# Airborne observations of surface winds, waves and currents from meso to submesoscales

Luc Lenain, Nick Pizzo, Mara Freilich, Luke Colosi, Laurent Grare and Nick Statom
*Scripps Institution of Oceanography - UCSD*

Ben Smeltzer, Simen Ellingsen
*NTNU*

*Mesoscale and Frontal-Scale Air-Sea Interactions Workshop*
*Boulder, CO – March 7 2023*

*Lenain, L., Smeltzer, B. K., Pizzo, N., Freilich, M., Colosi, L., Ellingsen, S., Grare, L., Peyriere, H. and Statom, N. (2023). Airborne remote sensing of upper-ocean and surface properties, currents and their gradients from meso to submesoscales. GRL (in review)*

# "Collocated and Coincident" airborne observations of surface winds, waves and currents from meso to submesoscales

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# Observational challenge: Resolving a broad range of scales

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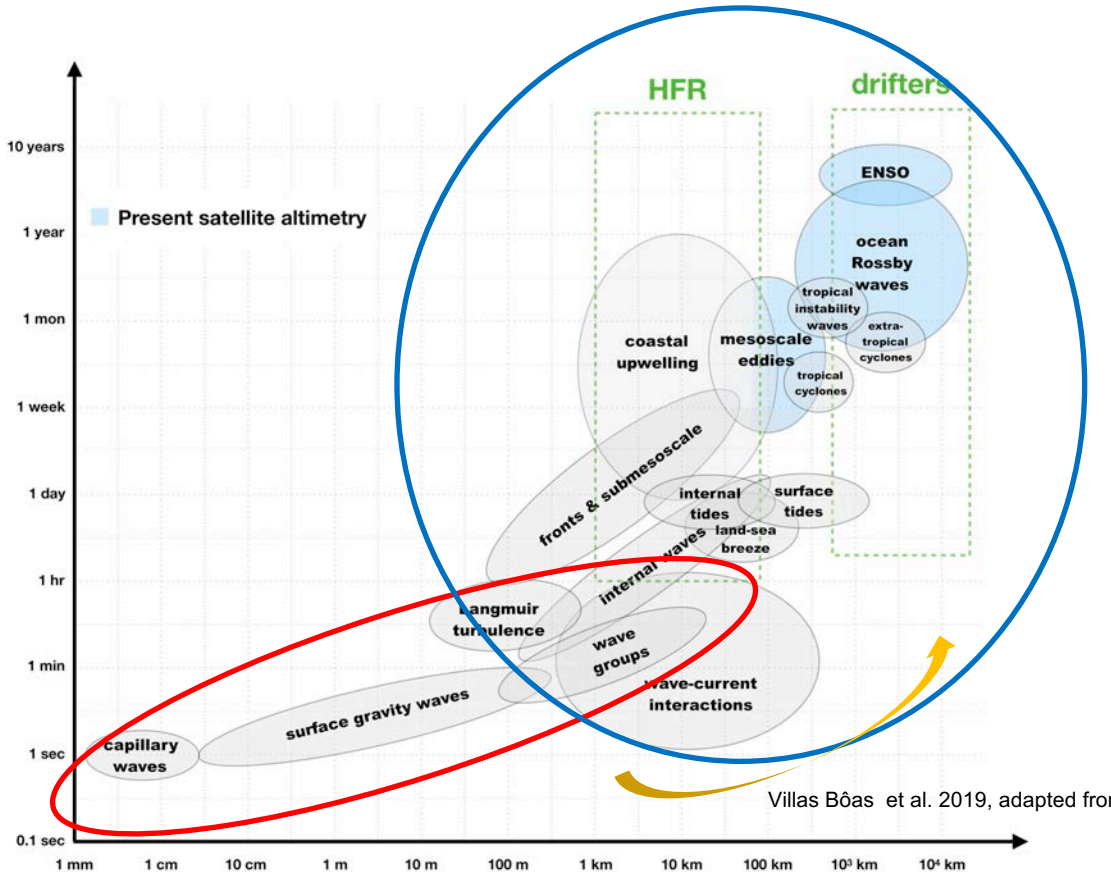
**Surface waves will also affect longer wavelength processes!**



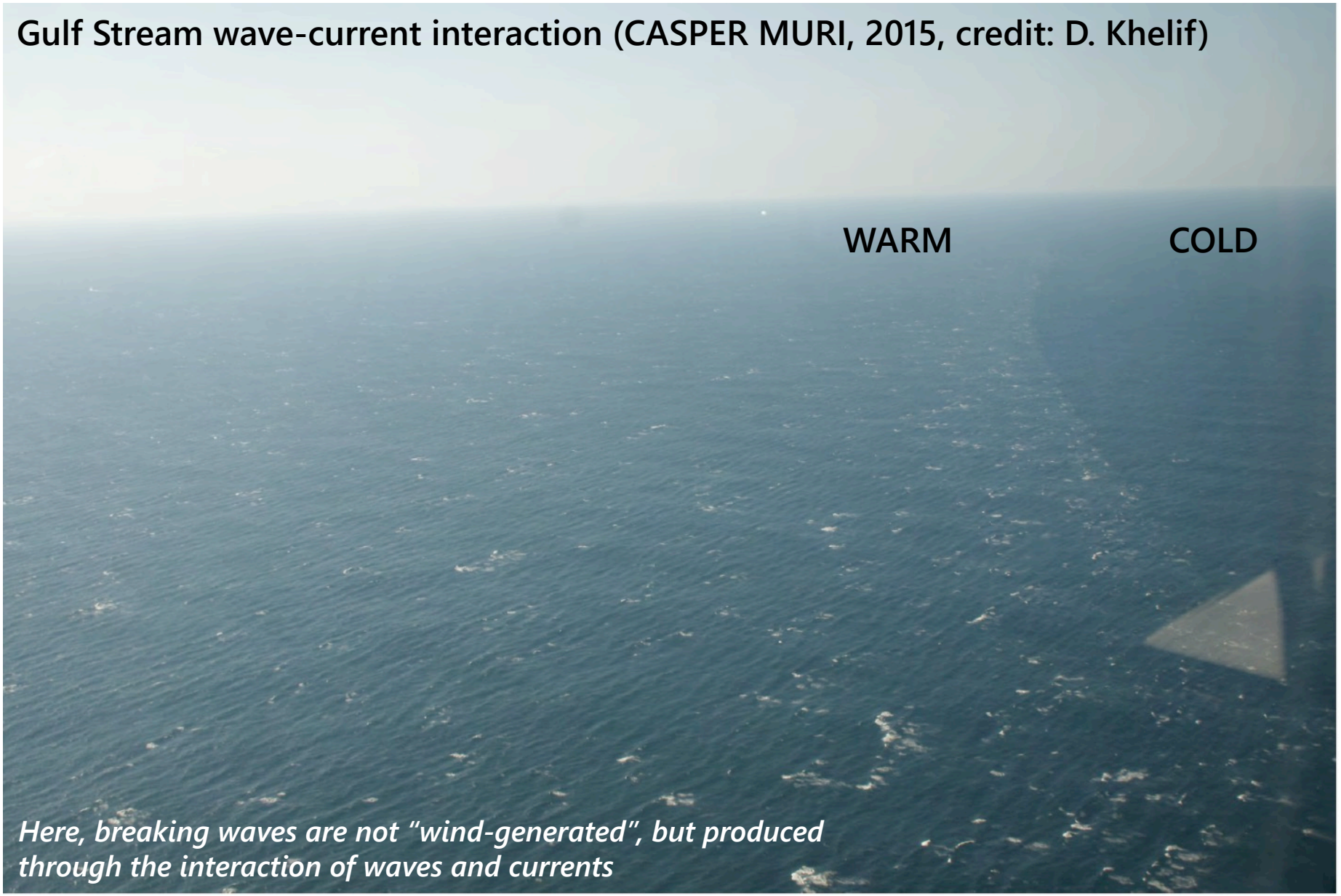

Villas Bôas et al. 2019, adapted from Chelton et al. 2001

subsecs to hours

mms to kms

Spatial and temporal scales of multiple ocean and atmosphere process

## Gulf Stream wave-current interaction (CASPER MURI, 2015, credit: D. Khelif)



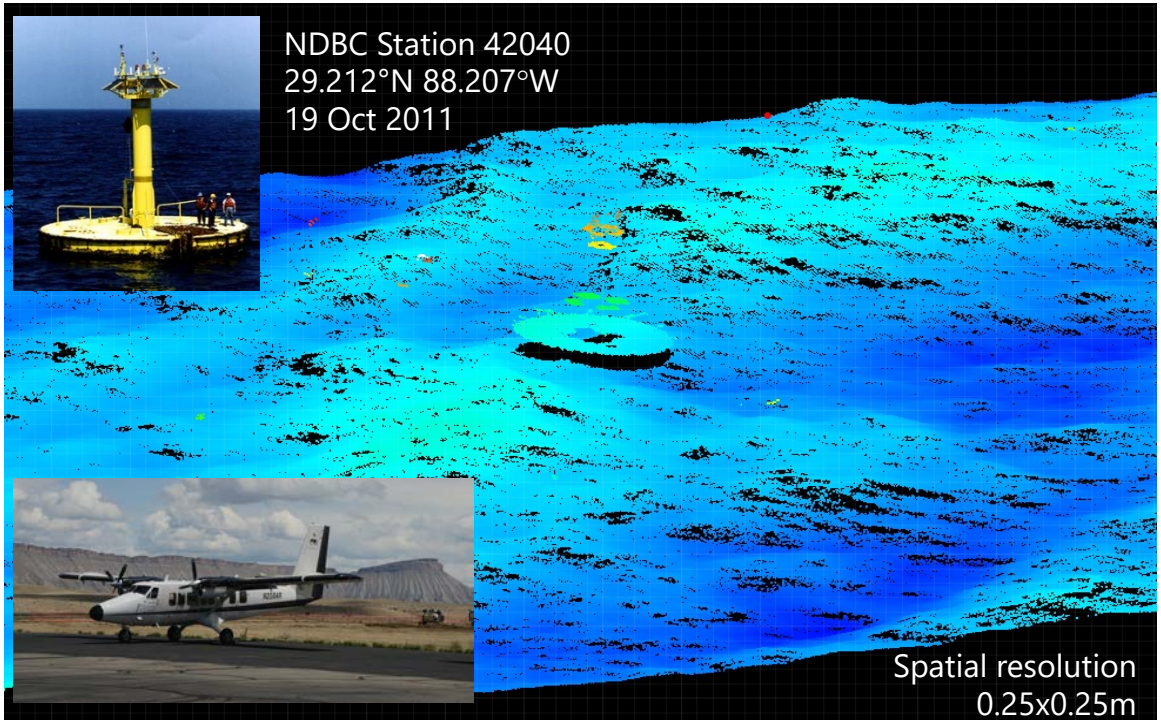

*Here, breaking waves are not "wind-generated", but produced through the interaction of waves and currents*

