Ocean Altimetry and Wind Applications of a GNSS Nanosatellite Constellation

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ABSTRACT

Recent developments in electronics and nanosatellite technologies combined with modeling techniques developed over the past 20 years have enabled a new class of altimetry and wind remote sensing capabilities that offer markedly improved performance over existing observatories while opening avenues to new applications. Most existing spaceborne ocean altimetry and wind observatories are in polar low Earth orbits that maximize global coverage but result in either large gaps at the tropics or long time intervals between geolocation measurement revisits. This, combined with their use of radar systems operating in the C and Ku-bands, obscures key information about the ocean and the global climate. Using GNSS-based bi-static scatterometry performed by a constellation of nanosatellites in a non-polar low Earth orbit could provide ocean altimetry and wind data with unprecedented temporal resolution and spatial coverage across the full dynamic range of ocean wind speeds in all precipitating conditions – all with a system cost substantially less than existing and planned systems.

This paper contrasts the performance of a GNSS nanosatellite constellation with the existing monolithic remote sensing observatories while identifying synergies of the systems that can be exploited to achieve a more complete understanding of both ocean current and wind phenomena. Two specific applications are reviewed; ocean winds and ocean wave altimetry. The recently awarded Cyclone Global Navigation Satellite System (CYGNSS) mission will be used for the ocean wind comparison while a notional GNSS constellation will be used for comparison of the ocean wave altimetry application. Design requirements, applications, and system implementation are presented for the GNSS nanosatellite constellation.

Keywords: GNSS, Scatterometry, Ocean, Wind, Wave, Nanosatellite, Constellation

1. INTRODUCTION

Space borne ocean altimetry and wind observatories have enabled significant climate modeling improvement over the past 20 years but there exist critical gaps in ocean current and wind measurements. While present altimetry observatories provide superb data for large scale topographic studies, their spatial and temporal scales are not sufficient to resolve mesoscale ocean eddies which represent one of the largest sources of error for today’s global climate models. Meanwhile, tropical storm track forecast accuracy has improved by ~50% since 1990, largely as a result of improved synoptic modeling and assimilation of space-based observations. In that same period, inadequate observations of the inner core have resulted in essentially no improvement of intensity forecast accuracy due primarily to measurement obscuration by intense precipitation and the poor sampling available with conventional wind observatories during the rapidly evolving stages of the tropical cyclone life cycle.

Mission design for spaceborne ocean altimetry and wind observatories has historically used large monolithic spacecraft platforms operating in low polar Earth orbits. These orbits provide global coverage, but result in either large gaps at the tropics or long time intervals between geolocation measurement revisits. This, combined with their use of large radar payload operating in the C and Ku-bands, obscures key information about the ocean and the global climate. Leveraging
modern technology, GNSS-based bi-static scatterometry performed by a constellation of nanosatellites in a non-polar low Earth orbit could provide ocean altimetry and wind data with unprecedented temporal resolution and spatial coverage across the full dynamic range of ocean wind speeds in all precipitating conditions – with a system cost substantially less than existing monolithic systems. The GNSS Ocean Wind and Altimetry (GOWA) mission concept has been developed to provide this capability.

GOWA provides performance markedly improved over conventional wide swath imagers for key system parameters by combining the temporal sampling properties of a nanosatellite constellation with the spatial and all-weather performance of GNSS-based bi-static scatterometry. Global coverage is provided by 12 observatories in a highly inclined low Earth orbit. The observatories consist of a simple nadir pointed nanosat hosting a GNSS receiver/processor instrument based on a proven technical approach demonstrated on orbit. An autonomous implementation of nominal spacecraft operations and science data collection without the need for on-board command sequences, provides a straightforward constellation operations approach for the Mission operations team.

2. MISSION OVERVIEW

The GOWA mission concept provides datasets to fill critical gaps in present ocean current and wind measurements by combining the spatial performance of an all-weather GNSS-based bi-static scatterometer equipped nanosatellite observatory with synchronized data assimilation of the constellation.

