Ocean Finescale Dynamics

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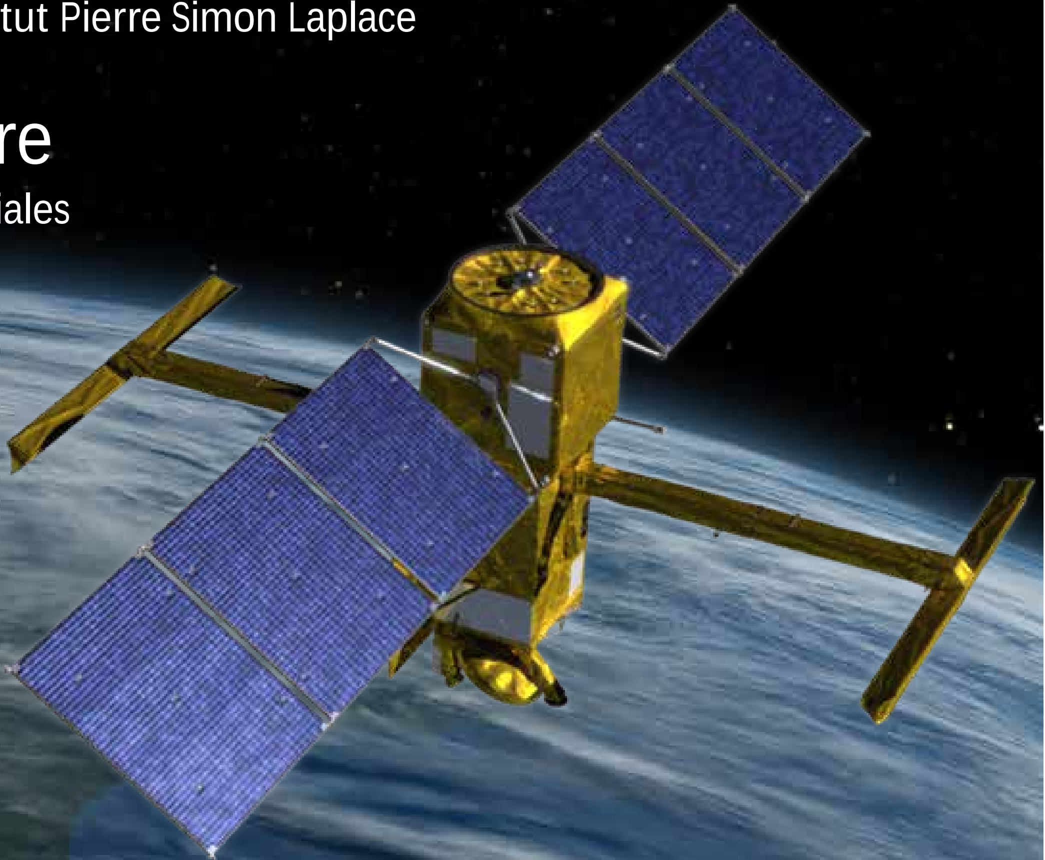


SWOT ST meeting:
2024 June 17

Preface

- This is a big-picture talk about SWOT's oceanographic science goal of measuring ocean eddies at scales of 10-100 km. (*Why do we have it and what do we want to learn?*)
- So let's start with why satellite altimetry is useful for studying ocean eddies: "geostrophic balance"

Sea surface height and ocean currents

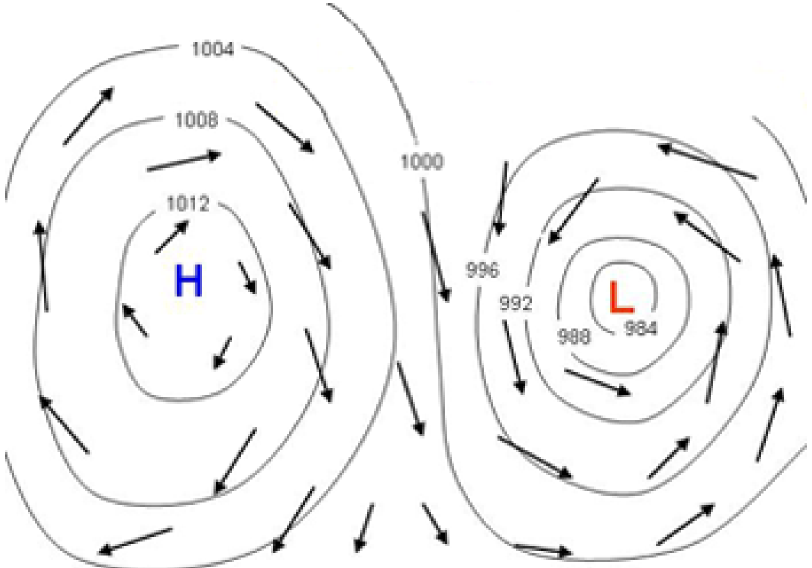
- High SSH = high pressure
- In our everyday experience water flows from high to low pressure

Photo by Pixabay: https://www.pexels.com/photo/water-drop-40784/

Image: Quick Response Fire Supply

Sea surface height and ocean currents

- High SSH = high pressure
- In our everyday experience water flows from high to low pressure
- At long time and space scales, Earth's rotation is important (Coriolis force)



"Geostrophic" approximation assumes:

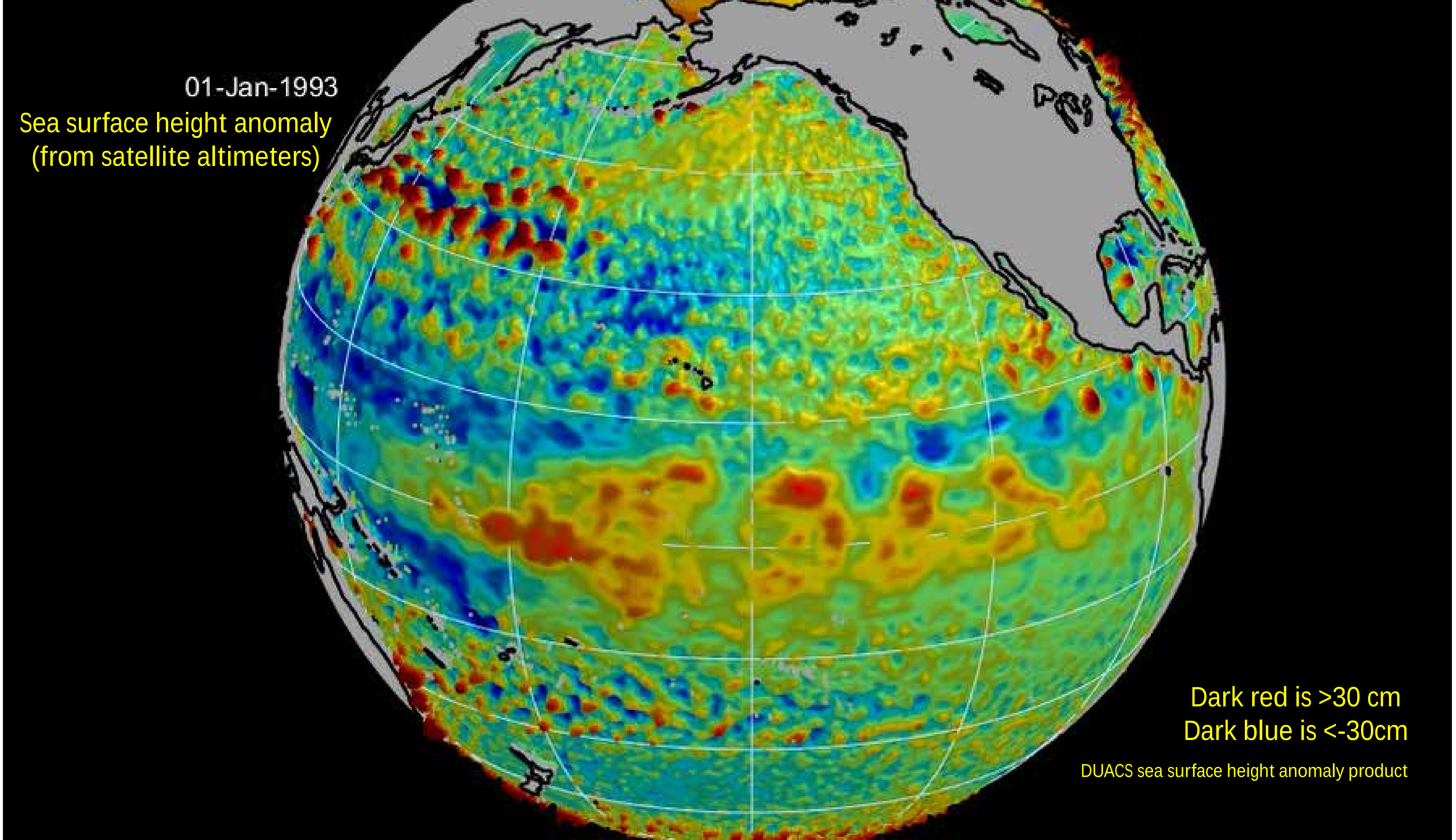
- Flow changes slowly (over many days)
- Velocity gradients are small

https://cimss.ssec.wisc.edu/satmet/modules/7_weather_forecast/wf-4.html

Eras of understanding ocean "fine scales"

SWOT

- ~1970's: Photographs from space hinted that the ocean has a complex flow field. The MODE and POLYMODE field programs hinted that the ocean was full of eddies.
- 1980's: Around the time of the launch of SEASAT, we started to have "mesoscale resolving" numerical models (like Cox, 1980, resolving 1000 km eddies!). GEOSAT altimeter, satellite sea surface temperature
- 1990's: US-French TOPEX/Poseidon altimeter
- With satellite altimetry and AVISO/DUACS, we finally fully appreciated that the oceans are full of eddies, and we have spent decades understanding what they do.


01-Jan-1993
Sea surface height anomaly
(from satellite altimeters)
Dark red is >30 cm
Dark blue is <-30cm
DUACS sea surface height anomaly product

Conventional Altimetry

Jason-type constellation

All-weather, global Sea Surface Height, resolution down to ~100km, ~2 weeks

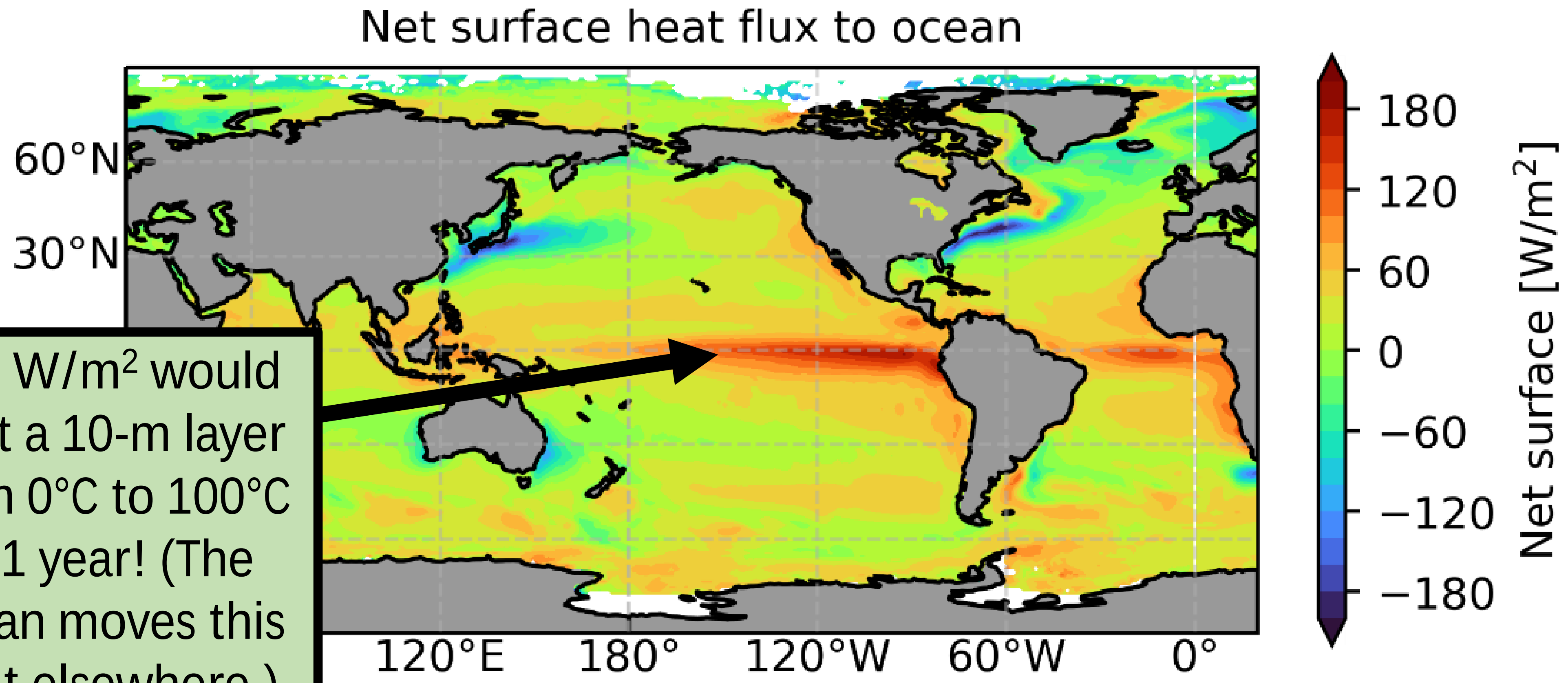
Scales <~100km, <~1 week

Ageostrophic dynamics

Coastal areas

Ocean eddies in the Earth system

The ocean absorbs heat and moves it around the planet

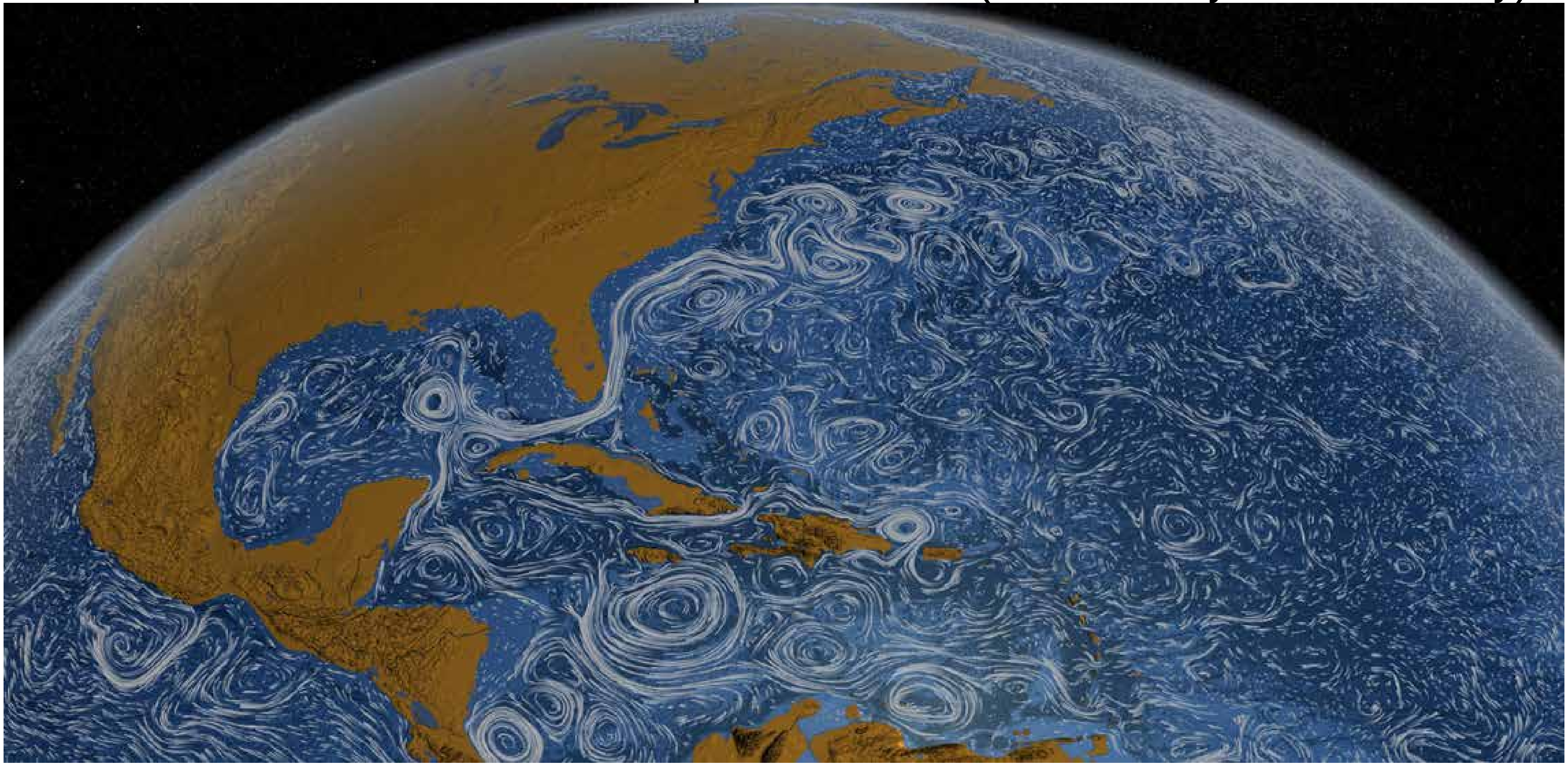


100 W/m² would heat a 10-m layer from 0°C to 100°C in 1 year! (The ocean moves this heat elsewhere.)

OAFlux product (Yu and Weller, 2007)