# Overview

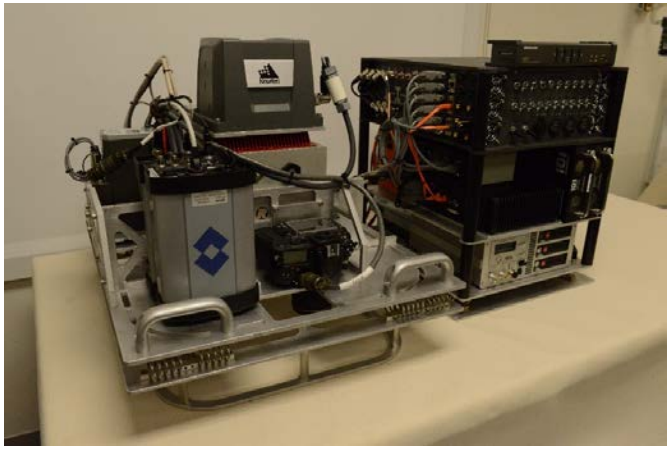
- We present unique coincident and collocated airborne observations of SST, surface currents, winds and properties of surface waves across submesoscales features
- A new airborne instrument enables observations of surface currents, vertical and horizontal shear to capture quickly evolving ocean features
- Such observations are crucial to develop better understanding of the physics of (sub)mesoscale processes (e.g. fronts) and wave-current interaction

- Related talk/posters:
  - Nick Pizzo et al.: **"Strongly modulated surface waves at a submesoscale front"**
  - Mara Freilich et al.: **"Observational characterization of the transition to submesoscale dynamics"**
  - Bia Villas de Boas' talk tomorrow (surface waves)

# SIO Modular Aerial Sensing System (MASS)



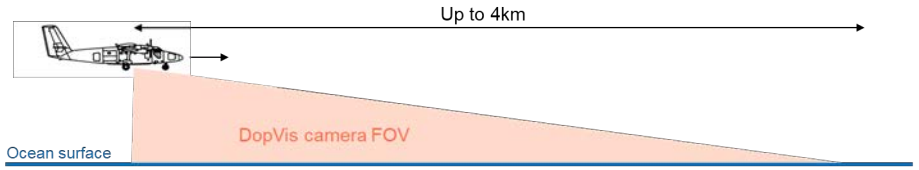

*Example of surface elevation as measured from the MASS during a 2011 experiment in the Gulf of Mexico, flying above NDBC buoy #42040. (wind~12m/s, Hs = 3.1m)*



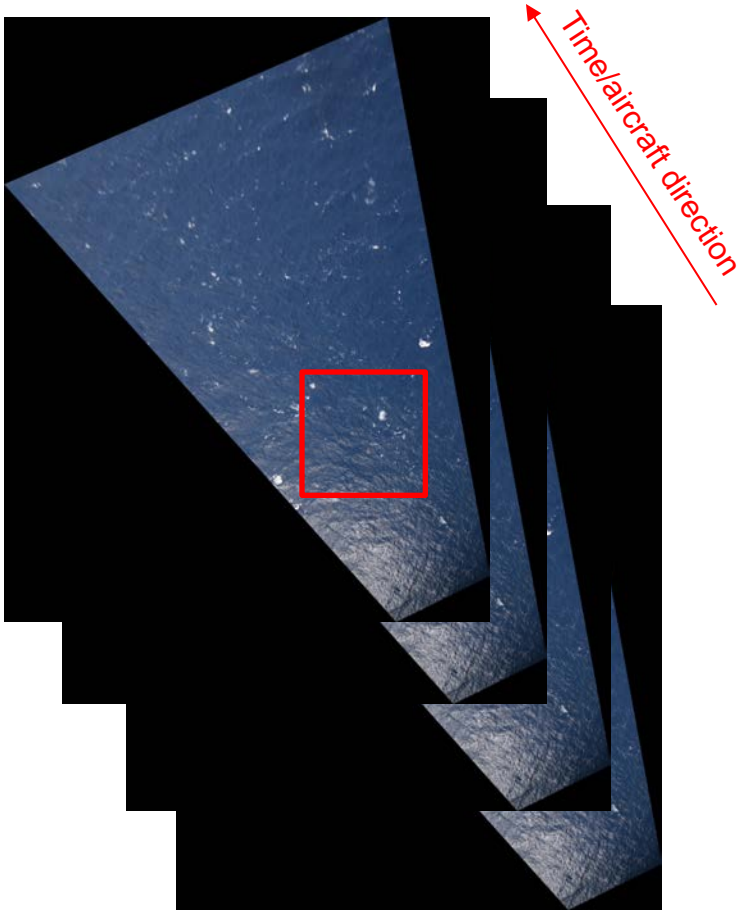
| **Instrumentation** | **Measurement** | |
|---|---|---|
| Scanning Waveform Lidar | Riegl Q680i | Surface wave, surface slope, directional wave spectra (vert. accuracy ~2-3cm) + surface winds |
| Long-wave IR Camera | FLIR SC6000 (QWIP) | Ocean surface processes, wave kinematics and breaking, frontal 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 |
| **DoppVis (NEW)** | | **Surface currents, vertical shear, wave breaking statistics** |

# MASS DoppVis instrument

**DoppVis instrument concept:** Capturing upper-ocean current profiles (first few meters) along the track of the aircraft through observations of the spatio-temporal evolution of surface waves (**dispersion relationship method**), following the work of Dugan et al. (2001) and more recently the Fugro ROCIS team.




"Stack" georeferenced images together to identify overlapping region (256x256m squares)



