WRITTEN TESTIMONY OF
THOMAS R. KARL, L.H.D.
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

HEARING ON
SATELLITES AND CLIMATE
BEFORE THE
COMMITTEE ON APPROPRIATIONS
SUBCOMMITTEE ON COMMERCE, JUSTICE, SCIENCE, AND RELATED AGENCIES
U.S. HOUSE OF REPRESENTATIVES

March 18, 2009

Introduction

Good day, Chairman Mollohan, Ranking Member Wolf, and other Members of the Committee. I am Thomas R. Karl, Director of the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center and the Lead for developing and executing NOAA's climate services. I thank you for the opportunity to testify about the unique and critical role satellites play in monitoring climate change. Our ability to monitor changes in climate is fundamental to understanding past, present, and future global climate change across the Nation and the world.

The well-established interconnectivity of the Earth's terrestrial, atmospheric, and oceanic systems requires a comprehensive and global perspective in climate monitoring. Satellites play a central and irreplaceable role in our Earth observing infrastructure, and they provide information that is fundamental to successfully understanding and anticipating climate change.

It is important to note raw satellite data and rapidly produced weather products derived from satellite sensors are rarely useful for climate change studies. Rather, an ordered series of sophisticated technical processes, developed through decades of scientific achievement, are required to convert raw satellite sensor data into Climate Data Records (CDRs). As defined by the National Research Council, a CDR is a time series of measurements of sufficient length, consistency, and continuity that can be used to assess current and foresee future climate variability and change. In practice, CDR development usually requires careful integration of archived data from many different satellites and sensor designs along with data from non-satellite observing systems. Climate scientists have generally had to acquire and process archived data of varying formats, granularity, accuracy and accessibility. As a result, these scientists have typically had to apply extraordinary effort over multiple years to derive CDRs of sufficient length and quality to address a variety of questions and issues related to climate change.

This morning, I will describe NOAA's new initiative – developed in coordination with NASA and in response to calls from the National Academy of Sciences and other expert bodies – to systematically and comprehensively develop and maintain authoritative CDRs. This initiative will lead to accurate long-term products and reduce the amount of time and effort put in to data reanalysis. As a result, our Nation's climate scientists and other professionals will routinely be able to focus on climate change analyses, hypothesis testing, climate change modeling, and climate change adaptation and mitigation studies using CDRs of known quality. The initiative includes state-of-the-art data stewardship and dissemination through NOAA's National Data Centers, and will help ensure CDRs are readily available to the public, easy to understand, and of the highest quality possible. This initiative will result in an acceleration of climate change understanding applicable to mitigation, adaptation, and risk assessment.

Climate Data Records Are Required for Climate Change

In its Fourth Assessment Report of 2007, the Intergovernmental Panel on Climate Change (IPCC) stated its consensus opinion on the state of and likely future changes of the Earth's climate. Although some points were expressed with notable confidence, others were carefully qualified due to the persistent uncertainties in the measurement and simulation of the large and complex Earth system. Indeed, the IPCC also listed key uncertainties and gaps in knowledge and research needs that must be addressed to significantly advance confidence in climate change prediction and understanding. For example, the IPCC found that:

1) Incomplete global data sets for extremes analysis and model uncertainties restrict the regions and types of extremes detection studies that can be performed;

2) The availability of observational data restricts the types of extremes that can be analyzed;

3) Multi-decadal changes in daily temperature range are not well understood, in part because of limited observations of changes in cloudiness and aerosols; and

4) Confidence in attributing some climate change phenomena to anthropogenic influences is currently limited by uncertainties in radiative forcing, as well as uncertainties in feedbacks and observations.

Most of the key gaps and uncertainties about climate, as identified by the IPCC, are directly or indirectly related to the availability of adequate observations and of CDRs when observations exist. This is because, without CDRs, we cannot effectively test our understanding of the climate system. For example, by comparing CDRs with climate model simulations researchers can evaluate and test climate model accuracy, as well as identify causes of particular elements of climate change. Because the ability to provide reliable scenarios of future climate is dependent upon CDRs, it is therefore unavoidably tied to the quality of available observational data sets.

