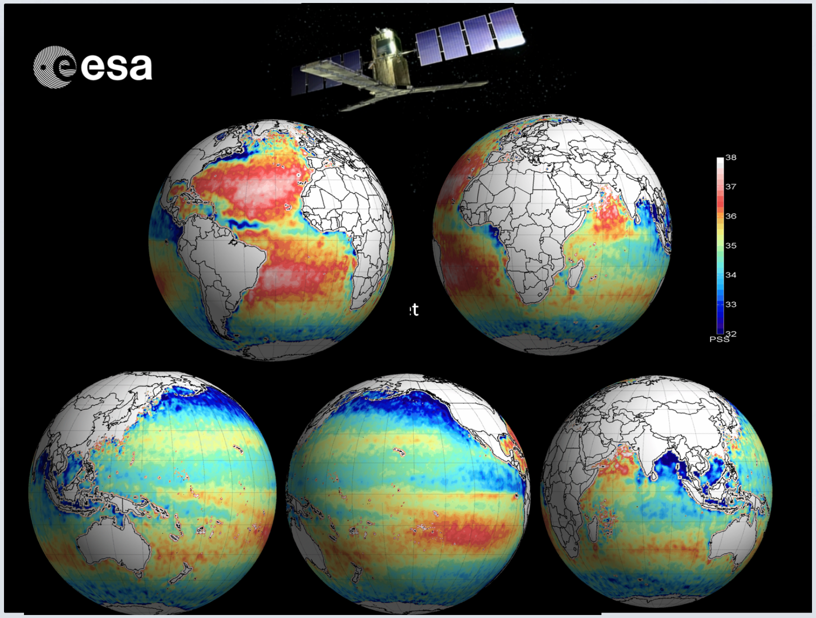
Ocean Salinity with SMOS

Ifremer

esa

→ 4th ESA ADVANCED TRAINING
ON OCEAN REMOTE SENSING



Nicolas Reul, SMOS Scientist (IFREMER)
With contributions from SM0S & Aquarius science team members

7–11 September 2015 | IFREMER | Brest, France

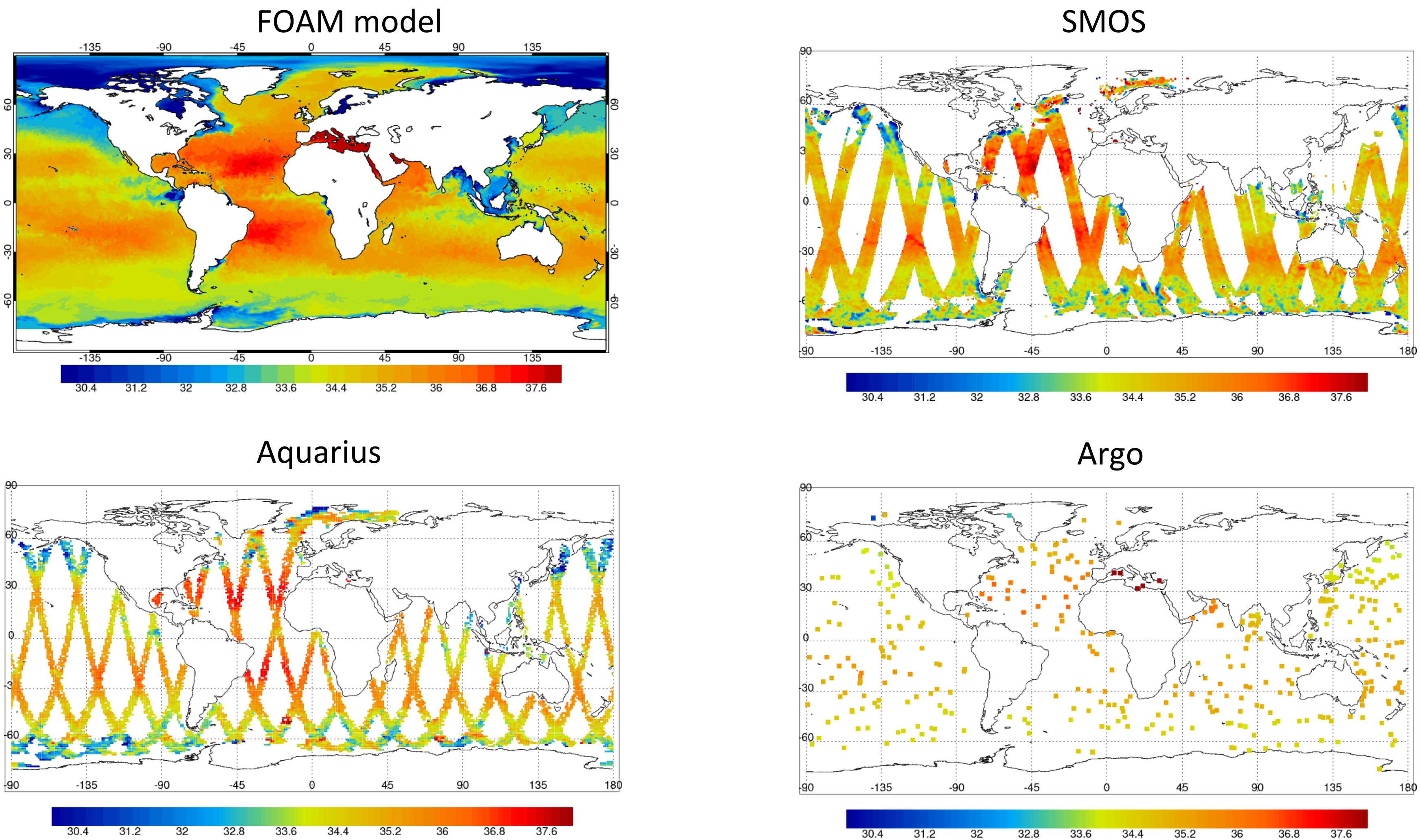
Outline

Highlights of Science Results:

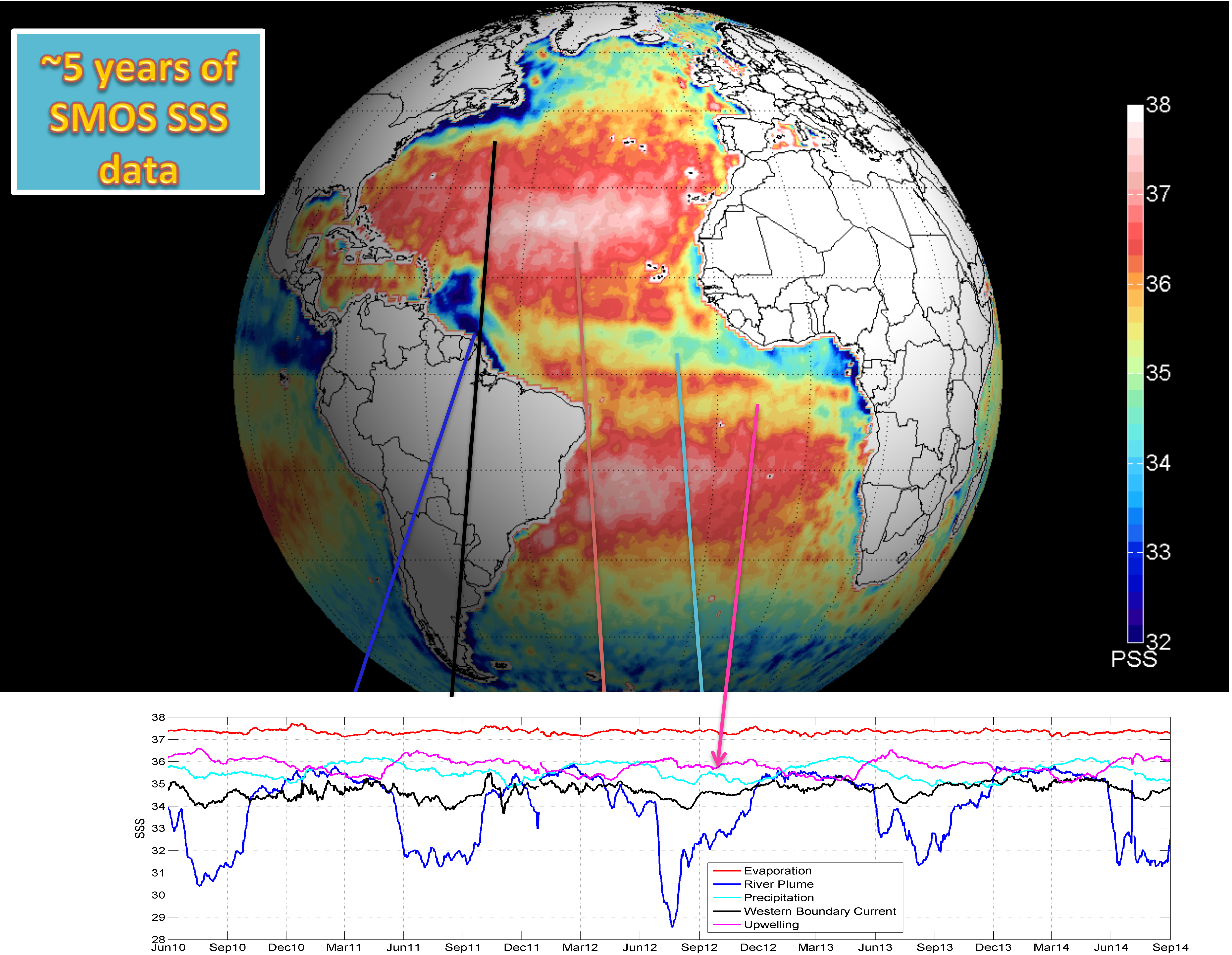
- ❑Where are we ?
- ❑Mesoscale variability of SSS (and density) in frontal structures, eddies
- ❑Ocean propagative SSS signals (e.g. TIW, planetary waves)
- ❑Large scale SSS anomalies related to climate fluctuations (e.g. ENSO, IOD)
- ❑ Freshwater flux Monitoring (precip, river run off)
- ❑Air-Sea interactions (upwellings, Tropical cyclone wakes)
- ❑T-S diagrams
- ❑Bio-chemistry
- ❑ Surface Wind Remote Sensing in Tropical Cyclones

- Where are we in term of SMOS SSS data quality ?

Daily SSS Sampling



Courtesy Mattiew Martin (UK Metoffice)


~5 years of SMOS SSS data
38
37
36
35
34
33
32
PSS
SSS
Evaporation
River Plume
Precipitation
Western Boundary Current
Upwelling
Jun10
Sep10
Dec10
Mar11
Jun11
Sep11
Dec11
Mar12
Jun12
Sep12
Dec12
Mar13
Jun13
Sep13
Dec13
Mar14
Jun14
Sep14
38
37
36
35
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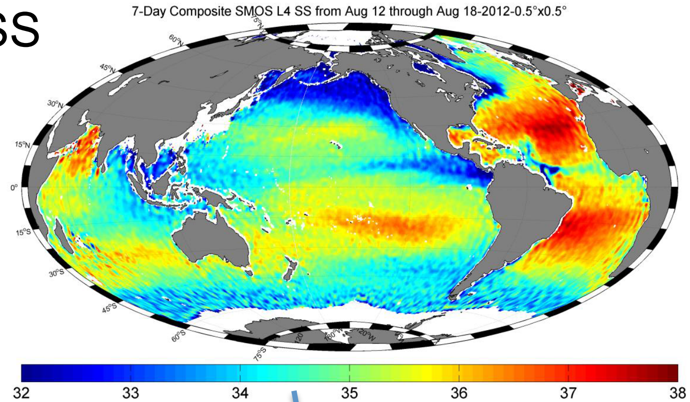
32
31
30
29
28

