Synergy Between Remote Sensing Variables: Level 4 Research Products of Sea Surface Salinity

M. Umbert, M. Portabella, S. Guimbard, J. Ballabrera-Poy and A. Turiel

SMOS Barcelona Expert Centre
Pg. Marítim de la Barceloneta 37-49, Barcelona SPAIN
E-mail: mumbert@icm.csic.es

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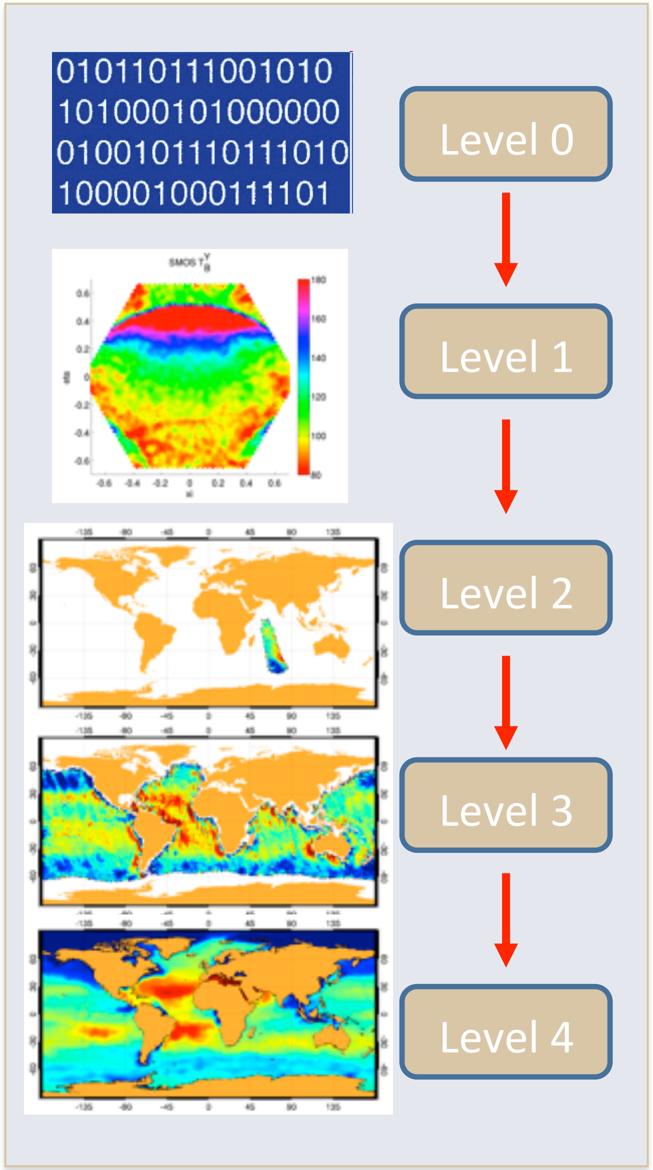
Motivation

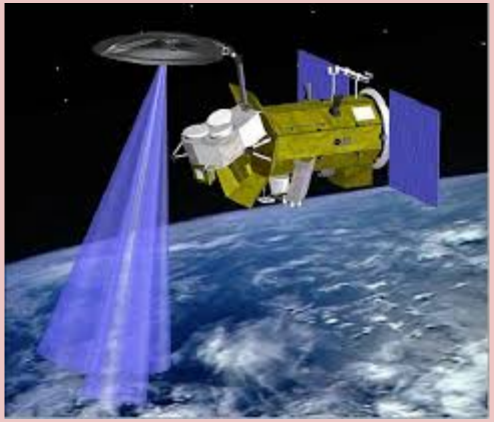


• Create the best possible **remote sensing geophysical products exploiting different satellite sources** for use in climate studies and operational applications.

• The **data fusion approach** presented here is a first step to produce high-quality remote sensing products **without involving a numerical model**.

• This method has been applied to produce **Level 4 SSS maps of SMOS and Aquarius** satellites.

Data



NASA Aquarius mission:

-Three L-band radiometers (θi= 29.36º, 38.49º, 46.29º), & an L-band scatterometer.

-Polar orbit: 6PM/6AM, 7-day repeat

-SSS retrievals

-Launch: June 2011

ESA SMOS mission:

-L-band synthetic aperture radiometer (θi from 0 to 68º), full-pol.

-Polar orbit: 6AM/6PM, 3-day repeat

-SSS retrievals

-Launch: November 2009

Data

NASA altimetry missions:
-Radar and microwave radiometer.
-Since 90’s
-Dynamical topography retrievals (SSH)

-Optimally interpolated daily products at 0.25° resolution.

NOAA AVHRR-Pathfinder mission:
-Advanced very high resolution radiometer
-Polar orbit: 3-day repeat
-SST retrievals

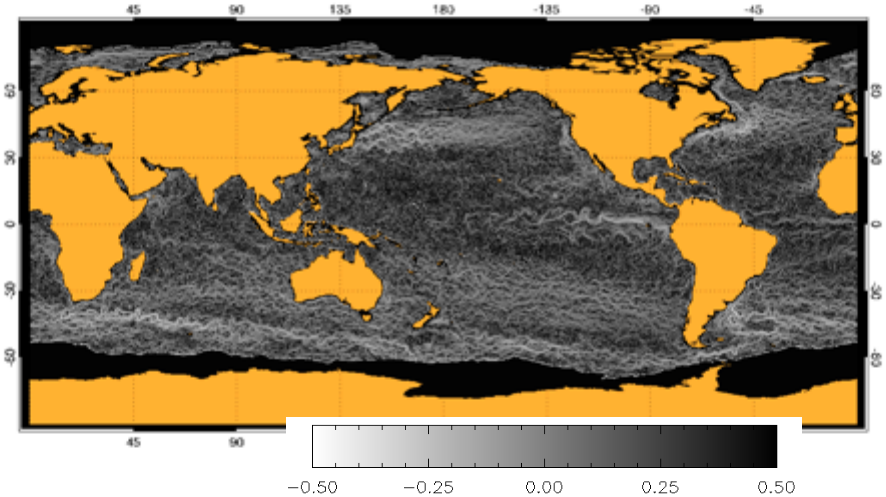
-Optimally interpolated daily products at 0.25° resolution.

Fusion algorithm

Singularity analysis is any technique capable of characterizing the **local regularity of a function.**

Singularity exponent

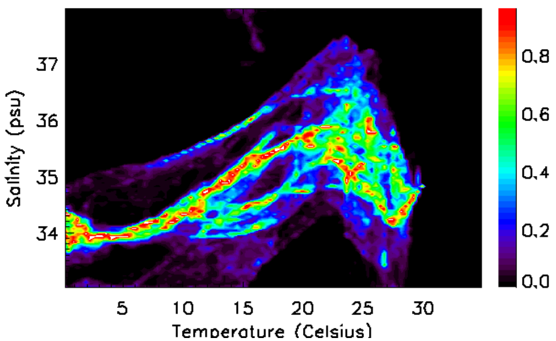
$$T_{\Psi}\left|\nabla s\right|(\vec{x},r)=\alpha_{s,\Psi}(\vec{x})\,r^{h(\vec{x})}+o\left(r^{h(\vec{x})}\right)$$

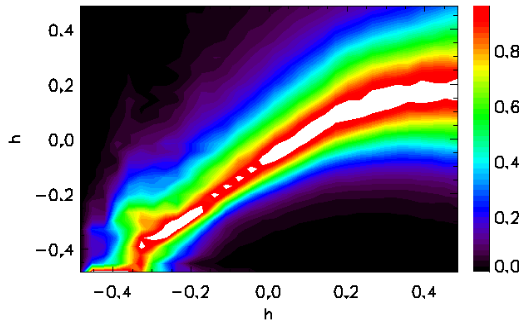


Singularity exponents are dimensionless local values, that allow detection of the local regularity of the ocean variable map. Singularity lines align with streamlines and allow to detect ocean structures. Shared **property of scalars advected by the turbulent flow**.

