

Airborne Measurements of Whitecap Kinematics and Dynamics in the High-Wind Regime: Source Functions for Marine Aerosols, Surface Currents and Turbulence

W. Kendall Melville
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0213
phone: (858) 534-0478 fax: (858) 534-7132 email: kmelville@ucsd.edu

Eric Terrill
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0213
phone: (858) 822-3101 fax: (858) 534-7132 email: et@mpl.ucsd.edu

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LONG-TERM GOALS

The long-term goals of this research are to improve our knowledge and understanding of the role of breaking in air-sea interaction. We are concerned with the role of breaking in the fluxes of momentum, energy (mechanical and heat) and mass (gasses & aerosols) across the air-sea interface. These processes are important for the generation of ocean currents, air-sea heat and gas transfer, surface-wave evolution and dissipation, upper ocean mixing and transport, and hurricane dynamics (Melville, 1996).

OBJECTIVES

The objectives of this effort are to demonstrate that visible and infrared remote sensing of whitecaps can be used to improve models of momentum transfer, turbulent mixing and aerosol generation in the high-wind and hurricane regime.

APPROACH

Our approach, which was first developed in the ONR Shoaling Waves Experiment (SHOWEX), is to use modern quantitative imaging techniques to measure the kinematics of breaking in the field and relate it to the fluxes of momentum, energy and mass across the air-sea interface through the use of simple scaling arguments and models.

The basis of the approach is the statistical description of breaking at the ocean surface in terms of $\Lambda(\mathbf{c})d\mathbf{c}$, the average length of breaking fronts per unit area of ocean surface moving with velocities in the range $(\mathbf{c}, \mathbf{c}+d\mathbf{c})$. This was introduced by Phillips (1985) who showed how the kinematics and dynamics could be related through simple scaling arguments (Duncan, 1981) that showed that the loss of energy from the wave field per unit length of breaking front was proportional to $\rho g^{-1} c^5$. This

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permitted Phillips to predict the breaking statistics for an equilibrium wave field in which there was a balance between wind input, wave-wave interactions and dissipation due to breaking.

Airborne visible imagery and motion instrumentation permit the measurement of $\Lambda(\mathbf{c})dc$ in the field. This was attempted in SHOWEX, using the methods of particle imaging velocimetry (PIV) to measure the kinematics of breaking in an Earth frame and thereby measure $\Lambda(\mathbf{c})dc$. In Melville & Matusov (2002) the results of those measurements from the LongEZ aircraft are presented along with supporting measurements of the wave field.

In the CBLAST Hurricane program our approach is to fly the imaging equipment (both visible and IR) along with a laser altimeter on board the NOAA "Hurricane Hunter" P3s based at MacDill airbase in Tampa, Florida. The laser altimeter has a useful range of 300-350m to the water surface and will give direct wave information bore-sighted with the images at low aircraft altitudes. This will permit coherent processing of the image and wave data to determine the characteristics of the breaking waves. At higher altitudes we expect to collaborate with Ed Walsh of NOAA whose radar wave measurements will provide a broader coverage of the surface wave field.

Measurements of $\Lambda(\mathbf{c})dc$ and its various moments will be used to infer surface renewal by breaking, whitecap coverage, mixing by breaking and the momentum and energy fluxes from waves to the mixed layer. Since the bubbles and sea spray generated by breaking are proportional to $\Lambda(\mathbf{c})dc$ (and perhaps other variables) we will work to interpret our measurements in the context of improved models of sea-spray generation. We will also develop image-processing algorithms to distinguish between whitecapping and the spume/spray generated by high winds shearing off the crests of the waves. Sea spray is an important contributor to the heat transfer in high winds and improved measurements and models of spray generation will lead to improved hurricane models.

Apart from the co-PIs, the key individuals working on this project are Peter Matusov who has developed the imaging hardware and software, and Jessica Kleiss a new PO student at SIO who will be involved in all aspects of the project.

WORK COMPLETED

With funding only starting late December 2001, and the first hurricane season of the project not yet over, there are no significant scientific results to report at this stage. However, we have made significant progress in the last 9 months in acquiring and building hardware, installing it on the NOAA P3 (N43) and conducting test flights including two during Hurricane Isidore in September 2002.

Figure 1 shows the the package consisting of the video camera, laser altimeter and inertial motion unit (IMU) installed on the mounting frame that is secured above the viewing port under the floor of the aircraft. Figure 2 shows an image of the sea surface taken from the side window of the P3 approximately 50 miles from the eye of hurricane Isidore. Note the density of whitecaps on the ocean surface.