Ocean eddies in the Earth system

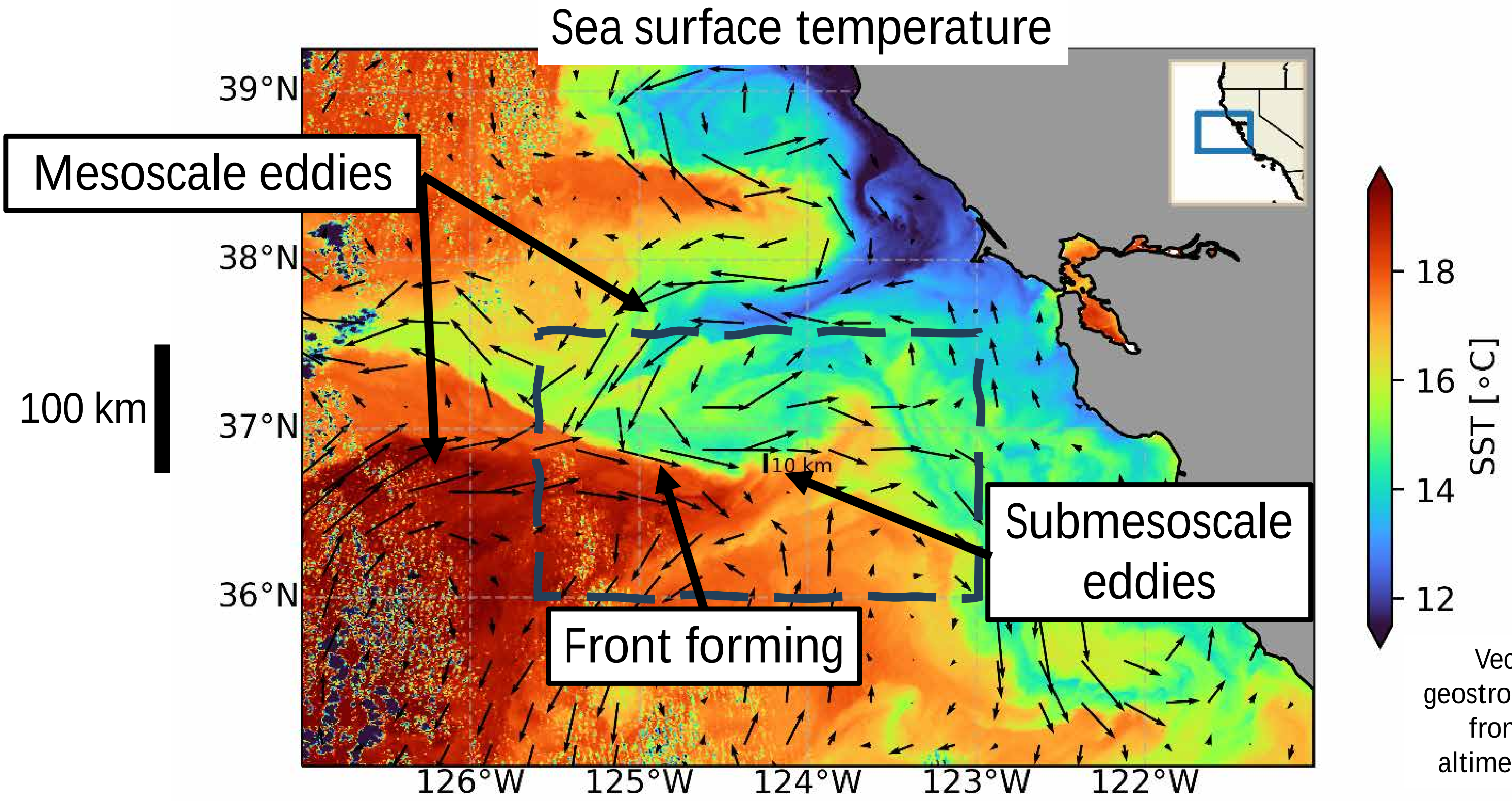
Ocean currents and eddies transport the heat (horizontally and vertically)



Ocean eddies in the Earth system

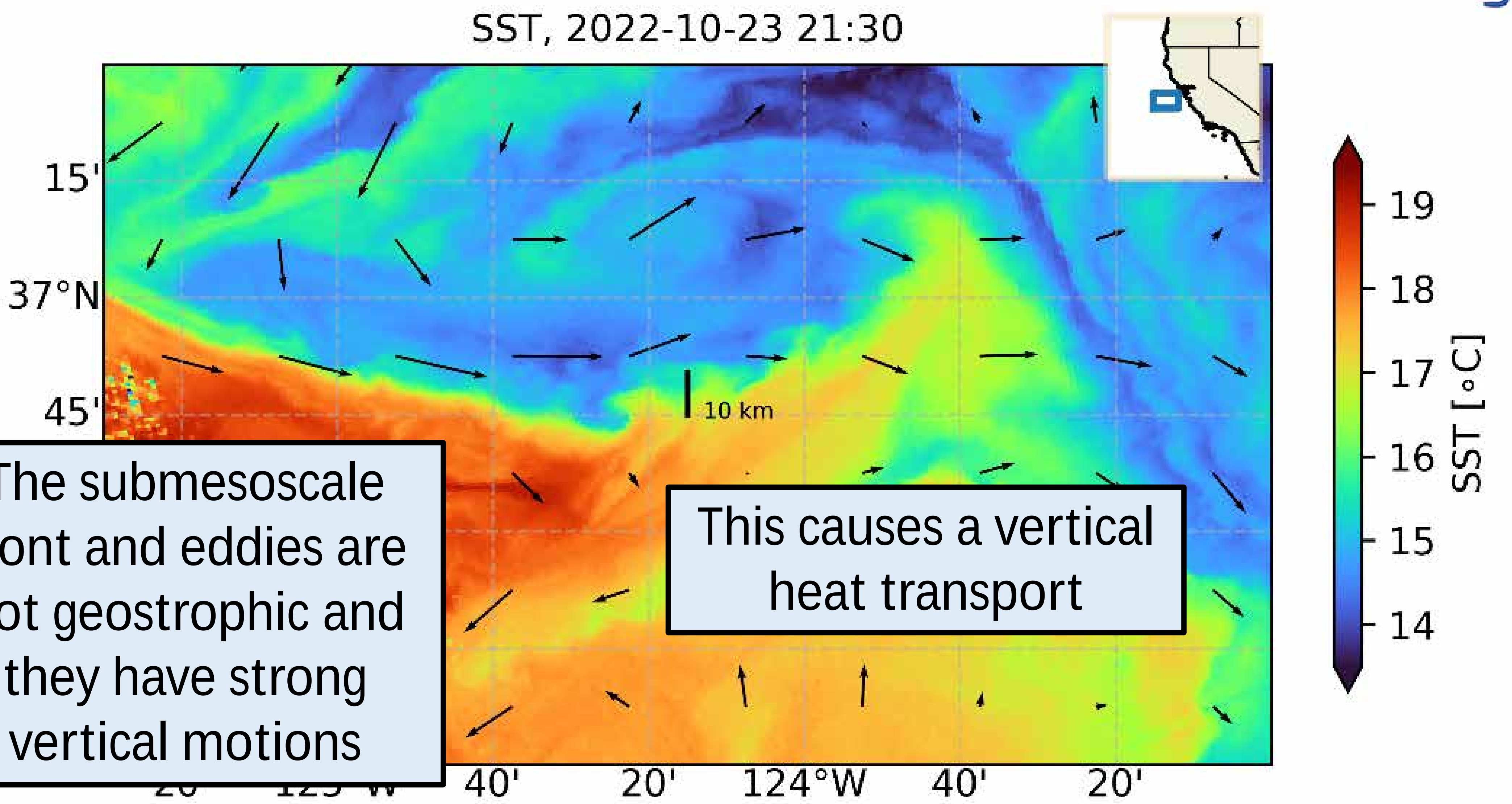
1. Planetary-scale currents are so strongly energized by the wind that they become unstable
2. This makes mesoscale eddies that stir the large-scale temperature gradients
3. The mesoscale stirring doesn’t mix the water: it intensifies gradients at small scales, causing *ocean fronts*
4. These fronts with km-scale gradients produce smaller-scale instabilities

Ocean eddies in the Earth system



Vectors are geostrophic velocity from DUACS altimetry product

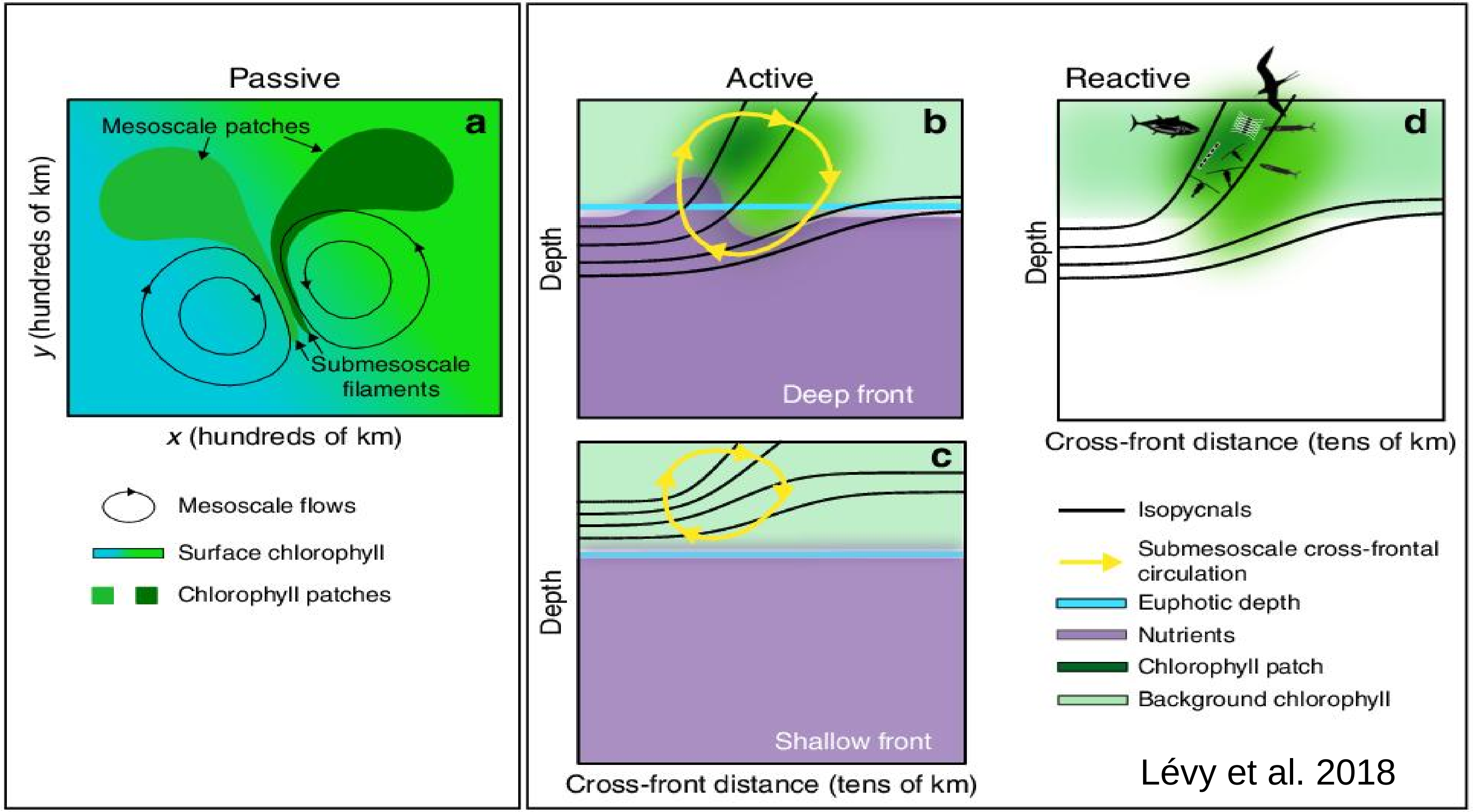
Ocean eddies in the Earth system



The submesoscale front and eddies are not geostrophic and they have strong vertical motions

This causes a vertical heat transport

The fine scale is recognised as a key structuring regime for biogeochemistry and ecology



Lévy et al. 2018

The blurred vision of conventional altimetry has limited our knowledge to large and energetic features, which in many oceanic regions are not common.

Conventional Altimetry

Jason-type constellation

All-weather, global Sea Surface Height, resolution down to ~100km, ~2 weeks

Scales <~100km, <~1 week

Ageostrophic dynamics

Coastal areas

Conventional Altimetry

Jason-type constellation

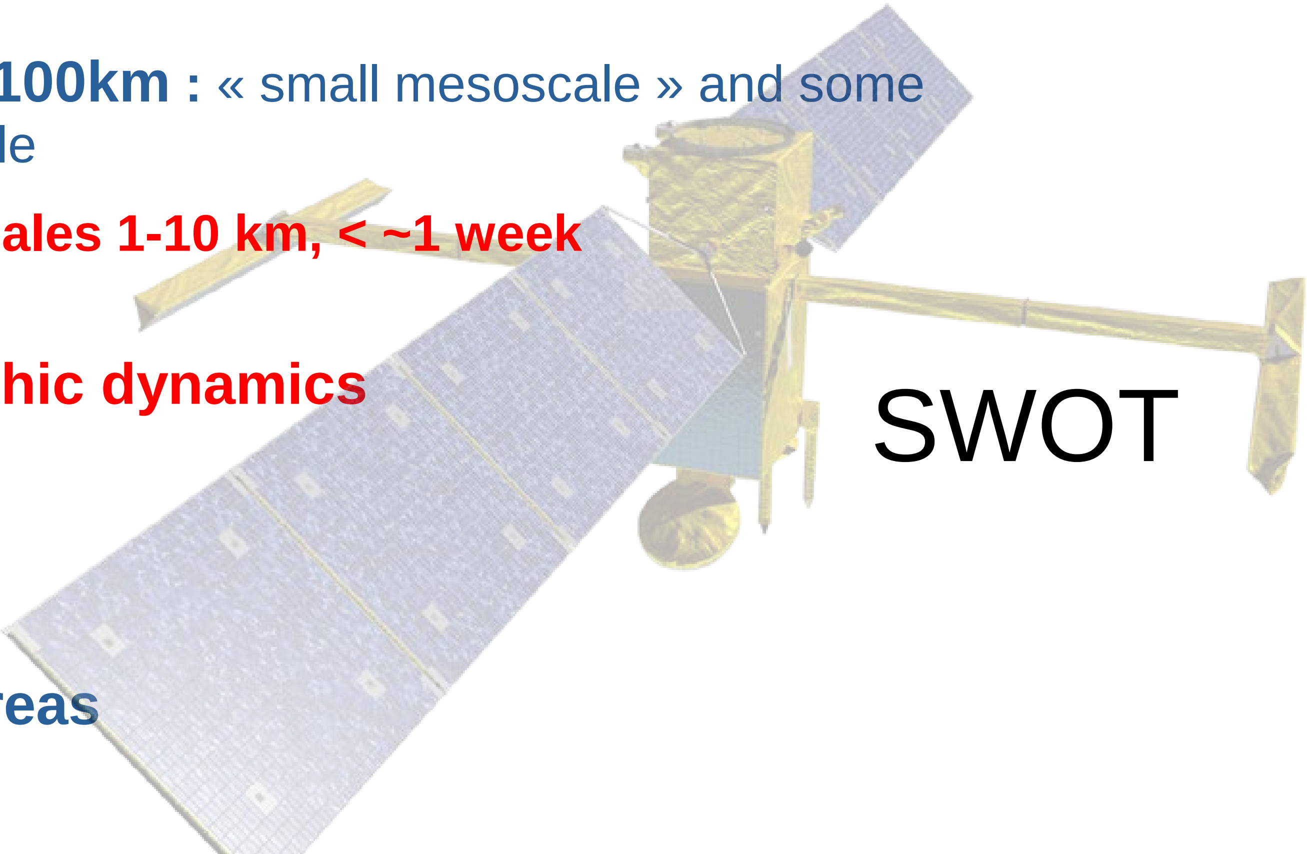
All-weather, global Sea Surface Height, resolution down to ~100km, ~2 weeks