Singularity correspondence in ocean scalars SSS and SST

Earth Simulation MODEL data





Fusion algorithm

As singularity exponents coincide between variables, a functional relation exists between their gradients by means of a smoothly varying matrix

Local linear relation approximation

$$s(\vec{x}) = a(\vec{x}) \cdot t(\vec{x}) + b(\vec{x})$$

$$a(\vec{x}) = \frac{\sigma_{st}(\vec{x})}{\sigma_s^2(\vec{x})}$$

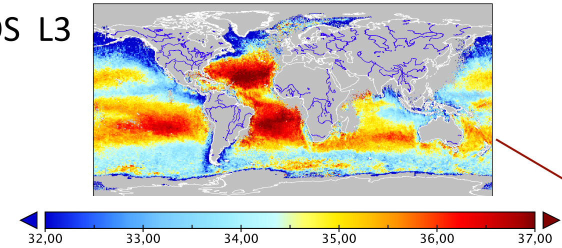
$$b(\vec{x}) = \langle s \rangle_{\vec{x}} - a(\vec{x}) \langle t \rangle_{\vec{x}}$$

$$\nabla s(\vec{x}) = \Phi(\vec{x}) \cdot \nabla t(\vec{x})$$

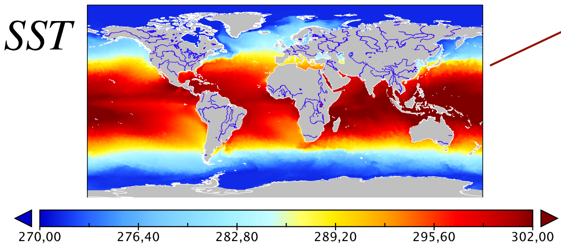
- $\nabla s(\vec{x})$: gradient of target variable
- $\Phi(\vec{x})$: relating matrix
- $\nabla t(\vec{x})$: gradient of template variable

Level 4 research product is a combination of two variables with smooth functions a and b. Functions a and b are estimated by weighted linear regressions around each point.

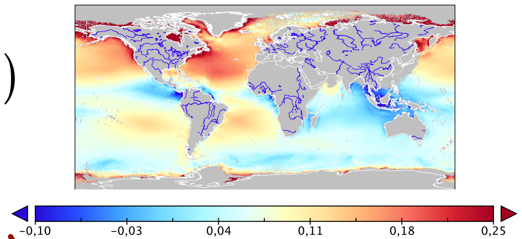
SMOS L3



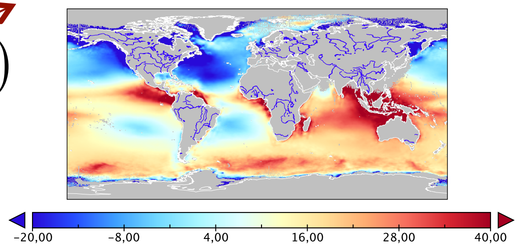
$t(\vec{x}) = SST$

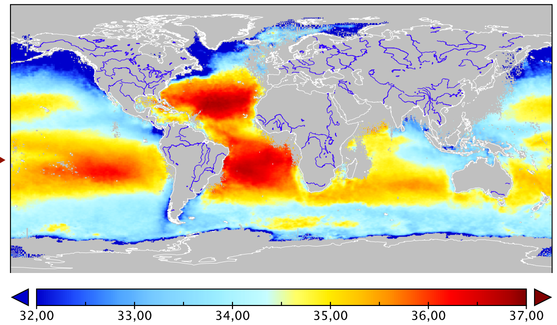


$a(\vec{x})$



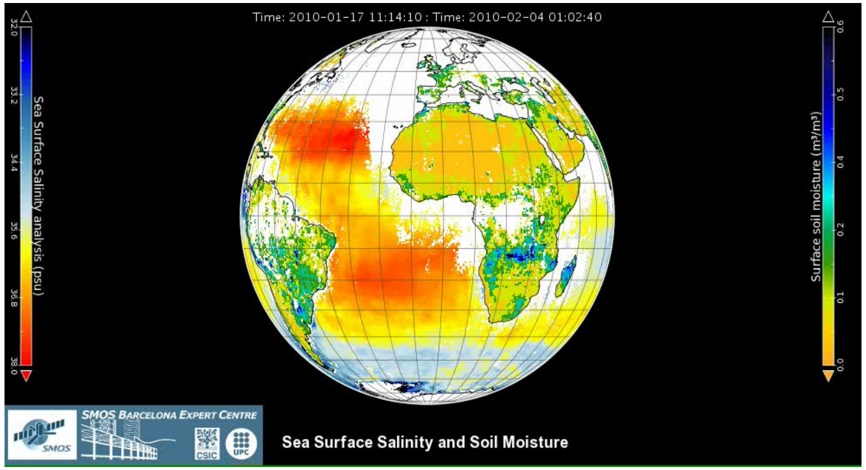
$b(\vec{x})$



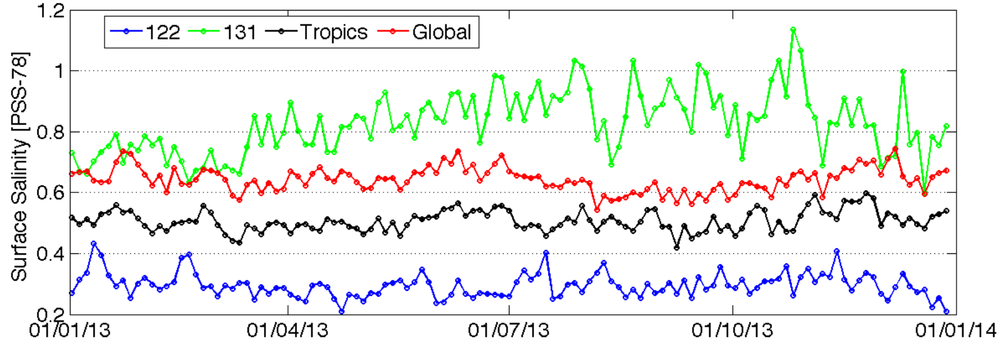


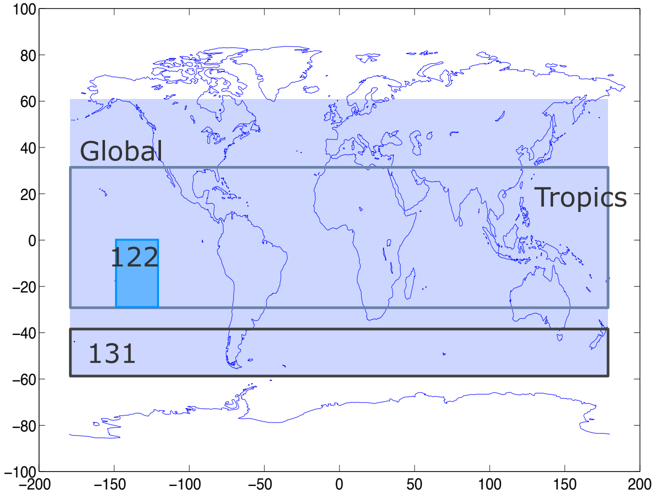
SMOS L4 research product

SMOS Level 4 research product SSS

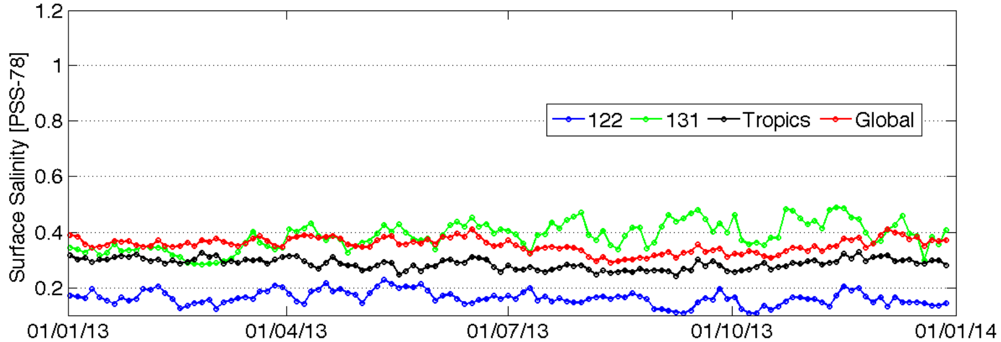


Level 3





Level 4



SMOS data and Quality reports available at:
http://cp34-bec.cmima.csic.es

- SMOS binned SSS product is compared with SMOS L4 (0.25° 9-day) research product. Validation with Argo floats shows **data fusion decreases standard deviation** error of SSS maps during all the SMOS reprocessed dataset (Years 2010-2013).

