

Upper Meter Processes: Short Wind Waves, Surface Flow, and Micro-Turbulence

Bernd Jaehne

Physical Oceanography Research Division 0230

Scripps Institution of Oceanography

La Jolla, CA 92093-0230

phone: (619) 534-6860 fax: (619) 534-8509 e-mail: bjahne@ucsd.edu

Jochen Klinke

Physical Oceanography Research Division 0230

Scripps Institution of Oceanography

La Jolla, CA 92093-0230

Xin Zhang

Physical Oceanography Research Division 0230

Scripps Institution of Oceanography

La Jolla, CA 92093-0230

Award # N00014-93-1-0093

LONG-TERM GOAL

The primary goal of this project is to advance the knowledge of small-scale air-sea interaction processes at the ocean surface, focussing on the dynamics of short waves, the surface flow field and the micro-turbulence. Since ground truth on the small-scale shape of the sea surface and the processes forming it is still widely missing, a better understanding of the physics of these upper meter processes is of utmost importance for the study of electromagnetic backscatter from the sea surface.

OBJECTIVES

The scientific objective of this research project includes the development and use of novel experimental methods based on imaging optical techniques to measure both short wind waves and the turbulence and flow field at the ocean interface. The area extended data resulting from these instruments are combined with meteorological ground truth to obtain a better insight into the dynamics of the interaction between short wind waves and the turbulent drift layer at the ocean surface as a function of wind stress, surface films, surface currents, and swell.

APPROACH

Our experimental approach is centered around a drifting buoy that carries an improved imaging wave slope system (ISG) and an infrared imaging system for the simultaneous measurement of the wave slope and microscale temperature fluctuations within the same foot print. Image sequences from the infrared system are evaluated with image sequence processing techniques to determine the flow field at the surface of the ocean.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 1998		2. REPORT TYPE		3. DATES COVERED 00-00-1998 to 00-00-1998	
4. TITLE AND SUBTITLE Upper Meter Processes: Short Wind Waves, Surface Flow, and Micro-Turbulence				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of California, San Diego, Scripps Institution of Oceanography, La Jolla, CA, 92093				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002252.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

WORK COMPLETED

1. After the computer system failure of the wave buoy during the North Atlantic CoOP cruise in June/July 1997 a complete redesign of the computer and control system was required. This has been completed now and the whole system is currently been tested in the Scripps Hydrolab. Because of the importance of high slopes for radar backscatter the wave imaging system has carefully be checked and calibrated for high wave slopes. It turned out that the system is capable of measurements of slopes up to 1.2 (50 degree) over the whole image sector - more than we initially expected.
2. Image sequence processing algorithms have been developed to determine the surface flow field from infrared imagery. With this development it is possible to measure the surface flow field simultaneously to the phase speed of the short wind waves (obtained from the wave slope images) and thus to determine phase speeds of the waves relative to the surface flow field. The image processing algorithms are exact enough to allow also for the determination of derivatives of the flow field such as the divergence and rotation of the flow field (Jaehne et al., 1998; Haussecker and Jaehne 1998)
3. Our large base of laboratory data, which has proven essential for the comparison with field data, has been extended with additional measurements from the Wallops wind/wave flume.
4. A new technique has been developed to analyze wave slope images in the space/wave number domain in order to determine the local wave numbers and the direction of the waves. This new technique is based on a scale space decomposition of the wave images including a decomposition in 6 directional components using steerable filters (Carstens, 1998). Since such filters can be steered in any direction, it is possible to generate a four-dimensional data structure that determines the distribution of waves in wave number and direction for each point in the image. With a nonlinear regression technique, up to three superimposed wave components can be detected simultaneously. This novel technique gives a spatially resolved distribution of wave numbers, including the individual amplitude of the waves. Thus it gives much more insight than conventional Fourier transform techniques and power spectra.

