Blending AIS data and altimetric measurements to estimate sea surface currents in the Gulf of Mexico

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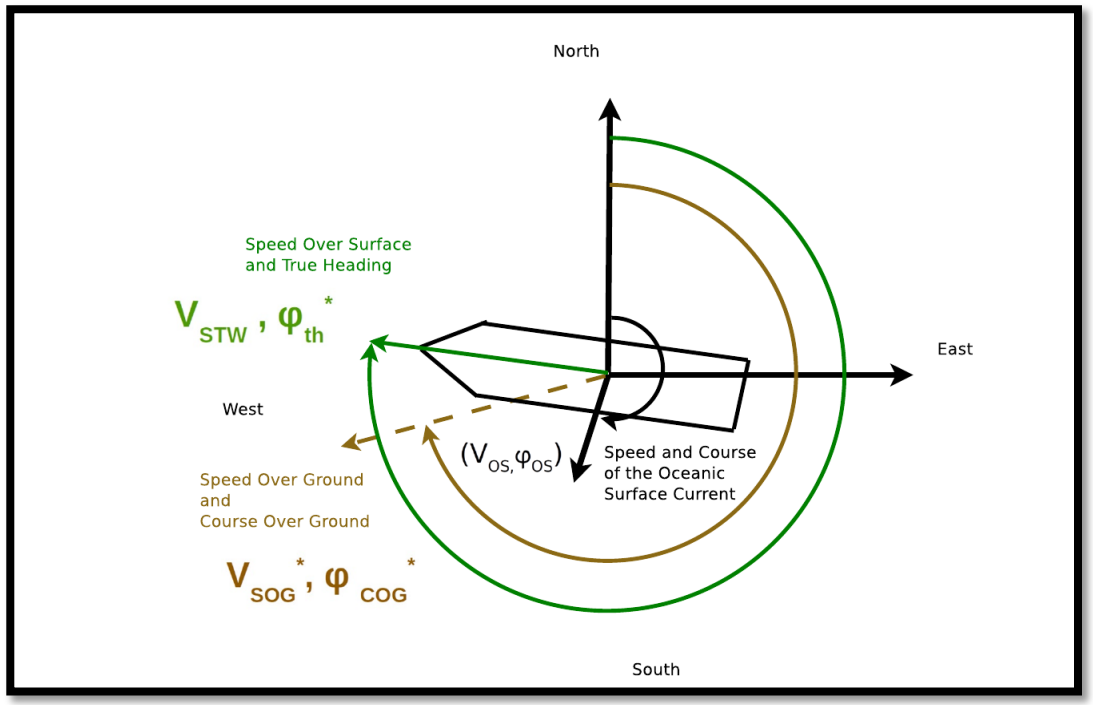
Method

Asumption: the vessels shares the same current in a spatio-temporal windows typically 1/8° and 24h

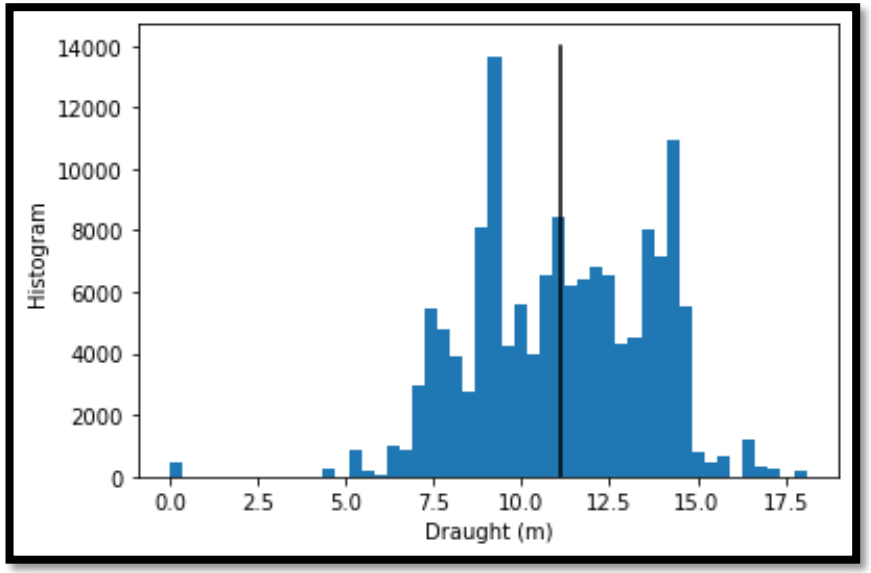


$$\overrightarrow{V_{Boat/Ground}} = \overrightarrow{V_{Boat/Sea}} + \overrightarrow{V_{Sea/Ground}}$$

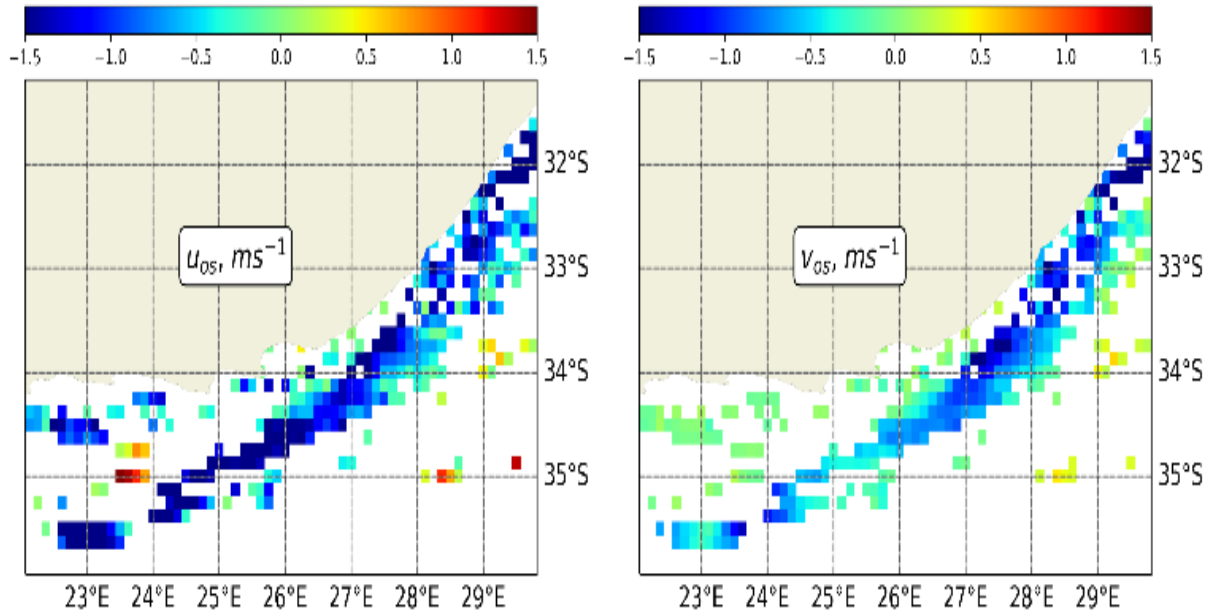
$$\begin{cases} V_{sog}^* sin(\varphi_{cog}^*) = V_{stw} sin(\varphi_{th}^*) + u_{drift} & (\text{zonal}) \\ V_{sog}^* cos(\varphi_{cog}^*) = V_{stw} cos(\varphi_{th}^*) + v_{drift} & (\text{meridional}) \end{cases}$$

$$\begin{cases} V_{sog_1}^* sin(\varphi_{cog_1}^*) = V_{stw_1} sin(\varphi_{th_1}^*) & + u_{os} \\ V_{sog_1}^* cos(\varphi_{cog_1}^*) = V_{stw_1} cos(\varphi_{th_1}^*) & + v_{os} \\ \vdots \quad \vdots & \vdots \\ V_{sog_n}^* sin(\varphi_{cog_n}^*) = V_{stw_n} sin(\varphi_{th_n}^*) & + u_{os} \\ V_{sog_n}^* cos(\varphi_{cog_n}^*) = V_{stw_n} cos(\varphi_{th_n}^*) & + v_{os} \end{cases}$$

Which Depth ??



