# Surface layer on the North Atlantic subtropical gyre: SPURS

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## Introduction

**Scientific context: Is the increase in SSS witnessed until the late 1990s in the region of highest surface salinity of the NA subtropical gyre the result of changes in surface forcing (increased evaporation, for example, or changes in the winds)?**
**Practical goal: how well can we estimate the budgets of surface salinity on seasonal/interannual time scales? Are eddy scales contributing, even in this eddy-poor region, as suggested by model analysis and other data sets? How does Ekman act in the presence of vertical circulation at sub-meso scales? (subduction/entrainment )**

**Data/model context:**

- **SPURS program in 09/2012-09/2014 with French contribution on TSG (SO SSS and other merchant/scientific vessels), salinity drifters (data of nearly 100 drifters validated by us) and a cruise in stratified season (Strasse 08-09/2012)**
- **test site for SMOS SSS products; higher resolution altimetric current products (purposed-made by CLS)**
- **real time Mercator analysis PSY2V4R2/R4: can it also be used for budget studies, as well as to evaluate limitations of observed mapped products?**

**LEFE/GMMC project:**
**1: response to wind (Ekman)**
**2: spatio-temporal characteristics of variability**
**3: validating/transferring SSS data and mapped products**

## 1 – Response to wind - Ekman

PSY2V2R2/R4 MLDs tend to be a little deeper than in situ ones (with same criteria).
In summer during Strasse, 10 day of HR (1-m) ADCP profiles (Sutherland et al., 2016, Louis Marie, communication):
PSY2V2R2/R4 indicates (with 30-m ref) a rather striking Ekman spiral. It is harder to conclude for the in situ one, as the reference had to be taken rather close to the surface 20-m), because of geostrophic shear. However, in in situ data the shear is larger close to surface (due to surface daily-trapping of momentum)., and there is less rotation with depth. Also, in the model the average transport is close to the Ekman formula (green dot), and less so in observations (black dot).

