A Review of NOAA's Future Satellite Program: A way forward

- Affordable
- Flexible
- Robust

A Report from the NOAA Science Advisory Board
December 2012

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INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) and its predecessor organization, the Environmental Sciences Services Administration (ESSA), have about five decades experience of developing and successfully operating weather and environmental satellites. NOAA, working in conjunction with the National Aeronautics and Space Administration (NASA), has provided increasingly advanced operational satellite systems that have been a critical component and backbone for improving weather forecasts for protection of life and property, for supporting numerous societal benefits and for use in national and environmental security. In addition, NOAA has built strong relationships with both national and international partners as part of an environmental satellite enterprise.

These operational satellites have evolved from basic weather satellites of the early 1960s to the complex environmental satellites of today, with applications related to numerical weather forecasting (including severe weather related to hurricanes and tornadoes), space weather, oceans, climate change, detection and monitoring of forest fires, drought conditions, volcanic ash, floods, and the ozone hole.

As these weather and environmental satellites have become increasingly more complex they have, likewise, become substantially more expensive. As a consequence, NOAA is facing unprecedented budget challenges. In view of these challenges, the NOAA Science Advisory Board (SAB) established the Satellite Task Force (SATTF) to provide advice on the National Environmental Satellite, Data, and Information Service (NESDIS) planning for future satellite systems. The purpose of this report is to provide the results and recommendations of the review conducted by the SATTF.

SATELLITE SYSTEM BACKGROUND

The NOAA satellite constellation is comprised of complementary operational polar-orbiting and geostationary satellite systems that have been primarily focused on weather. Historically, these satellites have been referred to as the Polar-orbiting Operational Environmental Satellites (POES) and the Geostationary Operational Environmental Satellites (GOES). More recently, NOAA is addressing satellite programs for space-based ocean altimetry, space weather, and climate.

Geostationary satellites provide a continuous view of weather systems making them invaluable for following the motion, the development, and the decay of atmospheric phenomena. Even short-term events such as severe thunderstorms, with a life-time of only a few hours, can be successfully recognized in their early stages and appropriate warnings of the time and area of their maximum impact can be expeditiously provided to the general public. The warning capability has been the primary justification for the geostationary spacecraft. The polar-orbiting satellite system provides the data needed to compensate for the space and time deficiencies in conventional non-satellite observing networks (such as ships, aircraft, balloons, buoys, ground-based sensors); it is able to acquire data from all parts of the globe in the course of a series of successive orbits. The polar-orbiting satellites are principally used to obtain daily global cloud cover and quantitative measurements of surface temperature and atmospheric soundings (vertical profiles) of temperature and water vapor; each polar satellite sensor acquires a global set of data. Together, the polar-orbiting and geostationary satellites constitute a meteorological satellite network covering the whole earth.

Each day, NOAA's NESDIS processes and distributes about ten terabytes of data and images to forecasters and other users globally. The timeliness and quality of the combined polar and geostationary satellite data have been greatly improved by enhanced computer installations, upgraded ground facilities, and data sharing agreements with U.S. military and international weather services.

After the termination of the joint civil and DoD National Polar-orbiting Operational Environmental Satellite System (NPOESS) in February 2010, NOAA established the Joint Polar Satellite System (JPSS). This next generation polar system is composed of satellites, a ground-control system, and a data processing/dissemination network. Building on current relationships, and as part of this effort, the United States has established a essential interdependence with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and an important collaboration with the Japan Aerospace Exploration Agency (JAXA) to provide long-term continuity of observations from polar-orbiting satellites that will continue and improve the operational meteorological and environmental forecasting and global climate monitoring services for system users.

NOAA is continuing its goal of keeping the latest in technology available for improved data to support the National Weather Service's goal of improving weather forecasts. Accordingly, NOAA has defined the next generation GOES series to include improved spacecraft and instrument technologies. These will result in more timely and accurate weather forecasts and improved support for the detection and observation of meteorological phenomena that directly affect public safety, e.g., hurricanes and tornadoes. At the same time, improved observations will both enable the ability to protect property and, ultimately, to enhance economic health and development.

In addition, as part of the planning phase, NOAA will be developing future mission investment plans with a goal to ensure data continuity in concert with national and international partners. Critical measurements include radar altimetry, solar wind and other space weather parameters, climate trends, ocean surface vector winds, and high fidelity radio occultation.

SATTF CHARGE AND PROCESS

In view of fiscal and technical challenges NOAA is facing with its satellite program, the SAB recognized that NOAA could benefit from a review of the effort underway within NESDIS to reevaluate future plans. The objective of the NESDIS effort is to "develop an executable plan which optimally serves NOAA's satellite needs while accommodating unprecedented uncertainty in future appropriations."

