Sea Surface Salinity from space: a promising future for operational oceanography?

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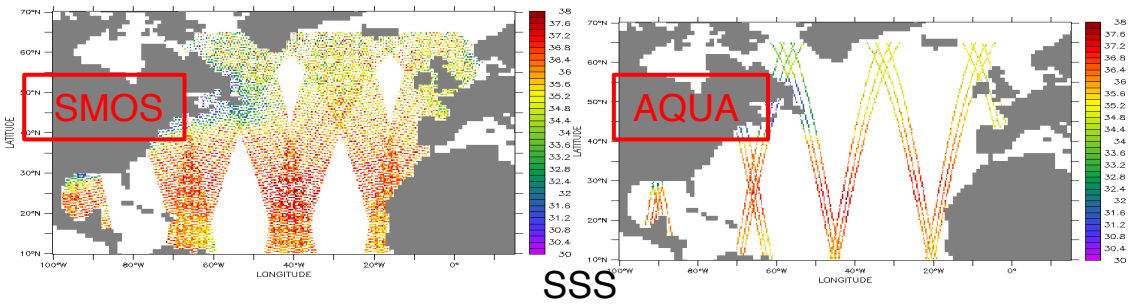
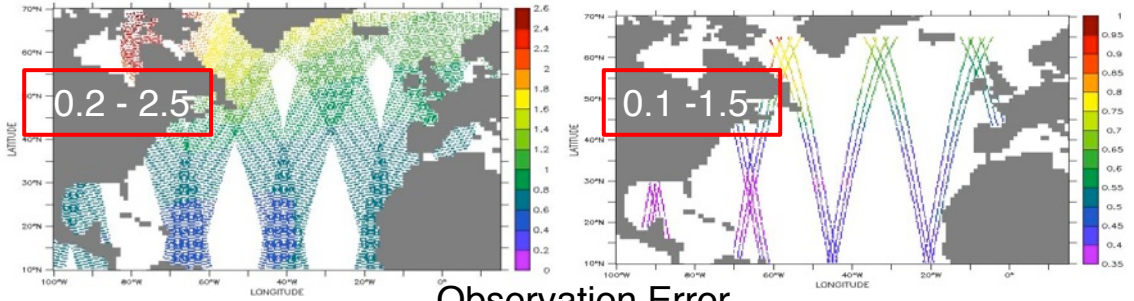
Goal of SSS from space in operational oceanography?

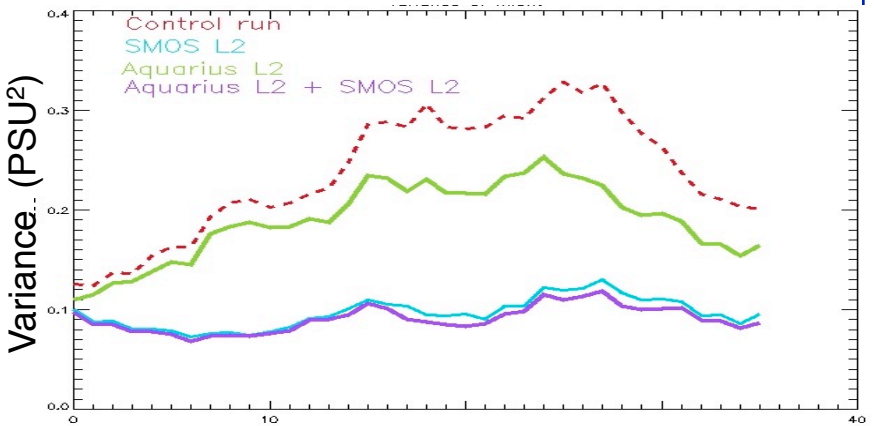
- To understand the impact of new SSS data on estimates of surface freshwater fluxes (E-P) ➔ difficult to estimate.
  - ➔Mixed layer depth
  - ➔Barrier layer
  - ➔Heat fluxes
  - ➔Consistency with other ocean observations
- To understand the complementarity of ARGO and Aquarius/SMOS data in data assimilation.
  - ➔ Consistency with other ocean observations (e.g. OSEs and OSSEs)
- To provide improved information about a time-varying near surface salinity field.

Theory: OSSE in Atlantic (1/3°) performed in 2007

see: **Tranchant et al., 2008**, Remote Sensing of Environment and **Tranchant et al., 2008**, Operational Oceanography







1. **The impact of the Aquarius L2 Products was weak compared to the SMOS L2 Products➔ space and time coverage**
2. **The assimilation of SMOS L2 was a better approach than the assimilation of SMOS L3 with a model at 1/3°.**

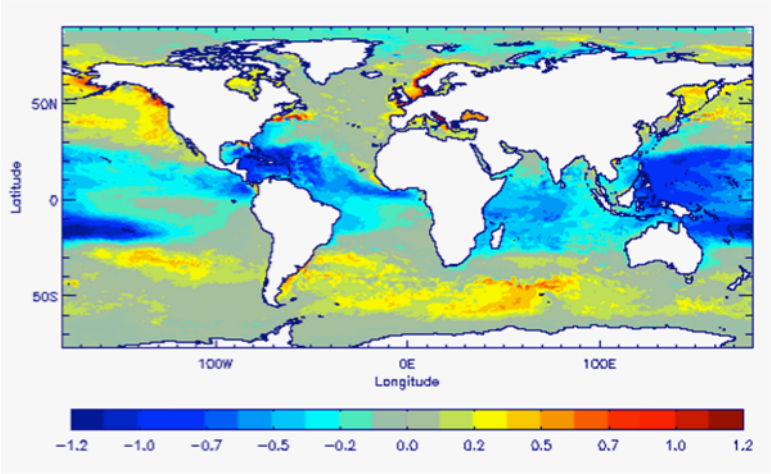
No large scale error, no bias and no E-P flux correction in the Data Assimilation system !

SSS in operational oceanography

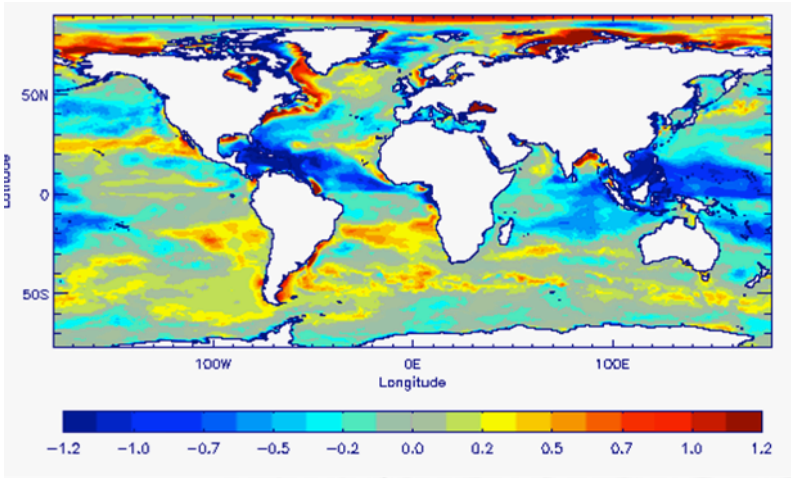
Hydrological cycle errors and SSS

Rainfalls fluxes errors and SSS spatial errors structures

SSS Anomaly (2002)



model (ERAI rainfall flux) – model (GPCPV2.1)

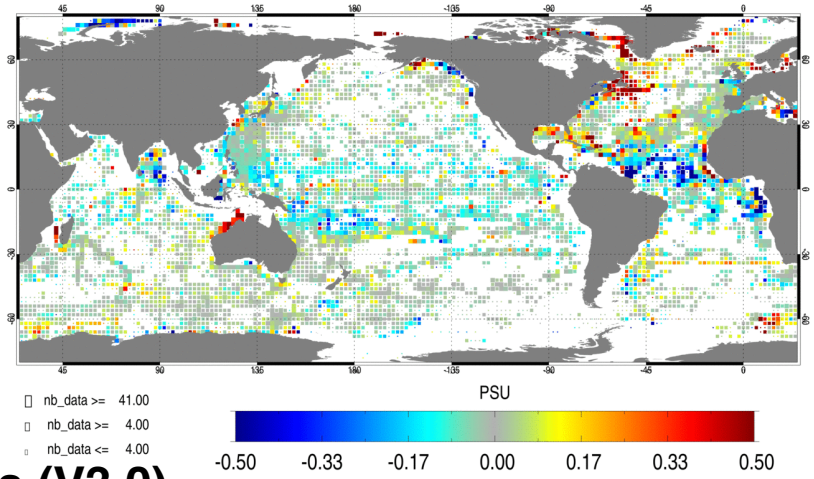


SSS model (ERAI rainfall flux) – SSS climatology (levitus 98)

- **Fresher** SSS anomaly in the tropics and **saltier** anomaly at mid-latitudes
- SSS anomallies : Similar patterns ➔ Particularly in the tropical band.

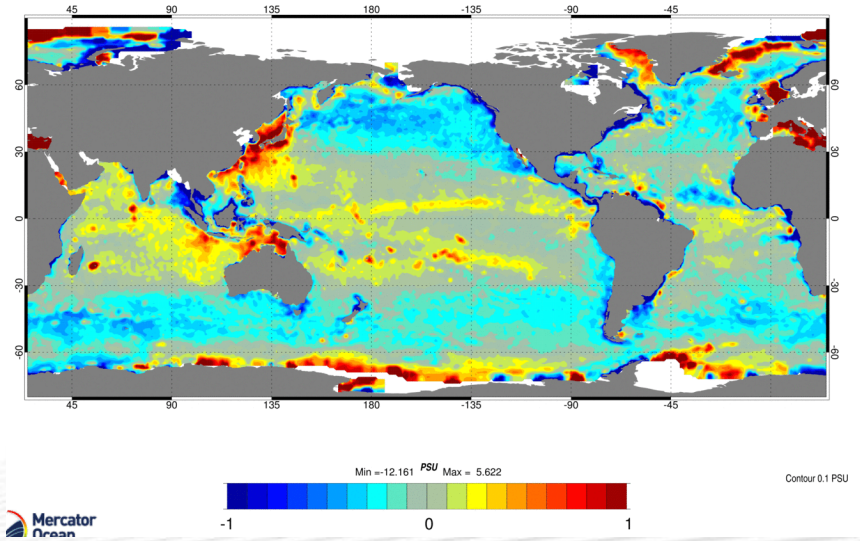
ARGO vs Aquarius and SMOS in the global operational ocean forecasting system at 1/12°

2013

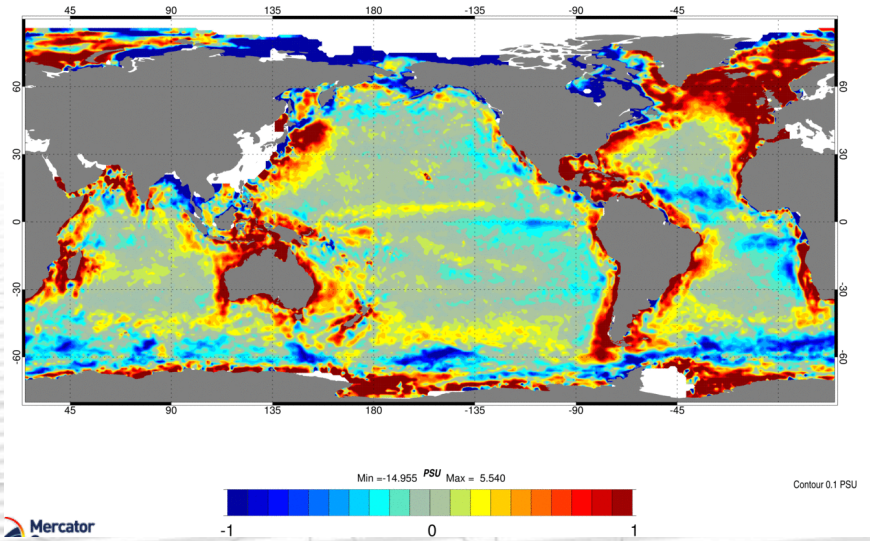


Analysis – in-situ : residual

Analysis – Aquarius (V3.0)

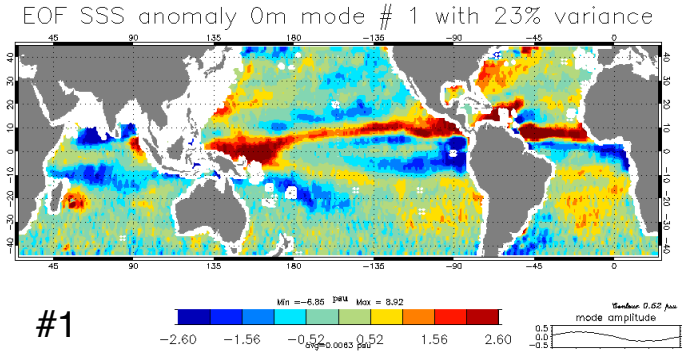


Analysis – SMOS (LOCEAN)

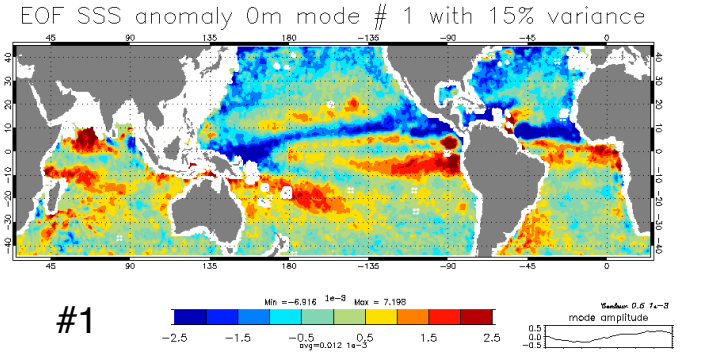


Dominant mode of SSS variability over the period : EOFs at mid-latitudes (-40°S-40°N)

Aquarius (L3/7 days V2.0)



SMOS (L3/AD, 10 days from LOCEAN)



- Modes are quite equivalent in the equatorial regions but inversed

Dominant mode of SSS variability over the period : EOFs at mid-latitudes (-40°S-40°N)

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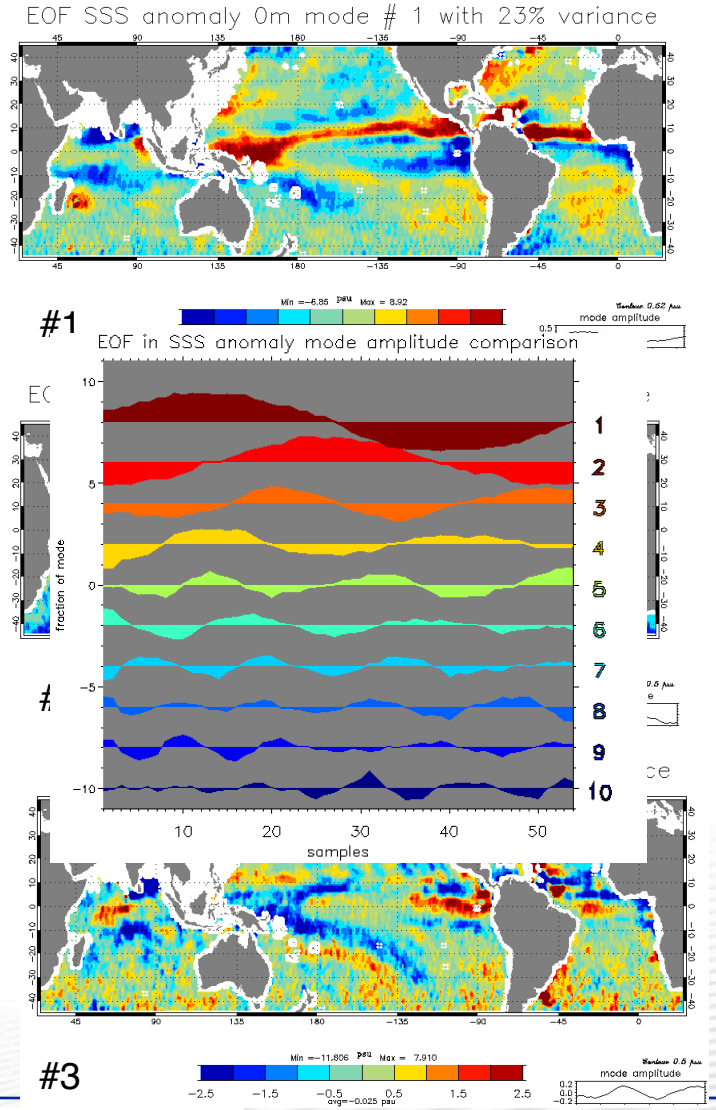

