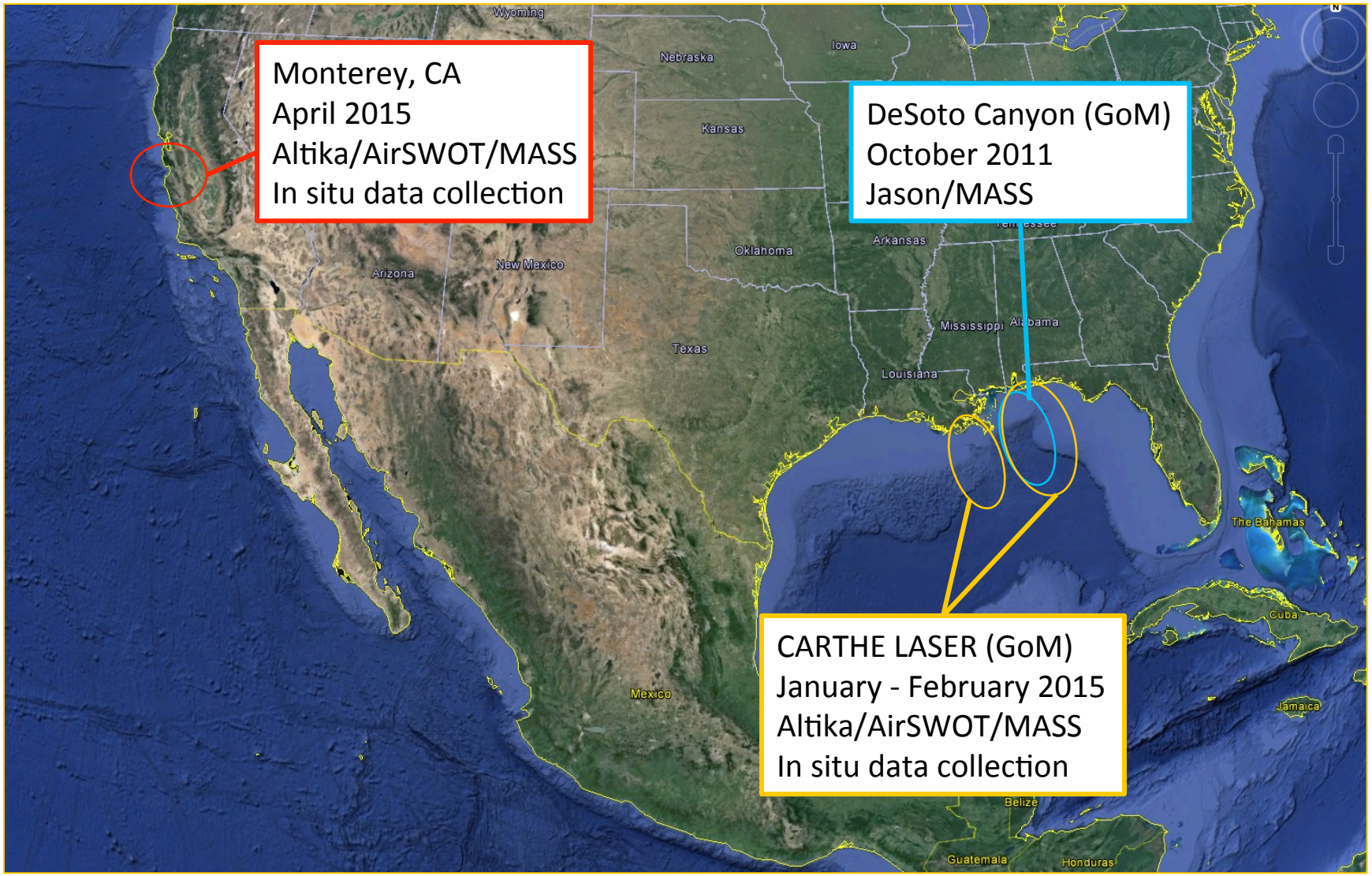
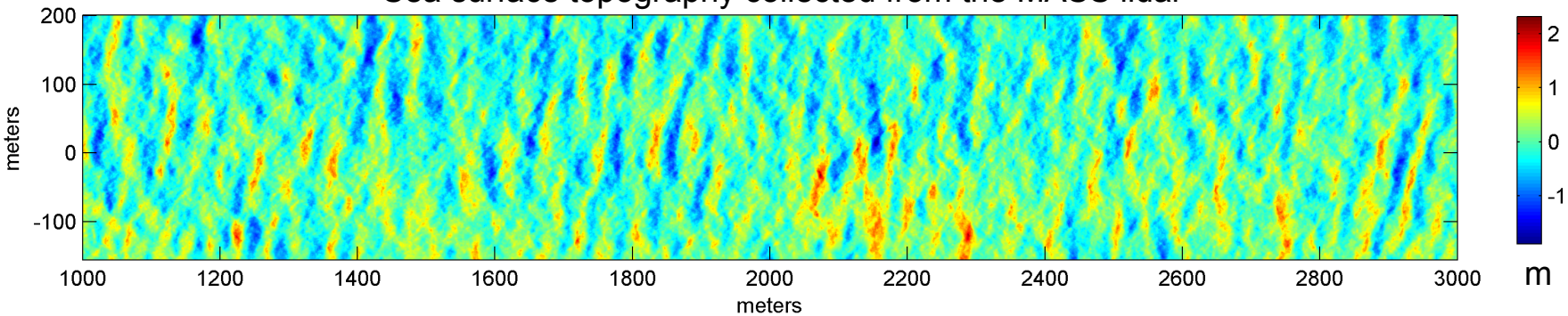
# Airborne Lidar in Cal/Val  Ken Melville & Luc Lenain



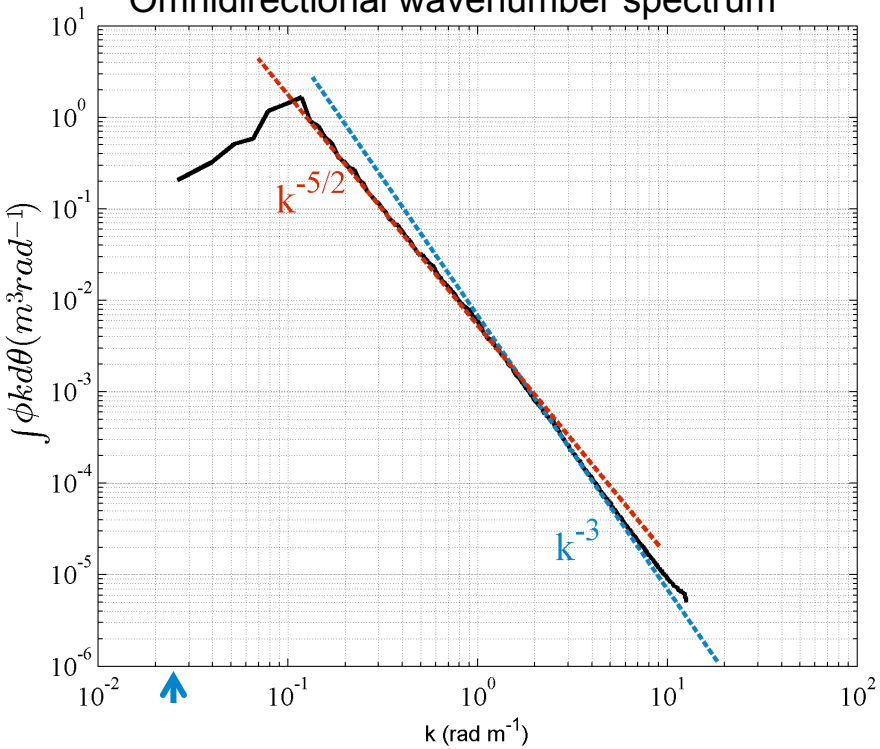
# Surface Waves Measured by the MASS Lidar