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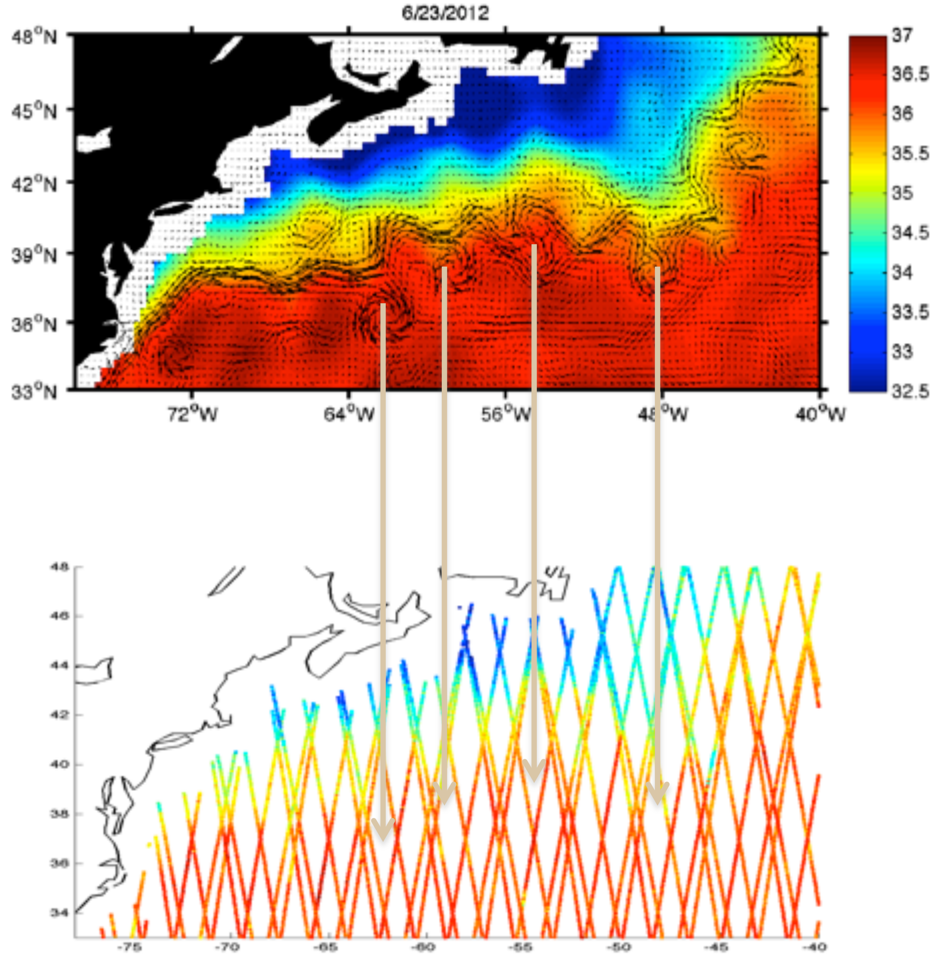
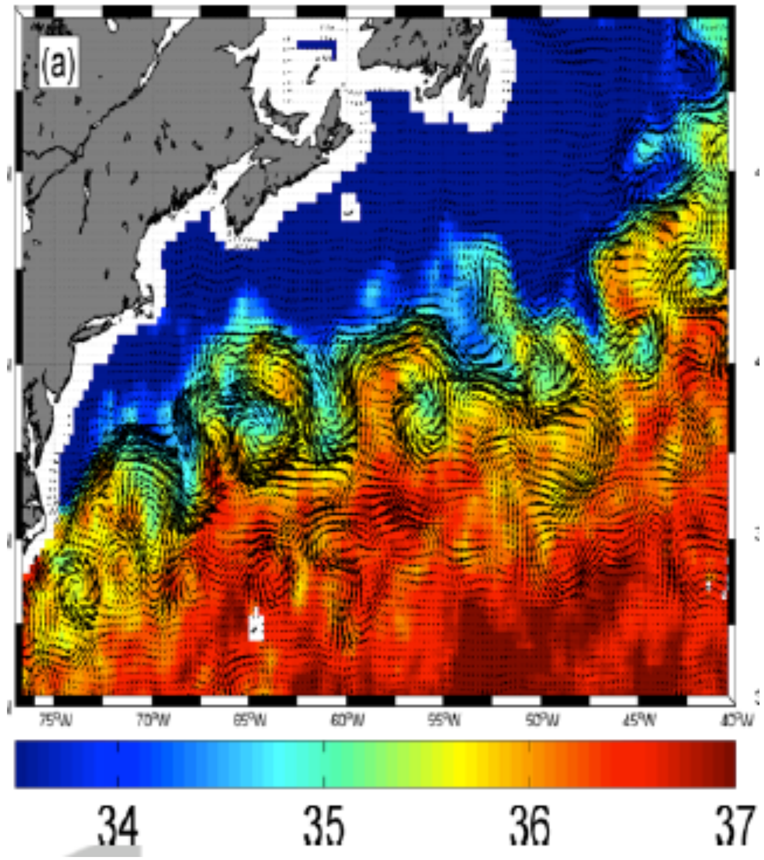
Aquarius Level 4 research product SSS



Aquarius SSS, week of June 23 2012

Kindly provided by *Hsun-Ying Kao, 2014 (ESR)*

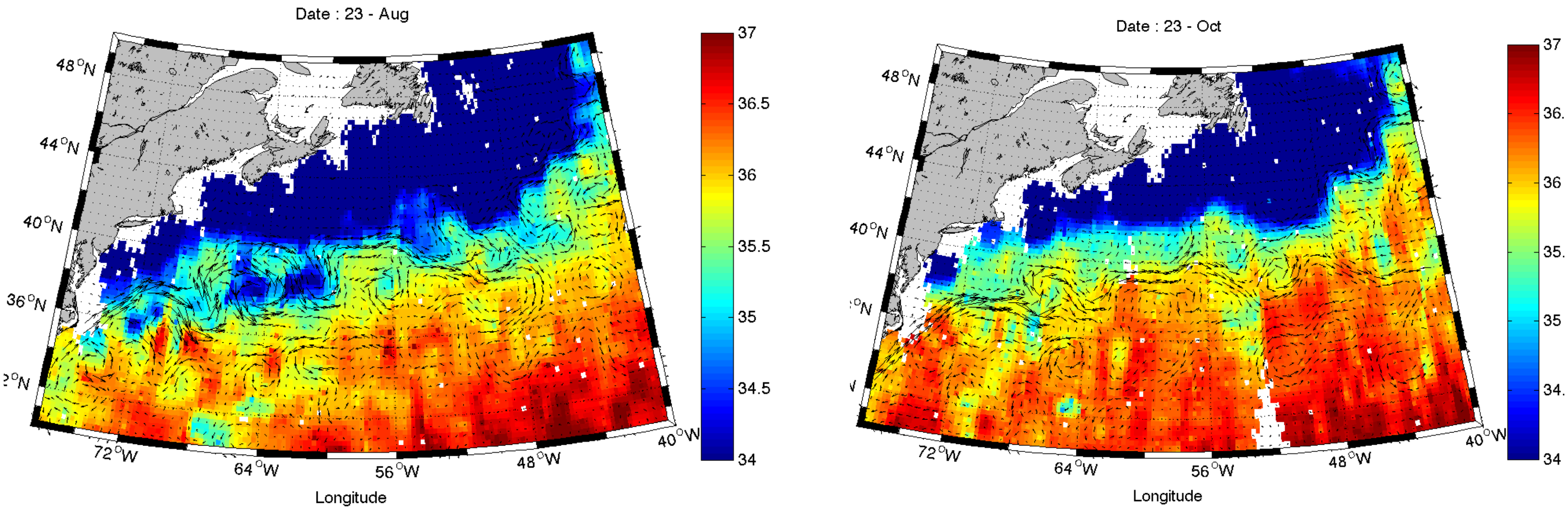
Rings of the Gulf Stream can be tracked with SMOS but are not resolved by the lower resolution of Aquarius observations.



[SMOS SSS August 15-25 Reul et al. 2014, GRL]