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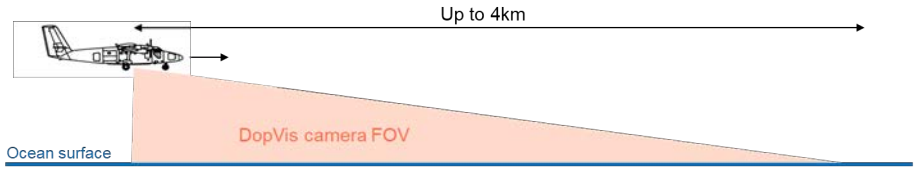
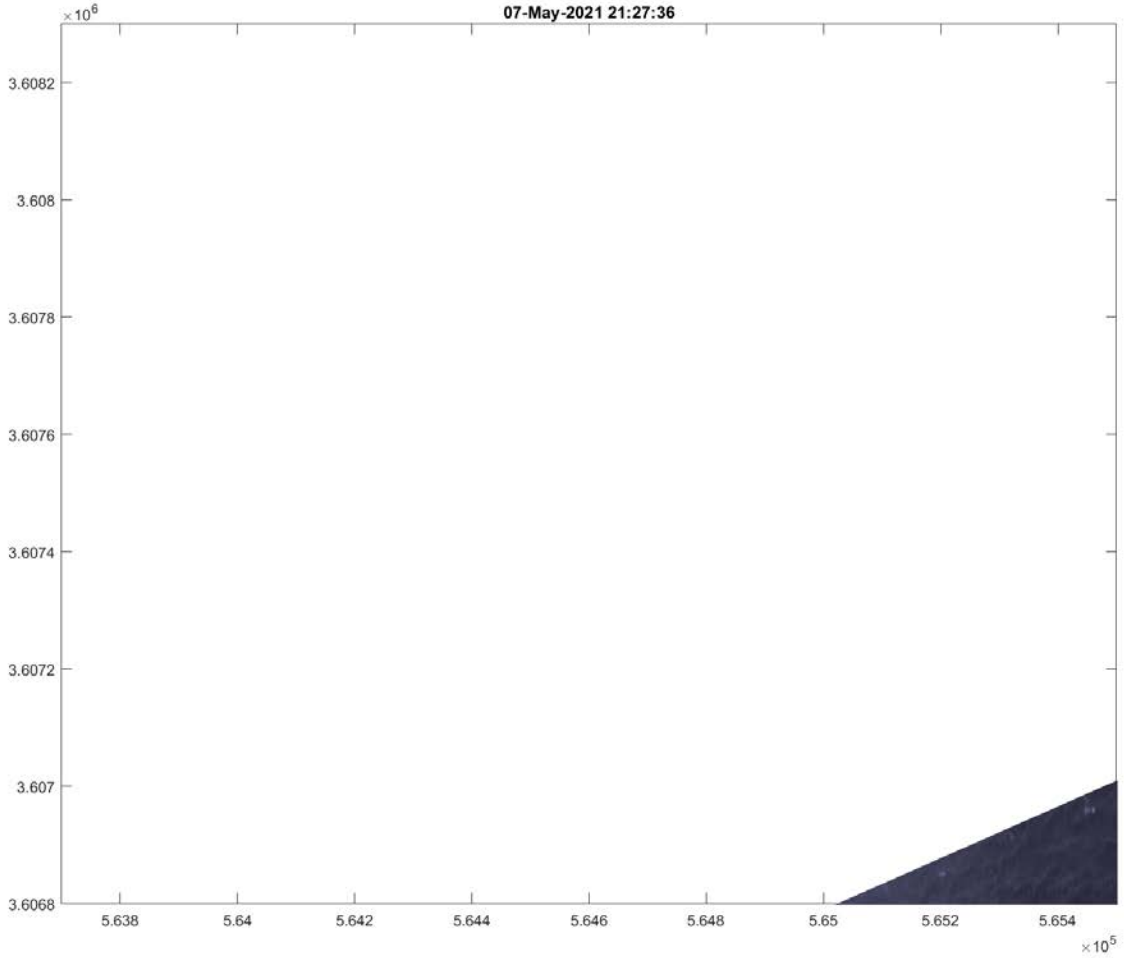
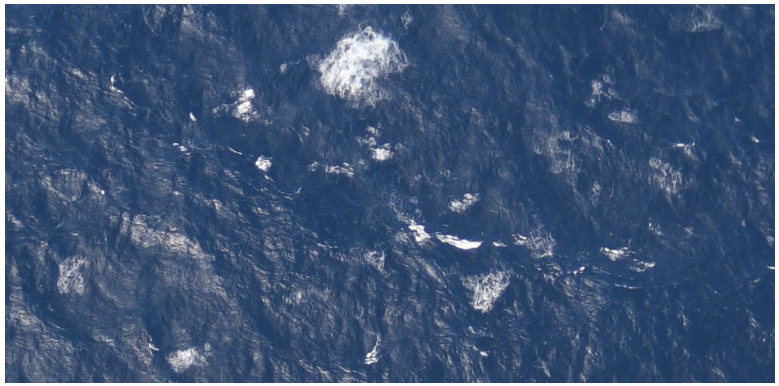
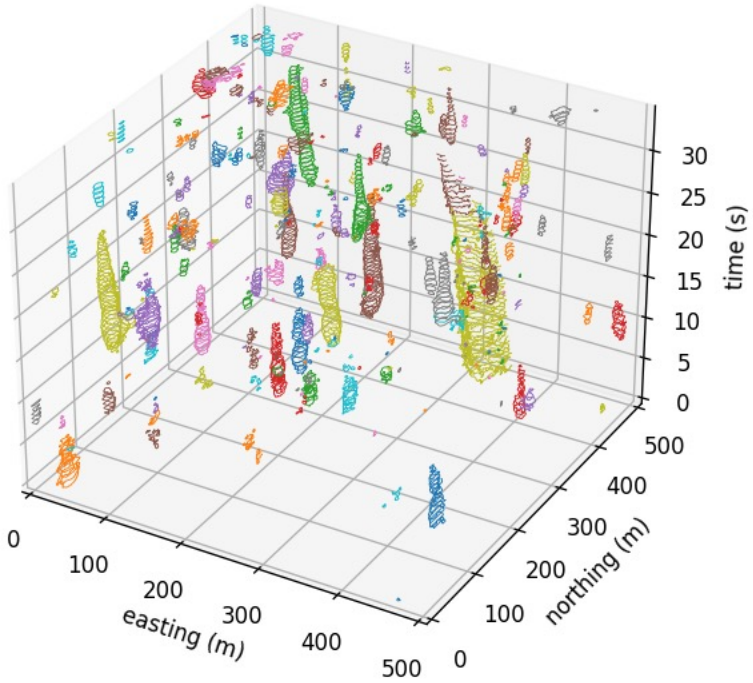


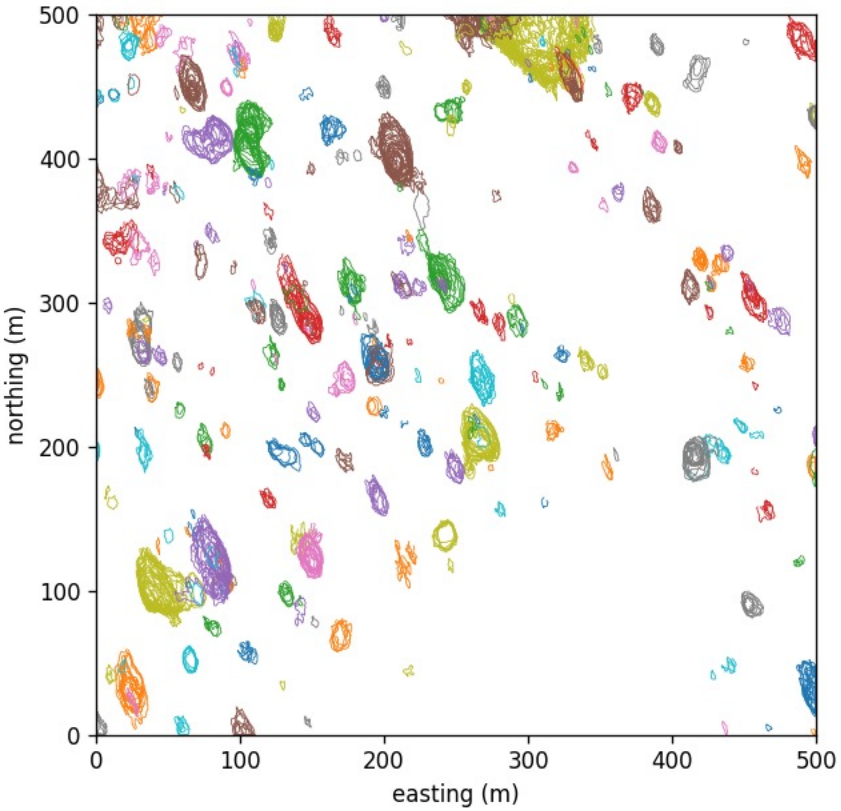
# Wave breaking Statistics from DoppVis



Enable ability to track breaking waves over longer periods of time as compared to traditional methods

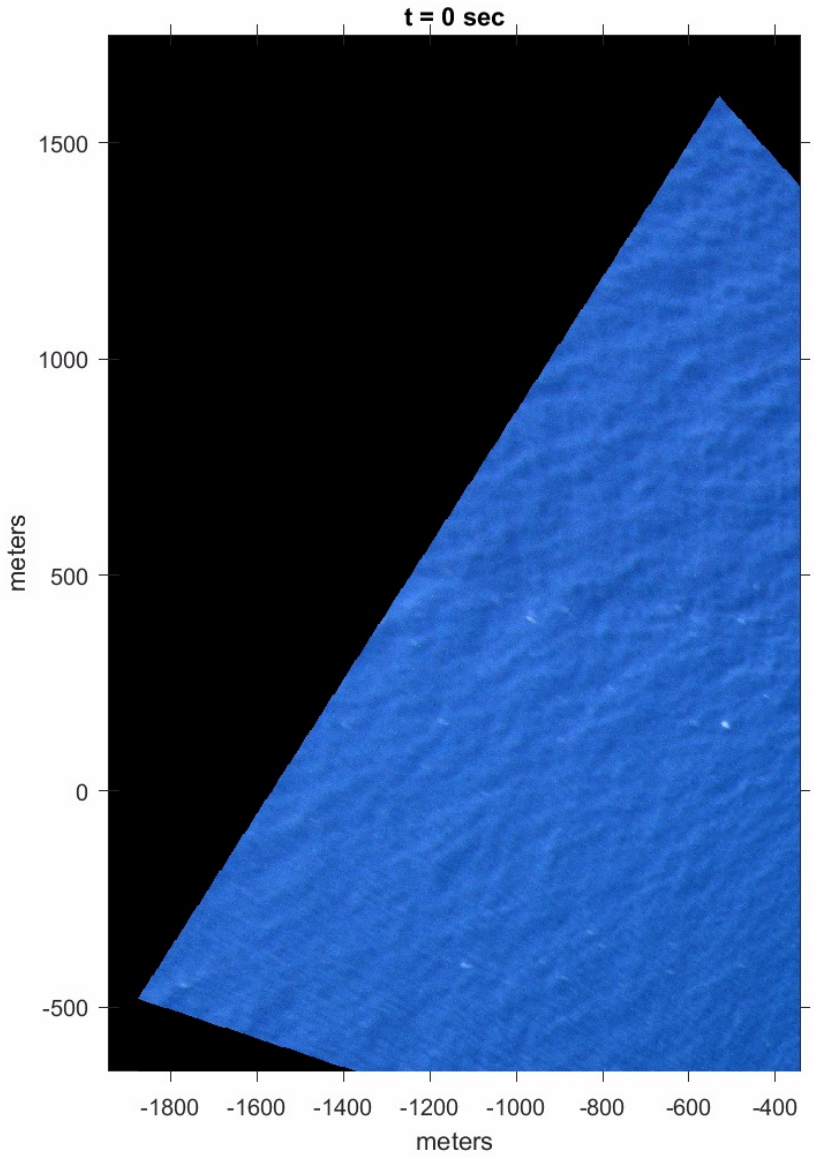



Wave breaking contours tracked in space and time and grouped by individual event




Ryan Saenger (SIO PhD student)

