A new synergetic approach for the determination of the sea-surface currents in the Mediterranean Sea

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GHRSST XIX, EUMETSAT, *Darmstadt, June 5th, 2018*

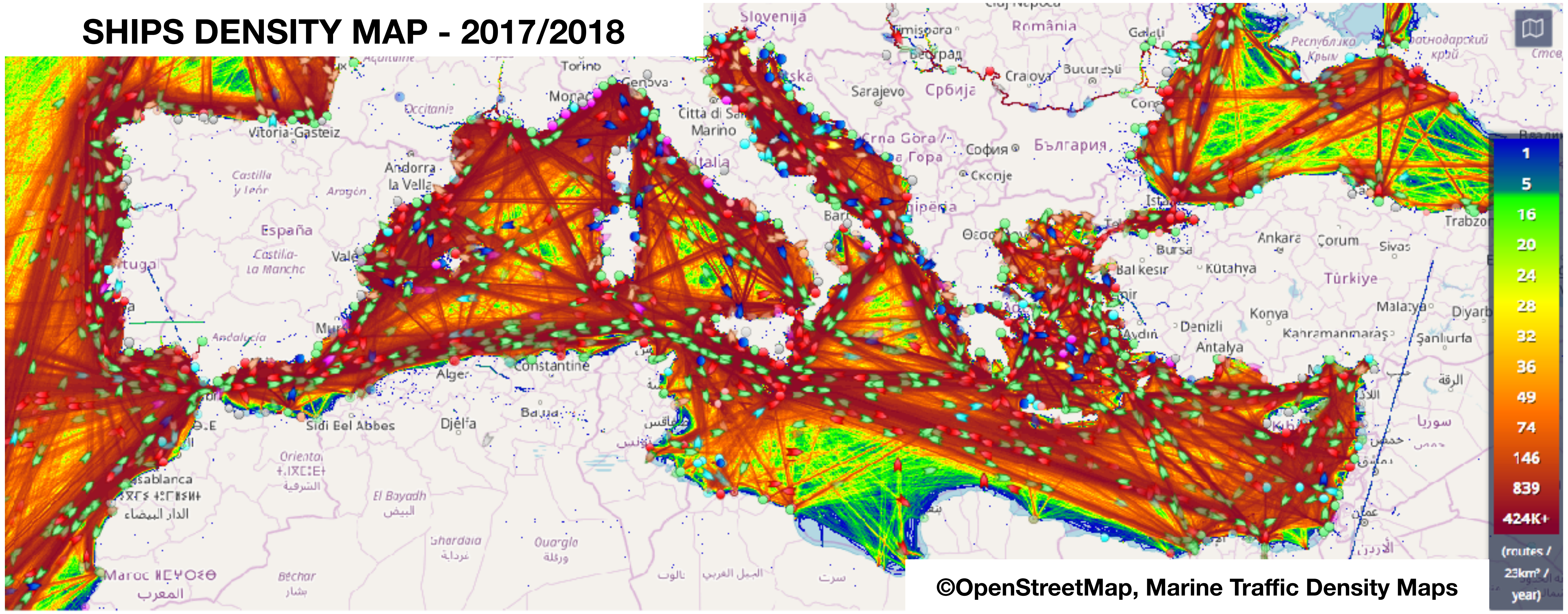
Context

Sea-surface currents: key variable in environmental sciences

Transport of oceanic tracers, Climate Studies, Application to human activities in the marine context

A Practical Example at Regional Scale: The Mediterranean Sea

SHIPS DENSITY MAP - 2017/2018



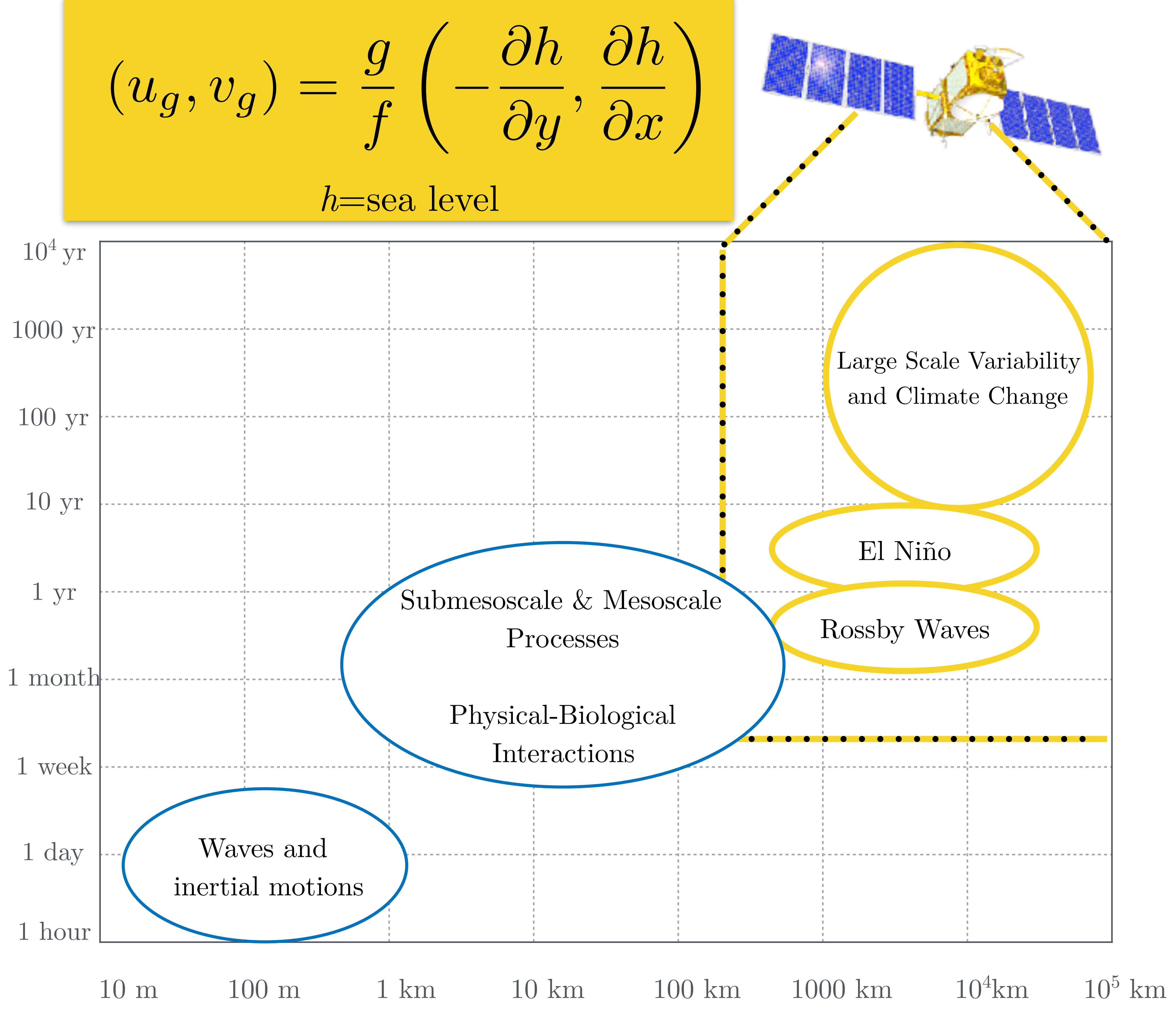
- Ship routing in the Mediterranean Sea: up to more ~400 k routes/20 km^2/year
- Relevance for the Marine Safety and Rescue Activities
- Estimated Illegal Oil Spill = 600 kTonnes per year (Pisano et al. 2016)

We need Synoptic, Repetitive, High Spatial and Temporal Resolution observations of the surface-currents

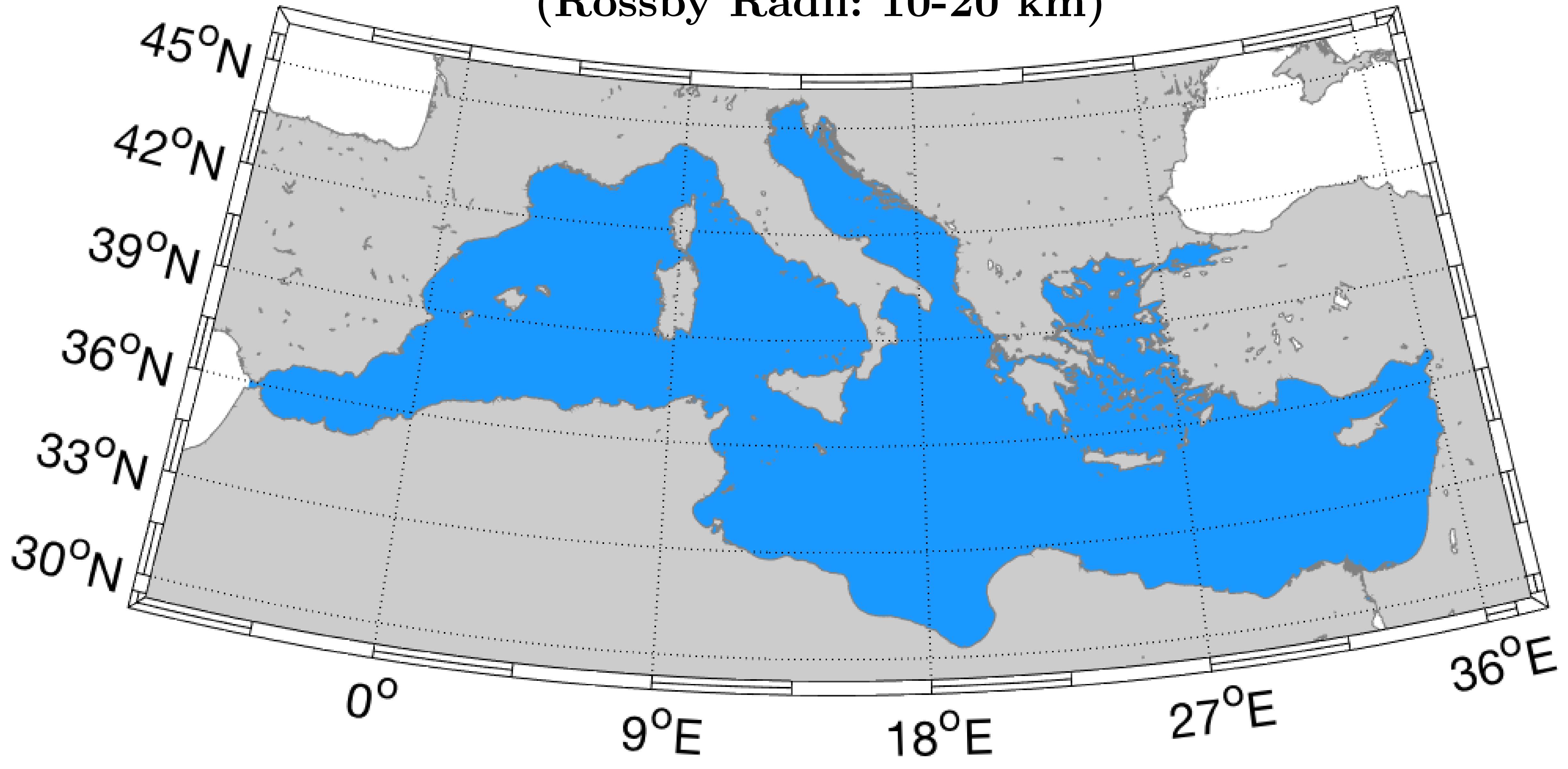
Satellite Altimetry: present-day synoptic monitoring of the sea-surface currents

$$(u_g, v_g) = \frac{g}{f}\left(-\frac{\partial h}{\partial y}, \frac{\partial h}{\partial x}\right)$$

h=sea level



Only the geostrophic component of the surface current is obtained: not satisfactory for the Mediterranean Basin (Rossby Radii: 10-20 km)

