New technologies in EM scattering to retrieve properties of ocean surface waves including tsunamis

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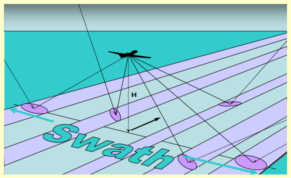
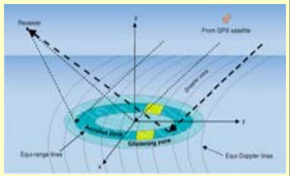
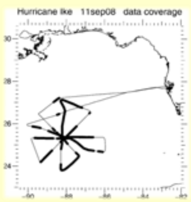
Sea surface height and wave measurements using GPS reflectometry

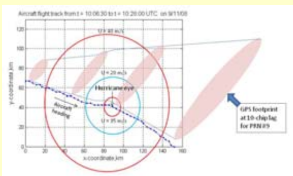
- A use of GPS (Global Positioning System) multistatic radar for ocean surface sensing was recently studied [1, 2]. This technique might be attractive when considering high altitude/long endurance (HALE) Unmanned Aircraft Systems (UAS) because of the small size, small weight, and low energy consumption of GPS receivers. Use of high-altitude (~ 20 km) UAS platforms is especially beneficial providing swaths ~100 km wide.
- The purpose of this project is to provide NOAA with a portable airborne sensor to monitor waves/winds and ocean surface heights from current and future NOAA aerospace vehicles. Currently, we are analyzing ocean scattered signals using a CU GPS software receiver installed on board of the NOAA P-3 and G-IV aircrafts and defining technical requirements for the future real-time Airborne GPS Ocean Surface Sensor.

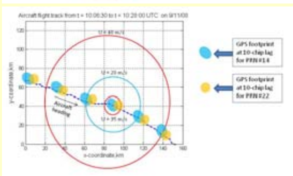




2008 NOAA P-3 experiment

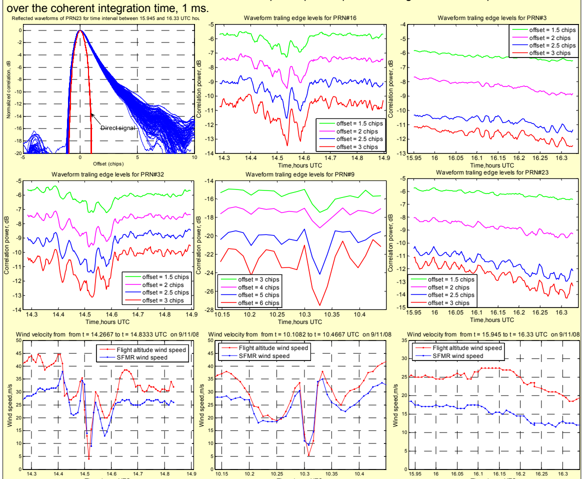






- The flights of the NOAA P-3 aircraft on September 10 and 11, 2008 originated from MacDill AFB near Tampa, Florida, and made multiple passes over Hurricane Ike in the Gulf of Mexico.
- Even though up to 12 GPS satellites were visible from the aircraft, only those at high elevation angles provided the necessary spatial resolution of the hurricane features.
- Transmitter-receiver geometry for low-elevation satellites created too stretched (up to several tens of kilometers) footprints.

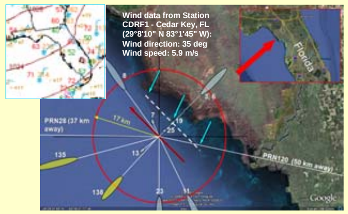
During two flights there was collected about 800 GB of raw data. The data processing procedure involves calculation of the cross-correlation between raw in-phase/phase-quadrature signals and the specific PRN code over the coherent integration time, 1 ms.



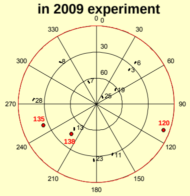
The presence on the aircraft of the Step Frequency Microwave Radiometer (SFMR) allowed comparisons between wind retrievals obtained with the SFMR and the GPS multistatic radar. The surface roughness retrieval and SFMR wind speeds correlate well at the vicinity of the hurricane eye/walls and less for the conditions of seas that are not in a full equilibrium with the local winds [2].

