Dynamic interpolation of SSH from along-track data: real data experiments and characterization of performances

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Outline

- Brief presentation of the method
- Dynamic Interpolation: tests with real data !
  - → Gulf Stream experiment
  - → Ongoing tests in ACC and Mediterranean
- Toward smaller scales mapped with SWOT?

Dynamic interpolation

• The DUACS Optimal Interpolation (OI) scheme merging the multi-satellite data has not significantly evolved for many years

• Effective resolution: ~170km in wavelength. Mostly limited by the inter-track resolution and temporal coverage.

• A simple non-linear propagator can be effective to mitigate poor temporal SSH coverage:

- **[1] Ubelmann, C., P. Klein and L-L Fu, 2015: *Dynamic Interpolation of Sea Surface Height and Potential Applications for Future High-Resolution Altimetry Mapping*. J. Atmos. Oceanic Technol.**

• The implementation to along-track data (inversion step) has been successfully tested in realistic OSSEs:

- **[2] Ubelmann C., B. Cornuelle and L-L Fu, 2016: *Dynamic Mapping of Along-Track Ocean Altimetry: Method and Performance from Observing System Simulation Experiments*. J. Atmos. Oceanic Technol.**

→ Here we show the application to real data (in a 4 satellite configuration) in the Gulf-Stream

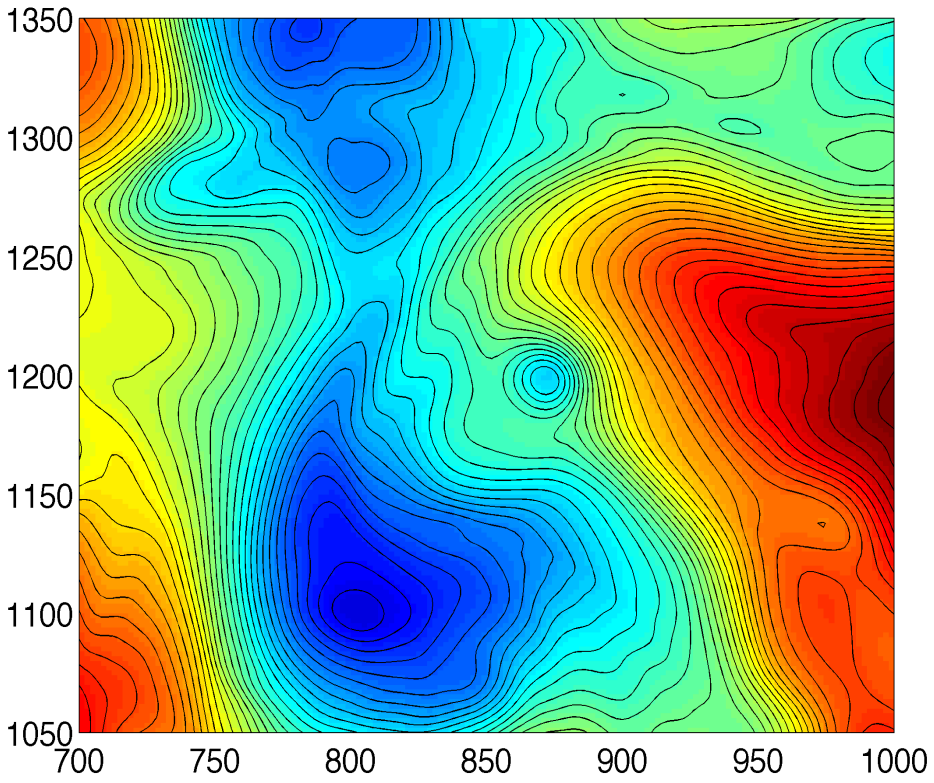
Interpolation through the first baroclinic mode PV

$$\psi = \frac{g}{f} SSH$$

$$q = \nabla^2 \psi - \frac{1}{L_R^2} \psi$$

$$\frac{\partial q}{\partial t} + J(\psi, q) - \beta \frac{\partial \psi}{\partial x} = 0$$

Propagated field



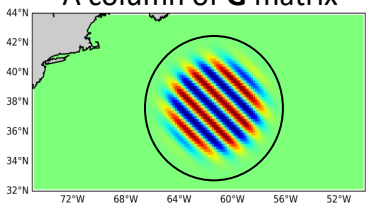
An effective method to reconstruct SSH between high-resolution maps (combination of forward and backward integrations, more details in [1])

The implementation to unevenly-distrubuted observations requires inversions described in the following.

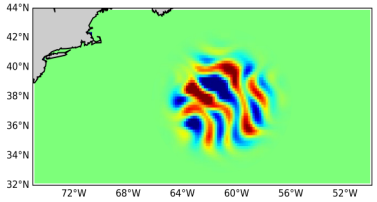
Implementation of dynamic interpolation

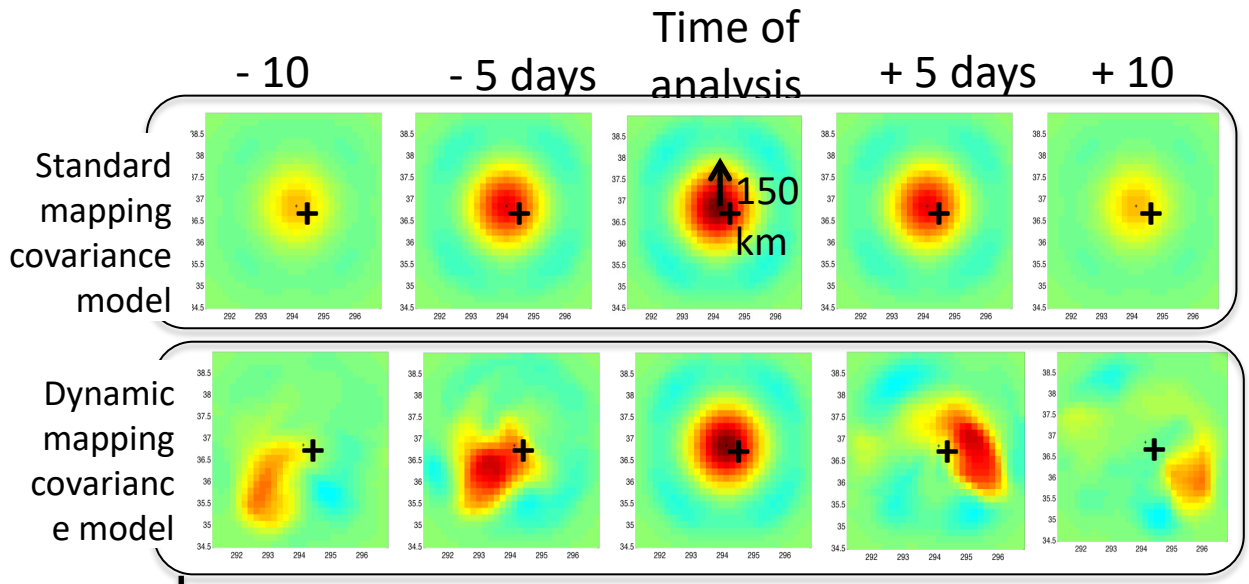
Covariances expressed through a 2D Fourier decomposition, then propagated:

A column of **G** matrix



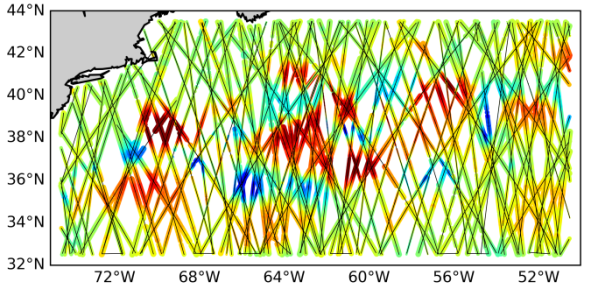
Propagation



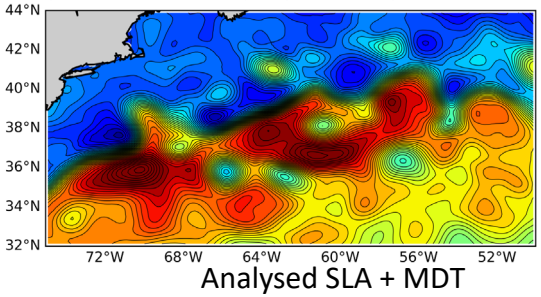


Flow-dependant covariances

$$\eta = (Q^{-1} + G^T R^{-1} G)^{-1} G^T R^{-1} y$$

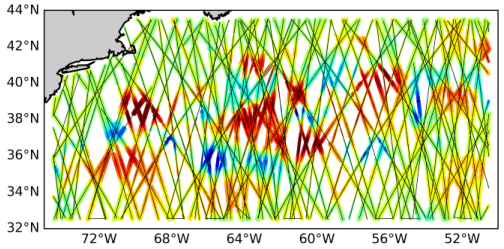


Fourier coef solutions projected in physical space:



