Impact of ocean eddies and submesoscales on the atmospheric water cycle

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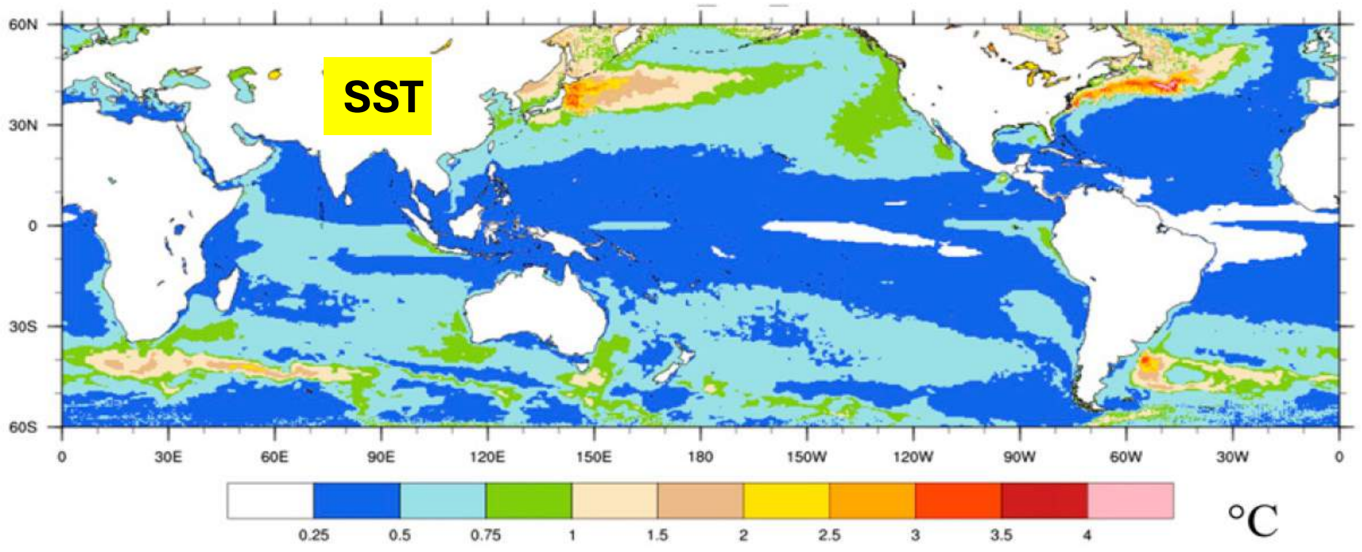
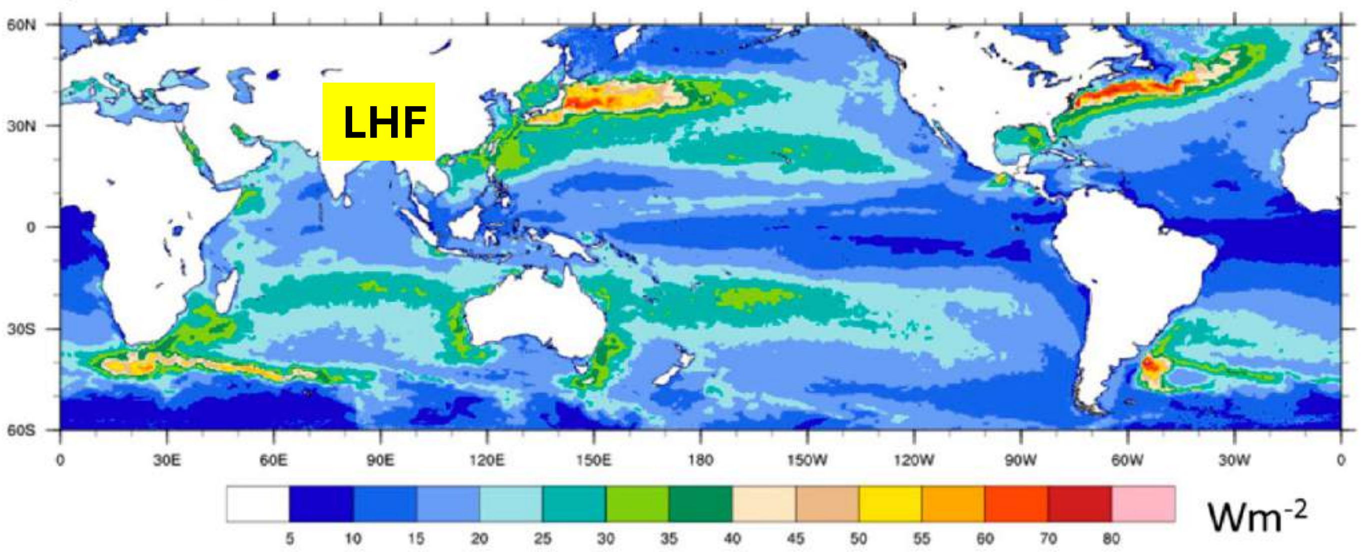
Sea surface temperature (SST) and latent heat variability





From Small et al. (JC 2019)

50% of the SST to the LHF anomalies in WBCs and ACC regions are **explained by mesoscale (100-300 km) eddies**

- Results based on a coupled simulation with 0.25^0 resolution

Consequence:

«Ocean mesoscale eddies moisten the atmosphere"

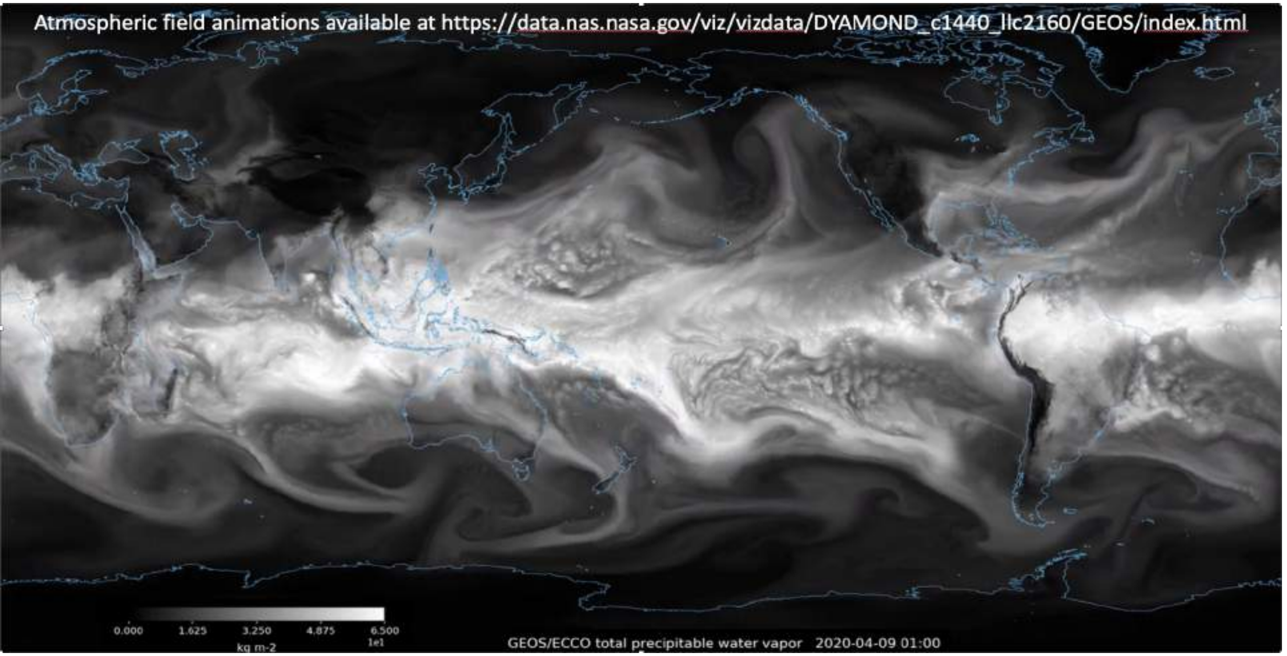
Such results need to be reassessed using coupled simulation with higher resolution

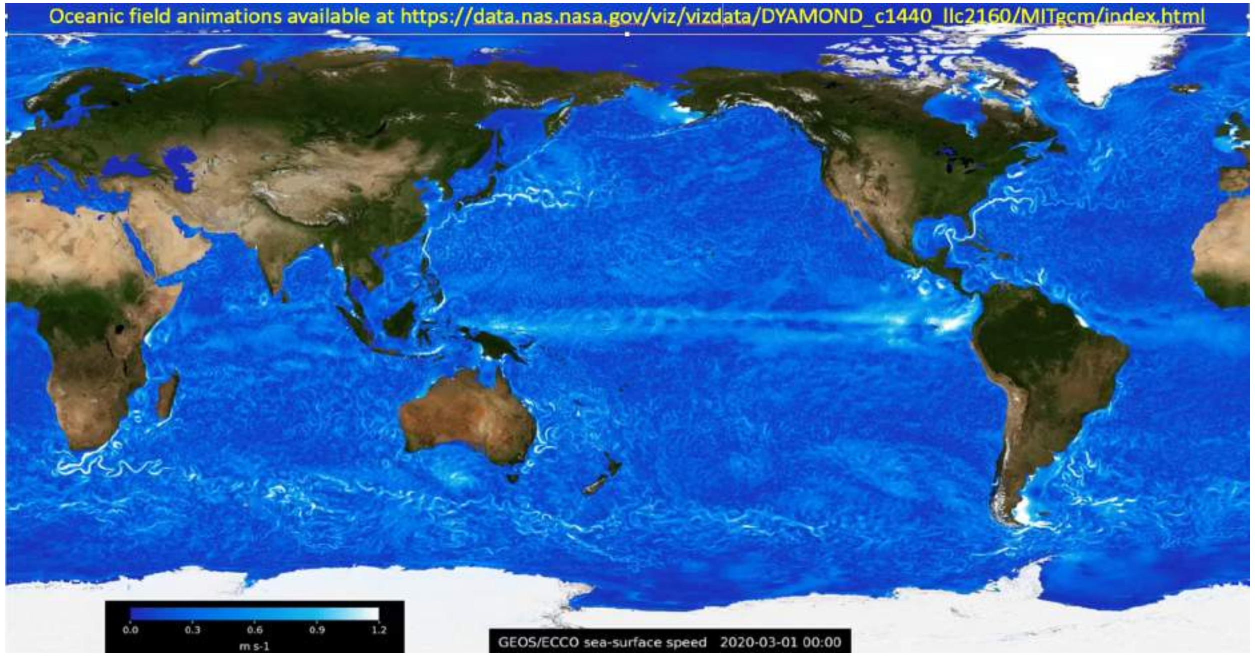
Studying mesoscale and submesoscale (10-30km) Air-Sea Interactions

