

- Transitioning CDRs from Research to Operations (R2O), dated March 13, 2014 [23]
- CDR Program IOC to FOC Transition Process, dated July 5, 2011 [24]
- NOAA Procedure for Scientific Records Appraisal and Archive Approval, dated September 2008 [36]

This new procedural document will clearly describe roles and responsibilities of all NOAA staff (and/or support contractors) in implementing each step of the end-to-end EDM life-cycle process. These roles and responsibilities will clearly identify decision points and the levels of staff/management authorized to make decisions.

6 An Afterword

Current and Future Technologies for Monitoring Temperature and Supporting Climate Models

This section presents prospects for future sources of data that might provide more-reliable and more-targeted tests to evaluate the credibility of climate models, together with guidance for their future development and refinement.

For climate surface temperatures, both LSTs and SSTs are just part of the state models for making predictions about future climate trends. For the atmosphere, the level of carbon dioxide (CO_2) and particulate concentrations are the main drivers. For the ocean, almost all of the net energy of the earth from the sun is absorbed in its volume from the surface to the bottom. More quantitatively, in the atmosphere/ocean system, approximately 95 percent of the heat is in the ocean. Therefore, it is essential that scientists know where this heat is being stored in the ocean water column, and how it might be impacting the circulation of the ocean, not just in the near surface region, but also at depth. Of concern is the possibility of warming in the Antarctic Ocean at depths that would impact the stability of continental ice sheets. At the other pole, melting of Arctic Ocean ice will result in significant amounts of fresh water entering the northern hemisphere, thereby changing ocean currents both horizontally and vertically in the water column, potentially having major impacts on the transport of atmospheric heat to the ocean by a disruption in the ocean circulation system. Hence, there is a need to increase the capability to measure changes in temperature and salinity to predict future changes and increase the accuracy of climate models.

There are two important aspects of this for the future. First, advances in technology, such as in autonomous floats, gliders, and ocean-depth profilers, are beginning to play a major role by providing information on understanding temperature, salinity, and current changes in the ocean. Argo floats[40] have been used for three decades to observe temperature, salinity, and currents for the ocean interior. The Argo fleet consists of approximately 3,800 drifting floats profiling the ocean interior worldwide to a depth of 2,000 meters in the water column. The data are transmitted to land-based facilities via satellite and are publicly available to all.

Other semi-autonomous drones, such as solar-powered and wind-powered sailboats, are being developed and offer another potential new approach to measure ocean parameters, including solar radiation, wind speed, gas exchange parameters, and ocean currents. These ocean and atmospheric data are then relayed via satellites in a cost-effective way [45].

Additional infrastructure supporting the availability of products to the scientific community includes data collected from beneath the ice cover, which is now supported by a series of Ice Tethered Profilers fielded by the Woods Hole Oceanographic Institution [46]. These units generate conductivity (salinity), temperature, and depth (CTD), and report the data back via the Iridium communication satellites. Other technologies include autonomous underwater vehicles (AUVs). While data from a single AUV is not useful for climate studies, the U.S. Navy is preparing to deploy a fleet with 150 units for Navy needs in operationally important regions.

Second, new and emerging satellite technology is enabling synoptic (i.e., summary) temperature measurements over land and the ocean, such as the Global Operational Environmental Satellites (GOES) [47], which do spectral analysis and other types of sensing to derive climate data from the readings. Several satellites are in polar orbits, so they fill a significant historic gap where

[40] http://www.argo.ucsd.edu/.

there is a paucity of data. These satellite systems operate in the active and passive modes and provide daily, worldwide data supporting many products, such as surface temperature, ocean height (altimetry), winds, and ice cover. The first systems, known as AVHRR (Advanced Very High Resolution Radiometers), usually operate near the visible band; hence, they have a very high resolution, but are limited by cloud cover. The second systems usually operate in the microwave band, so they have wide beams, but can see through clouds. Satellite technology for environmental variables has been emerging for several decades and is now operational, with websites supporting many products. There are also several active applications that can provide SST as well as other climatological information. These applications include sea surface height and altimetry for sea-level and ocean-surface currents, ocean winds, and sea-ice motion and thickness.

All of these types of measurements need to be calibrated, both *in situ* and remotely, to specific scientifically accepted standards to eliminate bias correction problems, and so that the data collected can be compared to other types of measurements. This is not a simple problem, operationally, because of the need to establish standards that can be applied to measurements made in the ocean along with measurements from the atmosphere and satellites. Like any new technology, these systems have had "teething" problems for providing well-calibrated data to the precision needed. Dedicated attention to bias and calibration will be needed in the future.

