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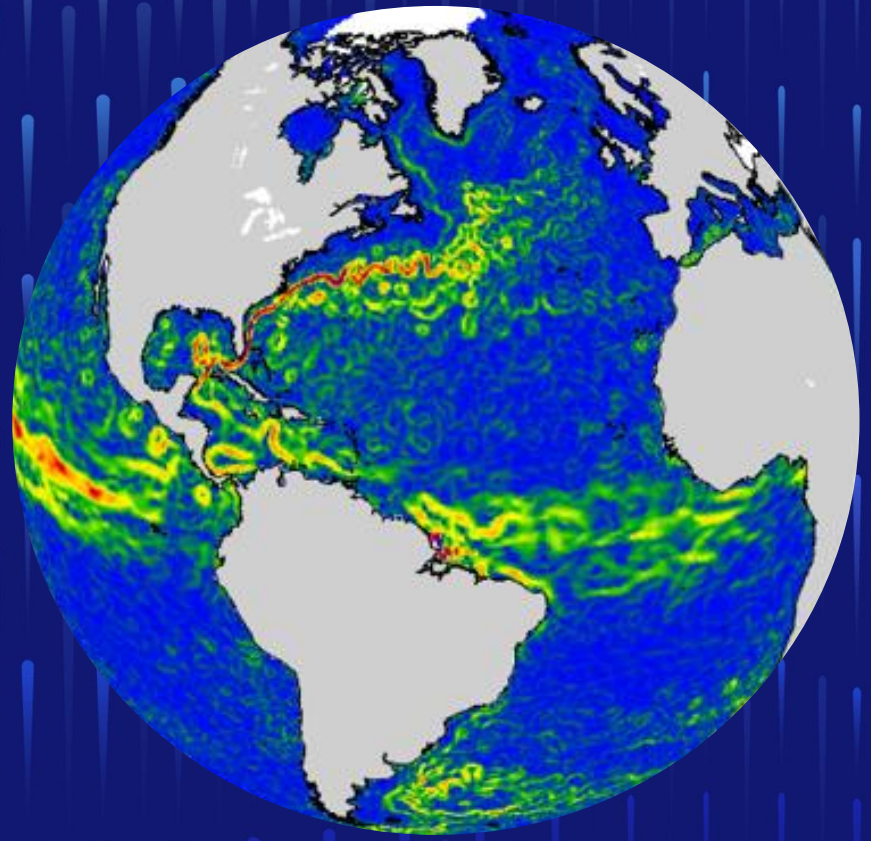
How to monitor the Ocean?



Ocean Currents

Marie-Helene Rio

ESA-ESRIN

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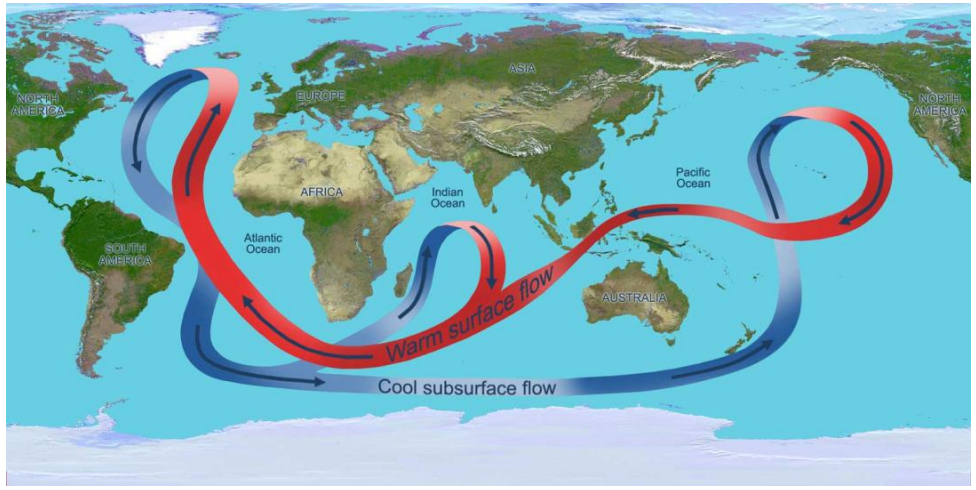
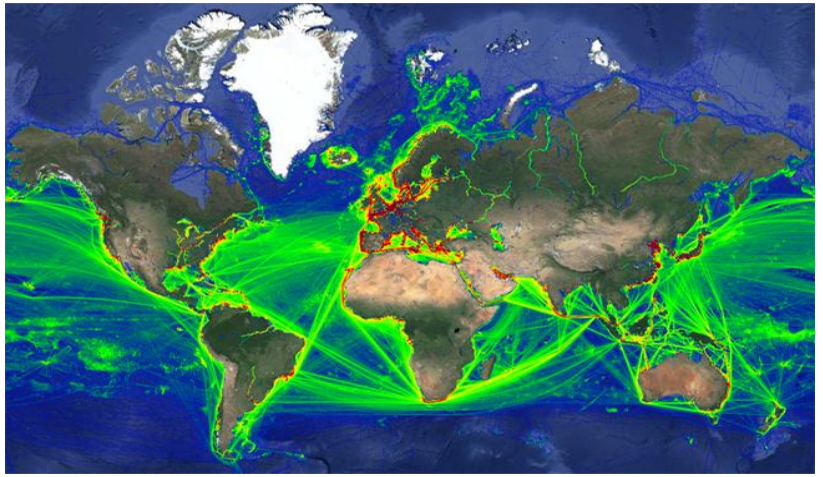
Why do we care?

- ✓ **Ocean currents influence the world climate and weather**



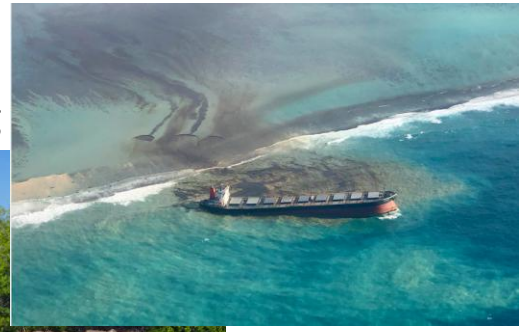
- ✓ **They are key for ocean navigation and transportation**



- ✓ **They transport material (both helpful and harmful) and energy to different regions and depths of the ocean**

- ✓ They support marine life by transporting vital nutrients between different marine ecosystems and serve as vital highways for marine species. By transporting nutrients, eggs, larvae across vast distances they ensure genetic diversity and population connectivity among marine ecosystems

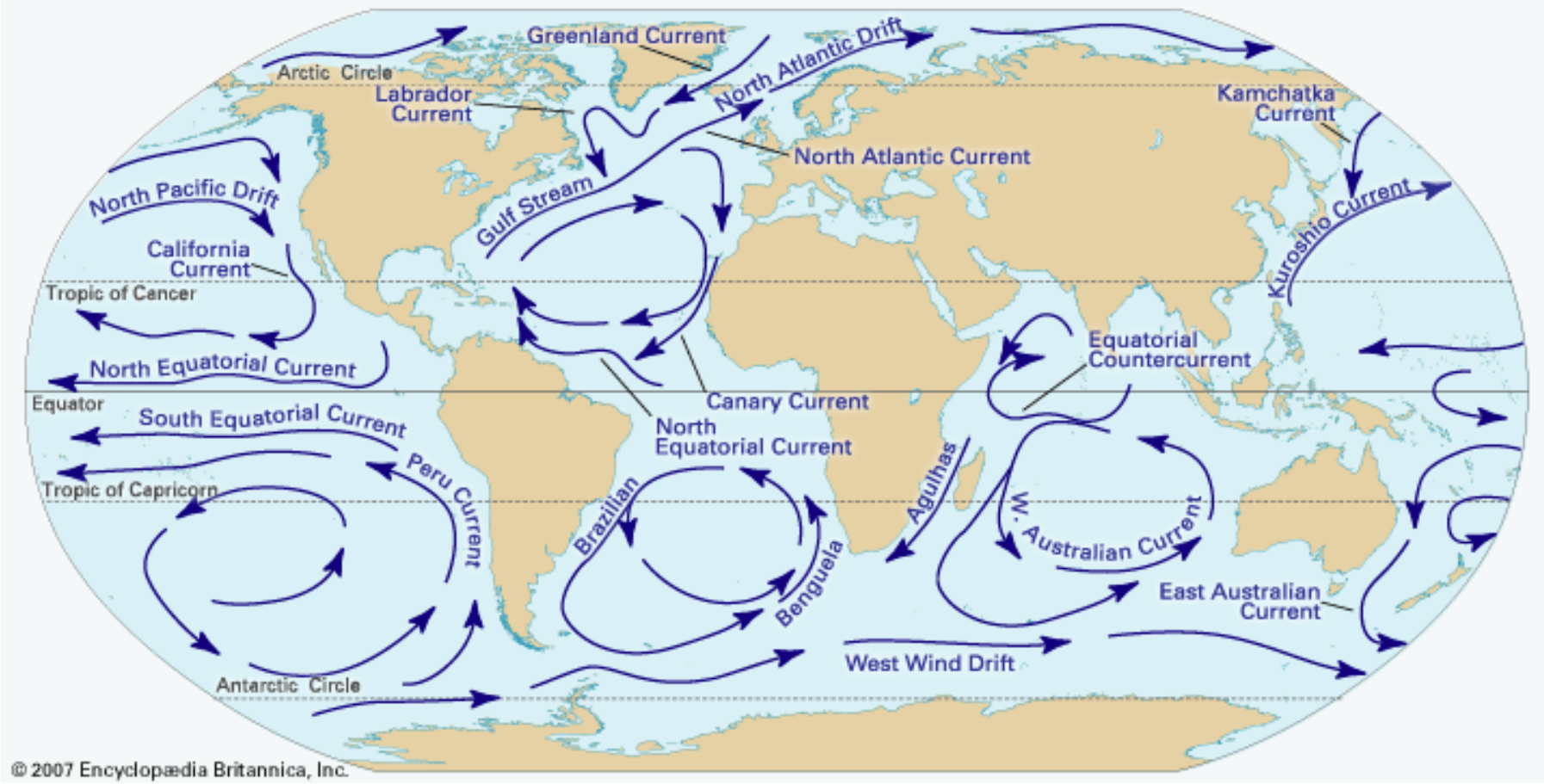
Oil spill



Sargassum beaching

Large scale ocean surface currents

This map of the Gulf Stream appears in the book by Benjamin Franklin and dates from 1769.