Optimal Interpolation



$$x^s = x^b + K\left(y - Hx^b\right),$$

$$P^s = B - KHB,$$

with the gain $K = BH^\top\left(HBH^\top + R\right)^{-1}$,

$$\gamma(\Delta_s, \Delta_t) = R + \sigma^2\left(1 - \exp\left(-\frac{\Delta_s}{L}\right)\exp\left(-\frac{\Delta_t}{T}\right)\right)$$

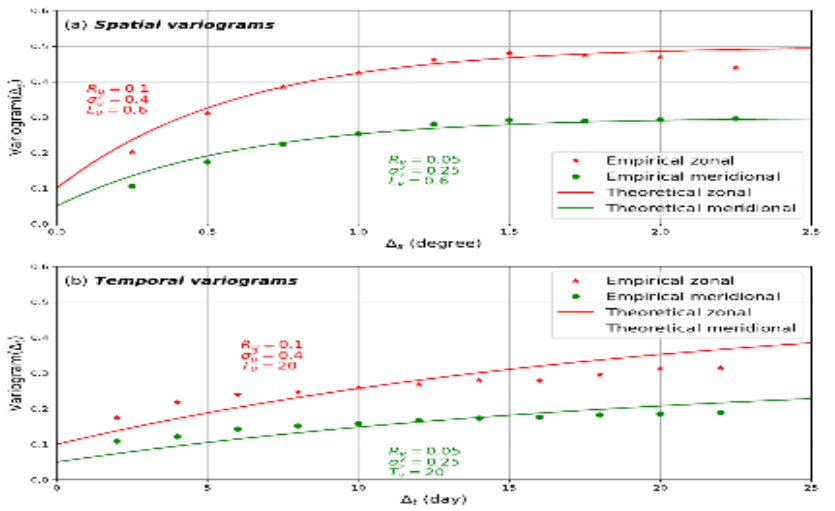


Figure 6. (a) Empirical and theoretical spatial variograms of the zonal and meridional current components. (b) Corresponding temporal variograms.