2.1. Sea Surface Height and Ocean Currents

Recent altimetry observatories such as Jason and GFO provide spatial resolution of topographic features with temporal resolution measured in days (Table 1). While this performance addresses key data needs for basic scale features (100’s of km) supporting analysis of global sea level science issues, it is not sufficient to study mesoscale issues such as ocean eddies and currents. Mesoscale eddies represent one of the largest global climate modeling errors and play an important role in the transport of momentum, heat, salt, nutrients, and other chemical properties of the ocean [1]. Global measurements of mesoscale eddies have not been possible by orbiting radar altimeters such as Topex/Poseidon, Jason, GEOSAT, or GFO due to their measurement spatial and temporal scale thus representing one of the most prominent limitations of these observatories [2].

Temporal limitations of the existing mission could be mitigated by developing and launch additional observatories but budget constraints will prevent this option given current estimates of ~US$500M [3] per observatory. GOWA addresses data needs for both the climate science (addressing many global sea level issues) and operational communities (supporting surface currents computations of the surface height distribution gradient) with significantly improved temporal characteristics and comparable measurement accuracies using GNSS scatterometry with mission costs less than half that of a single monolithic observatory.

Table 1- GOWA performance resolves small scale ocean topography and eddy currents with significantly improved temporal performance

<table>
<thead>
<tr>
<th></th>
<th>JASON</th>
<th>GFO</th>
<th>GOWA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>~3cm</td>
<td>~5cm</td>
<td>~7-20cm</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>300km</td>
<td>100km</td>
<td>25km</td>
</tr>
<tr>
<td>Revisit time</td>
<td>10 days</td>
<td>17 days</td>
<td>0.25-2 days**</td>
</tr>
</tbody>
</table>

**Function of constellation orbit inclination and density
2.2. Winds

Measurement of surface roughness characteristics from which the rms of wave slopes are attained can be used to obtain an indirect measurement of wind speed and direction. The recently awarded NASA Earth Venture (EV-2) Cyclone GNSS Satellite System (CYGNSS) mission, presently being developed by the Southwest Research Institute® of San Antonio Texas, will be a direct demonstration of this capability.

U.S. tropical storm track forecasts have improved in accuracy by ~50% since 1990, largely as a result of improved mesoscale and synoptic modeling and data assimilation. In that same period, there has been essentially no improvement in the accuracy of intensity forecasts [4]. CYGNSS is a spaceborne mission focused on tropical cyclone (TC) inner core process studies. CYGNSS will resolve the principle deficiencies with current TC intensity forecasts, which lies in inadequate observations and modeling of the inner core. The inadequacy in observations results from two causes: 1) much of the inner core ocean surface is obscured from conventional remote sensing instruments by intense precipitation in the eye wall and inner rain bands while 2) the rapidly evolving (genesis and intensification) stages of the TC life cycle are poorly sampled in time by conventional polar-orbiting, wide-swath surface wind imagers. The CYGNSS mission is comprised of 8 observatories in 500 km circular orbits at an inclination of ~35°. Each one is capable of measuring 4 simultaneous reflections, resulting in 32 wind measurements per second across the globe. CYGNSS has a spatial resolution of 25km and temporal resolution of 4hrs (mean revisit time) and full ground coverage <15hrs. Figure 1 provides an illustration of the CYGNSS ground coverage. Each CYGNSS Observatory includes a Delay Doppler Mapping Instrument consisting of a multi-Aquisition of ocean wind data from a satellite constellation designed to provide global coverage could provide the synchronized acquisition of a global wind dataset. A GOWA constellation would enable such a dataset in a cost-effective manner. Its performance capabilities would also enable improvements in weather modeling and operational forecasting in critical areas such as tropical storms. GOWA’s unprecedented temporal resolution (Table 2) and spatial coverage, under all precipitating conditions and across the full dynamic range of wind speeds enables improvement in our predictive capability for extreme weather events by providing a dataset to investigate how dynamics within tropical cyclones determine intensity at landfall and how moist atmospheric thermodynamics, radiation and convection interact to control the development of tropical cyclones.