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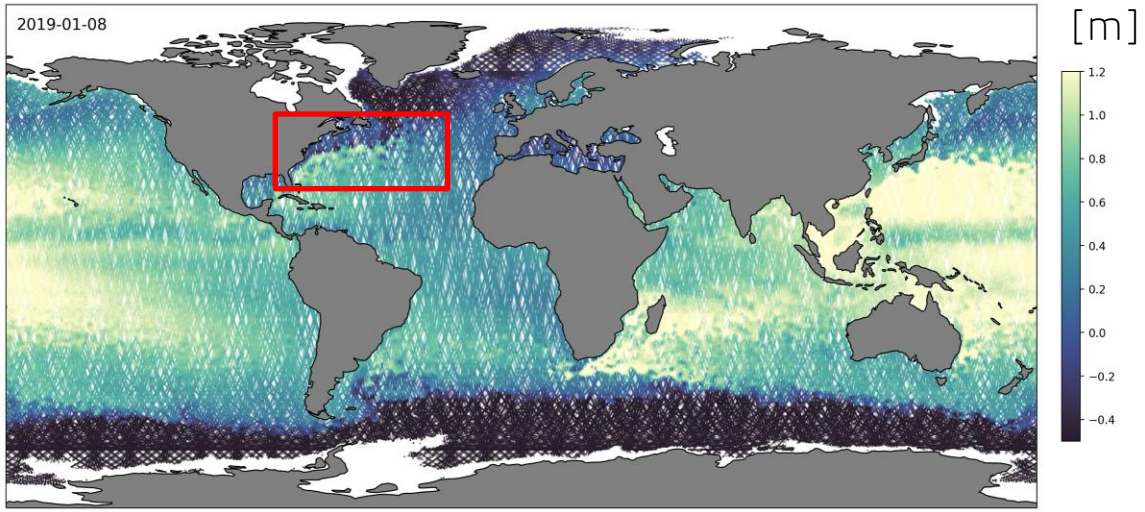
Altimeter-derived surface currents



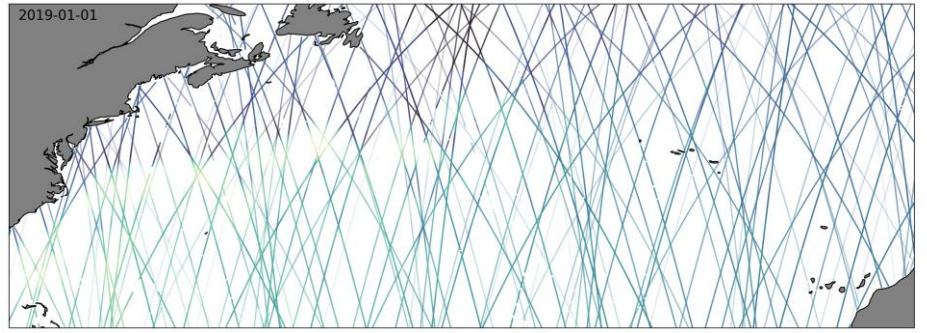
Gec

To a first approximation, o
currents can be inferred fr
the ocean surface topogra

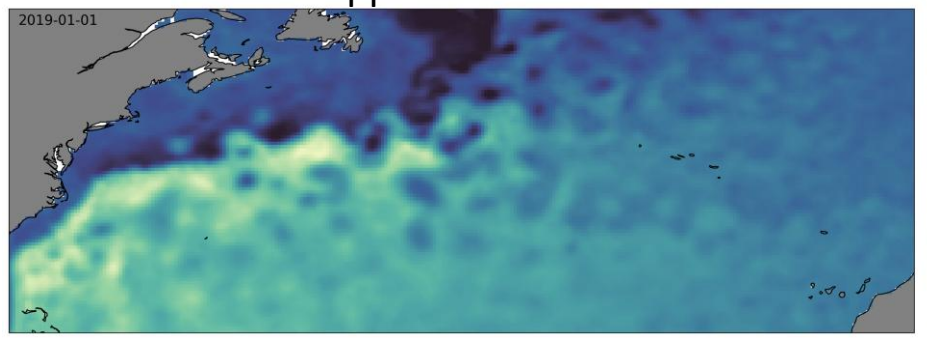
$$u_{GEO} = -\frac{g}{f}\frac{\partial h}{\partial y}$$

