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ADVANCED TECHNOLOGIES
FOR FUTURE ENVIRONMENAL SATELLITE SYSTEMS

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1. INTRODUCTION

Environmental satellites today are designed to meet the most requirements possible within the constraints of budget, reliability, availability, robustness, manufacturability, and the state of the art in affordable technology. As we learn more and more about observing and forecasting, requirements continue to be developed and validated for measurements that can benefit from for advances in technology. The goal is to incorporate new technologies into operational systems as quickly as possible. Technologies that exist or are being developed in response to growing requirements can be categorized as "requirements pull" whereas technologies rooted in basic research and engineering exploration fall in to a "technology push" category.

NOAA has begun exploration into technologies for future NOAA satellite systems. Unmet requirements exist that drive the need to locate, explore, exploit, assess, and encourage development in several technologies. Areas needing advanced technologies include: atmospheric aerosols; cloud parameters; precipitation; profiles of temperature, moisture, pressure, and wind; atmospheric radiation; trace gas abundance and distribution; land surface; ocean surface; and space weather components such as neutral density and electron density.

One of the more interesting ideas in the technology push category is a constellation of satellites at Medium Earth Orbit (MEO) altitudes, here described as circular orbits near 11,000 km altitude. Consider the vision of being able to observe the environment anywhere on the Earth, at anytime, with any repeat look frequency, and being able to communicate these measurements to anyone, anywhere, anytime, in real time. Studies suggest that a constellation of MEO satellites occupying equatorial and polar orbits (inclination = 90 degrees) could, in principle, accomplish this task.

Also new on the horizon is solar sail technology. NOAA has been looking at solar sails as providing a propulsive system that could be used to maintain a satellite in a position closer to the Sun than L1. L1 is that point between the Earth and the sun where the gravitational forces of the Earth and the sun are equal. The sail would allow the increased gravitational force from the Sun to be balanced by the propulsive force of the solar sail. This capability could increase the lead-time for measuring and predicting the impact of solar events. Solar sails could also allow a satellite to be positioned over the Earth's polar regions continuously, filling a critical gap in current orbital observations and services.

The combination of these technologies will enable the NOAA Satellites and Information Service to meet important requirements currently unmet and help satisfy NOAA strategic goals.

2. TECHNOLOGY INSERTION

The U.S. Department of Commerce's National Oceanic and Atmospheric Administration is heavily involved in technology insertion (TI). NOAA Information and Satellite Services (NESDIS) and their strategic partner, NASA's Earth Sciences Enterprise, are co-chairing a working group to improve the process and timelines needed to incorporate new technologies into satellite operations. NOAA hopes to identify and nurture key technologies, which best serve NOAA strategic goals of Ecosystems; Climate; Weather and water; and Commerce.

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NOAA began the process of technology push and requirements pull to identify needs, which in turn help to identify needed technologies. Unmet needs and potential candidates are continuously identified in this on going process. NESDIS is currently building a roadmap and schedule to achieve implementation of technologies. Figure 1 depicts the TI process. Three promising technologies; MEO satellites, microwave sounder and solar sail missions; are discussed in detail below.