# Enhanced breaking at a front




Nick Pizzo's poster: **"Strongly modulated surface waves at a submesoscale front"**

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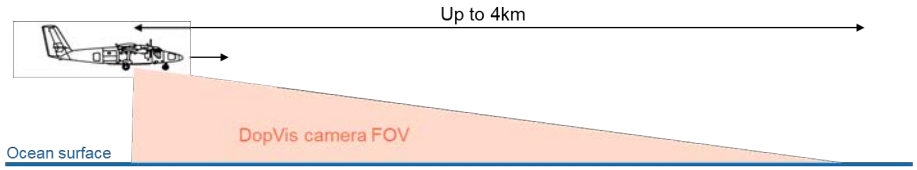


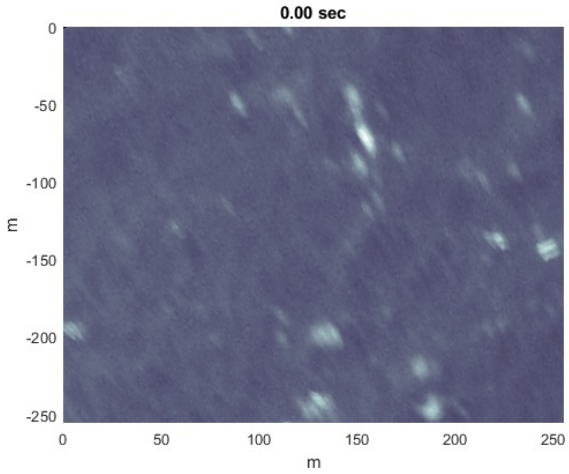


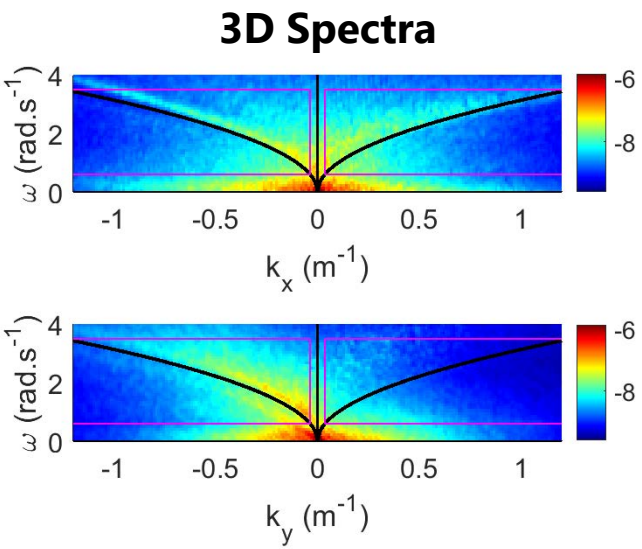


**Invert for upper ocean currents and shear (vertical and horizontal)**

Horizontal resolution: 128-1000m
Depth range: 0.5-3m (wave conditions dependent)
*here depth-averaged currents

In collaboration with B. Smeltzer and S. Ellingsen (NTNU)

NTNU
Norwegian University of Science and Technology

*See Stewart & Joy (1974), Campana et al. (2016), Smeltzer et al. (2019) among others for more details on the approach*

# How well does DoppVis surface currents agree with in-situ observations?

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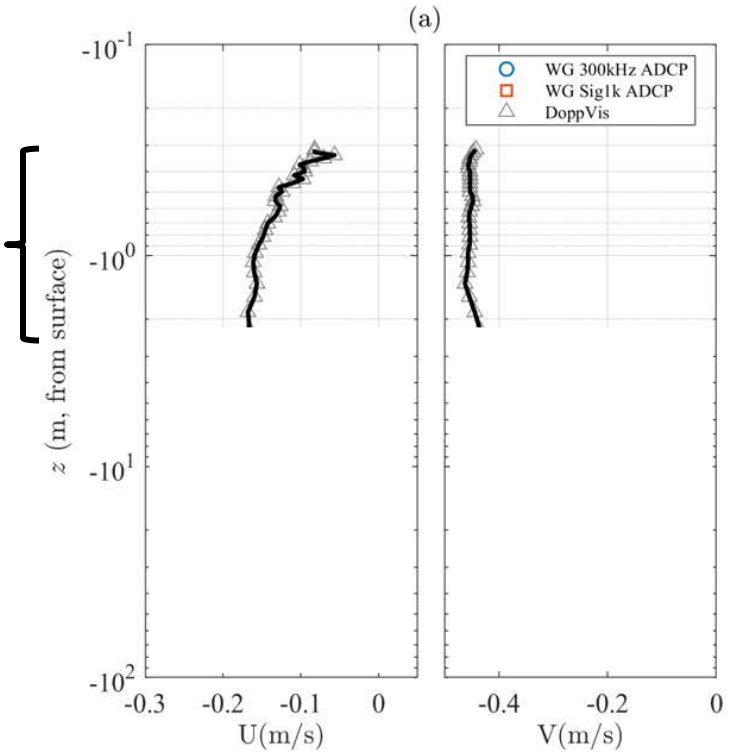
**Comparing DoppVis near surface current profiles to upward and downward ADCPs installed on the wave glider using coincident (within 5min), collocated (within 500m) observations.**

DoppVis



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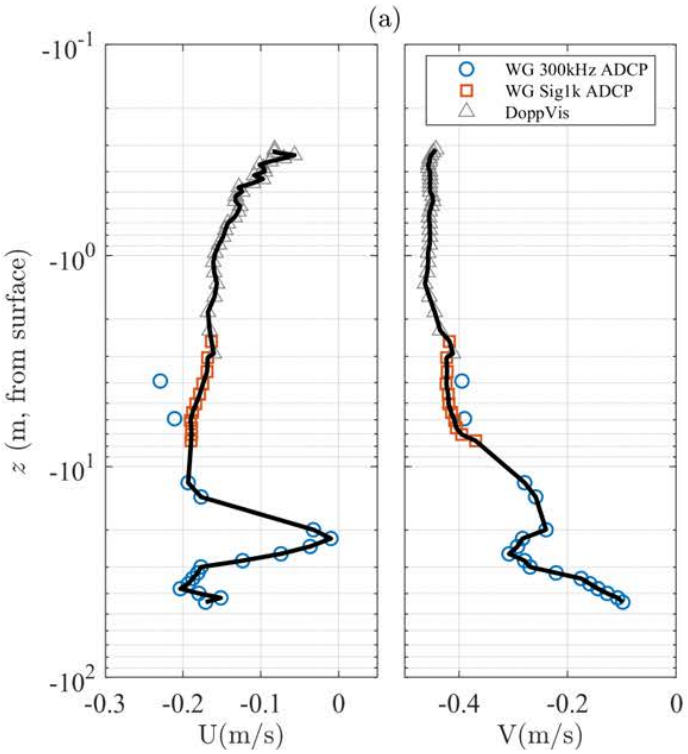
DoppVis