Because the opportunity for collecting data is increasing, the volume of scientific data is increasing dramatically along with the need for greater precision, which will certainly require larger data storage, interrogation, and retrieval processes and facilities through new technologies. Exabyte scales of data storage and their access are easily foreseeable. Satellite systems lead to data and their derived products at phenomenal rates; therefore, serious planning is needed for these data to be archived, and so that the software/hardware is maintained and documented such that they can be used efficiently. For NOAA, this implies an investment in very-high-end storage technology and computers to facilitate model predictions. Note that the European investment for this is significantly greater than the U.S investment.

There is another aspect for the future regarding the oceans. Global surface temperatures are easily understood and are historically available by land sensors and ships of opportunity and by a few buoy systems, such as the NOAA-supported Tropical Ocean-Global Atmosphere/Tropical Atmosphere Ocean arrays in the Pacific and the Prediction and Research Moored Array in the Atlantic.[41] However, as noted above, for climate studies, it is imperative to understand that there is significant heat stored in the interior ocean. Any future climate models that do not incorporate data from the interior of the ocean and at depth could lead to erroneous predictions. The MITRE Committee noted above the advances in technology; however, the ongoing problem is that the oceans are under-sampled, both temporally and spatially. Temporally, the problem is that acquiring synoptic time series data from the ocean's interior has been a historically formidable technical problem. Ship-based CTD surveys have been the method used by physical oceanographers. These data are spatially sparse and episodic. Arrays of moored sensors on buoys that are ship-deployed and ship-recovered have also been used. These are also sparse and are delayed because of the long time between deployment and recovery. The Argo float system is the most encouraging solution to date. While Argo data are timely for climate studies, their ocean coverage is sparse. Finally, acoustic tomographic arrays provide regional data, but, again, are delayed a year before data are available. These systems exploit the dependence of sound speed upon temperature and use complicated mathematical inversion methods for the tomography.

[41] https://www.pmel.noaa.gov/gtmba/.

Ocean basin tomographic systems have been proposed, but encountered resistance from the marine mammal community.

In summary, the technology for synoptic measurements of the ocean interior remains a technical challenge for the future, but is imperative for future climate studies. Specifically, there is a critical need for more technology to overcome the under-sampling in time and space. This involves increased support for current buoy, float, and glider systems and the development of new, more-accurate sensors and the "telemetry" to retrieve these data. For climate, as opposed to weather, scientists can suffer a bit of being time-late. For time and space, there are just too many scales for various ocean processes to be dismissed in climate models. Hence, new technologies are essential to decide on their relevant importance in climate modeling and prediction.

7 References

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Appendix A Department of Commerce Statement of Work

The MITRE Statement of Work (SOW) from the Department of Commerce (DOC) requires the MITRE Committee to:

> a) *Assess whether the National Oceanic and Atmospheric Administration (NOAA) followed a proper scientific review process for assurance of unbiased decision making when completing and publishing the "hiatus" Study; and*
>
> b) *Determine whether there were merits to Dr. John Bates' complaints regarding the data and conclusions made in the "hiatus" Study.*
>
> *MITRE will review the communications of Dr. John Bates, Thomas Karl, and other scientists associated with the Karl Study as deemed relevant. MITRE will consider the data selected for use in the study, the methods by which it was selected and applied, as well as the publication process for the Study. Additionally, MITRE will consider NOAA departmental standards and scientific processes and assess their application to the "hiatus" Study. MITRE will provide recommendations, as warranted, for how NOAA can strengthen its scientific review processes as well as their implementation.*

The SOW also included the following 10 directions:

1. *Examine NOAA Scientific Integrity Policy*[42] *and Procedural Handbook*[43] *and documents cited therein, with a focus on NOAA Information Quality and Peer Review Guidelines, Code of Scientific Conduct, and Code of Ethics for Science Supervision and Management*

2. *Assess how NOAA scientific integrity policy and procedures compare with scientific integrity standards and best practices as determined by MITRE*

3. *Examine the application of NOAA scientific integrity policy and procedural handbook and the scientific integrity standards and best practices to the acquisition, production, and preservation of Climate Data Records (CDRs), with a focus on the procedures NOAA uses to process research data sets into both initial and full operational capability*

4. *Examine whether the "hiatus" Study, including the processing of research data sets to both initial and full operational capability, used procedures consistent with NOAA scientific integrity policy and procedural handbook*

5. *Examine how the procedures used in the "hiatus" Study, including the processing of data sets, compare with scientific integrity standards and best practices as determined by MITRE*

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[42] http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_202/202-735-D.pdf.