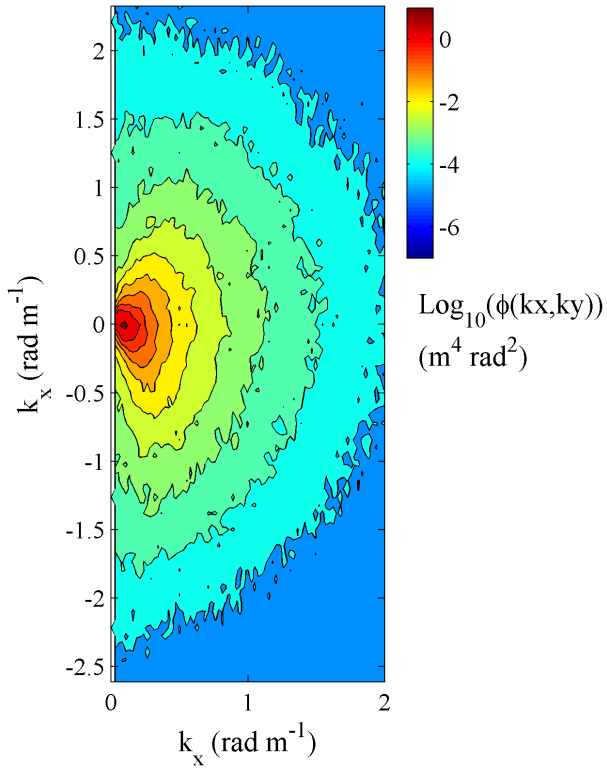
Sea surface topography collected from the MASS lidar