Validation of satellite SSS with In Situ Observations

Satellite SSS

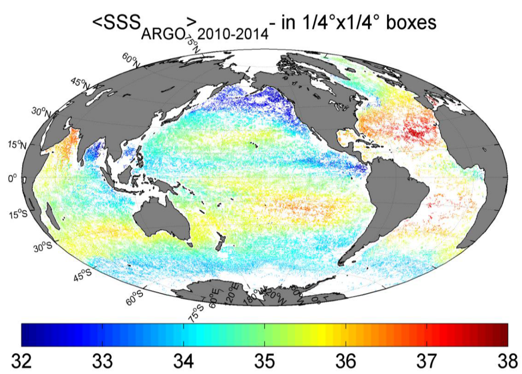


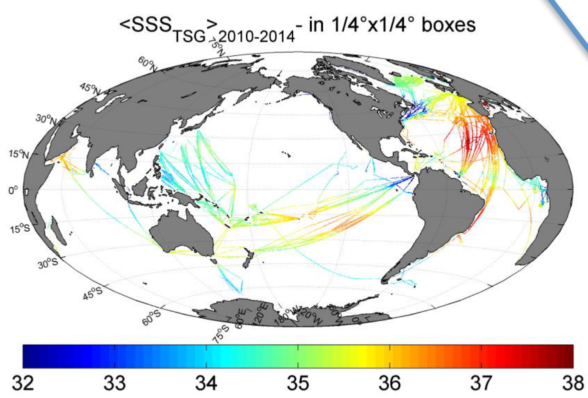
ARGO floats SSS

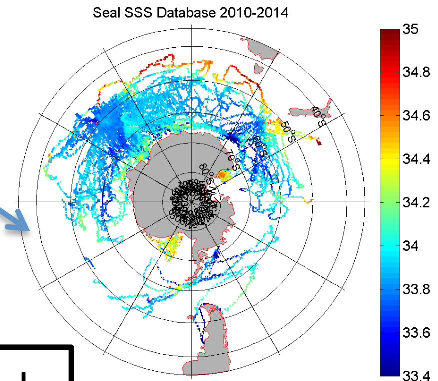
Ship TSG SSS

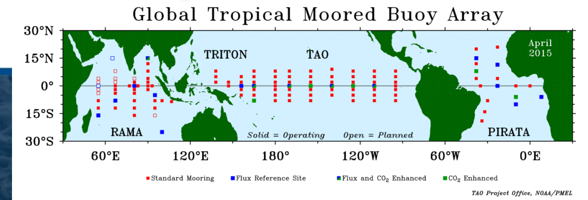
Equipped Mammals SSS

Tropical Moorings SSS









Validation of Level 3 SMOS SSS with In Situ Observations

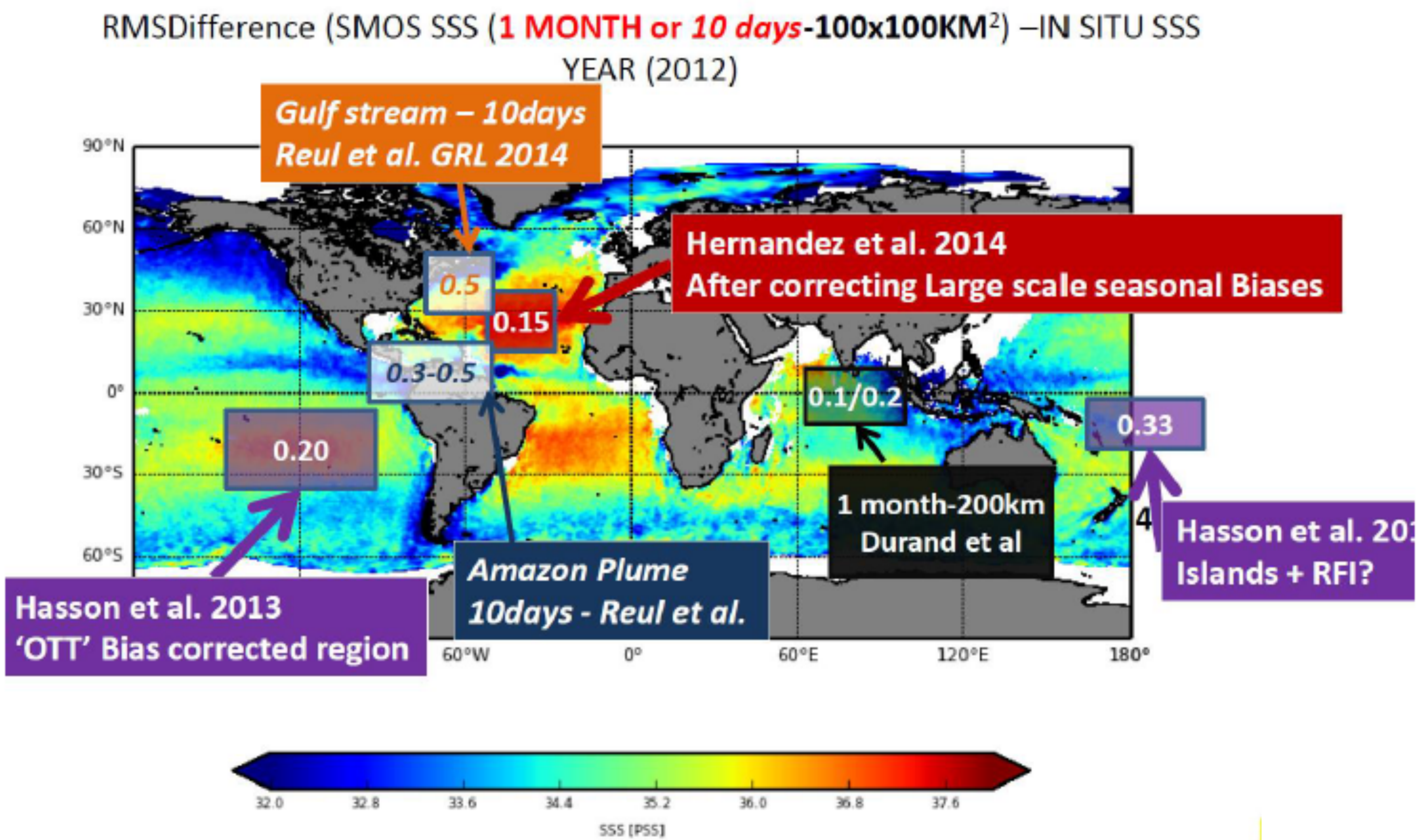
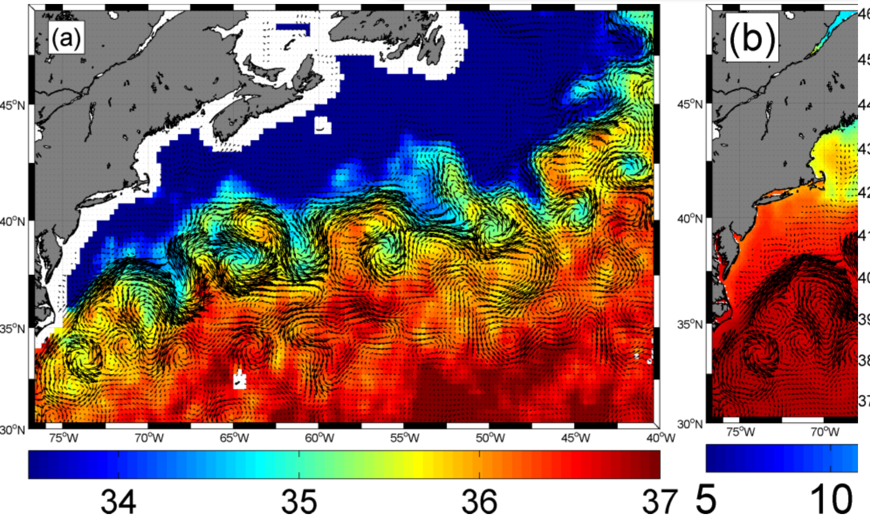
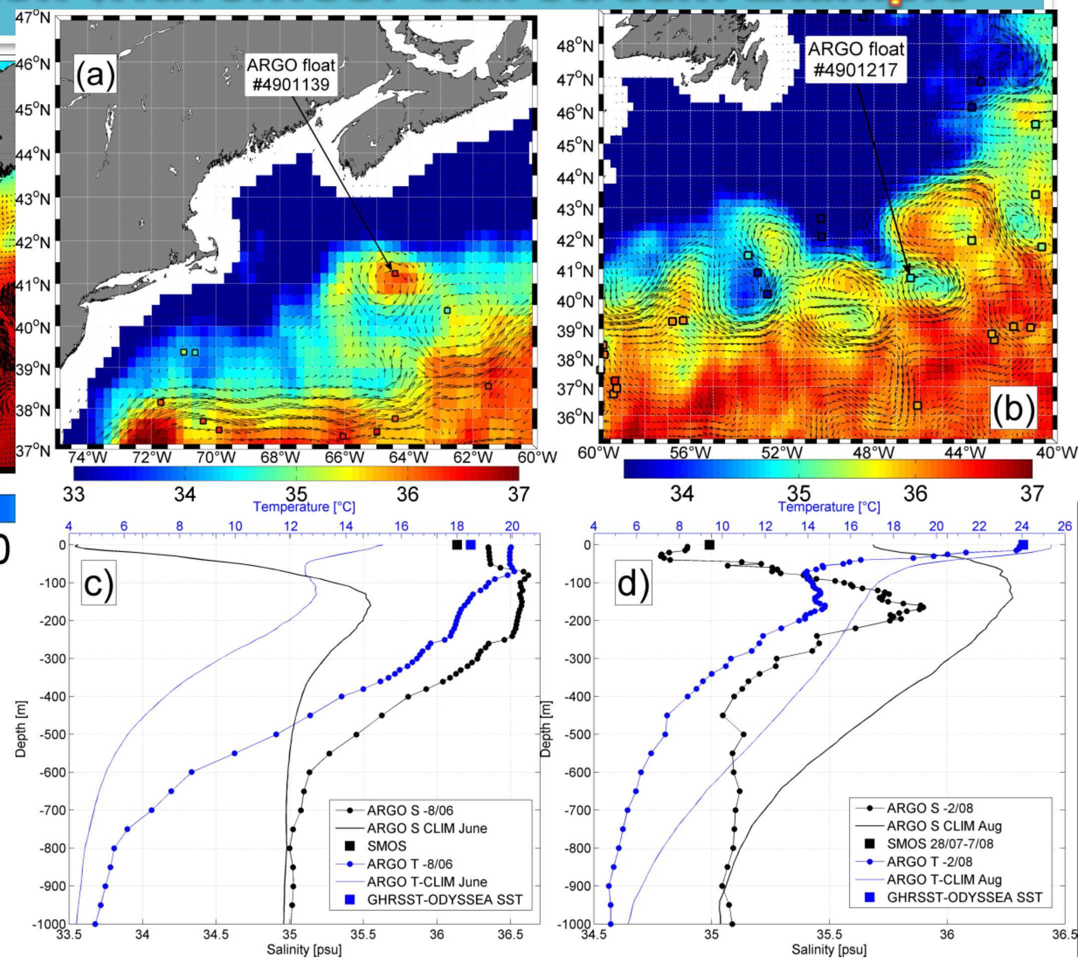


Figure 2: Regional Comparisons between SMOS Level 3 data (here CATDS CEC-LOCEAN, CEC-IFREMER and CATDS/OPER) and in situ data including ARGO profiler, moorings and TSGSSS data (1-10m depth). The numbers given show the rms difference between Level 3 data and in situ observations averaged over 100km-1 month (otherwise specified).

- SMOS monitoring of Mesoscale variability of SSS in frontal structures, eddies

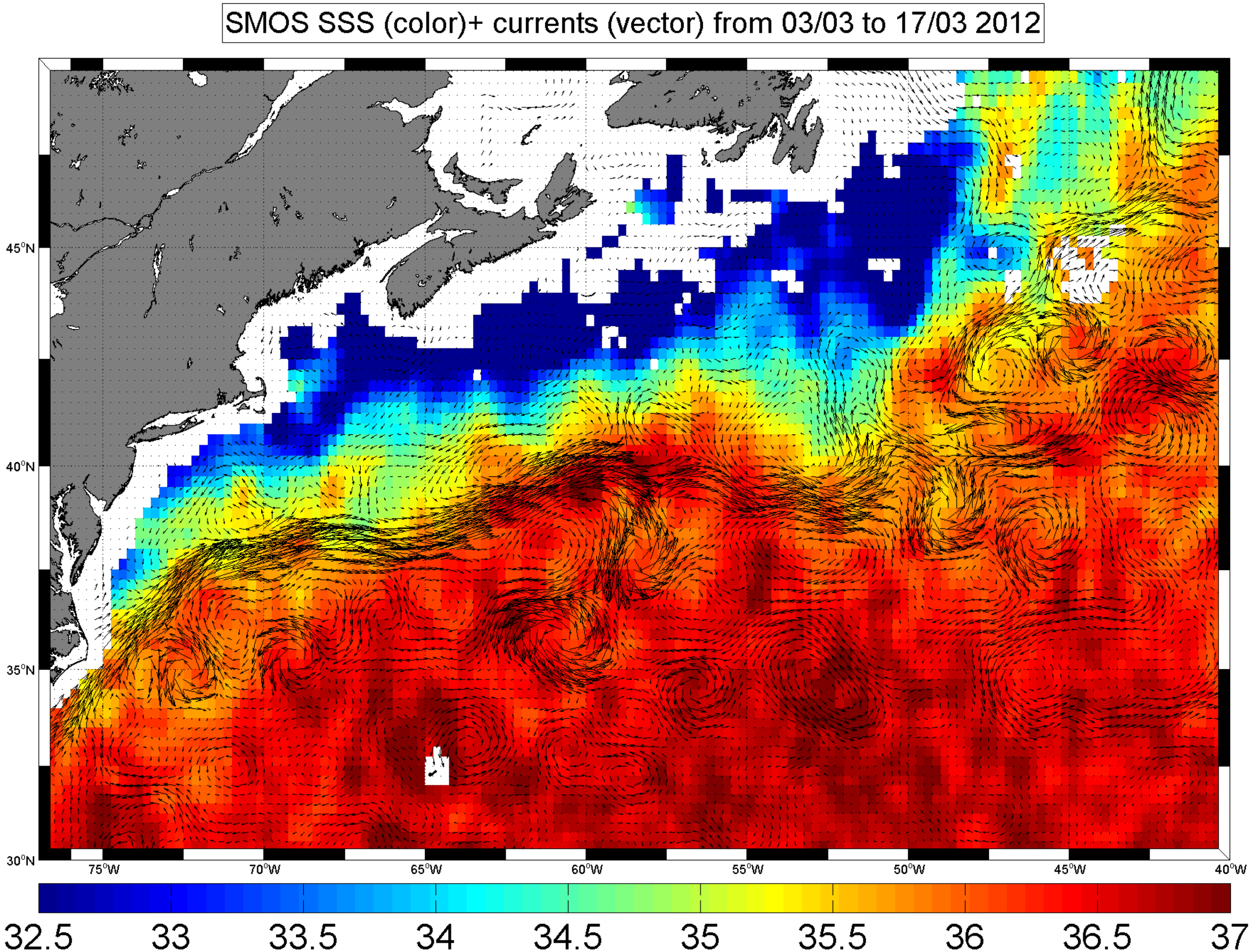
Monitoring Salt Exchanges in Strong water mass Boundary region with SMOS: Gulf Stream Example





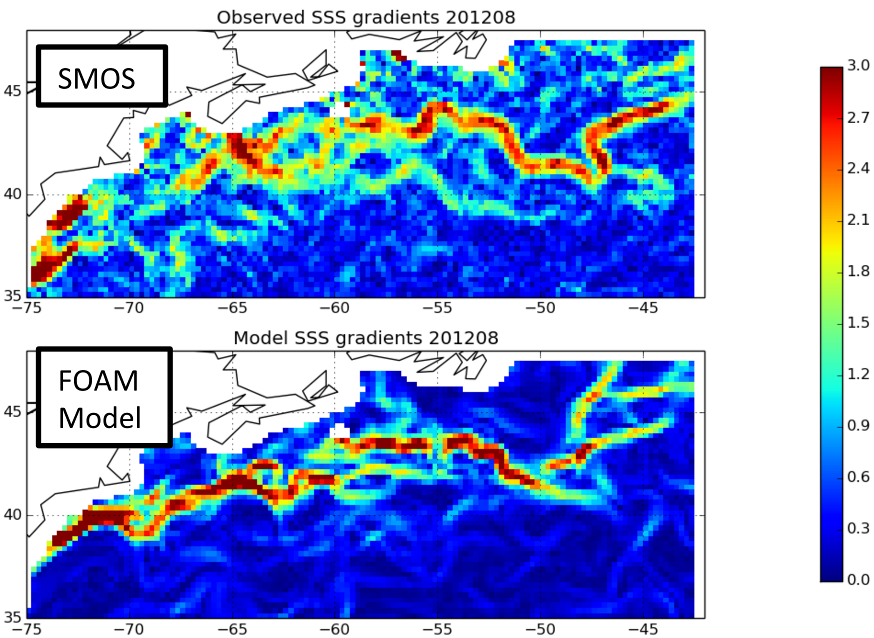
- SMOS reveals SSS structure of the Gulf Stream with an unprecedented Space and time resolution
- Cold/fresh Core rings are better captured by SSS observations than by SST during summer.
- Chl concentration in the separated Gulf Stream significantly correlated with SSS
- Synergistics analysis SSS-SST-SSH-Color
- Perspective : Surface salt-transport estimates By Eddies Subtropical⇔Subpolar Gyres