[43] http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_202/Procedural_Handbook_NAO_202-735D_%20FINAL_Aug2017%20Ammendment.pdf.

6. *Examine the means by which NOAA evaluated and selected the journal for publication of the study*

7. *Examine the integrity of NOAA internal and external publication review process and its use for the "hiatus" Study*

8. *Review NOAA internal decision making processes used to finalize studies before sending manuscripts to publication*

9. *Review and evaluate NOAA protocols addressing scientific concerns*

10. *Provide recommendations, as warranted, for how NOAA can strengthen (a) its scientific integrity policy and procedures as well as their application to the acquisition, production, and preservation of CDRs; and (b) procedures to transition research datasets into both initial and full operational capability*

Appendix B Background on Data Sets and Select Organizations

Table 2. Relevant Data Sets

Name	Agency/ Organization	Summary
Berkeley Earth Land + Ocean	Berkeley Earth	Berkeley Earth is an independent non-profit 501(c)(3) organization, established in 2010 to address concerns of climate change skeptics. They publish a monthly detailed summary of the changes in Earth's global average surface temperature estimated by combining the Berkeley Earth land-surface temperature field with a re-interpolated version of the HadSST ocean temperature field. **Website**: *http://berkeleyearth.org/data/*
COBE-SST (Centennial *in situ* Observation-Based Estimates)	Japan Meteorological Agency (JMA) / Tokyo Climate Center	JMA monitors long-term changes in global average surface temperature anomalies for monitoring global warming. The COBE-SST is a part of the gridded data sets called COBE, Centennial *in situ* Observation-Based Estimates of the variability of SSTs and marine meteorological variables (Ishii et al., 2005). The COBE consists of global objective analyses from the late 19th century to present, using historical observations from ICOADS and the Kobe Collection data sets. The COBE-SST provides a long-term homogeneous data set with high spatial resolution (one-degree mesh), which is of great value for monitoring global climate change. **Website**: *https://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/explanation.html*
ERSST v4	NOAA	The Extended Reconstructed Sea Surface Temperature (ERSST) data set is a global monthly sea surface temperature data set derived from the International Comprehensive Ocean–Atmosphere Data Set (ICOADS). This monthly analysis begins in January 1854 continuing to the present and includes anomalies computed with respect to a 1971–2000 monthly climatology. **Website**: *https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v4*
ERSST v5	NOAA	The ERSST data set is a global monthly sea surface temperature data set derived from the ICOADS. This monthly analysis begins in January 1854 continuing to the present and includes anomalies computed with respect to a 1971–2000 monthly climatology. The newest version of ERSST, version 5, uses new data sets from ICOADS Release 3.0 Sea Surface Temperatures (SST). SST comes from ARGO floats above 5 meters, Hadley Centre Ice-SST version 2 (HadISST2) ice concentration. ERSSTv5 improved absolute SST by switching from using Nighttime Marine Air Temperature as a reference to buoy-SST as a reference in correcting ship SST biases. Scientists have further improved ERSSTv5 by using unadjusted First-Guess instead of adjusted First-Guess. **Website**: *https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v5*
GHCN	NOAA	The Global Historical Climatology Network (GHCN) is an integrated database of climate summaries from land surface stations across the globe that have been subjected to a common suite of quality assurance reviews. The data are obtained from more than 20 sources. Some data are more than 175 years old while others are less than an hour old. GHCN is the official archived data set. **Website**: *https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn*