The Challenge of Developing Climate Data Records

Most experts agree that a CDR must extend over multiple decades to unambiguously discern changes in climate. Within shorter time periods, climate signals or effects can be misinterpreted or altogether masked due to normal environmental variability, changes in instrument characteristics or behavior, changes in satellite orbits, and the lack of information about operating conditions in the environment around the satellite sensors. Due to the volume of observations required, CDR development cannot be constrained to a single satellite mission. Thanks to nearly 50 years of satellite weather observations and more than 35 years of operational satellite data in NOAA's computer archives, NOAA can now construct a comprehensive set of global CDRs. NOAA (and its predecessor agency, the Environmental Science Services Administration) has archived data from 41 polar orbiting and 15 geostationary satellites. NASA, currently with 15 on-orbit research satellites, and other national and international agencies have complemented NOAA's operational satellites with more than 50 other Earth-observing satellites. The National Polar Orbiting Environmental Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP) satellite, which will be launched before the series of NPOESS satellites, will sustain even more detailed and comprehensive observations in coming decades. Each satellite carries multiple remote sensing instruments. The grand challenge in CDR development is to scientifically stitch together these data.

Much of the data derived from these satellites have been used successfully for rapid weather forecast and hazard assessment – helping to save countless lives and investments. However, without significant additional research, analysis, and data archive investments, these data are, without question, unsuitable for addressing contemporary climate change questions from IPCC and others. In fact, there is now ample evidence that significant climate change information lies latent in these archives. For example, in the mid-1990s NOAA and NASA worked cooperatively to develop a pathfinder satellite-derived data set that was then used by a Boston University-led team[1] which worked exhaustively to develop a CDR that corrected for biases and instrument inter-calibration related to vegetation growth. These data were derived from a number of NOAA's polar orbiting satellites. After nearly four years of effort, the study revealed an unmistakable correlation between increased vegetation growth in the northern hemisphere and longer growing seasons associated with climate change. These findings also helped to independently confirm observations from other observing systems, including surface-based systems. Similarly, researchers at NOAA's National Climatic Data Center spent four years carefully merging and inter-calibrating a patchwork of data from 29 geostationary satellites – both U.S. and foreign – to develop a CDR to facilitate efficient global analysis of hurricanes. Within a year of completing the CDR, a team of scientists from Florida State University and University of Wisconsin used the resulting data set to objectively determine increases in hurricane intensity in the major ocean basins around the world since the early 1980s[2]. More often than not, however, a single team of scientists using a specific observing system to develop a CDR cannot effectively resolve climate change signals. CDRs that are not developed using multiple approaches and multiple satellite and Earth-based observing systems are often problematic. For example, in 2006, NOAA led a United States Climate Change Science Program (CCSP) Synthesis and Assessment Report that examined the apparent discrepancybetween changes of temperature observed in the atmosphere and those observed at

---

[1] Myneni, R.B., C.D. Keeling, C.J. Tucker, G. Asrar, and R.R. Nemani, 1997: Increased plant growth in the northern high latitudes from 1981-1991. Nature, 386, 698-702.

[2] Elsner, J.B., J.P. Kossin and T.H. Jagger, 2008: The increasing intensity of the strongest tropical cyclones. Nature, 455, 92-95.

the Earth's surface[3]. The discrepancy was largely resolved by carefully comparing competing CDRs, thereby highlighting the importance of having CDRs calculated using multiple approaches and multiple observing systems. These comparisons enabled a confident statement of certainty, something that was impossible to do without multiple CDRs for essentially the same climate variable.

Based on these and other studies, the World Meteorological Organization, National Research Council, CCSP, Global Climate Observing System, and other noted authorities have increasingly called for a comprehensive CDR program engaging multiple teams of scientists using independent observing systems to develop CDRs. The Strategic Plan for the CCSP and the Global Climate Observing System Plan (developed internationally with U.S. leadership) have identified 44 Essential Climate Variables (ECVs) for which CDRs can and should be developed[4]. Due to the massive amounts of new data that will be generated following the launch of NPP and the series of operational NPOESS satellites, preparatory work is required to assure climate research-quality processes and data ingest capabilities are in place so these new data can be exploited for climate change work as soon as possible.

