The collection of GPS signal scattered off a wind-driven ocean with a down-looking GPS receiver: polarization properties versus wind speed and direction

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Abstract - **A GPS transmitter-receiver pair form a bistatic radar for ocean remote sensing when the receiving platform carries a downlooking antenna capable of collecting the GPS signal scattered off the ocean surface. The aggregate GPS signal scattered by the ocean and received in a general bistatic configuration has been calculated for representative geometries and a variety of wind speeds and directions, using the Integral Equation Method (IEM) combined with a realistic ocean correlation function (spectrum). The role of polarization of the reflected signal is investigated and its dependence on wind speed and direction is analyzed to assess its suitability as a detector of the wind vector. The complexity of the scattering calculations is handled by an efficient integration scheme based on combining Gaussian quadrature with a local interpolation of the surface correlation function. Additionally, since a large number of scattering contributions are required the code has been parallelized for efficiency. Some relevant features of the parallelization scheme are outlined.**

1. INTRODUCTION

The Global Positioning System (GPS), which was first conceived and built for the purpose of navigation, has been successfully used as an Earth remote sensing tool in the past fifteen years for solid earth and atmospheric probing. More recently, the possibility to utilize the GPS signals scattered off the ocean and sensed by an air- or space-borne receiver in a bistatic radar geometry, as a means of doing altimetry and scatterometry. The advantage of GPS is twofold: the transmitted signal is global and is present at all times and in all weather conditions and the receiver technology is rather inexpensive, compared to alternative remote sensing systems. To take advantage of this new possible measurement one needs to understand the characteristics of the received signal and how they relate to the ocean properties such as sea surface height and winds.

The fundamental process being observed is the bistatic scattering from the rough ocean surface, driven by winds. When the GPS signal impinges on the ocean it scatters in all directions. At any given observation time, one specific area of the ocean forming an elliptical annulus stretching between transmitter and receiver contributes to the overall received power, through a collection of scattering contributions with varying local scattering geometries. The extent of this variation depends on the incidence angle and the altitude of the receiver. A pictorial representation is provided in Fig. 1. By combining the surface contributions that arrive at the receiving antenna at the same time, the impact of the ocean state and the geometry and system parameters on the received power waveform is studied. This point is important when trying to understand the features of the scattered signal since not in all cases the received signal is primarily in the forward scattering direction, and to account for the actual aggregate polarization.

It is expected that the polarization of the received signal is sensitive to the wind speed and possibly its direction. Furthermore, this sensitivity is dependent on the observation geometry; for example, for high elevation GPS satellites the vertical polarization of the scattering is greatly reduced over the horizontal one with consequences on the aggregate scattered signal. To investigate polarization one needs a sophisticated bistatic scattering theory capable of predicting all components of scattering cross section coefficients for a rough surface realistically representing a wind driven ocean. The simple Geometric Optics limit of the Kirchhoff approximation, used to model the received GPS signal [1], is inadequate, particularly for off-specular directions. We use the Integral Equation Method (IEM), combined with an ocean correlation function obtained from a recently derived spectrum [2]. The applicability of this version of IEM to bistatic scattering at L-band has been recently investigated [3], for the purpose of determining the sensitivity of wind speed to reflection geometry. In this paper we carry out general calculations of the aggregate GPS received power for a variety of geometries and wind vector values and investigate the behavior of like and cross polarizations. A recent study [4] using the Small Slope Approximation (SSA) bears some analogies to ours, although the theoretical premises of the two approaches are somewhat different and the scattering calculations were performed only in the main scattering plane, where the azimuthal angle were the same for incident and scattered radiation. Additionally, in that study only one reflection geometry was investigated, and hence it is not possible to see the relative behavior of the like and cross-polarized components of the received power as this parameter is varied.

II. FORMULATION

The typical scattering cross section coefficient in IEM has the form

$$\sigma_{pp}^{0} = \frac{k^2 \left| f_{pp} \right|^2}{4\pi} \int_{-\infty}^{+\infty} e^{-k^2\sigma^2(\cos\theta_s + \cos\theta)^2} \times$$

$$\int_{-\infty}^{+\infty} \left\{ \left[e^{k^2\sigma^2(\cos\theta_s+\cos\theta)^2 \rho(r,\varphi)} - 1 \right] \right. \quad (1)$$

$$\left. e^{jk\left(\sin\theta_s\cos(\phi_s-\varphi)-\sin\theta\cos(\phi-\varphi)\right)} rdrd\varphi \right\}$$

where $\rho()$ is the wind dependent surface correlation function and is itself an integral of the sea surface spectrum. The angles θ,ϕ and θ_s,ϕ_s refer to the local incident and scattering directions, respectively. A complete description of all the symbols appearing in (1) in given in [3]. Because the GPS transmits a right-hand circularly polarized signal (RHC), it is convenient to study the received circular polarizations, given by

$$\sigma_0^{LHC(RHC)} = \frac{\sigma_{vv}^0 + \sigma_{hh}^0 + \sigma_{vh}^0 + \sigma_{hv}^0}{4} + (-)\frac{\sigma_{vvhh}^0 - \sigma_{vhhv}^0}{2} \quad (2)$$

The received GPS reflected power versus time is

$$P(\tau) = A\int \left[\frac{\Lambda_m^2\left(\tau - (R_1(\xi)+R_2(\xi))/c\right)}{R_1^2(\xi)R_2^2(\xi)} \sigma_0(U_{10},\xi) \quad F(\Delta f(\xi))\right] d^2\xi \quad (3)$$

where where τ is the observation time measured relative to the arrival of the contribution from the specular reflection point, Δ_m is the correlator function accounting for the statistical distribution of heights, $R_1(R_2)$ is the distance between transmitter (receiver) and the generic point on the ocean, F(.) is the spatial filtering function associated with the receiver integration time, and the integral is performed over the ocean surface, whose generic point is represented by the vector ξ with origin at the specular reflection point. The constant *A* is a scaling factor which represents the incident GPS power and the receiving antenna gain assumed constant.

