High-Resolution Airborne Waveform Lidar for Oceanographic Research

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1. Introduction

It is now accepted that to better understand the coupling between the atmosphere and the ocean, surface-wave processes must be taken into account. Traditional airborne lidar systems and in situ instrumentation have limited directional and frequency responses and do not have the resolution required to fully test modern theories of directional wave spectra. Directional observations at lower and higher wavenumbers, the latter being close to the end of the gravity-wave range, are especially limited, but are important as they need to be resolved in current wind-wave models.

Over the past two years, we have integrated a novel, portable, high-resolution airborne topographic lidar with video and hyperspectral imaging systems. The scanning waveform lidar is coupled to a highly accurate GPS/inertial measurement unit permitting airborne measurements of the sea surface elevation and whitecap coverage with swath widths of up to 800 m under the aircraft track over water, and horizontal spatial resolution as low as 0.2 m. We describe system performance, and present preliminary results from recent measurements, where we obtained wave directional spectra down to wavelengths of 0.8 m.

2. Modular Aerial Sensing System (MASS)

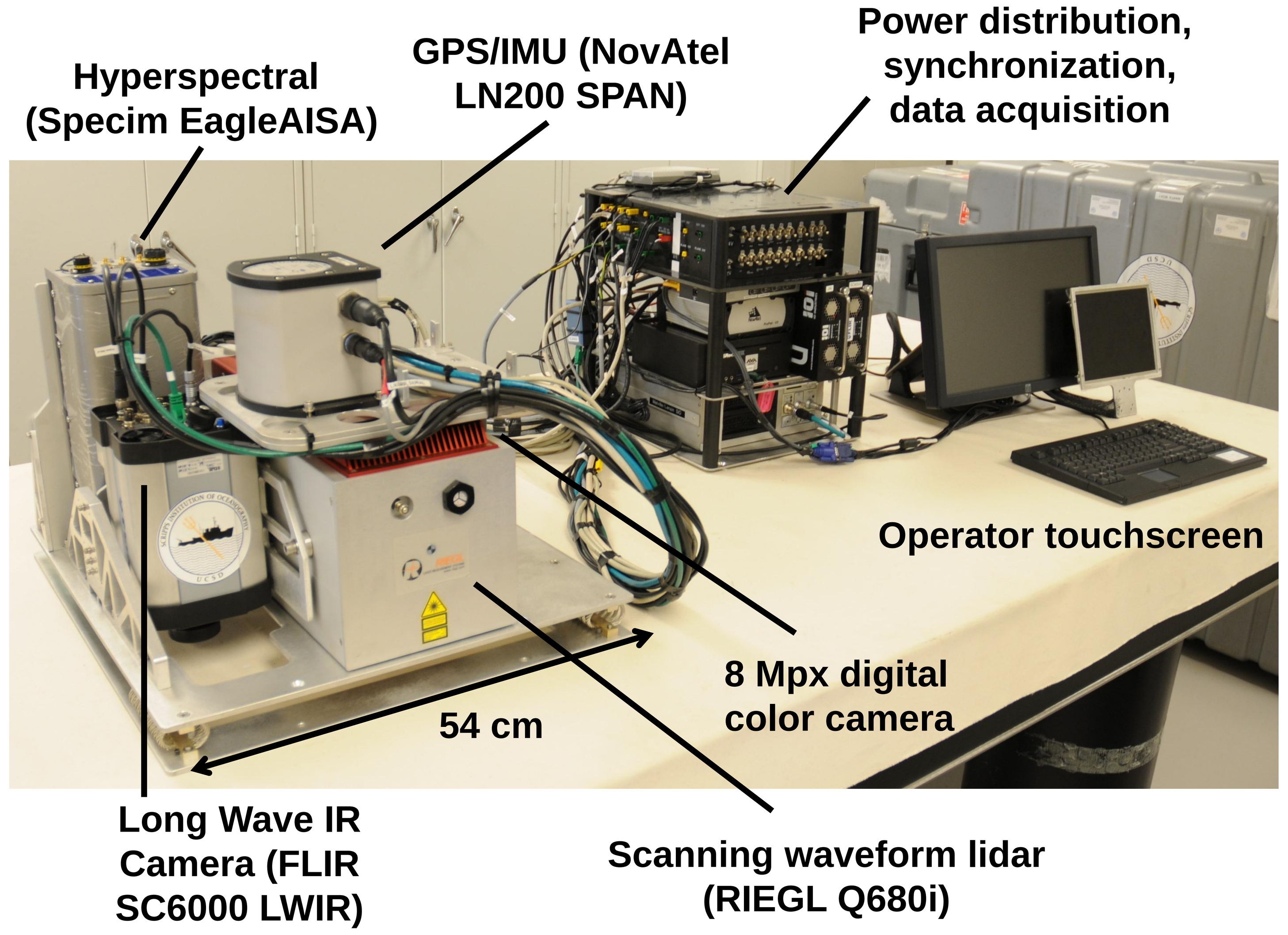


Fig. 1. (top panel) Modular Aerial Sensing System (MASS) at the Air-Sea Interaction Laboratory, Scripps Institution of Oceanography (upper panel) prior to a deployment in the Gulf of Mexico in October 2011. The instrument package was installed on an AspenHelo Partenavia P68 aircraft (bottom panel) for the Gulf of Mexico experiment, October 17-31 2011. The airborne system includes a scanning waveform Lidar, Long-Wave Infrared (LWIR) camera, SST sensor, visible high resolution camera, hyperspectral (VNIR) imager, and a GPS/IMU system.

Weight	120 kg total (including acquisition rack)
	79 kg without hyperspectral
Power requirements	600 W total, 400 W without hyperspectral

