Airborne Lidar in support of Ocean Topography Missions and Science

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Introduction

With the growing interest in understanding air-sea interaction, upper ocean dynamics and thermodynamics, increasing emphasis has been placed on submesoscale ocean processes. Meanwhile the interest in coastal oceanography also requires both spatial and temporal resolution beyond the typical (ten-day) repeat cycle of satellite altimetry. As we move to higher spatial resolution, for example, the 2-km requirement and 500-m goal of the Surface Water and Ocean Topography (SWOT) mission, the surface wave field will become of more significance both for the dynamics and for the sea-state bias corrections since the wave field correlates with the submesoscale dynamics through wave-current interaction. As the community moves into this regime of ocean dynamics, some of these needs can be met by the use of airborne lidar for the measurement of ocean topography from mesoscales of O(100) km to gravity-capillary waves of wavelengths O(1) cm. Thus airborne lidar can be used in the pre-launch and calibration/validation phases and to supplement the science goals of the mission. In this talk we present the results of airborne lidar measurements synchronized with Jason 1 altimeter tracks in the Gulf of Mexico. We compare the airborne lidar measurements of the sea-surface topography and significant wave height (SWH) with Jason 1 data. In the Gulf of Mexico we also use coincident airborne hyperspectral and infrared imagery to characterize the gradients in sea surface topography and surface wave variables across the Loop Current boundary and eddies.

Modular Aerial Sensing System (MASS)