$$v_{GEO} = \frac{g}{f}\frac{\partial h}{\partial x}$$

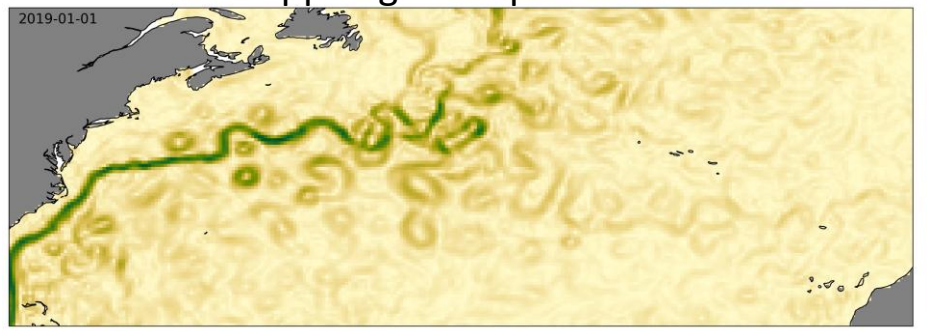
Along-track sea level



Mapped sea level

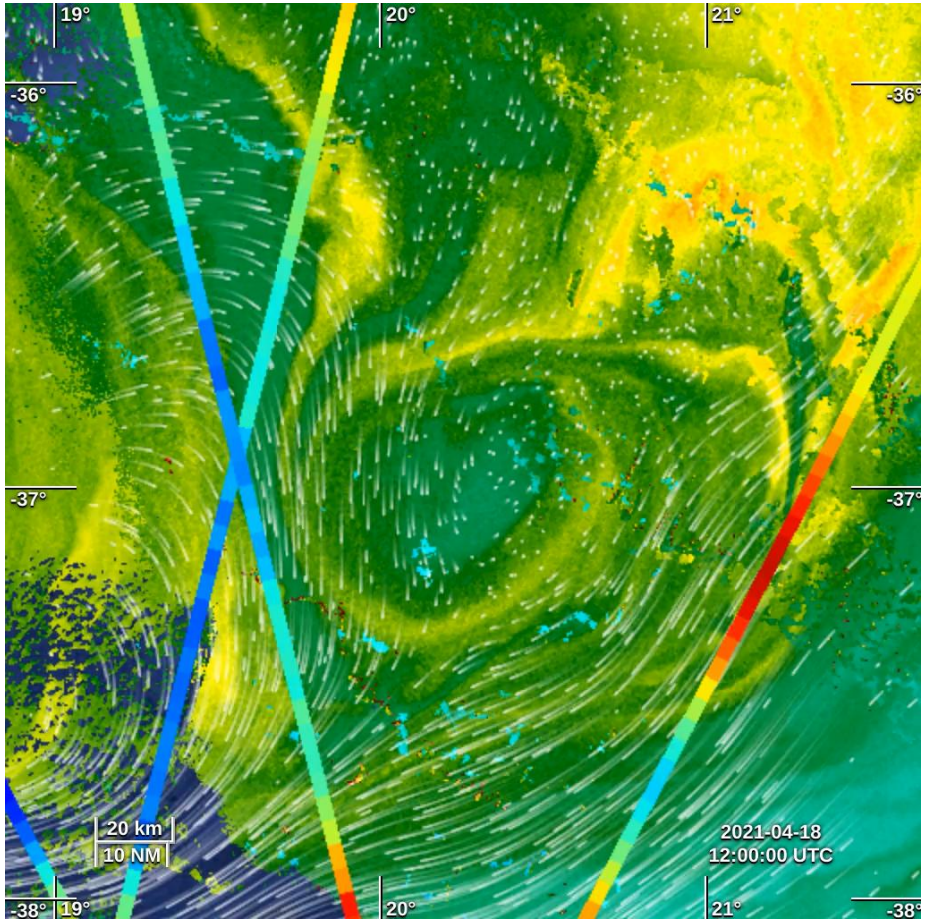


Mapped geostrophic currents

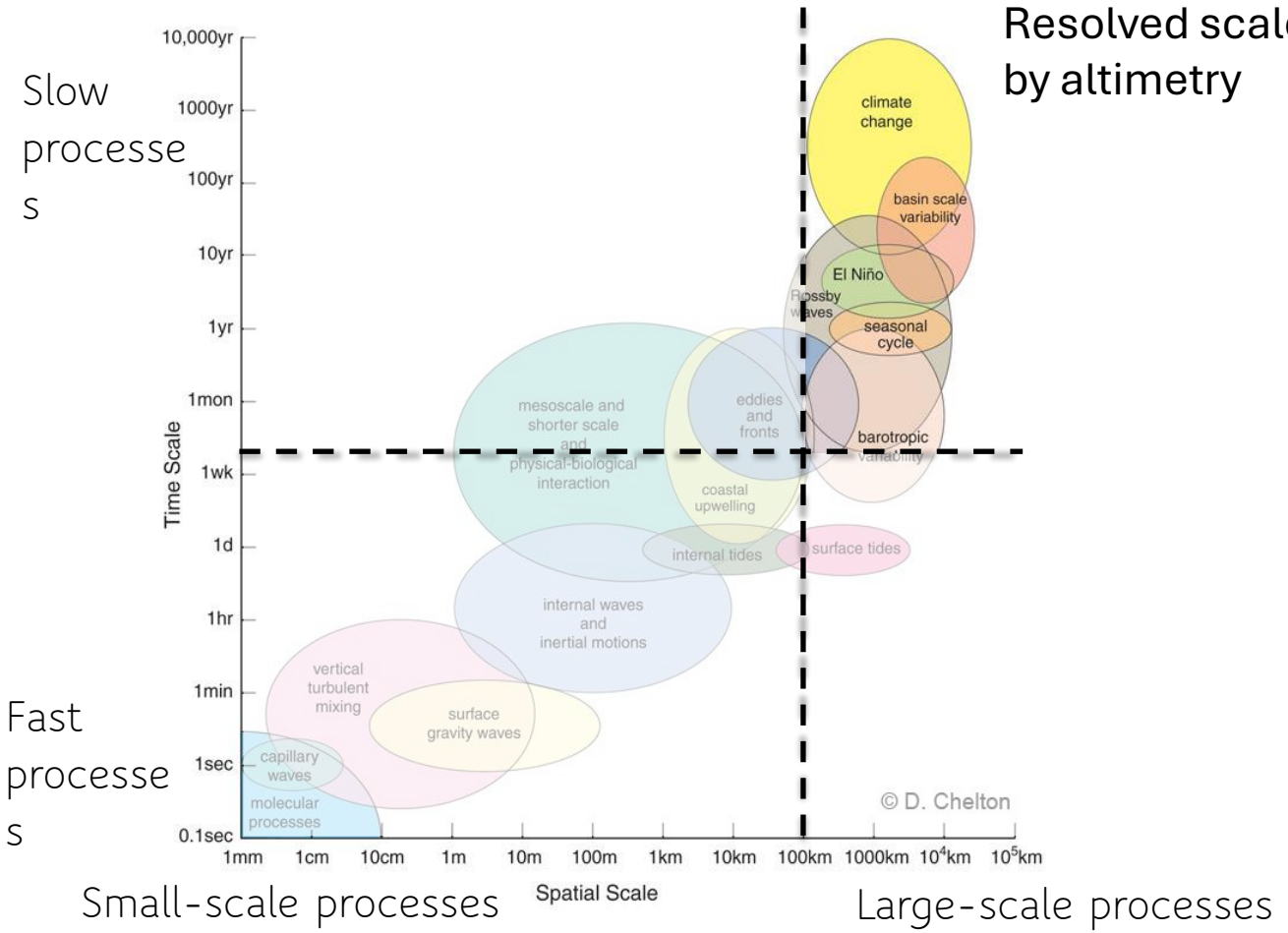


Courtesy: Florian Le Guillou

Limit of altimetry for resolving small scales



Background: High Resolution Infra-Red SST from Sentinel-3



Courtesy: Florian Le Guillou

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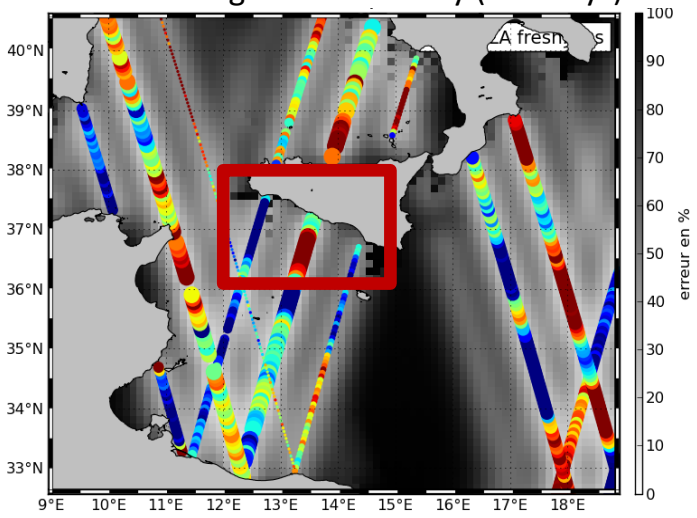
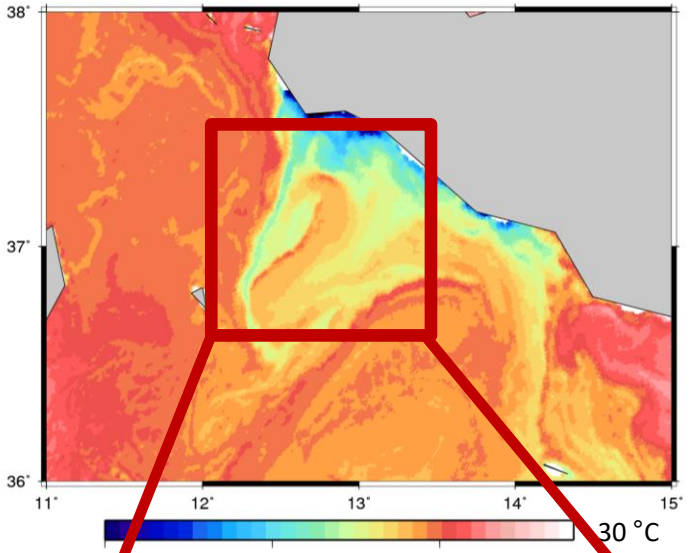
Merging altimetry and High Resolution Sea Surface Temperature

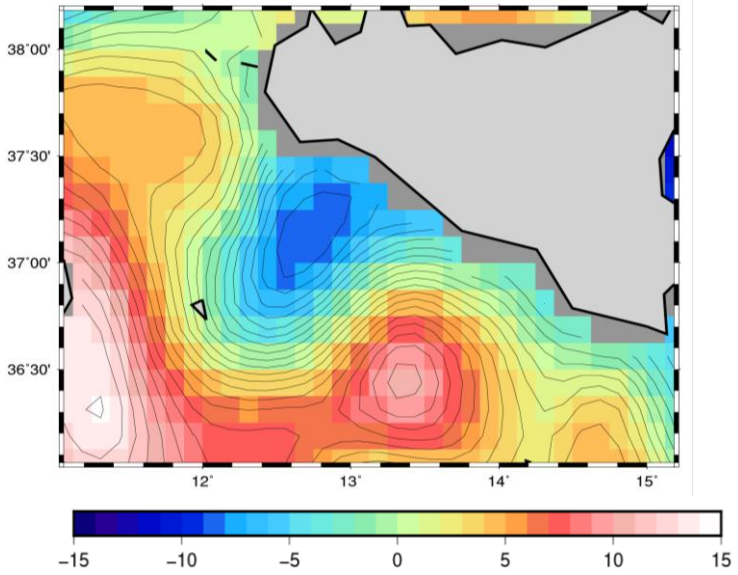
along-track altimetry (+- 5 days)



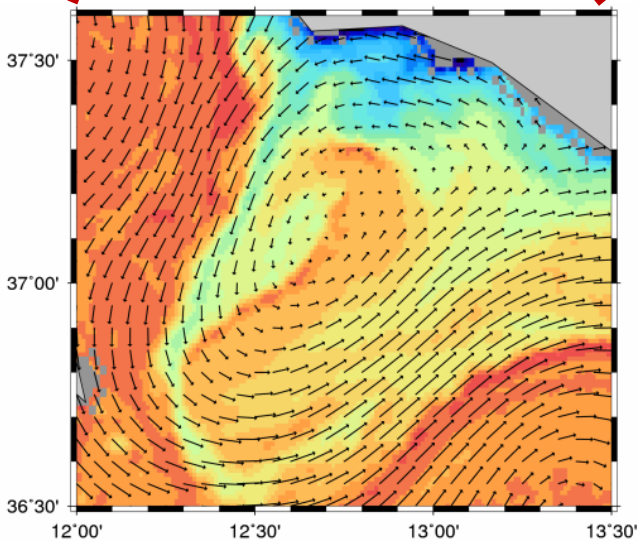
Sea Surface Temperature (S-3)