The SATTF was established to conduct a short term review of the NESDIS proposed replanning activities and was charged to: "recommend a way forward for NOAA's satellite program, starting with initial NESDIS recommendations and seeking a **more affordable, flexible and robust satellite and services architecture."** The terms of reference for the SATTF, containing considerations for the review and a listing of SATTF members are provided in Appendices A and B, respectively. See Appendix C for National Space Policy extracts considered by the task force. Thus, the considerations of the SATTF and this report focus on a review of the NESDIS activities related to future satellite system architectures for both geostationary and polar-orbiting missions, the ground system for these satellites, the budget and policy environment, the requirements, the collaborative relationship of NESDIS with its partners and the risks associated with uncertainty in a fiscally constrained environment.

The study process involved meeting with NESDIS staff over a period of months to conduct a detailed review and assessment of the NESDIS planning efforts and related activities. In addition, the SATTF reviewed external programs to better understand alternative approaches to satellite architectures. The results and recommendations of this review are presented as statements of Observations, Findings, and Recommendations. The SATTF believes these statements provide sufficient information to the SAB for NOAA to use as guidance for future planning and modifications by NESDIS as it develops a way ahead for its satellite system planning and organization. The SATTF believes NOAA NESDIS management understands fully the challenges ahead and has taken steps to address those challenges; however, much work remains and there are opportunities to improve and build on the on-going planning efforts.

FISCAL AND TECHNICAL CHALLENGES

NOAA is faced with a number of key challenges as it plans for the nation's future weather and environmental operational satellite systems. These challenges provide a context and backdrop that make planning and reprogramming difficult. Although there are various challenges and issues that must be addressed, the four listed below are particularly important considerations.

1. Increasing satellite system costs and uncertain fiscal environment – Continuing increases in costs for satellite systems, including launch vehicles, exacerbate budgeting in a relatively constant or declining fiscal environment, resulting in a decreased ability to invest in future capability and capacity. Budget resources are uncertain and will be limited for the next decade in light of the national economy and the high cost of satellite systems. Figure 1, the NESDIS satellite funding profile through 2017, illustrates the projected decrease in funding starting in 2015.

