How to exploit the synergy of using different satellite observations to retrieve the meso/submesosale dynamics

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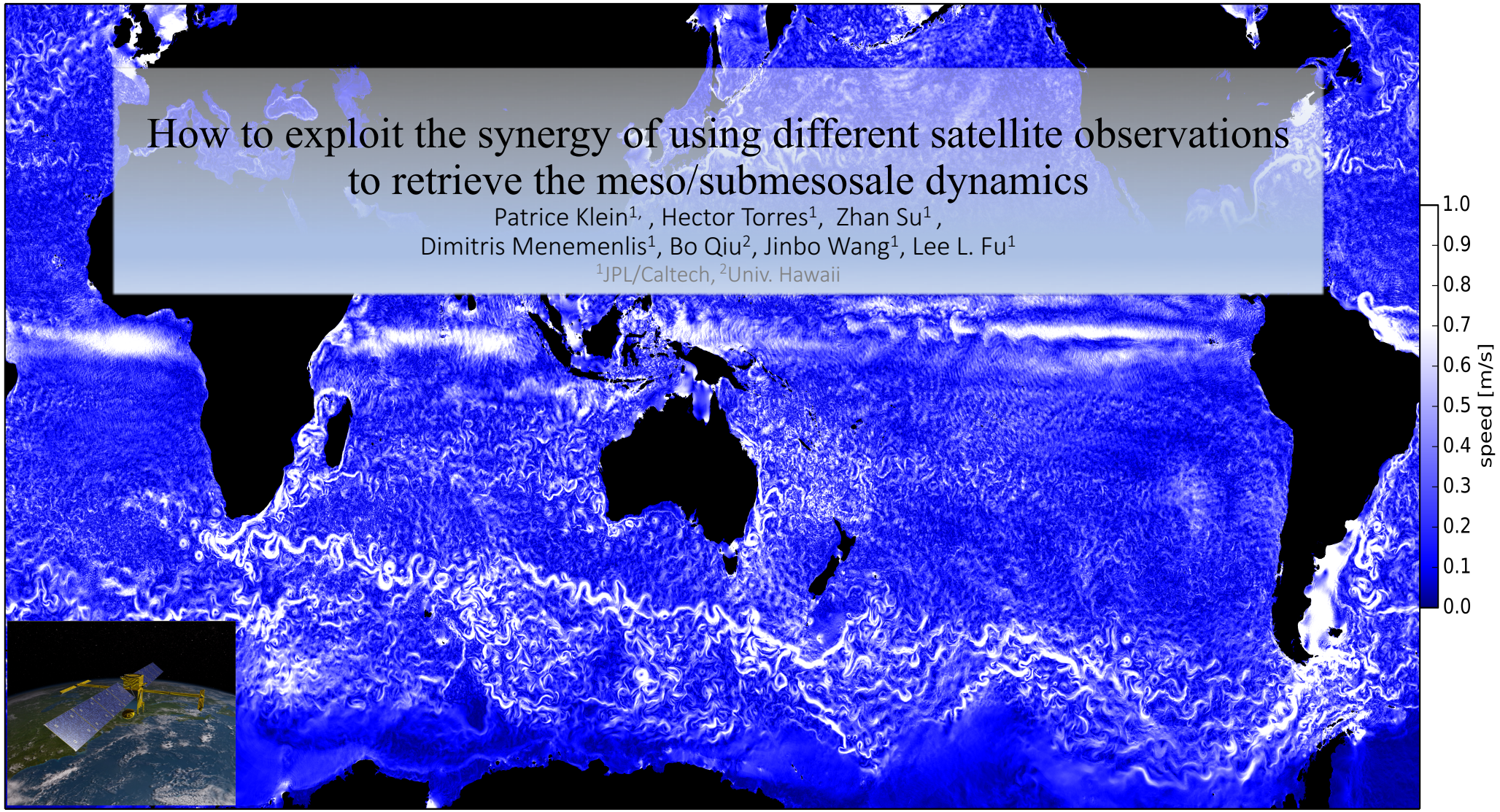

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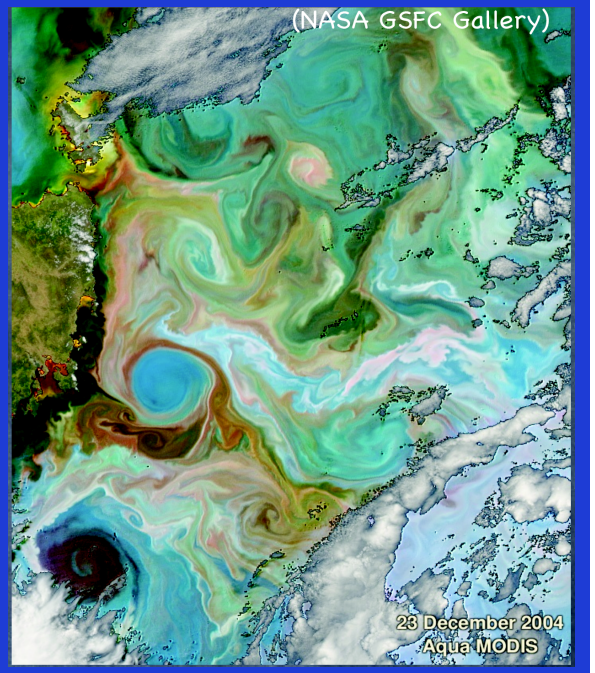
Because of their very high spatial resolution, satellite images have highlighted for a long time the richness of the spatial variability of the ocean dynamics.

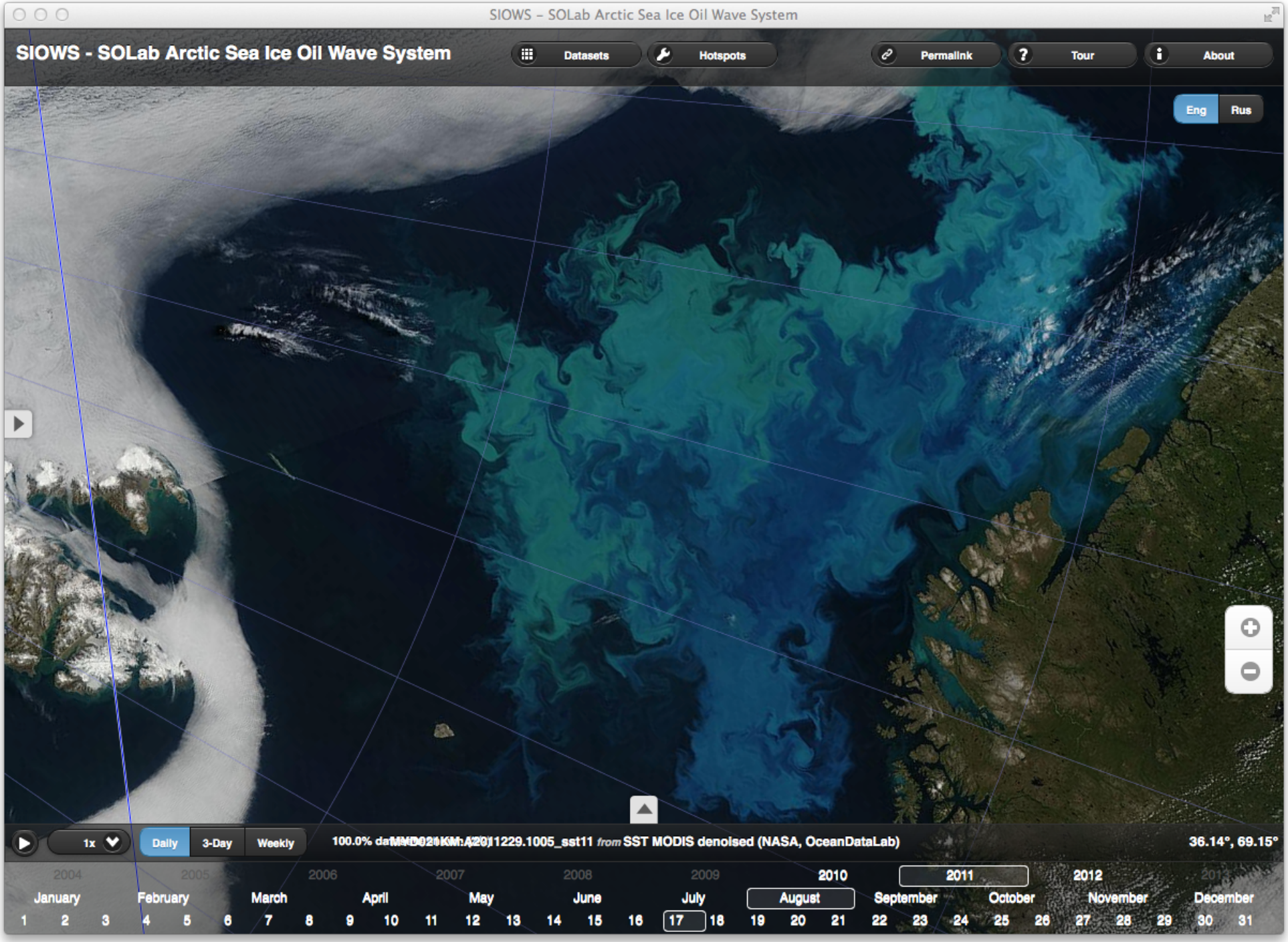


They mostly concern:
- **Infrared images (1km): Sea Surface Temperature**
- **Ocean color images (1 km): Chlorophyll**
- **Synthetic Aperture Radar images (100 m): roughness due to the interaction between surface waves and currents.**

These images reveal not only mesoscale eddies (100-300km) but also smaller scales (5 km-40 km) called submesoscales that are ubiquituous.

in the World Ocean!

