A MEDIUM EARTH ORBIT CONTELLATION FOR POLAR WIND MEASUREMENTS

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ABSTRACT

Low Earth orbits (LEO) and Geostationary Earth orbits (GEO) orbits have traditionally been the venues of choice for observations, albeit for very different reasons. LEO provides high spatial resolution with low temporal resolution while GEO provides for low spatial resolution, but high temporal resolution. NOAA utilizes both venues for their environmental satellites. The NOAA Polar-orbiting Operational Environmental Satellites (POES) reside in LEO Sun synchronous orbits at approximately 830 km in altitude, as do the Defense Meteorological Satellite Program (DMSP) satellites of the Department of Defense. In the near future the POES and DMSP satellites will be merged into a new satellite system referred to as the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The NOAA Geostationary Operational Environmental Satellite (GOES) system, as the name specifies, resides at the other preferred observational venue of GEO. At the same time, wind information from NASA's MODIS sensors on the satellite Terra and Aqua, has been shown to provide unexpectedly large improvements in numerical model predictions. This is true, even thought the winds are derived from images of cloud features which are separated by about 100 minutes. This study describes efforts to attain full coverage of regions of the Earth poleward of 60 degrees latitude (i.e., both poles) on a continuous basis, 24 hours a day, seven days a week. Such a system would be a welcome contribution to the Global Earth Observing Systems f Systems (GEOSS) be adding data to the already useful information from polar and geostationary satellites. This study examines the initial stages of an investigation into two possible ways to attain full time polar coverage: a Medium Earth Orbit (MEO) constellation of four equally spaced satellites in a plane oriented at an inclination of 90 degrees relative to the equator; and four Molniya satellites, two for the northern regions and two for the southern regions.

1. INTRODUCTION:

The Jet Propulsion Laboratory (JPL), under contract to NOAA, has been studying the characteristics of medium Earth orbits (MEO) and Molniya orbits. Here, MEO is defined as a circular orbit at an altitude of 10,400 km with an inclination angle of 90 degrees so that the plane passes directly over each pole with a period of six hours. The classical Molniya orbit is defined as an elliptical path, with a perigee of 600 km and an apogee of 39750 km at an inclination angle of 63.4 degrees.

Winds over polar regions are addressed as the primary focus of study because of the success shown by MODIS polar winds. All satellites eventually fail and when this happens to the two MOSIDS carrying satellite in the next few years, it is important to have a solution ready. In the longer term, the goal is to have a robust, replenishable constellation operational. Further, Satellite based wind vectors are derived from data that is measured at Earth intercept angles (elevation angles) greater than about 25 degrees, otherwise, there is too much atmosphere for the signal to traverse. If the systems can be made to be successful for winds, then they can be easily expanded to imaging and sounding data farther out from nadir at elevations approaching a few degrees. So, attacking winds first is the more challenging case. In addition, this study is a timely contribution to the International Polar Year (IPY) for 2007-2008. A further motivation to address polar regions is driven be strong operational requirements for high time resolution data over the Alaska Region of NOAA's National

Weather Service. Alaska, most of which lies north of 60 degrees latitude, is not well served by GEO satellites and only every orbit from polar satellites.

2. MEDIUM EARTH ORBIT (MEO)

The Medium Earth Obit (MEO) constellation considered here would compliment the existing Low Earth Obit (LOE) and Geostationary Earth Orbit (GEO) satellites by filling in with data over polar regions.

A path to implementing this constellation would be to launch one demonstration satellite into the 90 degree orbit for proof of concept and risk reduction. This would be followed by launching the remaining three satellites to fill out the full four satellite constellation. For this constellation, if one satellite fails, the remaining three could be rephrased to 120 degrees apart until the replacement satellite is launched and the constellation of four satellites can be reestablished (Figure 1).

The demonstration mission would place one MEO satellite in a 90 degree inclination over-the-pole orbit. Such an orbit offers a number of opportunities to demonstrate the concept, perform risk reduction, check out instrument concepts and data flow issues, and test and validate instrument scanning strategies. Instrumentation would consist of an imager, and infrared and microwave sounders.

For the North and South Poles and parts of Northern Europe the MEO would be available to take data continuously for 2 to 2 ½ hours (the higher number would be for a point exactly under the orbit track) out of every 6 hour orbit, giving four data periods of perhaps 15 minute interval data throughout the day. Numerical models would be able to test the advantages and benefits of having high fidelity, rapid-repeat vertical profiles of winds, temperatures, and moisture in cloudy and clear areas during four periods daily. Data from the demonstration mission would be very useful for examining varying look angles and resolutions at a point, and providing polar wind demonstration. Further, such a data stream would compliment data from existing and planned international geostationary systems by filling in the gap over the poles.

