Surface and Upper Ocean Circulation from the combined use of in situ and space borne observations

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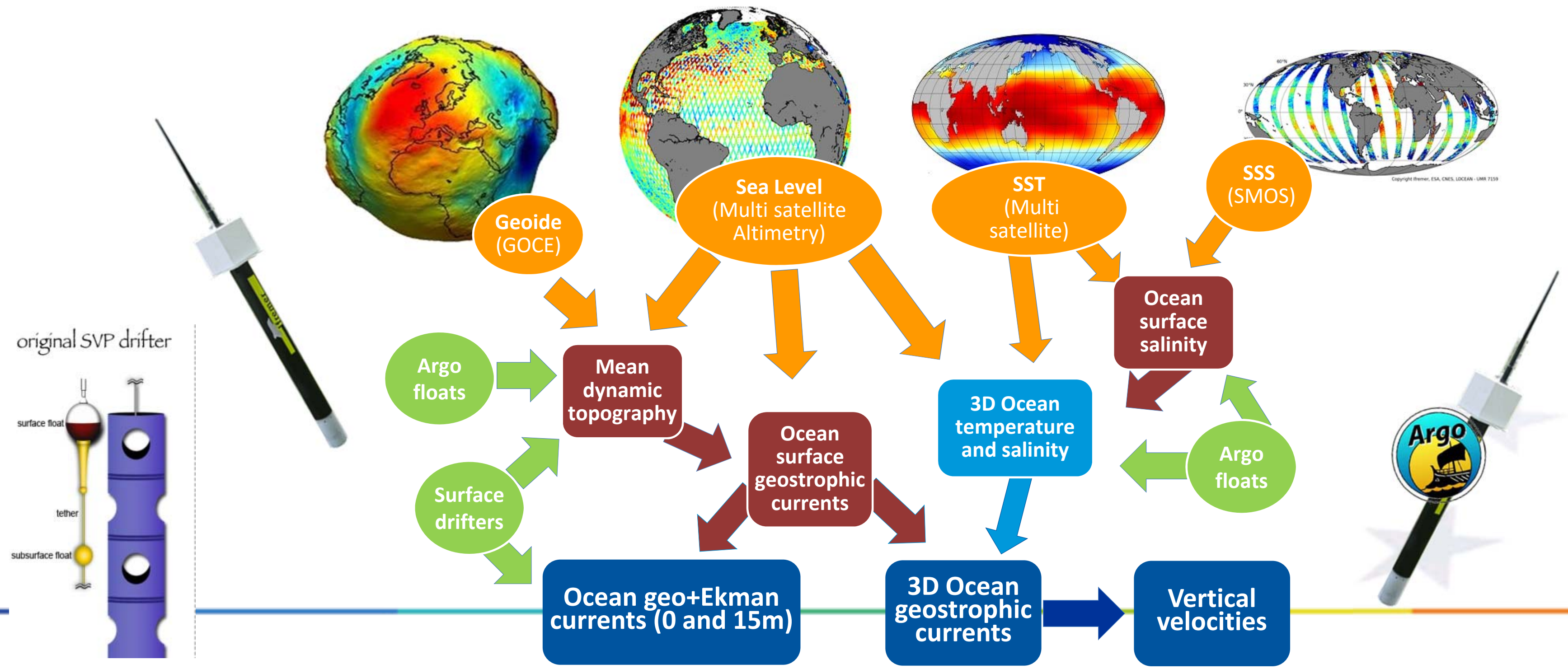
COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE
CMEMS OCEAN MULTI OBSERVATIONS TAC
Contract 83-CMEMS TAC MOB Until 31 March 2021

CLS

Copernicus Marine Service | Implemented by MERCATOR OCEAN INTERNATIONAL

What is MULTIOBS?

- The Ocean **Multi Observations** TAC of CMEMS
- Based on the combination of **satellite** & **in-situ** observations using **statistical methods.**



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- **Main idea : take advantage of the strength of the two main components of the GOOS**
  - **in-situ** observations: sparse but accurate and measurement at depth
  - **satellite** observations: higher resolution space/time but integrated/surface
- Variables (PHYS and BIO):

surface currents, 3D T/S/U/V, vertical velocities, SSS, SSD, MLD, pCO2, pH

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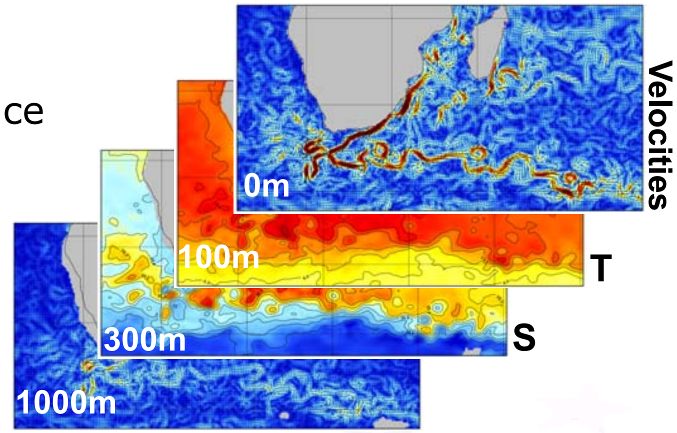
  Weekly/Monthly, 1/4°, [0-1500m] on 24 levels, REP (1993-2018) & NRT (D-7)



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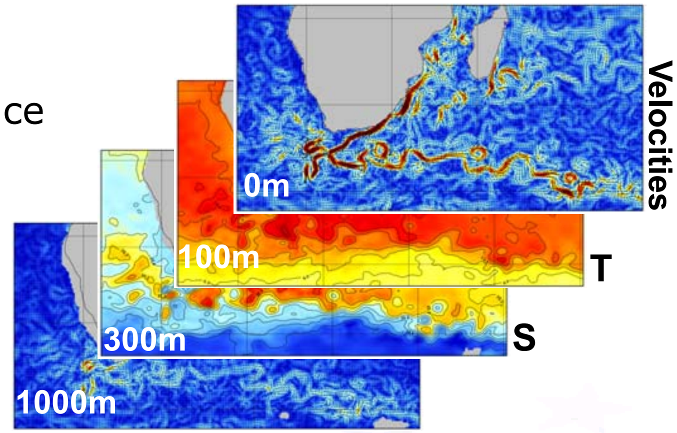

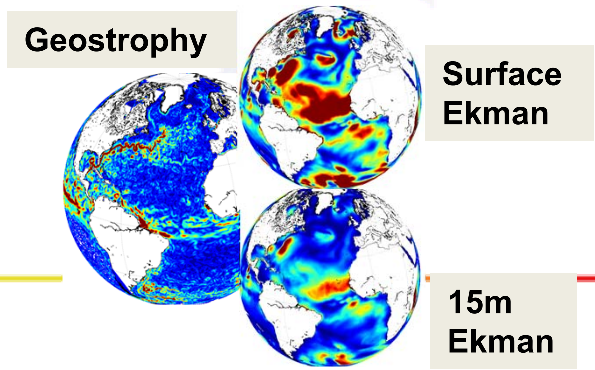

3D T/S/UVg – ARMOR3D

MULTIOBS_GLO_PHY_NRT_015_001 / MULTIOBS_GLO_PHY_REP_015_002

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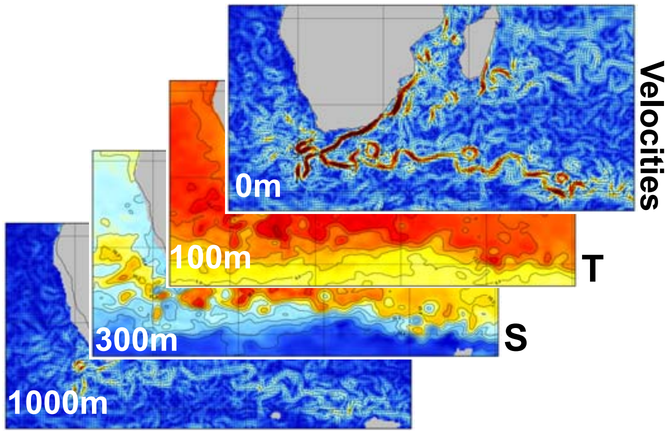

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3D T/S/UVg – ARMOR3D

MULTIOBS_GLO_PHY_NRT_015_001 / MULTIOBS_GLO_PHY_REP_015_002

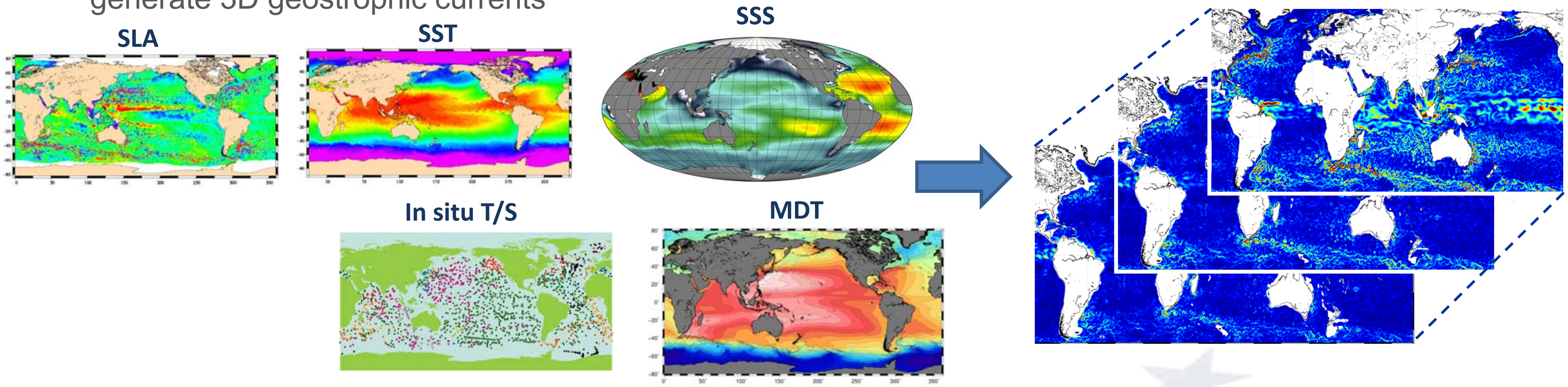
➔ 3D temperature, salinity, geostrophic velocities (Guinehut et al., 2012; Mulet et al., 2012)