Reul et al. GRL 2014

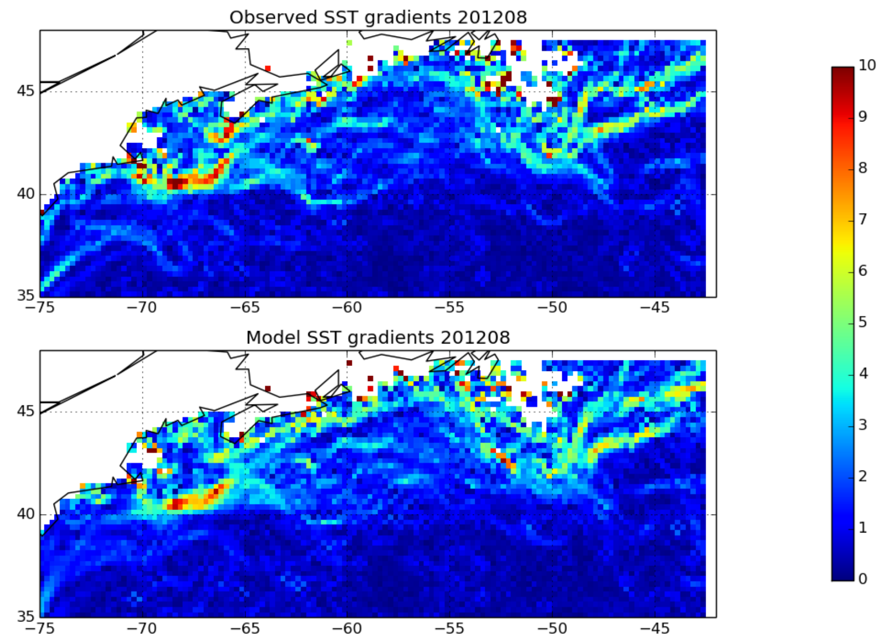

SMOS SSS (color)+ currents (vector) from 03/03 to 17/03 2012
45°N
40°N
35°N
30°N
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
32.5
33
33.5
34
34.5
35
35.5
36
36.5
37

Monitoring Fronts at Strong water mass Boundary region: Gulf Stream Example

SSS horizontal gradients



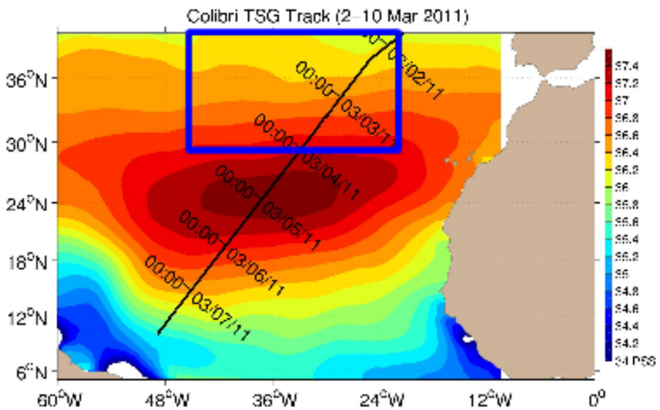
SST horizontal gradients

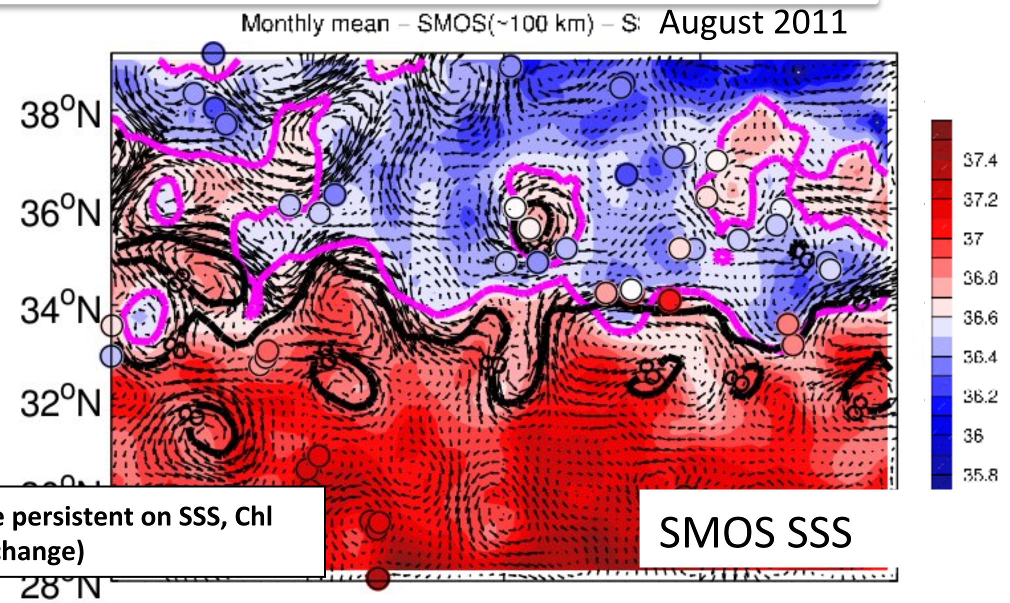


- SSS fronts agree well between model and SMOS observations
- However, SMOS data shows a frontal structure in the main part of the GS which the model doesn’t represent. Who is right ?
- Surface warming has masked the underlying structures in SST in summer, SSS comes as a natural complement to SST & SSH observations

M. Martin (UK Metoffice)

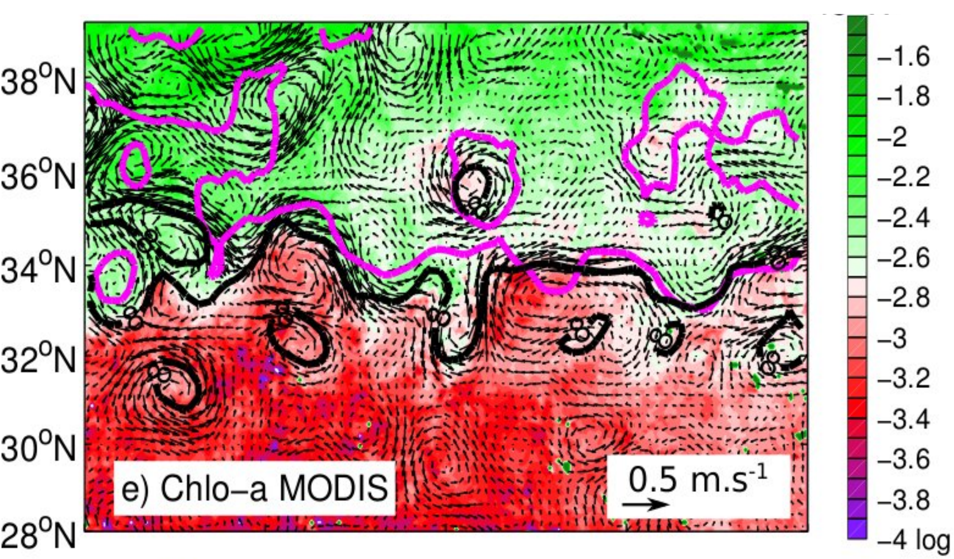
Azores current/Front Example

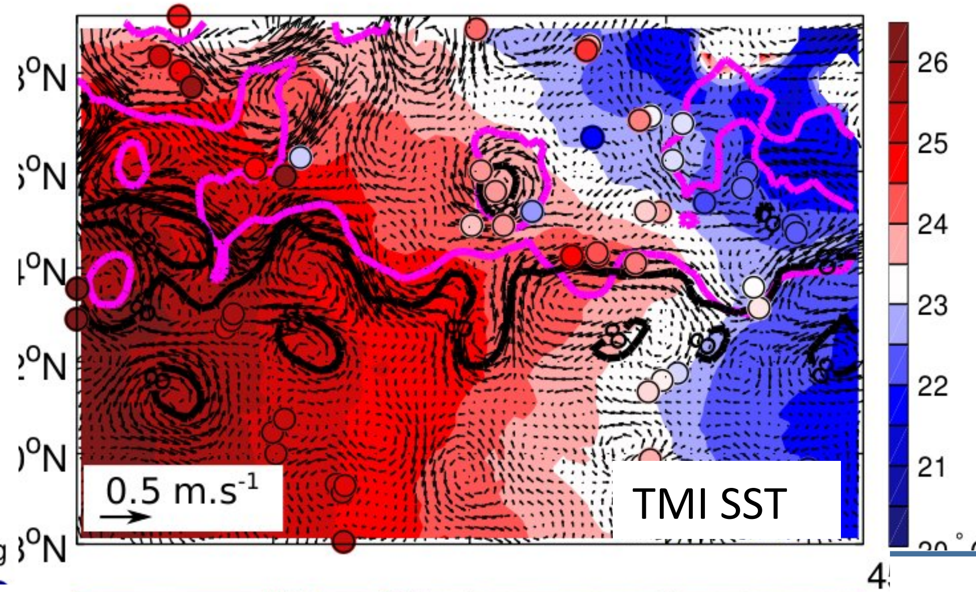




In summer, eddy signature persistent on SSS, Chl but not on SST (air-sea exchange)

MODIS Chl





(Kolodziejczyk et al., JGR, 2014)

Isohaline 36.6

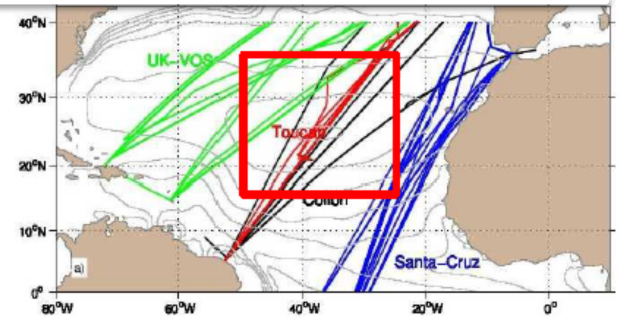
Vorticity 8 10^{-5} s $^{-1}$ (core of current)

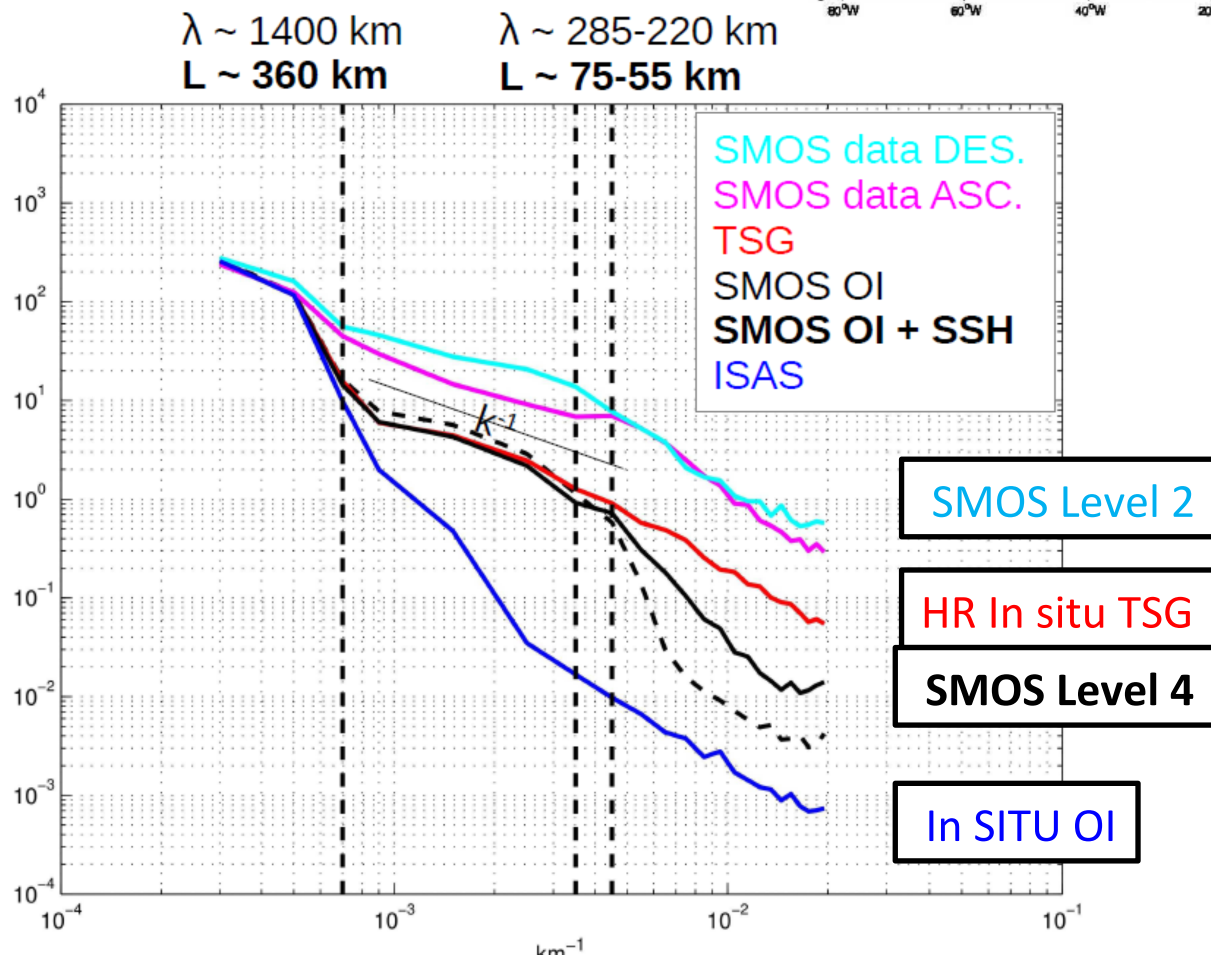
SMOS « sees » the Meso-scale SSS variability down to ~100-50 km