In support of DYAMOND (DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains), we have set-up with the following characteristics:

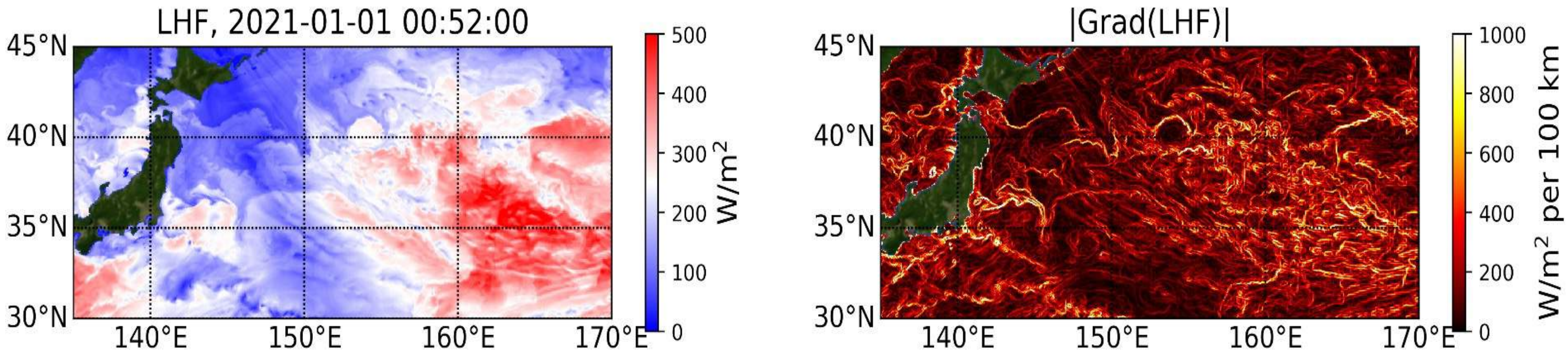
- **Resolution 1/16° atmosphere/land coupled**
- **Resolution 1/24° ocean simulation**
- **Next slides will show an overview of the lessons we have learnt in the past two years**

(Strobach et al., GRL, 2022; Torres et al., GMD, 2022; Torres et al., RS 2023; Bai et al., GRL, 2023).





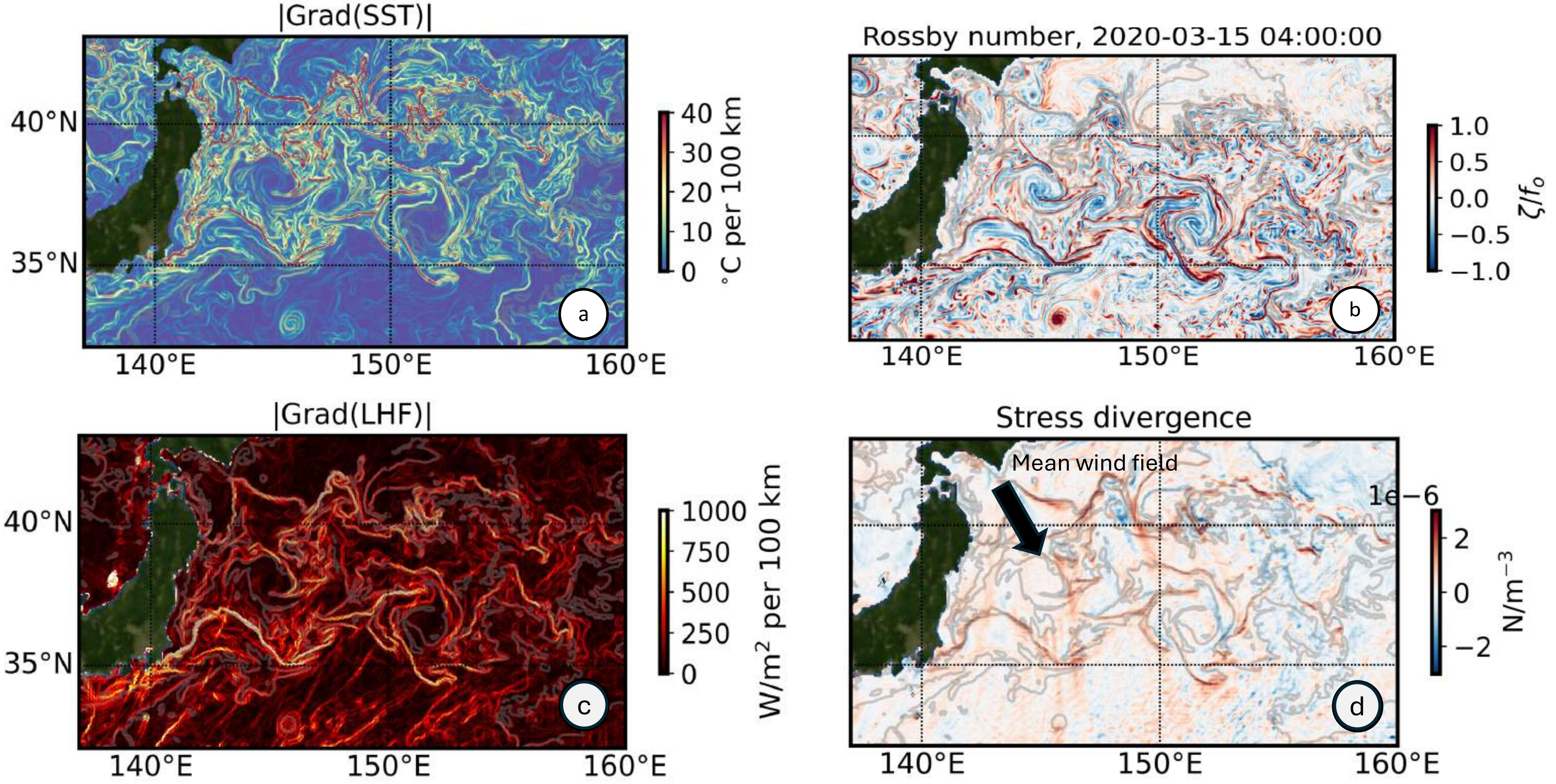
Latent heat fluxes (LHFs) in the Kuroshio Extension from MITgcm/GEOS5 Coupled Ocean-Atmosphere Simulation (COAS)



Animation. Latent heat flux and latent heat flux gradients in the Kuroshio Extension

- Two distinctive motions:
  - High-frequency ---> Atmospheric variability
  - Low-frequency motions ---> Ocean signature on the LHFs

Surface wind stress divergence collocated with LHFs gradients and SST gradients during southward winds

