U.S WEATHER AND ENVIRONMENTAL SATELLITES: READY FOR THE 21ST CENTURY?

Statement of

Antonio J. Busalacchi, Jr., Ph.D.
Chairman, Climate Research Committee
Chairman, Committee on Earth Science and Application:
Ensuring the Climate Measurements from NPOES and GOES-R
National Research Council
and
Director, Earth System Science Interdisciplinary Center (ESSIC),
University of Maryland

before the

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
U.S. Senate

JULY 11, 2007

Mr. Chairman, Mr. Vice Chairman, and members of the committee, thank you very much for this opportunity to testify. I am Dr. Tony Busalacchi, Director of the Earth System Science Interdisciplinary Center and Professor of Atmospheric and Oceanic Science at the University of Maryland. I also serve as the Chair of The National Academies' Climate Research Committee and of the Academies' "Panel on Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft." This latter study is in response to a NASA and NOAA request to the National Research Council (NRC) for a follow-on report to the Decadal Survey in Earth Science that focuses on recovery of lost measurement capabilities, especially those related to climate research, which occurred as a result of changes to the NPOESS and GOES-R satellite programs.

On June 19, 2007, our NRC Panel convened a three-day workshop, "Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft." The workshop attracted some 100 scientists and engineers from academia, government, and industry. The workshop gave the climate community a chance to review and comment on the NASA/NOAA assessments of the climate impacts associated with Nunn-McCurdy descopes of NPOESS, as well as offer input on a variety of suggested mitigation scenarios. A report of the workshop will be available later this summer. Presentations from the workshop are available for download at: <http://www7.nationalacademies.org/ssb/SSB_NPOESS2007_Presentations.html>. A final report, with findings and recommendations, will be issued in January. As this study is still underway, the views I express today are my own.

As requested, I will use my time this morning to summarize my views on the status and direction of the nation's current and planned constellation of weather and environmental satellites. In particular, I will focus on your request for information on the "budgetary, management, and schedule risks of these [weather and environmental] satellite systems, as well as the potential lost capabilities in climate monitoring, modeling, and forecasting that are possible under the current program."

This hearing takes place against the backdrop of significant developments in NOAA weather and environmental monitoring programs and NASA's Earth Science Program:

- In June 2006, the next-generation National Polar-orbiting Operational Environmental Satellite System (NPOESS) completed its "Nunn-McCurdy" certification.[1] As a result, the planned acquisition of six spacecraft was reduced to four, the launch of the first spacecraft was delayed until 2013, and several sensors were canceled or descoped in capability as the program was re-focused on

[1] NPOESS was created by Presidential Decision Directive/ National Science and Technology Council (NSTC)-2 of May 5, 1994 wherein the military and civil meteorological programs were merged into a single program. Within NPOESS, NOAA is responsible for satellite operations, the Department of Defense (DoD) is responsible for major acquisitions, and NASA is responsible for the development and infusion of new technologies. In 2000, the NPOESS program anticipated purchasing six satellites for $6.5 billion, with a first launch in 2008. Costs have since escalated dramatically and the expected date of first launch slipped to 2013. By November 2005, it became apparent NPOESS would overrun its cost estimates by at least 25%, triggering a so-called Nunn-McCurdy review by the Department of Defense.

"core" requirements related to the acquisition of data to support numerical weather prediction. "Secondary" sensors that would provide crucial continuity to some long-term climate records and other sensors that would have provided new data are not funded in the new NPOESS program.

- Costs for NOAA's next generation of geostationary weather satellites, GOES-R, have risen dramatically and late last year NOAA canceled plans to incorporate a key instrument on the spacecraft—HES (Hyperspectral Environmental Suite). HES was to provide GOES-R spacecraft with significantly advanced three-dimensional vertical profiles of atmospheric temperature and humidity, and coastal waters imagery to help scientists monitor events like harmful algal blooms or to assist in fisheries management.

