

## **Wave-Phase-Resolved Air-Sea Interaction**

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### **LONG-TERM GOALS**

The long-term goals of this program are to measure and model air-sea interaction coherently with the surface wave field. That is, resolve air-sea interaction at the phase of the surface waves.

### **OBJECTIVES**

To conduct a field experiment off the coast of Southern California (SoCal2013) using R/P FLIP, airborne remote sensing with the Modular Aerial Sensing System (MASS) flown in a Partenavia P68 aircraft and two autonomous surface vehicles (ASVs: Liquid Robotics Wave Gliders) instrumented for surface-ocean-lower-atmosphere (SOLA) measurements (See Figure 1).

### **APPROACH**

For three weeks in November 2013 the PI, along with Eric Terrill (SIO) on the R/V Melville, and colleagues from the EO Division of SPAWAR and NSWCCD on both FLIP and the Melville (SSCPAC PIs: Hammel & Tsintikidis, NSWCCD: Merrill), conducted an experiment centered around FLIP, which was moored NW of San Clemente Island. While the experiment was focused on phase-resolved measurements of air-sea interaction, the SPAWAR and NSWCCD teams conducted detailed EM and laser propagation studies in the MABL between the research vessel and FLIP.

The experiment provided the opportunity to test three significant improvements in our experimental capabilities.

1. Flying the MASS system with its higher resolution Riegl Q680i topographic waveform scanning lidar for surface wave measurements down to sub-meter horizontal scales, and high resolution visible and IR cameras for imaging ocean surface processes (breaking waves and Langmuir turbulence).
2. Testing the capabilities of two Wave Gliders (WGs) with SOLA instrumentation to make such measurements consistent with the measurements from FLIP. This also included testing the capability of the WGs to be maneuvered in upwind and crosswind tracks in close proximity to FLIP.

3. Testing a new extendable mast instrumented with atmospheric sensors at 5 stations from approximately 2 m above the highest waves to approximately 15.5 m above the mean sea level (MSL). The mast permitted the testing of models of wind-wave generation that include predictions of the decay with height of wave-induced flow above the surface.

## **WORK COMPLETED**

The SoCal2013 experiment was completed in November 2013. Analysis of the data is continuing.

## **RESULTS**

Data from the MASS lidar with resolution down to wavelengths of less than a meter are showing a clear transition in the omnidirectional spectrum from an equilibrium regime,  $k^{-5/2}$ , to a saturation regime,  $k^{-3}$ . See Figure 2.

Data from the atmospheric mast on FLIP are showing a clear scaling of the wave-coherent flow with height above the surface consistent with critical flow models of wind-wave generation.

The WGs proved very successful in measuring the initial development of cross-wind structure in the surface layer of the ocean following the onset of a wind event. Their ability to maneuver in close proximity to FLIP and the Melville was confirmed. In a related effort (Lenain & Melville 2014) it was shown that a WG could make SOLA measurements within 36 km of the eye of a Category 3 tropical cyclone. With this experience in SoCal2013 and a tropical cyclone, we expect WGs to become an important asset in air-sea interaction research (Figure 3).

Data from a scan-beam ADCP on FLIP was consistent with surface signatures of Langmuir turbulence obtained with visible imagery from FLIP (Figure 4).

We are in the process of writing this work up for publication in several papers.

## **IMPACT/APPLICATIONS**

Although preliminary, the direct impact of the results of the SoCal2013 experiment is in demonstrating that we can coherently measure and interpret processes of air-sea interaction and SOLA kinematics and dynamics at the scale of the surface waves.

As a result of this work we are now in a position measure and interpret many of the major processes that contribute to the influence of the surface wave field on the lower atmosphere and upper ocean. This will contribute significantly to improved algorithms for air-sea interaction that depend on more than just a wind speed and sea surface temperature (SST).

Furthermore, our colleagues at SPAWAR and NSWCCD, working on EO propagation and scattering, have expressed the benefits of making such measurements with all the supporting data we provided in SoCal2013.