![Figure 1](image1.png)

**Table 2 - GOWA provides all-weather performance comparable to existing systems**

<table>
<thead>
<tr>
<th></th>
<th>QuikScat</th>
<th>ASCAT</th>
<th>GOWA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic range</td>
<td>≤ 25 m/s</td>
<td>&lt; 55 m/s</td>
<td>&gt; 70 m/s</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>25 km</td>
<td>25 km</td>
<td>25-35km</td>
</tr>
<tr>
<td>Revisit time</td>
<td>1 day</td>
<td>1 day</td>
<td>0.25-2 days**</td>
</tr>
</tbody>
</table>

**Function of constellation orbit inclination and density**
2.3. Other GNSS Bi-static Scatterometry Applications

The NASA EV-2 CYGNSS mission will validate the GNSS bi-static scatterometry approach. As part of the mission, CYGNSS will develop a high-fidelity, end-to-end simulation that will allow detailed analysis and prediction of GNSS bi-static scatterometry performance. Additional Earth-based remote sensing parameters that are measurable by GNSS bi-static scatterometry include tsunami detection/warning [5], ocean salinity [6], ice edge sensing [7], [8], [9], soil moisture [10], [11], and vegetation sensing [12]. The CYGNSS simulator will enable detailed studies of these applications.

3. TECHNOLOGY BASIS

When electromagnetic radiation reflects off the ocean surface, the scattering process changes the characteristics of the propagating signal in a way that is dependent on the characteristics of the reflecting surface. These changes contain information on the sea surface waves and indirectly on the near-surface meteorological conditions. While previous radar based ocean remote sensing missions for both altimetry and winds are founded on this general principle, they have all actively transmitted radar pulses and then detected the received power from the backscattered radiation. An alternative signal source using Earth reflected GNSS signals as a means of sensing the ocean surface was proposed in 1988 [13] (Reference Figure 2). Researchers developed this sensing technique during airborne experiments [14] and subsequently used data from the 2003 GNSS-R experiment on the UK-DMC satellite to demonstrate that signal retrievals of sufficient signal-to-noise ratio could be used to perform successful ocean wave and wind estimation from a spaceborne platform [15], [16], [17]. These results show that it is possible to detect reflected GNSS signals from space across the full range of ocean surface wind and wave conditions using a relatively modest instrument configuration thus enabling a cost-effective alternative to active sensing ocean remote sensing.

![Figure 2 - GNSS Scatterometry Geometry](image)

The fundamental measurement made during each quasi-specular reflection contact between a GNSS transmitter and a GOWA receiver is the broadening of the region of scattering due to ocean surface roughness. A perfectly smooth surface reflects at the specular point while a rough surface scatters across a distributed “glistening zone”. The Delay Doppler Map (DDM) created by the GOWA instrument is an image of that scattering cross-section across the glistening zone. The DDM is an information-rich measure of the ocean surface roughness statistics, providing a direct measurement of the wave height statistics and is intimately related to the surface wind vector.

Several methods to link reflected signals to the ocean conditions have been developed and demonstrated over the past 10-15 years using both aircraft and space-based GNSS scatterometry [1]. This work has developed ground-based data processes that accurately fit the DDM to a model waveform originally described by Zavrotny [18] providing wind and ocean wave measurement from the DDM dataset. The GOWA team includes key individuals that originally developed the technique of bistatic scatterometry and conducted the demonstrations of its effectiveness (Gleason, Katzburg,
Garrison, Zavrotny, etc). Appendix C provides a more detailed summary of the GNSS scatterometry basis and references for the associated data processing.

