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FRACTAL MODELS OF FOAM COVERAGE FOR OCEAN MICROWAVE REMOTE SENSING

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Introduction. Methods of fractal geometry are widely used in geophysics and remote sensing for analyses of natural objects and dynamical systems beginning from the fundamental works of Mandelbrot [1]. In particular, in the mid 1990s, a number of authors [2, 3, 4, 5] established an idea that wave breaking and foam/whitecap fields observed in stormy oceans have a universal (multi)fractal characterization. Such a concept was based on an airborne optical and infrared imagery and multiscale data analysis. Indeed, in view of remote sensing (e.g., [6, 7, 8, 9, 10]) fractal methods seem to be a convenient tool for estimations of ocean surface dynamic characteristics including wave breaking processes and foam/whitecap coverage statistics.

Objective. By analogues with the visible and near-infrared ranges of electromagnetic waves, we propose to expand fractal-based approach on the case of thermal microwave radiance. Actually, it is a challenging task to explore the scaling behavior and self-similarity of ocean surface phenomena through a variability of microwave-radiation fields. Another important problem discussed concerns remote sensing measurements and the recognition of geophysical fractal features using passive microwave radiometers/imagers.

Description. Theoretically, fractal representation of ocean microwave radiance fields can be developed in terms of the fractal probability distribution of spectral emissivity $\kappa(\vec{r},t)$ and/or brightness temperature $T_B(\vec{r},t)$ which are both integral functions of many physical parameters including surface wave frequency spectra and foam/whitecap coverage fractions, usually parameterized by wind speed (V); $\vec{r}=\{x,y\}$ are the coordinates and t is time. So, in the case of stationary brightness-temperature fields, statistical fractal scaling is described by the formula $T_B(\lambda\vec{r}) = \lambda^H T_B(\vec{r})$, where λ is a scaling factor, and H is the Hurst exponent ($0 < H < 1$). For two-dimension field (e.g., flat image) the fractal dimension is $D = 2 - H$ ($1 < D < 2$), and for three-dimensional surface $D = 3 - H$ ($2 < D < 3$). The two-dimensional local Hurst exponent H is computed from experimental data using wavelet transform.

To provide an appropriate numerical study, we employ fractal generators with different statistics (e.g., using an inhomogeneous Poisson distribution) to create two-dimensional discrete random fields of radio-brightness. The key point here is that these fields should comprise geometrical fractal sets of distinct objects modelling foam/whitecap coverage. Their spectral emissivity (radio-brightness) and shape are variable parameters according to our definition of foam/whitecap properties at microwave bands [4].

To illustrate possible fractal realizations, we present and explain hypothetical microwave pictures of the ocean surface at variable wind conditions (an example is shown in Fig. 1). In fact, at low winds ($V < 7$ m/s) we model stochastic microwave background associated with surface roughness, and at high winds ($V \geq$ 10-12 m/s) we model foam/whitecap coverage signatures observed in the field of microwave radiance. Spatial evolutions and scale transformations (cascades) of the surface as a whole are characterized by the change in the fractal dimension. So, in certain scale factors (scaling) foam/whitecap signatures become self-similar and the stochastic complexity is reached. In other words, we obtain a (multi)fractal *microwave remote-sensing equivalent* of the Beaufort scale for sea-state. Analogical conclusion has been made from optical data as well [3, 4]. The result indicates also that the estimated "optical" and "microwave" fractal dimensions are closely related at strong and whole gales and lie within the range $D \approx 1.5 - 1.8$.

Conclusion. We report our new theoretical and numerical studies concerning fractal properties of ocean microwave radiance. The results obtained demonstrate that radio-brightness fields of wave breaking and foam/whitecap (i.e., microwave signatures) can be represented as a statistical (multi)fractal geometrical set. Indeed, in certain spatial scales and strong winds the foam/whitecap coverage becomes self-similar natural object that can be observed using advanced multi-resolution optical/microwave imagery. We suppose that this novel issue has a practical value for global remote sensing monitoring of oceans from space and the retrieval techniques as well. It is interesting to note the appearance similarity between oceanic wave breaking fractal fields and Galactic fractal structures.

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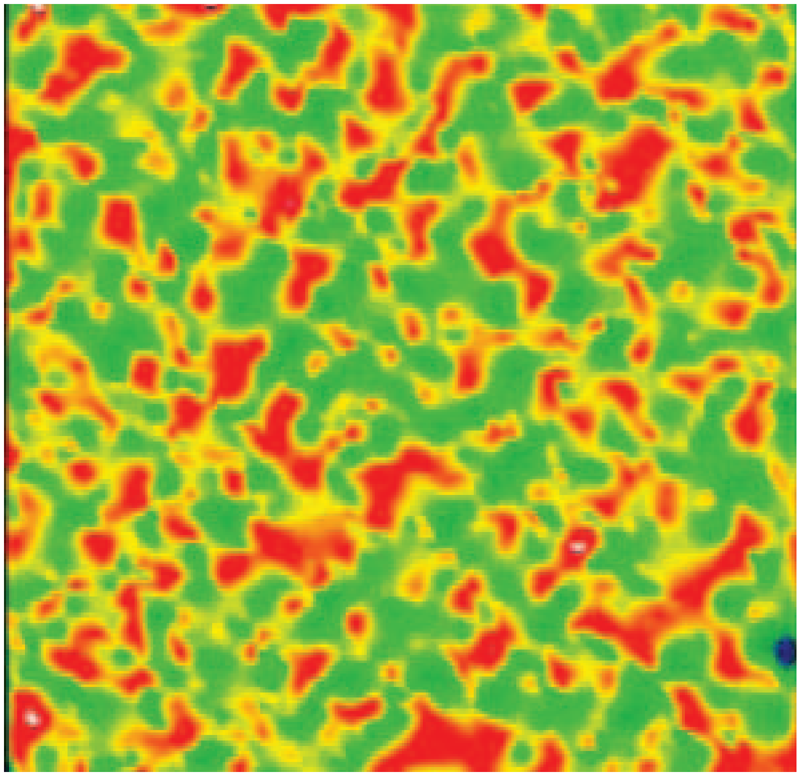

Figure 1. Hypothetic high-resolution radio-brightness picture of ocean wave breaking field (2048 x 2048). Foam/whitecap microwave signatures are revealed as a fractal geometrical set of bright (red) objects. Contrast characteristics can be varied.