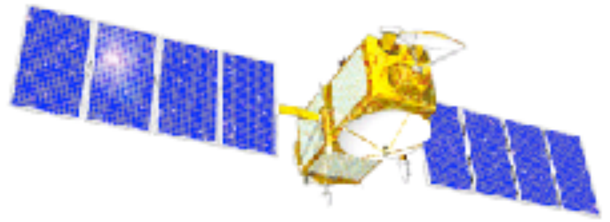


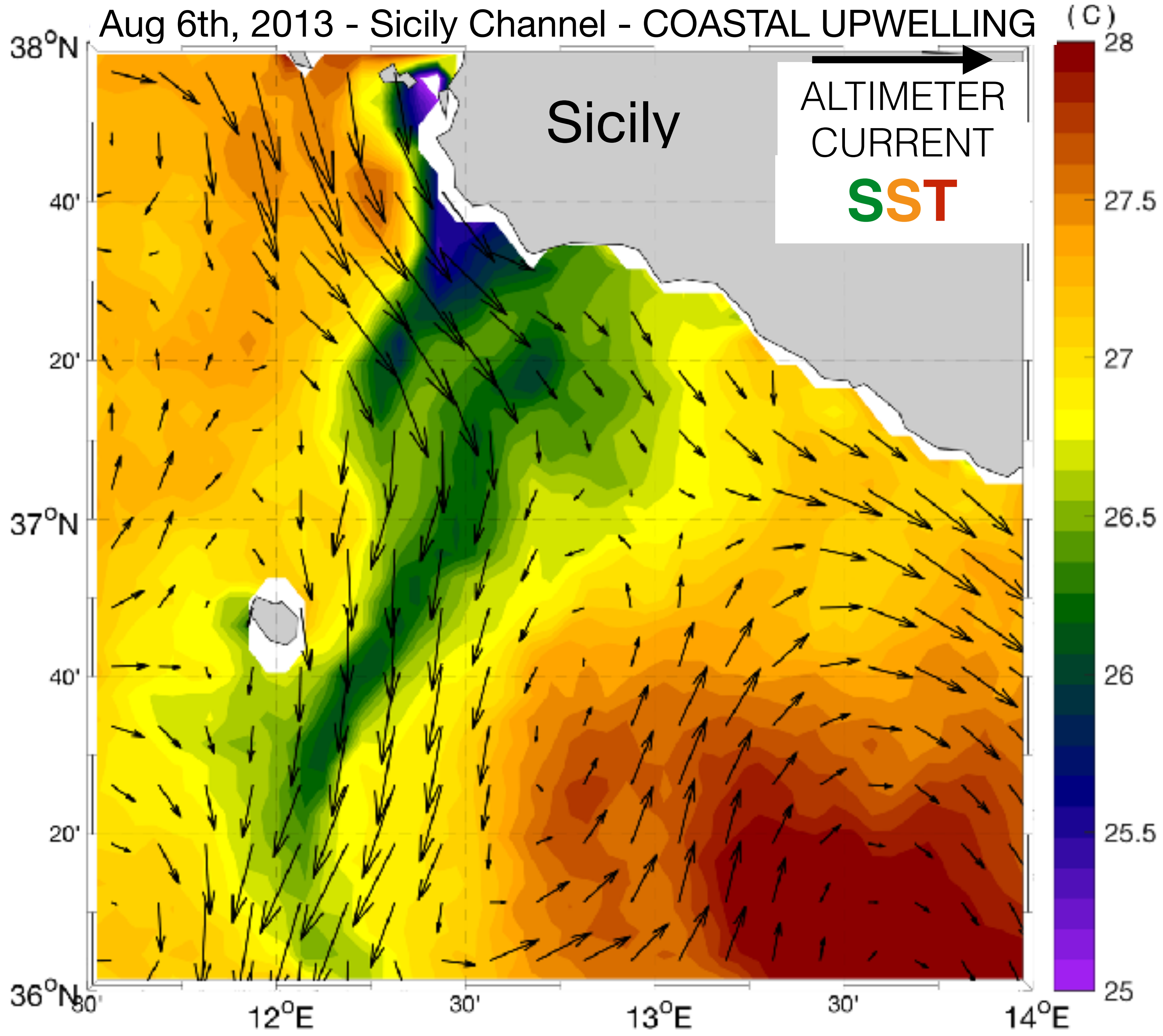
The Altimeter-derived circulation cannot entirely describe the surface motion in the Mediterranean Basin
In order to go beyond the altimeter system limitations, **new methodologies must be explored**

Context

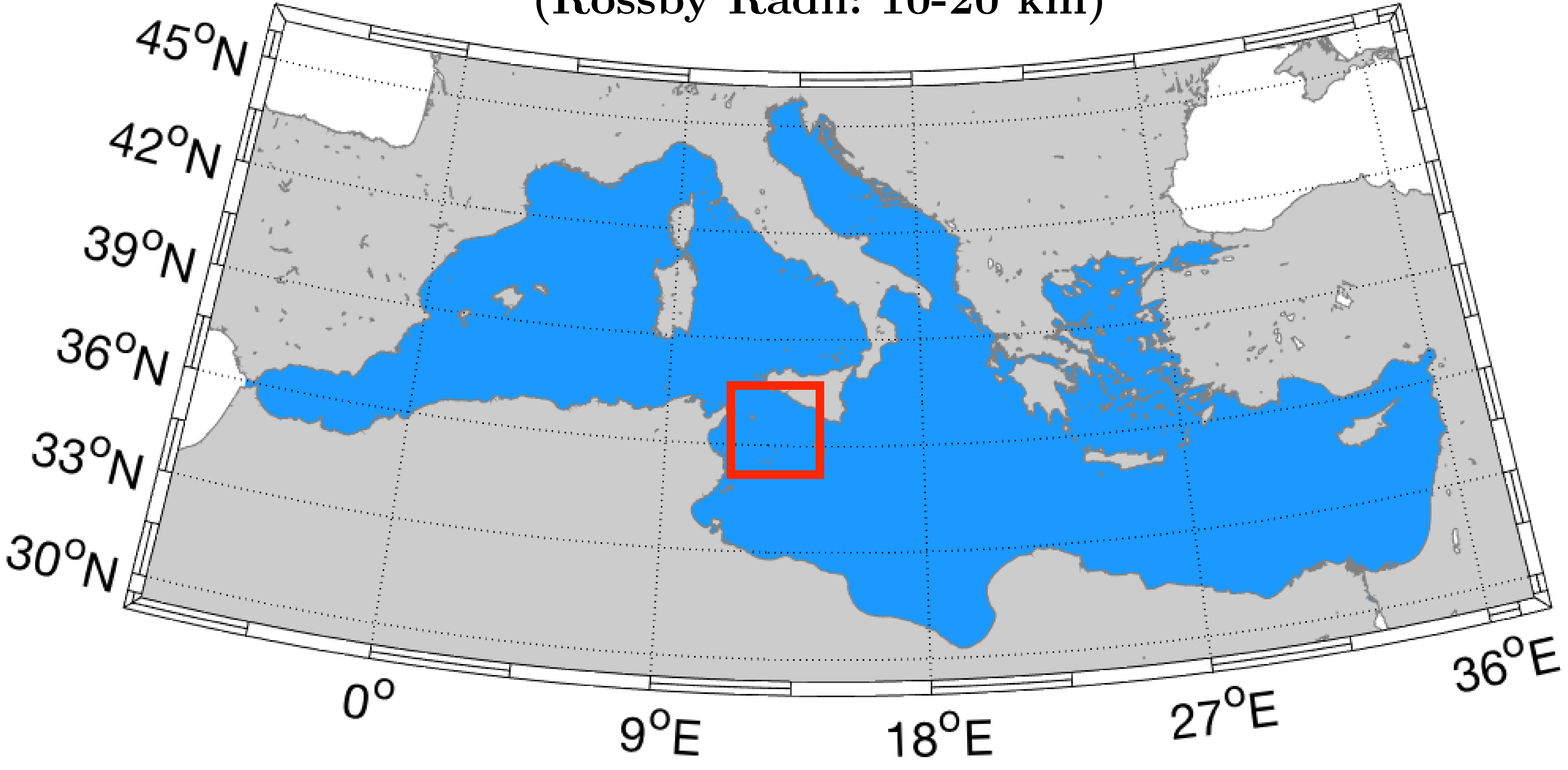
Satellite Altimetry: present-day synoptic monitoring of the sea-surface currents

Altimeter estimations in ageostrophic conditions





Only the geostrophic component of the surface current is obtained: not satisfactory for the Mediterranean Basin (Rossby Radii: 10-20 km)



The Altimeter-derived circulation cannot entirely describe the surface motion in the Mediterranean Basin, like suggested by the SST pattern

We aim at improving the currents retrieval merging the altimetric and the thermal (SST) observations

Outline

- Materials and Methods: Improvement of the Altimeter-Derived Currents
- Results: comparisons with Satellite, Model and In-situ derived data
- Conclusions and perspectives