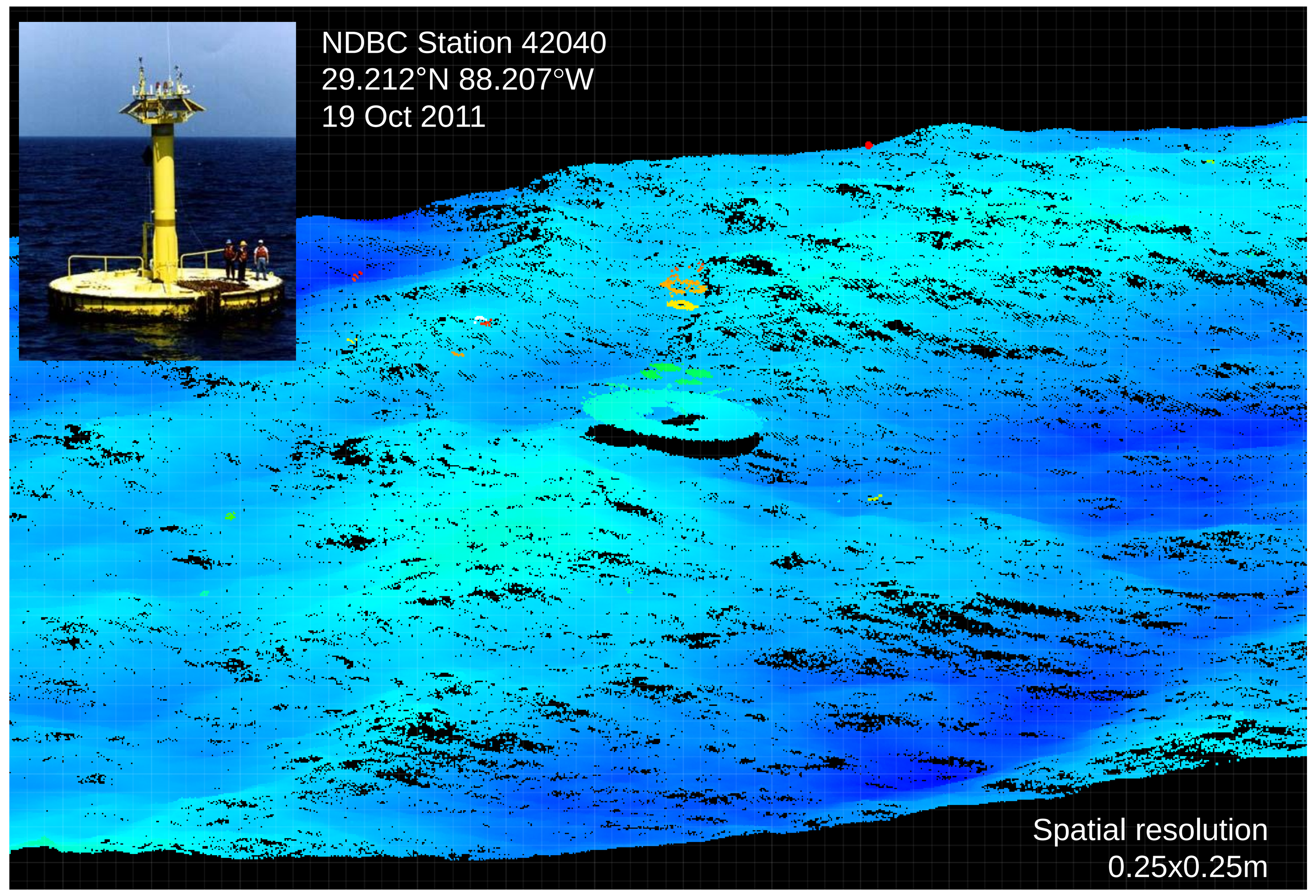


Fig. 2. Example of surface elevation as measured from the MASS during a recent experiment in the Gulf of Mexico, flying above NDBC buoy #42040. (wind~12m/s, Hs = 3.1m)

Instrumentation	Measurement
Scanning Waveform Lidar Riegl Q680i	Surface wave, surface slope, directional wave spectra (vert. accuracy ~2-3cm)
Long-wave IR Camera FLIR SC6000 (QWIP)	Ocean surface processes, wave kinematics and breaking, frontal processes
High-Resolution Video JaiPulnix AB-800CL	Ocean surface processes, wave kinematics and breaking, frontal processes
Hyperspectral Camera Specim EagleAISA	Ocean surface and biogeochemical processes
GPS/IMU Novatel SPAN-LN200	Georeferencing, trajectory