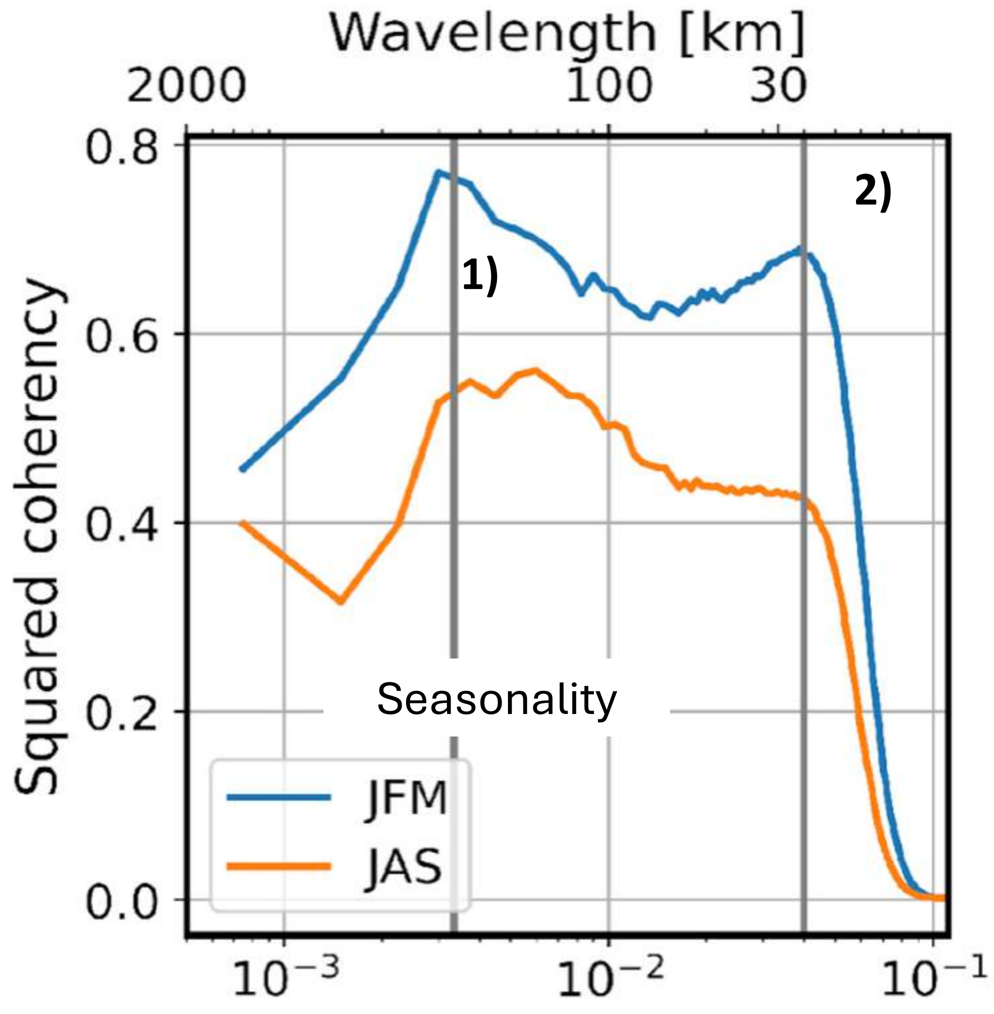


- Submesoscale SST fronts are usually found at the edges of mesoscale eddies

Spectral coherence seasonality between LHFs and ocean SST

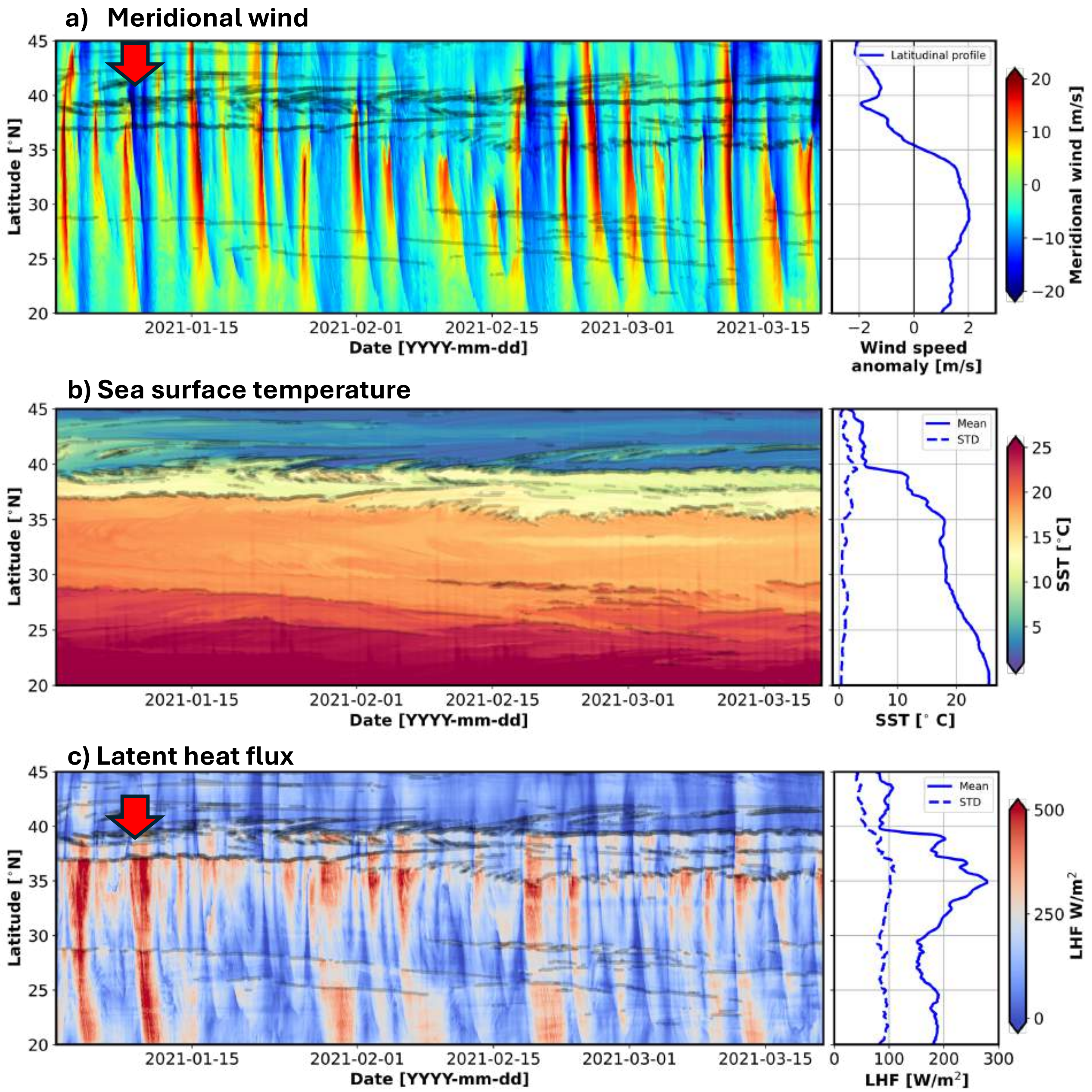
- Seasonality of small scales
- High coherence in wintertime
- Two peaks in the coherence:
  - 250 km
  - 25 km

➢ The coming slides will show the atmospheric response of submesoscale motions during wintertime

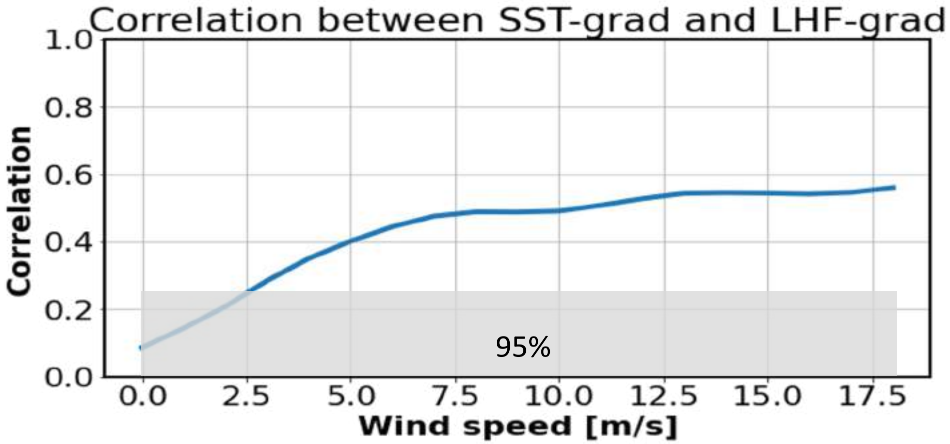


1) Mesoscales 2) Submesoscales

Spatiotemporal variability of LHFs as function of wind speed and SST



- Southward winds enhances LHFs and LHFs gradients
- High values of LHFs right before SST gradients
- High correlation between LHF gradients and SST gradients at wind speed above 5 m/s
- Are LHFs gradients sufficient to trigger vertical motions in the atmosphere?
  - ❖ Two scenarios: northward winds and southward winds



Southward wind case:

Geophysical Research Letters

RESEARCH LETTER
10.1029/2021GL097003

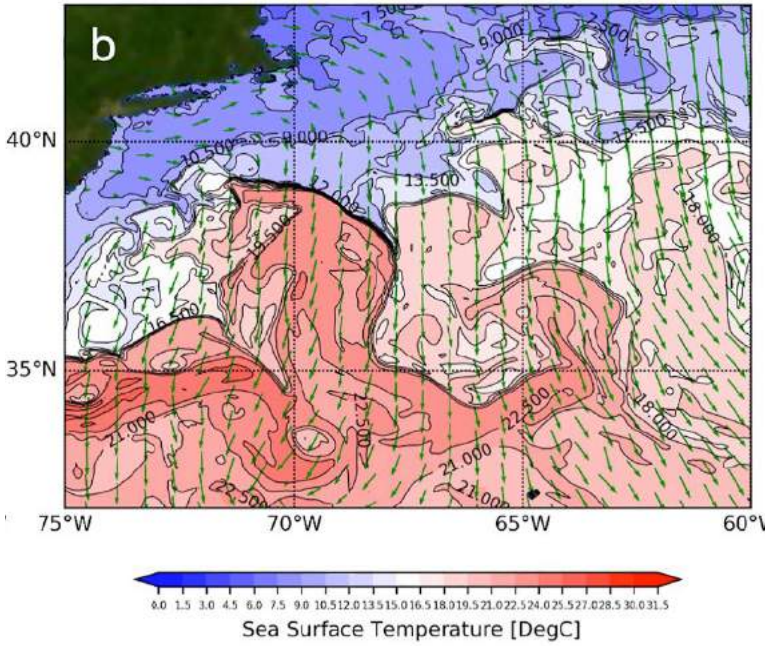
Local Air-Sea Interactions at Ocean Mesoscale and Submesoscale in a Western Boundary Current

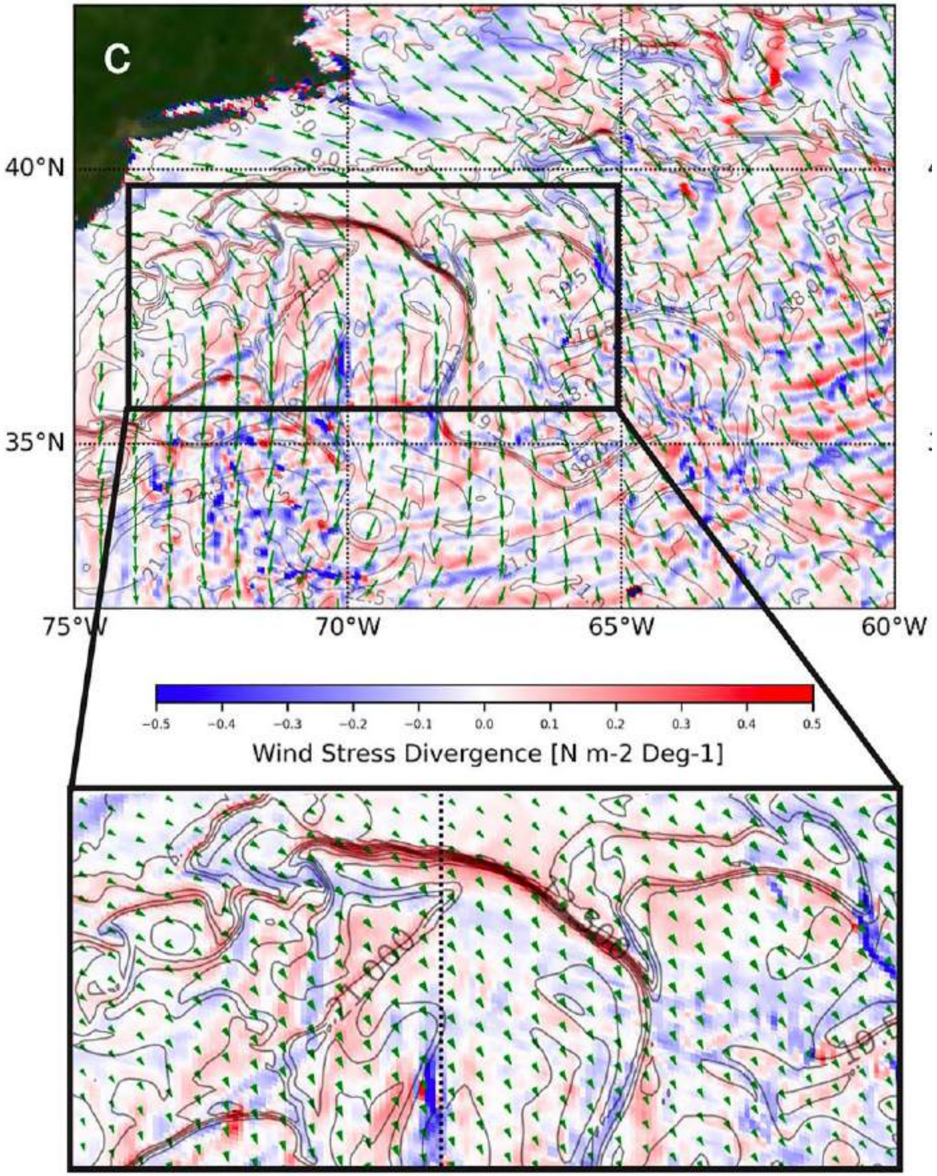
Ehud Strobach[1], Patrice Klein[2,3], Andrea Molod[4], Abdullah A. Fahad[4,5], Atanas Trayanov[4,6], Dimitris Menemenlis[7], and Hector Torres[7]

