POTENTIAL FOR SMALL SATELLITE USE IN NOAA'S OPERATIONAL POLAR PROGRAM

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ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) manages operational satellite systems for the remote sensing of the Earth System, including the Polar-orbiting Operational Environmental Satellite (POES) system. A new configuration of the POES system will be introduced about 1998. Small satellite technology is being investigated by NOAA as a supplement for the future POES system. The baseline payload for the new POES configuration is known and under development. Candidate payload additions are also known. Both payload categories are described. NOAA perceives POES mission advantages as being associated with the use of small satellites in the future system. These advantages, and possible roles for small satellites in POES, are discussed. NOAA is in the early period of its evaluation of small satellite use in its systems. To date, this includes: conducting a general study to establish small satellite options and costs at the order of magnitude level; investigating the technical advantages of transferring the Search and Rescue mission to small satellites; and starting the technical and programmatic review of the possibilities of a small satellite mission for collecting warning data about the onset of geomagnetic storms. These and other evaluations are reported. NOAA's plans and schedules for developing the next-generation POES system, and reaching decisions on small satellite use, are presented.

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INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce conducts the Federal program for the civil operational remote sensing of Earth from space. NOAA manages the Geostationary Operational Environmental Satellite (GOES), the Landsat, and the Polar-orbiting Operational Environmental Satellite (POES) systems. Small satellite technology is being investigated by NOAA as a potential supplement for its POES system.

The POES system has provided unbroken operational service since its first launch in 1966: 22 POES have been orbited successfully; three were lost before achieving orbit; and seven additional spacecraft are in queue to provide coverage into the late 1990s. In a few months, NOAA will initiate the Phase A study to determine the technical options available for the next configuration of the POES system. One component of this study will be a closer, more detailed examination of the capabilities of small satellites to support the POES mission.

The essential aspect of the POES mission is that it is operational. Both to protect the continuity of the operational mission data stream and to control costs, NOAA avoids the risks of developing its own space technology wherever possible. Proven or close-heritage technology from a dependable commercial source is the preferred approach.

POES MISSION AND OPERATIONS

Mission

The POES mission is to provide daily operational environmental observations covering the whole of Earth in both sunlight and darkness and to provide the unrestricted, real-time broadcast of sensor information for receipt and use by any properly equipped ground station. The requirement that the system be operational means that, for primary sensors, there be no significant breaks in data delivery schedules and that system changes and modernizations do not adversely impact the application procedures of users who employ the data in real-time or research modes. The requirement for the direct broadcast of sensor information, without need for notification from receiving ground stations, means that details of the POES system be available on a free and open basis to all interests.

POES Operations Through the Late 1990s

NOAA presently maintains a two-spacecraft POES system. The two satellites are in near-polar, Sun-synchronous, circular orbits at a mean altitude of 850 km. One satellite is in "afternoon" (PM) orbit, in that it has a northbound Equatorcrossing time of 1340 Local Solar Time (LST); the second, the morning (AM) satellite, has a southbound crossing time of 0730 LST. Launches are from the Western Test Range at Vandenberg Air Force Base, California. Satellites in the series are called "NOAA", with an alphabetical designation when in production and a numerical designation when they become operational. NOAA 10 and NOAA 11 are in operation now.

The current POES series is based on the Advanced TIROS-N (ATN) bus, manufactured by General Electric Astro Space Division. The nominal mass of the satellite reaching orbit is 1010 kg, of which about 375 kg represents the payload comprising of instruments, a system to relay data from automatic environmental sensor platforms, a system to relay distress signals from emergency radio transmitters, and tape recorders. Some instrumentation, cited later, and the two radio relay systems are contributed by other nations. Recent experience indicates that these satellites will provide an average operational lifetime of a little more than 31 months, once they have survived launch, orbit-insertion, and check out.

