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Breaking Ocean Waves

Geometry, Structure, and Remote Sensing

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Preface

The surface of the ocean has drawn the most intent attention of human beings from the very beginning of mankind's history. The breaking of large oceanic waves has an especially hypnotic effect on any ordinary man or woman observing this magnificent phenomenon. These natural processes have repeatedly been the themes in painting (see Plate 1), literature, and music. Very few—if any—people have remained indifferent to this manifestation of the greatness of nature. No less important are the oceanic wave breaking processes for scientific concepts and views in the study of the World Ocean as well.

The study of the physical and dynamic characteristics of gravity waves on the sea surface while they break and the subsequent foam activity and formation of drop-spray clouds are amongst the major problems facing modern satellite oceanology, physics of the ocean–atmosphere interaction, and oceanic engineering (see Plate 2). In particular, the contribution of foam and drop-spray systems of various types to mean values and spatiotemporal variations in microwave (radio emission and backscattering), infrared, and optical parameters of a rough sea surface is significant. Knowledge of the detailed statistical characteristics of breaking wave fields is also important in the study of the dynamics of sea waves (generation of waves, nonlinear interactions, dissipation, etc.).

Despite the external accessibility and seeming simplicity of visual and instrumental observation of the oceanic wave breaking process, detailed scientific data on spatial breaking fields in many different areas of the World Ocean obtained in field remote-sensing experiments are still not yet available. This is principally due to the high spatiotemporal variability in the process of breaking gravity oceanic waves under rough sea conditions and high values of wind speeds over the oceanic surface. Under such complicated aerial navigation conditions, there arise both field experimental methodological complications in remote sensing of these rapid processes by ships and airplanes, and complications of administrative character (e.g., banning of air flights under complex meteorological conditions). And space-borne instruments still do not

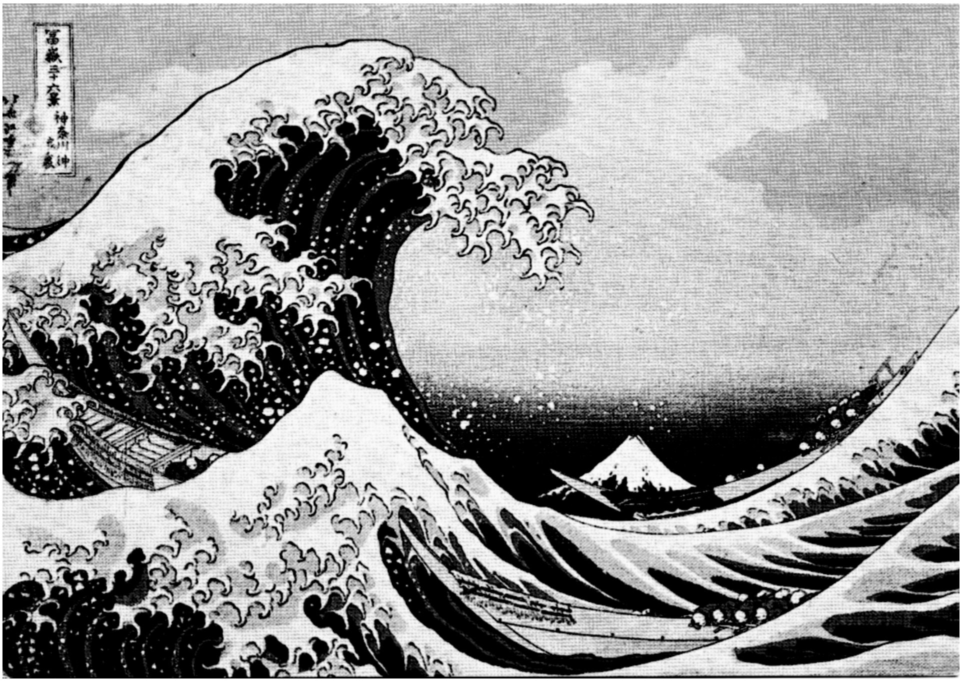

Plate 1. Thirty-six views of Mt. Fuji: View through waves off the coast of Kanagawa, by Katsushika Hokusai (18th century).

possess the spatial resolution sufficient for remote recording of oceanic wave breaking processes.

