Backscattering of Wide-Band HF Signals from Evolving Ocean-Like Surface: 2-D Direct Numerical Simulations and Analysis

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***Abstract*— Direct numerical simulations are used to calculate wide-band HF radar backscatter from evolving ocean-like surfaces in 2-D space. With the attainable spatial resolution of about 15 m, the large-scale wave pattern is visible in range-time plots of backscatter magnitude. The double Fourier transform of the signal magnitude or power in range and time reveals strong harmonics located along the dispersion curve of the propagating long waves. The signature is not predicted by the 1st-order Small Perturbation Method, and considering the next, 2nd order is required. It is shown that the spectral components along the expected dispersion curves in the *ω-K* domain can be used to retrieve the deterministic wave height of the surface.**

I. Introduction

Vertically polarized sea surface backscatter in the High-Frequency (HF) band (3-30 MHz) is used in a number of maritime remote sensing applications, such as measuring and mapping oceanic currents. With the HF wavelengths ranging from 100 to 10 m, a simple Bragg scattering concept is often adequate to describe the observed effects, making data analysis and surface feature retrieval appealingly simple. Another attractive aspect of HF radiowaves is strong backscatter level at vertical polarization even for large distances, which allows gathering information about surface regions tens of kilometers away. Lately, there has been interest in wide-band (WB) HF applications, with mapping the instantaneous wave height being one of the goals. While implementation of such wide-band systems today can still present certain technological challenges, direct numerical simulations (DNS) can be used to gauge the expected performance, assess the data information content and check the adequacy of analytical scattering models intended to describe the received data and guide the system development.

II. Problem Setup and Simulation Details

We consider a short electric dipole (serving as a transmitting antenna) placed at a height of 10 meters above a surface, as shown in Fig. 1. No variation is assumed along the *y*-axis that points into the page, meaning the 2-D nature of the problem. The surface is planar on average; the Earth's curvature (that in practice will be appreciable at the distances of 40 km) can be included, but is not of primary concern in this study. Only vertically polarized signals and monostatic (backscattering) configuration are considered. The simulation approach, described in detail in [1]–[3] combines an ocean surface model with computationally efficient, exact calculations of the electromagnetic backscatter from any given surface profile.

A. Ocean-Like Surfaces

A surface is generated as a realization of a Gaussian random process with the 1-D version of the Pierson-Moskowitz spectrum [2]. The latter contains a wind speed (at a 19.5-m height) as a parameter. This study used surface realizations corresponding to several wind speeds varying from 5 to 20 m/s, with Fig. 1 showing a 20-m/s profile. No non-linear interactions between surface harmonics (described, for example, by a Creamer transform [1], [2]) are introduced. Time evolution of a particular realization is achieved by varying phases of the surface harmonics according to the free gravity wave dispersion relation [1]. The profiles representing the evolving surface are generated with a time step of 0.2 s and serve as inputs to the numerical scattering technique.

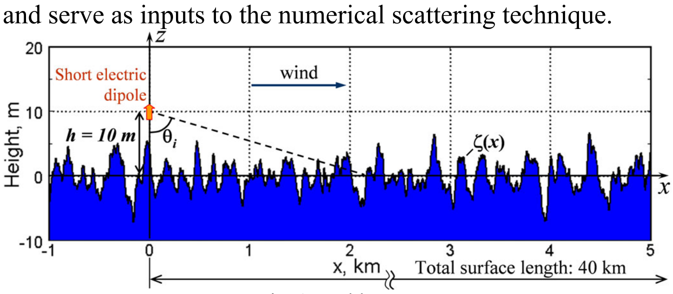

Fig. 1 Problem setup.

B. Scattering calculations

Surface backscatter at a particular electromagnetic frequency is computed using the Method of Ordered Multiple Interactions (MOMI) – a first-principles technique that solves a discretized boundary integral equation for the surface electric current [4]. The method shows robust convergence even as incident field direction approaches grazing. To further reduce computational times, the Novel Spectral Acceleration technique [5] is applied. Dielectric properties of sea water are accounted for by using the impedance boundary condition. For benchmarking purposes and for comparisons with