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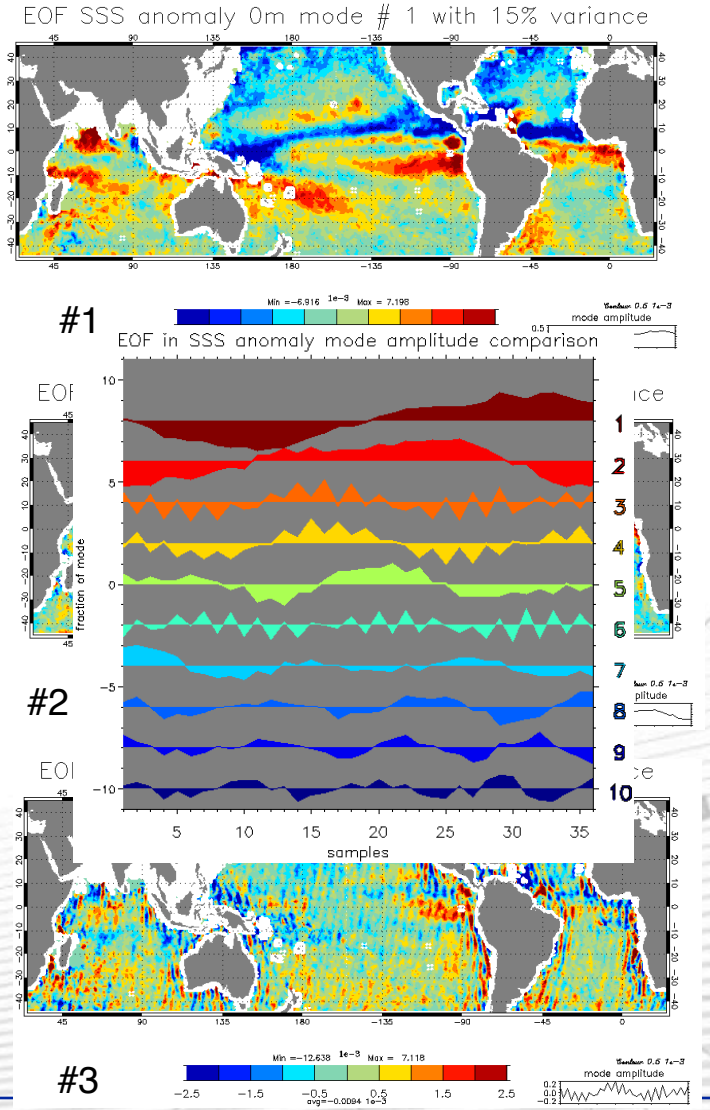


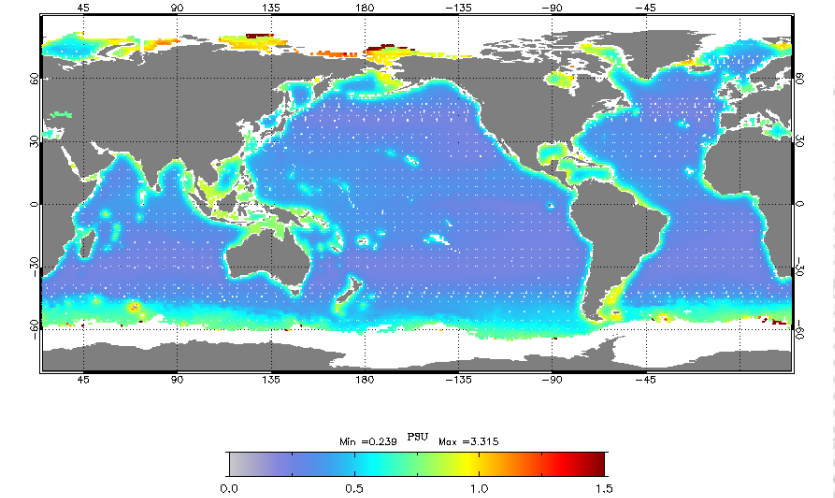
- Modes are quite equivalent in the equatorial regions but inversed

Practice: OSE with the Global Ocean forecasting system at ¼° of Mercator ocean performed in 2012

- **Global ocean forecasting system at ¼° and 50 vertical levels**

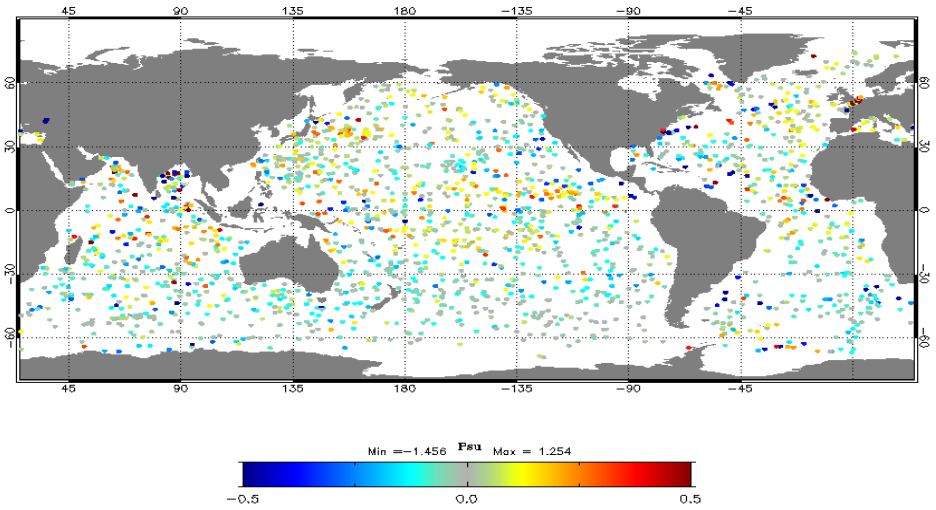
- **Period→ September 2011-April 2012 (With and Without** D.A. of various L3 SSS **Aquarius** data products, CAP, V1.3 weekly and **V2.0** daily and **weekly)**

- **Observation Error** : Regression error with the Aquarius error (ARGO – Aquarius) function of SST and the SST^2 and some distance to the coast (RFI + mesoscale pattern). (best fit)

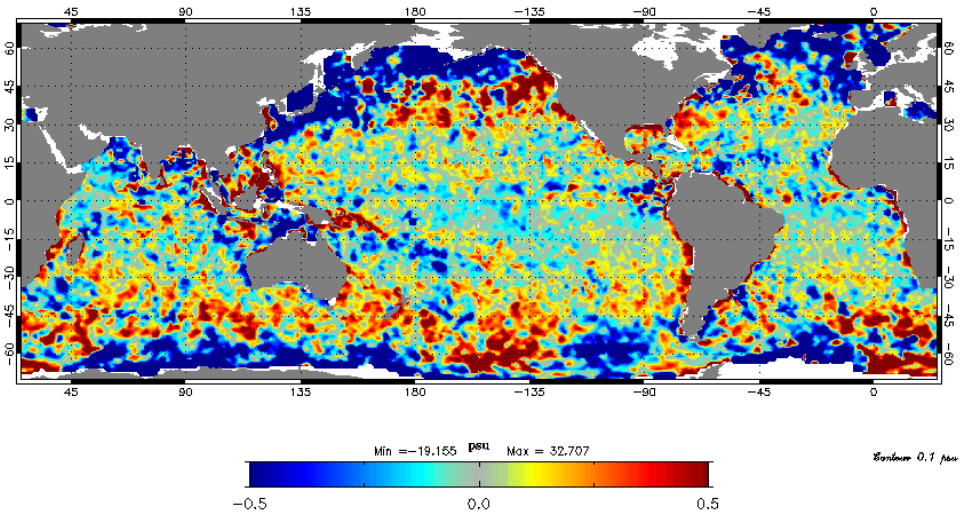


SSS Bias with DA of Aquarius V2.0

Innovation (insitu – model)



Innovation (insitu – model)

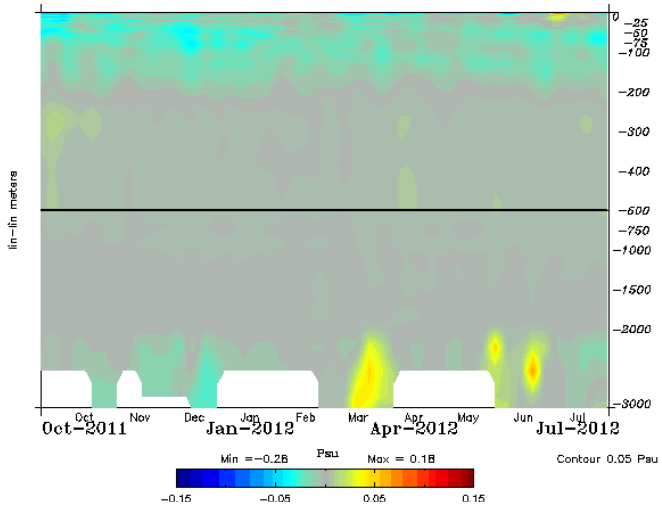


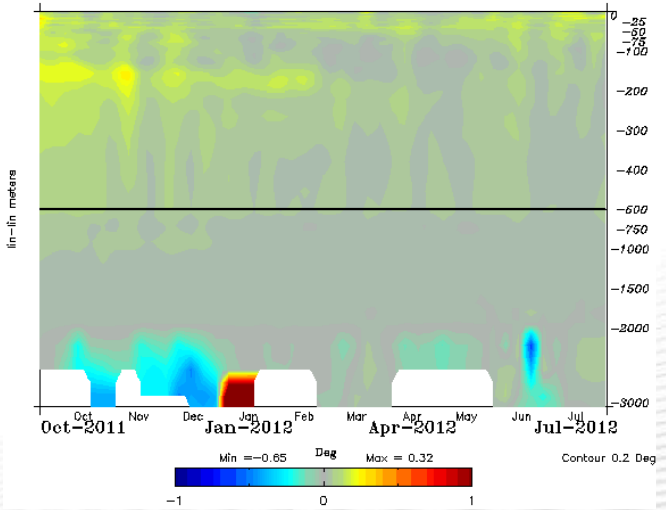
- **Valuable informations from AQUARIUS data are still dominated by large scale biases.**
- **This biases vary with time, with a prominent seasonal signal.**

Results with 7 days V2.0 data: impact on in-situ (global)

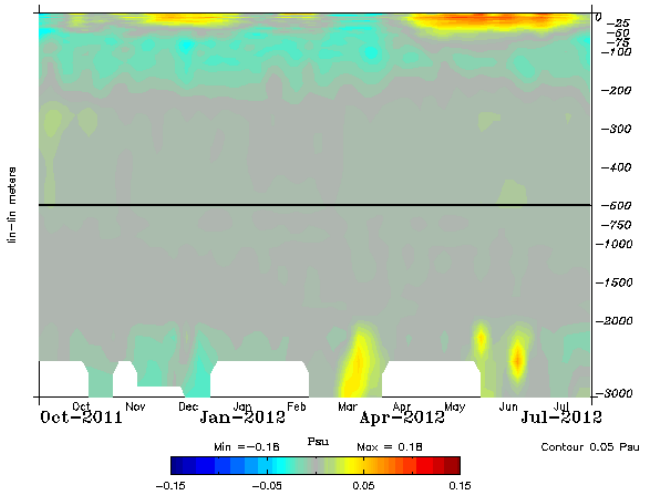
Bias: mean misfit (obs. - model forecast)

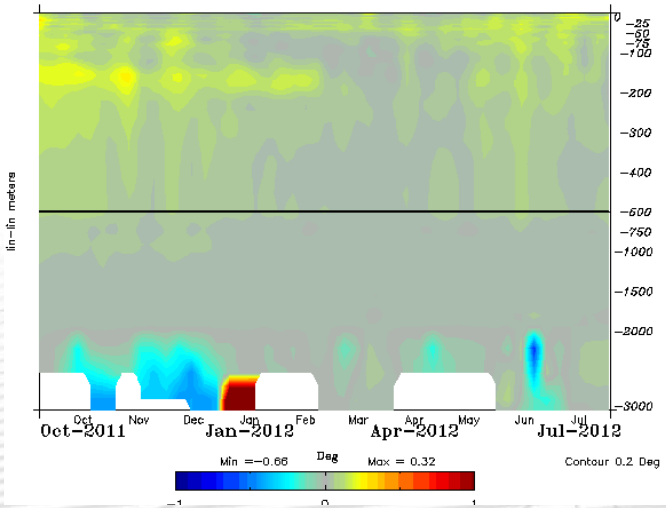
Without DA of SSS





With DA of SSS





Salinity profiles

- Strengthening of a positive bias near the sea surface → freshening trend
- Lower impact in sub-surface (model is saltier than observations)

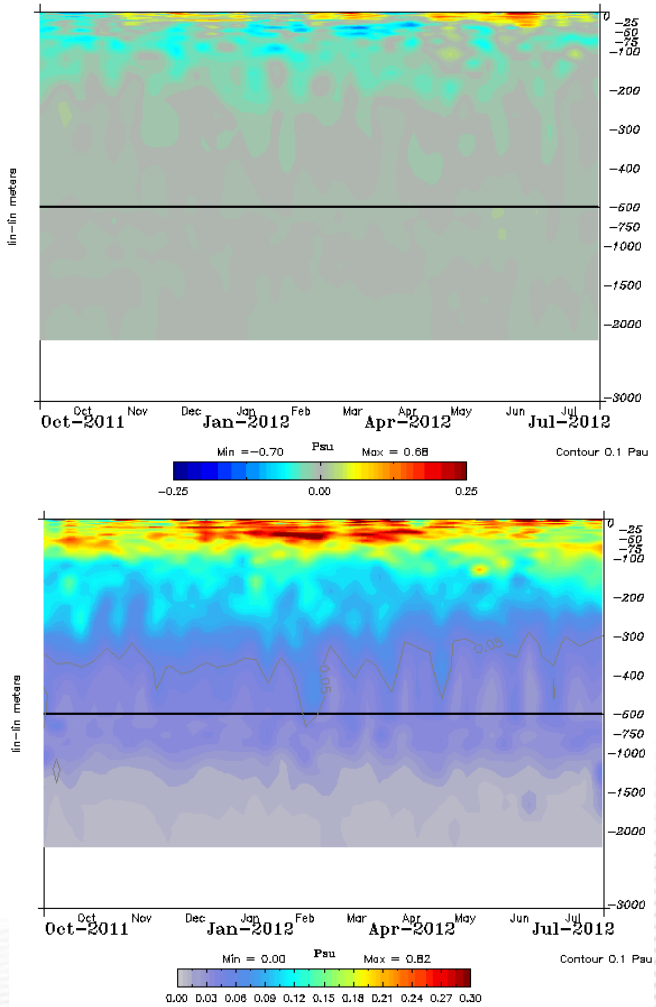
Temperature profiles

- No important changes
- Slight positive bias
  → Model forecast is :
  - colder than observations (0-800 m)
  - Warmer than observations (beyond 2000 m)

