Improving the altimeter derived geostrophic currents using sea surface temperature images: feasibility study and application on real datasets

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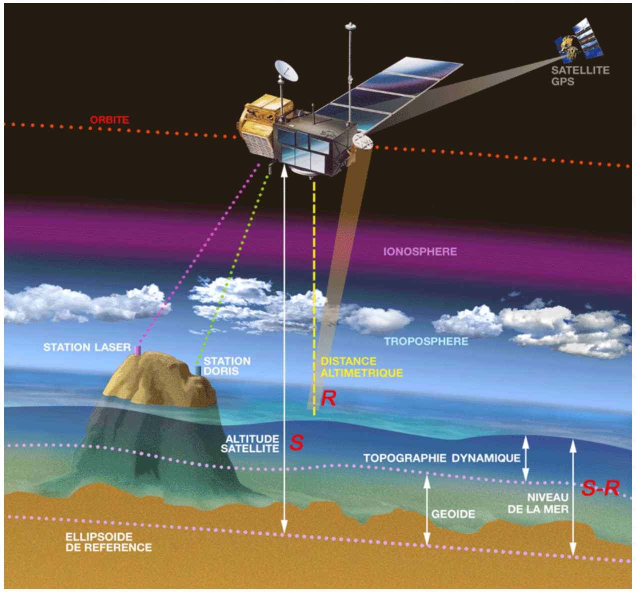
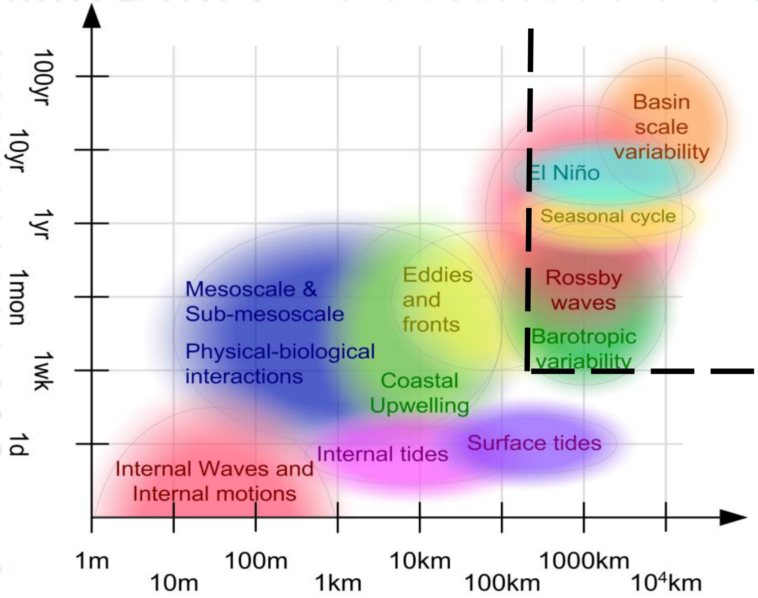
CONTEXT

➢ Limitations of the altimetry system for ocean current estimation



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

$$v = \frac{g}{f}\frac{\partial h}{\partial x}$$

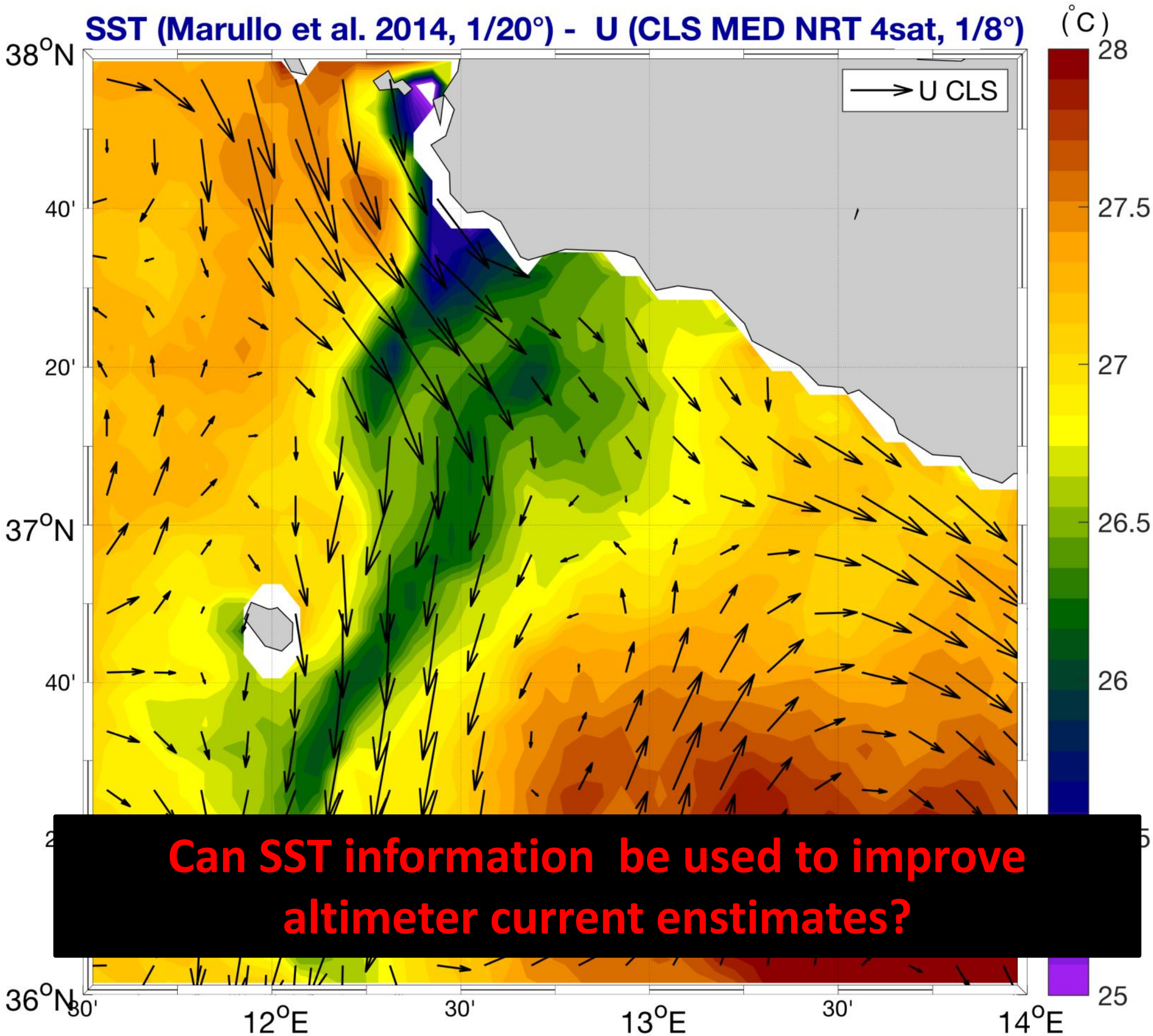


❖ Only the **geostrophic component of the surface current** is obtained

❖ For a **limited part of the spatio-temporal spectra**

In order to go beyond the altimeter system limitations, **new sensors and new methodologies must be explored**

Our aim is to use SST field data to improve altimeter current enstimates



Can SST information be used to improve altimeter current enstimates?

METHOD

Require the velocity field (u,v) to obey the SST evolution equation and inverse it for the velocity vector:

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

F(x,y,t) represents the source and sink terms (insolation, net infrared radiation, latent and sensible heat fluxes)

Challenge: only **along-gradient velocity** information can be retrieved from the tracer distribution at subsequent times in **strong gradients areas**.

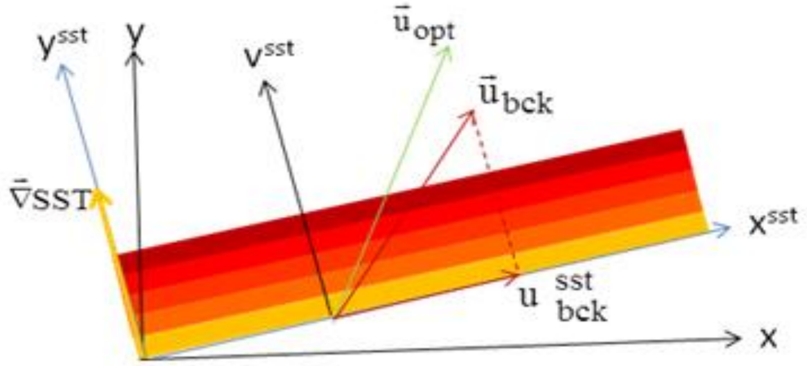
Piterbarg et al, 2009; Mercatini et al, 2010 : Use a background velocity information (u_{bck}, v_{bck}) so that the satellite tracer information is used to obtain an optimized 'blended' velocity (u_{opt}, v_{opt}).