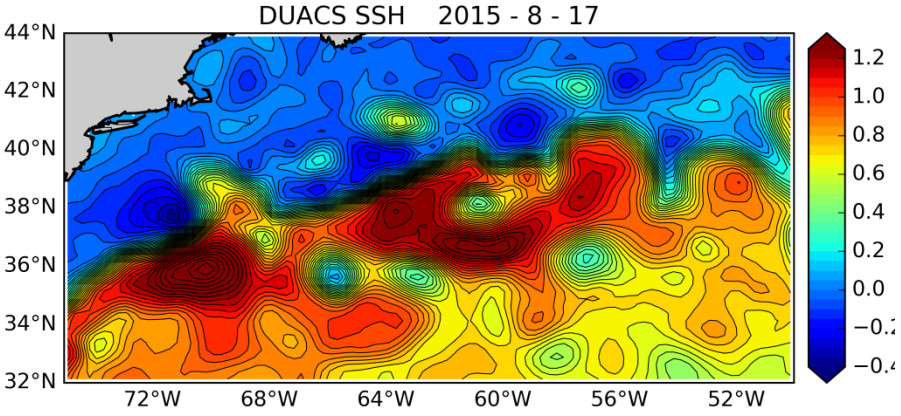
Analysed SLA + MDT

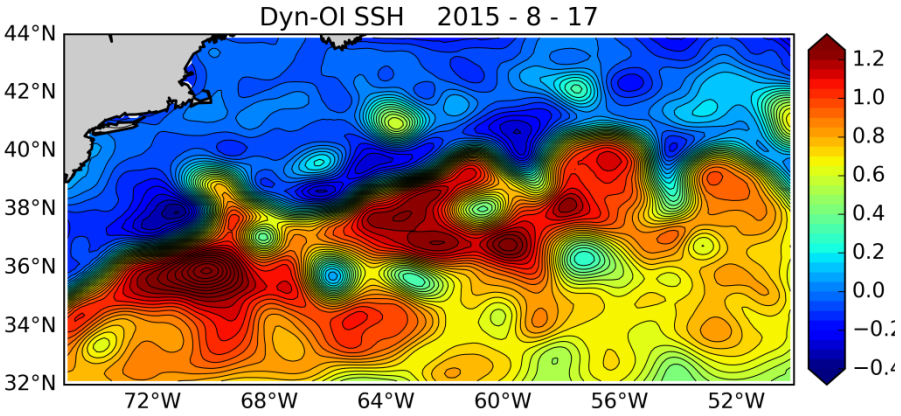
Experiment from a 4 satellite configuration

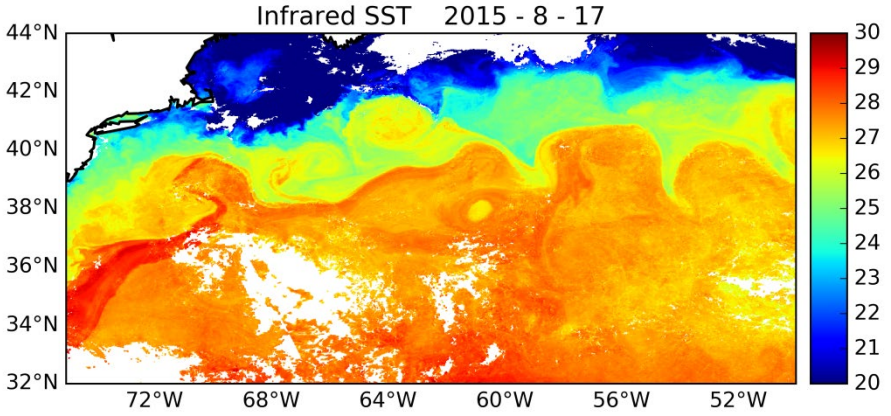


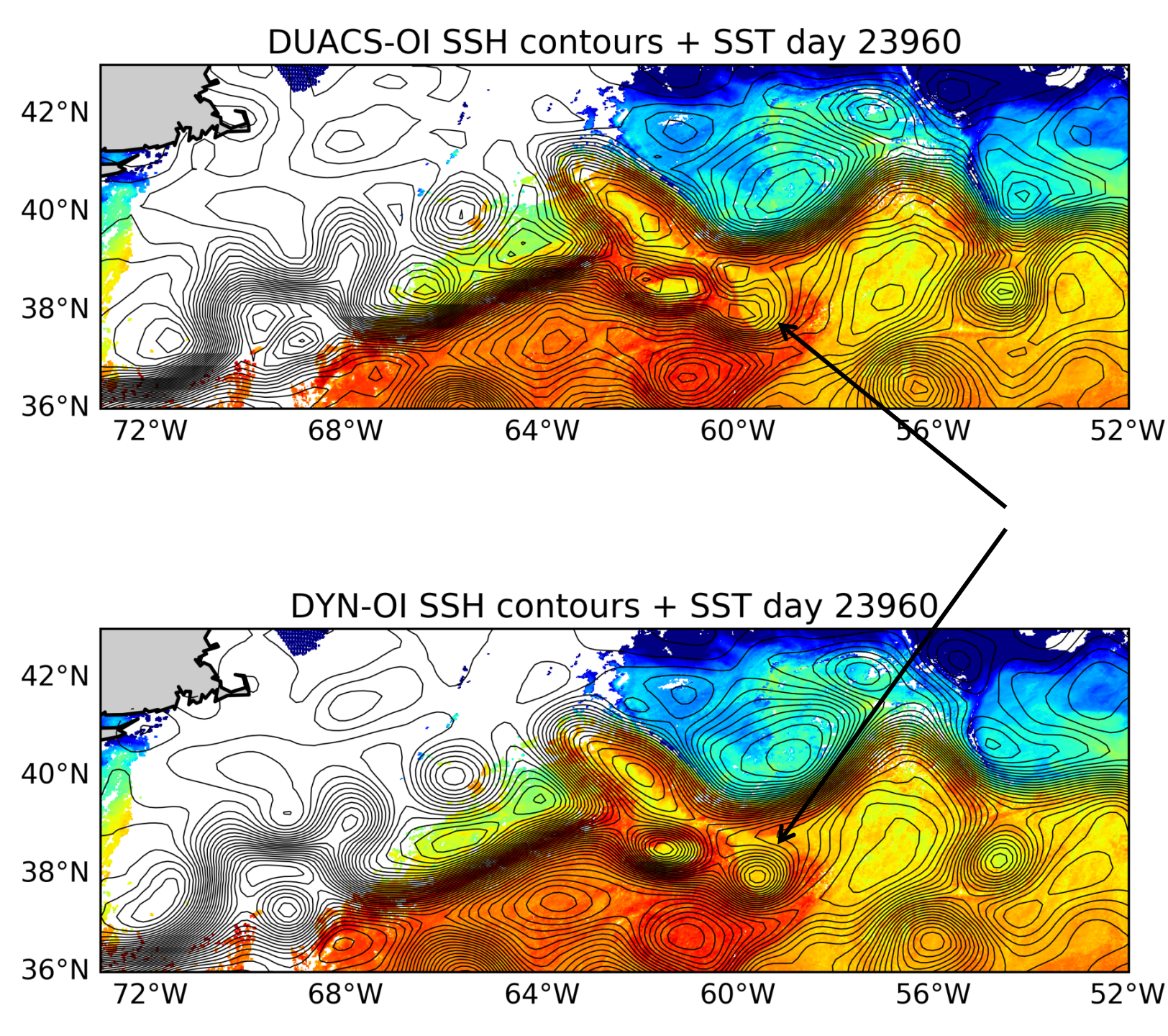
<u>Input data</u>: 1-year worth of Jason-2, AltiKa, Cryosat2 and Hy2 in 2015

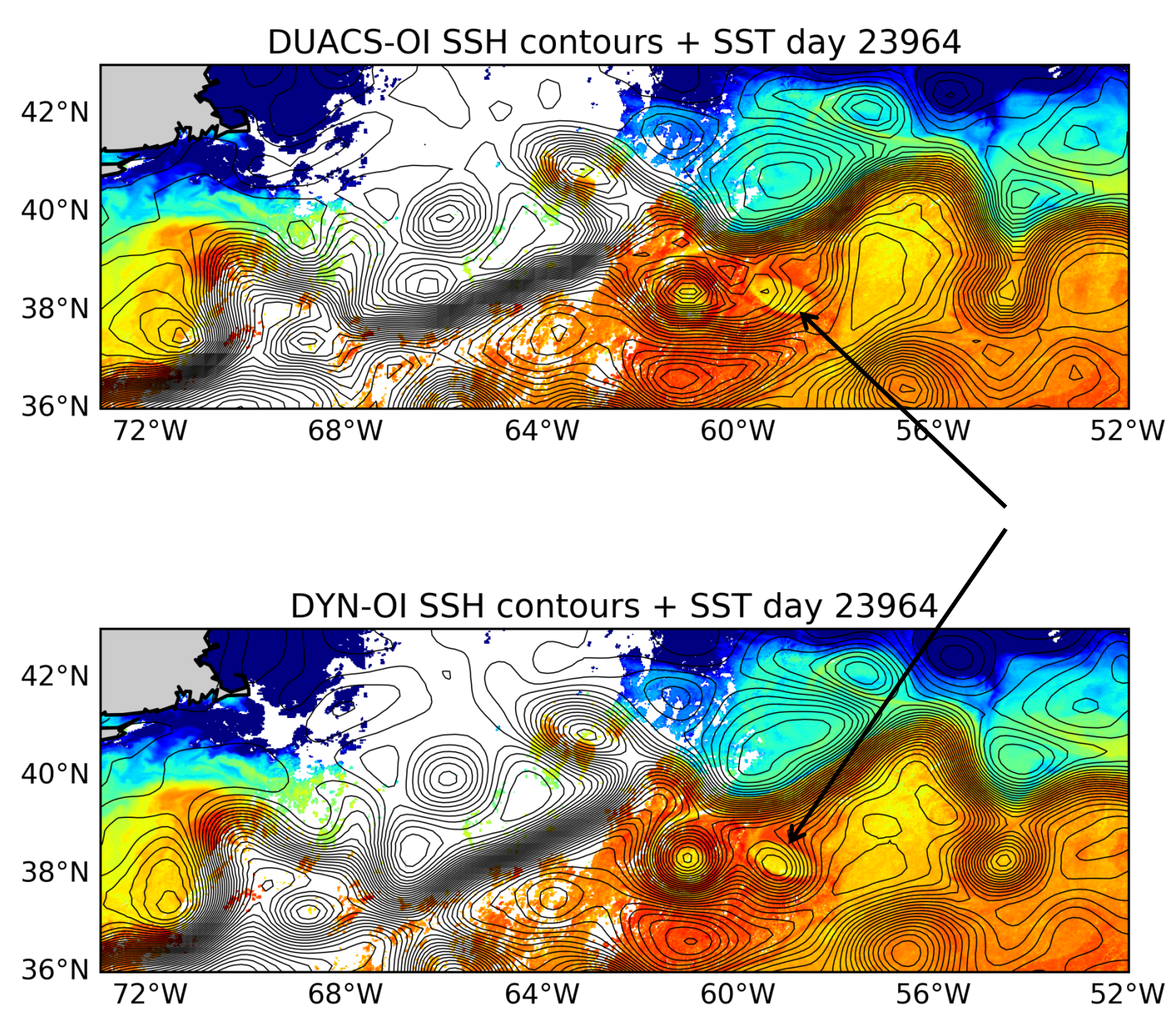
<u>Outputs</u>: Gridded maps with standard and dynamic OI