- Based on a 3 steps method starting from a first guess T/S climatology (WOA)

(1) Satellite data (SLA + SST + SSS) are projected onto the vertical using a **multiple linear regression** method

(2) Combination between step 1 fields with T/S in situ profiles using an **optimal interpolation** method

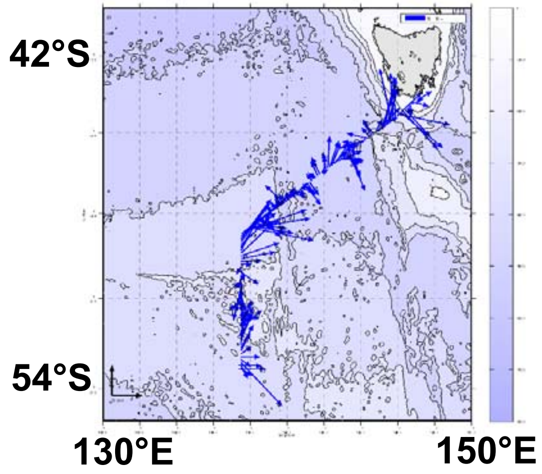
(3) Use of the **thermal wind equation** to combine the 3D T/S fields with surface geostrophic current fields to generate 3D geostrophic currents



Guinehut S., A.-L. Dhomps, G. Larnicol et P.-Y. Le Traon (2012). High resolution 3-D temperature and salinity fields derived from in situ and satellite observations. Ocean Sci., 8(5):845–857.
Mulet S., M.-H. Rio, A. Mignot, S. Guinehut et R. Morrow (2012). A new estimate of the global 3D geostrophic ocean circulation based on satellite data and in-situ measurements. Deep Sea Research Part II : Topical Studies in Oceanography, 77–80(0):70–81.

Validation with WM-ADCP observations

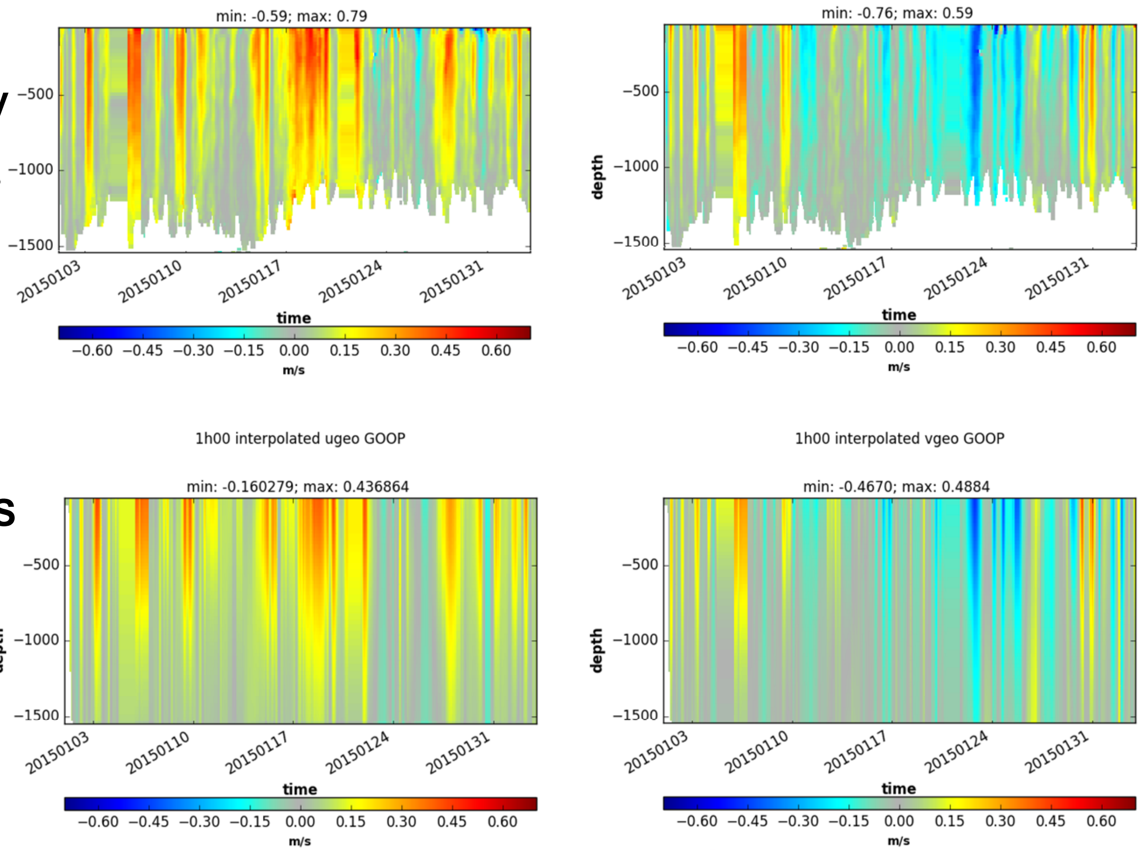
Coriolis data base



U | **V**

ADCP 6-hourly mean

MULTIOBS

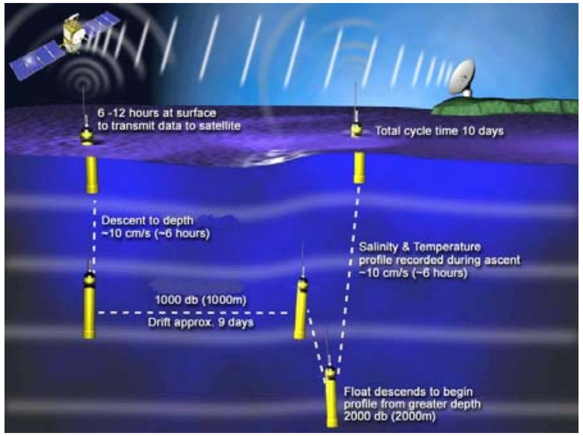


- ➢ Good agreement with independant ADCP data
- ➢ Limitation: slighly too barotropic below 1000m because the vertical gradients of the T/S fields are too smooth (thermal wind equation)

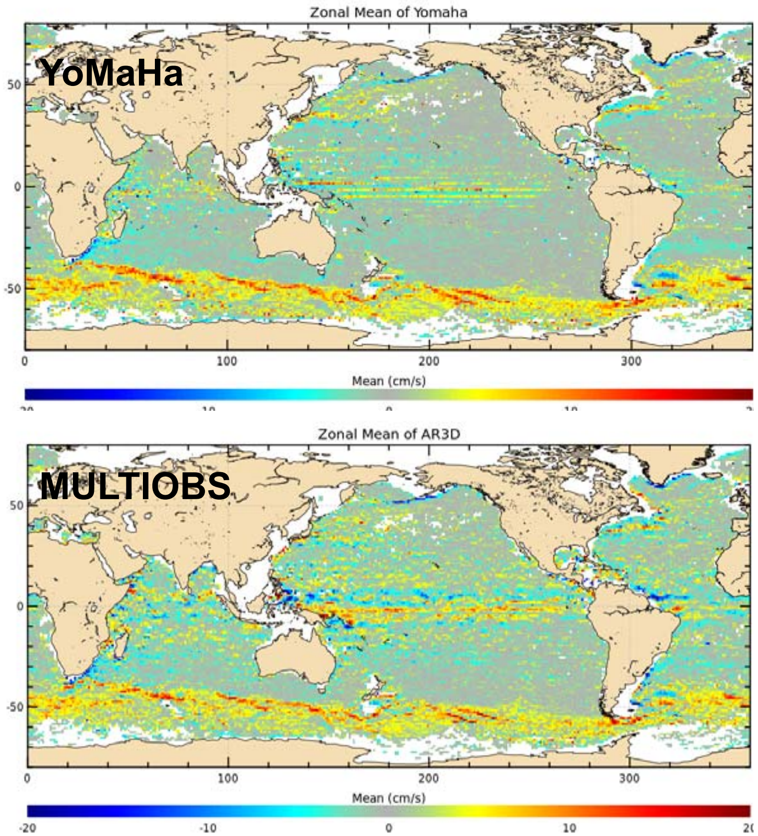
Validation with velocities from Argo drift at depth

