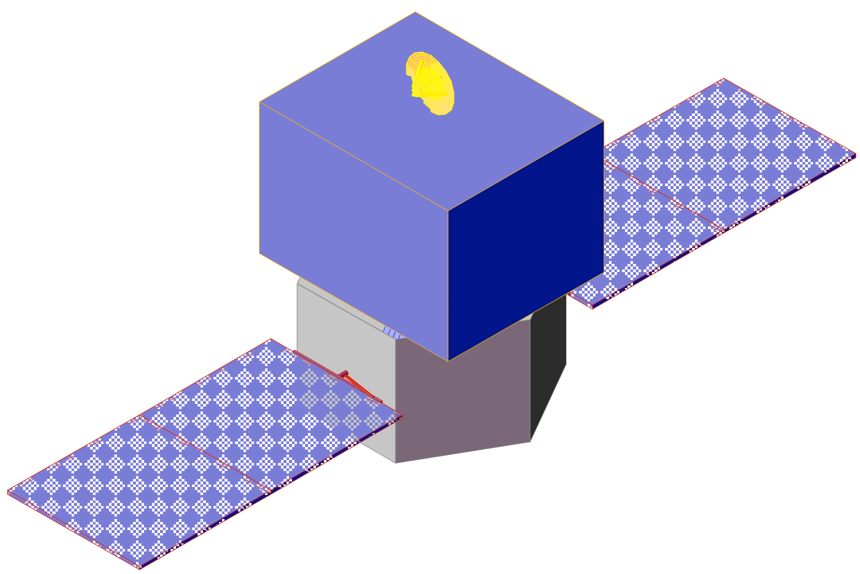
Virtual Polar Geostationary Satellite (VPGS)



A Trade Study for the
NASA Earth Science Technology Office

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Virtual Polar Geostationary Satellite Trade Study
ESTO Trade Study Final Report

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1. Introduction

A recent science workshop sponsored by the NASA/NOAA Advanced Geostationary Systems (AGeoS) Program evaluated science benefits from and needs for measurements from geostationary (GEO) orbits (Chesters and Adler, 1998). Discussion at this workshop emphasized the wide-ranging and countless benefits and synergisms for earth observational science derived from the current NOAA equatorial geostationary satellite program, and looked toward future technology and science innovations to improve and economize follow-on missions (e.g., GAO, 1998). Much of the discussion at that workshop centered on how to apply updated imaging (e.g., ultraviolet, high-resolution visible, near and far infrared) and sounding (e.g., optical and microwave) technology to observations from geostationary and geosynchronous platforms. In addition, there was discussion on strategies for geostationary high-temporal resolution observations (e.g., GOES "rapid-scan" utilizing a new 1min/observation mode). There was also discussion of how to implement better high-latitude observational strategies (e.g., at latitudes greater than ±55º).

This Virtual Polar Geostationary Satellite (VPGS) trade study is a direct outgrowth of discussions held at the AGeoS Workshop, as well as previous deliberations of the (now adjourned) NASA Geostationary Earth Observatory (GEO) Science Working Group. Under this task, we have conducted a trade-study of a new overall strategy for a constellation of satellites that would constitute a kind of "virtual" geostationary presence over the Earth's North Pole. As envisioned here, such a constellation would be capable of acquiring very frequent geostationary-like data over the entire Northern Hemisphere, thus extending the very substantial and amply demonstrated benefits and synergisms of essentially continuous multispectral imaging to latitudes that are necessarily inaccessible to current equatorial geostationary observational instruments.

2. Objectives--

2.1 "Why are continuous high latitude observations needed?"

Geostationary satellites, by definition, reside in equatorial orbits. By virtue of the observing geometry from (equatorial) geostationary orbit, equatorial and mid-latitude observations are optimized. Upper-mid to high latitude observation opportunities, (except for low-resolution limb sounding) are more problematic. Nadir polar observations are thus essentially impossible from traditional geostationary orbits.

To mitigate an exactly analogous communications satellite difficulty for high northern latitudes, Soviet specialists pioneered the use of Molniya orbits to provide communications and surveillance capabilities at high latitudes across Russia and Siberia. For Northern Hemisphere observations, Molniya orbits are highly elliptical, have fast perigees over the Antarctic, but provide slow "looping" apogees over arctic regions. For typical 12hr Molniya orbits, orbital velocities drop below 2km/sec at perigee+2hrs, and essentially go to near zero at perigee. A 12hr period Molniya orbit provides quasi-geostationary "staring" coverage for 8hrs on every orbit. Because of the mass distribution of the earth, Molniya orbits at 66.3º inclination are stable (i.e., will not "progress" as in the 90º inclination case).

In this study, we looked at two types of Molniya constellations: (a) three satellites spaced equidistantly apart along one orbit in one orbit plane, and (b) three satellites in three separate orbital planes each separated by 120º of geocentric longitude. The latter proved to be a far better match to science objectives than the former. With three satellites in three phased orbits, essentially continuous (i.e., "virtual or quasi-geostationary") observational coverage of most of the Northern Hemisphere is possible (Figures 1, 2, and 3).