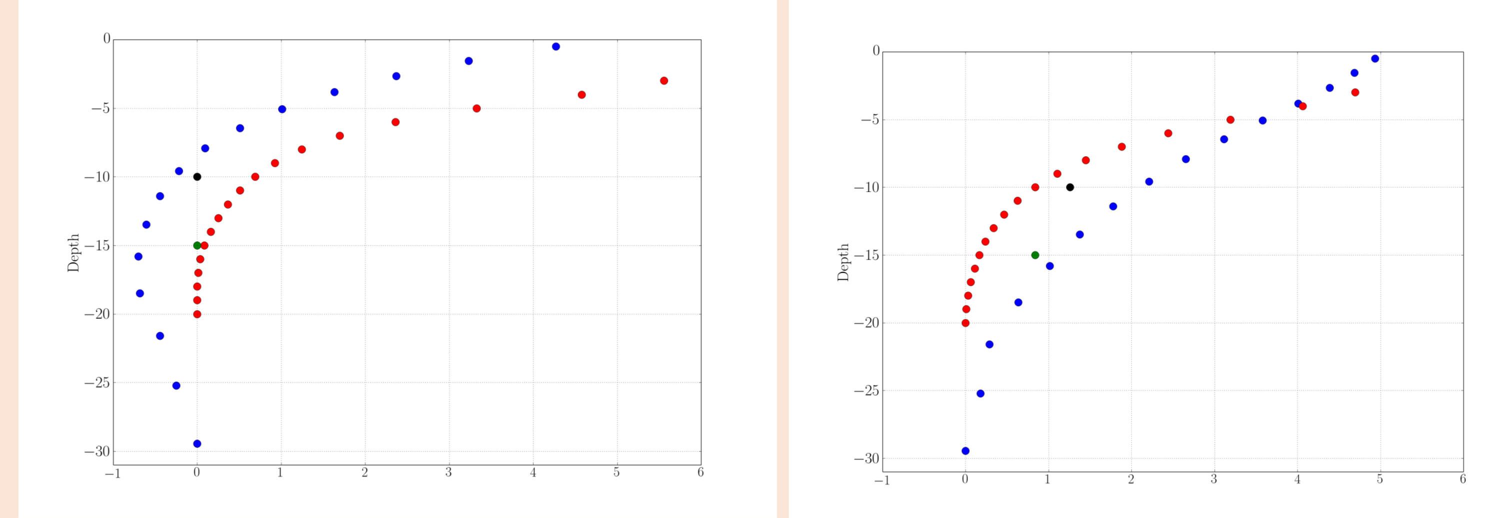
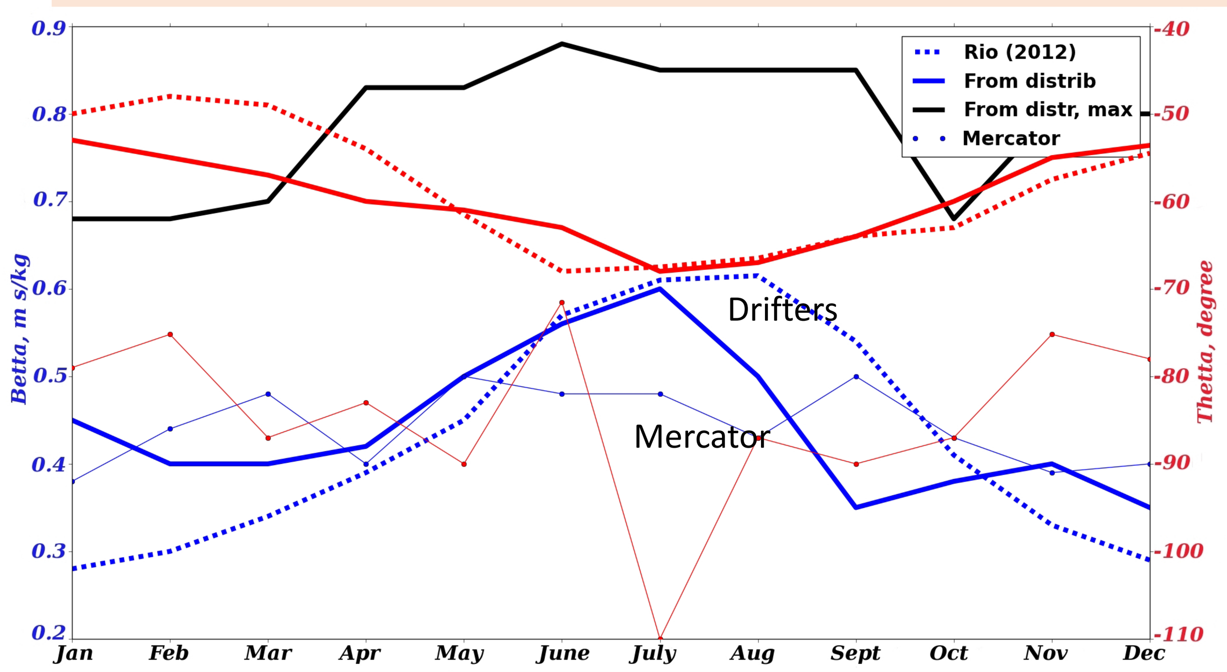


**Figure 3**. Average current profiles during Strasse, parallel to wind (left) and orthogonal to wind (right) (blue, Mercator rel. 30-m; red, ADCP relative to 20-m)



The other set of comparison is following Rio's approach (Rio, 2012), to check the relation between non-geostrophic currents at 15-m, and wind stress.

This is done, first removing meso-scale geostrophic currents (in data from altimetry, and in Mercator, from sea level), and then using vectorial filtering of wind stress and currents, estimating:
an angle Θ between the residual current and the wind stess and an amplitude β of the response.
The data illustrate a seasonal cycle, which is dependent on MLD, with smaller amplitudes in winter (deep MLD), and larger angles in summer.