MEAN of MULTIOBS versus YoMaHa, 1998-2017 in 1°x1° boxes (cm/s) – **1000m**

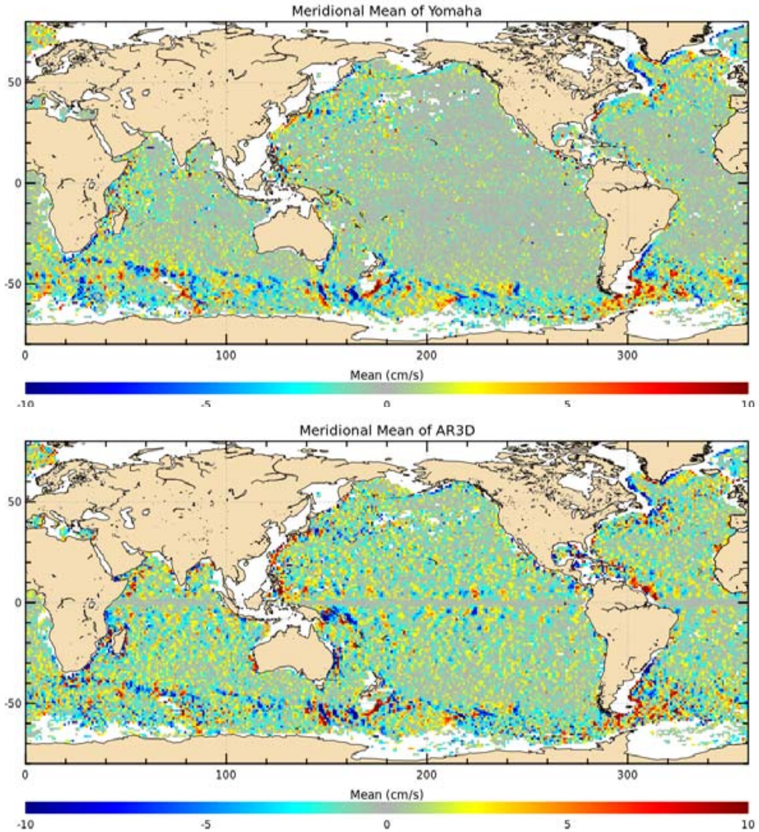
YoMaHa
Lebedev et al., 2007



Zonal



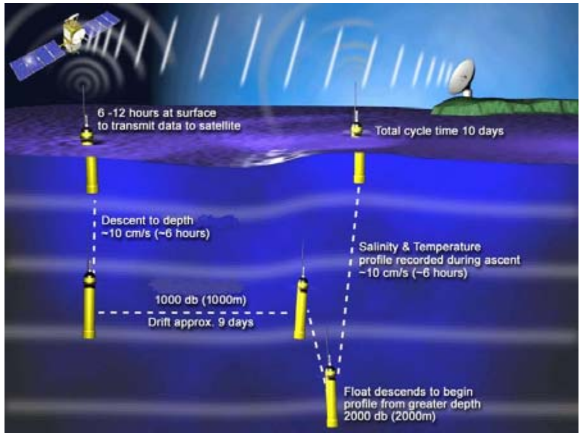
Meridional



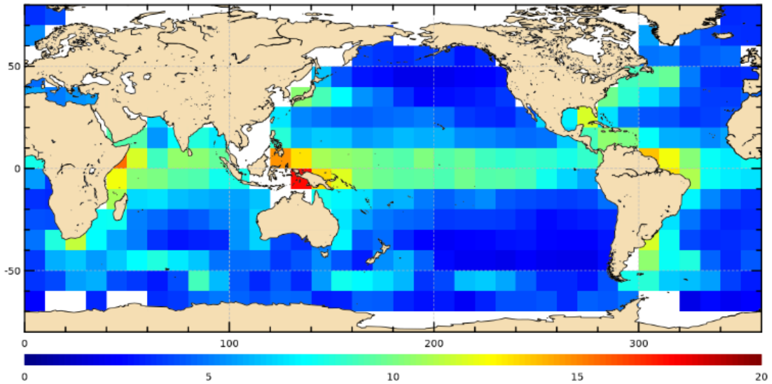
Validation with velocities from Argo drift at depth

RMSD of MULTIOBS versus YoMaHa, 1998-2017 in 10°x10° boxes (cm/s) – 1000m

YoMaHa
Lebedev et al., 2007

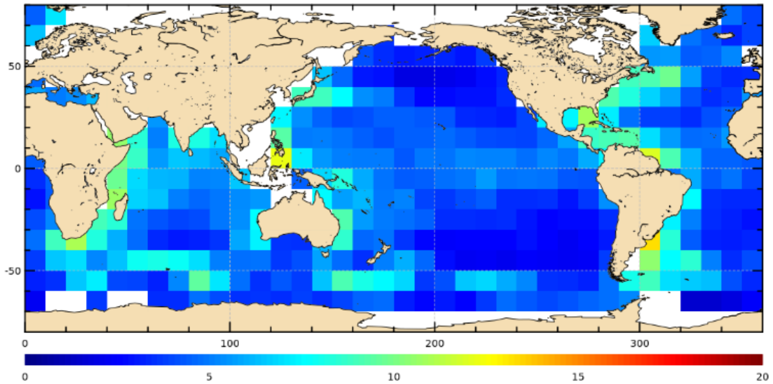


Zonal



0 cm/s 20 cm/s

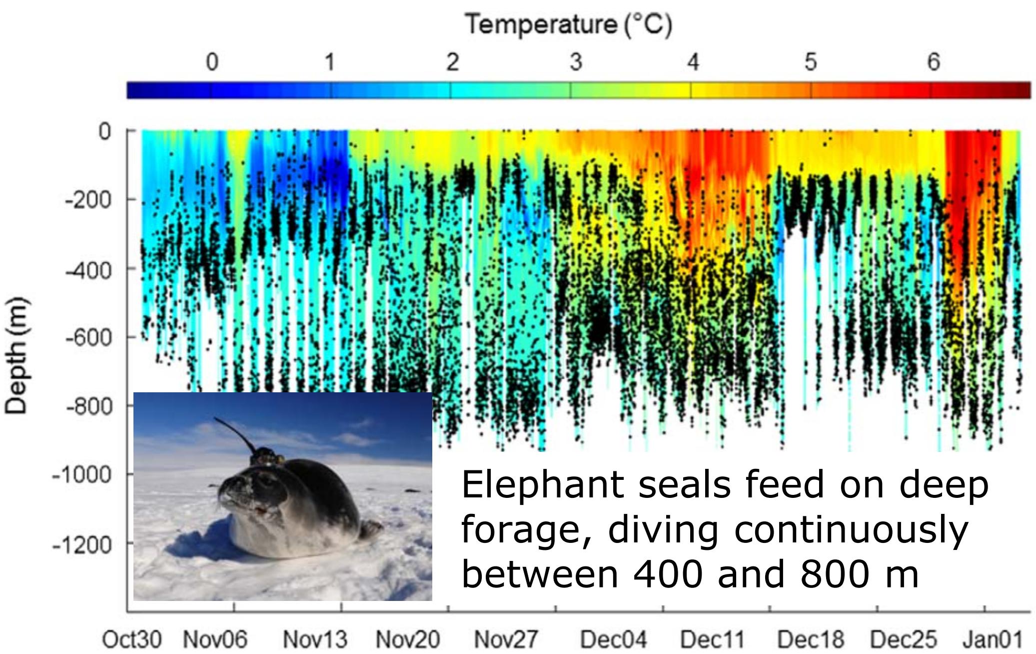
Meridional



0 cm/s 20 cm/s

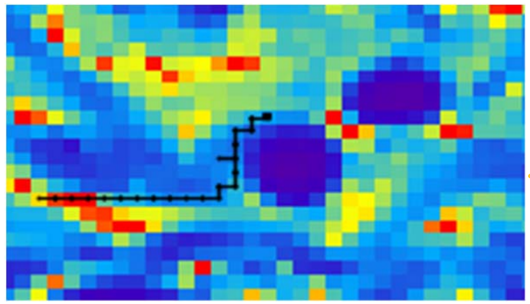
Application for biogeochemical study

Elephant Seal tracks (black) match very well with **micronekton biomass** in mesopelagic layer estimated from **SEAPODYM** model forced by **MULTIOBS**



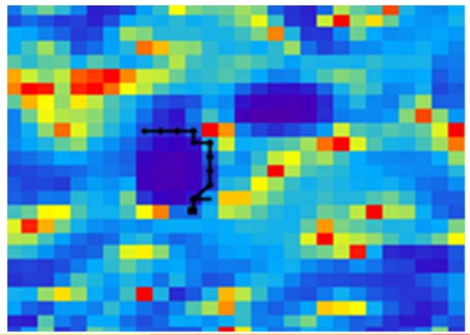
Elephant seals feed on deep forage, diving continuously between 400 and 800 m

