A New Paradigm for Implementing NOAA's Low Earth Orbit Architecture

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ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) Satellite Observing System Architecture (NSOSA) study, conducted from 2014-2018, indicated that disaggregating low earth orbit measurements using smaller satellites and instruments was highly favorable. The first initiative to disaggregate low earth orbit is to more carefully investigate atmospheric temperature and moisture soundings. In 2019 NOAA issued a Broad Agency Announcement (BAA) to seek proposals for sounder instrument and mission concepts. Contracts were awarded to the most relevant studies and are expected to be completed in the fall of 2020. These studies are expected to inform NOAA of new ideas and capabilities that can be quickly inserted into the current constellation.

Quick and efficient access to space is becoming a reality which will allow NOAA to demonstrate and develop our expertise in launching more satellites more quickly so we can augment current sounding measurements, such as those occupied by the Defense Meteorological Satellite Program (DMSP) and Polar Operational Environmental Satellites (POES), test new technologies, and eventually transition into the NOAA sounding operational system in the 2030s. In this paper we will discuss this concept and how orbital diversity can be maintained or expanded, new technologies can be improved and inserted quickly into the constellation, and overall program risk can be reduced. Based on this new paradigm, capabilities can be flown on "regularly scheduled" launches which will allow for a more adaptable, resilient, and flexible measurement system that can be expanded to include additional low earth orbit measurements.

INTRODUCTION

With the successful launch of GOES-16, GOES-17, and NOAA-20, the United States has begun operating a new generation of weather, space weather, and environmental remote sensing satellites. These include the Joint Polar Satellite System (JPSS) low Earth orbit (LEO) satellites, Geostationary Operational Environmental Satellite – R Series (GOES-R) geostationary (GEO) satellites, the Deep Space Climate Observatory (DSCOVR), Jason-3, and the second generation of the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC-2) satellites. The National Environmental Satellite, Data, and Information Service (NESDIS) Program of Record (POR) will supply essential weather and environmental satellite services into the late 2020s or somewhat beyond, depending on the particular service.

Given the newness of these capabilities, it might seem premature that NOAA is already planning for the generation after these systems. But examination of the most likely lifetimes of the current generation of satellites and typical development timelines for major satellite programs shows that it is far from too early. Opportunities exist to affect next generation systems within two years. If change is needed, it will be necessary to make major decisions on a similar timeframe.

Considering the rapidly changing face of the space enterprise and the need to replenish and replace the existing system, NESDIS has generated ambitious strategies to redefine its future environmental data collection programs. For example, NESDIS intends to "Advance observational leadership in geostationary and extended orbits," and activities are well underway to support that vision. For the NESDIS satellites flying in low Earth orbit, NESDIS plans to "Evolve LEO architecture to enterprise system of systems that exploits and deploys new observational capabilities."

This approach will create resilience for the existing flight programs and allow NOAA to augment its space-based observing system. NESDIS currently operates one LEO primary satellite (NOAA-20) and one backup satellite (S-NPP) in the early afternoon sun-synchronous orbit. In addition to hosting a high-quality, multi-purpose visible/infrared imager, these satellites host infrared and microwave sensors to provide atmospheric temperature and moisture profiles essential to weather forecasts produced by the National Weather Service (NWS).

NESDIS also continues to operate, for the time being, several "legacy" LEO satellites (NOAA-15, 18, 19) that provide imagery and sounding data in other sun-synchronous orbits. Finally, NOAA also operates the Defense Meteorological Satellite Program (DMSP) series of satellites for the US Department of Defense (DoD) that provides similar data in the terminator orbit.

However, both the NOAA legacy satellites and those flown as part of the DMSP program are rapidly approaching their end-of-life. Once these satellites fail or are decommissioned, NOAA, and the entire weather community, will lose critical data, possibly resulting in degraded numerical weather forecasting capability. In order to add resiliency to NOAA's primary early afternoon orbit, and to maintain or expand orbital diversity of sounding data that are critical to NWS forecasts, NESDIS plans to build, launch, and operate a new collection of small, modular, and less costly satellites to retrieve atmospheric temperature and moisture profiles. This new constellation of satellites will take advantage of the existing flagship satellites (JPSS-1 through 4) and will allow for maintaining or increasing orbital diversity while improving NOAA's ability to take advantage of new technology.