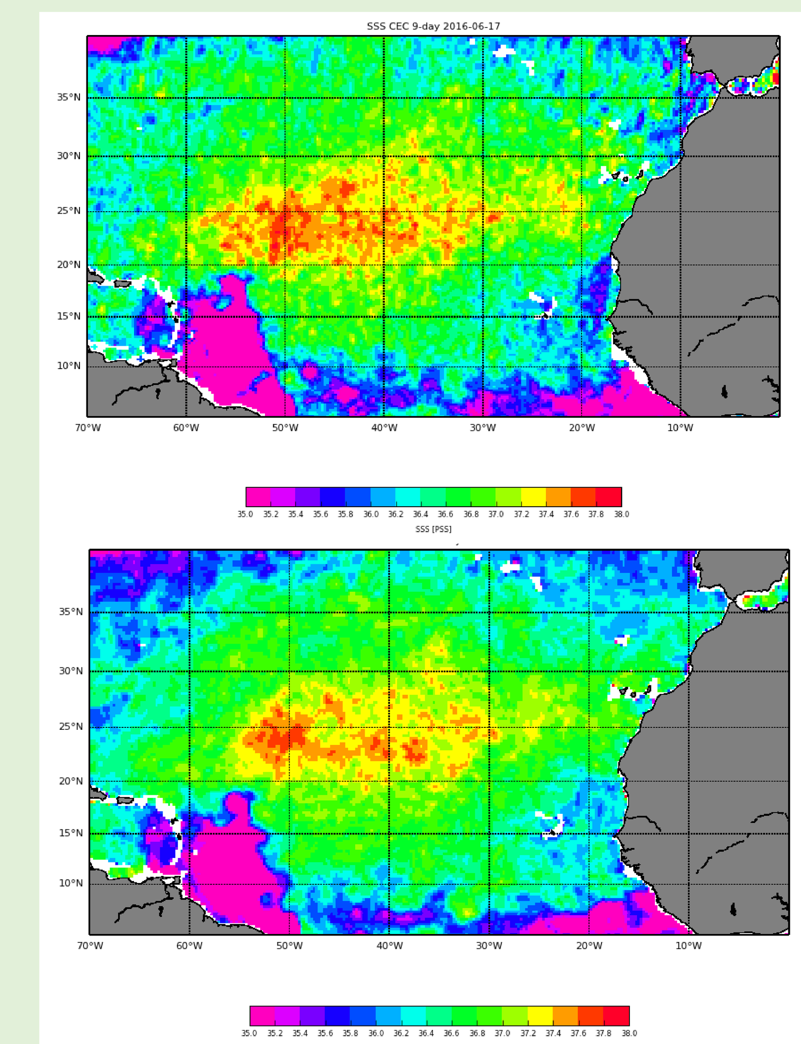
Mercator PS2V2R2/R4 results for 15-m currents are compared to the data:
The angle is closer to 90° in PS2V2R2/R4 and varies less seasonally as well as the amplitude.
This suggests again a different vertical redistribution of momentum by mixing,
With more rotation with depth, maybe again effect of daily cycle and other high frequencies.

## 3 – Data and products

- CLS regional altimetric product (2 years available)
- All drifter data from SPURS validated and transferred to Coriolis (CORA)
  We also decided to revisit all the SSS drifter data since 1992 and transferred them to Coriolis (and later Coriolis DAC)
- SMOS CATDS CEC LOCEAN debias_v2 products.
  (Favorable comparison also with SMAP products)
- Objectively analyzed surface products retaining meso-scales been done at LOPS (work in progress)

We present for a recent period SMOS debias_v2 products with respect to SMAP products at the same date (SMAP is a NASA L-band satellite mission)
Illustrating great hope in identifying the same eddy structures, rather consistent in SMOS and SMAP. Key was not to average too much in time or space. Still 'noisy' products, but instead of -0.02 psu/year in eddy advection contribution with earlier mapped product, this yields -0.07 psu/year estimate. The effect is more consistent with the effect of smoothing in eddy advection estimates suggested in PSY2V2R2/R4.