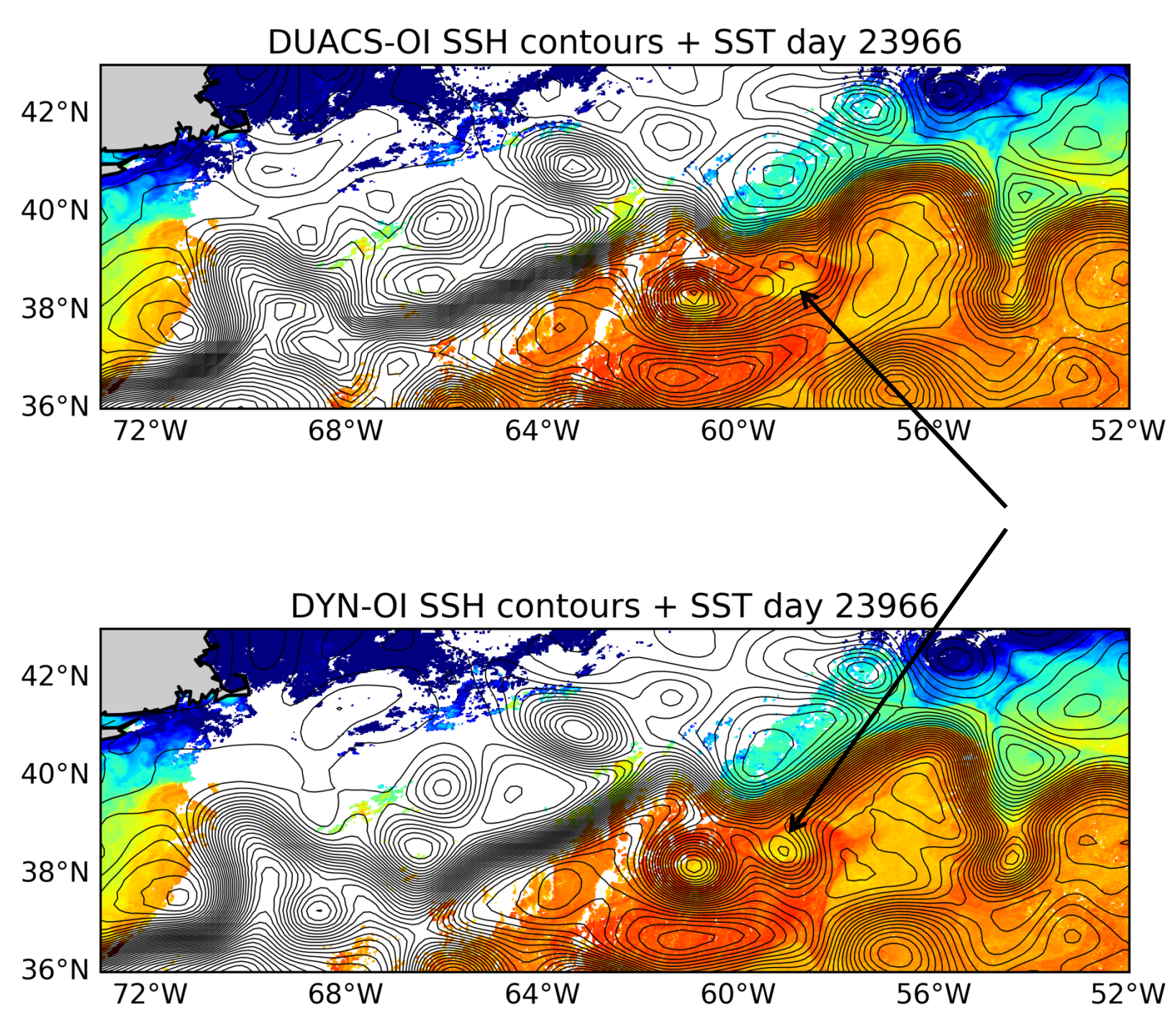


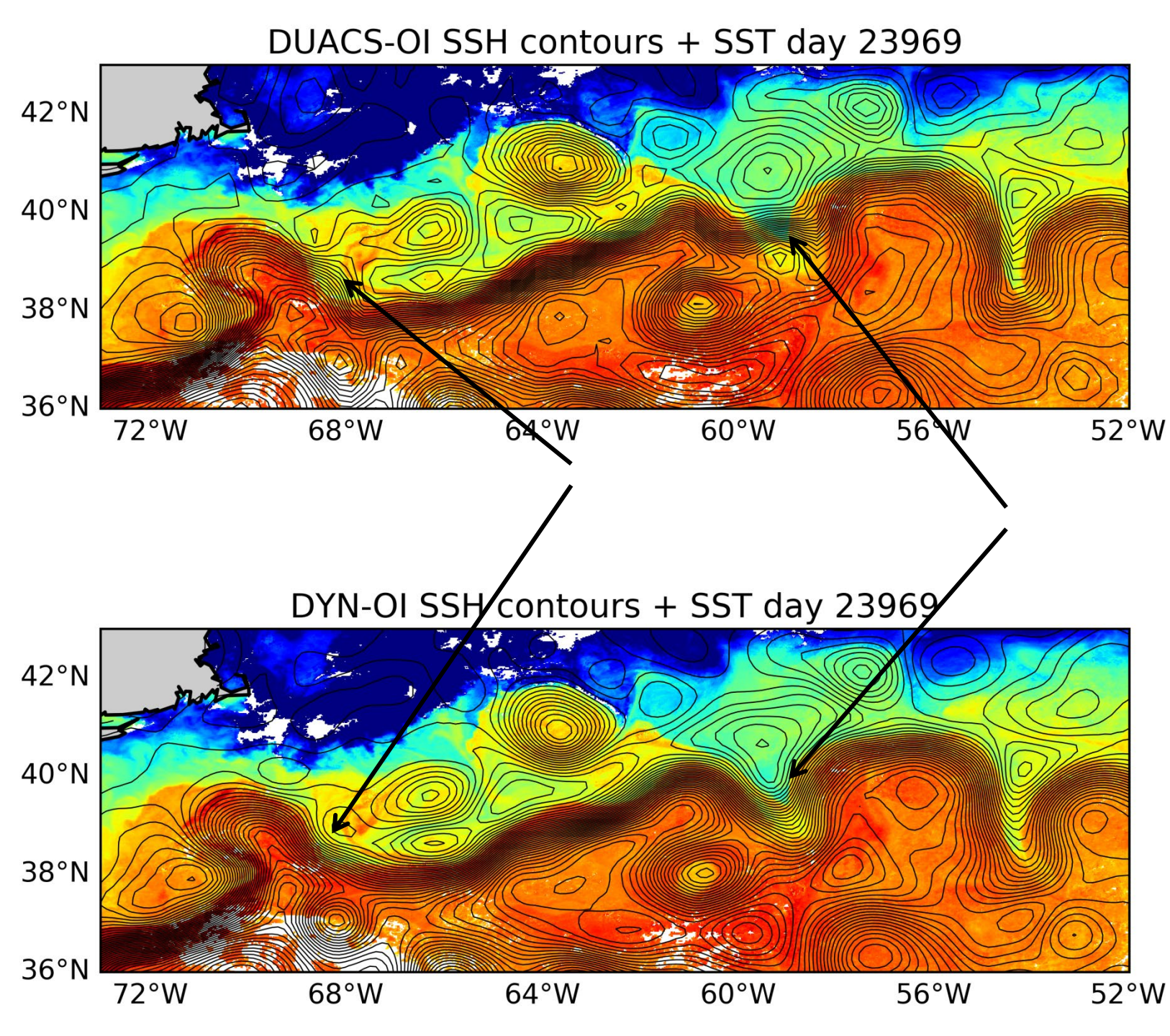




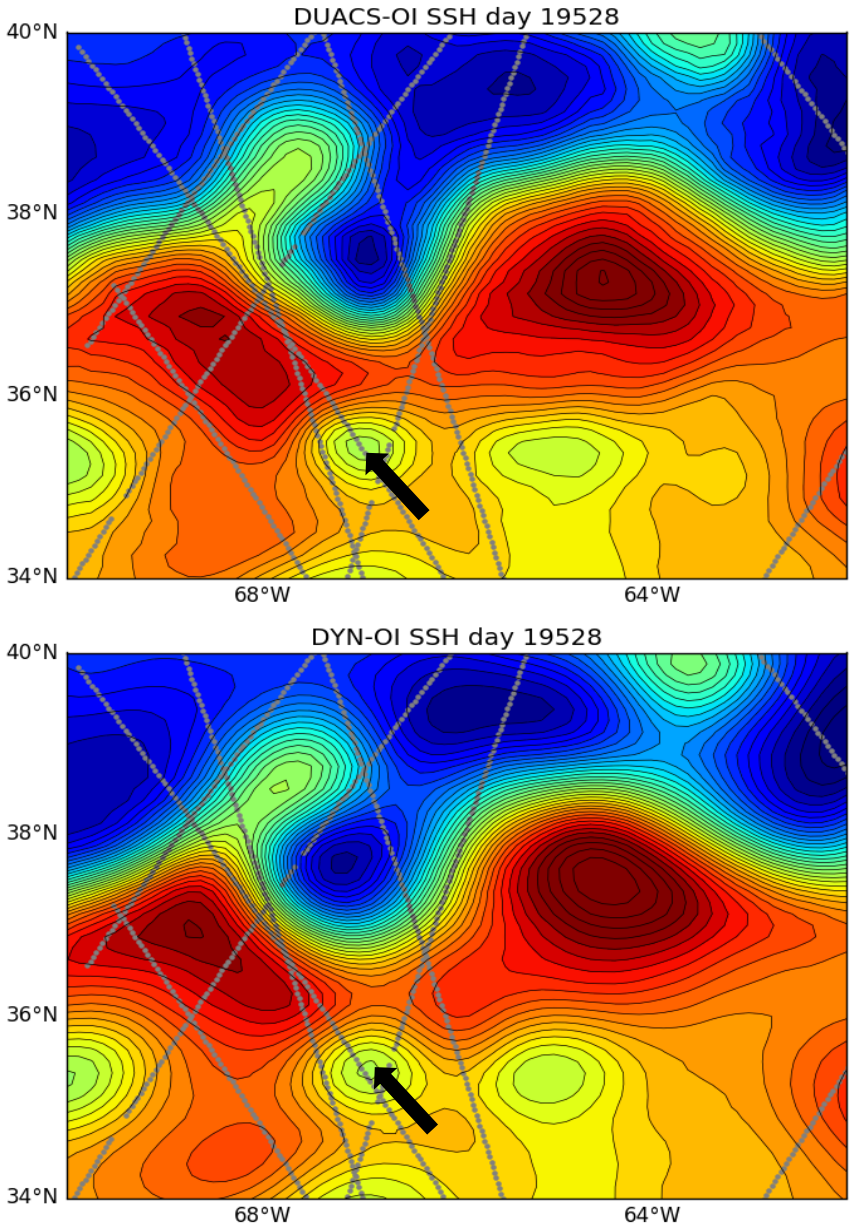

DUACS-OI SSH contours + SST day 23960
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W
DYN-OI SSH contours + SST day 23960
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W