Comparing SST, Ocean Color and SAR images emphasizes a very strong coherence in particular at meso and submesoscales.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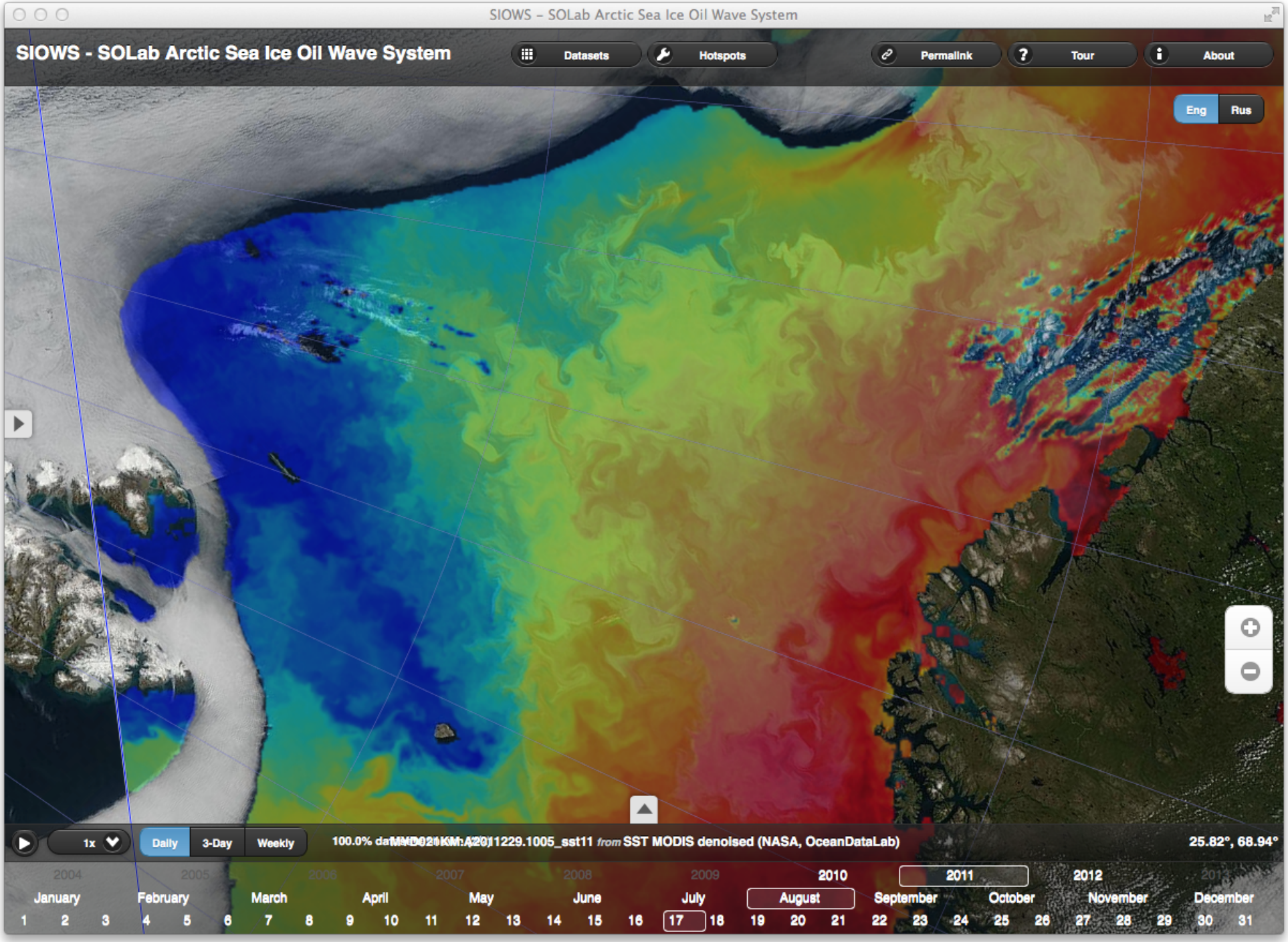
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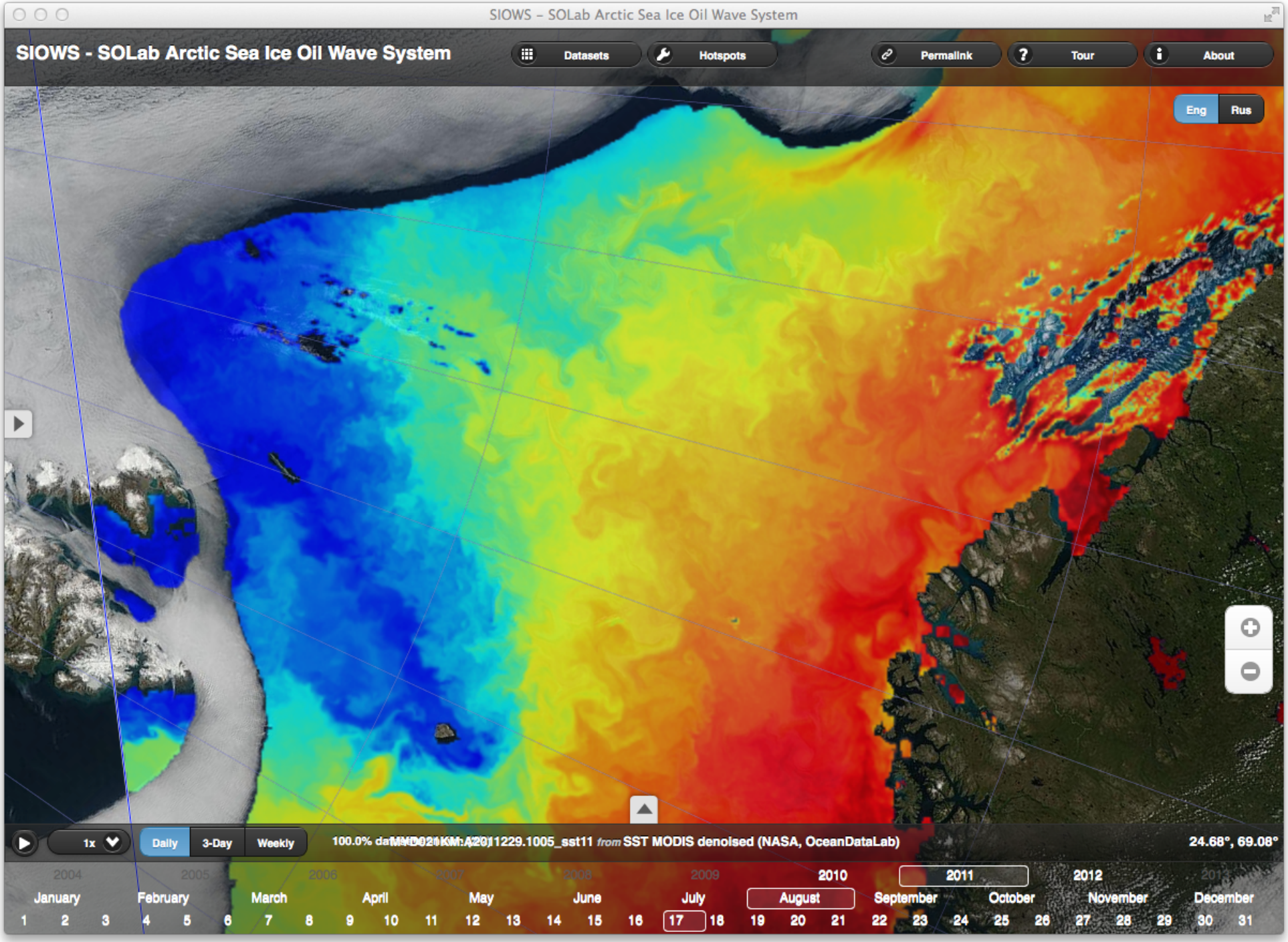
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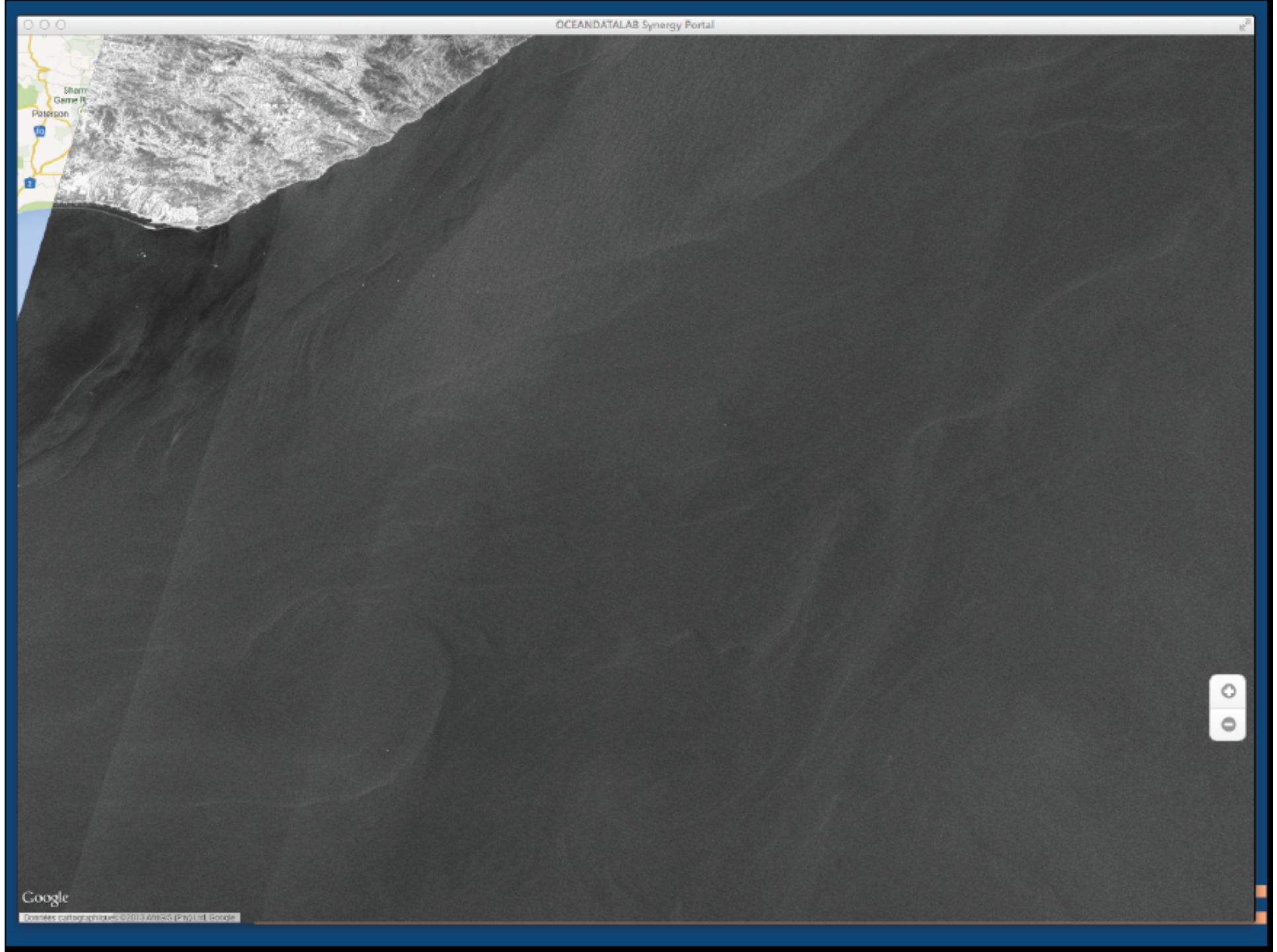