Materials and Methods

Improvement of the Altimeter-derived currents

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

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

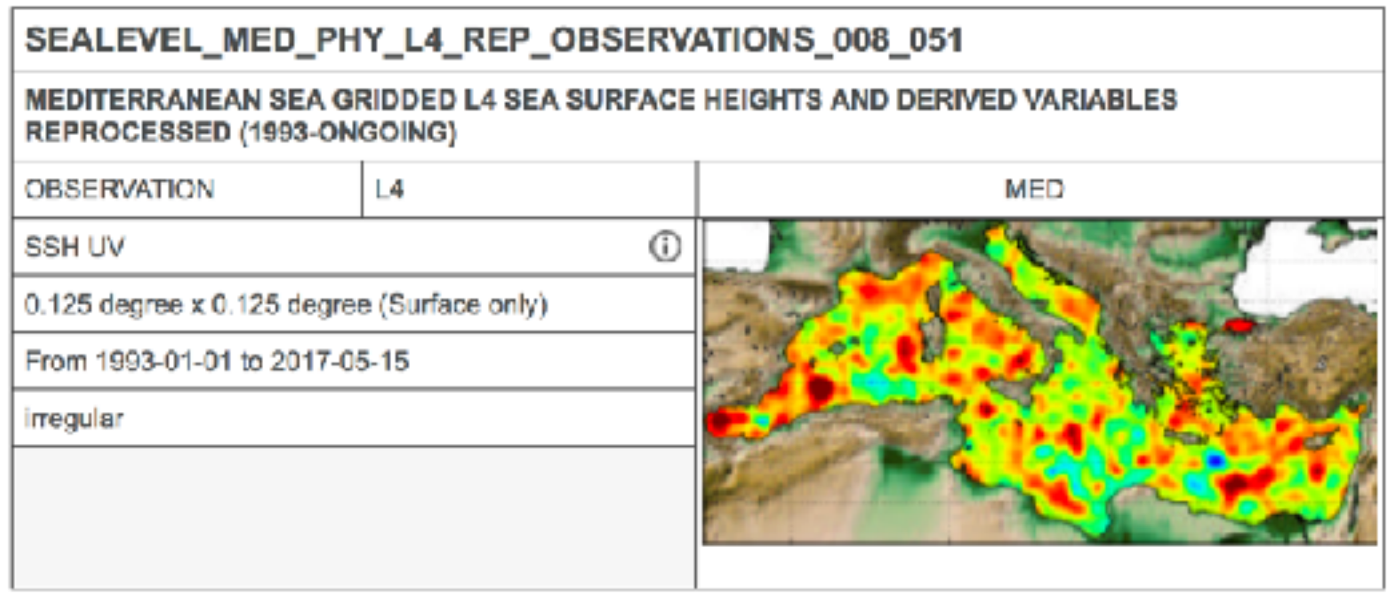
$F(x,y,t)$ = source and sink terms (solar input, net infrared radiation, latent and sensible heat fluxes)

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

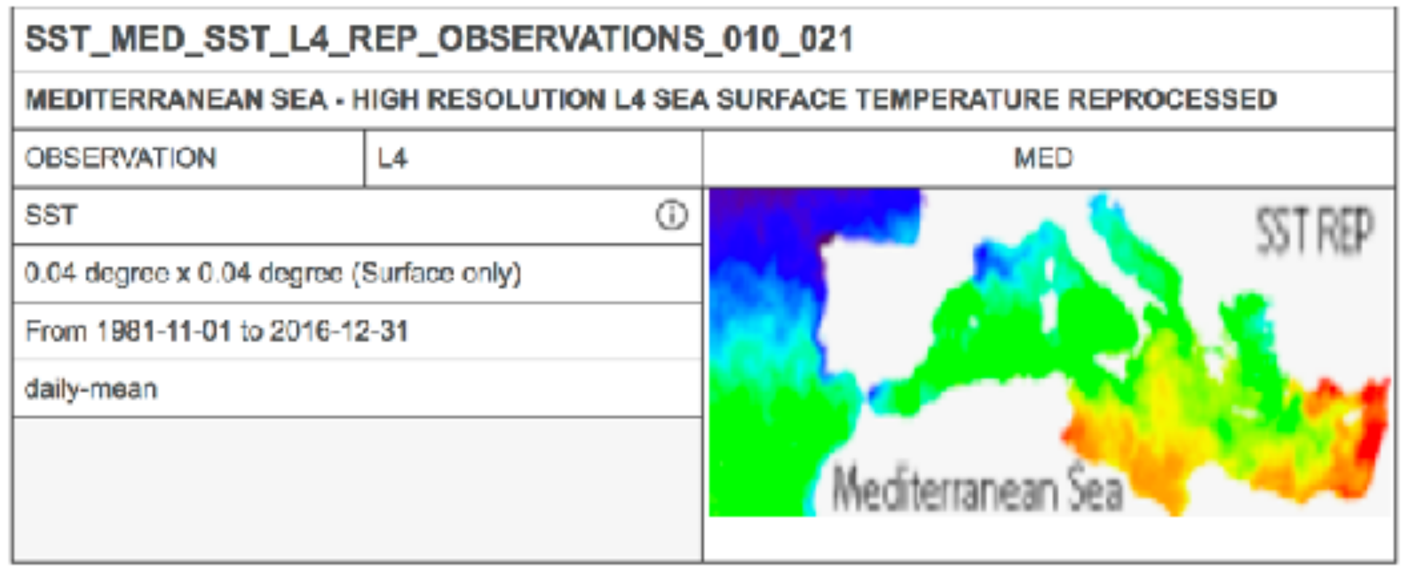
SOLUTION: **Piterbarg et al, 2009; Mercatini et al, 2010 :** Use a **background velocity** information (u_{bck}, v_{bck}) so that the satellite tracer information is used to obtain an **optimized merged velocity** (u_{opt}, v_{opt})

We applied the methodology to successive SST images using the low resolution, geostrophic altimeter velocities as background velocities (CMEMS Data: daily)

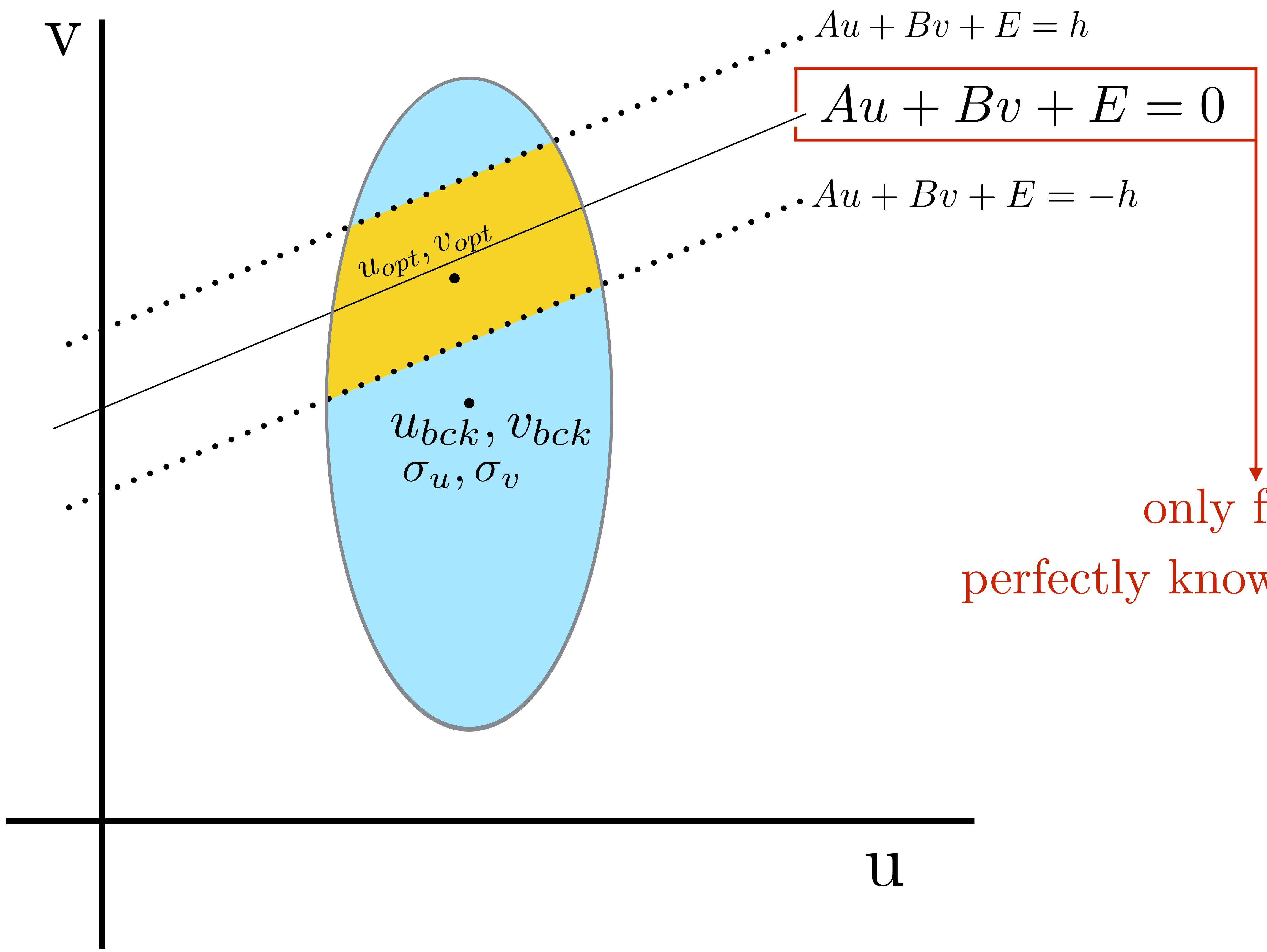
Background (SSALTO/DUACS)


SEALEVEL_MED_PHY_L4_REP_OBSERVATIONS_008_051
MEDITERRANEAN SEA GRIDDED L4 SEA SURFACE HEIGHTS AND DERIVED VARIABLES REPROCESSED (1993-ONGOING)
OBSERVATION | L4 | MED
SSH UV
0.125 degree x 0.125 degree (Surface only)
From 1993-01-01 to 2017-05-15
Irregular

SST (CNR)


SST_MED_SST_L4_REP_OBSERVATIONS_010_021
MEDITERRANEAN SEA - HIGH RESOLUTION L4 SEA SURFACE TEMPERATURE REPROCESSED
OBSERVATION | L4 | MED
SST
0.04 degree x 0.04 degree (Surface only)
From 1981-11-01 to 2016-12-31
daily-mean