26 Nov 2011



Key element → exact position of mesoscale structures

3 Dec 2011



Courtesy of Lehodey

Surface and 15 UV – Copernicus/Globcurrent

MULTIOBS_GLO_PHY_NRT_015_003 / MULTIOBS_GLO_PHY_REP_015_004

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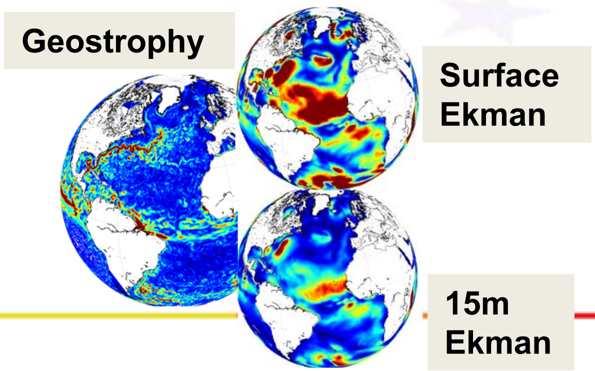
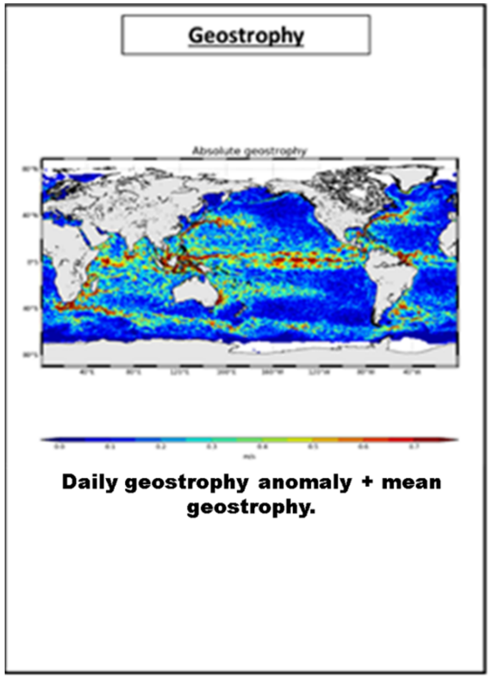
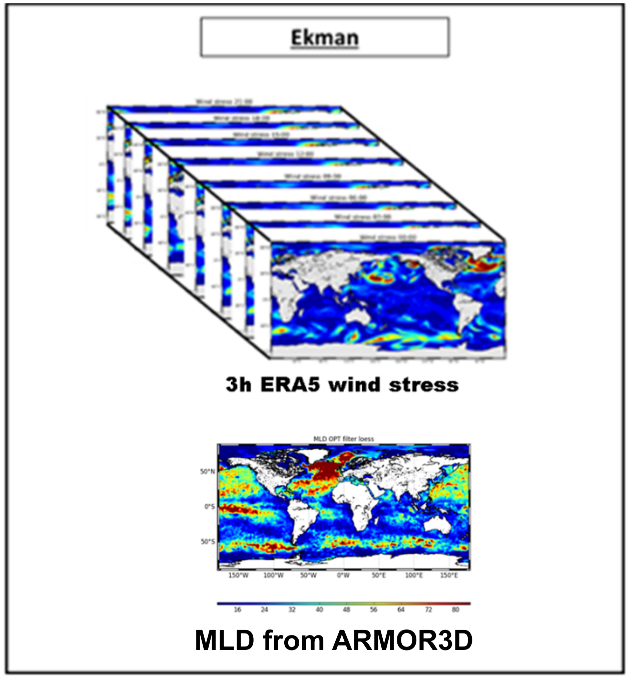


Copernicus/Globcurrent: new version on Dec 2019

- <u>The geostrophic</u> component is derived from altimeter multimission fields (DUACS / CMEMS SLA maps, **Taburet et al, 2019**) and the new **CNES-CLS18** Mean Dynamic Topography (Rio et al, in prep).

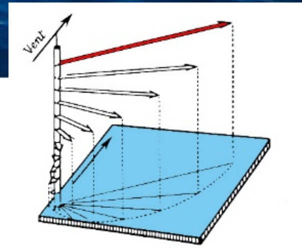
- <u>Wind driven component</u> at the surface and 15m: from an empirical model forced by wind-stress fields: **ERA5** upgraded version of the Rio, 2014 method.





M.-H. Rio, S. Mulet, and N. Picot (2014): Beyond GOCE for the ocean circulation estimate: Synergetic use of altimetry, gravimetry, and in situ data provides new insight into geostrophic and Ekman currents. Geophys. Res. Lett., 41, doi:10.1002/2014GL061773.

Modeling Wind-driven Currents (Ekman+Stokes) NEW MODEL



$$\vec{u}_w = \beta \; e^{i\theta} \; \vec{\tau}^{\alpha}$$

$\vec{u}_{buoy} - \vec{u}_{alti}$

low pass filtered 30 hours

Wind stress from ERA5

Old model (Rio et al, 2014):

β and θ are estimated through least square fit by month and 4°x4° boxes

New model:

β and θ = f(lat , MLD)

0.25° x 1m resolution

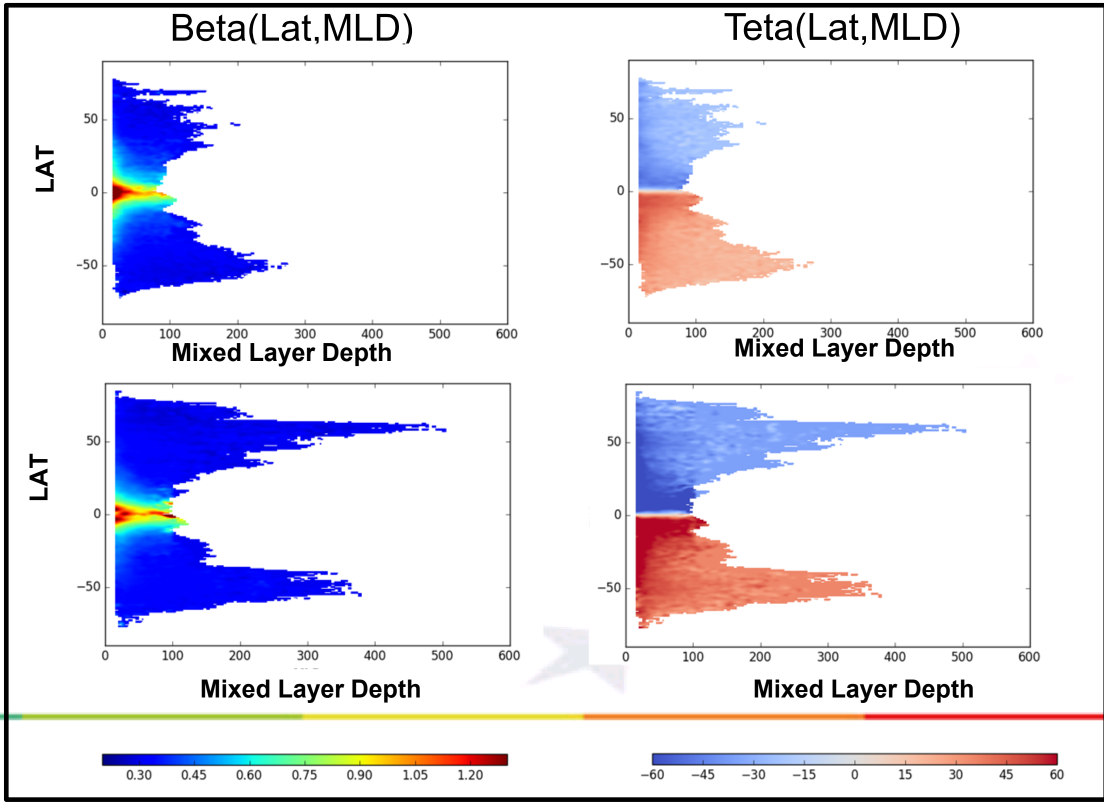
MLD
- Include temporal variability
- from ARMOR3D T/S fields with Boyer Montégut et al, 2004 formulation.

SURFACE

$$\vec{u}_w(z=0) = \beta_0 e^{i\theta_0} \vec{\tau}^{0.6}$$

15m depth

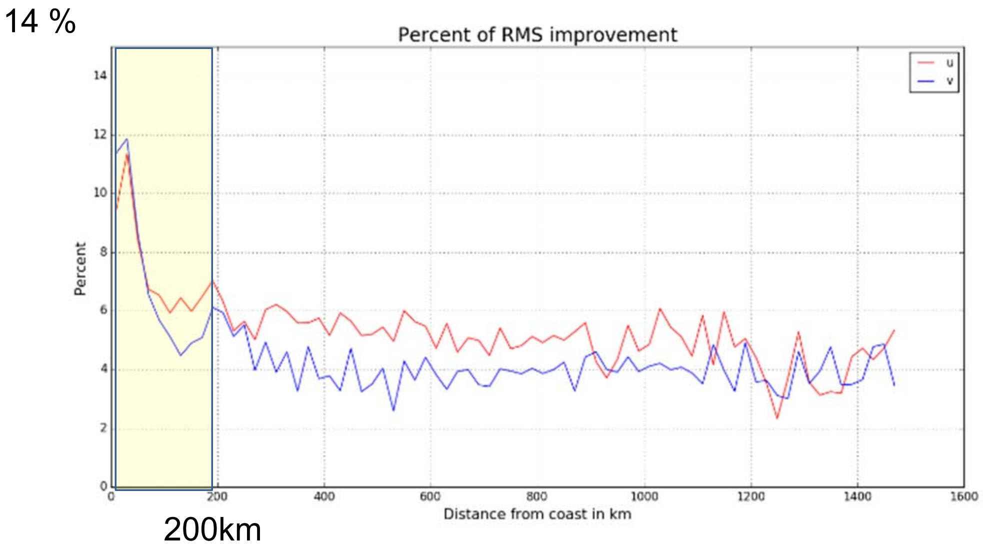
$$\vec{u}_w(z=15) = \beta_{15} e^{i\theta_{15}} \vec{\tau}^{0.7}$$