Key Points:

- Strong turbulent flux discontinuities observed at ocean fronts suggest the

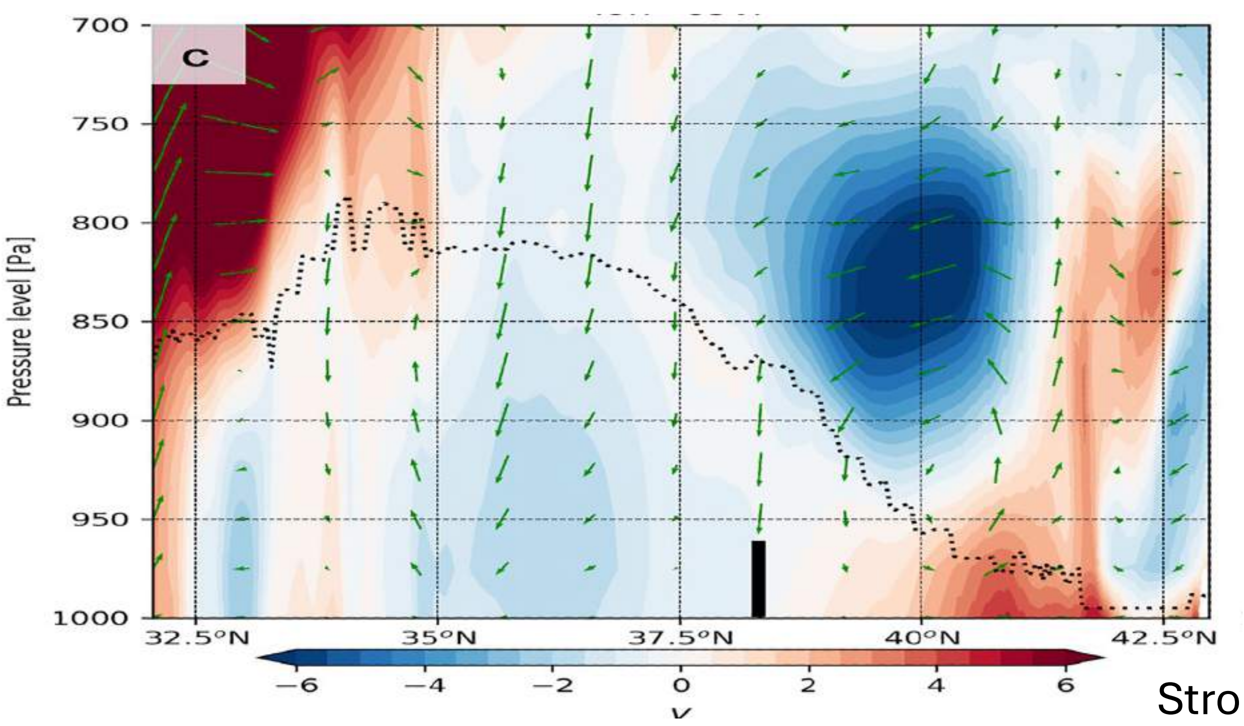
- They are closely associated with wind stress divergence that **triggers intense vertical velocity (~1m/s)** in the atmosphere up to the tropopause level





New paradigm:

Wind convergence and divergence explained by submesoscale SST fronts trigger **a secondary circulation** that transfers dry air and momentum down to surface. Which **leads to intensify LHF by 30%.**



Strobach et al. (2022)

Wind divergence and convergence triggered by submesoscale SST fronts **do impact mesoscale LHF.**

Northward wind case: Work in progress

Cloudiness at 3000m during northward winds

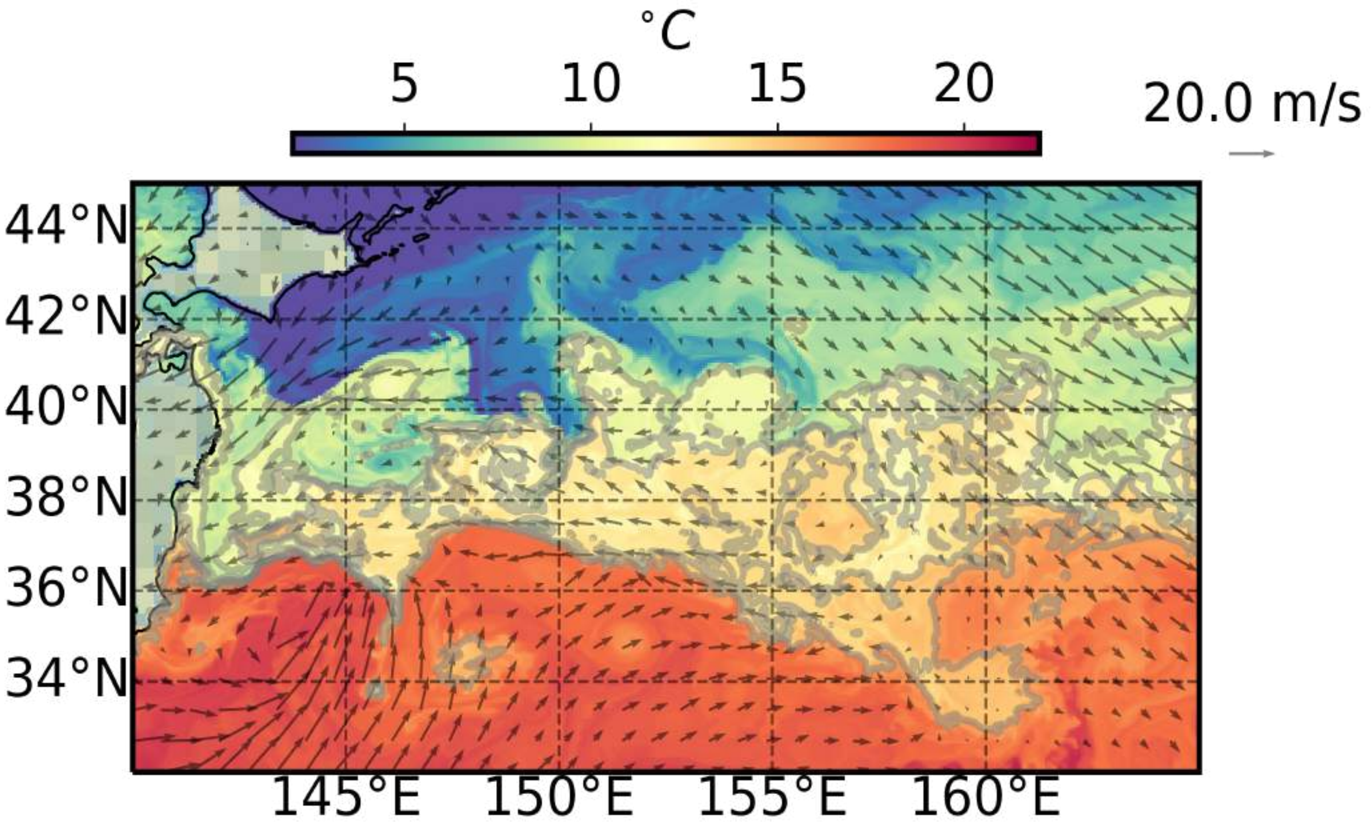


Figure. SST (colormap) and surface wind field (arrows)