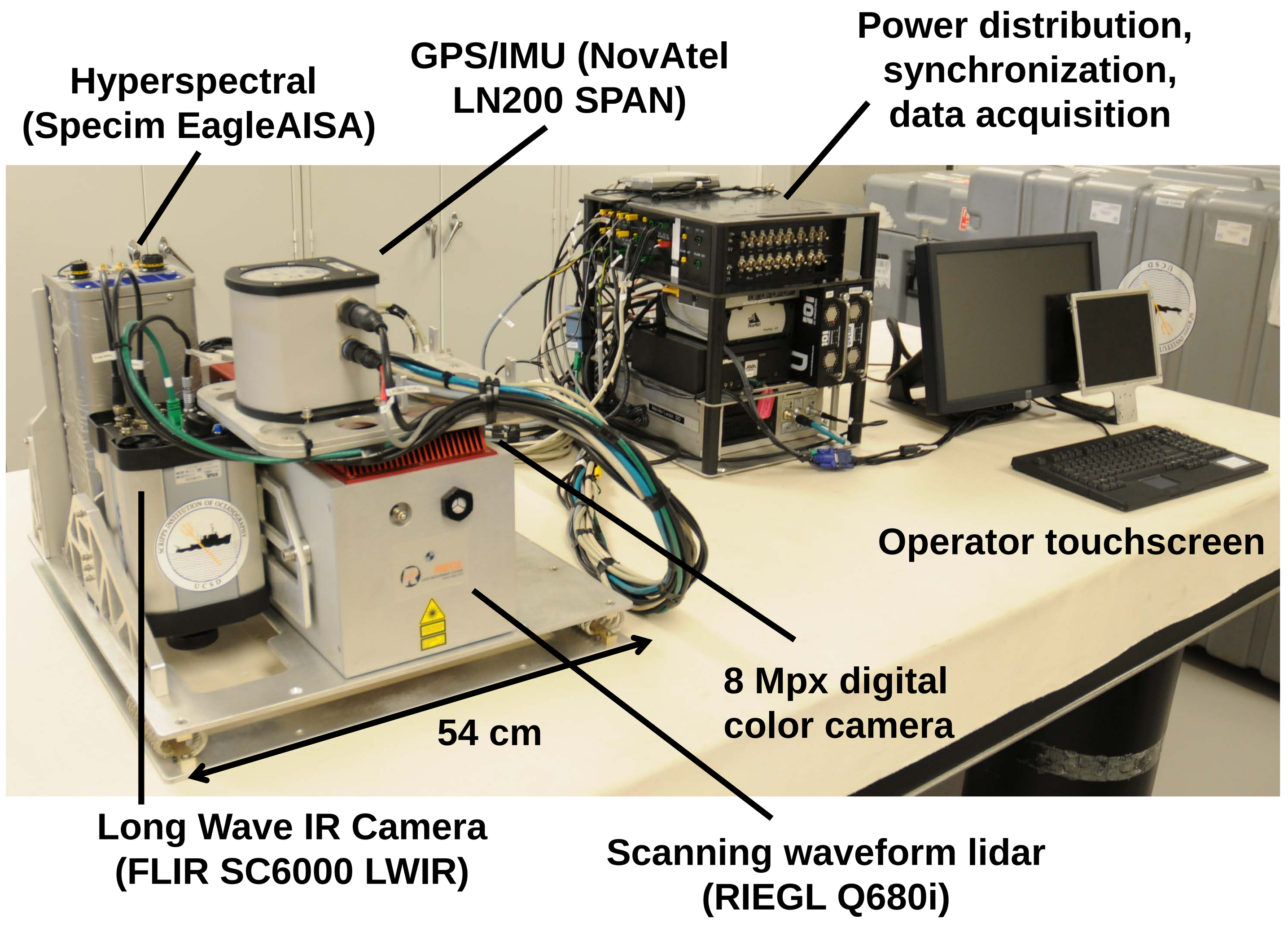


Fig. 1. (top panel) Modular Aerial Sensing System (MASS) at the Air-Sea Interaction Laboratory, Scripps Institution of Oceanography. The instrument package was installed on an AspenHelo Partenavia P68 aircraft (bottom panel) for the Gulf of Mexico experiment, 17-31 October 2011. The airborne system includes 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 imager
Power requirements	600 W total, 400 W without hyperspectral imager

Instrumentation	Measurement
Scanning Waveform Lidar Riegl Q680i	Surface waves, surface slope, directional wave spectra (vert. accuracy ~2-3cm per point)
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