RESULTS

The comparison of the wave number spectra of short wind waves from the lab and the field show large scatter of the spectral densities at low wind speeds. This can be attributed to the effect of surface films and background wave conditions. For higher wind speeds the dependence of the spectral density on the friction velocity is found to vary with the wave number from linear for short gravity waves to almost cubic for capillary waves.

Other investigators (Hara et al. (1994) and Hwang et al. (1996)) observed significantly higher spectral densities at low wind speeds than our laboratory data (Jaehne and Riemer, 1990) from the Delft wind wave flume at 100 m fetch. As one possible explanation they offered the fluctuating component of the wind field, which is high in the field but low in the laboratory. Meanwhile, however, we have accumulated much more detailed data including measurements from the Delft, Marseille, Heidelberg, and Wallops facilities. The data show that the 1988 Delft data have the lowest spectral densities.

Especially the spectral densities in the Heidelberg facility with unlimited fetch, are a factor of 2-4 higher at low wind speeds and therefore similar to the field data. This suggests another explanation for the higher spectral densities of short waves at low wind speed under oceanic conditions. Since the pioneering experiments of Cox (1958), it is known that steep short gravity waves generate parasitic capillary waves without applying wind. In the field, where additional sources exist for the generation of short gravity waves, it is natural that parasitic capillary waves should be produced more frequently.

The novel technique to analyze waves slope images as described in section WORK COMPLETED 4 has been used to compute distributions of the slope amplitude as a function of the wave number. In contrast, the Fourier transform essential gives only the mean value of this distribution. These "amplitude resolved" spectra show very interesting results. At low wind speeds, the spectral density of capillary waves is much lower than that of short gravity waves. However, the mean steepness of the capillary waves is still higher. The capillary waves just occupy a much smaller area. At high wind speeds, when the saturation range of the capillary waves is higher than that of short gravity waves, the slope distribution of capillary waves and short gravity waves is similar, except for a long tail towards steeper slopes in the distribution for capillary waves.

IMPACT/APPLICATION

The data acquired during MBL ARI 1995, during the CoOP cruise 1997, and future measurements from the SIO Marine Observatory will finally allow for a systematic study of the parameters influencing the wave number spectra of short wind waves. As demonstrated by the recent results, the quantitative comparisons with our detailed measurements of wave number spectra in laboratory facilities under controlled conditions will be an invaluable asset for the understanding of the wave number spectra measured at sea.

The new wave imaging buoy permits the study of the interaction of surface turbulence and surface waves, by using the wave slope imaging technique in combination with the infrared imaging of the water surface. It is also suitable to measure the modulation of short waves by long waves.

TRANSITIONS

The IR surface turbulence imaging technique is now being used by K. Melville (Scripps Institution of Oceanography) in an NSF project on generation and evolution of Langmuir circulation in the laboratory and by A. Jessup (APL, University of Washington, Seattle) to study the influence of microscale wave breaking on gas transfer. In the last year we have assisted even more researchers, devices including K. Melville (Scripps Institution Oceanography), N. E. Huang (NASA/Goddard Space Flight Center) and S. Long (NASA/Wallops Flight Facility), and taught them how to use the wave slope imaging technique. More recently, M. Donelan (University Florida, Miami) has inquired about the use of the technique. Given the significant number of researchers that are now using the observational techniques developed by our research group, it is fair to say that our research, sponsored by the ONR in the last eight years, has triggered a new quality in the experimental investigation of small-scale air-sea interaction processes.

