Estimation de la salinité par radiométrie microonde depuis l'espace

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…

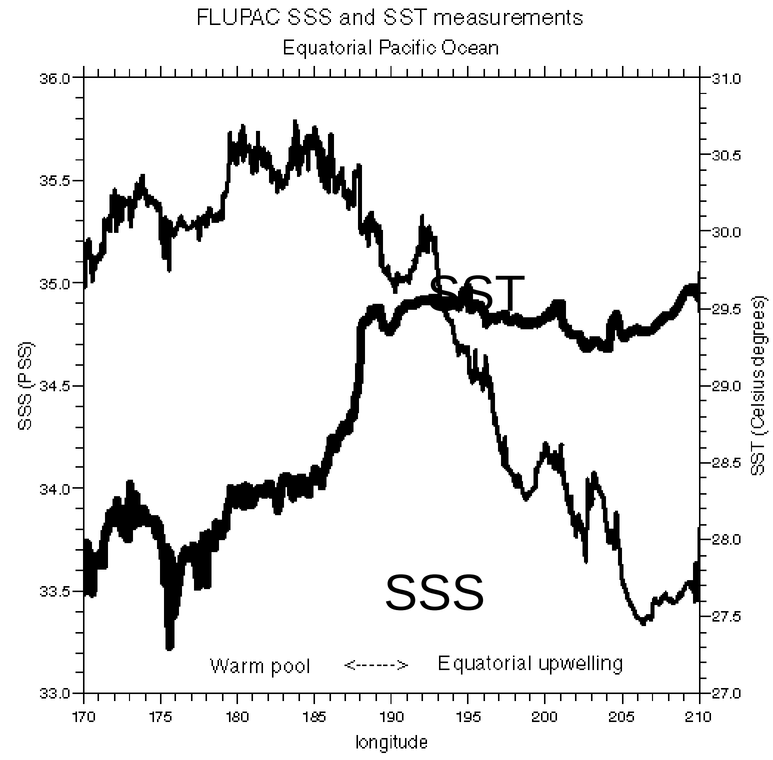
Why measuring Sea Surface Salinity (SSS) ?

- Influence of salinity on water density

  → oceanic circulation

- Detect surface fronts better seen on SSS than on SST (because SST more affected by atmospheric exchanges)

- Better constrain fresh water fluxes at the ocean surface

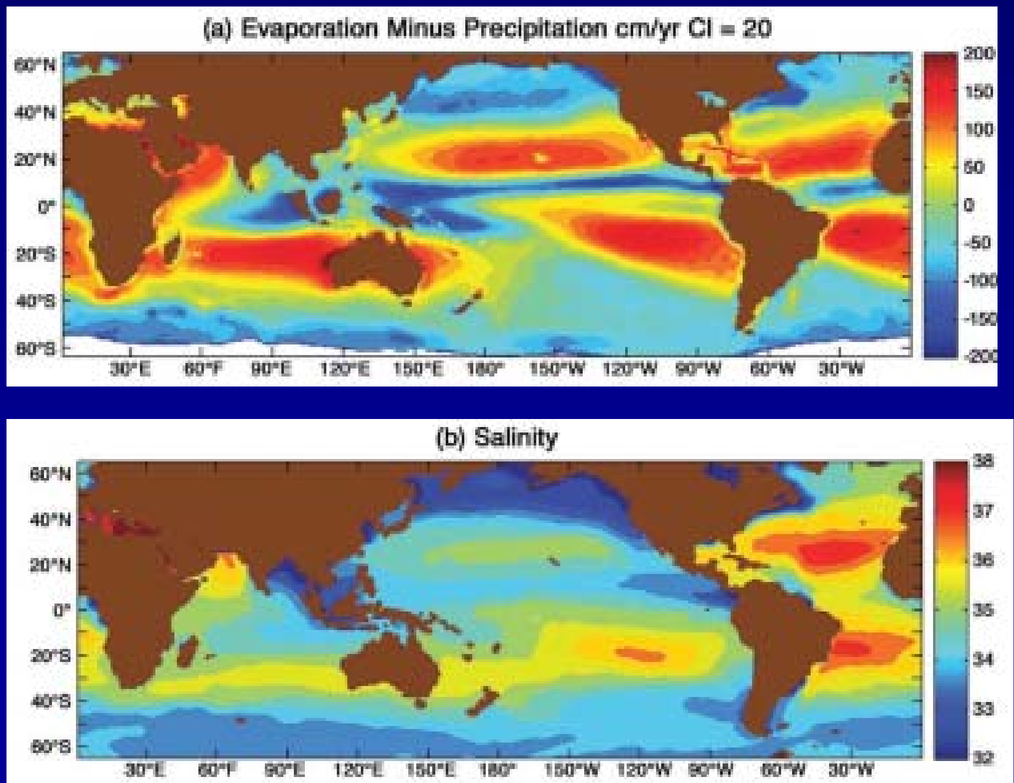


Rodier et al., JPO, 2000)

Ocean role in the water cycle

- 86% of evaporation over the ocean
- 78% of precipitations over the ocean

Sea surface salinity is a tracer of this fresh water flux:



Climatological mean of E – P (top) , Annual mean of SSS from World Ocean Database (bottom).

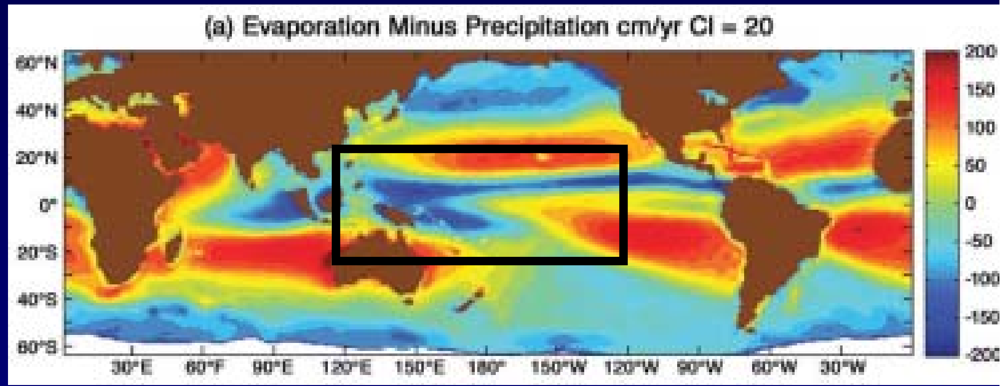
Ocean role in the water cycle

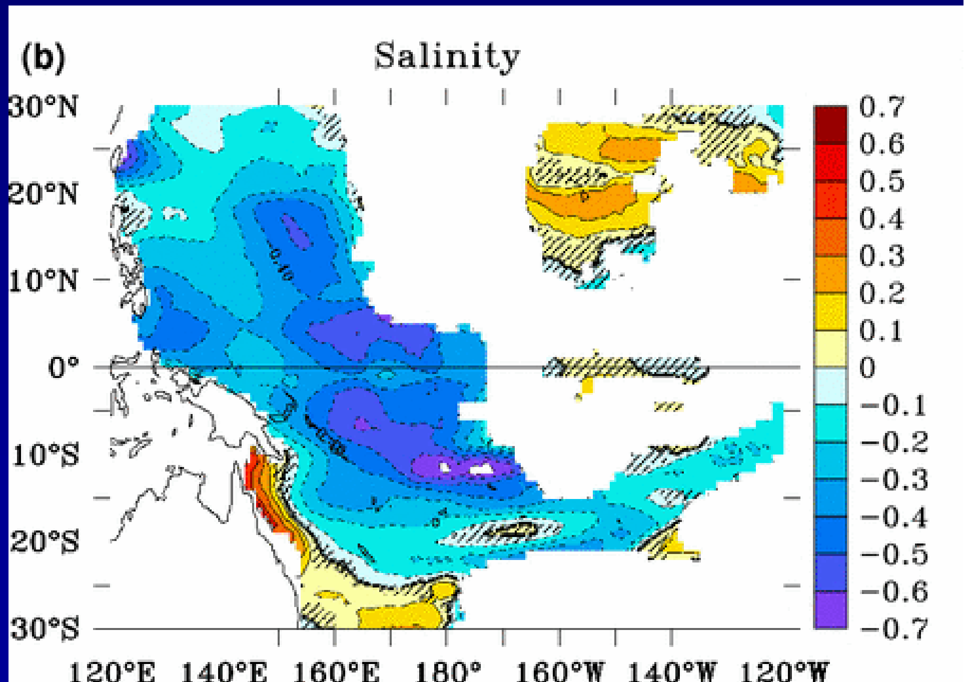
- ↗ atmospheric temperature=> ↗ evaporation in warm regions; ↗ content of water vapor in the atmosphere => ↗ precipitations in rainy areas

but this thermodynamic theory is partly balanced by atmospheric circulation

- Observations???...