Wave Directional Observations down to wavelengths of 0.8m

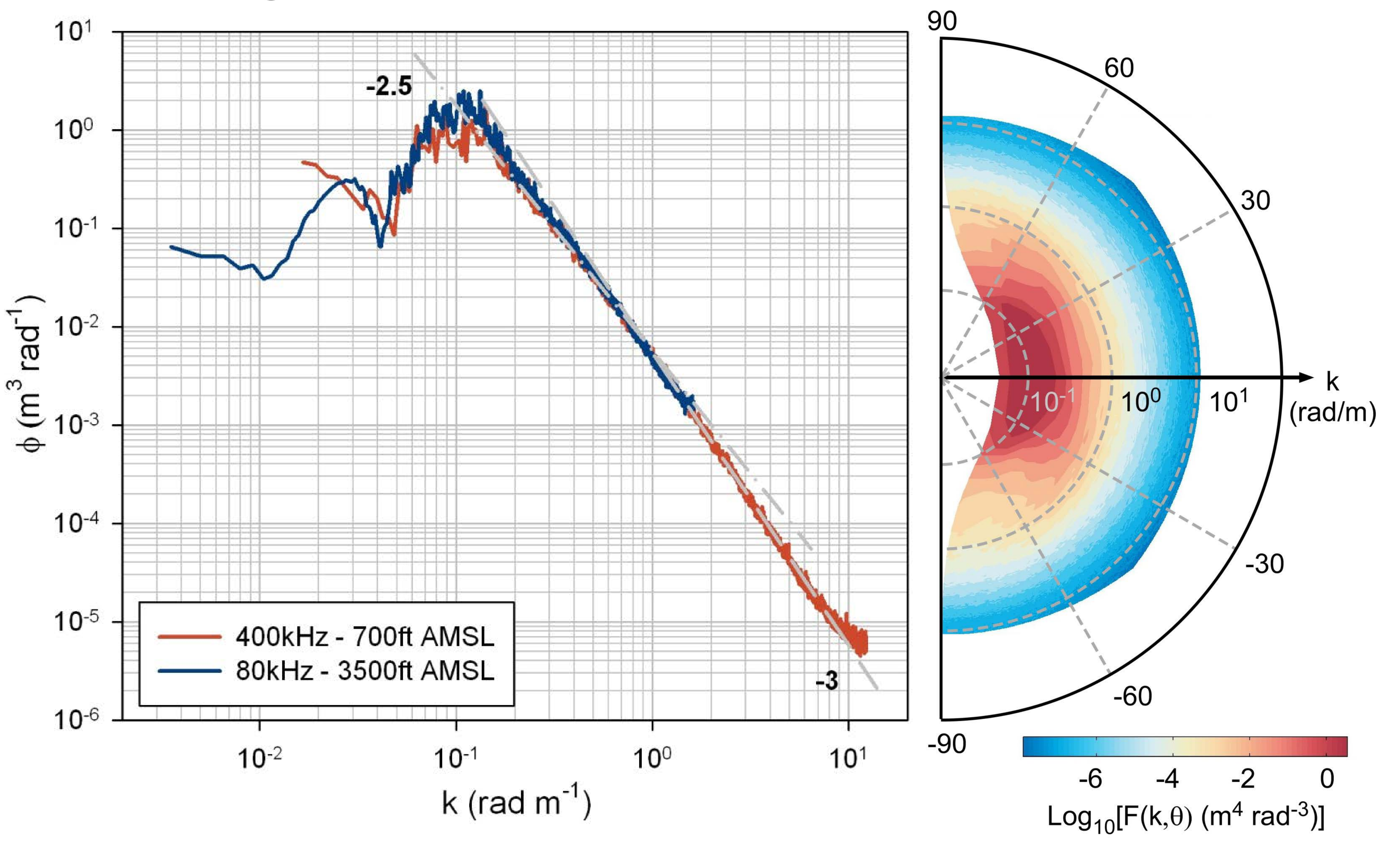


Fig. 2. (left) Omnidirectional wavenumber spectra for two passes flown at two different altitudes: 1100 m AMSL in blue, swath width 800 – 1000 m, spatial resolution of 1.2 m; 200 m AMSL in red 200 m swath, 12 – 25 cm spatial resolution from sea surface topography data recorded using the MASS on 4 Aug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