OCEANDATALAB Synergy Portal
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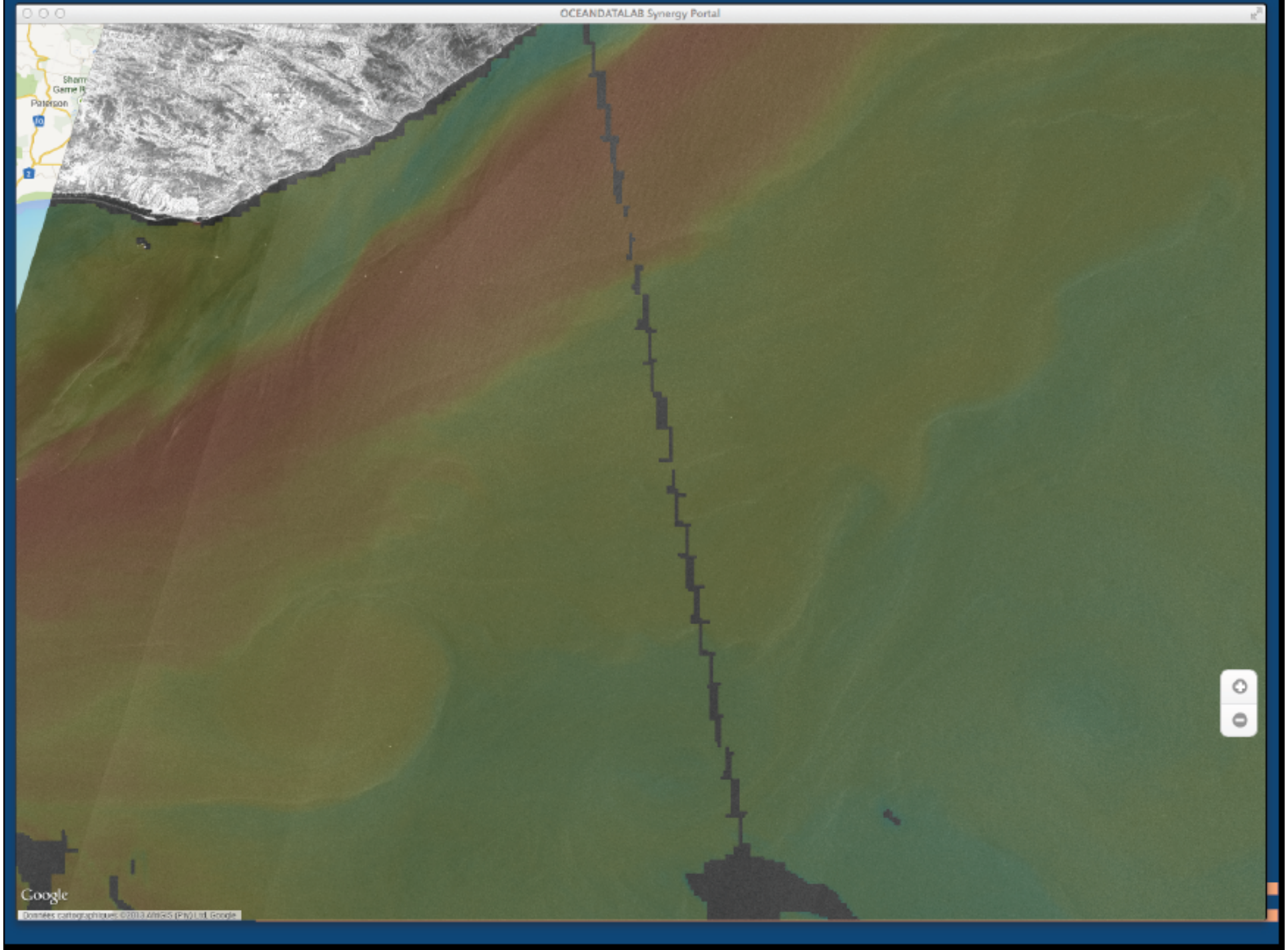
Google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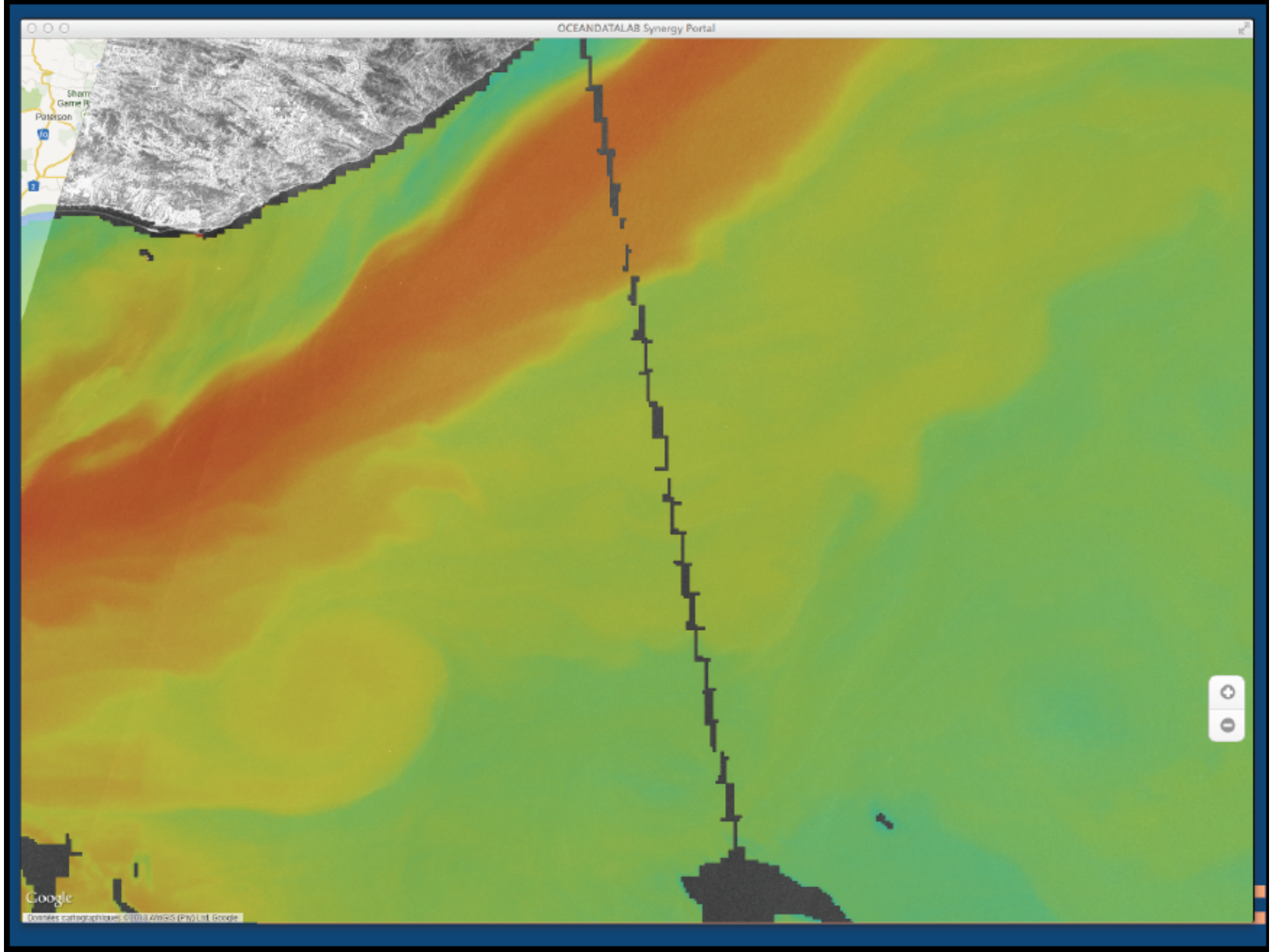
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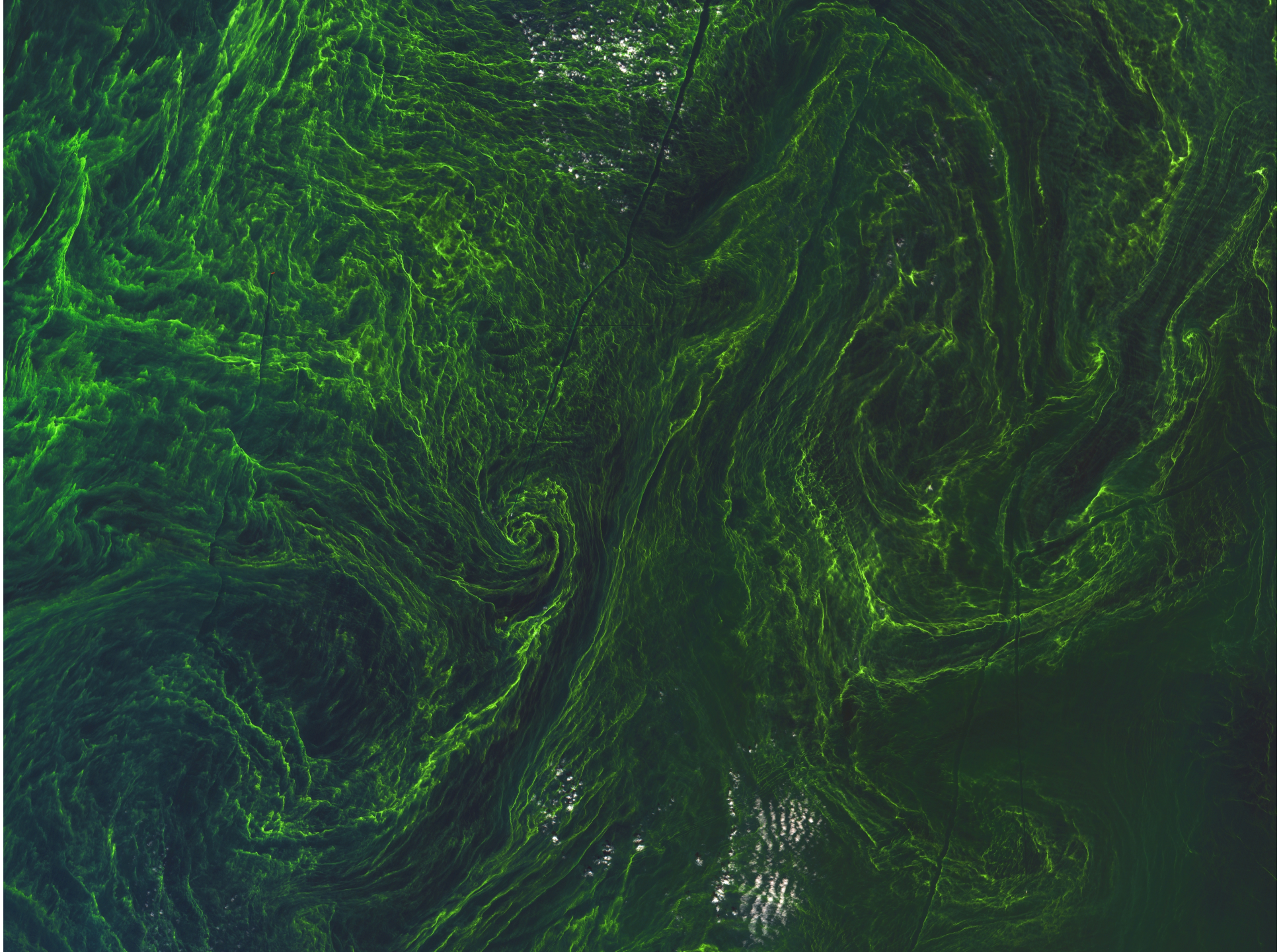
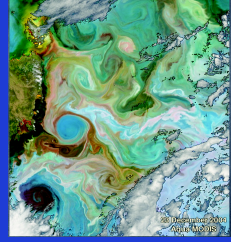