POES Operations Beyond the Late 1990s

Planning is underway and agreements are being established to continue the two-spacecraft coverage of the POES system as a collaboration between the United States and Europe, beginning in the last year or two of the 1990s. NOAA will be the U.S. agent and system operator in the collaboration; the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) will fulfill these roles for Europe. NOAA will be responsible for providing the PM spacecraft and its operation; EUMETSAT will provide the AM spacecraft and operation. Foreign providers of instruments and radio relay systems will continue their contributions to the collaborative system. NOAA will equip its PM satellite with the remainder of the full payload and, in addition, will contribute the necessary primary instruments (imager and sounding array components) for the European AM satellite. Ground control and the acquisition of taped data will be at the NOAA ground stations in Fairbanks, Alaska and Wallops, Virginia, and a EUMETSAT station to be established in high-latitude Europe. NOAA satellites will have 36 month design lifetimes.

Beyond this planning baseline for the future POES operation is the expectation that NOAA will be called upon to expand its global POES coverage to include new types of environmental observations. Concerns about global environmental change and its consequences are leading to a National Aeronautics and Space Administration (NASA) program of research and development in the environmental sciences that will result in the development and proof of new remote sensing instruments for observing the Earth System from space. NASA's Earth Observation System (EOS) proposal includes instruments that have been categorized as "pre-operational", implying that they could be transferred to NOAA operation when proven. The transfer would ensure the long data record necessary for climate research, as well as the day to day benefits of an operational data stream.

Additionally, there are already-demonstrated environmental sensor capabilities that could be deployed by NOAA if the national need dictated and the POES system capacity allowed. Some of the considerations here are: the balance among national priorities and resources for providing environmental data of differing types in support of public service and research programs; the probable availability of like data from another United States or foreign source, government or private; the capacities of the space and ground components of the POES system; and the risks and costs of further developing technology-demonstration sensors for use in an operational system.

The issues of coordinating an international approach to satellite monitoring for global change purposes are being resolved by the nations and international agencies involved, with NOAA a participant in the deliberations. Although these issues are beyond the scope of this paper, NOAA anticipates that their resolution will result in a broadening of POES data requirements. To prepare for this, a NOAA condition on the space capabilities of its next POES configuration is that it provide a growth factor of at least 25%--in power, payload mounting area and volume, and payload mass--above that called for by the baseline payload.

REQUIREMENTS OF THE COLLBORATIVE POES SYSTEM

The three command and data acquisition ground stations of the NOAA-EUMETSAT collaborative system will eliminate "blind" orbits. On each orbit, each satellite will have six to eight minutes of simultaneous up- and down-link time available with at least one ground station. Contact will be with the most available ground station. Downlink of all "raw" data (sensor, housekeeping, engineering) recorded during the orbit is planned.

The U.S. spacecraft and launch vehicles that NOAA will use in the collaborative system will support the performance requirements imposed by payload specifications, communications demands, and orbit restrictions. In the orbit instance, for example, the spacecraft will be required to maintain altitude within about five kilometers and to control solar time drift within 10 to 20 minutes. For reference, the following paragraphs outline the more prominent requirements of the system, including the characteristics of its communications, baseline payload, and possible payload additions, additions which could emerge either from NASA's development of pre-operational sensors or other origins.

Planned Collaborative System Communications

The highlights of the communications proposed for the system follow.

- Command: 2025.0 MHz; at least 1.0 MHz bandwidth.
- Stored data downlink: to command stations only; 7455.0 MHz; 100 MHz bandwidth; 50 megabits per second.
- Low Rate Picture Transmission: continuous broadcast, to any receiver, of real time data; two discrete frequencies in the 137-138 MHz band; 150 KHz bandwidth each. (Note: LRPT includes spacecraft telemetry data.)
- High Rate Picture Transmission: continuous broadcast, to any receiver, of real-time data; 1704.5 MHz; 10 MHz bandwidth.
- Data collection system spacecraft receiver: 401.650 MHz; 46 KHz bandwidth.
- Search and Rescue: spacecraft receiver frequencies are 121.5 MHz, 243.0 MHz, and 406.5 MHz; downlink at 1544.5 MHz, with 700 KHz of bandwidth.

Planned NOAA Baseline Payload

Sensors and systems of the NOAA baseline payload of the collaborative system are identified in this section by their acronym and function only. The Appendix gives their full names. Dimensions are approximate. All sensors have a 100% duty cycle.

Table 1 summarizes this baseline payload.