Interpolated map of sea level

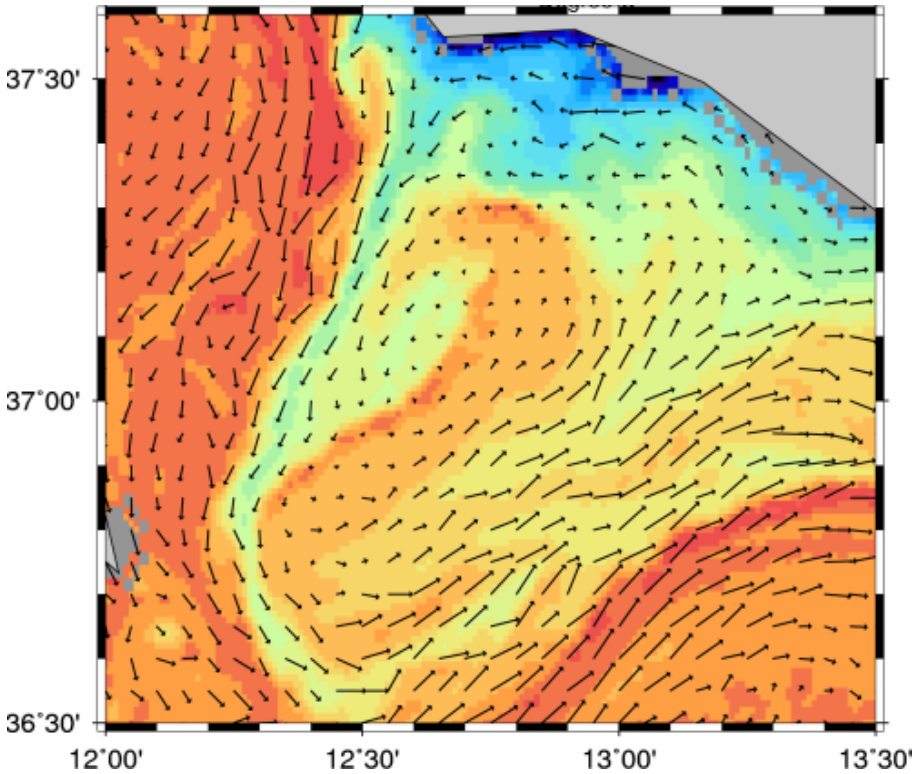


Altimeter derived velocities



July, 28th 2016

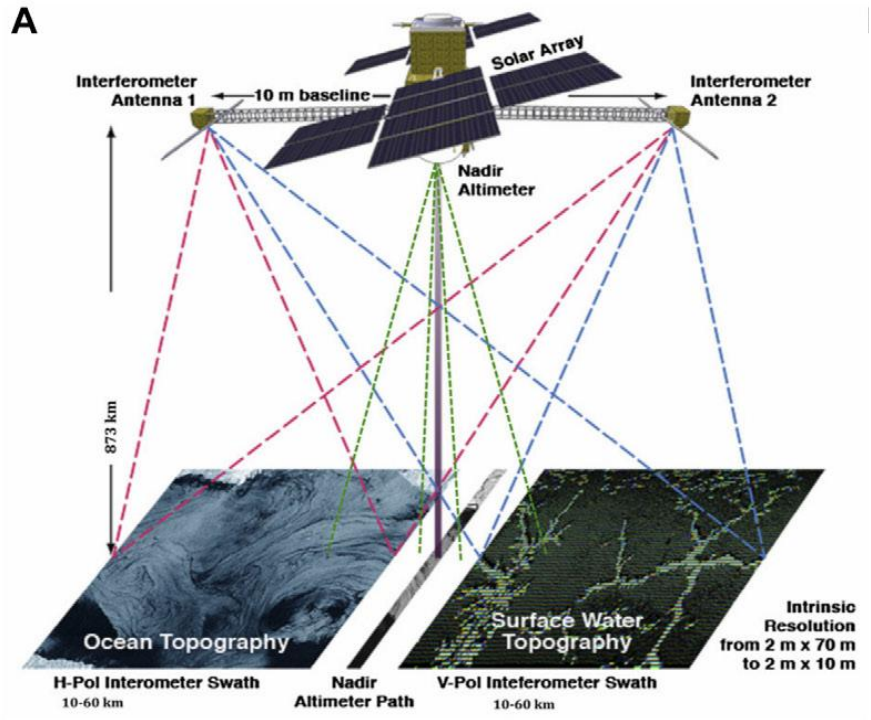
Altimeter + SST derived velocities



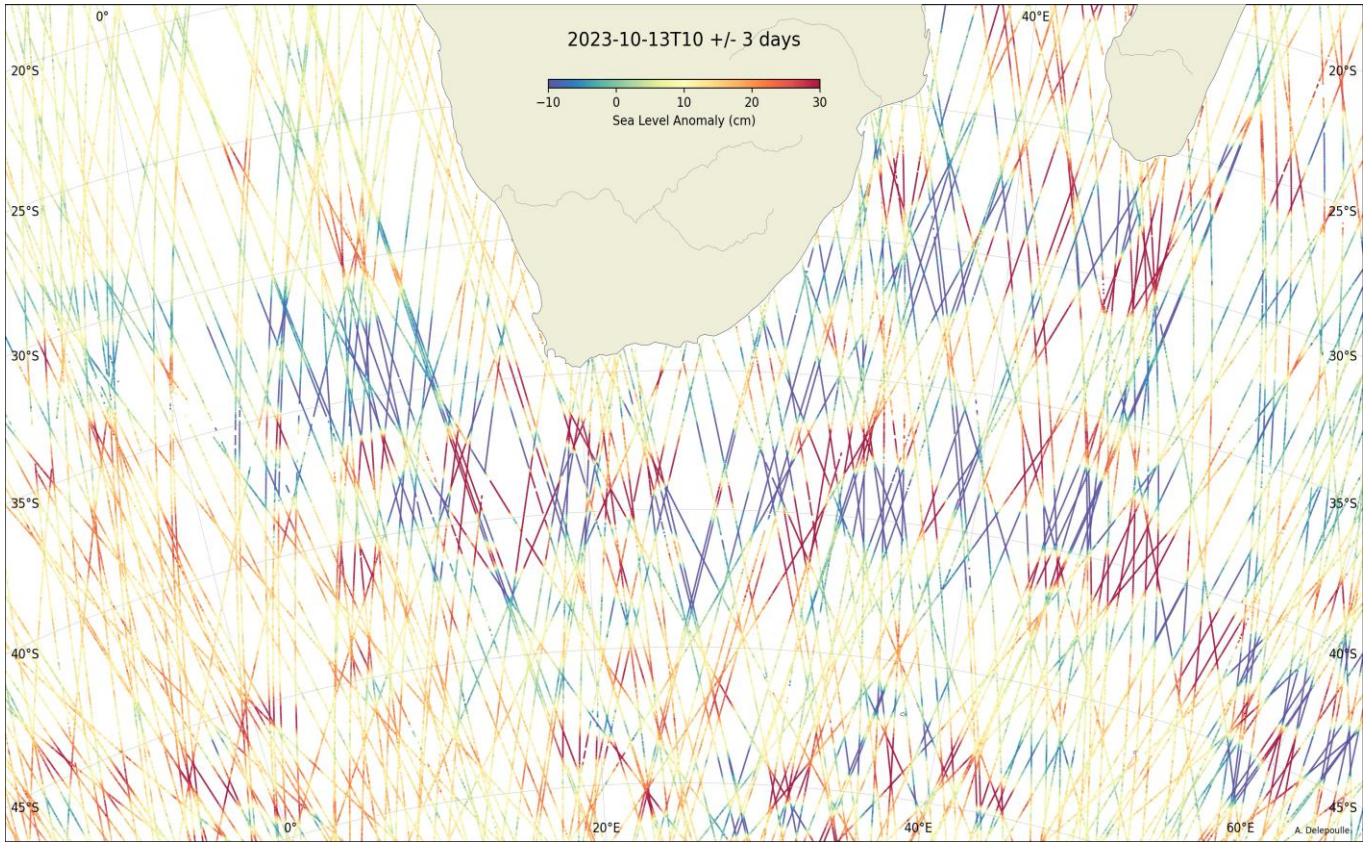
Rio et al, 2019

SWOT opens the way of high-resolution SSH maps

The Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, provides 2D observations of sea-surface height using SAR radar interferometric techniques. SSH is measured at a 15-30 kilometers resolution within a 120km swath.