By adding three more MEO satellite to the same 90 degree orbit plane and spacing them equal distances apart, continuous polar data would be available as a point is viewed first by one MEO satellite, then by the next one, then the next one, and so forth, all with overlap. For the first time, there would be full and continuous global coverage, meaning the full four-pi steradians of the globe. There would be a continuous data from anywhere, all the time, in real time – a substantial contribution to the Global Earth Observation Systems of Systems (GEOSS). If one of the four satellites should fail, the remaining three could be re-phased to a spacing of 120 degrees apart and still acquire almost continuous data until a replacement MEO can be launched. By studying the percent of time each 2.5 degree latitude–longitude square is seen by four MEO satellites, it is found that there is essentially 100% coverage poleward of about 50 degrees latitude for elevation angles down to about 5 degrees (Figure 2).

3. MEO DEMONSTRATION MISSION

The rationale for a MEO demonstration mission is to validate that basic imaging, temperature sounding, and wind and liquid/solid water profile measurement requirements can be met from 10,400 km MEO altitude and provide a communications backbone for a variety of NASA, NOAA, and NPOESS IPO missions. The overarching purpose of such a mission would be to demonstrate a sustainable, extremely capable system that is superior to current implementations and affords significantly reduced long-term costs compared to other implementations that could deliver similar data products and capabilities. Recognizing that observational requirements dictate temporal resolution, spectral coverage and resolution, spatial resolution and radiometric performance, an objective of the study is to provide definitive studies and trades as input to roadmaps for MEO and other satellite constellation options.

An evolutionary MEO road map to a long term observational capability must support continually improving weather predictions, plus climate and environmental assessments and forecasts, with near real-time data availability, total global coverage, 0.5 km at 0.5 microns instantaneous geometric field of view or better spatial resolution, improved spectral coverage (including microwave for cloudy weather conditions) and globally consistent, long-term accurate and stable data collection. Based on architecture studies performed by JPL to-date, a MEO demonstration system could be developed to serve three functions: (1) to demonstrate MEO-observing capabilities with GOES-like instrumentation, (2) to provide an operational communications system, and (3) to provide a risk retirement test bed for evaluating new instruments developed to exploit MEO opportunities and provide NOAA a cost-effective, risk-reduction path for developing environmental observation instruments for future orbital and ground systems architectures.

The MEO demonstration plan calls for launching a satellite augmenting the capabilities of GOES-R, all the other LEO and GEO international meteorological satellites, and NPOESS while continuing the usage of NPOESS for the Polar Regions. Furthermore, it provides a platform for validating/demonstrating new instruments to substantially improve the environmental data collection and weather prediction capabilities of NPOESS and GOES-R, such as an advanced optical and infrared imaging and sounding and a high-performance microwave radiometer/sounder with spatial resolution of the order of 1 km at 15 microns and 50 km respectively.

MEO mission requirements are derived from requirements in the GOES-R Preliminary Requirements Document. The constellation of four satellites would make observations over the entire range within 60 degrees of the ground track, and include interleaving hemispheric (full disk), synoptic (regional CONUS) and mesoscale (rapid-scan) imaging. Full disc imagery data would be taken every 15 minutes, and CONUS imagery data taken every 5 minutes – an equivalent GOES-R “full disc” as seen by the MEO constellation being a composite image from sensors on the multiple satellites. For severe weather activity, updated satellite imagery data covering areas at least 1000 km square area would be taken every 30 sec.

Mesoscale measurements would provide imaging and derived high-density wind products. Data bands would include visible and long- and short-wave infrared (IR) and IR water vapor (300-500 hPa) essential for NWS forecast operations, and to meet future NWS cloud, moisture, and surface observation and liquid-solid water profiling requirements. Visible imagery data would have a spatial resolution of 0.5 km or better, and IR imagery data a spatial resolution of 2 km or better for all bands. IR soundings would have a spatial resolution of 10 km or smaller, with an objective of 2 km. Temperature and moisture soundings would be made over an area of 12,000 km x 12,000 km within each hour. The accuracy of Earth-location sounding data would be 2.5 km or better in both normal and rapid scan modes. The precision of temperature soundings would be within 2°C per 3 to 5 km layer or better. The precision of moisture soundings would be within 20% of the nominal reading. The four-satellite constellation would be expected to have an operational availability of at least 98%.

4. MOLNIYA ORBITS

A Molniya orbit has the unique characteristic of appearing to hover over a point near 60 degrees latitude for four to eight hours of its 12 hour orbit. This study investigated a Molniya orbit which has one of its apogee points located over Alaska (150 degrees West Longitude). Twelve hour later, the other apogee would be nearly over Helsinki (30 degrees East). Analyses of areal coverage show that nearly geostationary positioning would be available about eight hours out of every 12 hour orbit. Two Molniya satellite are required for continuous coverage of the North Pole all the time. Four Molniya satellites are required to cove both poles all the time, two for the North Pole and two more for the South Pole. Taking in to account the ability to view beyond the Earth’s pole, results demonstrate that a four Molniya constellation would provide coverage of regions poleward of about 50 degrees 100% of the time (Figures 3 and 4).