DUACS-OI SSH contours + SST day 23964
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W
DYN-OI SSH contours + SST day 23964
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W


DUACS-OI SSH contours + SST day 23966
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W
DYN-OI SSH contours + SST day 23966
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W


DUACS-OI SSH contours + SST day 23969
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W
DYN-OI SSH contours + SST day 23969
42°N
40°N
38°N
36°N
72°W
68°W
64°W
60°W
56°W
52°W

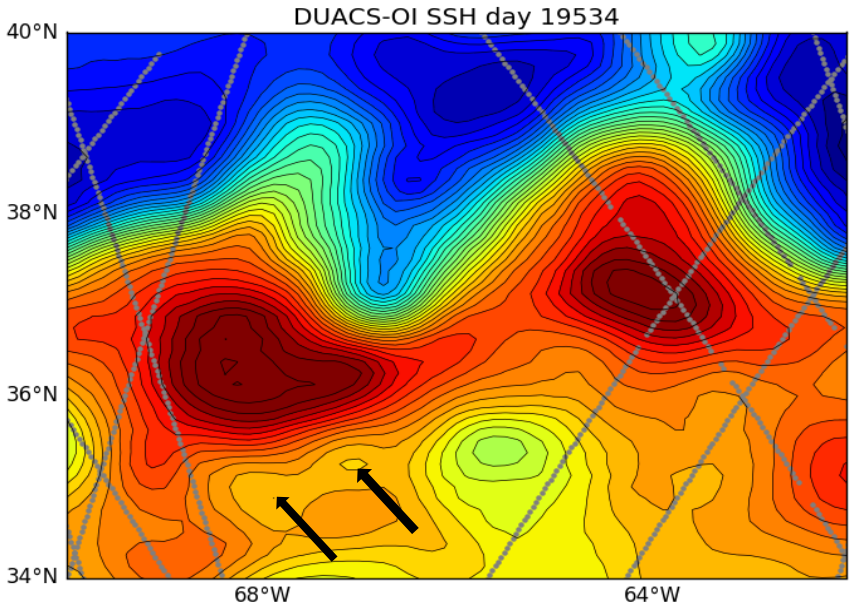
A classic example: lost eddies

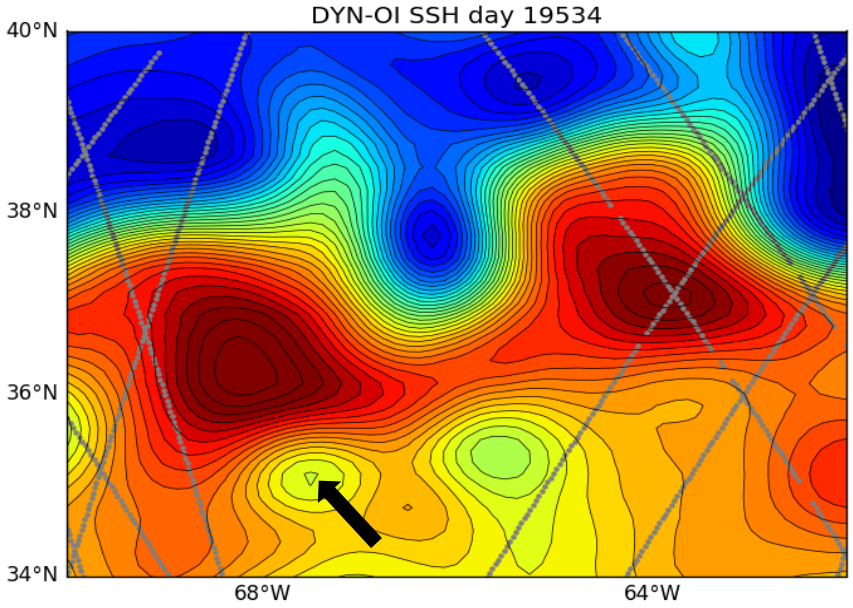


The eddy shown by the black arrow is similarly well resolved in standard and dynamic OI.

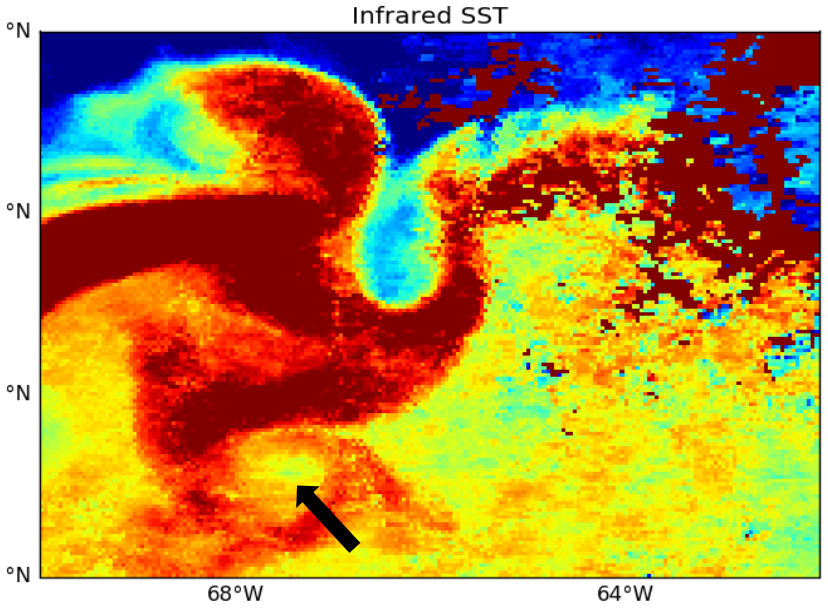
+/- 2 day altimetry tracks are indeed crossing the eddy.

A classic example: lost eddies



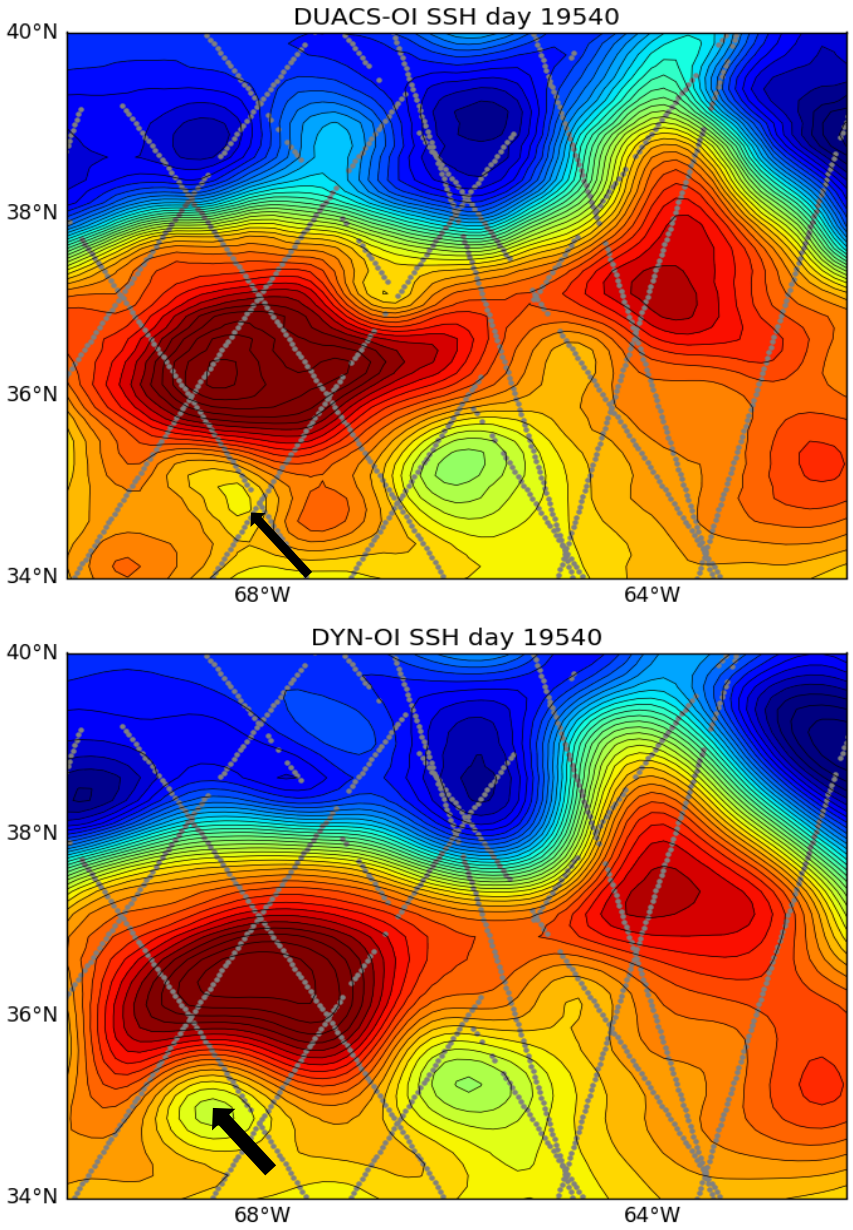


6 days later:
Absence of along-track data near the eddy → eddy not resolved in standard OI