Need for long temporal series of observations well sampled in space and time

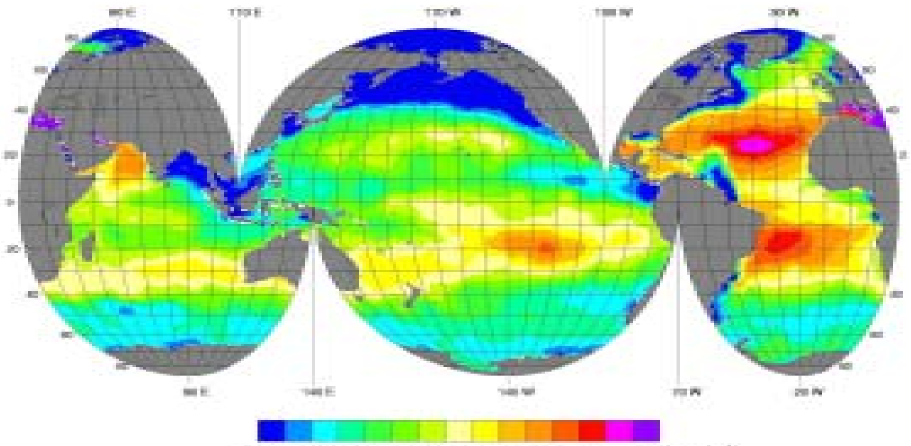




Linear trends in SSS. Units are pss/50 years. Cravatte et al. 2009

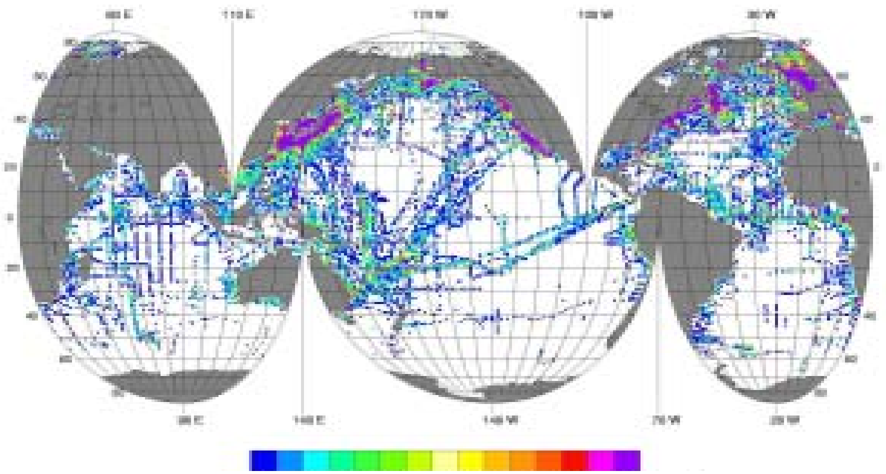
In situ measurements of SSS

Atlas Levitus – Juillet 1998

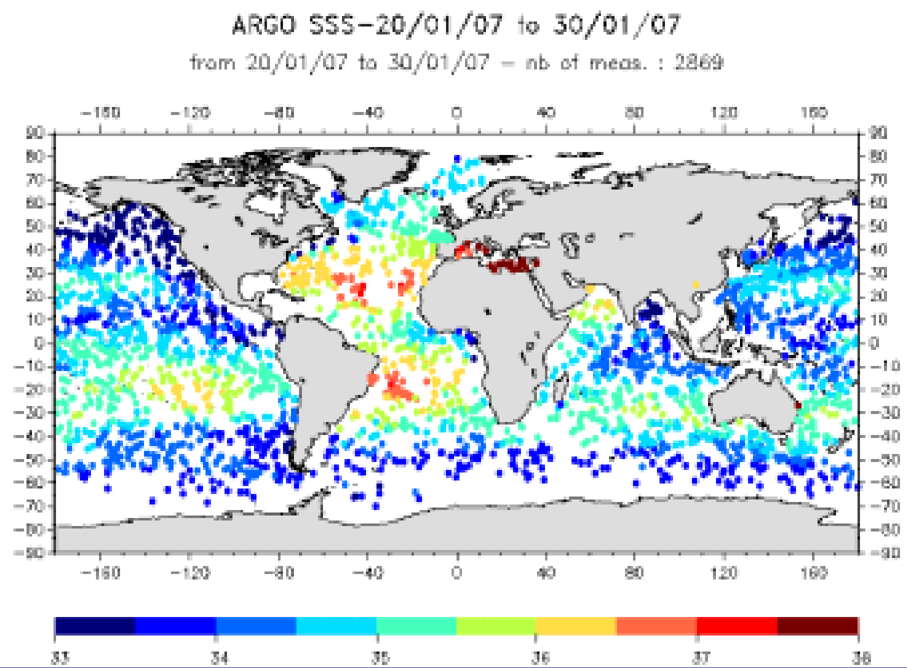


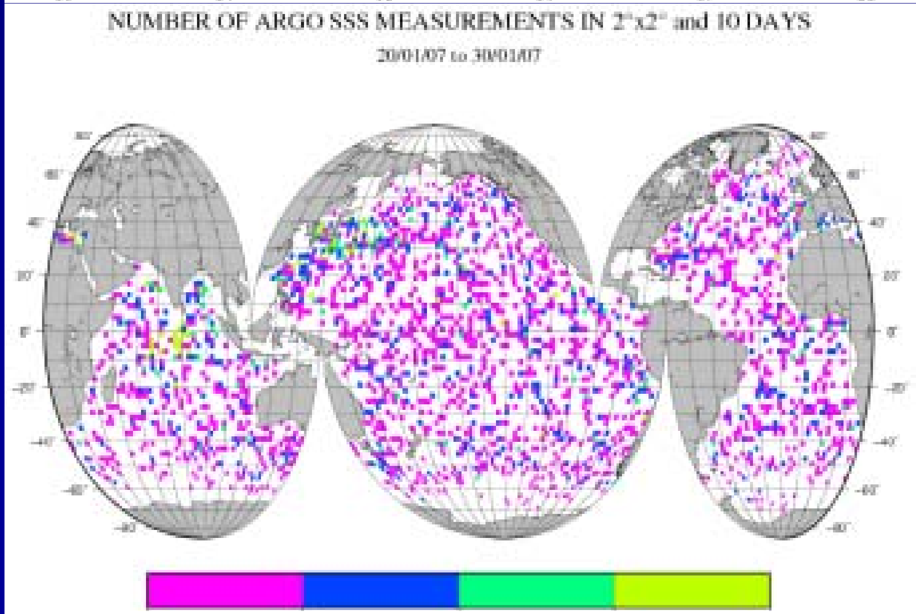
33 35 37 38 psu

Nombre de mesures bateau(1°x1°)



1 5 10 15





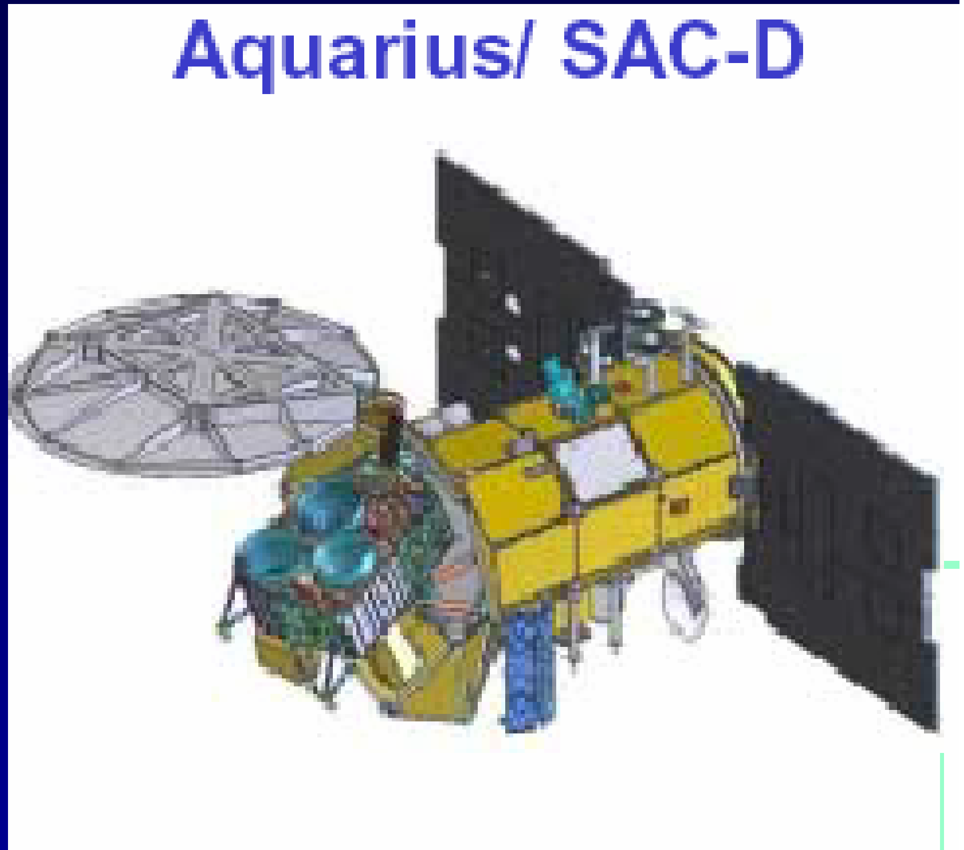
1 2 3 4 5

SSS measurement using microwave radiometry:

L-band (1.4GHz, 21cm)

SSS remote sensing: 2 L-band radiometers

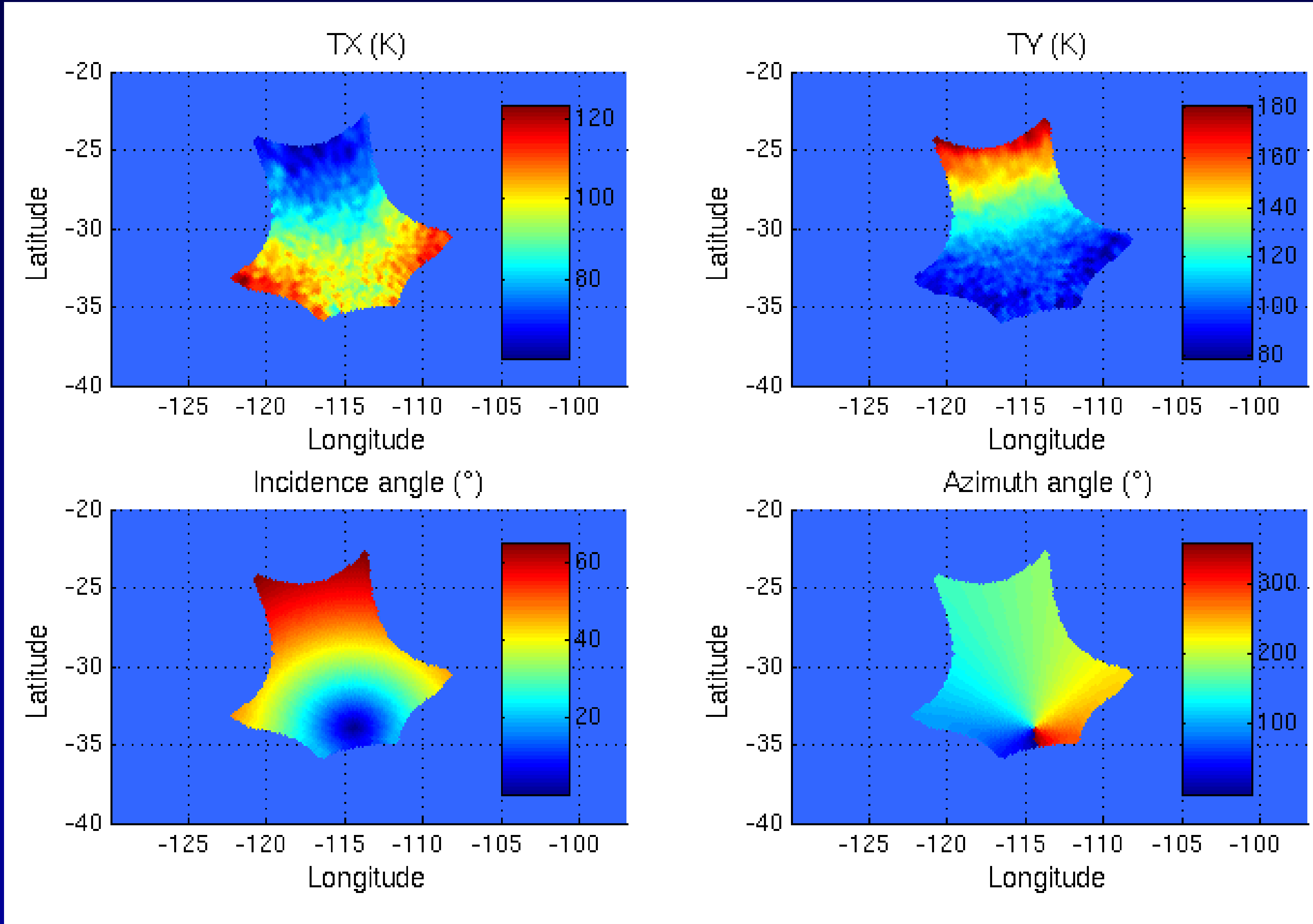
objective: precision 0.1-0.2 on SSS averaged 200x200km² 10 days



MIRAS onboard SMOS mission:
2-D interferometer;
Field of View ~1000x1000km;
spatial resolution ~40km
Launched in Nov 2009

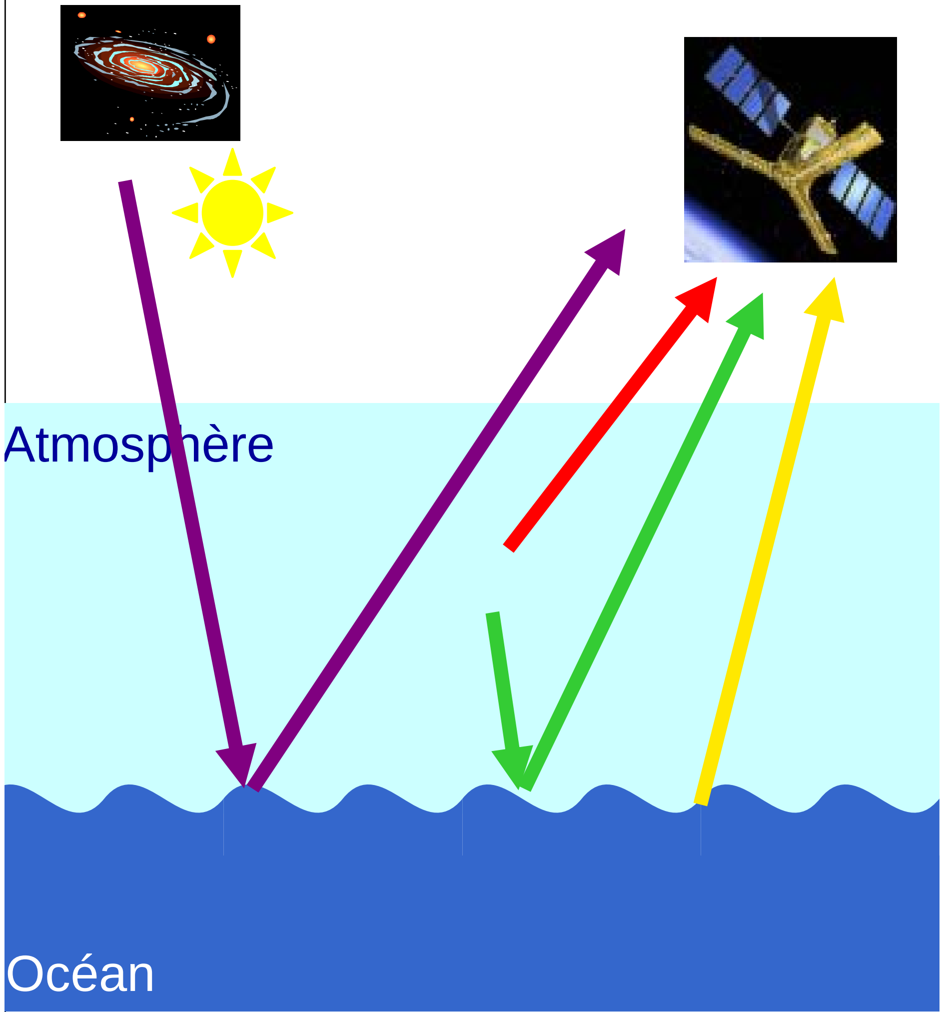
Aquarius onboard SAC-D:
3 real aperture antennas; Field of View ~300km;
~70-150km spatial resolution;
Launched in June 2011

Example of SMOS ocean measurements



Validation of SMOS measurements and pre-launch direct model

Pre-launch Forward Model (ESA L2OS processor)



Sea surface emissivity models

Dielectric constant of sea water (Klein and Swift, 1977)