Aquarius Level 4 research product SSS

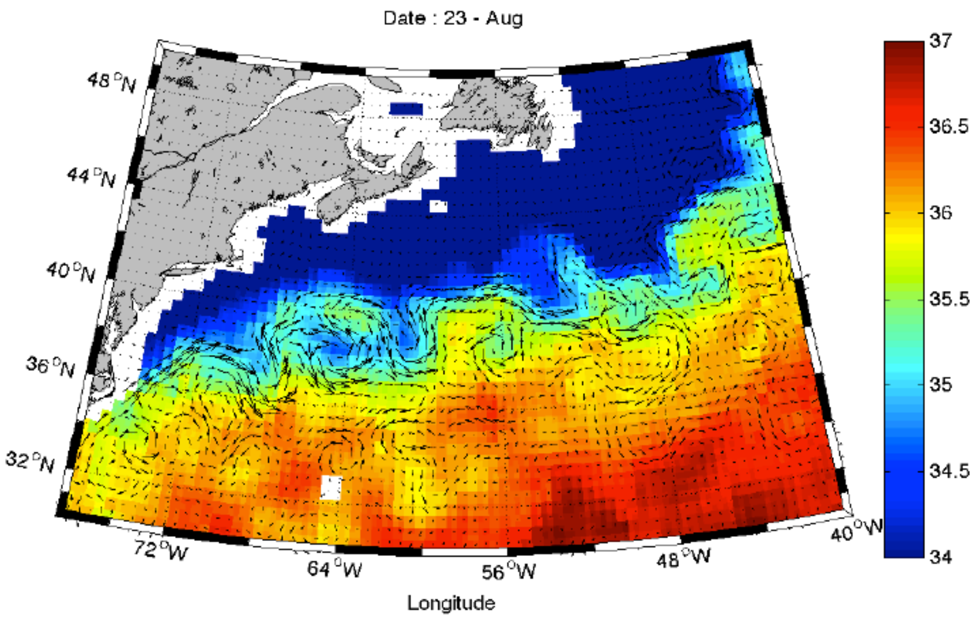
Aquarius L3

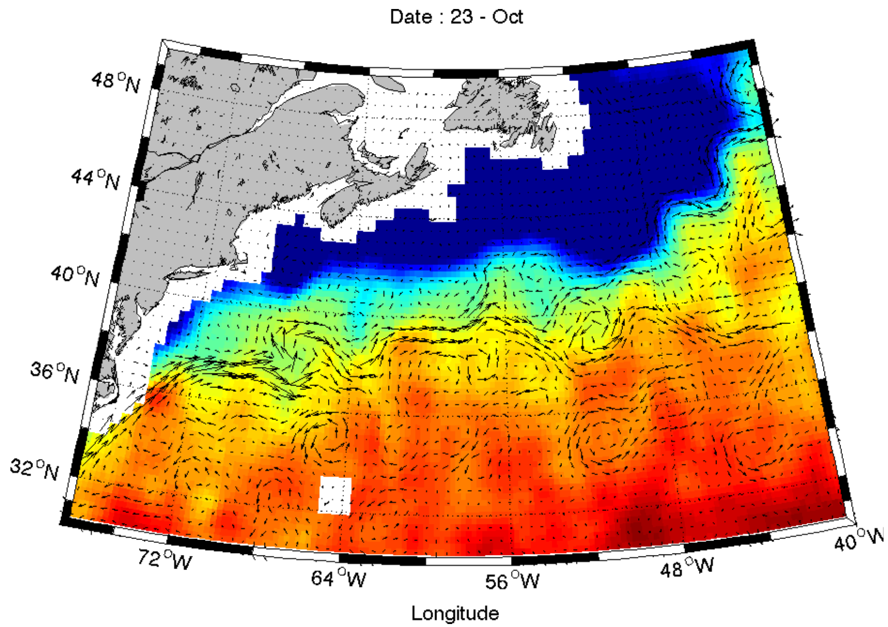


- **Aquarius L3** poorly resolves rings shed by Gulf Stream due to the relatively low spatial and temporal resolution
- Three different L4 products built with data fusion using three different templates: **L4-SSH** (from AVISO), **L4-SSS** (from SMOS) and **L4-SST** (from AVHRR).
- Aquarius L4 product fused with SSH best resolves CCR SSS signature and temporal evolution.

Aquarius Level 4 research product SSS

L4-SSS





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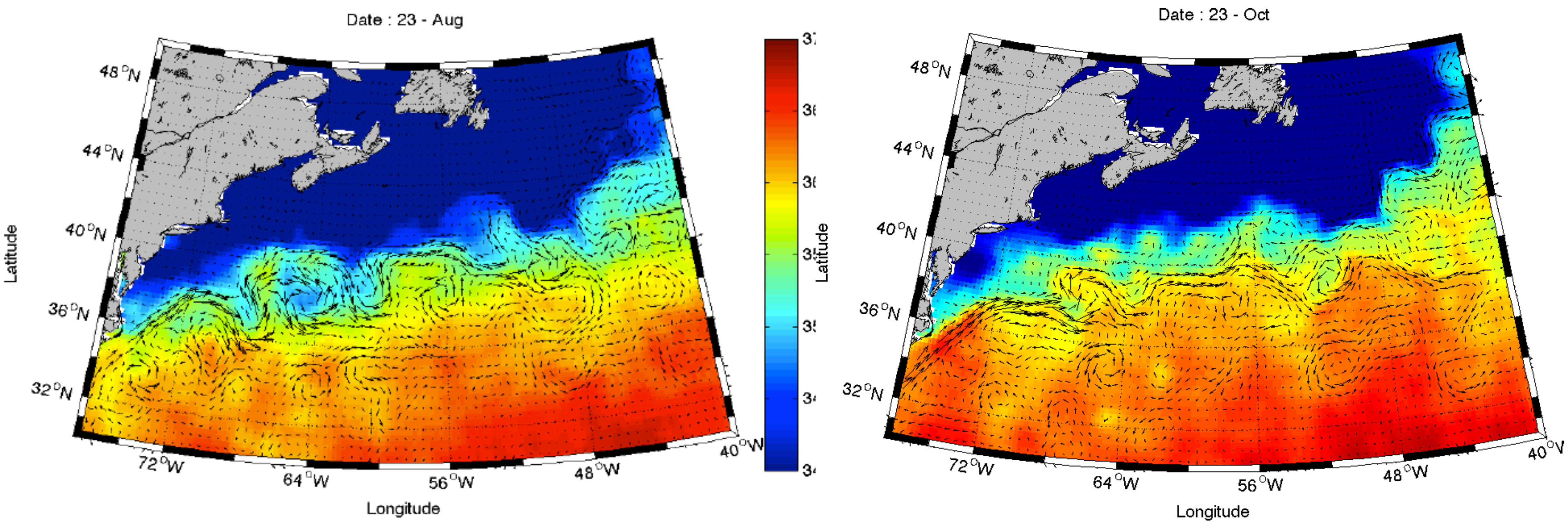
Aquarius Level 4 research product SSS

L4-SST



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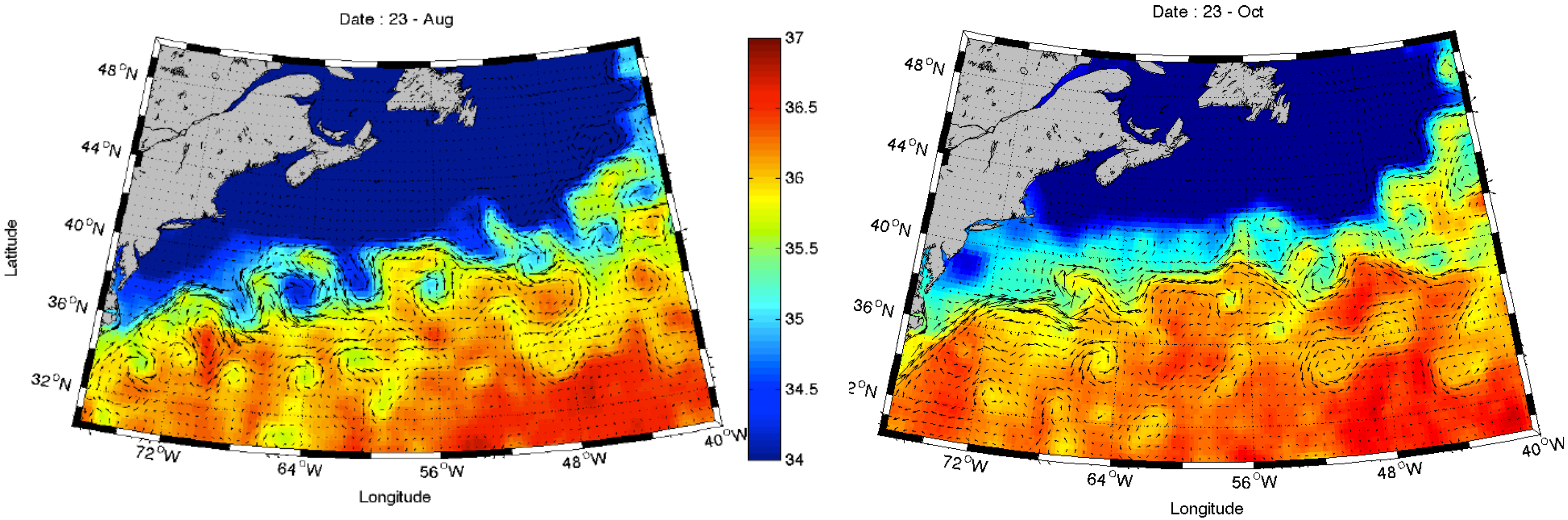
Aquarius Level 4 research product SSS