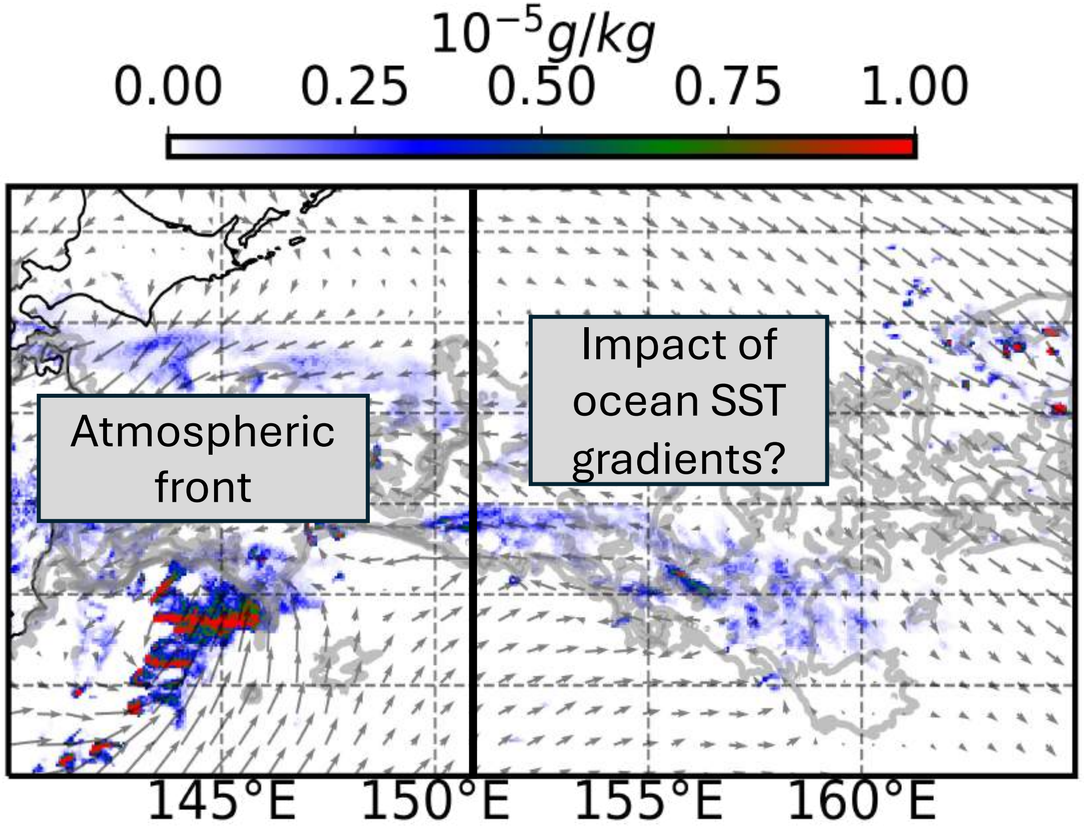
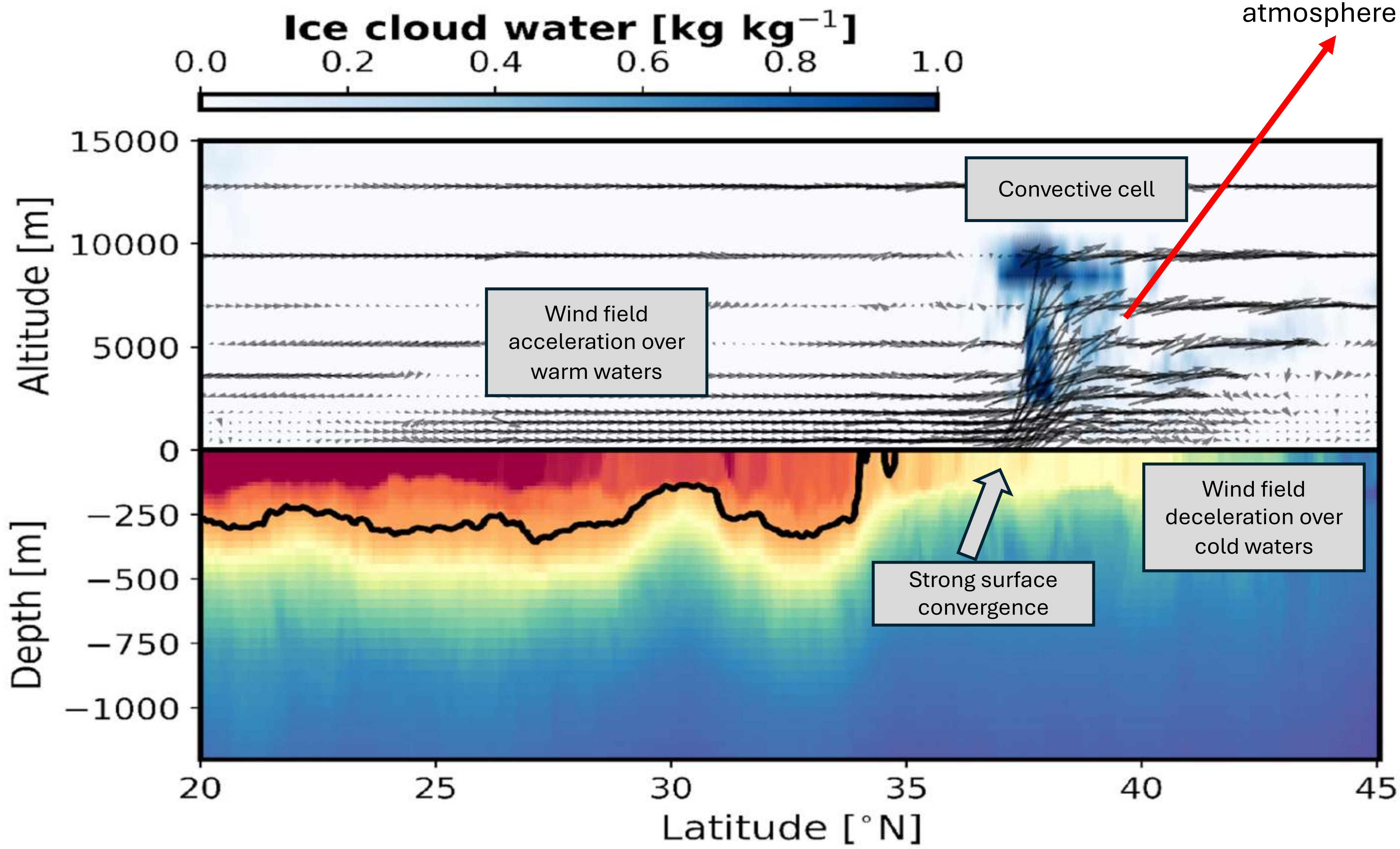


Figure. Cloud ice water ratio at 3000 m altitude (colormap)

Upward motions collocated at ocean temperature gradients

Need for separating the contribution of the ocean to vertical velocity from the atmosphere variability



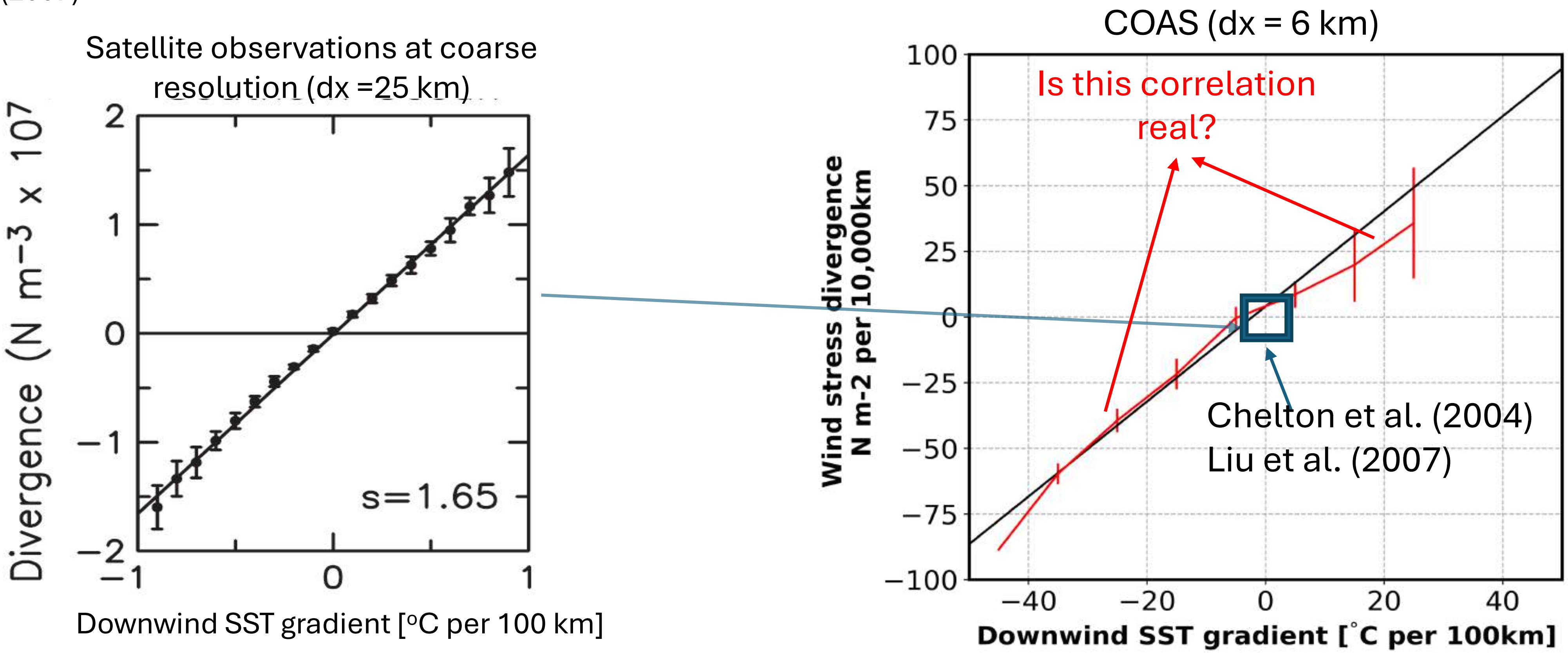
- COAS is allowing us to understand the connection from the base of the mixed-layer depth in ocean up to the tropopause in the atmosphere

  The main goal of the team

- Due to the kilometer-scale resolution of COAS, we can interpret the impact of the resolution on the air-sea coupling →

Strong correlation between wind stress divergence and SST gradients: Impact of the resolution

Chelton et al. Sci (2004)
Liu et al. JC (2007)