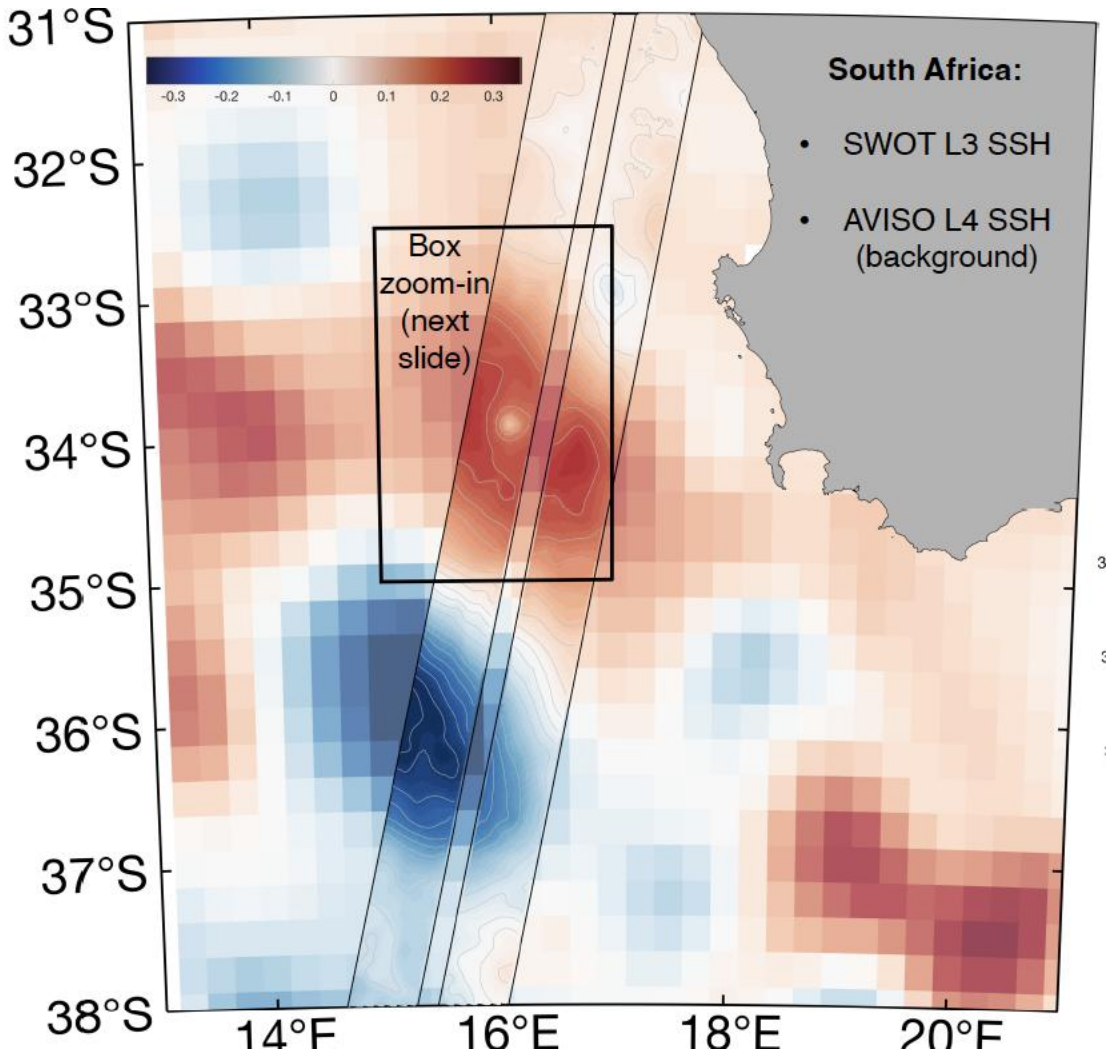


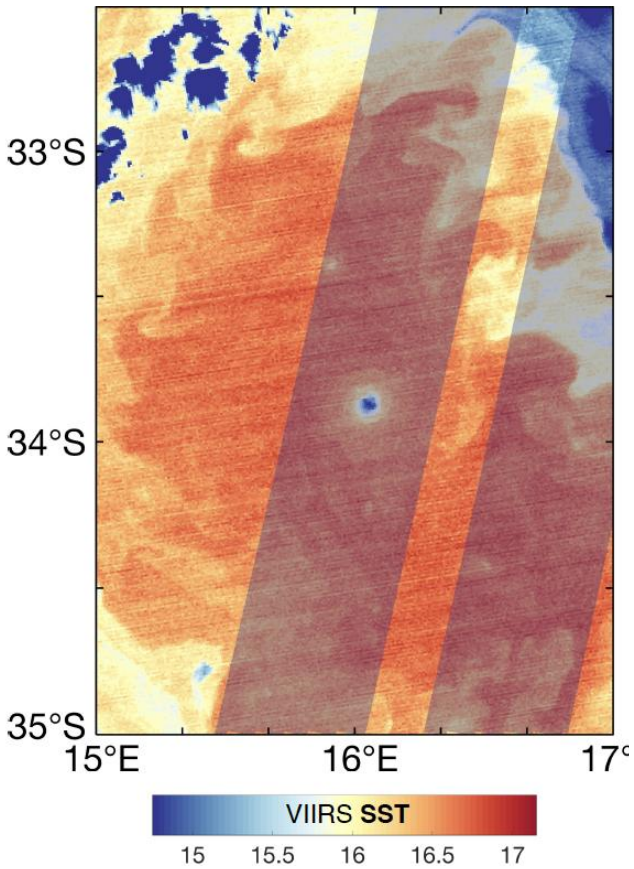
Morrow et al, 2019

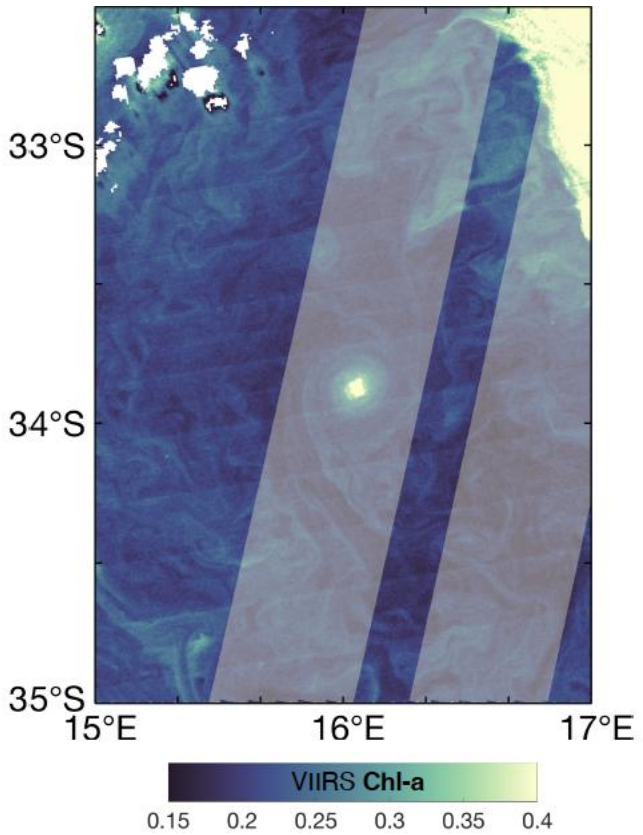


Courtesy: Florian Le Guillou

SWOT opens the way of high-resolution SSH maps





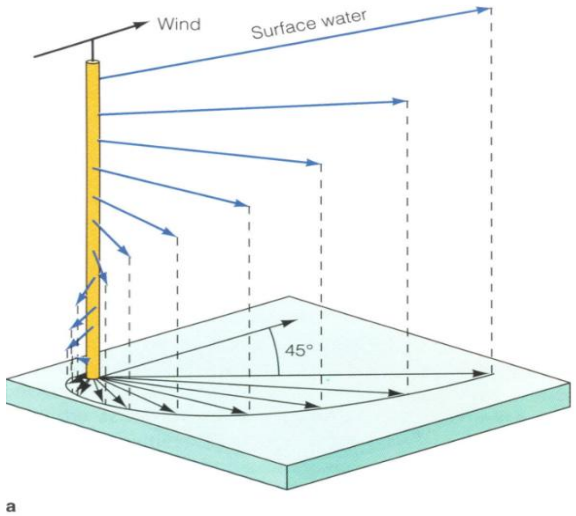


SWOT allows the observation of structures of size < 10km

Courtesy: Florian Le Guillou

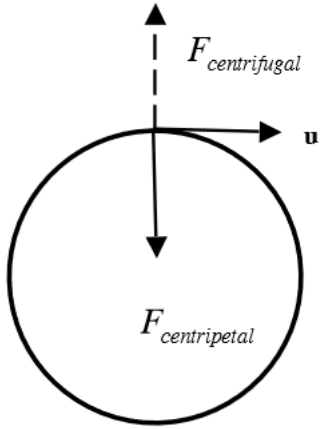
Beyond geostrophy

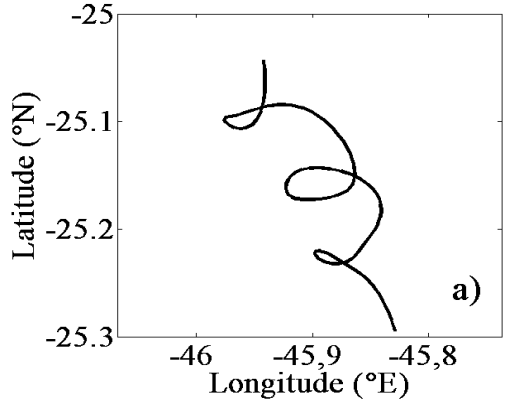
Wind-driven currents



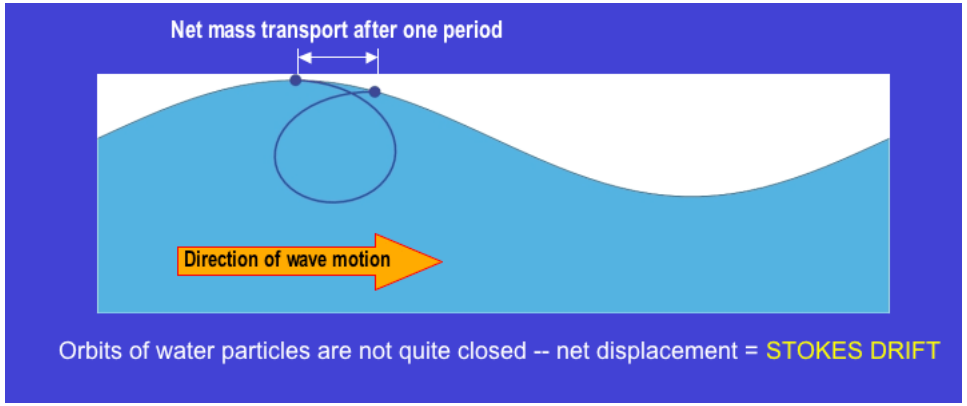
Ekman currents

Inertial Oscillations

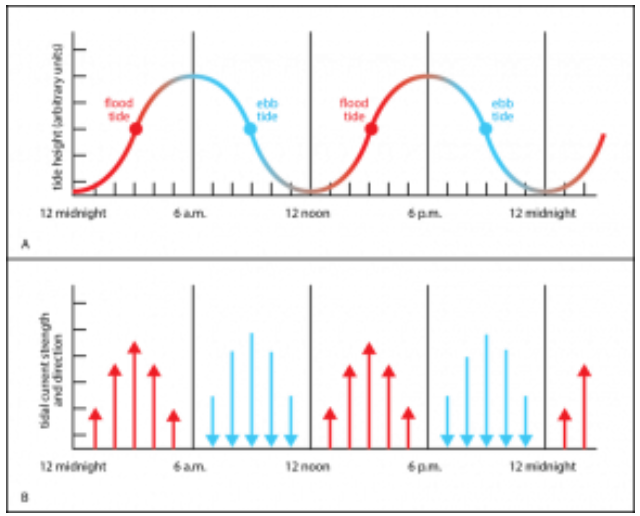




Stokes drift



Tidal currents



Tide height and tidal current change direction and strength throughout the day in one location. Longer arrows indicate stronger tidal currents

Image by Byron Inouye

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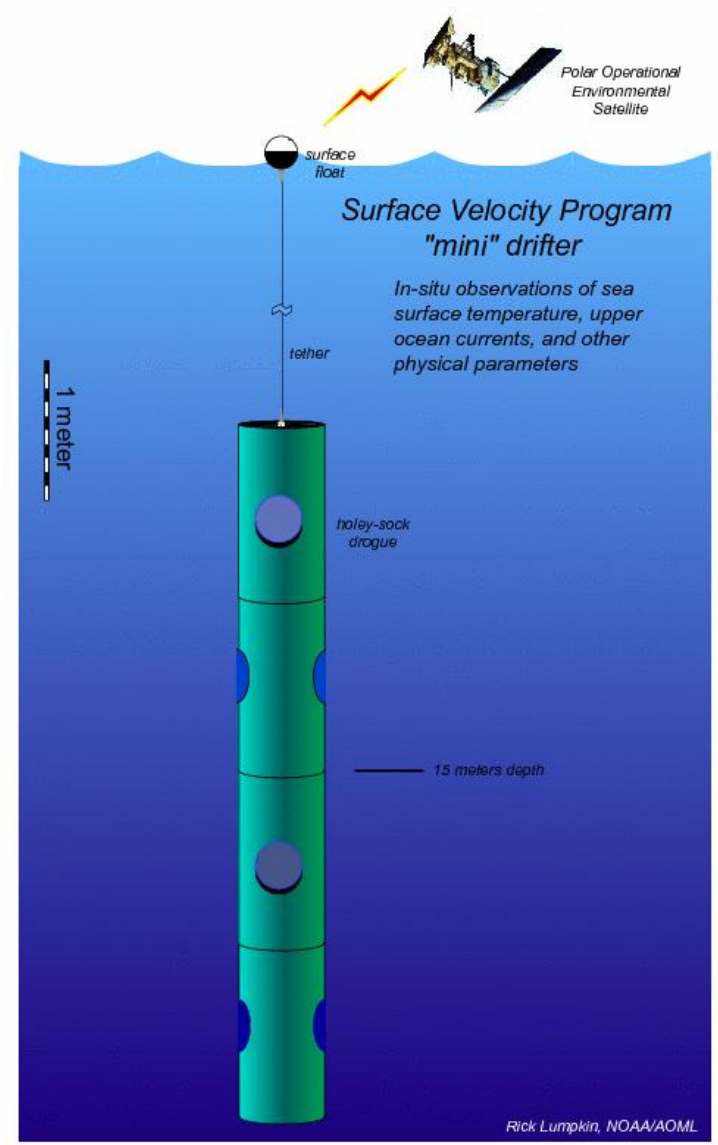
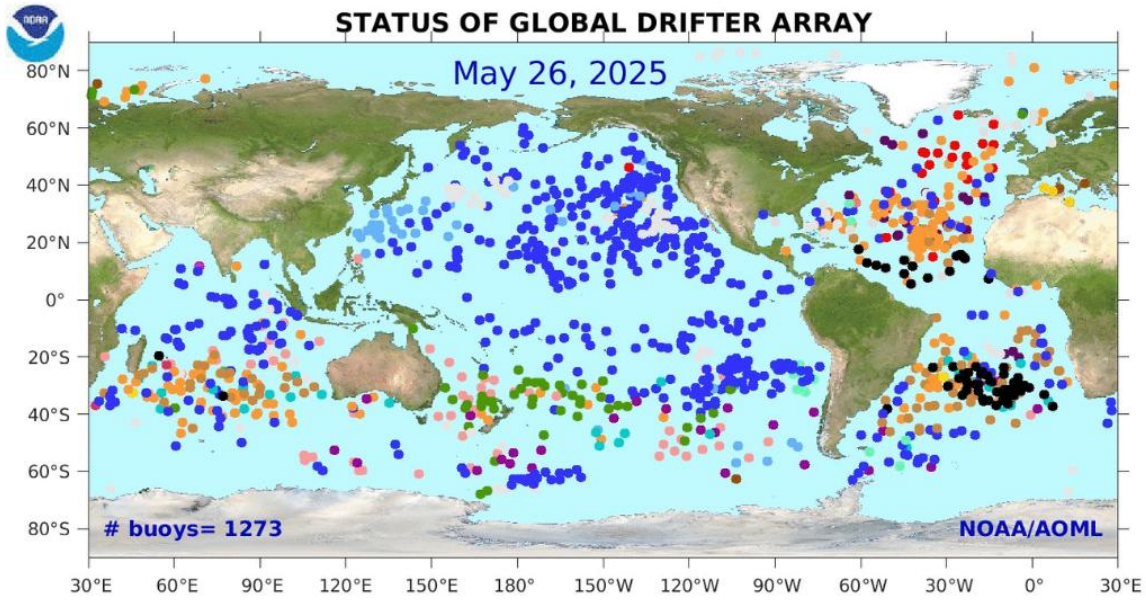
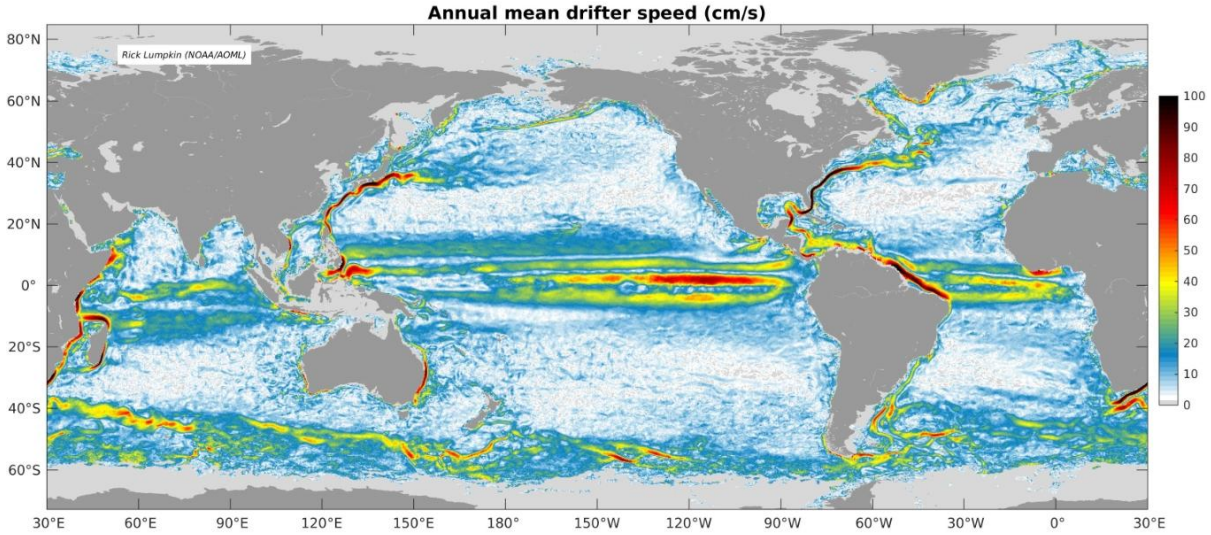
How to monitor the Ocean?