We applied the methodology on successive SST images using the low resolution, geostrophic altimeter velocities as background velocities

Perfectly known forcing F

Require the velocity field (u,v) to obey the SST evolution equation and inverse it for the velocity vector:

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



$$u_{opt} = u_{bck} - \frac{A(Au_{bck} + Bv_{bck} + E)}{A^2 + B^2}$$

$$v_{opt} = v_{bck} - \frac{B(Au_{bck} + Bv_{bck} + E)}{A^2 + B^2}$$

Change of coordinates (x,y) -> (x^{sst},y^{sst})

$$\frac{\partial SST}{\partial x^{sst}} = 0 \quad \Rightarrow \quad v^{sst} = \frac{F - \frac{\partial SST}{\partial t}}{\frac{\partial SST}{\partial y^{sst}}}$$

u^{sst} :infinite solutions

use of a background information (u_{bck},v_{bck})

Where:

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

u_{bck}, v_{bck} -> altimer geostrophic velocity

Piterbarg et al, 2009

Forcing term estimate (F_{bck})

The Heat conservation Equation

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

The source and sink terms F

$$F = \frac{1}{H}\int_{z=0}^{z=H} -w(z)\frac{\partial T(z)}{\partial z}dz + \frac{\kappa_x}{H}\int_{z=0}^{H}\frac{\partial^2 T(z)}{\partial x^2}dz + \frac{\kappa_y}{H}\int_{z=0}^{H}\frac{\partial^2 T(z)}{\partial y^2}dz + \frac{\kappa_z}{H}\int_{z=0}^{H}\frac{\partial^2 T(z)}{\partial z^2}dz + \frac{Q(H)}{\rho C_p H} - \frac{w_e}{H}(T_m - T_b)$$

Vertical advection → ~0

Diffusion → ~0

Heat fluxes → Large spatial scale of $\frac{\partial SST'}{\partial t} = Fbc_k$

Entrainment velocity (0 in case of shoaling)

From Rio et al, 2016

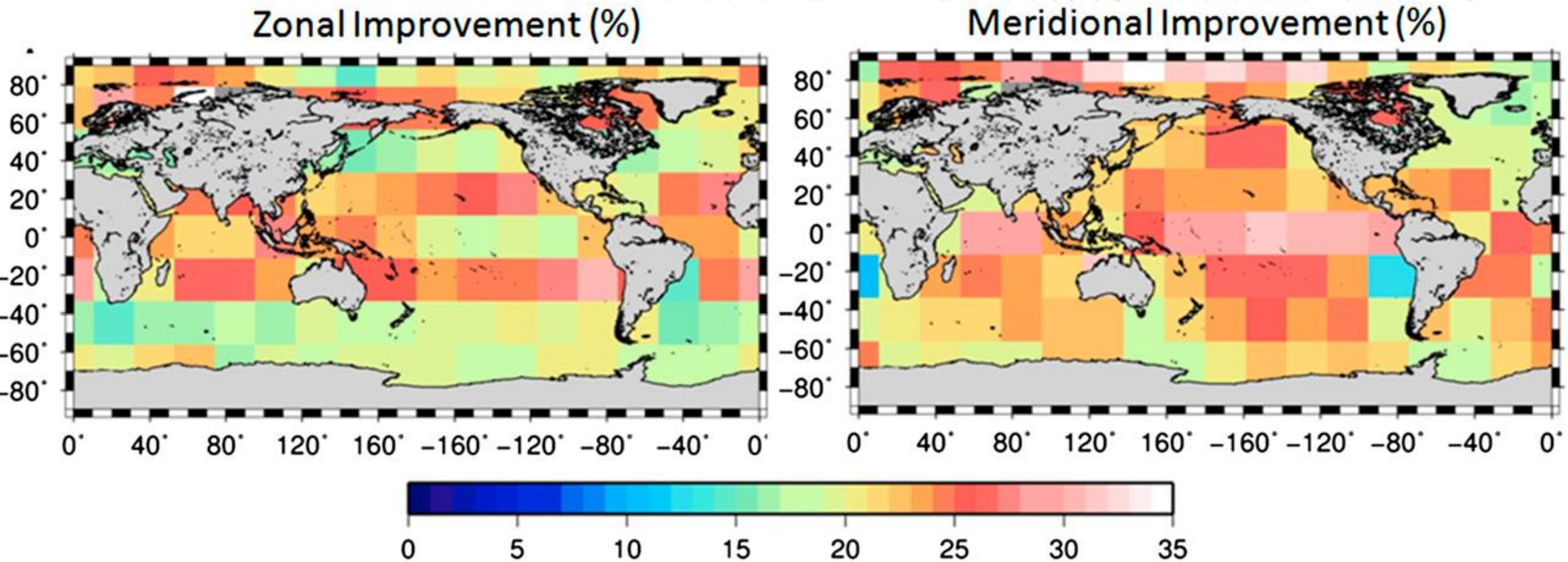
$$\frac{\partial SST}{\partial t} = \frac{\partial SST'}{\partial t} + \frac{\partial SST''}{\partial t}$$

$$E = \frac{\partial SST}{\partial t} - \frac{\partial SST'}{\partial t}$$

Test of the Method: OSSE Experiment

Method tested using model data of the Mercator Ocean Global Model Forecsting system.

- Mercator ORCA12: model resolution 1/12°, one year (2013)
- Model data: sea surface height, temperature, and surface velocity
- **Altimeter surface geostrophic currents simulated from the modeled SSH**
- **Maps of SST simulated from model SST**
- **Model surface currents –> reference velocity**



everywhere, >30% on the meridional component in the equatorial band

Rio et al JTECH 2016

Test method with real SST data: DATA used

- Altimetry: DUACS L4 gridded products: « twosat » and « allsat »

- Sea Surface temperature: L4 OI maps from REMSS (100km, 4 days):
  - MW: based on microwave sensors only
    - resolution ¼°, daily maps
  - MW_IR: based on both microwave and infrared sensors
    - resolution ~9 km, daily

1 year of SST DUACS data: 2013

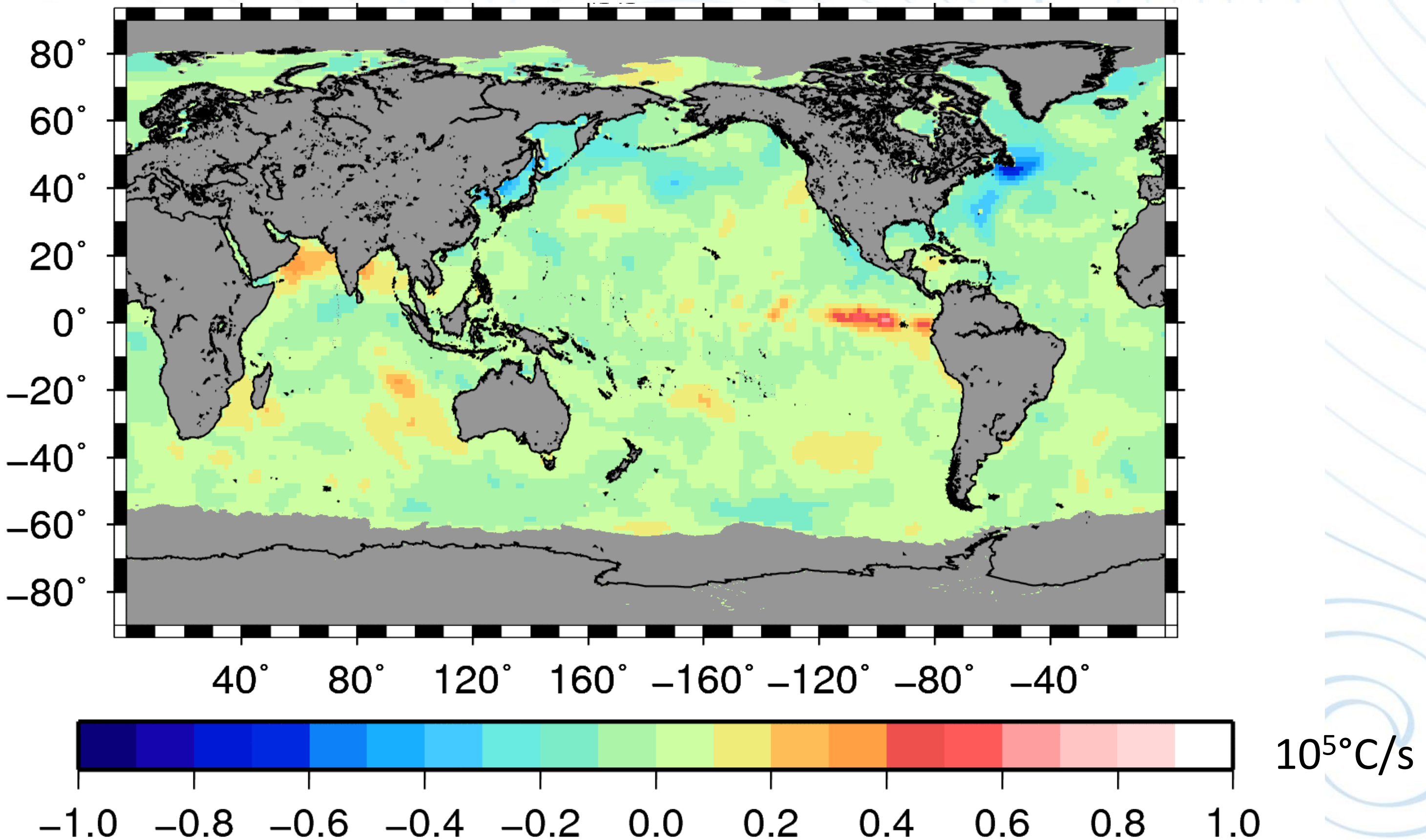
For validation (independent data):