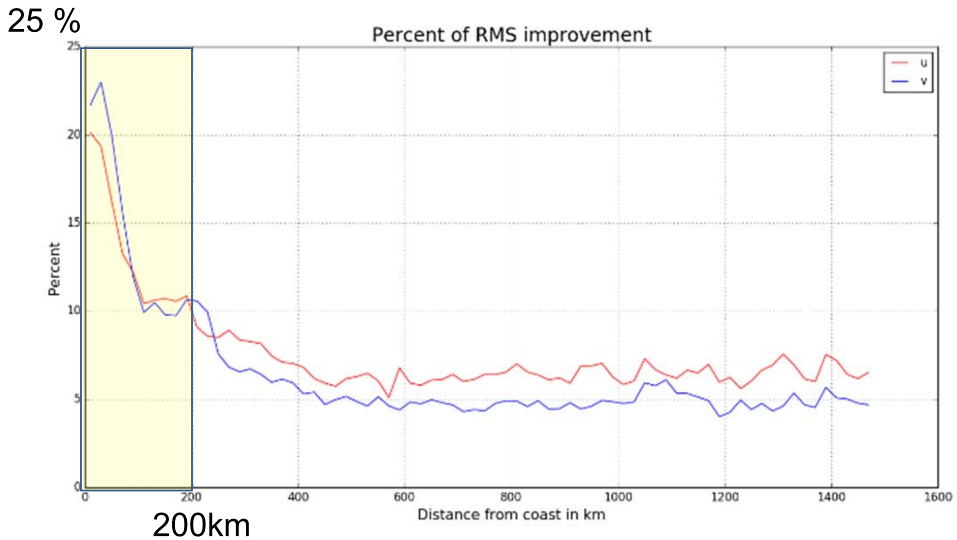
% improvement from previous Copernicus/Globcurrent version

Version	SLA	MDT	Wind driven model	Wind forcing
Old	CMEMS/DUACS 14	CNES-CLS13	β and θ = f(lon,lat,month)	ERA Interim
New (Dec 2019)	CMEMS/DUACS 18	CNES-CLS18	β and θ = f(lat , MLD)	ERA5

Surface



15m



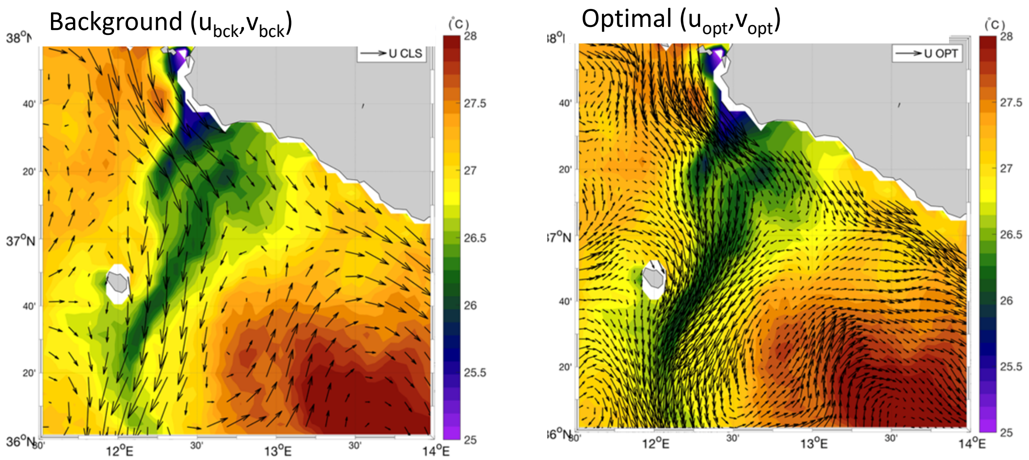
- ➢ Near the coast improvement thanks to CNES-CLS18 MDT.
- ➢ Global variability improvement thanks from ERA5 fields

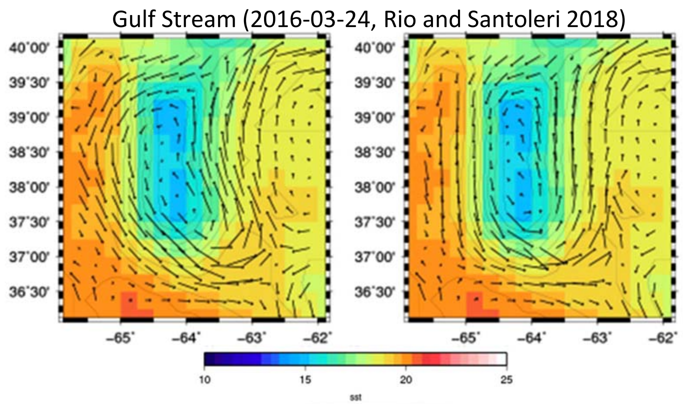
Future work:
Improved near-surface currents using SST

New in 2020

- ➔ Based on the **inversion of the heat conservation equation** for the horizontal velocities
- ➔ Using the **altimeter geostrophic velocities** as background and prescribing source and sinks terms a priori values and associated errors, **+ successive SST fields** (Piterbarg, 2009)
- ➔ Rio and Santoleri, 2018

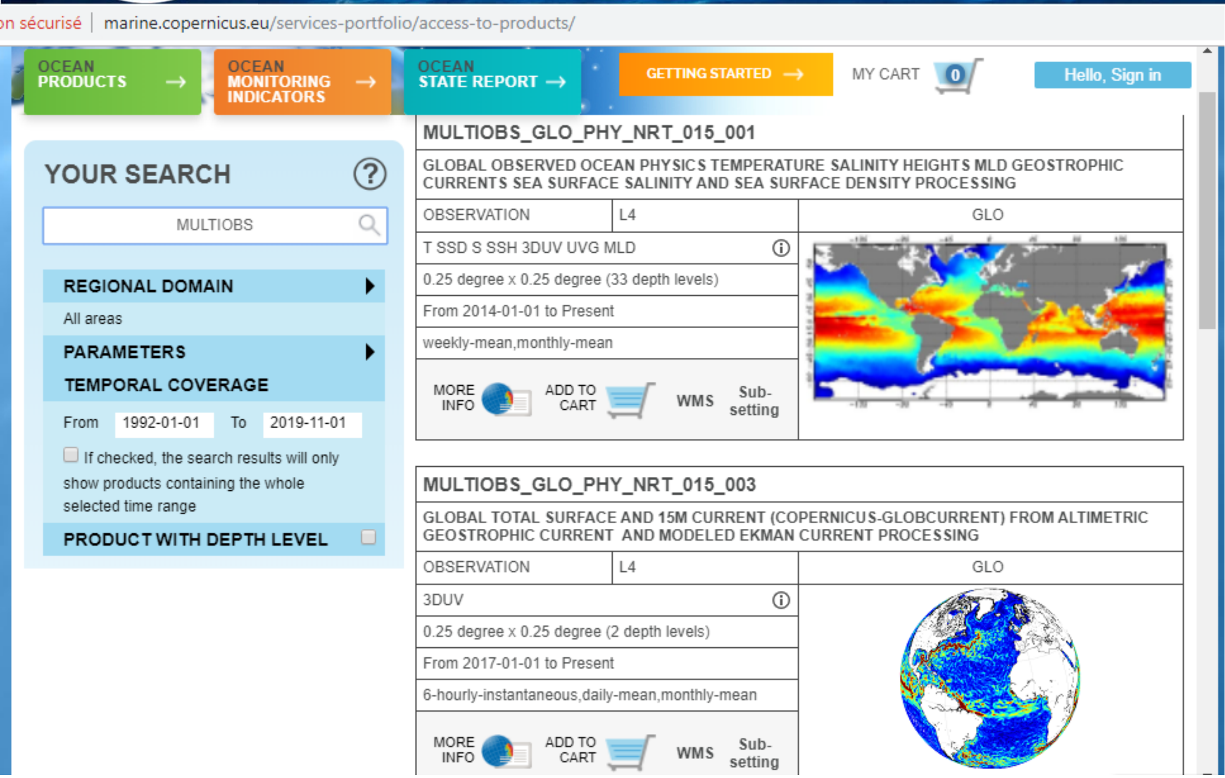
Upwelling (Med Sea)
Courtesy of Santoleri

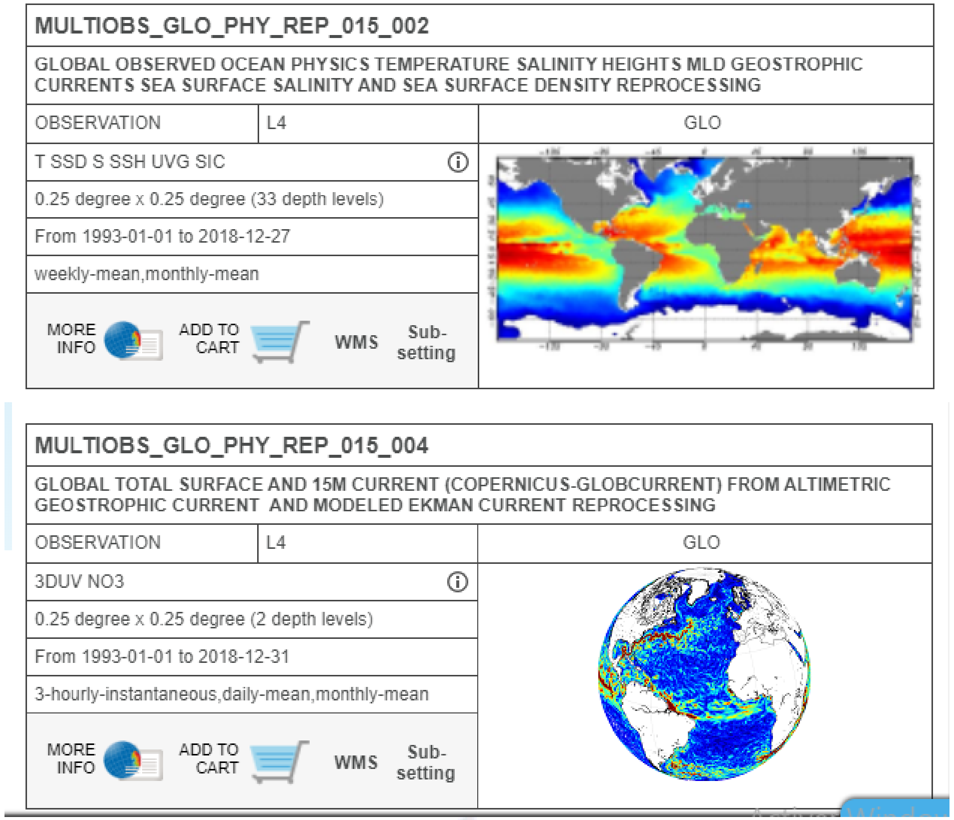




M.-H. Rio, and R. Santoleri, 2018: Improved global surface currents from the merging of altimetry and Sea Surface Temperature data, Remote Sensing of Environment, https://doi.org/10.1016/j.rse.2018.06.003.