- The 2005 National Research Council report, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*[2] described the national system of environmental satellites as "at risk of collapse." That judgment was based on the observed precipitous decline in funding for Earth-observation missions and the consequent cancellation, descoping, and delay of a number of critical missions and instruments.[3] The report also identified the need to evaluate plans for transferring capabilities from some cancelled or scaled back NASA missions to the NOAA-DoD NPOESS satellites. Since the publication of that report, NPOESS and NOAA have experienced the problems noted above and NASA has canceled additional missions, delayed the Global Precipitation Mission (GPM) another 2.5 years, and made substantial cuts in its Research and Analysis program.[4]

This hearing also occurs shortly after the completion of the first National Academies Decadal Survey in Earth Science and Applications from Space and the recent release by the Intergovernmental Panel on Climate Change of their Fourth Assessment Report. In addition, as you are all aware, there have been numerous news accounts in recent days regarding the fate of a particular spacecraft—QuikSCAT, which measures sea surface wind speed and direction.

Sustained Earth Observations for Operations, Research, And Monitoring

Scientific breakthroughs are often the result of new exploratory observations, and therefore new technology missions stimulate and advance fundamental knowledge about the planet. Analysis of new observations can both test hypotheses developed to elucidate fundamental mechanisms and lead to the development of models that explain or predict important Earth processes. The data from these new technology missions sometimes

---

[2] National Research Council, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, Washington, D.C.: The National Academies Press, 2005.
[3] Ibid, Table 3.1, p. 17.
[4] Total R&A for NASA science missions was cut by about 15% in the President's 2007 budget (relative to 2005). In addition, the cuts were made retroactive to the start of the current fiscal year. Over the last 6 years, NASA R&A for the Earth sciences has declined in real dollars by some 30 percent.

provide early warning of changes in the Earth system that are critical to our well-being, such as declining ice cover in the Arctic Ocean, developing holes in the protective ozone layer, or rising sea level. To determine the long-term implications of the changes or to uncover slowly evolving dynamics, the measurements must be continued, usually with one or more follow-on missions.

Access to uninterrupted space-based global observations of the atmosphere, oceans, and land surface have enabled breakthroughs in predicting natural climate variability beyond the day-to-day weather time scale. Today's coupled climate models, initialized by global satellite observations, now routinely issue short-term climate forecasts from seasons out to a year in advance with the realistic prospect of extension to years and decades. To discriminate between natural climate variability and anthropogenic climate change requires instrument accuracy and stability greater than is normally required to support weather prediction. Interruptions to the continuity of these climate data records without such accuracy and stability can induce uncertainty that may be as large, or larger, than the climate signal being monitored.

Sometimes data from a new technology mission become critical to an operational system, such as the wind speed and direction measurements from NASA's QuikSCAT mission and precipitation measurements from NASA's Tropical Rainfall Measurement Mission (TRMM), both of which are used in weather and climate forecasting. An obvious but often difficult consequence is that these *research* measurements need to be transitioned into *operational* systems and continued for many years. This is a recognized and well-studied challenge, but, the record of transitioning new technology into the operational system is, at best, mixed.[5] More often than not, the operational utility of data from these research missions is realized toward the end of the design life of the instruments. By then however, it is usually too late to begin the planning of a follow-on operational mission if continuity is to be maintained.

The difficulties in combining the climate and weather requirements on NPOESS as well as the problem in executing what is sometimes referred to as the transition from NASA "research" missions to NOAA operations (which, is effectively the source of the current controversy surrounding the aging QuikSCAT spacecraft) are different aspects of an overarching problem: *the United States lacks a coherent strategy to manage its earth observation programs in general and its climate observations in particular*. The Nunn-McCurdy certification of NPOESS exposed the difficulty in sustaining long-term climate observations within a program managed by agencies with different priorities and missions. Whereas NOAA and DoD have complementary priorities with respect to weather prediction, the same does not hold for climate. Moreover, the stability, calibration, and technology refresh requirements for climate observations call for a flexible systems approach consisting of a mix of small climate-specific satellites,