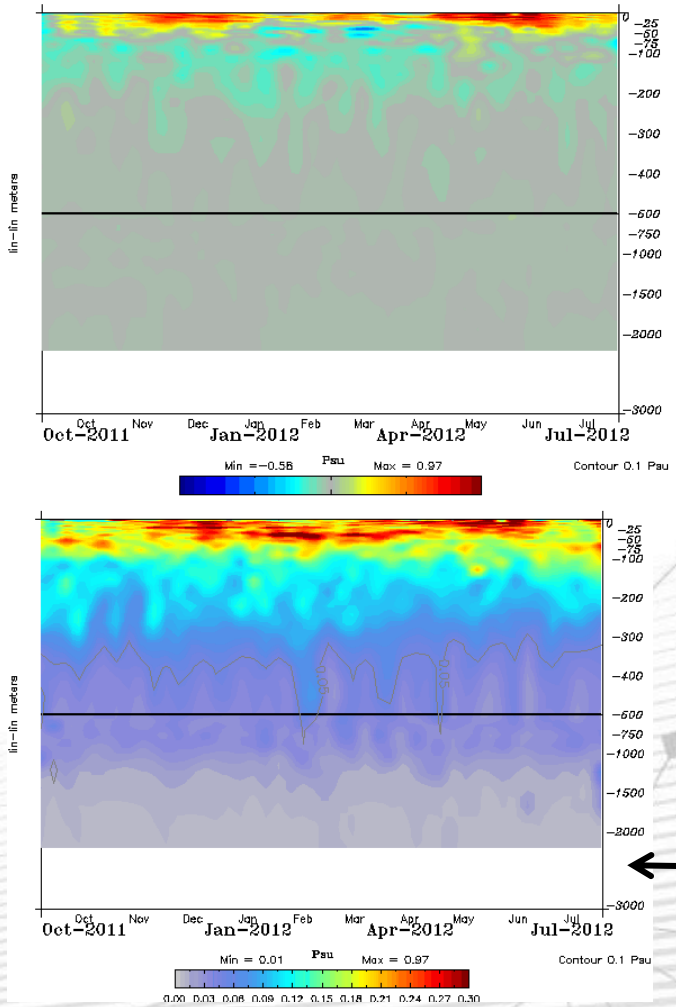
Results: impact on in-situ (South Indian)

mean and rms difference between obs. and model forecast (Salinity)

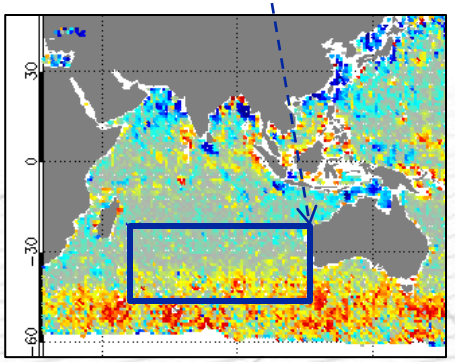
Without DA of SSS



With DA of SSS



Strengthening of a positive bias near the sea surface → <u>freshening trend</u>



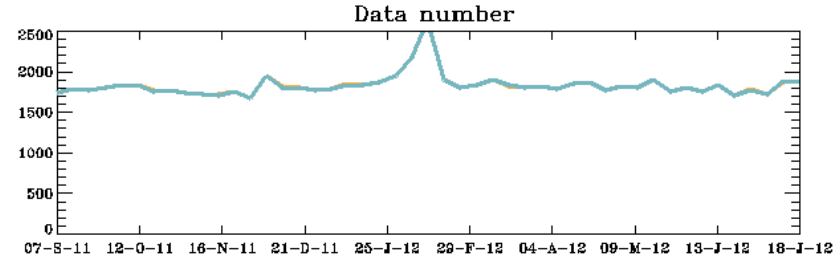
RMS difference is not significantly impacted

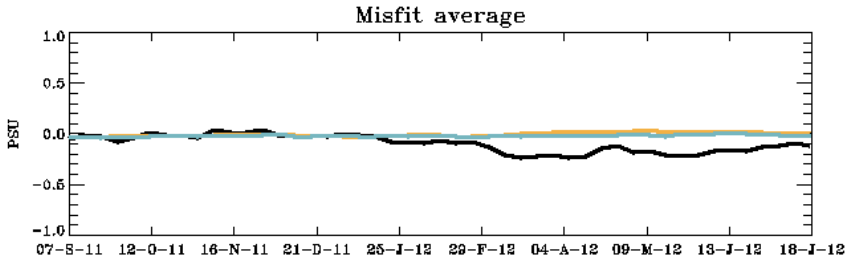
Results: Score (Global & North tropical pacific)

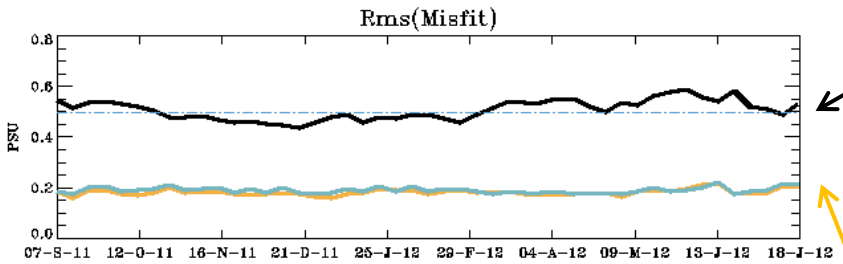
mean and rms difference between obs. and model forecast (Salinity)

GLOBAL

Black: SSS Aquarius V2.0, Orange: SSS Insitu (Ass.) Blue: SSS Insitu (ref)

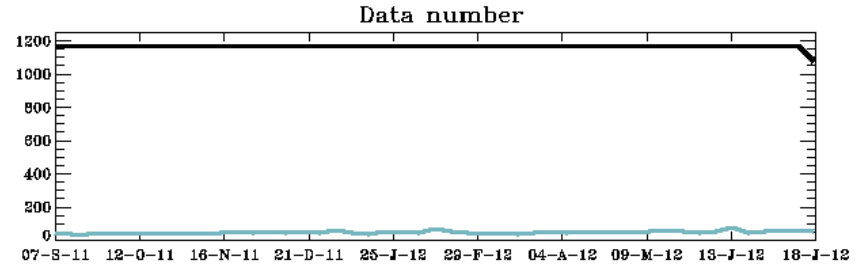


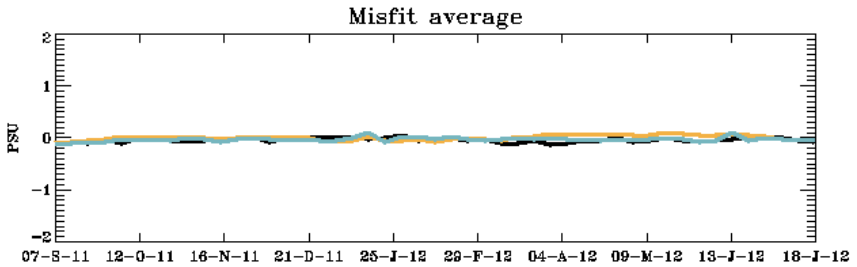




N. Tropical Pacific

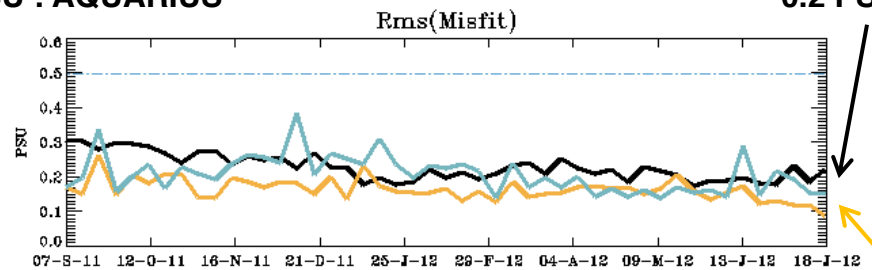
Black: SSS Aquarius V2.0, Orange: SSS Insitu (Ass.) Blue: SSS Insitu (ref)





0.5 PSU : AQUARIUS

0.2 PSU : AQUARIU



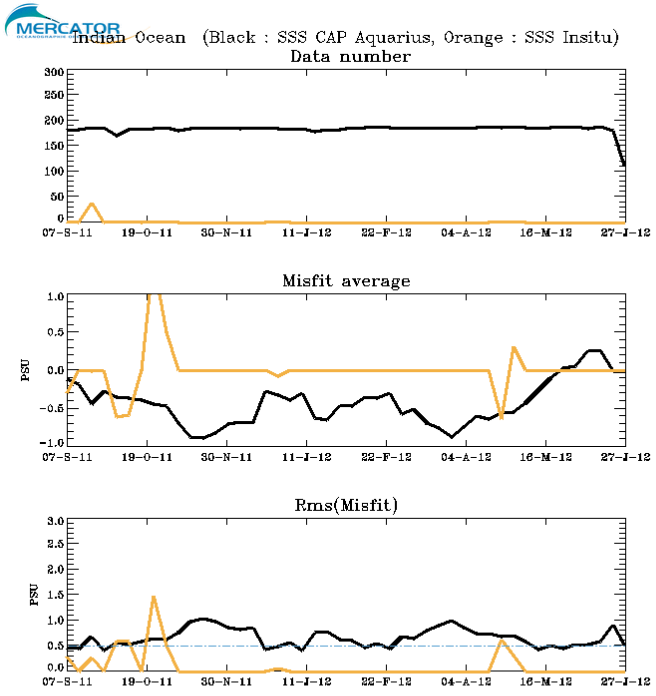
0.2 PSU : Insitu

0.1 PSU : Insitu

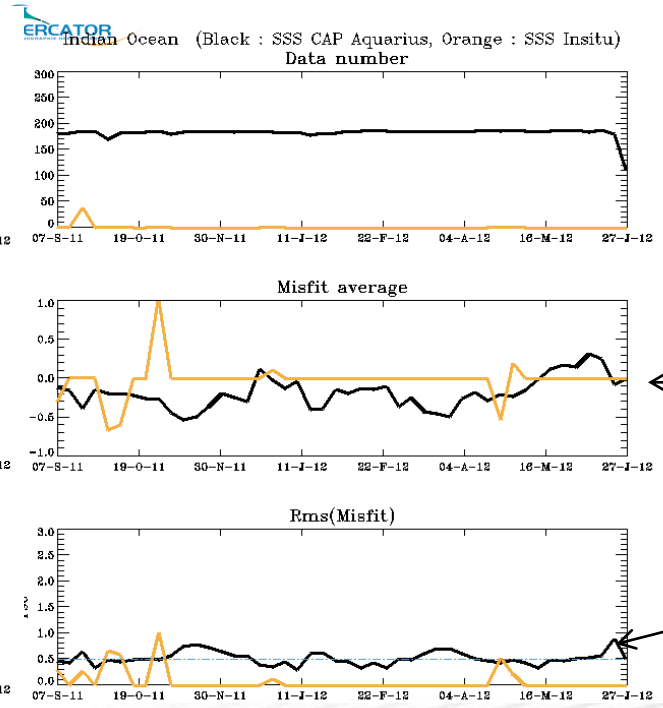
Impact on SSS where few in-situ data are available

Mean and RMS difference between obs. and model forecast

Without DA of SSS

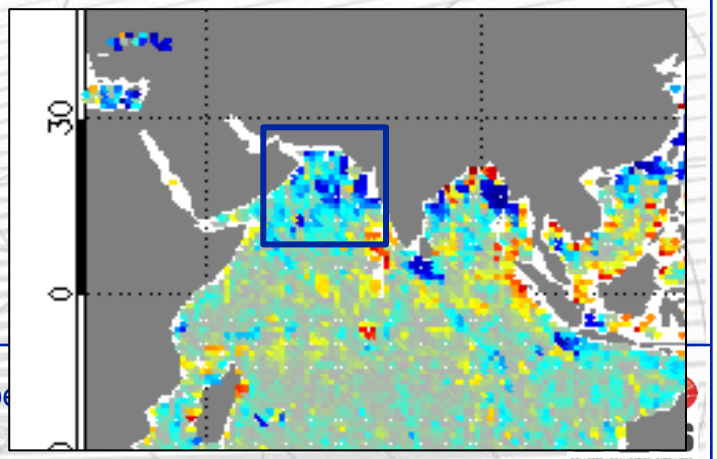


With DA of SSS



← **Bias improvement**

RMS improvement : 0.5-0.6 PSU

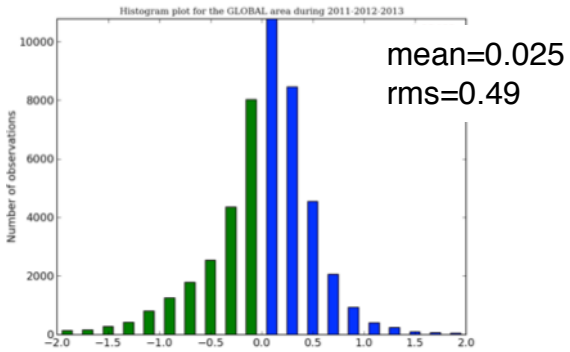


- **Bias and error improvement for SSS Aquarius and in-situ**

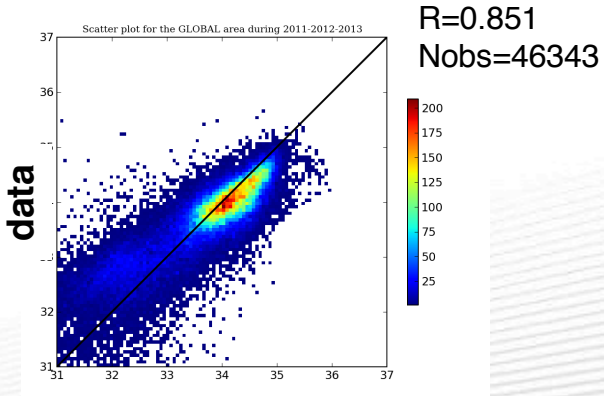
Operational System in Indonesia (1/12° including tides) – INDESO
http://www.indeso.web.id

Validation : monthly SSS data vs model (2011-2013)

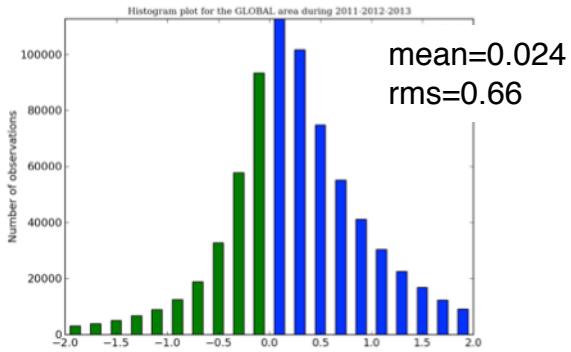
Aquarius V3.0



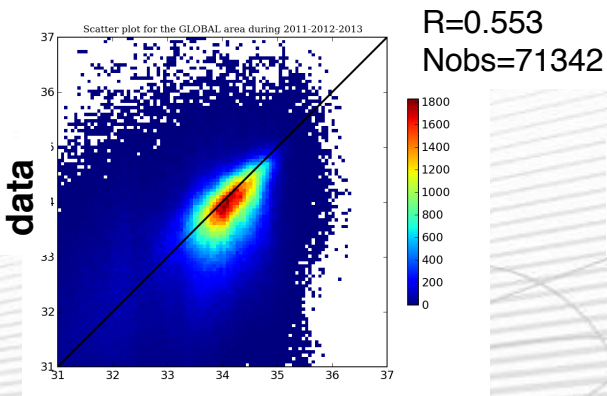
model - data



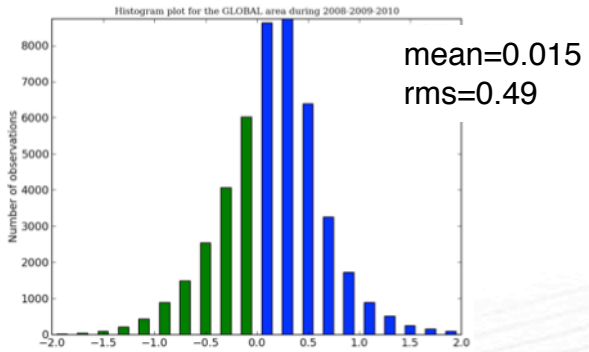
SMOS (LOCEAN)