Table 1
BASELINE PAYLOAD

ACRONYM	FUNCTION	VOLUME (cm^3)	MASS (kg)	DATA RATE (kbps)	PEAK POWER (W)
AVHRR/4	IMAGER	240000	100	1200.0	50
HIRS/4	SOUNDER	63000	45	2.5	40
AMSU-A1	SOUNDER	135000	55	6.5	90
AMSU-A2	SOUNDER	295000	55	6.5	90
AMSU-BE	SOUNDER	190000	50	6.0	85
SEM	SPACE MONITOR	32000	26	9.6	20
SBUV	OZONE	65000	41	1.0	20
TOMS	OZONE	8000	30	1.0	30
SARSAT	SEARCH & RESCUE	75000	45	2.6	60
ARGOS	DATA COLLECTION	38000	62	2.6	50
Recorder*	STORE DATA	40000	70	(30 Gb)	60

*More than one unit may be required

Candidate Payload Additions

NOAA's planned baseline sensor suite will be expanded if national requirements are established for new or increased operational monitoring of the Earth System. Needs for improved monitoring for which NOAA would be responsible are most likely in the areas of global weather, ocean state, atmospheric contamination, and Earth's radiation budget. NASA's EOS planning has proposed instruments for monitoring these conditions. When demonstrated, these NASA-designed instruments could be transitioned to NOAA POES operation. Among these NASA instruments, the strongest candidates for becoming NOAA POES payload additions are those shown on Table 2.

Table 2
CANDIDATE OPERATIONAL INSTRUMENTS

ACRONYM	FUNCTION	VOLUME (cm^3)	MASS (kg)	DATA RATE (kbps)	PEAK POWER (W)
AIRS	SOUNDER	125000	110	1800.0	350
ALT	ALTIMETER	300000	275	80.0	250
HIMSS	SOUNDER	8000000	210	45.0	200
HIRDLS	LIMB SOUNDER	1000000	150	15.0	150
STIKSCAT	SCATTTER-OMETER	400000	280	5.0	300
CERES	RADIATION BUDGET	1000000	45	10.0	120

Interdependent POES Instruments

Some POES instruments are interdependent and must fly together. The POES imager (AVHRR/4) and the POES sounders (AMSU-A1, -A2, -BE, and HIRS/4) are interdependent instruments. Imager data are essential for interpreting sounder output. They are used to determine the presence of cloud in the sounded column and the temperatures at the bottom of columns. The POES system design must enable the data from each source to be superpositioned to high accuracy in space and time. The most practical approach is to fly these instruments together on the same spacecraft.

The SEM measures the magnetic and electric fields around the satellite and detects encounters with charged solar particles. These measurements are valuable of themselves and also are used to interpret anomalous events aboard the satellite. The advantages of having coincident, diagnostic SEM data available from a spacecraft housing the mission-critical imager and sounder instruments make it useful, but not essential, to fly the SEM along with the imager and the sounders.

An advanced infrared sounder, such as the AIRS, is expected to replace HIRS/4 in the out-years of the program. It, too, will depend upon and deploy with the imager.

The remaining components of the baseline and candidate payloads can be flown independently. The Search and Rescue system is a special case; its capabilities would be increased if flown at a higher altitude (near 1000 km) and in an environment with a lower potential for electromagnetic interference than aboard a busy POES. Greater altitude would speed the detection of distress signals and their relay to ground stations. An electromagnetically quiet satellite would improve the prospect of recognizing a weak distress signal.

Broadcasts of Real-Time and Stored Data

All raw data produced by sensors and systems and recorded during an orbit are to be downlinked to one of the command stations. An adequate on-board data storage system is needed to hold these data until downlinked. Low Rate and High Rate Picture Transmissions are, respectively, reduced and full resolution real-time, continuous broadcasts of sensor, subsystem, and telemetry data. On-board data handling is required to format the data for broadcast and load the data to the data storage system. The data handling and broadcast subsystems, including antennae, are spacecraft items, not payload.