L4-SSH



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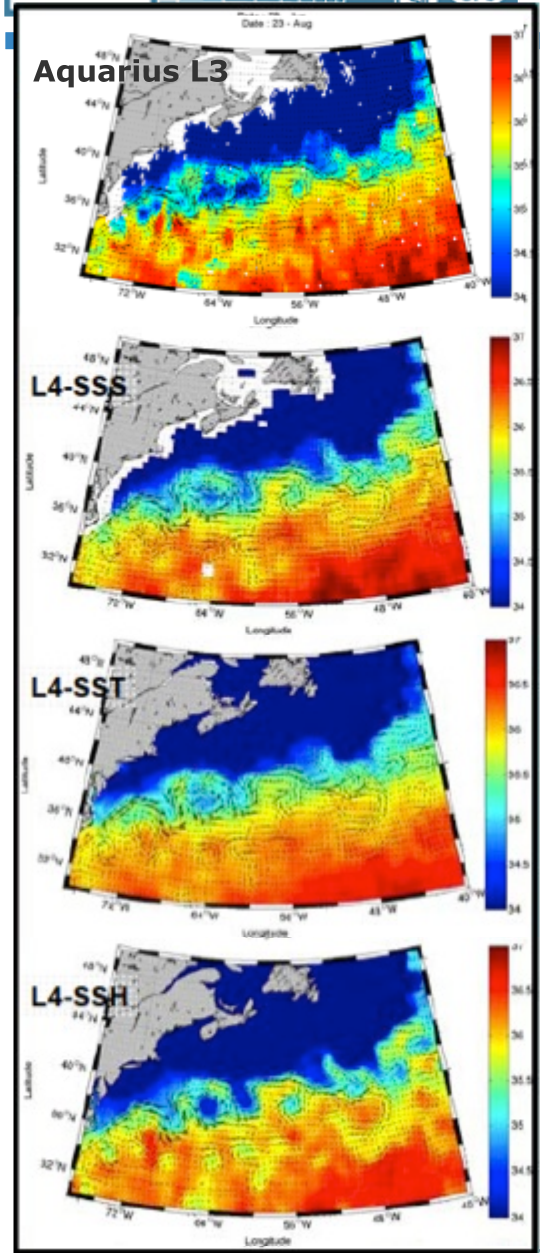
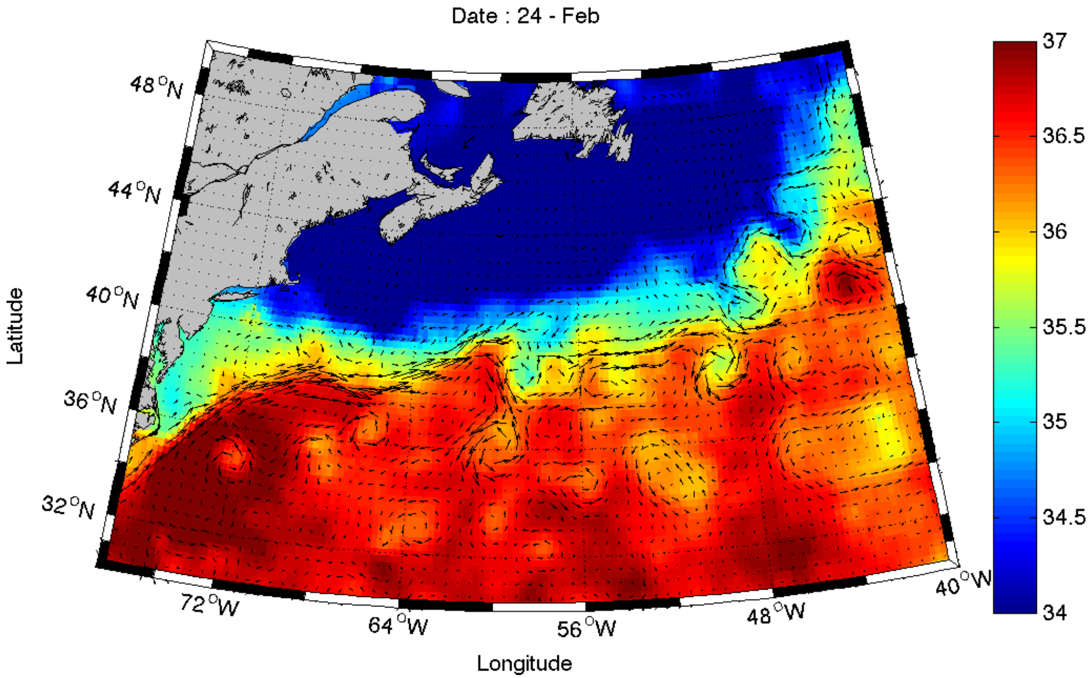
Aquarius Level 4 research product SSS





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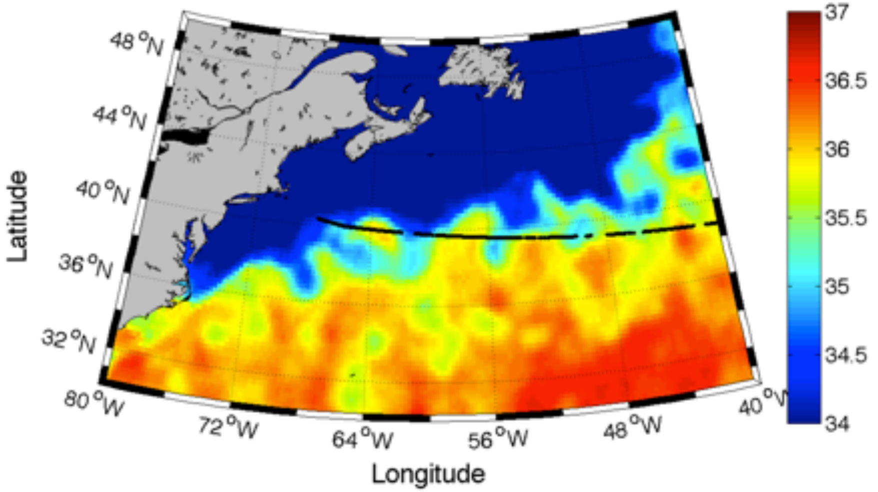
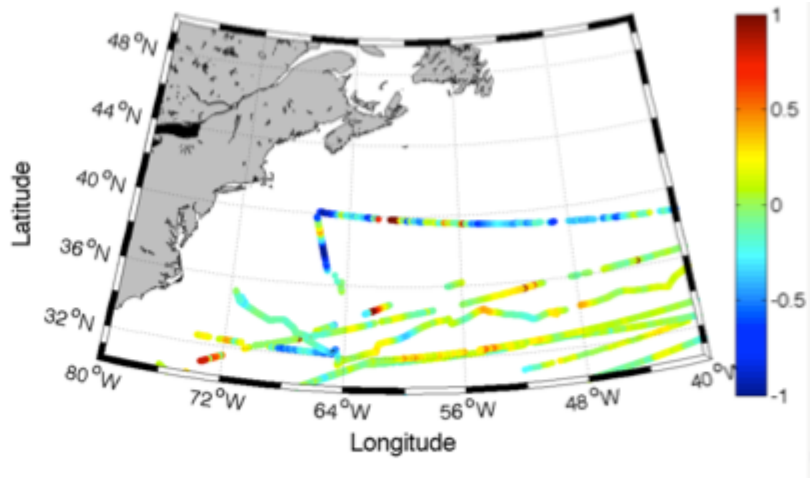
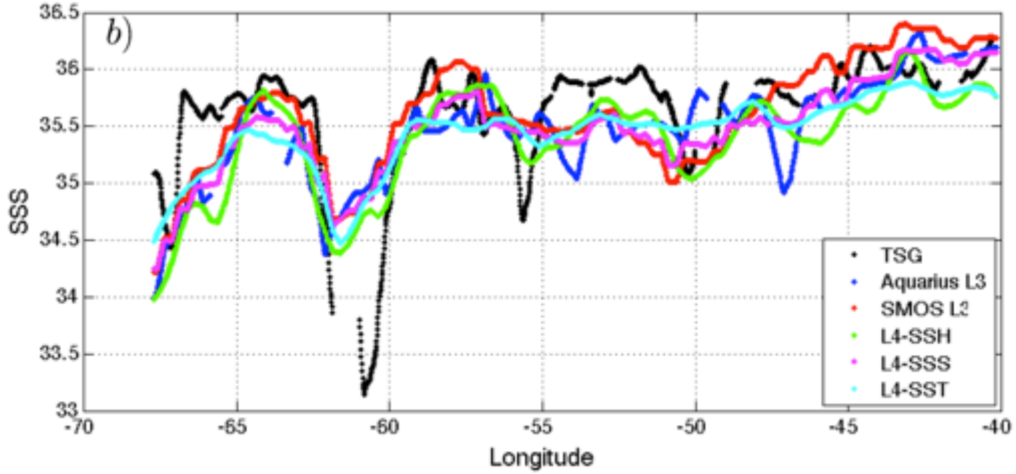
Aquarius Level 4 research product SSS

L4-SSH



L4-SSH - TSG





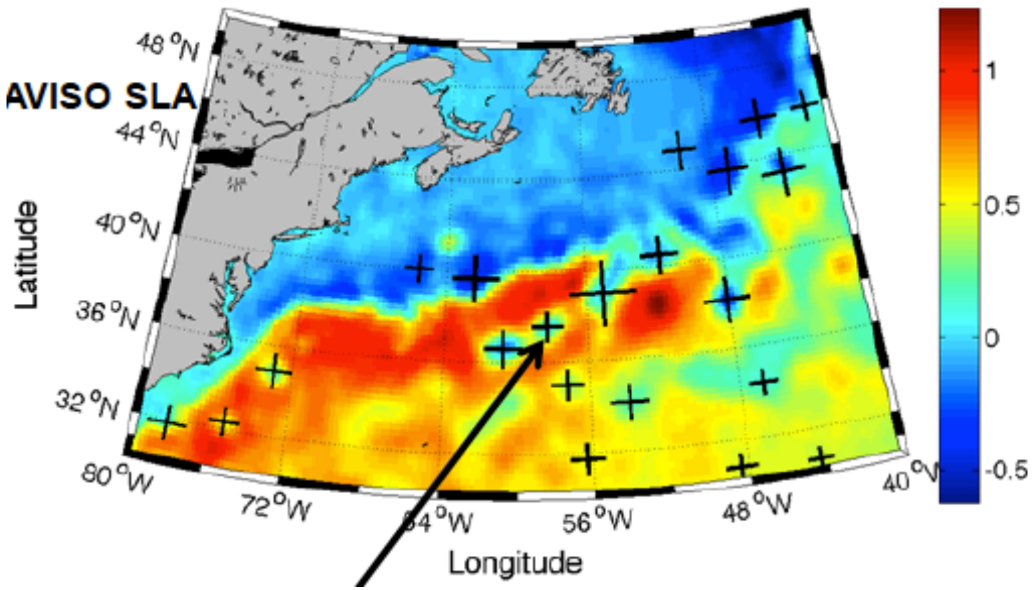
TSG transect from Explorer vessel (August 13-17) with a spatial average of 25 km.