Scales 10-100km : « small mesoscale » and some submesoscale

Scales 1-10 km, < ~1 week

Ageostrophic dynamics

Coastal areas

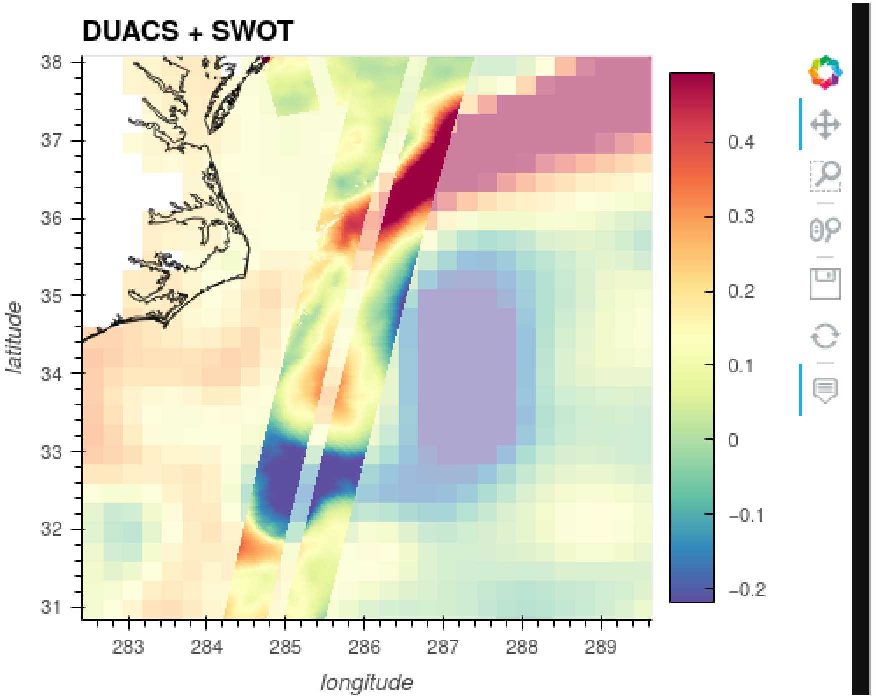


SWOT

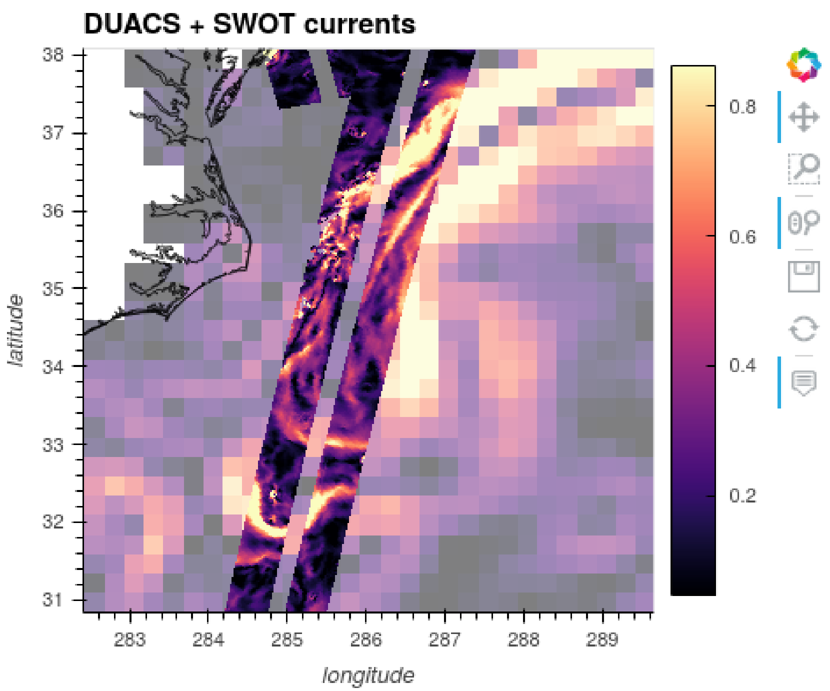
SWOT's Primary ocean objective: resolving ocean currents and eddies

Improving the resolution of ocean topography (sea level) and 3D ocean circulation
Conventional altimetry > 200 km, with SWOT > 10 km

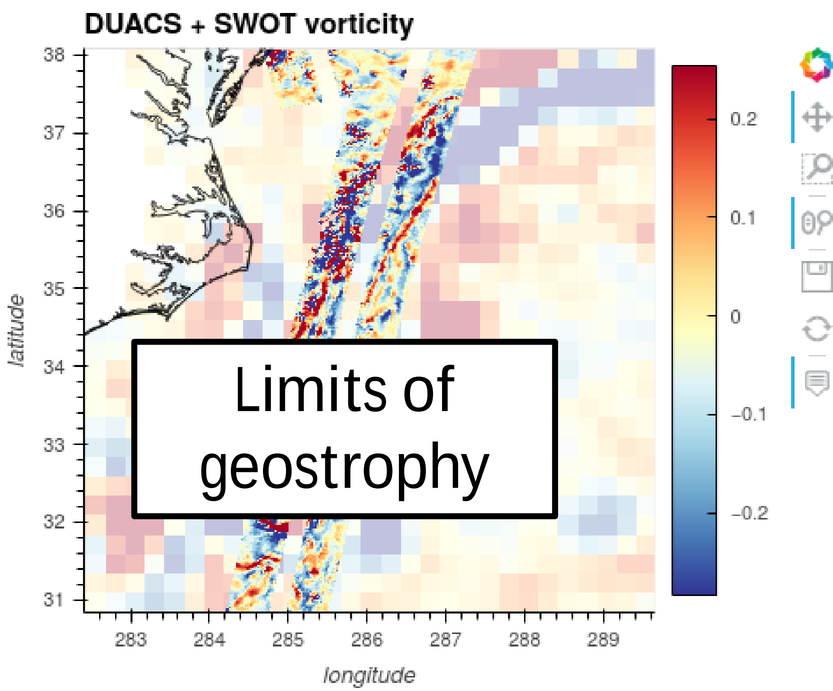
Ocean topography / Sea level



Horizontal Currents

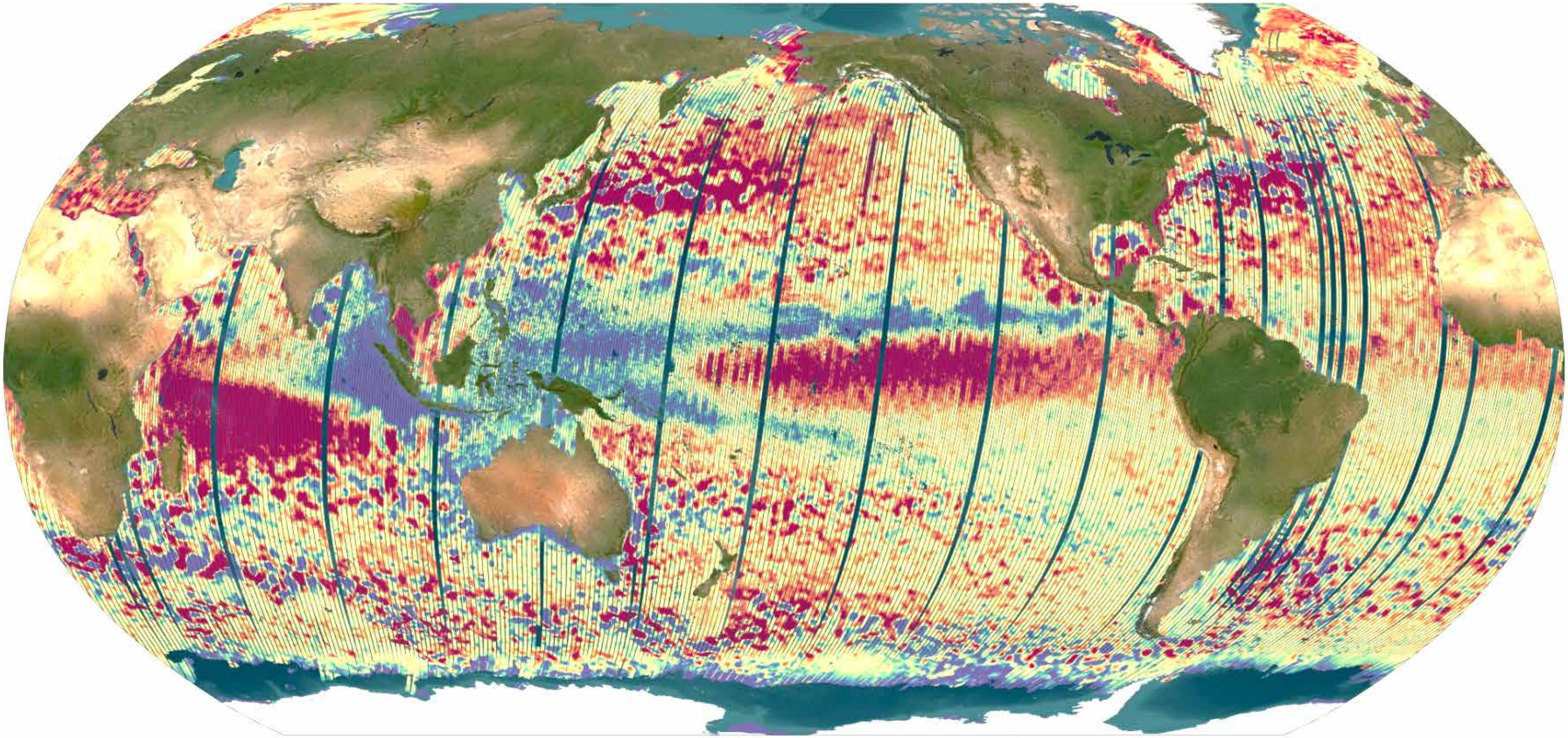


Vorticity => Vertical Currents



Gulf Stream snapshot: 1st June 2023

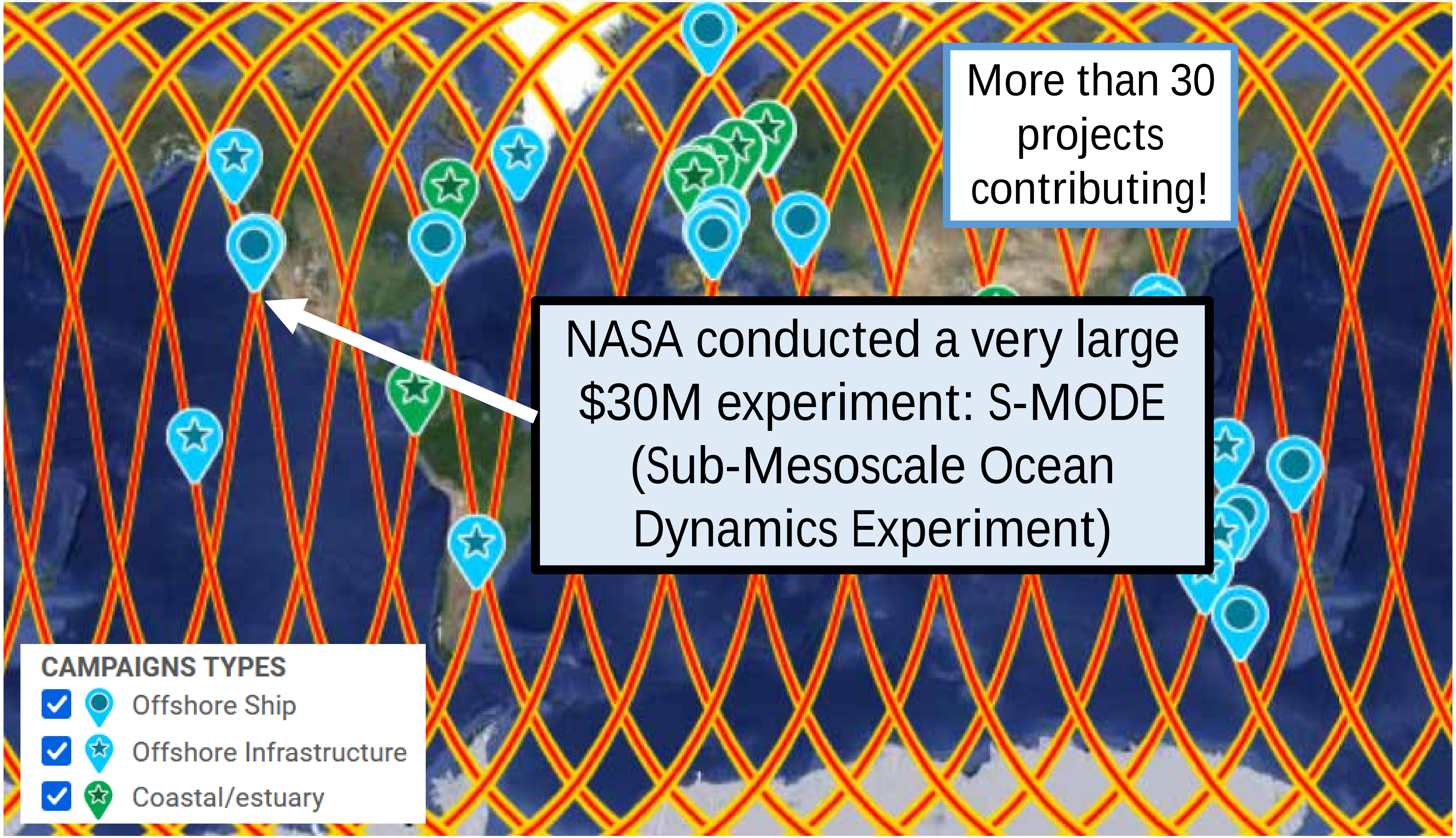
Ten days worth of Level-3 SWOT SSHA in November 2023