As most of the earth's inhabitants live in the Northern Hemisphere, weather there deeply impacts commerce, quality of life, health, and safety of much of the world's population. Equatorial geostationary satellites now add crucial short-timescale information on the physical state of the atmosphere, cloud dynamics, and wind fields. Myriads of other applications from land cover to ocean dynamics to stratospheric and tropospheric processes to natural hazards (e.g., volcanic eruptions) are covered in the AGeoS report. All of these applications provide would equally benefit from a new "polar-geostationary" perspective. Of particular interest with respect to the "polar geostationary" perspective would be:

(a) unprecedented high-time-frequency monitoring of the dynamics of polar tropospheric cloud systems, (e.g., continuous determination of wind fields),
(b) corroborative monitoring of stratospheric ozone at high (1-10km/pixel) spatial resolution),
(c) unprecedented temporal monitoring of the evolution of transient polar stratospheric clouds,
(d) prompt detection of high-latitude explosive volcanic eruptions and tracking of eruption products (e.g., ash and SO_2 plumes), with particular attention to airline safety issues related to busy sub- and trans-polar routes, and
(e) observations of other trace gas constituents in the Northern Hemisphere.

Thus, our main objectives were to:

(1) Evaluate the need for high latitude observations in the context of both science and operational needs, including a variety of hazards-related science applications;
(2) Evaluate the utility of Molniya orbits to achieve these science and operational objectives;
(3) Investigate a candidate mission structure in the context of meeting these science goals. We feel we achieved all of these objectives.

2.2 "Why these are these observations and capabilities important for future Code Y science?"

It is clear that the often-neglected Polar Regions of the earth play an integral role in shaping the weather and climate of the planet. Thus, in the context of providing a complete library of observations of the earth's surface and atmosphere, observations at polar and sub-polar latitudes are crucial. For instance, particularly during the northern winter months when the North Polar Vortex (NPV) is strong, the interaction of the NPV with the temperate latitude circulation strongly modulates the weather that affects most of the world's population (with annual, interannual, and even decadal periodicities). The zone of interaction (typically 50-65degN latitude) between the NPV and meridional circulation is formally chaotic, and thus small perturbations in weather source regions (e.g., Siberia and the Russian Far East) at these latitudes can produce widely diverging end states over the continental US and Canada. Thus, very frequent virtual geostationary imaging at high latitudes can provide insight into very dynamic, rapidly changing high latitude frontal systems—comparable to that provided by equatorial geostationaries at lower latitudes—that is not now available. In addition basic scientific investigations of the onset and dissipation of polar stratospheric clouds, important as heterogeneous chemistry nucleation sites for ozone destruction at certain times of the year, will be materially aided by systematic short timescale images. In the area of volcanological science, the detection of an eruption, and subsequent very rapid imaging at its onset and early stages, would provide important and otherwise unavailable information on time-variable physical properties (e.g., temperature, extent, injection altitude, eruption energy) of volcanic eruption columns. Such observations are crucial to a basic understanding of this very potent natural phenomenon.

Beyond the investigation of basic science issues, there is a variety of compelling operational issues that can be confronted with quasi-geostationary polar data. Perhaps the most important is the ability to provide markedly improved short-term weather forecasting capability, comparable to that available at lower latitudes using equatorial GEO platforms (Hufford, NWS Alaska, 1998—personal communication). This capability has direct benefit to the many international airlines operating on northern polar tracks, in particular for aircraft safety issues (e.g., routing to alternate airfields in an emergency over remote polar and sub-polar areas) and for fuel economy. In addition, the prompt (<5 minutes after onset—Capt. P. Foreman, Canadian Airlines, ICAO, 1996—personal communication) detection of explosive eruptions, and the tracking of resulting stratospheric and tropospheric volcanic ash plumes can provide substantial mitigation of airborne ash hazards to domestic and international commercial aviation (Hufford, *et al.*, 1999). Many high latitude volcanoes are quite remote (e.g., Aleutian Islands, Kamchatka Peninsula, Kurile Islands) and often eruption detection occurs only through remote sensing. Current GEO satellites have difficulty in detecting the onset of eruptions at high latitudes because of infrequent systematic imaging (typically 30min/observation) and because current ash-plume detection algorithms depend on observations in the 10-12micron bandpass (the so-called "split-window" technique). This technique is demonstrably unreliable for young opaque eruption plumes with high water vapor content (Simpson *et al*., 1999). LEO instrumentation suffers from the same bandpass difficulties, and additionally often suffers from 1-3 hour gaps in temporal coverage. Thus, to effectively mitigate pressing airborne volcanic ash hazards, any new system must not only provide more comprehensive temporal coverage, but must add additional bands for better ash plume detection. Finally, ash plumes erupted into moist and cloudy marine atmospheres are generally opaque to upwelling TIR radiation during their early stages (e.g., 1-3 hours at least), and are thus undetectable at thermal wavelengths (e.g., the "split window" approach). To provide for prompt detection, a continuously scanning radiometer in the 3-5_m bandpass, that will detect the initial "thermal spike" associated with an eruption, is also necessary (Pieri, 1999).