SMALL SATELLITES AND THE POES PROGRAM

U.S. industry is developing small satellite technology covering a range of capabilities. If development expectations are met, small satellites will become readily available, be offered at comparatively low cost, and be supported by customer services that provide timely payload integration and launch. Given these developments, small satellites would have mission advantages making them candidates for roles in NOAA's POES program. These mission advantages and potential roles are discussed below.

Mission Advantages

NOAA's present view is that the main mission advantage of small satellites would be to enable NOAA to continue to use medium-sized launch vehicles for the bulk of its payload, while sharply increasing mission flexibility. There are huge added costs associated with moving up from a medium- to a large-sized launch vehicle. NOAA's baseline payload for the late 1990s is pushing the upper limit of medium launch vehicle capability. If new requirements drive the NOAA payload beyond this limit, a transfer of some payload to small satellites could preserve the medium launch vehicle margin.

The forecast of small satellite attributes includes fast acquisition, payload integration, and launch. These would make new flexibility possible in the POES program. Some of this flexibility is reflected in the following comments.

- Accommodate payload growth. Now, it may take a decade or more to add new payload, even small additions, either because the spacecraft of the series are full or the costs of design changes are not justified. Small satellite availability could overcome these restrictions.

- Recover from failures. Numerous failure scenarios become more tractable if small satellites are included, such as: fly a critical sensor or two, following catastrophic failure and when the replacement pipeline is empty or slow; fly a replacement for a single failed sensor when the data need warrants; backup the essential sensor of a satellite series with a hot-spare small satellite on the ground; use small satellites to supplement satellites with partial failures (sensors or subsystems), but with long, otherwise useful lifetimes ahead.

- Optimize coverage. POES spacecraft are in orbits best suited to mission-critical sensors. Mentioned earlier was the Search and Rescue payload that would give better performance at a higher altitude. Some other components of the payload, like ozone instruments flown closer to noon, also might do better in different orbits.

- Increase launching opportunities. Launch pad conflicts interfere with mission achievement. The less complex launch operations of small satellites would mean better accommodation of POES schedules and more freedom in POES planning.

- Reduce development needs. Small satellites are being developed in the context of providing adaptable systems for users. NOAA would expect this to result in a reduced need for the delays, labors, and risks normally associated with the development work necessary for adapting payloads to spacecraft.

- Conduct tests. New sensors, subsystems, and data handling methods are proposed for testing on POES, but usually rejected because of lack of spacecraft accommodation margins, risk to the main payload, threat to schedules, or other reasons. Small satellites could be used to handle some of the worthy testing that is proposed.

Potential Roles for Small Satellites

The potential roles for small satellites in the POES program include:

- Recovery missions. Small satellites used to plug data gaps induced by complete or partial satellite failures.

- Payload trade-off missions. Small satellites used to accommodate added payloads earlier and/or more economically and to avoid/delay a move to large-size launch vehicles.

- Orbit optimization missions. Small satellites used to carry selected payloads in orbits that are payload-optimized.

- Test and development missions. Small satellites used to conduct tests and evaluations of developmental sensors and systems; used to conduct risky testing without jeopardy to the main payload.

EVALUATING SMALL SATELLITE USE

NOAA is evaluating small satellites for use in the POES program. The major issues that must be resolved about this use include: is it practical; is it beneficial; and is it affordable? These considerations, and the NOAA approach to resolving them, are discussed below.

Practicality

NOAA's use of a given space technology is preconditioned by the judgement that the technology and its supply have the long-term reliability needed to support an operational program. Twenty or more years will pass between the start of planning and the end of service of a POES series. Stability in the supporting technology is critical. In the small satellite instance, where POES mission flexibility could be the prime motivation and a surge in development is only recently under way, NOAA will be cautious and conservative in its judgement. NOAA will use the Phase A study of options for the design of the collaborative system for a close review of the potential of small satellites to contribute to POES program capabilities.

The issue of practicality also involves NOAA's ability to manage a program that is based on more that one class of polar-orbiting satellite. Here, "manage" implies conducting planning, developments, budgets, procurements, and operations. NOAA's POES program management resources could be overloaded by small satellite activities which could not be handled through fairly simple, direct, and commercial-like processes.