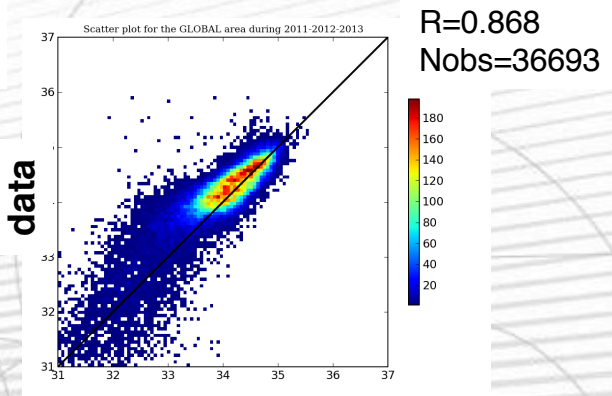
model - data



JAMSTEC (ARGO,TRITON, CTD)



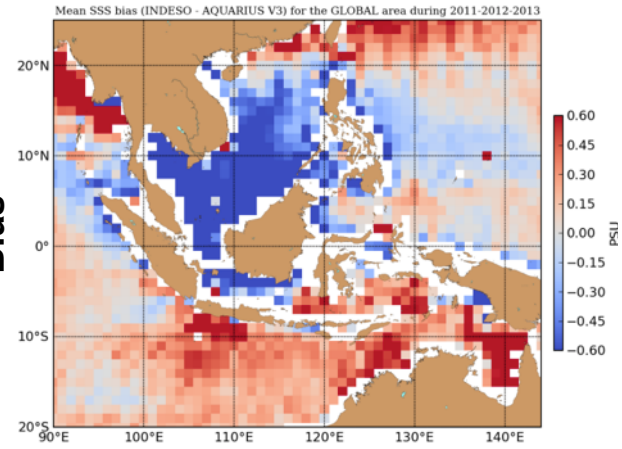
model - data

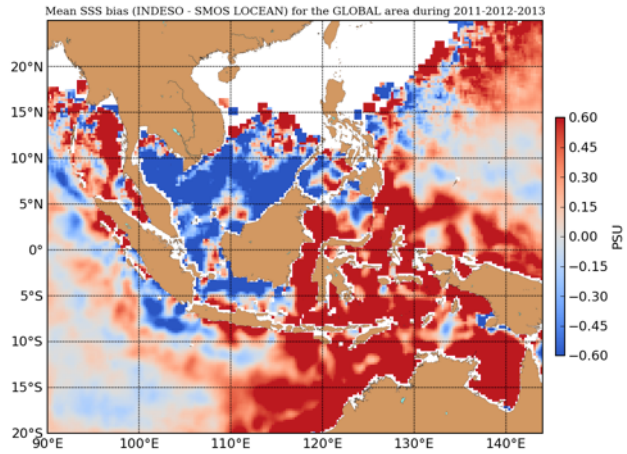


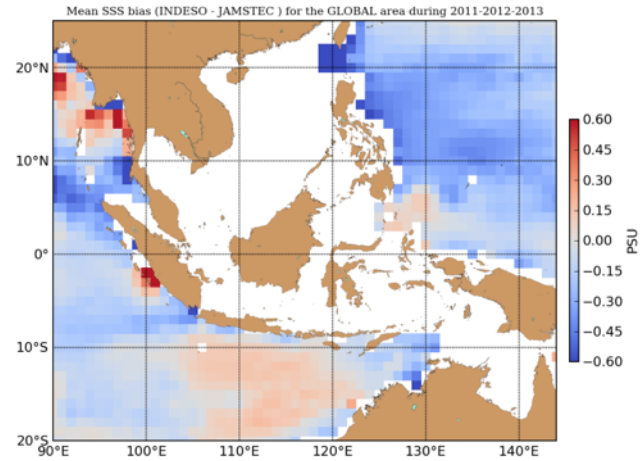
Operational System in Indonesia (1/12° including tides) – INDESO validation : monthly SSS data vs model (2011-2013)

Aquarius V3.0 | **SMOS (LOCEAN)** | **JAMSTEC**

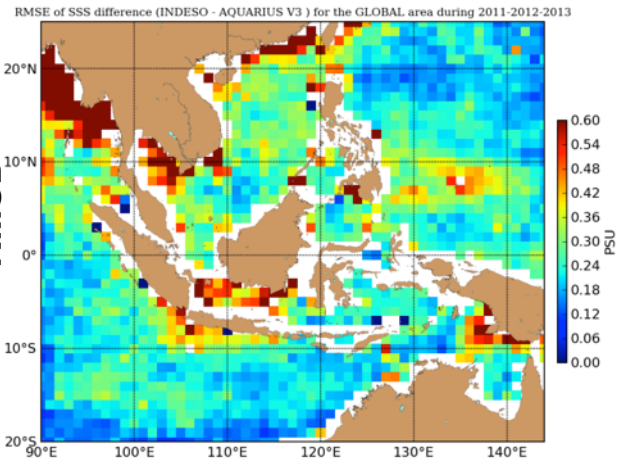
Bias

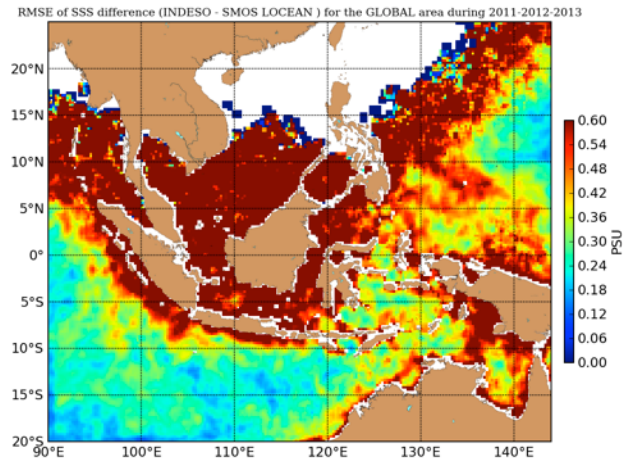


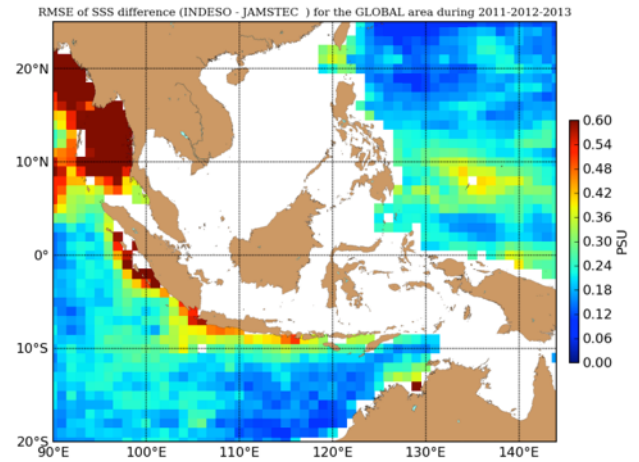




RMSD

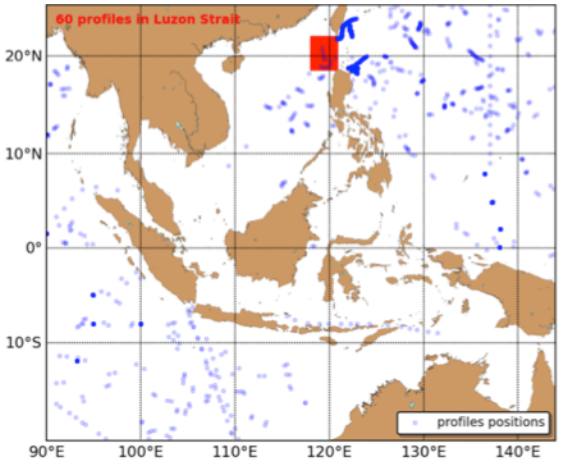


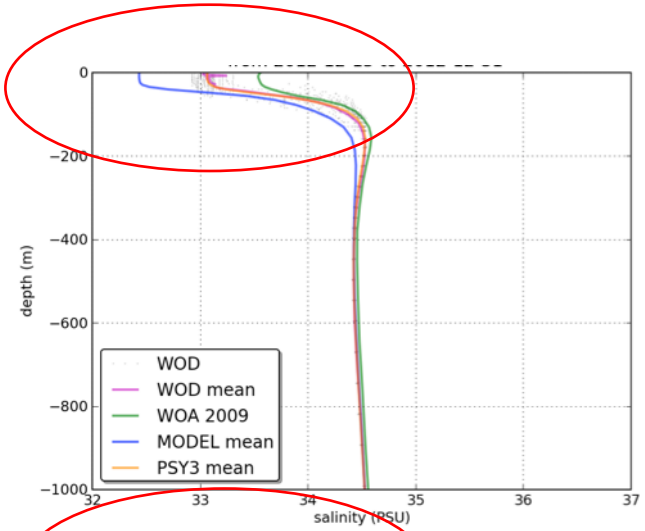




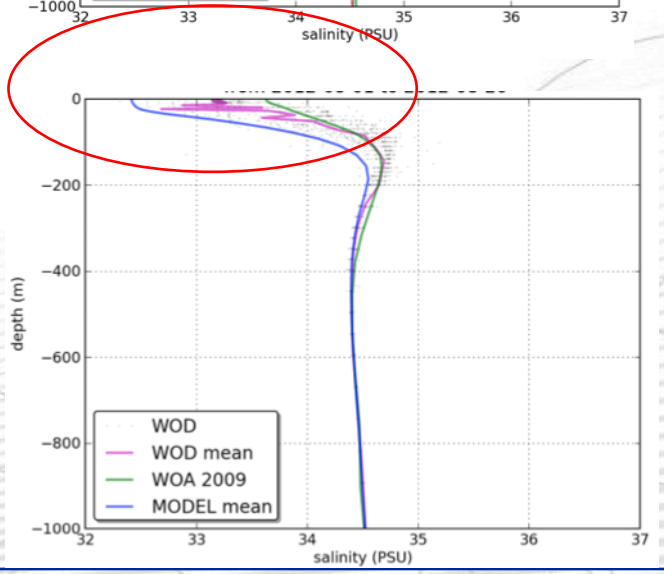
SSS biais in South China Sea: in-situ validation

Biais is in the model !





2 weeks December 2012



2 weeks August 2012

Conclusions

- **Important biases exist in SSS measured from space**
  - May introduce biases in some regions: Equatorial band (ITCZ, SPCZ) etc
  - Aquarius/SMOS data look similar to altimetry with a large orbit error?

- **Biases still exist in operational model**
  - **With and without DA**
  - **Rainfall fluxes errors**

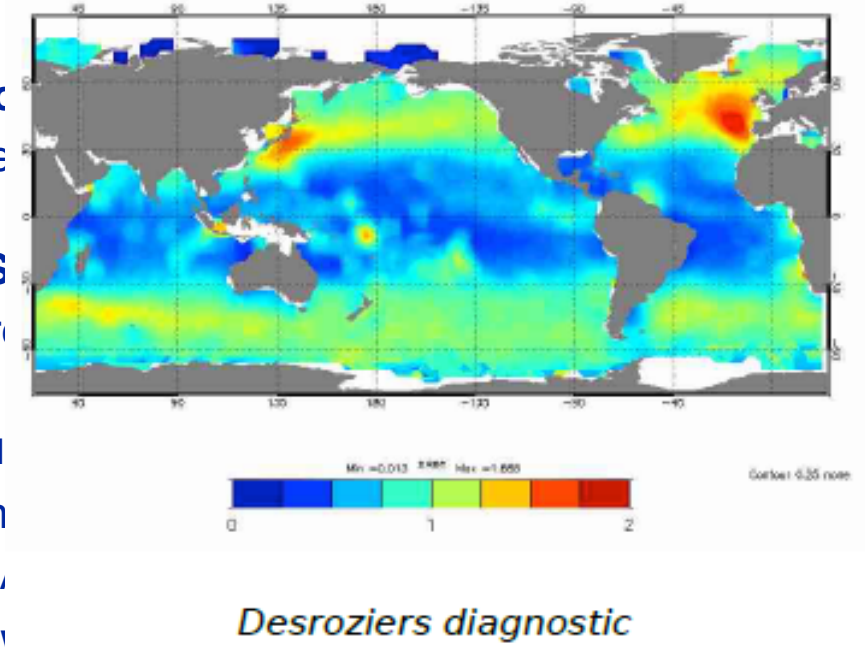
- **Data assimilation of Aquarius data V2.0:**
  - Has a **sligthly** positive impact on the system.
  - **Does not disrupt equilibrium with other data** : unchanged assimilation diagnostics (RMS of SST, SSS, SLA innovation at global scale)
  - Has the ability **to detect meso-scale features** even in mid-latitudes and in cloudy conditions, but this potential is still limited by the large scale biases.
  - **Can fill in-situ data gap** (Arabian sea, Bay of Benguale, Amazon, Indonesia SCS, etc..)

Perspectives

- **Dedicated impact studies with the new SMOS and Aquarius data and improved data assimilation schemes are required to better understand the SSS (hydrological cycle)**
  - Remove the **bias** before assimilating **SSS is an important issue ➔ Biais correction of SSS** (3Dvar)
  - **Adaptive tuning of observations errors** to fit with others errors (model and observations)
    - Estimate observation error covariance matrix R using innovation statistics (Desrozier et al., 2005):
  - Assimilate **other SSS data** : L2/L3/L4 ?, **SMOS and Aquarius** data together
  - Work with Data Production Center **to better understand/assimilate** data we use ➔ best strategy?
- **OSSEs to define future requirements of salinity missions by taking into account:**
  - Argo measurements
  - Last versions of DA systems
- **More fundamental work on SSS data assimilation are required**
  - Correction of freshwater fluxes,
  - Assimilation of brightness temperatures
  - 4D error covariances, ensemble approach

Perspectives

- **Dedicated impact studies with the <u>new SMOS and Aquarius data</u> and <u>improved</u> data assimilation schemes are required to better understand the SSS (hydrological cycle)**
  - Remove the **bias** b… **e ➔ Biais correction of SSS** (3Dvar)
  - **Adaptive tuning o…** …s (model and observations)
    - Estimate obse… …ation statistics (Desrozier et al., 2005):
  - Assimilate **other S…** …data together
  - Work with Data Pr… **…ilate** data we use ➔ best strategy?
- **OSSEs to define fu… …by taking into account:**
  - Argo measuremen…
  - Last versions of D…
- **More fundamental … …uired**
  - Correction of freshwater fluxes,
  - Assimilation of brightness temperatures
  - 4D error covariances, ensemble approach



Desroziers diagnostic

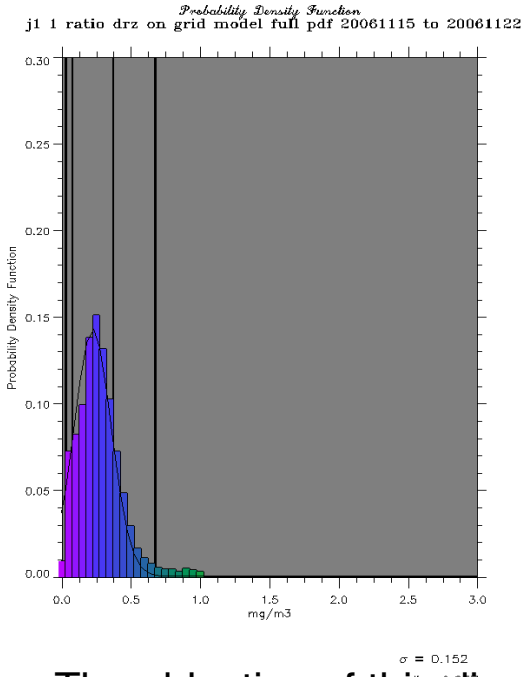
Adaptive tuning of observations errors

The observation errors in the assimilation systems is often a rough estimate…

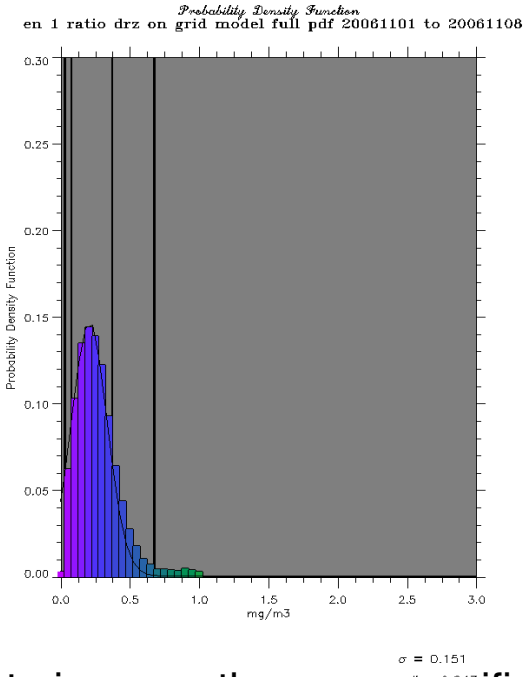
$$\textbf{Ratio}_{\textbf{Desroziers}} = \frac{E\,[\,\textbf{residual (innovation)}^T\,]}{\alpha\,\mathbf{R}}$$