Comparison with TSG

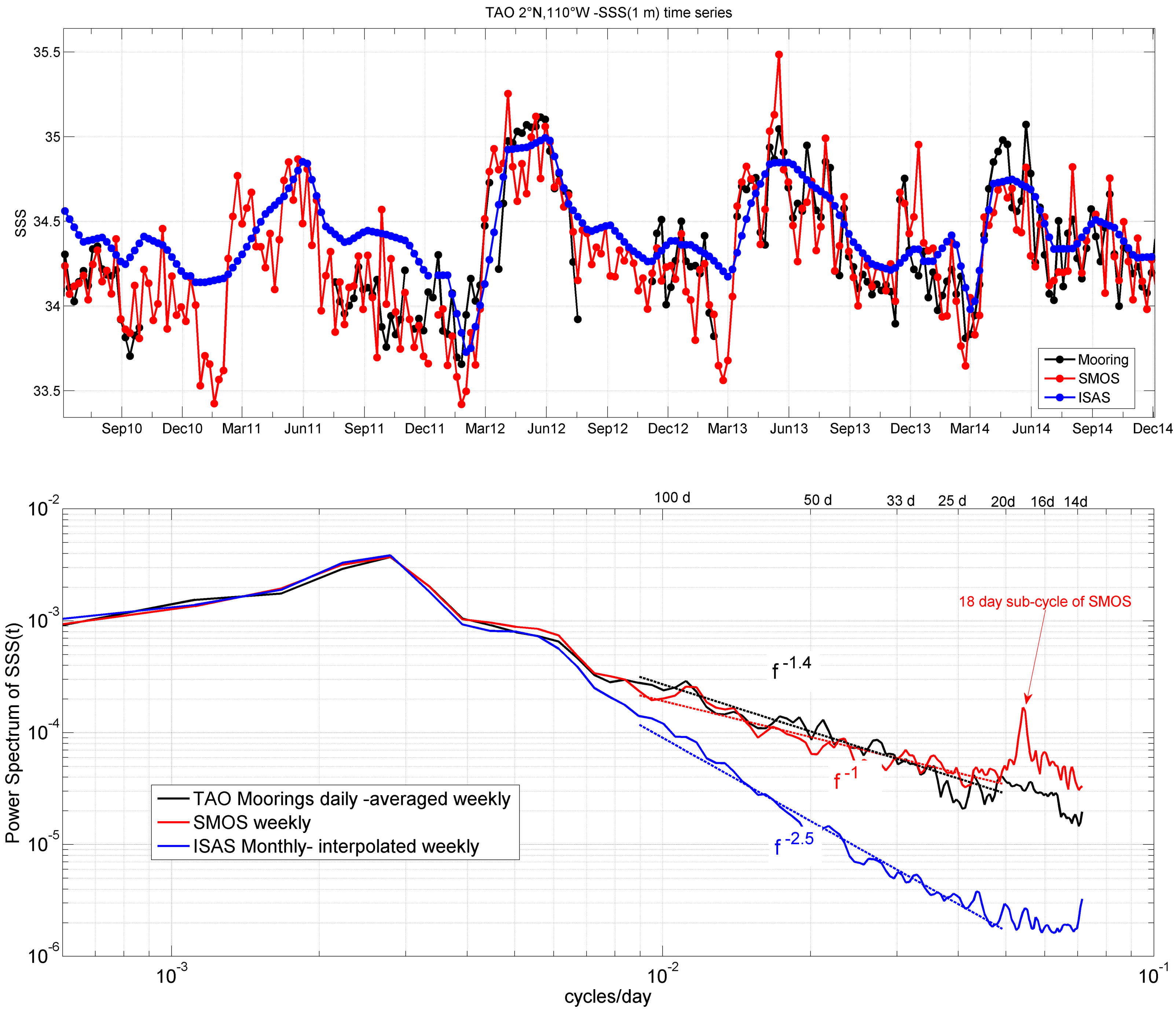
→ Power Spectra

→ 32 TSG section (Colibri & Toucan)





See N. Kolodziejczyk's talk


TAO 2°N,110°W -SSS(1 m) time series
35.5
35
34.5
34
33.5
SSS
Sep10
Dec10
Mar11
Jun11
Sep11
Dec11
Mar12
Jun12
Sep12
Dec12
Mar13
Jun13
Sep13
Dec13
Mar14
Jun14
Sep14
Dec14
Mooring
SMOS
ISAS
100 d
50 d
33 d
25 d
20d
16d
14d
18 day sub-cycle of SMOS
f -1.4
f -1
f -2.5
TAO Moorings daily -averaged weekly
SMOS weekly
ISAS Monthly- interpolated weekly
Power Spectrum of SSS(t)
cycles/day

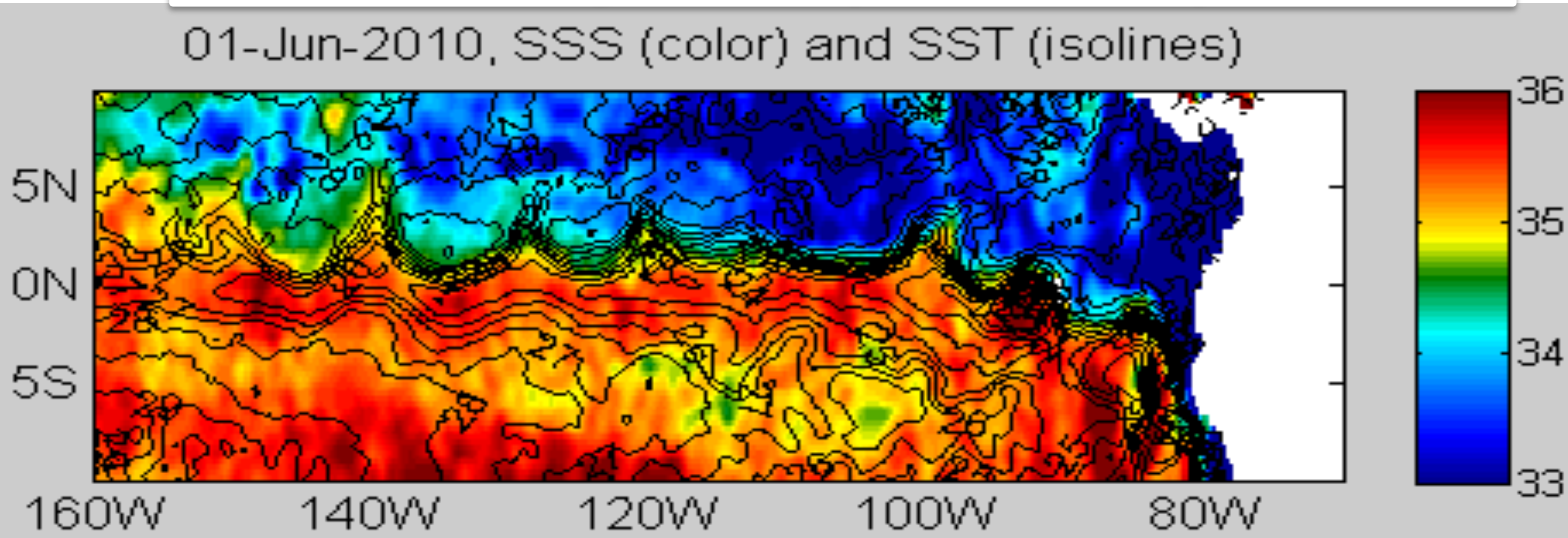
- SMOS monitoring of Ocean propagative SSS signals (e.g. TIW, planetary waves)

SMOS Sea Surface Salinity signatures of tropical instability waves

Xiaobin Yin[1,2], Jacqueline Boutin[1], Gilles Reverdin[1], Tong Lee[3], Nicolas Martin[1] and Sabine Arnault[1]

1. Laboratoire d'Océanographie et du Climat-Expérimentation et Approches numériques / Institut Pierre Simon Laplace – UMR 7159 CNRS/IRD/UPMC/MNHN, Paris, France
2. ARGANS, Plymouth, UK
3. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

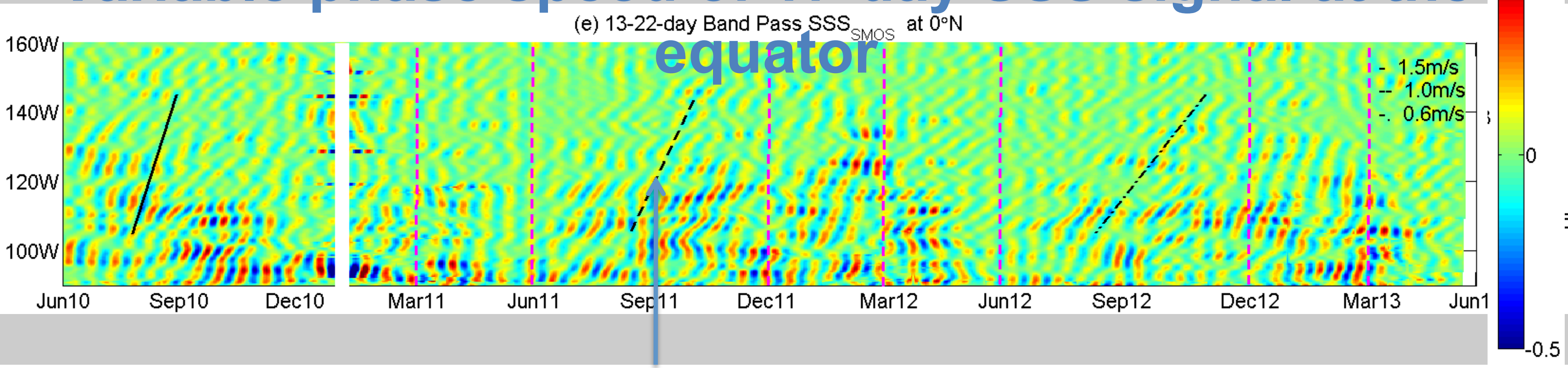
SMOS SSS signal of Tropical Instability Waves



Yin et al., JGR 2014

Decrease in TIW speed at the equator during La Niña-> El Niño transition

Variable phase speed of 17-day SSS signal at the equator

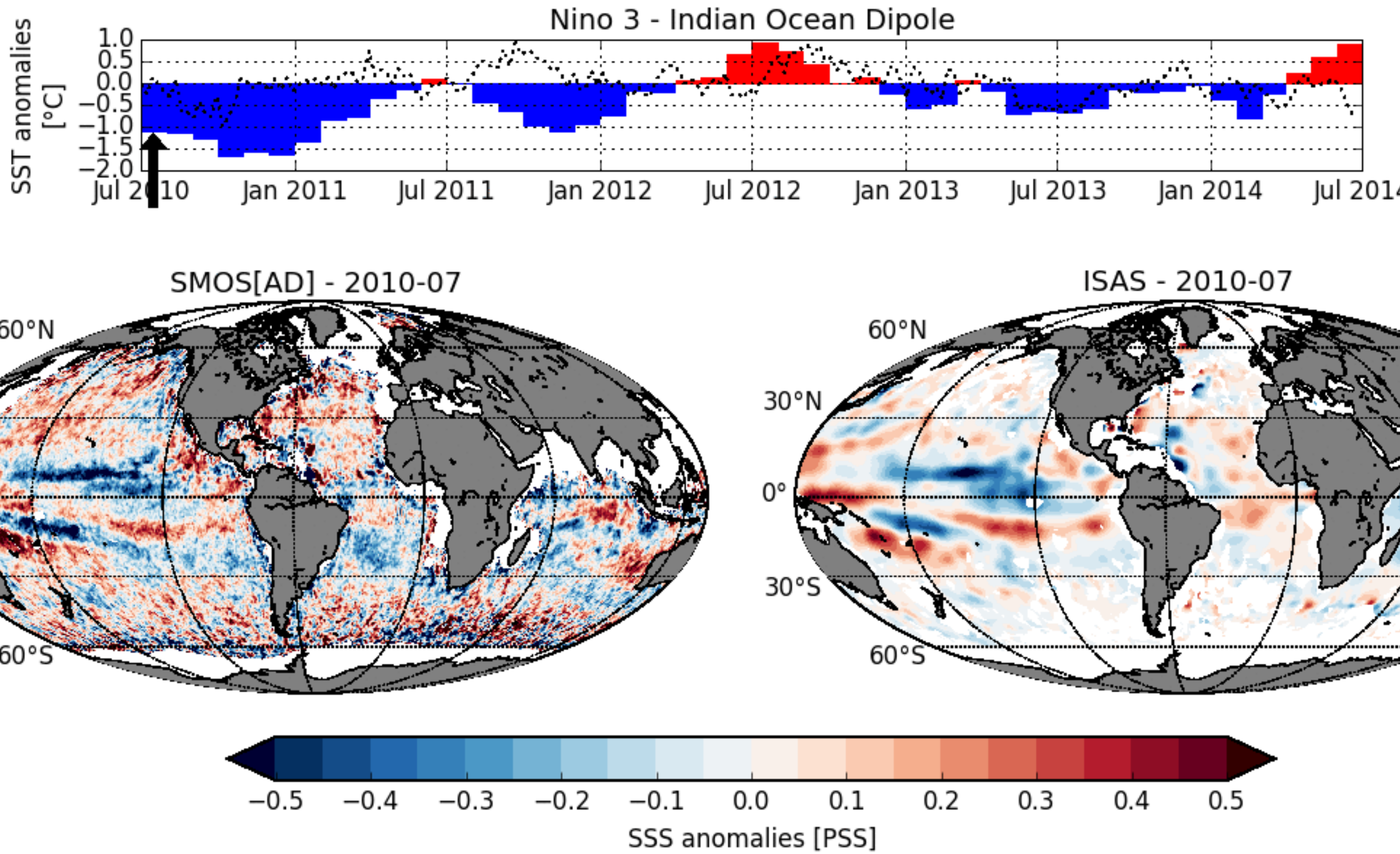


Consistent with Aquarius result (Lee et al. 2012) during this period

- Detection and monitoring of Large scale SSS anomalies related to climate fluctuations

(e.g. ENSO, Indian Ocean Dipole)

Interannual anomalies SMOS/ ARGO OI (ISAS)



Boutin et al 2014

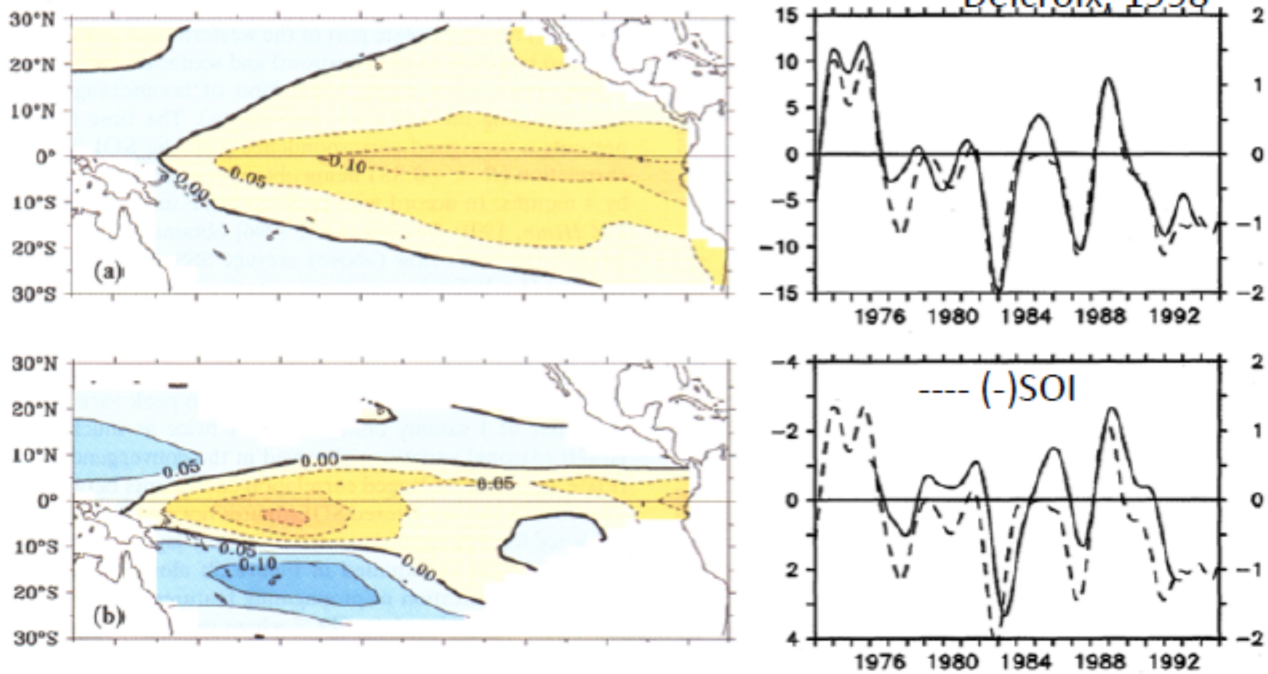
SST and SSS ENSO Signature

- **SST** ENSO signature **located on the Equatorial Eastern half of the basin** and **in phase with SOI**
- **SSS** ENSO signature **located on the Equatorial Western half of the basin** and under the **SPCZ**, **following SOI** with a few month lag