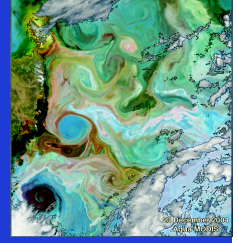


Less than two decades ago, sub-mesoscale structures were thought to have no dynamical impact and were usually parameterized as a dissipation of kinetic energy.

The new vision that emerges 10 to 15 years ago:

Sub-mesoscale structures (mostly fronts) capture most of the vertical velocity field in the upper ocean,

which implies they are associated with energetic 3-D dynamics and can be a source of kinetic energy.



What do we know so far :

The new vision that emerges 10 to 15 years ago:

Sub-mesoscale structures (mostly fronts) capture most of

the vertical velocity field in the upper ocean,

which implies submesoscales are associated with energetic 3-D dynamics.

Some consequences:

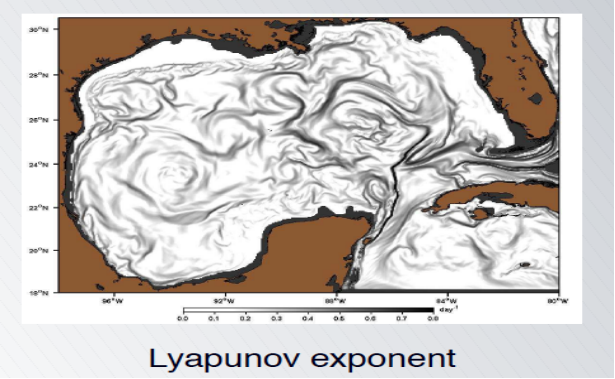
Sub-mesoscales strongly impact:

- **the 3-D dispersion of any tracers or pollutants (Carthe, Haza et al'14, Sinha'18)**
- **the vertical heat fluxes down to 500 m (Su et al.'18)**
- **the vertical buoyancy fluxes: acting as a source of KE (Sasaki et al.'14, …)**
- **the bio-diversity (Perruche et al'10, Levy et al.'14, 16)**

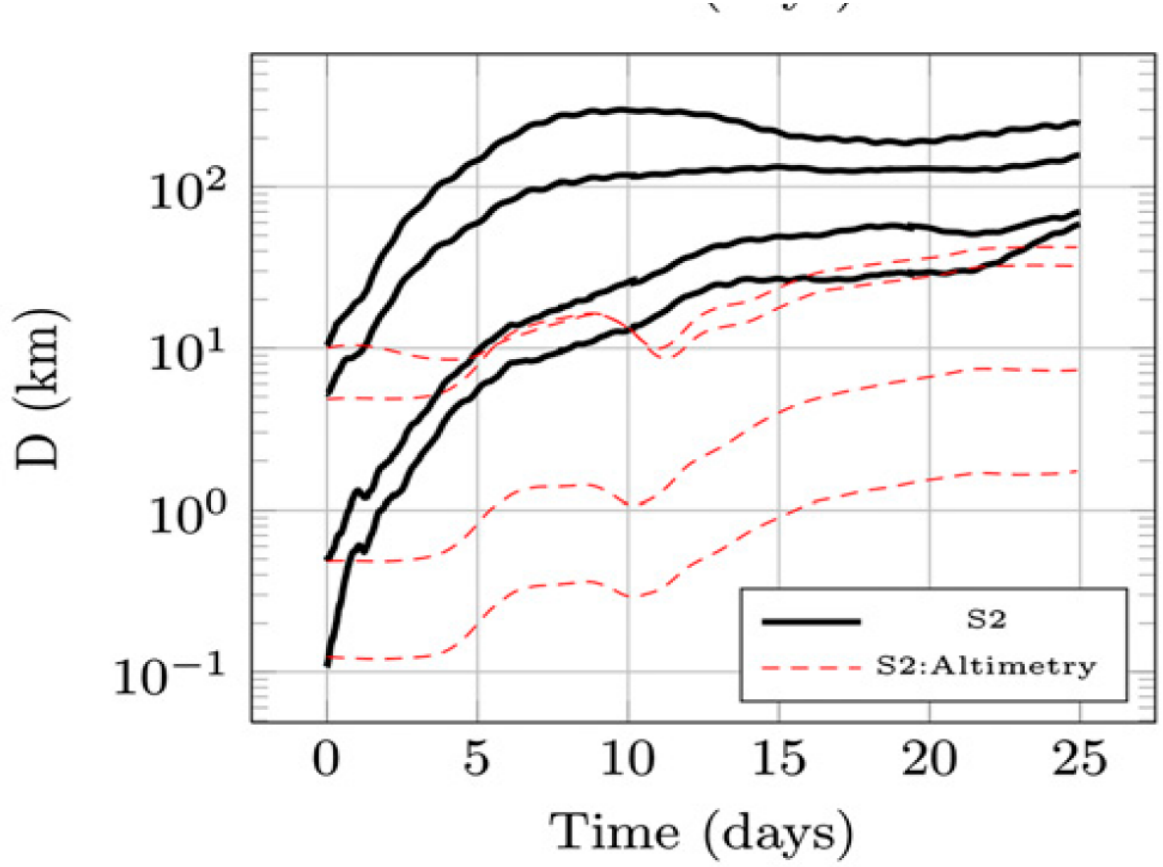
Dispersion by submesoscales in the Gulf of Mexico

Separation distance of a particle pair, D(t), estimated

- using HR data from 300 drifters (**black curves**): submesoscales are taken into account;
- using LR AVISO data (**red**): submesoscales are NOT taken into account.

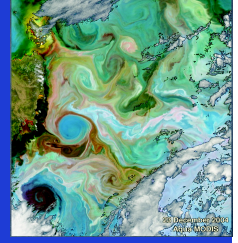


Lyapunov exponent



- Dispersion is 10-100 times larger when submesoscales are taken into account !

(from Poje et al.'14)