Helmholtz-Hodge Decomposition

$$\vec{\xi} = \vec{r} + \vec{d} + \vec{h}$$

Total

Free Divergent

Free Rotationnal

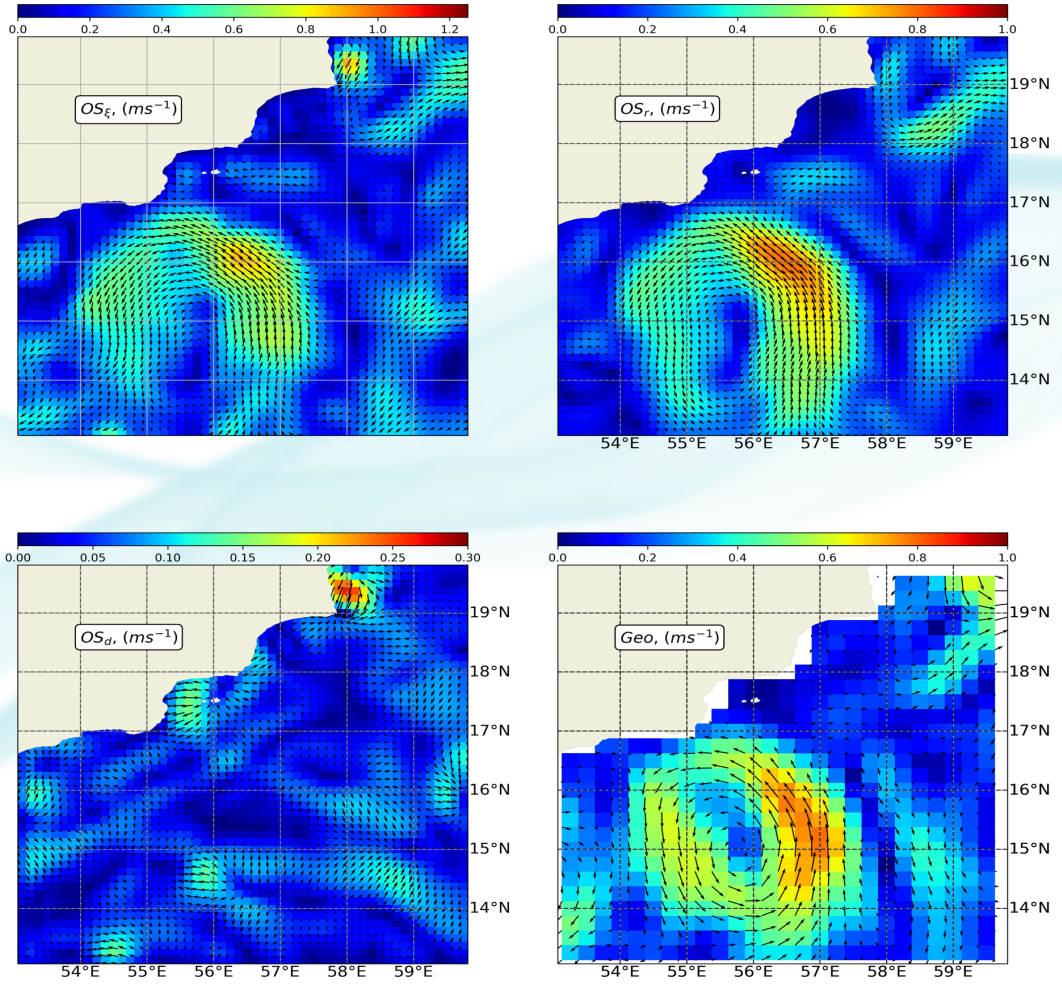
Translation

Resolution : 2 Poisson equations

$$\nabla . \vec{d} = \nabla . \vec{\xi}$$

$$\nabla \times \vec{r} = \nabla \times \vec{\xi}$$

→ Potential Function



More details and explanations here

Monitoring the Greater Agulhas Current With AIS Data Information

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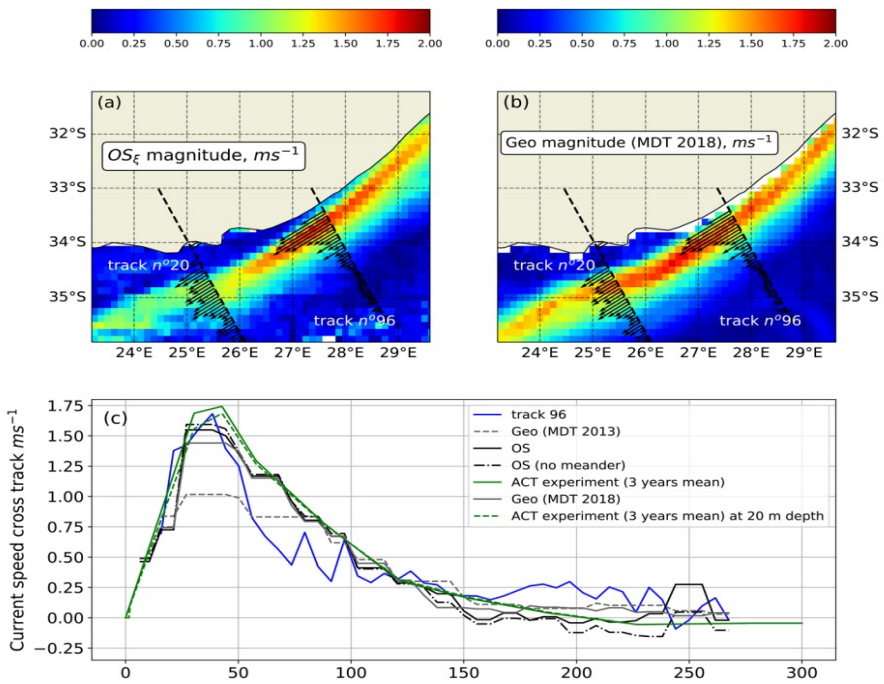
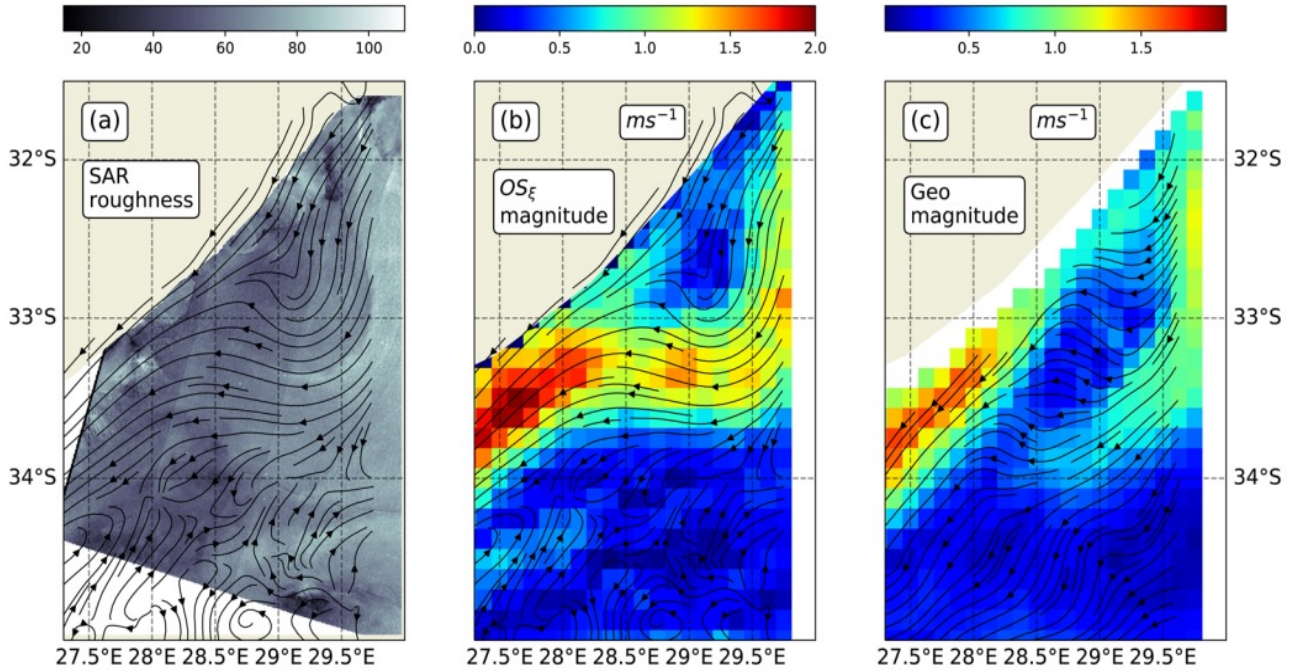
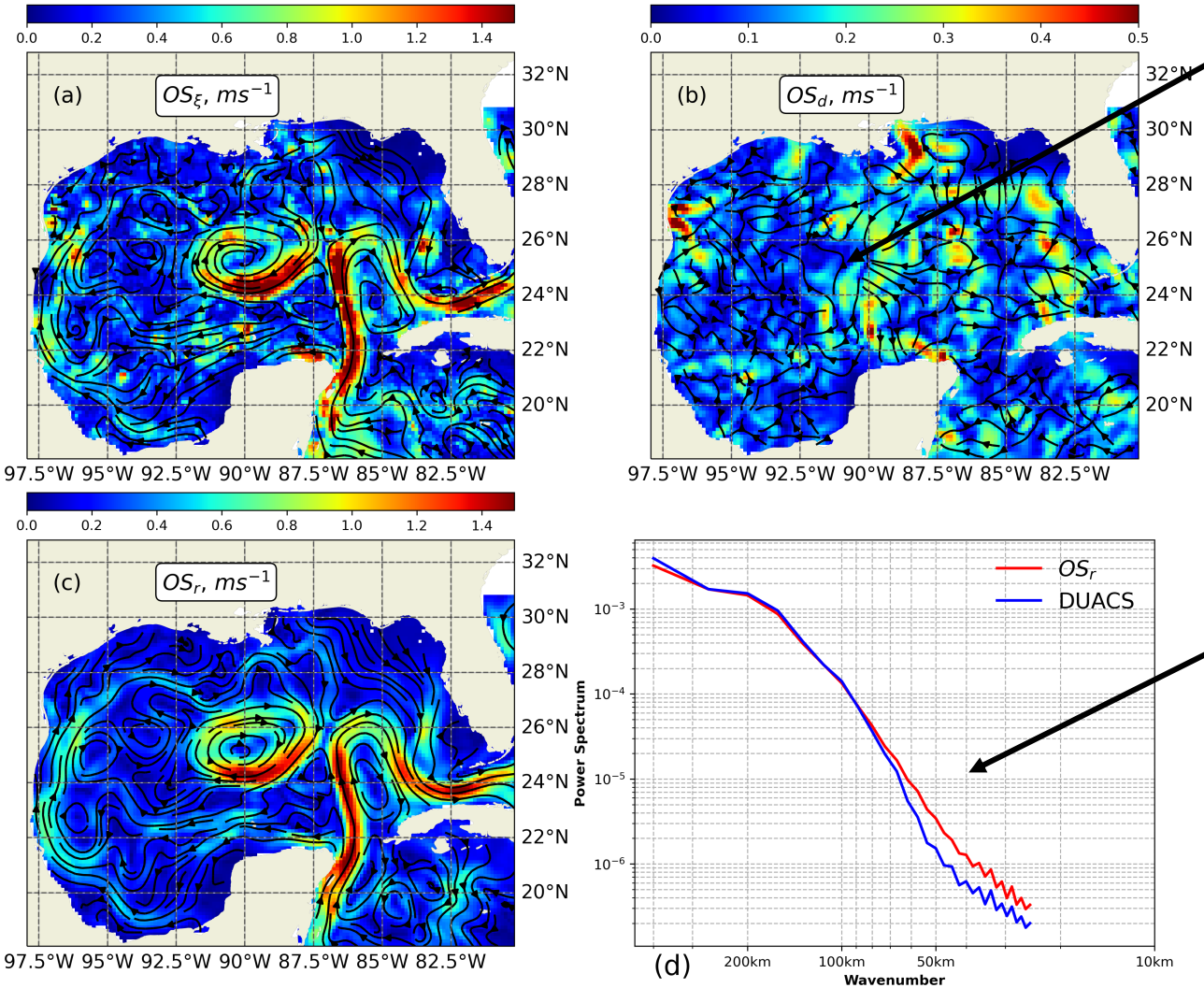
Example of validations





Gulf of Mexico



Downwelling in the center of the Anticyclone eddy loop in the northern hemisphere August the 30th, 2019.

Coriolis Effects on Wind-Driven ocean currents ??