3. Work performed

Mission Science-Driven Requirements—The VPGS Team formulated science and operational requirements for a potential VPGS mission. These requirements were:

(a) Provide continuous opportunity to acquire imaging of the Earth's Northern Hemisphere above latitude 45ºN.
(b) Spatial resolution of approximately 2km/pixel at apogee.
(c) Multispectral capability (Table 2)
(d) Report full disc images every 15 minutes.
(e) "Event detection" observation every 20 seconds (separate 3-5_m band scanner).
(f) Automatic "event monitoring" mode when a thermal event is detected (200x200km subscene).

In addition, the VPGS Team conducted volcanic ash-plume detection sensitivity studies to help understand bandpass requirements for ash plume discrimination in the presence of water vapor clouds in both wet and dry atmospheres.

The VPGS Team concluded that a three-satellite constellation in three (phased) Molniya-type orbits with a GOES-type multispectral imager, combined with a small scanning 3-5_m event detector (imager) could meet essentially all science and operational requirements. Jim Anderson of the VPGS Team generated a preliminary design of the main imaging instrument.

Given these mission and instrument specifications, the Virtual Polar Geostationary Satellite mission was reviewed by JPL's Team X, in concert with the VPGS Science Team, during three design sessions on 1, 3, and 4 September 1998. The purpose of the study was to review the mission development plans and to provide suggestions for improvements. A report, which constitutes the results of the Team X—VPGS Science Team study, was generated, and parts of its executive summary are included in the next section. It is only a representative solution, intended to demonstrate feasibility and to estimate the equipment, mass, and cost required to implement a potential VPGS mission, but nevertheless we feel it provides a reasonable framework for the study. The areas covered were: mission analyses (e.g., orbit analyses, instrumentation analyses, spacecraft design, launch system, ground data system), analyses of the spacecraft environment (e.g., radiation, thermal loading), discussions of autonomous data acquisition strategies, and total mission cost.

While this work provides a reasonable framework, clearly, further definitive studies would have to be carried out before such a mission could be implemented. In that context, the logical next step would be to conduct a study to optimize instrument design, focusing on optimized electronics and sensor design, optics design, and bandpass optimization. In addition, ground data system optimization was not considered here, beyond deciding on receiving station potential locations and requirements for antenna size.

4. Mission Results, Recommendations, and Trades

4.1 Mission Measurement Objectives

The primary mission objectives, include:

(1) providing continual real-time images (visible light and TIR) of the northern latitude regions to complement the GOES data for weather forecasting, and

(2) detecting and imaging the development of volcanic eruptions in northern latitudes to provide rapid prediction of volcanic ash plume locations for aircraft warning and for scientific purposes.

4.2 Mission Design

In order to provide continuous coverage of the northern polar and mid-latitude regions, a constellation of three spacecraft in *Molniya* orbits was designed. Each Molniya orbit is highly elliptical and inclined and has an apogee near 40,000-km altitude at maximum latitude of 63.3° north. These spacecraft are in different orbit planes and are phased so that they all have the same ground track, which optimizes coverage of the northern part of the "Ring of Fire" around the Pacific and of Iceland in the Atlantic. At any time one of the three spacecraft will be above 47°-north latitude over the Pacific and another will be above 47°-north latitude over the Atlantic; one of those two "on-station" spacecraft will be above 60°-north latitude. Three options were considered in this study. In the Option 1 all three spacecraft would be launched together into low Earth orbit with each spacecraft separately inserting itself into the Molniya orbit. In Options 2 and 3, each spacecraft would be launched individually directly into the Molniya orbit.

4.3 Flight System

There were three options examined to achieve this mission (Table 1). The first option was for a single launch vehicle with three spacecraft (Option 1). The profile for this mission included the injection of all three spacecraft to LEO and allowing them to precess to achieve the desired inclination before injection into the Molniya orbit. Option 2 was for three individual launch vehicles with direct injection but using the same flight components as Option 1 with the exception of a smaller propulsion system. Option 3 was to take Option 2 and use X-2000 advanced, lightweighted, and radiation-hardened electronic avionics components to reduce the mass and power constraints. X-2000 components are not currently flight qualified. Command and control components proposed for Options 1 and 2 (VME) are flight qualified.

Overall the flight system for all three options can be described as a $1 m^3$ instrument with a communications antenna sitting on an avionics bus with two identical solar panels on each side. In Option 1, this configuration is mounted on a large propulsion system. In Options 2 and 3, a much smaller propulsion system is incorporated into the avionics bus.