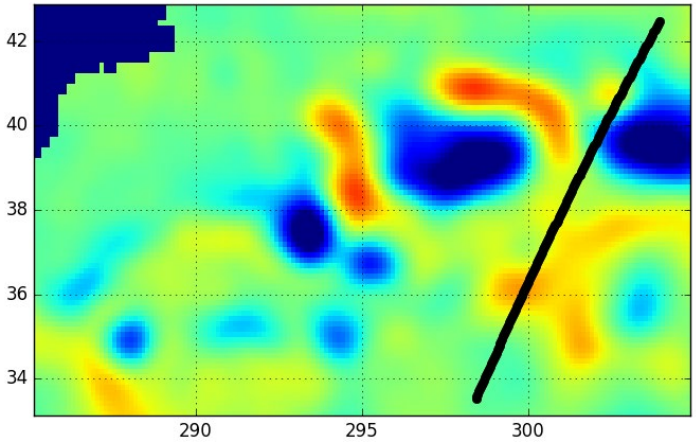
From SST filaments: This cyclonic eddy is still in shape !
It is resolved with dynamic OI

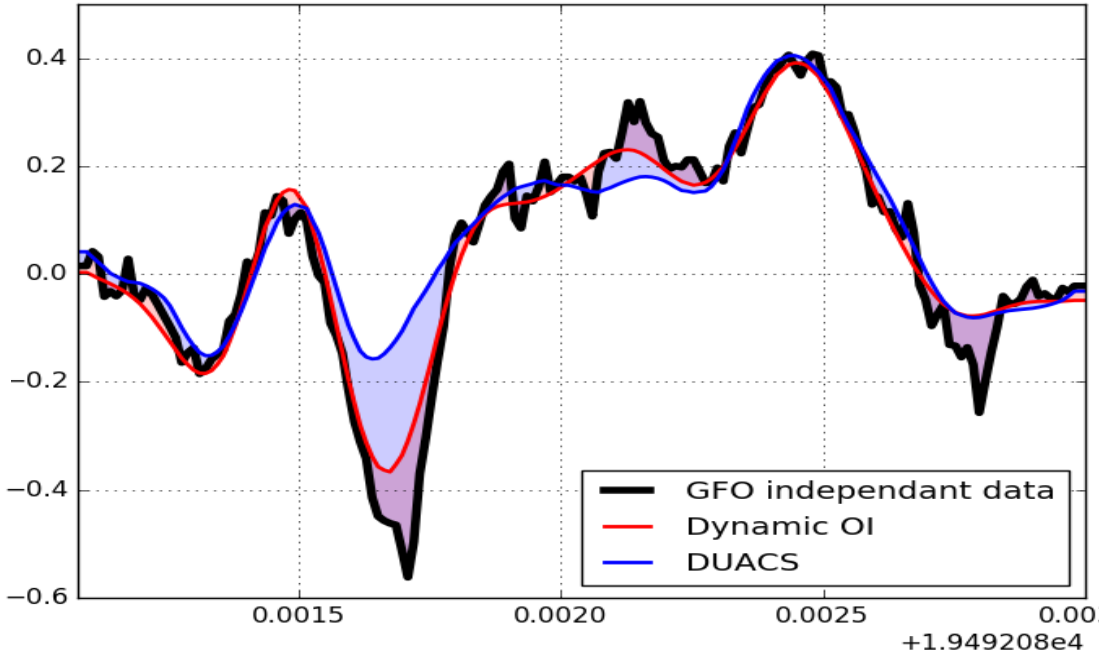
A classic example: lost eddies



12 days later:
Some tracks sample the eddy again.
The eddy reappeared in standard OI,
but slightly shifted toward the tracks.

Quantification of improvements: error variance



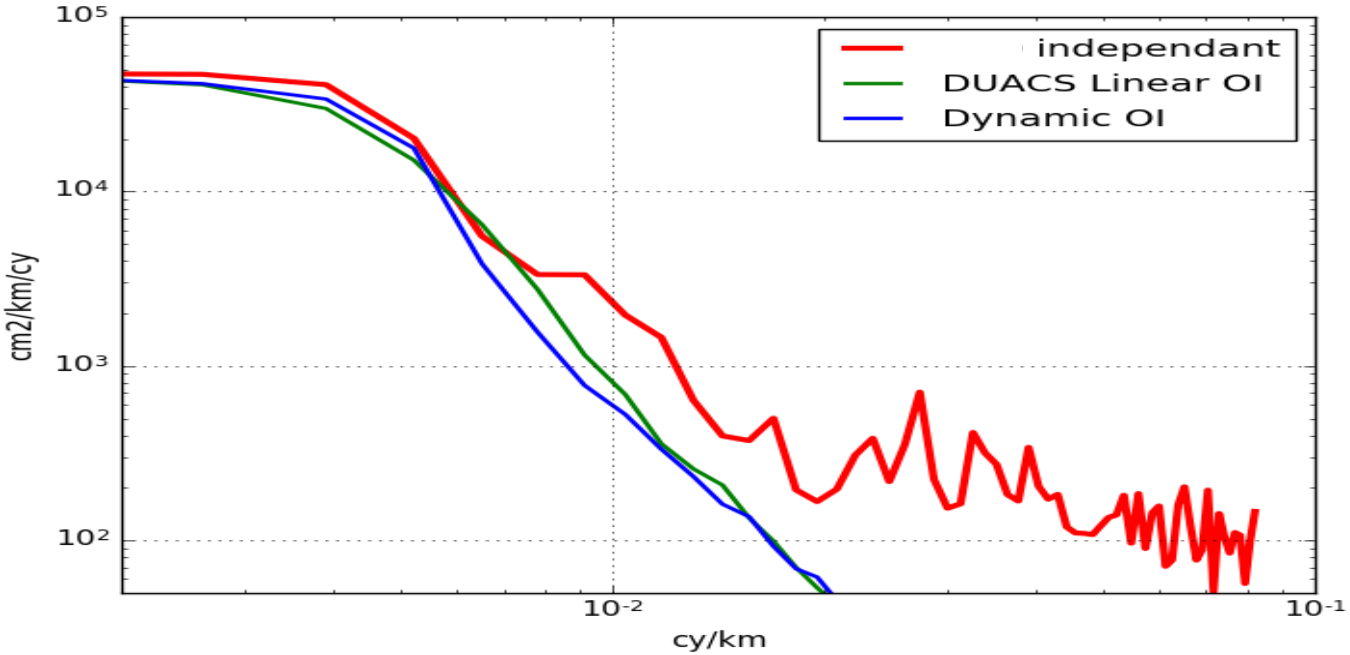


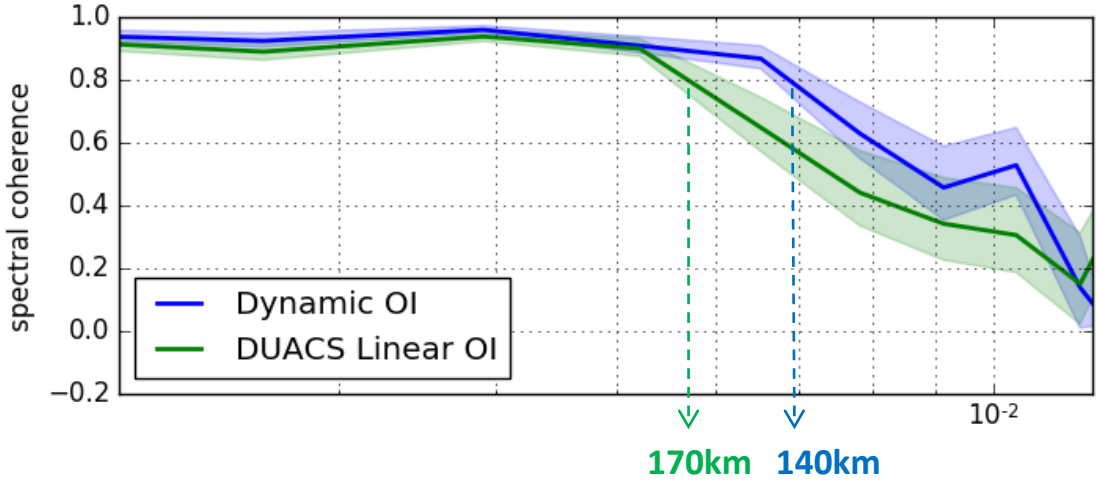
Variance of error over 1-year worth of independant GFO data:

- DUACS maps: 66.9 cm^2
- Dynamic OI maps: 51.9 cm^2

} **<u>~20% error reduction</u>**, consistent with OSSEs results from **[2]**

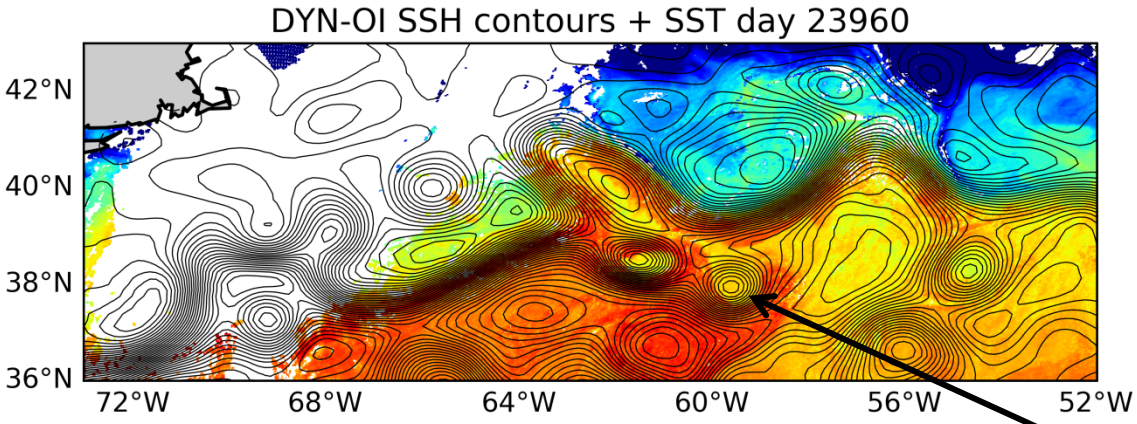
Quantification of improvements in spectral domain