Note also that—depending on the scientific approaches and particular tasks of remote sensing and sea hydrodynamics—the basic characteristics of the breaking process should now be considered in two principally different aspects at least: in the individual aspect (i.e., in the form of a temporal set of individual breakings) and in plural representation (i.e., in the form of a spatial field of breaking oceanic waves). It should further be noted that—depending on the geometrical characteristics of a remote-sensing system (flight altitude, instantaneous field of view, and time constant of signal storage)—the contribution from the same disperse structure or from a set of structures can in principle be different.

This book represents the first detailed analytical description of the state of remote investigations (in the optical and microwave ranges of electromagnetic waves) of one of the major nonlinear elements of sea dynamics: the process of breaking gravity waves and their subsequent evolution and the dynamics of dispersed foam systems of various classes and the drop-spray phase. Issues in the methodology of multi-scale optical and microwave remote measurements are considered; and the techniques used to study individual breakings and meso-scale, discrete, breaking, random point fields are described. The results of field investigations are presented. The advantages and

Plate 2. Oil platform in rough seas (the North Sea basin).

limitations of various remote complexes, used to reveal the spatiotemporal features of the fields of gravity wave breaking and disperse systems from air carriers of various classes, are also considered in the book. The latest achievements in the field of electrodynamics of emission and scattering of electromagnetic waves by polydisperse close-packed polyhedral media, as well as in the field of electrodynamics of dense flows of the spherical particles of water, are fully described in the book.

The principal feature of the book consists in an integrated description of the spatiotemporal and structural properties of breaking oceanic waves along with its electrodynamics. Emphasis is placed on the physical aspects of breaking processes necessary to judge the possibilities and limitations of remote-sensing methods in specific cases of oceanic surface observation. Numerous practical applications and illustrations, based on air-borne, ship-borne, and up-to-date laboratory experiments, are given in the book.

The book is based on scientific findings from several Russian scientific airborne remote-sensing expeditions to the Far East (the Pacific Ocean), the Black Sea, the Caspian Sea, and the Barents Sea, as well as from several scientific marine expeditions to the tropics and, once more, to the Far East as part of a number of major research projects of the Russian Academy of Sciences. These findings were presented in lectures by the author at the Moscow Physical and Technical Institute (in Dolgoprudnyi, near

Moscow) and at the Moscow University of Geodesy, Mapping, and Aero-Photo Surveying to students of physics and geophysics.

In the field of application of remote observations of the oceanic surface, a book is needed that would represent a systematic and unified statement of the fundamental concepts and issues of the theory of breaking gravity waves, the electrodynamic properties of disperse systems arising during the breaking process, as well as of the various instrumental and methodological issues of microwave and optical remote measurements. In addition, it would be useful to provide a unified and systematic description of the latest achievements in the field of microwave sensing of a rough sea surface (i.e., one that is easily accessible to undergraduate students, post-graduate students, researchers, engineers, and instrument operators). The present book was conceived to give as large a systematized idea of the possibilities and modern achievements of methods of the remote sensing of a rough sea surface as possible to a wide range of specialists and interested readers.

The format of the book is constructed in such a way that the reader could acquire the necessary knowledge of the physical mechanisms of breaking gravity waves that he or she needs, in addition to the most complete information available on the modern level of development of microwave and optical remote diagnostics of a rough sea surface. The content of the present book is essentially broader than the requirements that are usually set out in a handbook for students. Much of it contains detailed information and can be used as a reference book to the many special issues of the microwave and optical remote diagnostics of the oceanic surface.