- Ideally, ratio=1
- ratio < 1 => obs. error overestimated
- ratio > 1 => obs. error underestimated

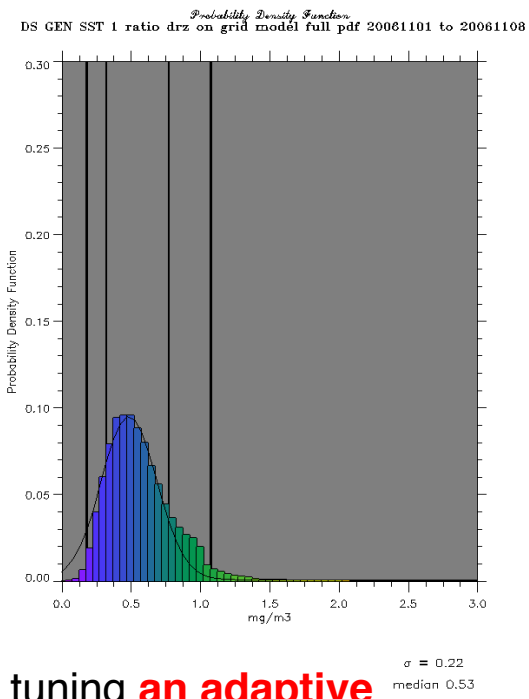
Jason1



Envisat



SST



The objective of this diagnostic is to improve the error specification by tuning **an adaptive weight coefficient α** acting on the error of each assimilated observation.

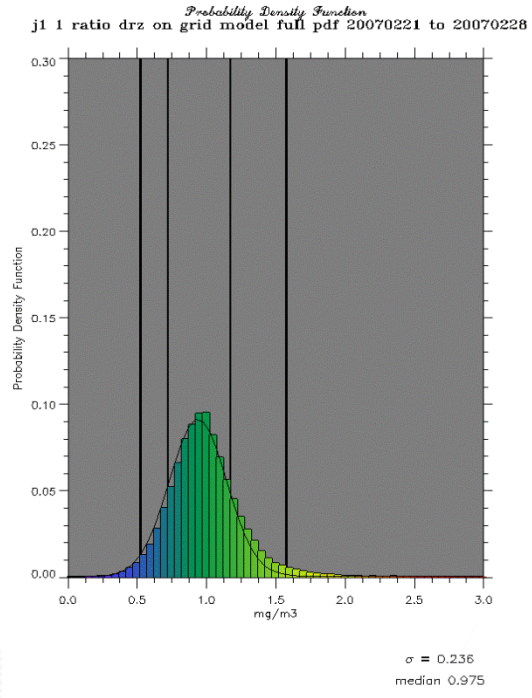
Adaptive tuning of observations errors

The prescription of observation errors in the assimilation systems is often too approximate...

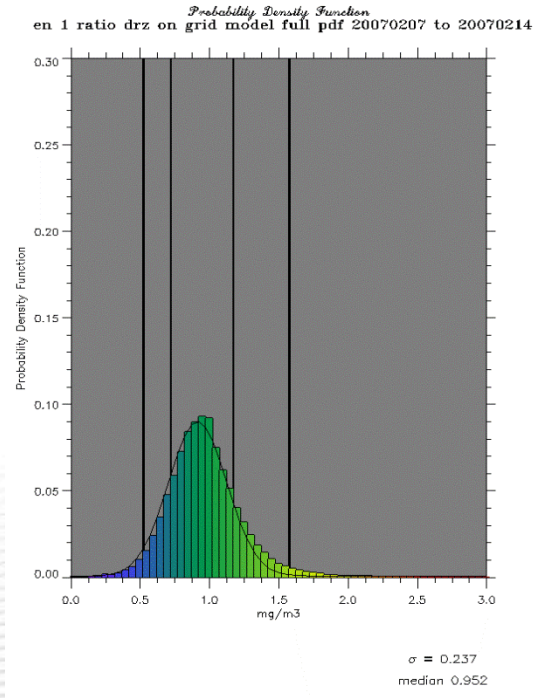
$$\textbf{Ratio}_{\textbf{Desroziers}} = \frac{E\,[\,\textbf{residual (innovation)}^{T}\,]}{R}$$

- Ideally, ratio=1
- ratio < 1 => obs. error overestimated
- ratio > 1 => obs. error underestimated