Roughness model: Dinnat et al., 2003

(2-scale, Durden and Vesecky spectrum×2)

no **Foam**

Other contributions

Atmosphere

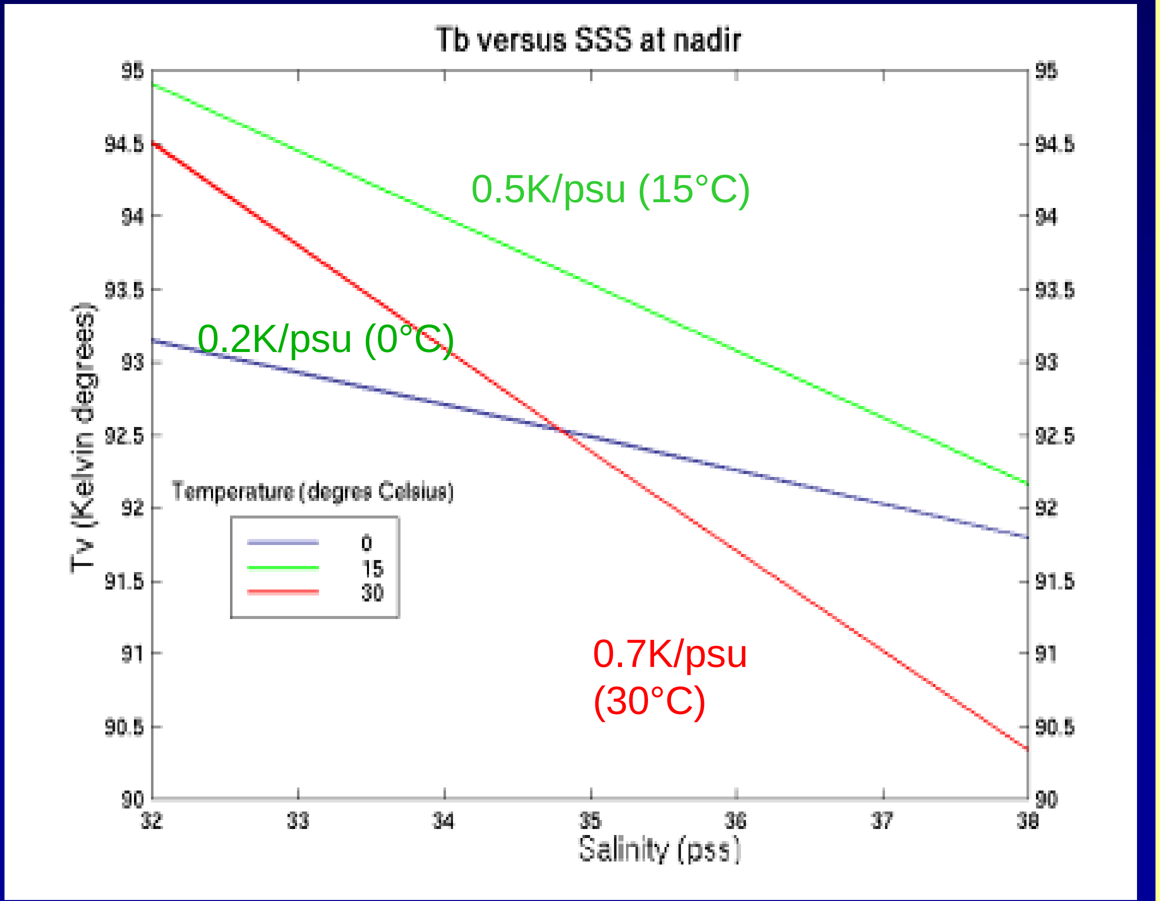
Tropospheric contribution (Liebe, 1993)

Faraday rotation

Sky radiation (reflected/scattered) (Reul et al 2007)

Compare SMOS Level 1c Tb with Tb simulated with forward model using ECMWF forcings and WOA05 SSS climatology, in SMOS instrument coordinates.

Sensitivity of Tb (L band) to SSS and SST
Flat sea (*Klein and Swift model)*



dTb/dSSS weak:
always < 1K/psu
(need for a very good precision)

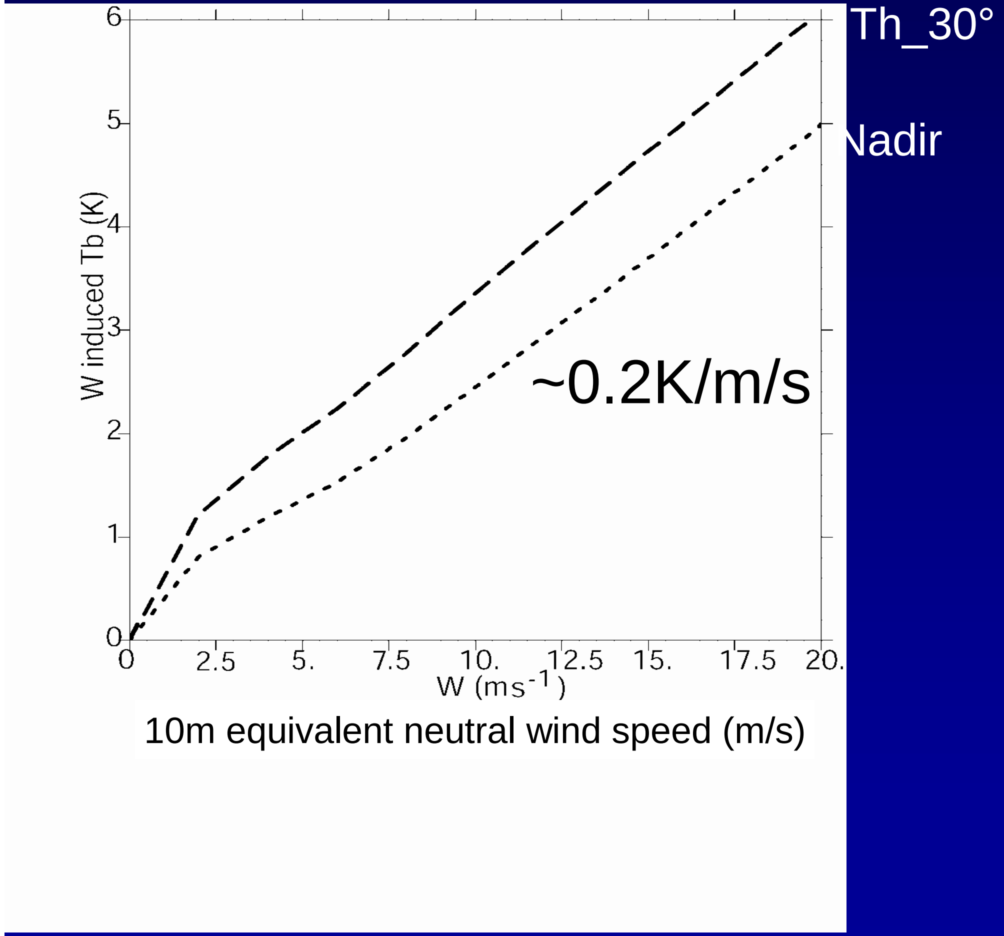
Better sensitivity in warm waters

dTb/dSST always very weak :

- 0.1 K/°C à 0 °C
- 0.005 K/°C à 15°C
- -0.16 K/°C à 30°C

Pre-launch roughness model 1
(2-scale-DV2 model (Dinnat et al.))

2 scale emissivity model: small waves superimposed on large tilted waves
Wave spectrum from Durden and Vesecki multiplied by an **arbitrary factor 2 (to fit data)**



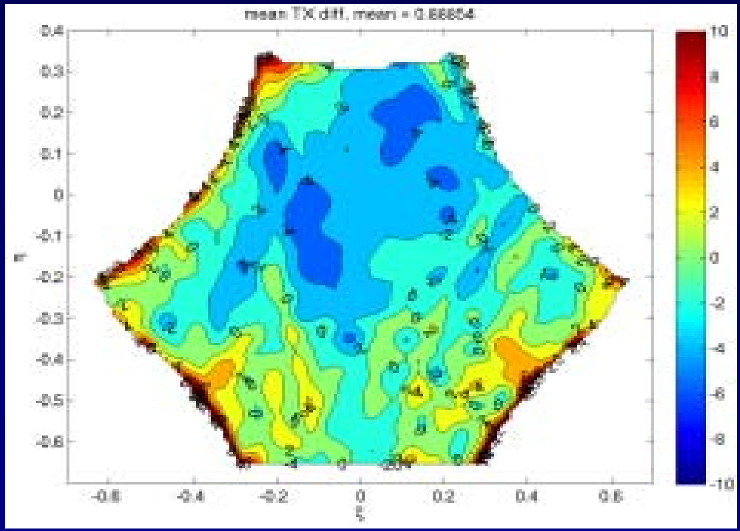
Rough sea (without foam)

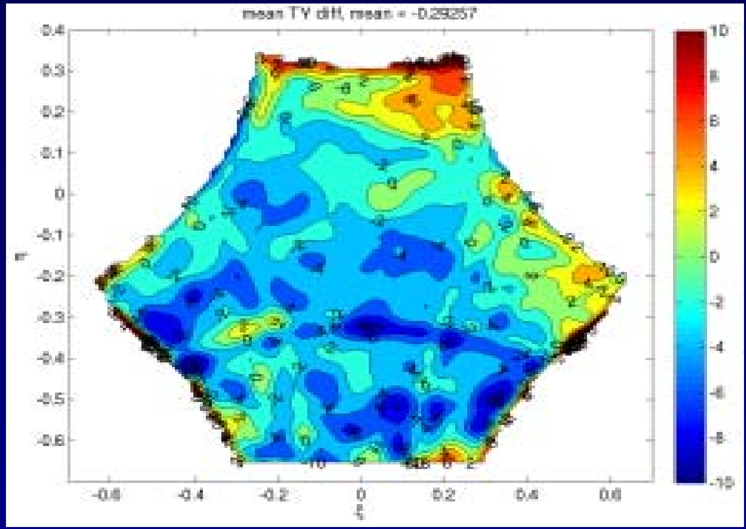
At 15°C, a 0.1K Tb variation can be generated by :
-0.2psu SSS variation
or
- 0.5m/s wind speed variation

Dinnat et al., IJRS, 2002, Radio Science, 2003

Systematic biases of Tb in the FOV

- Measured minus modeled Tb



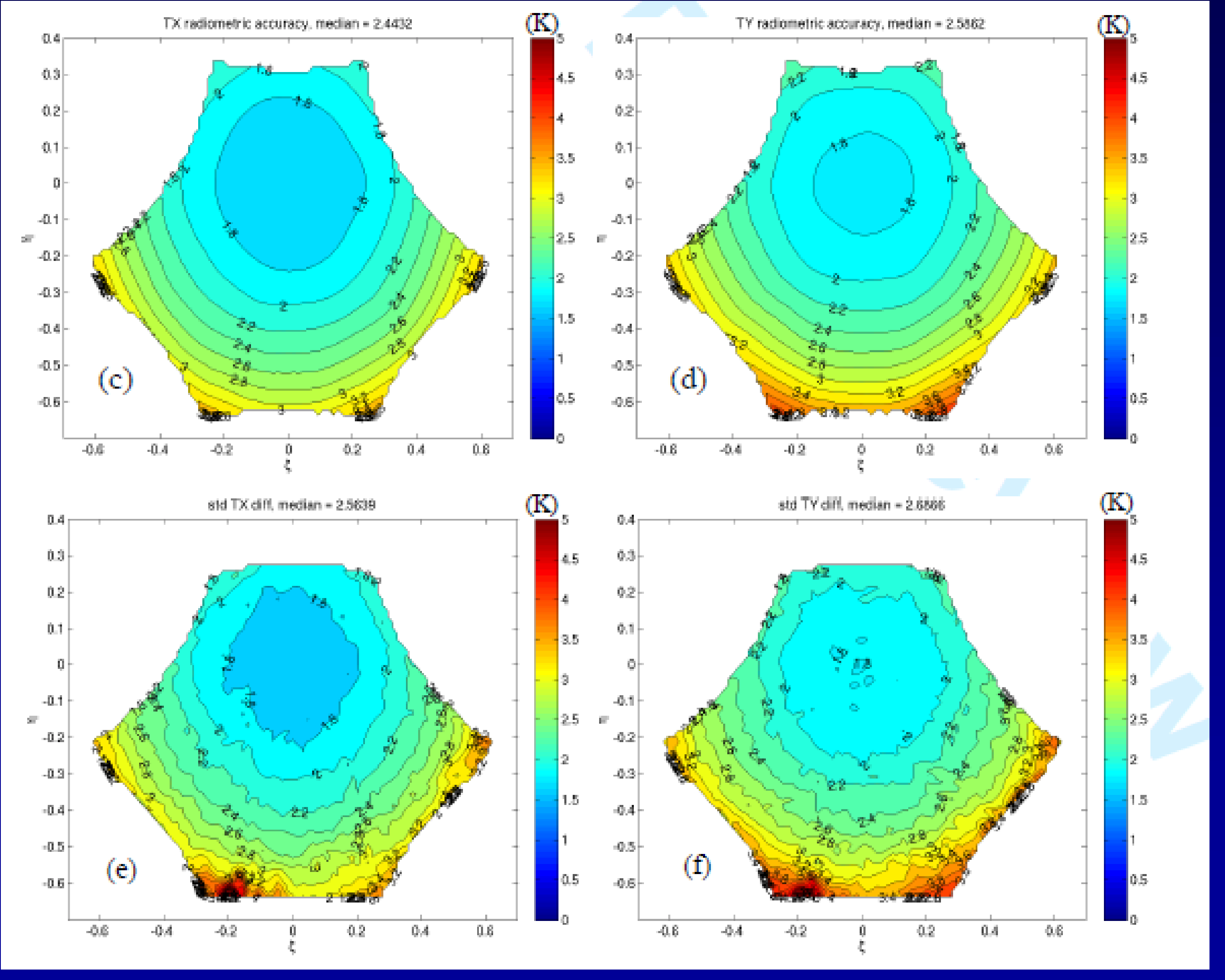


  - Spatial pattern persistent along and in different orbits
  - Similar using different ocean emissivity models: mainly related to instrument and image reconstruction imperfections
  - Removal techniques being tested: Ocean Target Transformation (OTT, mean residual bias over homogeneous ocean areas) now implemented in operational processor