3. Wave Directional Observations down to wavelengths of 0.8m

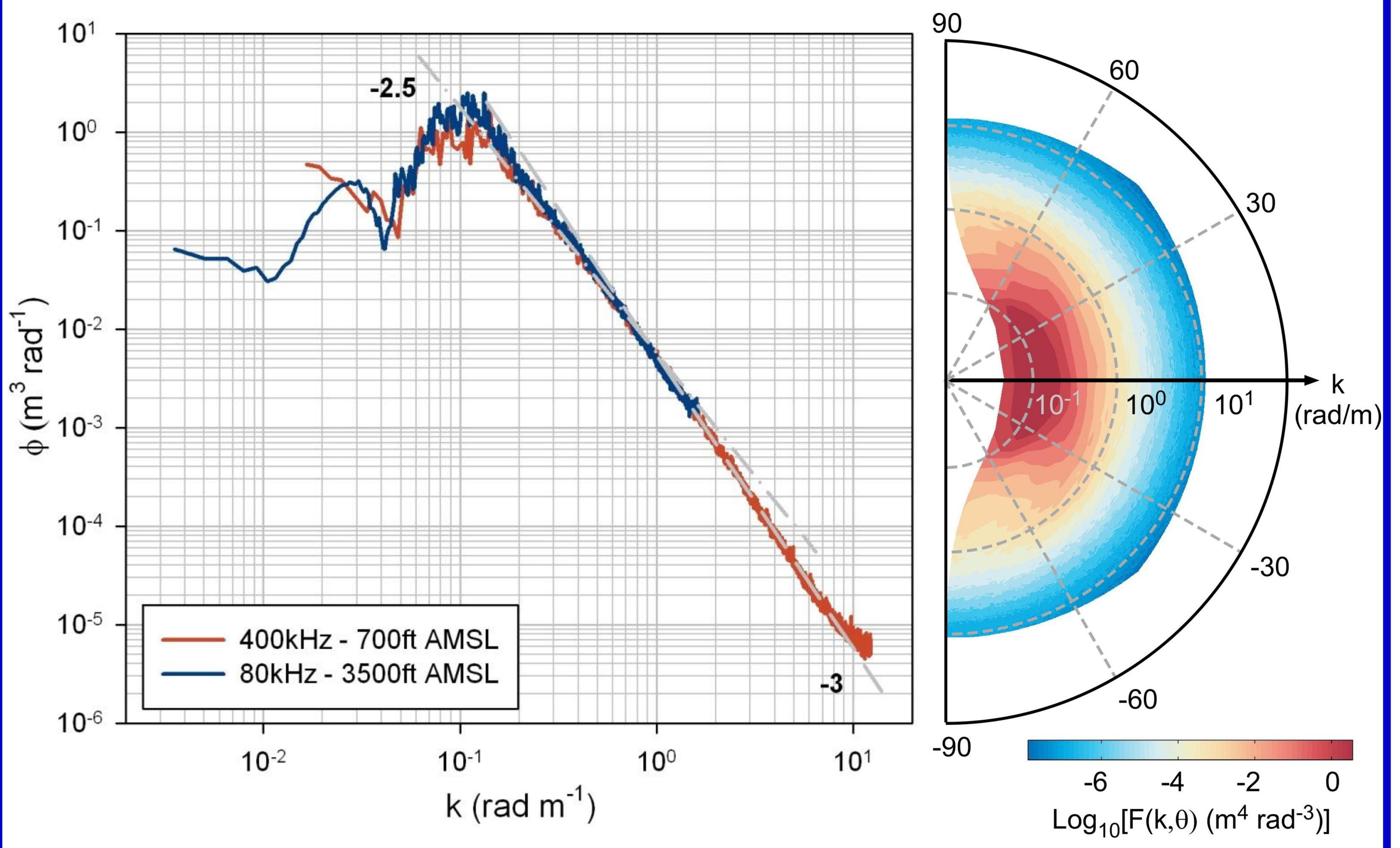
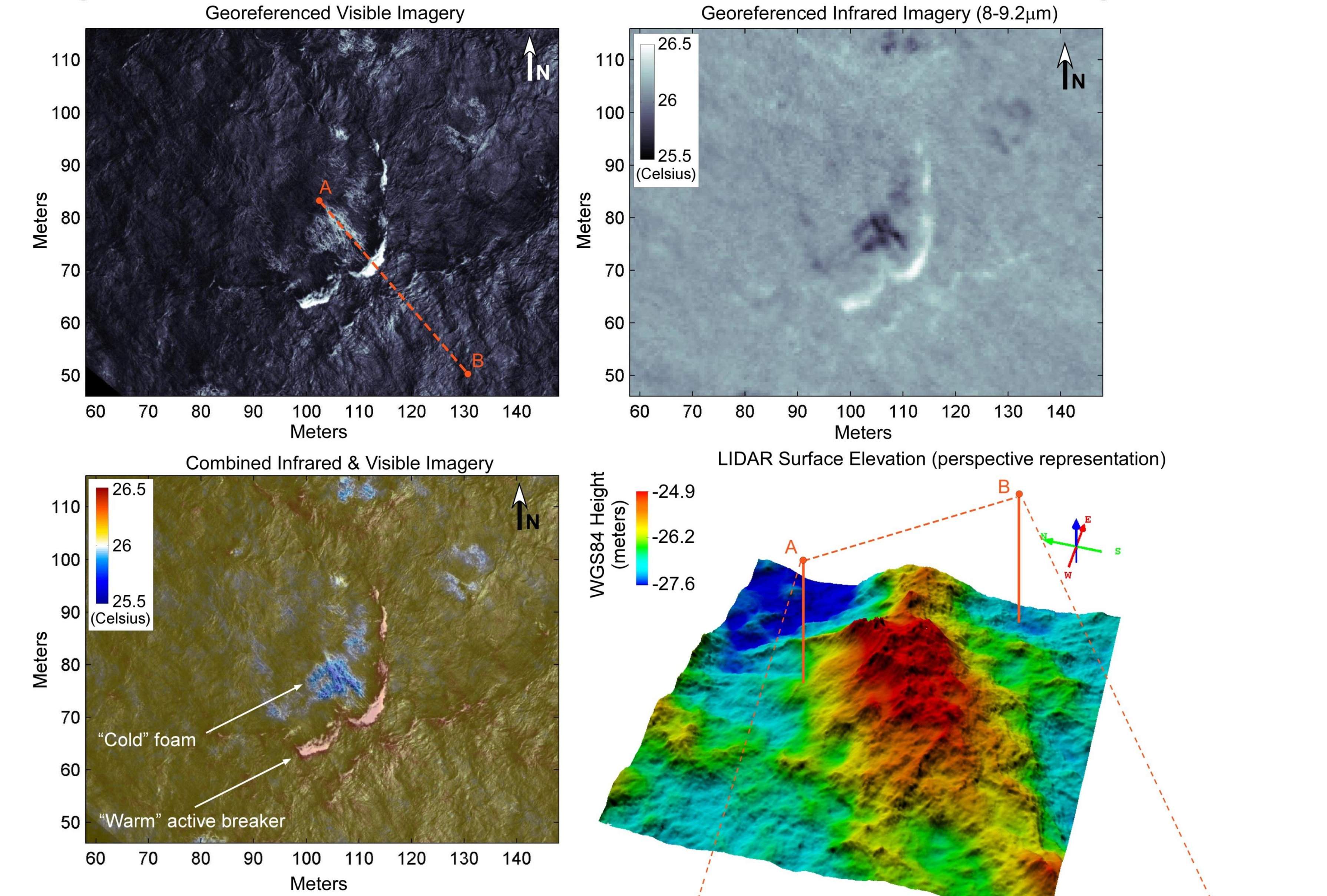