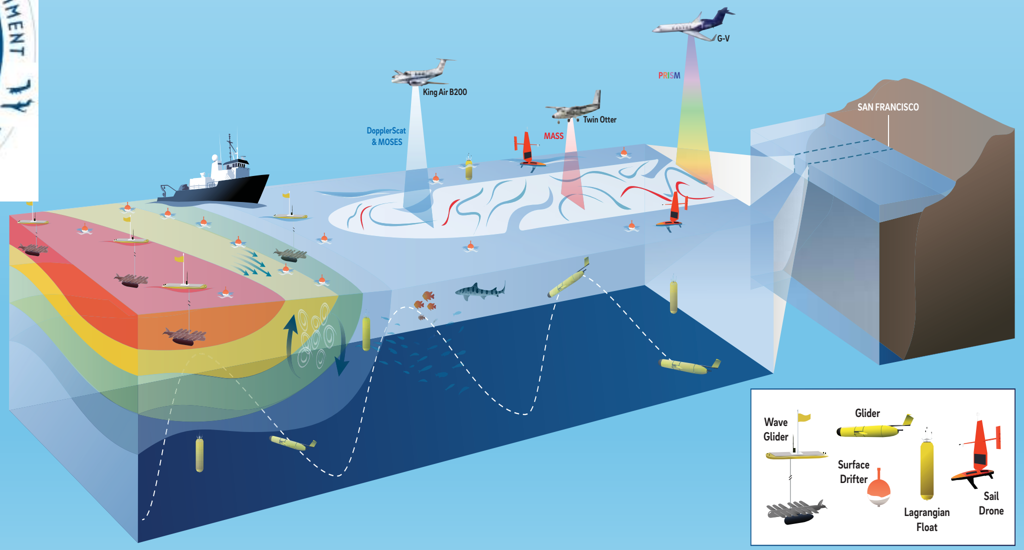


- These results need confirmation by observations with sufficient resolution to capture submesoscale gradients

Sub-Mesoscale Ocean Dynamics Experiment (S-MODE)
provided evidence of strong air-sea coupling at submesoscales!

Airborne observations challenge state-of-the-art coupled ocean-atmosphere simulations at kilometer-scale

Sub-Mesoscale Ocean Dynamics Experiment (S-MODE), NASA EVS-3
Multiscale 4D Measurement program



Farrar et al. (2020)

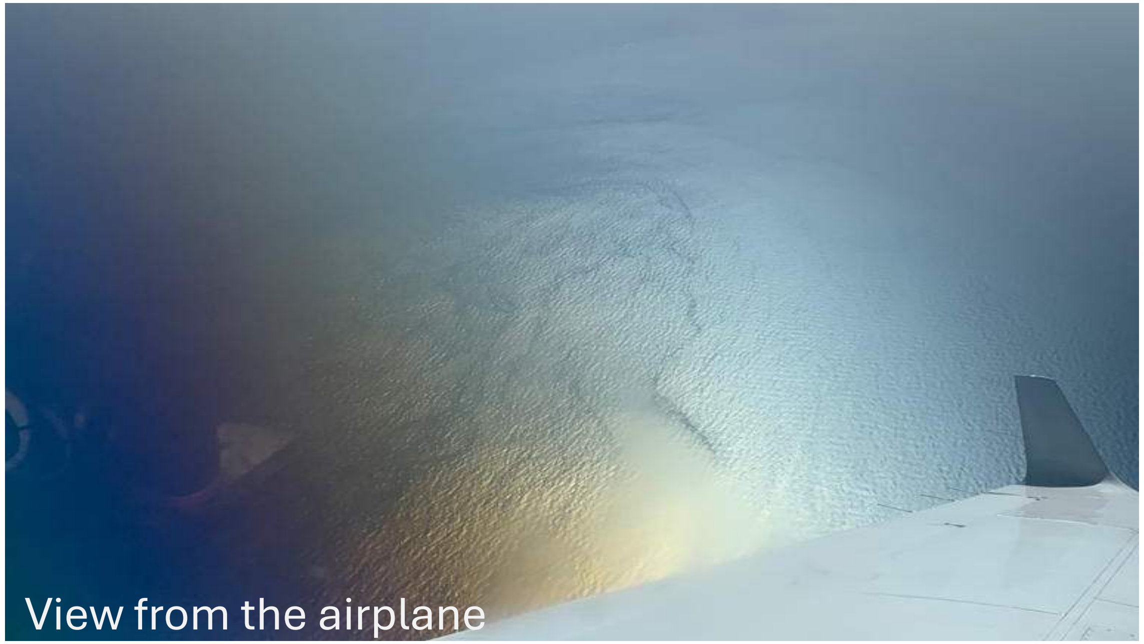
Air-Sea coupling during S-MODE campaign

Two study cases:

1) Atmospheric rolls case

- Stripes in cloud formation aligned with stripes on ocean surface
- Changes in surface roughness
- Atmosphere driving the ocean surface

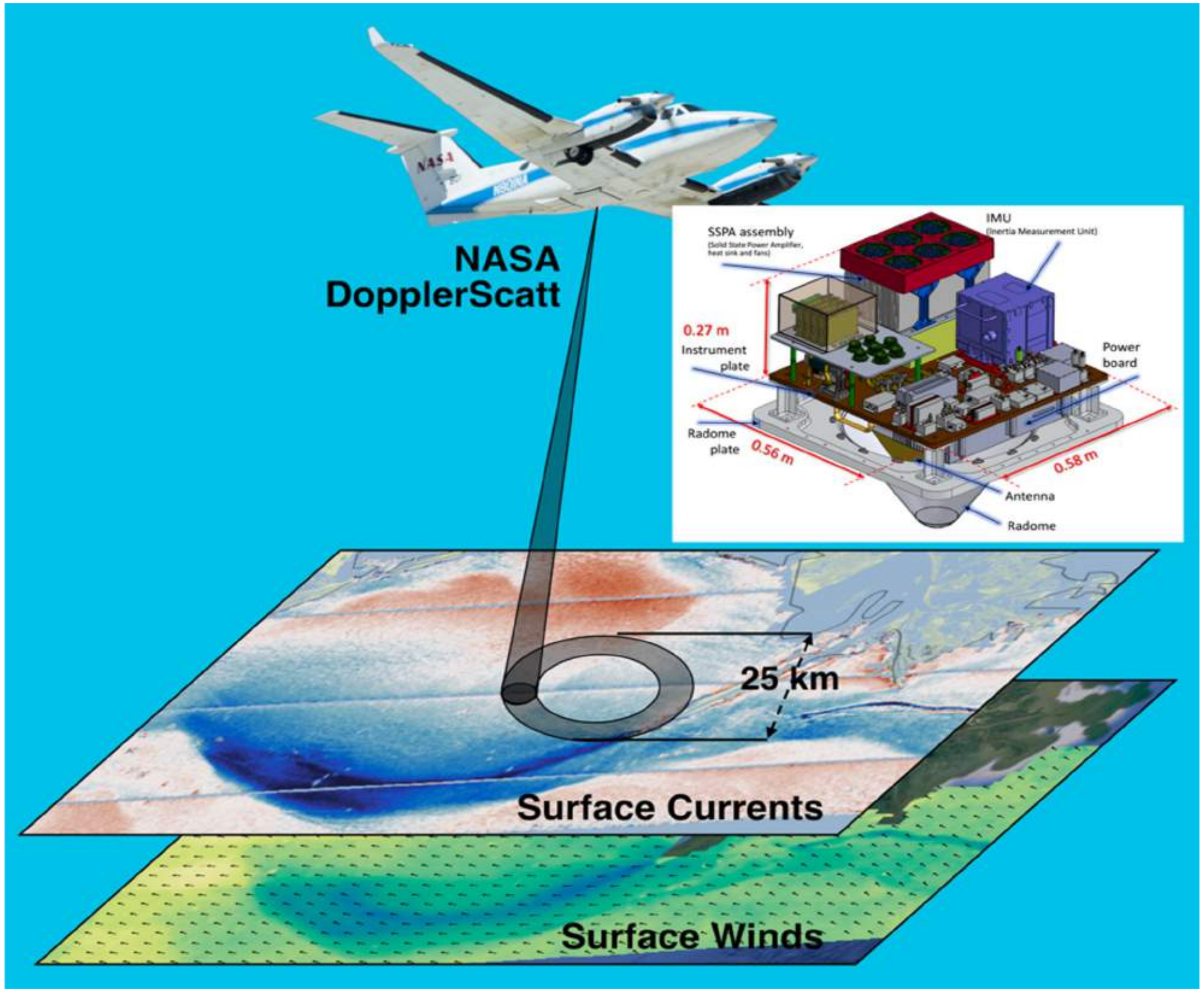
2) Submesoscale filaments



- Filamentary features on surface
- Do they have signature on wind field?