Key to GOWA’s innovative approach for providing global wave and wind data is its temporal and all-weather performance…

- **Temporal Sampling** – The GOWA constellation provides excellent temporal sampling of the global ocean surface. With a mean revisit time of 12 hr and 90% of the globe revisited in 24 hr or less, localized dynamics such as 10-100 km scale eddy currents and rapid storm intensification are observable with radically better fidelity than conventional monolithic scatterometers observatories.

- **Precipitation Attenuation** (Reference Figure 3) – The one-way slant path atmospheric attenuation experienced by a GNSS (green), ASCAT (yellow) and QuikScat (red) signal propagating through a typical tropical storm (5 km freezing level) as a function of surface rain rate. Rain has a negligibly small effect on the GNSS signal, even at the highest rain rates. ASCAT is attenuated enough at the highest rain rates to severely impact its ability to retrieve surface winds. QuikScat signals are effectively blocked by heavy rain and cannot sense the surface at all.

![Figure 3 - Precipitation Attenuation for GOWA vs ASCAT and QuikScat](image)

4. MISSION IMPLEMENTATION

GOWA combines the rain penetrating capabilities of GNSS-based bistatic ocean scatterometry with the high frequency sampling of a nanosat constellation to provide a cost effective alternative to standard single observatories. The number of observatories and orbit inclination are chosen to optimize the sampling properties providing a dense cross-hatch of sample points on the globe as a function of mission requirements. Each observatory consists of a nanosat platform hosting a GNSS receiver modified to measure surface reflected signals.

4.1. Performance requirements

A detailed software simulator of the GOWA mission that models all critical variables of the GNSS bi-static scatterometry process has been developed by the GOWA development team to identify the performance of the GOWA constellation. It heavily leverages the experience and expertise of those members of the GOWA team who pioneered the theoretical conception and experimental development of GNSS remote sensing of the ocean surface over the past 10+ years. A constellation of 12-observatories in a 1-orbit plane LEO case study was used in this white paper as an example to identify constellation performance such as global coverage and revisit statistics. The actual GOWA mission design will require specific mission objective analysis to determine the optimal constellation configuration. Performance requirements and characteristics have been developed based on the case study mission.
4.1.1. Instrument requirements

Instrument performance is driven by mission goals and the selected instrument technology. A summary of this flowdown relationship is provided in Table 3.

<table>
<thead>
<tr>
<th>Measurement Requirements</th>
<th>Observables</th>
<th>Physical parameters</th>
<th>Instrument Functional Requirements</th>
<th>Projected Performance</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observables</td>
<td>TC Cat 5 ≤ 100 mm/hr</td>
<td>Atmospheric path attenuation</td>
<td>&lt;10% (5 km freezing level, slab rain model)</td>
<td>3.8%</td>
<td>62%</td>
</tr>
<tr>
<td>Physical parameters</td>
<td>Greater of 2 m/s or 10% of wind speed</td>
<td>DMR receiver noise figure</td>
<td>&lt; 3 dB</td>
<td>2.5 dB</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Variable from 5x5 to 50x50 km^2</td>
<td>Nadir antenna gain</td>
<td>&gt;11.5 dBi</td>
<td>12.6 dBi</td>
<td>9%</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>Performance unaffected by full-range of precipitation</td>
<td>Precision of Doppler Shift increments in DDM</td>
<td>&lt;500 Hz</td>
<td>250 Hz</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Performance over full wind speed dynamic range</td>
<td>Precision of Time Delay increments in DDM</td>
<td>&lt;122 nsec</td>
<td>61 nsec</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Mean Revisit Time</td>
<td>DMR minimum detectable signal</td>
<td>&lt; -170 dBW</td>
<td>-174 dBw</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Earth coverage</td>
<td>Antenna FOV</td>
<td>&gt; 140° x 30° centered on nadir</td>
<td>140° x 30°</td>
<td>Complies</td>
</tr>
<tr>
<td></td>
<td>Earth coverage Refresh Rate</td>
<td>Track and compute DDM for simultaneous specular contacts</td>
<td>≥ 6</td>
<td>6</td>
<td>Complies</td>
</tr>
<tr>
<td></td>
<td>Geolocation Knowledge</td>
<td>Orbital Position</td>
<td>&lt; 12.5 km</td>
<td>&lt;20m (95%) (L1 Only)</td>
<td>62400%</td>
</tr>
</tbody>
</table>