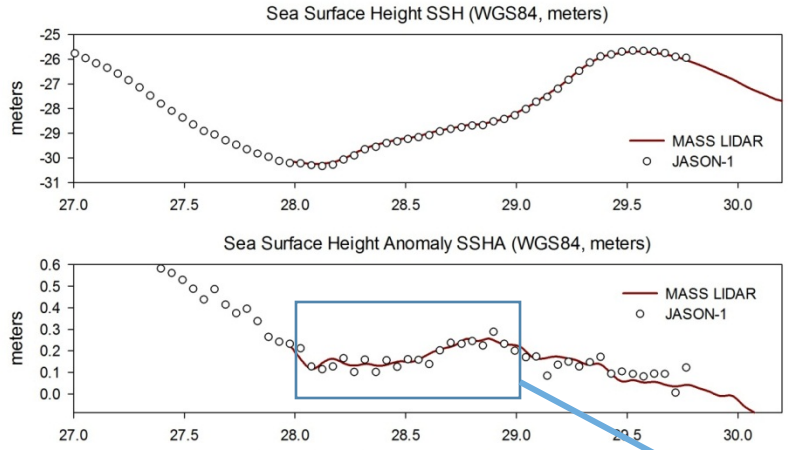

Omnidirectional wavenumber spectrum

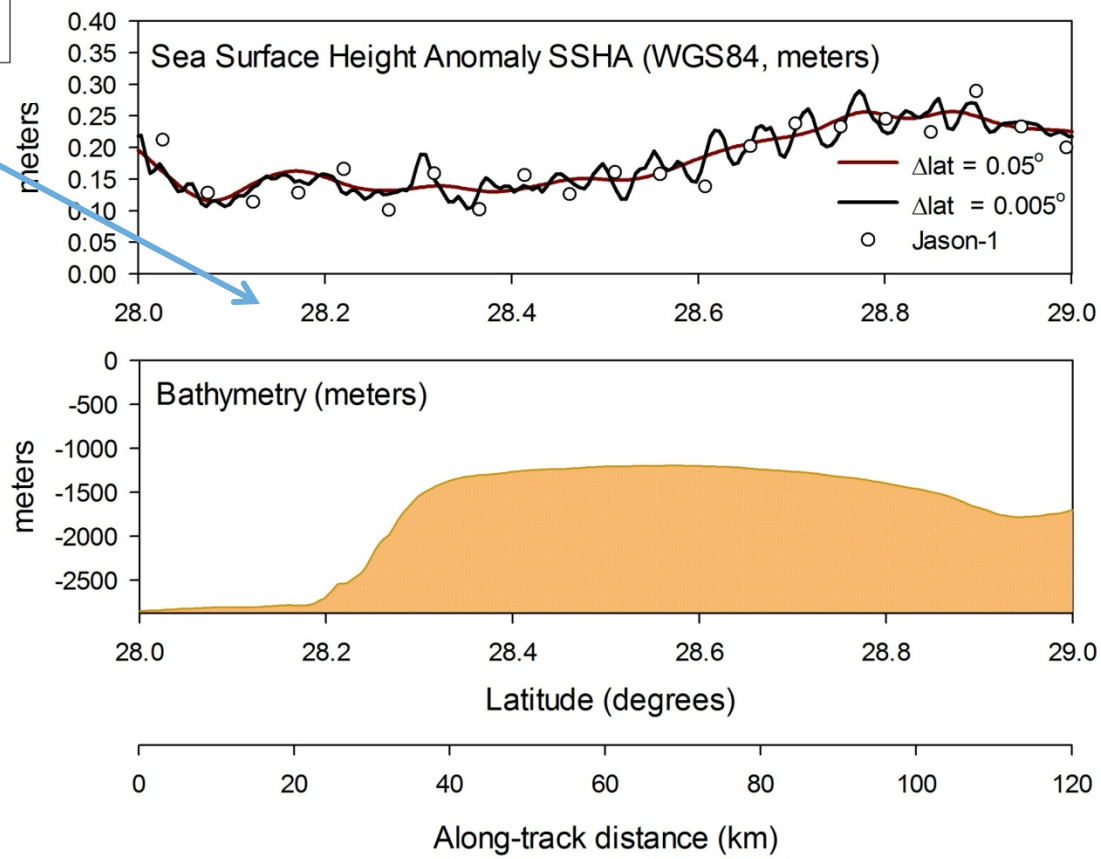


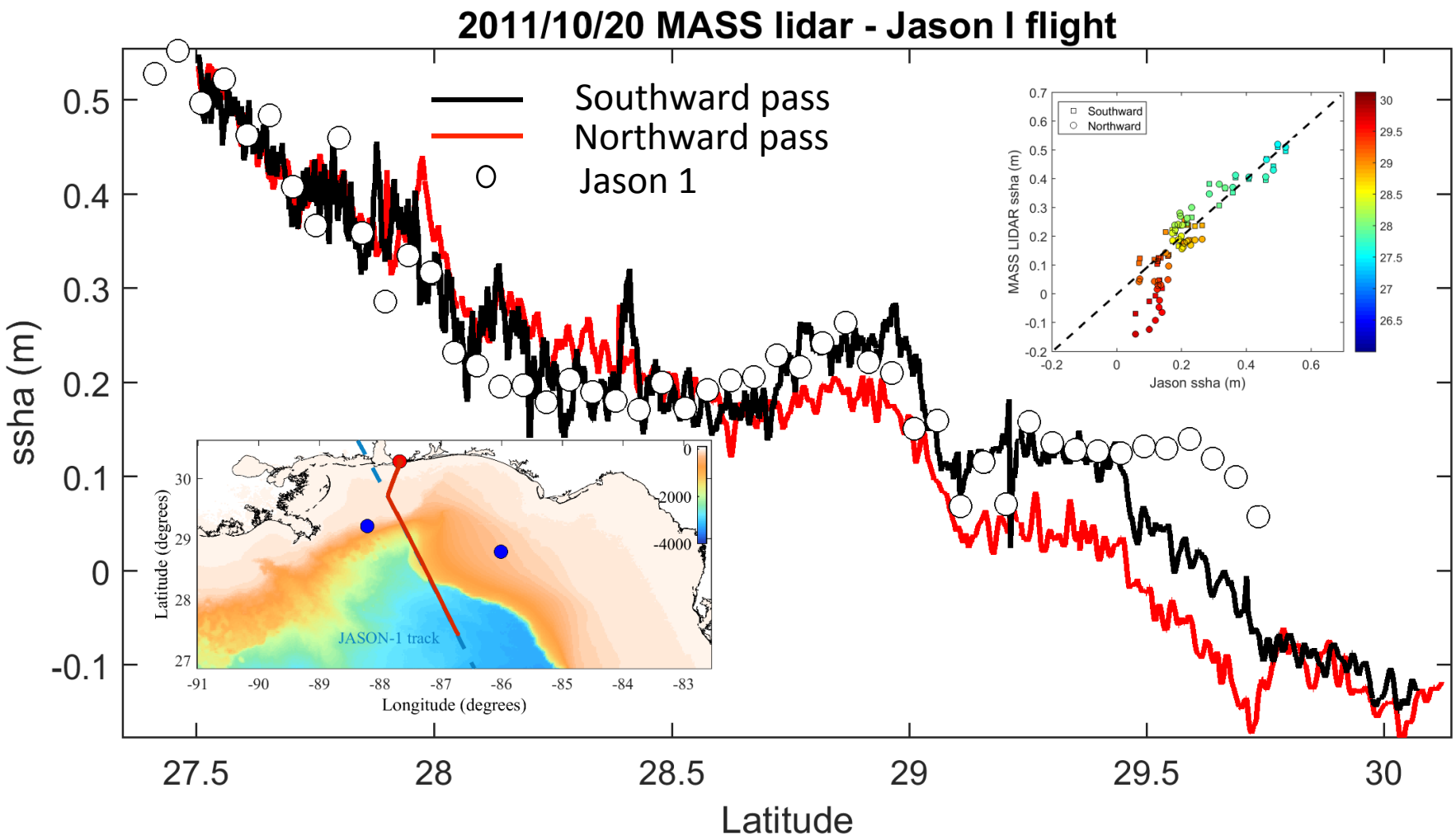

directional wavenumber spectrum



# High-Resolution SSHA from Airborne Altimetry

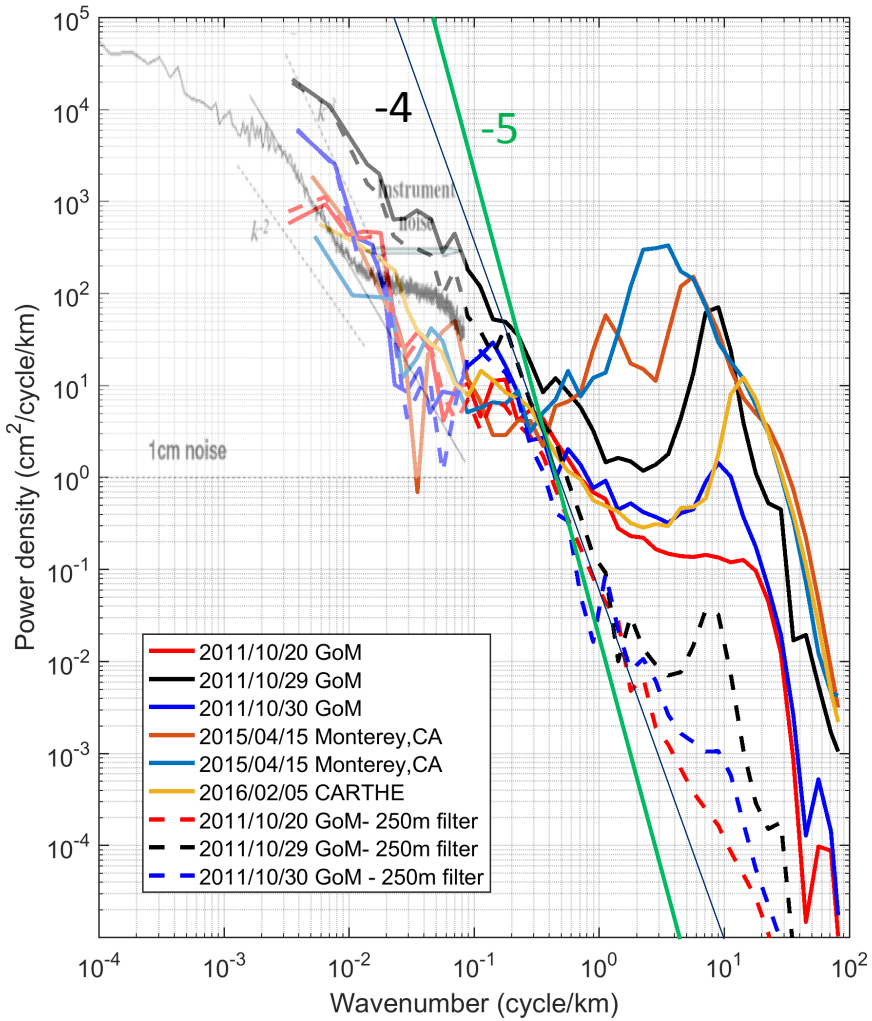




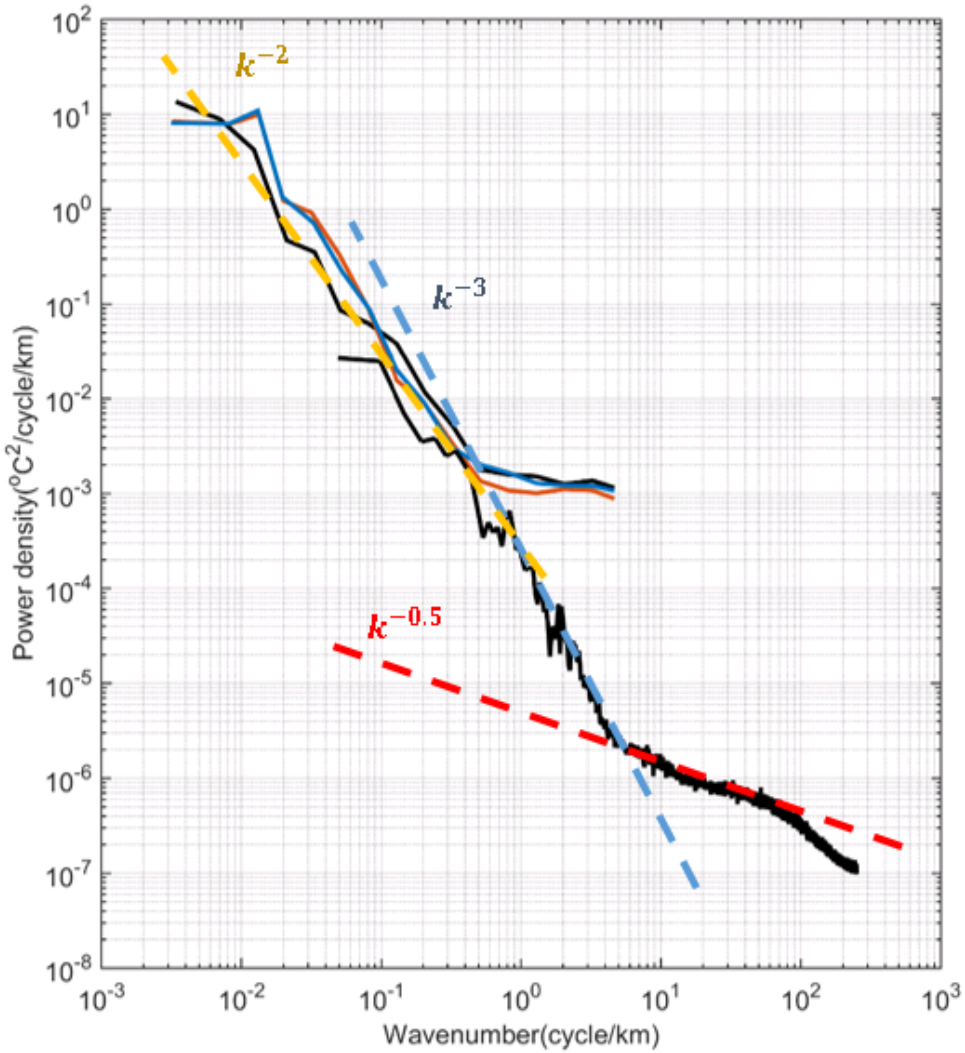

SSHA estimated from two MASS lidar passes ("northward" and "southward") over the same Jason-I track (see insert). Note that the satellite pass occurred in the middle of the southward lidar pass (black).

# SSHA spectra

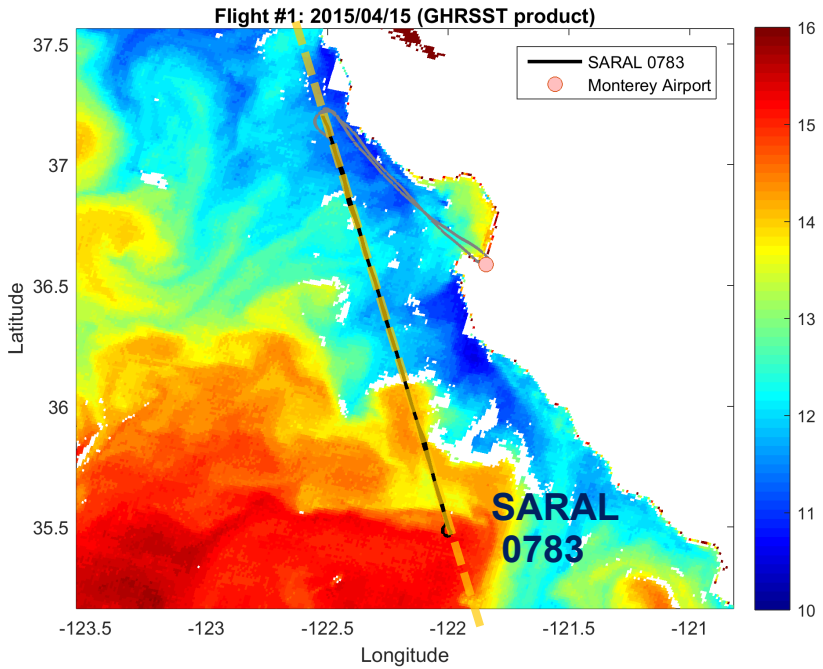


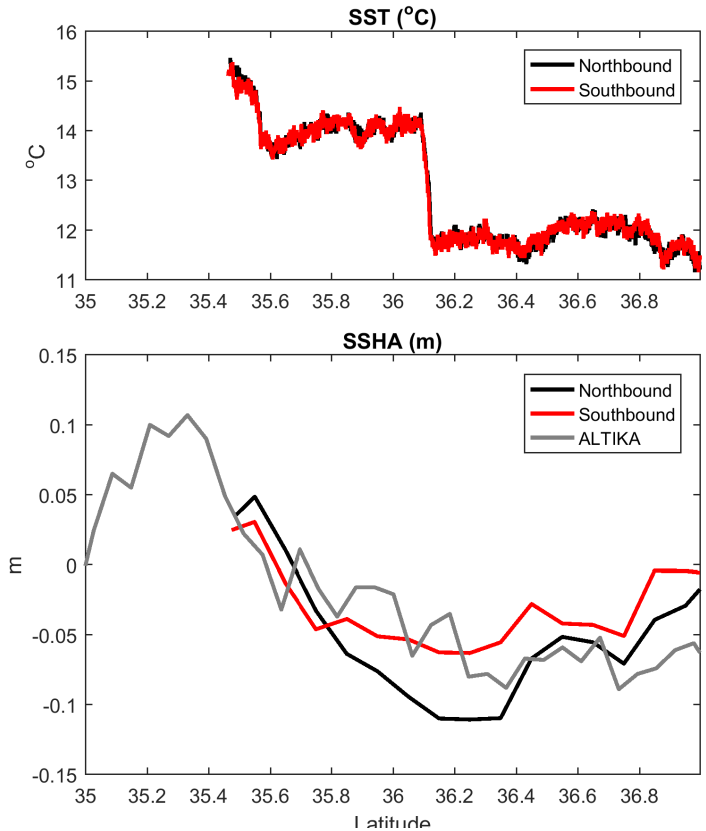