- Drifting buoy velocities, SVP drogued, 6 hourly resolution along the buoy trajectory
- Chlorophyll L4 maps distributed by CMEMS, resolution 4km, daily

Forcing term estimate (F_{bck})

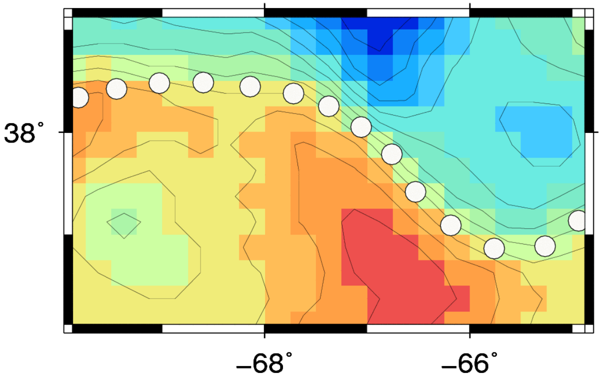
$$F_{bck} = \left(\frac{\partial SST}{\partial t} \right)_{scales>500km}$$

Example on September, 20th 2010

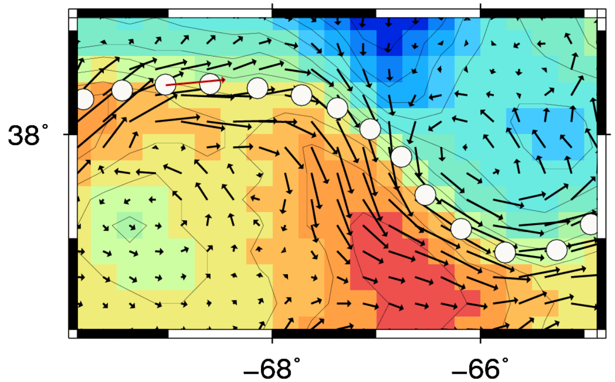


Example 1: Gulfstream, September 21st 2010

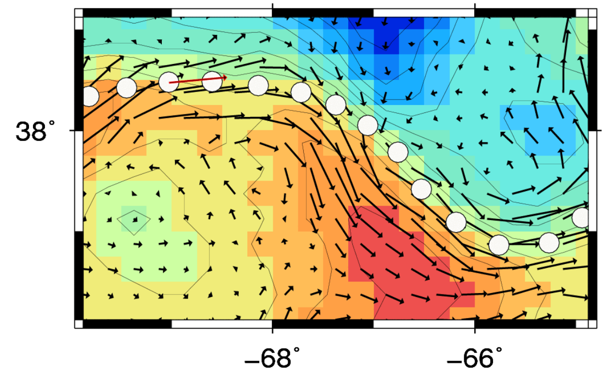
SST REMSS MW +
Buoy #88532



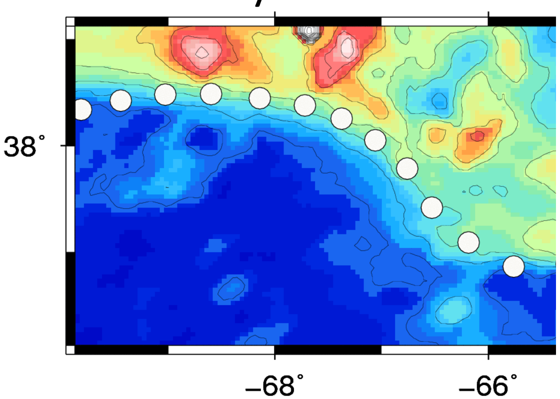
Alti (2SAT)



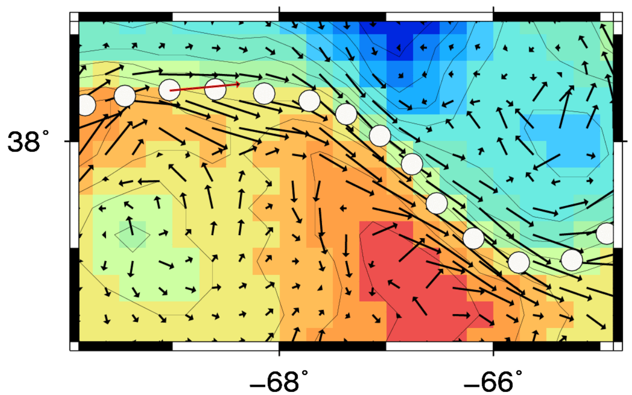
Alti (ALLSAT)