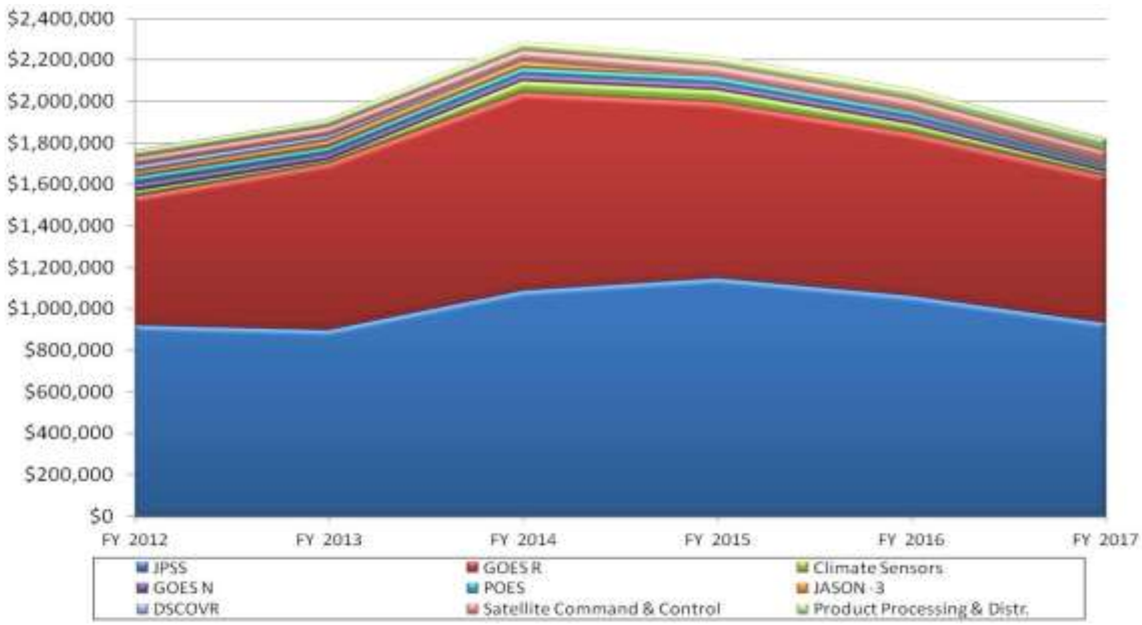

Figure 1: FY2012 to FY2017 projected funding profile

2. Maintaining satellite continuity – Observations from satellite systems are essential components of weather forecasting, hazard warning and assessment and response, climate trend detection, and space weather monitoring. These observations have significantly contributed to improved numerical weather predictions. Increased costs in satellite systems (including delays in development and acquisition), coupled with budget uncertainty, could lead to a break in the continuity of satellite system observations and service. Such a potential break in continuity would have a detrimental impact to weather forecasting, as well as to other applications. Figure 2 illustrates the current plan for maintaining polar satellite continuity. Mitigation plans must be developed to avoid negative impact if this plan is not successful.

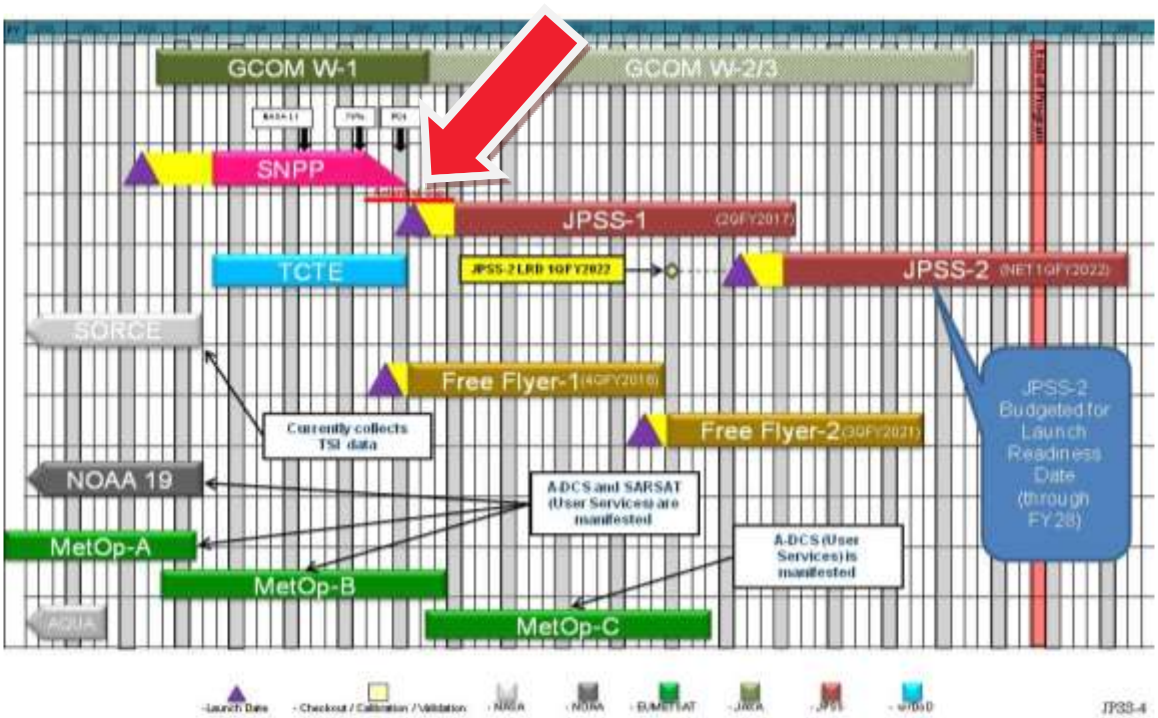

Figure 2: Continuity of Operational Polar-orbiting Observations – The red arrow points to a gap if Suomi National Polar-orbiting Partnership (SNPP) only survives to its design life. In addition, a JPSS-1 failure would create a major gap in coverage.

3. Balancing requirements push and technology pull – The technology and complexity for satellite observations has expanded notably in the past 25 years resulting in expanded missions, new and improved sensors, increased observation resolution, and integrated approaches for data collection and analysis. Keeping pace with technology, together with increasing demands and expanding requirements by the user community across NOAA and government agencies, is an increasingly difficult challenge.

4. Sustaining Partnerships – The value of partnerships has been clearly demonstrated as a means to reduce or avoid costs, while leveraging the international collaborative satellite enterprise in support of national needs. Partnering has grown considerably in the past two decades. While the reliance on partners brings an inherent risk and challenge, it also provides the opportunity to obtain additional or new data, mitigate potential breaks in satellite continuity, and increase coverage. For partnerships to be successful, careful attention needs to be paid to establishing appropriate agreements, identifying and maintaining the collaboration, and defining suitable data exchanges to the benefit of the partners. As an example, figure 3 illustrates how NOAA is planning to provide and maintain ocean altimetry observations through partnerships.