**Figure 6**. (up) CATDS CEC_LOCEAN debias_v2 9-day and (bottom) SMAP SSS 8-day map on 16/06 2016
(seasonal+ spatial biases not adjusted between the two products)



## Data, products and validation

- The drifter data were validated and corrected (Reverdin et al (2015)). MLD montly statistics estimated from Argo profiles .
- SMOS SSS fields of the 'core' budget result from first a correction of biases (coastal effects, RFIs) similar to Kolodziejczyk et la. (2015). Then, an objective mapping of the data resolving scales on the order of 75 km was applied. Alternatively, the CATDS CEC LOCEAN debias_v2 SMOS SSS mapped products are used from a fairly similar first step (see a description in http://www.catds.fr/Products/Available-products-from-CEC-OS/L3-Debiased-Locean-v2).
- Current products are from CLS regional remapping, optimizing the noise/ratio cut-off from the different satellites based on the spectra, and with a new average field.
- Finally, Mercator PS2V2R2/R4 daily fields are used as an alternative to diagnose the budgets. (forcing by ECMWF and assimilation of data, whereas ERA-interim for in situ budgets)

Figure 1. SSS from mapped 2D analysis from SMOS data after large-scale bias correction (top) and from Mercator PSY2V2R2 (R4) on 18-24 June 2013. SSS data from the SVP-S drifters are overlayed

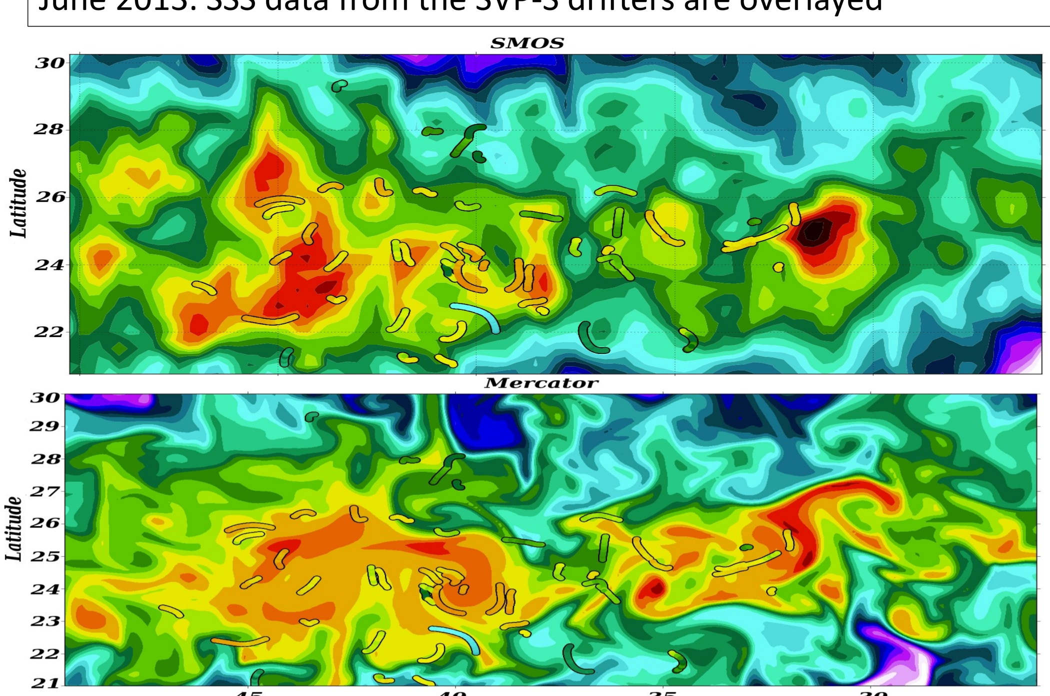
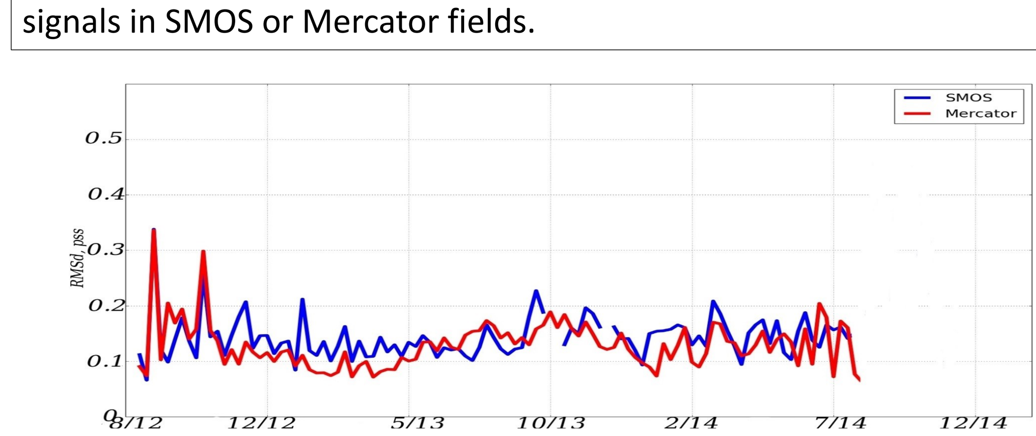
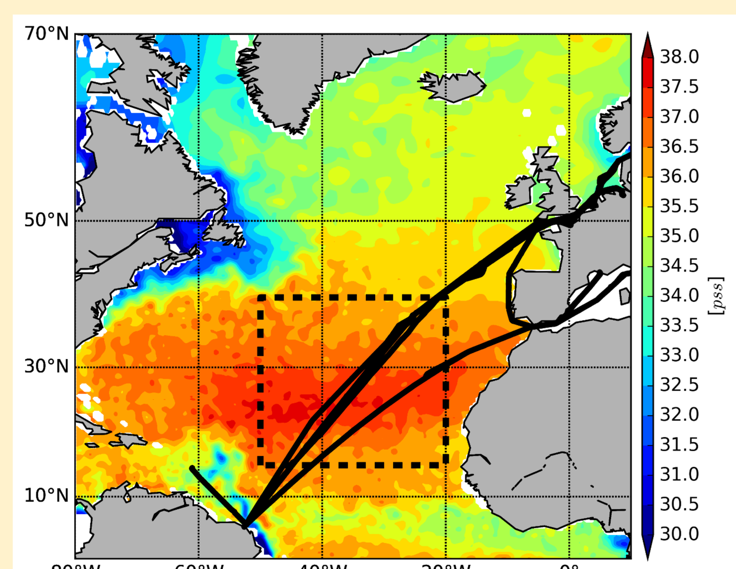