Technology Infusion Process

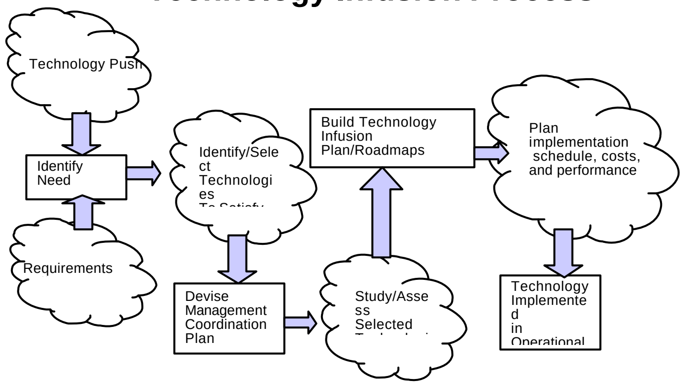
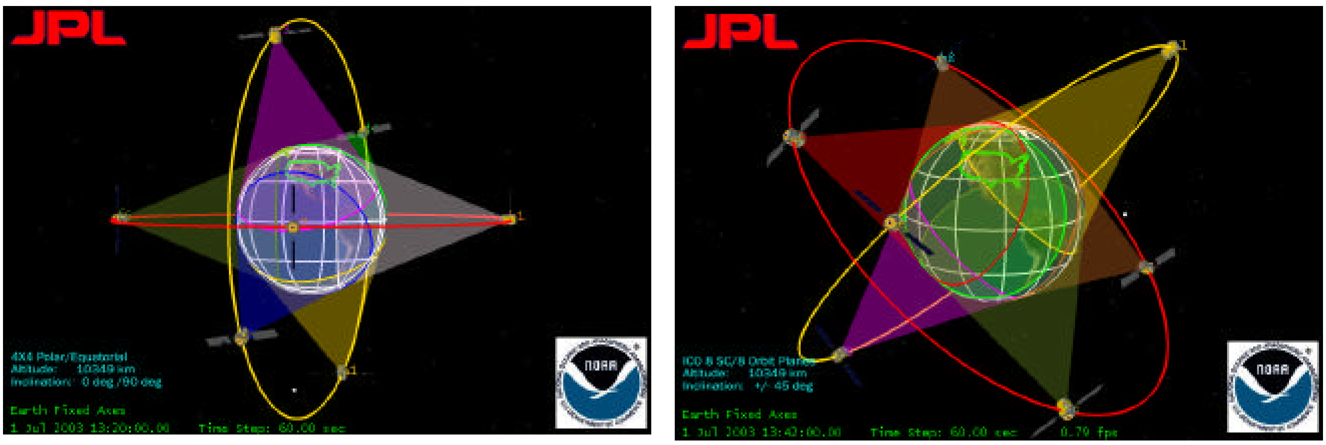


Figure 1 – Tech Infusion Process

3. MEDIUM EARTH ORBITS

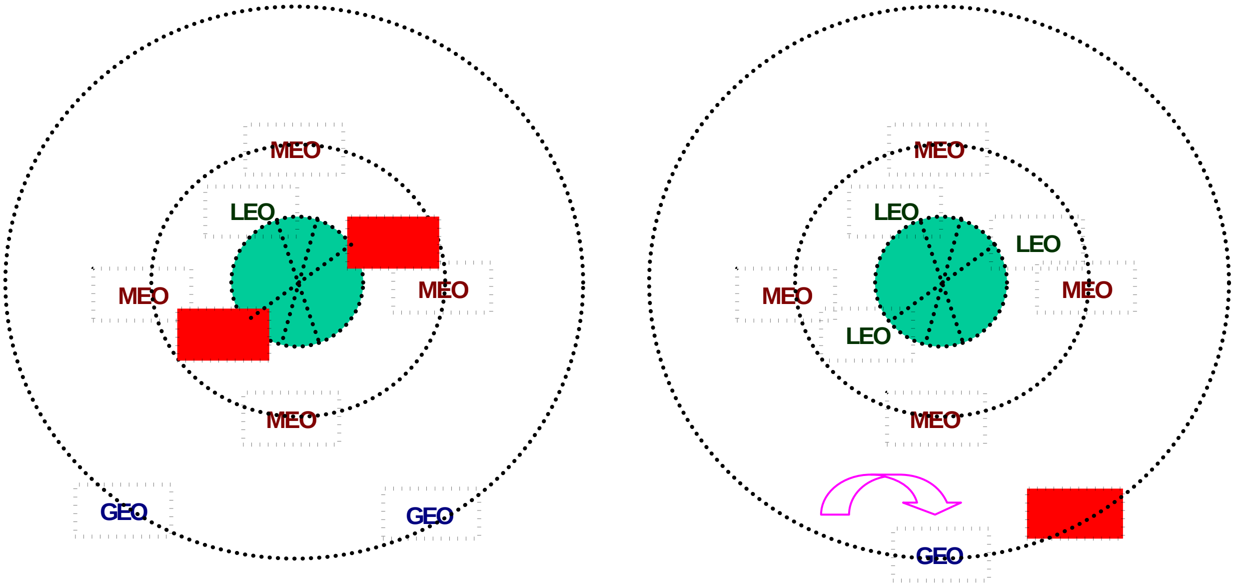
NOAA operates a constellation of low earth orbit (LEO) and geostationary orbit (GEO) satellites to provide continuous weather, climate, and environment monitoring. NOAA, with the assistance of NASA/JPL, is investigating the practical use of Medium Earth Orbits (MEO) as a means to improve coverage rates and revisit times. MEOs under study are situated at 10,400 km compared to the lower LEO (833 km) and higher GEO (35,786 km) altitudes. MEO satellites due to the closer range require smaller apertures to provide the same spatial resolution as GEO. Non-equatorial MEO satellites can observe the Earth's poles and all MEO have increased revisit times compared to LEO orbits. MEO satellites have a period of 6 hours (100 min LEO) and revisit times of 8 hours (12 hours LEO). NOAA and JPL are now examining the use of 4 and 8 satellite constellations for future architectures. One promising constellation is based on an eight satellite ICO constellation; consisting of two orbit planes 90 degrees apart. Figures 2 and 3 illustrate two promising MEO constellations: polar/equatorial and ICO.



