Polar Environmental Monitoring, Communications, and Space Weather from Pole Sitter Orbit

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Summary

In late May of 2005, the first Solar Sail spacecraft, COSMOS-1, will be launched from a Russian Submarine in the Barents Sea on a Volna rocket (Planetary Society, 2005). This effort will mark humanity's first effort to test Solar Sail spacecraft, bringing to reality the theory and dreams of a potentially powerful propulsion system. Prior to this, efforts by Robert Forward and work by Colin McInnes at the University of Glasgow demonstrated the possibility of Artificial Lagrange orbits (ALOs), non-Keplerian orbits, where a solar sail power spacecraft could in theory orbit above or below the ecliptic plane of the solar system (McInnes, 1999). This development leads to the potential to launch solar satellites that would be able to be positioned in a polar sitting or "pseudo-stationary" orbit over the North and South Polar regions of the earth. It is not a true stationary position; these satellites co-orbit the sun with the earth, but from a position above or below the planet in the ecliptic. Thus despite some motion that is seasonal as well as daily, the platforms always view the poles (See Figure 1). Example polar sitter spacecraft are shown above and below the earth in Figure 2. Such a spacecraft would be in a position to accomplish several tasks – of which primarily three are introduced in this report:

- Continuous environmental and meteorological monitoring of the polar regions of earth,
- Unique perspective on space weather monitoring of the Sun-Earth system,
- Unprecedented constant communication links between the deep polar regions and the rest of the world.

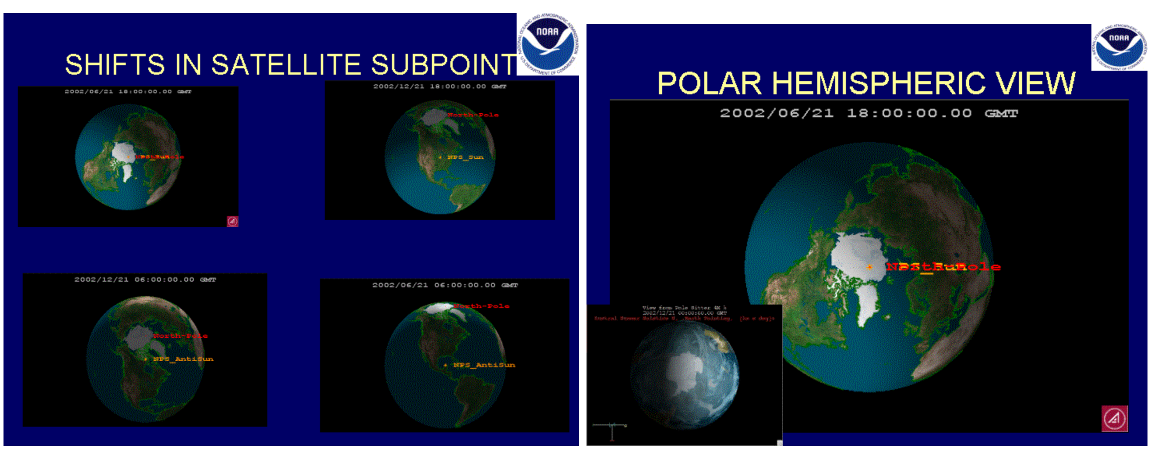

Figure 1 Simulated sample seasonal views of the earth from a pole sitter satellite (*Courtesy of Pat Mulligan/NOAA*).