---

[5] Transition failures have been exhaustively described in previous NRC reports. See National Research Council, *Extending the Effective Lifetimes of Earth Observing Research Missions*, Washington, D.C.: The National Academies Press, 2005 and National Research Council, *Satellite Observations of the Earth's Environment: Accelerating the Transition from Research to Operations*, Washington, D.C.: The National Academies Press, 2003. These publications are also available on-line at <http://www.nap.edu/catalog/11485.html> and < http://www.nap.edu/catalog/10658.html>, respectively.

formation flying, and single sensor "free flyers", as opposed to the (small school bus) one-size fits all series of "Battlestar Gallactica" NPOESS platforms.

Our ability as a nation to sustain climate observations has also been complicated by the fact that no single agency has the mandate and requisite budget for providing routine climate observations, prediction, and services. As stated in the January 2007 National Research Council pre-publication of the "Decadal Survey," *Earth Science and Applications from Space*:[6]

> The committee is concerned that the nation's institutions involved in civil space (including NASA, NOAA, and USGS) are not adequately prepared to meet society's rapidly evolving Earth information needs. These institutions have responsibilities that are in many cases mismatched with their authorities and resources: institutional mandates are inconsistent with agency charters, budgets are not well-matched to emerging needs, and shared responsibilities are supported inconsistently by mechanisms for cooperation. These are issues whose solutions will require action at high-levels of the government.

For example, in a recent NRC review of NASA's 2006 Draft Science Plan[7] the committee noted that the "NASA/SMD (Science Mission Directorate) should develop a science strategy for obtaining long-term, continuous, stable observations of the Earth system that are distinct from observations to meet requirements by NOAA in support of numerical weather prediction." Accordingly, the Decadal Survey committee recommended that, "The Office of Science and Technology Policy, in collaboration with the relevant agencies, and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs."

I will now turn to the specific questions about the programs under consideration:

What are the potential lost capabilities in climate monitoring, modeling, and forecasting?

NPOESS: As noted in a recent NASA-NOAA report, which was performed at the request of the White House Office of Science and Technology Policy, "For more than thirty years, NASA research-driven missions, such as the EOS, have pioneered remote sensing observations of the Earth's climate, including parameters such as solar irradiance, the Earth's radiation budget, ozone vertical profiles, and sea surface height. Maintaining these measurements in an operational environment provides the best opportunity for

[6] National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, The National Academies Press, Washington, D.C., 2007. Available online at: <http://www.nap.edu/catalog/11820.html>.

[7] National Research Council, *A Review of NASA's 2006 Draft Science Plan: Letter Report*, The National Academies Press, Washington, D.C., 2006. Available online at: <http://www.nap.edu/catalog/11751.html>.

sustaining the long-term, consistent, and continuous data records needed to understand, monitor, and predict climate variability and change."[8] However, the Nunn-McCurdy certification placed a priority on the continuity of operational weather measurements at the expense of climate measurements. In addition, the post-certification constellation eliminated the "mid-morning" orbit and reduced the planned acquisition of six spacecraft to four. NASA and NOAA have completed their preliminary assessments of the impacts of these changes, focused primarily on the de-manifested sensors. Their assessment is documented in a white paper prepared for OSTP. Rather than go into the details of their assessment or repeat it here, a brief summary of the climate impacts associated with de-manifestation of these sensors is included in the appendix.