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



only for
perfectly known forcings

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

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

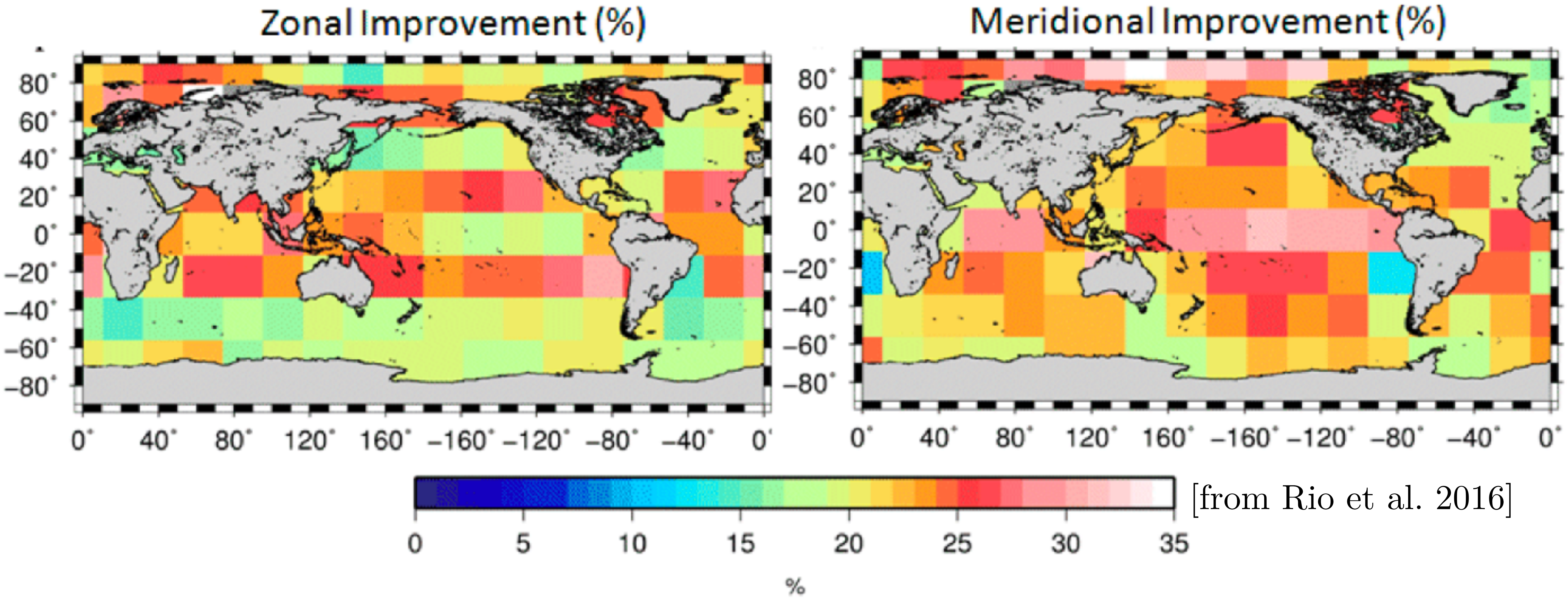
$$\phi = f(A, B)$$
$$u_0 = f(A, B, \overline{u}_{bck}, \sigma_u, \sigma_v, h, \partial_t SST, \phi)$$
$$v_0 = u_0 \cdot f(\phi, \sigma_u, \sigma_v)$$

Piterbarg et al, 2009

Materials and Methods

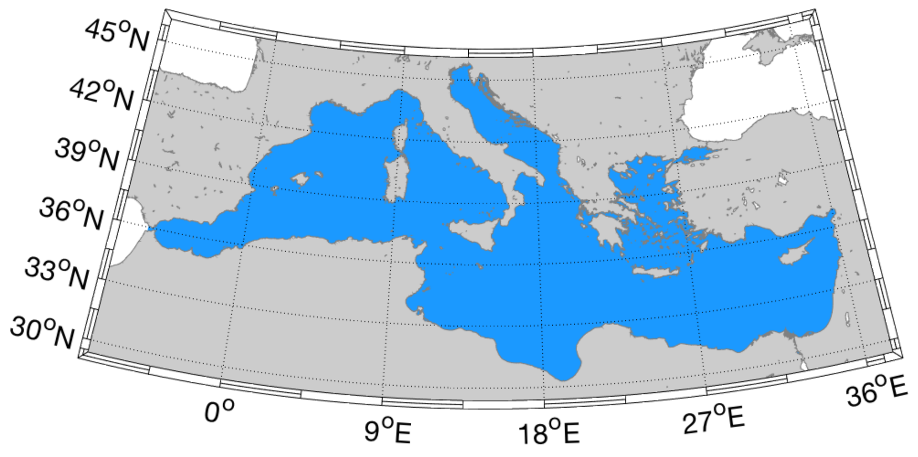
Improvement of the Altimeter-derived currents

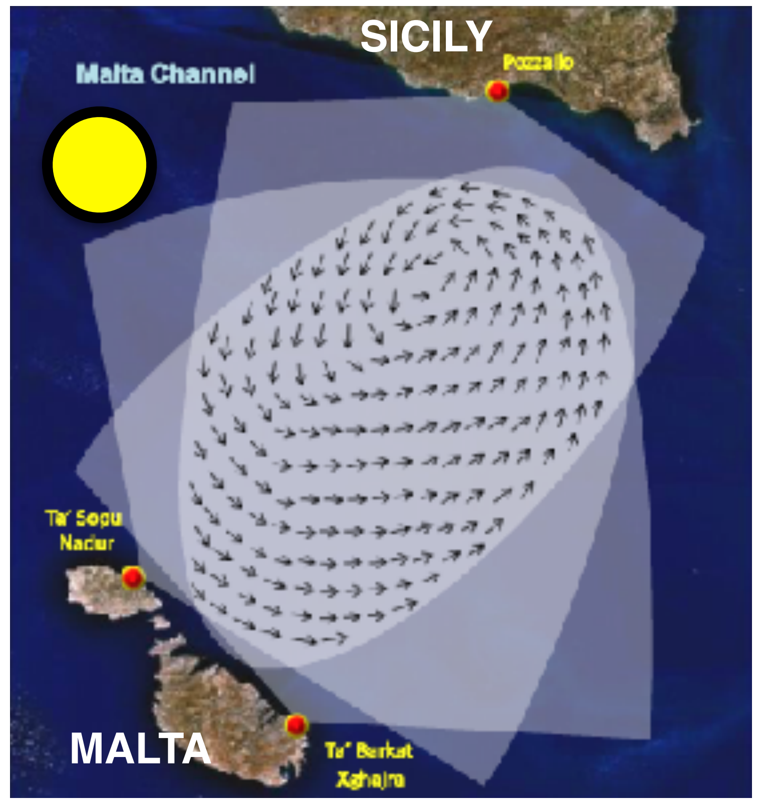
In the framework of a global-scale Observing System Simulation Experiment, the Altimeter-derived currents were improved up to 35% (Rio et al. 2016)

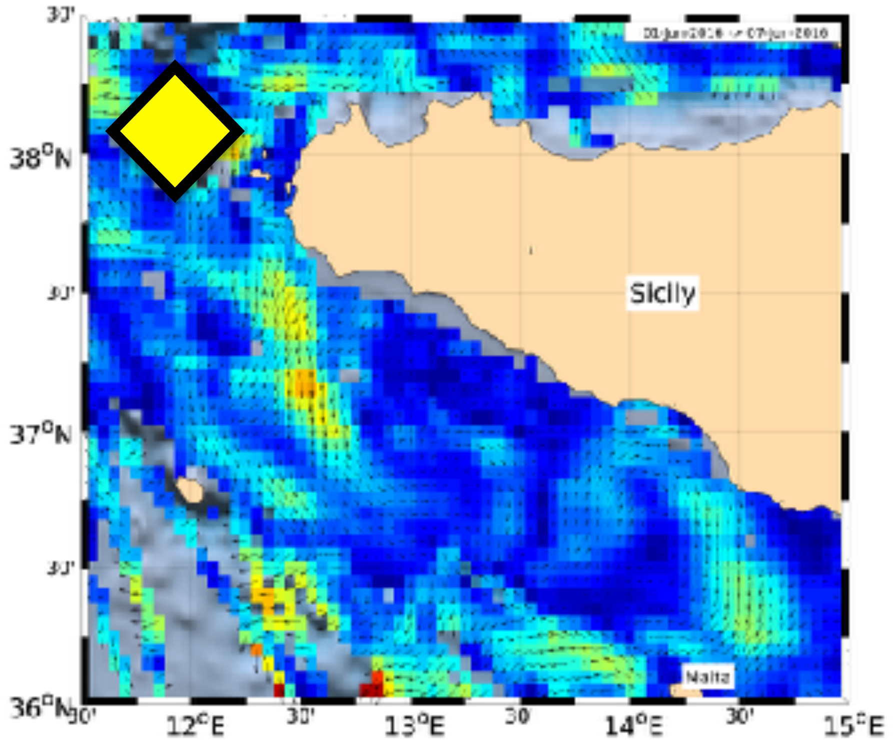


[from Rio et al. 2016]

The method has recently been applied to real satellite-derived datasets at global scale (Rio et al. 2018, in press on RSE)







1.**SSALTO/DUACS surface currents (regional, Mediterranean Sea)**
daily fields (DT, ALLSAT MERGED) dx=1/8°

2.**CNR SST L4, (regional, Mediterranean Sea)**
daily fields, dx=1/16°

3.**OPTIMAL currents** (Synergy 1+4 based on Rio et al. 2016, Piterbarg et al. 2009)
daily fields (sea-surface), dx=1/16° (higher spatial and temporal resolutions: underway)

4.**MERCATOR global operational model**
daily fields (near-surface level=-0.49m), dx=1/12°

5.**Mediterranean Forecasting System (MFS - regional, Mediterranean Sea)**
daily fields (near-surface level = -1.47m), dx=1/24°

6.**Drifting Buoys derived surface currents (Mediterranean Sea, OGS, Trieste, Italy)**

7.**HF RADAR - CALYPSO Project (University of Malta) - (Malta-Sicily Channel)**
hourly fields (sea-surface), dx=1/37°

8.**AIS-Ship-derived surface currents (e-Odyn, Brest, France)**
7-days mean fields, dx=1/20°