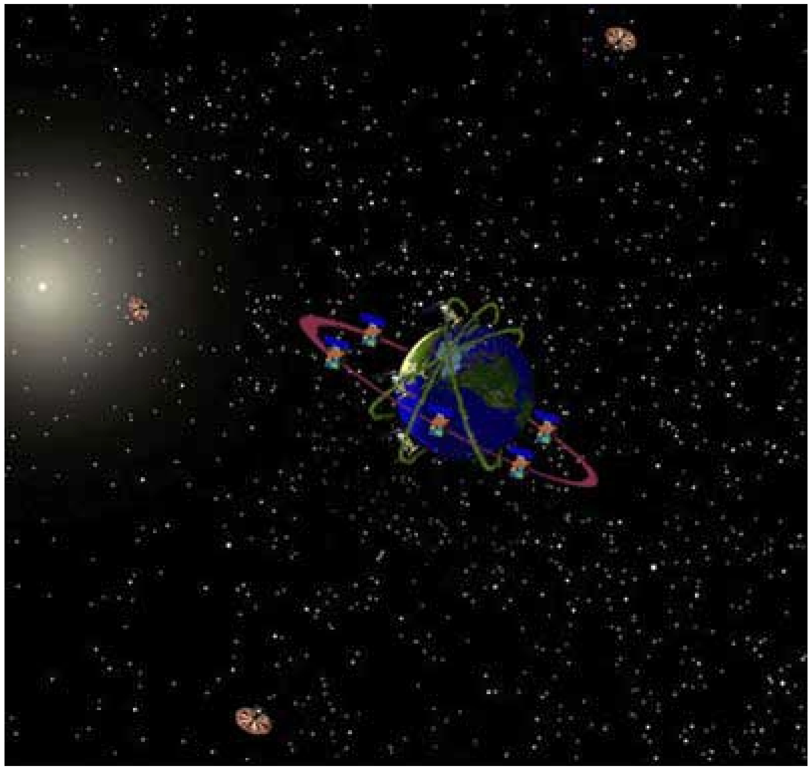

Figure 2 One vision for the future satellite fleet, including pole sitter satellites - one for the Arctic and one for the Antarctic (*Courtesy of Pat Mulligan/NOAA*).

Clearly, the proposed system would have the potential to achieve at least the aforementioned three goals, among a larger list of potential mission objectives, which time and space here does not allow. The proposal here is to consider having one or perhaps more satellites orbit above each polar region. One option would be a single satellite for each pole, both in extremely high ALO with the ability to view the entire polar region. A second option would be to have two satellites at lower altitudes out of the ecliptic, one north and one south of either the L1 or L2 points. They would be able to constantly view the poles by switching satellite coverage for each pole near the time of the equinoxes (See Figure 3). It is important to note that the critical concern with solar sail spacecraft is the triple trade-off between payload-spacecraft mass, the orbital altitude, and the performance of the solar sail (McInnes, 1999 and McInnes and Mulligan, 2003). In short, the larger the mass of the spacecraft, and the greater the distance from earth, the higher the performance requirement on the solar sail to support and power the spacecraft. There is a balance that will need to be struck to meet all of the mission objectives at the lowest cost, within the realm of the technological capability.

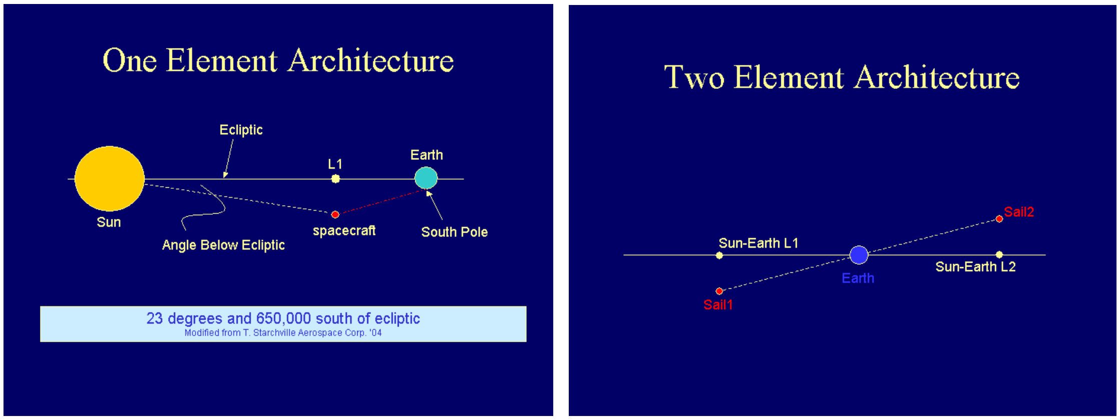

Figure 3 Depictions of one-element pole sitter architecture as compared to a two-element architecture (Courtesy of Pat Mulligan/NOAA).

One focus of these missions would be primarily on the remote sensing and monitoring of polar regions of the earth. Here, the observational variables would include visible reflectance as well as infrared radiances and temperatures – the very same observational variables nearly taken for granted from other meteorological space based platforms (GOES, etc.).