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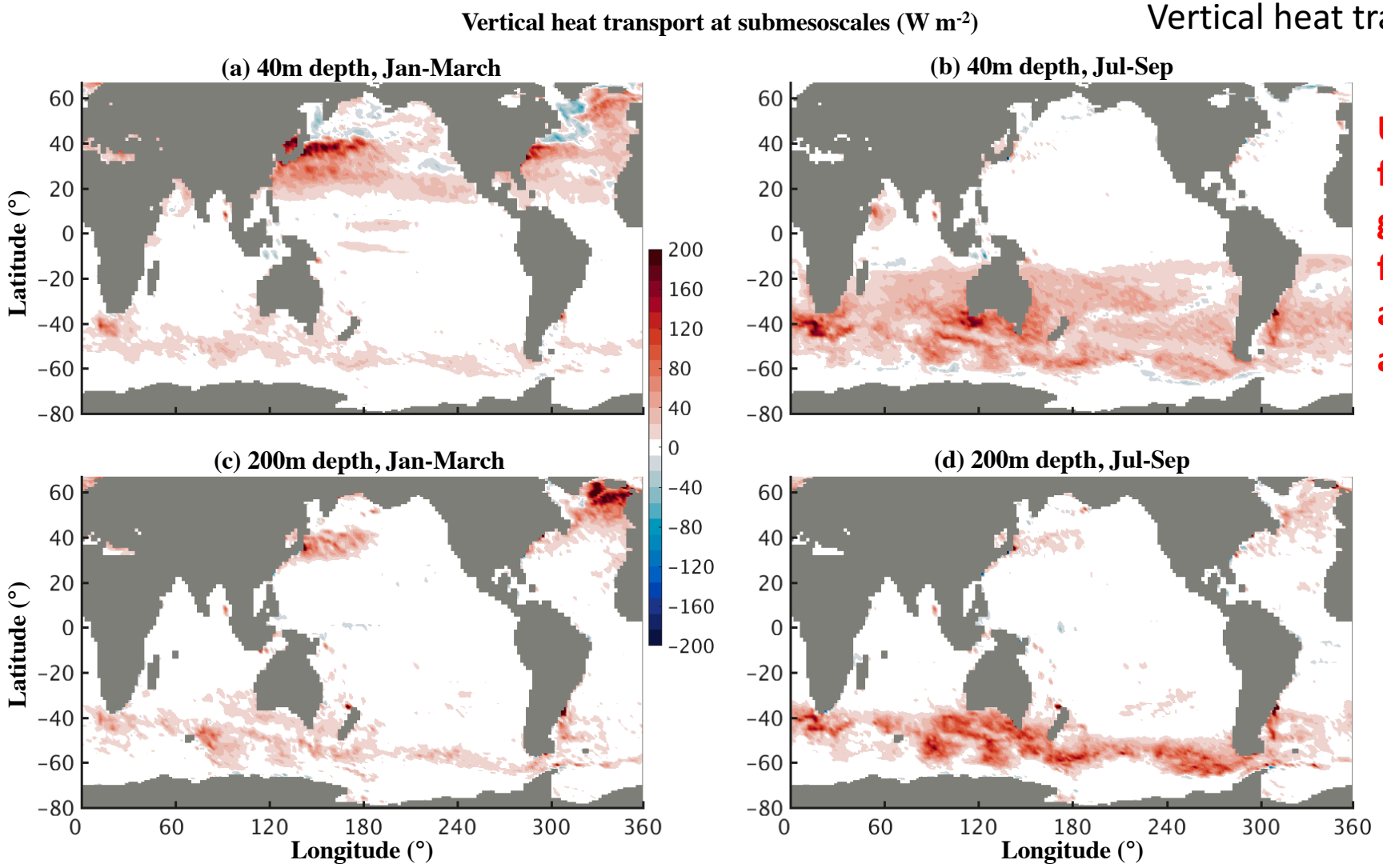
Strong impact of submesoscales on the (upward) vertical heat fluxes: up to 100-200 W/m^2 --> air-sea interactions



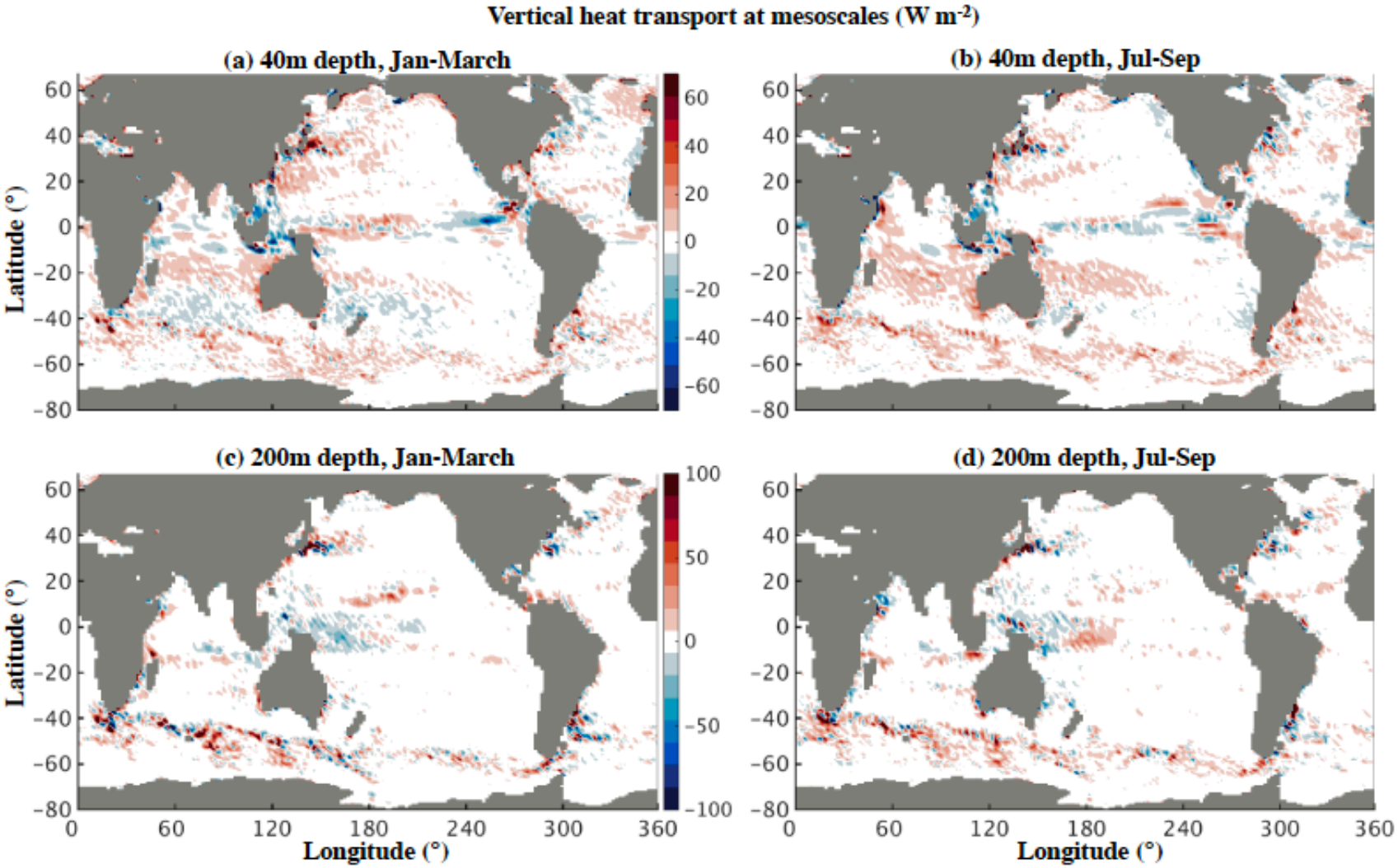
Vertical heat transport at submesoscales

Up-gradient vertical heat fluxes and not down-gradient vertical heat fluxes (Fox-Kemper et al.'08, '11; Thompson et al.'16)

Su et al. Nature Comm., 2018.

Global maps of the vertical heat transport in the **submesoscale band [2 – 50 km]** (W/m^2). **20-200 W/m^2.**

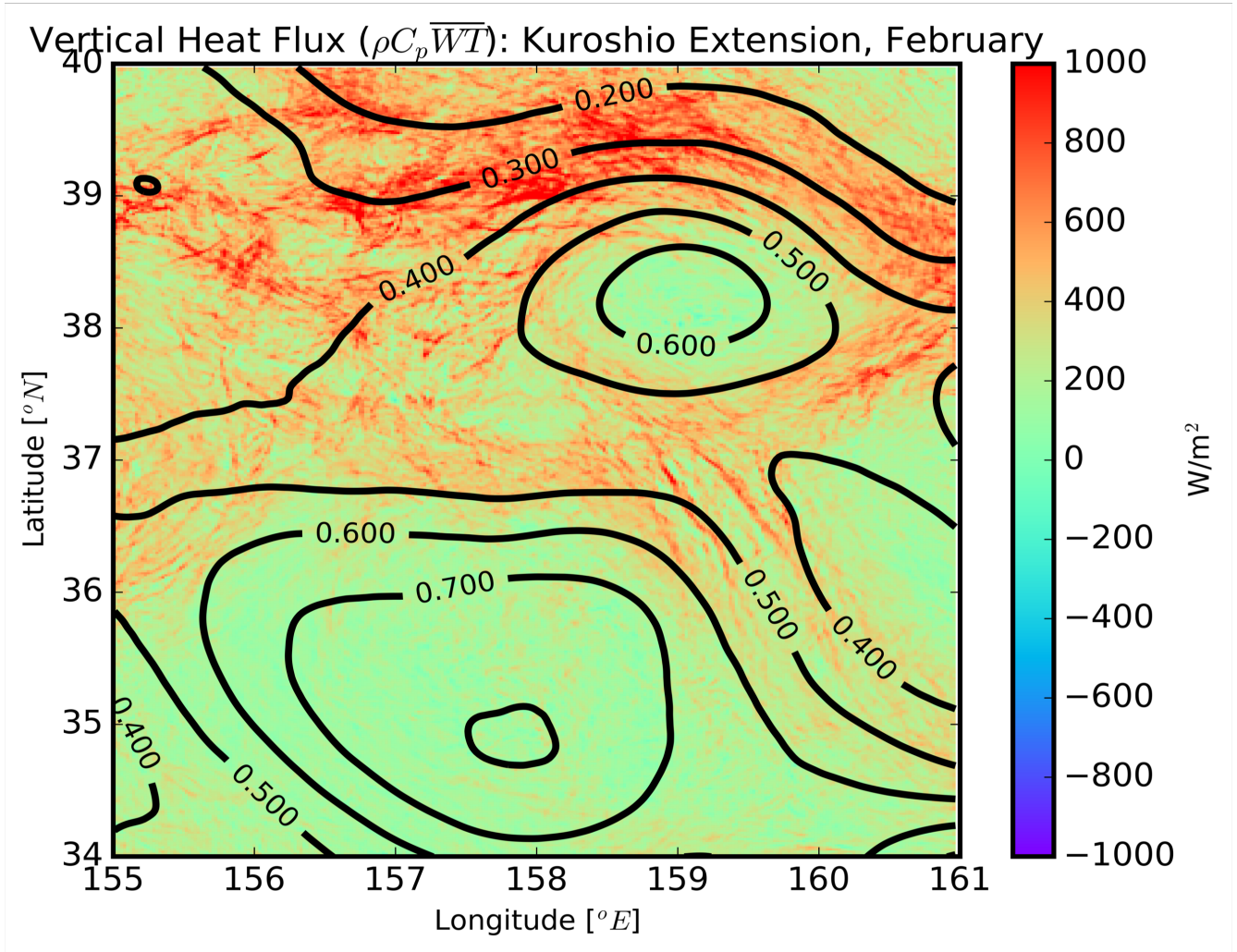
Mesoscale eddies have a weak impact on the vertical heat fluxes



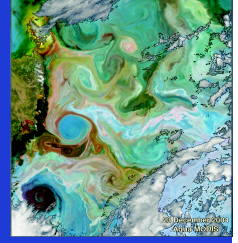
3 times smaller than the submesoscale part!