QuikSCAT: QuikSCAT continues to function well and provide all-weather observations of ocean surface wind speed and direction, although it is five-years beyond its design lifetime and it is operating on a backup communication system. Should QuikSCAT fail, the United States would have to rely on the ASCAT instrument on the European MetOp system and on data currently provided by the WindSat spacecraft. Both of these systems have drawbacks compared to QuikSCAT—ASCAT has large gaps in coverage compared to QuikSCAT and analyses to date of WindSat data expose serious concerns about the utility of passive polarimetric measurements of surface wind speed and direction in low and high wind regimes for research and operational applications. Further, the capabilities of the successor to Windsat, the MIS instrument planned for NPOESS, are still unknown and NOAA does not plan to incorporate the instrument on NPOESS until launch of the second spacecraft in 2016 at the earliest. The National Academies Decadal Survey recommended a follow-on mission to QuikSCAT—XOVWM—to be launched in the 2013-2016 timeframe. It is my understanding that the survey's choice of this time period, versus one sooner, was based on an examination of expected resources and the need to launch other priority missions.

GOES-R: the loss of HES is of higher priority for numerical weather prediction and monitoring of coastal waters than it is for climate. The impact to climate research is the loss of ability to track changes in the intensity and frequency of extreme events such as hurricanes, floods, wildfires, and harmful algal blooms as modulated by climate variability and change.

Overview of Climate Needs

The climate community has three basic observational needs: (1) sustained (continuous, and often overlapping) measurements of certain key climate parameters critical to monitor long-term climate trends and to validate climate models, (2) observations to initialize and force coupled climate prediction models, and (3) new or improved measurements of additional key parameters to advance climate science and reduce uncertainty in our understanding of climate processes and interactions within the coupled

[8] "Impacts of NPOESS Nunn-McCurdy Certification on Joint NASA-NOAA Climate Goals," NOAA-NASA Draft White Paper, January 8, 2007.

climate system. It is the first and second category of needs which are now threatened by NPOESS, though the third category – and indeed all of Earth science – is implicitly threatened by the cost overruns of NPOESS, which have had great impact on already-tight Earth science budgets. This impact will increase as the agencies attempt to assure continuity of the most critical of climate records by altering upcoming flight manifests, restoring instruments to NPOESS, or designing "gap-filler" missions.

Mitigation Challenges

Any strategy to mitigate the impacts of the loss of these sensors begins with a prioritization of their importance and an assessment of the cost and risk of various recovery options. Such an assessment is the subject of the ongoing National Research Council study that I chair; it is also the subject of an Office of Science and Technology Policy (OSTP)-requested study that is being executed by NASA and NOAA. The range of options under study include re-manifesting selected sensors to the NPOESS platforms, making use of ongoing and planned missions by international partners, launching selected sensors on missions of opportunity or on new spacecraft, and assimilating data from multiple sources to help reconstruct the lost data.

It is also important to recognize the limitations of some of the climate sensors on NPOESS even before the Nunn-McCurdy actions. For example, from its sun-synchronous orbit, altimeter measurements of sea-surface height (SSH) via the ALT instrument would contend with the effects of tidal aliasing. The precise record of SSH that began with the Topex/Poseidon mission (and continues with Jason-1 mission, which should overlap with the 2008 of Jason-2) derives from instruments on spacecraft that are *not* in sun-synchronous orbit. Moreover, as emphasized repeatedly in recent NRC studies, the generation of credible climate records requires investments in pre-launch instrument characterization, on-orbit calibration and validation, and a ground support system that has the requisite resources to archive, disseminate, analyze, and periodically re-analyze the data. Appropriate investments in this critical part of the chain from raw data to climate data record were never part of the NPOESS program. Indeed, their absence is indicative of the problem that arises when the very different needs of the climate community are effectively piggybacked on the needs of numerical weather forecasters from both the DoD and civil communities.

Recovery strategies also must take account of plans for execution of the NRC Decadal Survey. The Decadal Survey was sponsored by NASA (Office of Earth Science), NOAA (NESDIS), and the USGS (Geography). While cognizant that space-based observations were only part of a credible Earth observing system, it was charged with:

- Articulating priorities for Earth system science and the space-based observational approaches to address those priorities.

- Establishing individual plans and priorities within the sub-disciplines of the Earth sciences as well as providing an integrated vision and plan for the Earth sciences as a whole.