Figures 2 & 3 – MEO polar/equatorial and ICO constellation

Equatorial MEO constellations provide worldwide remote sensing and communications relay capabilities with a minimum of additional assets. A four-satellite MEO constellation can cover almost the full disk (+/- 60°) from all sides; provide a two-hour revisit time, and worldwide relay services. These near real time communications services could augment domestic and international environmental assets.

A combination of all three orbits provides a synergistic transition to a robust, observation system. The addition of four MEO satellites to NOAA existing satellites provides a low cost, highly robust global observing system. This improved constellation could survive the loss of GEO or LEO satellites and still provide necessarily coverage. Coverage can still be realized with a small number of assets and coverage easily maintained by shifting assets. Figures 4 and 5 illustrate the robustness realized with a four-satellite MEO constellation when added to NOAA nominal LEO and GEO constellations (75° W and 135° W). In Figure 4, Global coverage is still maintained despite the loss of two LEO satellites (shaded or red). In Figure 5, loss of a GOES can be mitigated by shifting the remaining GEO to the middle at 105° W and utilizing the timeliness of the remaining MEO/LEO combinations can continue Continental US coverage.



Figures 4 and 5 – Robustness of a combined LEO, MEO, & GEO constellation

4. PASSIVE GEO MICROWAVE SOUNDER

Advanced technology is also important for NOAA's next-generation geostationary Operational Environmental Satellite (GOES-R), scheduled for launch in 2012. GOES-R is expected to provide significant advances in earth coverage, environmental data, and prediction capabilities. GOES' unique vantage point provides continuous, near-real-time updates of weather and environmental conditions for the Americas and large portions of the Atlantic and Pacific Oceans.

In general, GOES-R sensors improvements arise from more frequent updates; finer spatial resolution and increased data rates.

GOES R improved sensors include are Advanced Baseline Imager (ABI), Hyperspectral Environmental Suite (HES) sounder/coastal waters imager, advanced Solar Imaging Suite (SIS) and improved Space Environmental Imaging Sensor Suite (SEISS). NOAA is also considering Pre-Planned Product Improvement (P^3I) sensors as instruments of opportunity for technology infusion. The GOES-R P^3I instruments under consideration are a hyperspectral imager, solar coronagraph, passive microwave imager, passive microwave sounder, and solar irradiance sensor.

InfraRed (IR) sounders, such as the AIRS and HES, provide excellent observations in clear conditions. Critical information, within clouds and under cloud cover however, is not available in the IR spectrum. Microwave sounders can provide synergistic coverage by their ability to observe moisture through clouds. A combined suite of HES and Geo Microwave Sounder (GMS) can provide complete geostationary sounder coverage through our hemisphere.