4.1.2. Physical accommodation within a nanosat physical constraint

GNSS nadir antenna FOV and orientation (tilt and rotation) constraints define the overall observatory physical configuration. A wide range of antenna configurations were analyzed to meet the observatory performance requirements.

4.1.3. On-board data processing

The GOWA mission is enabled by the GNSS receiver’s capability to convert raw I/Q data to DDM. Without onboard data processing, nanosatellite downlink capabilities would limit instrument operations to only a 0.01% duty cycle. The back-end processing capability of the GNSS Receiver to generate the DDM data products enables a 1% instrument duty cycle. The fully resolved DDM contains many highly correlated image pixels, as well as many pixels that do not contain information about the local wave/wind field in the scattering region. Additional data processing provided by the nanosat flight software to further reduce the on-board data volume using a DDM sub-sampling algorithm that results in a 100% instrument duty cycle data downlink volume of 56.2 MB/1.5 days.
4.1.4. Pointing

Given the statistical global coverage nature of the GOWA data acquisition, point control is not critical to performance. Pointing knowledge uncertainty does though directly translate into an uncertainty in the antenna pattern gain in the direction of the specular reflection point producing an uncertainty in calibration of the scattering cross-section needed to estimate wind speed. Analysis using our GOWA performance model revealed that a ±2.7 deg (RMS-3σ) pointing knowledge requirement results in retrieval uncertainty of <1% maximum absolute error for wind speeds <20 m/s and <6.2% maximum relative error for wind speeds between 20 and 60 m/s.

4.2. Operational Concept

The GOWA observatory consists of a simple nadir pointed nanosat hosting a GNSS receiver/processor instrument based on a proven technical approach demonstrated on orbit. Global coverage is provided by 12 observatories in a highly inclined low Earth orbit. While the constellation is central to meeting data sampling requirements, the individual observatories act independent of one another, with no need to synchronize with the others. They are identical in design but provide their own individual contribution to the GOWA science data set. Additionally, there are no attitude maneuvers required, only simple nadir pointing. After activation and calibration operations are completed, the GNSS instrument and its host nanosat are placed into nominal Science mode, where the observatory operates continuously. No commanding of the instrument is required except for periodic engineering/calibration operations (bi-annual). The Observatory Mode Flow is illustrated in Figure 4.

![Figure 4 - Observatory Mode Flow](image)

A space-based constellation represents unique operational requirements related to operational tempo (for the 12 observatory case, 12 contacts within 1.5 days), configuration control, and reaction to potential systemic issues in both Flight and Ground Segments. Mission operations support for GOWA is based on a straightforward approach to manage the GOWA constellation. The simple observatories are designed to autonomously implement nominal operations and science data collection without on-board schedule command sequences. Science and engineering data files (L0 data products) are generated and stored on-board, then autonomously downlinked during one communication pass per 1.5 days using a CFDP file transfer engine located on a GOWA mission operations server (with hot backup) in the ground element’s network management center. The observatory and ground element design allow the ground station to automatically establish the communication link and then initiate the reliable downlink of the on-board data files (Reference Figure 5). Automated ground element data pipelines extract the nanosat information necessary for observatory health and status monitoring and flow the data to the mission operations center while payload data files are routed to the payload data processing center for L1, L2, and L3 data processing.