5. CHALLENGES

This study has focused on areal coverage to ensure continuous viewing of polar regions. Yet, further questions remain. For the spacecraft, engineering questions must be examined especially the charged particle environment and mitigation, especially since knowledge of the spatial and time distribution of charged particles at MEO altitudes and latitudes is not well known. The ability to obtain data and design concepts for scanning the Earth from MEO or Molniya remains to be validated. One could hypothesize that for a Molniya imager, the image rotates as the satellite approaches its apogee and then begins to descend to lower latitudes. Questions remain about the extent to which this is an issue. Developing an algorithm from which to derive wind vectors may also be a challenge and needs to have a good look. Further, when wind vectors are produced, it is important to estimate the impact on numerical prediction models using Observation System Simulation Experiment (OSSE), possibly using the NOAA-NASA Joint Center for Satellite Data Assimilation (JCDSA). Each of these issues should be examined for both MEO and Molniya solutions in order for a determination to be made on how best to proceed.

6. CONCLUSIONS

This study demonstrates that in terms of areal coverage, either a four satellite MEO constellation or a four satellite Molniya constellation would be capable of viewing polar regions on a continuous basis, 24 hours a day, seven days a week. In the short term, that is, in the next few years after the MODIS sensors are no longer operable, a single Molniya satellite with apogees over Alaska and Scandinavia would seen to be an attractive solution, especially taking onto account the relative technical maturity of both Molniya satellites and GEO instrumentation. In the long term, that is, in the decades to come, the four satellite MEO constellation may be more attractive, primarily due to its robustness in the face of satellite failures over time, and the closer distance to the surface.

7. REFERENCES

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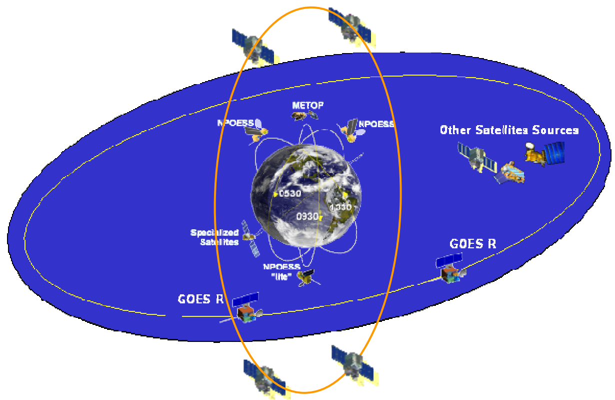

Figure 1. Diagram of four MEO satellites in an over-the-pole plane along with two of the nearly half dozen international Geosynchronous systems.

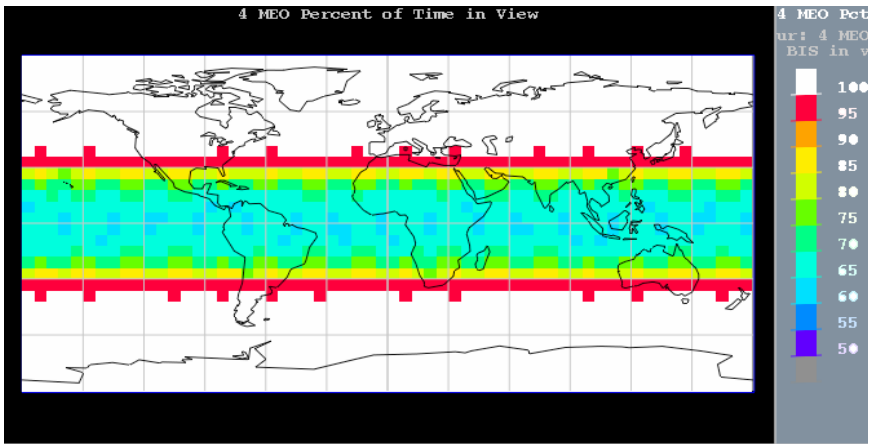

Figure 2. MEO Coverage (4 satellites). Percent of a 24 hour period when a 2.5 x 2.5 degree square is seen by at least one satellite. White is 100%, yellow is 75%, and dark blue is 50% of the time.