Name	Agency/ Organization	Summary
GISTEMP	NASA	The GISS Surface Temperature Analysis (GISTEMP) is an estimate of global surface temperature change. Graphs and tables are updated around the middle of every month using current data files from NOAA GHCN v3 (meteorological stations), ERSST v5 (ocean areas), and SCAR (Antarctic stations), combined as described in the December 2010 publication (Hansen et al. 2010)[44]. These updated files incorporate reports for the previous month and late reports and corrections for earlier months. **Website**: *https://data.giss.nasa.gov/gistemp/*
HADCRUT4	Hadley Centre	A Global temperature data set with both land and ocean components. The HADCRUT data set was developed by the Hadley Centre (HAD) and the Climatic Research Unit (CRUT) (University of East Anglia). **Website**: *https://crudata.uea.ac.uk/cru/data/temperature/*
HADISST	Hadley Centre	The Met Office is the UK's National Meteorological Service. The Met Office Hadley Centre for Climate Science and Services (Hadley) provides climate science for the UK. One of the data sets maintained by the Hadley Centre is the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) data set. HadISST replaced the Global Sea Ice and Sea Surface Temperature data set. **Website**: *https://www.metoffice.gov.uk/hadobs/hadisst/*
ISTI	NOAA	International Surface Temperature Initiative—The Global Land Surface Temperature Databank contains monthly timescale mean, maximum, and minimum temperature for approximately 40,000 stations globally. It was developed as part of the International Surface Temperature Initiative. This is the global repository for all monthly timescale land surface observations from the 1800s to present and uses data deriving from sub-daily, daily, and monthly observations. It brings together data from more than 45 sources to create a single merged data set. **Website**: *https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.ncdc:C00849*

[44] https://data.giss.nasa.gov/gistemp/references.html.

Table 3. Significant Organizations and Reports

Organization	Description
AR(X)	The IPCC prepares and releases Assessment Reports that detail the current state of climate change. The first Assessment Report (AR 1) was produced in 1990. The Fifth Assessment Report (AR5) was completed in 2014. The IPCC is currently preparing AR6, the sixth Assessment Report, with a completion date of 2022. Assessment Reports consist of three working group reports followed by a synthesis report, including a summary for policymakers, and take years to develop and publish. The working group reports are published first (and separately). The summary report is the final piece of the assessment. Special reports on topics of interested may also be published. The final set of all published reports becomes the AR. **Website**: *http://www.ipcc.ch/activities/activities.shtml*
Hadley Centre	The Met Office is the UK's National Meteorological Service. The Met Office Hadley Centre for Climate Science and Services (Hadley) provides climate science for the UK. HadleyCRUT is the Climate Research Unit of the Hadley Center. **Website**: *https://www.metoffice.gov.uk/climate-guide/science/science-behind-climate-change/hadley*
IPCC	The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by the World Meteorological Organization and the United Nations Environmental Programme to "provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation." Hundreds of scientists from around the world volunteer their time to provide assessments that can be used by policymakers at all levels of government to make sound, evidence-based decisions. Specifically, the assessments do not tell policymakers what actions to take, but they can and do present options, scenarios, and risks. **Website**: *http://www.ipcc.ch/*
JMA	As part of Japan's government, the Japan Meteorological Agency (JMA) focuses its efforts on monitoring the earth's environment and forecasting natural phenomena related to the atmosphere, the oceans and the earth, as well as on conducting research and technical development in related fields. **Website**: *http://www.jma.go.jp/jma/indexe.html*
World Climate Research Programme	The World Climate Research Program is an international program sponsored by three international entities: The World Meteorological Organization (United Nations), the International Council for Science (an independent organization), and the Intergovernmental Oceanographic Commission of UNESCO (the UN Educational, Scientific, and Cultural Organization). It consists of volunteer scientists who contribute expertise, a scientific steering group, and a secretariat. In addition to supporting climate research, the WCRP develops international standards for climate science. **Website**: *https://www.wcrp-climate.org*

Appendix C NOAA MITRE Committee Members

This appendix contains short bios for each of the eight members of the MITRE Committee assembled by MITRE to support the NOAA Assessment project.

Arthur B. Baggeroer is a Ford Professor (emeritus) in the Departments of Mechanical and Electrical Engineering & Computer Science at the Massachusetts Institute of Technology (MIT). He received the BSEE from Purdue University in 1963 and the ScD from MIT in 1968. He has been on the MIT faculty for his entire career. He has been affiliated with the Woods Hole Oceanographic Institution (WHOI) in several roles including the Director of the MIT/WHOI Joint Program and the MIT Lincoln Laboratory. He was elected to the National Academy of Engineering in 1995 and awarded a Secretary of the Navy / Chief of Naval Operations Chair for Ocean Science in 1998. He is a Fellow of the IEEE and the Acoustical Society of America. He has awards from the IEEE, ASA, Purdue and the NDIA for his work on sonars and signal processing. He also has served on the Naval Studies Board and Ocean Studies Board for the National Research Council plus many special committees for the Navy.