Su et al. 2018, Nature Comm.,

Global maps of the vertical heat fluxes in the **mesoscale band [50 – 100 km]** (W/m^2).



Su et al. 2018, In prep.



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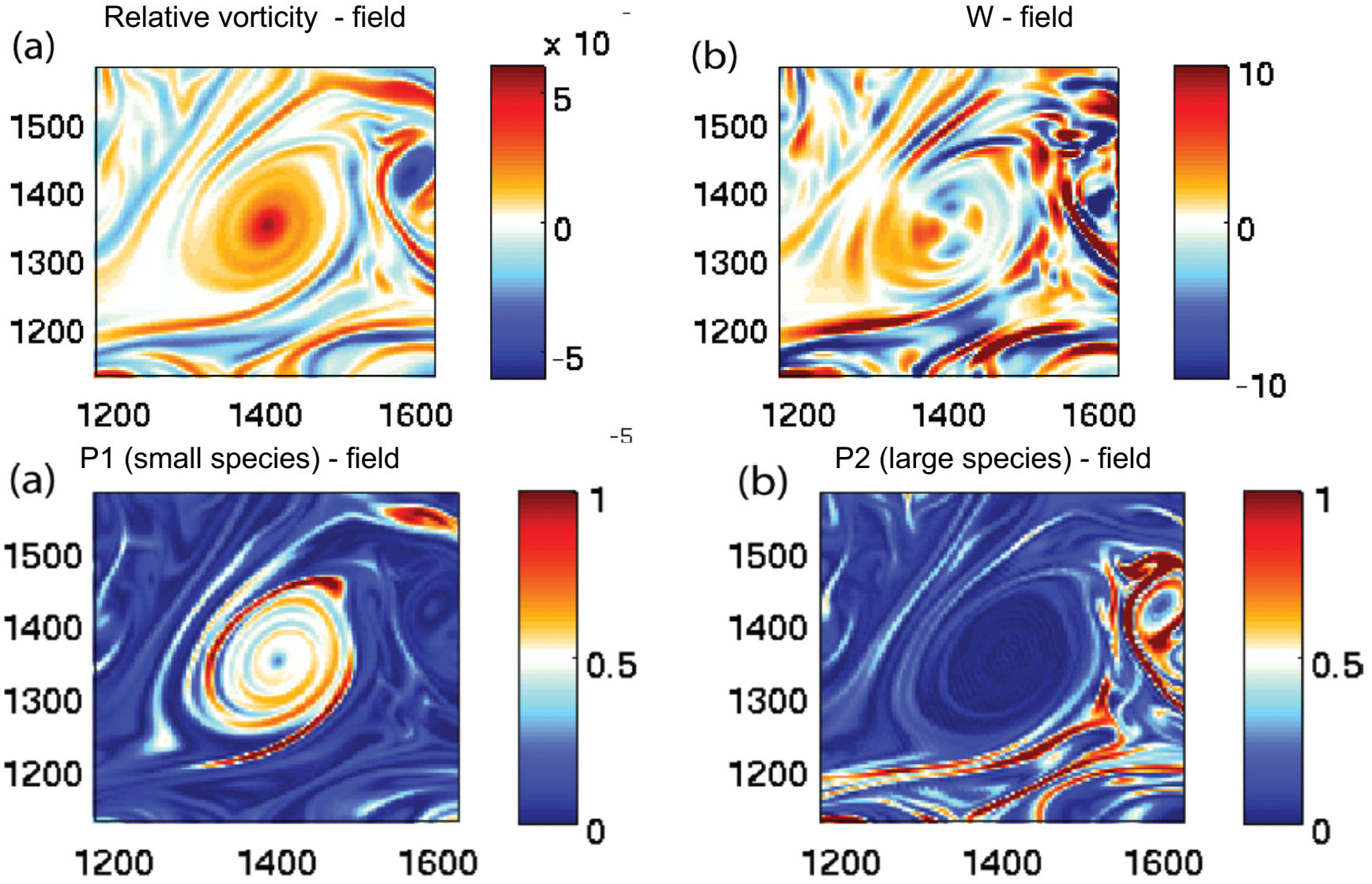
- **the bio-diversity (Perruche et al'10, Levy et al.'14, 16)**

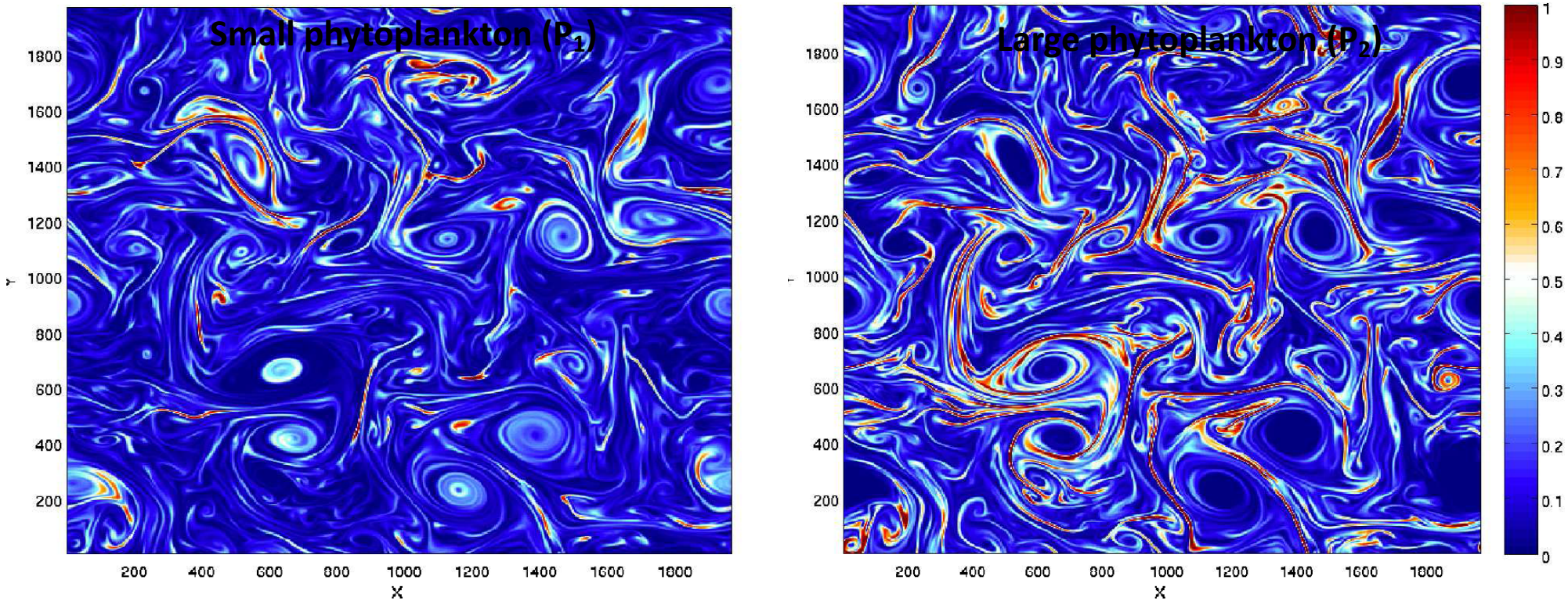
Mesoscale eddies and **sub-mesoscales organize the biodiversity**

Mesoscale eddies (100-200 km) and submesoscales (1-10 km) are ecological niches that shelter DIFFERENT phytoplankton species: (Perruche et al.'11, Levy et al. 2014, 2016)



Meso/submesoscale turbulence organize the biodiversity

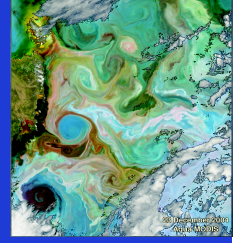
(Perruche et al. JMR 2011)