- Each product is compared against **in-situ TSG data.** All data fusion products reduce bias and random errors:

	Aquarius L3	L4-SSS	L4-SST	L4-SSH
Error median (bias)	0,12	0.05	-0.03	-0.01
Error IQR (spread)	0.33	0.32	0.28	0.26

45% reduction in error variance!

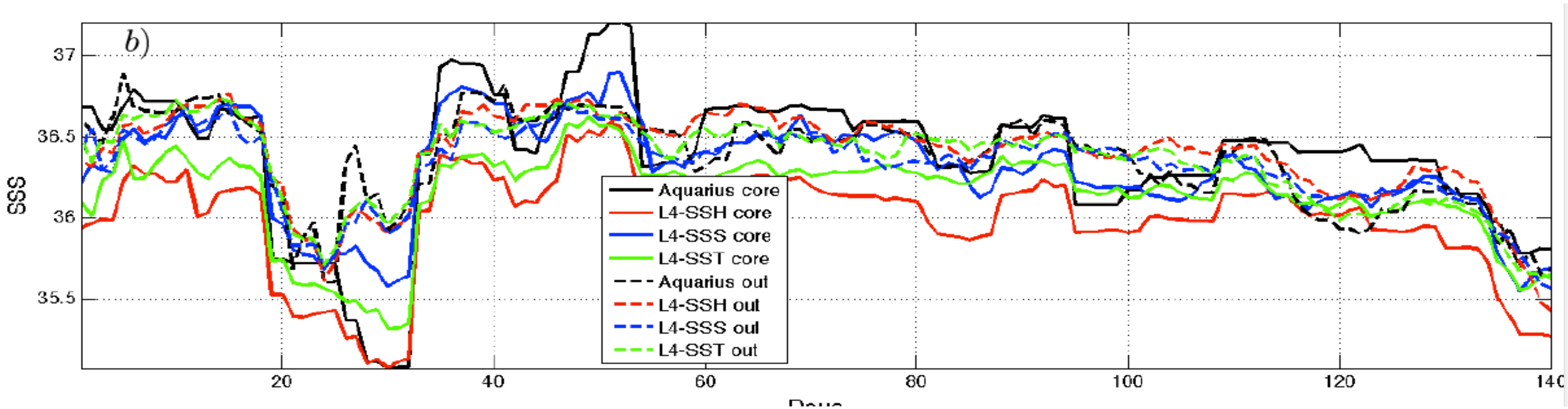
Aquarius Level 4 research product SSS



- **Cyclonic eddies** detected from sea level anomalies (SLA) by an automatic eddy-tracker

(**Mason et al., 2014**. *A New Sea Surface Height–Based Code for Oceanic Mesoscale Eddy Tracking*)

- The realism of L4 products is assessed by comparing **SSS signal inside cyclonic eddies**
- L4 products enhance the **salinity anomaly associated to ring structures**



Summary and conclusions

- A new **method to synergize ocean variables** based on the common turbulent signatures between variables has been developed and applied to SMOS SSS and Aquarius SSS.
- This method allows **reducing the error** of the resulting Level 4 product of one variable using another as a template (example SMOS SSS using SST as template).
- Data fusion **improves the mesoscale information** in the Aquarius L4 salinity maps, the result contains mesoscale structures such as the meanders and rings of the Gulf Stream.

✧ Umbert M., Hoareau N., Turiel A., and Ballabrera-Poy J. **New blending algorithm to synergize ocean variables: the case of SMOS sea surface salinity maps.** *44th International Liège Colloquium Special Issue, Remote Sensing of Environment.* 2014.

✧ Umbert M., Guimbard S., Lagerloef G., Thompson L., Ballabrera-Poy J., Portabella M. and Turiel A. **Remote sensing synergy between surface salinity and sea level: Detection of Gulf Stream cold-core rings from Aquarius data.** *Early scientific results from the salinity measuring satellites Aquarius/SAC-D and SMOS Special Issue, Journal of Geophysical Research.* 2014. Submitted.

SMOS-Mission Oceanographic Data Exploitation

SMOS-MODE

www.smos-mode.eu
info@smos-mode.eu

SMOS-MODE supports the **network** of SMOS ocean-related R&D

Final event: **2nd SMOS Science Workshop** (Madrid, May 2015)

Thank you

Linear regression coefficients

$$\sigma_s^2(\vec{x}) = \langle s^2 \rangle_{\vec{x}} - \langle s \rangle_{\vec{x}}^2$$

Variance of the signal

$$\sigma_{st}(\vec{x}) = \langle st \rangle_{\vec{x}} - \langle s \rangle_{\vec{x}} - \langle t \rangle_{\vec{x}}$$

Covariance between the signal and the template

$$a(\vec{x}) = \frac{\sigma_{st}(\vec{x})}{\sigma_s^2(\vec{x})}$$

$$b(\vec{x}) = \langle s \rangle_{\vec{x}} - a(\vec{x}) \langle t \rangle_{\vec{x}}$$

Angle brackets meaning local average of the variable around point *x*.

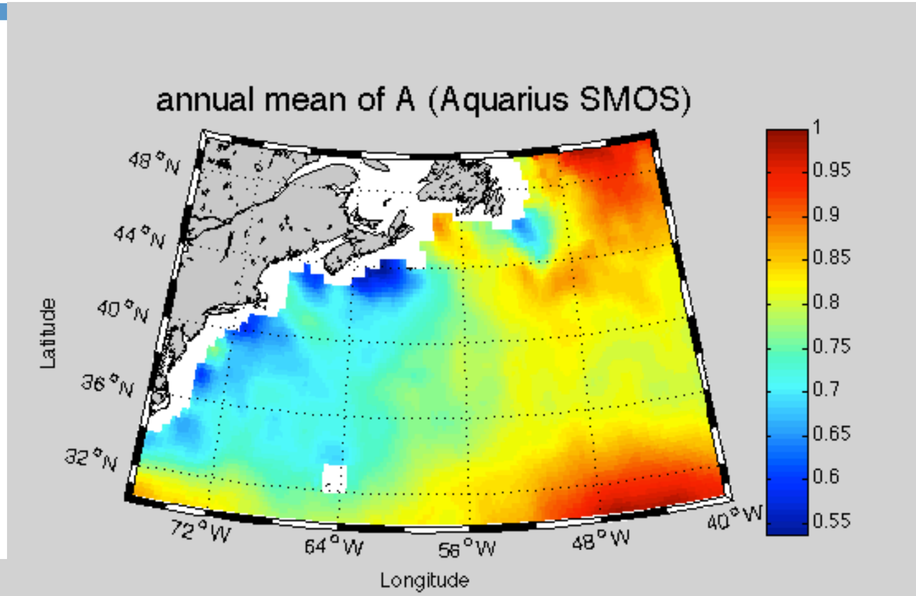
To local average we use a local averaging function proportional to the squared difference of the distance around the point.

