TITLE: Simulation of reflected BOC-modulated satellite navigation signals

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Remote sensing applications of reflected signals from Global Navigation Satellite Systems (GNSS-R) have been studied extensively, both in theory and simulation, as well as experimentally from stationary platforms, aircraft, balloons and satellites. The design of GNSS signals, optimized for range measurement, requires a very narrow autocorrelation function. When these signals are reflected, this narrow autocorrelation has the effect of filtering the reflected power from regions on the scattering surface, approximated as the space between two iso-range ellipses. If there is a sufficiently large velocity between the transmitter and receiver, such that the Doppler spread over the surface is larger than the bandwidth set by the coherent integration time, then this filtering of the scattered power extends to a two-dimensional map of the surface. One application of this 2-D delay-Doppler map is the inversion of a scattering model to estimate the parameters describing the statistics of a random rough surface. In the case of ocean scattering, empirical models have been used to infer surface wind speed from these estimates of surface roughness. Much of the initial work on GNSS-R was directed at such an application as a bistatic radar alternative to active scatterometers. Recently, however, new interest has developed in the direct application of the surface slope statistics retrieved from GNSS-R delay-Doppler waveforms. Specifically, we have hypothesized that such measurements could be used for the correction of surface roughness effects in the sensing of sea surface salinity (SSS) through passive microwave radiometry. The frequencies used for sensing salinity are in L-band and very close to those allocated for GNSS. Furthermore, emission models have a similar form to bistatic scattering models.

Two significant questions must be addressed before GNSS-R measurements could be seriously considered for this application. First, the uncertainty in equivalent brightness temperature, estimated from GNSS-R, must be within the SSS error budget. Second, the sampling density of GNSS-R measurements, which are dependent upon the time-varying GNSS constellation geometry, must be large enough to provide roughness corrections at a rate comparable to the microwave radiometer spatial resolution. The first question is being addressed through the aforementioned aircraft, balloon and satellite experiments, which provide data to validate models that would be incorporated into end-to-end system simulation models. To address the second question, we have performed preliminary simulations of the satellite geometry for a salinity mission with the same parameters as Aquarius, and found that the use of GPS signals provided GNSS-R specular point measurements within the radiometer footprint only 26 percent of the time, which would probably not be able to meet the mission requirements. Addition of measurements from the EU Galileo system, increased this figure to 63 percent. Thus, we concluded that the combined use of reflected GPS and Galileo signals would be required.

At the present time, however, broadcast signals are only available from two Galileo test satellites, GIOVE A and B, and the only in-space GNSS-R receiver (on UK-DMC) does not have a large enough bandwidth for recording the full Galileo spectrum. Therefore, we have begun to develop simulators for reflected Galileo signals.

While GPS uses a simple Bi-Phase Shift Keyed (BPSK) modulation, Galileo will employ various forms of Binary Offset Carrier (BOC) modulation, which have more complex autocorrelations than BPSK. We have applied models that were derived earlier for GPS signals, to incorporate the BOC autocorrelations, and numerically generate the scattered signal waveform, as well as the coherence time of each sample of the waveform. A frequency-domain version of this model was used to produce filters, which will shape the spectrum of simulated white Gaussian noise, to produce stochastic time series for each delay-Doppler measurement, having the correct coherence properties. With these filters, simulated GNSS-R measurements can be produced, and used as synthetic input to the surface roughness retrieval algorithms, to assess the uncertainty in the brightness temperature correction. Figure 1 shows the output of this simulation, for both a Galileo BOC(1,1) signal as well as a GPS BPSK(1) signal for comparison.

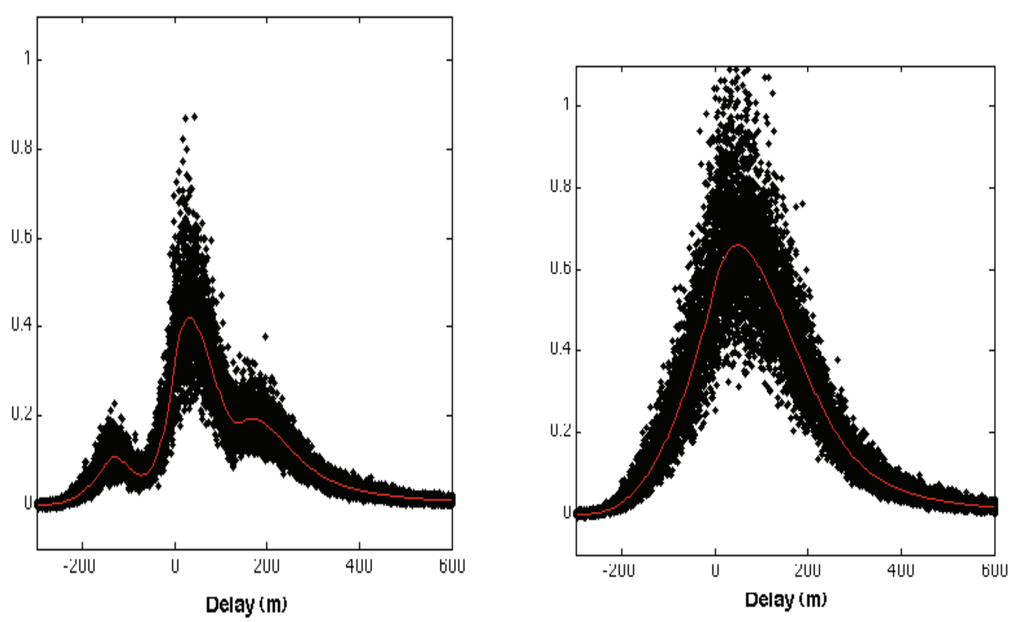

Figure 1. Simulated data for an airborne receiver (3.3 km altitude). Left, BOC(1,1) signal, as on the Galileo L1 channel. Right, BPSK(1) signal, as on the GPS L1 channel.