Measured radiometric noise very similar to expected one

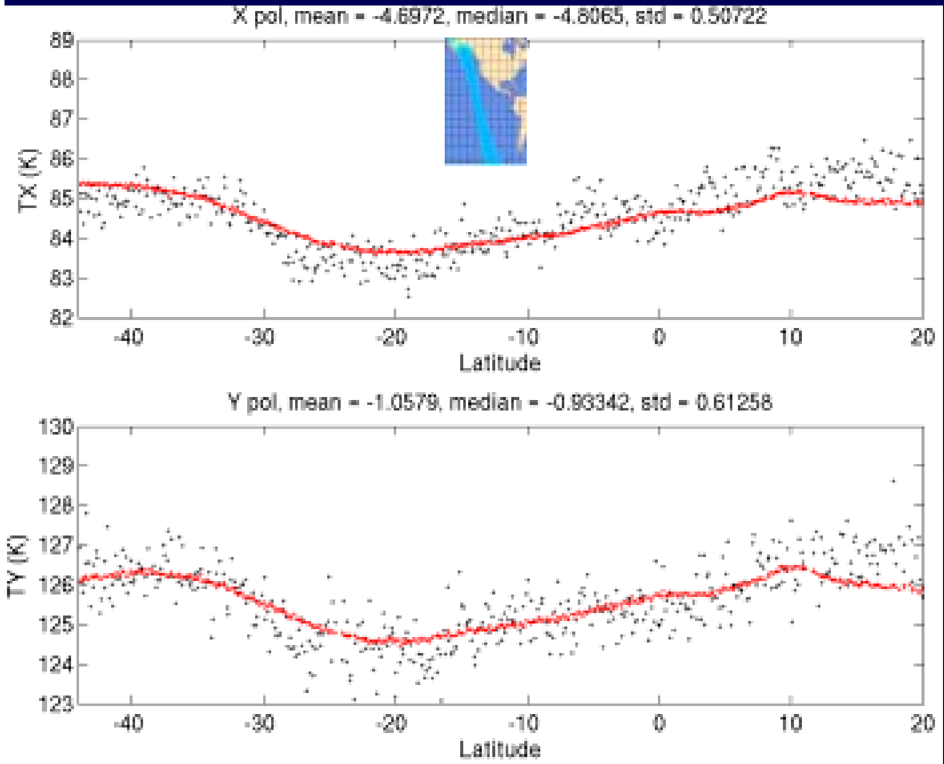
Expected radiometric accuracy

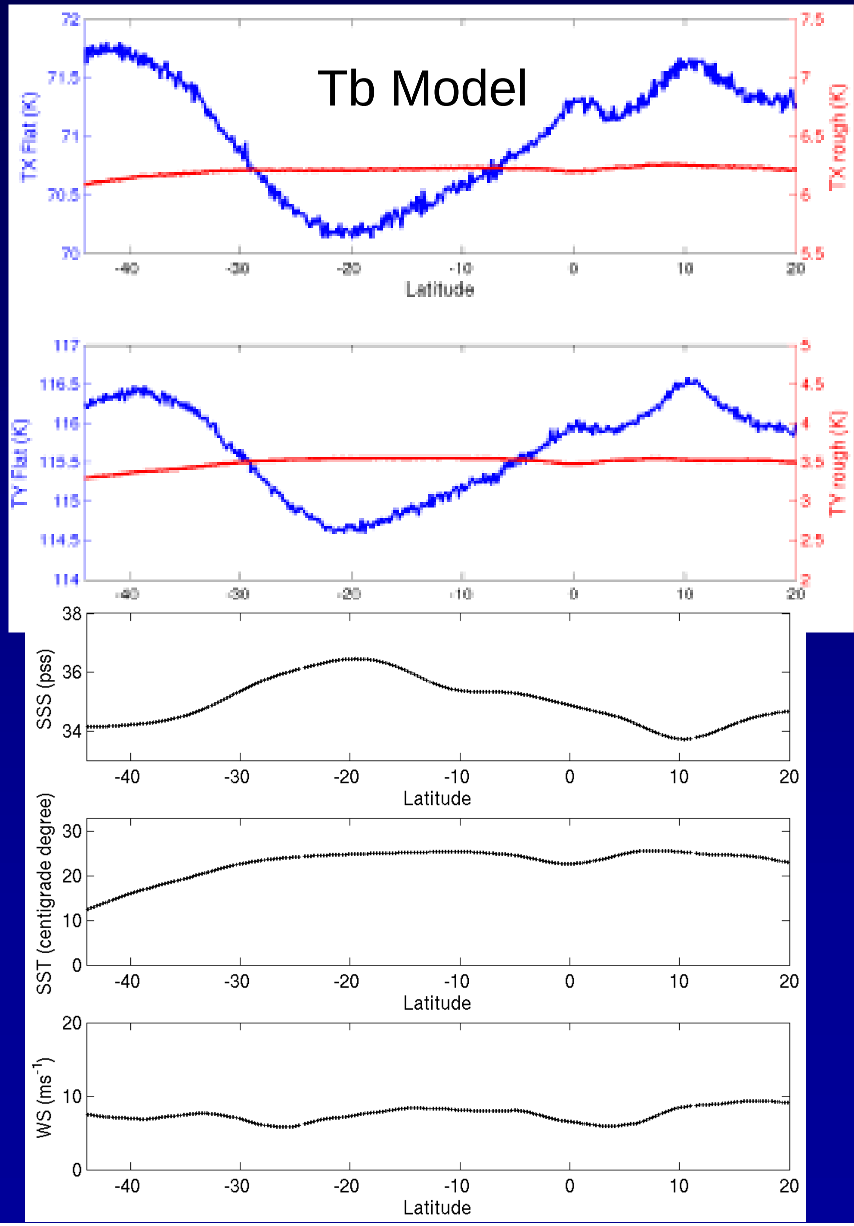
Observed radiometric accuracy (std(Tbmeas-Tbmodel))



Yin et al. 2011

Interpretation of first SMOS Tbs moderate wind speed

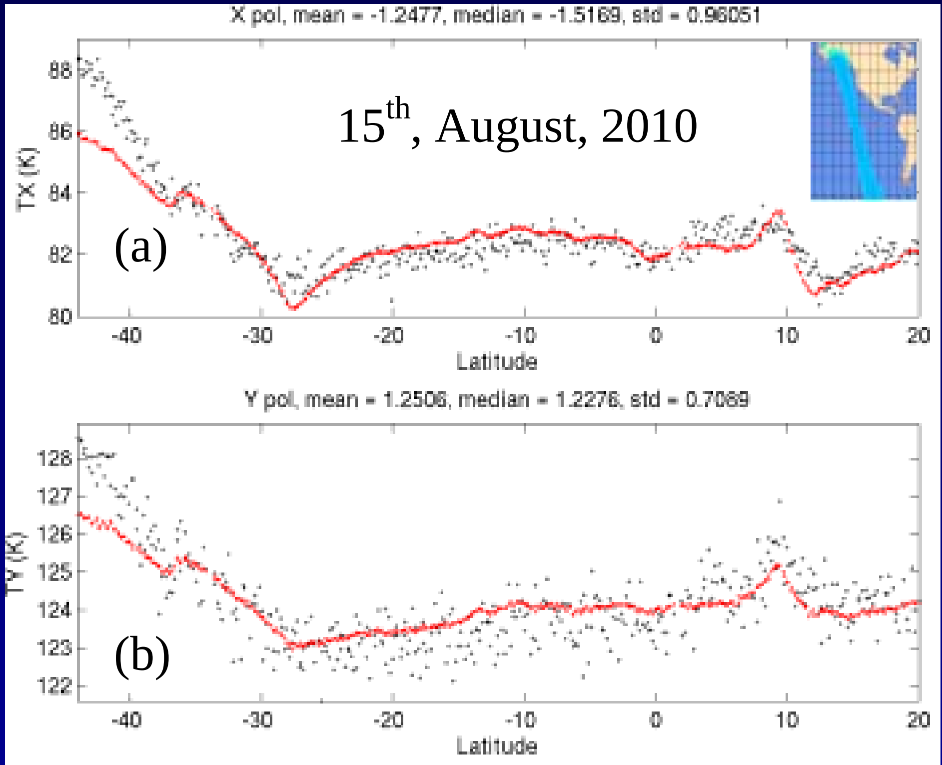


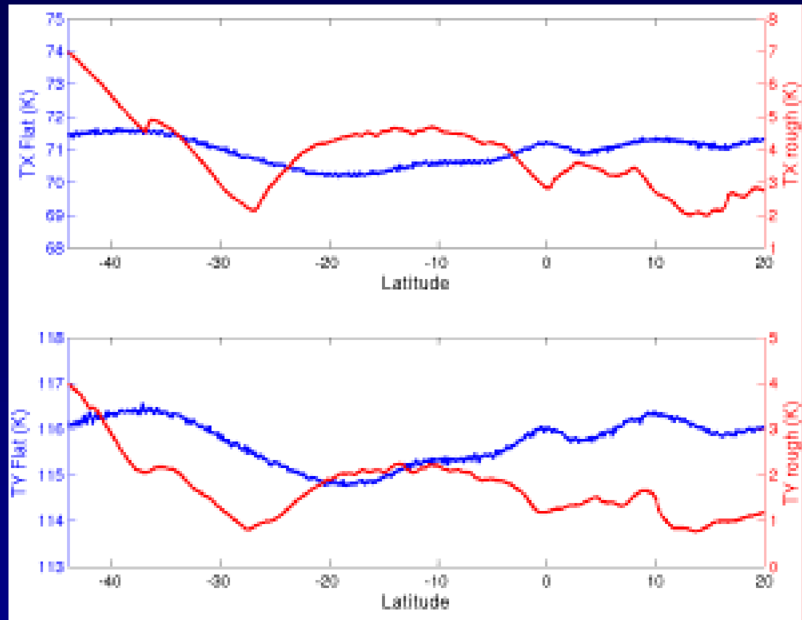


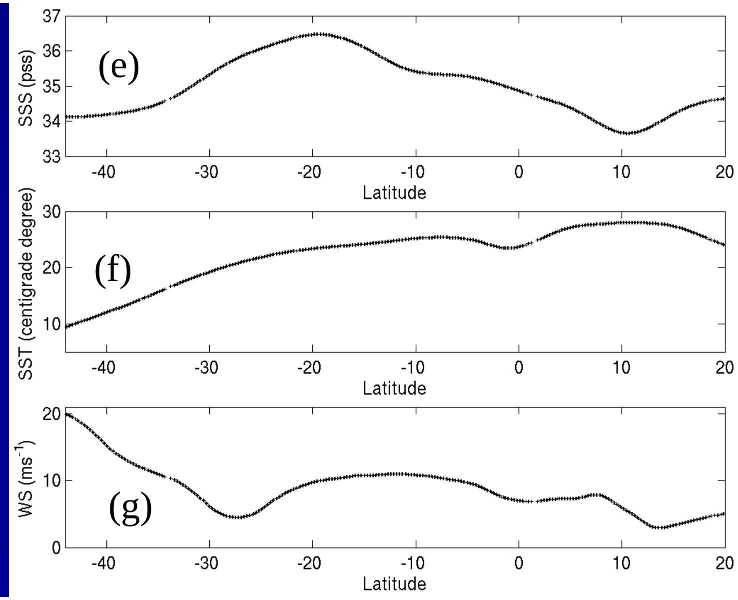
Measurements (black) & model (red)

Yin et al. 2011

Interpretation of first SMOS Tbs
(high wind speed latitudinal gradient)