NSOSA

In 2013, under the "Strengthening NESDIS" initiative, the newly formed Office of Systems Architecture and Advanced Planning (OSAAP) within NOAA/NESDIS began preparations to study NOAA's satellite architecture. These studies identified the need to begin the decision-making process early to shape the next generation satellite systems, identified priority areas within the problem and solution spaces needing further study, and examined whether or not significant departures from the current program of record (POR) architecture could have significant cost or performance benefits[1,2]. On the basis of these preliminary studies, in 2015 NOAA/NESDIS initiated the NSOSA study[3] focusing on the next generation weather and environmental remote sensing satellite architecture.

The study purpose is concisely stated as:

> Determine the most cost effective space segment architectures for performing NOAA weather, space weather, and environmental remote sensing missions (excluding land mapping), beyond the POR to 2050. Architecture alternatives should be compatible with an estimated annual capped NESDIS top line budget.

From the past study of weather satellite constellations, we know that value is primarily determined by choice of instruments, distribution of instruments over orbits, and replenishment policies. Cost depends on instrument complexity encountered in development and on integration and testing. One large factor in development risk is instrument technology maturity level. Operational risk, primarily the risk of capability gaps or asset wastage, is determined mostly by constellation management policy. Thus, the definition of a next generation architecture must encompass instrument capabilities and enabling technologies, allocation to orbital platforms, and launch and replenishment policies. We have studied and included these elements in the NSOSA study.

NESDIS deliberately scoped the study to the architecture of the satellite portion of the enterprise and excluded the ground segment. The differing timelines for decisions and implementations between space and ground segments make it acceptable to separate the studies. While separate, the cross-dependence of the satellite architecture on architectural decisions in the ground segment and in the larger weather enterprise are understood and provisions for accounting for them are included in the study. While excluded from NSOSA, NESDIS has recently initiated a ground enterprise architecture study to determine the most cost effective enterprise ground capability in the 2030-2050 time frame[4].

Although the NSOSA study examined capabilities across a wide range of satellite configurations, instruments, and orbits, we shall focus on those that are often satisfied by instruments flying in LEO (Figure 1). To enable NESDIS to provide products that maximize NOAA's mission satisfaction, the NSOSA study recommended that NESDIS develop a LEO portfolio that provides the following foundational measurements.

i. Vertical profiles of temperature and moisture in clear or cloudy atmospheres
ii. Passive microwave radiances of the earth's surface
iii. Global precipitation measurements
iv. Global non real time imagery of the earth and clouds
v. Measurements of the vertical profile of the wind vector (3D winds – exemplified by a Doppler lidar in Figure 1, but could be satisfied by other means)