The instrument was identical for all three options. Only the shielding varied for Option 3. The three-axis attitude control subsystem was designed to a pointing requirement of 1440 arcsec with a required pointing knowledge of 720 arcsec. Stability as determined by the payload was 20,000 arcsec/s. The C&DH system was designed to a storage requirement of 1.8 Gb with an instrument data rate of 115 Mb/s. The power system was sized to accommodate data taking while communicating 8 hr per day. The solar arrays are articulated. For Option 1, The propulsion system is a bi-mode system with an I_{sp} of 325 s to achieve a ΔV of 2800 m/s. This results in a propulsion mass that constitutes 60% of the vehicle. Options 2 and 3 reduce this to about 15% with a monoprop system with a ΔV of 250 m/s. Structure for the spacecraft was assumed to be conventional and was largely driven by the propulsion system. For configuration purposes, the instrument was mounted at one end of the spacecraft, with the avionics and the propulsion system in the structure below. Data return is 10 Mb/s using an X-band link with a single antenna and a 5-W RF power amplifier. An emergency link uses two omni antennas. The active instrument cooler drove thermal design for the spacecraft.

Virtual polar geosynchronous satellites are technically feasible with fairly simple Earth sensor/inertial sensor (gyro)–based *bus attitude determination and control system* (ADCS) design. The simplicity of the bus ADCS design is enabled by the articulating, two-axis fast-steering mirror in the high-resolution imager instrument. Unique software to command the imager's fast steering mirror is provided by ADCS and integrated with the autonomous volcano-plume feature recognition and commanding science software onboard the spacecraft.

The large propulsive requirements for Option 1 accounted for over 60% of the total loaded spacecraft mass. Options 2 and 3, where the launch vehicle placed each spacecraft into its final orbit, only required a very simple blowdown hydrazine system.

The Power subsystem for the VPGS uses state-of-the-art components with an X-2000 technology cutoff. For Options 1 and 2 the power subsystem components are flight qualified and will have flown in several missions before the mission is launched. The Option 3 X-2000 avionics reduce the mass of the power subsystem due to the lighter weight of the components and the lower power requirements of the other spacecraft systems. If X-2000 delivers the promised subsystem mass and power numbers during the specified timeframe, Option 3 becomes exceptionally attractive and may qualify for a smaller launch vehicle.

The thermal control system for the spacecraft will consist of passive with electric heaters for propulsion elements and the battery of the EPS. For instrumentation, because of the Molniya orbit, which brings the flight elements within 500 km of the Earth, and the associated pointing requirements, it is recommended that an active cooler be used. A Stirling cooler with a 1-W capacity would have a mass of 20 kg and require 70 W of electrical power.

Telecommunications will use an X-band frequency (8300 to 8500 MHz) for uplink and downlink. Downlink will occur with a data rate of about 10 Mbps using a 0.3-m-diameter parabolic reflector antenna and a 5-W RF power amplifier. Antenna pointing will be done with a two-axis gimbal to prevent interference with the science instrument. The spacecraft will also carry two omni antennas that to be used for launch and emergency operations. The receiving station will be the LEO-T style 5-m ground station. The telecom system will use the Space Transponding Modem (STM) and will be shielded to accept a 200-rad TID.

Table 1: Relevant Mission Parameters

	Options 1	Options 2	Option 3
Launch	2003	2003	2003
Launch Configuration	Delta III	Taurus XLS + AUS-51	Taurus XLS + AUS-51
Number of Launches	1 piggyback	3 separate	3 separate
Primary Mission Duration	5 yr	5 yr	5 yr
Additional Extended Mission	TBD	TBD	TBD
Redundancy Required	Block Redundant	Block Redundant	Block Redundant
Technology Cut-off Date	1998	1998	2001
Phase C/D Duration	24 months	24 months	24 months
Telecom Uplink Rate	2 kbps	2 kbps	2 kbps
Telecom Downlink Rate	Up to 10 Mbps	Up to 10 Mbps	Up to 10 Mbps
Number of Instruments	2	2	2
Science Data Input Rate	115 Mbps	115 Mbps	115 Mbps
Science Data Processing Requirements—Compression required	2:1	2:1	2:1
Science Data Volume (Memory)	1.8 Gb	1.8 Gb	1.8 Gb
Mass Limitations	TBD	TBD	TBD
Power Limitations	TBD	TBD	TBD
Radiation (Total Ionizing Dose)	193.5 krad	193.5 krad	193.5 krad
Power Source	Batteries & Solar Panels	Batteries & Solar Panels	Batteries & Solar Panels

Mission Class	B/C	B/C	B/C
Avionics (CDS)	VME (Flight qualified)	VME (Flight qualified)	X-2000 (unqualified)
Bus CDS Shielding	21.4kg (VME)	21.4kg (VME)	0.53kg (X-2000)
Parts Class	Commercial and Mil-Std-883B screened	Commercial and Mil-Std-883B screened	Commercial screened

Each of the three spacecraft is required to provide frequent (15-minute repeat cycle), coverage of the Earth's disk in nine visible and IR bands. These bands are shown in Table 2.