The Gulf of Mexico Experiment

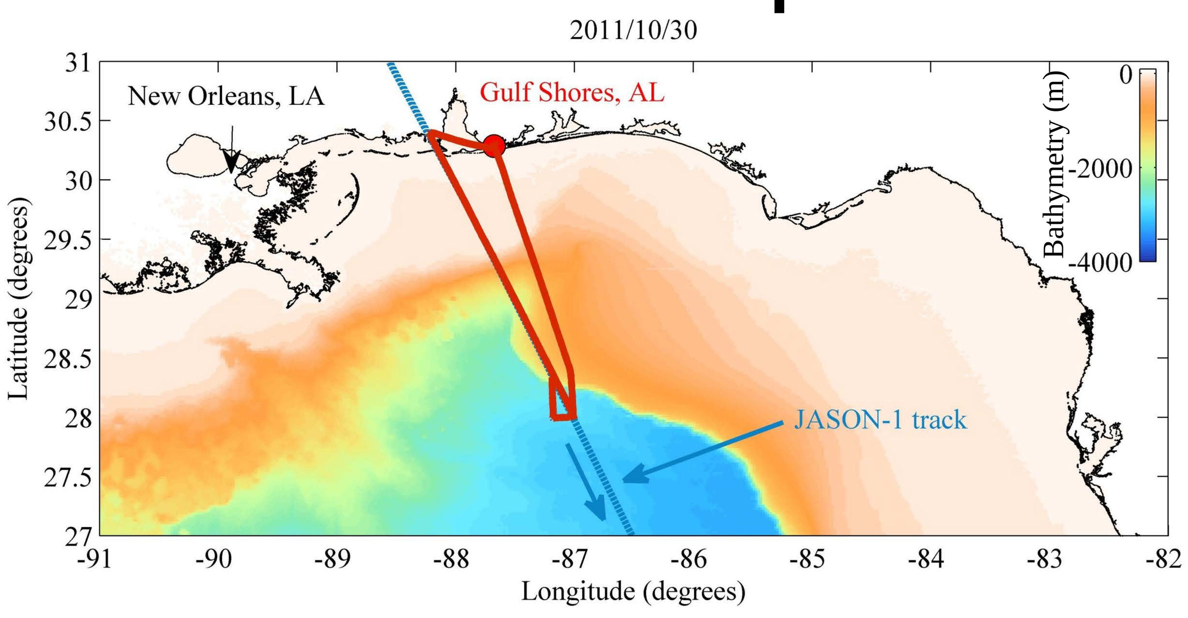


Fig. 3. Jason I and Airborne LIDAR flight track on October 30, 2012, in the Gulf of Mexico. Flights were scheduled to coincide with the satellites overpass. The aircraft track is shown in red.

SSHA from Airborne and Satellite Altimetry

$$ssha_{lidar} = ssh_{lidar} - mean\_sea\_surface_{Satellite} - ocean\_tides - Tidal\_loading - solid\_earth\_tides - pole\_tide$$

Ocean tides: Corrections for solid earth and sea surface height variations due to the attraction of the Sun and Moon (FES2004 model)
Solid earth tides: Corrections for solid earth variations due to the attraction of the Sun and Moon (McCarthy and Petit, IERS Conventions 2003)
Pole tides: Corrections for variations due to the attraction of the Sun and Moon.
Tidal loading: Corrections for height variations due to changes in tide-induced forces acting on the Earth's surface (FES2004 model)