## REFERENCES

Luc Lenain and W. Kendall Melville, 2014: Autonomous Surface Vehicle Measurements of the Ocean's Response to Tropical Cyclone Freda. *J. Atmos. Oceanic Technol.*, **31**, 2169–2190.  
doi: <http://dx.doi.org/10.1175/JTECH-D-14-00012.1>

## RELATED PROJECTS

The work described in this report benefits greatly from our other SOLA research, especially projects that include both manned and unmanned airborne air-sea interaction research. These projects include:

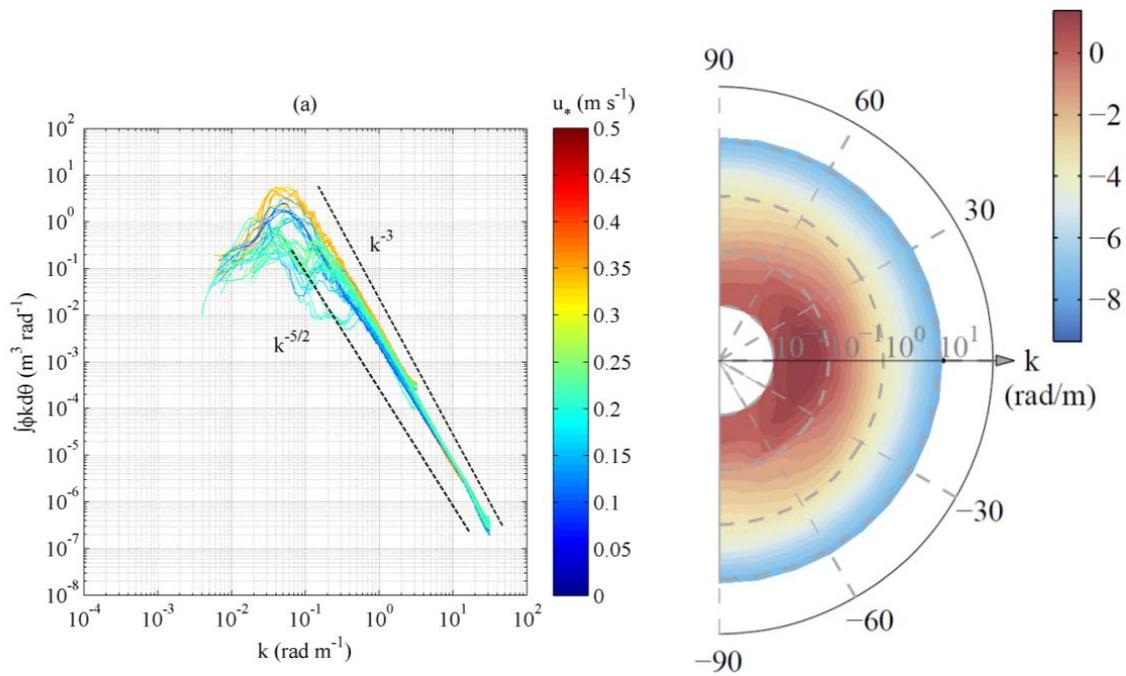
1. Ship-Based UAV Measurements of Air-Sea Interaction Processes in the Equatorial Indian Ocean (Expansion for UAV Science Operations from the R/V Knorr, June 2013) N00014-13-1-0193;
2. Measurements and modeling of the kinematics and dynamics of surface wave breaking in directional wave fields, NSF, OCE 11-55403

