Ocean Wave Slopes from XM-Radio Reflections for Brightness Temperature Corrections

Nicole Quindar (nquindar@purdue.edu), James Garrison (jgarrison@ecn.purdue.edu)
School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN, USA

Bistatic radar, or reflectometry using Global Navigation Satellite System (GNSS) signals as illumination sources, has been shown to produce estimates of ocean roughness that are strongly correlated with L-band microwave brightness temperature measurements and surface wind speed. Retrievals of mean square slope (MSS) from GNSS reflectometry, can be empirically parameterized in term of brightness temperature. A recent experiment has shown that S-band digital communications signals can be utilized in the same manner, offering several promising advantages over GNSS, including much higher transmitted signal to noise ratio (~30 dB) and fixed scattering geometry due to geostationary transmitters. This poster will present the results of MSS retrievals from XM reflectometry data acquired from a February 2012 airborne experiment over the Chesapeake Bay, VA. By exploiting signals of opportunity from XM, it is proposed that a novel instrument can be designed to perform within NASA science requirements, with an order of magnitude reduction in size, weight, and power to correct the roughness effects in radiometer brightness temperature measurements.

Motivation

- Tracking global sea surface salinity (SSS) provides critical information about global heat circulation and climate trends.
- L-band brightness temperature measurements are dependent on SSS, and can be measured using GPS and XM signals in bi-static radar configuration. τw estimates must be corrected for roughness [Voo].

Waveform and Scattering Model

- The electromagnetic scattering model is derived from the Geometric Optics Limit of the Kirchhoff Approximation [Zavorotny, Voronovich].
- Ocean roughness is quantified by inverting the model for the bi-static scattering cross section σ(ρ), sensitive to the PDF of surface slopes.

\[
|Y(t, \tau, f)|^2 = \frac{1}{T_c} \int \frac{D(\rho)S(\rho - f(\rho))A(\tau - R_0 - R)}{4\pi R_0^2 (R^2(\rho))} \sigma(\rho) d^2 \rho
\]

- Higher winds correspond to wider distribution of backscatter power over larger range of delays, and increased MSS values.
- Experimentally, this measurement is produced from the cross-correlation waveform between the direct and reflected signal as a function of time delay and Doppler.

XM vs. GPS L1 Signal

| XM | Signal is random noise, can be used to generate delay bins. | 32 range-coded PRNS globally available |
| GPS | Free transmission on four carriers at S-band (LHCP 2332.5 to 2345.0 MHz) | L-band frequency very near that at which radionauts operate (RHCP 1575.42 MHz) |
| | Geostationary orbit yields convenient geometry, eliminates Doppler | Can utilize full Delay-Doppler Map for retrievals of MSS |
| | Post-correlation SNR 49.5 dB vs. 14.5 dB for GNSS | Proven heritage on various experiments within the past decade at aircraft, balloon, and satellite altitudes |
| | BPSK modulated | QPSK modulated |

Experiment & Instrumentation

- Series of experimental flights from approximately 5 – 9 AM, February 16 – 24, 2012 over Chesapeake Bay, VA
- Flower pattern ground track over CHLV2 buoy

| XM GPS | Universal Software Radio Peripheral (USRP) | LHCX XM and RHCP GPS Direct Signal Antennas Zenith, RHCP XM and LHCX GPS Reflected Signal Antennas Nadir |
| | Auxiliary measurements from Delay Mapping Receiver (DMR) and STARRS (Salinity, Temperature, and Roughness Radiometer System). |

Estimation Algorithm

| Raw Data (Level 0) | In-phase and quadrature components of the direct and reflected signals are recorded at 4 MHz sampling and 4-bit quantization. |
| Waveform (Level 1): Data Read From Recording Files | Direct and reflected signals are fitted to isolate visible noise. Reflected data are cross-correlated with the corresponding direct signal. Waveforms are incoherently averaged. |
| Pre-Processing (Level 1A): Data is Prepared for Estimation | Noise floor removed, specular delay points aligned, waveforms are geo-referenced and stored in batches of 50 waveforms. Time tags, latitudes, longitudes, altitudes, azimuths, and elevations of each waveform are stored. |
| Estimation (Level 2): NLSQ For Each Batch of Data | 1-D Estimator with 3-parameter state vector: [MSS, Scale Factor, Delay] = [ρω0, S, τw] |

Results

| Fig. 6: February 17 XM MSS Retrieval CHLV2: 9.8 m/s (MSS = 0.0130) Rhythm: 10.46 m/s (MSS = 0.0141) |
| Fig. 7: February 18 XM MSS Retrieval CHLV2: 3.8 m/s (MSS = 0.0030) Rhythm: 3.98 m/s (MSS = 0.0033) |

- Higher winds > rougher oceans > higher MSS values
- Higher slopes > wider distribution of delays > wider waveform
- Geometric Effect
  - Higher altitude > wider waveform
  - Lower elevation > glistening zone widened

Summary

- GPS and XM Reflectometry can provide ocean wind speed estimates and corrections to SSS measurements.
- Ocean wave MSS estimates from reflectometry using XM Satellite Radio more accurately reflect ground truth that GNSS-R due to much higher SNR (~30 dB)
- Small, low power, autonomous instruments can provide comparable measurements to scatterometers.

References


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