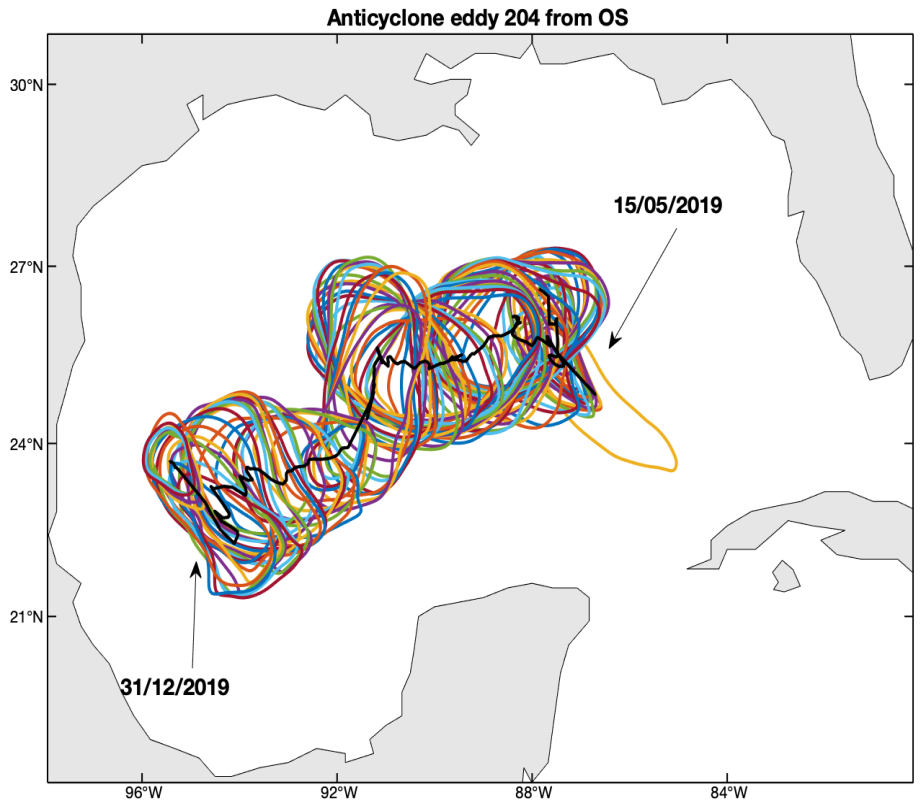
Mean Spectrum of Kinetic Energy Duacs and the divergent free part of the AIS derived current (OS_r)

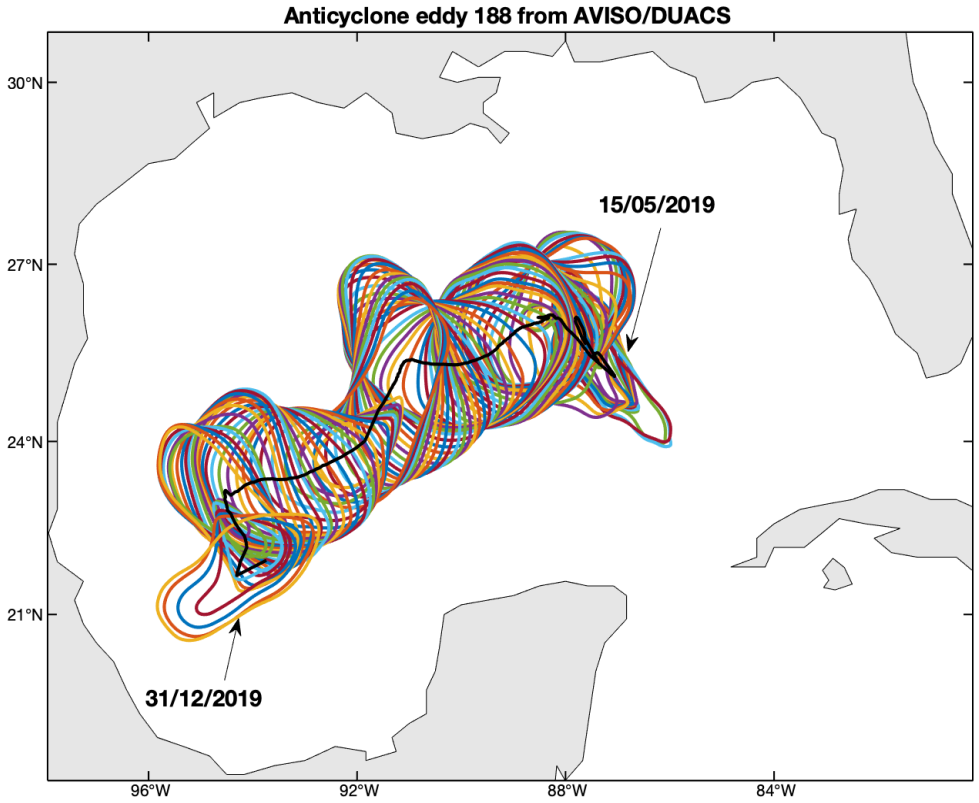
More Kinetic Energy at smaller scale ??

Gulf of Mexico

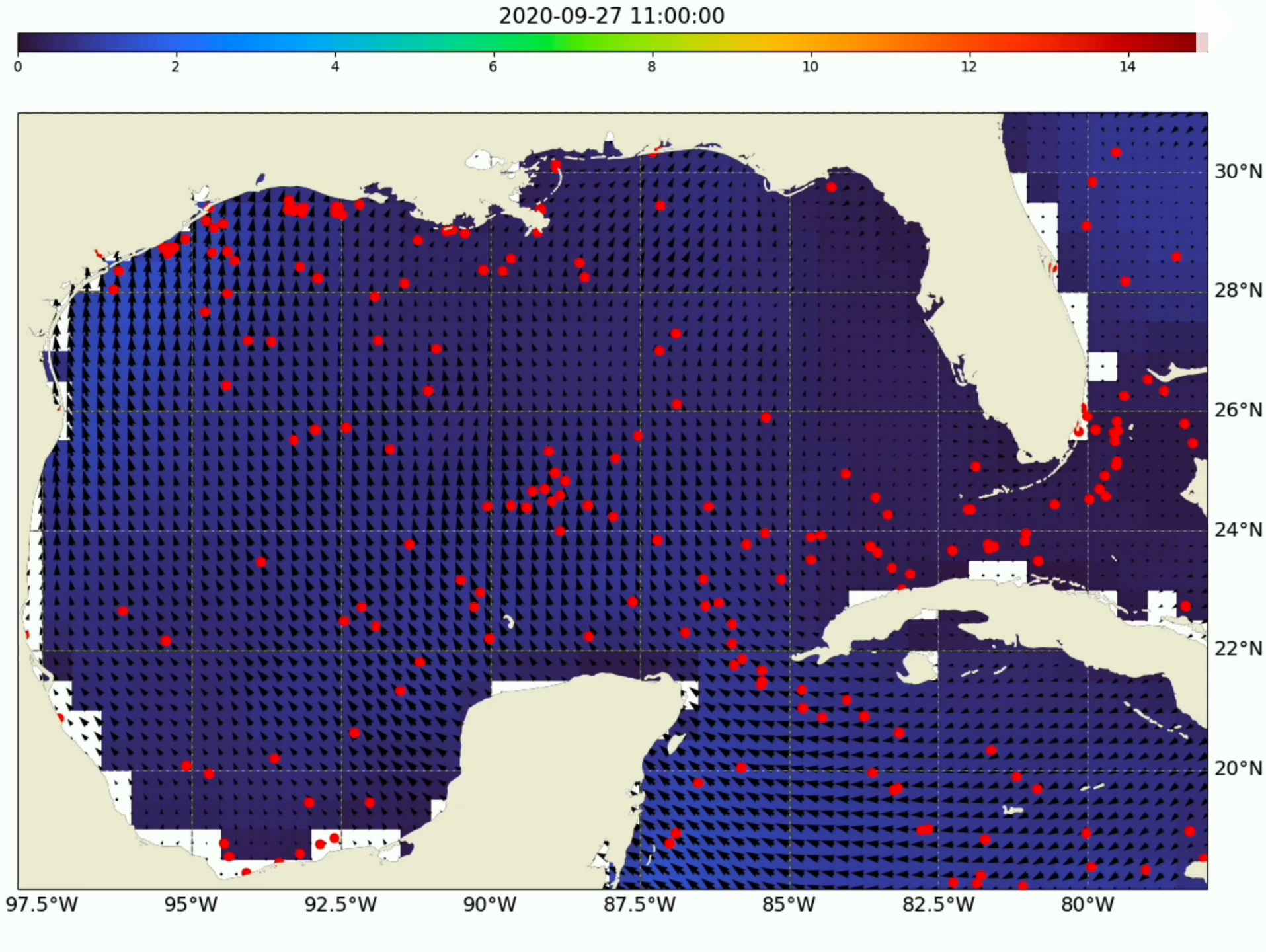
Tracking Loop current eddy from the AIS derived field Divergent free part (OS_r)