Credits: CLS/CNES

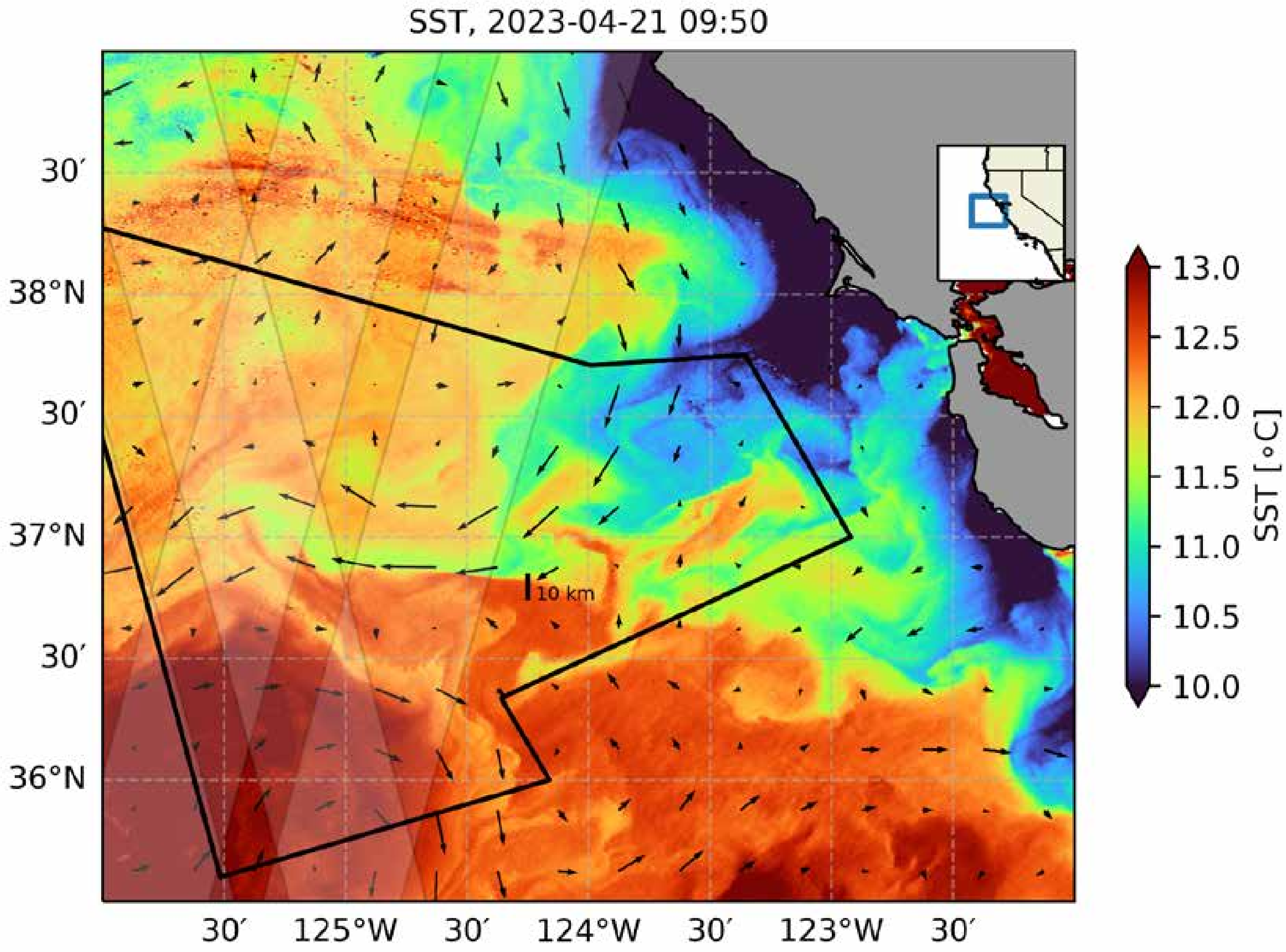
-15cm „ +15cm

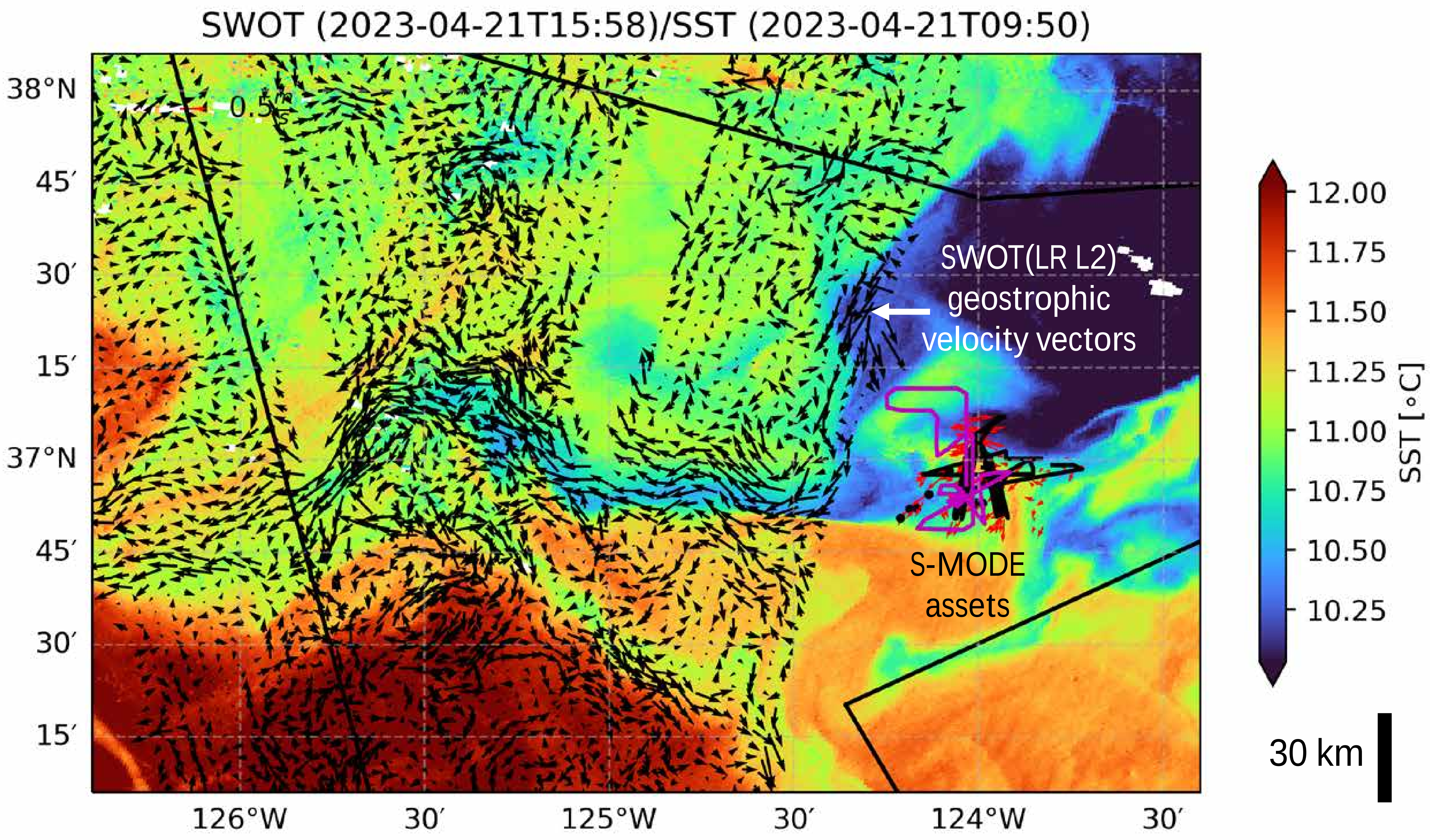
SWOT inspired the International Adopt-a-Crossover program

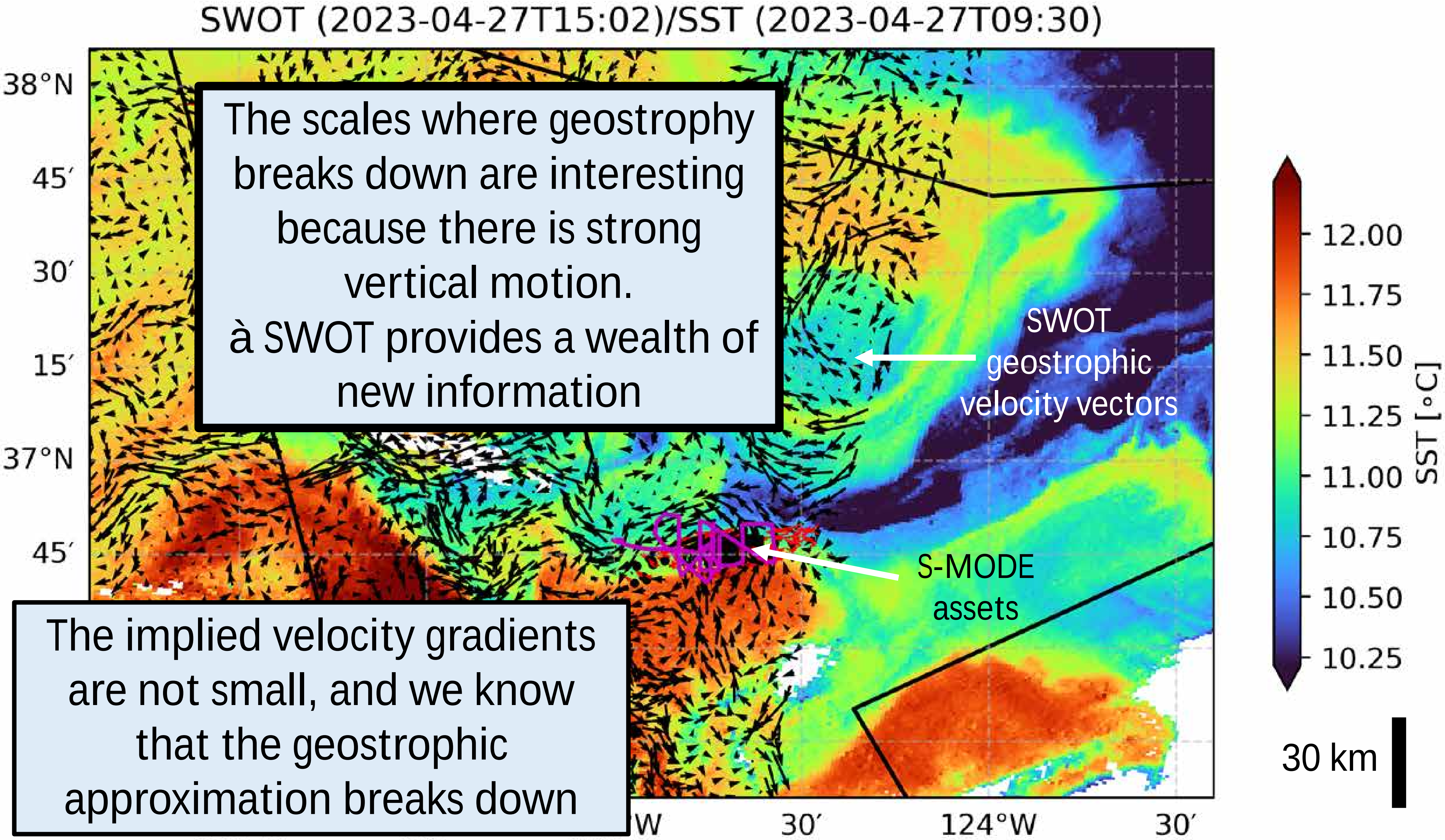


d'Ovidio et al. (2019)

Ocean eddies in the Earth system




SWOT (2023-04-21T15:58)/SST (2023-04-21T09:50)
38°N
45′
30′
15′
37°N
45′
30′
15′
126°W
30′
125°W
30′
124°W
30′
0.5 m/s
SWOT(LR L2) geostrophic velocity vectors
S-MODE assets
12.00
11.75
11.50
11.25
11.00
10.75
10.50
10.25
SST [°C]
30 km



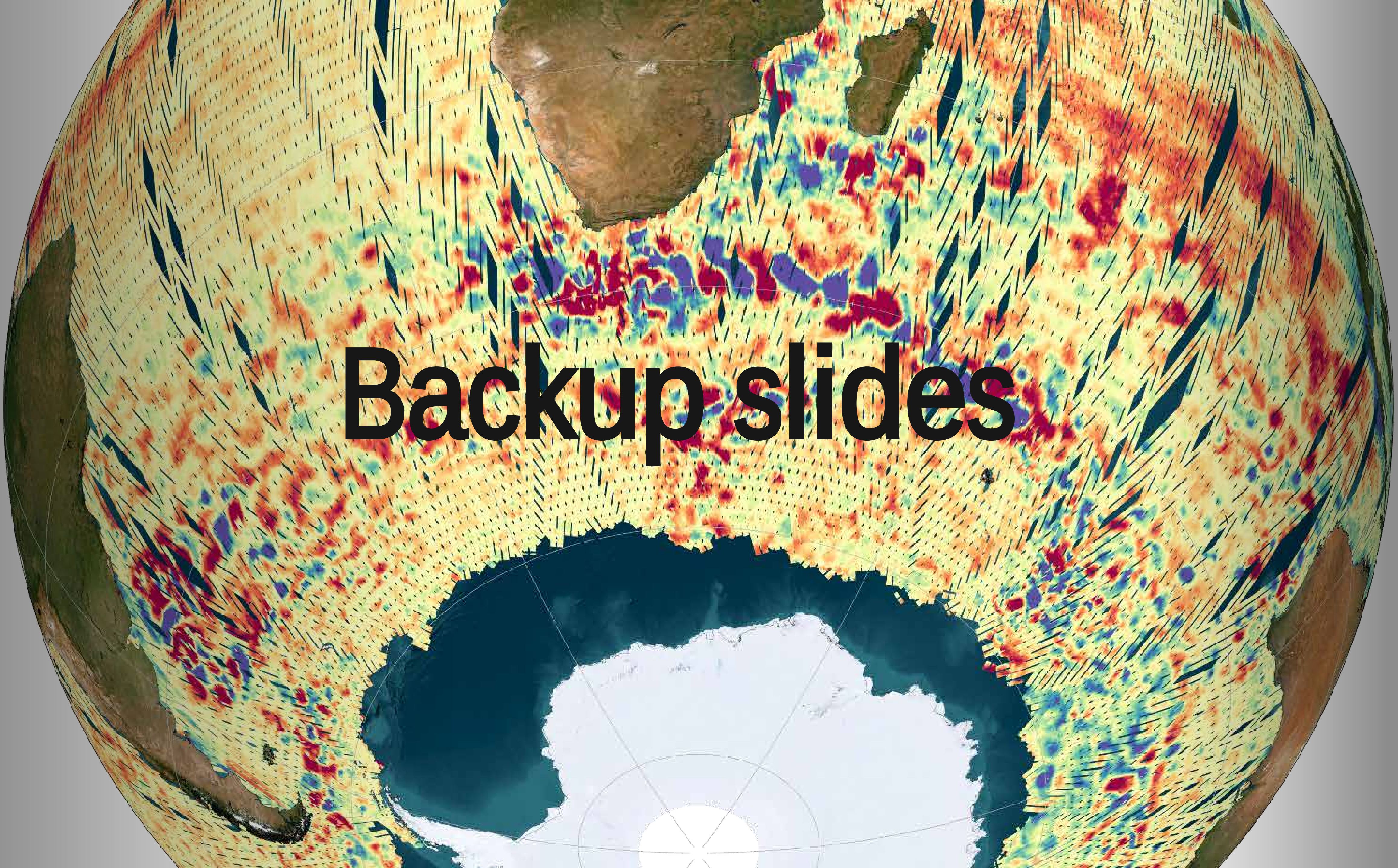
The scales where geostrophy breaks down are interesting because there is strong vertical motion.
à SWOT provides a wealth of new information

The implied velocity gradients are not small, and we know that the geostrophic approximation breaks down

Conclusions: Ocean finescale dynamics and SWOT

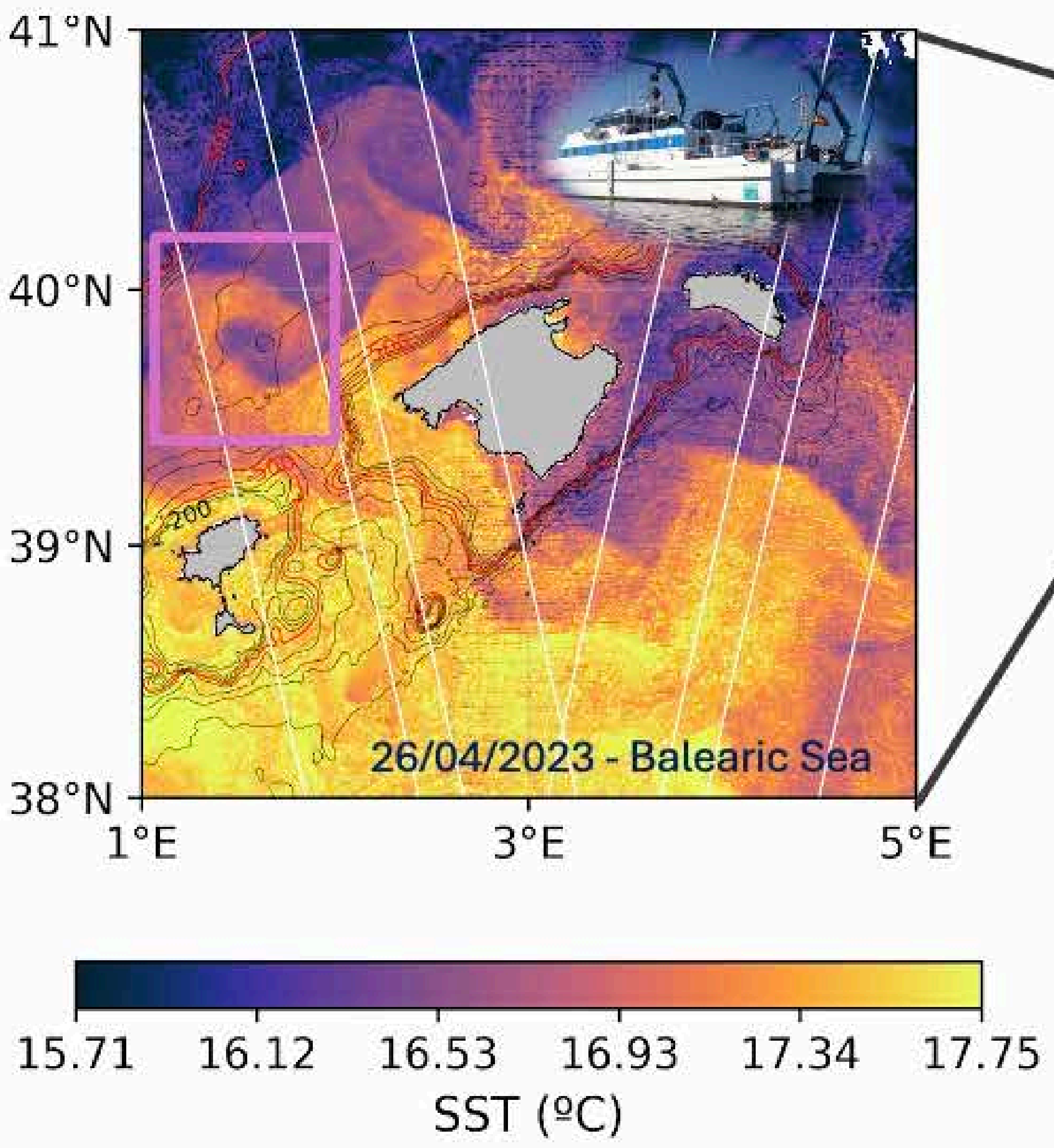
- SWOT is providing a firehose of new dynamical information about ocean variability on 10-100 km scales
- We're entering a new era for understanding the dynamics of the variability at these scales
    - Our models will be tested and challenged with these new global observations.
    - We will learn a lot about ageostrophic dynamics as we compare SWOT to other data at these newly accessible spatial scales