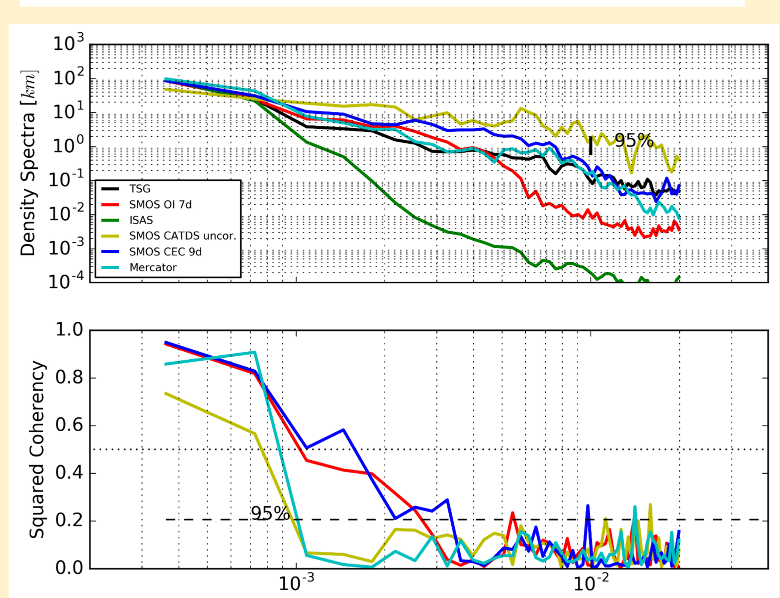
Figure 2. Weekly rms differences of SMOS (blue) and Mercator (red) with in situ SSS (spikes at beginning and near end originate from insufficient spatial sampling). Tendency for Mercator to fit a little better to drifter data (except summer). Differences comparable to meso-scale signals in SMOS or Mercator fields.