2009 NOAA Gulfstream-IV experiment

- A modified version of the CU multistatic radar with a larger bandwidth front end was installed on the NOAA Gulfstream-IV jet aircraft and operated during a flight on October 19, 2009 to test the system at higher altitudes, ~10 km, which should give insight into the feasibility of using this technique for higher-altitude UAS platforms.
- The portion of the flight track ran across the Gulf of Mexico, and the GPS reflected signal during 100 s was recorded from ten GPS and two geostationary WAAS satellites.

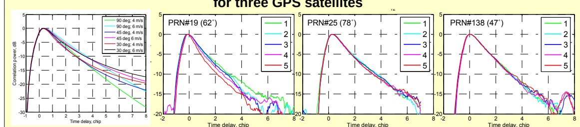


GPS constellation in 2009 experiment



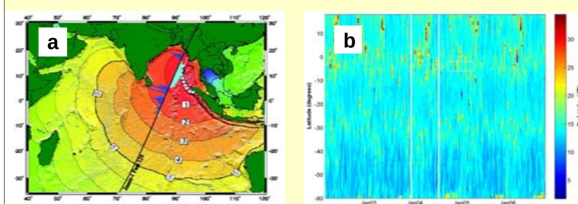
Centerline coordinates: 29˚23.3'N, 83˚24.8'W; time: 15:07-15:09 UTC Oct. 19, 2009; aircraft altitude: 12 km; heading: 316.7°, speed: 770 km/h.

Comparison between modeled and five consecutive measured waveforms for three GPS satellites



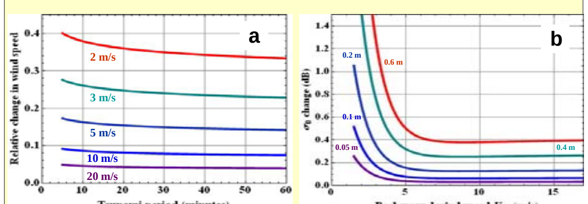
- Despite a limited data obtained the results of the experiment indicate that the GPS bistatic radar technique of surface wind measurement works well under conditions where an equilibrium between local wind and the surface waves exists and elevation angles higher than 30˚.
- Plans are to participate in long-duration aircraft missions under uniform sea wave conditions for a refinement of this technique for wind speed and wind vector retrievals from high-altitude UAS platforms. It is expected that these flights will be accompanied by wind measurements using SFMR and GPS dropsondes.

Tsunami "shadows:" Towards a new approach to tsunami early detection and warning



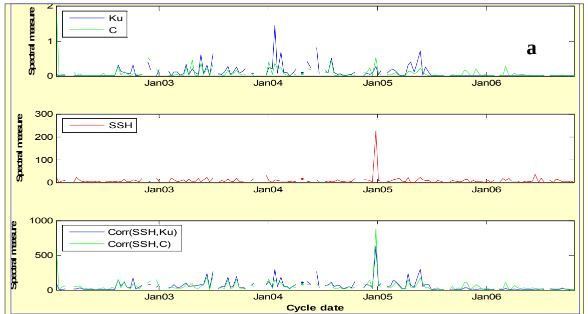
Radar backscattering strength, σ_0, data from the Jason-1 altimeter

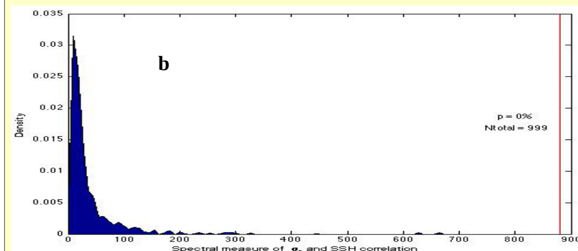
a. The Jason-1 ground track and C-band σ_0 data for pass 129 encountering the Sumatra-Andaman tsunami is superimposed on contours of the tsunami leading wave front at hourly intervals after the earthquake. The σ_0 data are shown for the portion of the ground track where the tsunami wave had arrived. White stars show location of the tsunami wave sources. (Tsunami wave front graphic is courtesy of the National Geophysical Data Center/NOAA). **b.** Ku-band σ_0 values for 10 day repeat cycles 1 through 170 from ascending path 129 from 60˚S to landfall in the Bay of Bengal.