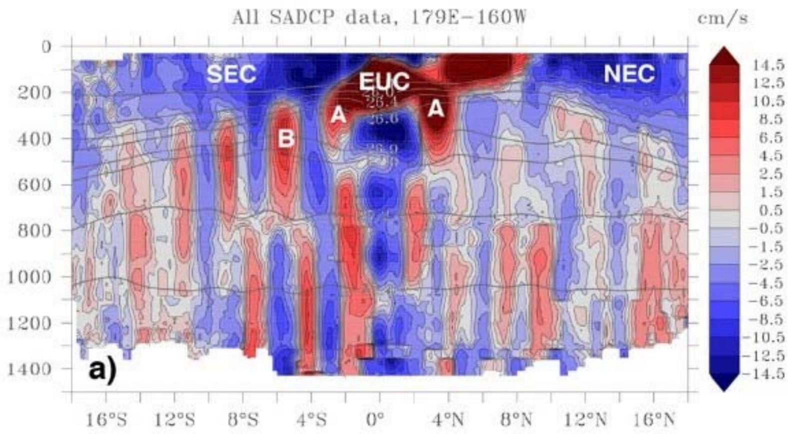
Availability of the products throught CMEMS



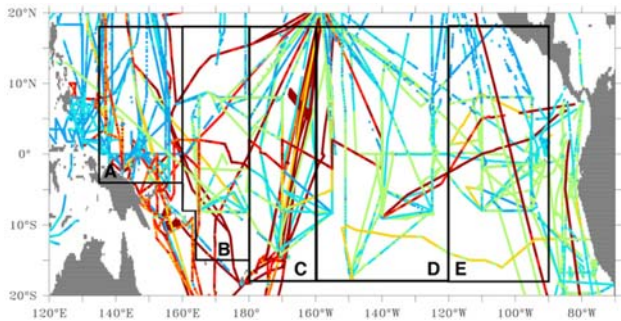


- If you use these products: any feedbacks are very welcome and useful.

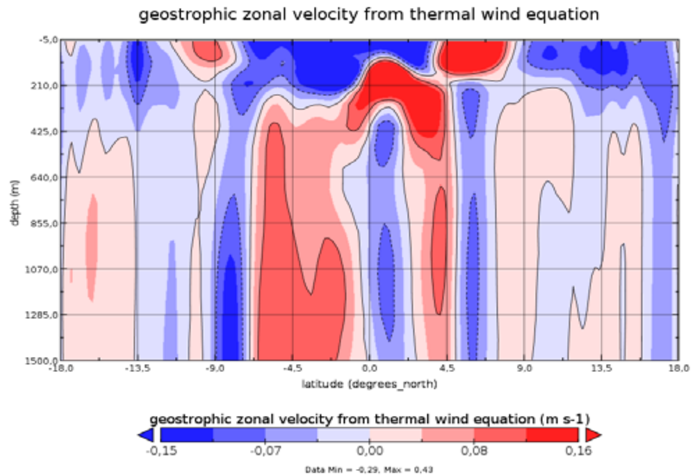
Validation with WM-ADCP observations
Equatorial currents



Cravatte & al., JPO 2017

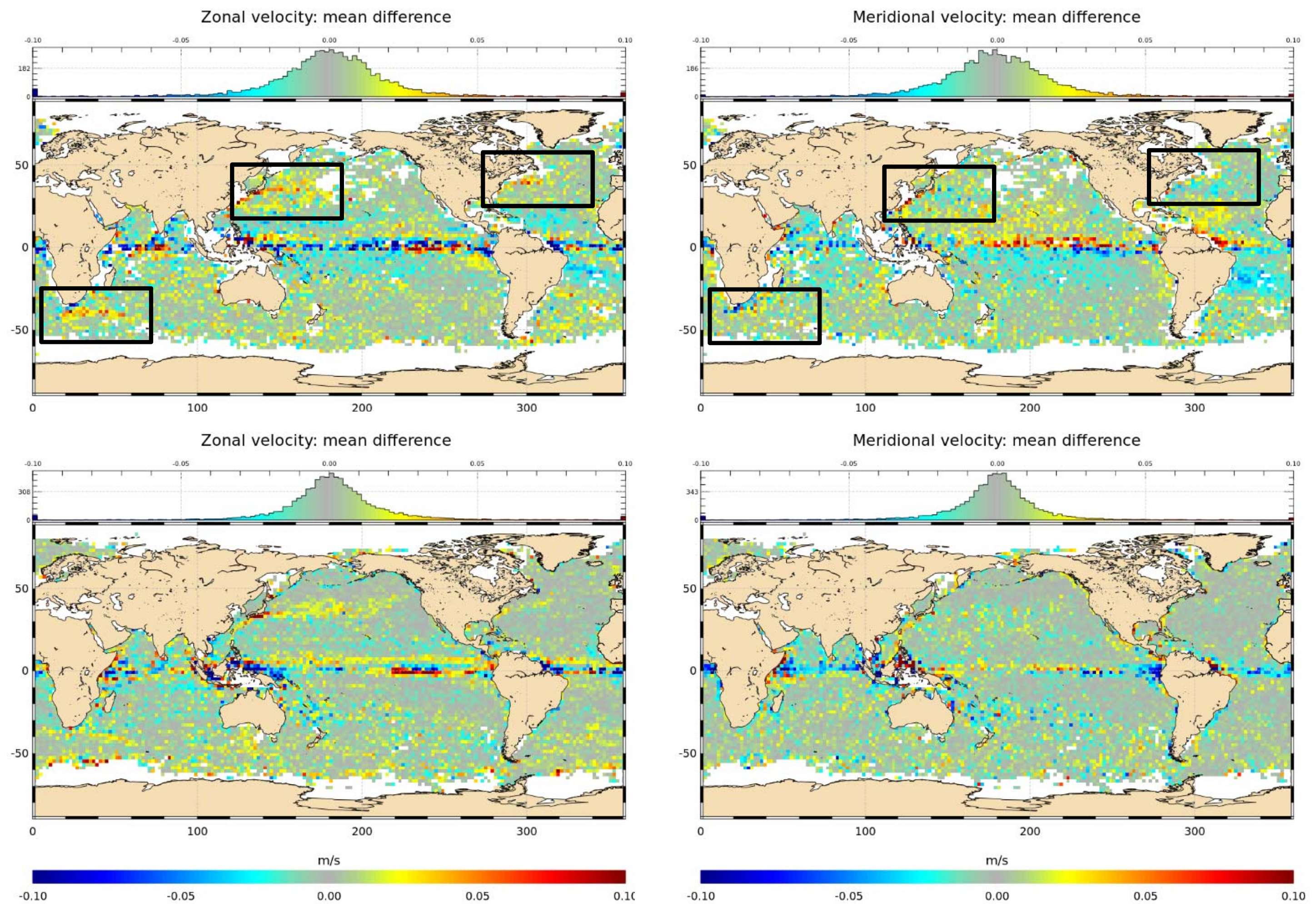


solution from historical Argo&ADCP dataset **(1993-2015)**



MULTIOBS (2013 mean, 170°W)

Cravatte, S., E. Kestenare, F. Marin, P. Dutrieux and E. Firing, Subthermocline and Intermediate Zonal Currents in the Tropical Pacific Ocean: paths and vertical structure, accepted for publication in JPO, https://doi.org/10.1175/JPO-D-17-0043.1



YoMaHa measurements (upper), mean differences between surface MULTIOBS current (westward and northward components) and quadratic error in % (westward and northward components) in a 2°x2° bins.

0m

ERA5 too cyclonic at mid latitudes.
→ Ekman bias.