Fig. 3. (left) Omnidirectional wavenumber spectra for two passes flown at two different altitudes: 1100 m AMSL in blue, swath width 800 – 1000 m, spatial resolution of 1.2 m; 200 m AMSL in red 200 m swath, 12 – 25 cm spatial resolution from sea surface topography data recorded using the MASS on 4 Aug 2011 in the Santa Barbara Channel. These data give spectra down to wavelengths of 0.8 – 0.9 m, with directional resolution there of 0.2º, and 3.6º at the peak of the spectrum, λ = 64 m. Note -5/2 and -3 spectral slopes. (right) Directional spectrum from the sea surface topography recorded at 200m AMSL.

4. High-Resolution Measurements of Breaking Waves



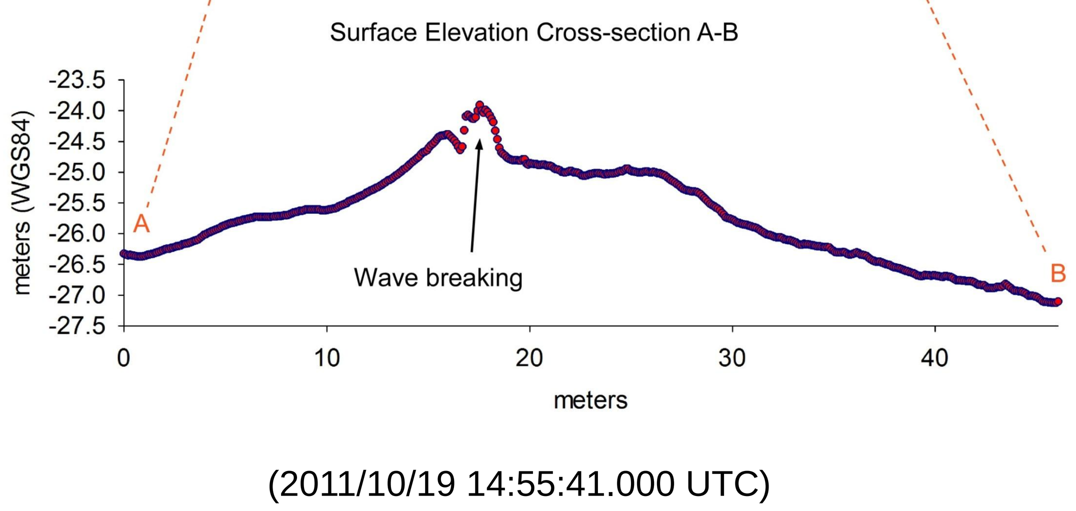
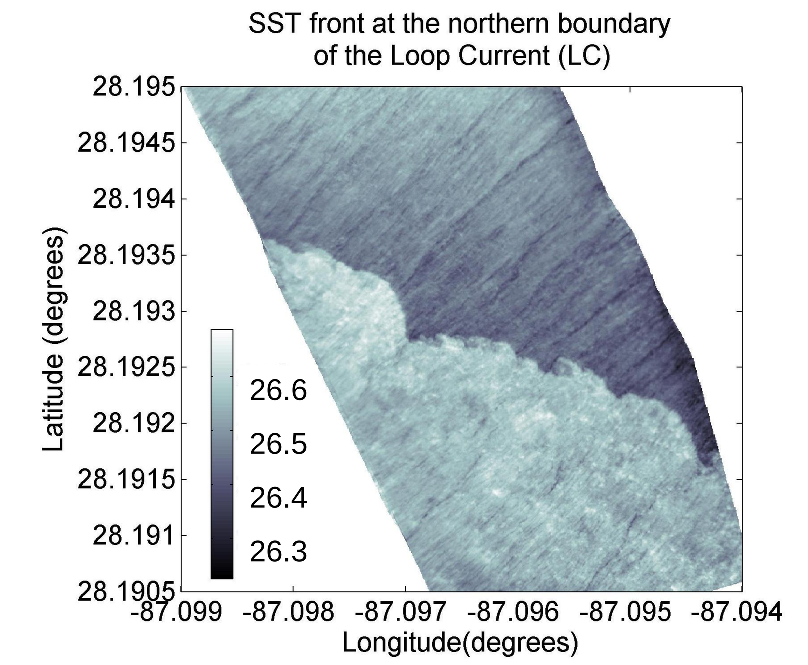


