THE CYGNSS NANOSATELLITE CONSTELLATION HURRICANE MISSION

Christopher S. Ruf[1], *Scott Gleason*[2], *Zorana Jelenak*[3], *Stephen Katzberg*[4], *Aaron Ridley*[1], *Randall Rose*[5], *John Scherrer*[5] *and Valery Zavorotny*[6]

[1]University of Michigan, Ann Arbor, MI USA

[2]Concordia University, Montreal, QC, Canada

[3]NOAA/NESDIS/StAR-UCAR, Silver Spring, MD USA

[4]South Carolina State University, Orangeburg, SC USA

[5]Southwest Research Institute, San Antonio, TX USA

[6]NOAA Earth System Research Laboratory, Boulder, CO USA

ABSTRACT

The Cyclone Global Navigation Satellite System (CYGNSS) is a spaceborne mission concept focused on tropical cyclone (TC) inner core process studies. CYGNSS attempts to resolve the principle deficiencies with current TC intensity forecasts, which lies in inadequate observations and modeling of the inner core. CYGNSS consists of 8 GPS bistatic radar receivers deployed on separate nanosatellites. The primary science driver is rapid sampling of ocean surface winds in the inner core of tropical cyclones

Index Terms— *GNSS, Tropical Cyclones, GPS*

1. MISSION OVERVIEW

Tropical cycle 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. 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. 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. CYGNSS is specifically designed to address these two limitations by combining the all-weather performance of GNSS bistatic ocean surface scatterometry with the sampling properties of a constellation of satellites [1, 2]. The use of a dense constellation of nanosatellite results in spatial and temporal sampling properties which are markedly different from conventional imagers. Detailed simulation studies will be presented at IGARSS 2012 which examine the sampling as functions of various orbit parameters of the constellation. Detailed historical records of actual TC storm tracks are overlaid onto a simulated time series of the surface wind sampling enabled by the constellation. For comparison purposes, a similar analysis is conducted using the sampling properties of several past and present conventional spaceborne ocean wind scatterometers. Differences in the ability of the sensors to resolve the evolution of the TC inner core are examined. A candidate low-cost spacecraft and GNSS receiver design are considered which could practically be used in an affordable constellation mission. Compromises in some aspects of the design are necessary (e.g. limiting the downward looking antenna gain) in order to keep the system small and affordable. The signal-to-noise ratio of the measured scattered signal, and the resulting uncertainty in retrieved surface wind speed, are also examined.

2. GPS-BASED BISTATIC QUASI-SPECULAR OCEAN SURFACE SCATTEROMETRY

Fig. 1 (left) illustrates the propagation and scattering geometries associated with the GNSS approach to ocean surface scatterometry. The direct GPS signal provides a coherent reference for the coded GPS transmit signal. it is received by a RHCP polarized receive antenna on the zenith side of the spacecraft. The quasi-specular forward scattered signal from the ocean surface is received by a downward looking, LHCP polarized antenna on the nadir side of the spacecraft. The scattered signal contains detailed information about its roughness statistics, from which local wind speed can be derived [3]. The scattering cross-section image produced by the UK-DMC-1 demonstration spaceborne mission is shown in Fig. 1 (right). Variable lag correlation and Doppler shift, the two coordinates of the image, enable the spatial distribution of the scattering cross-