Much of the background effort on the Triana satellite mission would be have application here. Even though the Triana mission (now called DSCOVR) was meant to be stationed in the ecliptic, it would have operated at a distance comparable to some pole sitter orbits and demonstrated the advantage of real time hemispheric remote sensing. The polar regions troposphere would be the primary focus, with some observing of the middle latitudes as well as some information on the cryosphere and oceans. Of course, any part of the atmosphere would be possible to remotely sense from this platform. The Triana mission projected achieving 8 kilometer resolution with its polychromatic imager, and anticipated significant improvement in observations of UV surface radiation, ozone, clouds, aerosols, vegetation index and radiation budget (Triana web site, 2005).

Another focus would be space weather monitoring of the Sun-Earth system. The National Oceanic and Atmospheric Administration (NOAA) and the United States Air Force (USAF) have reviewed the desirability of shifting near-Earth space environment measurements from the National Polar-orbiting Operational Environmental Satellite System (NPOESS) to pole sitter observations. They concluded that auroral boundary, energy deposition, and imagery would be significantly improved from the Polesitter platform and that improvements might also be made to the electric field, electron density profile, Ionospheric scintillation, and neutral winds environmental data records (NPOESS Government Advisory Team, 2003). Out of ecliptic satellites are also candidate platforms for various solar imagers and radiometers such a coronal mass ejection imagers. A particular advantage of the orbital position is the lack of a solar eclipse period. Many ALO stations are also suitable for measurement of solar wind data and monitoring of potential geomagnetic storms.

A third focus would be communications. Here data communications at a reasonably high data rate, on the order of 20 to 40 Gigabits per second, would be able to flow to and from the deep polar regions of the earth (McInnes and Mulligan, 2003). More recently, NASA's Space Communication Architecture Working Group has included pole sitter architectures that can relay up to 300 Mbps for the 2020 to 2030 timeframe. Currently, inclined geostationary satellites offer the only available communications for locations such as South Pole, and even that is limited to only portions of a day due to the availability of spacecraft (NASA, 2001). Although systems such as Iridium offer some solutions, they do not offer high data rates, and have an uncertain long-term future. In such locations having 24 hour/7days a week communications is critical for operational needs, logistics, and telemedicine as well as the movement of science data. Beyond this, communications from this unique position could be of benefit to other operational and science communities as well, with the potential to have the pole sitter satellite be able to relay communications such as between polar orbiting and geostationary satellites, between satellites or missions to the Moon or Mars, etc.

Advancing Science and Operational Capabilities

Currently, the environmental monitoring of the polar regions is done best via polar orbiting environmental satellite systems such as the NOAA's Polar-orbiting Operational Environmental Satellite (POES) system, the Department of Defense's (DoD) Defense Meteorology Satellite Program (DMSP), the National Aeronautical and Space Administration's (NASA) Earth Observing System (EOS) satellites such as Terra and Aqua, and soon the new NPOESS (Lazzara et al. 2003a). However, these platforms do not provide the temporal resolution that is current enjoyed over the mid-latitudes and tropics from geostationary environmental monitoring such as with NOAA's Geostationary Operational Environmental Satellite (GOES) platforms. Meantime, efforts have been underway for the Antarctic over the last 12 years to take the best of both satellite types and merge them into a single view as shown in Figure 4 (Lazzara et al. 2003b). Hence, monitoring from a pole sitter point-of-view will give meteorologists and earth scientists the first ever look at polar processes from space on a temporal resolution usually reserved for mid-latitude thunderstorms and tropical hurricanes: namely rapid scan and super-rapid scan 5 minute and 1 minute imagery and data collection, respectively. In fact, the very composite in Figure 3 will be able to be generated using observations from a pole sitter platform, and eliminate the "hole" or gap seen in that and in most Antarctic composites. Weather forecasting has been and continues to be critical for the National Science Foundation's (NSF) United States Antarctic Program (USAP) (Cayette, 2002), especially as it relates to medical evacuation situations that have occurred over the last few years (Monaghan, et al. 2003). Additionally, satellite observations are critical for the flight safety and field camp work of the USAP and other national programs in the Antarctic. Much needs to be studied over the polar regions to improve our understanding of the meteorology in these regions and how the interact and relate with the rest of the globe (e.g. Bromwich and Parish, 2004).