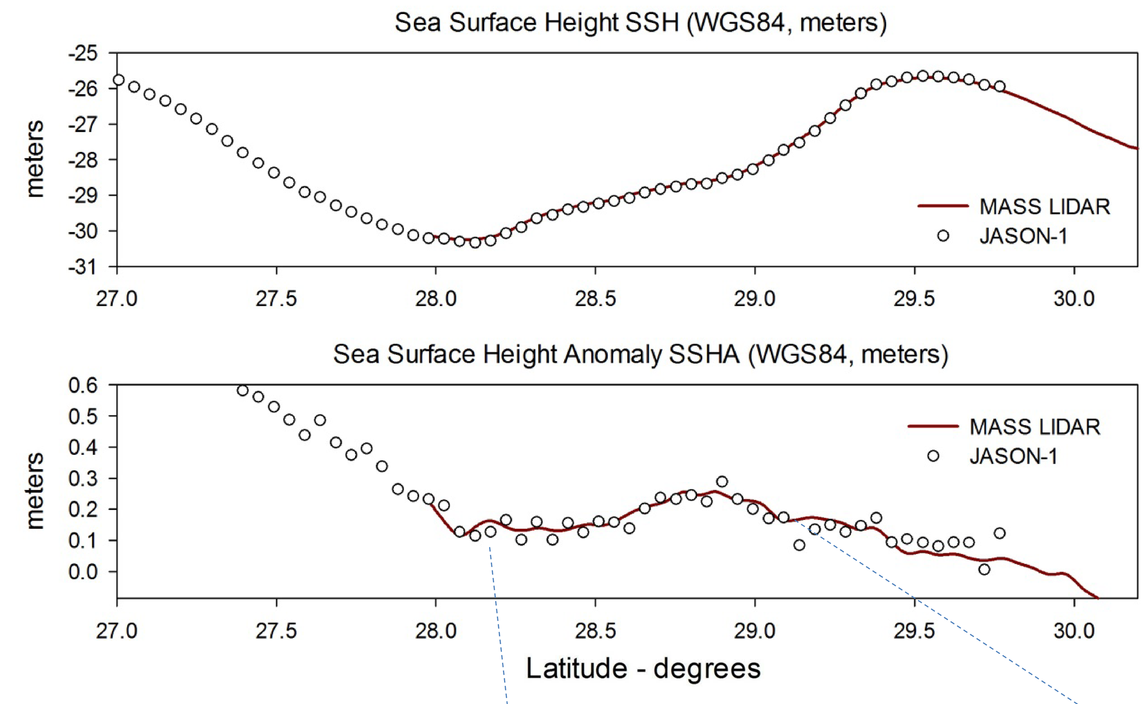
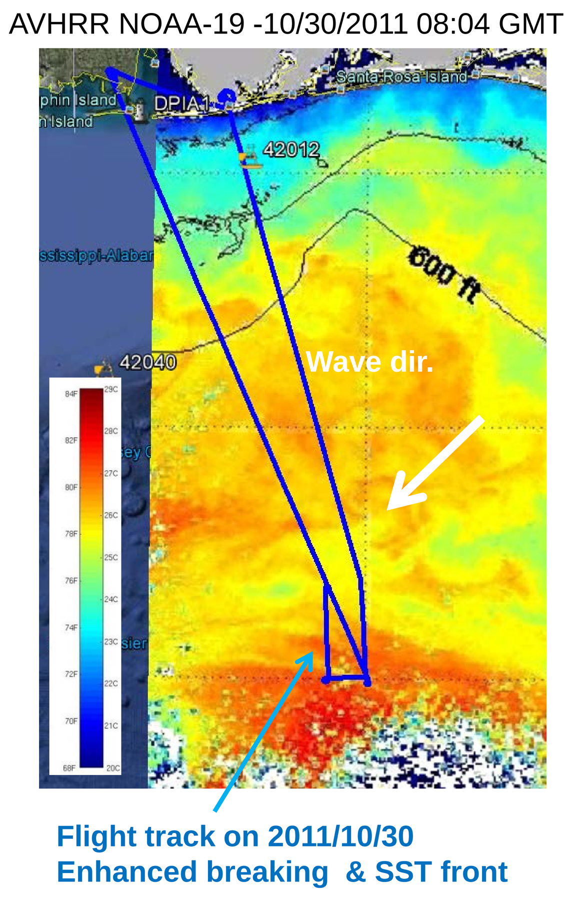


Fig. 4. Sea Surface Height (SSH), Sea Surface Height Anomaly (SSHA) measured from Jason-I satellite altimeter and the MASS Lidar.