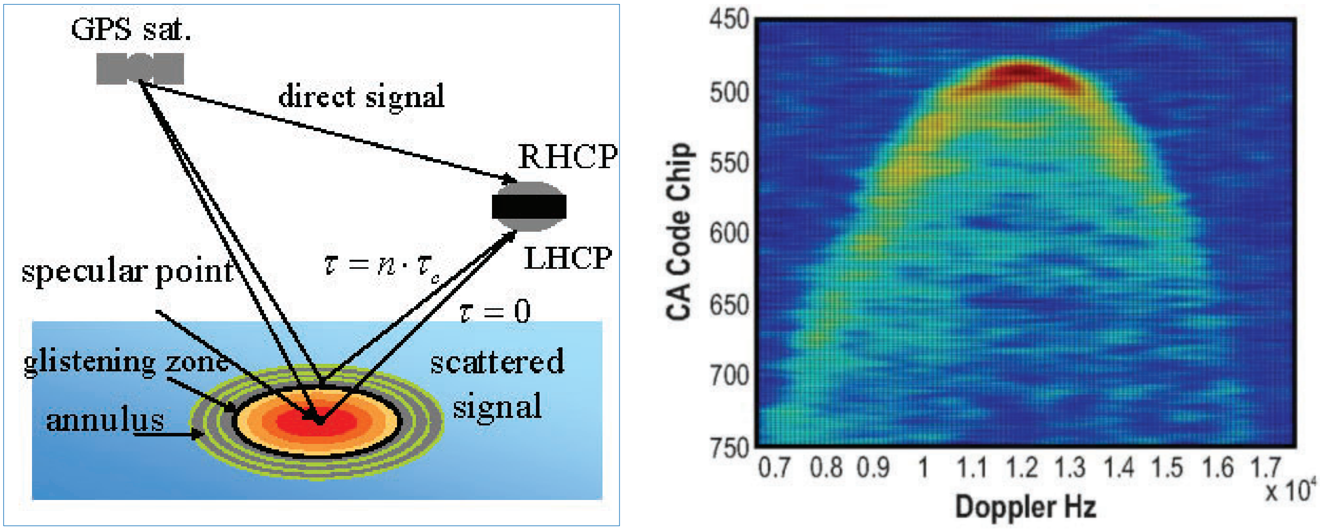

Figure 1. (left) GPS signal propagation and scattering geometries for ocean surface bistatic quasi-specular scatterometry. (right) Spatial distribution of the ocean surface scattering measured by the UK-DMC-1 demonstration spaceborne mission – referred to as the Delay Doppler Map [5].

section to be resolved [4, 5]. This type of scattering image is referred to as a Delay Doppler Map (DDM). Estimation of the ocean surface roughness and near-surface wind speed is possible from two properties of the DDM. The maximum scattering cross-section (the dark red region in Fig. 1-right) can be related to roughness and wind speed. This requires absolute calibration of the DDM. Wind speed can also be estimated from a relatively calibrated DDM by the shape of the scattering arc (the red and yellow regions in Fig. 1-right). The arc represents the departure of the actual bi-static scattering from the purely specular case that would correspond to a perfectly flat ocean surface, which appear in the DDM as a single point scatterer. The latter approach imposes more relaxed requirements on instrument calibration and stability than does the former. However, it derives its wind speed estimate from a wider region of the ocean surface and so necessarily has poorer spatial resolution. Development of wind speed retrieval algorithms from DDMs is an active area of research.

3. CYNSS OBERVATORY

Fig. 2 shows details for one of the eight CYGNSS observatories. Included are all of the spacecraft support subsystems (e.g. avionics, power and communication) as well as the science payload.