## 2 – Spatio-temporal variability: SSS

The different mapped SMOS products and PSY2V2R2/R4 were compared (spectra) with 2013 TSG sections acorss the NA subtropical gyre.
The spectra (density and coherence) suggest that meso-scale signals recovered for wavelength longer than 200 km in LOCEAN CEC or SMOS OI, as well as in PSY2V2R2/R4 (but no coherence).





## 2 – Spatio-temporal variability: SSS budget

- Thus, the mapped fields of SSS and currents can be considered by Gaussian smoothed with 75 km width.
- Applying the filter on Mercator fields, only marginally reduces spatial rms variability in SSS; On the other hand, the estimate of the eddy-advection term u'.grad(S') is diminished from close to -0.32 to -0.09 psu/year
- In our estimates, time filtering applied to sepearate scales (by removing 90-day running averages) instead of spatial filtering to avoid losing too much spatial domain. In Mercator, using time-filtering instead of spatial filtering does not lower much eddy variability. In both cases, fast time varying Ekman currents dont contribute much to the box averaged budget (however, both spatial and temporal smoothing applied remove part of low frequency, large scale contributions)

## 2 –MLD SSS budgets: box average

$$\underbrace{\frac{\partial\langle S\rangle}{\partial t}}_{\text{MLS tendency (I)}} = \underbrace{-\langle u'\nabla S'\rangle - \langle \bar{u}\nabla\bar{S}\rangle}_{\text{Advection (II)}} \underbrace{-\frac{(\langle S_{10m}\rangle - \langle S_{-entr}\rangle)}{h}\left(\frac{\partial h}{\partial t} + \langle w_{-h}\rangle\right)}_{\text{Entrainment (III)}} \text{ + AIR SEA FLUXES}$$

$$u = u_{Ekm} + u_{geos} + u_{ageos}$$

In situ mapped budgets far from being closed (Sommer et al., 2015) with strong positive residuals,
whereas in Mercator PSY2V2R2/R4 (and despite influence of assimilation updates), average budget nearly closed, albeit with some seasonal residuals).
Both portray similar seasonal variations in entrainment, surface forcing and advection