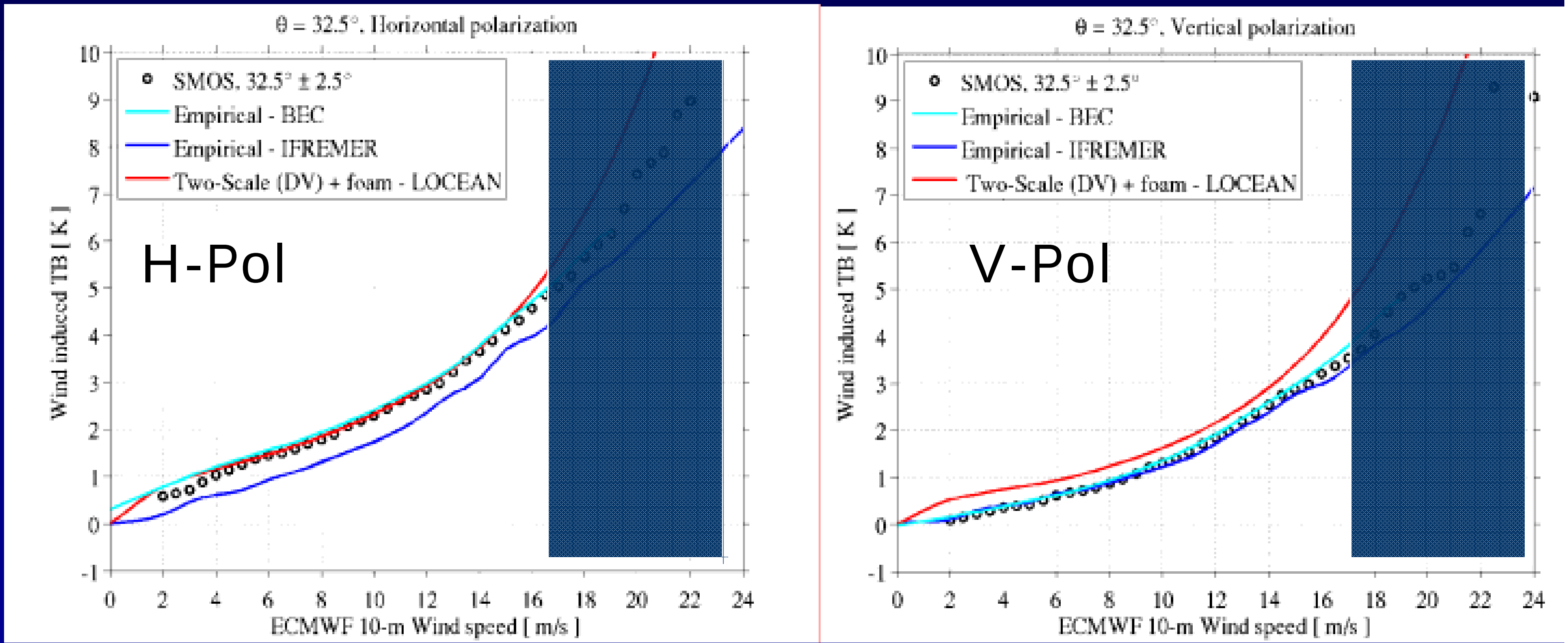
Measurements (black) & model (red)

August 2010

Yin et al. 2011

Forward model improvement

Wind induced brightness temperature at θ=32.5°



- Relatively good agreement between all tuned models and SMOS sensitivity to ECMWF wind speed
- Clear non-linear behavior with wind speed

Guimbard et al. 2011

SMOS SSS retrieval method (along track)

SMOS SSS along track is retrieved through a least square minimisation of the quadratic difference between SMOS and modeled Tb.

Retrieval of SSS (σ=100psu), SST (σ=1°C), WS(σ=2m/s) through the minimisation of:

$$\chi^2 = \sum_{i=0}^{Nm-1} \frac{\left[T_{bi}^{meas} - T_{bi}^{\mathrm{mod}}(\theta, P)\right]^2}{\sigma_{T_{bi}}^2} + \sum_{j=0}^{Np-1} \frac{\left[P_j - P_{j,\,prior}\right]^2}{\sigma_{P_j}^2}$$

=> estimate of SSS error

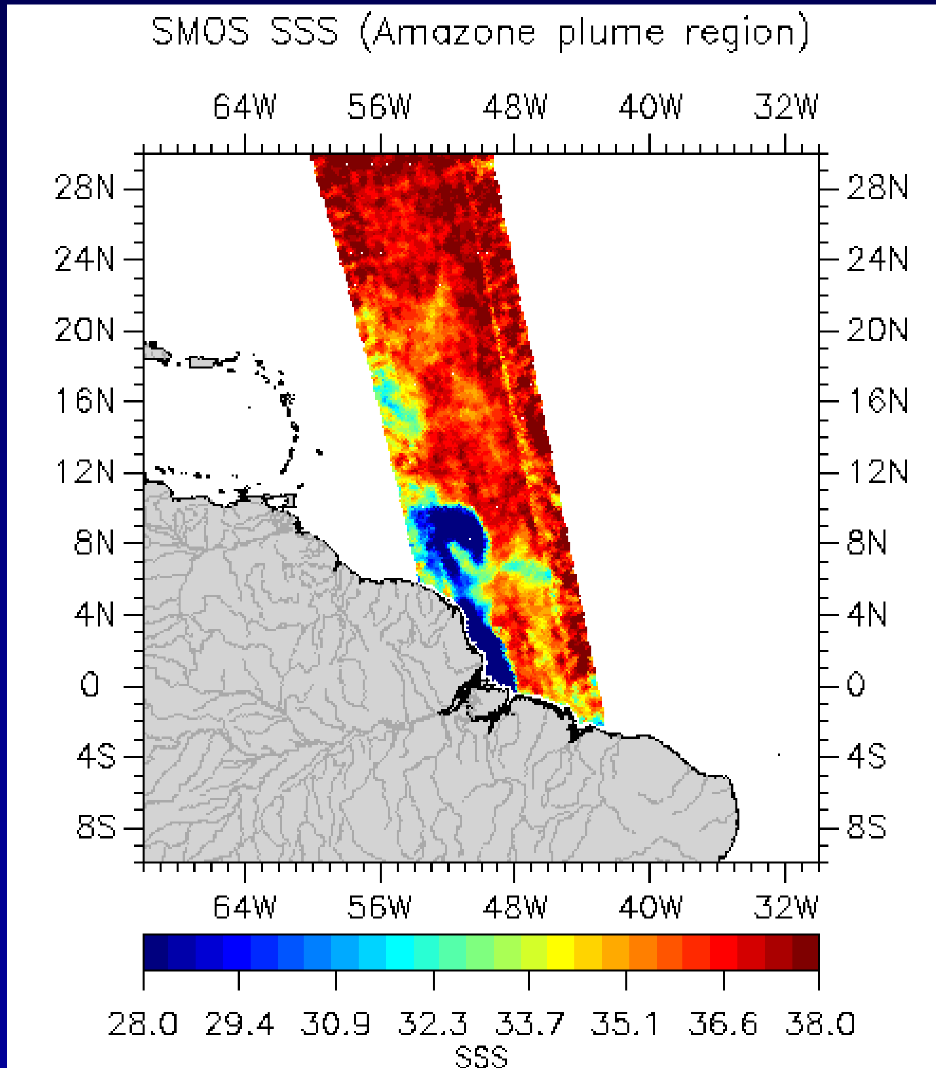
(Levenberg & Marquard algorithm)

Use of :

-SMOS Tbs after removal of a systematic bias estimated over an ascending orbit in the south east Pacific (50S-10N ascending orbit on 5th August)

-ECMWF wind and SST fields as prior

Amazon plume



July 2010, L1 & L2 V500

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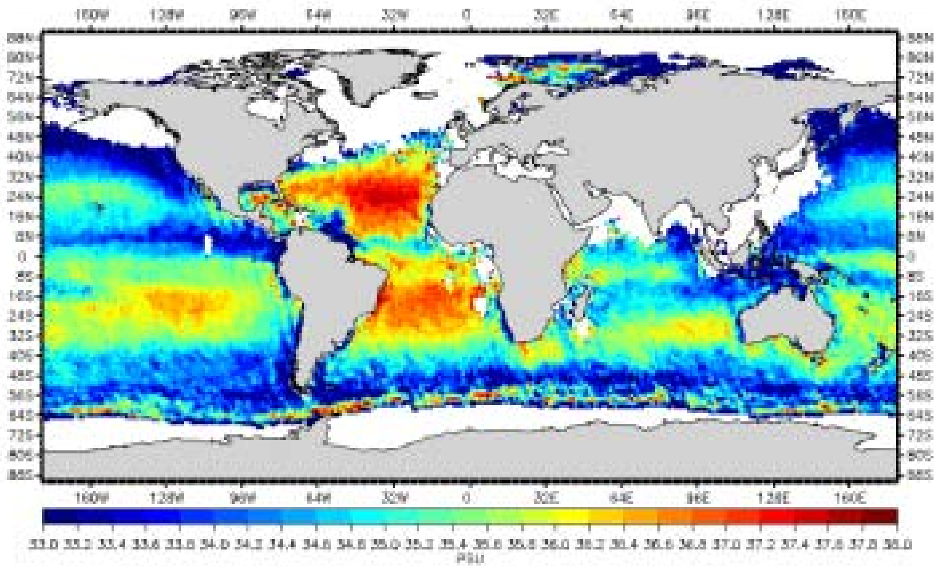
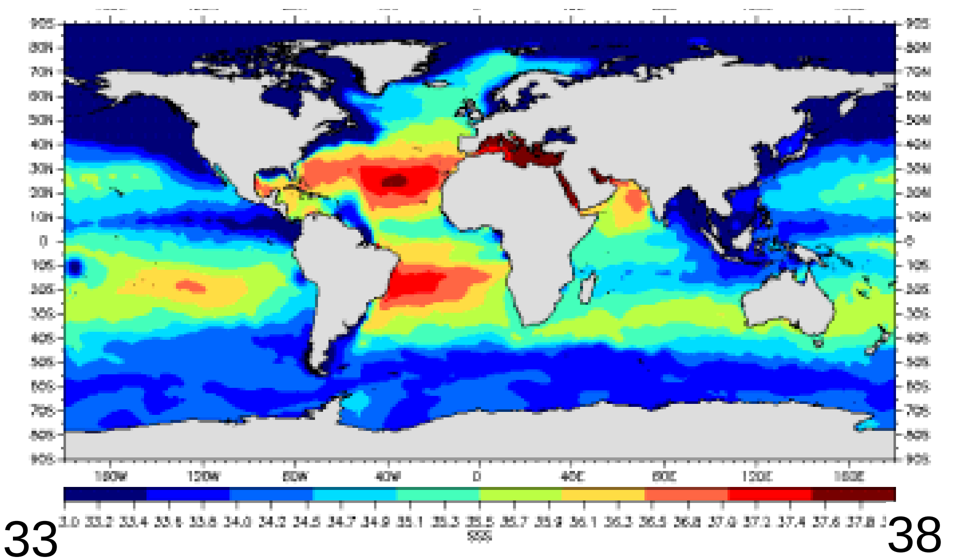
10days-100km SSS maps computed from averages of SMOS SSS weighted by their spatial resolution and error (derived by the retrieval)

SSS retrieved along track in July 2010
L2 v5.00 Ascending & center swaths

L1 v500



ARGO objective analysis (Gaillard et al.



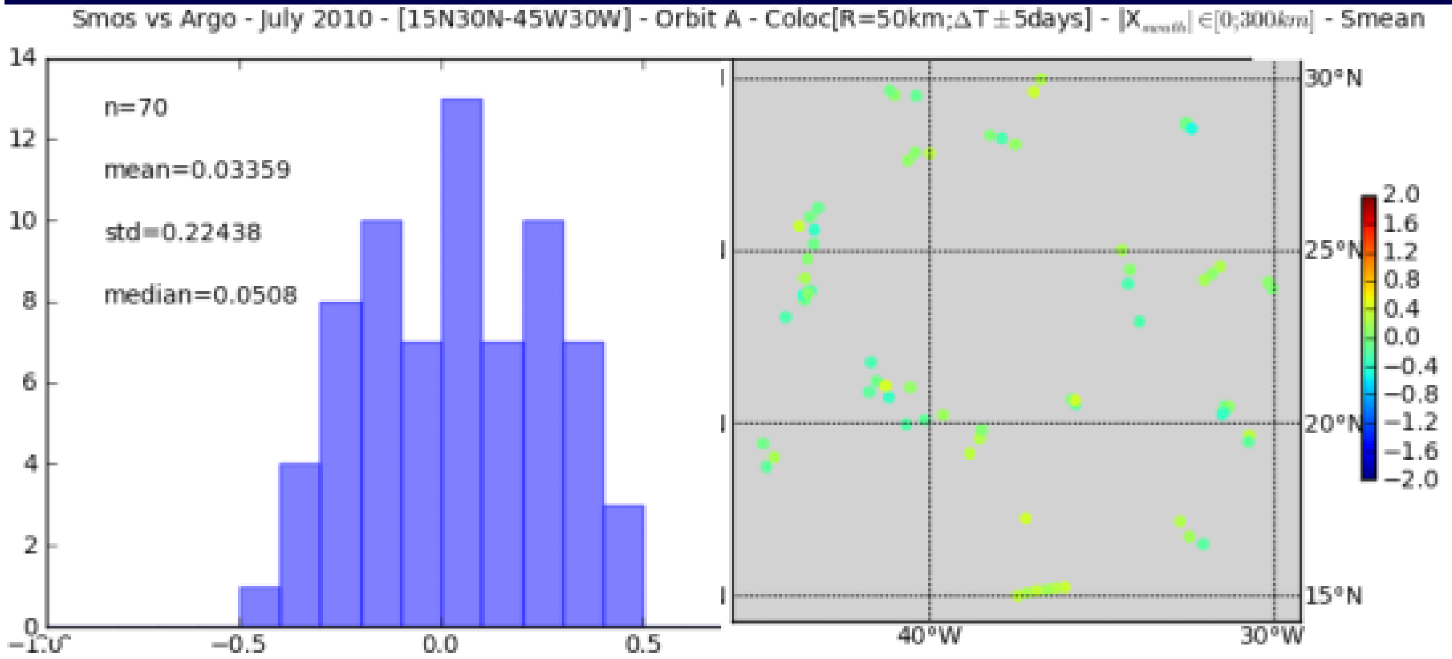
Spatial features of SSS well reproduced:
-Salty Atlantic & Subtropics
-fresh convergence zones & high latitudes, Amazone plume)