Table 2: Imaging bands

Band	Wavelength, in _m
1	0.65
2	1.36-1.39
3	1.55-1.65
4,5	3.0-5.0
6	8.5
7	9.59-9.88
8	10.2-11.2
9	11.5-12.5

Simultaneously (using a separate 3-5 _m continuous scanner), the s/c is required to search for thermal spikes indicative of eruptive volcanic activity capable of generating ash plumes dangerous to aircraft ($10^3 m^3$/sec volumetric eruption rate, penetration to at least 10km ASL). Detection of an event (thermal spike at 3-5 _m) potentially indicative of such activity will divert the operation of the global coverage to focus on the event area to allow greatly increased frequency of coverage for a minimum of five minutes. After this brief period of intensive data taking, observations would revert to the nominal full disk coverage.

4.4 Mission Operations

Either NASA or NOAA could operate this mission. One option is based on using NASA GSFC–provided tracking and operations facilities. The other is based on NOAA–provided tracking and operations facilities. Costs associated with the NASA–based option are provided in the Cost and Programmatics section. Total costs associated with the NOAA–based option are unknown. The NOAA–based option is likely to be the cheaper, but more programmatically complex of the two options.

4.5 Programmatics

The schedule is controlled by the development of the instrument focal plane assembly and any pre-project work in that area that could reduce risk should be supported. Getting the spacecraft contractor on board early may require some careful pre-project procurement activity. X-2000 technology would not be available for a 2002 launch but could be used for a launch 1 year later. The STARDUST Project has evolved an effective means to facilitate communication between geographically separate project elements, and such an approach could be considered here, as well.

4.6 Costs:

Table 3:

Total Mission Cost by Phase, in FY'98 $M.

	Delta III (Opt. 1)	Taurus (3) (Opt. 2)	Taurus (3) with X-2000 Technology (Opt. 3)
Phase A Total	4	3	3
Phase B Total	16	14	14

Phase C/D Total	431	387	391
Phase E Total	31	31	31
Launch Vehicle	86	90	90
Project Total	568	525	530

Table 4:

First-Unit Spacecraft Costs, Phases C/D

(implementation through on-orbit checkout) in FY'98 $M.

	Delta III (Opt. 1)	Taurus (3) (Opt. 2)	Taurus(3) with X-2000 Technology (Opt. 3)
4.0 Spacecraft (1)	149	134	134
4.1 Spacecraft Bus	68	56	56
4.2 Instrument	52	52	52
4.3 Integration and ATLO	8.5	8	8
4.4 Government Burden and Contractor Fee	20	18	18

5. Programmatic Aspects: Results, Issues, and Recommendations.

5.1 Basic results

The preliminary trade study carried out here indicates that Virtual Polar Geostationary constellation of three satellites (VPGS) in phased 12-hr period Molniya orbits could fill the classic gap in the POES and GOES spatial and temporal coverage of the northern hemisphere. The VPGS constellation would provide otherwise unobtainable time-series data, and would fulfill a number of important operational and scientific objectives. These include improved weather forecasts, strengthened environmental monitoring (e.g., ozone), and would make an important contribution to aircraft safety (e.g., volcanic ash plume tracking and prompt eruption reporting) and airline operating efficiencies (e.g., better wind field modeling and validation on high latitude routes).

The VPGS mission is "do-able" from the standpoint of current and projected technology readiness levels required. This study suggests that a 5 year life-time mission is feasible with hardware that is essentially off-the-shelf hardware, and can be improved with the modest addition of hardware projected to be available near-term (e.g., X-2000 electronics).

5.2 Outstanding Issues

Cost emerges as an overriding issue. Esoteric scientific and practical operational benefits from such a system are manifest. The system studied here encompassed instrumental and operational strategies that met the complete range of scientific objectives. Any mission that meets these objectives will be expensive from the standpoint of research satellite programs (~$500M for a 5 year mission), although perhaps less so from the perspective of what it costs to build and maintain a GOES-like system. Essentially, that is what is being proposed here: another GOES-like system that will fill an important gap in coverage. Current budgets appear not to be able to accommodate such a new start. Perhaps such a system could be built incrementally, starting with small research satellites that would demonstrate components of the technology (e.g., event detection) and data utilization (e.g., integrating VPGS data in airline routing). The key advantage of the VPGS system, namely the time-continuous coverage, would be lost under those circumstances.

Autonomous data acquisition strategies for implementing "event detection" remain a challenge. The volcanic eruption quick response requirement is a demanding one, and requires essentially continuous surveillance capability in the 3-5um range. The selection and tuning of such a data stream will require judicious phenomenological insight and on-station experience in order to minimize false alarms and yet not miss eruptions at the minimum 10m3/sec (ash cloud reaching 10000m) threshold.