*SSHA spectra measured by three flights of the scanning lidar along a descending Jason-1 track in the Gulf of Mexico (October 2011), Altika track off Monterey Bay (April 2015) and during CARTHE (February 2016). The data are plotted over satellite altimeter data from Figure 1 of Fu & Ferrari (2008), noting the O(100)km resolution of the traditional satellite altimeters.*

# SST wavenumber spectra (KT19 and IR imagery)



# April 15 2015 – SARAL 0783 overflight -SSHA

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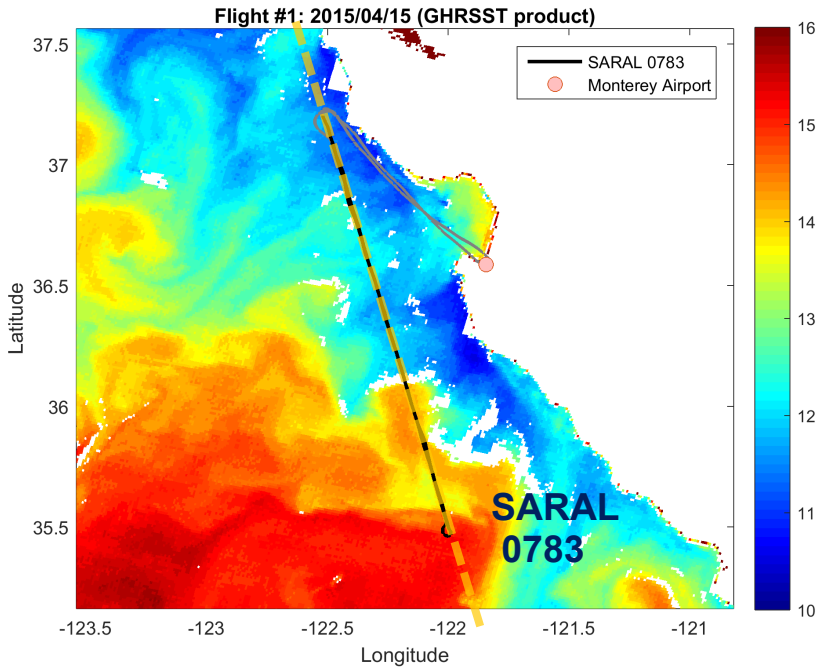
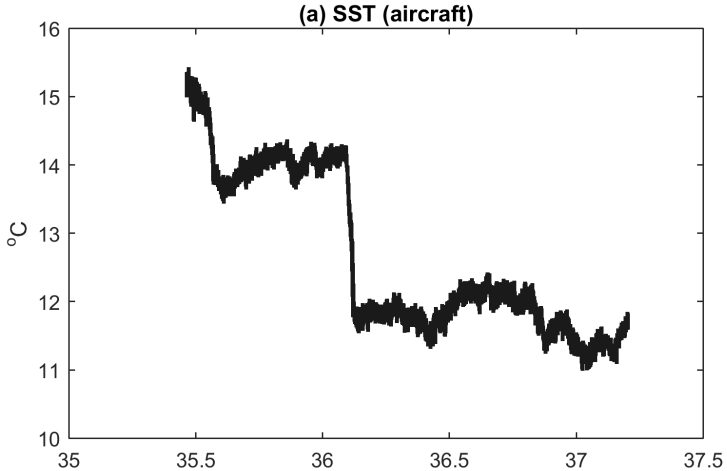
(provided by L. Marie' – IFREMER)