Two GMS designs are proposed. Both designs would benefit from the Advanced Microwave Sounder Unit (AMSU) heritage and already existing retrieval algorithms. The GOES R Geo Microwave Sounder (GMS) designs would use similar frequency bands as the Advanced Microwave Sounder Unit (AMSU) and benefit from already existing retrieval algorithms. The GEoMicrowave Sounder (GEMS) is based on a MIT/LL and NOAA/ETL design. GEMS uses a mechanically steered, solid 2 m dish antenna and 43 channels covering five frequency bands (54, 118, 183, 380 & 424 GHz). Another design is JPL's Geostationary Thinned Aperture Radiometer (GeoSTAR), which utilizes a sparse aperture strip antenna and 10 channels across three frequency bands (54, 89 & 183 GHz). Both radiometer designs provide hourly moisture and temperature profiles. Spatial resolutions are frequency dependent and vary from 25 to 100 km for GEM. The GeoSTAR spatial resolutions are 25-50 with flexibility of achieving even better by adding more elements. Both GMS designs take advantage of the latest developments in sensor technology, retrieval algorithm development, and super resolution. NOAA and NASA Goddard Space Flight Center are working together evaluating designs for 2015 launch.

4. SOLAR SAILS AND UNIQUE ORBITS

NOAA is actively following solar sail research. Solar sail propulsion technology has the capability to permit operations in orbits never practically achievable before. One interesting subgroup, the Artificial Lagrange Orbits (ALOs) may provide unique solutions to meet a variety of NOAA requirements. ALOs are special trajectories in space extending from the Sun-Earth LaGrange L1 and L2 points out of the plane of the Earth ecliptic, and inward toward the sun. Figure 6 depicts examples of contours on which a given additional force from a solar sail could provide a stable satellite position relative to the Earth. Higher values indicate stronger forces are needed.

ALO orbits are much farther away from the Earth compared to traditional satellite altitudes: ALO satellites therefore offer unique advantages. ALOs are synchronized with the Earth in a one-year orbit around the Sun; they have continuous hemispheric views of the Earth and moon; and provide an unobstructed view of the Sun. ALO satellites orbit outside the Earth's magnetic field and can be situated closer to the sun. ALO positions sunward of the L1 point permit much earlier warning of geomagnetic storms and positions below or above the Earth ecliptic plane allow continuous visibility of polar regions for communications and remote sensing - a capability which is now totally unavailable.

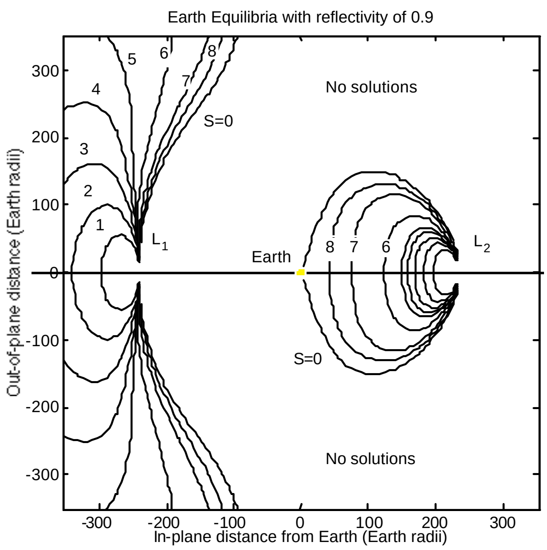


Figure 6 – Solutions for stable Artificial LaGrange Orbits (adapted from McInnes, 2003)