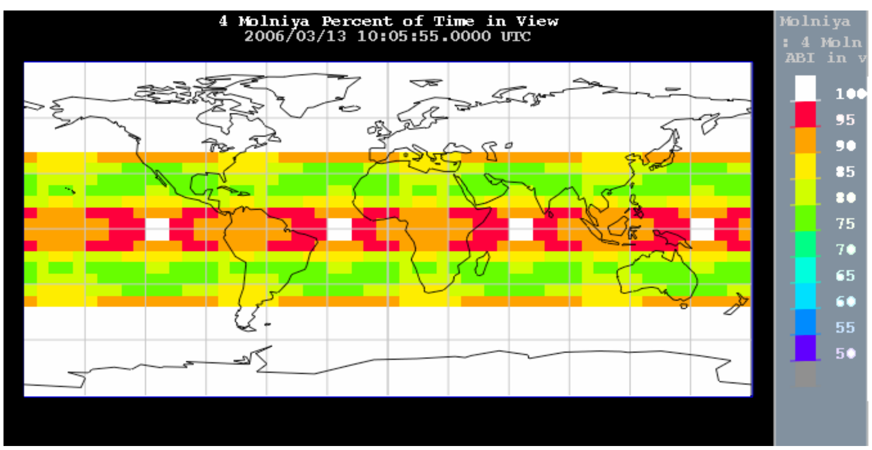

Figure 3. Molniya Coverage (4 satellites). Percent of a 24 hour period when a 2.5 x 2.5 degree square is seen by at least one satellite. White is 100%, yellow is 75%, and dark blue is 50% of the time.

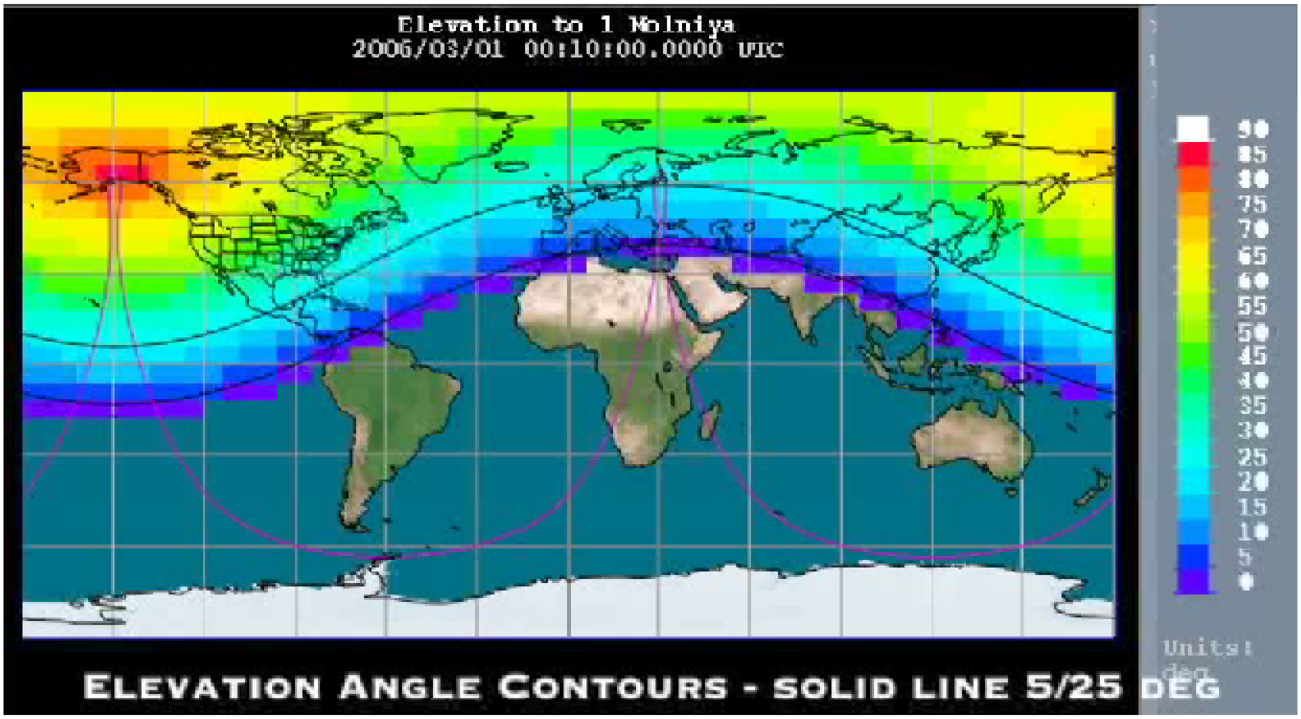

Figure 4. Molniya Ground track (1 satellite). Colors show elevation angles from zero (dark blue) to more than 85 degrees (red) for a Molniya satellite at the apogee over Alaska. Solid black lines represent elevation angles of 5 and 25 degrees. The ground track, in dark purple, shows the other apogee 12 hours later over Scandinavia.