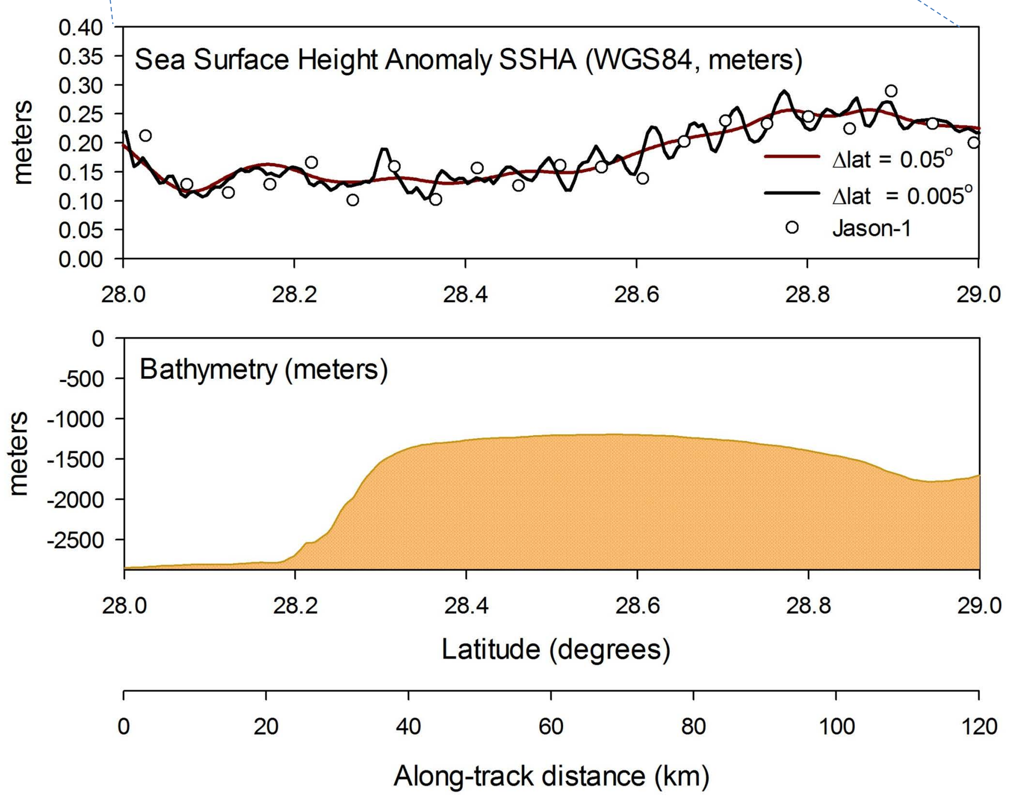


Fig. 5. (top panel) SSHA estimated from the MASS Lidar for two averaging lengths, 0.05° and 0.005°. Sea Surface Temperature (SST) from the AVHRR satellite for the same day is shown on the right panel with the flight track overlaid.

SWH from Airborne and Satellite Altimetry

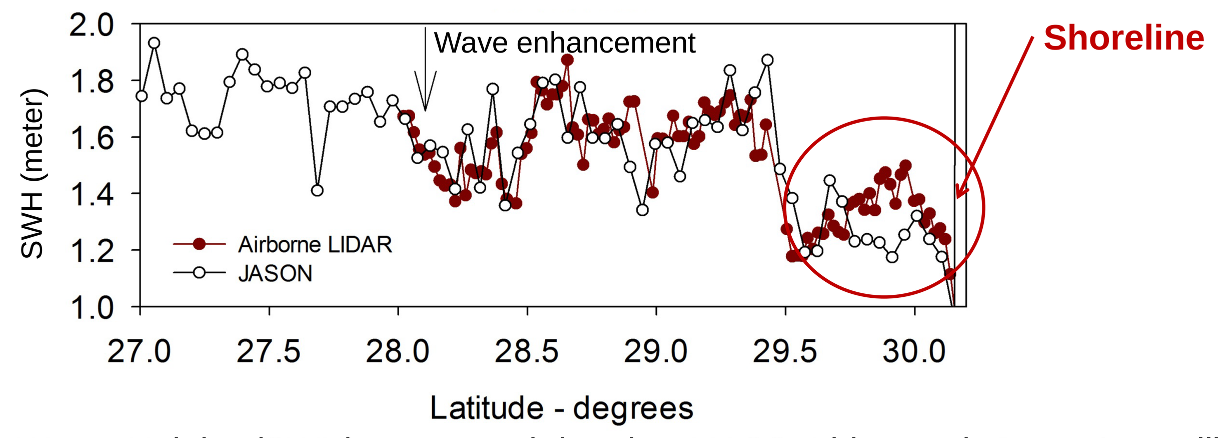
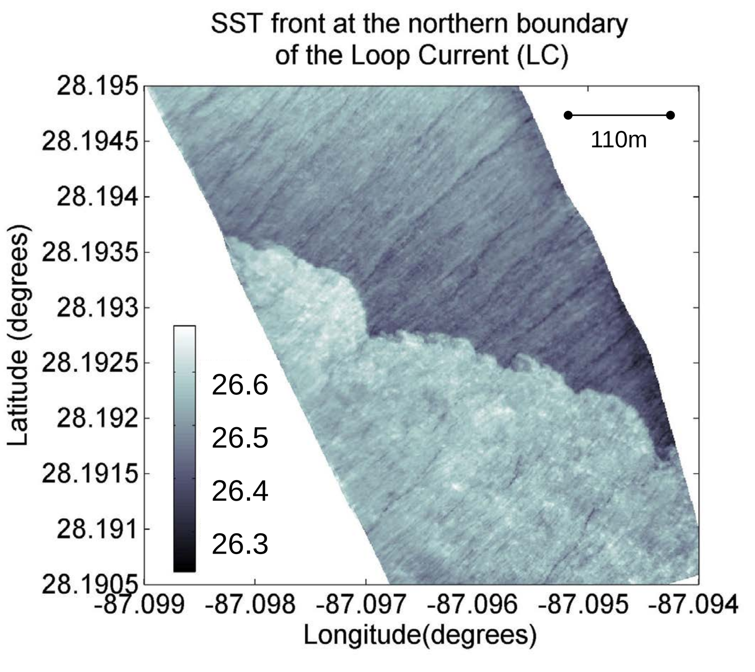