The first chapter of the book considers the scientific and applied aspects of remotely sensing the sea surface, the role and place of optical and microwave methods and instruments in the study of breaking waves, the basic concepts of the modern theory of breaking gravity waves, the possibilities of passive and active methods of microwave diagnostics of a rough sea surface. The second chapter is devoted to the results of airborne sensing of spatial fields of breaking sea waves in two modes: limited fetch and fully developed sea state. On the basis of experimental data, important modeling ideas are proposed for the spatial field of breaking sea waves that occur as a result of the formation of Poisson's point field of non-interacting centers. The third chapter presents the results of experimental investigation into the geometrical characteristics (linear and two-dimensional sizes) of the process of individual breaking gravity wave (whitecapping) and foam fields of various types. On the basis of experimental data, the statistical models of breaking processes are constructed. Critical analysis of existing theoretical concepts of wave breaking as a result of the threshold mechanism for a random Gaussian three-dimensional field (breaking criteria, threshold mechanism restrictions, etc.) is carried out. The fourth chapter gives the results of experimental investigations into the lifetime of the disperse phase of a whitecapped gravity wave: in particular, revealing the exponential character of the temporal evolution of a whitecapping crest and patch foam structures, and detection of a specific group of gravity wave breaking (microbreaking). The fifth chapter is devoted to studying the nature of formation of the disperse structure and the contribution of a drop-spray phase—formed as a result of breaking—to the mass and moisture exchange in the ocean–atmosphere system. The sixth chapter contains a detailed analysis of the electrodynamics of absorption and emission of close-packed media of colloid-type foam. The generally colloidal, physical, and disperse properties of close-packed foam structures are considered in detail. Great attention is given in this chapter to the methods of describing the electromagnetic properties of rarefied and close-packed disperse structures; also the results of detailed experimental investigations are presented in which two types of colloidal structures were found that essentially differ in their emissive characteristics (viz., a monolayer of multiple emulsion and a foam layer of polyhedral structure). An entire spectrum of electromagnetic models of foam systems is analyzed in the chapter, and a model is found that agrees well with experimental data—namely, a model of the inhomogeneous dielectric layer that involves the scattering of hollow spheres and a non-sharp transitional phase boundary. The seventh chapter is devoted to studying the electrodynamics of a drop-spray phase as a flow of highly concentrated drop medium. Optical models for rarefied flows in the radiative transfer theory and their restrictions are considered. Then, the results of specialized experiments on studying the electromagnetic properties of dense drop flows and the possibilities of their use for forming the electromagnetic models of a drop-spray phase of breaking waves are analyzed in detail. Chapter 8 is devoted to detailed analysis of remote field investigations of the transition zone in the ocean–atmosphere system by means of optical, IR, and microwave air–space missions, beginning with the first successful Russian missions on the "Cosmos-243" and "Cosmos-384" satellites carrying microwave multi-frequency instruments. The results of field experiments carried out onboard research vessels by means of microwave active–passive instruments in the Indian Ocean are outlined in detail. Prominence is given in this chapter to the description of modern models of the state of the ocean–atmosphere system under storm conditions (models, hypotheses, preliminary experiments, etc.). The modern situation in the instrument field of potential microwave remote missions, the ways of developing observation techniques and methods, and the exploiting of new frequency ranges for detailed studying of the state of the oceanic surface are all fully considered.

A detailed bibliography is given at the end of the book that should be useful both for undergraduate students and post-graduate students of applicable specialties, as well as for researchers.

The book is aimed at researchers, university teachers, and undergraduate and postgraduate students working in geography, meteorology, climatology, atmospheric physics, geophysics, oceanography, and in the environmental science areas of remote sensing and geophysics.

Many of the experimental and full-scale results, used in preparing the book, were obtained by the author during his work at the Space Research Institute of the Russian Academy of Sciences (SRI RAS). The full-scale laboratory experiments performed during 1974–1993 by SRI co-workers using highly sensitive optical and microwave instruments, as well as the unique results obtained with their help, have determined in many respects the design of future air–space microwave instruments for studying the state of the oceanic surface.

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Figures

Tables

Abbreviations and acronyms

ADP	Antenna Directional Pattern
AFA-100	Type of Russian aerosurveying camera
AFA-TE-100	Type of Russian aerosurveying camera
AN-30	Antonov-30 (Russian research aircraft)
DSP	Drop-Spray Phase
EBS	Effective Backscattering Surface
ESA	Effective Scattering Area
HF	High-Frequency
IL-14	ILyushin-14 (Russian aircraft)
IR	InfraRed
IW	Internal Wave
JONSWAP	Joint North Sea Wave Project
LF	Low-Frequency
MB	MesoBreaking
MGPI	Moscow State Pedagogical Institute
MKF-6	Type of Russian space-borne multiband photographic camera
OI	Optical Image
PSD	Polar Scattering Diagram
RAS	Russian Academy of Sciences
RCS	Radar Cross-Section
RFT	Rapid Fourier Transformation
RHV	Research Hydrographical Vessel
RTI	Range–Time–Intensity (diagram)
RV	Research Vessel
SAS	Surface-Active Substance
SRI	Space Research Institute
VH and HV	Cross-polarization