. 65% of the biomass is inside filaments

. Competition : P_1 : inside eddies P_2 : inside filaments

Impact on the biodiversity confirmed by Levy et al.'14 using 100 species



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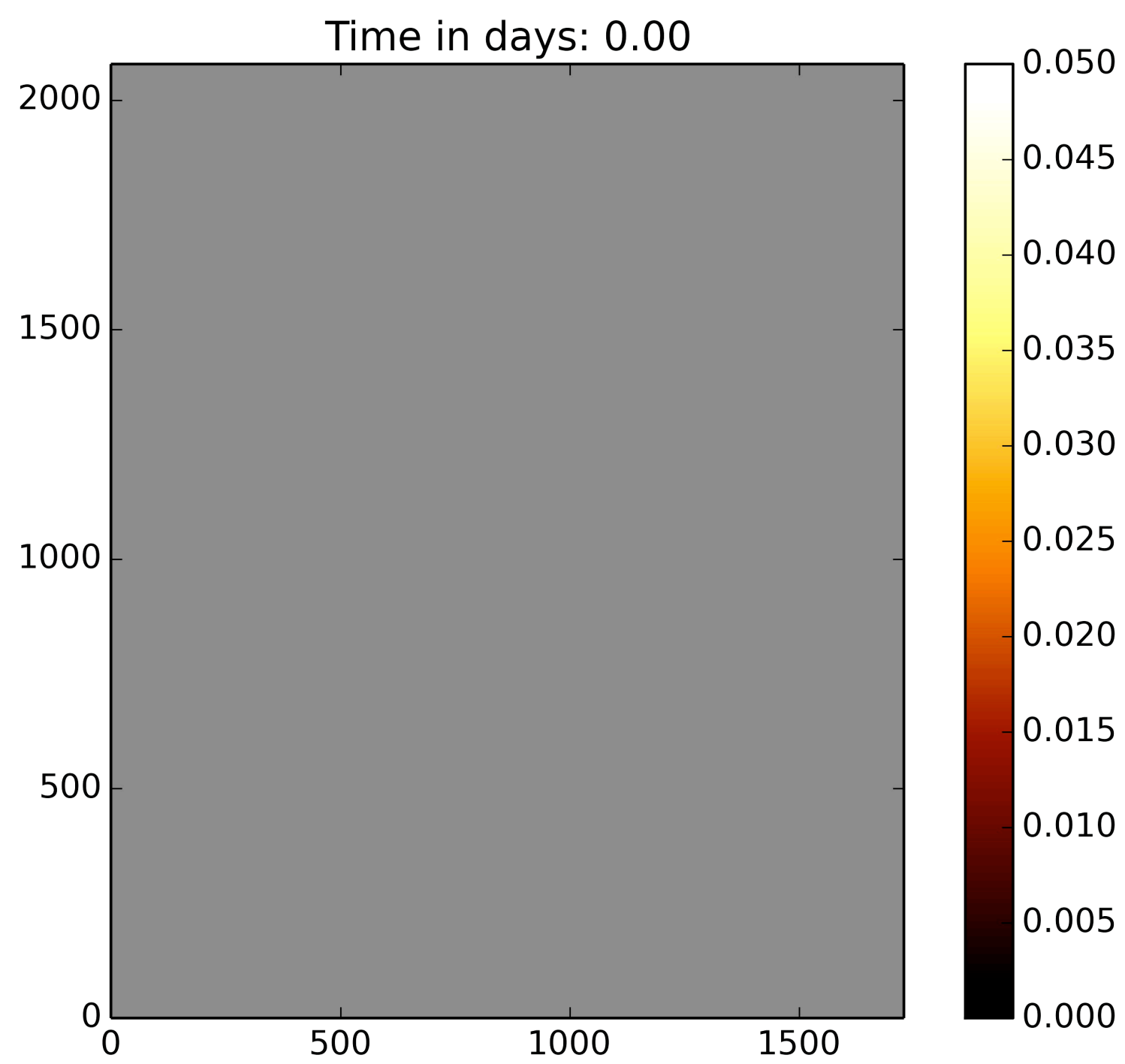
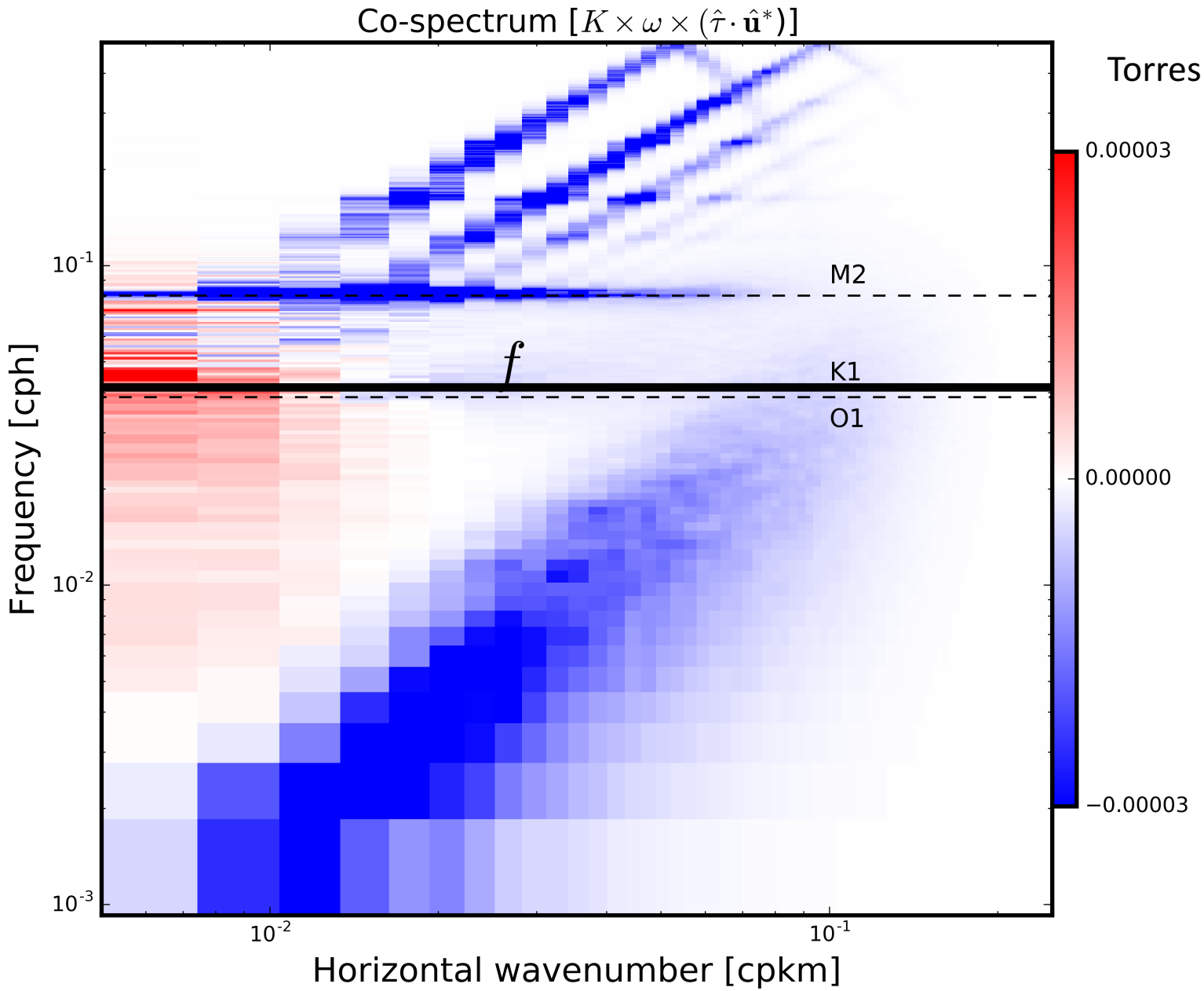
- **the air-sea interactions**



Torres et al. 2018 In prep.

How do the windstress curl and divergence (driven by submesoscales) impact the air-sea heat fluxes and clouds?



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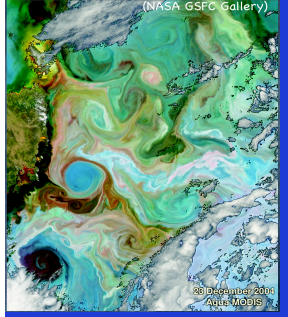
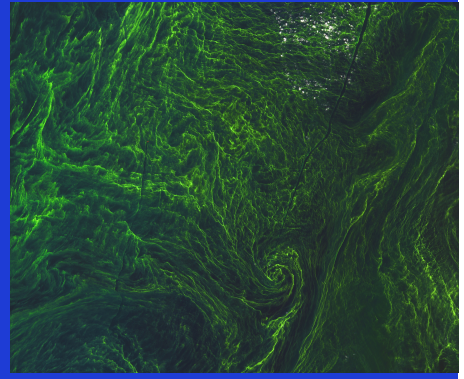




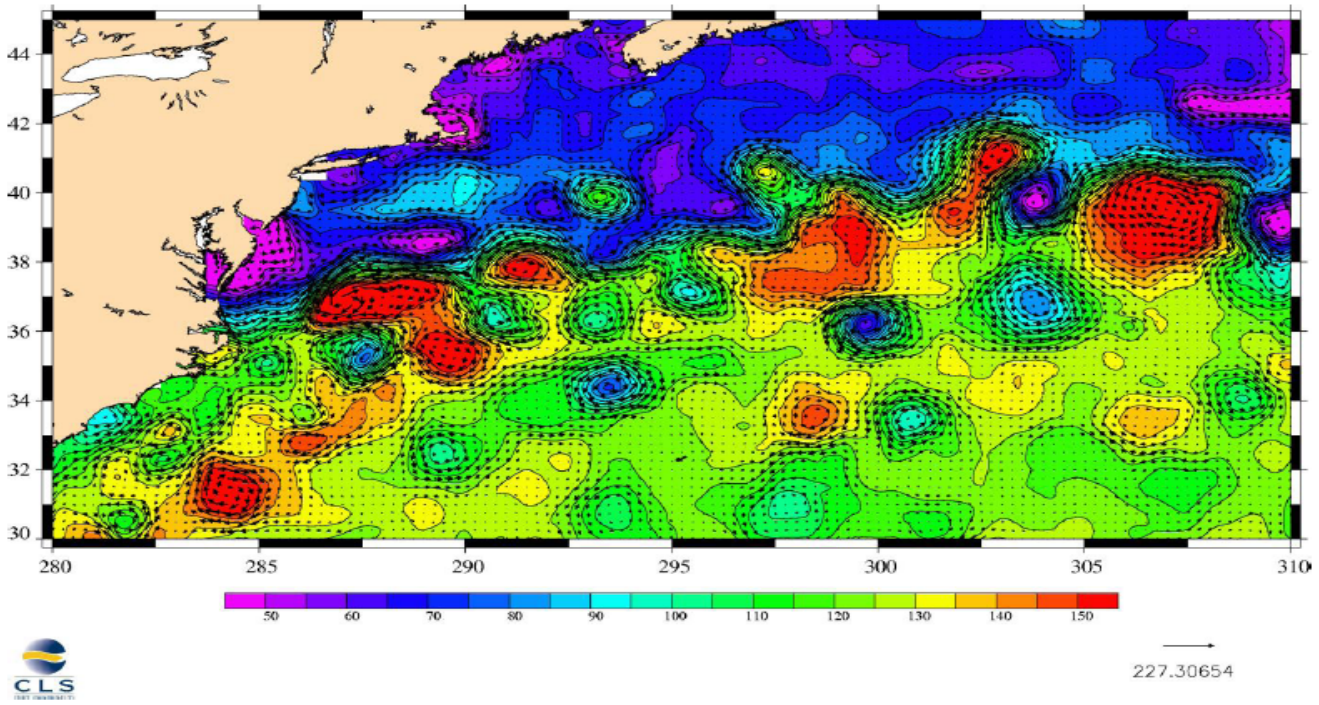
Can we infer sub-mesoscale 3-D dynamics (W included) from satellite observations?