Smoother trajectory of the eddy is obtained with the DUACS field



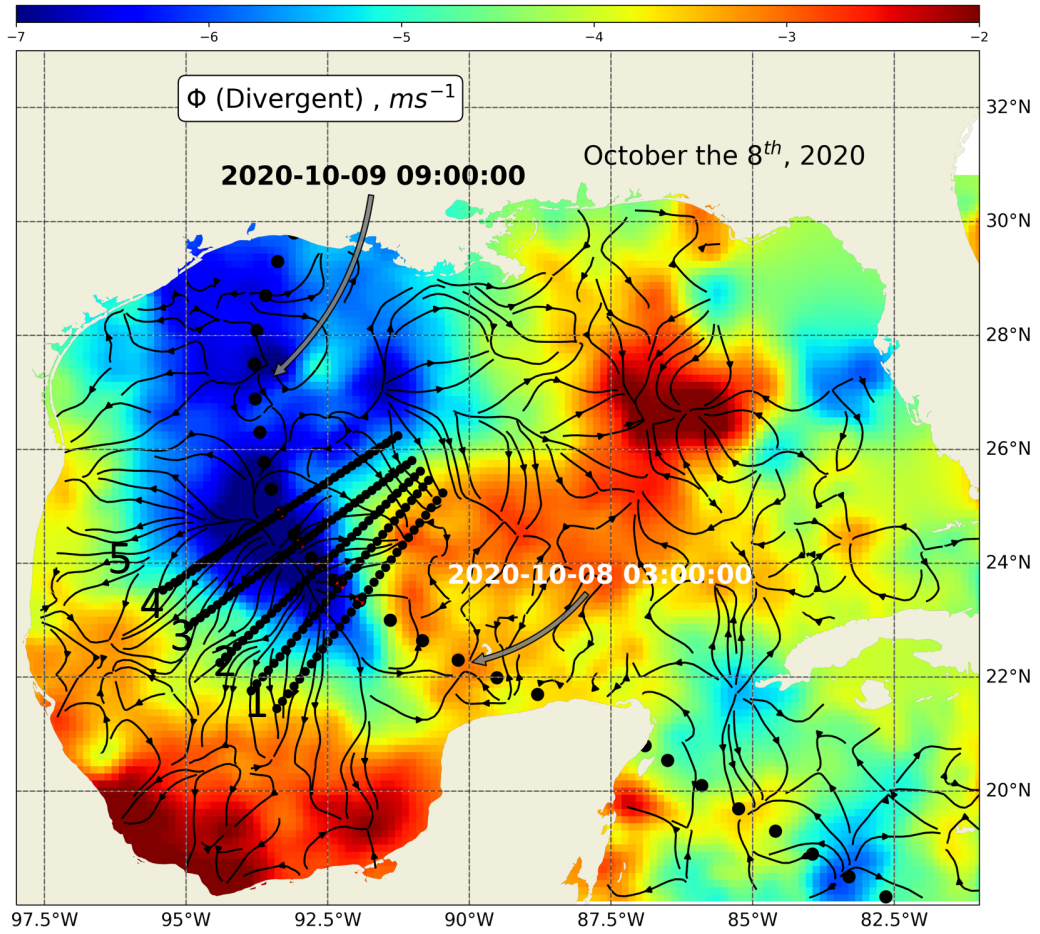


Tracking is done through the use of AMEDA (Le Vu et al 2018)