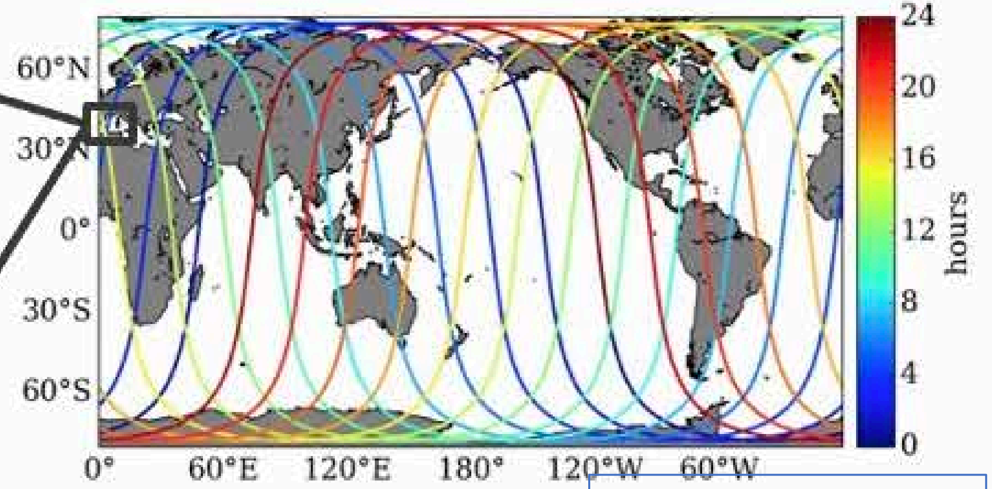
Backup slides



Example: FaSt-SWOT project

E. Verger-Miralles, L. Gómez-Navarro, B. Mourre, A. Pascual



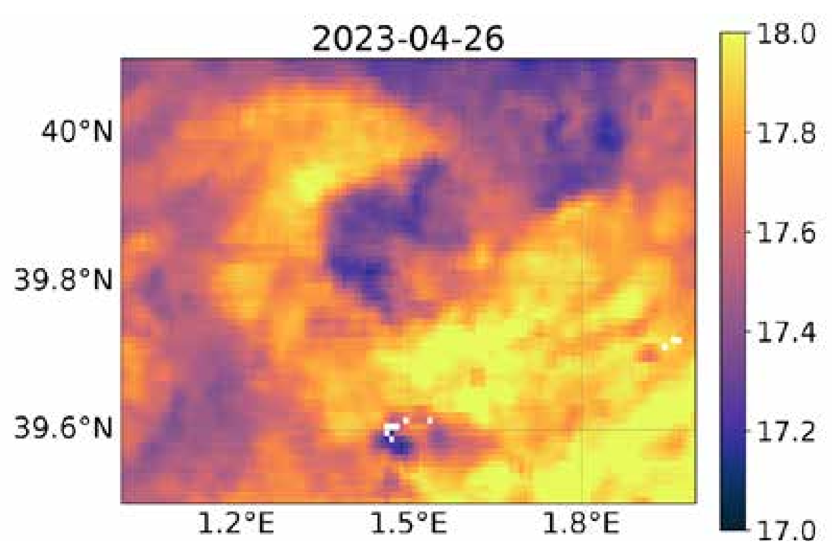


(d'Ovidio *et al.*, 2019)

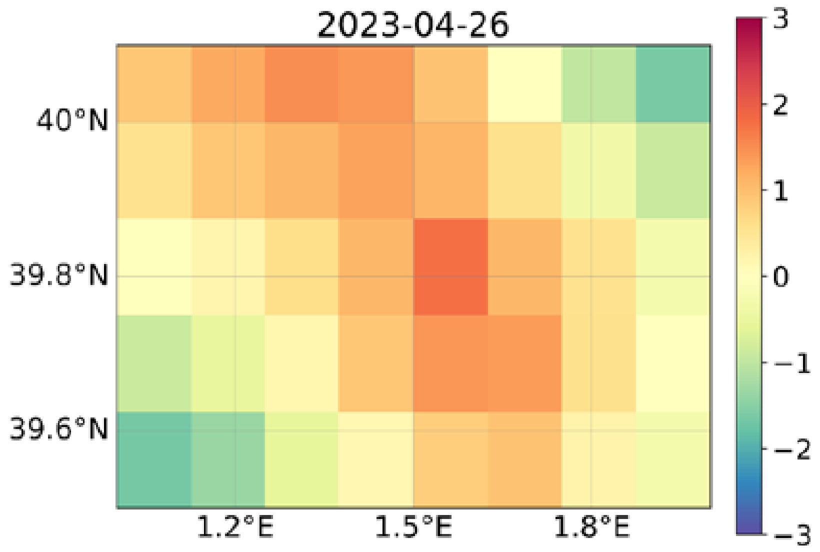
- Region around the Balearic Sea selected for SWOT validation (2 passes daily)
- 2 high-resolution multi-platform experiments
- In-situ sampling of a small-scale eddy during the SWOT fast sampling phase; Repeat sampling after 10 days to track the evolution.

Observation of a small anticyclonic mesoscale eddy

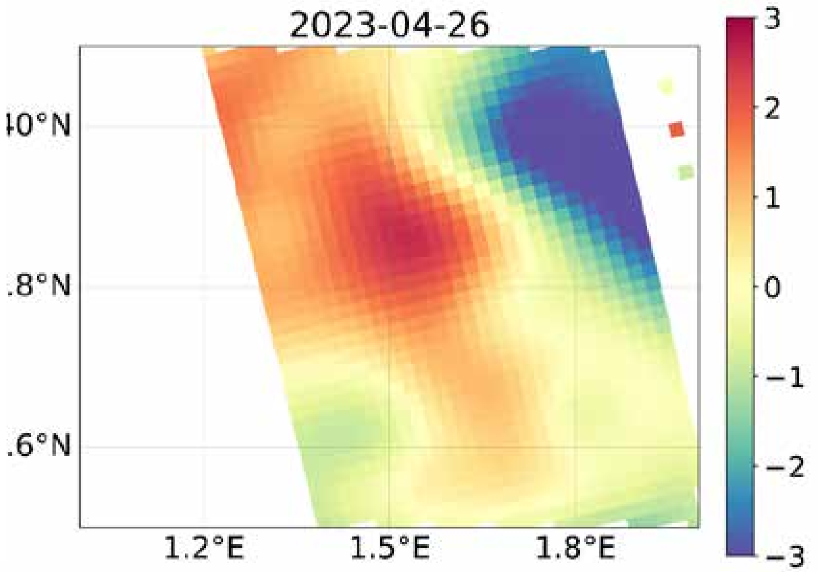
SST (ºC) NRT L3 - CMEMS



SSH (cm) **Gridded** L4 SSH - CMEMS



SSH (cm) **SWOT** L3 beta filtered - AVISO

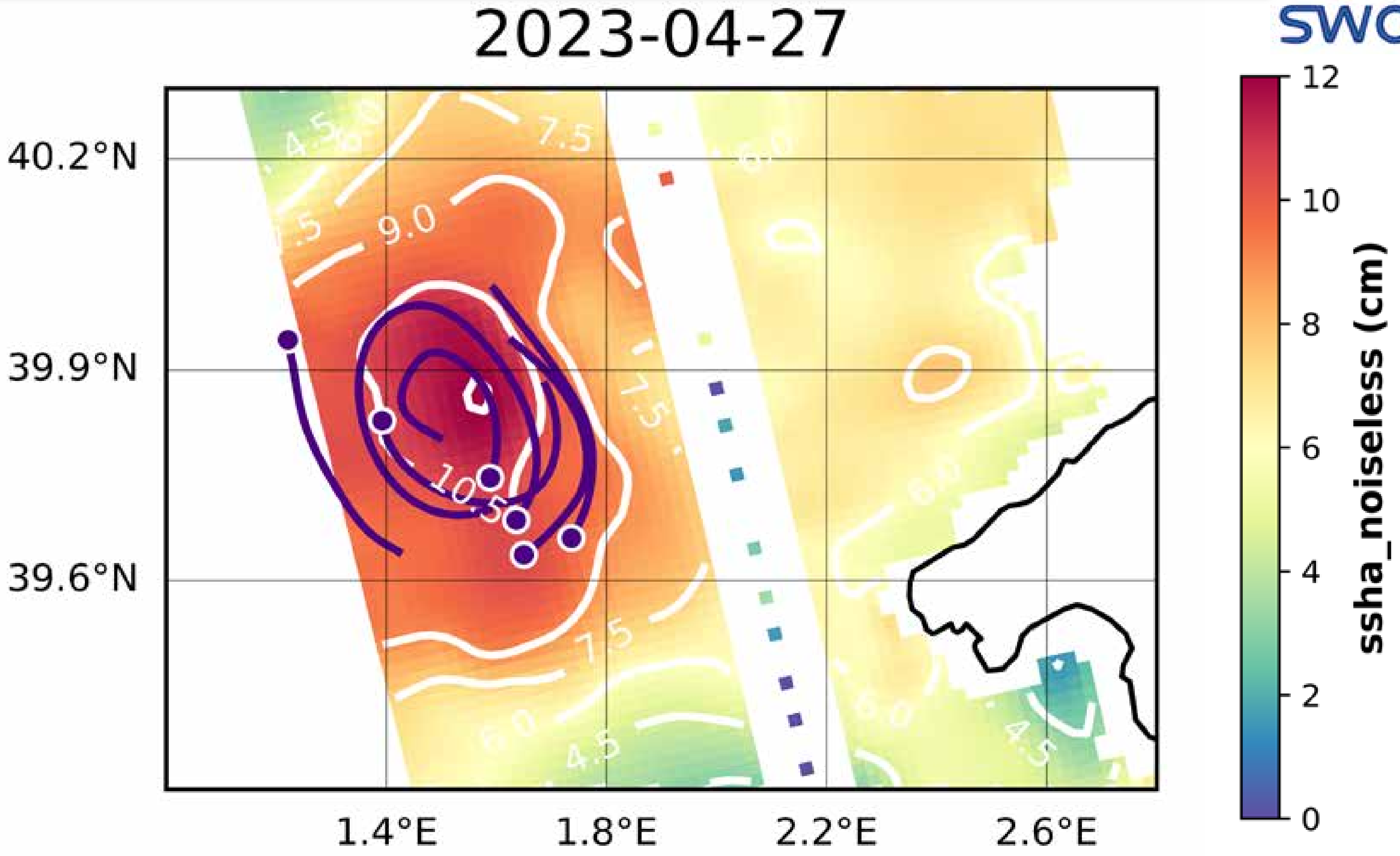


(Credits: E. Verger-Miralles, FaSt-SWOT project)

- Sea level signature of the small mesoscale eddy observed in SST represented with a much higher level of detail by SWOT compared to the gridded altimeter product.

Observation of a small anticyclonic mesoscale eddy

- Very good agreement between SWOT contours (noiseless, v0.3 L3)
  and drifter trajectories (SVP-B with drogue at 15m, inertial oscillations filtered).

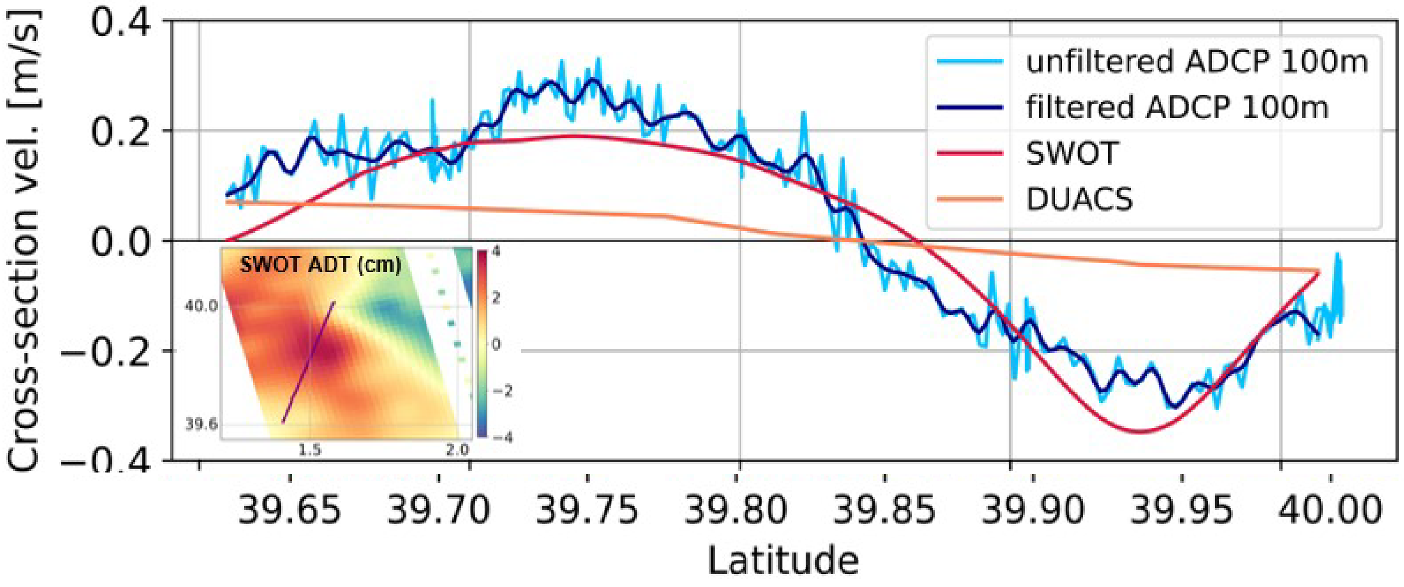


(Credits: L. Gomez-Navarro amd E. Verger-Miralles, FaSt-SWOT project)

Comparisons with ADCP

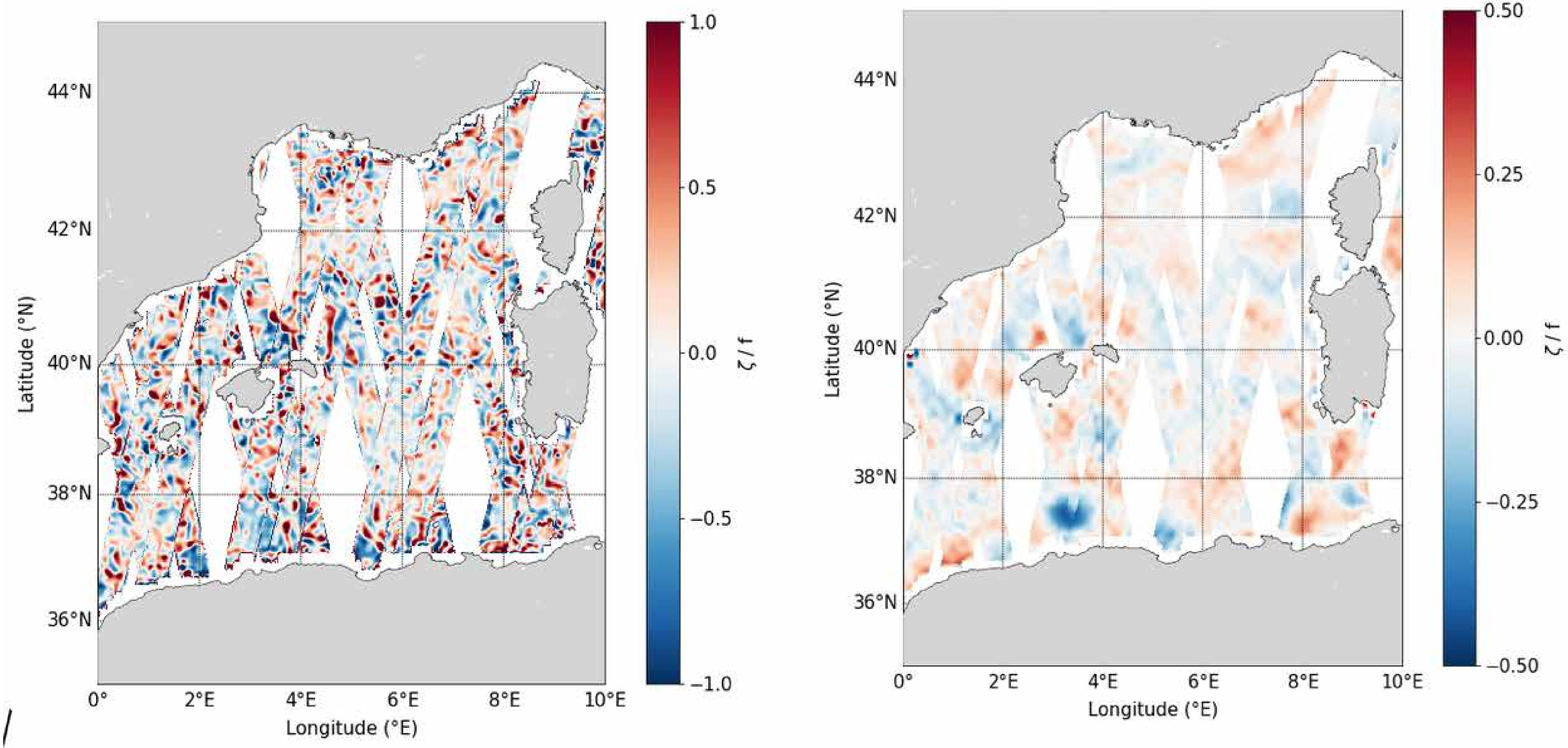
Eddy cross-section horizontal velocities