The relevance of the recommended Decadal Survey missions mapped against de-manifested NPOESS sensors is shown in Table 1 below. It is important to note that the decadal strategy covers all of Earth science, including but not limited to climate science. Though I am limiting my remarks here to discuss those elements related to climate and of relevance to the NPOESS and GOES-R considerations, I support the report's call for a balanced Earth science program. Of particular interest for NPOESS mitigation strategies in the near-term is the recommendation for an early start of the CLARREO radiance mission. A more capable ocean vector wind follow-on to QuikSCAT—XOVWM—is also called out to start in the period from 2013-2016.

In summary, our climate monitoring capabilities are neither adequate to meet the needs of the climate research community nor the needs of decision-makers. The NPOESS descopes highlight what has for too-long been a precarious and loosely coordinated series of climate observations in which the long-term generation and support of climate data records are left out of key agency's long-term planning. The Nunn-McCurdy certification of NPOESS has exposed the fact that we do not have an agreed upon national strategy for long-term, continuous, and stable observations of the Earth system. As the recent Decadal Survey committee pointed out, sustained measurements with both research and operational applications do not fall clearly into any one agency's charter. This results in a metaphorical relay race between NASA and NOAA, where no runner is waiting to be passed the baton.

As it pertains to climate monitoring, the relative roles and responsibilities of NASA and NOAA remain uncertain. As a direct consequence, we are faced with a likely gap in critical long-term climate records and a diminished capability to understand and predict climate and related changes on our planet for generations to come. As we seek to mitigate this situation, applying a band-aid if you will, I urge members of this committee to carefully consider how we might avoid having a similar hearing in the not too distant future. Right now, we are in a reactive mode with respect to what can only be referred to as the NPOESS debacle. Our nation needs a deliberate, forward looking, and cost-effective strategy for satellite-based environmental monitoring. The nation requires a coherent strategy for Earth observations which provides for operational climate monitoring and prediction, scientific advances, *and* the continuation of long-term measurements. The Nation *deserves* such a strategy. Thank you for the opportunity to appear before you today on this important topic. I am prepared to answer any questions you may have.

Table 1. Contributions of recommended Decadal Survey missions to continuation or expansion of Environmental Data Records (EDRs) as defined by the NPOESS Integrated Operational Requirements Document (2001). Current status of NPOESS's planned capabilities to obtain the EDRs is also shown. NOTE: MetOp contributions to EDRs and space weather-related EDRs are not listed here.

Descoped/Degraded EDR	**NPOESS Status**	**Relevant Decadal Survey Contribution**
Soil moisture	Degraded	SMAP
Aerosol refractive index/single-scattering albedo and shape	Demanifested	ACE
Ozone total column/profile	Reduced Capability (Column only)	GACM
Cloud particle size distribution	Demanifested	ACE
Downward LW radiation (surface)	Demanifested	CLARREO
Downward SW radiation (surface)	Demanifested	CLARREO
Net solar radiation at TOA	Demanifested	CLARREO
Outgoing LW radiation (ToA)	Demanifested	CLARREO
Solar irradiance	Demanifested	CLARREO
Ocean wave characteristics/Significant wave height	Reduced Capability	XOVWM
Sea surface height/topography - basin scale/global scale/mesoscale	Demanifested	SWOT
EDR dependent on CMIS replacement	**NPOESS Sensor**	**Relevant ESAS Contribution**
Atmospheric vertical moisture profile	CrIS/ATMS/CMIS(replacement)	PATH, GPSRO, CLARREO
Atmospheric vertical temperature profile	CrIS/ATMS/CMIS(replacement)	PATH, GPSRO, CLARREO
Global sea surface winds	CMIS(replacement)	XOVWM
Imagery	VIIRS/CMIS(replacement)	HyspIRI
Sea surface temperature	VIIRS/CMIS(replacement)	PATH
Precipitable water/Integrated water vapor	CMIS(replacement)	ACE
Precipitation type/rate	CMIS(replacement)	PATH
Pressure (surface/profile)	CrIS/ATMS/CMIS(replacement)	GPSRO, CLARREO
Total water content	CMIS(replacement)	ACE
Cloud ice water path	CMIS(replacement)	ACE
Cloud liquid water	CMIS(replacement)	ACE
Snow cover/depth	VIIRS/CMIS(replacement)	SCLP
Global sea surface wind stress	CMIS(replacement)	XOVWM
Ice surface temperature	VIIRS/CMIS(replacement)	
Sea ice characterization	VIIRS/CMIS(replacement)	SCLP, ICESat-II