## HONORS/AWARDS/PRIZES

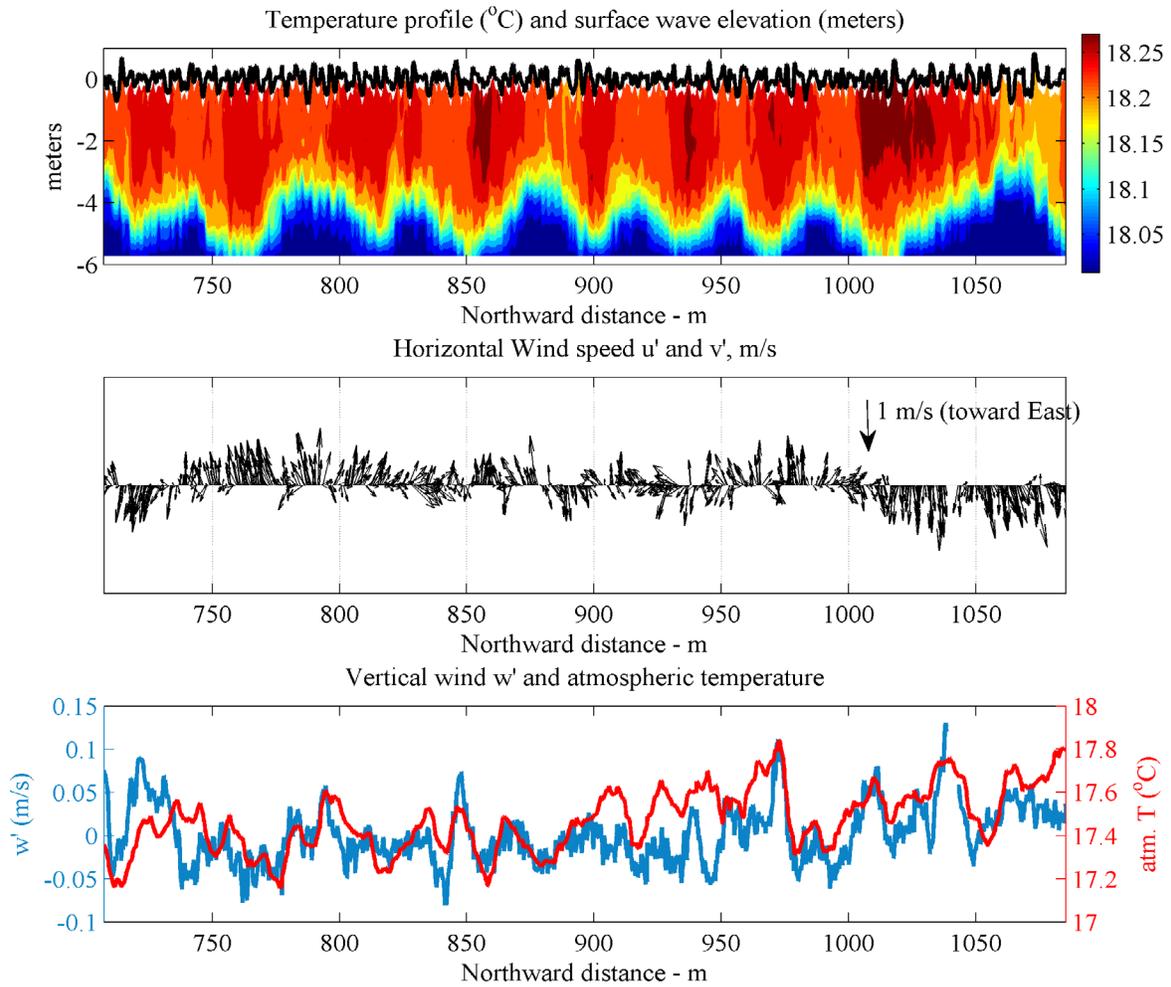
Not previously reported: The PI was awarded the 2013 Sverdrup Gold Medal of the American Meteorological Society for "... pioneering contributions in advancing knowledge on the role of surface wave breaking and related processes in air-sea interaction."