The Challenge of Data Stewardship for Climate Data Records

For decades, NOAA has worked with NASA to develop, design, test, launch and maintain operational polar-orbiting and geostationary weather satellites. NASA has complemented NOAA's operational series with research satellite missions to test advanced systems and breakthrough technologies while acquiring critically important observations to improve our understanding of the global integrated Earth system, including discoveries on mechanisms causing changes in Earth's climate. Increasingly, the international community has flown additional environmental satellites. The cumulative investment in these satellites has been tremendous, and the payoff continues to be realized long after their mission lifetimes because of past and present data archive policies that allow for subsequent development and analysis of CDRs.

Across this diverse array of satellites, technological advances led to epic jumps in the quality, quantity and types of space-based measurements of Earth. Such improvements were often countered by the effects of an unforgiving space environment and changes in temporal and spatial sampling, resolution, orbital configurations, and calibration methods. Moreover, some satellite systems suffer premature disabilities, and all sensors degrade continuously once in orbit. The end result is our satellite data archives are now filled with an expansive patchwork of data which, while invaluable, were collected by many disparate sensors and platforms using different methodology and operating in different stages of health; this is one of our major data stewardship challenges.

---

[3] U.S. Climate Change Science Program, Synthesis and Assessment Product 1.1 "Temperature Trends in the Lower Atmosphere, Steps for Understanding and Reconciling Differences", April 2006.

[4] List of Essential Climate Variables provided in Appendix

Coping with the sheer volume of data from existing and planned satellites, along with the considerable ancillary data necessary to produce quality CDRs, is also a formidable challenge. Providing adequate data stewardship and access to these massive multi-petabyte archives requires comprehensive stewardship and information systems, such as those being operated by NOAA's National Data Centers. Data stewardship enables scientists and other users efficient and effective access to a variety of comprehensive data sets for CDR development and use.

NOAA's CDR Program

It is a privilege to report to you today that over the past two years, NOAA and NASA have been working on a coordinated interagency solution to develop and sustain CDRs[5]. Through this new initiative, as part of an effort to recover capabilities removed in the 2006 restructuring of NPOESS, these agencies defined a systematic program for identifying and transitioning the mature techniques from NASA's Earth Observing System (EOS) and other research programs into NOAA operations.

Thanks to satellite climate sensor and CDR funding in the 2009 American Recovery and Reinvestment Act, NOAA will begin to implement its part of the program which includes harvesting mature research technologies and applying them to decades of archived satellite data. Further, NOAA will continuously expand the range of CDR variables for climate change and extend the resulting CDRs using U.S. and international current and future satellite observations, including those from EOS, NPOESS and NPP.

To most rapidly facilitate integrated analysis, NOAA is focusing its early CDR development on environmental variables, which comprise critical components of the Earth's climate. For example, NOAA is currently reviewing proposals that would support advancements in understanding and modeling the Water and Energy Cycles. These are the climate system components, which impact lives, jobs and investments on a daily basis. Our ability to effectively mitigate and adapt to global climate change depends on our understanding of these components of the climate system. In future years, NOAA will focus on other key climate components, such as the Carbon Cycle.

Given the unique knowledge and extensive experience required to develop high-accuracy CDRs, NOAA will largely execute its program through competitively selected experts in academia, industry, non-profits, NOAA Cooperative Institutes, and other Federal agencies. NOAA will work to ensure that community knowledge gained through state-of-the-science research programs, such as NASA's EOS, is captured and incorporated into NOAA operations.

NOAA will also be upgrading its world-class data archive and access systems. Indeed, keeping up with the sheer volume of data coming from existing and planned satellites – along with the ancillary and validation data – that are necessary to produce, maintain and distribute CDRs requires comprehensive stewardship systems. NOAA is currently operating and continuing to

---

[5] The Joint NOAA/NASA Working Group for Sensors and Climate Data Records for NPP and NPOESS reporting to the NOAA Assistant Administrator for Satellites and Information and the NASA Headquarters Director of the Earth Science Division

develop its Comprehensive Large Array-data Stewardship System, which will provide the information technology necessary to support NOAA's CDR Program, among other programs.