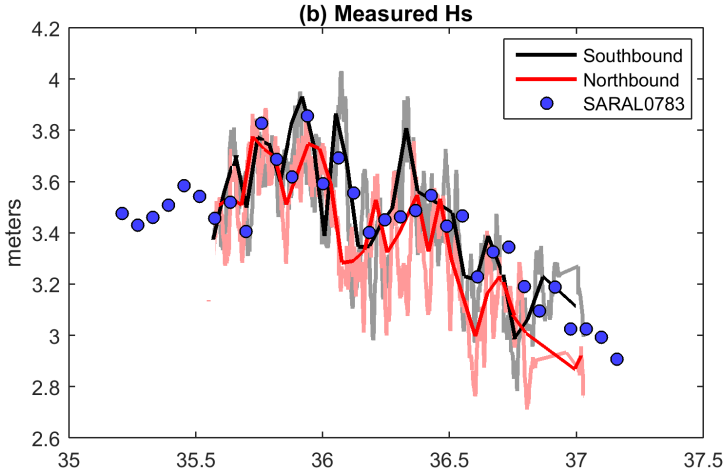
**SST SATELLITE DATA collected ~ <u>4hrs</u> after end of the research flight**

- Clear skies, $H\downarrow s$ =3.2-4 m, $U\downarrow 10 = 10\ m/s$
- SARAL-0783 overflight time: 13:42-13:47 (UTC
- SIO aircraft on "station": 13:20 to 14:50 (UTC)

# April 15 2015 – SARAL 0783 overflight - Hs

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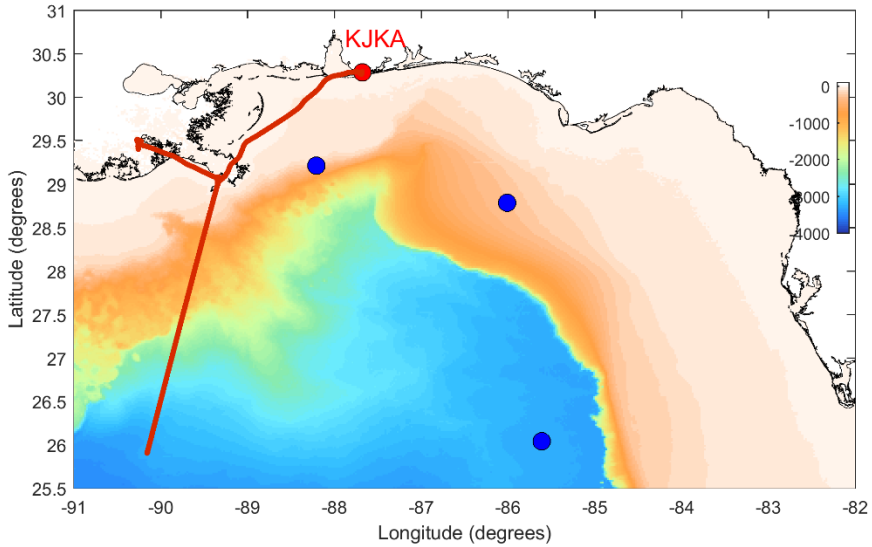
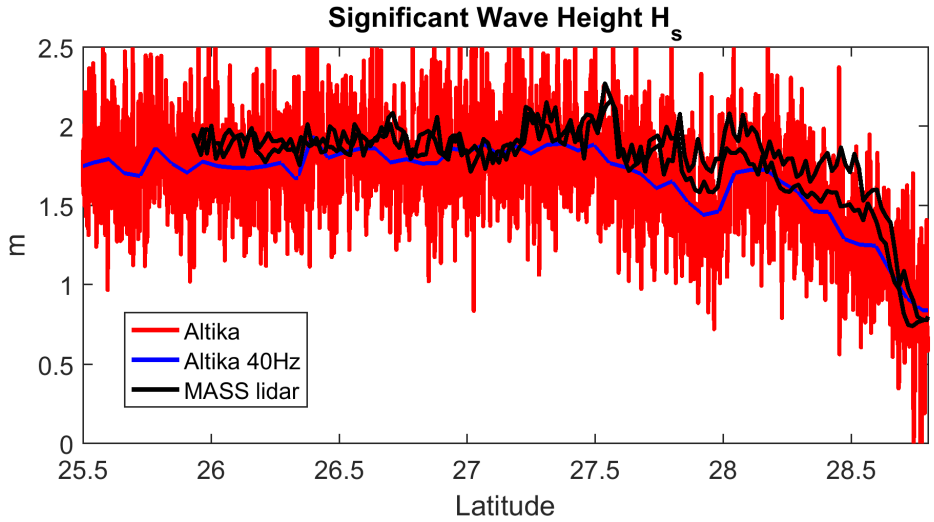
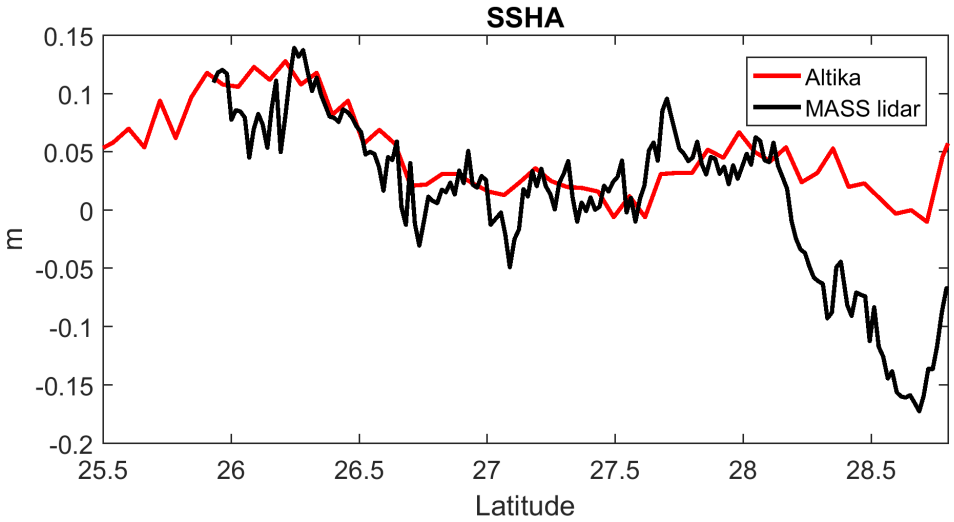
(provided by L. Marie' – IFREMER)