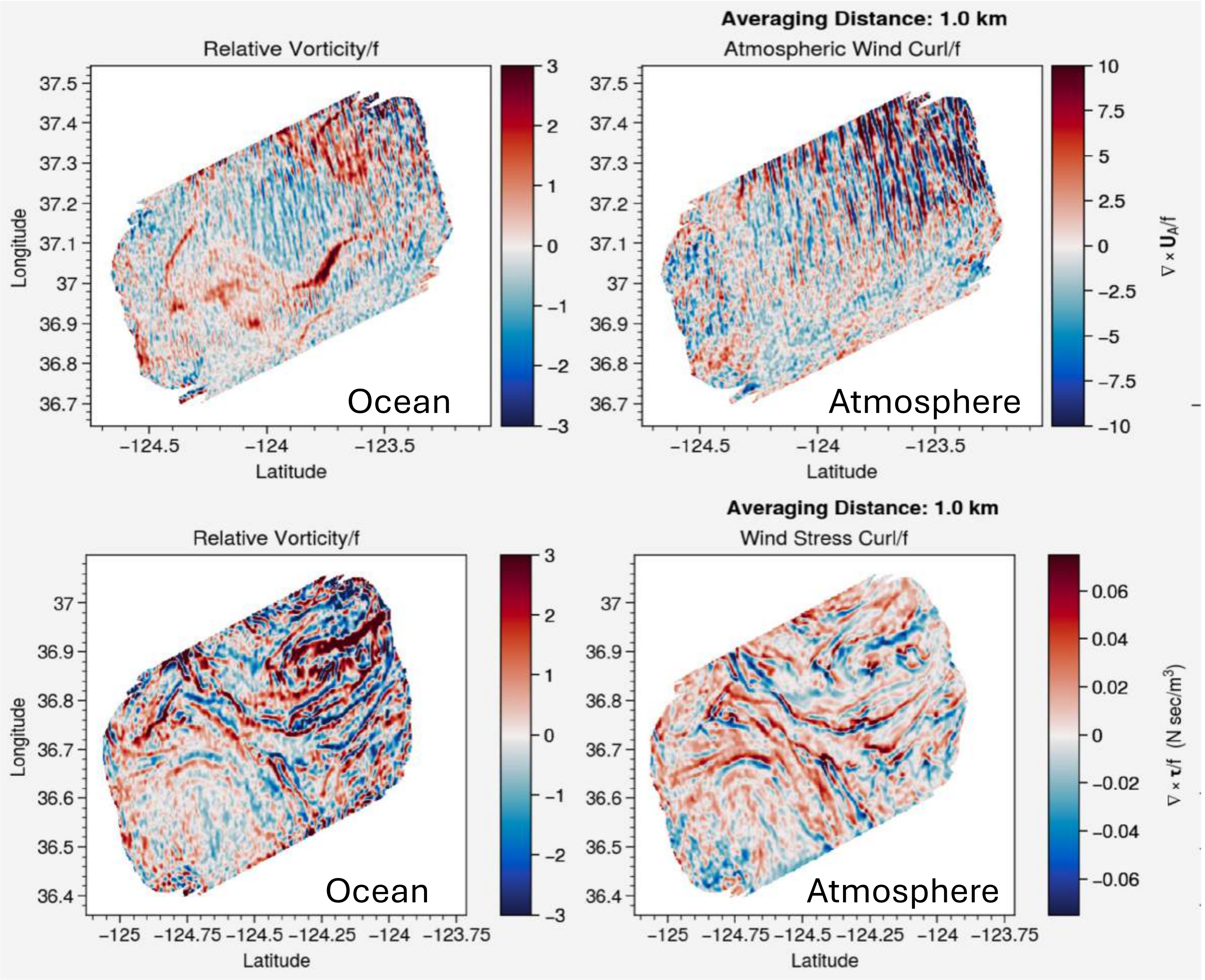
JPL/NASA DopplerScatt

- Ka-band Doppler scatterometer to measure winds and currents simultaneously (*Rodriguez et al., 2018; Wineteer et al., 2020*)
- **200 m resolution**
- During NASA EVS-3 S-MODE, it acquired near daily 100km x 40km synoptic maps
- Data available in NASA PODAAC



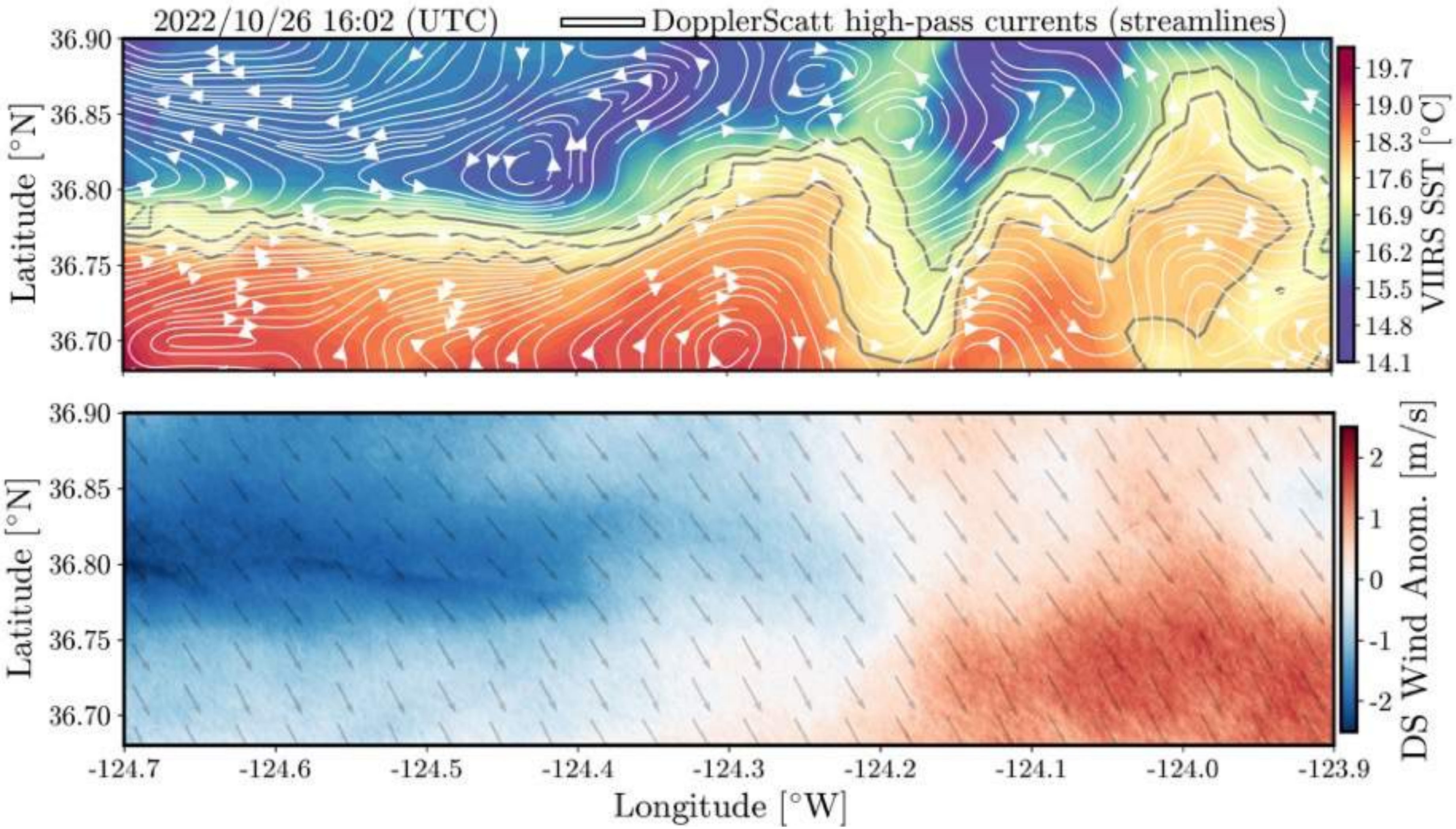
Air-Sea coupling at submesoscales

- Patterns are associated with rolls and submesoscale ocean filaments
- Very strong wind divergence, 10 times Coriolis frequency
- Integrating over just 100 m results ~10 km vertical motion per day
- This vertical velocity is about 10 times larger than the vertical velocity in COAS

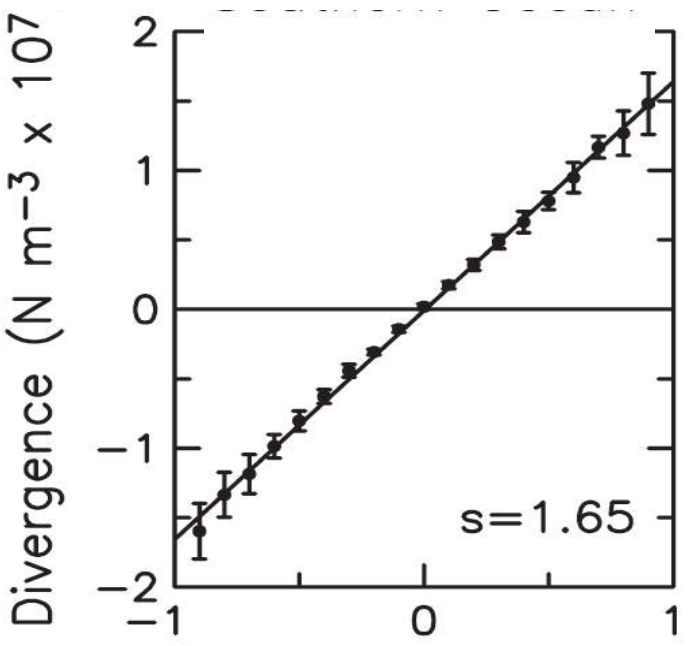


Impact of SST on the wind field

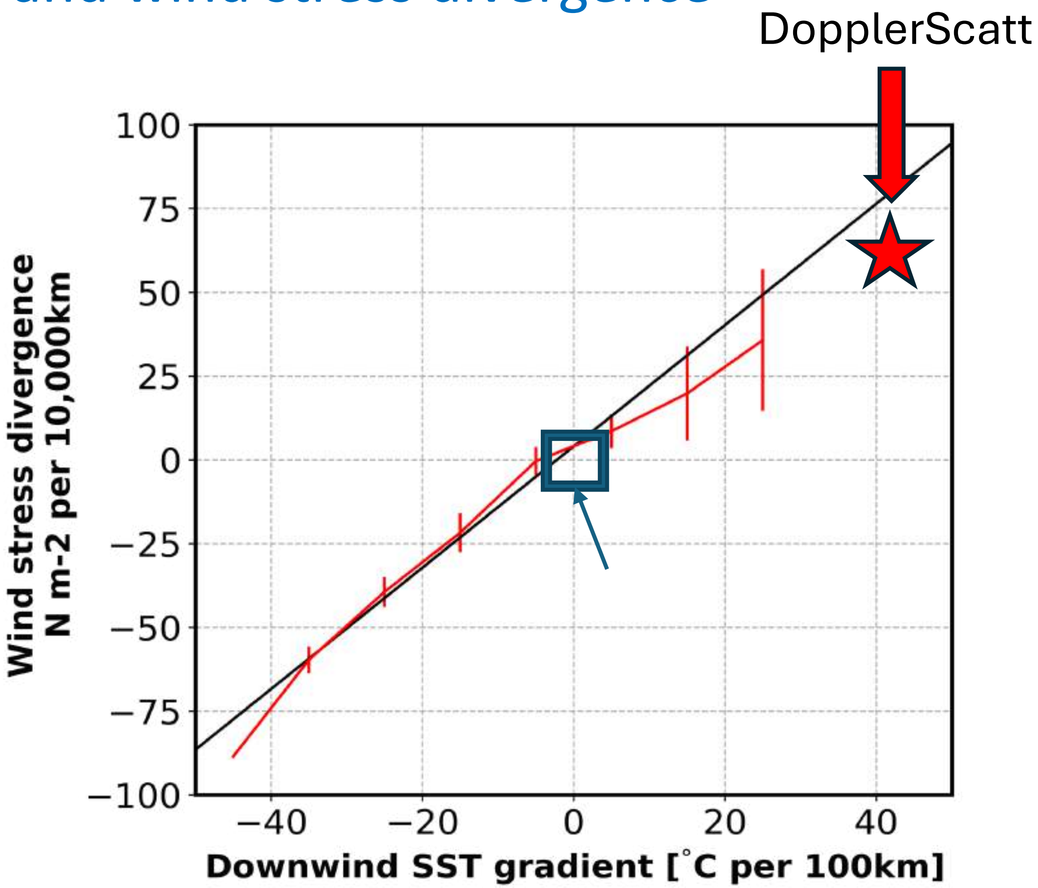
NASA B200



DopplerScatt confirmed the strong correlation between submesoscale SST gradients and wind stress divergence