Outline

- Materials and Methods: Improvement of the Altimeter-Derived Currents
- **Results: comparisons with Satellite, Model and In-situ derived data**
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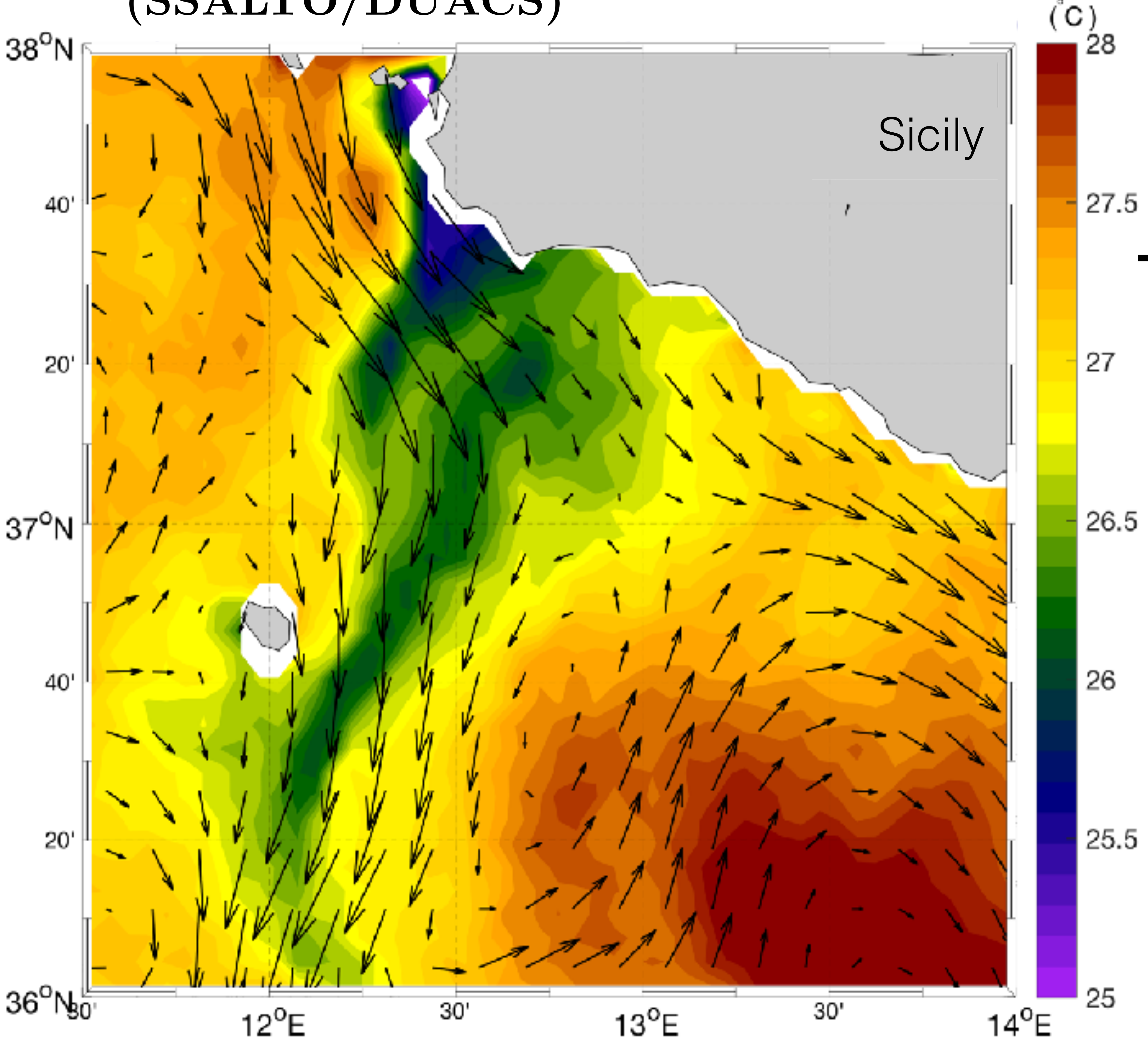
Results

Improvement of the Altimeter-derived currents: a first example

BACKGROUND (SSALTO/DUACS) (u_{bck}, v_{bck})



SYNERGY OF
-**SSALTO/DUACS** surface currents
-**CNR daily SST**, dx=1/16°
(CMEMS products)

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

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

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

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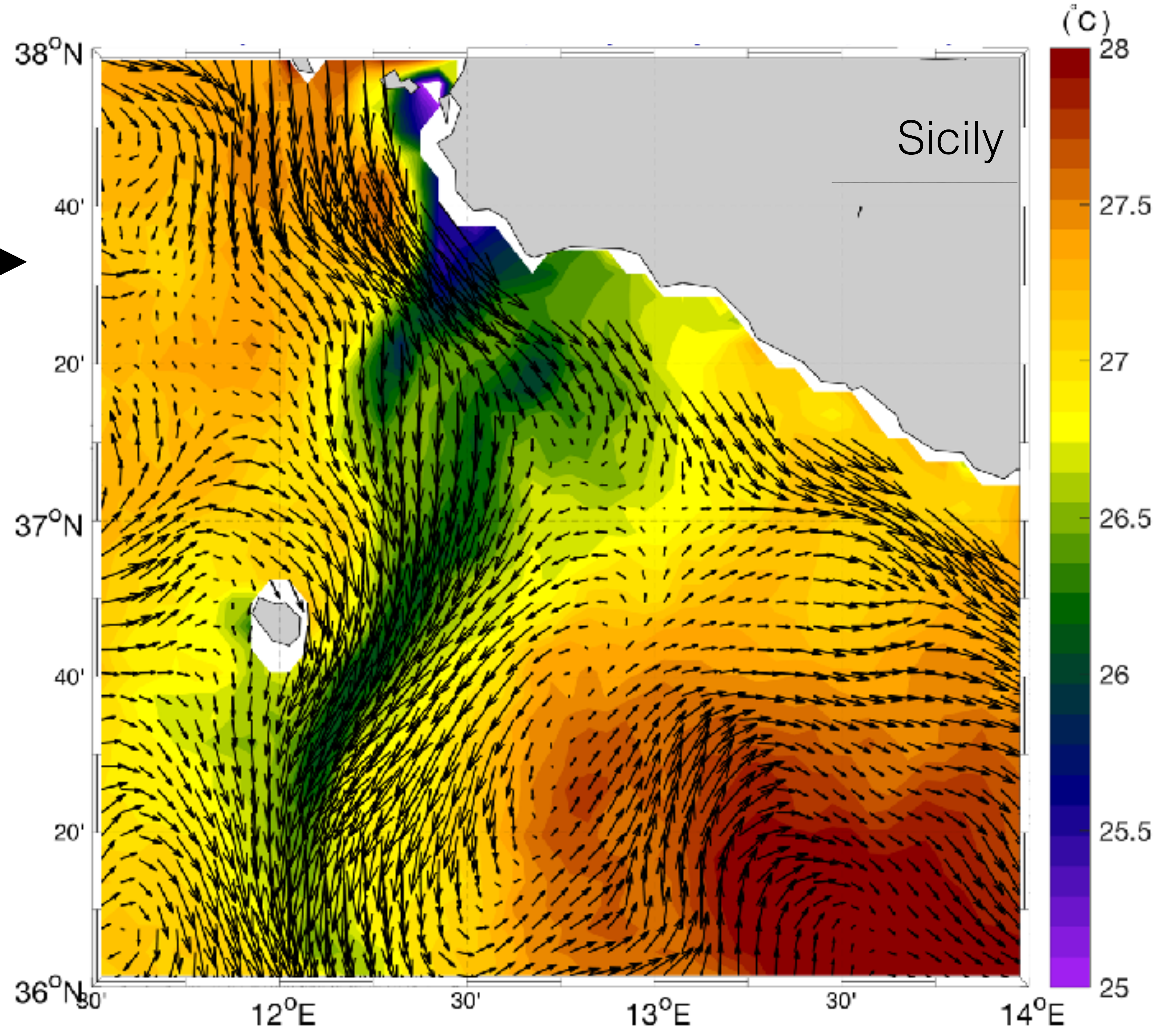
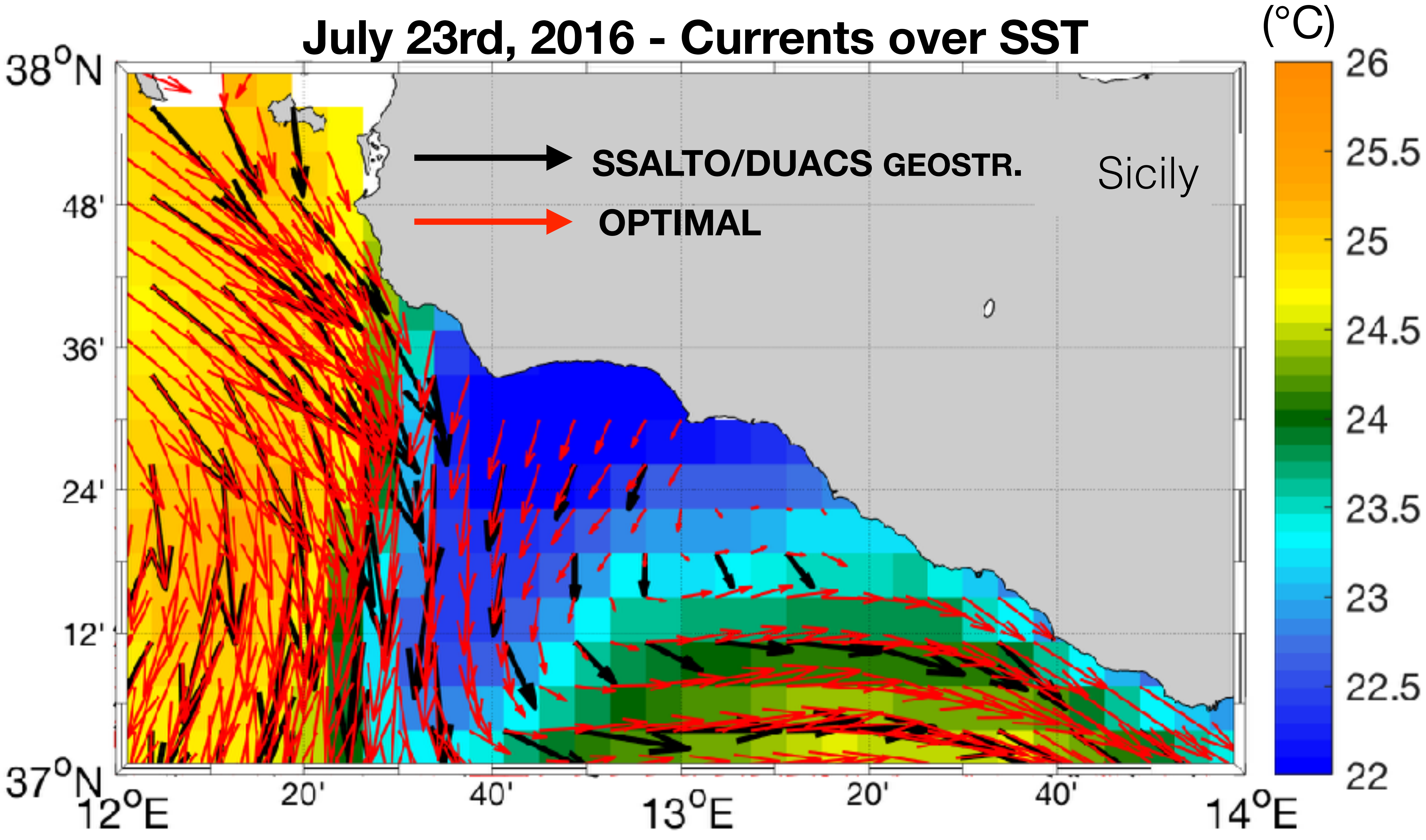
$h =$ F ERROR