Cindy Lee Van Dover is the Harvey W Smith Distinguished Professor of Biological Oceanography in the Nicholas School of the Environment at Duke University, where she served as Director of the Duke Marine Laboratory and Chair of the Division of Marine Science and Conservation for a decade. Dr. Van Dover's work focuses on the exploration and characterization of deep-sea ecosystems. She is an early adopter of new deep-submergence technologies, and is a pioneer in the emergent field of deep-sea environmental management. She received her PhD from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Biological Oceanography, served as a Navy-qualified pilot of the Human Occupied Research Vessel Alvin, and holds honorary degrees from the Universitetet i Bergen (Norway) and the Université Catholique de Louvain (Belgium).

Robert B. Gagosian is President Emeritus, Woods Hole Oceanographic Institution (WHOI) and President Emeritus, Consortium for Ocean Leadership. This past year he was the Acting President, Desert Research Institute. He is a Fellow of the American Academy of Arts & Sciences and was a Faculty Fellow of the World Economic Forum, a Member of the Science Advisory Panel of the U.S. Commission on Ocean Policy and a Commissioner of the U.S. National Commission for UNESCO. He is the recipient of Monmouth University's Champion of the Ocean Award and was awarded Honorary Doctor of Science Degrees from Long Island University and Northeastern University. He currently serves on the Board of Trustees for the Bigelow Laboratory for Ocean Sciences and the Desert Research Institute Foundation, and on the External Advisory Board for the University of New Hampshire's School of Marine Science and Ocean Engineering. He is also a Member of the Corporation of WHOI, the Board of Overseers of the Sea Education Association, and is a Member of the Leadership Council of the Joint Ocean Commission Initiative. He received an S.B. from Massachusetts Institute of Technology and a Ph.D. in chemistry from Columbia University.

Domenico Grasso is the Chancellor of the University of Michigan-Dearborn. Previously he was Professor of Engineering & Policy and Provost of the University of Delaware, Vice President for Research and Dean of the Graduate College at the University of Vermont, and earlier Dean of the College of Engineering and Mathematical Sciences at UVM. Prior to joining UVM, Dr. Grasso was Rosemary Bradford Hewlett Professor and Founding Director of the Picker Engineering Program at Smith College, the first engineering program at a women's college and one of the few in a liberal arts college in the United States; and Professor and Head of Department in Civil & Environmental Engineering at the University of Connecticut. Dr. Grasso holds engineering degrees from Worcester Polytechnic Institute (B.Sc.), Purdue University (M.S.) and The University of Michigan (Ph.D.). He is a Diplomate of the American Academy of Environmental Engineers, and has been a registered Professional Engineer in the states of Connecticut and Texas. He is currently Chair of the National Academies Committee on Grand Challenges in Environmental Science and Engineering.

Michael B. McElroy (Co-chair) is the Gilbert Butler Professor of Environmental Studies at Harvard University. He has served in the past as Director of the Harvard Center for Earth and Planetary Physics, as Director of the Harvard Center for the Environment, and as Chair of the Department of Earth and Planetary Sciences. He currently leads an interdisciplinary project involving US and Chinese scholars devoted to studies of the challenges China faces in reconciling its goals for development with protection of the integrity of both its human and natural environments. In this context he was appointed as a member of a committee tasked with providing advice on these topics to the Chinese government. He has served elsewhere as advisor to US government agencies including NASA, NSF, DOE and CIA. He is the author of 3 books and more than 300 peer reviewed papers. His contributions have been recognized by several awards and by election as Fellow of several professional societies.

Jay J. Schnitzer (Co-chair) is Vice President and Chief Technology Officer (CTO) at the MITRE Corporation where he oversees MITRE's internal research and development (R&D) program and corporate technology transfer efforts, in order to 1) ensure a world-class internal R&D effort that supports the entire corporation, 2) deliver transformational capabilities that drive mission success and global leadership, 3) meet the needs of the direct work programs and federal sponsors through innovation, R&D, and transitioning technology directly to government, and 4) return value to the nation by transferring innovations to industry. Previously, Dr. Schnitzer was the Director of the Defense Sciences Office (DSO) at the Defense Advanced Research Projects Agency (DARPA), the Chief Medical Officer and Senior Vice President at Boston Scientific Corporation, and a staff pediatric surgeon at Massachusetts General Hospital and faculty member of Harvard Medical School. He received a Ph.D. in chemical engineering from the Massachusetts Institute of Technology, an M.D. from Harvard Medical School, and was board certified in surgery and pediatric surgery.