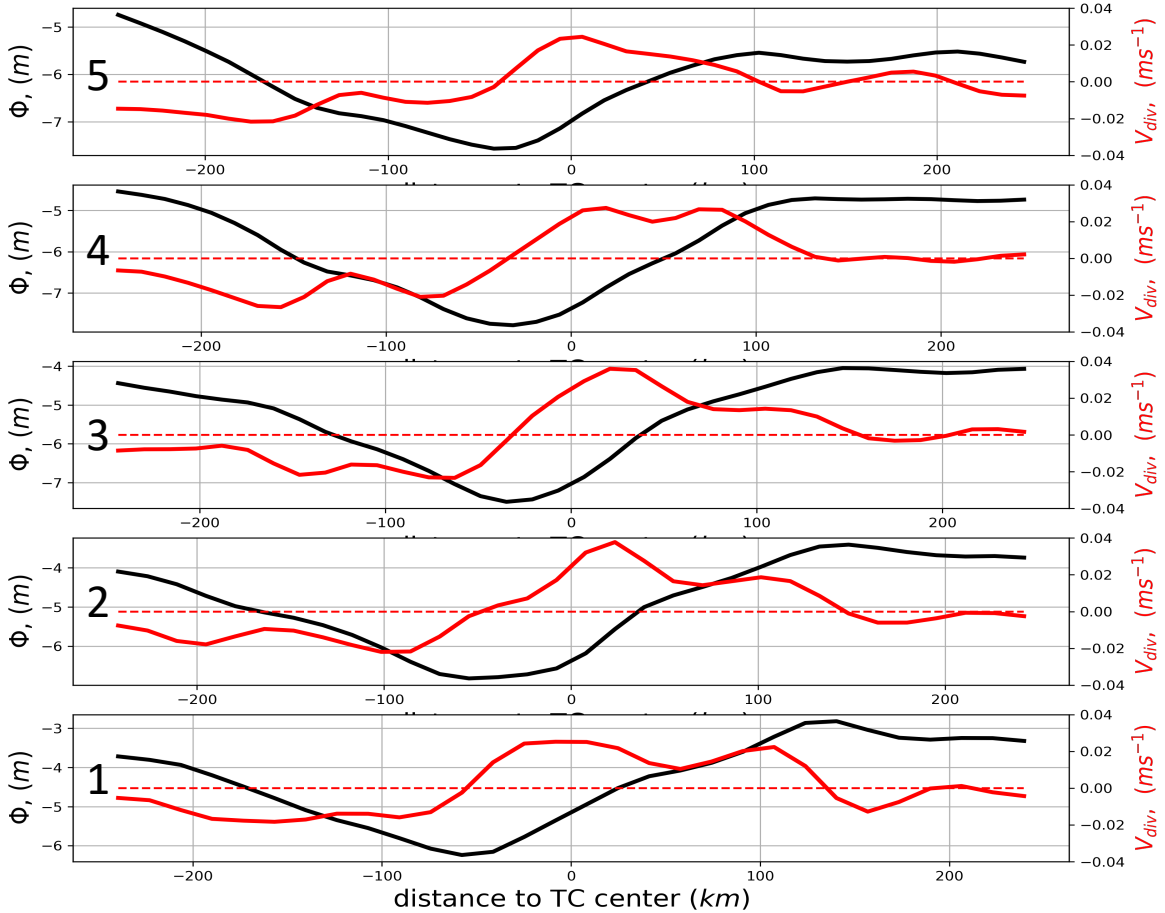

2020-09-27 11:00:00
0
2
4
6
8
10
12
14
30°N
28°N
26°N
24°N
22°N
20°N
97.5°W
95°W
92.5°W
90°W
87.5°W
85°W
82.5°W
80°W

Gulf of Mexico

Tropical Storm, Delta, October the 8th,2020



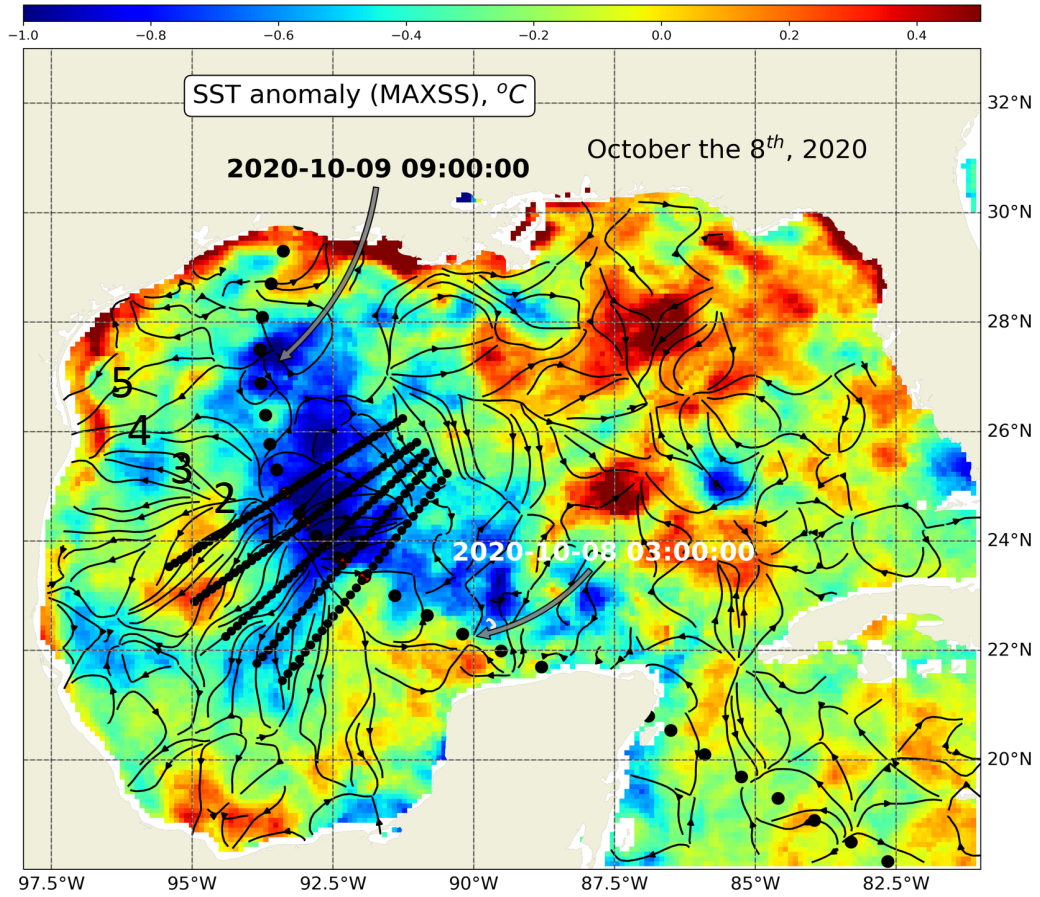
Values of the Potential Function along the Transect perpendicular to the trajectory. The gradient gives the divergent oceanic velocity in the direction of the transect



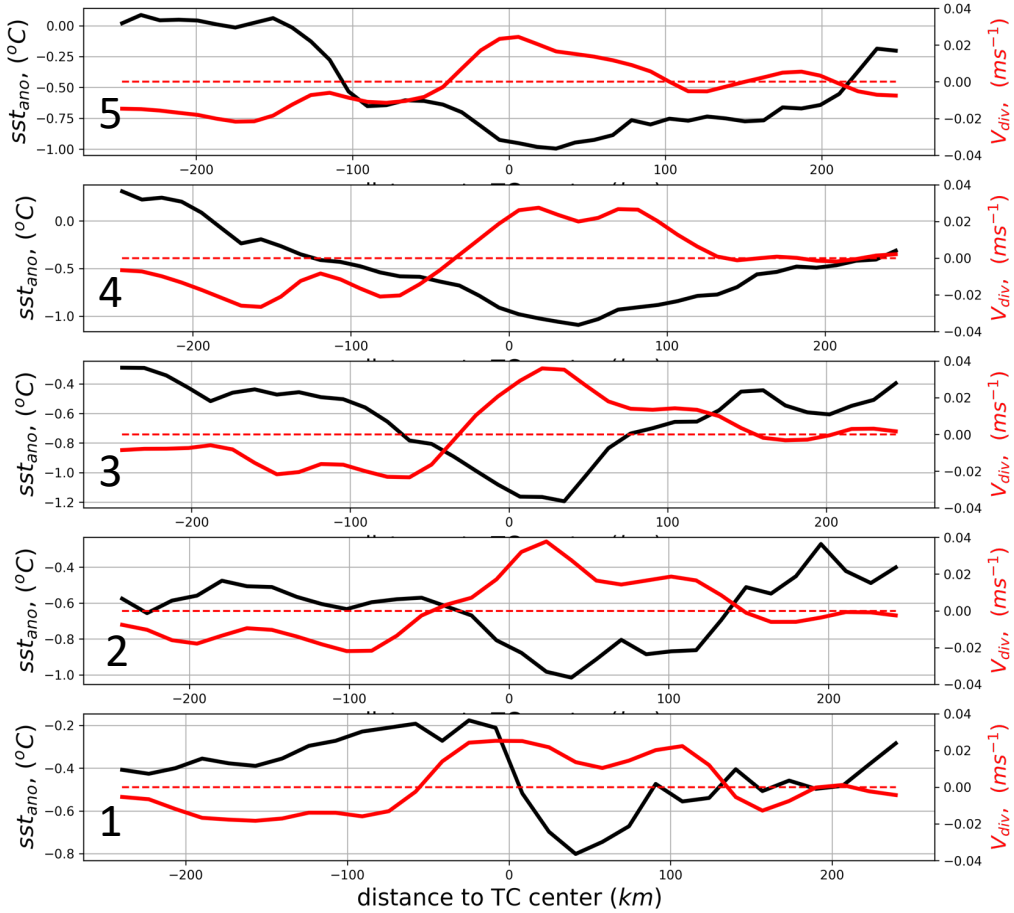
The water masses are removed from the track of the hurricane in a asymetric way.

Gulf of Mexico

Tropical Storm, Delta, October the 8th,2020



Values of the SST anomaly along the Transect perpendicular to the trajectory. The highest negative anomalies correspond to the highest divergent transport to the right of the wake



Possible validation of the model of Kudryatsev et al (2019)

Multiscale Inversion for Ocean Surface Topography (MIOST) tool

Objective Analysis: $\mathbf{x_a = BH^T(HBH^T + R)^{-1}y}$ — Ubelmann et al. (2021)

- $\mathbf{x_a}$: Estimate
- $\mathbf{B}$: (grid,obs) signal cov.
- $\mathbf{HBH^T}$: (obs,obs) signal cov.
- $\mathbf{R}$: (obs,obs) error cov
- $\mathbf{y}$: SLA obs

- Sherman − Morrison − Woodbury transformation: $\mathbf{x^a = \left(H^T R^{-1} H + B^{-1}\right)^{-1} H^T R^{-1} y}$

→ **Inversion in the state space** rather than in observation space (much bigger !)