15 m

Synergy SSH/SST: method based on Piterbarg 2009

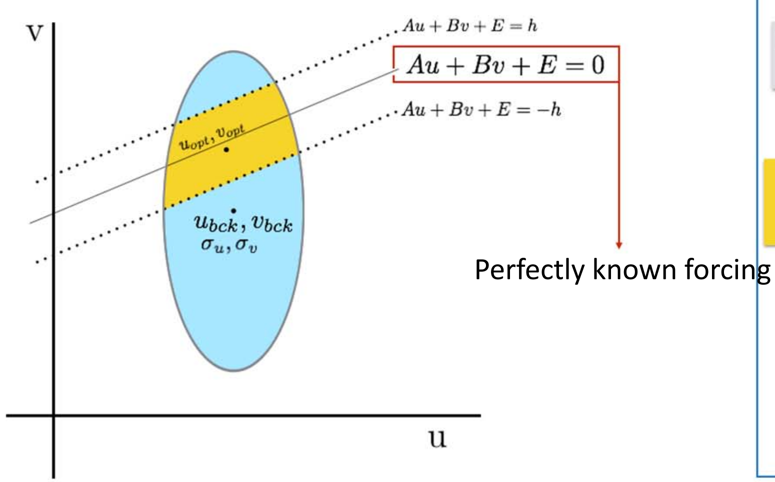
Require the velocity field (u,v) to obey to the SST evolution equation

$$\frac{\partial \mathrm{SST}}{\partial \mathrm{t}} + u\frac{\partial \mathrm{SST}}{\partial \mathrm{x}} + v\frac{\partial \mathrm{SST}}{\partial \mathrm{y}} = F$$

F= source and sink terms (solar input, net infrared radiation, latent and sensible heat fluxes)

Only along-gradient velocity information can be retrieved from the tracer distribution at subsequent times in **strong gradient areas**

→ **Piterbarg et al. 2009, Mercatini et al. 2010**: Use a **background velocity** information (u_{bck}, v_{bck}) so that the **satellite tracer information is used to obtain an optimized merged velocity** (u_{opt}, v_{opt})



Method Inputs:

$A = \partial_x SST;\ B = \partial_y SST$

$E = \partial_t SST - F;\ F = forcing$

$(\sigma_u, \sigma_v) =$ Bck ERROR

$h =$ F ERROR

$$v_{opt} = v_{bck} + u_0 sin\phi + v_0 cos\phi$$
$$u_{opt} = u_{bck} - u_0 cos\phi + v_0 sin\phi$$

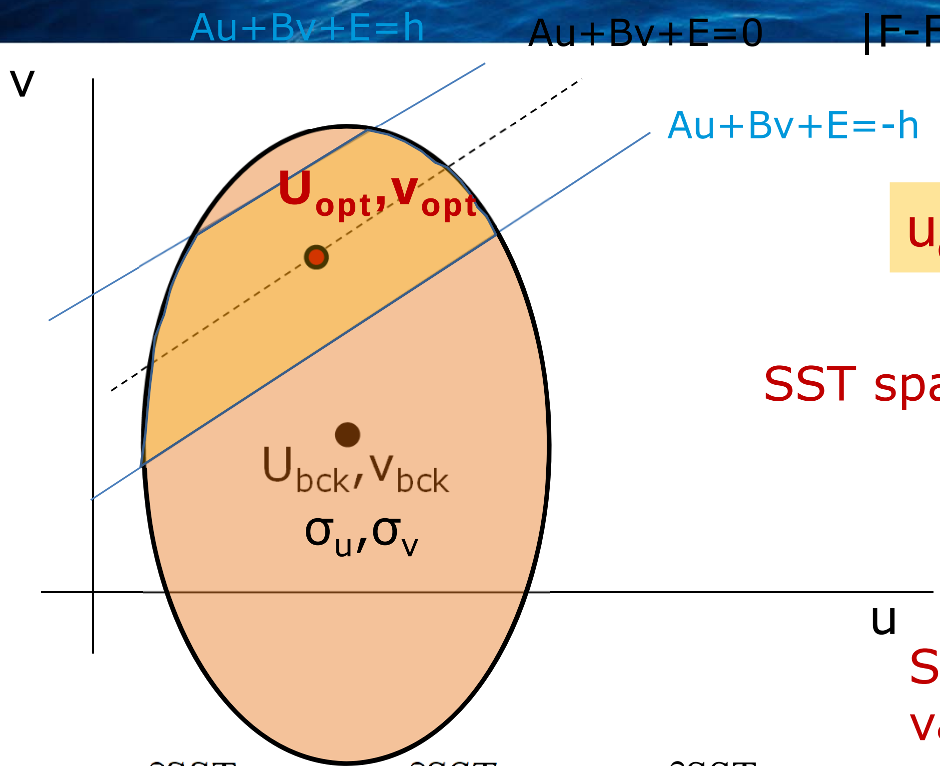
$$\phi = f(A, B)$$
$$u_0 = f(A, B, \bar{u}_{bck}, \sigma_u, \sigma_v, h, \partial_t SST, \phi)$$
$$v_0 = u_0 \cdot f(\phi, \sigma_u, \sigma_v)$$

$$F = [\partial_t SST]_{L>500km} \quad (\sigma_u, \sigma_v, h)$$

From *in-situ* measurements (drifters) (as in Rio and Santoleri, 2018.)

An accurate SST is crucial for the current improvement.

Synergy SSH/SST: method based on Pitterbarg 2009



$|F-F_{bck}|<h$

$$\frac{\partial SST}{\partial t} + u\frac{\partial SST}{\partial x} + v\frac{\partial SST}{\partial y} = F$$

F= source and sink terms.

$$A = \frac{\partial SST}{\partial x} \qquad B = \frac{\partial SST}{\partial y} \qquad E = \frac{\partial SST}{\partial t} - F_{bck}$$

$u_{opt}=u_{bck}+u_0\sin\phi+v_0\cos\phi \quad v_{opt}=v_{bck}-u_0\cos\phi+v_0\sin\phi$

$$\Phi = f(A, B)$$

$$u_0 = f\left(A, B, E, Ubck, \sigma_u, \sigma_v, h, \frac{\partial SST}{\partial t}, \Phi\right)$$

$$V_0 = u_0 f(\Phi, \sigma_u, \sigma_v)$$

SST spatial variations

Background velocity error

SST temporal variations

Forcing term error

Input data sets

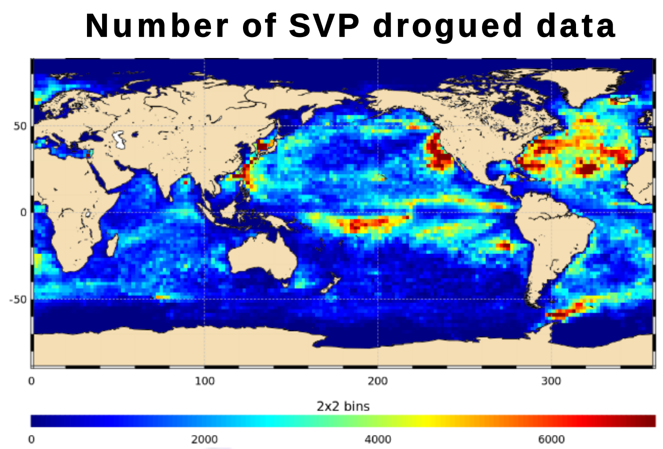
From 1998 to 2017:

- DUACS18 geostrophy (Reprocessed) daily map, 0.25 x0.25 spatial resolution

- REMSS MW SST (foundation SST≈10m depth) daily map, 0.25x0.25 spatial resolution
  from TMI, AMSR-E, AMSR2 and WindSat and GMI after 2014.

- SVP 15m drogued velocity 6 hourly

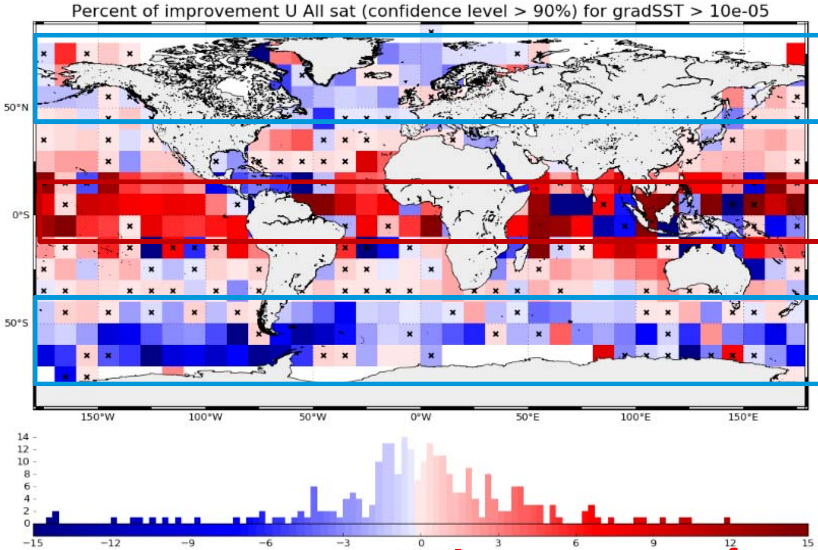
- SVP SST measurement 6 hourly



1998-2017 results

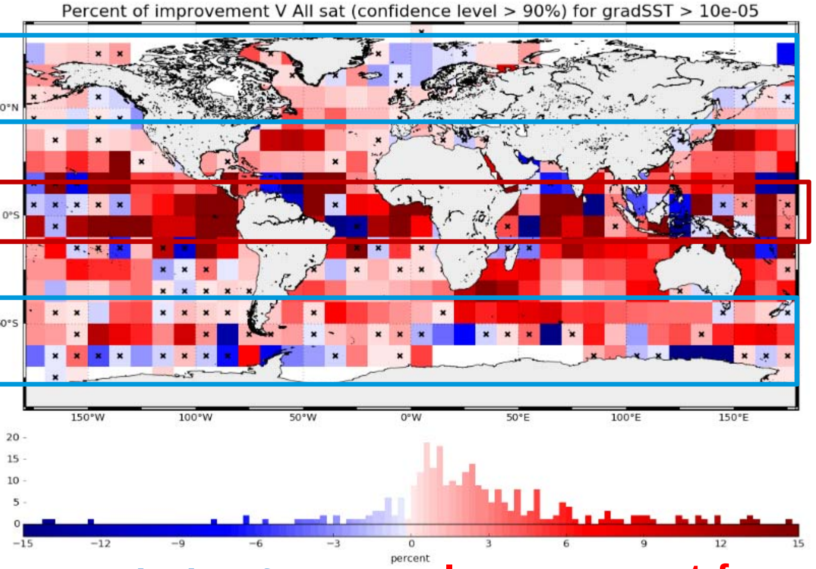
<u>% of improvement:</u> $100*(1-RMSU_{opt}/RMSU_{bck})^2$
(RMS from SVP)

Degradation at high latitudes.
In the ACC, the forcing error shows some local low values (less than 10^{-6} to 3.5 10-6 °C/s), but the error on the SST maps shows higher levels (see section 8 of Rio et al, 2018).