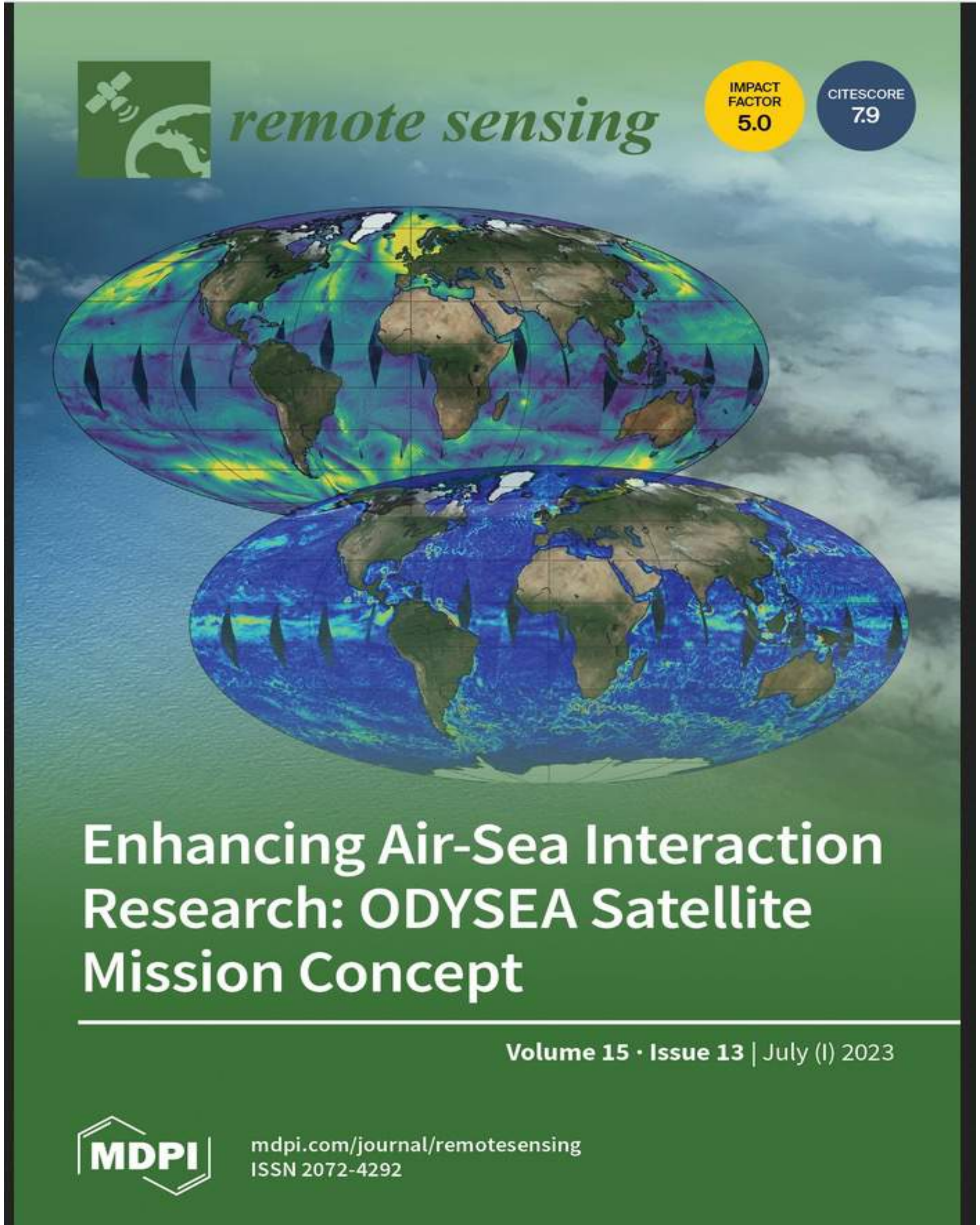


Chelton et al. Sci (2004)
See also T. Liu et al. JC (2007)



- Airborne observations carried out with DopplerScatt are challenging coupled ocean-atmosphere simulations

- **Current and future plans:**
  - ➢ Implementation of regional high-resolution coupled ocean-atmosphere simulation
  - ➢ Large Eddy Coupled Ocean-Atmosphere Simulation



Cover Story

Remote Sens., Volume 15, Issue 13 (July-1 2023)

Enhancing air-sea interaction research:
Anticipated capabilities of the ODYSEA satellite mission to observe wind-current coupling

Torres, H.; Wineteer, A.; Klein, P.; Lee, T.; Wang, J.; Rodriguez, E.; Menemenlis, D.; Zhang, H. Anticipated Capabilities of the ODYSEA Wind and Current Mission Concept to Estimate Wind Work at the Air–Sea Interface. *Remote Sens.* **2023**, *15*, 3337. https://doi.org/10.3390/rs15133337

COAS as tool for the developing of the satellite mission concept Ocean DYnamics and Sea Exchanges with the Atmosphere (**ODYSEA**)

In summary:

Submesoscale SST fronts trigger strong wind stress divergence, as well as strong LHF gradients, when combined with a synoptic atmospheric system

New paradigm:

Vertical velocities in the atmosphere, potentially, enhanced by submesoscale SST gradient field, promoting the formation of clouds not only within the atmospheric boundary layer, but up to the tropopause. <u>Work in progress…</u>

Mission planning:

Because of the potential impact of these mechanisms on the atmospheric water vapor cycle, we need collocated and contemporaneous high resolution wind field, SST and latent heat fluxes.

Two mission concepts currently in designing mode using MITgcm/GEOS

- **ODYSEA:** Winds and Currents mission concept
- **Butterfly:** Mission concept to measure air-sea turbulent heat fluxes

Explore digital ocean and atmosphere accelerate satellite mission development

Questions?

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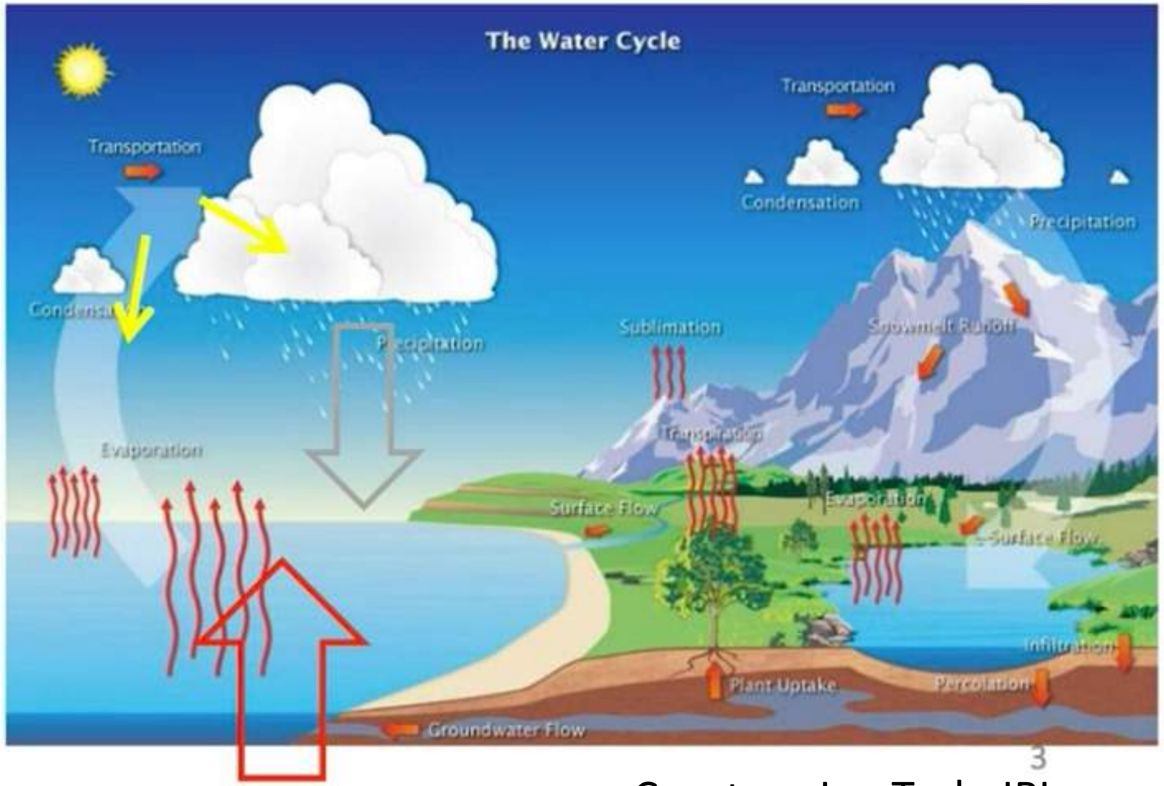
Backup

Atmospheric water cycle

Only about **one fourth** of the energy needed to drive the global atmospheric circulation comes form direct solar energy. The other **three-fourths** of the energy is transferred to atmosphere by evaporating water



Courtesy Joe Turk, JPL

- Efforts have been done to understand the role of mesoscale ocean eddies (100-300 km) in the context of the atmospheric water cycle