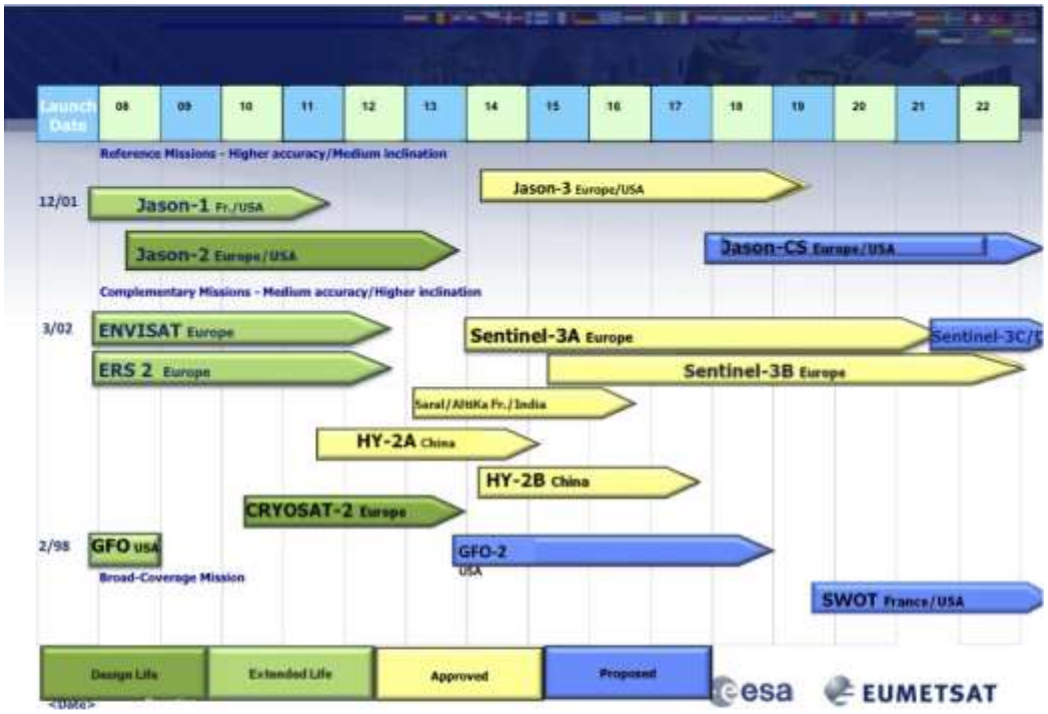

Figure 3: Flyout chart for Ocean Altimetry – An example indicating the international contributions/partnerships that make continuity of these observations possible.

SUMMARY FINDINGS AND OBSERVATIONS

1. NOAA's budget for currently planned space systems appears to be unsustainable
2. Today's fiscal environment could very well lead NOAA to increase risk or decrease scope while balancing satellite system cost, performance and schedule
   - NOAA NESDIS leaders clearly stated prioritized programmatic criteria for establishing an alternative space-based architecture (in the order of cost, schedule and level of performance)
3. The constrained fiscal environment will require prioritization of threshold space-based observational requirements
4. NOAA needs a total systems approach to satellite architecture development
   - NOAA is in a position to undertake this as it now has sole responsibility for both JPSS and GOES
5. NOAA needs to develop affordable, flexible and robust satellite architecture alternatives, using common measures of merit, to address the budget challenge
   - Building alternative architectures is not easy and requires organizational commitment as well as budget and programmatic flexibility and stability
   - NESDIS has developed options for future enterprise ground system architecture and alternative JPSS variants
6. NOAA is to be commended for taking steps to address the need for a future satellite system architecture
   - Significant challenges are inherent in developing satellite architectural alternatives
   - Additional effort and continued commitment is required toward meeting that goal, building on the progress to date
7. NOAA is to be commended for establishing a process capable of prioritizing needs for space-based observations; however, the process is incomplete, as it cannot always be used to demonstrate impacts from the removal of capabilities

SUMMARY RECOMMENDATIONS

NOAA should:

1. Advocate and foster, at the NOAA leadership level, a stable funding environment and management environment to support satellite activities within the budget guidelines provided to the agency
2. Establish a prioritized list of threshold space-based observational requirements that maintains high impact capabilities
   - Define NOAA core functions and align them with national space policy and agency guidance