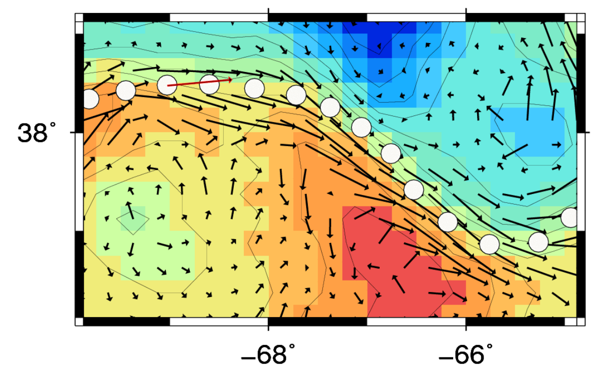
CMEMS CHL+
Buoy #88532

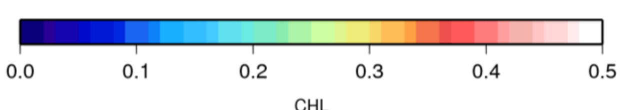


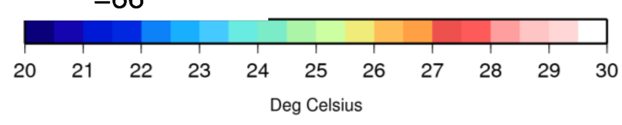
Alti (2SAT) + SST MW



Alti (ALLSAT) + SST MW

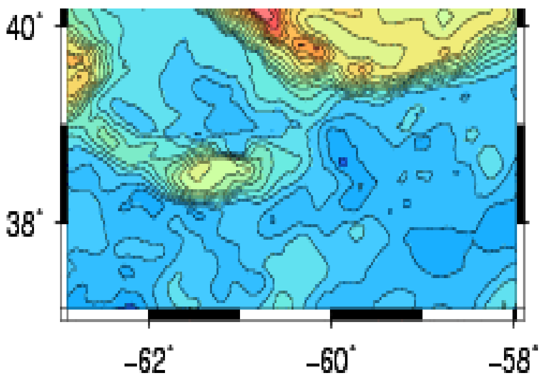




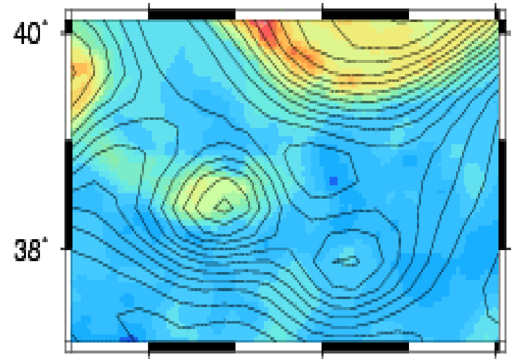


Example 2: Gulfstream, August, 8th 2015

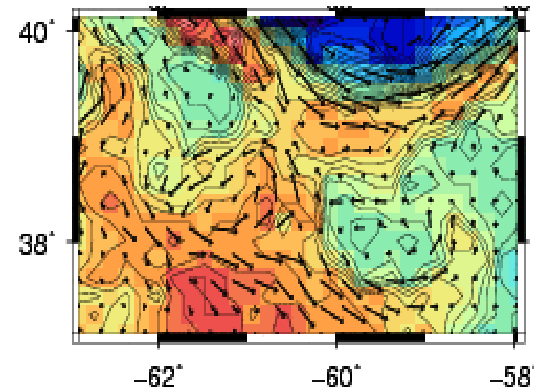
CHL

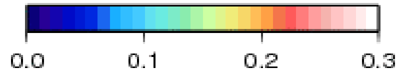


ALTI 2SAT
SSH isocontour

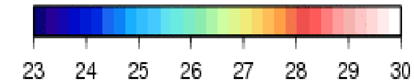


SST MW_IR



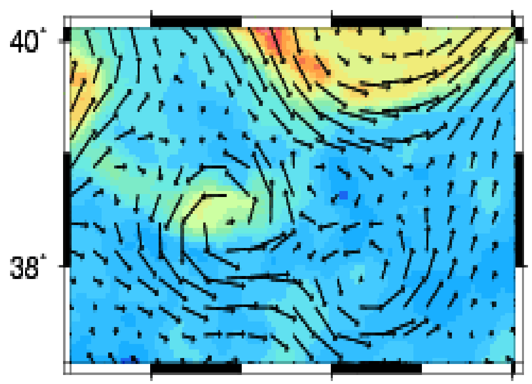


CHL

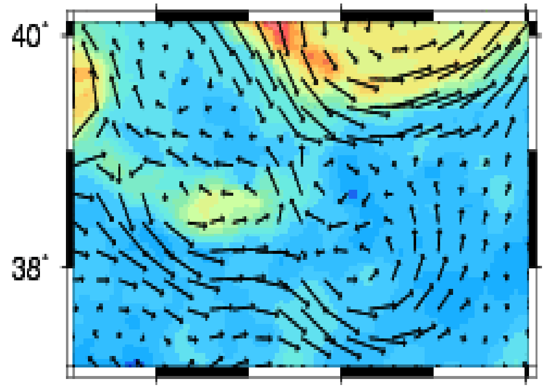


Altimeter velocities

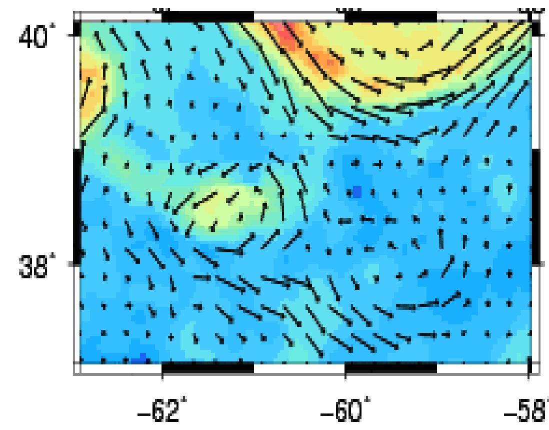
ALTI 2SAT



Alti ALL SAT

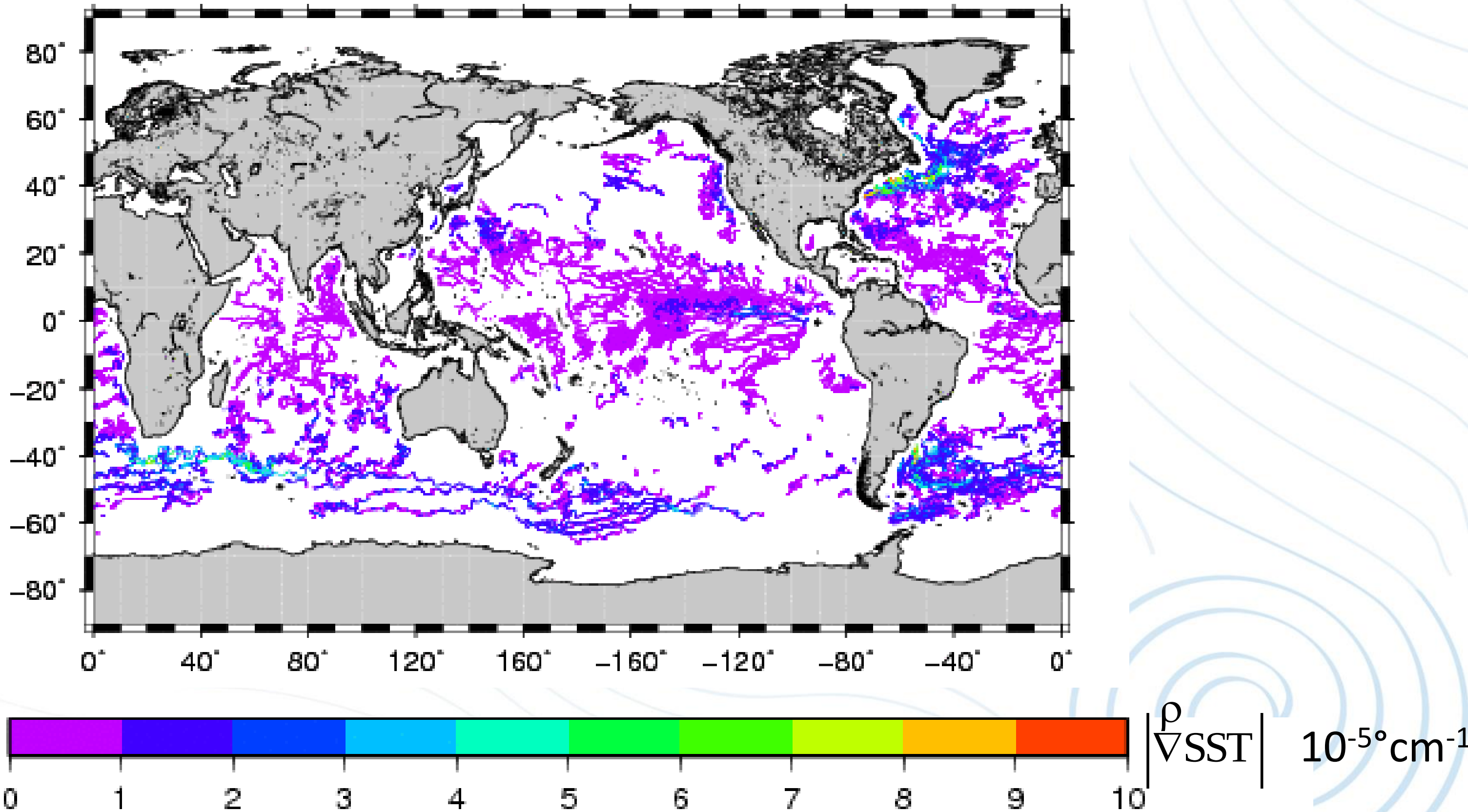


Optimal velocities



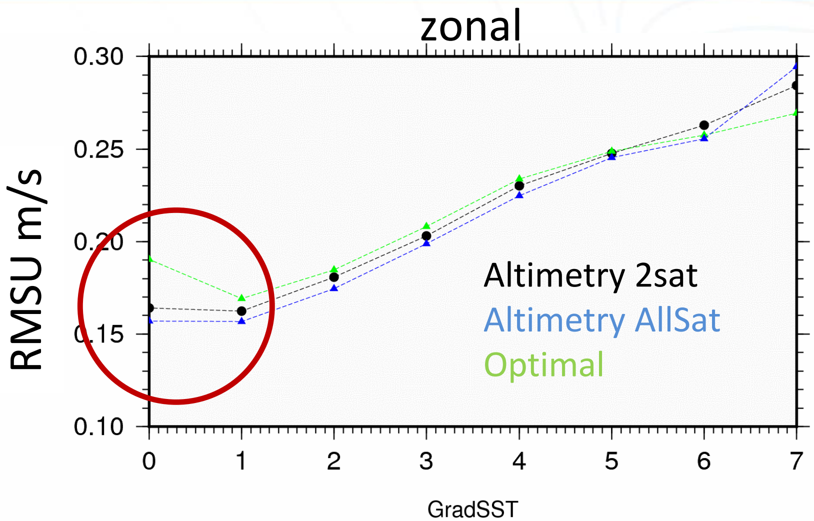
VALIDATION

1 year (2003) of global maps of optimal velocities have been calculated and compared to SVP-drogued drifting buoy velocities