Delcroix, 1998

1st EOF on **SST** interannual signal

1st EOF on **SSS** interannual signal

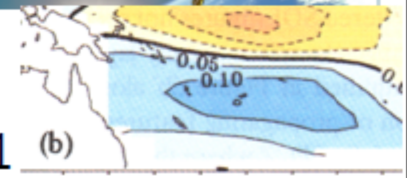


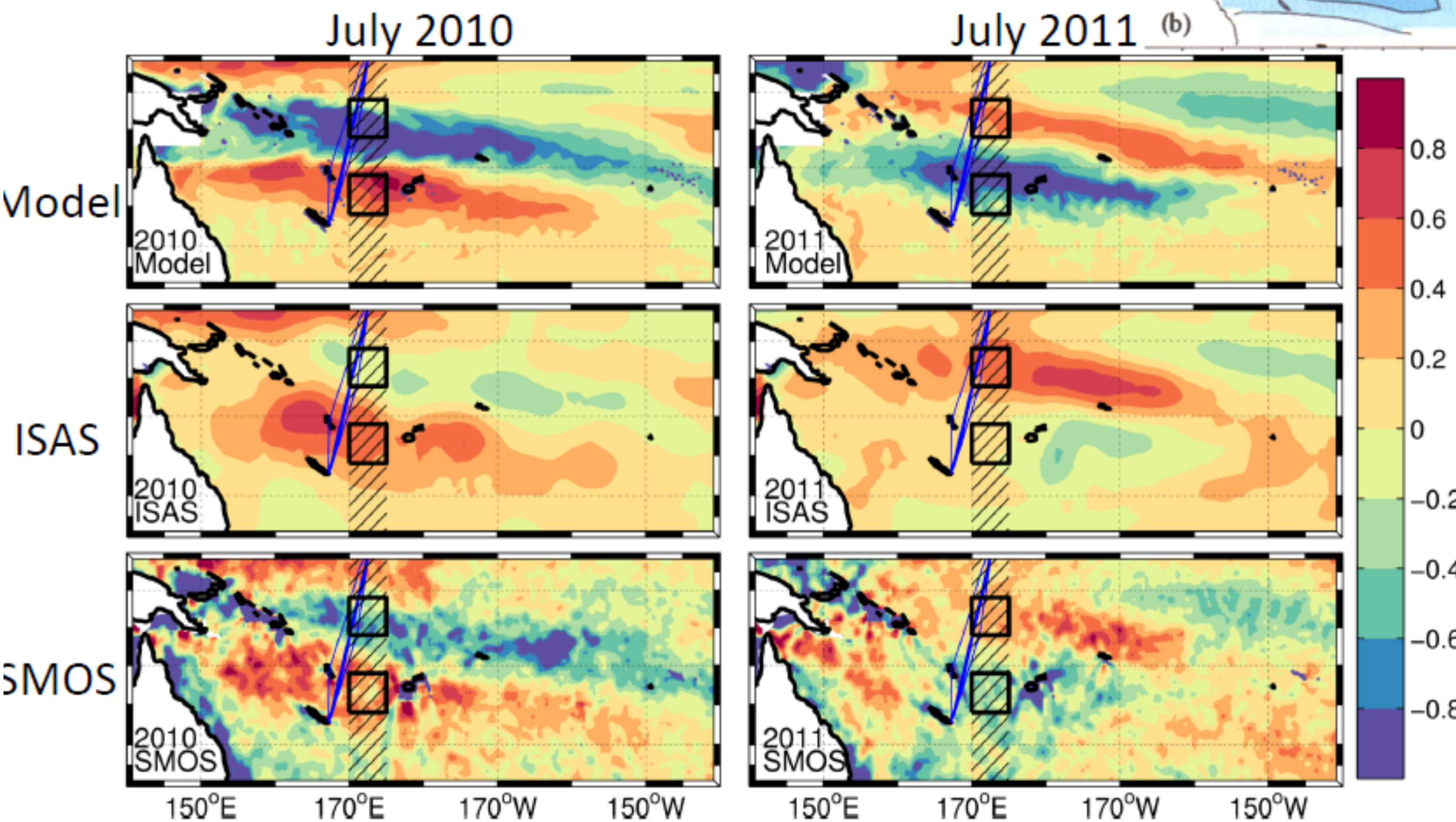
See also for similar results : Gouriou and Delcroix 2002 , Singh et al. 2011 etc…

Hasson et al. 2014

July 2010 & 2011 SSS Anomalies

Anomalies relative to mean July ISAS climatology.





Conclusions

The tropical Pacific Ocean has been in a La Nina phase from mid 2010 to early 2012.

0.6 pss expected SSS variation associated with ENSO from previous studies

Four complementary datasets were used to describe this event.

SMOS ability to capture the unusually strong bi-polar anomaly in the southwestern Pacific associated with La Nina has been shown.

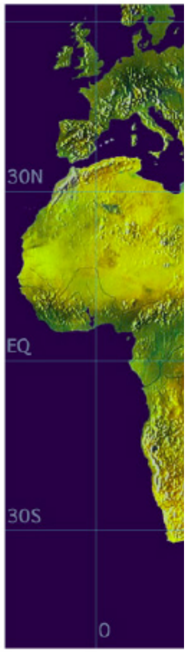
The **responsible processes** for this anomaly are quantified with the model output only.

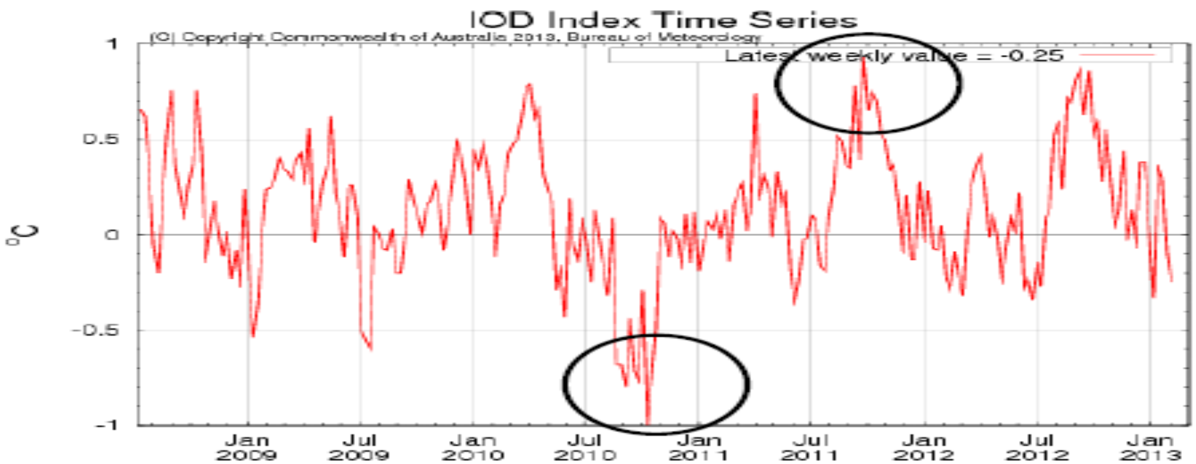
- The salinity tendency in the SPCZ region is in phase with NINO3.4
- The decrease is mainly driven by **Meridional Advection** caused by a steep change in the Meridional SSS gradient
- **Surface Forcing** strongly freshens the surface by the end of 2010 but is damped by **Subsurface Forcing**

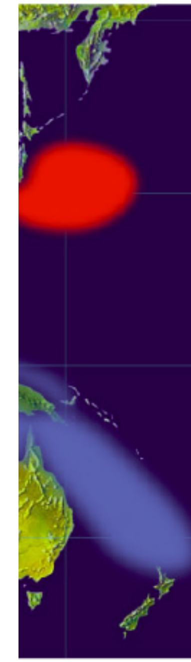
Indian Ocean Dipole

IOD events in 2010-2011

Negative Dip







© JAMSTEC

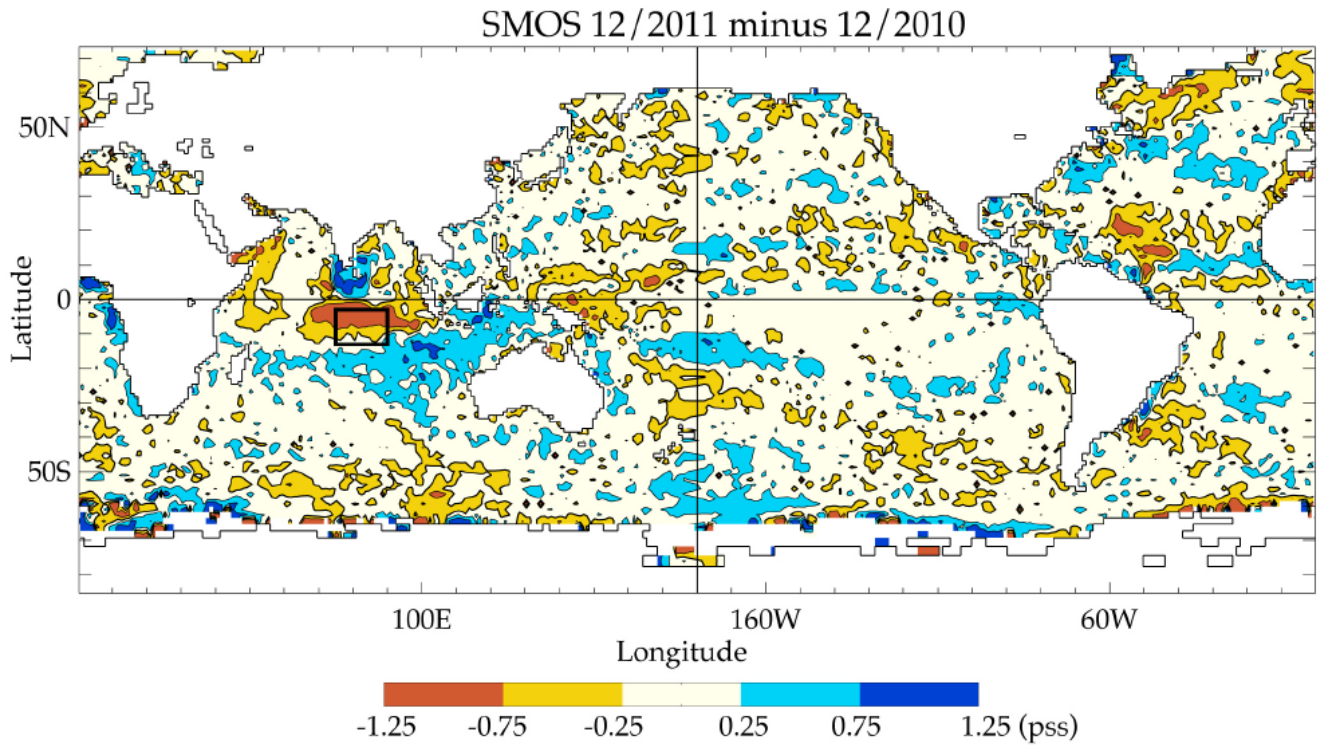
IOD-/IOD+ peaks in november 2010/2011

Reverdin et al., 1986; Webster et al., 1999; Saji et al., 1999

IOD: the dominant mode of climatic variability in the Indian Ocean

SMOS SSS variability in 2010-2011

Product: Level3, 1°×1°×1month from CATDS-CPDC



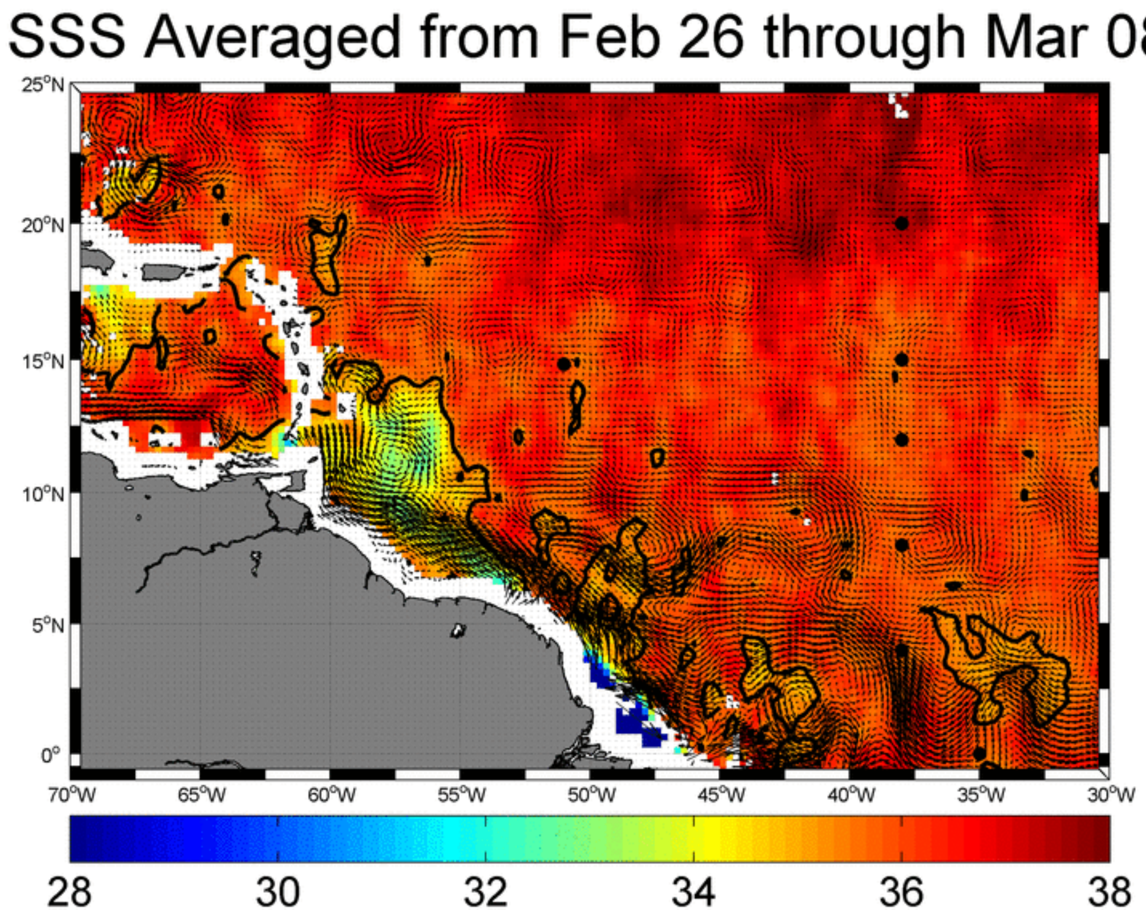
SMOS SSS difference between 12/2011 and 12/2010 in the Indian Ocean : the largest, longest-lasting year-to-year observed signal over SMOS period