   - Coordinate with all stakeholders (including national and international), with respect to prioritization of requirements and architectural tradeoffs
   - Update the prioritization process database regularly with current information from subject matter experts
3. Create a Chief Systems Engineering function within NESDIS to address the end-to-end link from goals, to architectures, to concepts of operation, to individual system development and finally to delivery of the integrated systems across the organization
4. Develop a cost-capped implementation plan for a NOAA Enterprise Ground System building on the recently completed study and analysis of alternatives
5. Develop an integrated master schedule addressing the entire satellite system architecture, including identification of the critical path(s)
6. Develop a tailored overarching risk-management plan consistent with alternative architectural decisions to ensure a sustainable future satellite program
7. Create a plan and a process for developing innovative and contingency options to mitigate gaps and potential reductions in capability and capacity
   - Establish a small, agile team to create the plan and process
   - Capitalize on technology developments across all sectors, e.g., industry, academia, national labs and other agencies
   - Consult other innovative organizations with space architecture experience; for example, DoD's Operationally Responsive Space (ORS) office provides one model for rapid response and lower capability alternatives, especially for observational reconstitution in the case of single instrument failures
   - Balance Technology Readiness Levels (TRL) with the criticality of the measurements
8. **Given the ten year timeline required to develop new satellite systems conduct an analysis of alternatives, starting in FY2013, considering cost, performance, risk and resiliency, and assessing trade space vs. requirements for at least the following approaches:**
   a) Continue JPSS and GOES architecture,
   b) Pursue new multi-sensor satellites,
   c) Establish a hybrid of current polar and geostationary satellites,
   d) Investigate a federated architecture with defined missions for individual partners, and
   e) Develop a new distributed architecture

SPECIFIC OBSERVATIONS and FINDINGS

1. Policy

- Severe budget cuts could dictate less capable satellites, leading to major policy implications, such as:
  - Inability to meet National Space Policy responsibilities (See Appendix C)
  - Inability to meet international commitments
  - Inability to meet the needs of NOAA and non-NOAA users in accordance with current policy
- The relationship is not clear between NOAA's operational requirements and its responsibility for national "requirements, funding, acquisition, and operation of civil operational environmental satellites in support of weather forecasting, climate monitoring, ocean and coastal observations, and space weather forecasting" (National Space Policy)
- Alternative architectures could lead to International Traffic in Arms Regulations (ITAR) challenges
- NOAA management commitment and policy guidance are required to implement alternative architectures, given potential hard choices and their impacts

2. Budget

- NOAA budget for currently programmed space systems may be unsustainable in today's fiscal environment
- Given the foreseeable future funding profile, NOAA will be challenged to deliver the same level of capability as today
- NOAA needs to be prepared for budget shortfalls, given uncertainty in fiscal future
- JPSS-2 alternative architectures provide an opportunity for minimizing potential cuts in capability while responding to a budget shortfall
- There may be opportunity for near-term cost-savings, such as increased automation of the ground system

3. Requirements Prioritization

- The prioritization inside NOAA for requirements in support of Weather, Climate and Space Weather is not clear
- There is not an agreement on the baseline necessary for NOAA operational continuity for satellite observations to maintain high impact capability

- The minimum capabilities required to sustain weather forecasting at today's level or to improve forecasts in the future are not clear
- The capability of assessing impact to outcomes from removing specific observations is important and was not demonstrated
- It is not clear how the external user community is providing inputs into the NOAA requirements process
- It is not clear what process is used for determining when NOAA relies on national or international partners for satisfaction of NOAA observing requirements

4. Systems Engineering

- An integrated and comprehensive systems engineering approach is needed within NESDIS to transition from the current segment-centric engineering approach (See figure 4, Notional Systems Engineering Strategy)