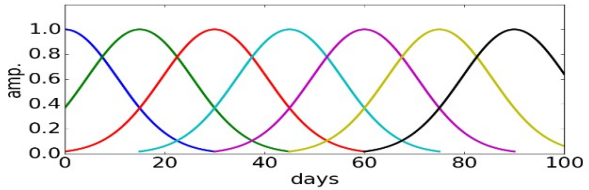
- Decomposition of the signal in different components:

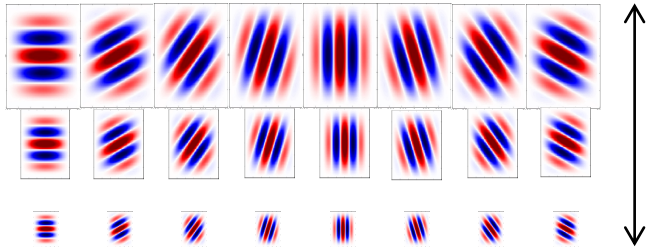
  $x = x_{geo} + x_{ek} + x_{inertie}$ …

- Projection of each component on a wavelet basis

  $\mathbf{x_{geo} = \Gamma_{geo} \eta_{geo}}$

Temporal decorrelation scale:
~10 days (depend on the area as in DUACS)

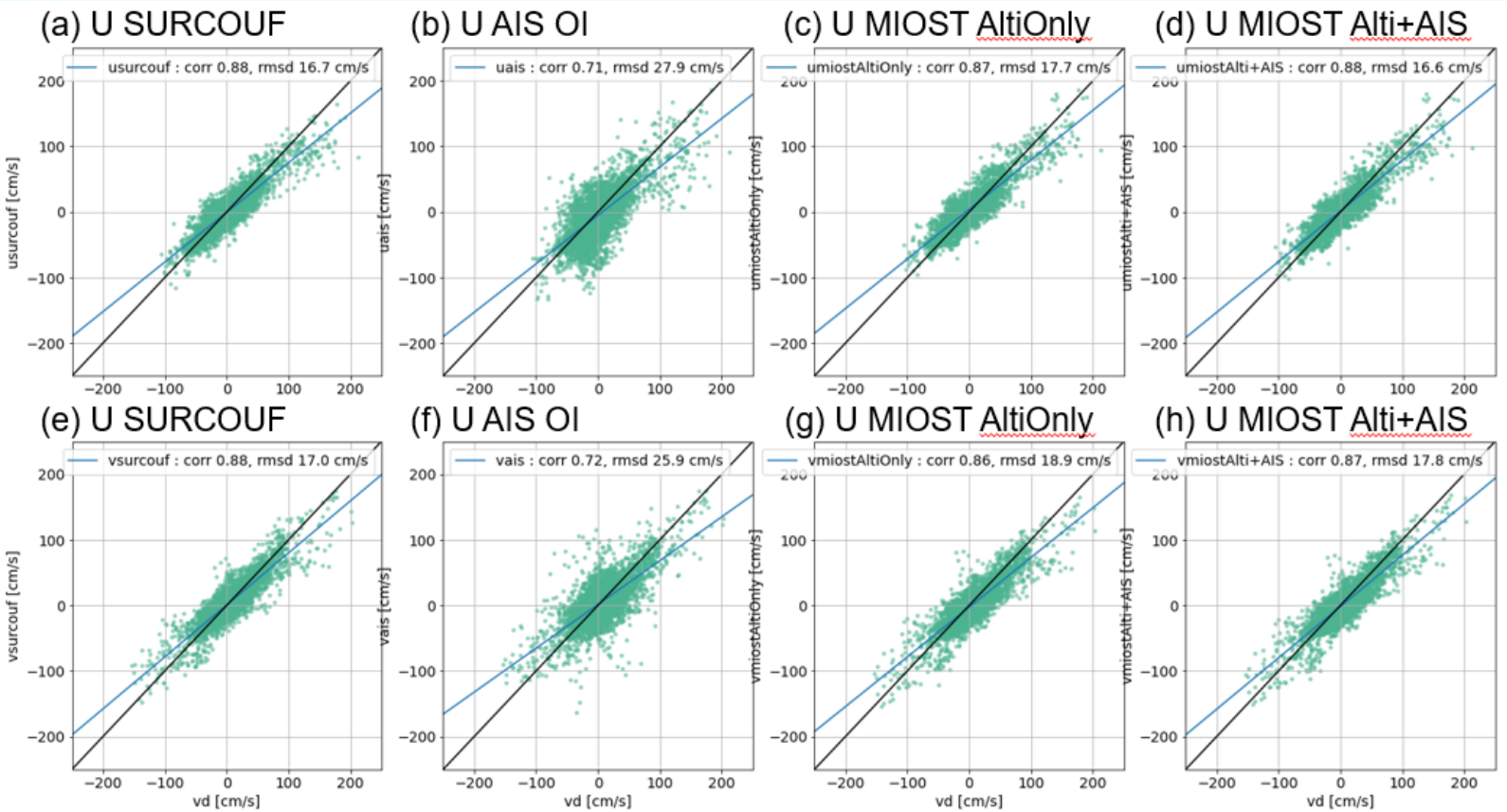




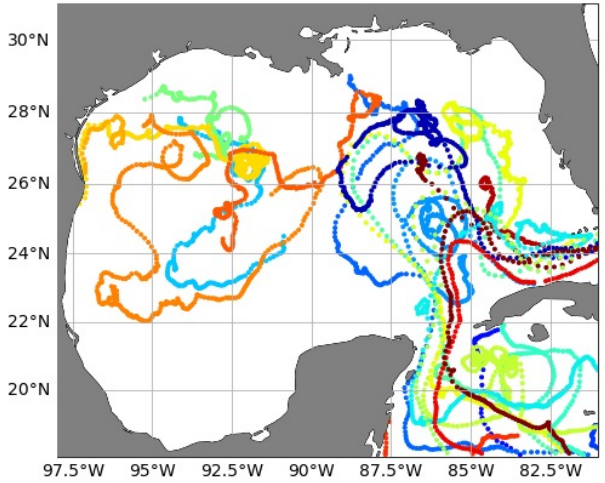
Spatial extension :
80 to 800 km

Ubelmann, C., Dibarboure, G., Gaultier, L., Ponte, A., Ardhuin, F., Ballarotta, M., & Faugere, Y. (2021). Reconstructing ocean surface current combining altimetry and future spaceborne Doppler data. *Journal of Geophysical Research: Oceans*, *126*, e2020JC016560. https://doi.org/10.1029/2020JC016560

Validation with independant drifters drogued and undrogued (slippage corrected) 2019-2020



(i) Drifter points used



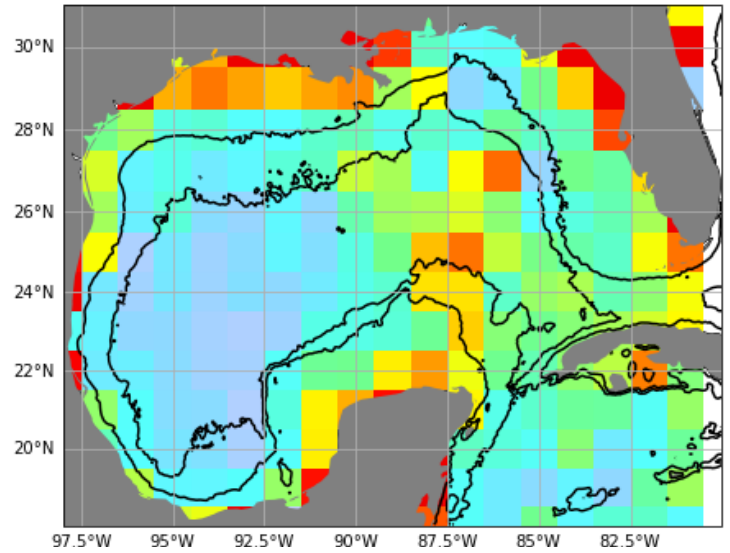
name	U correlation	U RMSE [cm/s]	Improvement U RMSE [%]	V correlation	V RMSE [cm/s]	Improvement V RMSE [%]
SURCOUF	0,88	16,68		0,88	17,03	
AIS OI	0,71	27,91		0,72	25,87	
MIOST AltiOnly	0,87	17,65		0,86	18,89	
MIOST Alti+AIS	0,88	16,62	**5,8**%	0,87	17,77	**5,9**%

