Behavior of GNSS Signals Reflected From an Ocean Surface at Weak Winds

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Satellite observations of GNSS signals scattered by Earth natural surfaces such as ocean or land show that in a majority cases they can be described as a result of a strong diffuse, non-coherent scattering. This regime is characterized by a large value of the surface roughness-to-radio wavelength Rayleigh parameter, $R_a >> 1$. For wind-driven waves and typical elevations of the GNSS satellites, $R_a \sim 1$ already at winds with $U_{10} > 2\text{-}3$ m/s, so for higher winds the scattered signal is always strongly diffuse. It is formed by summation of large number of uncorrelated field contributions originated from a large surface area. Corresponding delay-Doppler maps (DDM) have a typical "horseshoe" shape. However, sometimes the same observations show a presence of coherent component in the Earth's reflected GNSS signals. More likely, they are caused by reflections from calm seas, lakes, planar ice fields, or flatlands. These surfaces can be characterized by a relatively small Rayleigh parameter. Such mirror-like surfaces only insignificantly degrade the coherence of a reflected wave. Both the coherent component, which arrives from a specular direction, and the weak diffuse scattering, which originates from non-specular directions, might be simultaneously present in the GNSS reflection data. This phenomenon can be seen, for example, in the UK TDS-1 DDM data.

Here, we propose an analytical model for simulating DDMs in the regime of the coherent and weak diffuse scattering from ocean waves generated by very weak winds, or, in general, from the surfaces having a small Rayleigh parameter. This model consists of two terms: the coherent DDM which is a replica of the DDM for the direct signal modified by the Fresnel reflection coefficient multiplied by the de-coherence factor $\exp\left(-4R_a^2\right)$ and the non-coherent DDM expressed in the form of a standard bistatic radar equation which employs a weakly diffuse bistatic radar cross section (BRCS) σ. It differs from the case of the strongly diffuse BRCS, usually obtained with the Geometric Optics Limit of the Kirchhoff approximation. Here, σ is obtained using the first-order small slope approximation formula applied to the case of small-to-moderate values of R_a. We analyze modeling results for the DDMs for a range of winds from low to moderate. It is shown that the presence of the coherent component is responsible for the "*K*-shape" of the delay-Doppler maps.