The Global Drifter Programme
https://www.aoml.noaa.gov/phod/







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Combination of altimetry measurements and drifter data to model Ekman currents

$$u_e = \pm \frac{\pi\sqrt{2}}{\rho(f+w)D_e} e^{\frac{\pi}{D_e}z} * \tau_e * \cos\left(\frac{\pi}{4} + \frac{\pi}{D_e}z\right)$$

$$v_e = \pm \frac{\pi\sqrt{2}}{\rho(f+w)D_e} e^{\frac{\pi}{D_e}z} * \tau_e * \sin\left(\frac{\pi}{4} + \frac{\pi}{D_e}z\right)$$

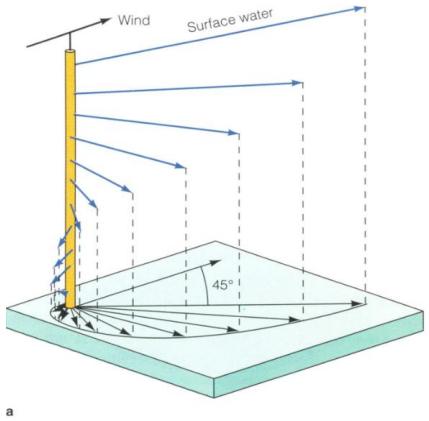
A θ

Model

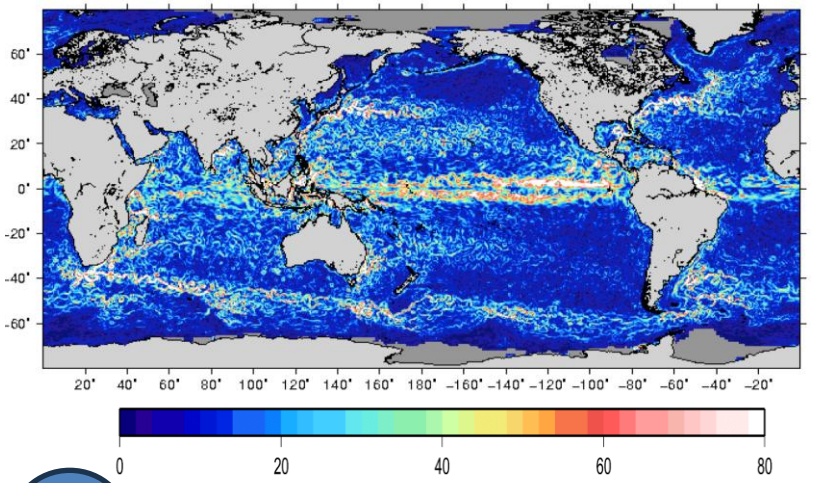
$$\vec{u}_e = A\vec{\tau}e^{i\theta}$$

$(\vec{u}_{buoy} - \vec{u}_{alti})_f$

Wind stress

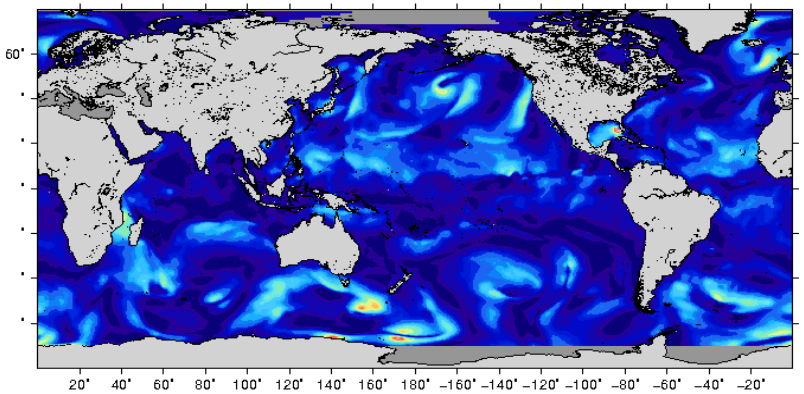


Altimeter derived Geostrophic currents



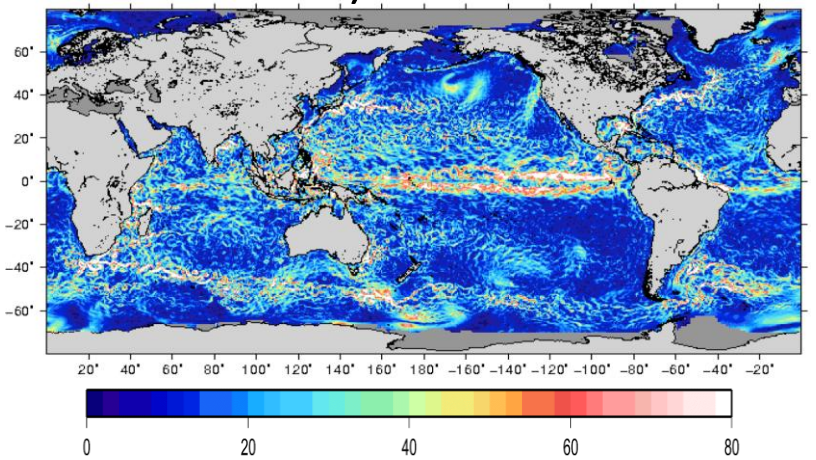
+

May, 5th 2016 Ekman currents

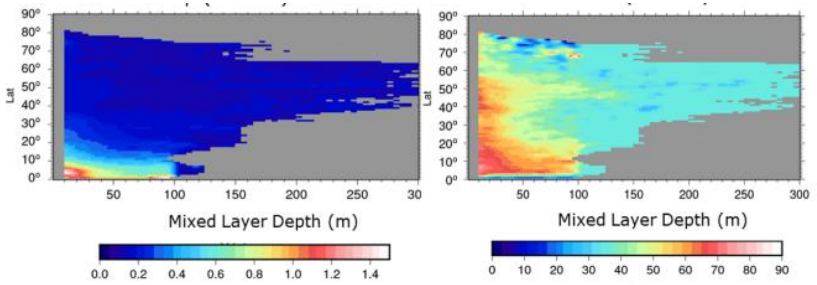


=

Total (Geostrophy + Ekman) currents

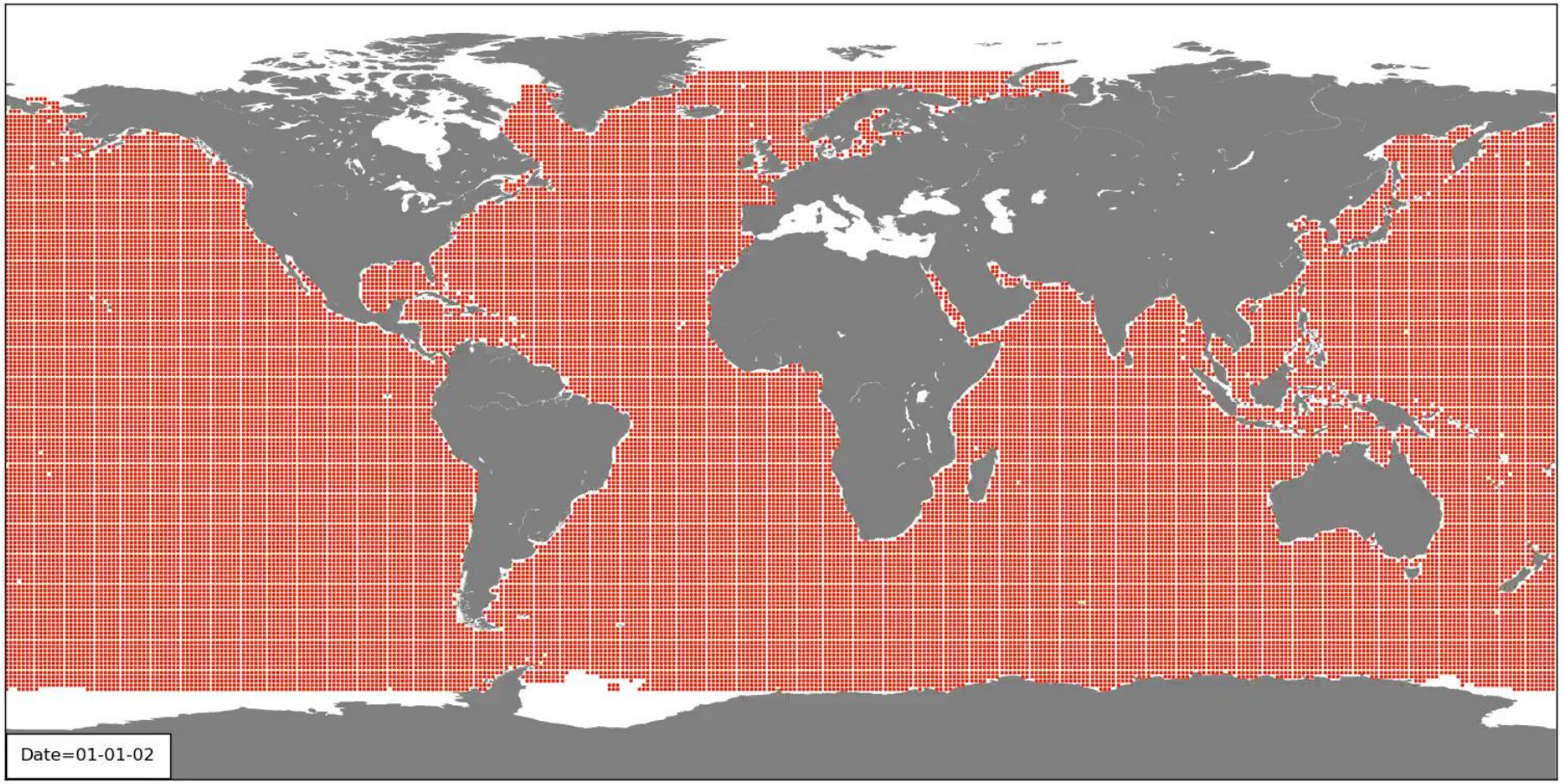


A θ



Rio et al, 2003, 2014; Mulet et al, 2018

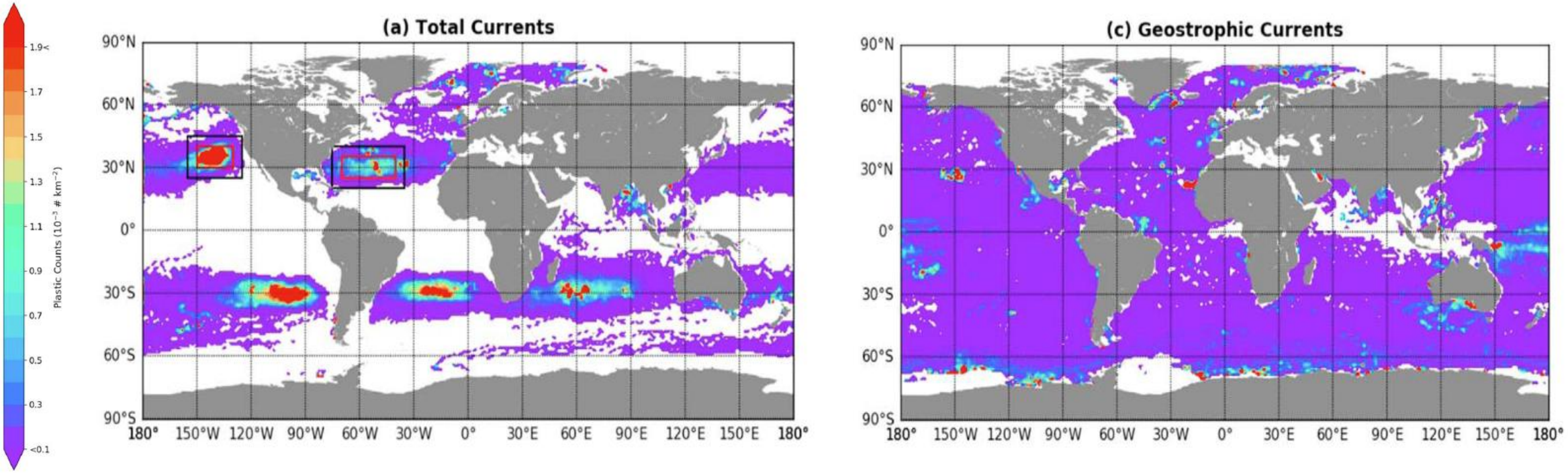
How do the giant plastic islands form?



Credit: Victor Onink et al, 2019 (Utrecht University)

How do the giant plastic islands form?