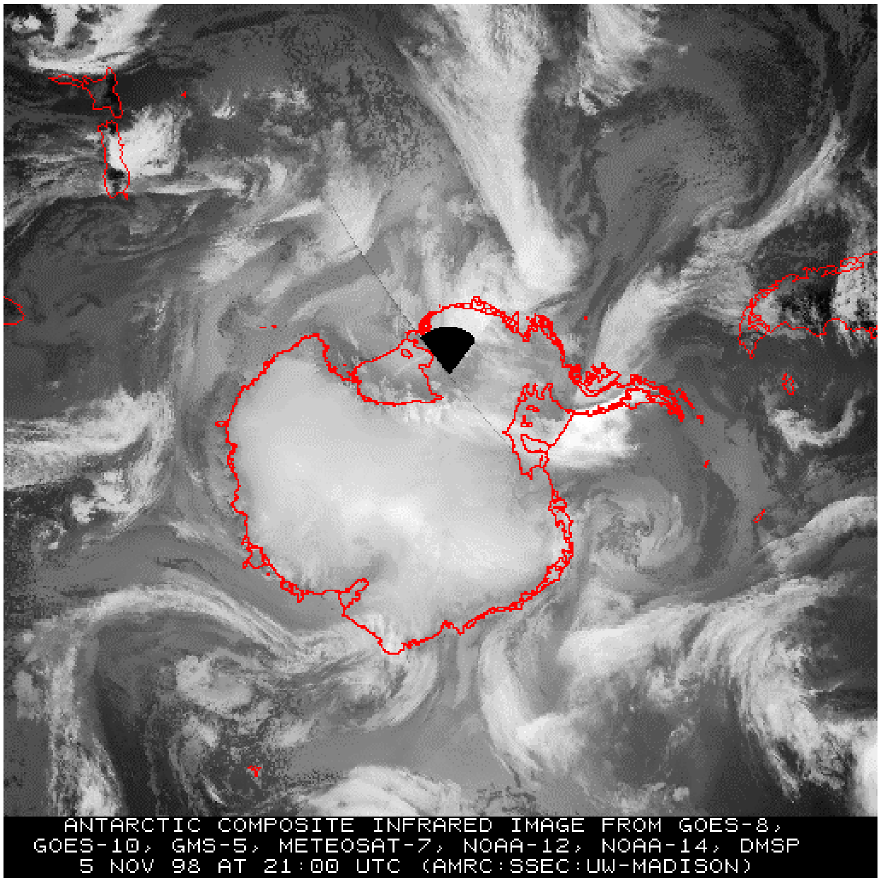

Figure 4 An example Antarctic composite image combining infrared data from both geostationary and polar-orbiting platforms (*Courtesy of the AMRC, SSEC, UW-Madison*).

Environmental monitoring from a pole sitter orbit offers several other improvements. One of the most significant would be the ability to generate cloud drift and water vapor target winds much like the current polar winds project does from Aqua, Terra and the POES satellite series (Key et al. 2002). One possibility would be to have the opportunity to fill a gap in coverage that there currently is between the polar winds and the geostationary satellite generated winds for the mid-latitudes and tropics (See Figure 5) Another area of environmental monitoring would include transoceanic volcanic ash detection and monitoring.

One area of improvement is satellite calibration. Pole sitters and satellites systems like Triana, offer the advantage of using other objects such as the Moon for long-term stable calibration. Additionally, pole sitters may offer the chance to remove the impact by diurnal cycle of temperature that is experienced by both GOES and NOAA polar orbiting platforms. Pole sitters offer the first opportunity to monitor ozone on a continuous temporal scale.