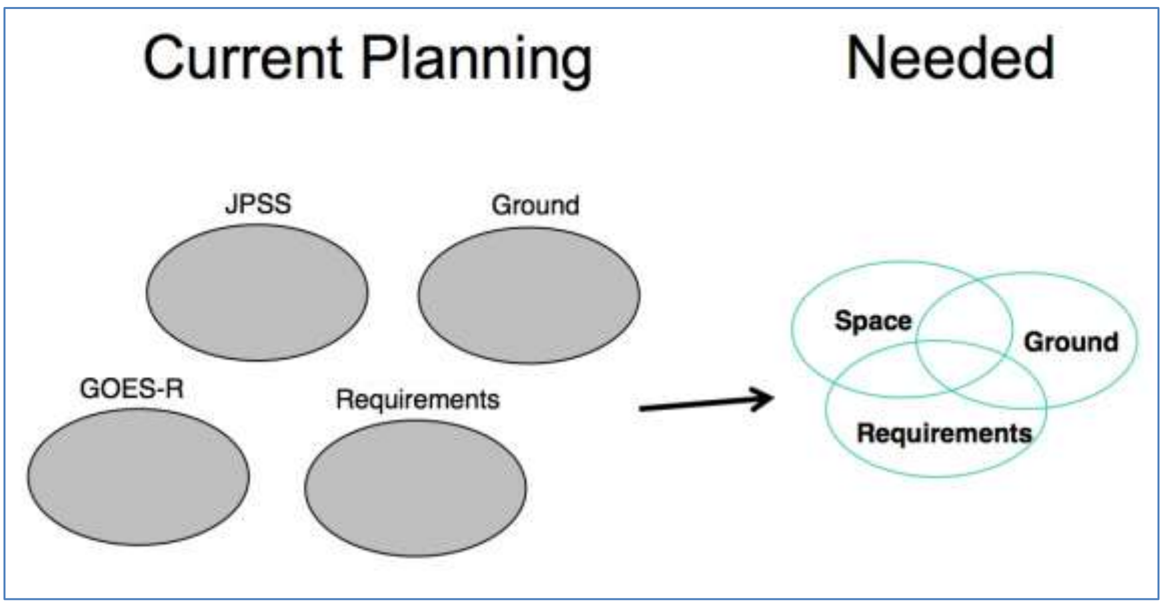

Figure 4: Notional Systems Engineering Strategy – transition from current status to future integrated approach

- An integrated master schedule was not presented
- The initial approach to satellite architecture design is fragmented (separate space and ground architecture studies) with no apparent link to a systems-level design nor clear link to a requirements process
- An integrated approach to a space-based observational strategy, including teaming with national and international partners, is not apparent

- The Satellite Operations Continuity Survey is a good first step, but needs to be further developed into a comprehensive constellation management plan

5. Alternative Architectures

- The JPSS program currently plans to launch multiple satellites; initially JPSS-1 and a smaller satellite with a complement of at least three instruments, which is the first step in implementing an alternative architecture
- NESDIS, working with Aerospace Corporation, took initial steps to evaluate JPSS 2-based alternatives from the JPSS-1 baseline:
  - The study was not a capabilities-based approach, but used a cost-capped budget-based approach
  - The study was a first step in looking at a distributed system; however, it was too narrow
- A broader spectrum of alternative space-based architectures, using a building block approach, has not been examined to date.
  - These include varying orbits, mixed instruments, hosted payloads, partners, and sensors on distributed satellites
  - Alternatives not based on the existing configuration and instrument complement may be more affordable and still meet the threshold requirements
  - DoD's Operationally Responsive Space office provides one model for rapid response, lower capability alternatives

  Figure 5 is an illustrative example of a distributed architecture based on the GOES satellites

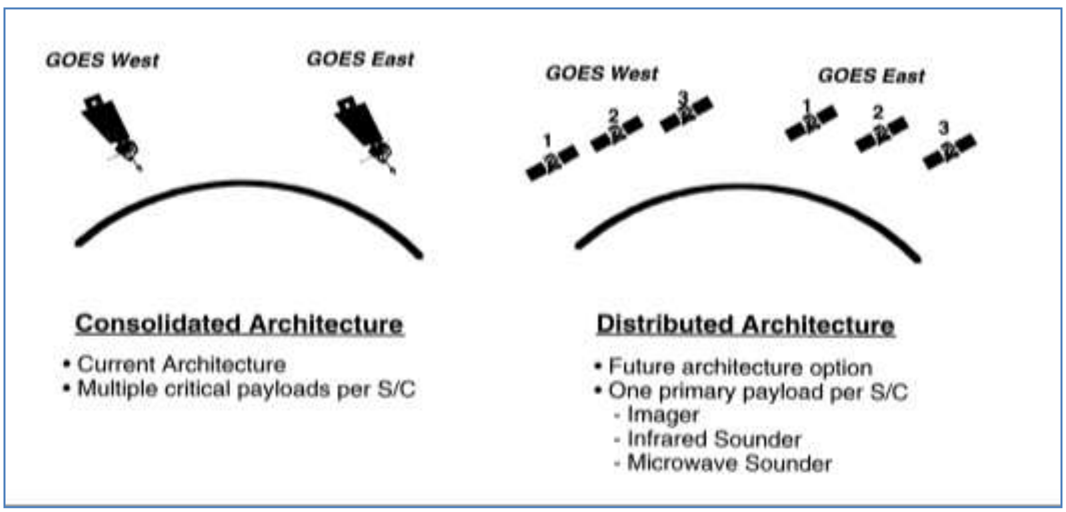

Figure 5: Illustrative Comparison of Consolidated vs. Distributed GOES architecture