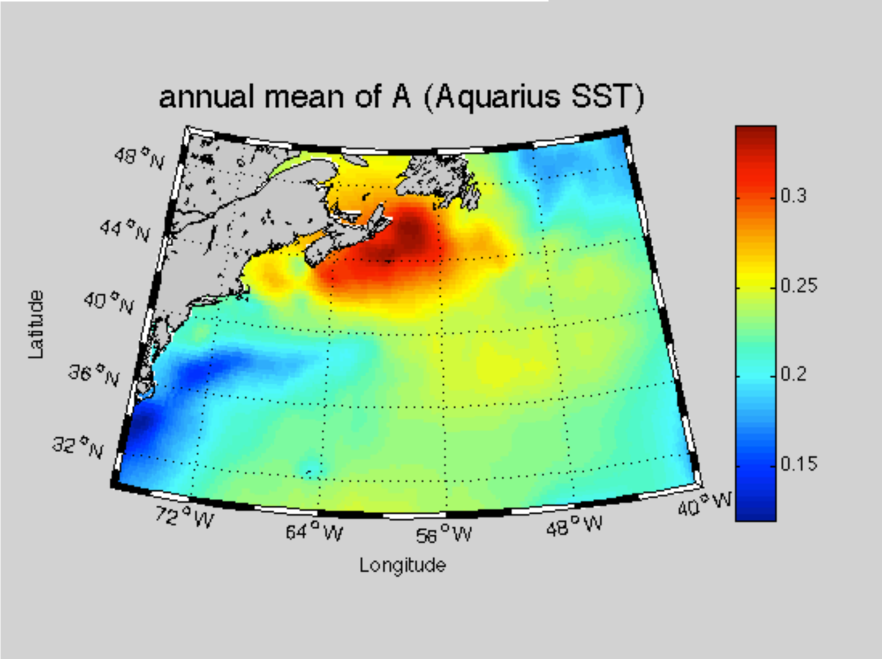
Weighting function

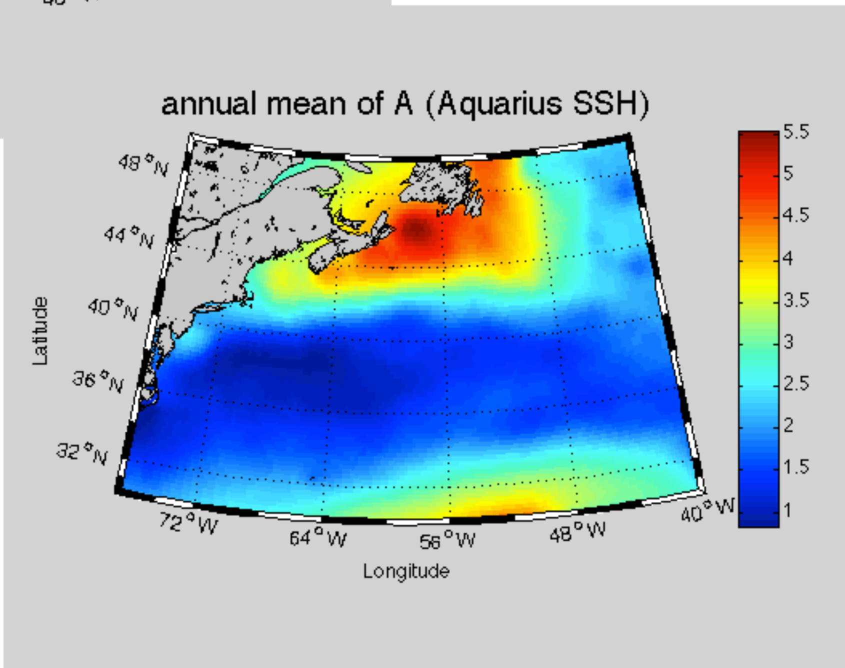
$$W(\vec{x}) = \sum_{\vec{x} \neq \vec{x}'} \frac{1}{|\vec{x}' - \vec{x}|^2}$$