- Encouraging agreement between SWOT-derived geostrophic velocities and ship-based ADCP measurements at 100m



(Credits: E. Verger-Miralles, FaSt-SWOT project)

Spectacular differences between DUACS and SWOT in regions with small Rossby radius



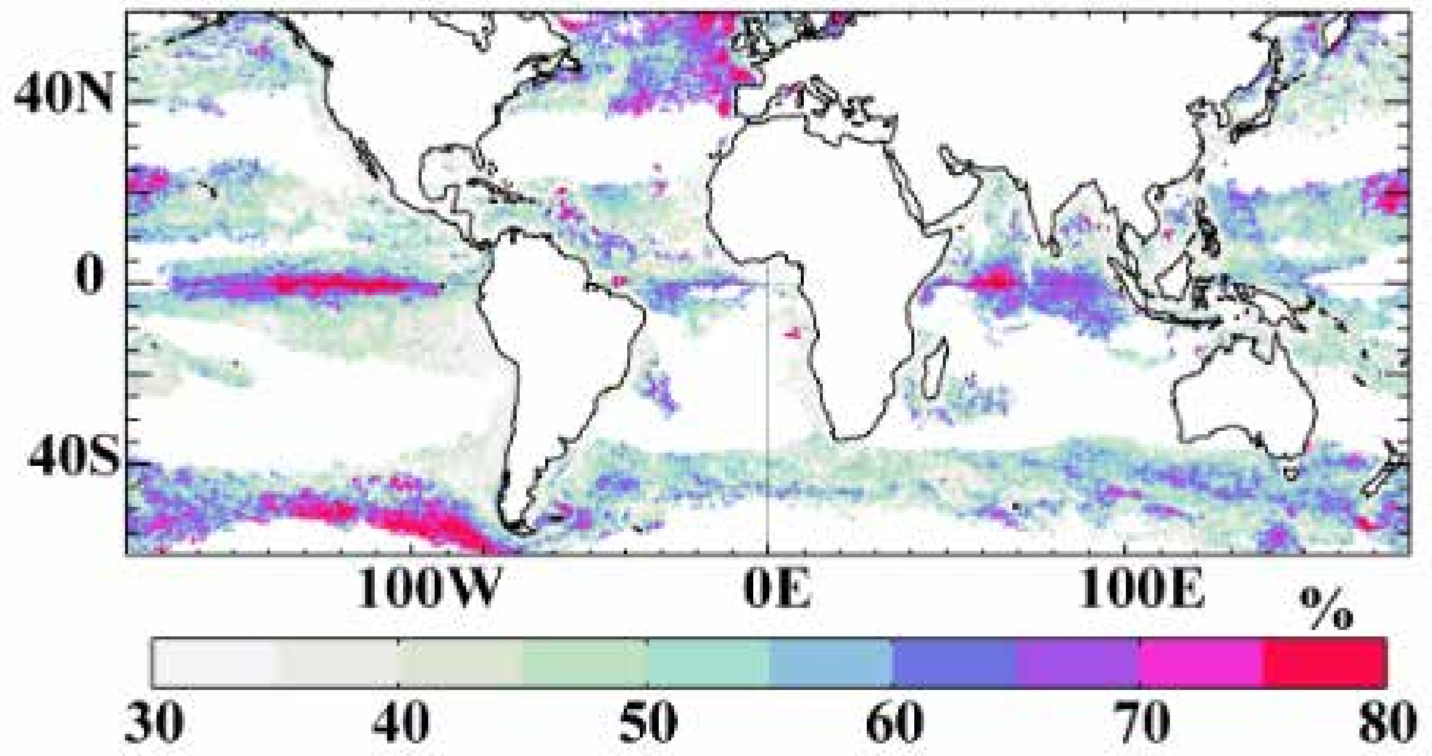
Master C. Goret

Biogeochemistry

Annual variations in phytoplankton biomass driven by small-scale physical processes

M. G. Keerthi, C. J. Prend, O. Aumont & M. Lévy

Nature Geoscience **15**, 1027–1033 (2022) | Cite this article



Percentage of the sub-seasonal SChl variance explained by sub-seasonal variations with spatial scales >100 km. Regions where sub-seasonal variations explain less than 30% of the total SChl variance is masked.

Grey area is where SWOT-scales may be important !

Marine resources

Fishermen Follow Fine-Scale Physical Ocean Features for Finance

James R. Watson[1,2], Emma C. Fuller[3], Frederic S. Castruccio[4] and Jameal F. Samhouri[5]*

RESEARCH ARTICLE | BIOLOGICAL SCIENCES |

Fisheries bycatch risk to marine megafauna is intensified in Lagrangian coherent structures

Kylie L. Scales, Elliott L. Hazen, Michael G. Jacox, +3, and Steven J. Bograd Authors Info & Affiliations

Lagrangian fronts and saury catch locations in the Northwestern Pacific in 2004–2019

S.V. Prants [a], M.V. Budyansky [a], M.Yu. Uleysky [a], V.V. Kulik [b]

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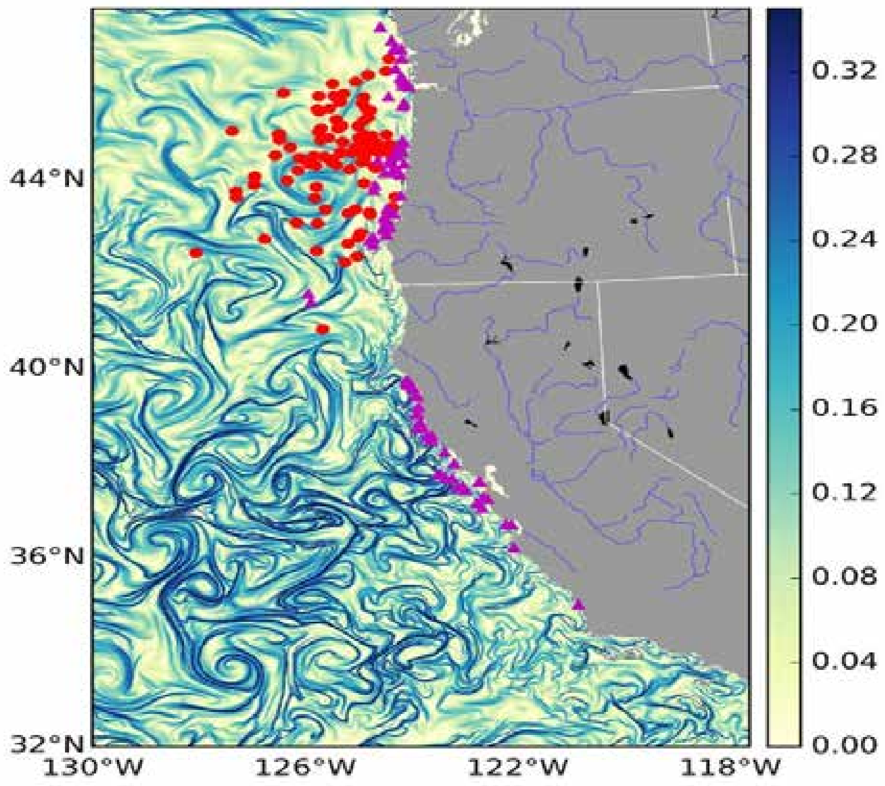


Watson et al., Front. Mar. Science 2018

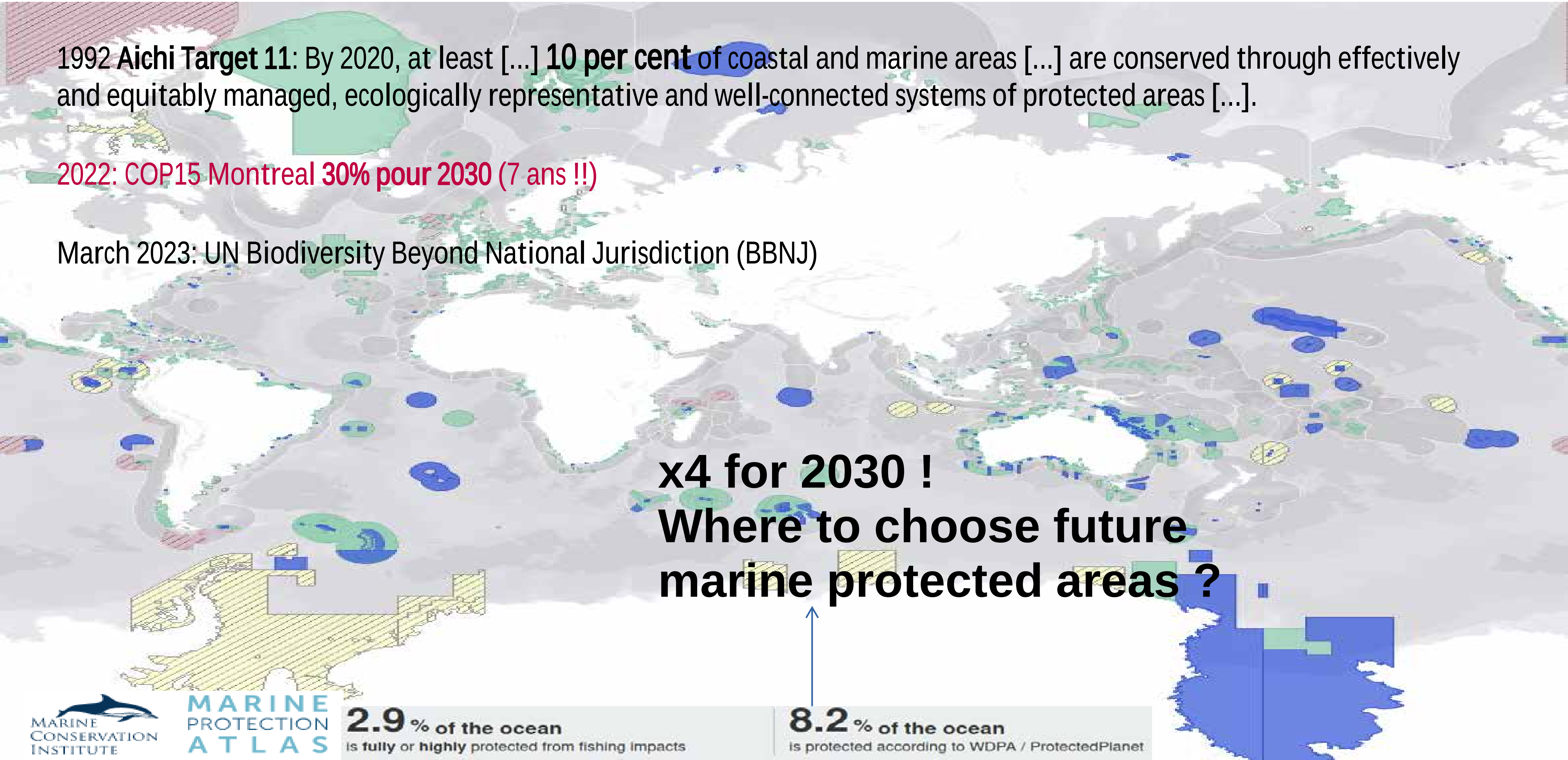
Accurate fine-scale information for the open ocean is urgently needed for conservation

1992 **Aichi Target 11**: By 2020, at least [...] **10 per cent** of coastal and marine areas [...] are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas [...].

2022: COP15 Montreal **30% pour 2030** (7 ans !!)

March 2023: UN Biodiversity Beyond National Jurisdiction (BBNJ)

x4 for 2030 !
Where to choose future marine protected areas ?



Argo floats

2 Rutgers gliders

3 PIES under S moorings

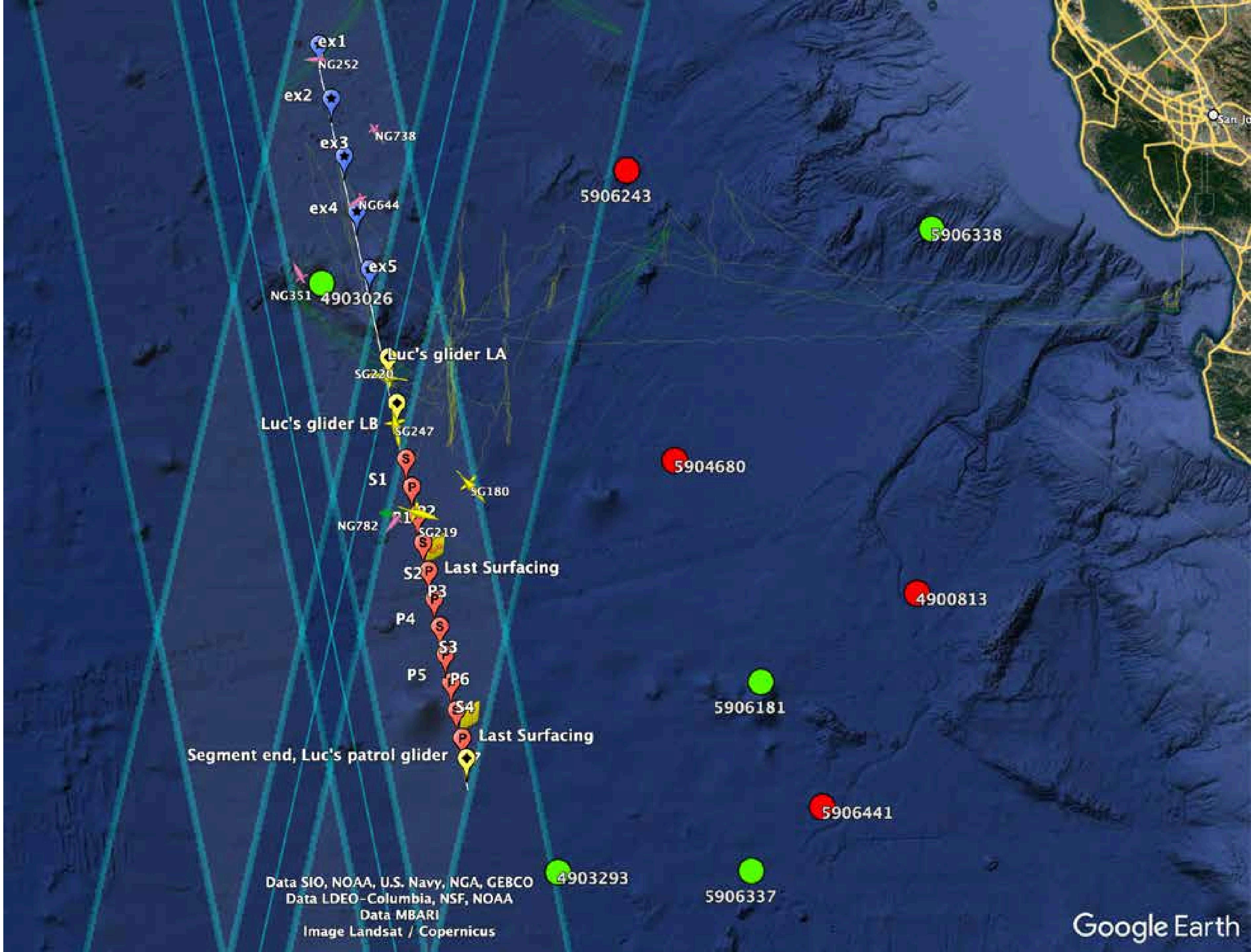
4 UW gliders

4 SIO deep moorings

5 NAVO gliders

7 NOAA/PMEL moorings

Numerous drifters
(not shown)



Geostrophy versus total surface currents

x-component of momentum equation:

Acceleration (time dependence) | Nonlinearity | Coriolis force | Pressure gradient | Viscous/turbulent stress (wind forcing)