The geostrophic currents alone are unable to describe the observed floating pollutants distributions in the global ocean



Credit: Daniele Ciani (CNR-ISMAR)

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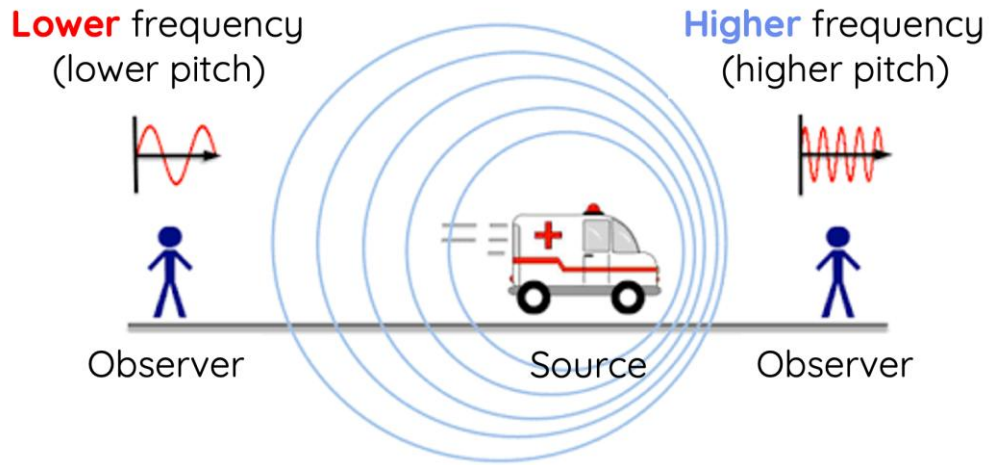
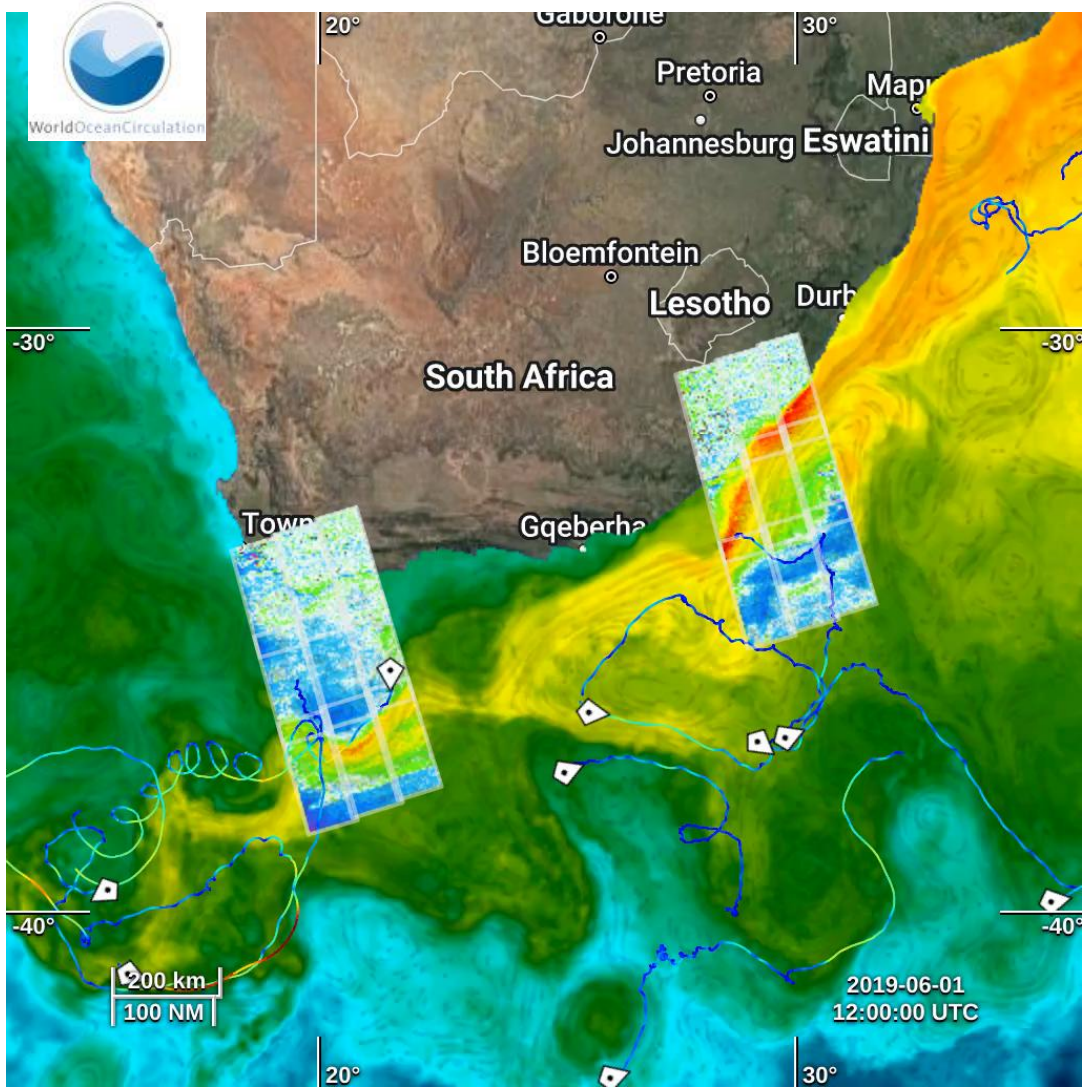
How to monitor the Ocean?

SAR derived velocities

Three years (May 2019 – April 2022) of improved high resolution surface currents in three areas (Agulhas current, Orkney islands, and Norwegian Coastal Current) from S-1 SAR Doppler shift observations.



Sentinel-1A/B Radial Velocities - Agulhas current



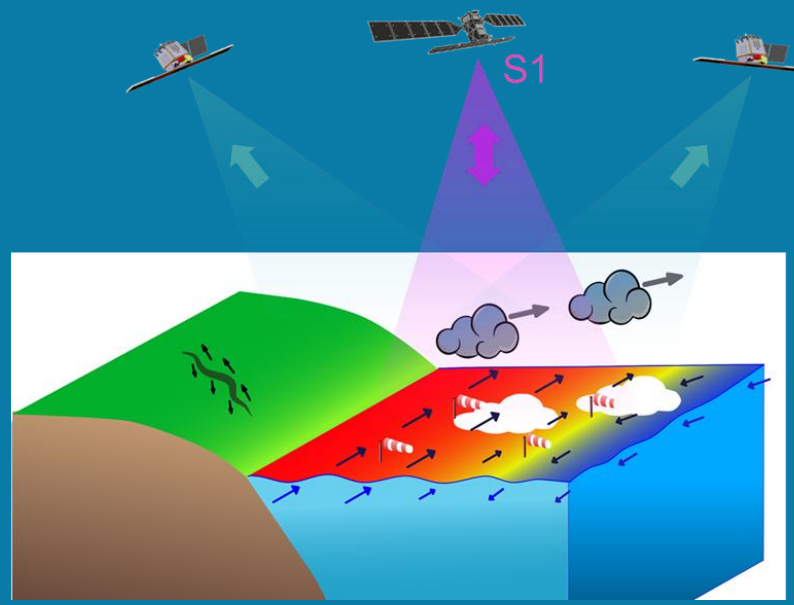
Moiseev, A., Johannessen, J. A., and Johnsen, H. (2022). Towards Retrieving Reliable Ocean Surface Currents in the Coastal Zone from the Sentinel-1 Doppler Shift Observations. *Journal of Geophysical Research: Oceans, 127, e2021JC018201,* https://doi.org/10.1029/2021JC018201

EE10 Harmony

esa

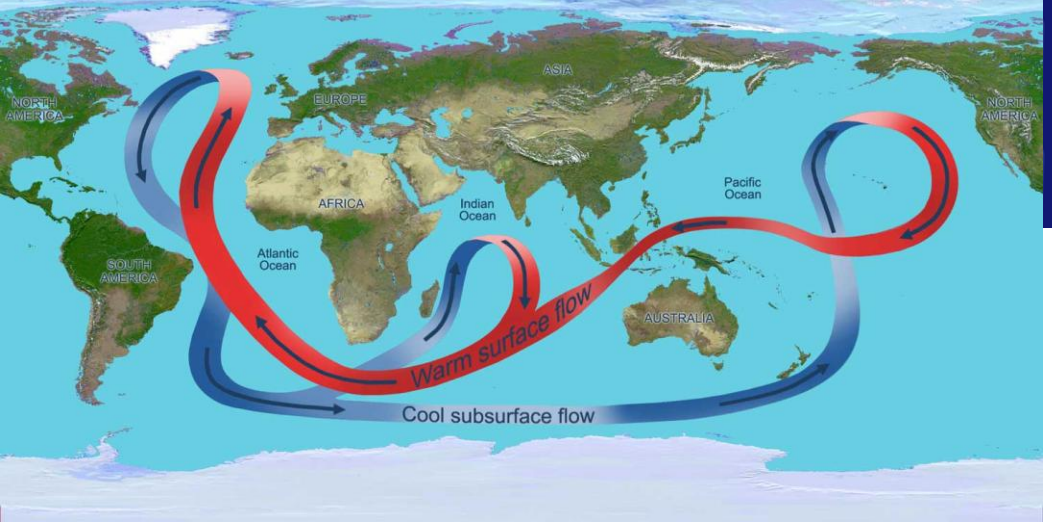
Harmony is ESA's Earth Explorer 10 mission, comprised of two companion satellites in a loose convoy with Sentinel-1D (along-track separation ~350 km)
Its payload suite consists of a passive SAR and a multi-view TIR instrument