Ground data system strategies are another challenge. From this study, it appears that a two or three station downlink network would be optimal. From a cost standpoint, it would be useful to understand the limitations on the system if only one downlink station was available. It also may be useful to consider direct broadcast modes for on-board processed (i.e., derived) weather products for direct use in the airline cockpit, and for the use of airline dispatchers. Clearly, high data-rate streams would be made available to regional weather centers but it may also be useful to consider a more distributed direct-broadcast of data subsets to other more specialized users such as universities and/or value-added commercial providers. Finally, as with other timely weather data, the provision of extracted products that could be distributed on the Internet would undoubtedly be of interest to a variety of non-science/ops users (e.g., school kids).

The identification of the entire potential user community, domestic and international, is another important task related to the issue of funding and mission justification. Clearly, there would be domestic consumption of VPGS data by operational and research weather workers, and their scientific colleagues in related fields. Undoubtedly, once such data were made available, it would appear on TV channels across the country, and web-based access could make VPGS and other types of satellite data useful in the domestic classroom. Non-US use of such data is harder to predict. Given the extreme utility and need for good GEO-type weather data at high latitudes, however, it is certain that a variety of non-US interests in northern Europe and the former Soviet Union will be interested in accessing data from the VPGS platforms, as would Japanese colleagues. Again, web-based access to VPGS data would facilitate that process and would cultivate a larger national and international user base.

5.3 Recommendations

Clearly, with respect to designing and implementing a VPGS-like system, this trade study is a start, by only a start. To move forward with this concept, follow-on studies that address the issues laid out in this initial trade survey will need to be carried out in at least the following areas:

A. *Instrumentation.*
Clearly further trade studies of size of focal plane and scanning strategies will need to be carried out to help constrain instrument design. The mode of focal plane cooling (e.g., passive vs. active) will need to be traded off against instrument reliability and complexity. Pointing requirements will have to be traded off against instrument complexity, operational/scientific need, and cooling requirements (e.g., the need to see space, rather than the earth).

B. *Data acquisition strategies*
Another key area will be further exploration of data acquisition strategies to detect and capture transient events. Prompt detection and reporting will be key benefits for aircraft volcanic ash detection and avoidance. High data throughputs may have to be managed autonomously, and data nuggets extracted from non-essential data.

C. *Development of the "event-detector" instrument* to respond to transient events like volcanic eruptions. Indeed, the strategies for building and implementing an "event-detector" instrument will need to be fully explored and integrated with autonomy approaches. Approaches that slave the master instrument to a secondary event-detector with a more limited spectral range (e.g., 3-5um for eruptions and fires), should be rigorously evaluated.

D. *Economics trade studies*
Perhaps the most central issue for VPGS is cost. Thus, it is imperative that further studies be carried out that address the trade off between science and operational objectives and cost. A variety of alternative cost-cutting strategies should be developed and evaluated in any future studies. This should include not only science vs. hardware tradeoffs, but also a look at alternative funding strategies, including strategies for commercialization of various mission components. The full range of domestic

and international user communities should be identified, including operational, scientific, commercial, and academic users, and their likely needs assessed.

6.0 Conclusion

VPGS uniquely fills a compelling and long-standing need for GEO-like data at high latitudes, however, it could be expensive. Because of its high scientific and operational value, however, continued exploration of the key areas and approaches identified in this study is clearly merited, with particular emphasis on how to bring down its projected costs without compromising unique VPGS capabilities.