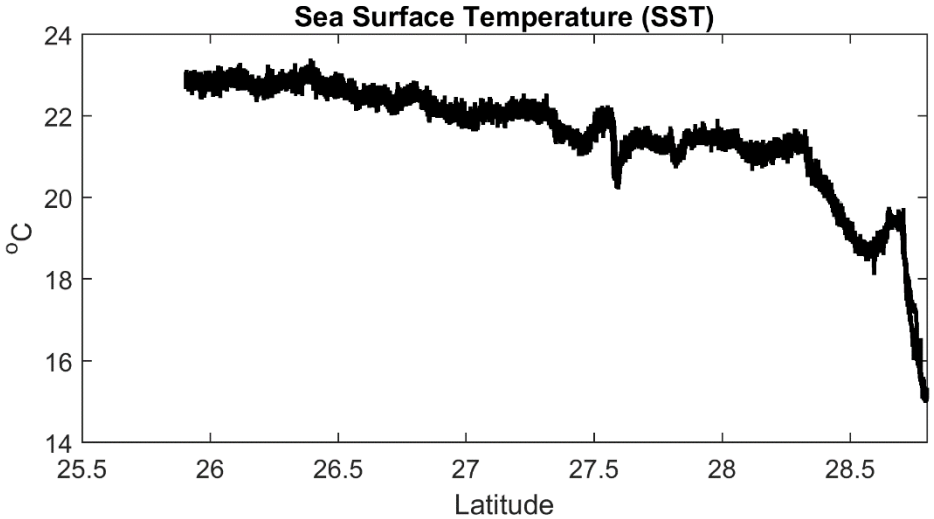
**SST SATELLITE DATA collected ~ <u>4hrs</u> after end of the research flight**