Linear regression coefficients

$$a(\vec{x}) = \frac{\sigma_{st}(\vec{x})}{\sigma_s^2(\vec{x})}$$

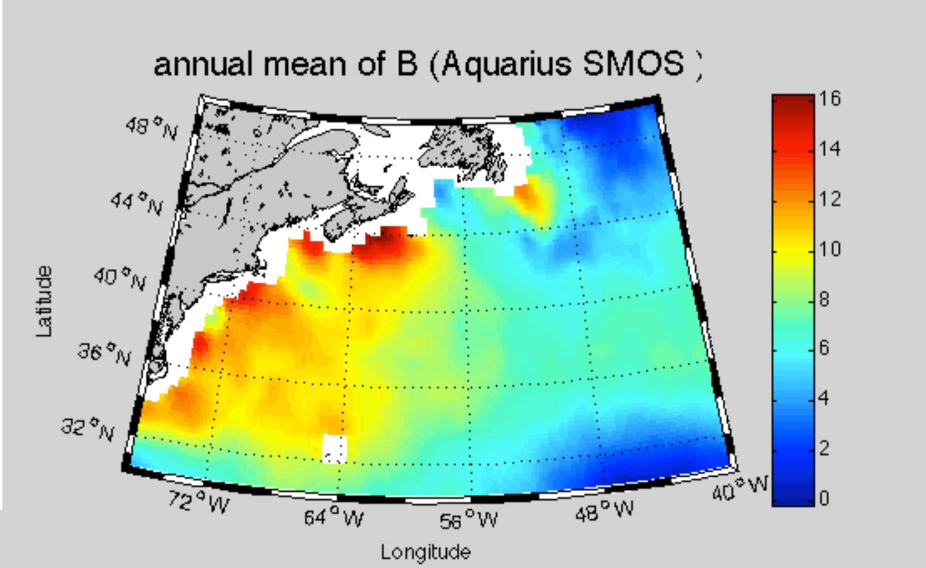


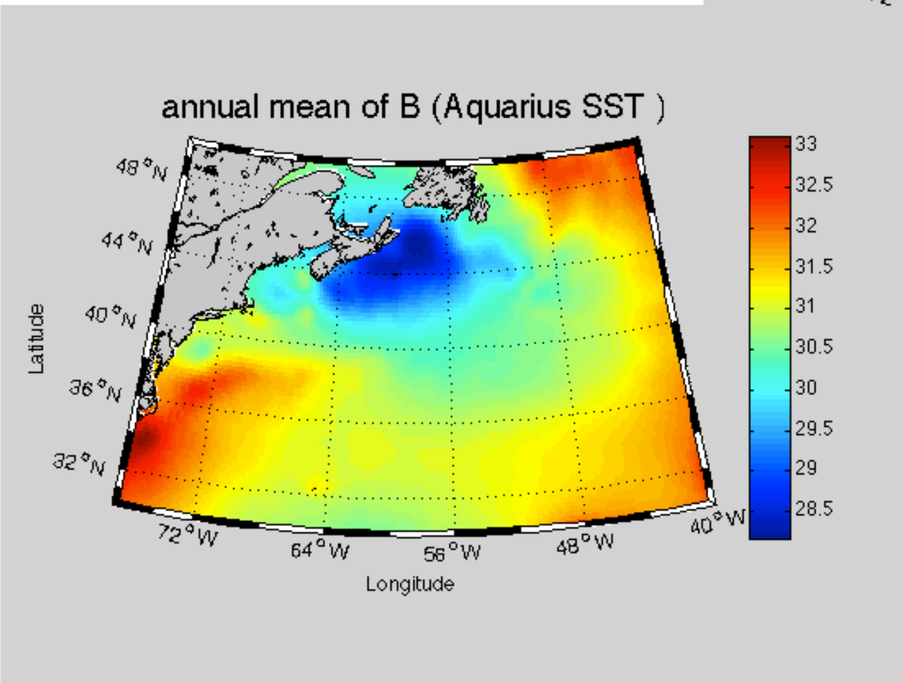


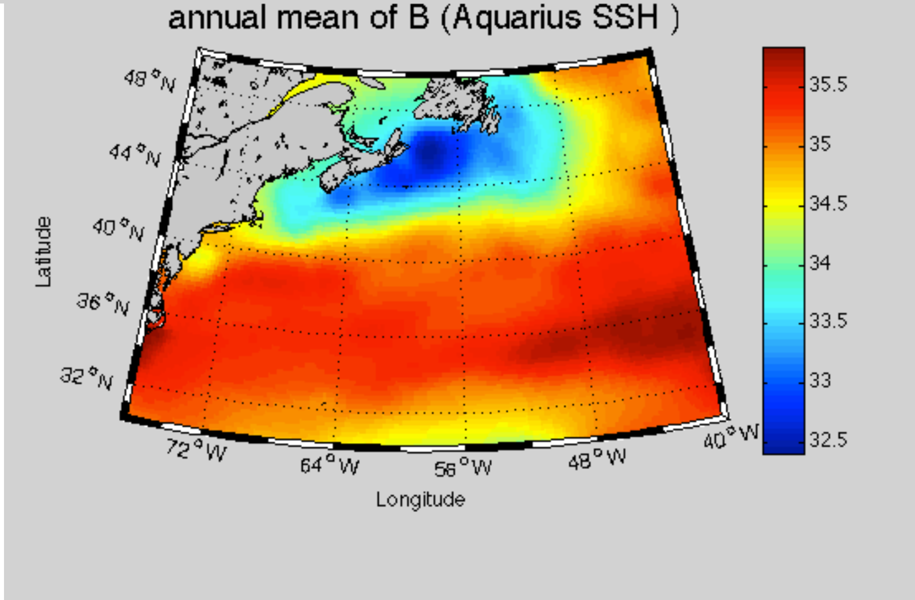


Linear regression coefficients

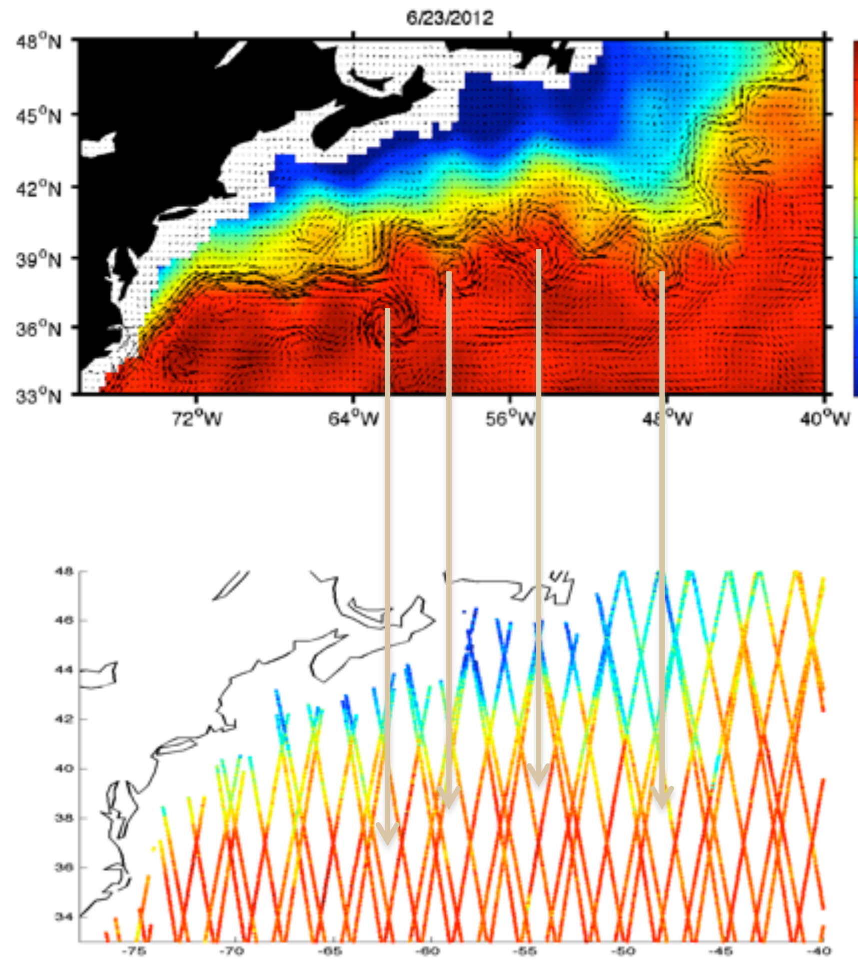
$$b(\vec{x}) = \langle s \rangle_{\vec{x}} - a(\vec{x}) \langle t \rangle_{\vec{x}}$$





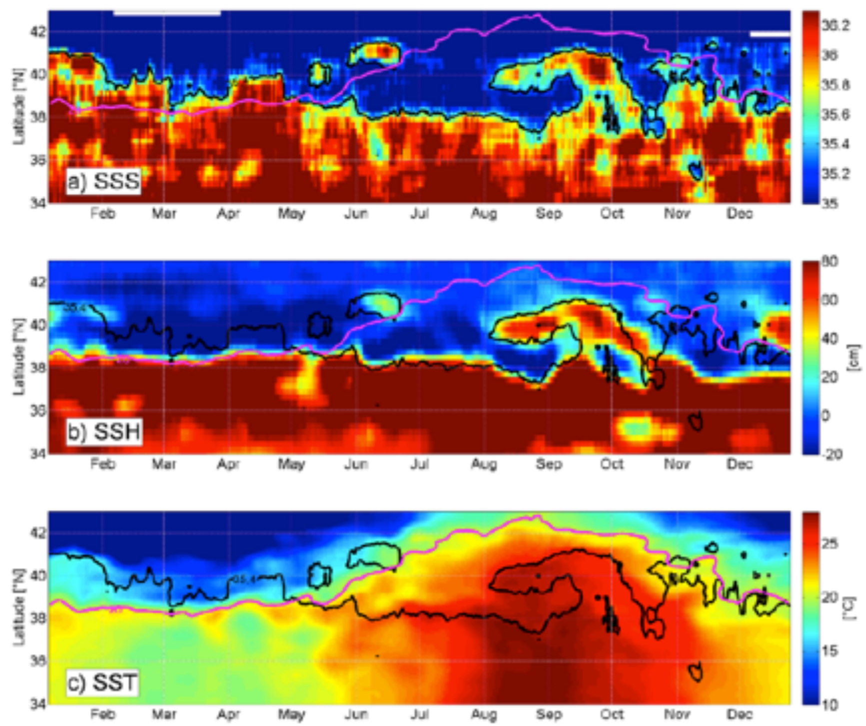


Aquarius Level 4 research product SSS



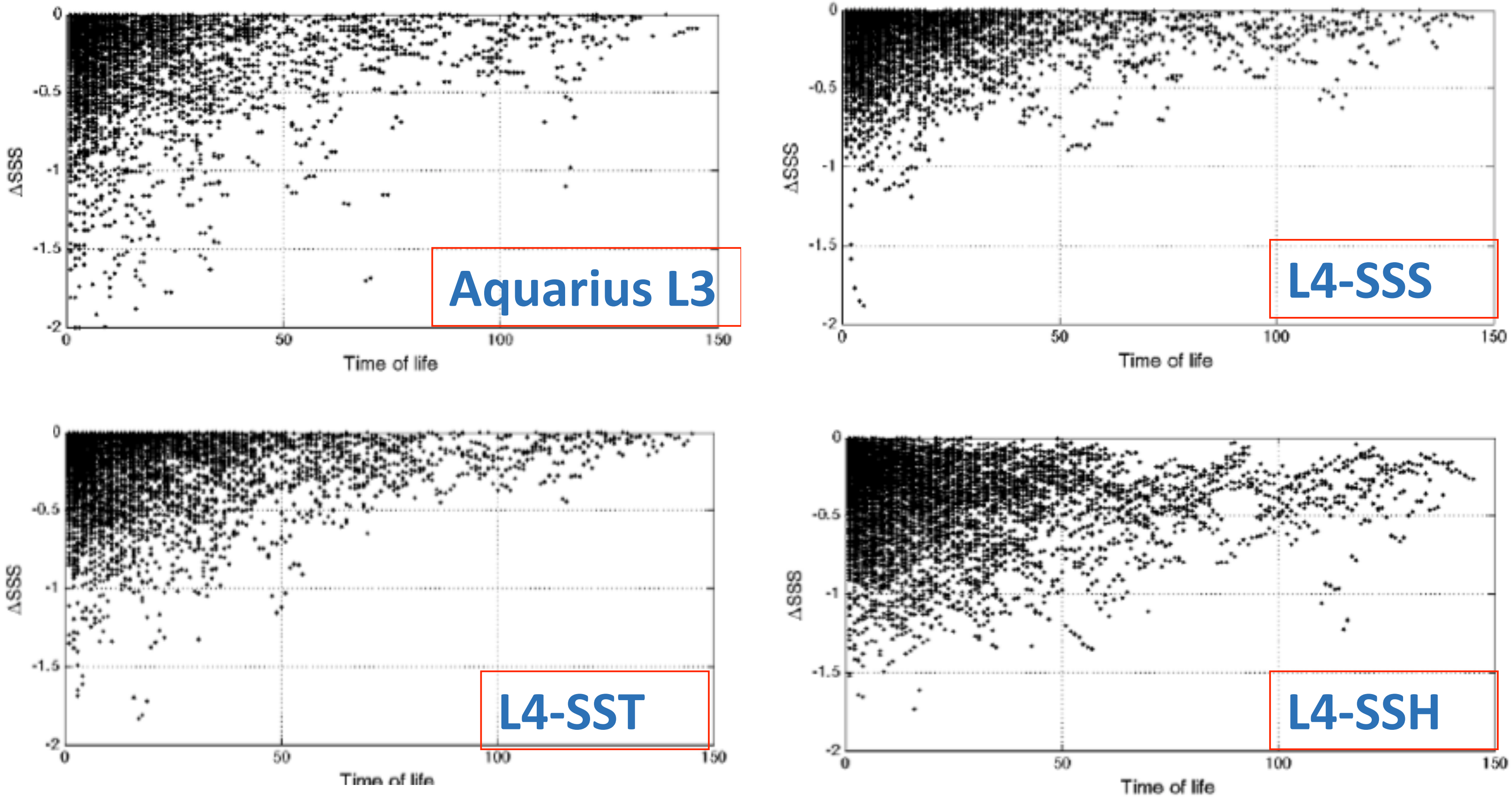
Aquarius SSS, week of June 23 2012

Rings of the Gulf Stream can be tracked with SMOS but are not resolved by the lower resolution of Aquarius observations.



SSH is a better proxy for the SSS variability in this region than the SST, especially during warm season. *[Reul et al. 2014]*

Aquarius Level 4 research product SSS



- Temporal evolution (days) of SSS gradient (outside – inside) CCRs