Technical practicality is a concern. Over its years of POES operations, NOAA has used relatively high-mass space hardware. Its hardware decisions favored rugged, simple designs over more sophisticated, newer concepts. NOAA accepted the mass penalty to gain reliability. The coming baseline sensors of the collaborative system are heritage instruments and will not be redesigned to reduce their mass or volume. In studying small satellite options, NOAA will look to the designs of the spacecraft and their subsystems for the margins (mass, power, volume) needed for carrying POES payloads.

Benefits of Small Satellites

The issue is mission benefits: can small satellites help NOAA conduct the POES mission more completely and/or better? A solid definition of the future POES mission is needed to answer the question. NOAA is working to develop that definition now. This month, NOAA completed a review and update of its known requirements for polar satellite data in 2000 and beyond. Some of these data will come from the future POES system; some from satellite systems operated by other agencies and nations. The plans of the other operators have to jell before the scope and priorities of future POES requirements can be set with accuracy, but NOAA already has started a formal process for establishing POES priorities.

While there are outstanding uncertainties about the full POES requirement after 2000, the payloads listed on Tables 1 and 2 provide a reliable estimate. NOAA will refine this estimate in the months ahead but, for the present, these payloads are shaping NOAA's approach to the design of the collaborative system, including the use of small satellites.

Affordability

Small satellites offer unique opportunities for cost tradeoffs in the POES program. NOAA is anxious to examine these in detail, both through the coming Phase A study and otherwise. For example, it is probable that some sensors and systems of the payload could remain in service longer if deployed on small satellites, rather than being clustered on a three-year lifetime satellite. Over an operational period of 12 or 15 years, savings from fewer instrument buys, along with fewer and less expensive integrations and launches, may provide significant cost off-sets. These would boost the arguments in favor of using small satellites.

Because the POES program is operational and will continue indefinitely, there is emphasis on controlling its long-term total cost and keeping its year to year budget profile as level as possible. Peaks in the budget profile often result from launch costs being added in a given year to some other major event in the program, such as laying-in long lead parts at the start of a procurement; at times, payments for multiple launches come due in single budget year. The use of small satellites in POES probably could be used to dampen budget peaks caused by launch payments. NOAA will conduct mixed-fleet (large and small satellites) scenario studies to test this perception.

The concept of "affordability" goes beyond total cost. It is meant to imply the balance between costs, which are clear in a budget, and mission achievement, which always includes intangibles. The new availability of small satellite capabilities for use in POES means that NOAA's management will have to resolve more and different kinds of affordability conflicts for the next system than for earlier ones. Between now and the time these decisions must be made, before Phase B begins, NOAA will continue to build its data base for decision-making.

Evaluations in Progress

NOAA's interest in small satellite use heightened about two years ago. It was motivated by preparations to undertake the development of the next POES system and the coincident upsweep in industrial activities in the small satellite area. The time since has been used by NOAA to inform itself better about small satellite capabilities and to get some formal study processes started or under contract.

One of these studies is very near completion. It examines options for deploying POES payloads aboard combinations of small, medium, and large spacecraft. The contractor will provide order of magnitude cost estimates and other assessments of POES operations conducted under scenarios of mixed-size spacecraft use. Although these results will be interesting, the more valuable product of this study is its organization of the parameters of the planned system in a manner that enables the use of small satellites to be assessed. Payload, spacecraft, launch vehicle, and ground system parameters are addressed. An early finding that this organization of parameters provides is that, currently, 25% or less of a small satellite's mass to a 450 km polar orbit could be available to a NOAA payload. This signals a need for innovation to increase this ratio or make better use of it.

NASA recently completed a substantial study of the technological issues of a transfer of the Search and Rescue payload from the main POES spacecraft to a dedicated small satellite. The study concluded that the transfer is feasible and would be accompanied by a number of mission advantages, including: reduced waiting time in alerting ground rescue forces; elimination of many conflicts in downlinking to S&R

ground terminals; improved receiver sensitivity through elimination of radio frequency interference (RFI); doubled expected-service lifetime; and cutting space segment replacement time from years to weeks. The transfer would involve increased costs for development work, spacecraft acquisitions, and launch services procurements. There are savings from reduced integration costs, which now include suppressing RFI on the main spacecraft, and deployments of fewer S&R space systems. The balance among tradeoffs is complicated by the fact that Canada and France provide the space payload, so these savings would not be reflected in the NOAA budget. NASA is willing "to provide good cost, schedule and performance estimates" if NOAA's further study of the programmatic issues so requires.