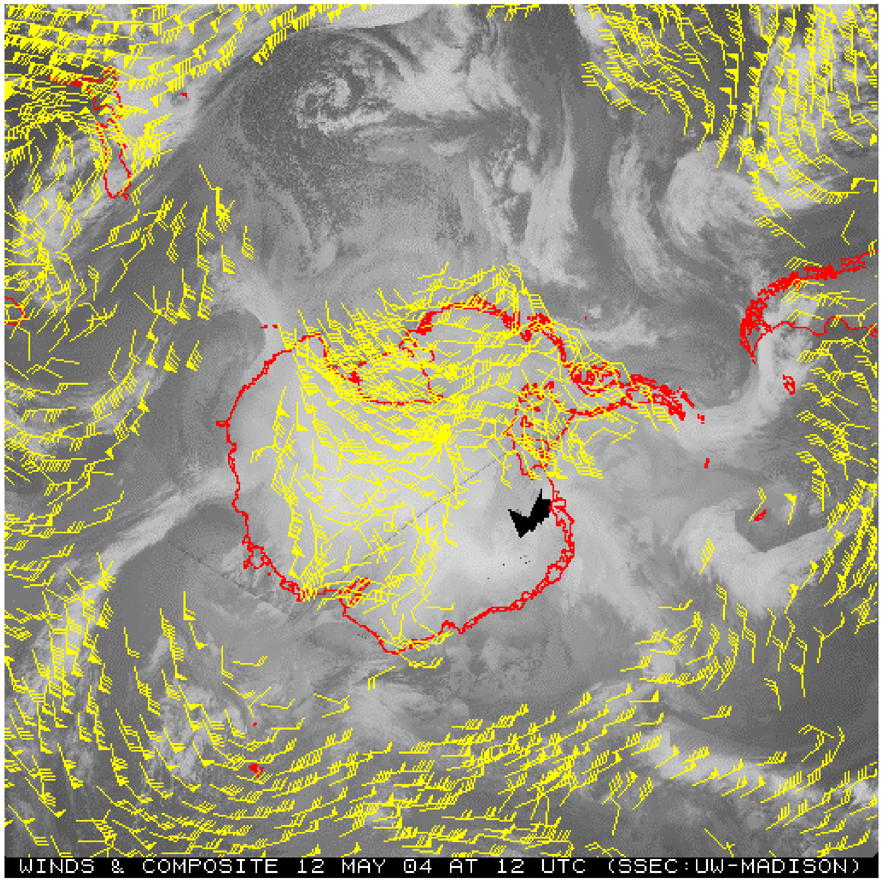

Figure 5 This is an Antarctic composite at 12 UTC on 12 May 2004 with satellite-derived winds plotted (925 hPa to 100 hPa) from the geostationary and polar orbiting satellites. This figure denotes the area roughly between 50 and 70 degrees South where there is little or no data available. The same would be the case for the northern hemisphere. (*Wind data courtesy of CIMSS/Composite satellite courtesy of AMRC, SSEC, UW-Madison*)

Pole Sitter orbits will be able to improve monitoring and advance the science of space weather, as described in the preview section (see Page 5). The proposed satellite system will have the ability of seeing the auroral oval continuously on a 24 hour, seven day a week basis. The satellite's location relative to the sun-earth magnetic field will allow it to monitor earth and other interplanetary geomagnetic fields, solar wind, and energetic particles. Clearly, this platform offers an excellent vantage point for monitoring the ever increasingly important environmental phenomena of space weather, as it can have significant impact on the operation of other satellite systems.

Improved communications to and from the deep polar regions, south of the area where viewing geometry of traditional geostationary satellite communications ends, will be valuable for operational and science data transmission uses. Without a doubt, the improvement will be most critical in the area of medical situations where telemedicine needs are essential (e.g. telemedicine that was needed for the diagnosis and treatment of Dr. Jerry Neilsen at South Pole in 2000-2001). Currently for a little over 12.5 hours a day, South Pole Station, Antarctica is without modern communications due to the use of inclined geostationary satellites (NASA, 2001). Having this improved to full-time coverage will be important to the safety and well being of the USAP participants deployed there. Similar benefit can and should be available to the Arctic as well. In addition, the high bandwidth offers the opportunity for research data collections and archives of data created locally (local data arrays, instruments weather stations, etc.) in the polar regions to be made available in real to near-real time. Currently, some of this data has to be recorded on tape and seasonally flown out of the Antarctic by plane before researchers can review and use the data collected. An implication of having a two pole sitter system will allow all NPOESS data to be cross-linked and delivered to earth in essentially real time. In turn, it could allow the closure of 13 out of 15 Safety Net NPOESS ground reception sites, which is a significant gross cost savings. Future studies will estimate the net cost savings this may realize.