6. Ground Segment

- NESDIS is to be commended for conducting an analysis of alternatives and embarking on a study for the Enterprise Ground System approach
- Implementation of an enterprise approach to the ground system architecture has potential for cost savings because of the integrated systems approach
  - NOAA is now in the position to undertake this as they now have sole responsibility for JPSS, GOES-R and legacy systems
- Implementing the full Enterprise Ground System approach in a manner that will result in life cycle cost savings will be challenging
  - Ultimate implementation of the enterprise ground system is dependent upon clear expression of the long-term vision and required next steps
  - Near-term cost saving activities, such as increased automation of the ground systems, appear to be possible
- The relationship between the ground and space segment architecture studies is not well-defined

7. Risk Mitigation

- No plan has been seen that mitigates gap risks or deals with tailored risk mitigation
  - Operational continuity and constellation reconstitution continue to be significant risks
- Fiscal constraints require approaches to prioritize risk mitigation efforts and resources
- Policy and requirements documents should be used to assess and prioritize risk mitigation
- Moving towards an alternative architecture, such as a distributed system, involves both risks and benefits
  - Alternative architectures require a tailored risk mitigation plan that defines levels of risk for different types of missions
- Reliability of international partners, given the current global economic conditions, can falter due to lack of adequate funding from any of the partners, including NOAA: thus requiring careful stewardship to ensure that the partnership can continue to deliver on its commitments
- Quick reaction capability is needed to help mitigate catastrophic failures at managed cost

CONCLUSION

NOAA has established a basis and starting point for assessing and replanning its satellite system architecture. NOAA is faced with a demanding and evolving set of challenges, and addressing those challenges will take time. Given the current planning for GOES and JPSS it may take up to a decade to establish an alternate, less costly satellite system architecture. Nonetheless, there are actions that can be taken in the near term. The recommendations provided as a result of the SATTF review of NESDIS replanning should assist in addressing today's challenges and strengthen the existing foundation. A desired outcome is to provide NOAA and the nation the means to address the core requirements of the user community, meet national policy guidance, continue to leverage the international satellite enterprise through partnerships and reduce risk with the ultimate result being a way forward for **"a more affordable, flexible and robust satellite and services architecture."**

Appendix A – Satellite Task Force (SATTF) Terms of Reference

1. Background

NOAA's Satellite and Information Service (NESDIS) is facing unprecedented budget challenges with substantial appropriation shortfalls and future budget outlooks that are inconsistent with current plans. These challenges are threatening service gaps in core services, loss of important remote sensing resources (e.g., the QuikSCAT ocean vector winds mission) and impairment of NOAA's ability to take full advantage of new NASA and international satellite resources.

In response to this austere environment, NESDIS is doing a comprehensive reevaluation of future plans. The objective is to develop an executable plan which optimally serves NOAA's satellite needs while accommodating unprecedented uncertainty in future appropriations. This reevaluation may lead to a significantly different approach to NOAA's satellites, which should have a careful and thorough review by the best-available outside experts. Furthermore, future changes may also significantly impact NOAA's ability to meet strategic goals. Thus, NESDIS considers both NOAA-wide and community-wide engagement to be critical before adopting new plans with potentially significant ramifications. The Science Advisory Board (SAB) will be asked to validate NESDIS' future plans or to recommend specific adjustments that will enhance overall value to NOAA while continuing to be executable.

The Satellite Task Force (SATTF) shall advise the National Oceanic and Atmospheric Administration (NOAA) SAB on NESDIS' proposed satellite service replanning. As experts in satellites, satellite technology and satellite applications, the SATTF will be a critical resource to the SAB's review and consideration of NESDIS plans.

2. Charge

The task force will provide advice to the SAB only and will act in the public interest in order to recommend a way forward for NOAA's satellite program, starting with initial NESDIS recommendations and seeking a more affordable, flexible and robust satellite and services architecture, while considering:

- long term sustainability of NOAA satellite programs (and gap risks)
- current plans, including flight segment of JPSS-2 and the GOES-T and beyond
- ground segment, including data receipt, distribution and processing
- cost estimates and the estimating methodology
- the National Space Policy call on NOAA for operational continuity
- research and technology plans and investments by NASA and others
- system adaptability to accommodate changing technical and programmatic environments
- international collaborations and opportunities

- collaborations and opportunities with DoD, NASA and the USGS
- effective and enhanced use of academia and the private sector
- feasibility, considering the anticipated difficulty in achieving needed future funding
- flexibility to accommodate unpredictable future appropriations

3. Meetings

The Task Force may meet in person at the discretion of the Chair, with the concurrence of the members and the sponsoring office (for financial considerations). Other meetings may be conducted by telephone or using other meeting technology.