IOD-/IOD+ peaks in november 2010/2011

Durand et al., Ocean Dynamics, 2013

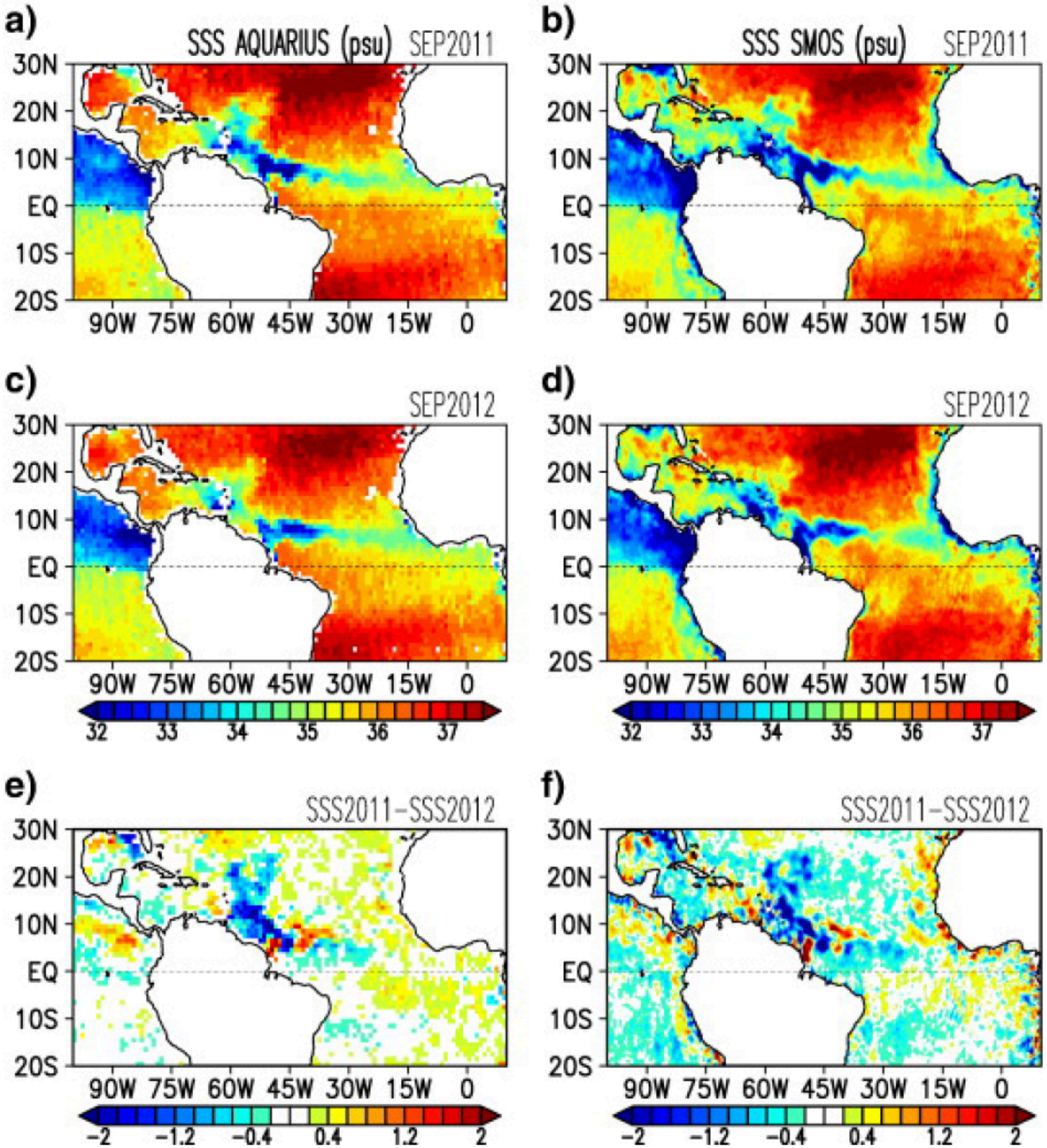
- Freshwater flux Monitoring
(precipitation induced signals, river run off)

Satellite SSS monitors variability of river discharges: Amazone and Orinoco River Plumes



Reul et al., Surv. Geophys., 2014

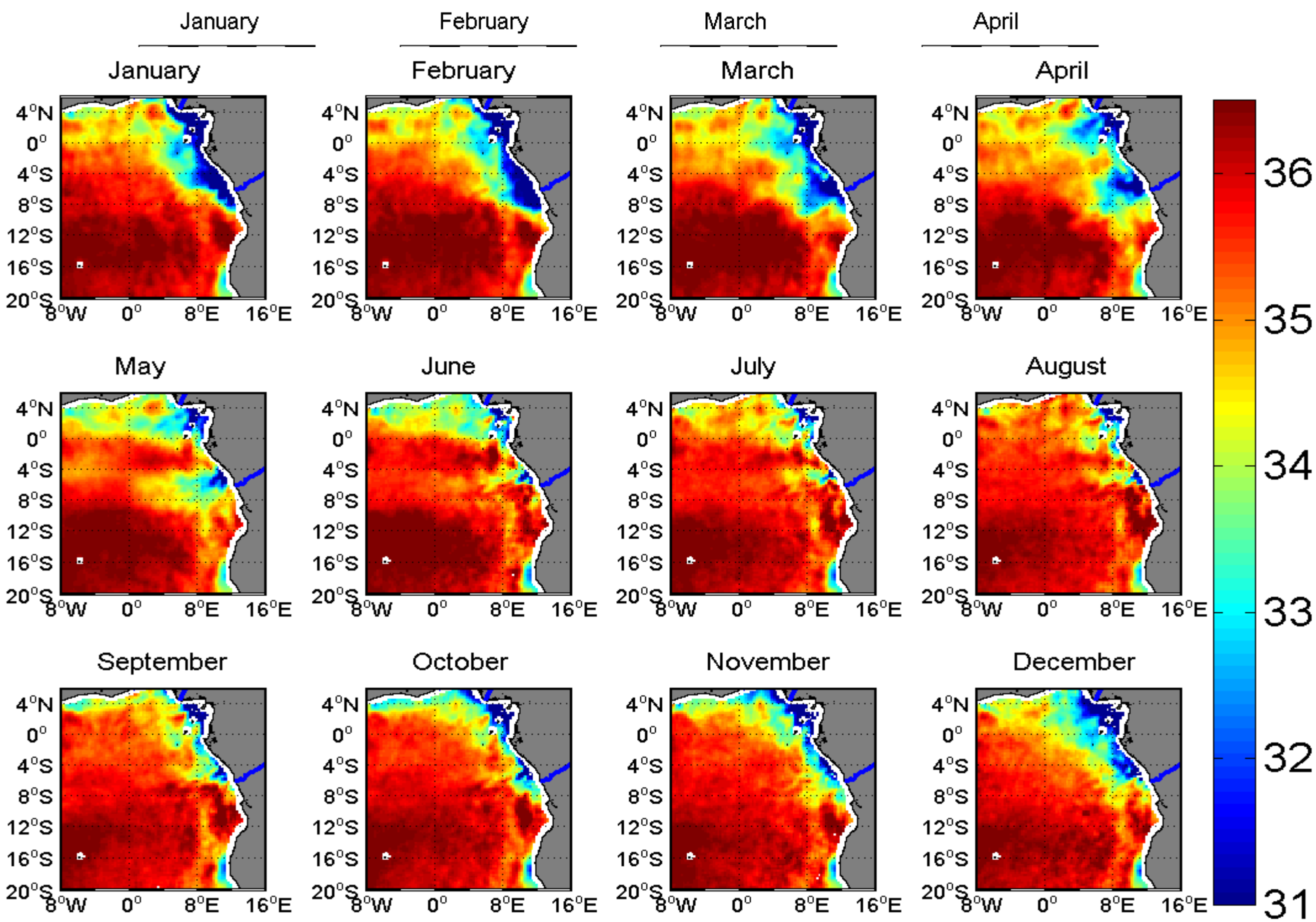
Variability of the Amazon plume: not only an effect of river discharge



The plume was 1 psu saltier in early fall 2012 than in the previous fall (despite a stronger Amazon discharge in 2012) - The most likely causes of the 2012 salinification are **a relative deficit of rainfall** over the inflow to the plume region well southeast of the plume in spring and a weaker North Brazil current in spring–summer.

Grodsky et al. RSE 2014

Monitoring the Congo river Plume Mean Seasonal Cycle



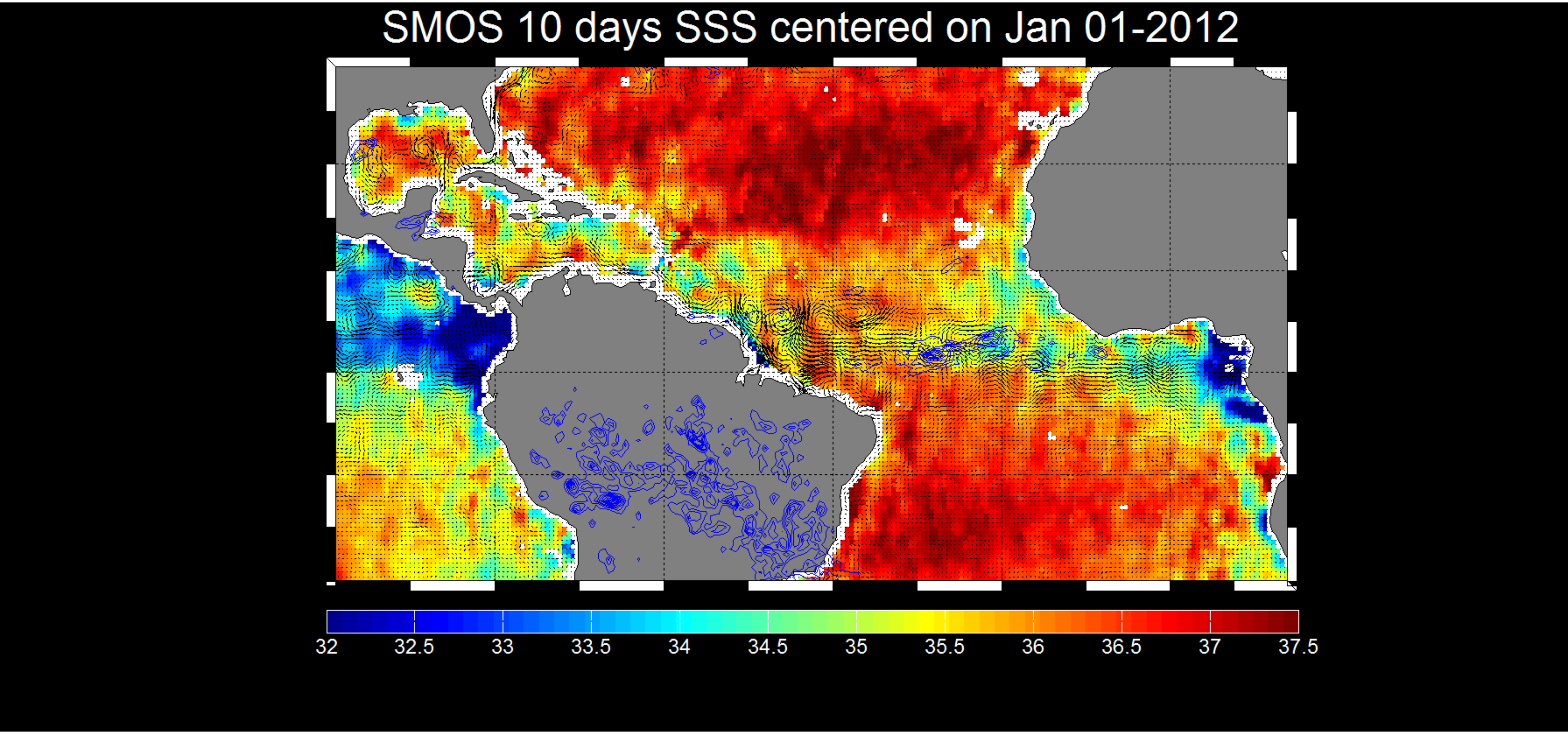
SMOS data collected during the period 2010-2012

Hopkins et al., RSE, 2013

Reul et al.,
Rev Geophys 2014

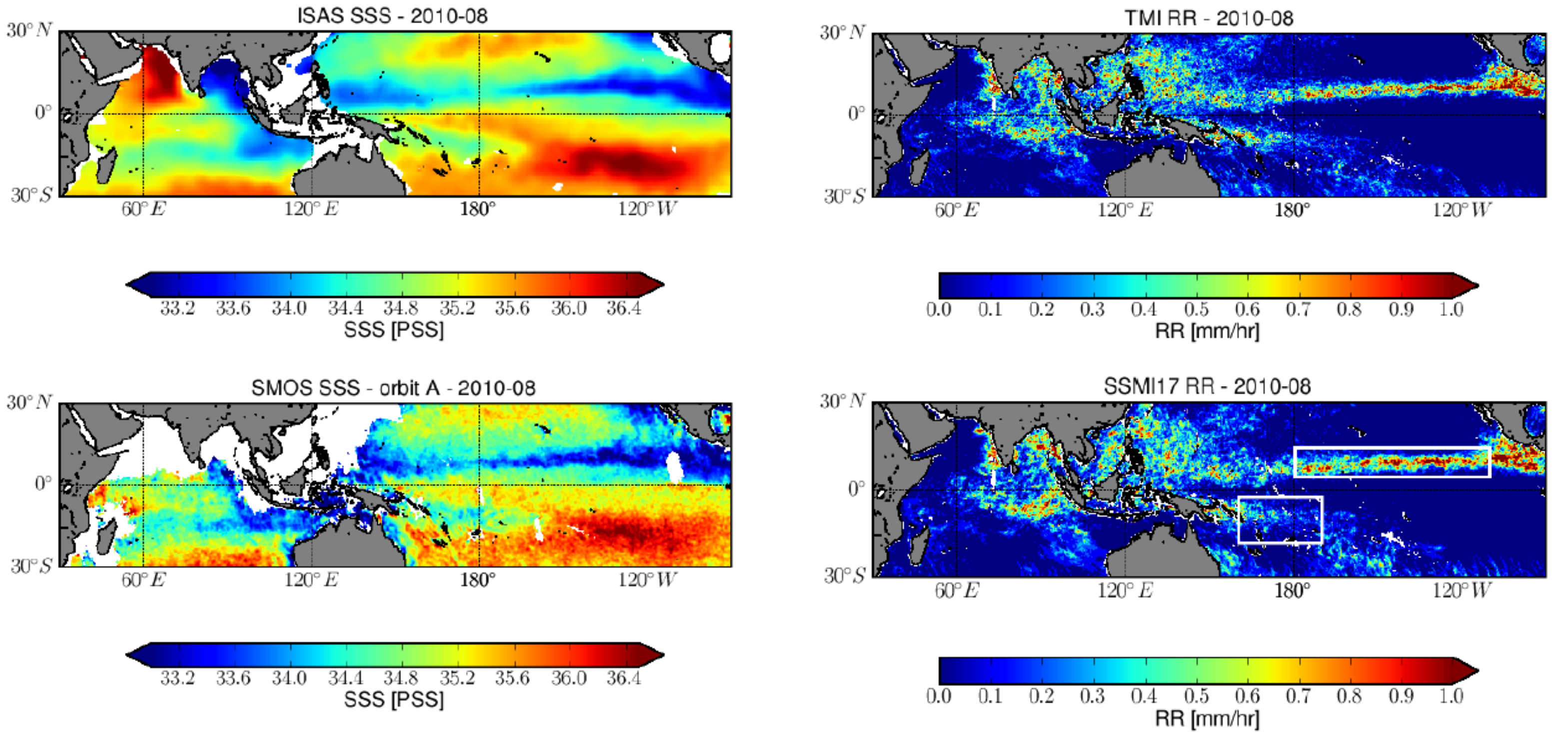
SMOS data now allow the regular monitoring of the seasonal & interannual variability in the discharge & advection of freshwater river plumes into the ocean