Costs

It is very likely that a solar sail pole sitter satellite system, including the instrumentation envisioned here along with the communications and ground station needs will potentially place this concept in the classification of a moderate sized mission that will cost 50 to 100 million dollars. However this estimate is just that – an estimate. Much will change as more is learned about miniaturization of instrumentation, experience with solar sail spacecraft, etc. before such a system is put in place. In addition, it is expected that such a mission would be a shared mission, including costs, among multiple agencies within the US Government (NASA, NOAA, NSF, etc.) and perhaps with other partner nations. Also, some evaluation will be needed to see if the smaller and less expensive two-element mission will satisfy the requirements of all partners and users. (Mulligan, pers. comms., 2005)

Several current activities will shortly refine likely costs for such missions. NASA's Centennial Challenge Program has recently announced a Partnership Opportunity for stationkeeping solar sail prizes. Elements of the Polesitter systems described herein, or prototypes are likely candidates for prizes. Several US agencies and the Canadian Space Agency have expressed interest in these prizes. In the longer term NOAA, the National Science Foundation and the NPOESS Integrated Program Office will soon award study contracts meant to define costs for acquiring solar wind data and telecom services from commercial Polesitter providers including the various options for ground systems. The opportunity clearly exists for a shared/collaborative effort. A research class Polesitter mission could collaboratively build upon earlier, more modest operational missions. This would potentially make the costs less burdensome for any single agency, nation or participant group.

Finally there is one other community interested in these orbits. Pole sitter orbits provide extensive visibility of the Moon for communications, navigation and remote sensing; excellent line of sight coverage to Mars for communications; and undoubted future applications similar to those now performed by the Deep Space Network. This advantageous position places a pole sitter platform a serious candidate for a part of the future Moon and Mars missions.

Contribution and Impacts

The envisioned system will have the opportunity to contribute and have an impact on several areas that are a part of the National Research Council's Decadal Study. Obvious impacts can easily be seen in the arena of weather and space weather. Improved monitoring of these contributes to improved forecasts, safety, saved lives and protected property. However, other areas are also benefited, such as long-term climate monitoring and hence aiding in climate change research (e.g., cloud properties such as cloud phase, and liquid and ice water content, etc.), observations that contribute to a more complete understanding and monitoring of the global hydrological cycle with an emphasis on the polar component, improving policy and logistic decisions in the polar regions (e.g. such as by the US Antarctic Program). The pole sitter satellite system will complete and compliment a full observation system for the earth as well as be a tool to be used by many agencies and nations around the world.

It is noteworthy that 25 of the environmental data records (EDR) only have horizontal resolution requirement of 25 kilometers for NPOESS program – quantifying several attributes of pole sitter orbit, which are under evaluation at this time, for possible particular relevance to climate measurements. These attributes are: long integration time for detectors, thermal stability of orbit, passive cooling provided by the sail, and constant lunar visibility for cross-calibration. It is believed that alone or in combination these attributes will impact the accuracy, precision, and long-term stability of several climate measurements currently proposed to be made by the NPOESS system, and other satellite systems.

Conclusion/Recommendations

Given the limited space requirements, this report only introduces this mission and satellite system concept. Hence, the goal of the report is to introduce this satellite platform rather than to offer comprehensive details. Yet, clearly, this platform offers great possibilities to accomplish many different and diverse activities for the benefit of operations, science and human kind.

Basic research, investigation activities, and future efforts are required leading up to having a pole sitter satellite system in place to monitor the polar environment and space weather, as well as to provide modern communications to the deep polar regions and beyond. The recommendations at this time are to:

1. Include the solar sail pole sitter mission and satellite system concept as a part of the National Research Council's Decadal Study – especially as a mid-term to long-term mission.
2. Encourage agencies and other nations that would likely benefit from this mission to participate in this effort and begin to include plans for this project in their future activities and budget.

3. Begin to fund and do “pre-phase A” styled studies of such a mission including the following key topics:
    a. A complete evaluation and initial scope of the project, including more detailed costs and specifications,
    b. Identification of possible partnerships and collaborations,
    c. A review all aspects including spacecraft and its related subsystems,
    d. A study of possible environmental monitoring sensors for the satellite including sensor characteristics (e.g. infrared interferometer with a CCD arrangement and visible sensors, spectral regions of perhaps 0.4 to 15 microns with 0.5 cm^-1 spectral resolution and approximately 10 km spacial resolution),
    e. Provide ground station support,
    f. Future product output possibilities,
    g. Complete evaluation of the two or more options for spacecraft (two per pole vs. one per pole),
    h. Considerations and costs associated with redundancies and continuations of the satellite series, etc.
4. Investigate other objectives and goals for this mission beyond those discussed here, including being a part of the future next generation Tracking and Data Relay Satellite System/Deep Space Communications Network, Support for future space missions (to the Moon and Mars), etc. With the recent Presidential announcement on the future Moon and Mars missions, agencies such as NASA will likely look seriously to the Antarctic as a testing and training environment. This could include the opportunity to have a pole sitter system be tested to provide telecommunications simulation environment and well as key platforms in support of these missions as well.
5. Consider sharing the cost of launching the Triana/DSCOVR mission, to begin to demonstrate the advantages of hemispheric imaging.