Degradation from background

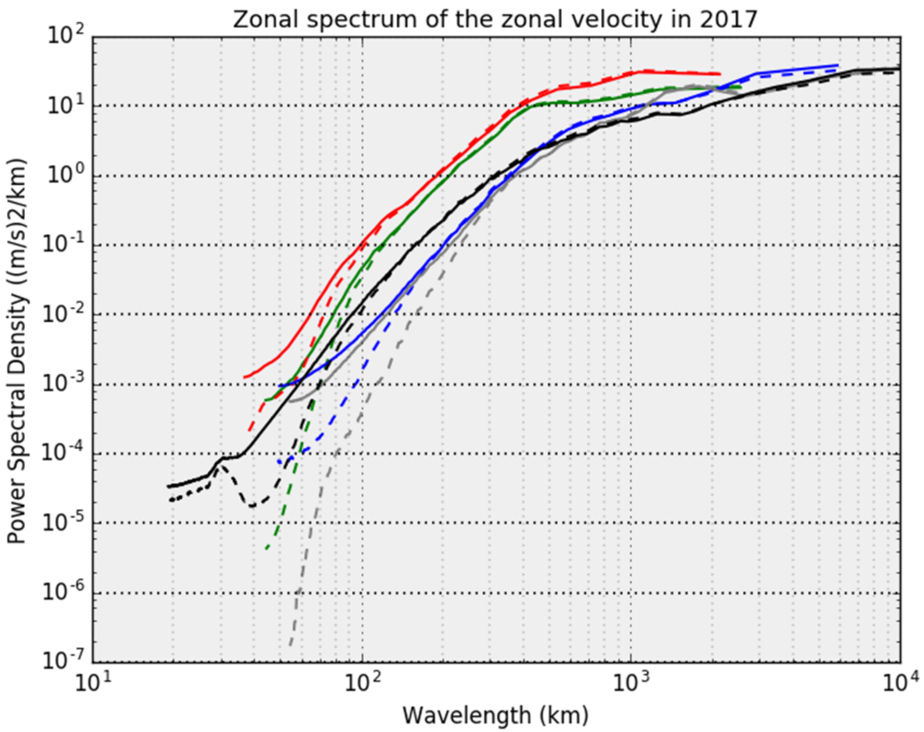
Improvement from background



Degradation from background

Improvement from background

1998-2017 results



background
optimized

Increase energy at scales below:

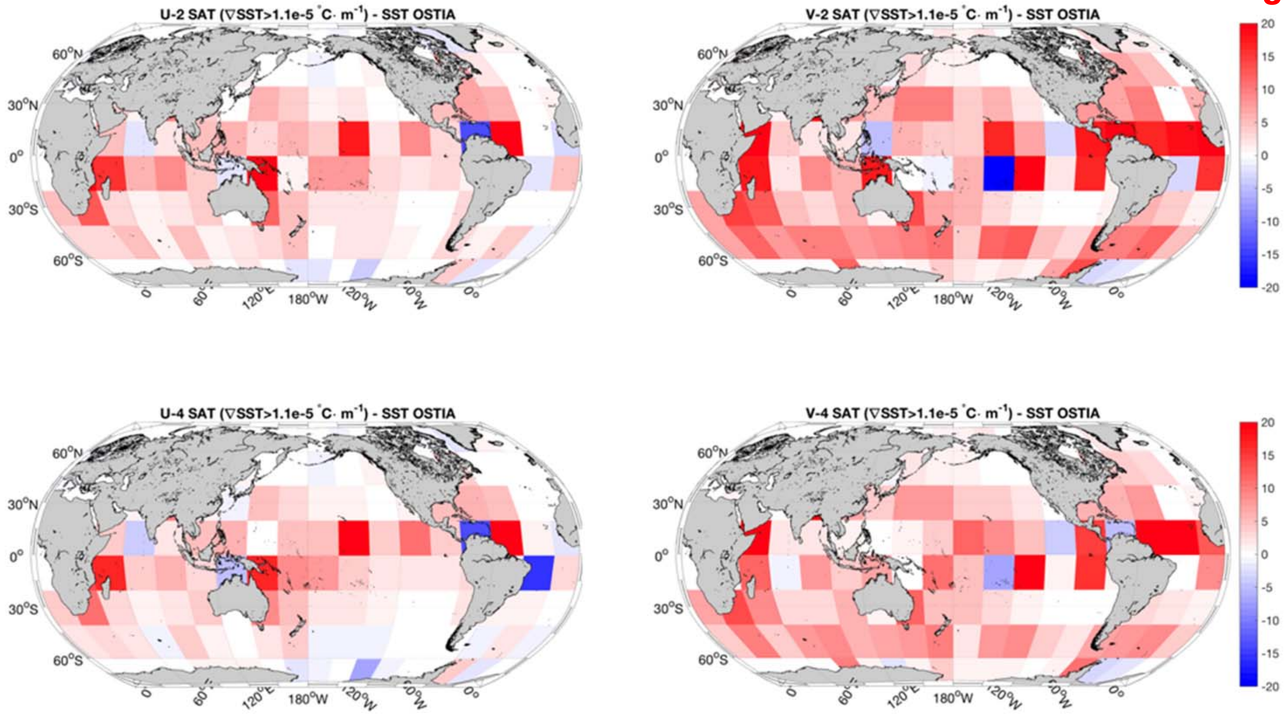
Global:	100km
Gulf Stream	100km
Agulhas	100km
Indian Ocean	150km
Tropical Pacific	300 km

Future work:
Improved near-surface currents using SST

$$\mathrm{IMPROVE}_{(\mathrm{U,V})} = 100 \cdot \left[1 - \left(\frac{RMS^{OPT}_{(U,V)}}{RMS^{BCK}_{(U,V)}}\right)^2\right]$$

DUACS18 + SST OSTIA

Improvement from background



Degradation from background

Validation against the SVP in-situ measured currents (% IMPROVEMENT, LOCAL STATISTICS, 20°x20° box)

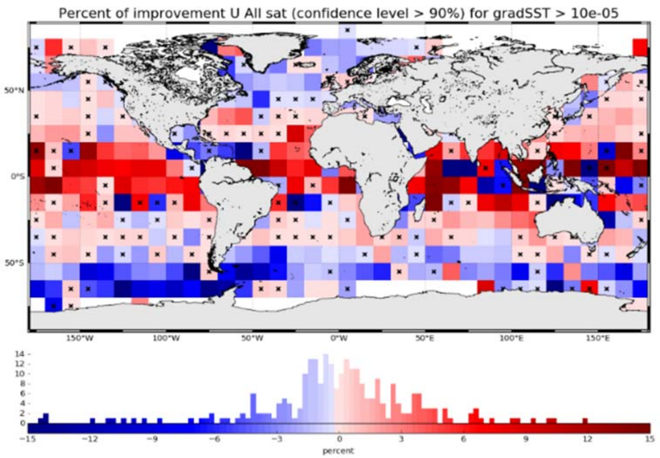
- Almost everywhere: improvement over the background from altimetry (CMEMS/DUACS 18)
- Area of degradation, especially at high latitudes that need to be further investigate
- Improvement mainly for meridional component

Perspectives: update error terms

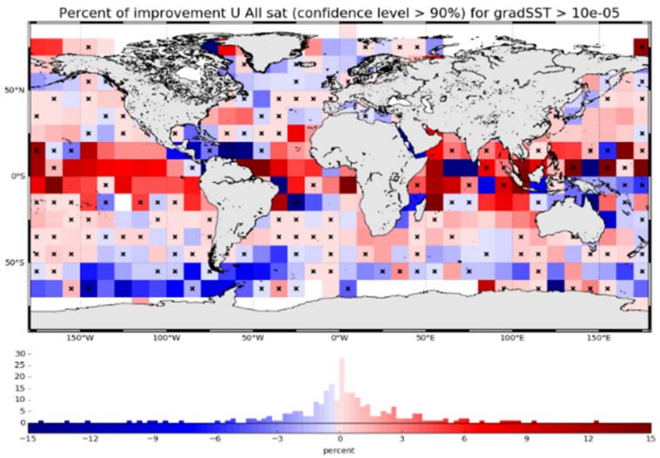
- Run the Optimal reconstruction with new calibration of the input parameters re-compute (σ_u, σ_v, h) consistently with the background currents and SST data used in the reconstruction. At the moment, maps computed as in **Rio and Santoleri 2018** are used**.**

Preminiminary results show a better performance at high latitude and on zonal velocity

Rio and Santoleri 2018 parameterization



Updated background error



Updated forcing error