Precipitation Signatures in Satellite SSS



SMOS SSS= color background fields
Oscar currents= arrows
Blue contours=TRMM 3B42 rain rate

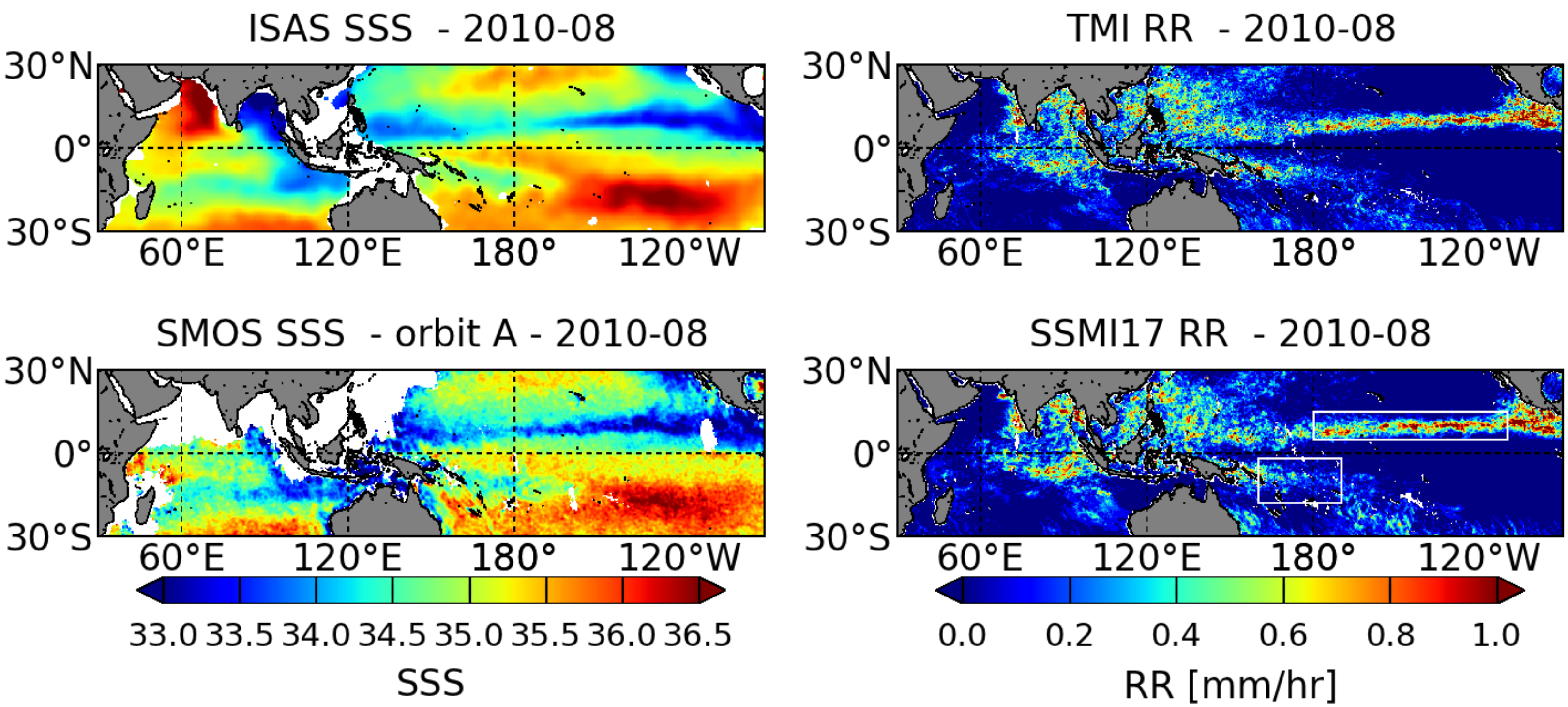
Impact of Rain on SMOS SSS



Boutin et al. (2014), JGR Oceans

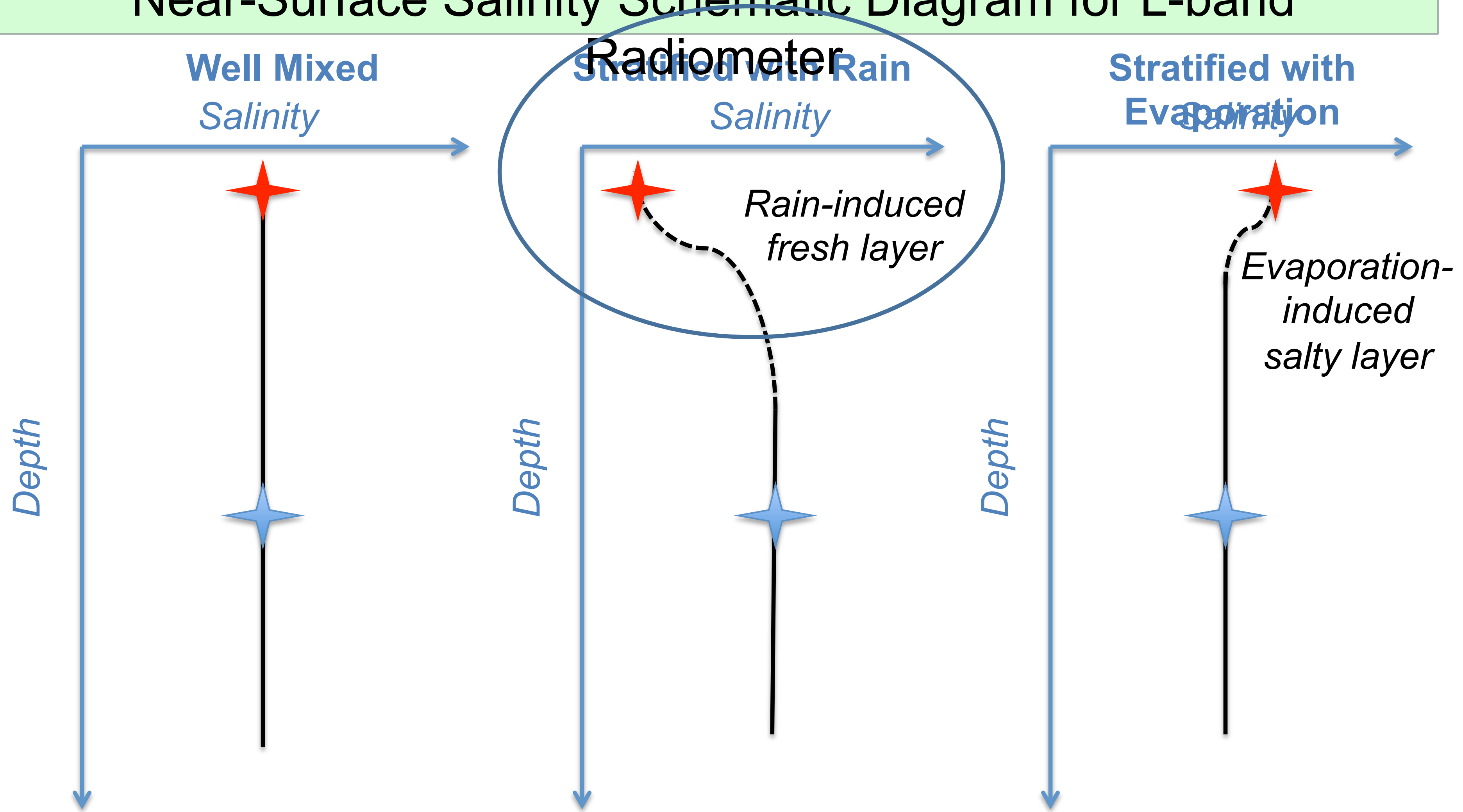
Through its links with Precipitations, SMOS salinity data provide a new tool to **better characterize the increase in the marine tropical hydrological cycle strength**

Impact of Rain on SMOS SSS



SMOS SSS lower than ARGO optimal Interpolated SSS maps in rainy regions (e.g. ITCZ, SPCZ..) : what part of this difference explainable by rain stratification/intermittency?

Near-Surface Salinity Schematic Diagram for L-band Radiometer



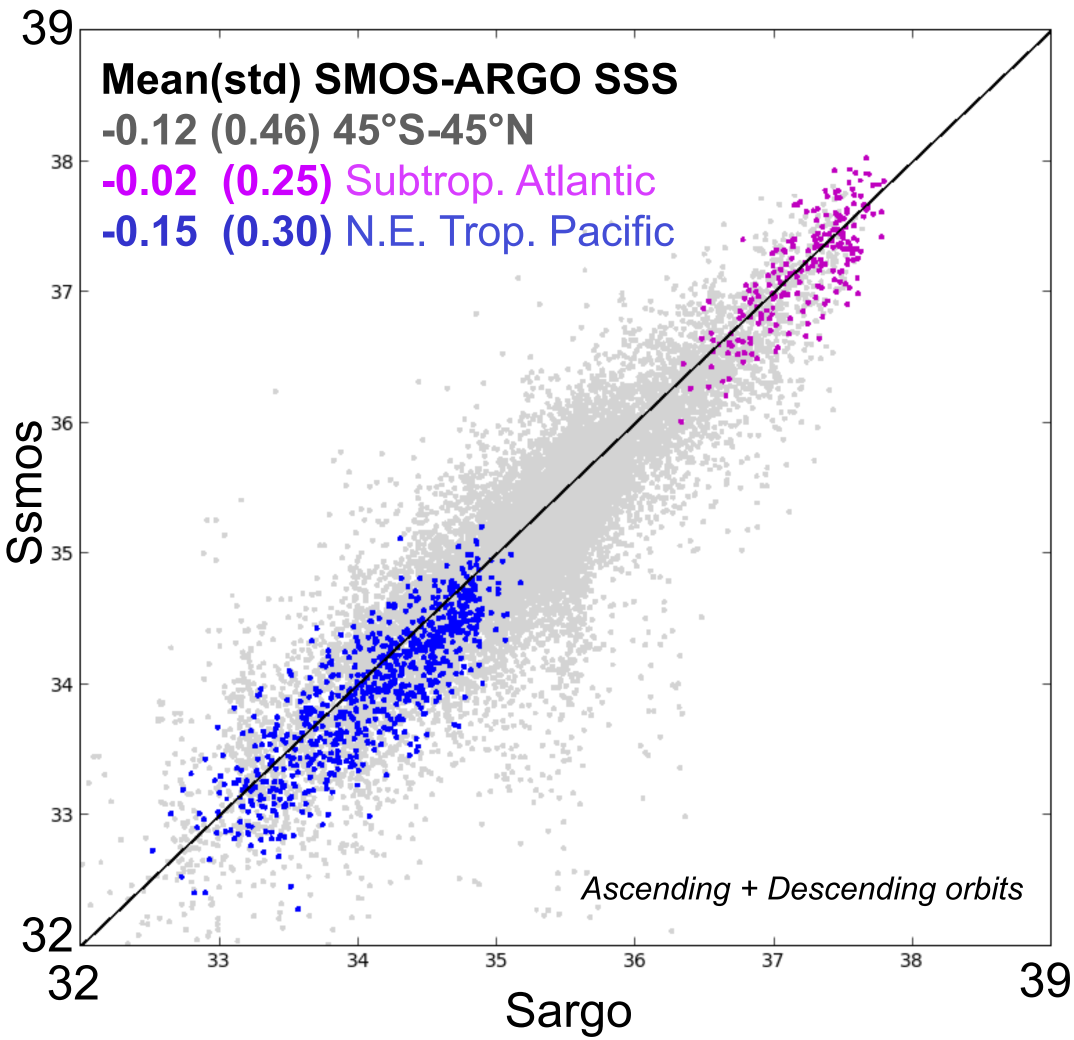
Satellite L-band radiometric salinity at depth range from 1 to 10 cm

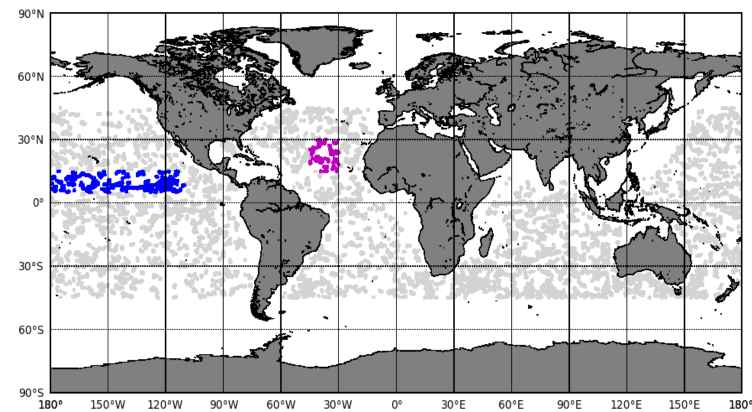
Salinity measured by in situ sensors/platforms at depth below 1 m

Schematic Diagram made by the SISS working gr

SMOS - ARGO (Jul-Sep 2010)

SMOS SSS averaged within +/-50km & +/- 5days around ARGO SSS





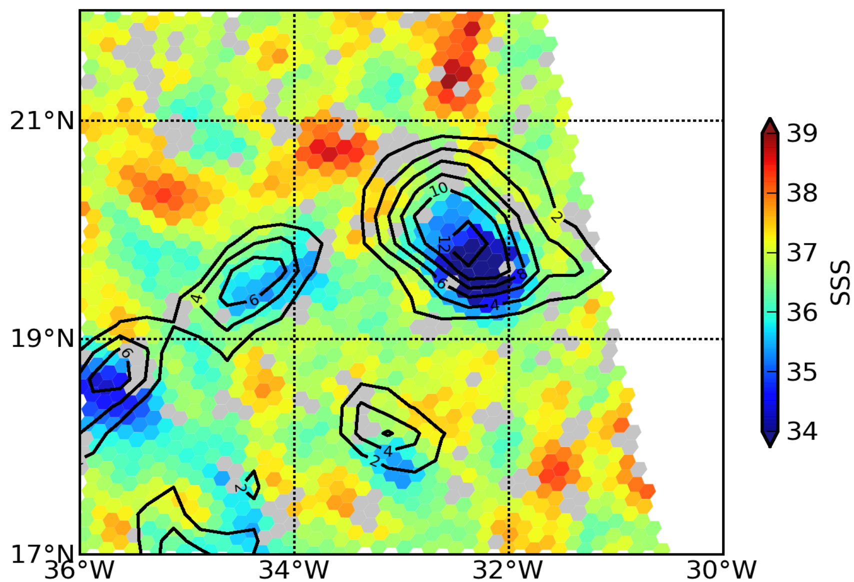
SMOS – ARGO SSS in tropical Pacific 0.1 fresher and <u>more variable</u>
than in subtrop Atlantic;
if SMOS rainy measurements are removed, std_diff in ITCZ and SPURS becomes the same => rain effect in ITCZ

Boutin et al., Ocean Science, 2013

Question

How reliable is the rain induced SSS variability measured by SMOS?