Theoretically predicted tsunami-induced variations in near-surface wind and radar backscattering strength

a. Tsunami-induced relative change in wind velocity. The relative change *M* in effective wind speed is shown as a function of the tsunami wave period for various values of the background wind speeds from 2 m/s to 20 m/s at a height 10 m above the ocean surface. Tsunami amplitude is 0.3 m, thickness of the logarithmic boundary layer *H* = 60 m, ocean depth is 4000 m. **b.** Amplitude of the tsunami-induced variations in the radar backscattering strength at nadir. One half of the peak-to-trough difference is shown as a function of the background wind speeds at a height 10 m above the ocean surface for sinusoidal tsunami waves with amplitudes ranging from 0.05 to 0.60 m. Tsunami period is 40 minutes, thickness of the logarithmic boundary layer *H* = 60 m, ocean depth is 4000 m.





Spectral measures of radar backscattering strength and sea surface height anomalies observed by Jason-1 and their correlation

a. Ku- and C-band backscattering strengths (top panel), sea surface height (middle panel) signals, and correlations (bottom panel) of Ku- and C-band backscattering strengths with the sea surface height in the range of spatial scales characteristic of the tsunami as observed between 6˚S and 2˚N along track 129 from cycles 1 through 174. **b.** Randomization tests of the co-spectrum of the spatially filtered C-band σ_0 and sea surface height anomalies. The anomaly and the co-spectrum are calculated for the tsunami event (red line) and compared to the results from 999 4˚ random windows. Statistical significance of the hypotheses that the correlation between spatially filtered surface roughness variations and sea surface height anomaly with and without the tsunami are not substantially different is found to be less than 0.1%.

Tsunamis are difficult to detect and observe in deep water because the wave amplitude there is much smaller than it is close to shore. The first detailed measurements of the tsunami effect on sea surface height and radar backscattering strength in the open ocean were obtained from satellite altimeters during passage of the 2004 Sumatra-Andaman tsunami. Satellite altimeters afford a unique opportunity to study the effects of a tsunami wave on the ocean surface through concurrent measurements of the sea surface height (SSH) and the radar backscattering strength. Using observations of the Sumatra-Andaman tsunami from the Jason-1 satellite, we have demonstrated experimentally for the first time that tsunamis in the open ocean cause distinct, measurable changes in ocean surface roughness. The same conclusion has been reached from statistical analyses of several different attributes of the radar backscattering data. The strongest evidence comes from the correlation of the σ_0 and SSH variations. Given the size of the set of random windows utilized in our analysis, uniquely high values of the correlation during the tsunami event translate into a statistical confidence of better than 99.9% of the conclusion that tsunamis in deep water are accompanied by substantial changes in ocean surface roughness away from shore. These results are in agreement with theoretical predictions and provide important insights into the physics of wave-wind interaction and methods for retrieval of a tsunami signal in radar backscattering data.

The tsunami-induced surface roughness variations, the existence of which has been established using satellite altimeter data, are likely to be most efficiently utilized operationally with other types of space- and airborne sensors. Unlike the sea surface height, which is measured at nadir points along the satellite ground track, tsunami-induced variations in sea surface roughness can be potentially measured over wider swaths with space-borne and airborne side-looking radars and scanning microwave radiometers. Instead of a correlation between surface elevation and radar backscattering strength, spatial averaging of radar backscattering strength or brightness temperature along hypothetical tsunami wave fronts would be used with these kinds of sensors to distinguish any tsunami signal from noise due to other sources of the roughness change. While further research is required to demonstrate tsunami detection with side-looking radars and scanning microwave radiometers, the much broader surface coverage of these sensors suggests that they are more promising for early tsunami detection than satellite altimeters and may be an important element in a future global system for tsunami detection and warning.

References

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