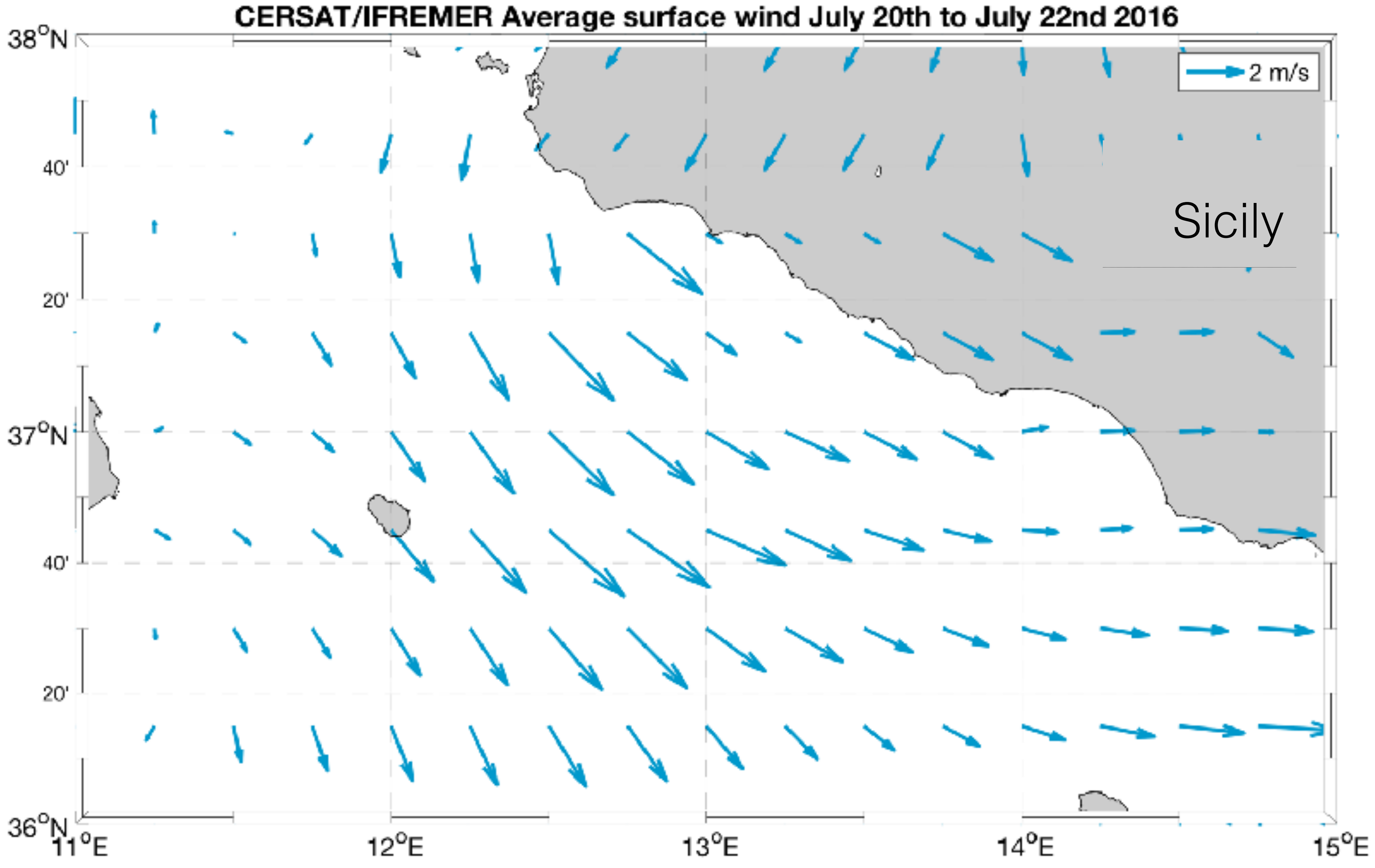
Piterbarg et al, 2009

OPTIMAL (u_{opt}, v_{opt})