Upward-looking ADCP

Downward looking ADCP



# Spatial observations of vertical current shear

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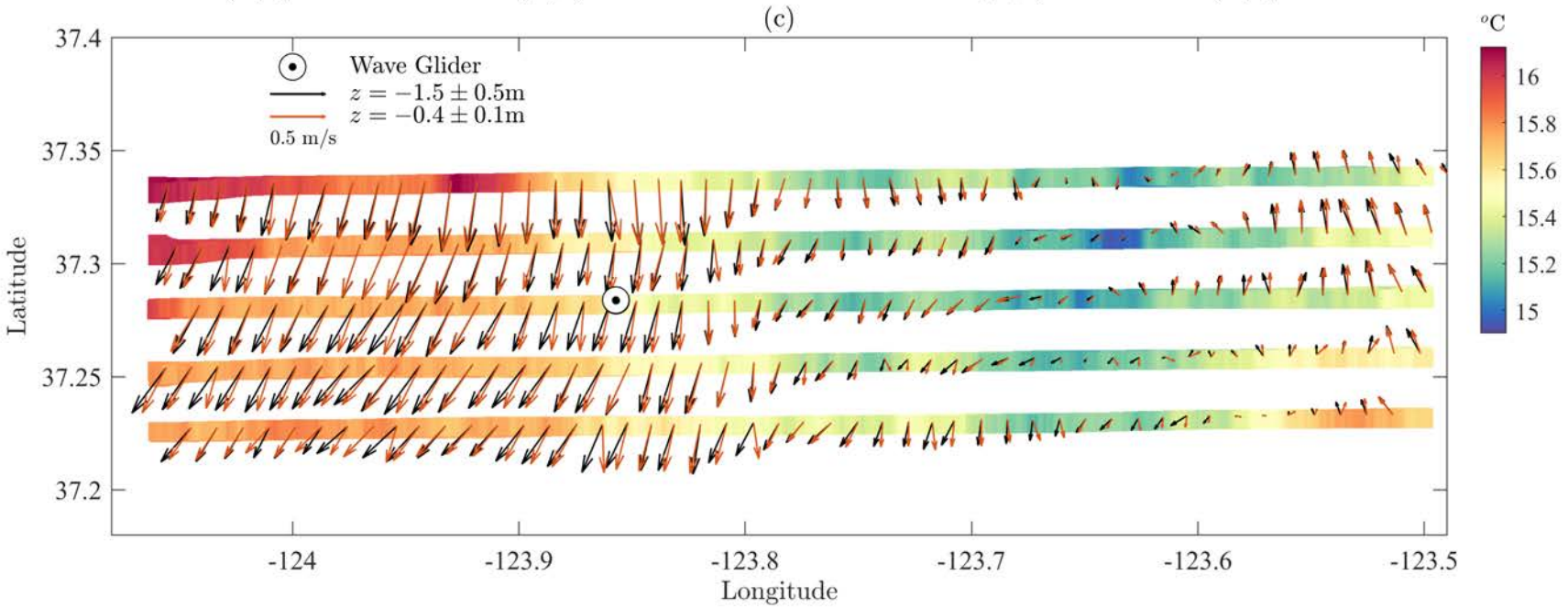
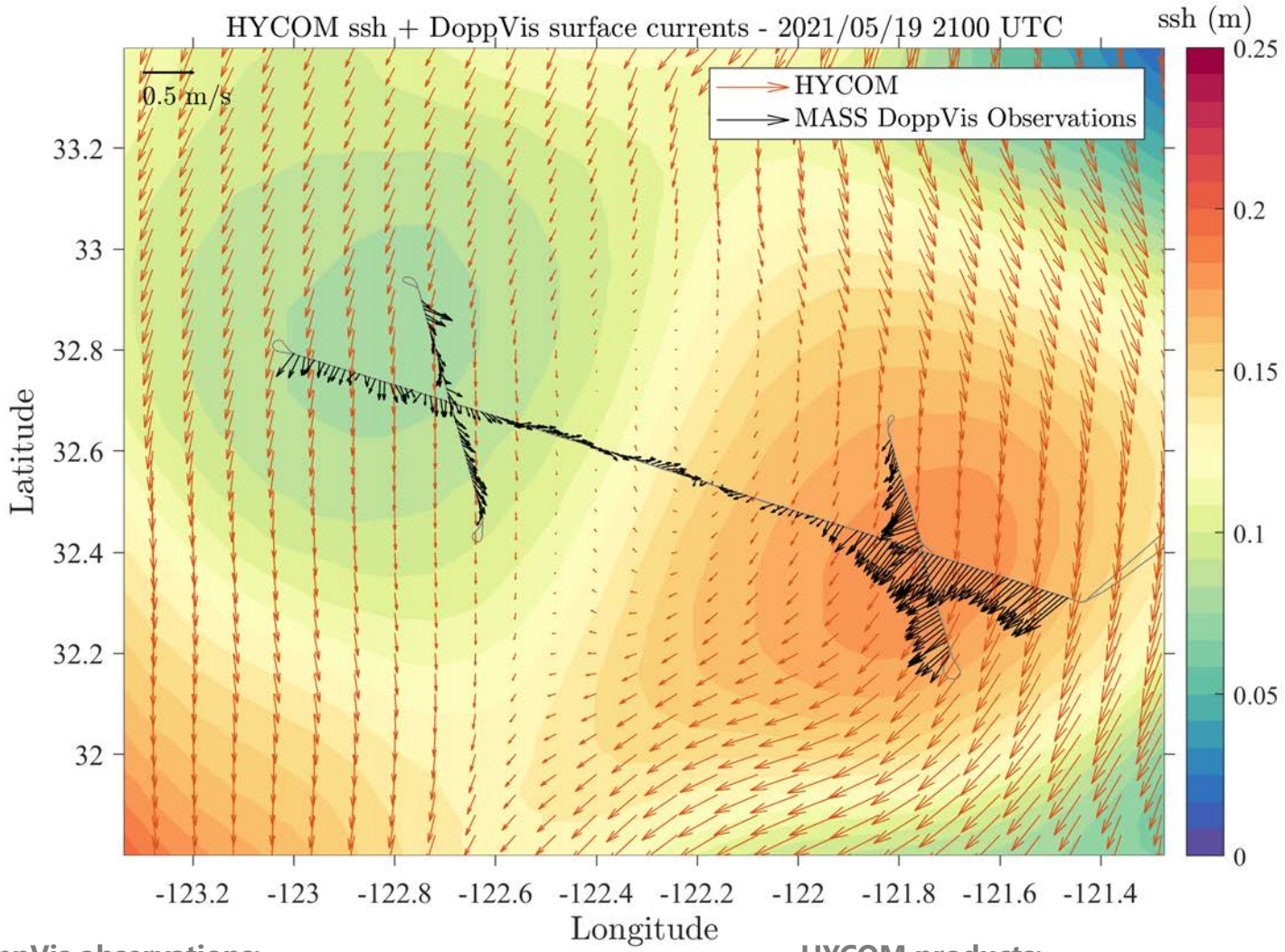
**2021/05/04 (flight #1)**

**Current maps at two depths, shallow (z = -0.4m) and "deeper" (z=-1.5m)**



# Comparing HYCOM and DoppVis observed currents




**MASS DoppVis observations:**

- Depth-averaged (~0.5-3m) currents, 1km horizontal
- Showing non-reciprocal passes for clarity

**HYCOM products:**

- Sea surface height anomaly (ssh)
- Surface currents (depth = 0m) plotted here

# DoppVis and SST observations at higher resolution (250m)

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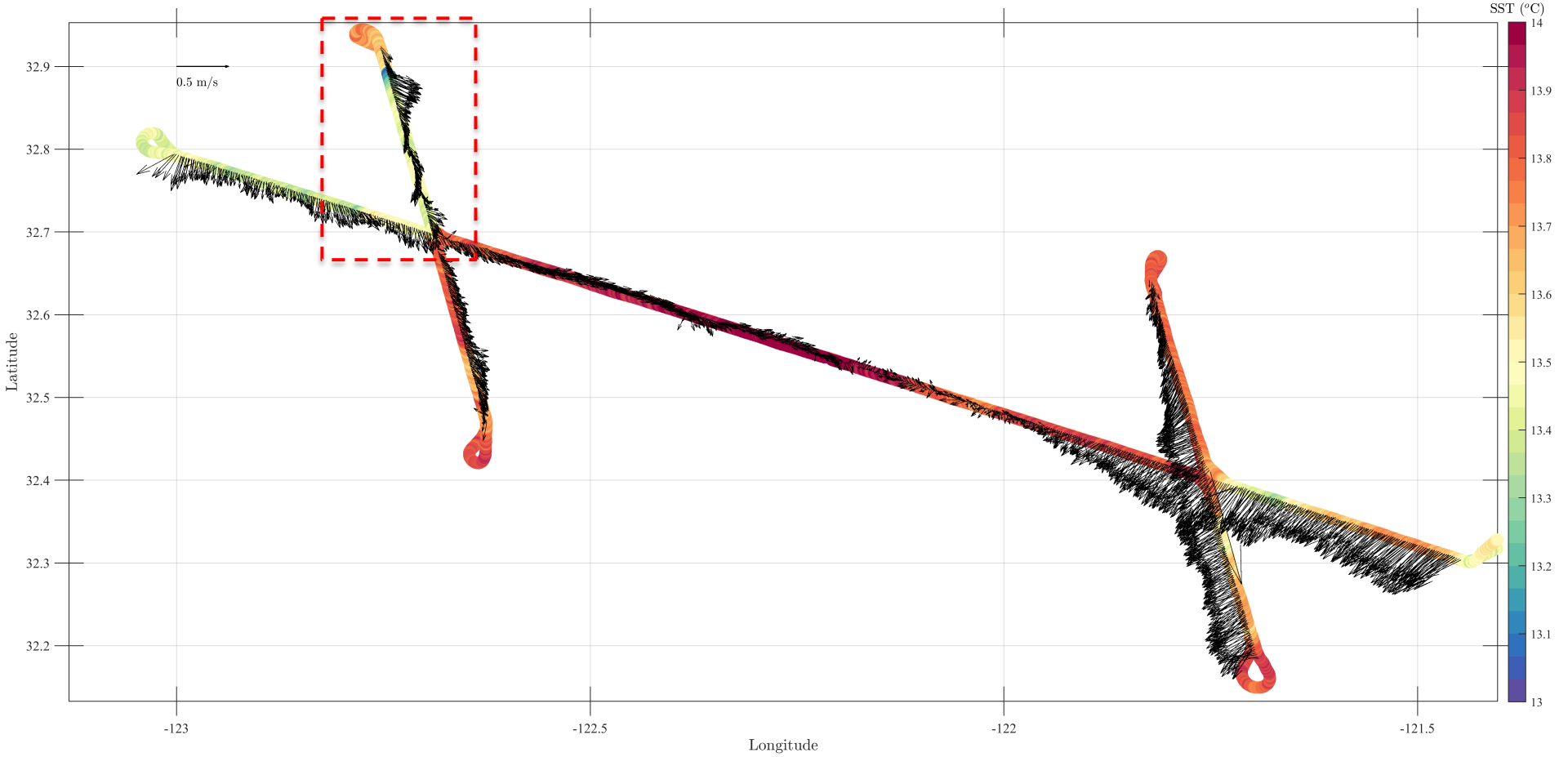
**HR MASS DoppVis observations for the entire flight (depth ~1m, 250m along-track resolution)**