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References

Bromwich, D.H., and Parish, T.R., (eds.). 2004. Antarctic Regional Interactions Meteorology Experiment (RIME) Implementation Plan. BPRC Miscellaneous Series M-427, Byrd Polar Research Center, The Ohio State University, Columbus, Ohio, 37 pages. [Available online at http://polarmet.mps.ohio-state.edu/RIME-01/rimeimp05h.pdf]

Cayette, A., 2002: Meteorology Satellite Requirements for Operations Conducted by the United States Antarctic Program: Submitted to NOAA/NESDIS. Unpublished.

Key, J., D. Santek, C.S. Velden, N. Bormann, J.-N. Thepaut, L.P. Riishojgaard, Y. Zhu, and W.P. Menzel, 2002, Cloud-drift and Water Vapor Winds in the Polar Regions from MODIS, IEEE Trans. Geosci. Remote Sensing, 41(2), 482-492.

Lazzara, M.A., and C.R. Stearns, 2004: The future of the next generation satellite fleet and the McMurdo ground station. UW SSEC Publication No.04.07.L1. Space Science and Engineering Center, University of Wisconsin-Madison, 40 pp. [Available from The Schwerdtfeger Library, University of Wisconsin-Madison, 1225 W. Dayton St., Madison, WI 53706 or online at http://amrc.ssec.wisc.edu/MGS/MGS-final-report.pdf]

Lazzara, M.A., L.M. Keller, C.R. Stearns, J.E. Thom, and G.A. Wiedner, 2003a: Antarctic Satellite Meteorology: Applications for Weather Forecasting. *Monthly Weather Review*, **131**, 371-383.

Lazzara, M.A., Stearns, C.R.; Staude, J.A., and Knuth, S.L., 2003b: 10 years of Antarctic composite images. Conference on Polar Meteorology and Oceanography, 7th, and Joint Symposium on High-latitude Climate Variations, Hyannis, MA, 12-16 May 2003. Proceedings. Boston, MA, American Meteorological Society, 2003, Paper 9.4.

Lazzara, M.A., 2004: Meteorological Satellite Report for SPAWAR Systems Center Charleston, Aviation Technical Services and Engineering Division (Code 67). UW SSEC Publication No.04.09.L1. Space Science and Engineering Center, University of Wisconsin-Madison, 42 pp. [Available from The Schwerdtfeger Library, University of Wisconsin-Madison, 1225 W. Dayton St., Madison, WI 53706 or online at http://amrc.ssec.wisc.edu/Satellite-Report2004.pdf]

McInnes, C.R., 1999: Solar Sailing: Technology, Dynamics and Mission Applications, Springer/Praxis Publishing, Chichester, UK 296 pp.

McInnes, C.R., and P. Mulligan, 2003: Final Report: Telecommunications and Earth Observations Applications for Polar Stationary Solar Sails. Report to the National Oceanic and Atmospheric Administration (NOAA) from the Department of Aerospace Engineering, University of Glasgow. 24 January 2003.

Monaghan, A.J., D.H. Bromwich, H. Wei, A.M. Cayette, J.G. Powers, Y.H. Kuo, and M.A. Lazzara, 2003: Performance of weather forecast models in the rescue of Dr. Ronald Shemenski from South Pole in April 2001. *Weather and Forecasting*, **18**, 142-160.

NASA, 2001: South Pole TDRSS Relay web site: http://msp.gsfc.nasa.gov/SPTR/

NPOESS Government Advisory Team Point Paper to NOAA, 2003 (1/06/03), W. Denig Chair, unpublished.

Planetary Society, 2005: COSMOS-1 web site: http://www.planetary.org/solarsail/

Triana web site, 2005: http://triana.gsfc.nasa.gov/instruments/epic.htm