REFERENCES

- Jaehne, B., Impact of Quantitative Visualization and Image Processing on the Study of Small-Scale Air-Sea Interaction, Proceedings Air-Water Gas Transfer, Selected Papers, 3rd Intern. Symp. on Air-Water Gas Transfer, edited by B. Jaehne and E. Monahan, AEON, Hanau, pp. 3-12, 1995.
- Klinke, J., and B. Jaehne, Measurements of Short Ocean Waves during the MBL ARI West Coast Experiment, Air-Water Gas Transfer, Selected Papers, 3rd Intern. Symp. on Air-Water Gas Transfer, edited by B. Jaehne and E. Monahan, AEON, Hanau, pp. 165-173, 1995.
- Klinke, J., Optical Measurements of Small-Scale Wind-Generated Water Surface Waves in the Laboratory and the Field, Dissertation, Univ. Heidelberg, Germany, 1996.
- Jaehne, B., Practical Handbook on Digital Image Processing for Scientific Applications, CRC-Press, Boca Raton, FL, USA, 1997.
- Jaehne, B., Digital Image Processing - Concepts, Algorithms, and Scientific Applications, 4th completely revised edition, Springer, Berlin.
- Balschbach, G., J. Klinke, and B. Jaehne, Multichannel shape from shading techniques for reconstruction of specular surfaces, Proc. 3D Image Analysis and Synthesis'97, Erlangen (Germany), November 17-18, 1997, H.-P. Seidel, B. Girod, H. Niemann (eds.), infix, Sankt Augustin, pp. 115-122.
- Haussecker, H., and B. Jaehne, A tensor approach for precise computation of dense displacement vector fields, Proc. Mustererkennung 1997, Braunschweig, 15-17. September 1997, E. Paulus und F. M. Wahl (eds.), Informatik Aktuell, Springer, Berlin, 199-208, 1997.
- Klinke and B. Jaehne, Wave number spectra of short wind waves: a comparative study with data from wind/waves facilities and the field, abstract submitted to the OS18 Special Session Dynamics of the Ocean Surface Mixed Layer, at the AGU Ocean Science Meeting, San Diego, USA, February 9-13, 1988.
- U. Schimpf, J. Klinke, H. Haussecker, and B. Jaehne, Novel instrumentation for synergetic studies of short wind waves, surface micro turbulence and air-sea gas transfer, abstract for poster submitted to the OS26 Special Session Recent Advances in Ocean and Fresh Water Science Instrumentation, at the AGU Ocean Science Meeting, San Diego, USA, February 9-13, 1988.
- J. Dieter and B. Jaehne, A new instrument to measure the statistical properties of short wind waves, abstract for poster submitted to the OS26 Special Session Recent Advances in Ocean and Fresh Water Science Instrumentation, at the AGU Ocean Science Meeting, San Diego, USA, February 9-13, 1988.
- Balschbach, G., J. Klinke, and B. Jaehne, Multichannel shape from shading techniques for moving specular surfaces, Computer Vision (ECCV'98), Proc. Vol. II, H. Burkhardt and B. Neumann (eds.), Lecture Notes in Computer Science 1407, Springer-Verlag, Berlin, pp. 170-184.

- Jaehne, B., H. Haussecker, H. Spies, D. Schmundt, and U. Schurr, Study of dynamical processes with tensor-based spatiotemporal image processing techniques, Computer Vision (ECCV'98), Proc. Vol. II, H. Burkhardt and B. Neumann (eds.), Lecture Notes in Computer Science 1407, Springer-Verlag, Berlin, pp. 322-335.
- Carstens, H., A scale space approach for the space/wave number domain analysis of wind-generated waves, Diploma thesis, University of Heidelberg, 1988.
- Haussecker, H., and B. Jaehne, Tensor-based image sequence processing techniques for the study of dynamical processes, invited paper, International Symposium on Realtime Imaging and Dynamic Analysis, Hakodate, Japan, June 2-5, 1998.
- Huang, N., Y. Toba, Z. Shen, J. Klinke, B. Jaehne, and M. Banner, Ocean wave spectra and integral properties, In Wind Stress Over the Ocean, Cambridge University Press, 1998, in press.
- Klinke, J. and B. Jaehne, Wave number spectra of short wind waves: a comparative study with data from wind/wave facilities and the field, 1998, to be submitted to JPO.
- Klinke, J., and Jaehne, B., A free-drifting buoy for short wave slope imaging, 1998, to be submitted to JAOT.
- Jaehne, B., H. Haussecker, and P. Geissler (eds.), Handbook of Computer Vision and Applications (3 volumes, approx. 2500 pages), Academic Press, 1999, in press.