III. IMPLEMENTATION

The calculation of (3) is time consuming because (2) must be evaluated over a large area of the ocean, corresponding to a multitude of different local incident and scattering directions. To improve on the speed we first generate the surface correlation function by integration of the spectrum at a very sparse grid only, and then perform a cubic spline interpolation to obtain its value at the generic integration point. Hence we deal with (1) as a two-dimensional integral instead of a four-dimensional one. The integration of (2) is carried out using a two-dimensional Gaussian quadrature, after breaking the integration interval (r,ϕ) into sub-intervals judiciously chosen according to the wind speed value, and hence the variation of $\rho()$. The integration in (3) is made efficient by parallelization, which allows to break the integration domain over the ocean into strips assigned to different nodes, in a master-slave strategy. Since each scattering calculation is independent of another, very little inter-node communication is generated.

IV. NUMERICAL RESULTS

We examined the cases of incidence angle of 5° and 45°, with winds U_{10} either at 4 m/sec or 20 m/sec. The direction of the wind was either parallel or perpendicular to the plane of incidence, shown in Fig. 1. We report the results for the GPS reflected power versus time in Figures 2-4. The receiver was assumed at a height of 10 km above the earth surface, with velocity of 200 m/sec directed perpendicularly to the plane of incidence. The coherent integration time was chosen equal to 20 msec. The receiving antenna gain was assumed constant since at airplane altitudes a relatively low gain antenna can be used. In all cases both the LHC and RHC polarized waveforms are reported.

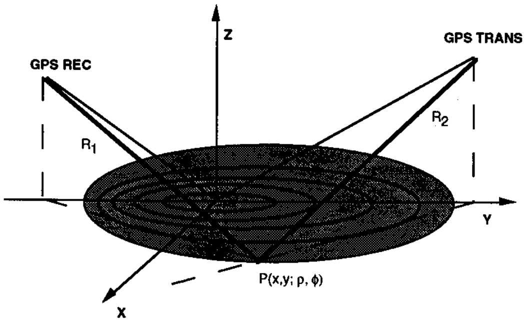

Figure 1. Illustration of equirange annuli contributing to mean reflected power received at progressively increasing times. The global and local scattering geometries used in the calculations are also noted.

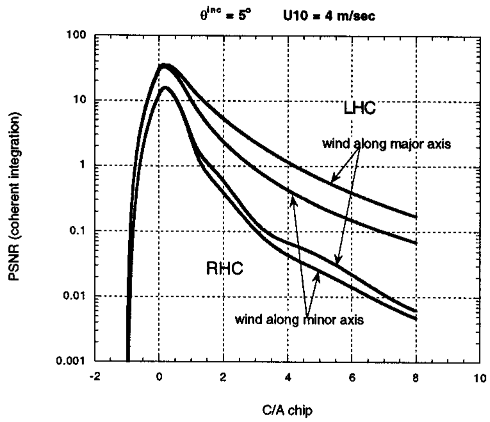

Figure 2. Received power for the case of incidence angle 5° and U_{10} equal to 4 m/sec. Both circular polarizations are reported.

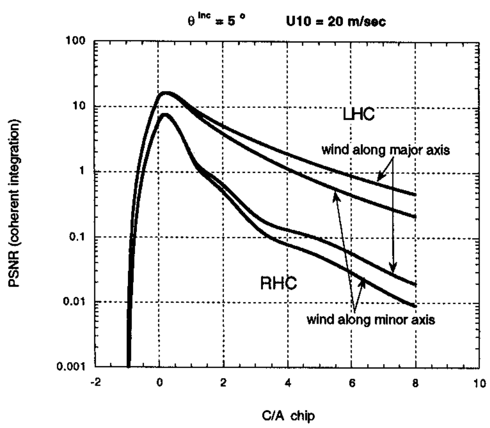

Figure 3. Received power for the case of incidence angle 5° and U_{10} equal to 20 m/sec. Both circular polarizations are reported.

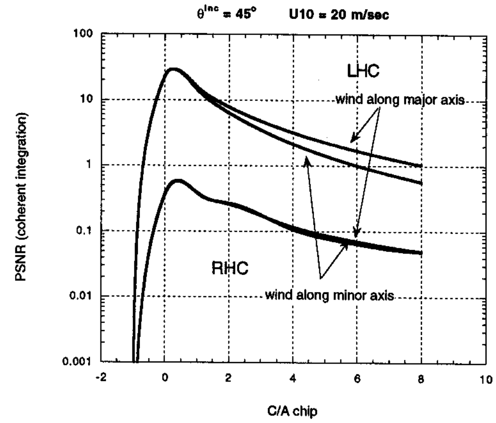

Figure 4. Received power for the case of incidence angle 45° and U_{10} equal to 20 m/sec. Both circular polarizations are reported.

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