A focus on the year 2016 - Sicily Channel

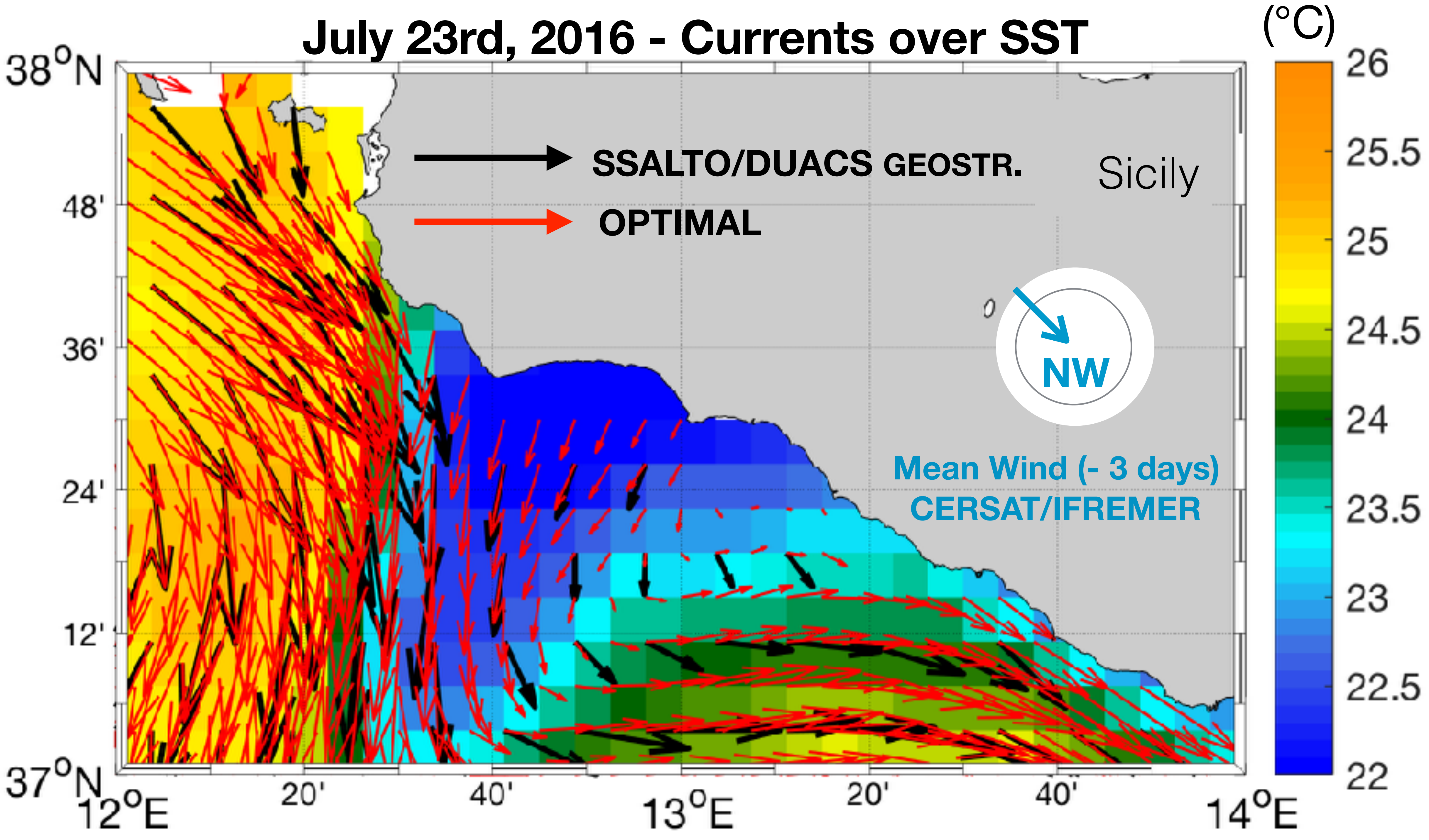


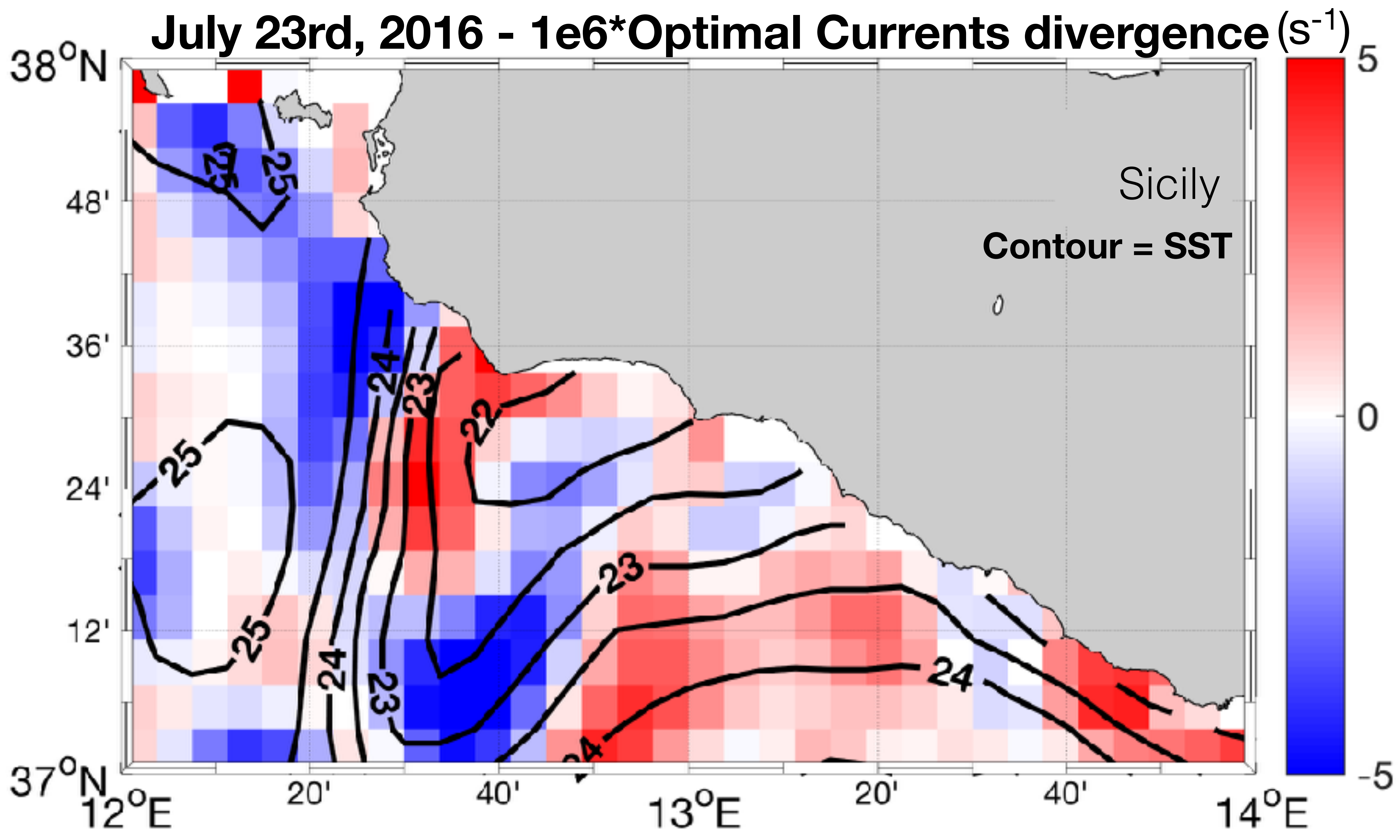


The upwelling is consistent with the NW surface surface winds during the previous three days [Piccioni et al. 1988]

Improvement of the Altimeter-derived currents: ageostrophic circulation

A focus on the year 2016 - Sicily Channel



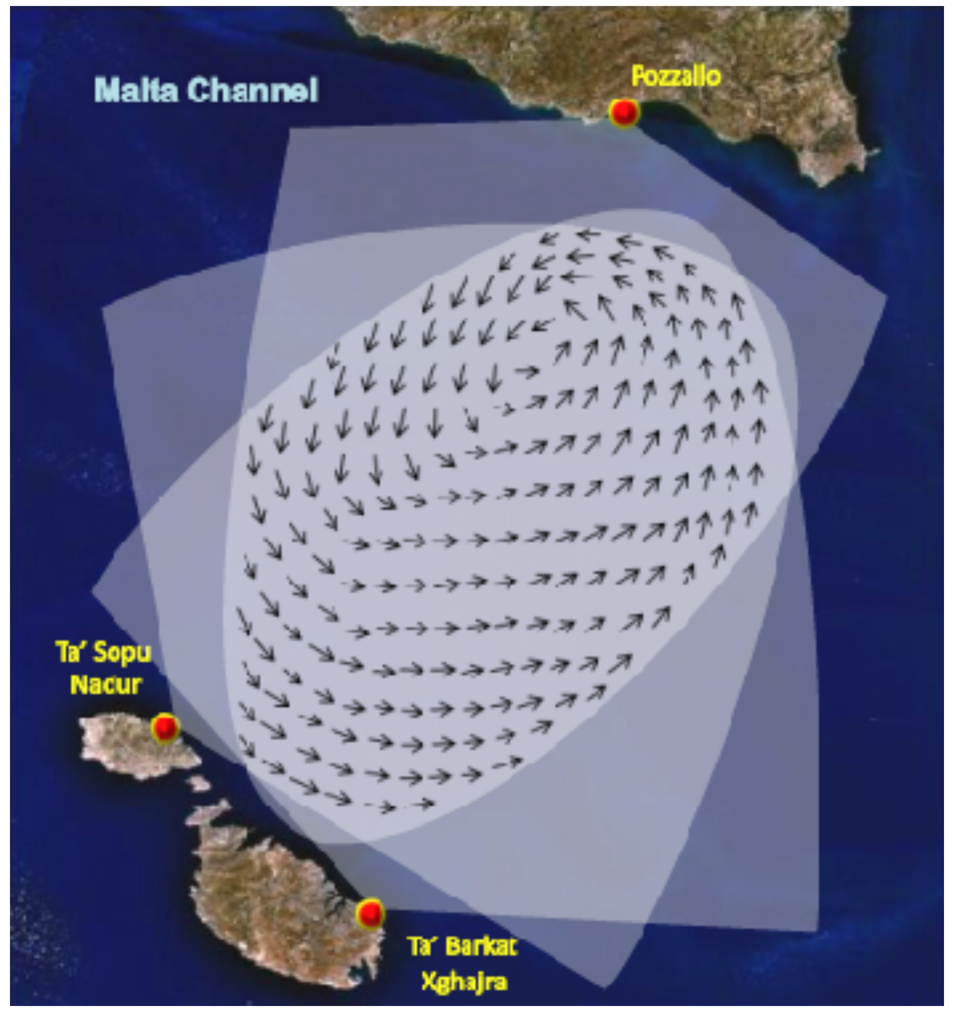


We obtain a surface motion exhibiting divergences comparable to the ones of a total current field [$\mathcal{O}(10^{-5}s^{-1})$]

Results

Comparisons with HF Radar in the Malta-Sicily Channel (2016)

Radar Calypso Project

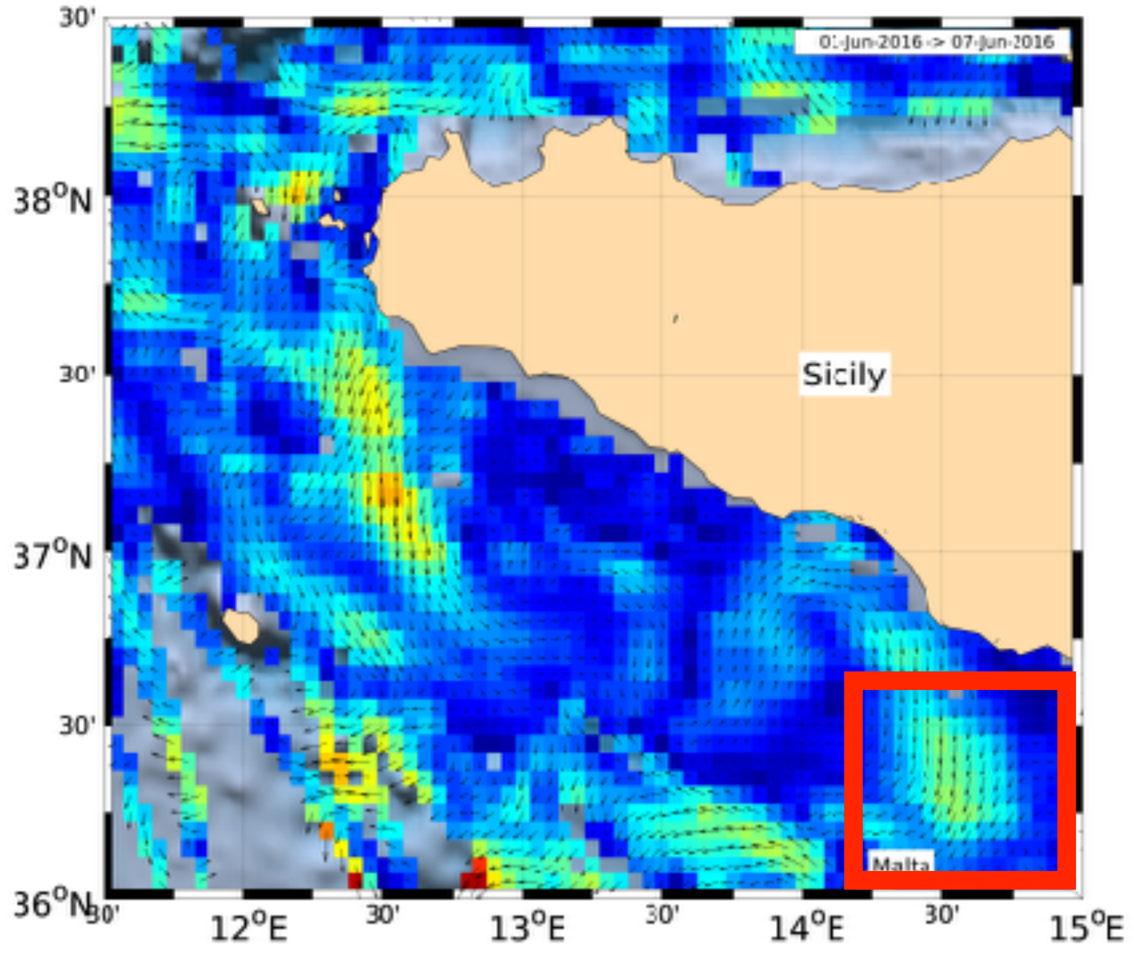


2016	RMS (cm/s) U	RMS (cm/s) V	BIAS (cm/s) U	BIAS (cm/s) V
OPTIMAL	10.12	9.00	3.60	1.40
SSALTO DUACS	11.23	9.12	4.39	1.30
MERCATOR	12.50	12.65	5.30	2.83
MFS	12.70	13.23	3.10	3.19