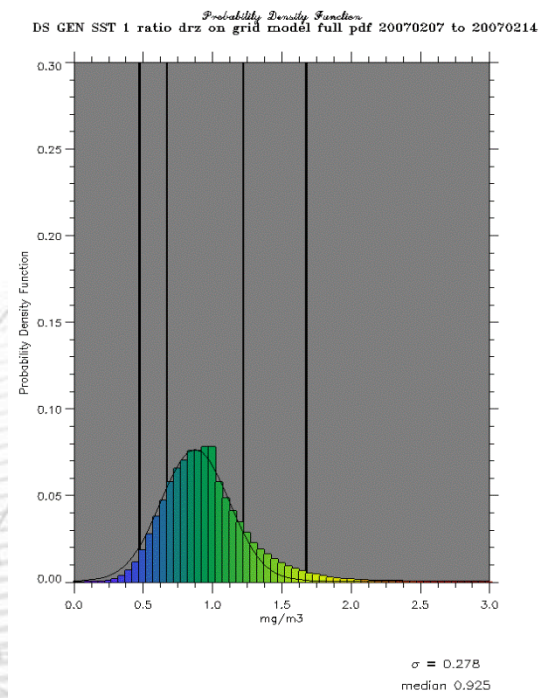
Jason1



Envisat

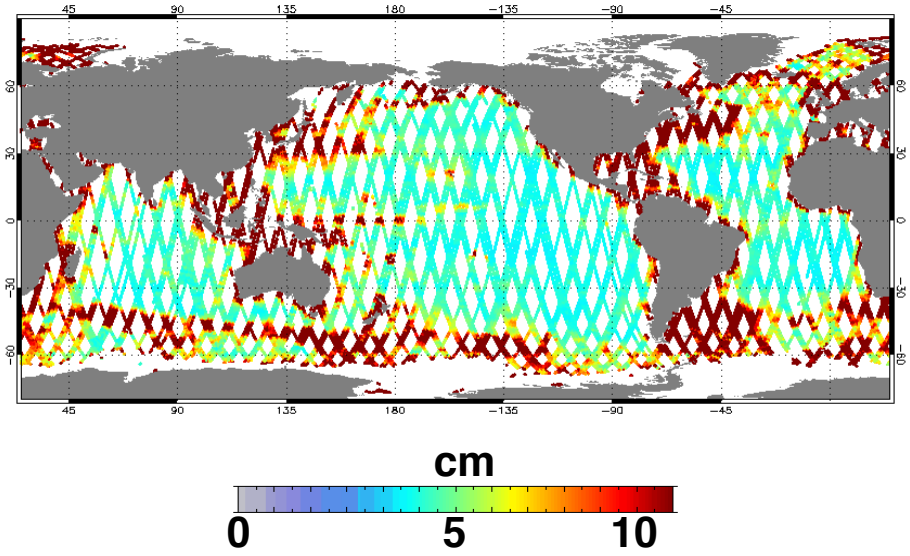


SST

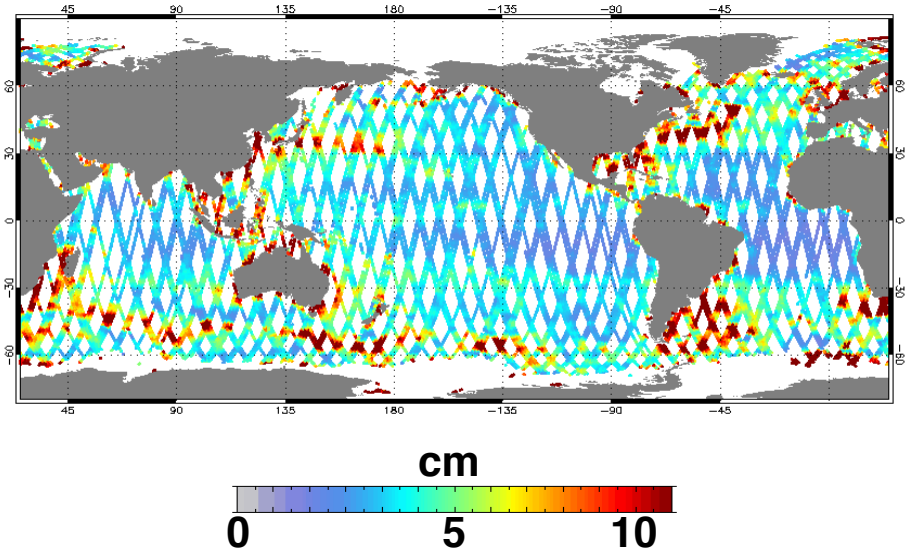


Adaptive tuning of observations errors - SLA -

Envisat error on 20061227 without tuning

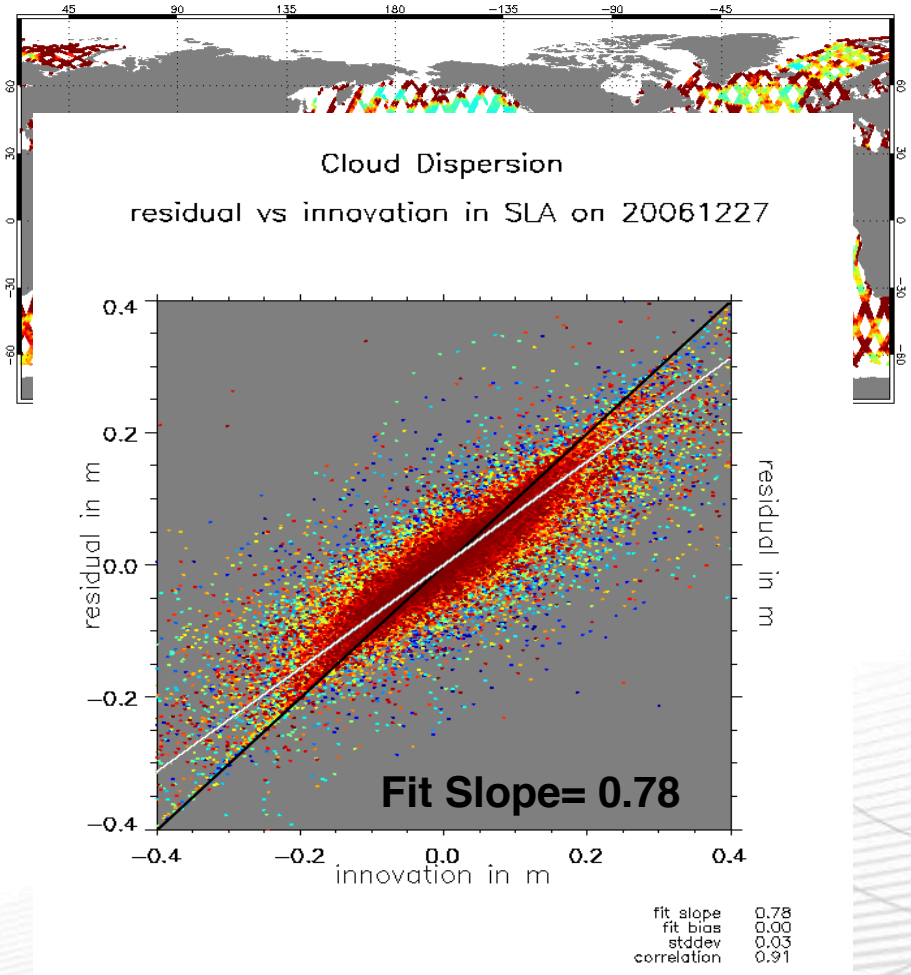


Envisat error on 20061227 with tuning

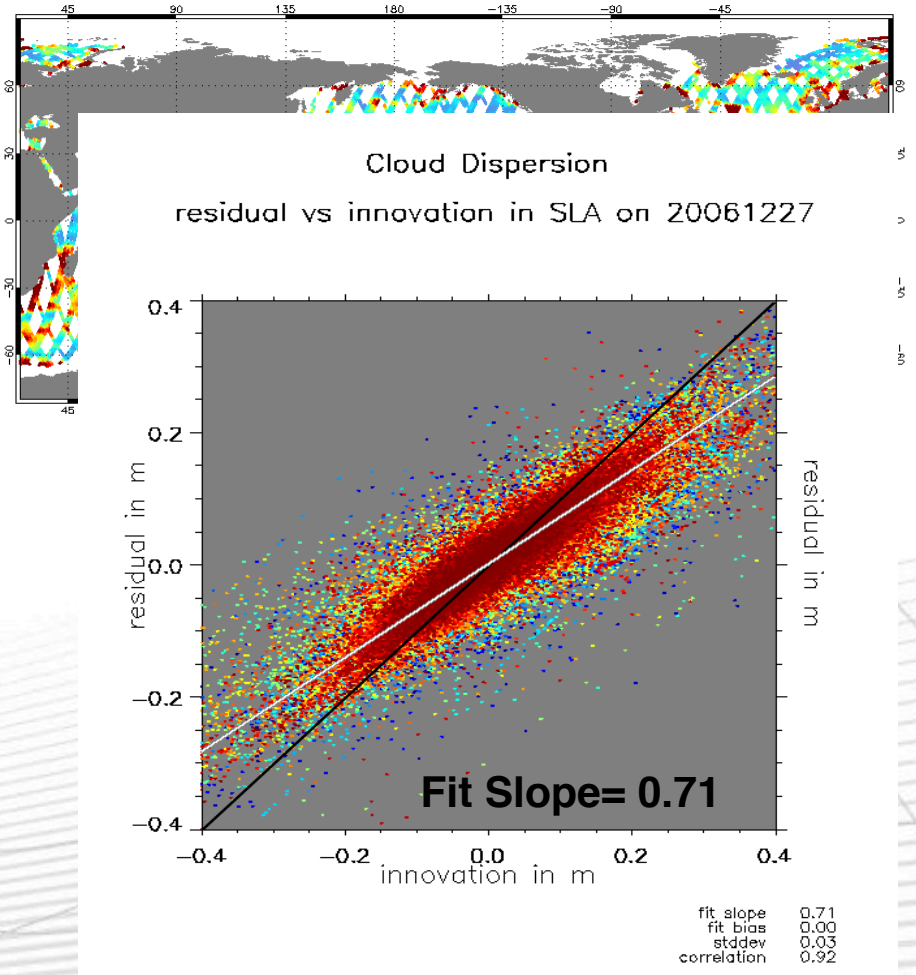


Adaptive tuning of observations errors - SLA -

Envisat error on 20061227 without tuning



Envisat error on 20061227 with tuning



Mode of variability vs innovation of SSS

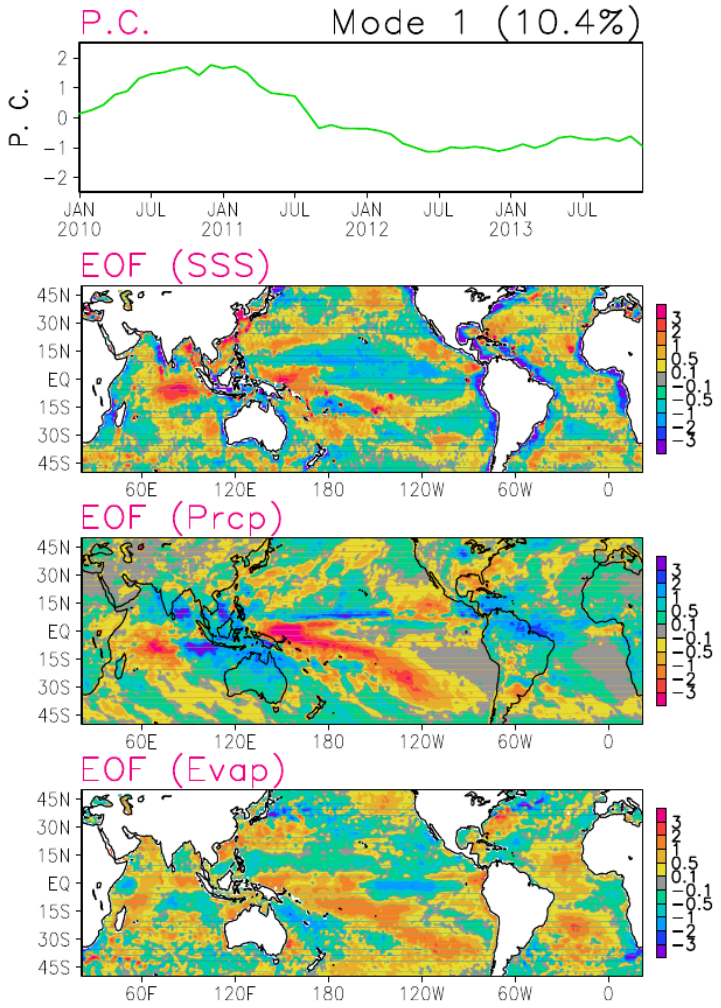
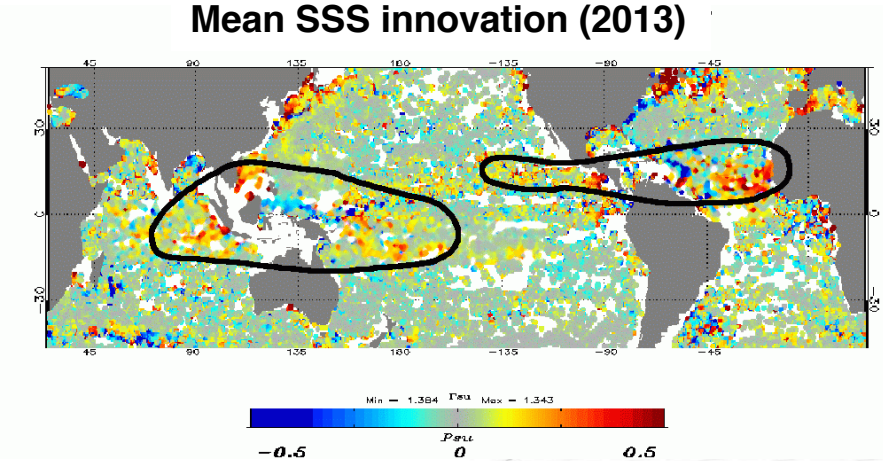


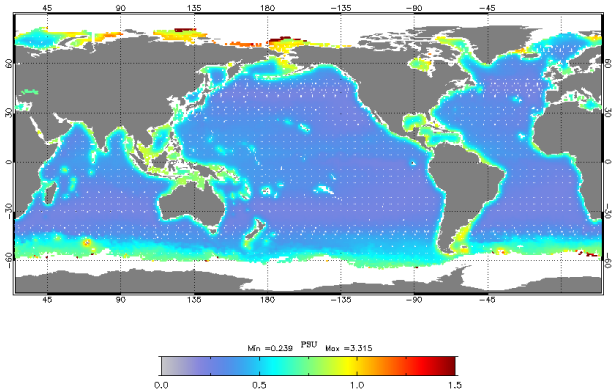
Figure 12. (first row) Time series of the principal component (PC) and the spatial loadings of the (second row) SSS, (third row) precipitation, and (fourth row) evaporation variability associated with the first mode of the combined EOF performed for a 36 month period from January 2010 to December 2012. Monthly anomaly fields of SSS, precipitation, and evaporation data are, respectively, from the BASS, CMORPH, and OAFlux.



Xie, P., T. Boyer, E. Bayler, Y. Xue, D.Byrne, J. Reagan, R. Locarnini, F. Sun,R. Joyce, and A. Kumar (2014), An in situ-satellite blended analysis of global sea surface salinity, J. Geophys. Res.Oceans, 119, 6140–6160, doi:10.1002/2014JC010046.

Practice: OSE with the Global Ocean forecasting system at ¼° of Mercator ocean performed in 2012

- **Global ocean forecasting system at ¼° and 50 vertical levels**
  - **Ocean Model** : ORCA025 LIM2 EVP from NEMO3.1
  - **3 hourly atmospheric** forcing from ECMWF (Bulk Formulae from CORE)
  - **Data Assimilation system** : SAM2v1 (SEEK kernel: Reduced Order Kalman Filter)
    - FGAT (First Guess at Appropriate Time)
    - IAU : Incremental Analysis Update
    - Bias correction from 3Dvar (in-situ)
  - **Assimilated data**
    - SST from AMSRE-AVHRR at ¼°
    - SLA from Jason1, Jason 2, ENVISAT
    - In-situ profiles from CORIOLIS centre

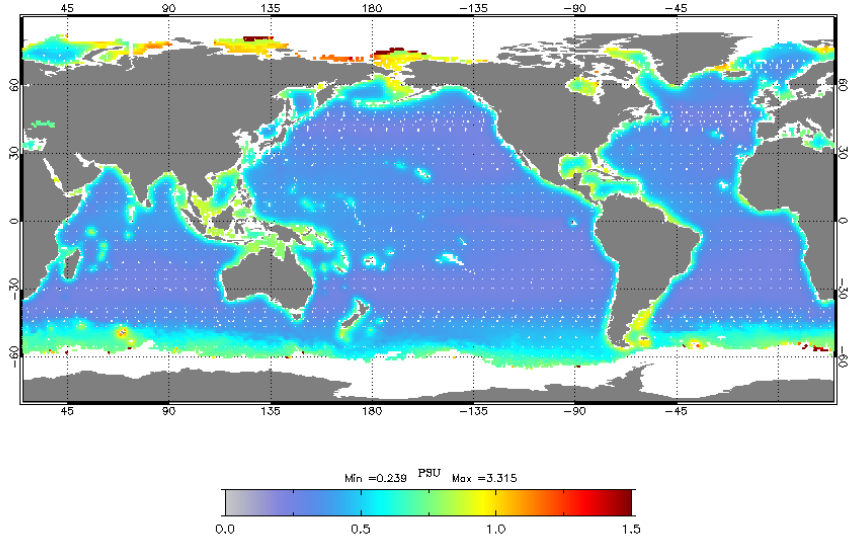


- **Period→ September 2011-April 2012 (With and Without** D.A. of various L3 SSS **Aquarius** data products, CAP, V1.3 weekly and **V2.0** daily and **weekly)**
- **Observation Error** : Regression error with the Aquarius error (ARGO – Aquarius) function of SST and the SST^2 and some distance to the coast (RFI + mesoscale pattern). (best fit)

First OSE with Aquarius data

- **Need** to have an appropriate **Observation operator**
  - innovation = **obs**. - **model equivalent**
  - **Model equivalent** : $SSS_{mod.} = \left[\overline{SSS}\right]$
    where [] denotes a weekly mean and $\overline{\ }$ denotes a spatial mean (shapiro filter ~ 1°)

- **Observation Error** : comes from a regression error with the Aquarius error (ARGO – Aquarius) function of SST and the SST^2 and some distance to the coast (RFI + mesoscale pattern). (best fit)

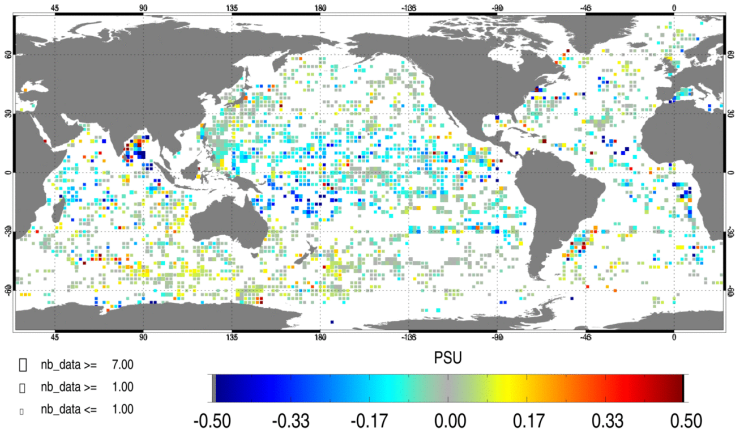


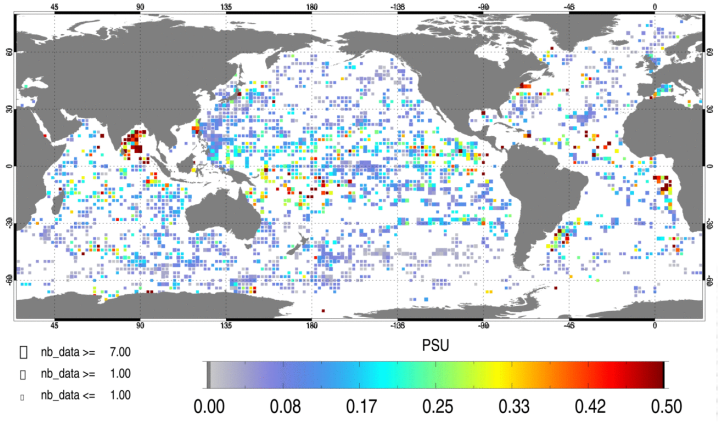
Exemple of observation error on October 7, 2011

SSS errors in operational oceanography

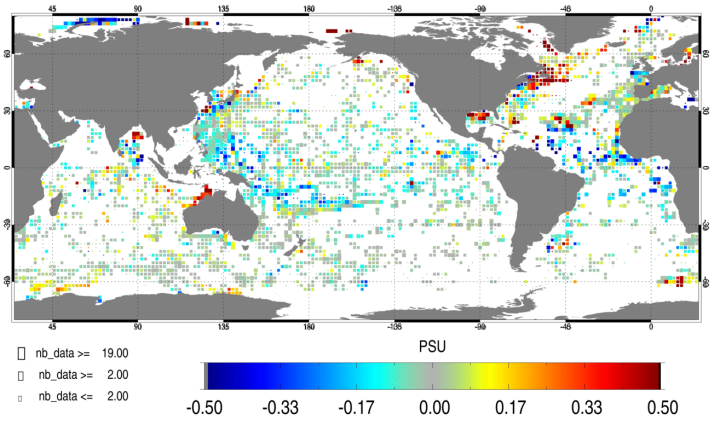
Validation of 1/12° global ocean fcst. Syst.: Analysis – observation (in-situ)

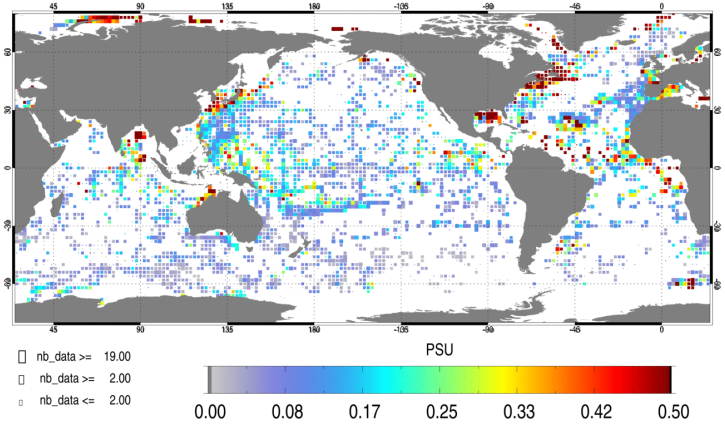
JFM 2013





JAS 2013





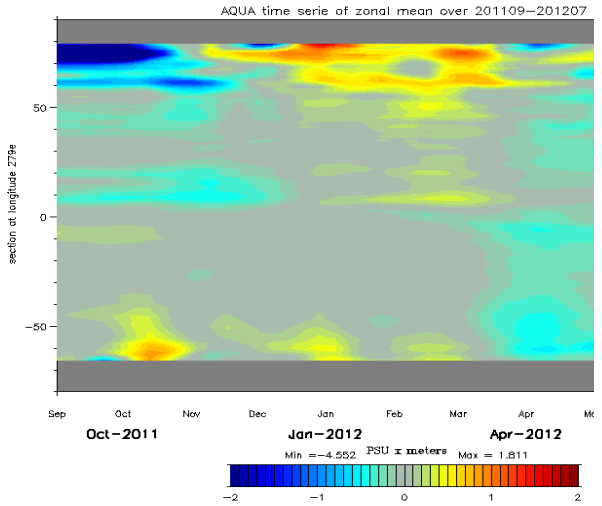
MEAN

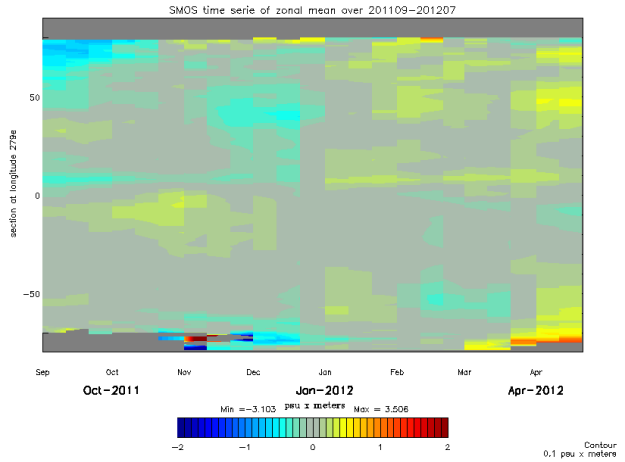
RMS

•Largest biases and errors are located near the river mouths, in the western and Eastern Pacific along the Equator, and where sub-meso-scale is significant.