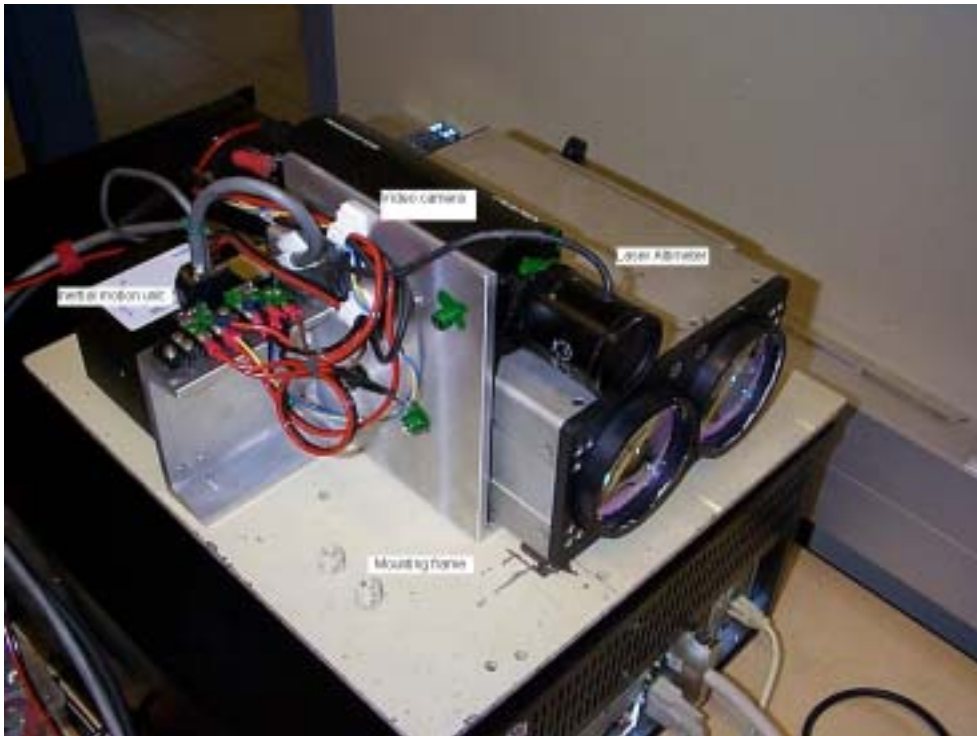


Figure 1. Imaging subsystem comprised of video camera, laser altimeter and inertial motion unit.



Figure 2. The sea surface at approximately 50 miles from the eye of hurricane Isidore

During the flight into Isidore, whitecaps with breaking fronts up to 200m long were imaged. Figure 3 shows an example of an image approximately 300mx300m in which can be seen a whitecap approximately 100m long. Note also the approximately linear streaks of foam from earlier whitecaps.



Figure 3. A large whitecap approximately 100m along the crest in hurricane Isidore.

RESULTS

During this first year we overcome most of the technical issues of mounting our equipment on the NOAA P3s and participating in hurricane flights. We still have to incorporate the IR imager into the suite of instruments and more fully integrate our equipment into the P3 data bus. With the hurricane season still active our efforts are concentrated on acquiring data and testing equipment rather than producing finished technical results.

IMPACT/APPLICATIONS

If successful, this project will produce very valuable data and models that represent the role of surface wave breaking and whitecapping on air-sea interaction in hurricane winds.

TRANSITIONS {BOLD, ALL CAPS}

None yet.

RELATED PROJECTS

This project is closely related to other P3-based projects in CBLAST/Hurricane under the leadership of Peter Black as Chief Scientist. We expect to collaborate most closely with Peter Black and Ed Walsh in relating our measurements of breaking to the atmospheric and wave variables they will measure.

The PIs have another CBLAST project (“Autonomous profiler measurements of the air-sea interface in very high sea states”, N00014-00-1-0894; Terrill, PI) that is developing an air-deployed variant of the PALACE float to provide high frequency, high resolution upper mixed layer and wave measurements under hurricanes. The projects will permit us to correlate the mixed layer profiles with mixing and air entrainment due to breaking.

Ken Melville is collaborating with Peter Sullivan and Jim McWilliams to incorporate breaking into DNS and LES models of coupled boundary layers. Sullivan and McWilliams are supported under CBLAST (N00014-00-C-0180; Sullivan, PI)

The PIs (along with Dariusz Stramski) are participants in ONR’s HYCODE program. Our component of this program is using acoustical and optical techniques to measure entrained air in the marine wave boundary layer (MWBL) and its effects on the inherent optical properties of near surface waters (N00014-02-1-0190; Terrill, PI).

The PIs are collaborating in the ONR Rough Evaporation Duct Experiment (RED), measuring bubbles and breaking waves in support of estimates of the source functions for marine aerosols which are important in em propagation. (N00014-01-1-0701; Terrill, PI).

REFERENCES

Melville, W.K. 1996, The role of surface-wave breaking in air-sea interaction. *Annu. Rev. Fluid Mech.*, 28, 279-321.

Melville, W.K. & Matusov, P. 2002 Measurements of breaking waves at the ocean surface: equilibrium and saturation subranges. *Nature*, **417**, 58-63.

Phillips, O.M. 1985, Spectral and statistical properties of the equilibrium range of wind-generated gravity waves. *J. Fluid Mech.*, **156**, 505-531.

PUBLICATIONS

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