OPTIMAL CURRENTS

Lowest RMS. BIAS in line with Altimetry

AIS e-Odyn



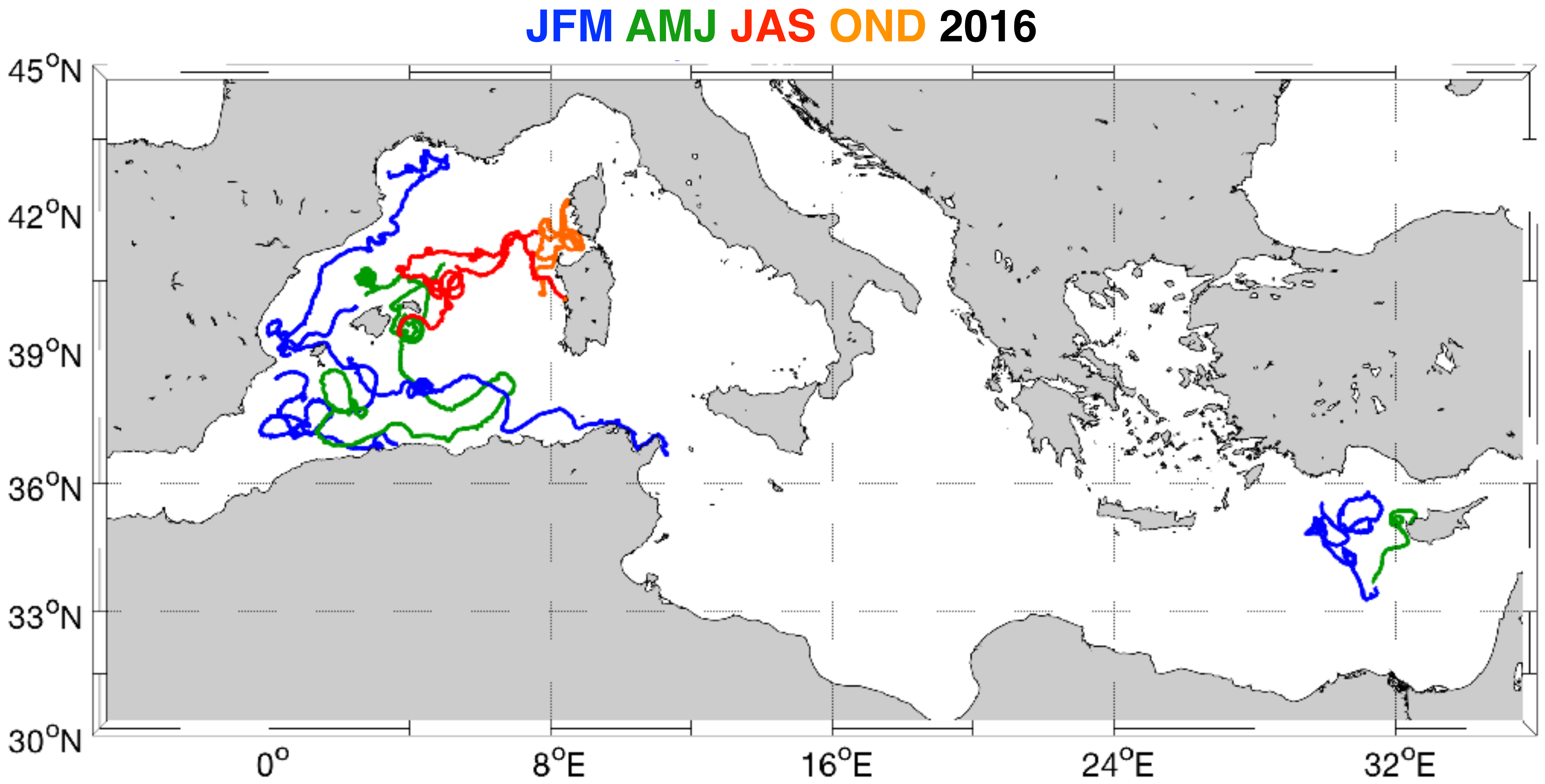
June/July 2016	RMS (cm/s) U	RMS (cm/s) V	BIAS (cm/s) U	BIAS (cm/s) V
OPTIMAL	11.00	10.01	7.50	5.10
SSALTO DUACS	12.00	10.03	7.61	5.15
MERCATOR	12.10	13.20	7.20	6.01
MFS	12.13	13.60	7.00	5.51
AIS	10.86	10.84	-6.20	5.02

AIS SHIP-DERIVED CURRENTS

Satisfactory RMS and BIAS (V component)

Results

Comparisons with drifters-derived surface currents (**OPTIMAL vs SSALTO/DUACS**)



Courtesy of M. Menna & P.M. Poulain (OGS, Trieste, Italy)

IMPROVEMENT

	RMS (cm/s) U	RMS (cm/s) V	BIAS (cm/s) U	BIAS (cm/s) V	RMS (cm/s) U	RMS (cm/s) V	BIAS (cm/s) U	BIAS (cm/s) V	RMS (cm/s) U	RMS (cm/s) V	BIAS (cm/s) U	BIAS (cm/s) V	RMS (cm/s) U	RMS (cm/s) V	BIAS (cm/s) U	BIAS (cm/s) V
OPT	19.41	19.72	5.96	-1.45	16.78	16.77	0.61	0.97	12.80	11.94	1.14	-0.77	17.66	15.70	-4.10	2.80
DUACS	19.43	20.21	7.70	-1.38	16.97	16.64	1.01	0.75	13.70	12.00	1.27	-0.91	18.20	15.70	-4.12	3.3

Optimal Currents: Overall Improvement with respect to Satellite Altimetry

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- Materials and Methods: Improvement of the Altimeter-Derived Currents
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- **Conclusions and perspectives**

Conclusions and Perspectives

- **Merging the Altimeter-derived currents with satellite tracer observations (SST) in the Mediterranean Sea, we could improve the currents retrieval compared to Altimetry:**
  Overall improvement of the RMS and BIAS with respect to Drifting Buoys, lowest RMS with respect to HF RADAR currents in the Malta-Sicily Channel

- **Retrieval of small scale geostrophic and ageostrophic motions**

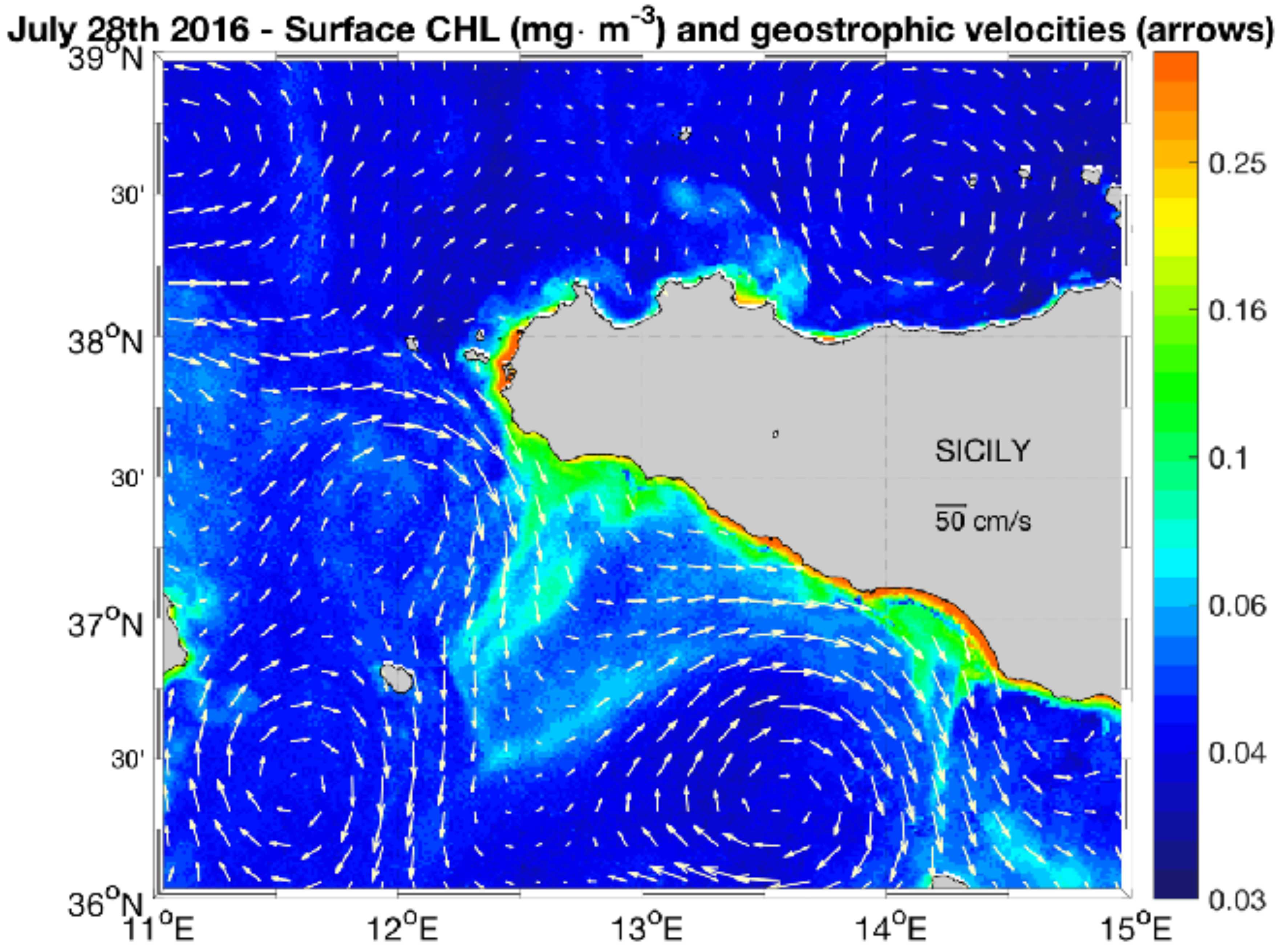
- **Satisfactory performance of the AIS ship-derived currents in the Sicily channel:**
  RMS with respect to HF RADAR comparable to Optimal Currents and Altimetry, though negative bias in the retrieval of the zonal component of the surface circulation

Conclusions and Perspectives

- Compute the Optimal currents at higher spatial (1 km) and temporal (1 h) resolutions

- Extend the Optimal Current validation period to the period (1993-2016). Computation of RMS, BIAS and Correlation Coefficients —> **larger HF RADAR currents time series**

- Evaluate the possibility of merging the Altimeter-derived currents with other oceanic tracers (e.g. CHLa)



Thank you!

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ENTE PER LE NUOVE TECNOLOGIE, L'ENERGIA E L'AMBIENTE