# DoppVis and SST observations at higher resolution (250m)

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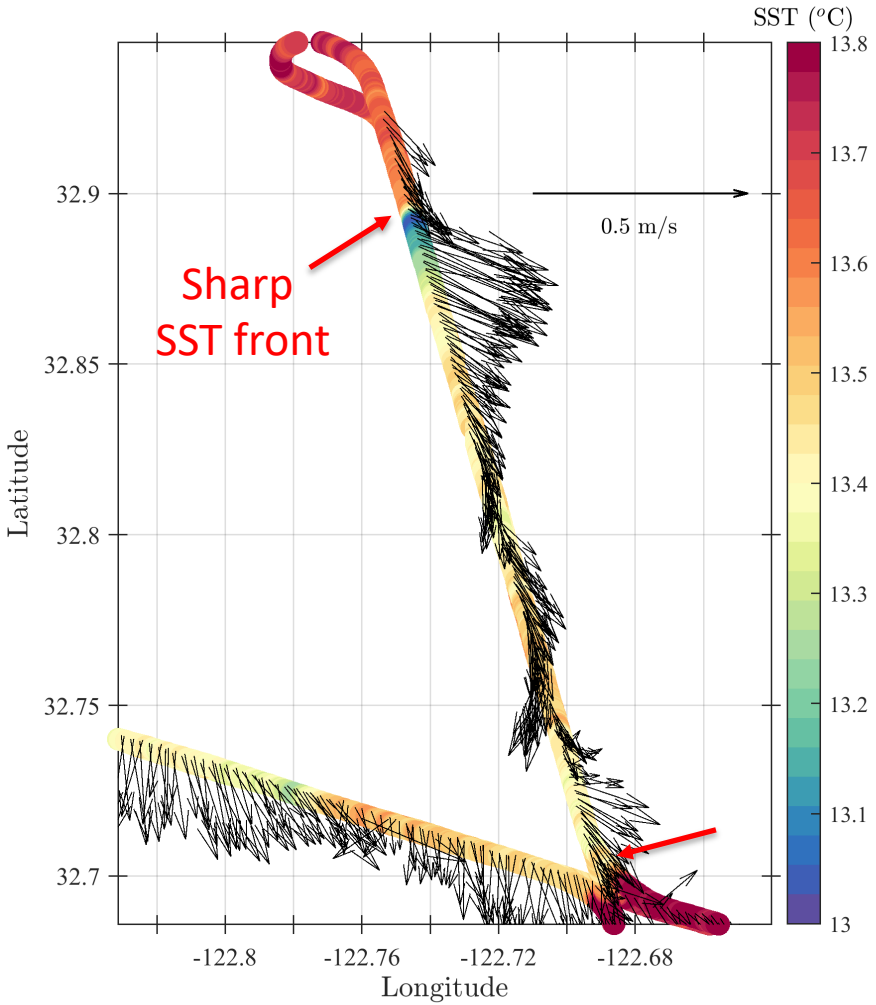
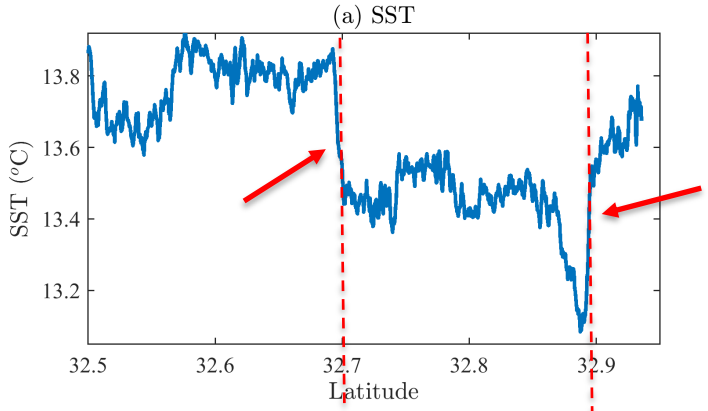
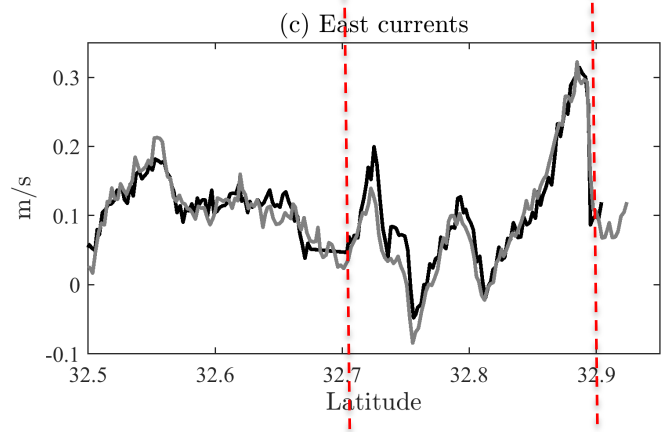
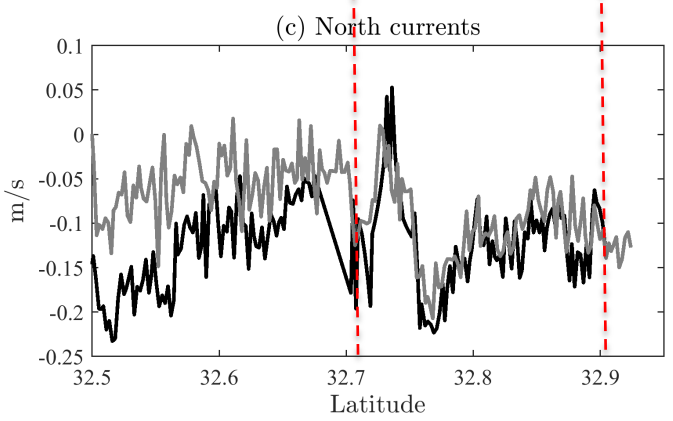
Very energetic submesoscale features
(few kms wavelength) and fronts



# DoppVis and SST observations at higher resolution (250m)

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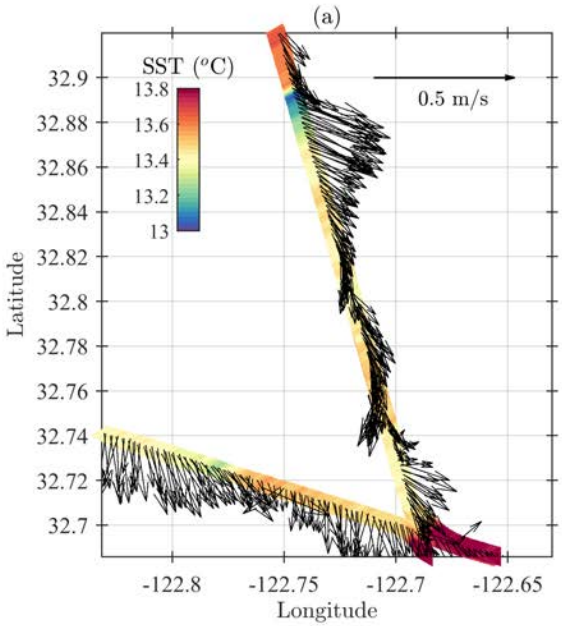
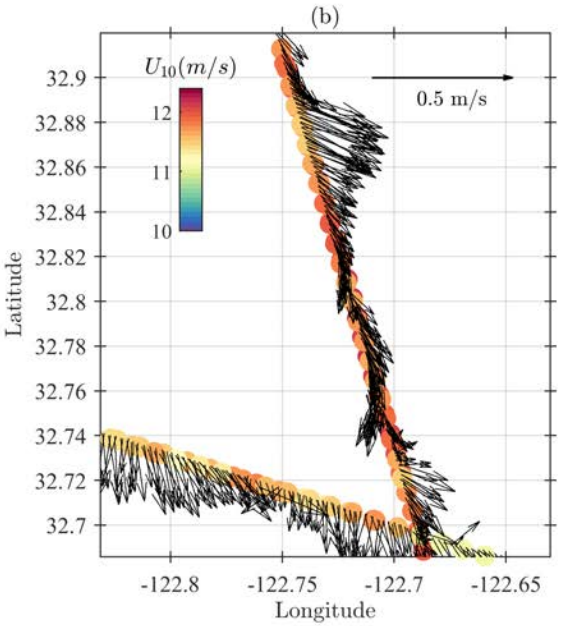
Coincident spatial observations of surface winds, currents, SST and surface wave properties

Currents +

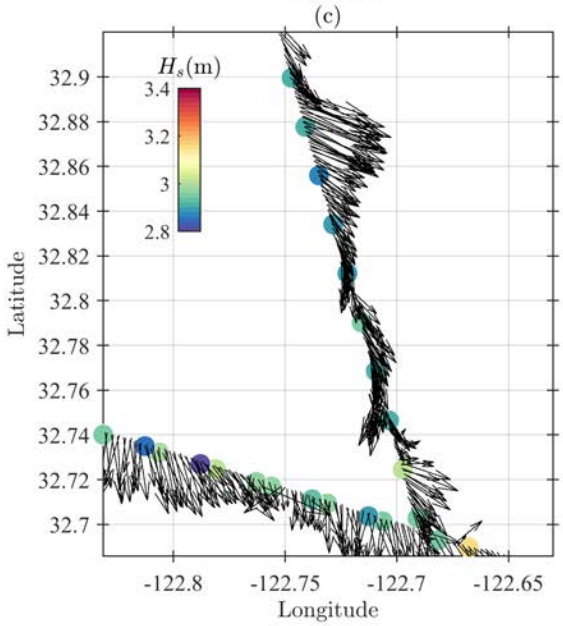
SST




Surface winds
(Lenain et al. 2019)