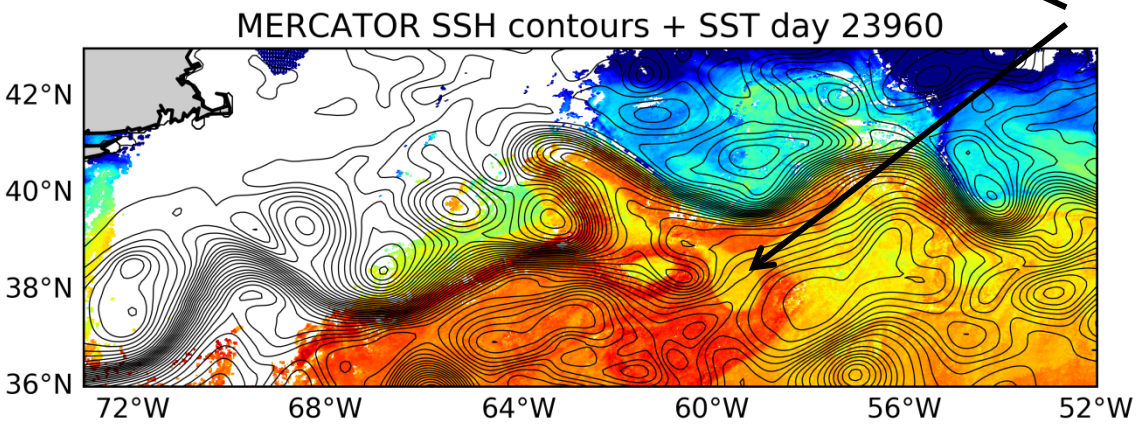


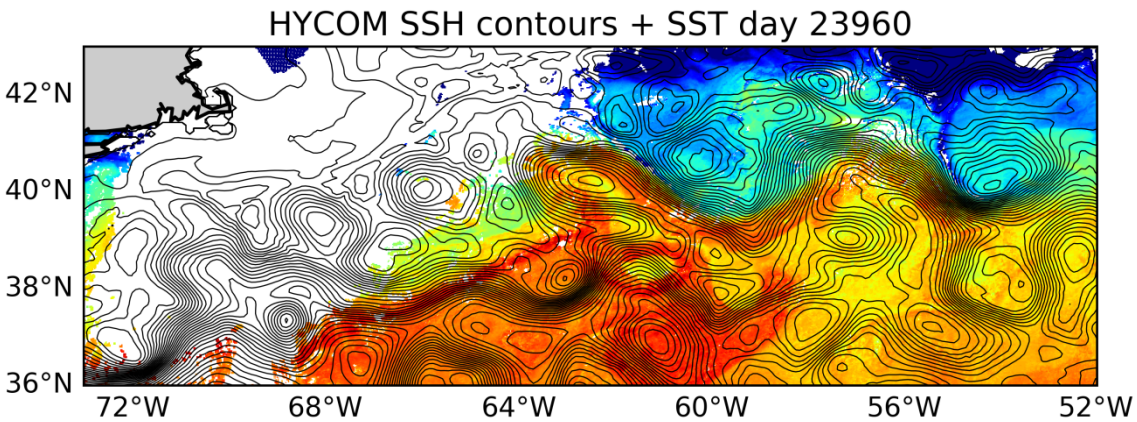


<u>Improvements occur mostly in the range 170km-140km</u>
(*consistent with the 150km eddy illustrated above*)

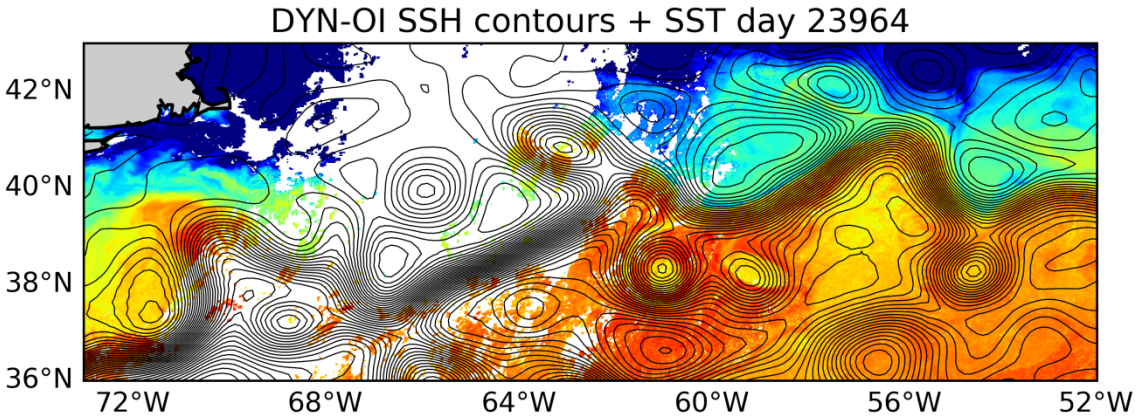
Comparison with assimilated products from PE models

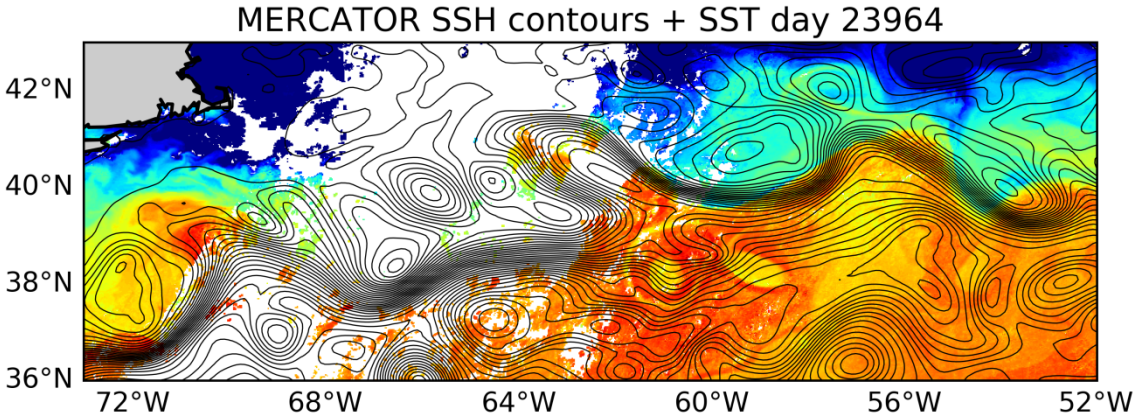


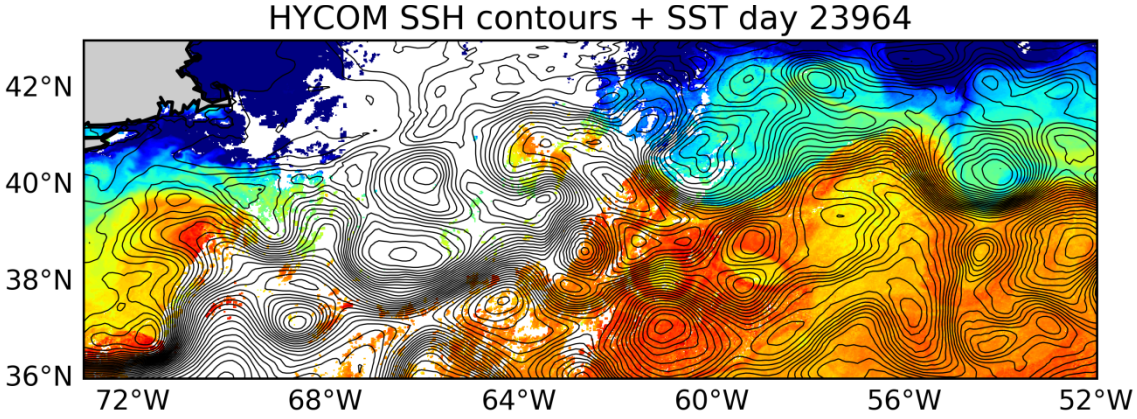




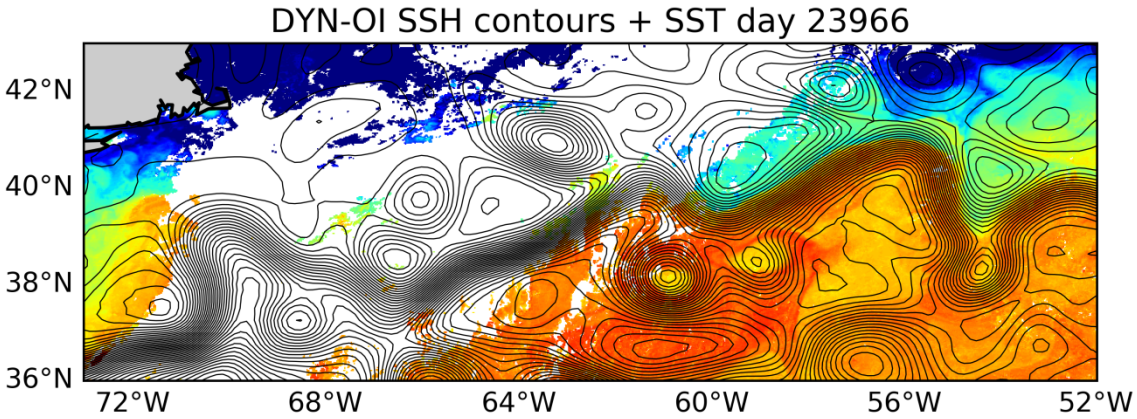
Comparison with assimilated products from PE models