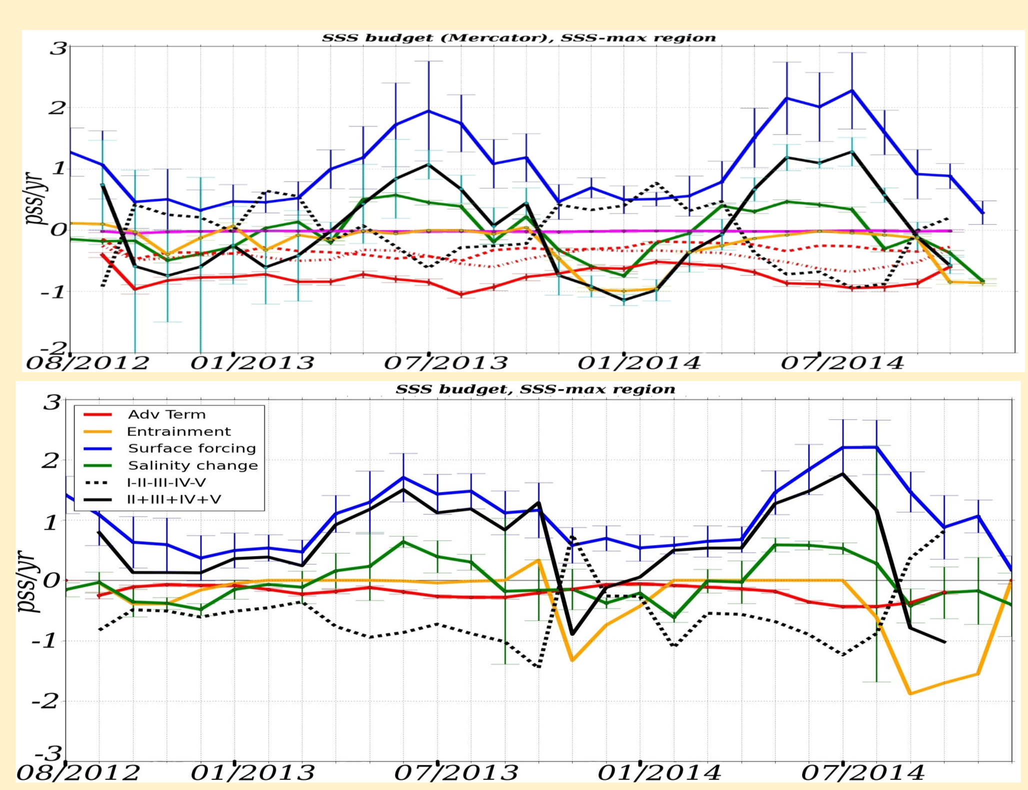


**Figure 5**. Domain-averaged budgets in PSY2V2R2/R4 (top), and using mapped SSS and geostrophic fields and assumptions on currents (Ekman with a low frequency MLD), entrainment term… vertical distribution of forcings on MLD

In PS2V2R2/R4, advection acts to evacuate excess salinity away from max region (actually, detrainment to subsurface).
Seasonal influence of entrainment not small (and influence of spatial time-varying gradients In MLD)

Large difference in advection terms between PS2V2R2/R4 budget (-0.76 psu/year)
and in situ mapped SSS/currents (-0.20 psu/year)
In advection term, the differences come from eddy term (geostrophy) and Ekman term (low frequencies)
For Ekman, strong influence of method and rotation of Ekman

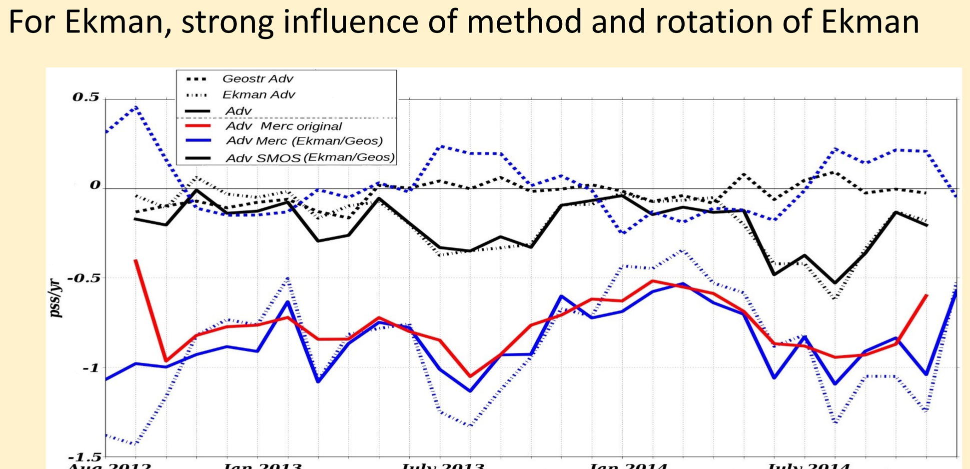


Figure 6: Black curves from in situ mapped fields. Red or blue from Mercator. Small change due to decomposing terms as done for the data (red versus blue).

Seasonal variations seem to be portrayed in similar way in the two estimations.
However, in Mercator, eddy term much larger with same magnitude as Ekman term

## Conclusions

- PSY2V2R2/R4 Mercator real-time analysis produces a 'reasonable' seasonal cycle of mixed layer SSS with relatively weak residuals.
- The current profiles within MLD (and maybe the total momentum trapped in it) however differ in this region from in in situ data (ADCP or drifters at 15-m). Thus differences on Ekman estimates when vertical averaging.
- Strong eddy contribution to budget, according to PSY2V2R2/R4 analysis (-0.32 psu/year). Eddies export horizontally salty water (import fresh water) counteracting effect of surface forcing or subduction export to the subsurface. These estimates are coherent with estimates from Argo float compilation (Amores et al) or diagnostic models (Büsecke et al., 2017).
- This eddy contribution was not found in estimates from earlier mapped SSS/current fields (Sommer et al., 2015), but more recent SMOS products yield estimates that are coherent with the spatio-temporal smoothing of SSS and current products.

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