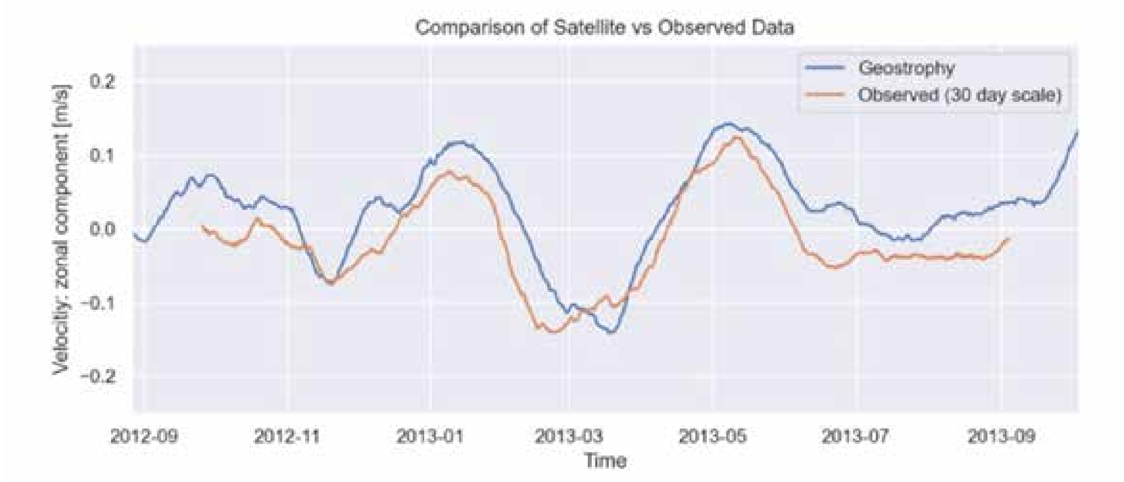
$$\frac{\partial u}{\partial t} + \vec{u} \cdot \nabla u - \underbrace{fv = -p_x}_{} + \frac{1}{\rho}\frac{\partial \tau^x}{\partial z}$$

Geostrophic balance of Coriolis force and pressure gradient—Requires all other terms be negligible

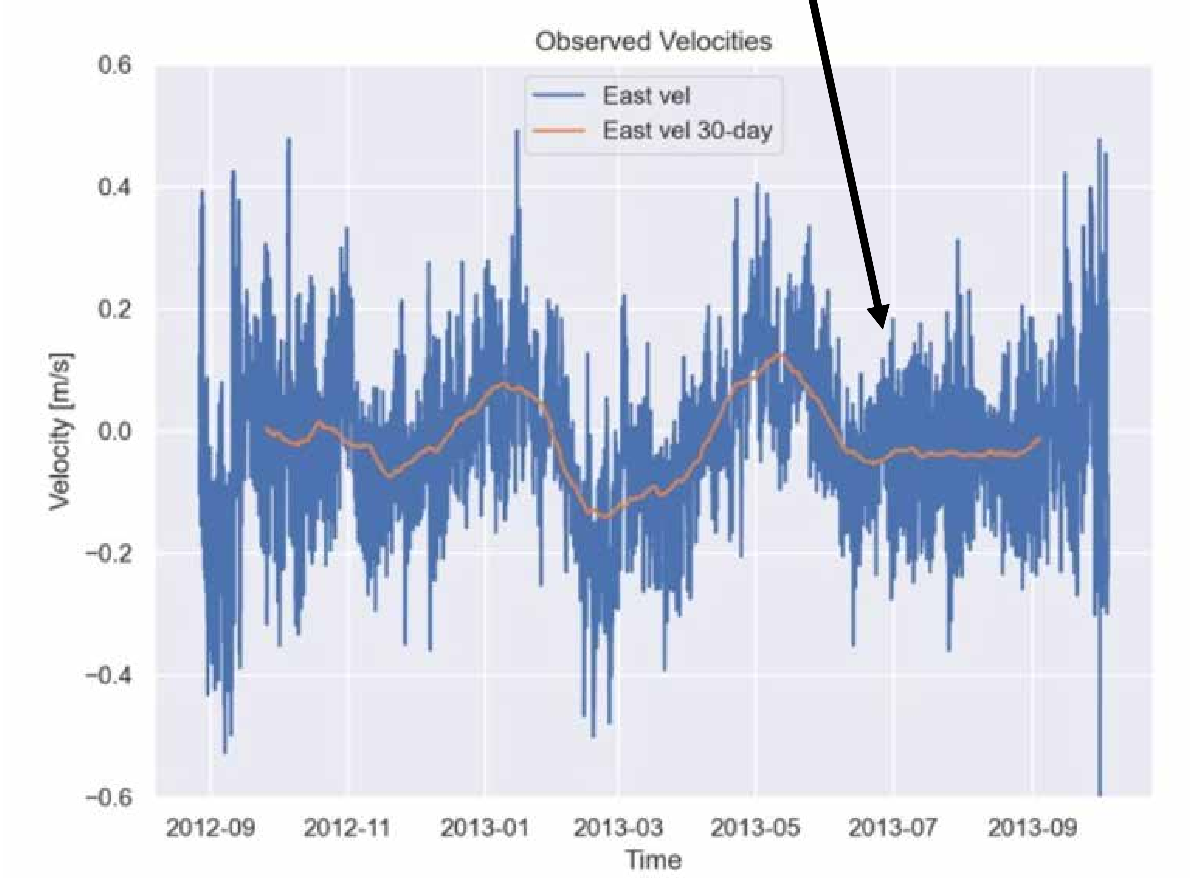
Geostrophy versus total surface currents
(Data from SPURS-1 central mooring)

Instantaneous velocity is not approximately geostrophic

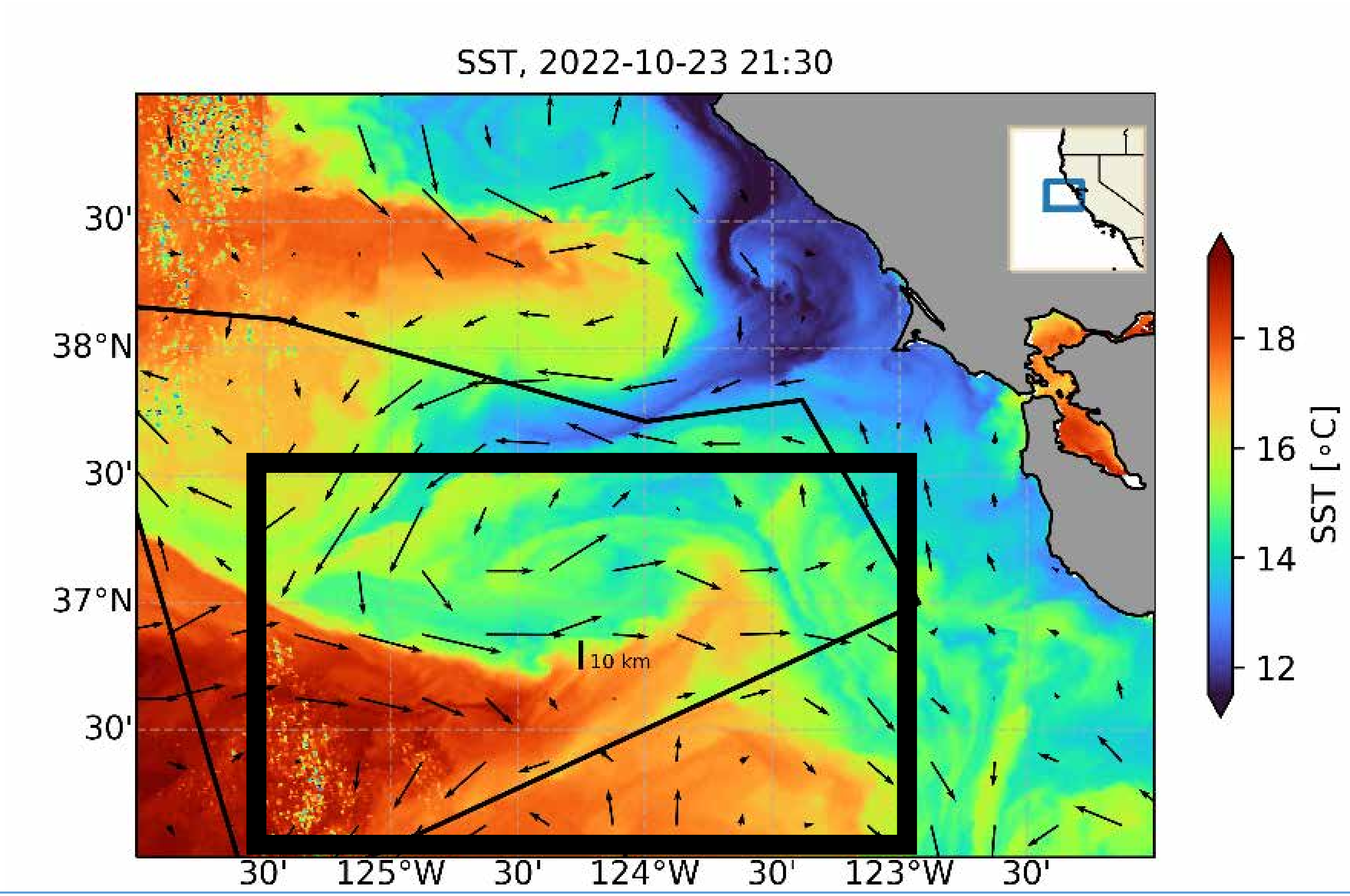
30-day average velocity is similar to geostrophic velocity, but can differ by ~50%



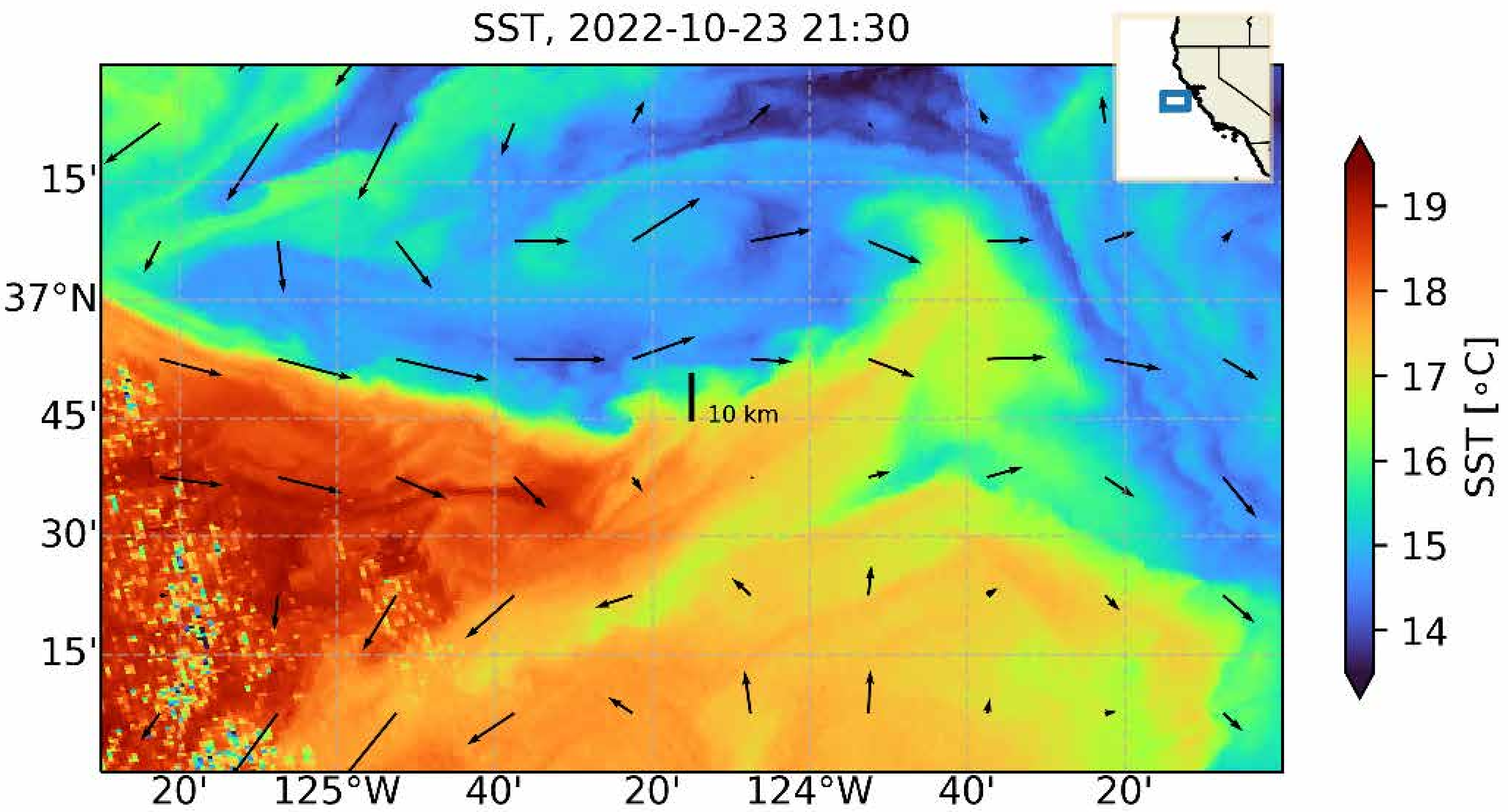
The difference at low frequencies is probably mostly due to wind-driven currents (which could be demonstrated)