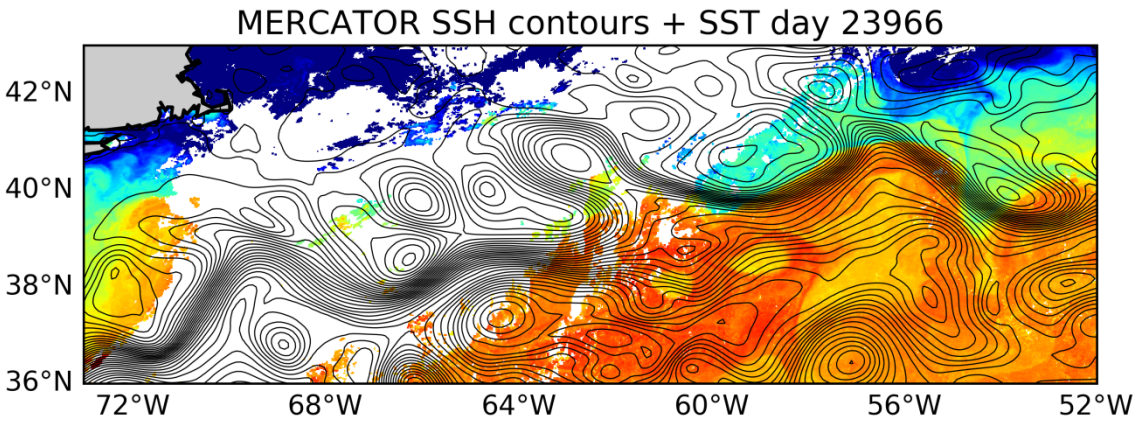


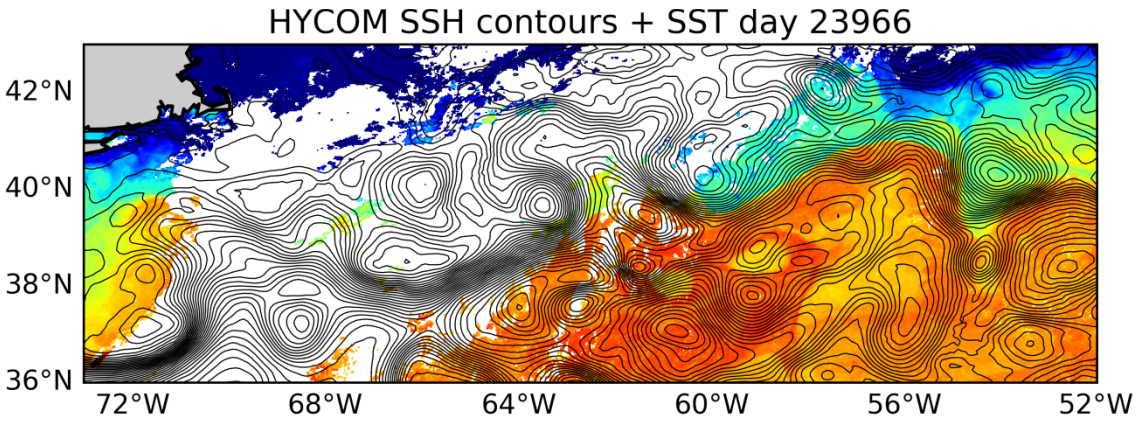




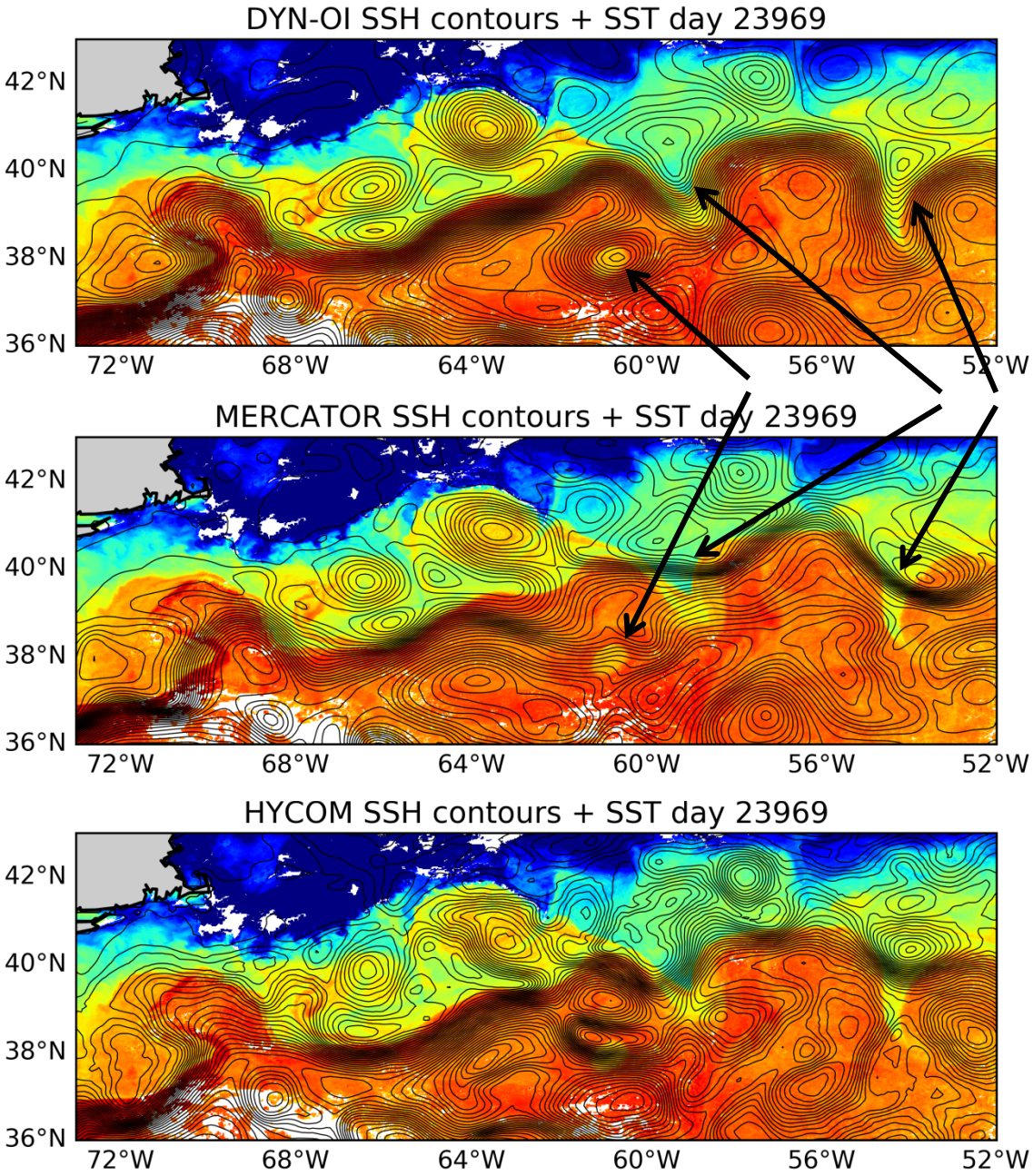
Comparison with assimilated products from PE models







Comparison with assimilated products from PE models

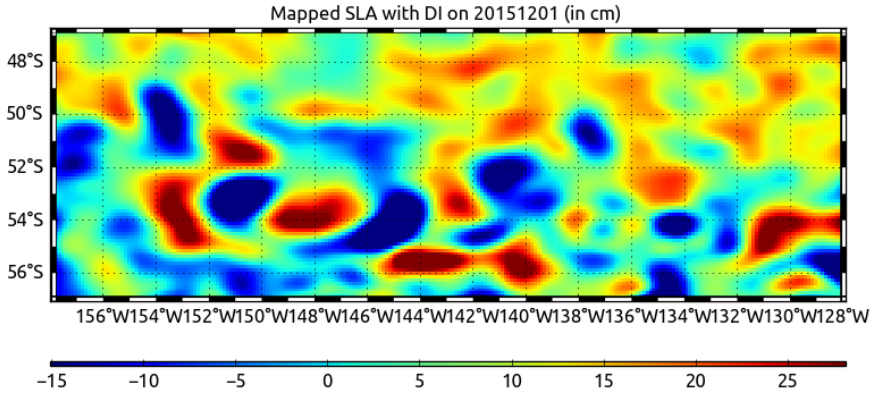


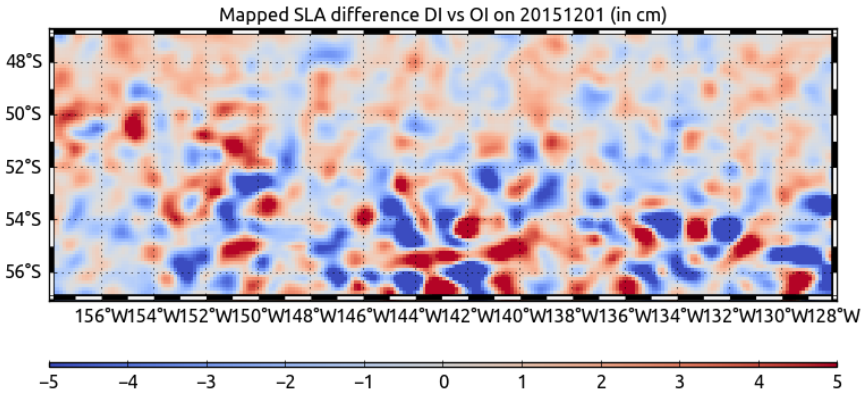
-**Overall agreement for large (>250km) mesoscale**

- In operational PE assimilated models mall-scales exhibit more departure from observed SST

- We are coordinating experiments with Mercator to test 4D assimilation schemes

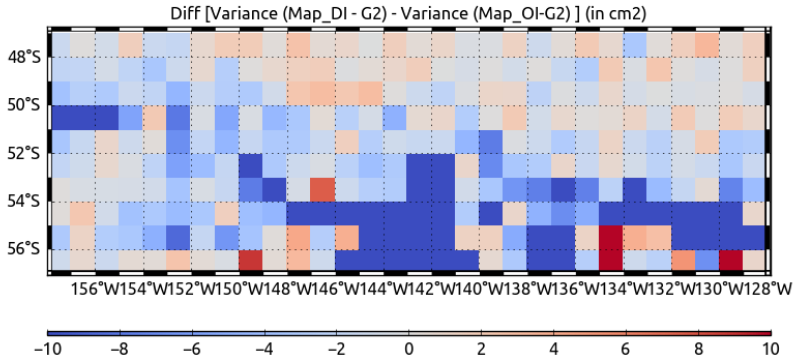
Ongoing tests in various regions : ACC (M. Ballarotta)