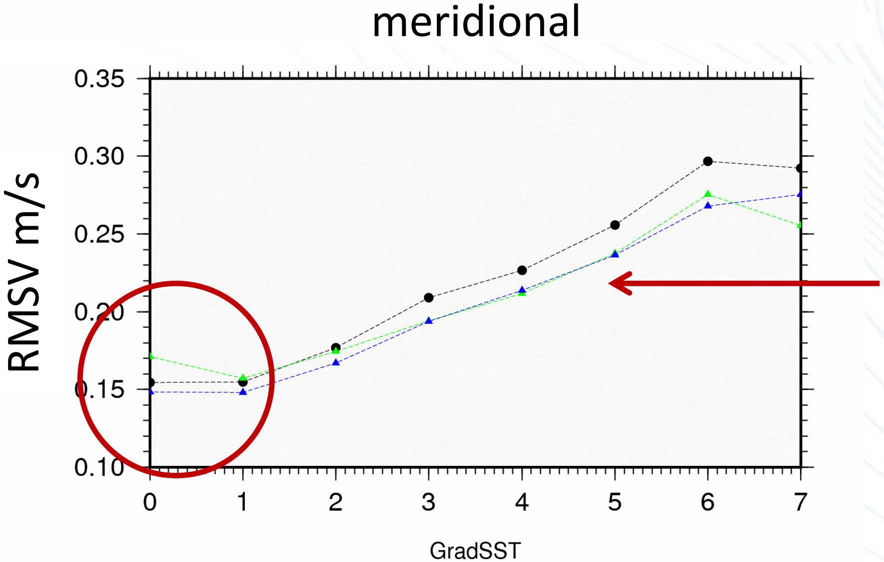
VALIDATION

Perfect Forcing F=F_{bck}



- Deterioration in weak gradients areas ($<10^{-5}$°/s)

Light degradation for the zonal component

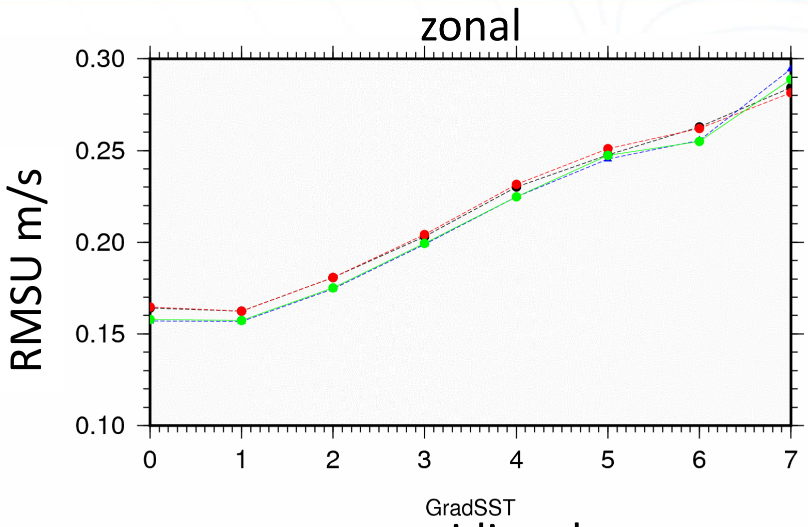


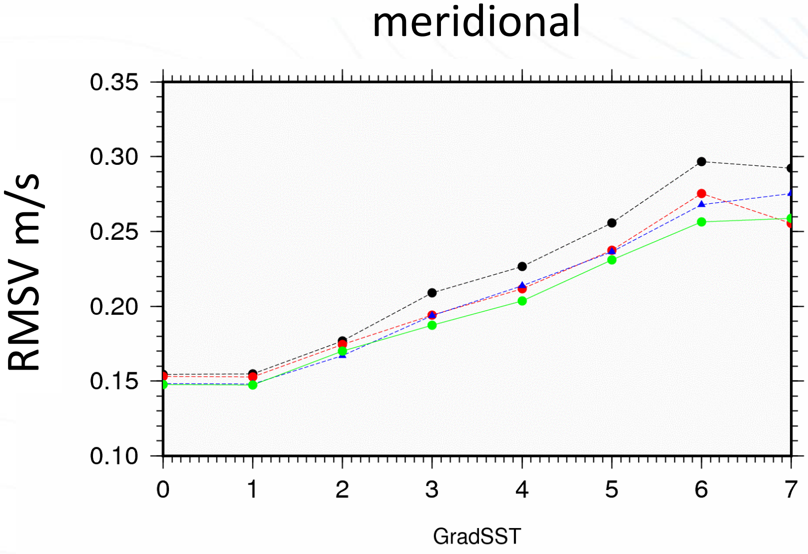
- Deterioration in weak gradients areas ($<10^{-5}$°/s)

- Strong improvement in strong gradients areas

2SAT+SST equivalent to ALLSAT

VALIDATION
Unknown Forcing $F=F_{bck} + \varepsilon$





Altimetry 2sat
Altimetry AllSat
Optimal unknown F (background=2SAT)
Optimal unknown F (backgound=Allsat)

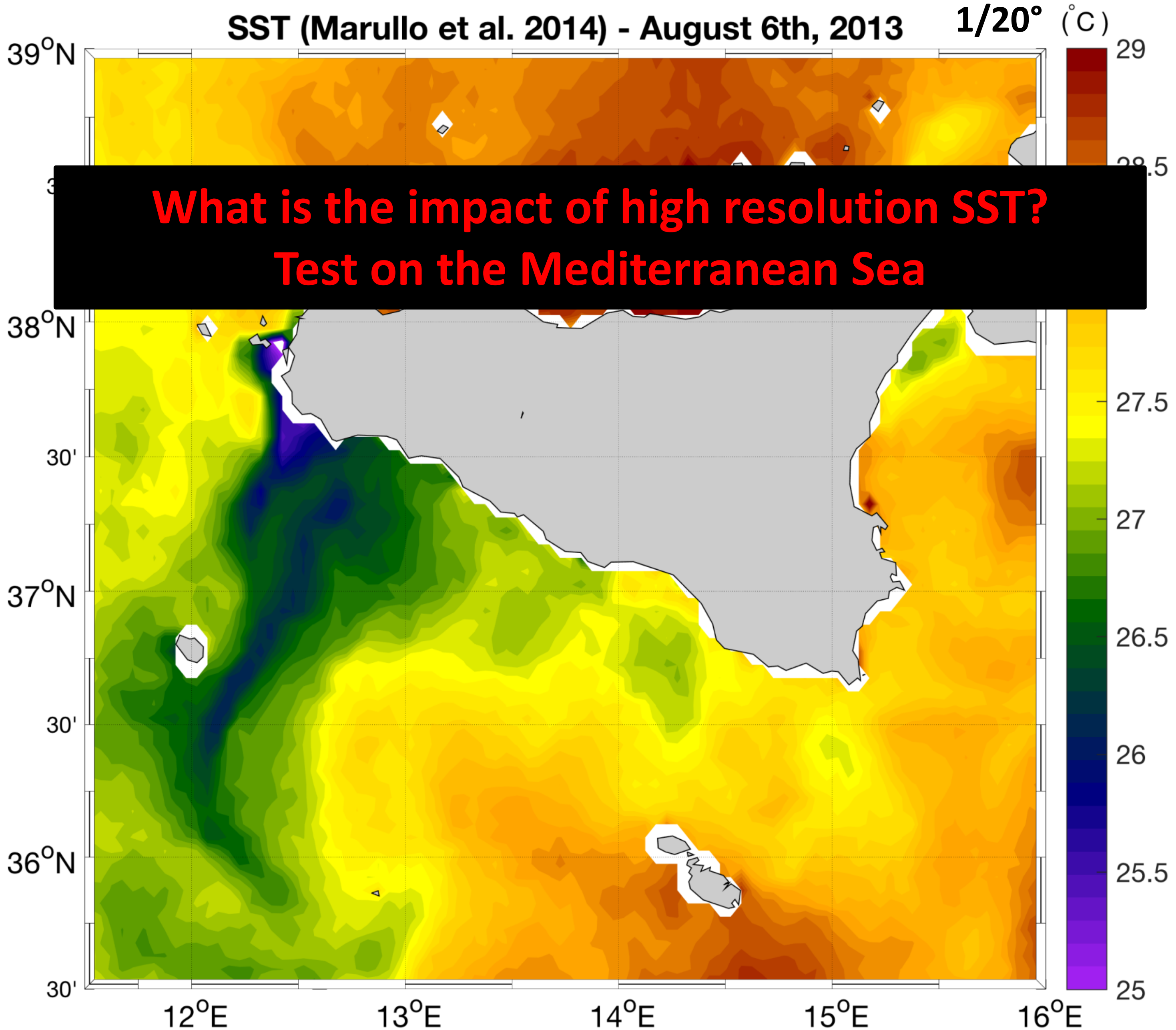
Further improvement obtained on the meridional component

