112 -- 2017-03-08 03:57:09

Session 2A Paper 3

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Ocean Remote Sensing by Oblique Incidence Sounding of the Ionosphere

Multiple-Hop Oblique Ionograms (MHOI) involve reflections from the ionosphere and from the earth's surface. The MHOI system is comprised of a ground transmitter sweeps the HF band and a companion HF receiver records the reflected signals at a large distance from the transmitter. The receiver data are processed to yield a range versus frequency curves that are separated by the number of hops and by the propagation modes of extraordinary (X) and ordinary (O). All of these curves involve specular reflections from the earth and refractions from the ionosphere with incident angles greater than the skip-zone critical angle at each frequency. The MHOI spectrum shows the maximum usable frequency (MUF) for each propagation mode for a given number of hops.

A careful examination of oblique ionograms reveals weak, diffuse elements with group ranges greater than that of the ionogram trace and frequencies greater than the MUF for 2 and greater hops. This diffuse component is attributed to scattering from the ocean or ground terrain. The ocean scatter properties are characterized by a wave height spectrum with Wave Height Energy (Sk, m4) for a given ocean Wave Number (k, m-1). The typical wave height spectrum has a peak near 0.025 m-1 corresponding to an ocean wavelength near 250 meters. For bistatic scattering from the ocean, HF (2 to 30 MHz) can have large Bragg scatter coefficients for selected incident, scatter angles. Propagation paths with out-of-plane scatter azimuths can have group delays much larger that the delays for the specular surface reflections. Any propagation path with different incident and scatter angles will be called incoherent. Specular reflections with equal angles of incidence and reflection in the plane of the ray will be called coherent. These are the designations used by Barrick in the Radar Cross Section Handbook [1970].

Frequency sweeps with the QVI (Quasi Vertical Incidence) transmitter provided by the Navy Over the Horizon Radar (ROTHR) near New Kent Maryland has been used to generate oblique ionograms using a receiver at the MIT Haystack Observatory in Massachusetts and a receiver near Laurel Maryland. A sample of the Maryland data can be viewed as a movie [Reference: Juha Vierinen, YouTube Oct 10, 2013]. This paper explores analyses of ocean scatter to determine the wave-height-spectrum of the ocean. The oblique ionograms from Virginia to receivers with intervening ocean show multiple-hops and diffuse spread from surface scatter of the rough sea.

By coupling an HF ray trace model with a description of ocean surface scatter, the diffuse component of oblique MHOI has be simulated. The model computes the scatter coefficient integrated around constant range contours at the ocean surface. The ionosphere model for the ray trace is adjusted to provide multi-hop oblique ionogram curves that match the observations. The diffuse components of the MHOI are estimated by considering the power reduction of pencil rays refracting in the bottomside ionosphere and illuminating the ocean surface. The scattered wave propagates along another ray tube to the ionosphere to be refracted down to the ground receiver or to another scatter site. The ray tube refraction and scattering are repeated an integer number of times depending on the number of hops. The diffuse component of the propagation model resembles incoherent features in the oblique ionograms. The model demonstrates that a line integral of the bistatic scatter coefficient of the ocean is a weighted measure of the ocean wave height spectra where the HF frequency is analogous to the ocean wave number the spectral power represents the wave height energy.

The limitation of the ground-to-ground oblique ionograms for measuring the ocean properties is that the results are integrated over a large area of the sea. The limitation if removed by placing the HF receiver on a satellite. The motion of the satellite allows characterization of the full wave height spectrum at as specific point on the ocean using synthetic aperture radar (SAR) techniques. This geometry is called Ground-Ionosphere-Ocean-Space. The scattered HF waves do not refract downward by the ionosphere but are refracted through the ionosphere in orbit above the F-layer peak. Interpretation of this data for ocean remote sensing requires knowledge of the F-layer profile where the HF sky wave is turned around to illuminate the ocean and knowledge of the second region of the ionosphere that defines an iris allowing penetration of the scatter HF wave to the satellite. The Canadian ePOP satellite have been used in conjunction with ground HF transmitters to collect HF data that describes the state of the ocean over 1000 x 1000 km region of the earth's surface. Analysis of the ePOP data has shown that propagation through an accurate model of the ionosphere is essential to measuring the properties of ocean swells.