Steven C. Wofsy is the Abbott Lawrence Rotch Professor of Atmospheric and Environmental Chemistry at Harvard University's John A. Paulson School of Engineering and Applied Science and in the Department of Earth and Planetary Sciences. Dr. Wofsy has published over 250 journal articles during career spanning more than four decades. He is the recipient of the American Geophysical Union's McIlwane prize and Revelle Medal, and he is a member of the National Academy of Sciences. Dr. Wofsy is a leader in greenhouse gas measurement methodologies, instrumentation and experimentation. His research emphasizes the effects of terrestrial ecosystems and human activity on the global carbon cycle and air quality. Dr. Wofsy studied Chemical Physics at the University of Chicago (B.S., 1966) and at Harvard (Ph.D. 1971).

Linda Zall is a retired SIS officer from the Central Intelligence Agency (CIA) where her career spanned both working the strategic technology assessments and research and development (R&D) issues applied to CIA's traditional operational missions to the more recent issue of the National Security impacts of Climate Change. She served as CIA's representative to the JASON program, and later directed the MEDEA Environmental Advisory group for the Intelligence Community and the White House. For over two decades she was the liaison between the

National Security, Civil government, and Scientific Communities on the issue of Climate Change, working within the highest levels of government to include the White House, and with CIA Directors, Directors of the National Reconnaissance Agency (NRO), and with Agency Heads within the Civil Community. Prior to government service she worked in the private sector in the Remote Sensing Industry on petroleum, mineral, and groundwater applications, and on the engineering site selection for the Trans Alaskan Pipeline. She was awarded both the CIA Career Intelligence Medal and the Intelligence Medal of Merit. She received her Ph. D and M.S degrees in civil and environmental engineering from Cornell University.

Appendix D Abbreviations and Acronyms

Acronym	Definition
AR5	Fifth Assessment Report
AUV	Autonomous Underwater Vehicles
CDIAC	Carbon Dioxide Information Analysis Center
CDR	Climate Data Record
CIO	Chief Information Officer
CMIP5	Coupled Model Intercomparison Project Phase 5
CMMI	Capability Maturity Model Integration
COBE	Centennial *in situ* Observation-Based Estimates
COBE-SST	Centennial *in situ* Observation-Based Estimates Sea Surface Temperature
CTD	Conductivity, Temperature and Depth
DO	Determining Official
DOC	Department of Commerce
EDM	Environmental Data Management
EPA	Environmental Protection Agency
ERI	Engine Room Intake
ERSST	Extended Reconstructed Sea Surface Temperature
FFRDC	Federally Funded Research and Development Center
FOC	Full Operational Capability
FRC	Fundamental Research Communications
FTP	File Transfer Protocol
GB	Gigabyte(s)
GCOS	Global Climate Observing System
GHCN-M	Global Historical Climatology Network – Monthly
GISS	Goddard Institute for Space Sciences
GISTEMP	Goddard Institute for Space Studies Surface Temperature Analysis
GMST	Global Mean Surface Temperature
GOES	Global Operational Environmental Satellites
HadCRUT4	Hadley Center/Climate Research Unit
HadISST	Hadley Centre Sea Ice and Sea Surface Temperature
HISA	Highly Influential Scientific Assessments
ICOADS	International Comprehensive Ocean–Atmosphere Data Set
IOC	Initial Operational Capability
IPCC	Intergovernmental Panel on Climate Change
IQA	Information Quality Act
ISI	Influential Scientific Information
ISTI	International Surface Temperature Initiative
JMA	Japan Meteorological Agency
L/SO	Line and Staff Offices
LST	Land Surface Temperature
MLOST	Merged Land-Ocean Surface Temperature Analysis
NAO	NOAA Administrative Order
NARA	National Archives and Records Administration

Acronym	Definition
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OGC	Office of General Counsel
OMB	Office of Management and Budget
ORR	Operational Readiness Review
OSTP	Office of Science and Technology Policy
PI	Principal Investigator
R&D	Research and Development
R2O	Research Output to Operations
SA	Submission Agreement
SOW	Statement of Work
SST	Sea Surface Temperature
UK	United Kingdom
WCRP	World Climate Research Program