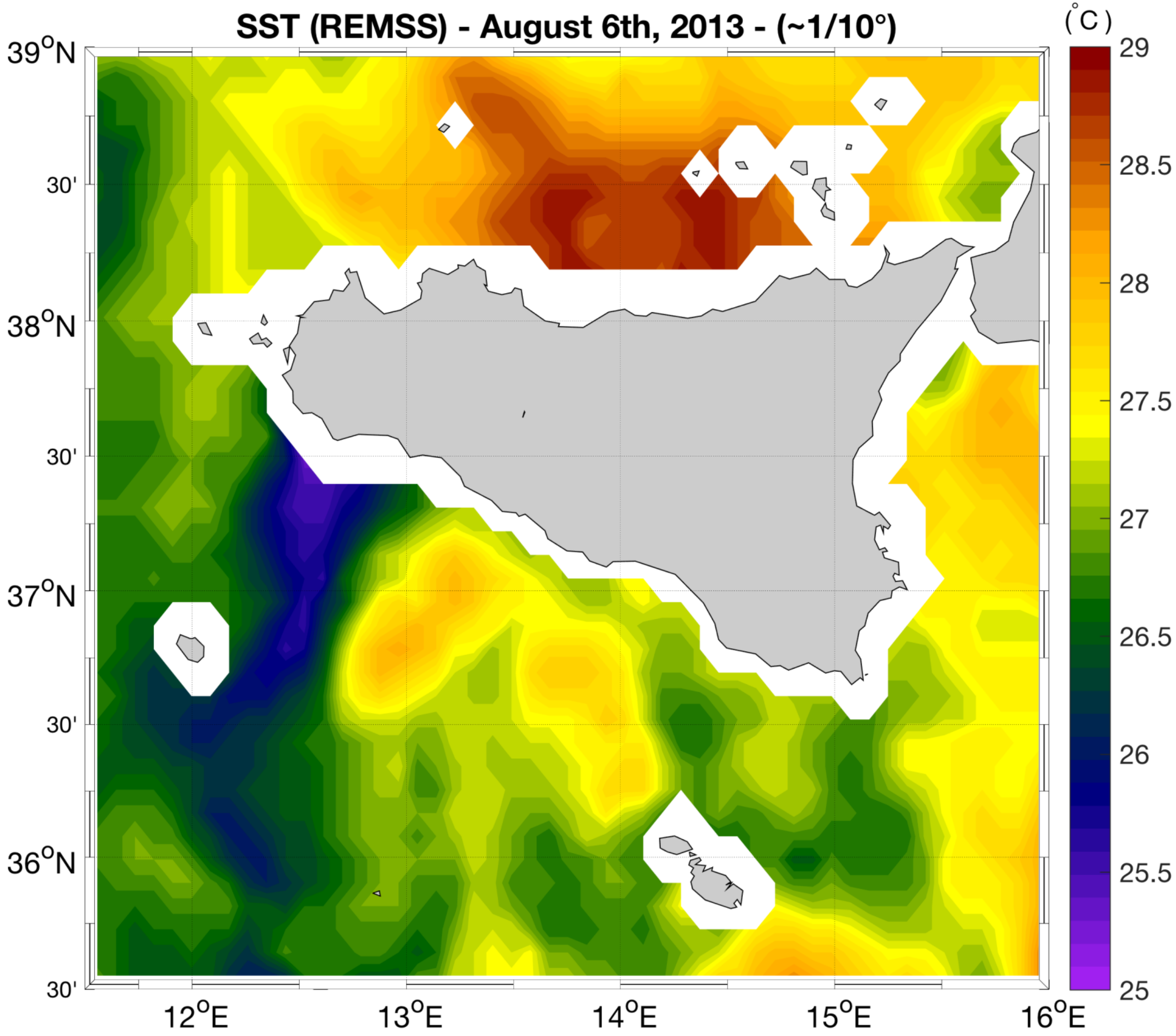
SST L4 MWIR REMSS Products 9km
OI maps **(100km, 4 days)**

Improvement expected at medium scales only

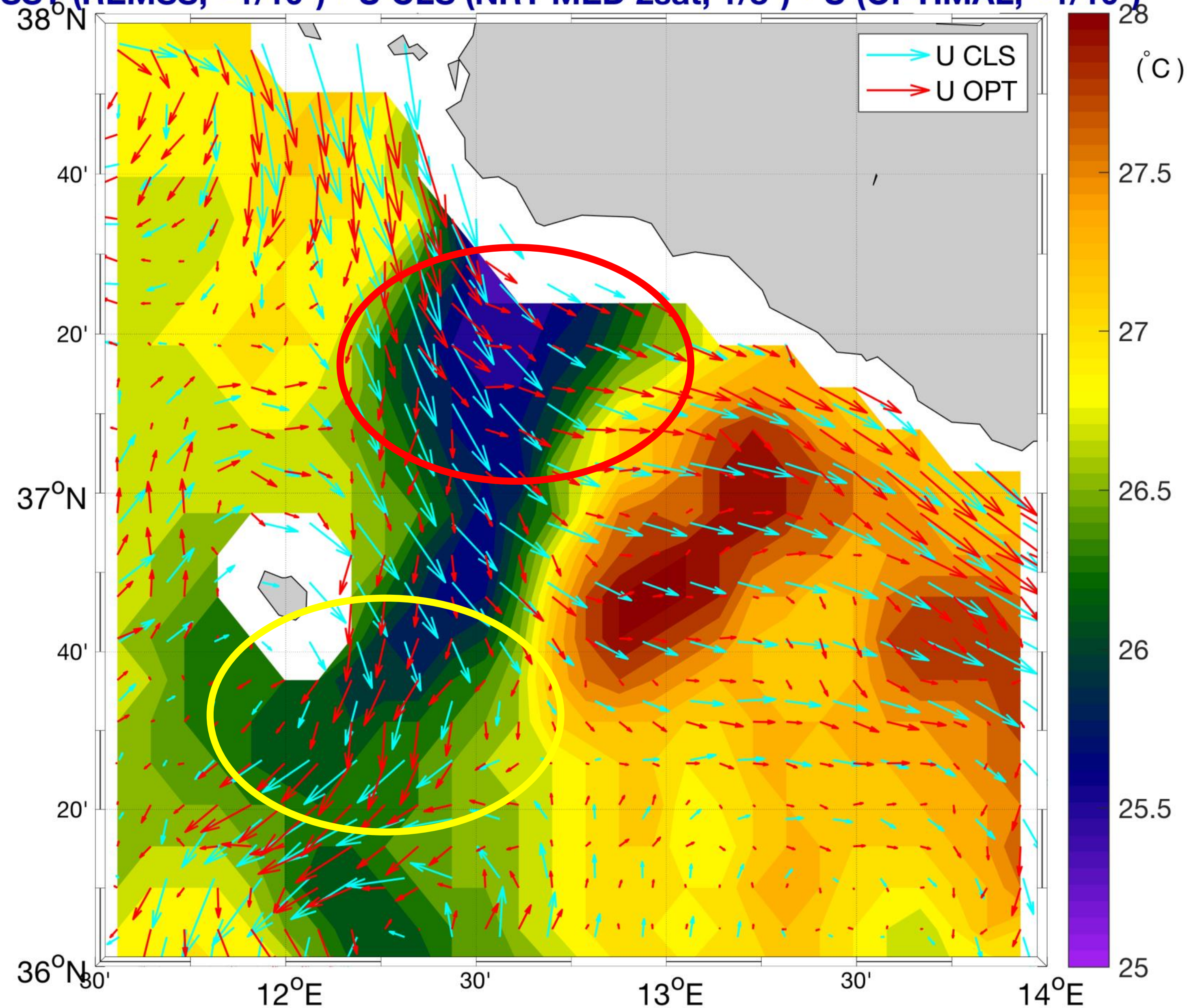
Further improvements expected using higher resolution SST products