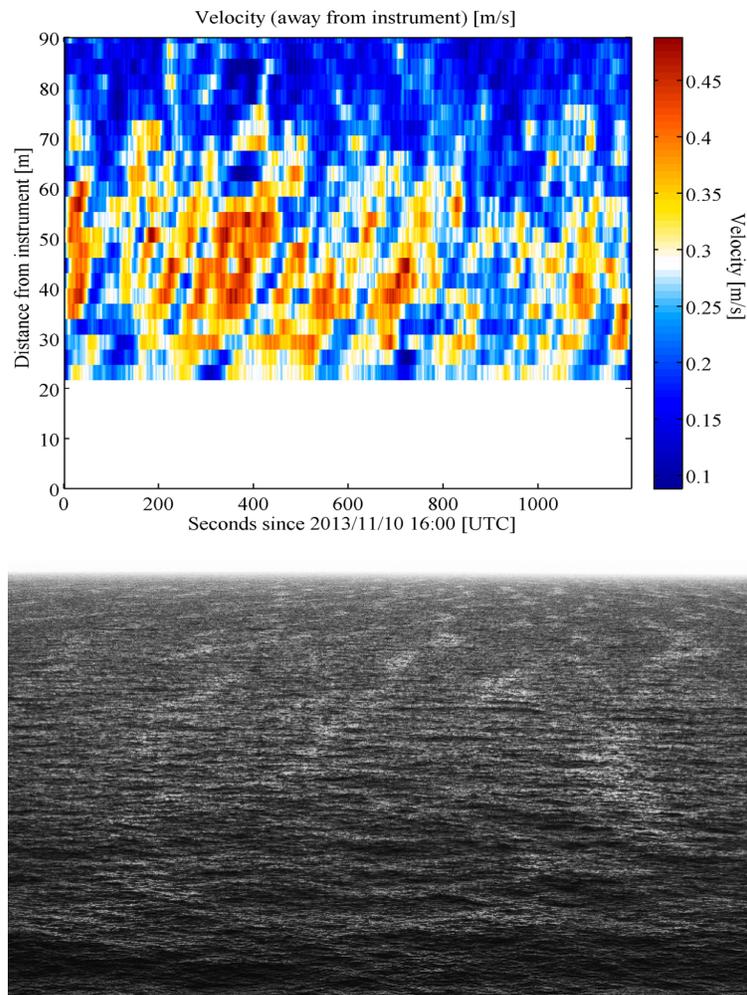
**Figure 1: Measurement platforms used during SoCal2013 experiment. Left panel shows the Partenavia aircraft making a low pass over R/P FLIP. Right panel shows a wave glider (yellow object in foreground) navigating between R/V Melville and R/P FLIP.**



**Figure 2:** (right) Directional wavenumber spectrum from the sea surface topography recorded at 150 m altitude above mean sea level (AMSL) using the MASS on a November 15 2013 flight off San Clemente Island during the ONR SOCAL2013 experiment at 20:08 UTC. These data give spectra down to wavelengths of 0.5 m. (left) Omnidirectional wavenumber spectra color coded for friction velocity  $u_*$  computed for the entire experiment. Note the  $-5/2$  and  $-3$  spectral slopes.



**Figure 3: Example of measurements collected from a Wave Glider “during the SOCAL2013 experiment on November 9, 2013 at 00:40 UTC during a cross-wind leg. The top panel shows the surface displacement (waves) measured from the glider float in black, and the underlying temperature profile down to approximately 6m. The middle panel shows the horizontal,  $u'$  and  $v'$ , components of the wind along the same track (respectively toward East and North). Finally the bottom panel shows the vertical wind  $w'$  and fast response measurements of atmospheric temperature. All wind measurements are from the sonic anemometer located 0.8 m above the water surface.**



***Figure 4: Observations of along-wind streak structures. Top panel shows cross-wind near-surface current velocity measured using a fan-beam ADCP mounted on FLIP's hull. The bottom panel is a (contrast enhanced) image taken by the video camera mounted on FLIP's crows nest showing streak structures at the surface. The regions of convergence in the ADCP data are thought to correspond to the streak structures seen in the visible imagery.***