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8.0 Study Participants

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9.0 Acknowledgements

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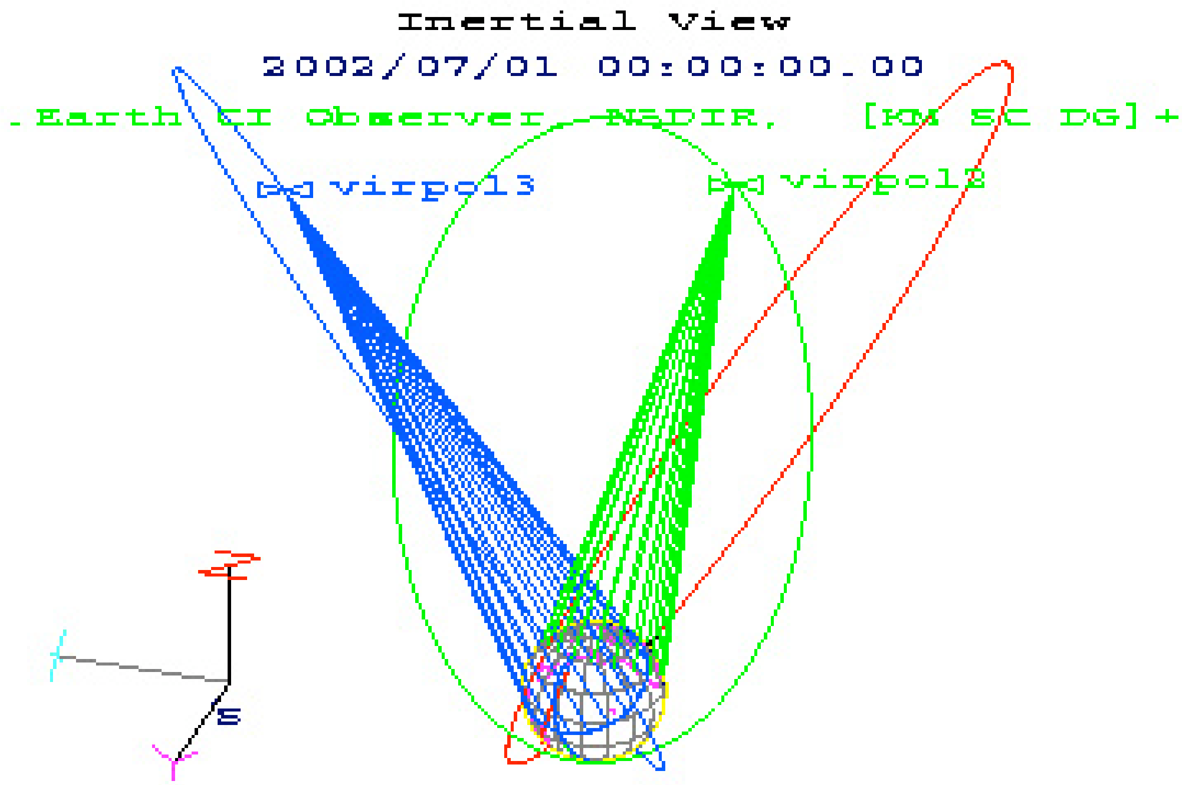

Figure 1: PVGS Orbital Tracks. Blue (Virpol 3) and Green (Virpol 2) are simultaneously covering the Earth's northern hemisphere, while Red (Virpol 1) is near perigee over the Antarctic. Apogee is at approximately 40,000km. The orbital period is 12hrs. (courtesy Dr. Ted Sweetser, JPL).