Appendix: Brief Summary of Climate Impacts due to De-Manifested NPOESS Sensors[9]

The certification eliminated five key NPOESS "climate" sensors—TSIS, ERBS, ALT, OMPS-Limb, and APS. Either as result of an instrument descope or as a result of the reduction from three orbits to two, the certification also impacted the capability of CMIS, VIIRS, and CrIS measurements that support climate research.

1. Total Solar Irradiance Sensor (TSIS), a de-manifested sensor:

Impact: These measurements monitor the energy of the sun incident on Earth. Measurements of TSI are essential to discriminate between natural and anthropogenic causes of climate change. Further, these measurements can be accurately determined only above the atmosphere. Any interruption of the 28-year data record of Total Solar Irradiance jeopardizes our ability to confidently resolve small changes in this most fundamental variable and adds uncertainty to climate change attribution.

2. Earth Radiation Budget Sensor (ERBS), a de-manifested sensor:

Impact: This measurement monitors the incoming and outgoing energy to the Earth-atmosphere system that maintains climate and it can be accurately determined only above the atmosphere. Overlap between space-based sensors is critical to confidently detect and monitor the small changes in the Earth's radiation balance capable of affecting climate.

3. OCEAN Altimeter (ALT), a de-manifested sensor:

Impact: Ocean topographical data are vital to study the role of ocean circulation and the associated thermal transport in the climate system, sea level rise, assessing the severity of hurricanes, tracking costal ocean currents, and aiding in the forecasting of natural disasters. Sea level measurements are the climate change indicators of most direct concern for a substantial proportion of the U.S. and the world's population, most of whom live near the coast. These observations provide critical input to El Nino and short-term climate forecasts.

4. Ozone Mapping and Profiler Suite Limb Subsystem (OMPS-Limb), a demanifested sensor:

Impact: Stratospheric ozone absorbs incoming solar ultraviolet radiation that can be harmful to humans and other organisms. Anthropogenic emissions of halogen-containing gases (e.g. Freon®) are now known to destroy stratospheric ozone. The Montreal Protocol on Substances Depleting the Ozone Layer has resulted in successful international actions to reduce atmospheric concentrations of halogen-containing gases.

[9] Adapted from "Impacts of NPOESS Nunn-McCurdy Certification on Joint NASA-NOAA Climate Goals," NOAA-NASA Draft White Paper, January 8, 2007

The continuation of stratospheric ozone observations is crucial to monitor and evaluate the recovery of the ozone layer.

5. Aerosol Polarimetry Sensor (APS), a de-manifested sensor:

Impact: Aerosol properties are a high priority in the U.S. Climate Change Science Program. The effects of aerosols on global temperature and cloud properties are significant and may be comparable in importance to the role played by “greenhouse” gases, such as carbon dioxide and methane, which contribute to the warming of the Earth’s surface. Given the expected continued industrialization of developing nations such as China and India, aerosol observations are a critical climate variable.

6. Conical Microwave Imaging Scanner (CMIS), a de-scoped sensor:

Impact: The original CMIS design was to provide information on the following essential climate variables: sea surface temperature (SST), sea ice and snow cover extents, vegetation, ocean surface wind speed, water vapor, and precipitation rates. Specifications for the reduced capability MIS will not be available until September. Serious concern exists regarding the SST and wind vector retrievals from such an instrument.