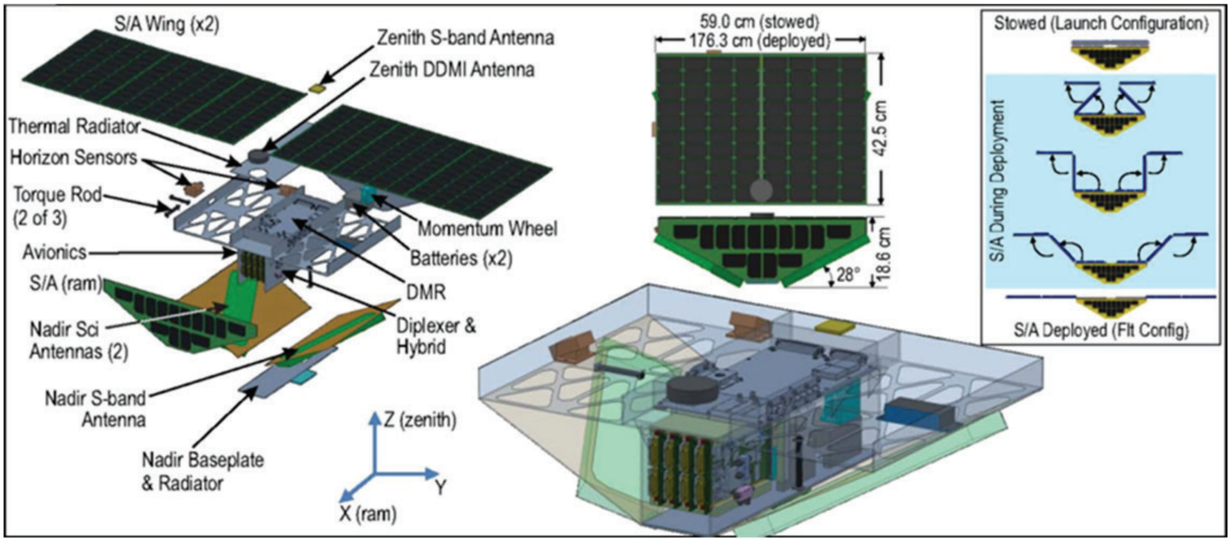

Figure 2. The CYGNSS Observatory. The exploded view shows individual subsystems, including the Delay Mapping Receiver ((DMR), which is part of the GNSS science payload. The other parts are the associated zenith and nadir antennas for receiving direct and scattered GPS signals, respectively. Solar Array deployment, performed after ejection from the launch deployment module, is also shown.

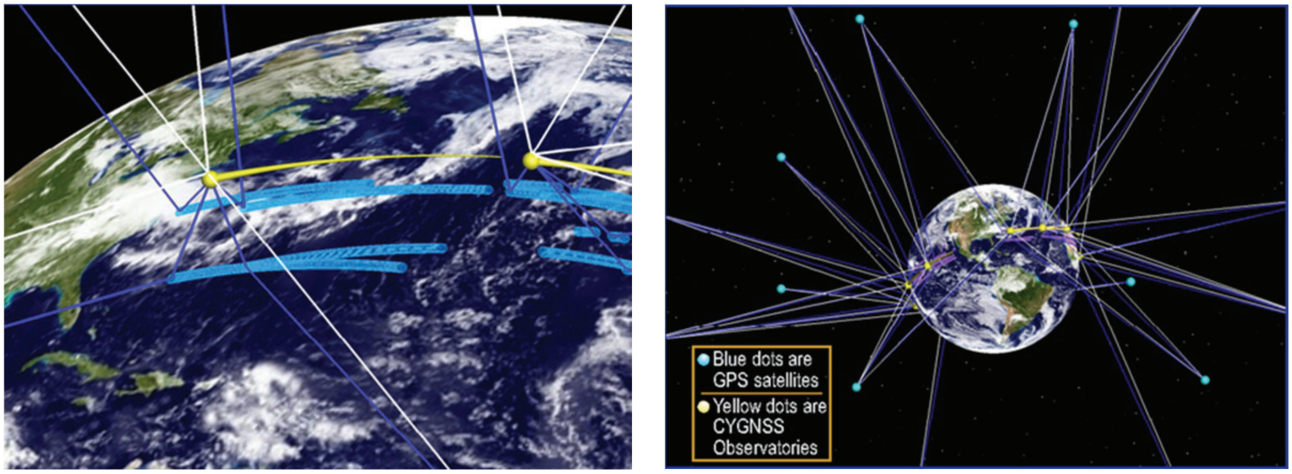

Figure 3. The CYGNSS Constellation. (left) The CYGNSS observatories are shown as yellow spheres. The white lines represent direct GPS signals and the blue ocean surface scattered signals. The lighter blue circles on the earth surface represent individual samples of the Delay Doppler Map. (right) The full constellation of GPS transmitters and CYGNSS receivers in the bistatic radar constellation are shown.