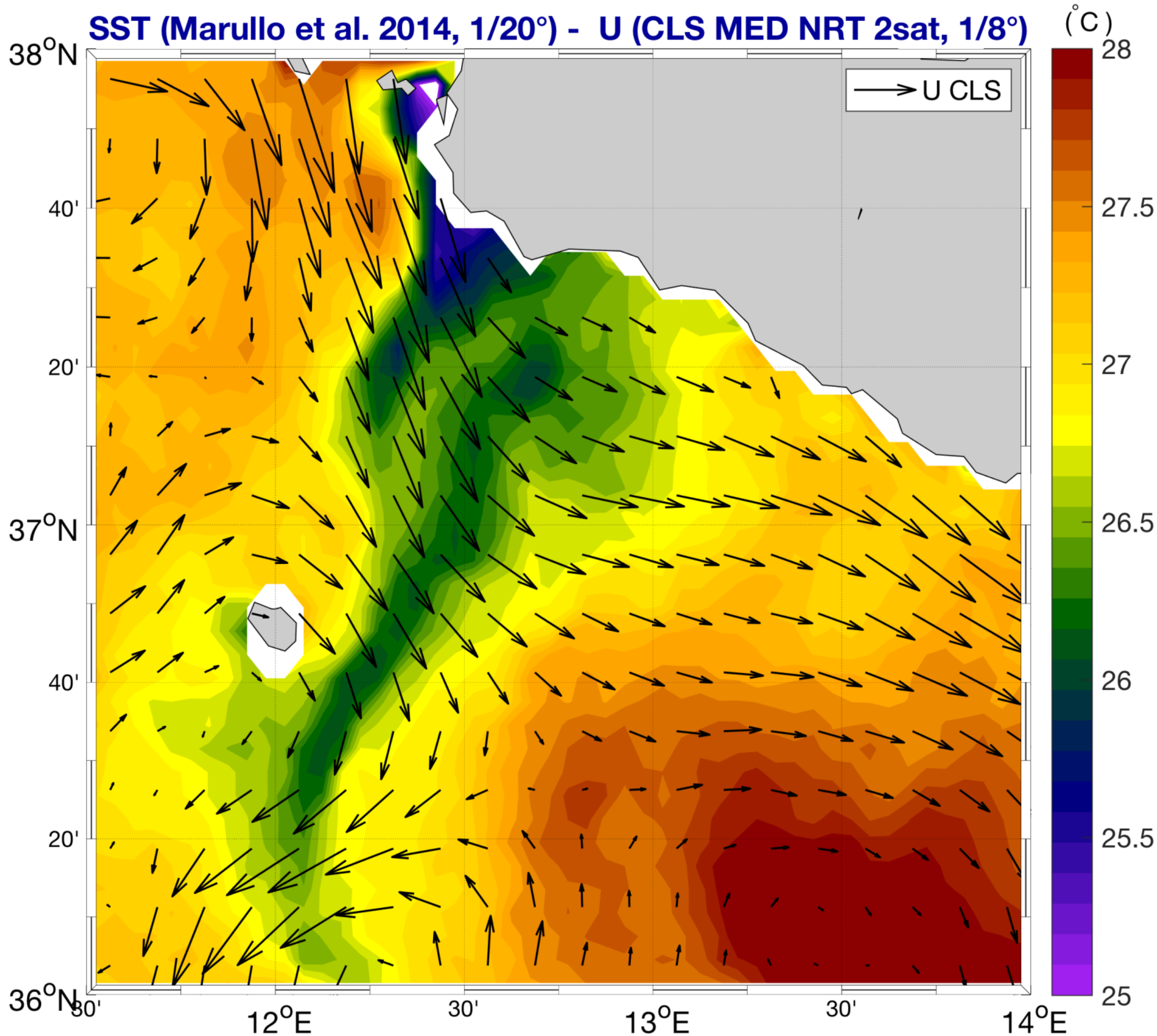
What is the impact of high resolution SST?
Test on the Mediterranean Sea



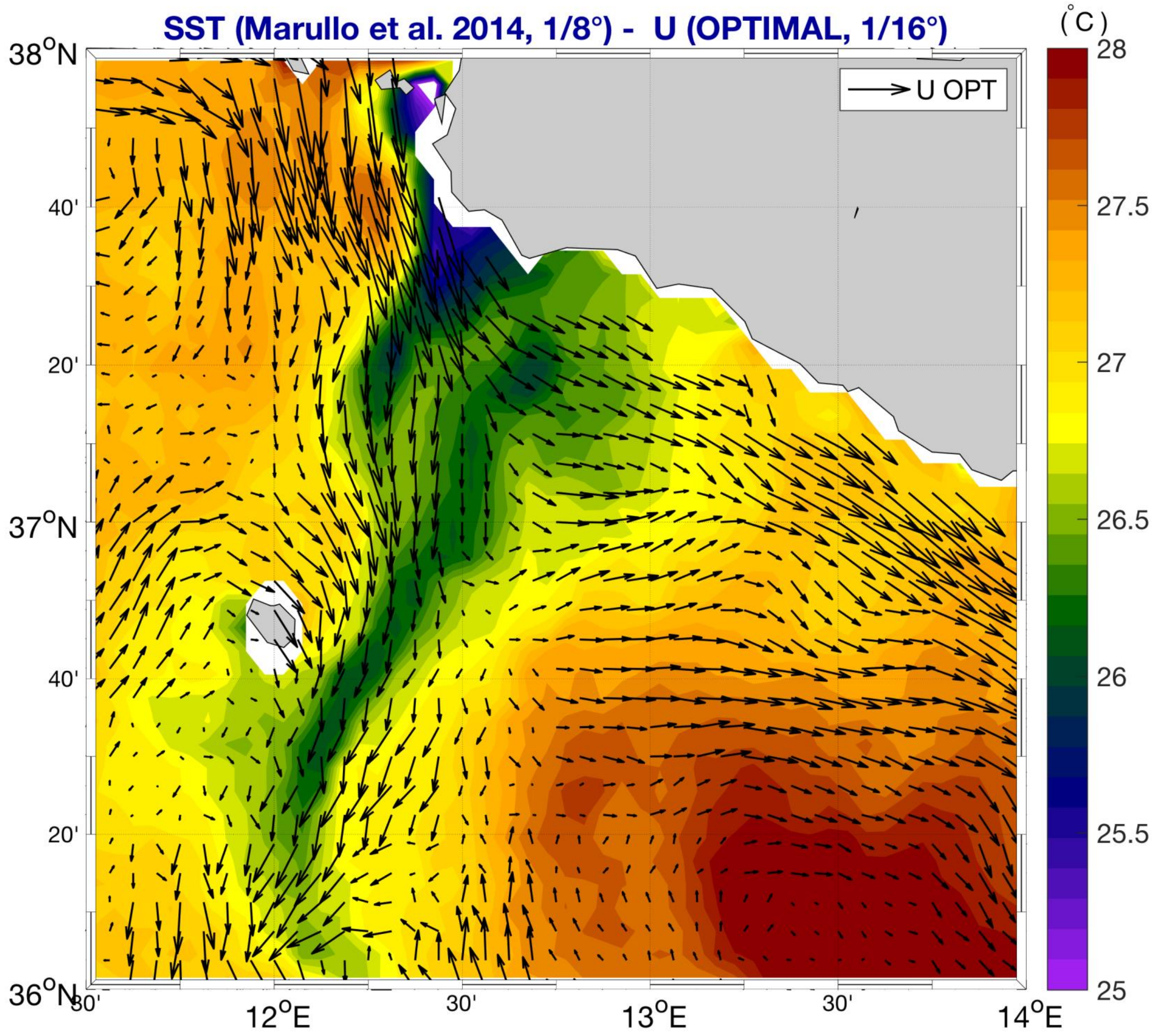

SST (REMSS) - August 6th, 2013 - (~1/10°)
39°N
30'
38°N
30'
37°N
30'
36°N
30'
12°E
13°E
14°E
15°E
16°E
(°C)
29
28.5
28
27.5
27
26.5
26
25.5
25