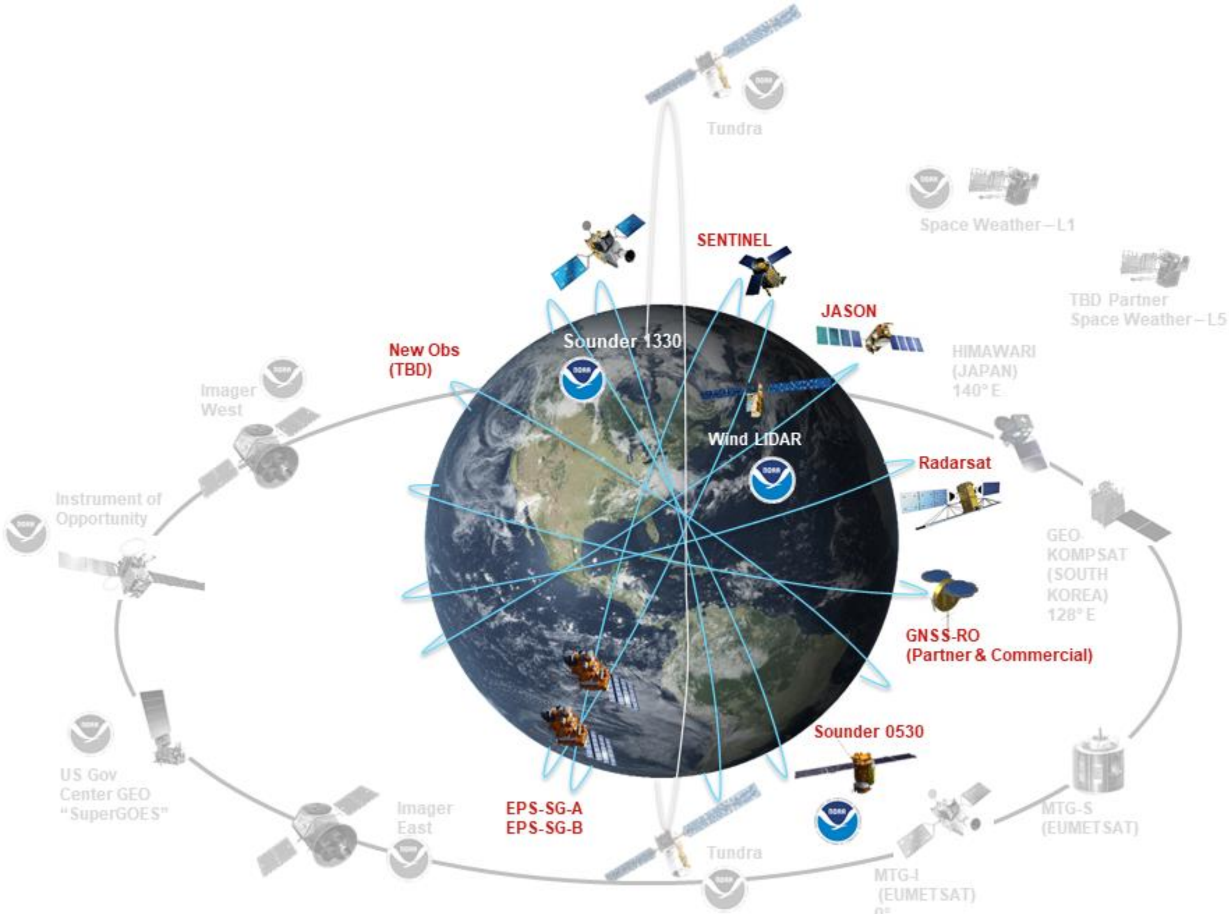

Figure 1: Notional Future LEO Constellation including partner contributions.

Typically many of these LEO observations are collected with a limited number of very large satellites that carry expensive instruments. For example, temperature and moisture soundings are produced using radiances in the infrared (e.g., CrIS, IASI) and microwave (e.g., ATMS, MTS). Noting the critical importance of soundings to numerical weather predictions (NWP), the NSOSA study concluded that NOAA could produce greater overall value by disaggregating that part of the LEO mission into smaller sounding-only satellites (known as SounderSat) launched with greater frequency. The sounding constellation needs to have the highest availability, so separating those measurements from the rest allowed for focusing resources most effectively. Lower availability measurements (e.g., global imagery (VIS, IR, and MW), ozone measurements, etc.) could be flown on a separate satellite that did not require the sustained launch rate of soundings.

BROAD AGENCY ANNOUNCEMENT

NOAA is currently investigating instrument and mission concepts, including data purchases, through a number of funded concept studies, as defined by a Broad Agency Announcement (BAA)[5]. These studies will be used to generate critical Sensor and Environmental Data Records (SDRs and EDRs) and support the NWS NWP systems. They are expected to identify potential technologies, systems, and Concepts of Operation (CONOPS) that, together, could be used to provide continuation of a portion of the capabilities now supported by JPSS. The instrument and mission concept studies may also illuminate potential new capabilities.

As mentioned previously, the NSOSA study identified disaggregation of LEO mission components as a favorable constellation approach. Because NOAA is interested in identifying new capabilities and concepts, the agency has yet to determine the exact mix of observations, performance levels, and number of satellite platforms that will, or should, be part of the next generation architecture. While the LEO BAA focuses only on sounding, it is only one step in a broader effort to develop a comprehensive architecture to meet critical NOAA observation needs. NESDIS will continue to seek details of methods and concepts to meet other observation needs in the near future, consistent with the availability of funds. Through this sustained engagement, NESDIS intends to work with the community to develop and deploy a more advanced and agile LEO architecture and make technology, platform, and business model innovations operational on a more rapid timeline.

NESDIS will use the results of the studies awarded from the BAA to inform decision makers as to the most viable instrument and mission concepts to make up the future operational constellation and form the basis for future acquisitions. The results may be used to:

1. Support the design and formulation of an optimal, mission-effective, agile and cost – effective constellation of space-based observing systems.
2. Support a future satellite acquisition targeted at providing a constellation supporting high update rate LEO observational capabilities
3. Support multiple demonstration missions as part of fly-before-buy future acquisition strategy for sounding or other LEO observations

The NSOSA study examined more than 150 different constellation concepts within a number of architectural frameworks. As the study progressed, the candidate constellations focused on more favorable architectures and examined significant cost/benefit trades. Several exemplar constellations were produced giving NOAA and NESDIS leadership guidance on the path forward. NESDIS defined one of these architectures as a reference for the BAA. This constellation model, which included mandatory sounding elements, functioned as the basis for vendor proposals to meet or exceed that mission need. It also serves as the baseline case against which variations to the reference constellation can be assessed. This reference constellation was developed only for planning purposes and as a guide to show the most important aspects of the sounding mission. NOAA has not made a determination to pursue this constellation and will use the results, in part, of studies conducted under this announcement to potentially alter the future constellation.