-Some biases remain close to land and ice *(Pb in image reconstruction under study)*
-Spots of low SSS in the Southern Ocean
-RFI in northern oceans and close to asiatic coasts prevent from SSS retrieval

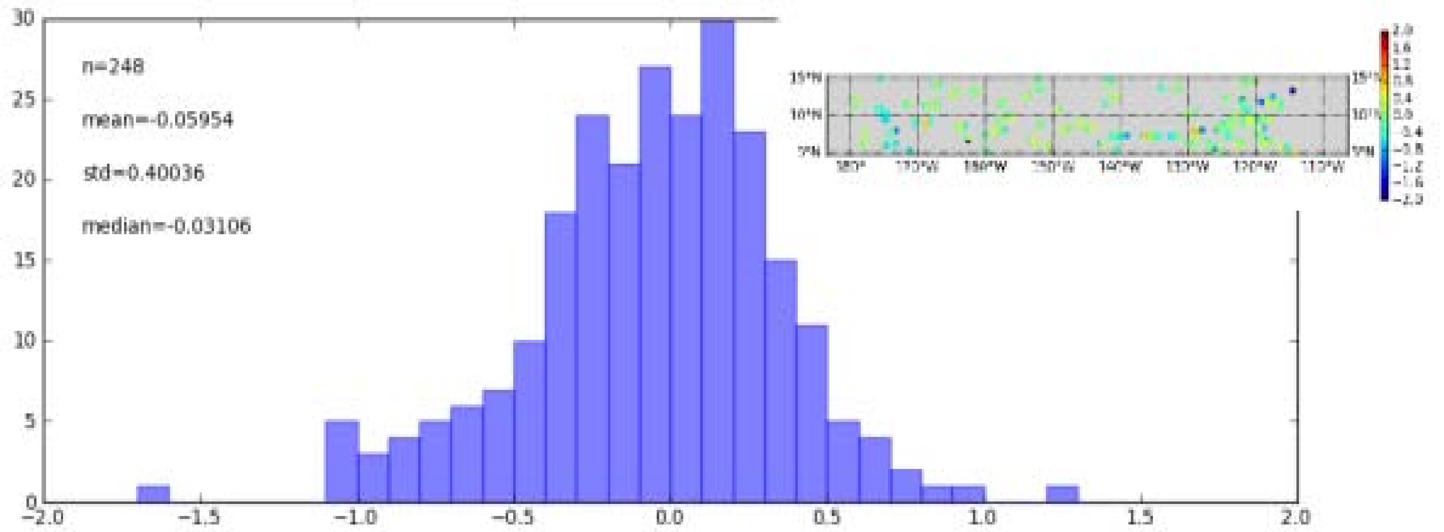
Comparison with ARGO (SMOS averaged at +/-5 days and +/-50km around ARGO SSS):
Mid-latitude (0-30N) : precision 0.2 to 0.4 (in rainy ITCZ region)
High latitudes (50S-30S): precision 0.6

Boutin et al. 2011

Comparison SMOS-ARGO SSS (SMOS 10 days-100x100km^2)



Subtropical Atlantic



ITCZ Pacific

Boutin et al. 2011

First SSS products from SMOS generated at the Centre Aval des Données SMOS

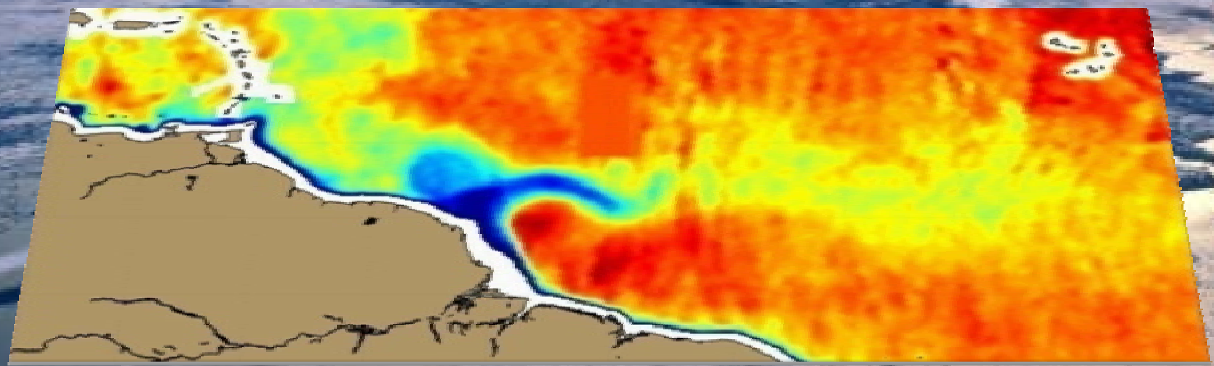
Nicolas Reul[1], J. Tenerelli[2], J. Boutin [3,]B.Chapron[1], F. Gaillard[4], CATDS & GLOSCAL teams

[1]IFREMER, Laboratoire d'Océanographie Spatiale, LPO[4,] Plouzané, France

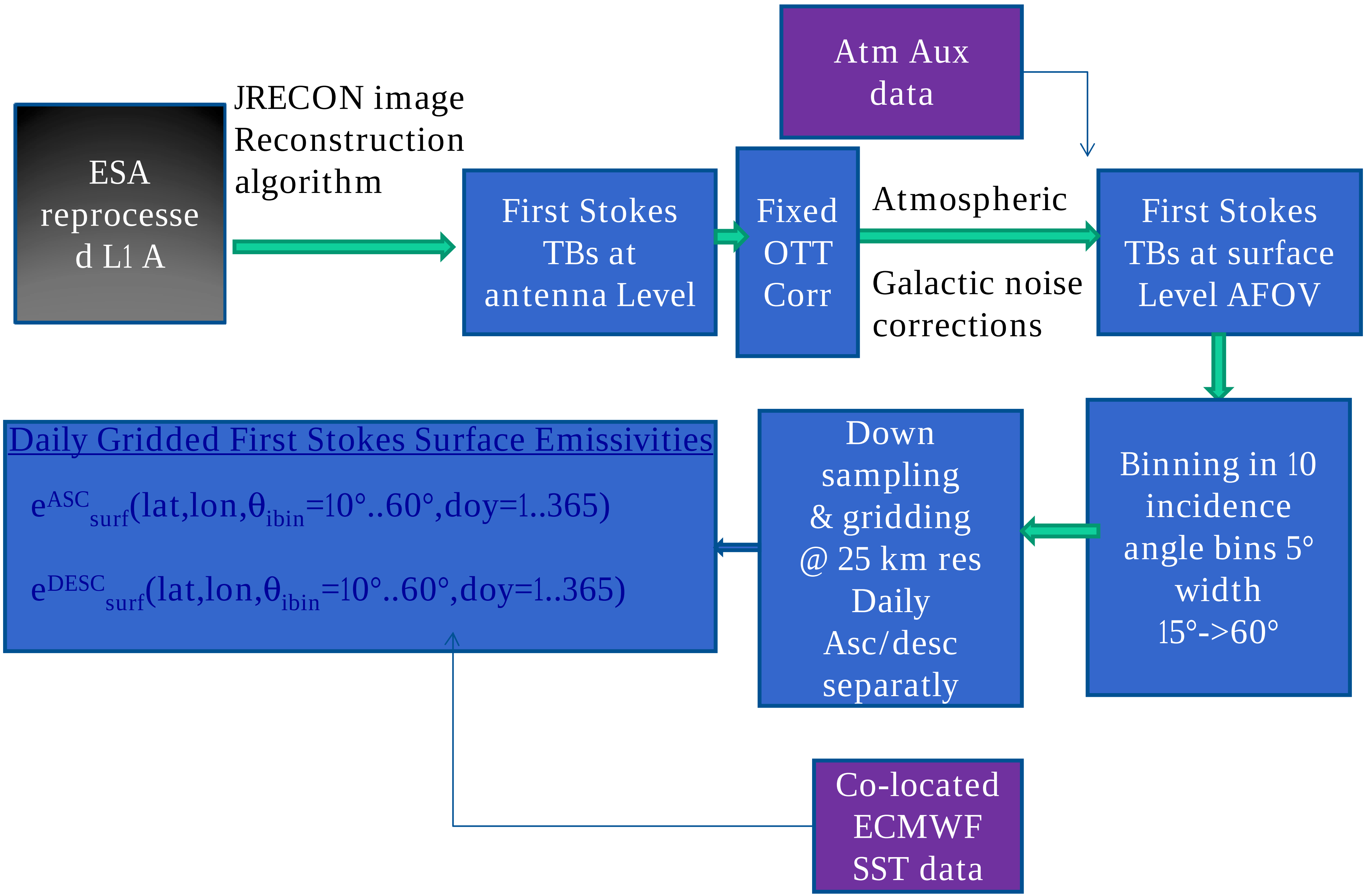
[2]CLS, Plouzané, France

[3]LOCEAN, Paris

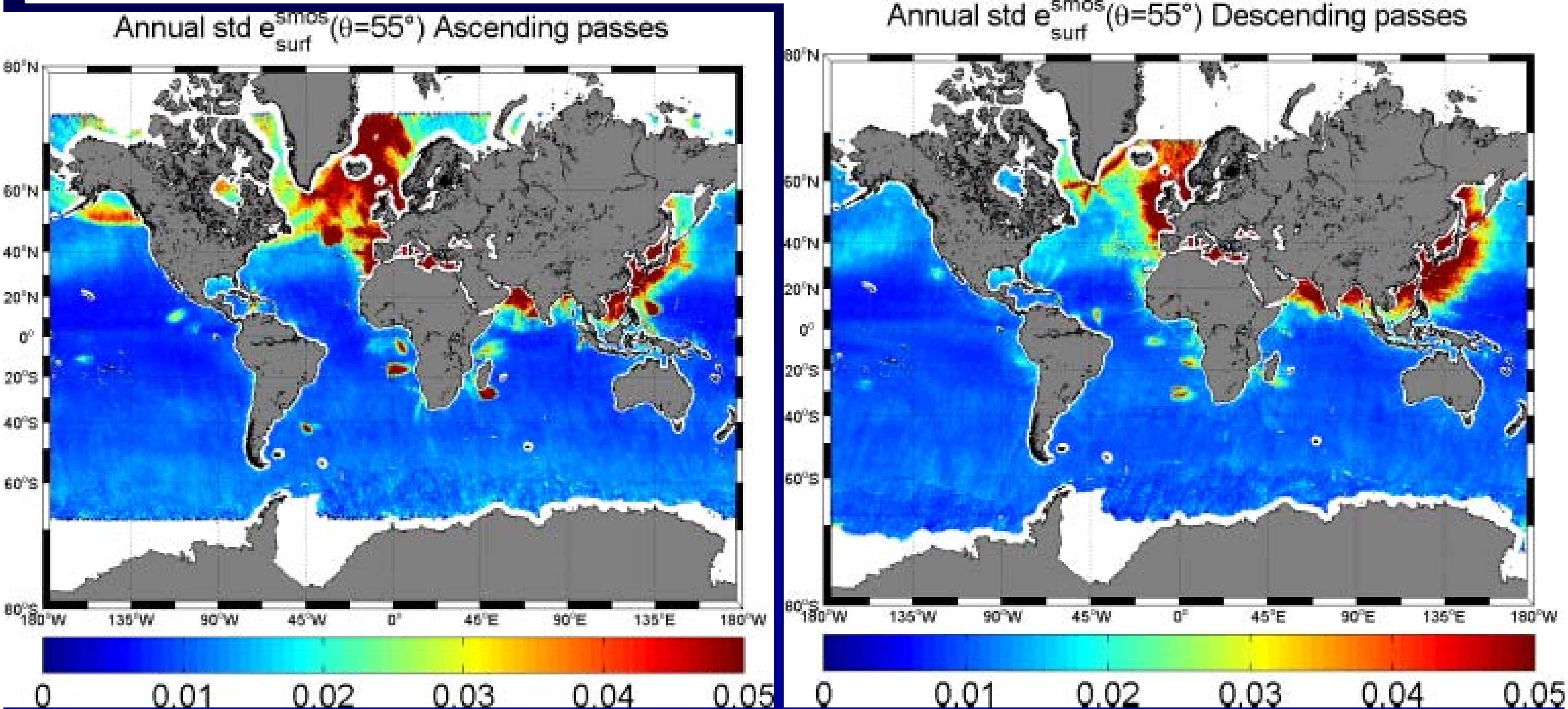
for more informations, see the dedicated web site:
http://www.salinityremotesensing.ifremer.fr/