# Feb 5 2016 – CARTHE Coincident AirSWOT/ALTIKA/MASS flights

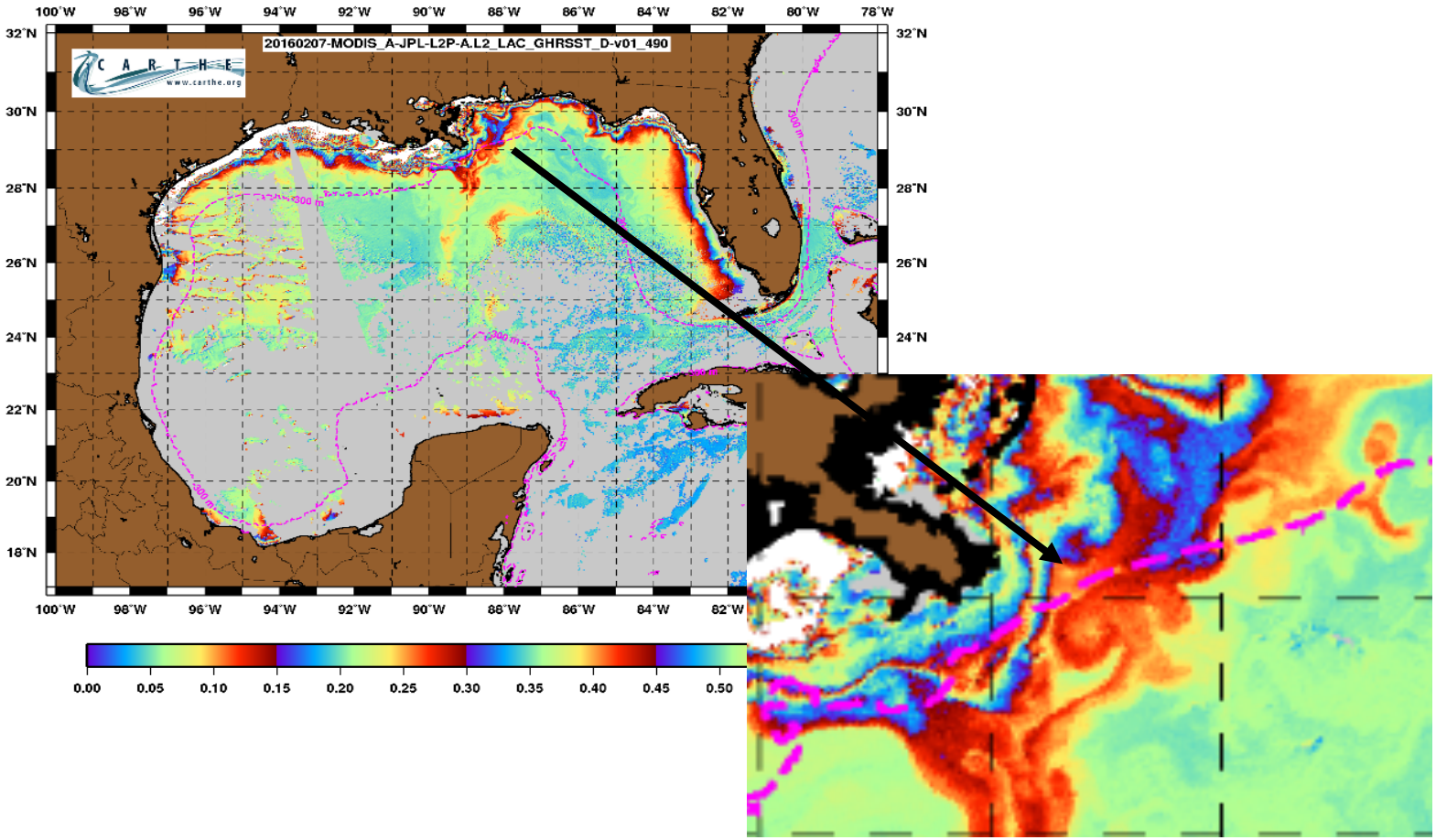


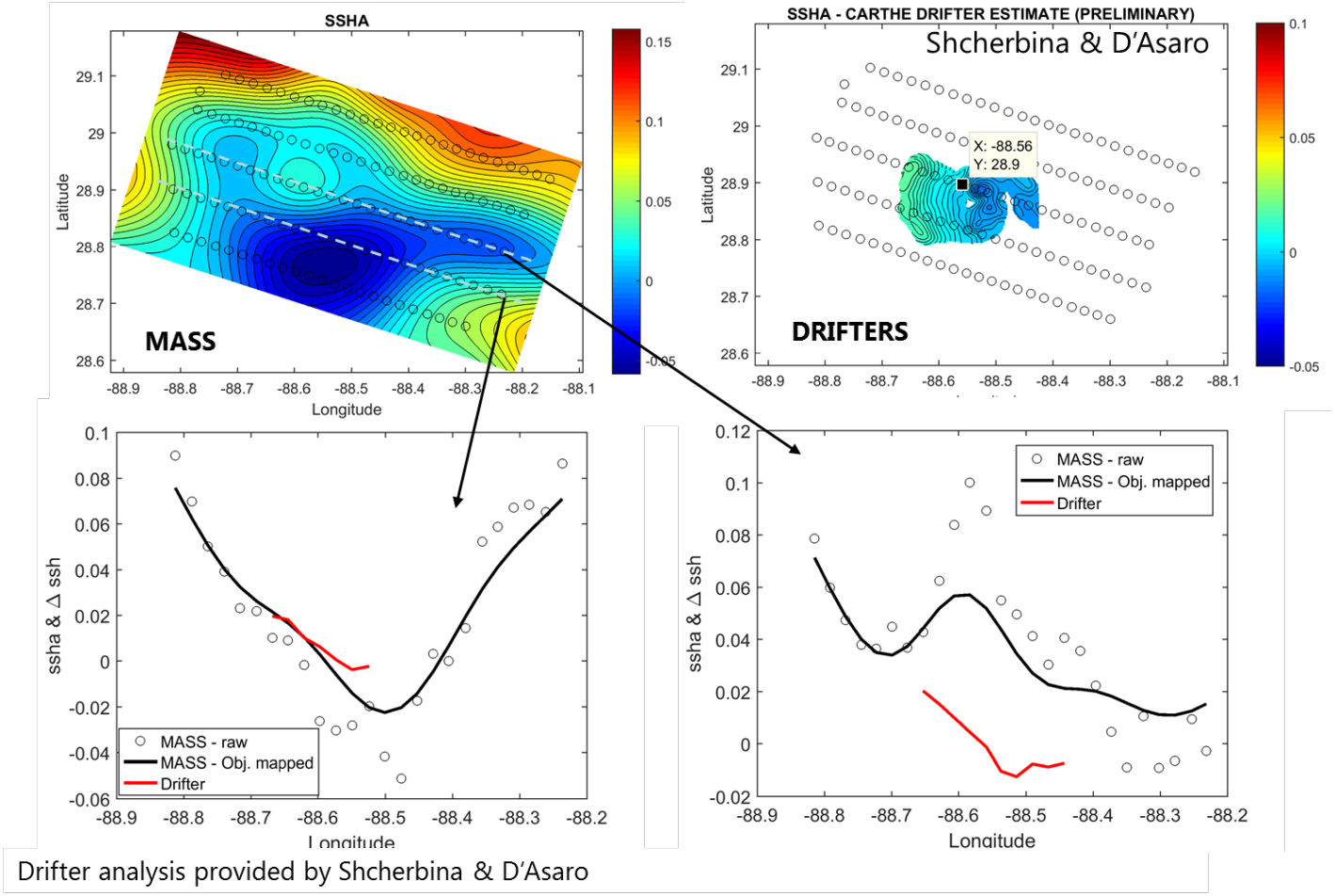



# Submesoscale Processes during CARTHE/LASER, Jan-Feb, 2016




"Hammerhead" submesoscale feature identified during the CARTHE LASER experiment in the Gulf of Mexico on February 7 2016 from a MODIS chlorophyll product. Flight tracks were specifically designed to characterize the ssha associated with this feature.

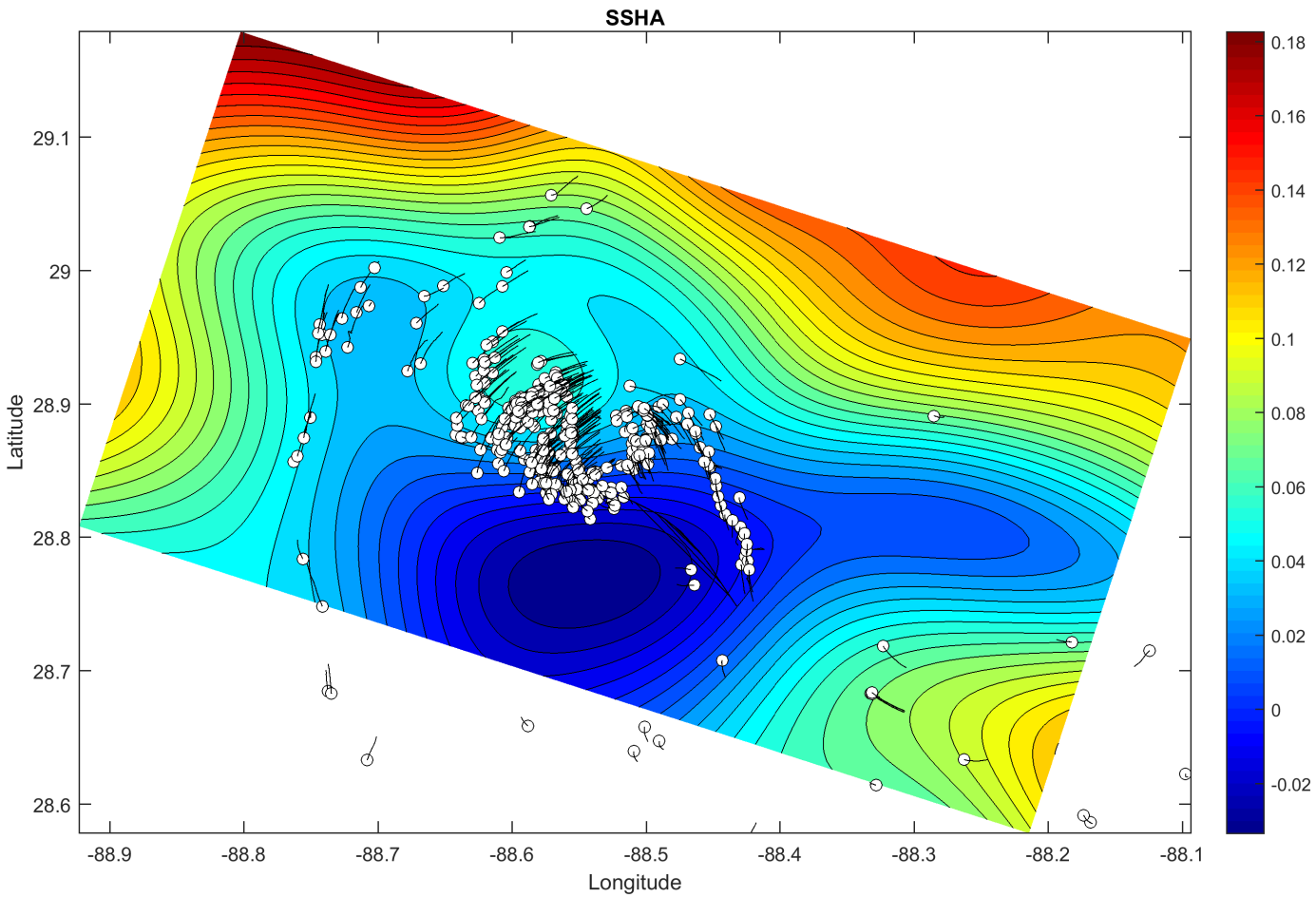
# “Hammerhead” - continued




Drifter analysis provided by Shcherbina & D'Asaro

(top left) Objectively mapped ssha measured by the MASS lidar (actual measurement locations are black circles), (top right) $\Delta ssh$ computed from the CARTHE LASER drifter trajectories (credit: Shcherbina & D'Asaro) over the same area and period of time. (bottom panels) Sample cross-sections showing the raw and objectively mapped MASS ssha products compared with the $\Delta ssh$ computed from the drifters.

# “Hammerhead” - continued




CARTHE/LASER drifter trajectories on February 7 2016 between 1830-2130 UTC plotted on top of the objectively mapped ssha measured from the MASS lidar over the same area and period of time.

# Airborne lidar at crossovers

Crossover is approximately 250 km along track

A small jet travelling at 750 km/hr (~400 kts) with an endurance of 5-6 hours would be able to make 15 along-track legs in that time with a separation of 8 km across track.

This flight would be centered at the crossover time

With the current MASS system that would have a lidar along-track resolution of approximately 1 m and sub-meter across track – sufficient to give very good surface-wave directional spectra.

This would cover wavelengths from 125km to 2 m along track and 60 km to O(1)m across track.

This should be supplemented by reciprocal flights out to 2000 km to extend along-track wavelengths out to 1000 km.

# Conclusions



The crossover scenario described here would provide SSH coverage within 2 1/2 hrs of the crossover time.

There appears to be no other way of *rapidly* measuring the SSH in the crossover areas independently of AirSWOT.