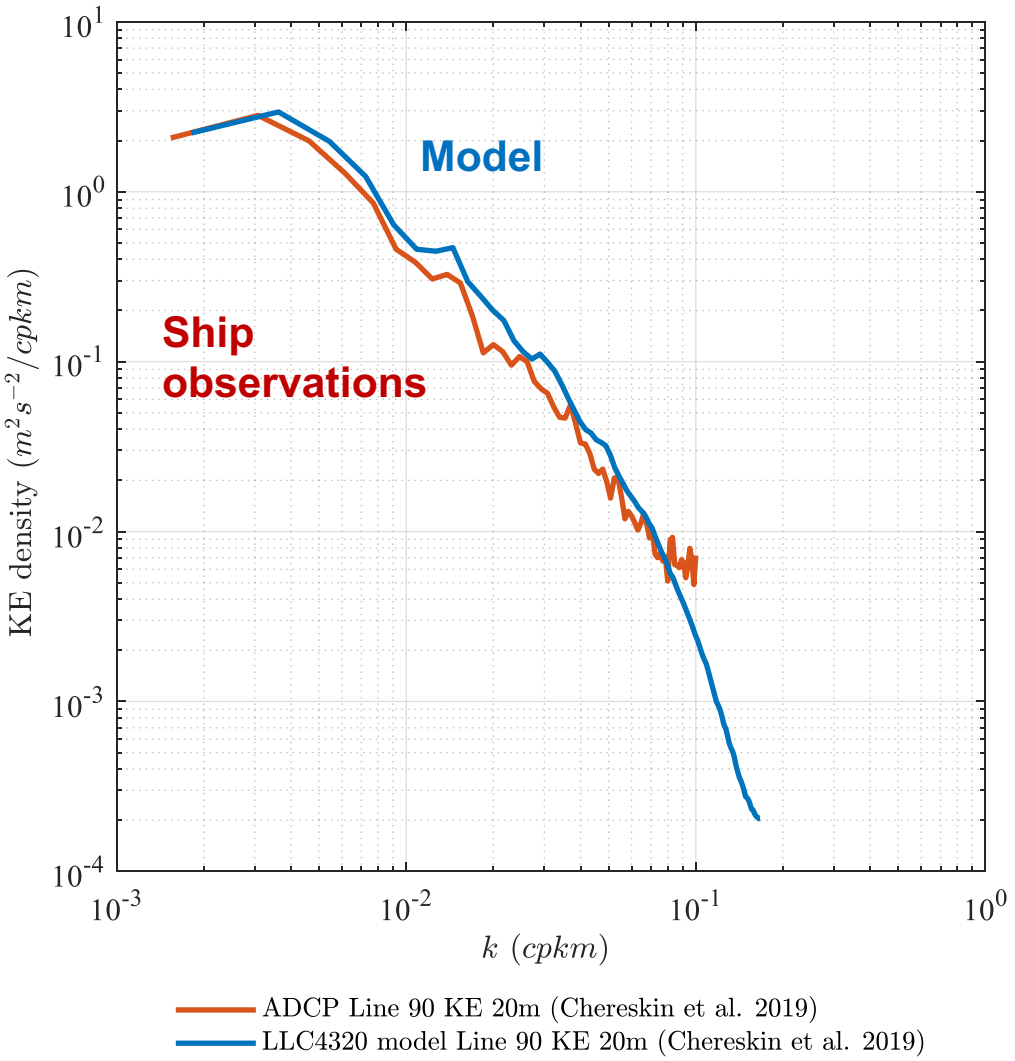



Surface waves



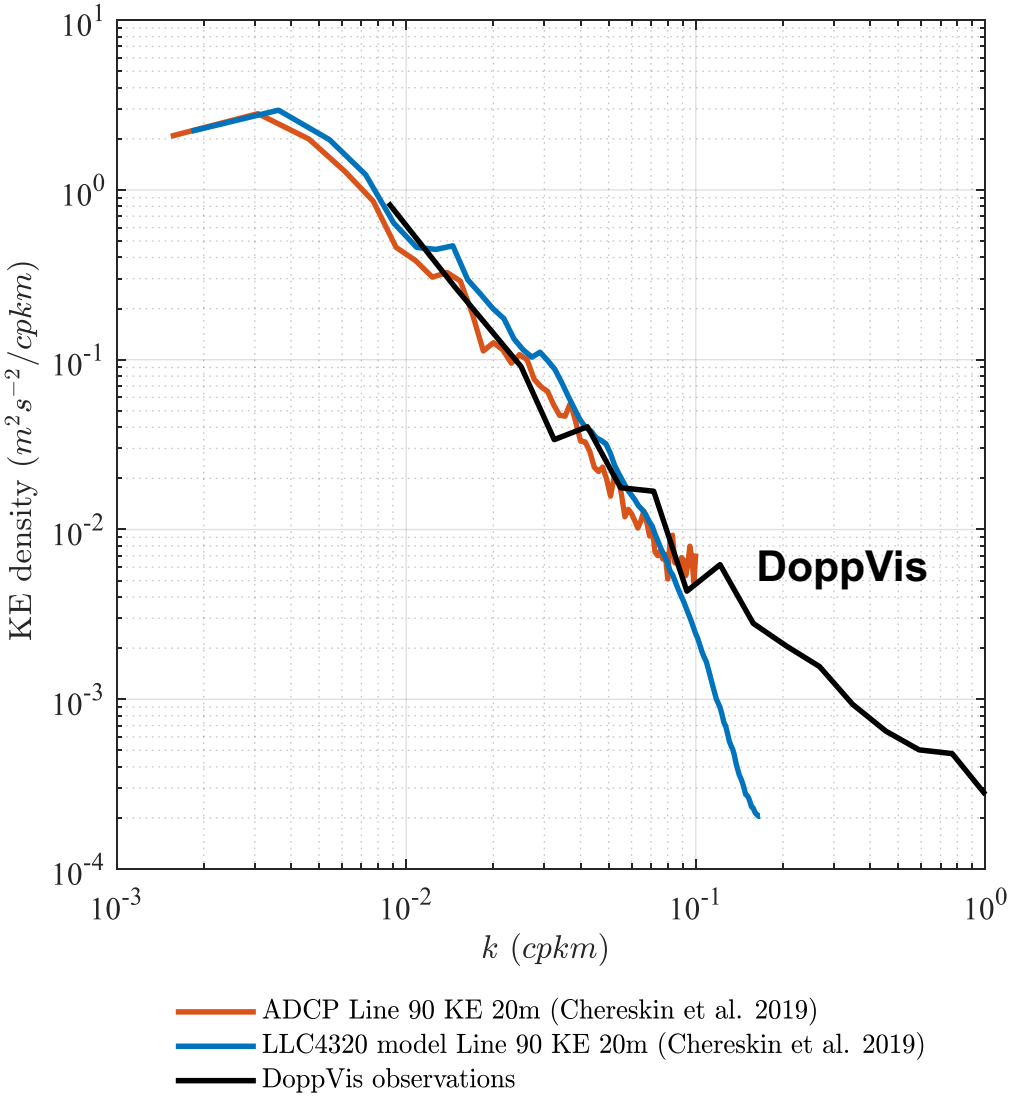
# Kinetic Energy spectrum





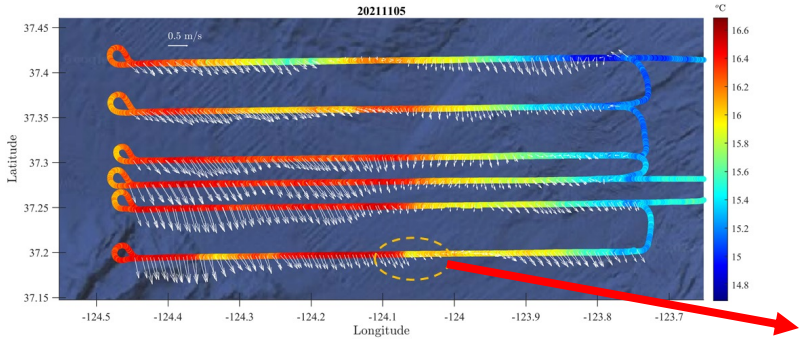

Chereskin et al. (2019): Characterizing the transition from balanced to unbalanced motion

# Kinetic Energy spectrum



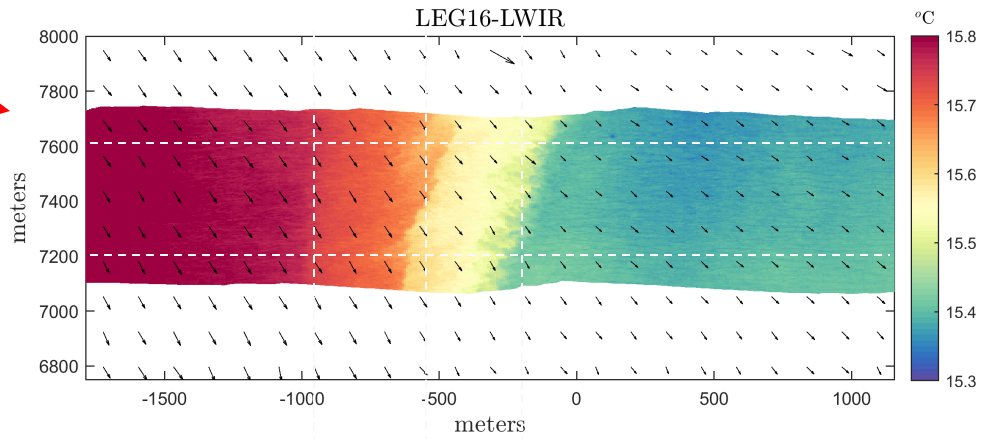

Mara Freilich's poster: **"Observational characterization of the transition to submesoscale dynamics"**