4. Timeline and Milestones

The task force shall be a short-term working group of the SAB. A preliminary draft report should be provided to the SAB approximately 90 days after receipt of NESDIS recommendations (which should be the end of calendar year 2011). If feasible, the preliminary draft report on the SATTF's assessment should be provided to the SAB by the spring 2012 meeting. The task force final report should be provided to the SAB at the next in-person SAB meeting following the presentation of the preliminary draft report.

5. Membership

The task force will consist of between six (6) and eight (8) members representing a diversity of expert knowledge relevant to the task force scope.

a. Task force members shall provide expertise regarding environmental satellites (broadly interpreted) or end-user applications.
b. The members will be nominated by a team consisting of SAB members and individuals in NOAA with an interest in the product. The SAB will approve the final membership.

Appendix B – Task Force Participants

Members of the Task Force:

Robert Winokur, Chair

- Deputy and Technical Director (Acting Oceanographer of the Navy)
  Oceanography, Space and MDA Division, Chief of Naval Operations

Dolly Perkins, consultant

- Former Deputy Center Director - Technical
  NASA Goddard Space Flight Center

Robert E. Gold

- Space Department Chief Technologist
  The Johns Hopkins University Applied Physics Laboratory (JHU/APL)

Thomas C. Adang

- Systems Director, The Aerospace Corporation
  Department of Defense - Operationally Responsive Space (ORS) Office

Michael D. Tanner

- Acting Deputy Director, National Climatic Data Center

Paul Menzel

- Professor/Senior Scientist, University of Wisconsin
  Formerly Chief Scientist, NESDIS STAR

Diane Evans

- Director, Earth Science and Technology Directorate
  Jet Propulsion Laboratory, Pasadena, CA

Liaisons to the Task Force:

J. Marshall Shepherd, SAB Liaison

- Department of Geography/Director, Atmospheric Sciences Program,
  University of Georgia

David Hermreck, NESDIS Liaison

- Senior Advisor, NESDIS Office of System's Development

Appendix C - National Space Policy decisions

http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

Version dated 6-28-10

NOAA shall:

- Transition mature research and development Earth observation satellite to long-term operations.
- Use international partnerships to help sustain and enhance weather, climate, ocean and coastal observations from space.
- Be responsible for the requirements, funding, acquisition, and operation of civil operational environmental satellites in support of weather forecasting, climate monitoring, ocean and coastal observations, and space weather forecasting.
- Primarily use NASA as the acquisition agent.
- Provide for the regulation and licensing of the operation of commercial sector remote sensing systems.

Appendix D: Acronyms and Abbreviations

A-DCS	Advanced Data Collection System
AQUA	an EOS satellite focusing on water
CRYOSAT	Europe's first satellite dedicated to the study of ice
DoD	Department of Defense
DSCOVR	Deep Space Climate Observatory
ENVISAT	Environmental Satellite
EOS	Earth Observing System (satellite)
EPS-SG	EUMETSAT Polar System – Second Generation
ERS-2	European Remote-sensing Satellite
ESSA	Environmental Sciences Services Administration
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FY	Fiscal Year
GCOM W	Global Change Observation Mission – Water
GFO	GEOSAT Follow On (US Navy)
GOES	Geostationary Operational Environmental Satellite
HY	Series of marine remote sensing satellite from China
ITAR	International Traffic in Arms Regulations
JAXA	Japanese Aerospace Exploration Agency
JASON	A series of ocean altimetry satellite missions
JASON-CS	JASON Continuity of Service
JPSS	Joint Polar Satellite System
LRD	Launch Readiness Date
METOP	METeorological OPerational (satellite)
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System

ORS	Operationally Responsive Space
POES	Polar-orbiting Operational Environmental Satellite
SAB	Science Advisory Board
Saral/AltiKa	**S**atellite with **AR**gos and **AL**tiKa (for ocean altimetry)
SARSAT	Search And Rescue Satellite Aided Tracking
SATTF	SATellite Task Force
S/C	Spacecraft
SENTINEL	a multi-satellite environmental monitoring system from Europe
SNPP	Suomi National Polar-orbiting Partnership
SORCE	Solar Radiation and Climate Experiment
SWOT	Surface Water Ocean Topography
TCTE	TSI Calibration Transfer Experiment
TRL	Technology Readiness Level
TSI	Total Solar Irradiance
USGS	United States Geological Survey