4. CYNSS CONSTELLATION

Fig. 3 illustrates the CYGNSS constellation concept. Eight observatories are positioned in low inclination (35^o) low earth (500 km altitude) orbit. Each of them simultaneously samples quasi-specular scattered signals from up to four available GPS transmitters. The resulting spatial and temporal sampling properties can provide excellent sampling of evolving TCs. This is illustrated by the following example.

5. HURRICANE OVERPASS CASE STUDY

A time lapse simulation comparing CYGNSS and ASCAT coverage of Hurricane Frances just before its U.S. landfall is shown in Fig. 4. The simulation was created by projecting satellite coverage models for each mission onto the archival storm track record for Frances. Each frame represents all samples taken within a 3 hour intervals. The TC inner core is shown as a large blue dot in each frame. ASCAT, with its relatively narrow swath width, only infrequently samples the inner core, whereas the much wider and more dispersed effective swath of the CYGNSS constellation allows for much more frequent sampling. The average revisit time for TC sampling is predicted to be 4.0 hr, and the mean revisit time will be 1.5 hr.

7. REFERENCES

[1] Katzberg, S. J., R.A. Walker, J. H. Roles, T. Lynch, and P. G. Black, “First GPS signals reflected from the interior of a tropical storm: Preliminary results from hurricane Michael,” *Geophys. Res. Lett.*, **28**, pp. 1981-1984, 2001.

[2] Katzberg, S.J., Torres, O. and G. Ganoe. “Calibration of Reflected GPS for Tropical Storm Wind Speed Retrievals,” *Geophys. Res. Lett.*, **33**, L18602, doi:10.1029/2006GL026825, 2006.

[3] Zavorotny, V. U., and A. G. Voronovich, “Scattering of GPS signals from the ocean with wind remote sensing application,” *IEEE Trans. Geosci. Remote Sensing*, **38**, 951-964, 2000.

[4] Gleason, S., Hodgart, S., Sun, Y., Gommenginger, C., Mackin, S., Adjrad M., and Unwin, M., “Detection and Processing of Bi-Statically Reflected GPS Signals From Low Earth Orbit for the Purpose of Ocean Remote Sensing,” *IEEE Trans. Geoscience and Remote Sensing*, **43**(5), 2005.

[5] Gleason, S., “Remote Sensing of Ocean, Ice and Land Surfaces Using Bi-statically Scattered GNSS Signals From Low Earth Orbit,” Ph.D. Thesis, University of Surrey (U.K.), January 2007.

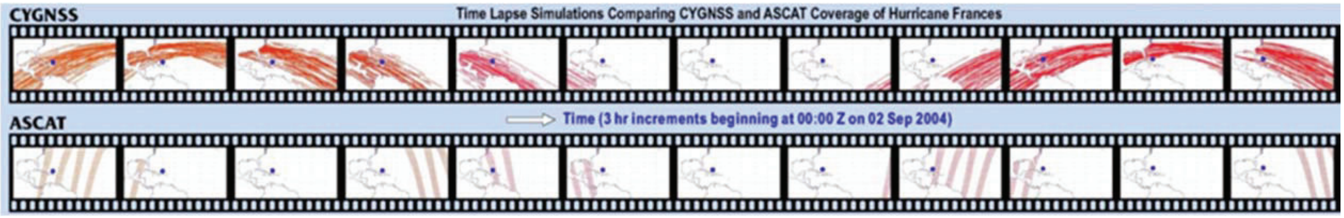

Figure 4. Time lapse simulation comparing the spatial and temporal sampling properties of CYGNSS and ASCAT, if they had both been in orbit during the Hurricane Frances U.S. landfall on 2 Sep 2004