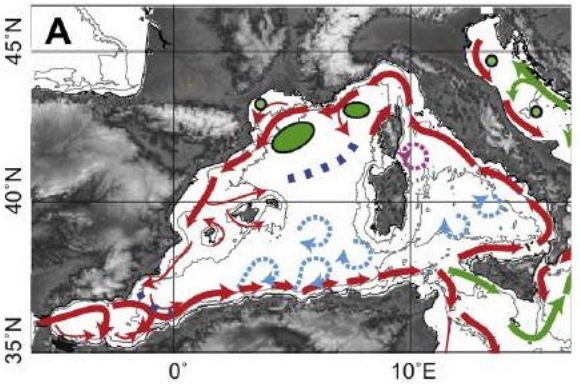
ACC →Overall improvment, some local circulation features (in red) need to be better accounted (implementing localized covariance functions, ongoing work)

Blue: variance reduction from independant Cryosat data:



Ongoing tests in various regions : Mediterranean (Rogé et al., JTECH 2017, in press)

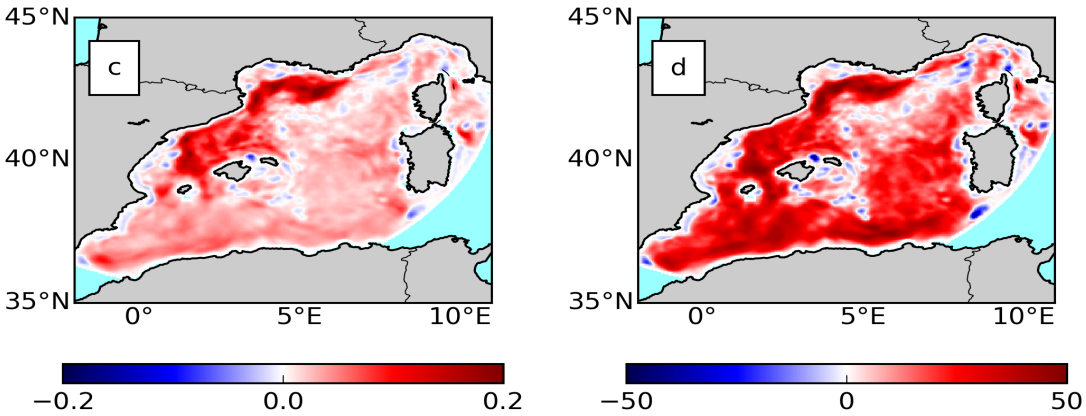
Mediterranean Sea → A complex and unhomogeneous circulation



→focus on tuning the QG propagator (using seasonnal MDT)

→Some results with real data soon !

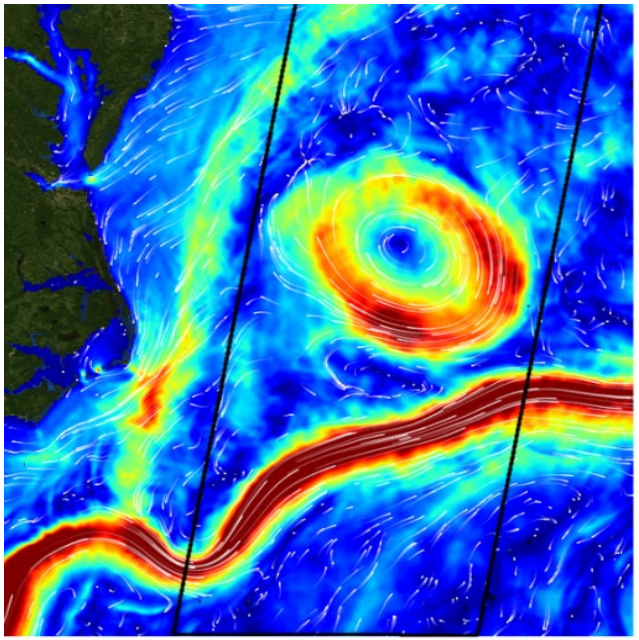
Error reduction from Linear to Dynamic field propagation



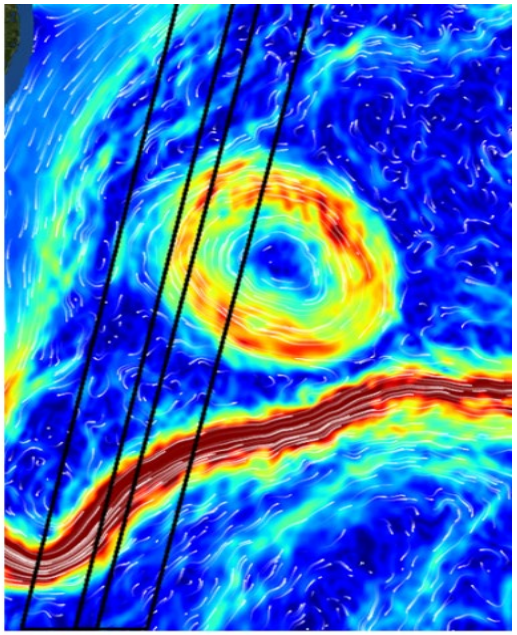
Conclusions of the Dynamic Interpolation experiments

- These real data experiments have confirmed the potentials of dynamic interpolation especially in Baroclinically Energetic regions
- In the Gulf Stream, we pushed the resolving capabilities from ~170km with standard Aviso maps down to ~140km with dynamic OI (tbc from longer series)
- Eddy trajectories are more continuous (‘lost-eddy’ effects mitigated)
- Regional products over the whole altimetry period will be available soon in Gulf Stream and ACC, maybe Mediterranean!
- Smaller scales with SWOT ?

Challenges for SWOT and multi-sensor approach for dynamic state reconstruction?



modeled current ("truth")

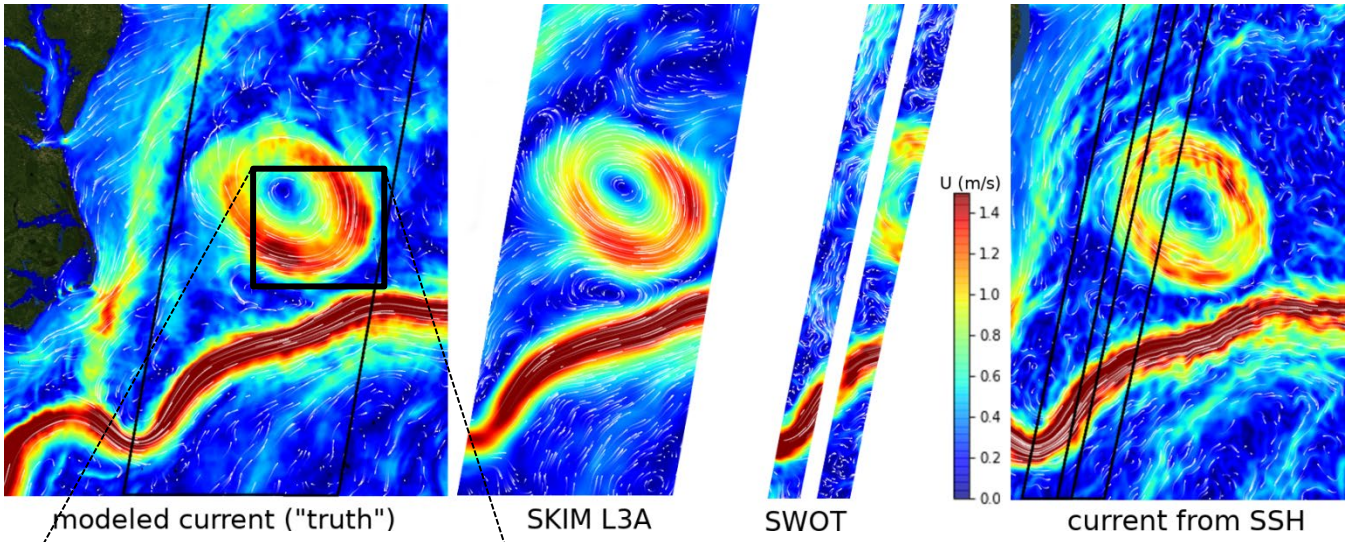


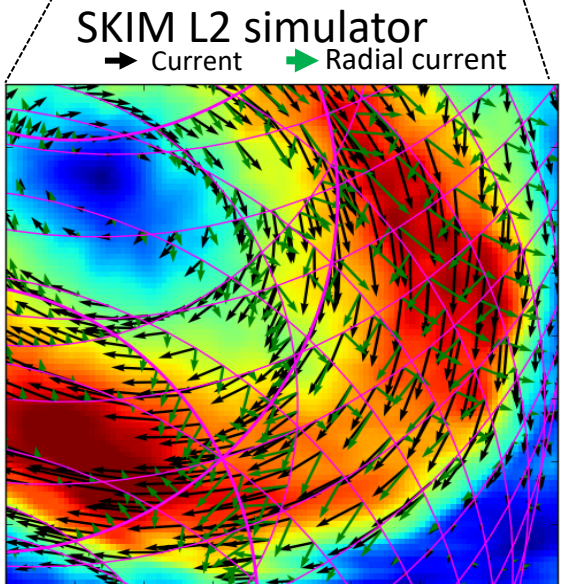
current from SSH

Lt in current: ~15 km
Lt in SSH: ~70km (see Bo's poster)

→ Even medium resolution (e.g. 50-100km) surface current mission would help with IW separation and dynamical state reconstructions

Challenges for SWOT and multi-sensor approach for dynamic state reconstruction?





- SKIM (proposed for EE9, ESA, F. Ardhuin) would provide medium resolution current
- Complementarity Current / Swath Altimetry would certainly push down the resolution limits of dynamic surface field reconstructions