Algorithm Overview: Part I From L1A to Surface emissivities

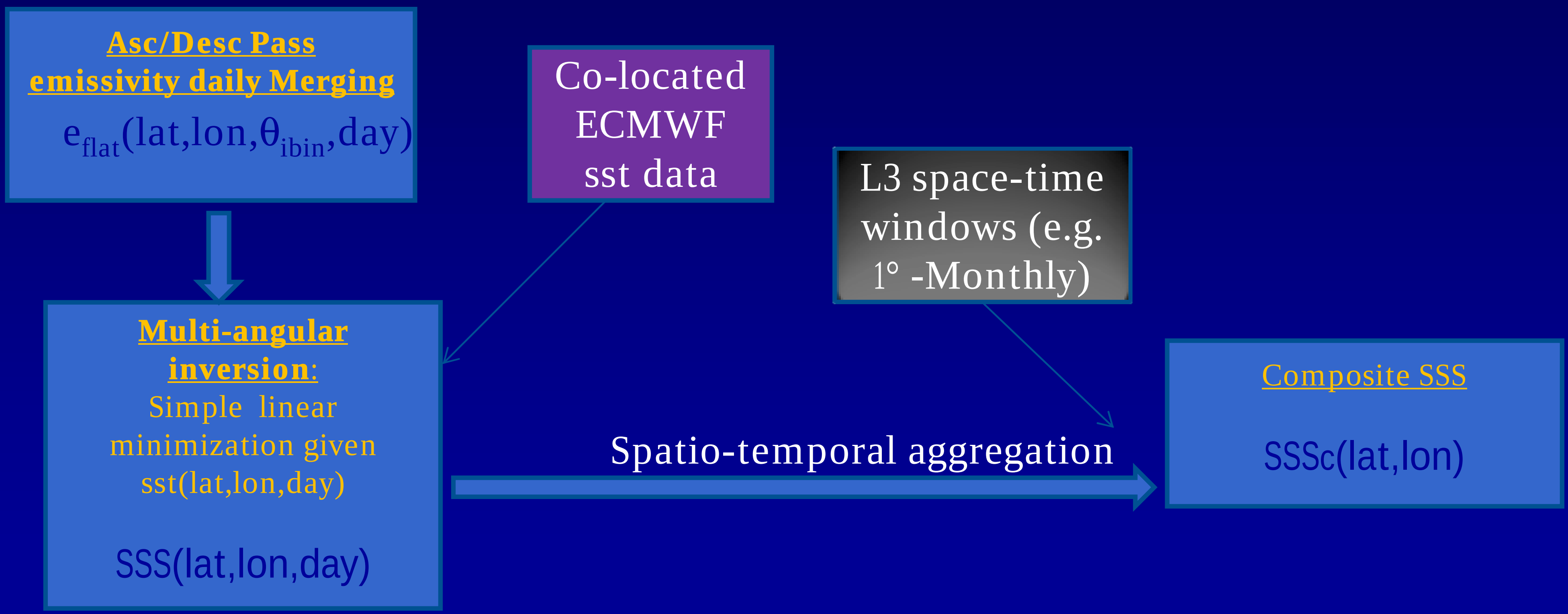


The RFI contamination issue
Over the oceans



Annual Variance of the surface emissivity over 2010 from 15° to 55° incidence
-both passes
All area with variances higher than 0.03-0.04 are clearly RFI contaminated zones

Algorithm Overview: Part III: emissivity data composite and SSS inversion



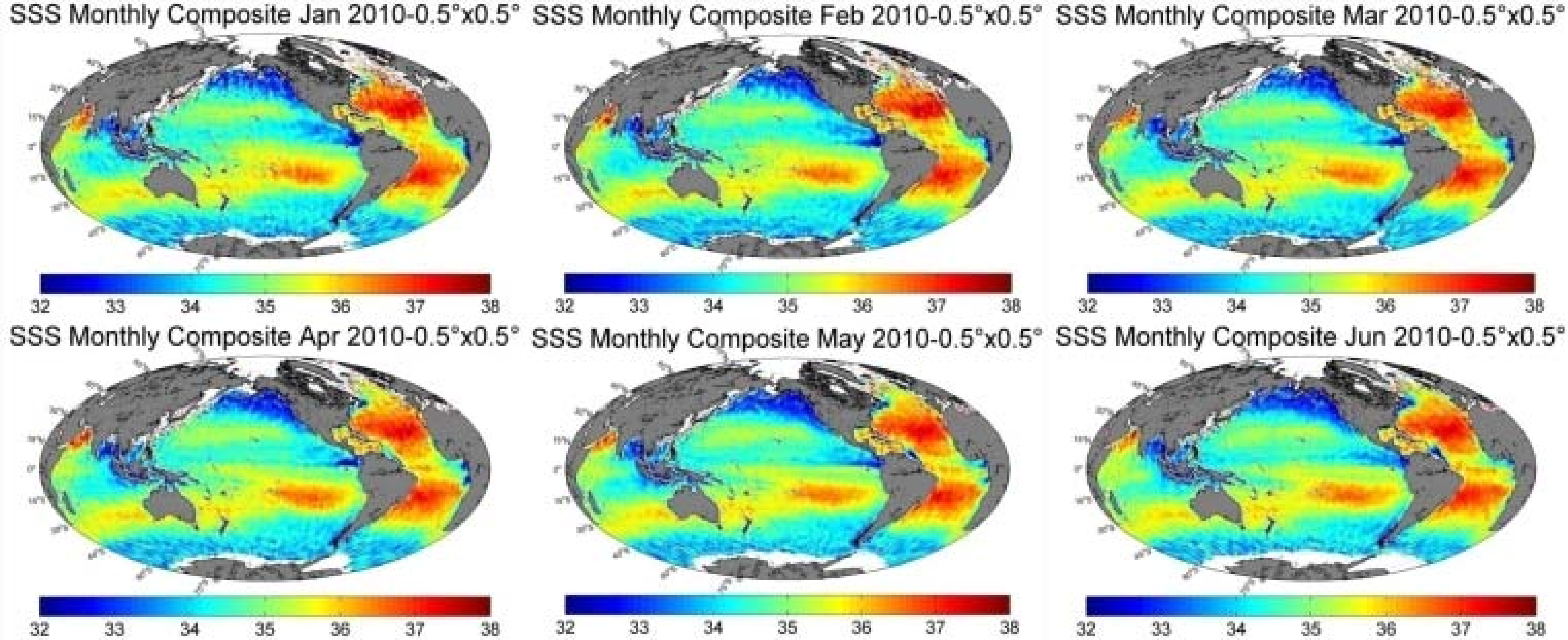
The L3 SSS CATDS-CECOS Products

Product Validation

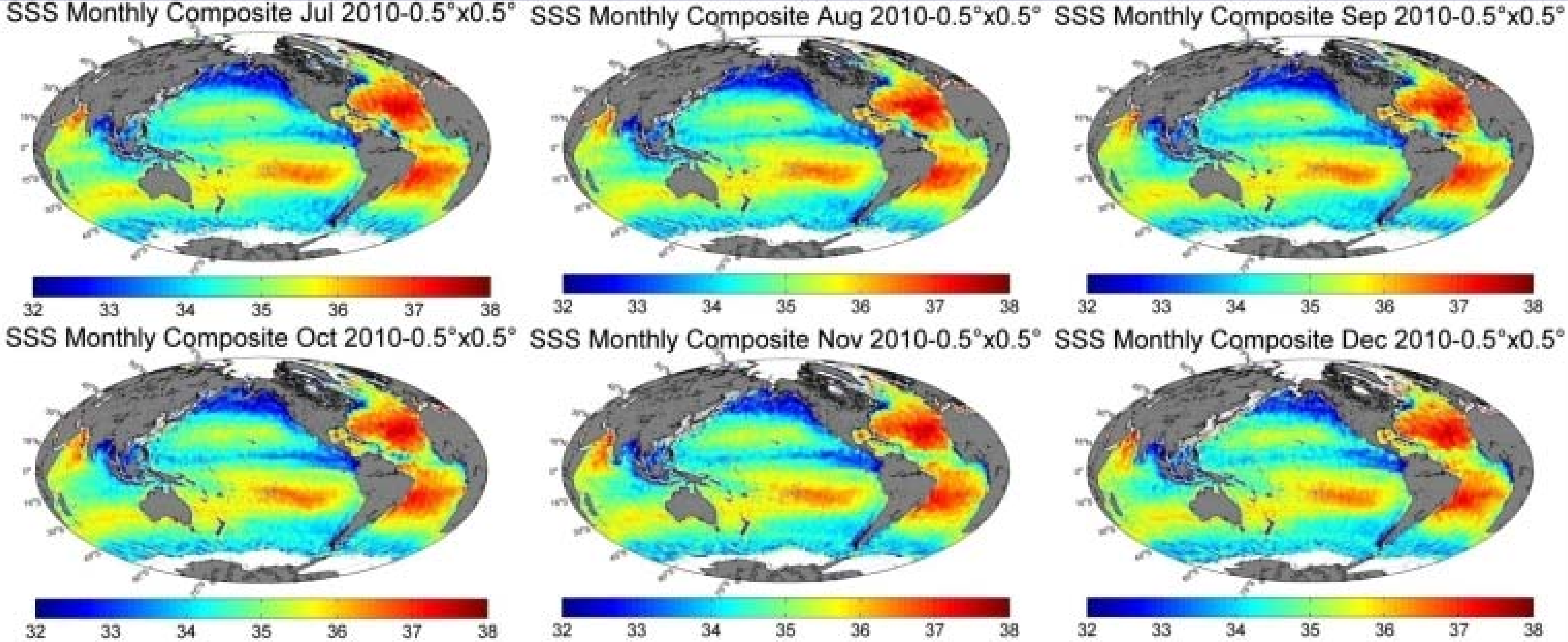
&

Oceanographic consistency

Exemple Monthly products at 0.5° Res: January to June 2010



Exemple Monthly products at 0.5° Res: July to December 2010



Averaged Spatial Distribution of $\Delta SSS = SSS_{in\ situ} - SSS_{SMOS}$

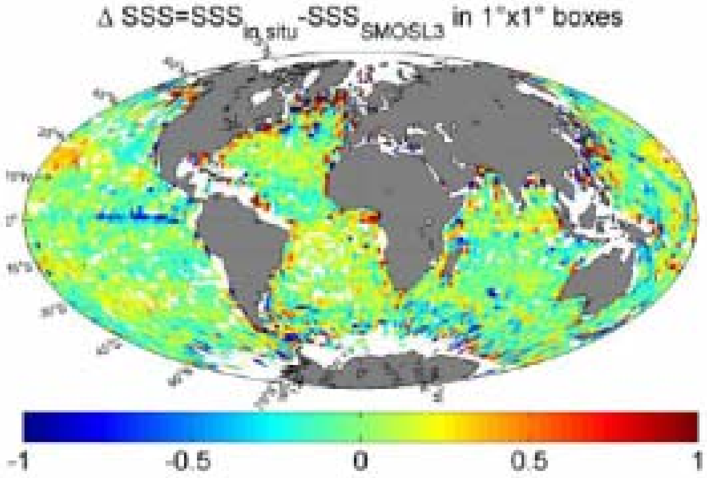
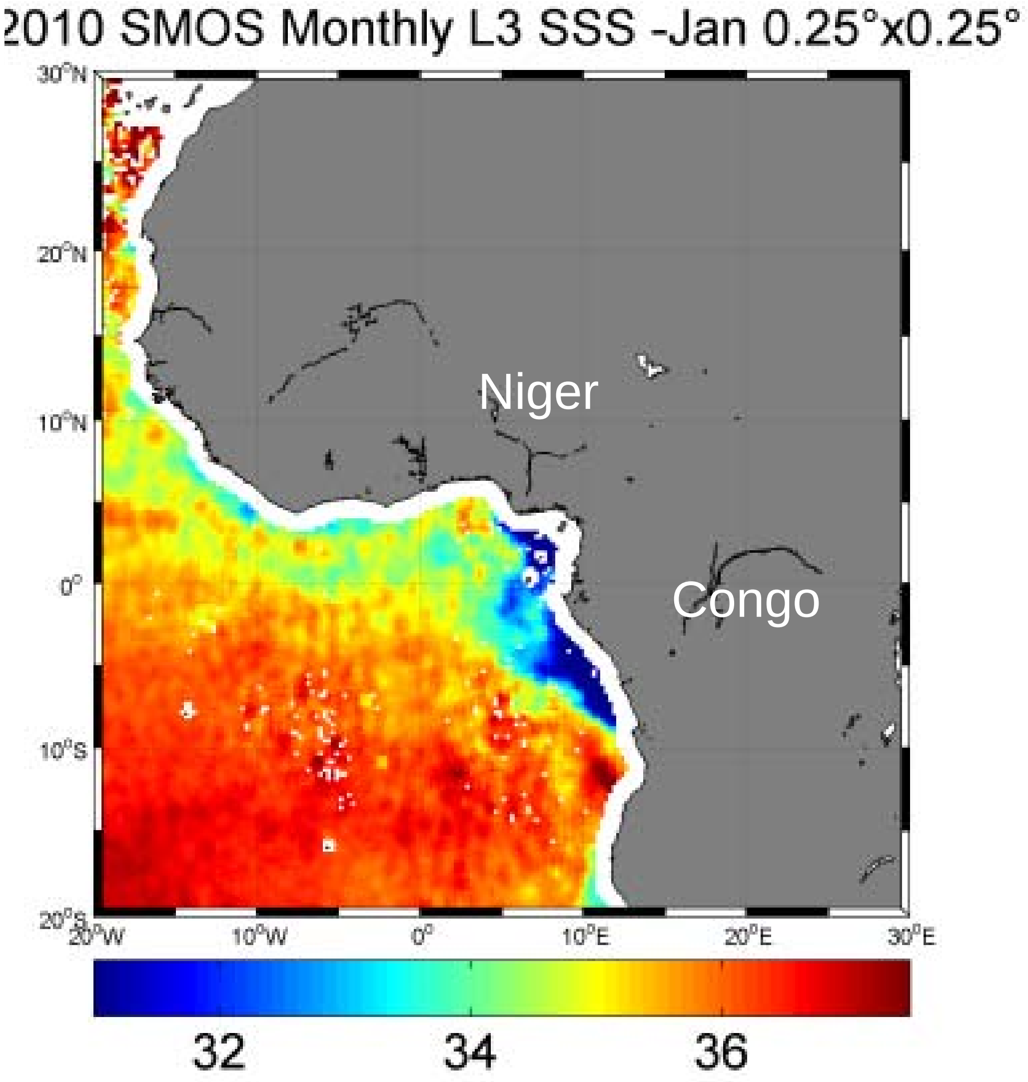