SMOS vs Aquarius data

Zonal mean anomaly of SMOS and Aquarius: period October 2011 to April 2012





SMOS vs Aquarius data

- Available SSS L3 data in August 2012 :
  - L3 SMOS data : V01 (CATDS Brest-Ifremer)
  - L3 Aquarius V1.3 CAP (JPL)

	SMOS data	Aquarius data
Level 3	1/2° - 10 days map	1° - 7 days map
RFI	yes+	yes
Latitudinal bias	yes	yes
Ascending/descending phases	yes	yes
Error at high latitudes	yes	yes
Wind (retrieval)/surface roughness	ECMWF	Scatterometer
SSS (retrieval)	Climatology	HYCOM

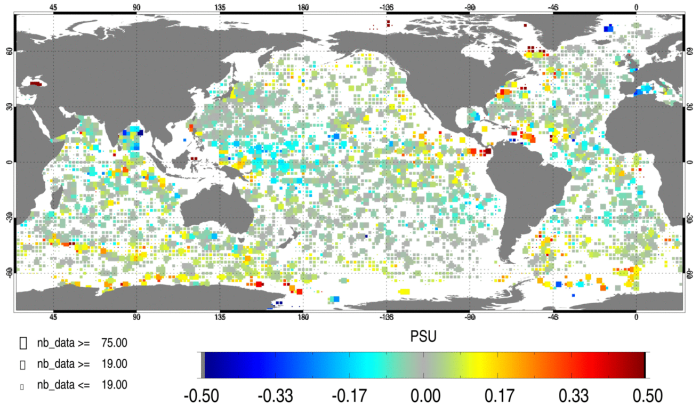
SSS errors in operational oceanography

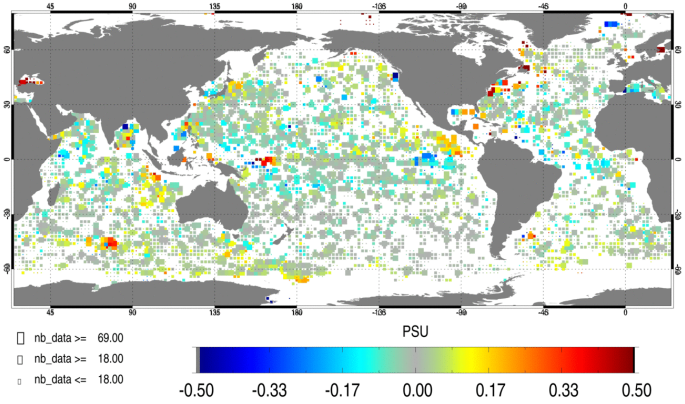
Analysis – observation (in-situ)

JFM 2012

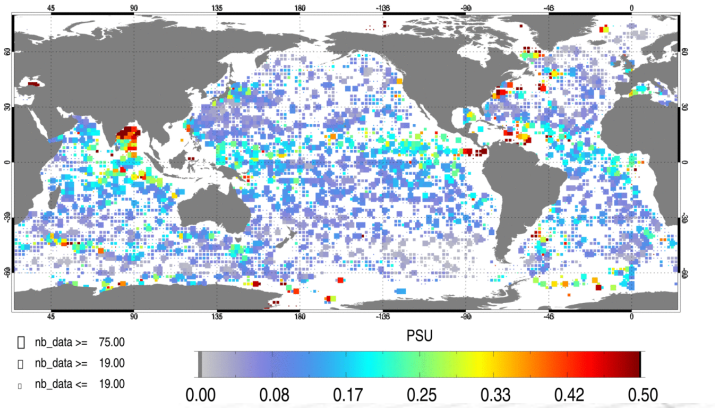
JAS 2012

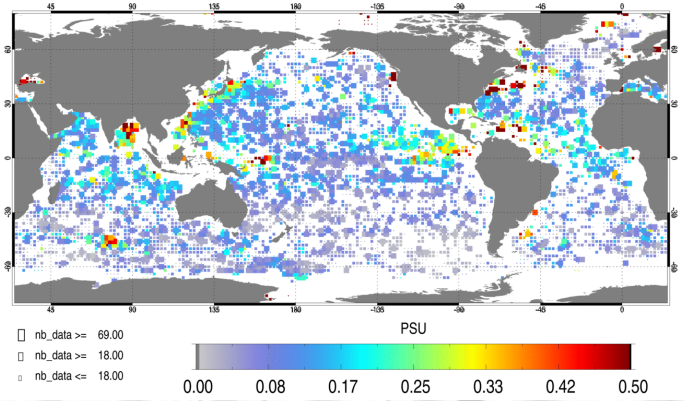
MEAN





RMS





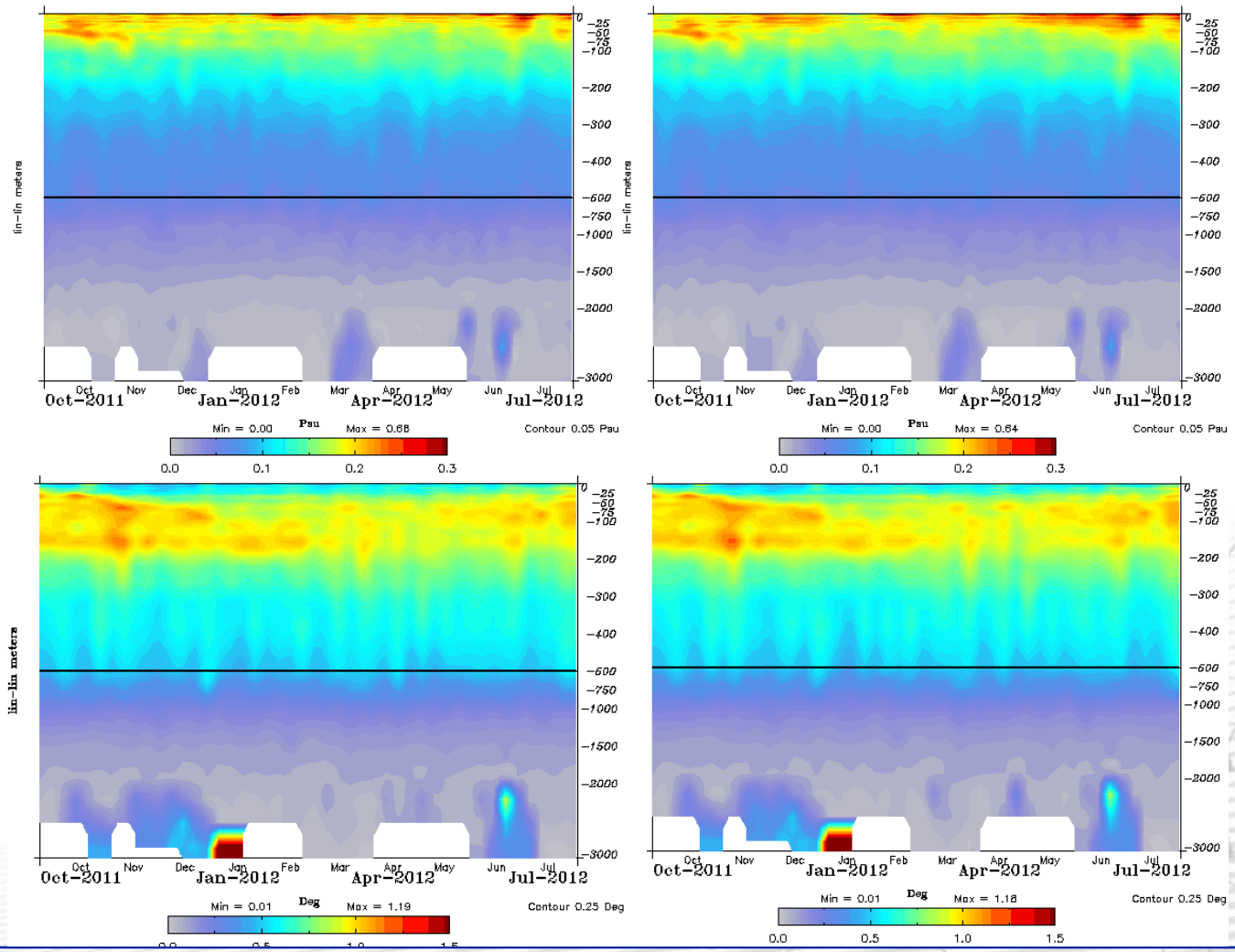
•Largest biases and errors are located near the river mouths, in the western and Eastern Pacific along the Equator, in the ACC and where sub-meso-scale is significant.

Results: impact on in-situ (global)

Error: RMS difference between obs. and model forecast

Without DA of SSS

With DA of SSS



Salinity profiles

- No important changes

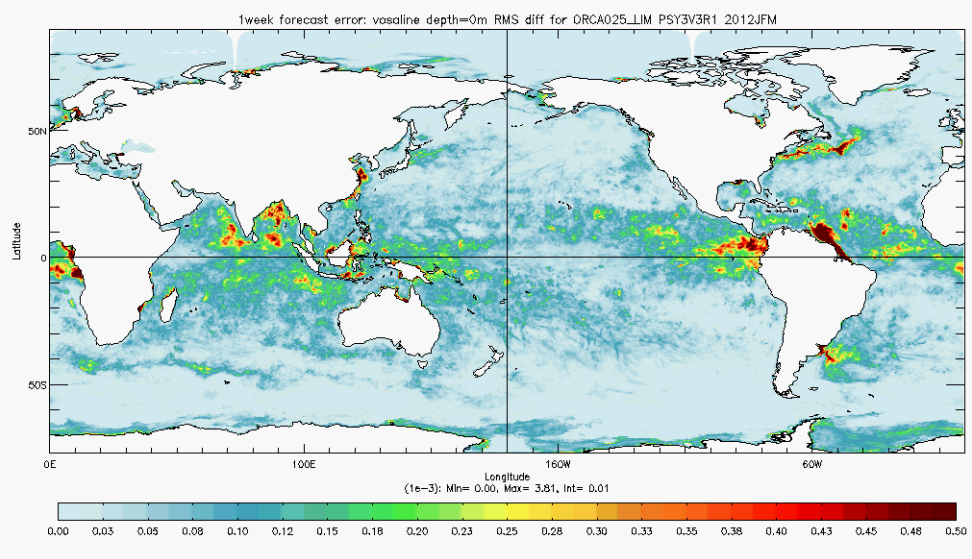
Temperature profiles

- No important changes

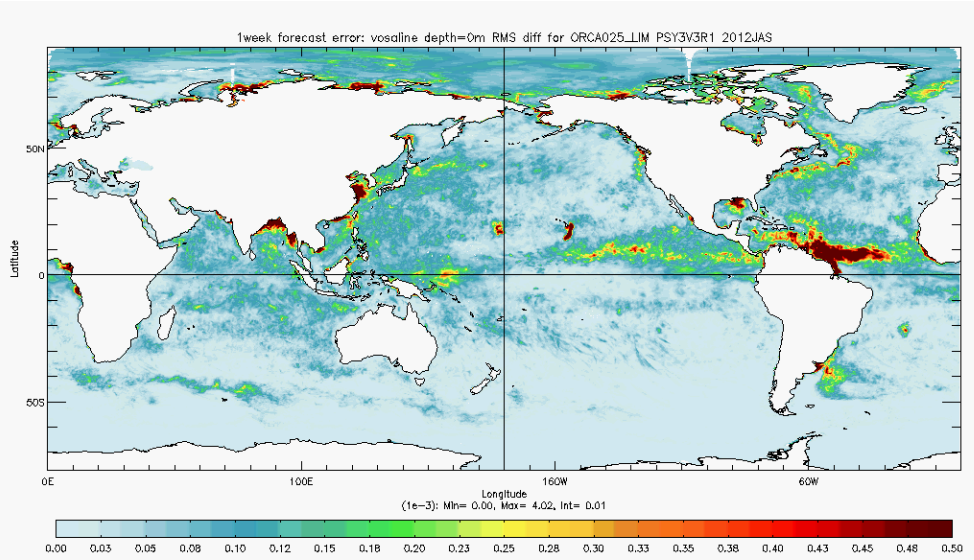
SSS errors in operational oceanography

Forecast error: RMS(Forecast-Hindcast)

JFM 2012



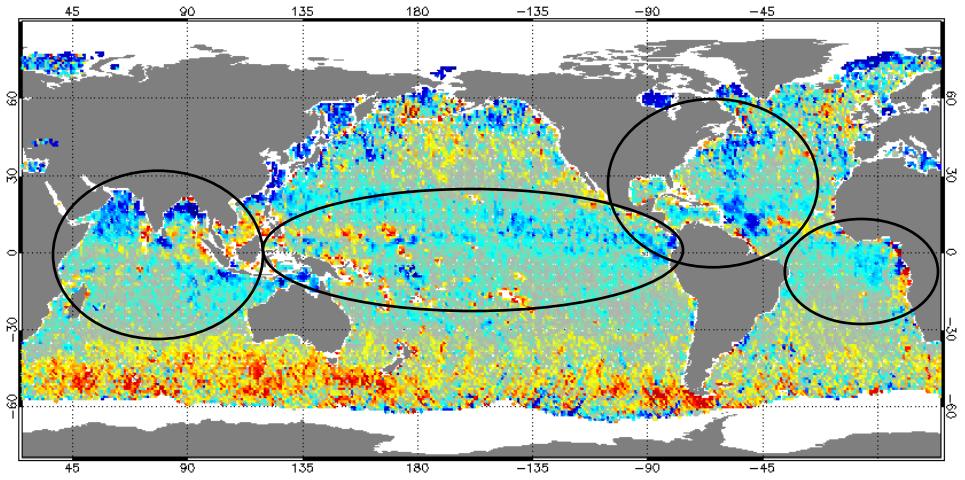
JAS 2012

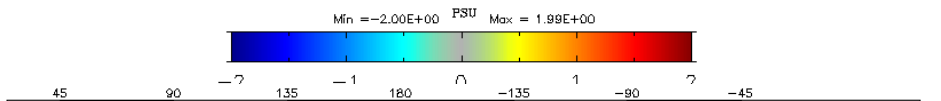


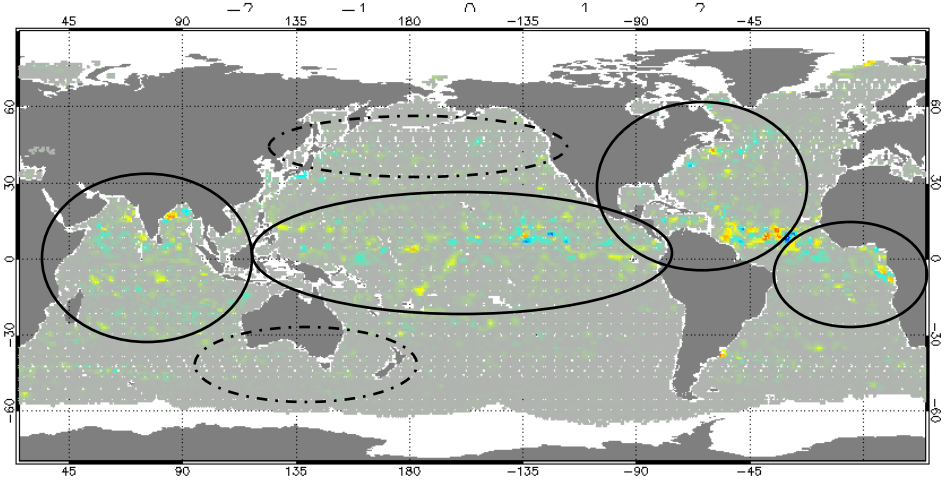
•Values do not exceed **0.2 PSU** excepted in western boundary currents, ACC, Zapiola eddy where errors can reach **0.5 PSU** and even more in region of high runoff (Gulf of Guinea, Bay of Bengal, Amazon and Sea Ice limit) or precipitations (ITCZ, SPCZ).