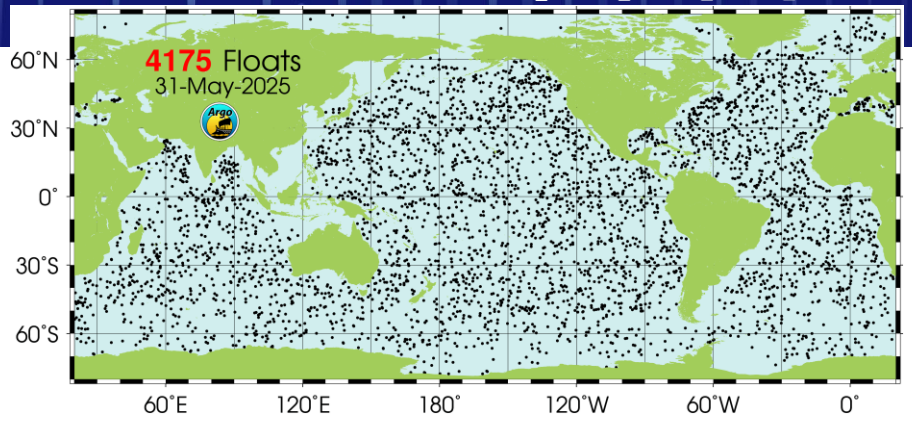
Total Surface Currents at 2-5 km resolution



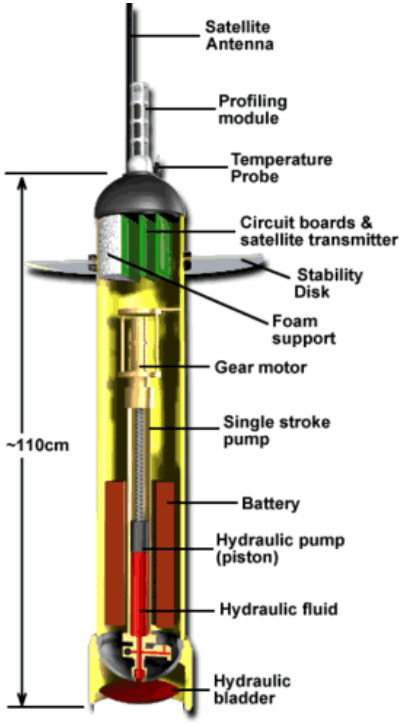
(Expected launch 2029)

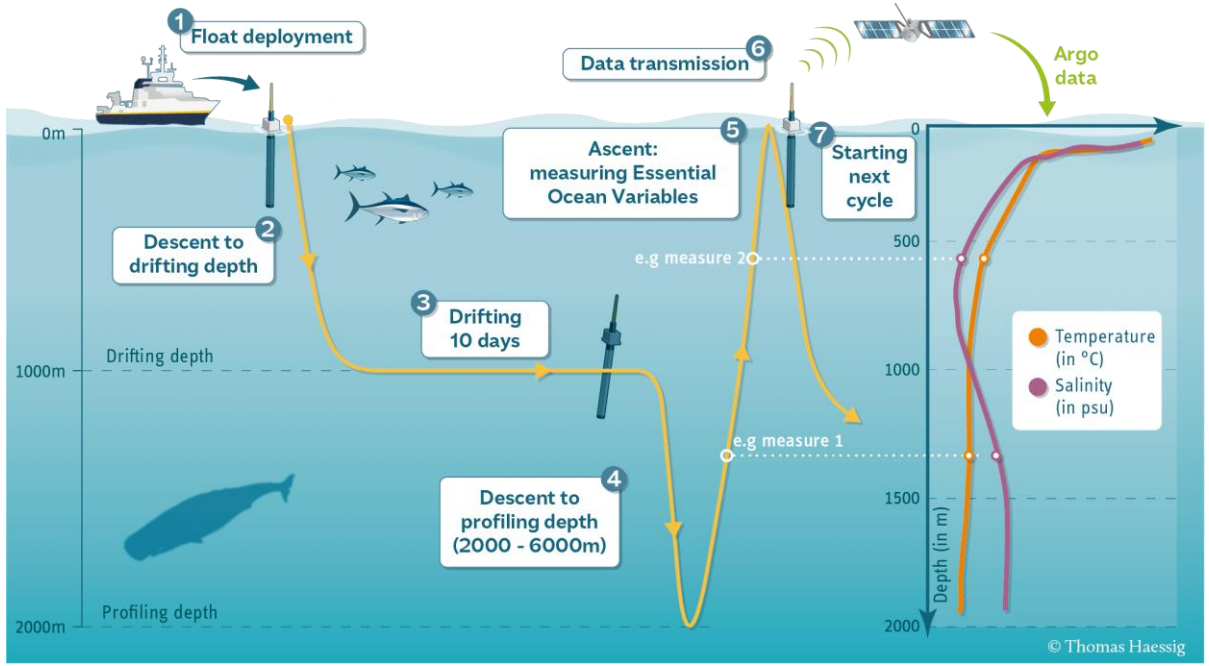
From surface to depth





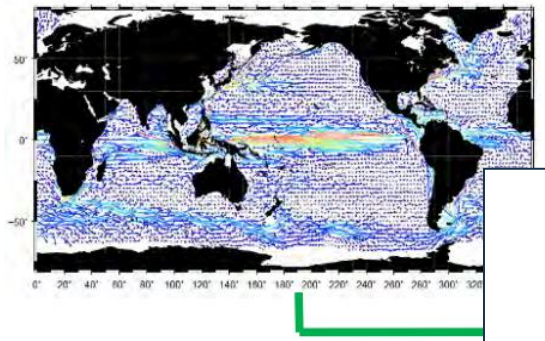
Argo profiling floats





From surface to depth

Altimetry :
Field of absolute geostrophic surface currents -



$$\nabla^2{}_h(N^2 w) + f^2 \frac{\partial^2 w}{\partial z^2} = \nabla_h \cdot \boldsymbol{Q}$$

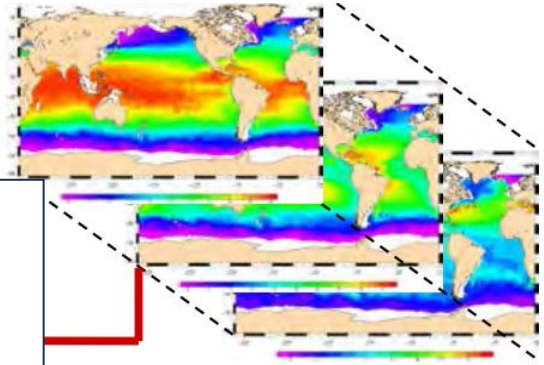
$$\boldsymbol{Q} = 2\boldsymbol{Q}_{twg} + \boldsymbol{Q}_{th} + \boldsymbol{Q}_{dm}$$

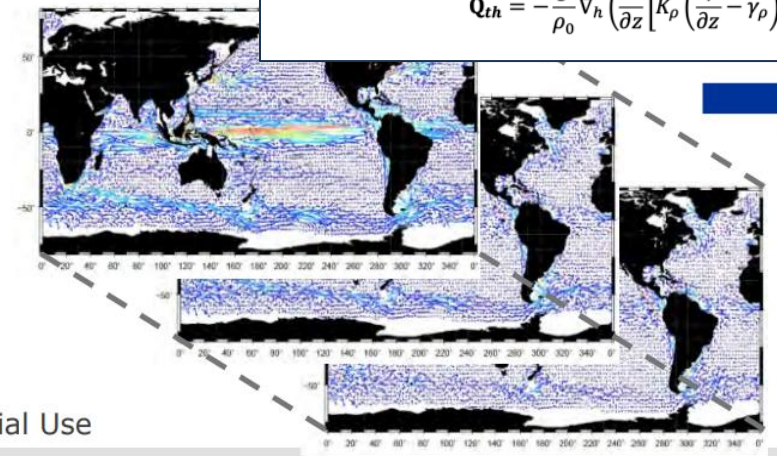
$$\mathbf{Q}_{twg} = \frac{g}{\rho_0}\left(\frac{\partial u_g}{\partial x}\frac{\partial \rho}{\partial x} + \frac{\partial v_g}{\partial x}\frac{\partial \rho}{\partial y}, \frac{\partial u_g}{\partial y}\frac{\partial \rho}{\partial x} + \frac{\partial v_g}{\partial y}\frac{\partial \rho}{\partial y}\right)$$

$$\mathbf{Q}_{dm\_woc} = \frac{f}{\rho_0}\left(\frac{\partial^2}{\partial z^2}\left[\rho K_m\left(\frac{\partial v_g}{\partial z} + \frac{\partial v_{Ekman}}{\partial z}\right)\right], -\frac{\partial^2}{\partial z^2}\left[\rho K_m\left(\frac{\partial u_g}{\partial z} + \frac{\partial u_{Ekman}}{\partial z}\right)\right]\right)$$

$$\mathbf{Q}_{th} = -\frac{g}{\rho_0}\nabla_h\left(\frac{\partial}{\partial z}\left[K_\rho\left(\frac{\partial \rho}{\partial z} - \gamma_\rho\right)\right]\right) = \nabla_h\left(\frac{\partial}{\partial z}\left[K_\rho\left(N^2 + \frac{g}{\rho_0}\gamma_\rho\right)\right]\right)$$

3D T/S fields





3D geostrophic current fields

Guinehut et al, 2012
Mulet et al, 2014
B.Nardelli et al, 2020a, 2020b, 2022

Summary and conclusions

- Ocean currents monitoring is key for a wide range of applications
- Today, no satellite mission provides direct measurements of the total surface currents
- Altimetry is by far the most used instrument for surface currents monitoring
- But it presents important limitations (geostrophic current only, medium space and time resolution)
- Swath altimetry (SWOT) is a game changer, but still only the geostrophic component is retrieved
- Synergy with other measurements (in-situ, space radiometry) is key to improve ocean currents retrieval, both at the surface and at depth
- Future missions will help bridge the gap and improve the retrieval of this crucial information (ESA Harmony, French-US Odysea)

Inspire

How to monitor the Ocean?

Thanks for your attention

Copernicus
Europe's eyes on Earth

EU MISSIONS
RESTORE OUR OCEAN & WATERS

Copernicus
Marine Service

PAVILION IMPLEMENTED BY
MERCATOR OCEAN
INTERNATIONAL