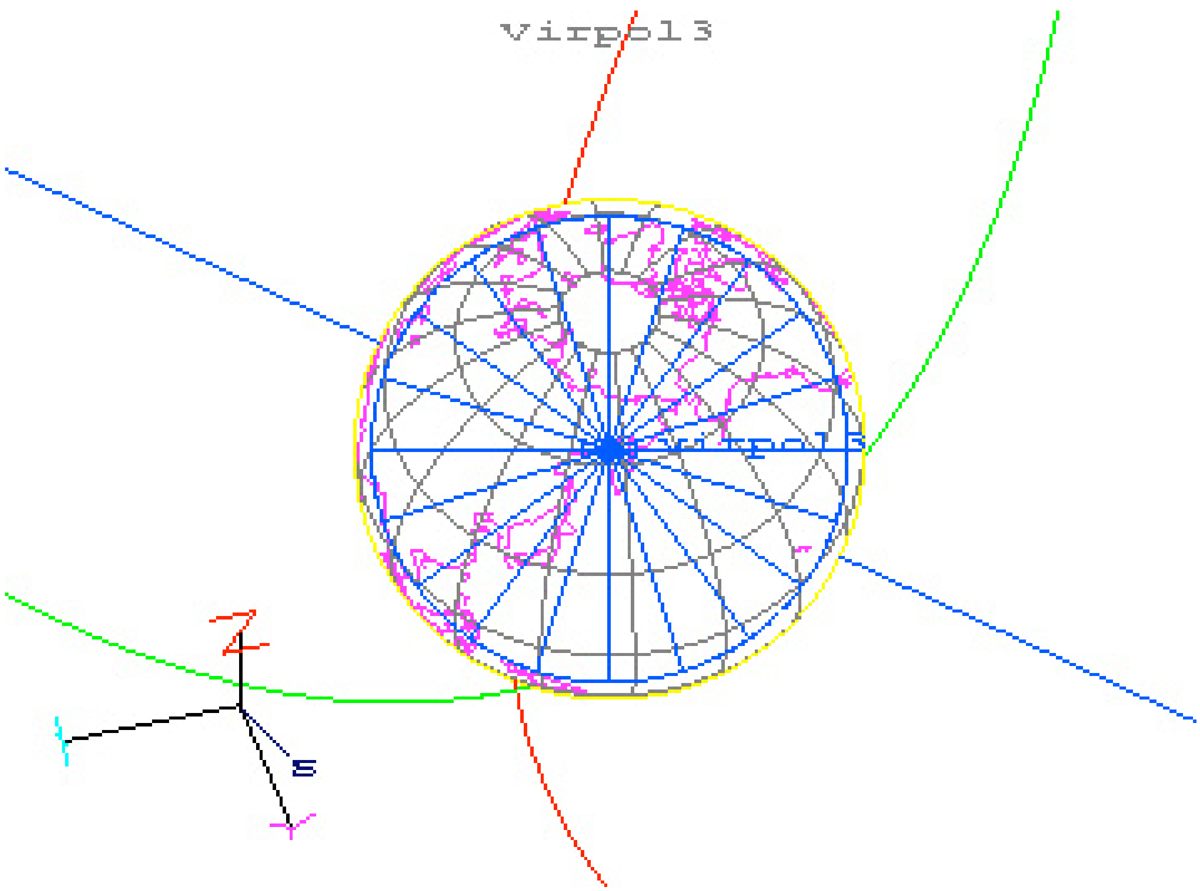

Figure 2. Down looking view from Virpol 3 (Blue—refer to Figure 1) with a FOV footprint directly over the Kamchatka Peninsula of the Russian Far East. The VPGS view from Molniya orbit is superior to that from the equatorial geostationary perspective (e.g., GOES, GMS, METEOSAT).

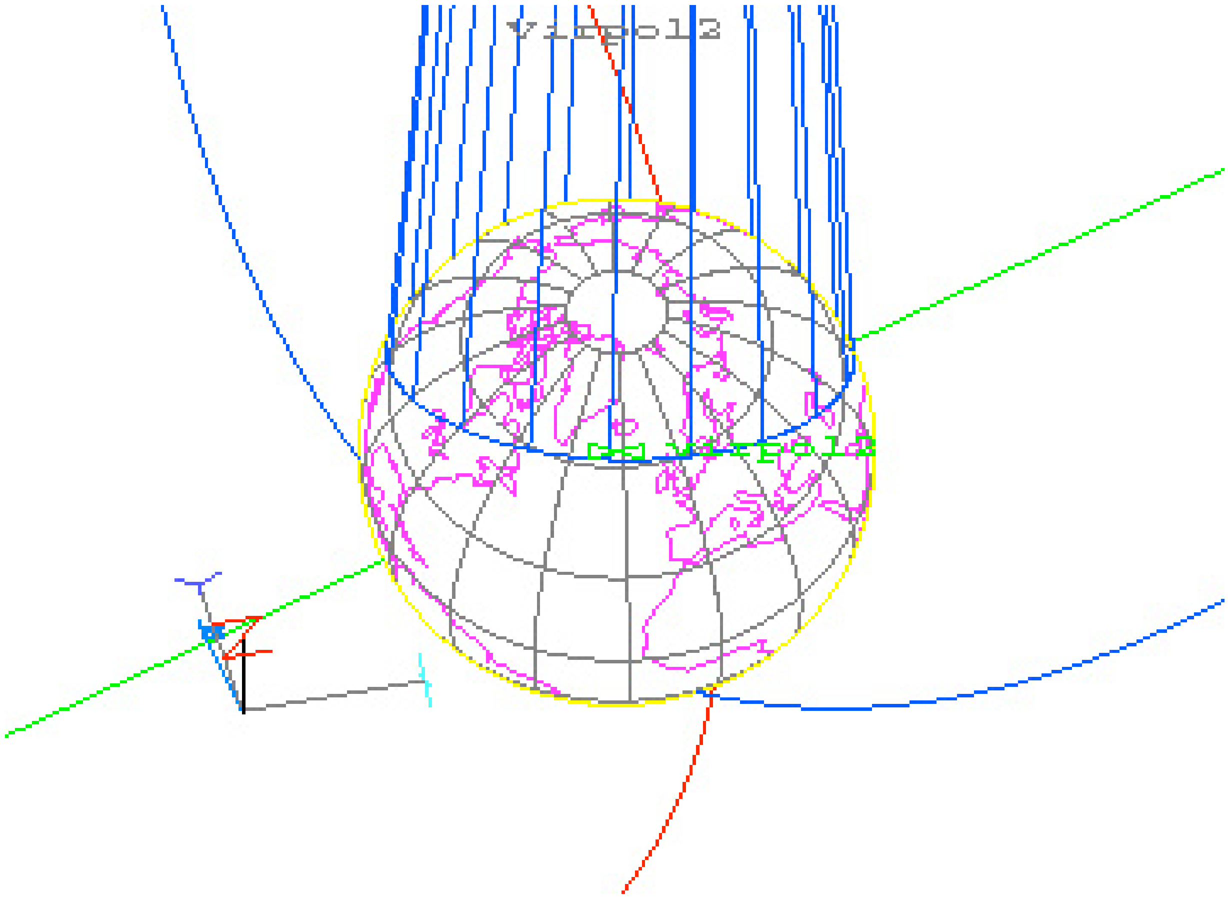

Figure 3. Down looking view from Virpol 2 (Green) of the North Atlantic with the center of the spacecraft FOV over Iceland. Notice the simultaneous coverage from Virpol 3 (Blue—refer to Figure 2).