Fig. 5. Significant Wave Height (SWH) measured by the MASS Lidar and Jason-I satellite altimeter. Note the divergence between the airborne and satellite measurements closer to shore.

Wave Enhancement at a SST Front



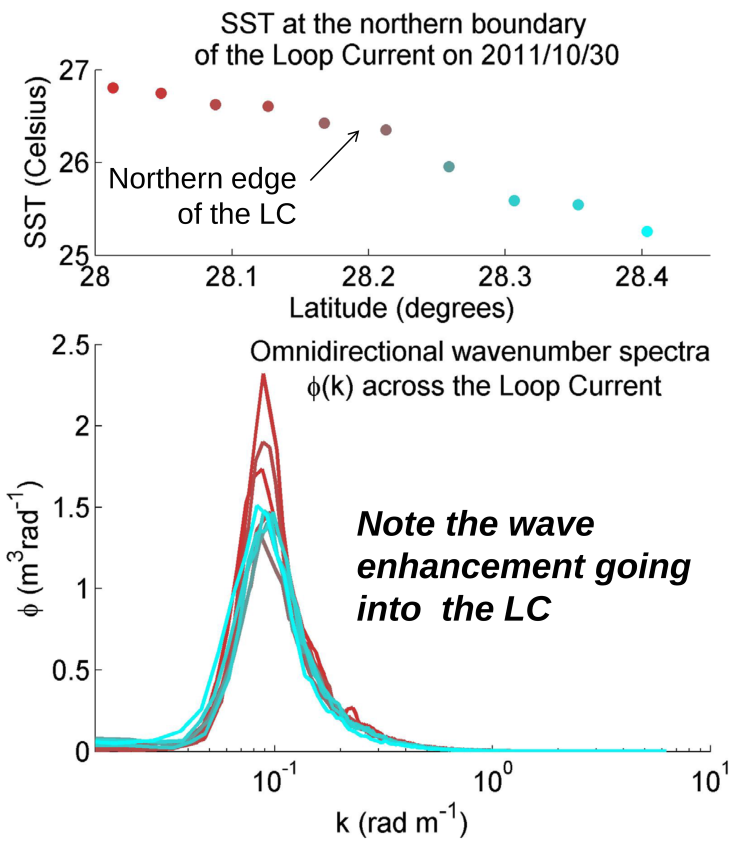


Fig. 6. (left) Sea surface temperature imagery of the northern edge of the Gulf of Mexico Loop Current on October 30 2011. (right) Evolution of the omnidirectional wavenumber spectrum as the aircraft flew across the Loop Current . The color scale represents the average SST over the length of the wave record (4 km) used in the spectral analysis, also shown as a function of latitude in the upper panel.

Summary

- Aircraft-based topographic lidar is an important tool for broadband micro- to meso-scale measurements of ocean surface processes
- Aircraft-based altimetry and imaging can be used to measure processes having response times much shorter than the typical repeat-cycle time of satellite altimetry and is amenable to use for rapid response applications (e.g. extreme waves, storm surge, tsunamis)
- Aircraft-based altimetry can serve as an important method of calibration/validation for radar altimetry and satellite imaging