Under investigation within NOAA now is an approach for detecting features of the magnetic field of the solar wind that induce damaging geomagnetic storms in the Earth System. It is known that a properly instrumented satellite, positioned between Earth and Sun, can provide a warning of the beginnings of these storms. Instrumentation would be, at least, a magnetometer, a plasma analyzer, and a particle detector. The satellite would be positioned at the first Lagrangian point (L1), where the gravities of Earth and Sun are in balance along the line connecting the two bodies. From this point (sometimes called a "libration" point), data from the satellite could provide 40 to 60 minutes of warning time.

This is being approached as a small satellite mission. NOAA is working with the interested community--industry, science, users, potential system operators--to define a realistic payload, size ground data processing requirements, and identify possible data ingest sites (L1 is not always in line of sight with NOAA's ground stations). When these requirements are somewhat better identified, probably in six to eight months, a decision will be made about the approach NOAA will follow.

Plans and Schedules

Key to NOAA's decisions about small satellite use in the POES program will be the findings developed during the Phase A study of the collaborative POES system. NASA will conduct this study for NOAA. It will examine the feasibility, costs, and risks of technical options for NOAA's POES system in the 2000s. Small satellites will be among these options.

The timing of this study appears good with respect to small satellite issues; the Phase A will begin in a few months, take about a year, and its results will be under review for the several months needed to initiate Phase B. The forecast for the small satellite industry is that, in about this same 24 to 30 months, it will be established on a solid commercial basis. Another favorable timing factor is that most national and multinational programs for Earth System monitoring will become clear during the same period, including those that impact POES. All of this implies that NOAA will have current, accurate information upon which to base its decisions about the use of small satellites in POES.

In addition to this Phase A study, NOAA expects to pursue small satellite matters by way of follow-ups to its current reviews and in new areas, such as determining the impacts on ground capabilities of operating additional satellites. NOAA's use of small satellites will come from programmatic decisions. The outlook is that NOAA will spend roughly the next 18 to 24 months in the investigation of pertinent programmatic issues.

CONCLUSION

NOAA has a strong interest in small satellite technology because of its potential for increasing flexibility and reliability in POES operations. This interest is reflected in the studies and reviews of small satellite use in POES that NOAA has undertaken and plans to conduct. Studies show that deployment of the Search and Rescue system on dedicated small satellites would improve mission performance; the funding issues of doing so are being investigated now. The concept of a "sentry satellite" to warn of geomagnetic storms is being discussed as a small satellite mission; technology issues, space and ground, and NOAA's role are being reviewed. Small satellite use is an explicit item to be investigated in the Phase A study of the future POES system. Most NOAA decisions about small satellite use are about two years away, timely in relationship to developments in the small satellite industry and lead-time for the next-generation POES system.

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APPENDIX

ACRONYMS

AIRS	ATMOSPHERIC INFRARED SOUNDER
ALT	ALTIMETER
AMSU	ADVANCED MICROWAVE SOUNDING UNIT (THREE COMPONENTS, -A1, -A2, AND -BE)
ARGOS	DATA COLLECTION AND PLATFORM LOCATION SYSTEM
AVHRR	ADVANCED VERY HIGH RESOLUTION RADIOMETER (IMAGER)
CERES	CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM
HIMSS	HIGH-RESOLUTION MICROWAVE SPECTROMETER SOUNDER
HIRDLS	HIGH-RESOLUTION DYNAMICS LIMB SOUNDER
HIRS	HIGH-RESOLUTION INFRARED SOUNDER
SARSAT	SEARCH AND RESCUE SATELLITE AIDED TRACKING
SBUV	SOLAR BACKSCATTER ULTRA VIOLET SYSTEM
SEM	SPACE ENVIRONMENT MONITOR
STICKSCAT	SIX STICK FAN-BEAM SCATTEROMETER
TOMS	TOTAL OZONE MONITORING SYSTEM