The enduring success of the Nation's CDR activities will require sustained involvement of NOAA, NASA, and USGS, among others. NOAA will transition mature research into operations and leverage new CDR research methods and integrate new observing technologies from other agencies to help ensure the Nation's CDRs are well maintained and able to provide authoritative records of Earth's changing climate. Plans for future climate sensors to be carried on satellite systems should require consideration of CDRs to ensure continued and effective use of climate measurements.

Conclusion

There is no question that significant climate change information is currently embedded in the world's archived satellite data sets. Given the length, breadth, and global nature of these data, it is not an exaggeration to state these data contain valuable climate change information that cannot be accessed from any other sources. Although the disparate types and states of these data provide a challenge for developing CDRs, NOAA is now embarking on a comprehensive, systematic, and sustained effort to unleash the potential of these data from past, present, and next generation operational satellites to inform the Nation about ongoing and future climate change. Through this effort, our Nation will be taking a key action to improve its resilience to climate change and variability, maintain its economic vitality, and improve the security and well-being of the public for generations.

Appendix. U.S. Climate Change Science Program's Essential Climate Variables[6]

The table provides a summary of "State" and "Forcing/Feedback" variables for the major components of the Earth system. It is adapted from: 2003 Strategic Plan for the U.S. Climate Change Science Program, Chapter 12, Observing and Monitoring the Climate System, available at www.climatescience.gov and published by the U.S. Climate Change Science Program, Washington, DC 20006. Only measurements identified for space-based instruments are shown here. Many of these variables require *in-situ* observational networks to ensure reliable and validated retrievals from space-based sensors.

(1) Atmosphere

STATE VARIABLES	EXTERNAL FORCING OR FEEDBACK VARIABLES
• wind • upper air temperature • surface air temperature • sea-level pressure (I) • upper air water vapor • surface air humidity/water vapor • precipitation • clouds • liquid water content	• sea surface temperature • land surface soil moisture/temperature • land surface structure and topography • land surface vegetation • CO2 and other greenhouse gases, ozone and chemistry, aerosols • evaporation and evapotranspiration • snow/ice cover • shortwave and longwave surface radiation budget • solar irradiance and shortwave/longwave radiation budget

(2) Ocean

STATE VARIABLES	EXTERNAL FORCING OR FEEDBACK VARIABLES
• upper ocean currents • sea surface temperature • sea-level/surface topography • sea surface salinity • sea ice • wave characteristics • ocean biomass/phytoplankton	• ocean surface wind and wind stress • incoming surface shortwave radiation • downwelling longwave radiation • surface air temperature/humidity • precipitation (freshwater/salinity flux) • evaporation • freshwater flux from rivers and ice melt • organic and inorganic effluents (into ocean) • biomass and standing stock • coastal zones/margins

---

[6] The international Global Climate Observing System maintains a similar list as applicable to the United Nation's Framework Convention on Climate Change.

(3) Terrestrial/Cryosphere

STATE VARIABLES	EXTERNAL FORCING OR FEEDBACK VARIABLES
• topography/elevation • land cover • leaf area index • soil moisture/wetness • soil structure/type • vegetation/biomass vigor • water runoff • surface ground temperature • snow/ice cover • subsurface temperature and moisture • land use • lakes and reservoirs • rivers and river flow • glaciers and ice sheets • water turbidity, nitrogen, phosphorus, dissolved oxygen	• incoming shortwave radiation • net downwelling longwave radiation • fraction of absorbed photosynthetically active radiation • surface air temperature and humidity • albedo • evaporation and evapotranspiration • precipitation • land use and land-use practices • deforestation • human impacts—land degradation • erosion, sediment transport • fire occurrence • volcanic effects (on surface) • biodiversity • Earthquakes, tectonic motions • coastal zones/margins