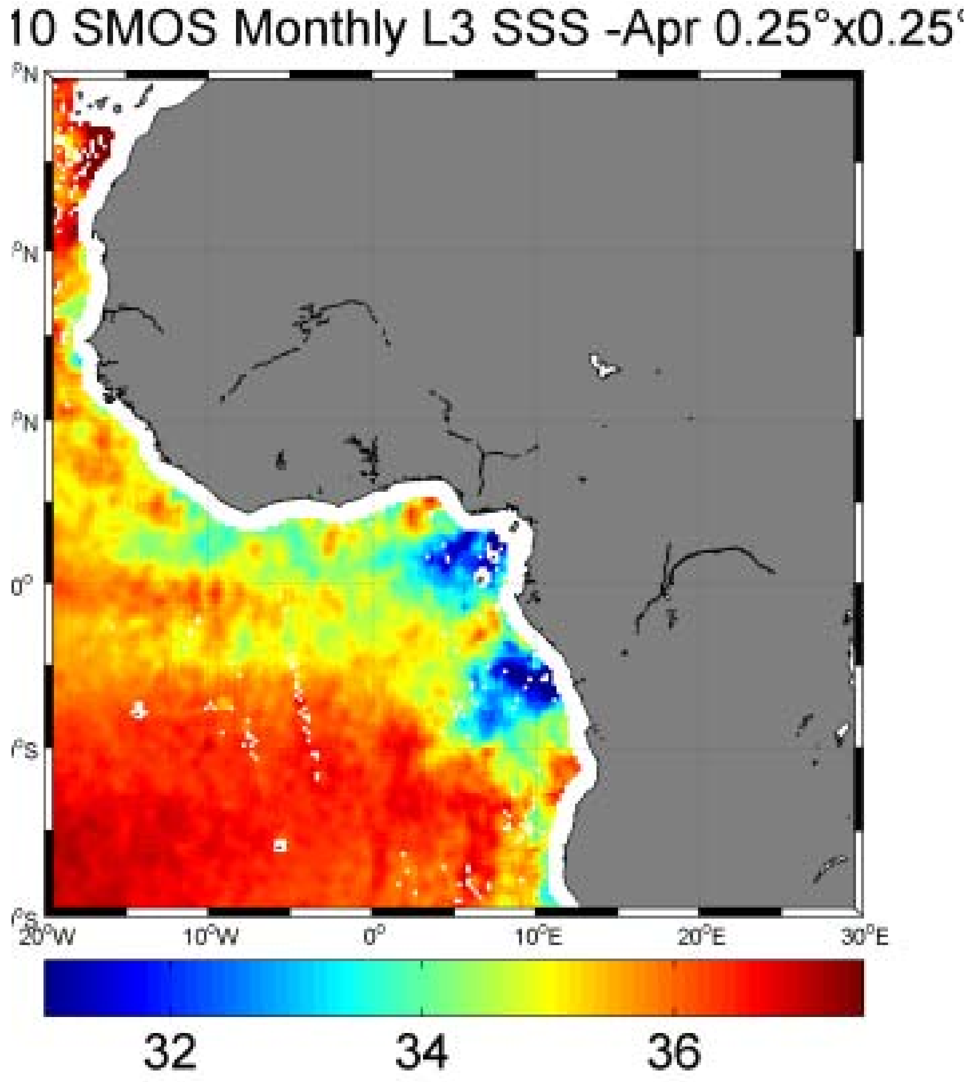
Figure: Spatial distribution of $SSS_{in\ situ} - SSS_{SMOS}$ monthly composite data at 0.25° resolution after averaging the ΔSSS 2010 data over 1°x1° boxes. Left: Map centered on the pacific. right: same map but centered on the Atlantic. Note that positive values signify $SSS_{SMOS} < SSS_{in\ situ}$

TABLE III: **SMOS LEVEL 3 1°x1°** MONTHLY COMPOSITE ΔSSS 95% PERCENTILE ERROR STATISTICS (PSS) OVER THE COMPLTE YEAR 2010

STATISTICS	GLOBAL OCEAN	ARCTIC OCEAN	NORTH ATLANTIC	TROPICAL ATLANTIC	SOUTH ATLANTIC	NORTH PACIFIC	TROPICAL PACIFIC	SOUTH PACIFIC	INDIAN OCEAN	SOUTHERN OCEAN
Mean	0.0060	1.6256	-0.0473	0.0698	0.0528	0.0132	0.0170	-0.0151	0.0279	-0.0266
Standard Deviation	**0.2876**	**1.0250**	**0.5720**	**0.2775**	**0.2580**	**0.3046**	**0.2525**	**0.2095**	**0.2470**	**0.2559**

Fresh water plumes in the Gulf of Guinea



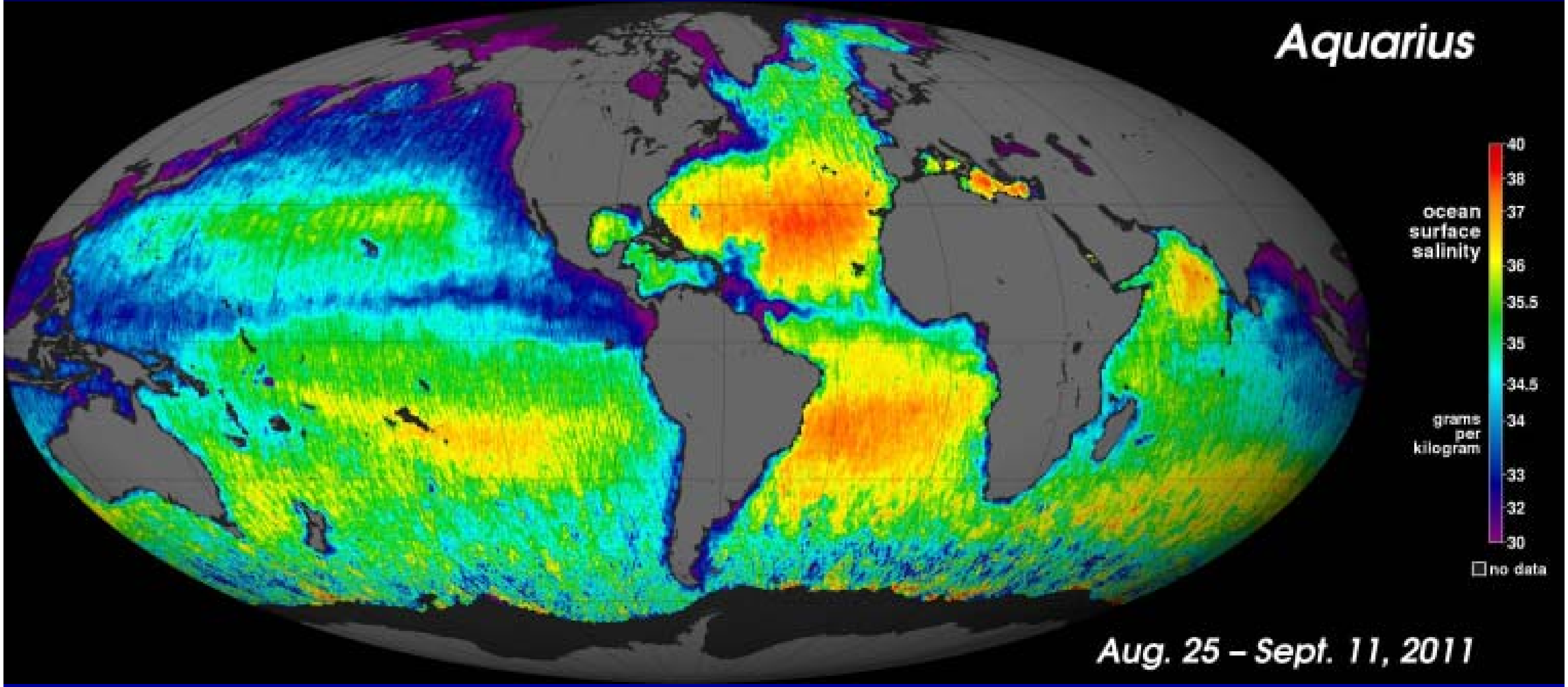


SSS SMOS

- Reprocessing ESA (v5.xx. dispo début 2011): des bugs (soleil) corrigés, inversion itérative => cohérence des Tb le long de dwell lines et inversion d'un vent 'radiométrique'

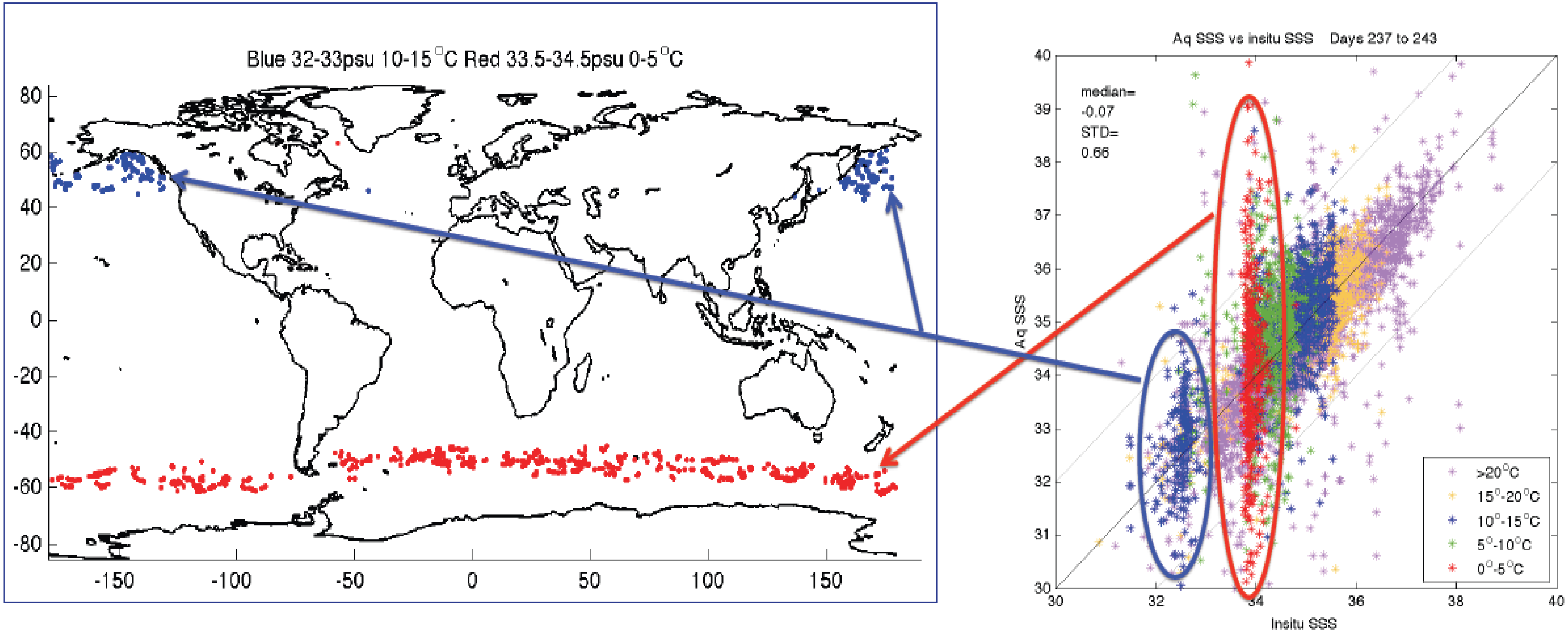
- Traitement CEC CATDS (2010 dispo): des bugs L1 corrigés, filtrage des Tb/angle d'incidence => amélioration du tri RFI, inversion simple

First SSS image from Aquarius (NASA)



Less affected by RFI than SMOS but
roughness issue in the SO and **radiometer drifts ~0.1K/week**

First comparisons of Aquarius and Argo SSS



Lagerloef et al, WCRP, 2011

Summary

- L-band radiometry => remote sensing of SSS works – With today processings, in optimal conditions, SSS precision ~.3 over 10 days-100km – How can we improve that???
- Still some drifts due to imperfect sun and galactic signal corrections, to imperfect modelling of antenna temperature response (SMOS)
- Interferometer radiometer works … still room for improvements in image reconstruction and for the conception of future radiometers (respect Nyquist criteria!)