REFERENCE CONSTELLATION

The reference constellation for the Broad Agency Announcement consisted of a subset of the NSOSA recommended constellation:

A small government-owned and operated satellite with a flexible enough design to allow it to be launched into multiple Low Earth Orbits with little or no modification. For example, the primary mission is to provide resilience to the early afternoon (1330 LTAN) orbit. However, the satellite would be adaptable enough to cover other polar sun synchronous orbits such as the terminator, as well as moderate inclination, non-sun-synchronous orbits. This satellite will have the following primary instrument manifest that jointly produce data in accordance with the observational specifications in the Appendix of the BAA:

1. Infrared Sounder
2. Microwave Sounder
3. GNSS-RO
4. A satellite bus (spacecraft) with non-proprietary standard mechanical and electrical interfaces for the instruments to allow the flexibility to add or replace instruments for future missions without re-design.

The concept may be extended to a common spacecraft bus that could be used for other LEO missions beyond the Sounder-Sat. The Satellite will be flown frequently enough to assure one to two satellites in each of three LEO orbits (1330 LTAN, terminator, and other high inclination orbits) with a launch cadence of roughly two to three years. Other orbits will be considered as a value-cost trade.

POTENTIAL FUTURE ACQUISITION

As NESDIS learns more instrument and mission concepts from the BAA studies, they will apply such knowledge to advance the path forward to new and more cost efficient ways to conduct business. The NSOSA study suggested that smaller sensors on smaller satellites, using smaller launch vehicles, while applying judicious risk tolerance to designs and development, will provide this. NESDIS is also interested in improving the resilience of future systems that are also adaptable to changing user needs and emerging technologies. This includes the likely addition of modular satellite buses that can be fitted with a variable mixture of sounder and non-sounder compatible payloads, including changes in manifest relatively late in the integration cycle.