Airborne measurements can be compared against in situ measurements (c.f. CARTHE/LASER)

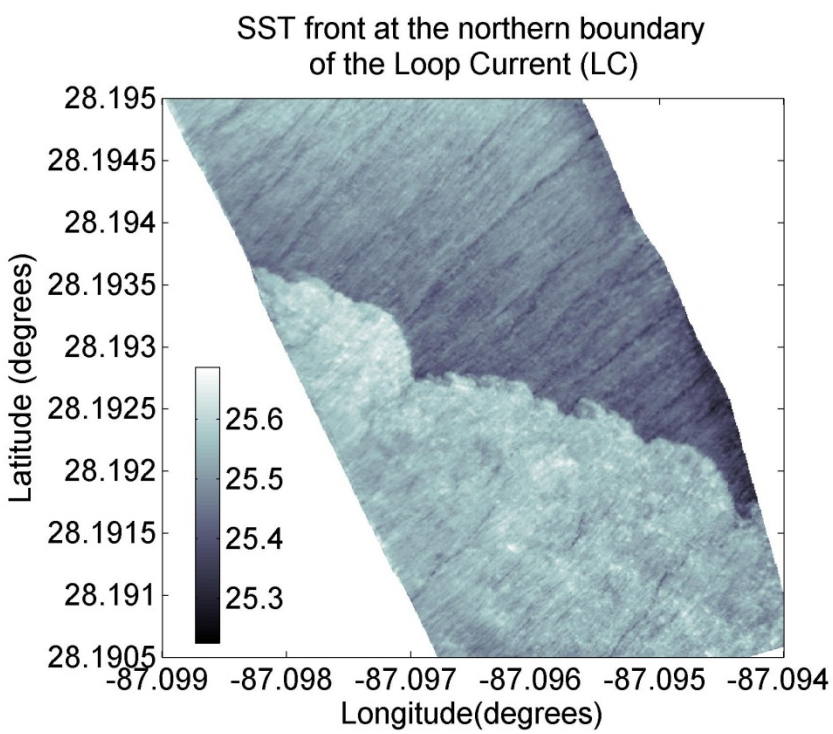
However, the lidar approach is not a solved problem.

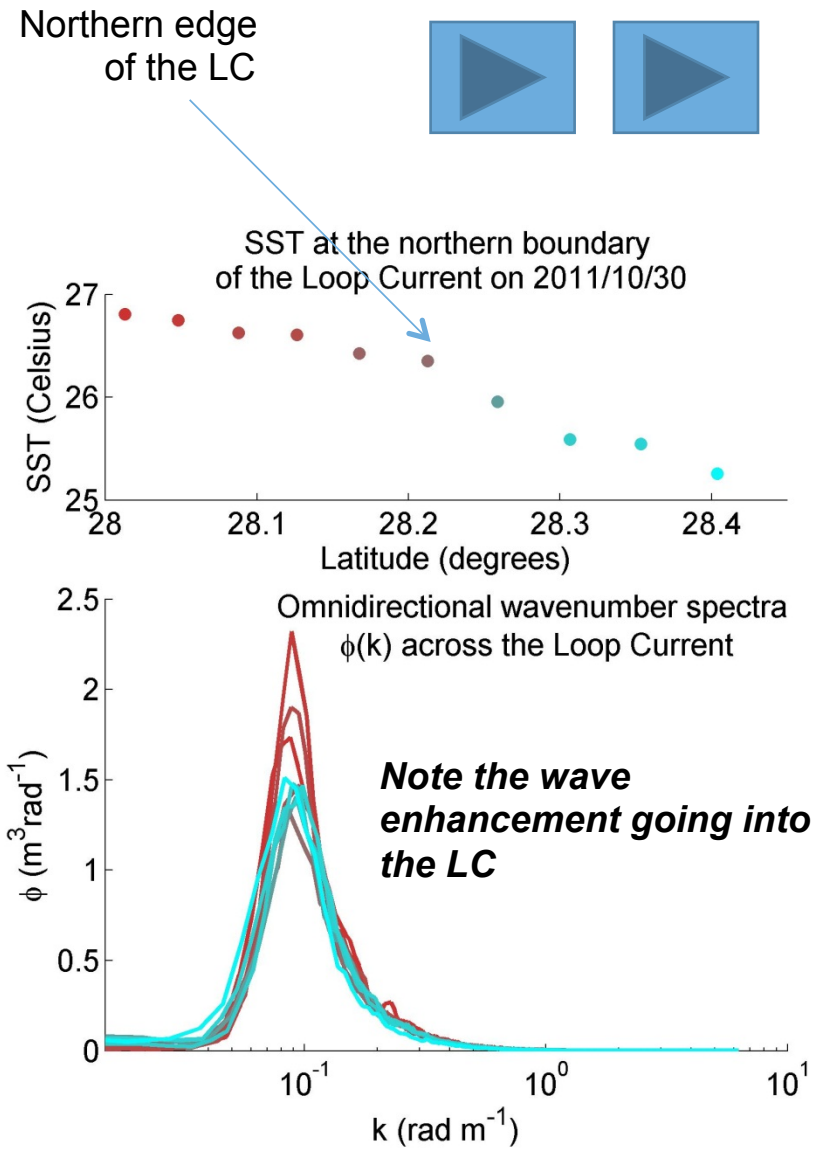
We have to demonstrate that we can come in under the required 2.5 cm rms error in 1x1 km.

This will require a rigorous study of all the error sources in both the lidar and the GPS/IMU system

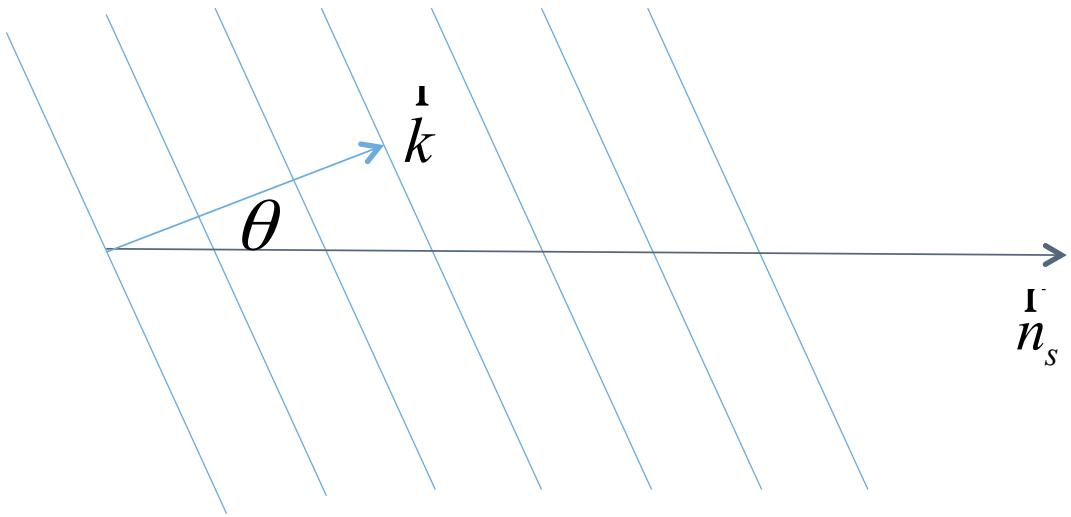
# QUESTIONS?

# Wave Enhancement at SST Front




(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.

# Aliasing of Waves into longer Wavelengths

If the wave field is given by $\eta \propto e^{i(\vec{k}.\vec{x}-\omega t)}$, where $\left|\vec{k}\right| \equiv k = \lambda / 2\pi$, and the unit vector along the satellite track is $\vec{n}_s$, then the measured wavelength along the satellite track $\lambda_s = \dfrac{\lambda k}{\vec{k}.\vec{n}_s} = \dfrac{\lambda}{\cos\theta}$. That is the waves will be aliased into lower wavenumbers.