# Combining SST imagery and DoppVis surface currents




Higher resolution DoppVis current map + SST imagery

Sharp SST front coincident with horizontal current shear in the DoppVis product

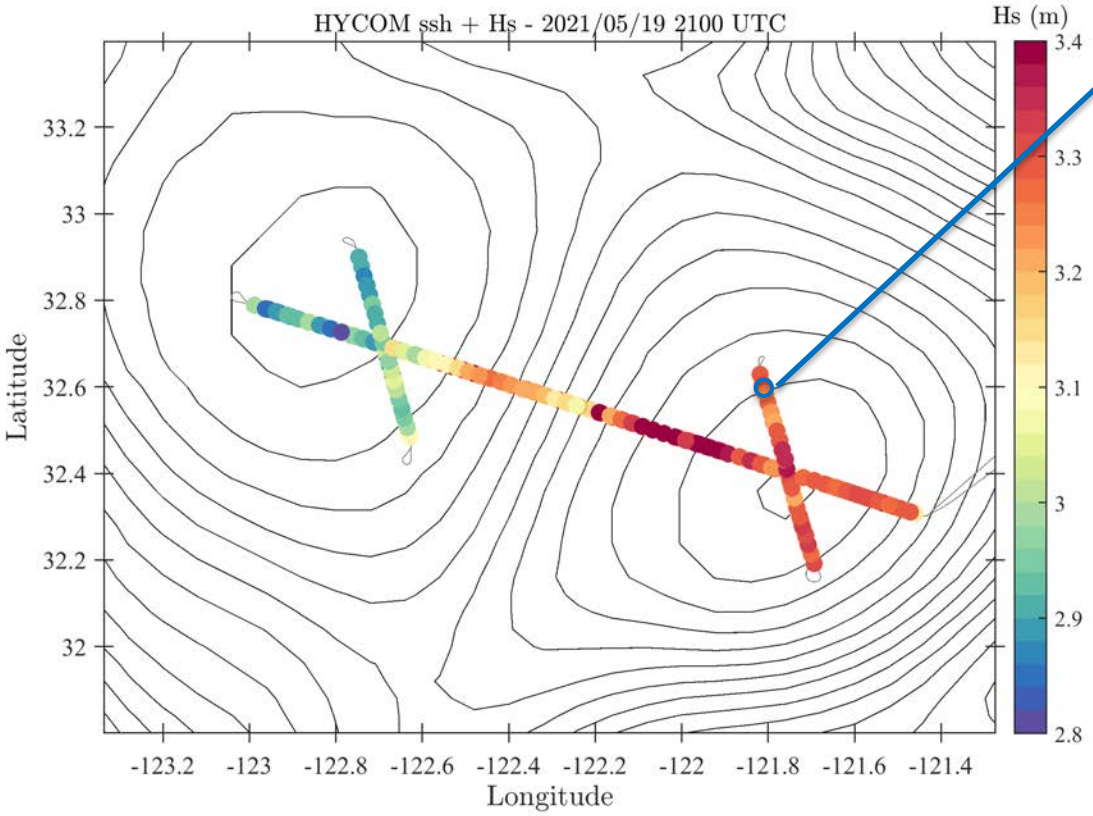



Velocity gradients, i.e. vorticity, divergence etc.

Mara Freilich's poster: "**Observational characterization of the transition to submesoscale dynamics**"

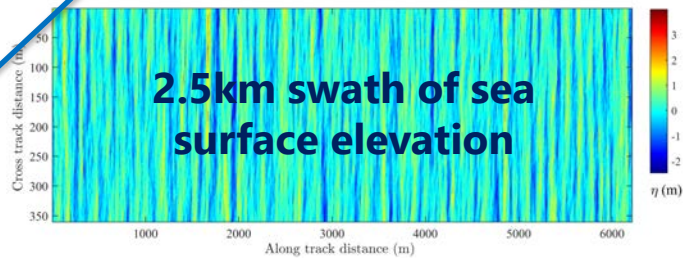
# Wave properties along the track of the aircraft

Significant **spatial** variability in surface gravity wave properties

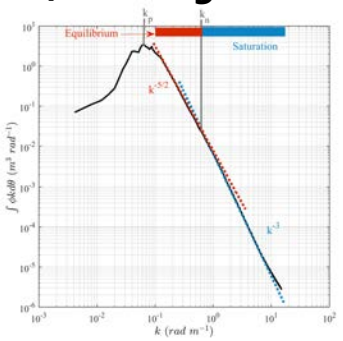


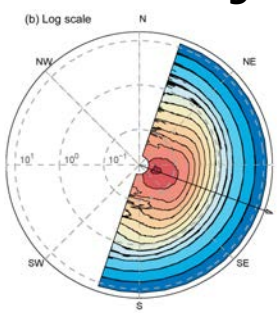

Hs computed using 2.5km long surface height segments

**For each "point":**




**Directional and omnidirectional spectra (resolving km to 50cm wavelength)**




**+ bulk wave statistics and surface winds (Lenain et al. 2019)**

# Summary

- We report a unique set of coincident and collocated observations of high-resolution surface currents, SST, winds and directional properties of surface waves collected from an airborne instrument, the Modular Aerial Sensing System (MASS)

- Direct spatial and temporal observations of the lower atmosphere, sea surface and upper ocean are crucial for improved knowledge of air-sea interaction. However, the broad range of scales, or equivalently the strong spatial and temporal variability of theses interactions make this a formidable theoretical, numerical, and observational challenge.

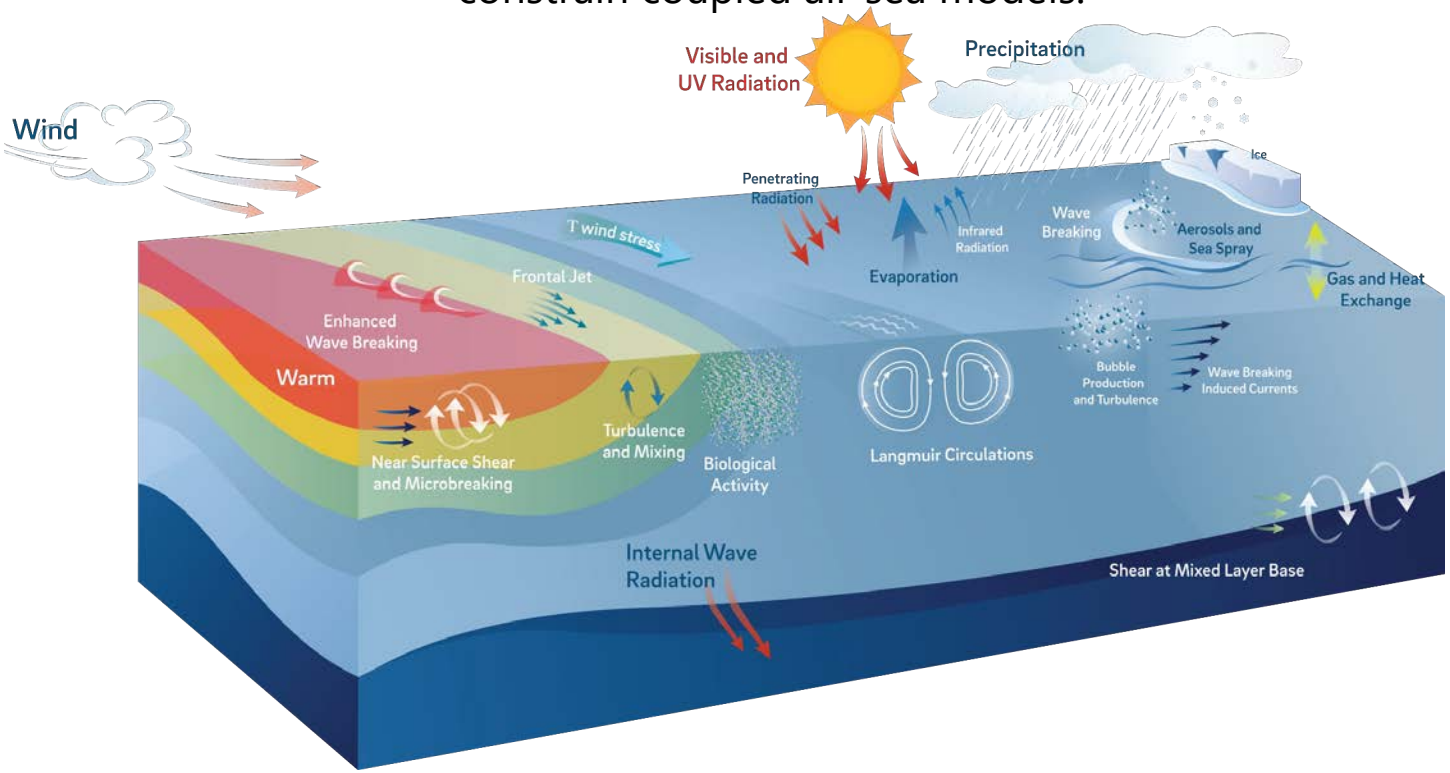
- Traditional in-situ assets such as moorings and buoys are limited by their spatial coverage or their potential spatial biasing, in particular near an ocean front where buoys or drifters can cluster, while satellite imagery estimates important quantities like wind, significant wave height and currents through indirect methods and can also only sample at sparse time intervals.

- While limited observations and models have begun to reveal the coupling processes between ocean currents and wind (Chelton & Xie, 2010; 382 Wenegrat & Arthur, 2018) and ocean currents and waves (Marechal & de Marez, 2022; 383 Wang et al., 2020) at both the mesoscale and submesoscale, we need new observational technologies like MASS, DoppVis and DopplerScat (Rodriguez et al., 2018a) to unravel the underlying dynamics of these rapidly evolving processes.

# Motivation

The ocean and atmosphere exchange mass, momentum, and energy, regulating Earth's weather and climate. These exchanges are particularly complex due to the **interactions across a broad range of space and time scales**

These processes need to be better understood and in turn better parameterized to better constrain coupled air-sea models.




**Spatial** observations of **surface wave** properties and **currents** are needed to develop better physical understanding of wave-current interaction processes (temporal, e.g. buoys, is not sufficient)