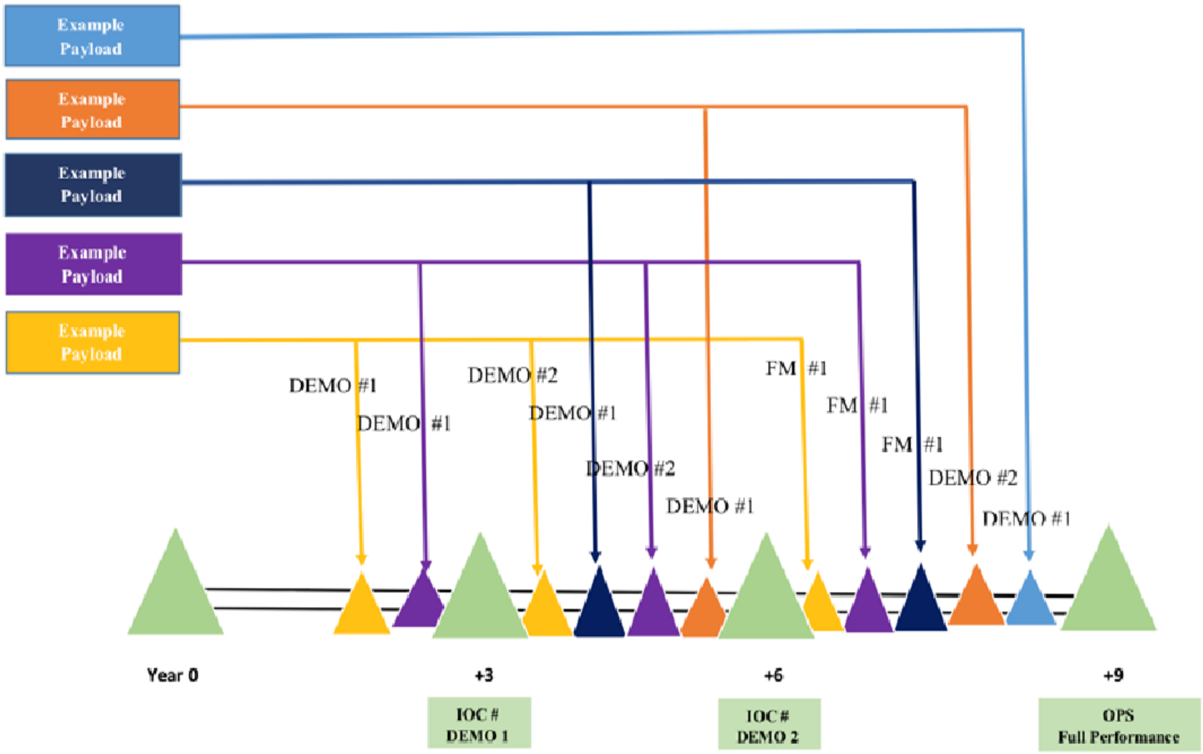

Figure 2: Potential Demonstration and Launch Schedule

As a complement to NESDIS investigating instrument and mission concepts, NESDIS is also looking for new or novel acquisition approaches that allow us to have a quicker launch cadence which would necessitate shorter development timelines. NESDIS expects to meet full operational capability performance in successive steps, taking advantage of near-term launch opportunities. The steps include potentially flying prototype or demonstration versions of sounding payloads that trade performance to meet launch date and cost targets. NESDIS is also contemplating a "fly-off" as part of the overall acquisition strategy, where equally funded vendors are challenged to meet a specific launch date, with the incentive of the remaining builds going to the best value implementation.

One aspect of NESDIS' new emphasis on availability, reliability, and adaptability is the concept of taking advantage of "new space" with lower instrument costs and significantly lower access to space costs. As a result of the development of new, smaller launch capability at a lower price, NOAA is considering a much more rapid launch and replenishment rate than was possible with the existing POR. NOAA is looking into the potential use of a common satellite bus to accommodate multiple payloads. The concept is that using a flexible satellite design, with standard interfaces, can host multiple sensors, with the ability to change that manifest, even at a late date, depending on the availability and maturity of the sensors.

A potential execution schedule (Figure 2) for the Satellite development could involve the following major milestones, with the expectation that feedback is gained from any prototype flights for the next instantiation of the instrument:

1. FY22 – Authority to Proceed – Multiple vendors are contracted for competitive instrument development
2. FY25 – 1st Prototype Launch – Opportunity to fly initial prototype instruments for purposes of a competitive fly off in performance. To meet schedule, it is expected that the Government would grant waivers for some of the instrument requirements, including design life and technology readiness levels (TRL). One or more satellites could be used to replenish orbits vacated by legacy NOAA or DMSP satellites.
3. FY28 – 2nd Prototype/Operational Launch – Opportunity to fly improved versions of prototype instruments for the purposes of final design verification and checkout prior to acquisition of operational units. Having an operational system at this point is acceptable. CONOPS, calibration, and data quality will be assessed during this phase.
4. FY30 – 1st Flight Operational Mission

NESDIS ON THE MOVE

Between 2016 and 2019 NESDIS conducted the NSOSA study which recommended a disaggregated LEO architecture. The first realization of this architecture is the SounderSat, a small collection of satellites that perform the global real time temperature and moisture sounding mission. The result of disaggregation and focusing on one of the core measurements required for NWP is a mission concept that consists of smaller instruments and smaller satellites that can be rapidly and cost effectively placed into traditional and new LEO orbits. To validate the NSOSA results and to explore evolving instrument and mission concepts, NESDIS released a BAA in late 2019. As of early June 2020, NESDIS had awarded 14 LEO SounderSat contracts from industry, academia, and others to provide the NESDIS new, possibly novel, instrument and mission concepts that could fulfill the global real time temperature and moisture sounding mission. The results of these studies will inform NOAA and NESDIS leadership as to what is possible as NESDIS develops the next generation of temperature and moisture sounding data acquisition.

Based on an ongoing analysis of user desires, technology development timelines, and projected budgets, NESDIS has been considering the "next steps" beyond not only JPSS, but also SounderSat. The NSOSA study provided a list of objectives in cost/benefit order, known as the "Order of Buy" table. This table contained a mixture of strategic and measurement objectives that showed, at the time of the study, the desires of NESDIS leadership blended with projected costs of various satellite configurations capable of providing the needed data. Soundings ranked near the top of the table which resulted in the SounderSat initiative. As the NSOSA study was being conducted, NESDIS also embarked on an analysis of all of the products produced by NESDIS. This Integrated Products List formed the basis of overall NESDIS requirements which describe what product categories NESDIS intends to provide for years to come. NESDIS intends to take advantage of new technologies with possible early demonstration launches aimed to quickly test new technology while under the "umbrella" of high-quality JPSS and partner soundings. This will lead to not only maintaining current sounding capability, but it could also lead to increasing orbital diversity of this critical set of measurements. NESDIS will continue to work with our national and international partners to provide continuity of current measurements and increase capability in the future. NESDIS intends to evolve the current LEO architecture to an enterprise system of systems that exploits and deploys new observational capabilities. In doing so, NESDIS will ensure the current set of LEO observations made by the JPSS series of satellites and extend sounding and other capabilities into the foreseeable future.

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