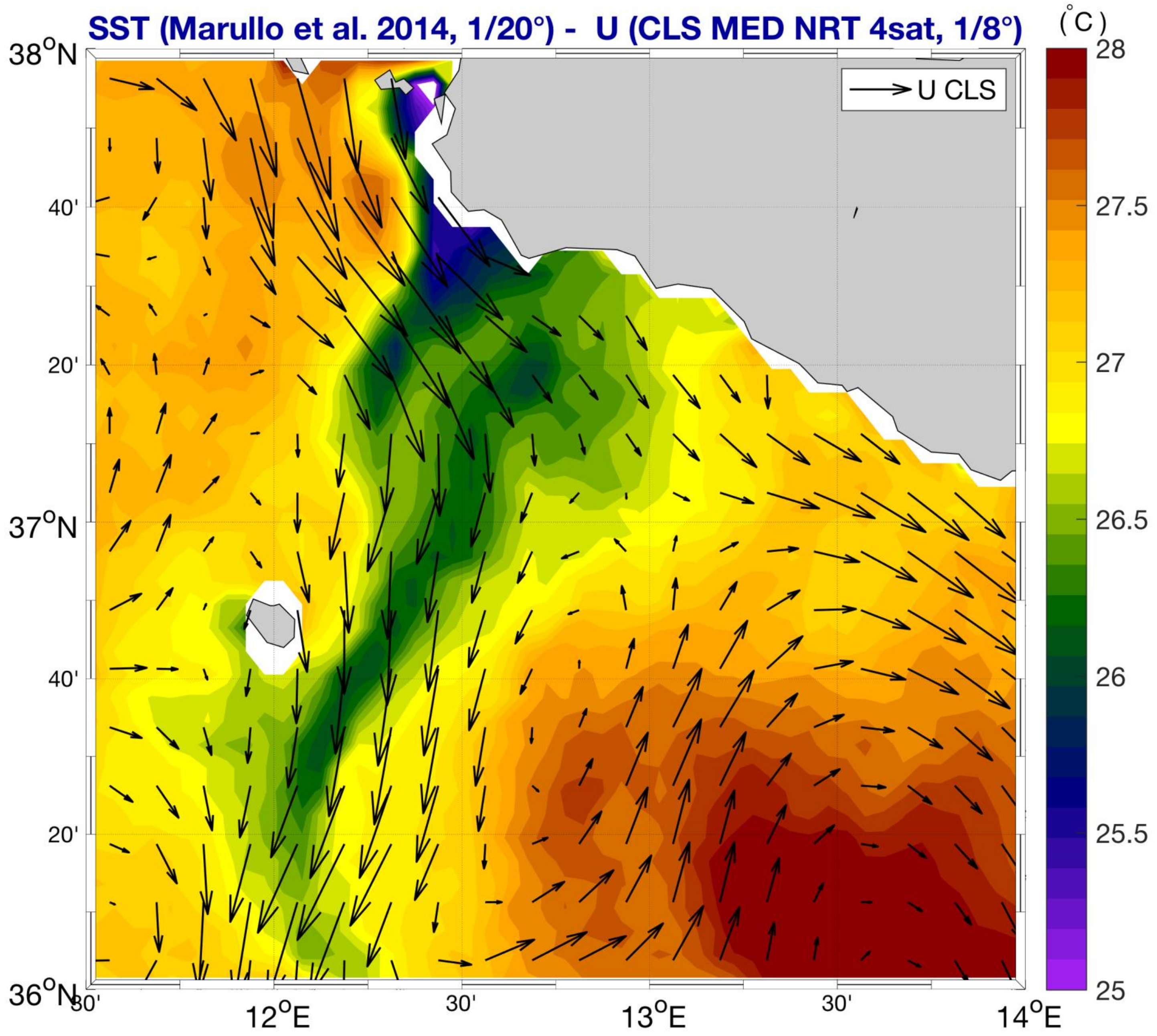
SST (REMSS, ~1/10°) - U CLS (NRT MED 2sat, 1/8°) - U (OPTIMAL, ~1/10°)





SST (Marullo et al. 2014, 1/20°) - U (CLS MED NRT 2sat, 1/8°)
U CLS
(°C)
28
27.5
27
26.5
26
25.5
25
38°N
40'
20'
37°N
40'
20'
36°N
30'
12°E
30'
13°E
30'
14°E


SST (Marullo et al. 2014, 1/8°) - U (OPTIMAL, 1/16°)
U OPT
(°C)
28
27.5
27
26.5
26
25.5
25
38°N
40'
20'
37°N
40'
20'
36°N
30'
12°E
30'
13°E
30'
14°E



SST (Marullo et al. 2014, 1/20°) - U (CLS MED NRT 4sat, 1/8°)
U CLS
(°C)
28
27.5
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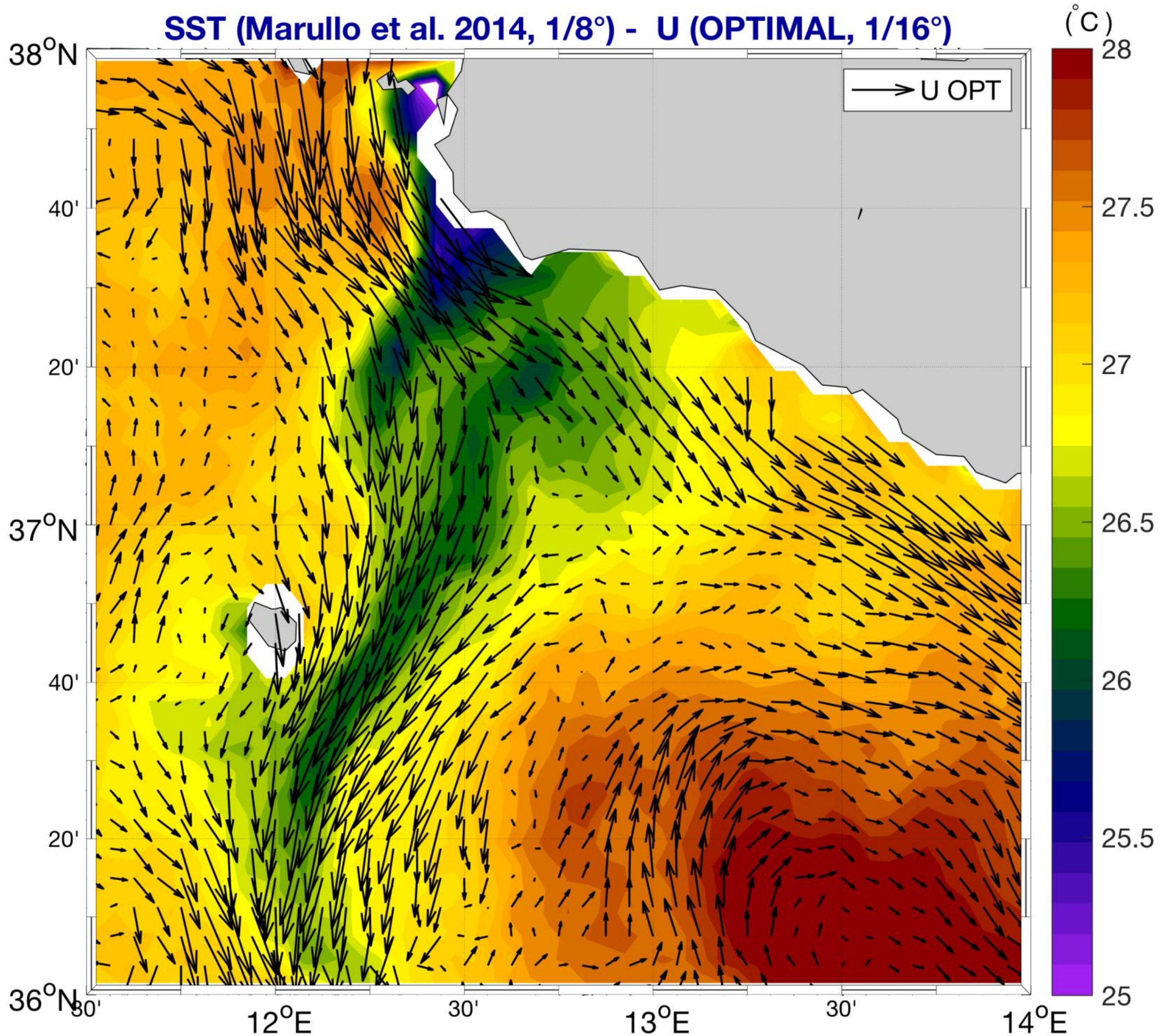
26.5
26
25.5
25
38°N
40'
20'
37°N
40'
20'
36°N
30'
12°E
30'
13°E
30'
14°E



SST (Marullo et al. 2014, 1/8°) - U (OPTIMAL, 1/16°)
U OPT
(°C)
28
27.5
27
26.5
26
25.5
25
38°N
40'
20'
37°N
40'
20'
36°N
30'
12°E
30'
13°E
30'
14°E

CONCLUSIONS

- A method has been implemented which **successfully combines SST and altimeter data** to **improve the altimeter derived surface currents**.

- **Systematic application for one year over the global ocean has been done and validated** through comparison to independent drifting buoy velocities.

- **Significant improvements (up to 20-30% locally)** are obtained in strong SST gradients areas for the meridional component of the velocity.

- In low gradients areas and for the zonal component of the velocity, weaker improvement is expected **by construction**. Still, a few % of improvements is obtained locally. In these areas, taking into account the forcing and background errors is **essential**.

- **Further improvements are expected** by:
  - Using higher quality, higher resolution (spatial and temporal) SST products
  - Better estimating the forcing term F and its error ε.