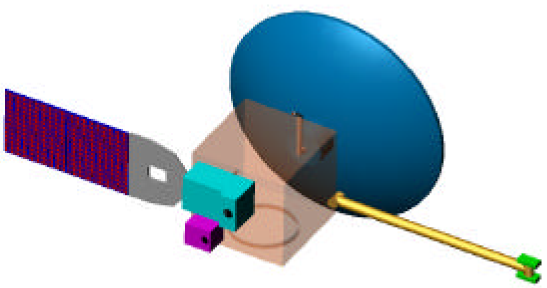
The benefits to NOAA from these orbits tend to fall into two categories: observations a communications. The unique perspective allows an integral improvement to a product such as the ability to image the entirety of the auroral ovals continuously. Also, orbital positions allow a space/sensor/ground architecture with fewer elements and possibly lower costs. They are especially advantageous for certain communications requirements. For example the proposed design of the NPOESS uses 15 ground stations to achieve its product latency of ~5 minutes. Cross linking the NPOESS data through two out-of-ecliptic satellites would require only two ground stations in the high northern and southern latitudes, and would deliver all the data in essentially near real time.

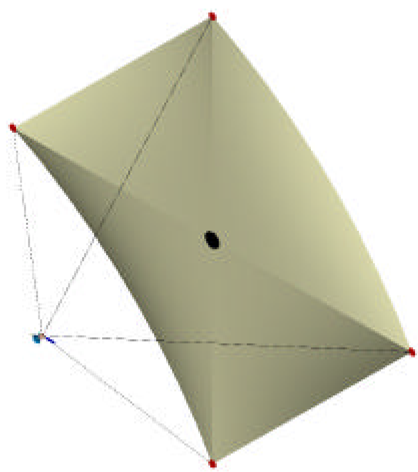
These orbits could also allow system level improvements of significance for climate measurements. The orbits are thermally very stable, have no eclipses, and permit significant cooling of sensors that are positioned in the sail's shadow. Positions out of the ecliptic allow constant views of the moon permitting inter-satellite calibration, which is very helpful for measurements with stringent requirements for long-term stability. Products developed from full hemispheric views may need simpler solar and scattering angle corrections compared to those made from polar orbiting platforms.

Other agencies have requirements, which can be addressed in these orbits and hold the potential for cost sharing on common satellite platforms. For example, real time continuous meteorological imaging of the Antarctic continent and its supporting flight corridors, and 12 month communications visibility to the South Pole would meet unmet requirements of the National Science Foundation's US Antarctic Program. An out-of-the-ecliptic architecture may provide the best real time communications/navigation system for NASA's new lunar missions, and serve as a prototype for a similar architecture at Mars.

NOAA recently completed a conceptual design for a new solar winds mission positioned at L1 or nearby ALOs. The latter option would use a solar sail for station keeping. This design assumes the satellite launch is planned for 2010 with a 5 year on orbit lifetime. The Solar Winds mission would provide 30 to 60 minutes advance warning of geomagnetic storms similar to the data received from NASA's Advanced Composition Explorer (ACE). NOAA's preliminary design consists of two magnetometers, a plasma ion detector and low energy ion detector.

NOAA is investigating providing secondary communications support to the aforementioned National Science Foundation South Pole expedition, crosslink capability to the NPOESS series, or other agency requirements on the same platform. Solar Winds instrument data would be collected 24 hours per day/7 days per week, with a latency of 5 minutes to NOAA's Space Environmental Center (SEC) in Boulder, CO. The ground station location is still TBD. Possible sites include Boulder, CO. Fairbanks, AK, and Wallops Island, VA. Figures 7 and 8 depict examples of satellite and deployed solar sail configurations.





Figures 7 and 8 – Solar winds satellite and solar sail

6. CONCLUSIONS

NESDIS, along with their government, industry, and international partners, continues to investigate a wide variety of technologies for future missions. New constellations in different orbits will increase coverage while reducing refresh and latency times. Reduced altitude orbits, such as MEO or Molynia, can increase spatial resolution without altering contemporary sensor designs. New technologies such as passive GEO microwave sounders and solar sails will enable NOAA to meet new challenges and strategic goals into the 21st Century. Emerging technologies enable innovative solutions to meet growing requirements and propel NOAA toward their goal of global observing systems. Alternative architectures and new sensors all contribute to NOAA's Observing Systems Architecture (NOSA).

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