4.3. Flight Segment Description

The GOWA flight segment consists of 12 nanosatellite-class observatories installed on a deployment module for launch (Reference Figure 6). The deployment module, using coordination signals from the launch vehicle, deploys the observatories into their proper initial orbit configuration. Global coverage is provided by the 12 observatories loosely dispersed about a circular 70° inclination, low Earth orbit. The mission profile does not require any orbit maintenance as random spacing of the observatories is preferred.
4.3.1. Instrument

GOWA accomplishes its science goal using a GNSS instrument on each observatory. The instrument, in total, consists of the receiver electronics unit, two nadir-pointing antennas for collecting reflected GNSS signals, and a zenith-facing antenna providing space-geolocation capability. The receiver is to be developed by Meisei Electric Co Ltd based on their existing GPS receiver technology. In addition to performing standard GNSS navigation and timing functions, the GNSS Instrument's enhanced digital signal processing capabilities enable GOWA by providing onboard processing to generate DDMs of GNSS signals scattered from the ocean surface (Reference Figure 7). The coordinates of a DDM are Doppler shift and time delay offset relative to the specular reflection point of the GNSS signal. Each pixel of the DDM is obtained by cross-correlation of the received signal with a locally generated replica time delay and Doppler shift. An open-loop tracking algorithm allows each DDM to be processed by predicting the position of the specular reflection point from the known positions of the receiver and GNSS transmitter. The processing chain and data flow is shown in Figure 8. Each DDM has 1212 delay pixels with resolution of 61 ns. The Doppler resolution is 250 Hz over a ±6.5 kHz range, resulting in 52 Doppler pixels. The GNSS instrument hardware is being developed to enable up to 6 GNSS signals to be tracked simultaneously, each with their respective data products.

Coherent integration time is limited to 1 ms by the rate of change of the propagation geometry due to receiver motion. Individual complex DDMs are then incoherently integrated (magnitude only) for 1 s to form the final DDM. Incoherent
integration reduces noise due to speckle and improves the signal-to-noise ratio. The incoherent integration time is limited to 1 s due to the degradation in spatial resolution caused by along-track motion.

![Delay Doppler Map from the UK-DMC-1 mission with post-processing](image1)

**Figure 7 - Delay Doppler Map from the UK-DMC-1 mission with post-processing**

![GOWA On-board Data Flow](image2)

**Figure 8 - GOWA On-board Data Flow**

4.3.2. Nanosat

The GOWA observatory with solar arrays deployed for flight is illustrated in Figure 9. It uses a single-string highly integrated H/W architecture (Figure 10) with functional and selective redundancy included for critical areas. The main drivers of the satellite design are accommodating the nadir GNSS antennas, the attitude determination and control requirements and the science data download.

**Structure and Thermal:** The nanosat’s shape is specifically configured to allow clear nadir and zenith FOV for the nadir and zenith GNSS antennas, while its structure integrates the nanosat and instrument electronic boards directly by creating avionics and GNSS Receiver “bays”. The avionics and GNSS receiver bays form the core of the nanosat; all other components are mounted to this backbone with structural extensions included to accommodate the Al honeycomb-based S/As and nadir GNSS antenna assemblies.
The thermal control design provides thermal stability while minimizing thermal gradients through an integrated design of multilayer insulation blankets (MLI), surface treatments, and localized radiators. The arrangement of internal equipment is used to aid thermal control and eliminate the need for supplemental heaters except for survival operations.

![Figure 9 - GOWA Observatory in flight configuration](image1)

**Electrical Power:** The EPS is based on a 28±4 Vdc primary power bus with electrical power generated by a 8-panel rigid S/A. Launch accommodations provide 4 of the 8 panels to be “z-folded” for launch as described in Figure 11. Electrical power storage for eclipse operations is provided by 2 1.5 A-hr Li-ion batteries connected directly to the primary power bus. Battery charge regulation for the GOWA EPS is a peak power tracking (PPT) type regulator. The TRL 6 PPT, developed using SwRI internal funds, matches S/A conductance to the observatory load through pulse-width modulation using an optimization control circuit that integrates S/A W-sec over a preset period of time.