Fig. 4. Sample georeferenced images of a breaking wave in the visible and infrared (8-9.2μm) bands during a recent experiment in the Gulf of Mexico. Note that the foam is colder (blue) due to rapid cooling (T_{water} - T_{atm} ≈ 8°C) while the active breaker is warmer (red), disrupting the surface skin layer and bringing warmer water from below. Also shown is a perspective view of the sea surface elevation for the same breaking wave color coded for WGS84 height (World Geodetic System 1984 datum). The lower panel shows the profile of the transect A-B marked in the georeferenced visible image.

5. Wave Enhancement at a SST Front (Loop Current)



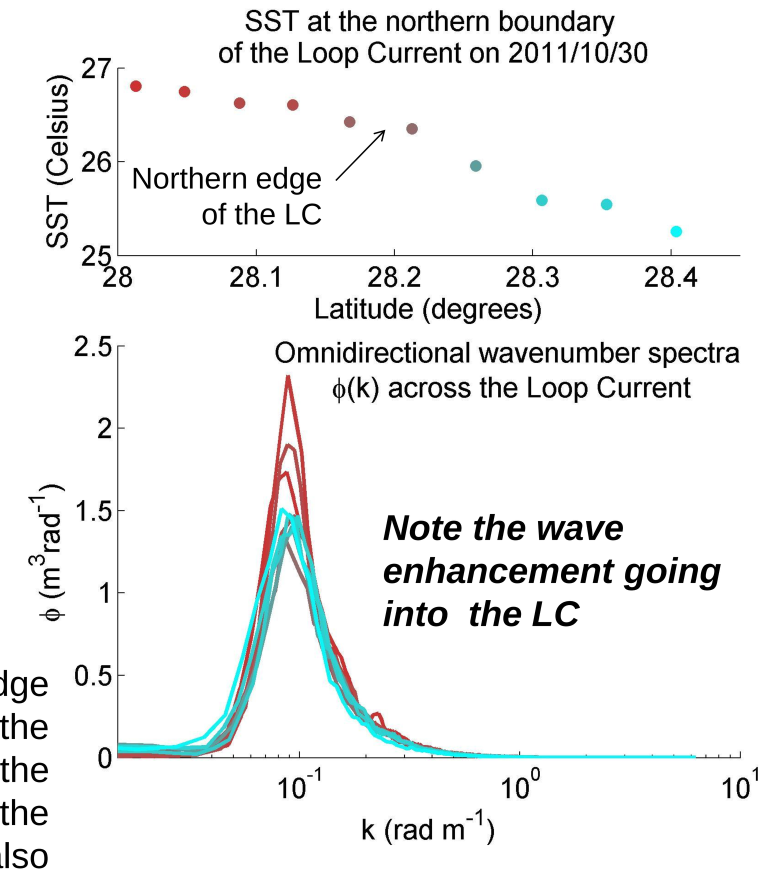


Fig. 5. (left) Sea surface temperature imagery of the northern edge of the Loop Current on October 30 2011. (right) Evolution of the omnidirectional wavenumber spectrum as the aircraft flew across the Loop Current . The color scale represents the average SST over the length of the wave record (4 km) used in the spectral analysis, also shown as a function of latitude in the upper panel.

6. Summary

- Over the past two years, we have integrated a novel, portable, high-resolution airborne topographic lidar, with video, infrared and hyperspectral imaging systems.
- High resolution airborne measurements of sea surface elevation and whitecap coverage with swath width of up to 800 m, and high horizontal spatial resolution of up to 4 – 5 cm.
- Unprecedented airborne measurements of high wave wavenumber directional spectra down to wavelengths of 0.8 m.