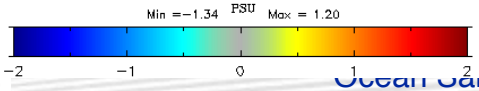
Results

Without DA of SSS

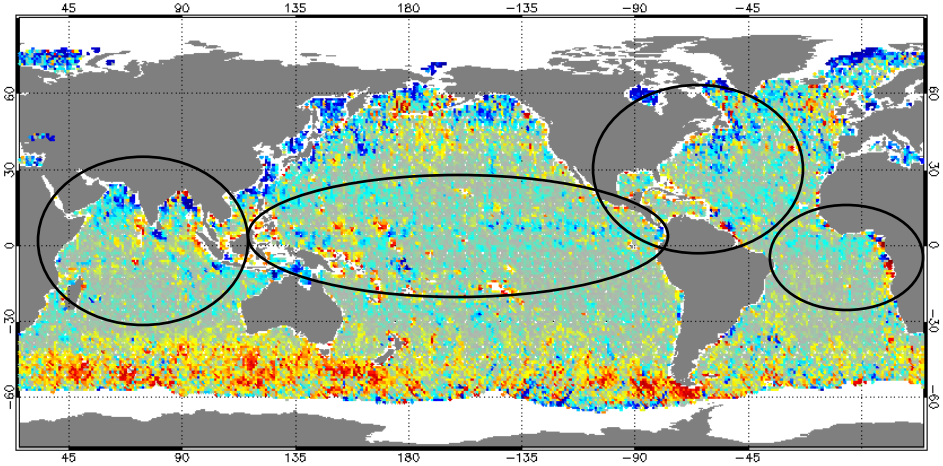


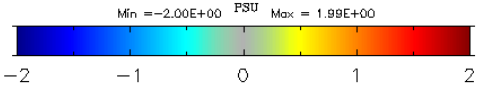


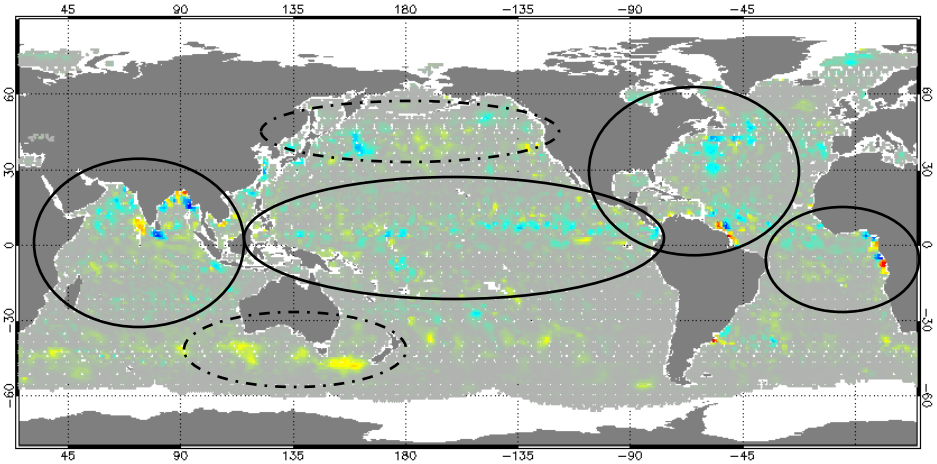


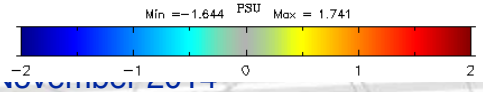


With DA of SSS









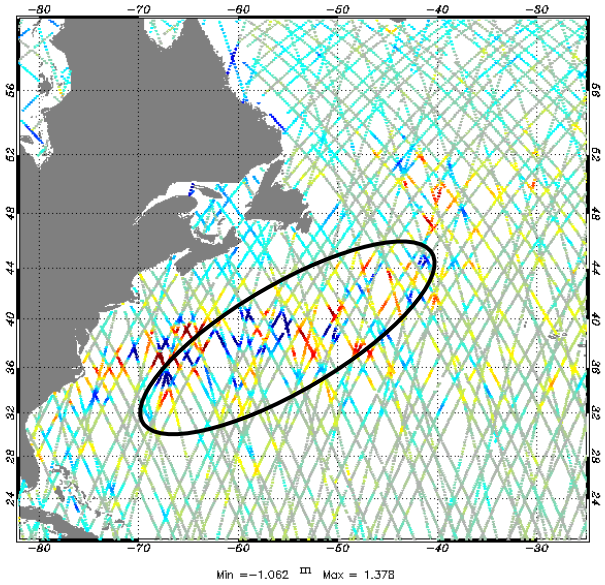
innovation

incrément

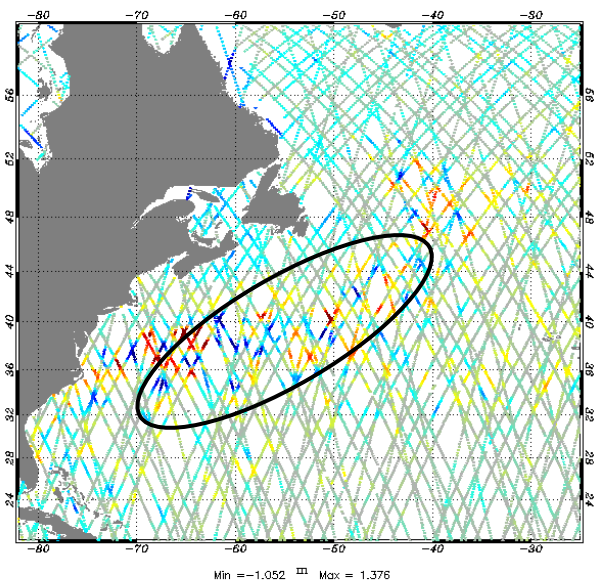
Impact on SLA

Obs-fcst in the G. Stream region

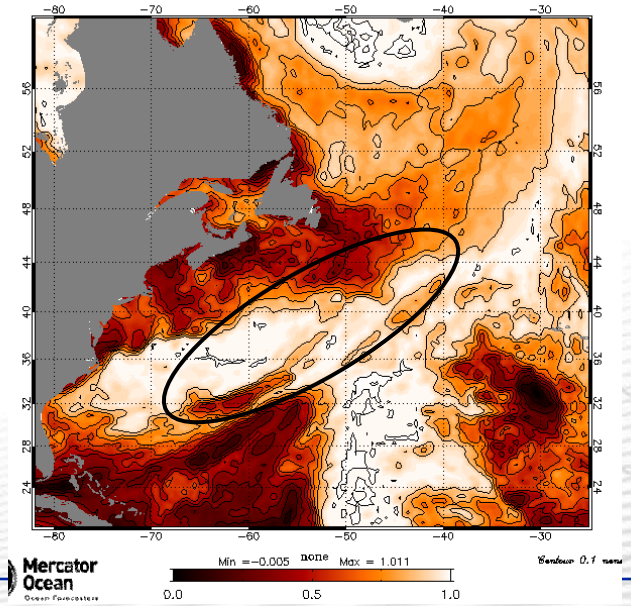
Without DA of SSS



With DA of SSS

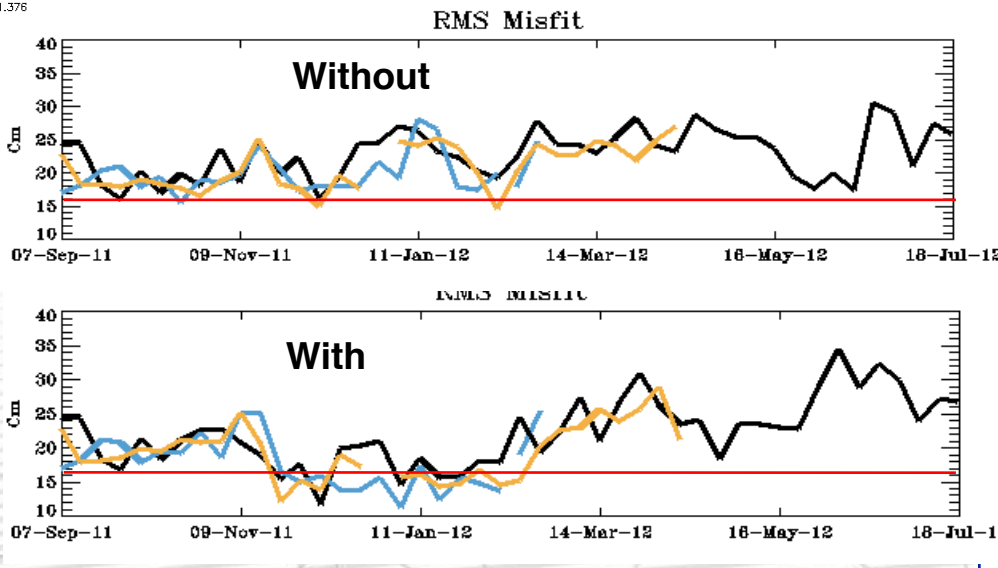


Cloud cover fraction on 20 Nov.. 2011 : the day where SST is assimilated



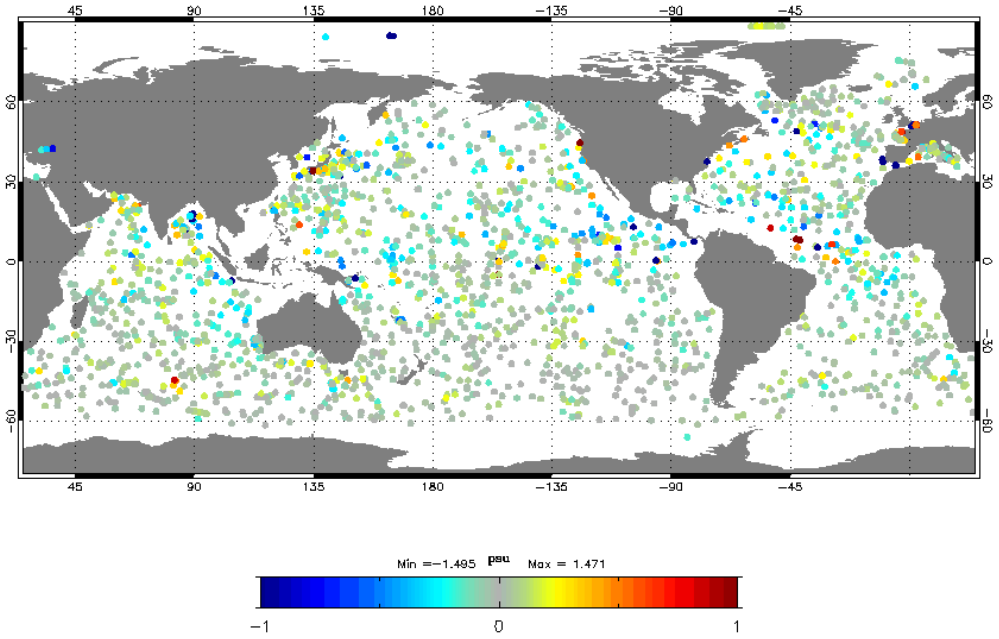
16 cm

16 cm

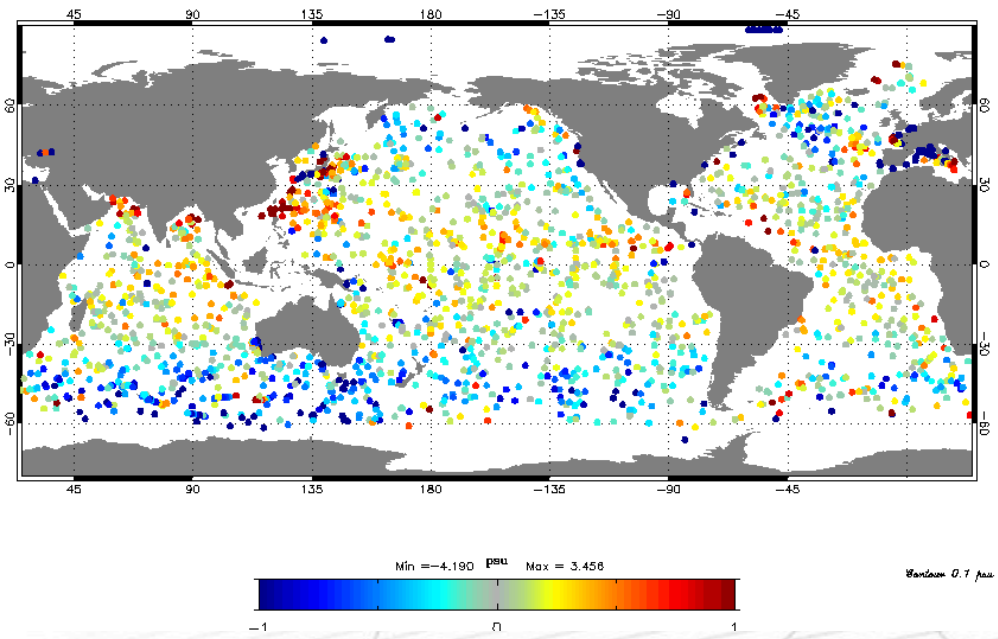


ARGO vs Aquarius (V1.3) in the ocean forecasting system

ARGO – PSY3 (14 Sept. 2011)

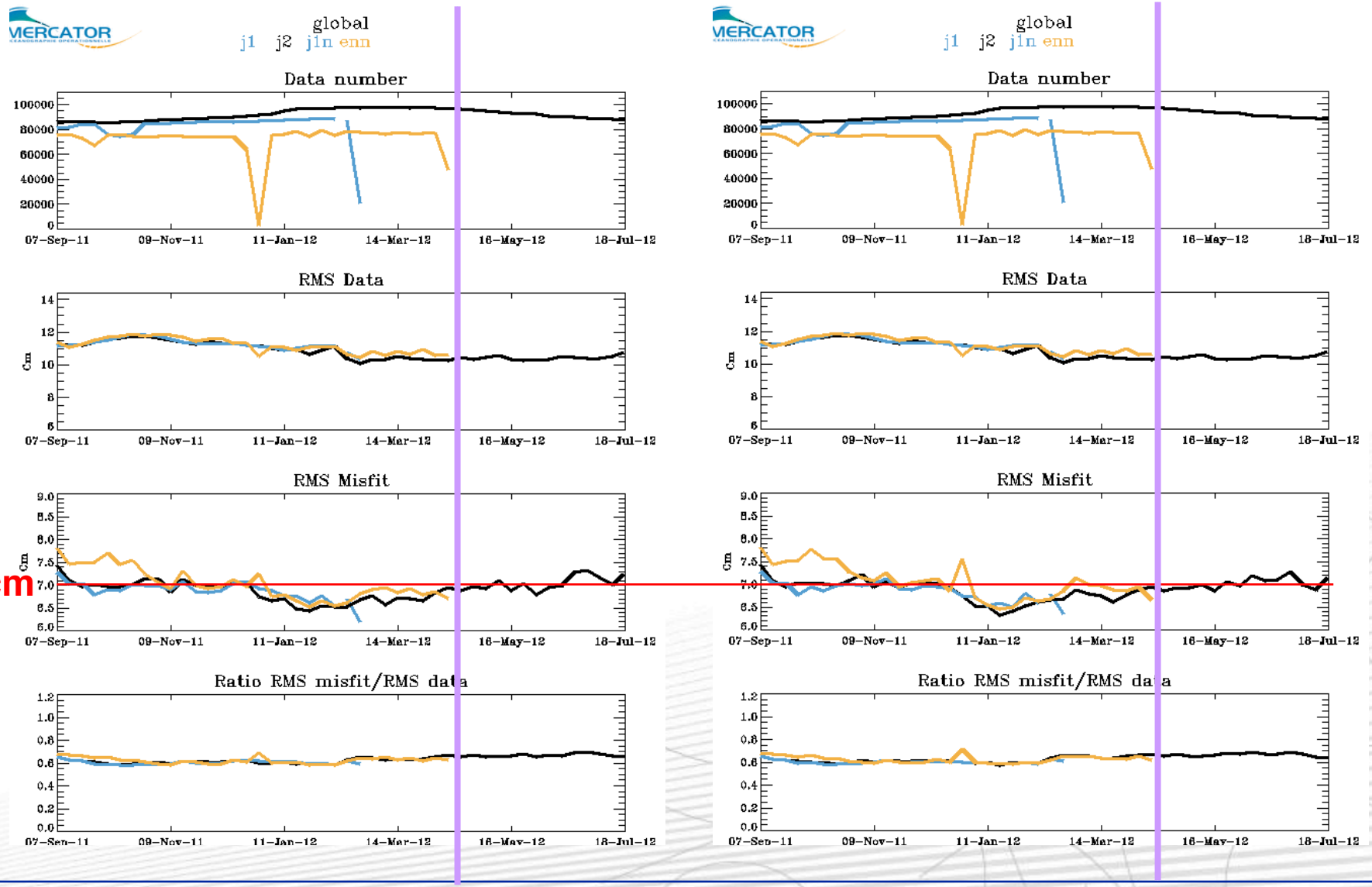


ARGO – Aquarius (14 Sept. 2011)



- Global ocean forecasting system has very little bias, it is too salty in the Eastern Pacific & in the Atlantic
- Aquarius is clearly biased with a predominant zonal pattern (too fresh in the tropics)

Impact on SLA : global scale



6.9 cm