Sea Surface Temperature in S-MODE IOP1



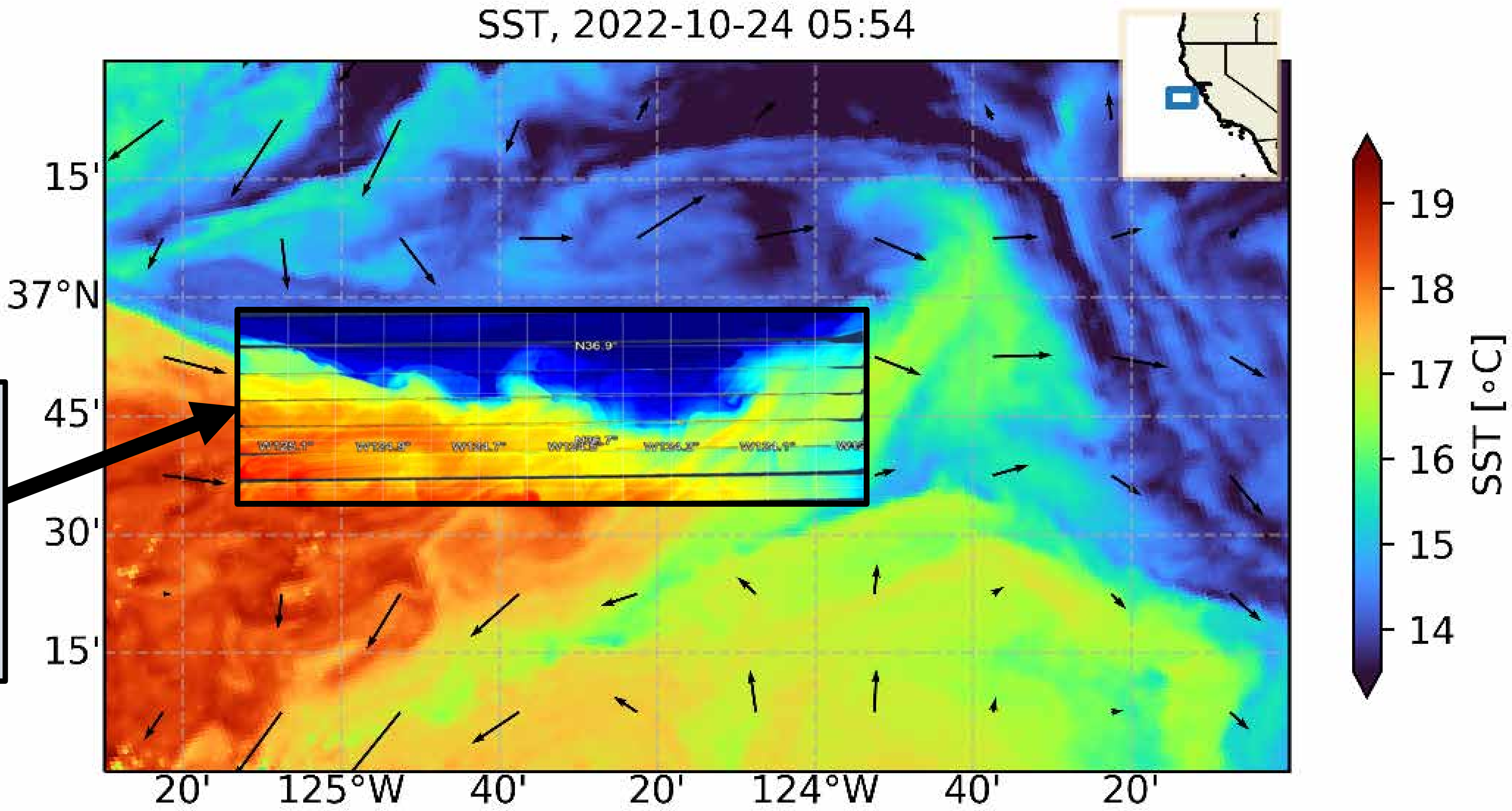
Sea Surface Temperature in S-MODE IOP1



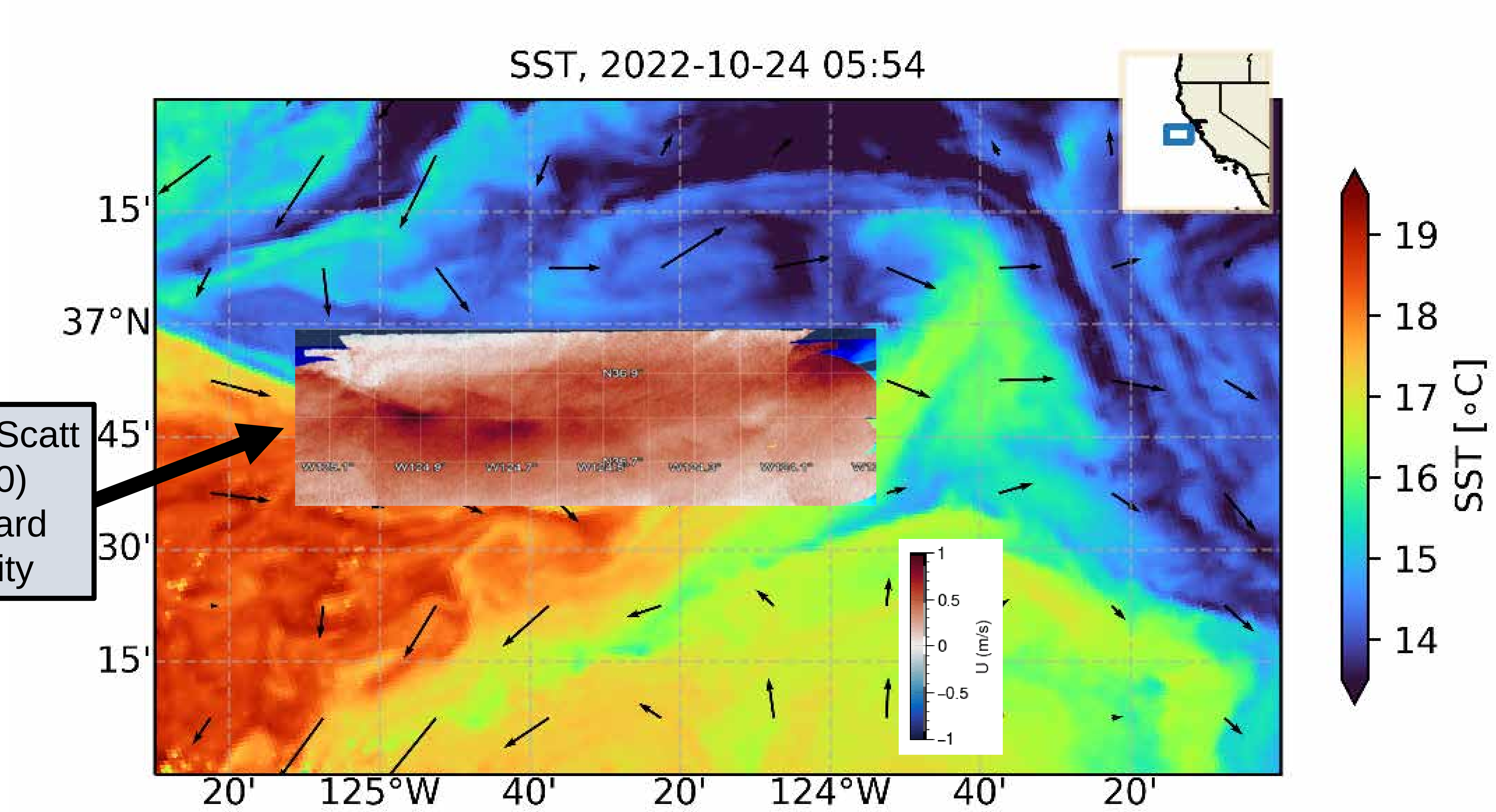
Sea Surface Temperature in S-MODE IOP1

6.5 hours later

MOSES (B200) SST 12 hours later



Sea Surface Temperature in S-MODE IOP1



DopplerScatt (B200) eastward velocity

Geostrophy versus total surface currents

x-component of momentum equation:

Acceleration (time dependence) | Nonlinearity | Coriolis force | Pressure gradient | Viscous/turbulent stress (wind forcing)

$$\frac{\partial u}{\partial t} + \vec{u} \cdot \nabla u - \underbrace{fv = -p_x}_{} + \frac{1}{\rho}\frac{\partial \tau^x}{\partial z}$$

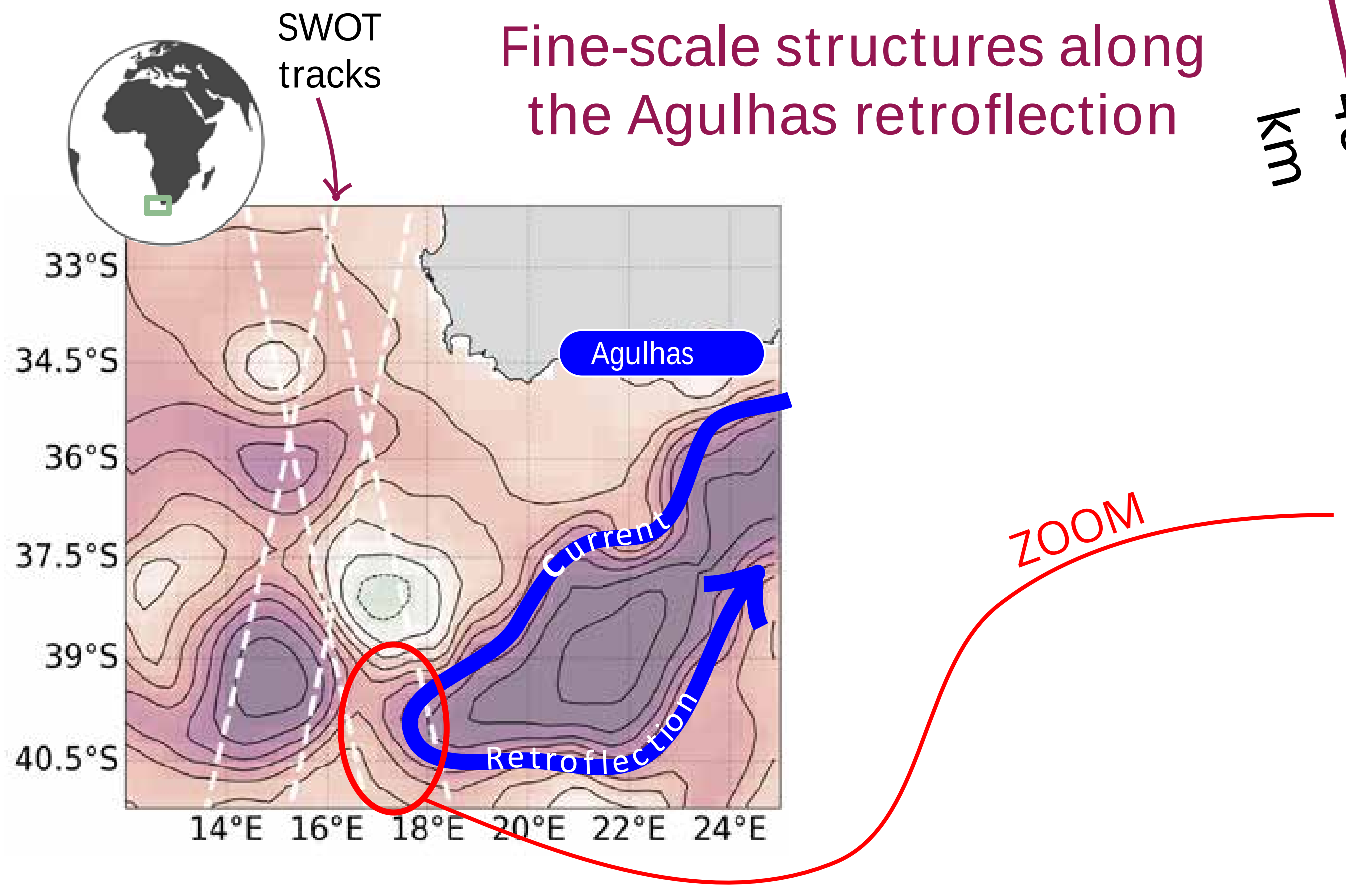
Geostrophic balance of Coriolis force and pressure gradient— Requires all other terms be negligible

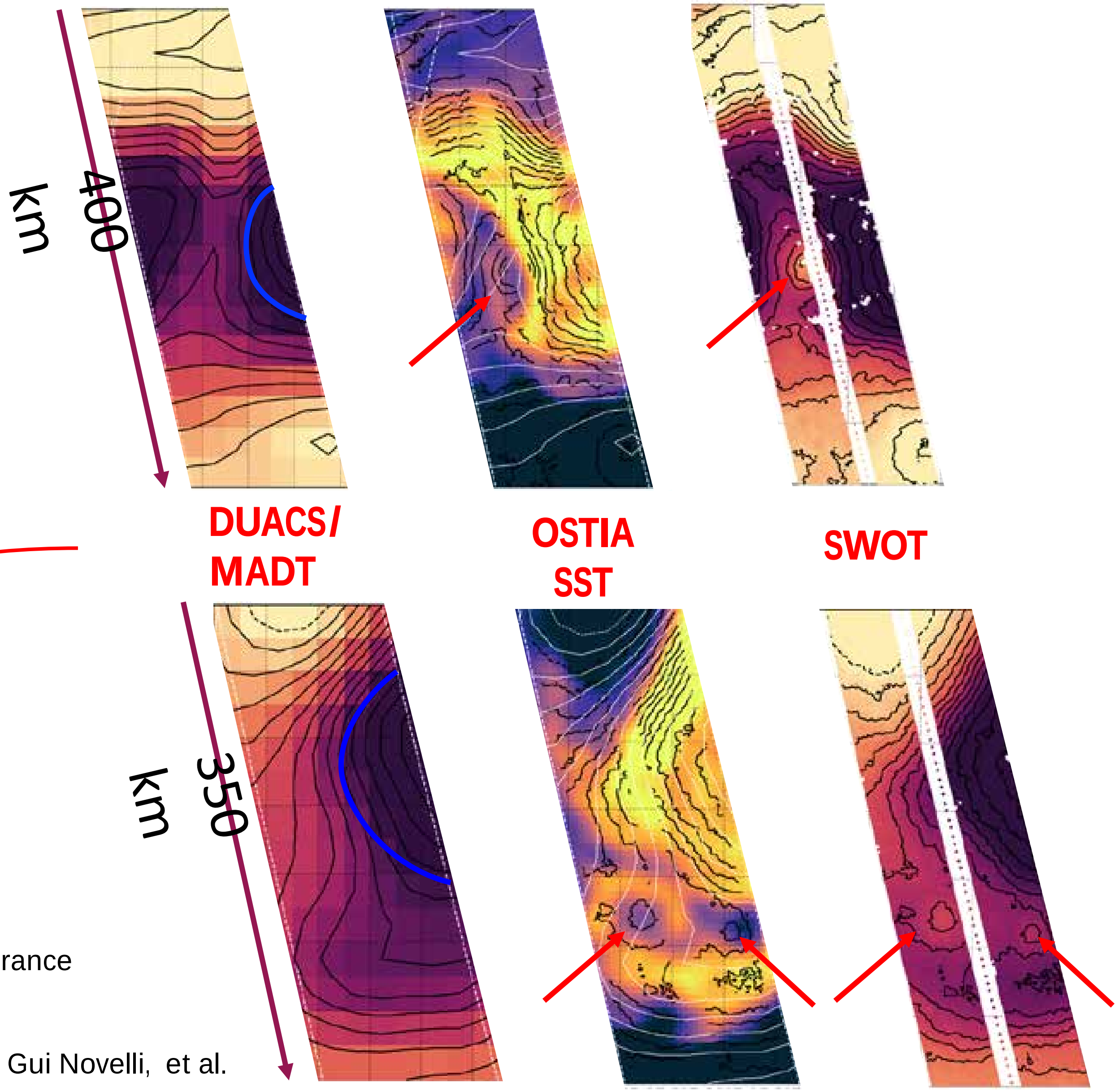
SWOT comparisons in the Cape Basin

solange.coadou-chaventon@lmd.ipsl.fr

Solange Coadou[1,2], Sebastiaan Swart[2], Sabrina Speich[1]

Fine-scale structures along the Agulhas retroflection





[1]Laboratoire de Météorologie Dynamique (IPSL), Ecole Normale Supérieure (PSL), Paris, France
[2]Department of Marine Sciences, University of Gothenburg, Sweden

In collab with the QUICCHE project: Lisa Beal, Kathy Donohue, Yueng Lenn, Chris Roman, Gui Novelli, et al.

Marine ecology

Research Article | Open Access

The Impact of a Southern Ocean Cyclonic Eddy on Mesopelagic Micronekton

astien Moreau, Ramkrushnbhai Patel, Rudy Kloser, Peter Gaube,

| https://doi.org/10.1029/2022JC018893 | Citations: 1

nature communications

Article https://doi.org/10.1038/s41467-024-49113-3

A rare oasis effect for forage fauna in oceanic eddies at the global scale

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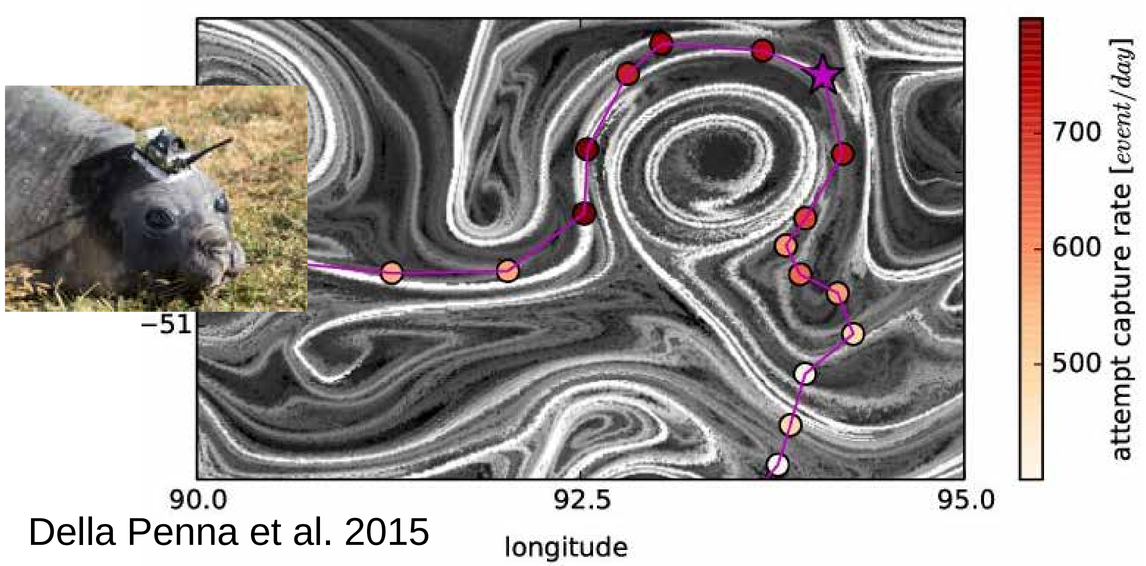
Aurore Receveur[1,2], Christophe Menkes[3], Matthieu Lengaigne[4], Alejandro Ariza[4,5], Arnaud Bertrand[4], Cyril Dutheil[4,6], Sophie Cravatte[7,8], Valérie Allain[1], Laure Barbin[1,3], Anne Lebourges-Dhaussy[9], Patrick Lehodey[1,10] & Simon Nicol[1,11]

Fine-scale structures as spots of increased fish concentration in the open ocean

Alberto Baudena[1,2], Enrico Ser-Giacomi[1,6], Donatella D'Onofrio[3,4], Xavier Capet[1], Cedric Cotté[1], Yves Cherel[5] & Francesco D'Ovidio[1]



Della Penna et al. 2015

Article | Published: 07 September 2022

Anticyclonic eddies aggregate pelagic predators in a subtropical gyre

Martin C. Arostegui, Peter Gaube, Phoebe A. Woodworth-Jefcoats, Donald R. Kobayashi & Camrin D. Braun

Nature 609, 535–540 (2022) | Cite this article