Some methods based on dynamical framework,such as the SQG paradigm using these images are promising but they have to take into account some main issues:

- **In winter, SST and Ocean Color images with HR are affected by clouds, in particular in highly energetic regions.**
- **In summer, SST and Ocean Color images with HR are affected by the air-sea fluxes.**
- **SSS images are not affected by the air-sea fluxes but have a LR.**
- **SAR images are scarce and provide informations only with moderate winds.**
- **AMSR (microwave) SST images are not affected by clouds but have a LR.**
- **Surface currents from conventional satellite altimeter have a low resolution (100 km)**

Conventional satellite altimetry (Sea Surface Height or SSH) allows to estimate the surface currents using the geostrophic approximation (balance between the SSH gradients and the Coriolis forces)

But the spatial resolution of the altimeter products (AVISO) is not better than 100-200 km



Future Satellite Instruments for Observations of Mesoscale to Submesoscale (10 - 40 km) Dynamics

1 – Surface Water and Ocean Topography Mission (SWOT: 2021)

- *SWOT will observe SSH across a swath of width 120 km with a 20 km nadir gap, a footprint of 1 km and a measurement error of 2.74 cm.*
- *SWOT will have an exact repeat orbit of 21 days.*
- ***SWOT is most limited by the sampling errors** (narrow swath and submesoscales evolving much within 21 days)*

2 – Winds and Currents Mission Concept (WaCM: NASA Decadal survey)

- *WaCM will observe surface winds and surface ocean velocity across a swath of width 1300 km with a 100 km nadir gap and a footprint size of 5 km. The expected measurements errors are 1.5 m/s for winds and 0.5 m/s (0.15 m/s?) for currents.*
- *WaCM will have an exact repeat orbit of 4 days.*
- ***WaCM is most limited by the measurement errors.***

Future Satellite Instruments for Observations of Mesoscale to Submesoscale Dynamics:

should be much affected by internal gravity waves

1 – Winds and Currents Mission Concept (WaCM: Decadal survey)

- *Internal gravity waves (not NIWs)) should affect surface currents as well. => need to improve dynamical methods based on the Helmholzt decomposition.*

2 – Surface Water and Ocean Topography Mission (SWOT: 2021)

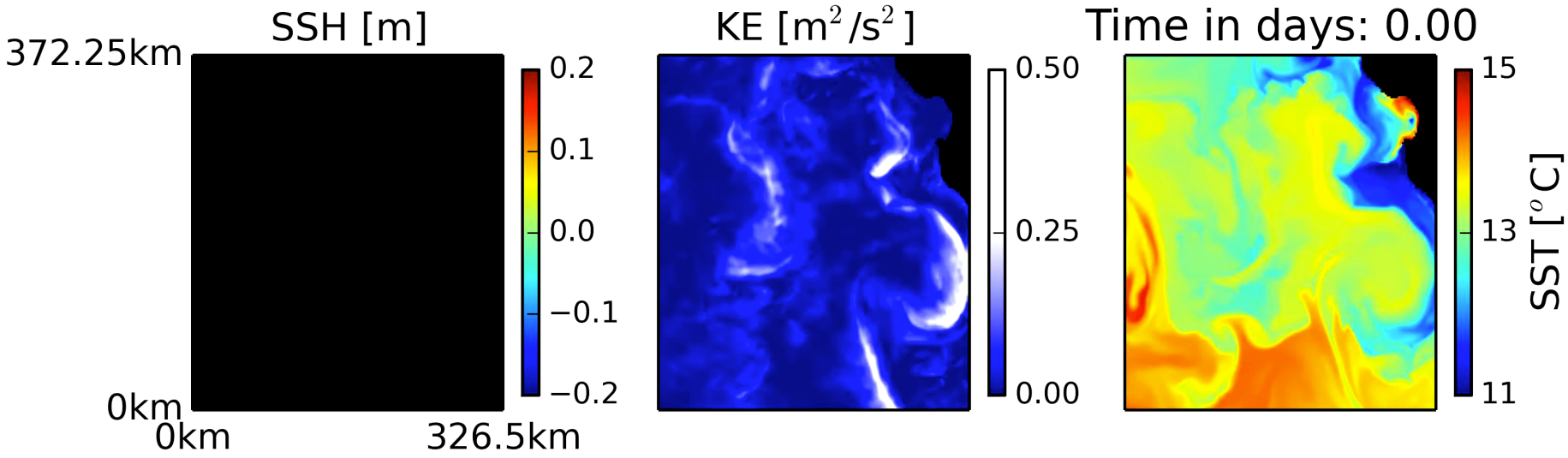
- *Internal gravity waves (not NIWs)) should affect SSH leading to a spectral slope discontinuity at scales from 20 km to 100 km (Qiu et al. 2017, Torres et al. 2018) => some hopes to discriminate balanced motions and IGWs.*

- *=> JINBO'S TALK!*

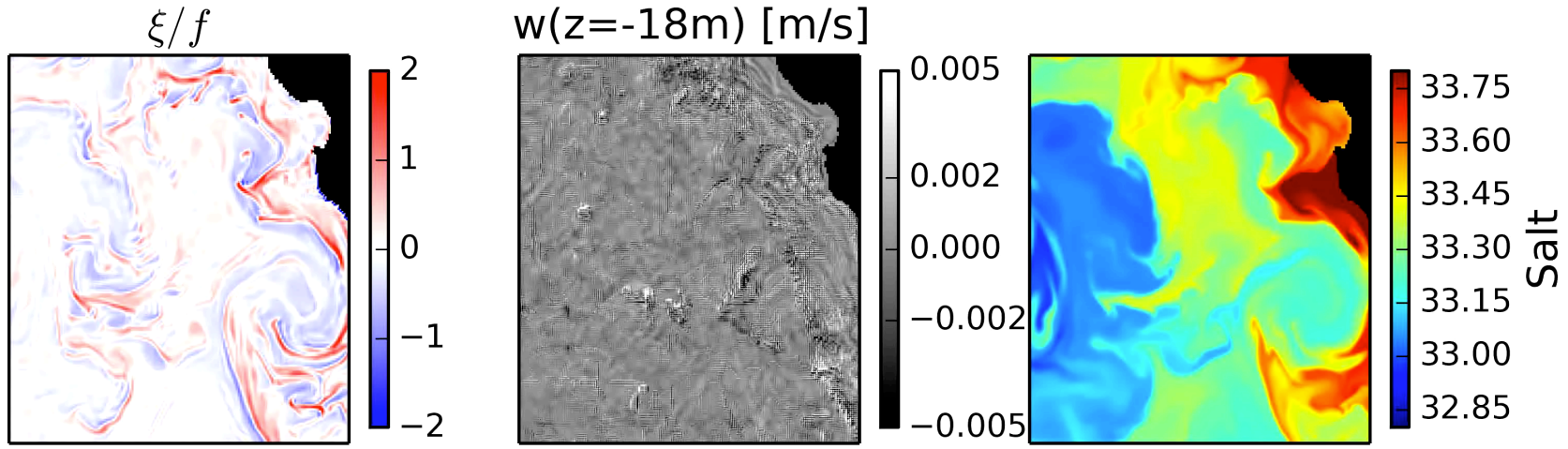
Signature of IGWs on satellite observations

(SSH, surface currents, SST, SSS, SAR images)

[Torres et al. 2017b]



TORRES ET AL.'18



How the meet the challenges related to all these issues

in order to diagnose the sub-mesoscale 3-D dynamics ?

One way is to exploit the synergy of using different satellite observations

by involving new methodologies based on a dynamical framework

Some earlier attemps:

- ***Dynamical interpolation method (Ubelmann et al.'14) new AVISO products;***

- ***Lagrangian + Stochastic methods (SSS, SST) (Dencausse et al.'15, Keating'13,'18);***

- ***Reconstruction of the 3-D dynamic (SQG paradigm) (Lapeyre et al.'06, Wang et al.'13);***

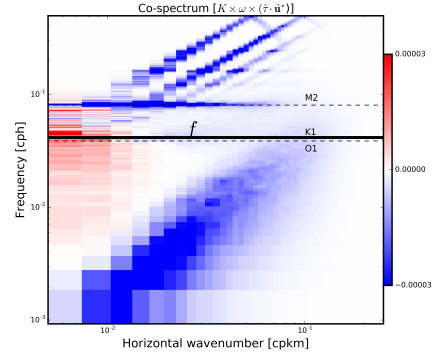
- ***Using SST and SSH to discriminate BMs and IGWs (Ponte et al.'13);***
- ***Scattering of internal tides by mesoscale eddies (Dunphy et al.'17,Kelly et al.'18);***
- ***…***

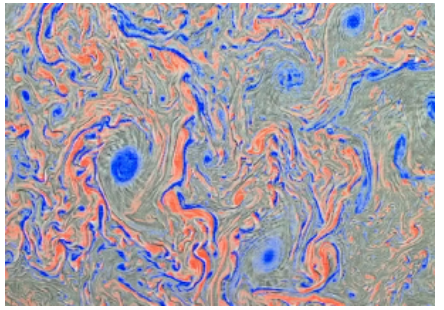
- ***We need to improve these methodologies and develop new ones ….***

Homework for the three working groups in the context of NASA satellite missions:

Air-Sea interactions:

- Energy exchanges between Oceans and Atmosphere at submesoscale.



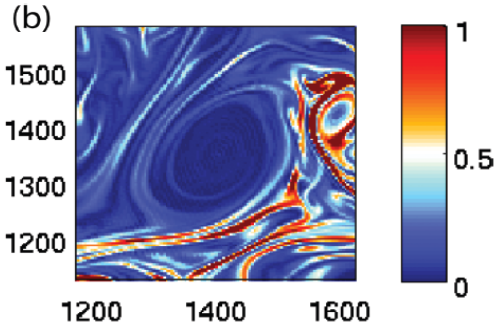


Dispersion and Mixing:

- Impact of submesoscales and IGWs.

Submesoscales:

- Impact on the ocean energy route and on the physical-biological interactions.



Thank you !