![Figure 10 - GOWA Observatory Functional Block Diagram](image2)
Command and Data: The GOWA spacecraft avionics core is SwRI’s Centaur board. The Centaur consists of SwRI’s space-qualified heritage Atmel SPARC12 processor integrated with heritage CCSDS compliant C&T interface, instrument data interface, and ADCS interface designs. The simple operational nature of the GNSS instrument and science profile allows the command data subsystem to operate autonomously during all normal science and communication operations. Command services include COP-0 uplink command processing with BCH error detect and correction. The Centaur also provides FSW-independent execution of a Level-0 command set used for ground-based fault management. All other commands are passed to the FSW Command Manager for execution or to the Stored Command Sequence Manager as onboard Absolute and Relative Time Sequences.

The FSW Telemetry Manager provides collection and high-level formatting of housekeeping data. These data are either downlinked in real-time or passed to the FSW Storage Manager to be stored for later downlink. A SwRI heritage H/W formatter forms CCSDS source packets into transfer frames and supports four separate Virtual Channel buffers to enable optimized data routing and processing within the GOWA Ground Data System. The heritage 4 GB Flash memory data store allows for >10 days of continuous science operations without downlink, providing significant margin for contingency operations.

S-band communication links are provided to uplink command sets and downlink science and H/K data. These links use two fixed omni-directional micro-strip patch antennas, one on the nadir baseplate and one on the zenith panel, to provide near 4π sr communications without interrupting science operations.

The S-band transceiver uses SwRI’s low-cost, radiation-tolerant, single card communication solution. The core of the transceiver is a Software Defined Radio architecture configured to provide S-band (2 GHz) communications. The transceiver provides O-QPSK encoded transmit data at 1.25 Mbps with a FSK uplink receiver supporting data rates to 64 kbps.

Attitude Determination and Control: The GOWA ADCS is a standard nadir-pointing, 3-axis, pitch momentum-bias design using pitch/roll horizon sensors and a 3-axis magnetometer for attitude determination with a pitch momentum wheel and 3-axis torque rods to provide attitude control (torque rods also provide momentum wheel desaturation). The only attitude “maneuver” required by GOWA is to recover from deployment module separation tipoff rates and establish a nadir-pointing configuration, allowing an extremely simple mode flow of nadir pointing for all operational states.
4.4. Launch and Deployment

The launch configuration of the full constellation is comprised of the 12 observatories mounted on a deployment module (DM) in 3 tiers of 4 observatories. The launch vehicle places the integrated constellation and DM into the target orbit where the DM deploys the observatories based on a pre-defined separation sequence. The LV orientation combined with the DM’s physical clocking and different separation spring forces, creates proper orbital dispersion. After deployment, the constellation disperses naturally throughout the orbit plane.

5. CONCLUSION

Recent developments in electronics and nanosatellite technologies combined with modeling techniques developed over the past 20 years have enabled a new class of altimetry and wind remote sensing capabilities that offer markedly improved performance over existing observatories while opening avenues to new applications. This paper described the GOWA mission concept for providing ocean wind and altimetry datasets with spatial resolution comparable to existing orbiting assets while providing unprecedented temporal resolution. GOWA is based on the recently awarded NASA EV-2 CYGNSS mission. CYGNSS will develop the necessary modeling/simulation tools and flight segment designs necessary to fully implement the GOWA concept.

ACKNOWLEDGEMENTS

The author would like to acknowledge the significant contributions of Dr. Aaron Ridley, University of Michigan related to orbit analysis and mission requirement definition. Additionally, congratulations and heartfelt appreciation is offered to the entire CYGNSS proposal team for their tireless development of the CYGNSS concept and the subsequent NASA EV-2 mission award.

REFERENCES