- 5,8% improvement on U
- 5,9% improvement on V

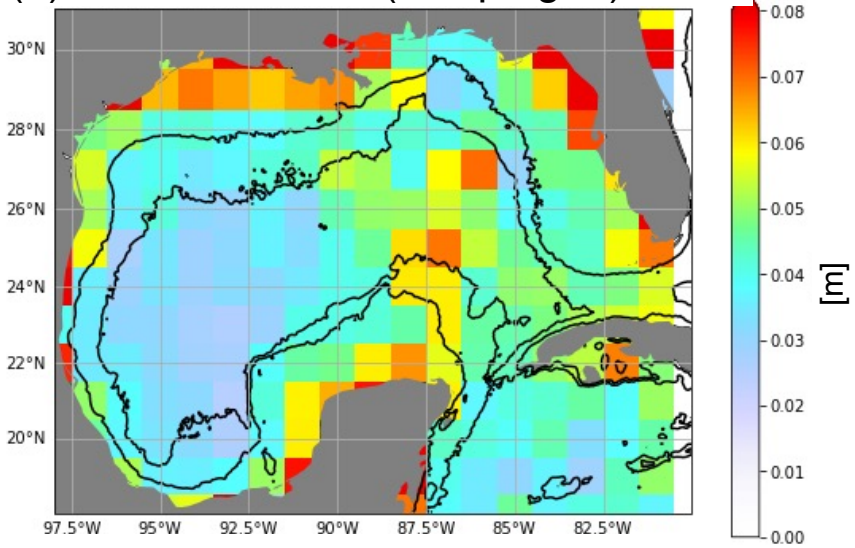
Validation with the independent altimeter SARRAL-AltiKA (all scales)

RMS of differences

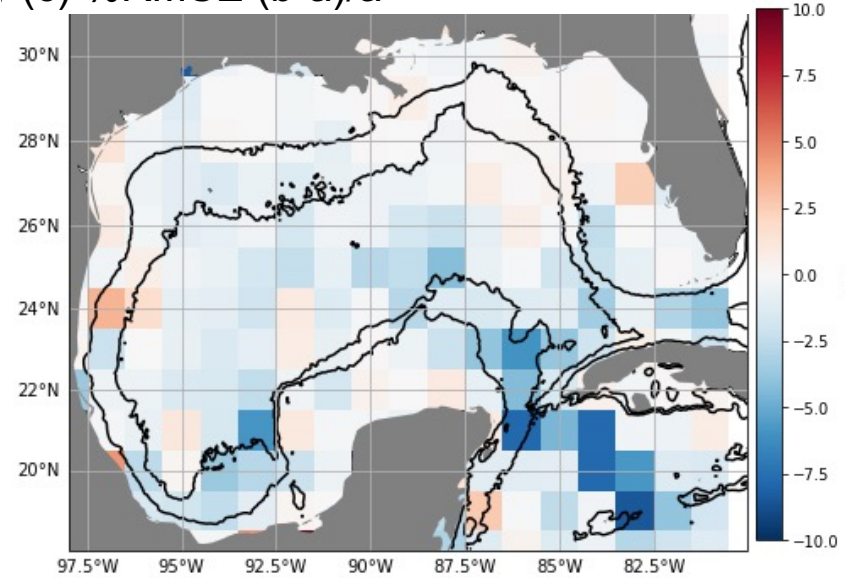
(a) MIOST Alti only (REFERENCE)



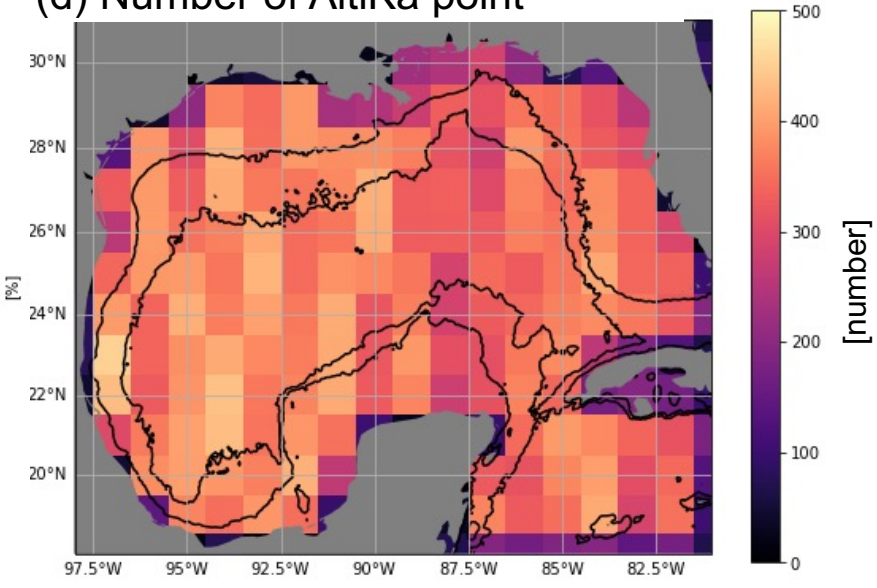
(b) MIOST Alti+AIS (comp ageo)



(c) %RMSE (b-a)/a



(d) Number of AltiKa point



(c) Score =

$$\frac{(RMSE_{MIOST\ Alti+AIS} - RMSE_{MIOST\ AltiOnly})}{RMSE_{MIOST\ AltiOnly}}$$

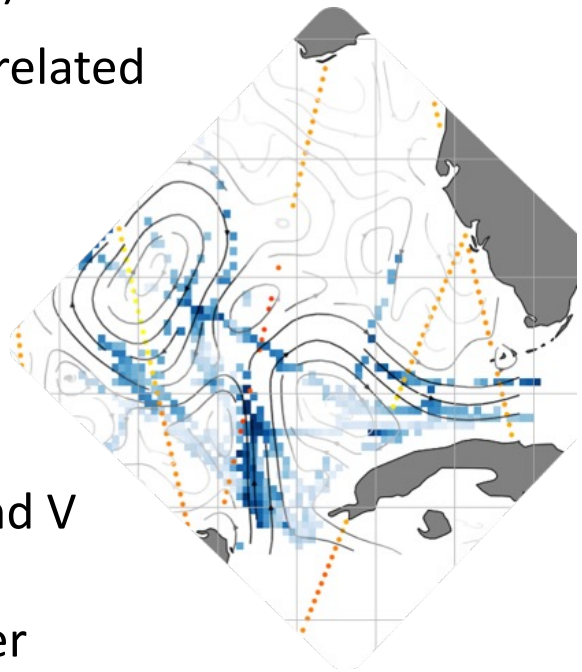
- Improvement over independent satellite in some areas and slight degradation of RMS of differences in some areas (ports?) compared to Miost with Altimetry only

RMSE reduction on all scales

	RMSE [mm]	
REF	45,8613	
MIOST Alti+AIS	45,5517	**-0.68%**

Conclusion AIS derived Current

- Helmholtz-Hodge Decomposition helps to reveal the Physical content of the AIS derived current
- There is still noise and the divergent part is sometimes over-estimated (not realistic)
- Difficulties to separate the physical content from the noise (no Gaussian, highly correlated error, stormy weather conditions)
- Inhomogeneity in the maritim traffic



Conclusion Merging

- Merge of AIS current data with successful altimetry: reconstruction of SSH and U and V current fields
- Improvement of currents compared to altimetry alone (comparison with total drifter currents)
- SSH improvement compared to altimetry alone (comparison with an independent altimeter)
- Errors associated with AIS inflated currents → need to improve to better take into account the AIS data signal