Can we confidently use satellite SSS for studying the influence of rain on sea surface (~1cm) salinity?



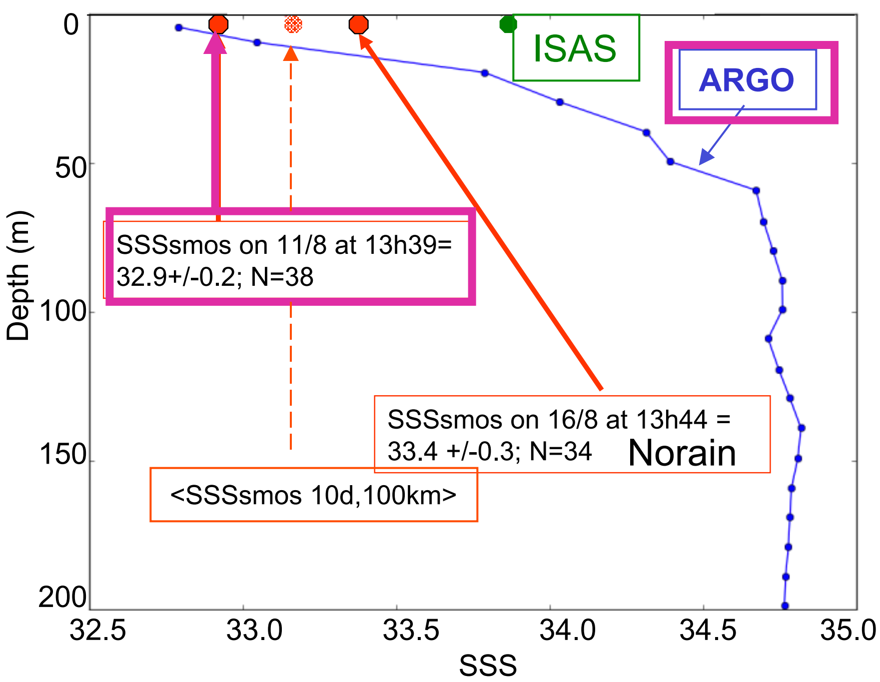
SMOS SSS (color) & SSM/I rain rate (isolines)

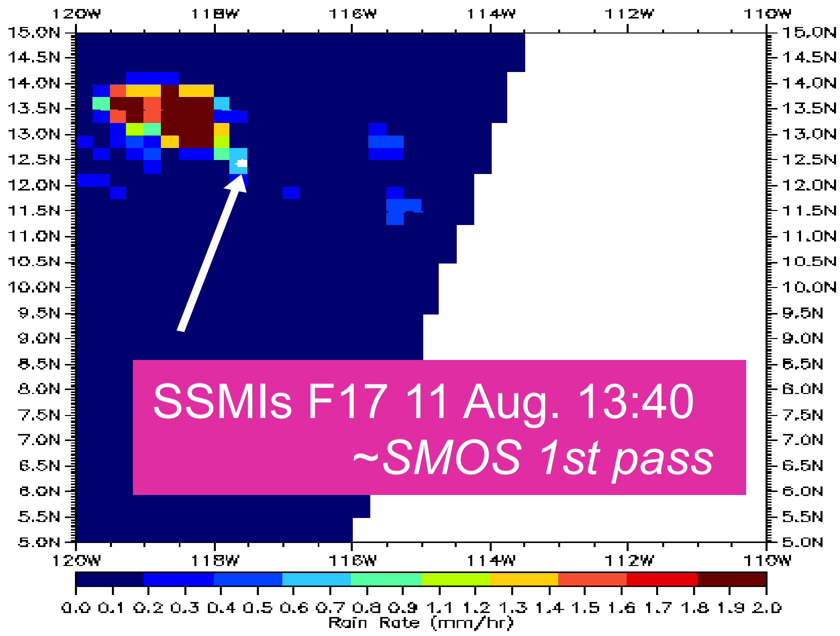
Train-Tsmos =0.5h

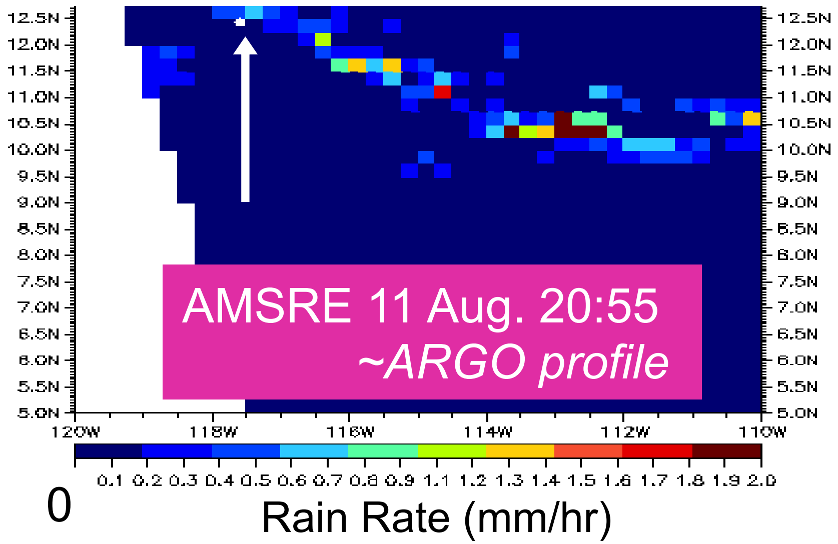
Boutin et al. JGR 2014 in press

Effect of rain on ARGO & SMOS (The closest colocated case)

a) ARGO profile on 11/8 20:00 UTC

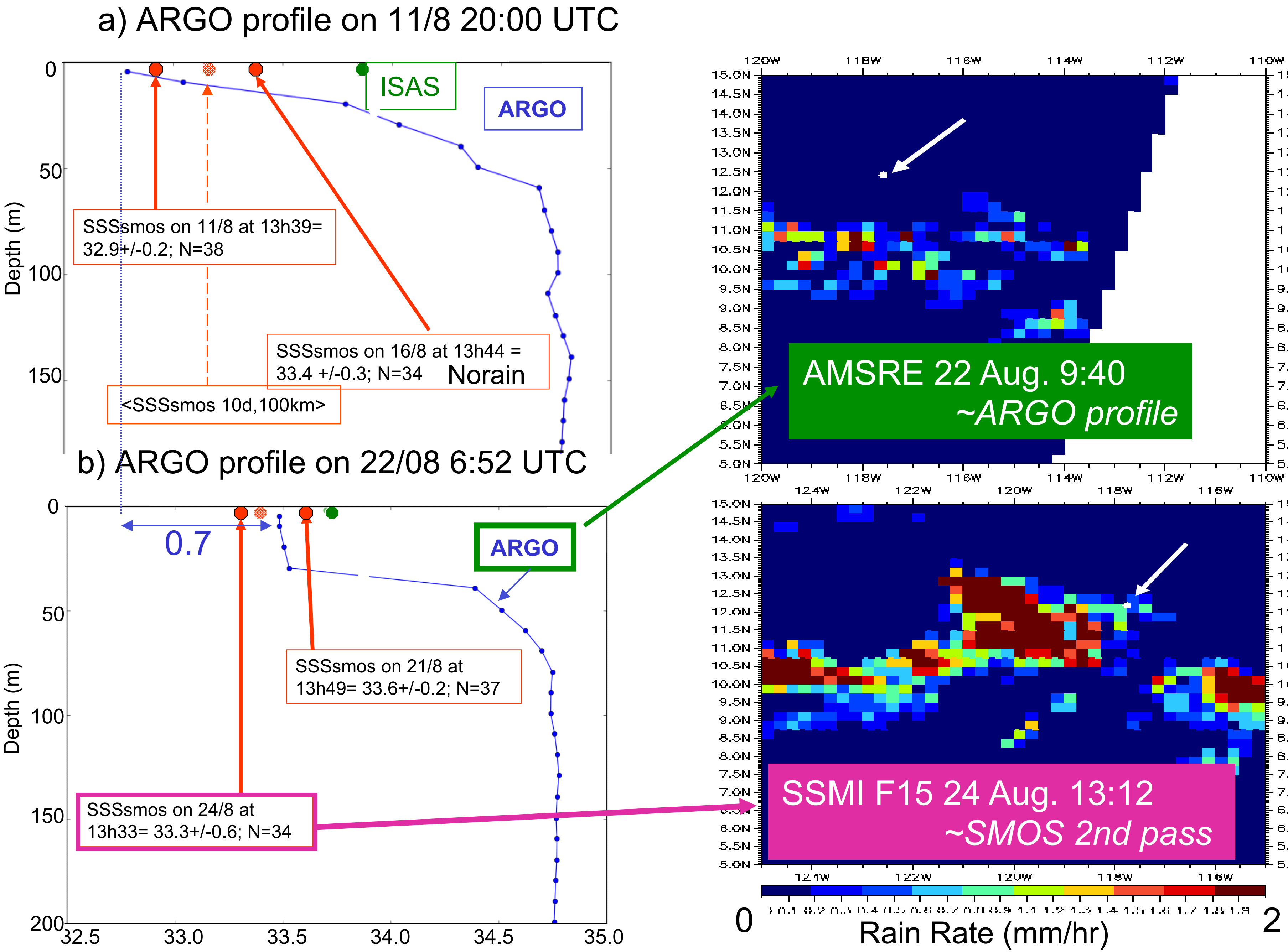






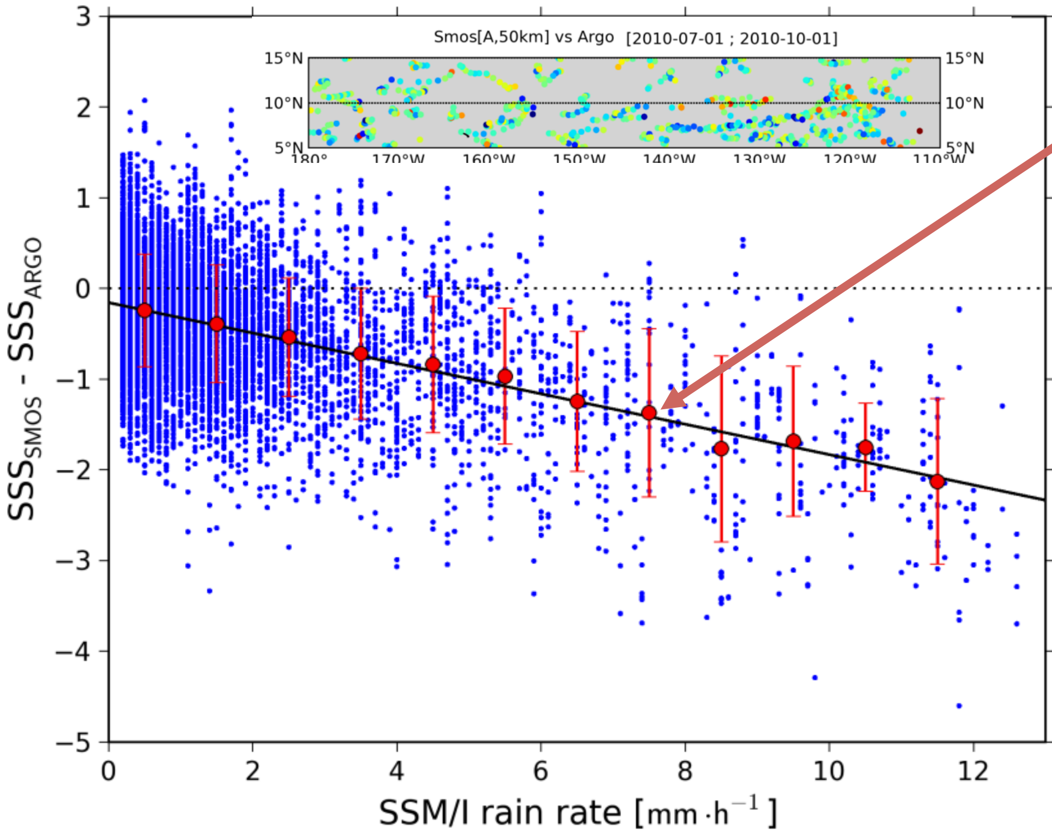
Boutin et al, 2013, Ocean Science

10 days after...

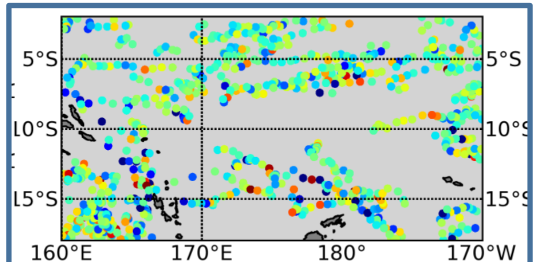


The impact of rain on SMOS SSS
SMOS SSS - ARGO_rainfree*[-2hr;+1hr]* SSS

SMOS SSS- ARGO SSS versus satellite RR
-Sept 2010)



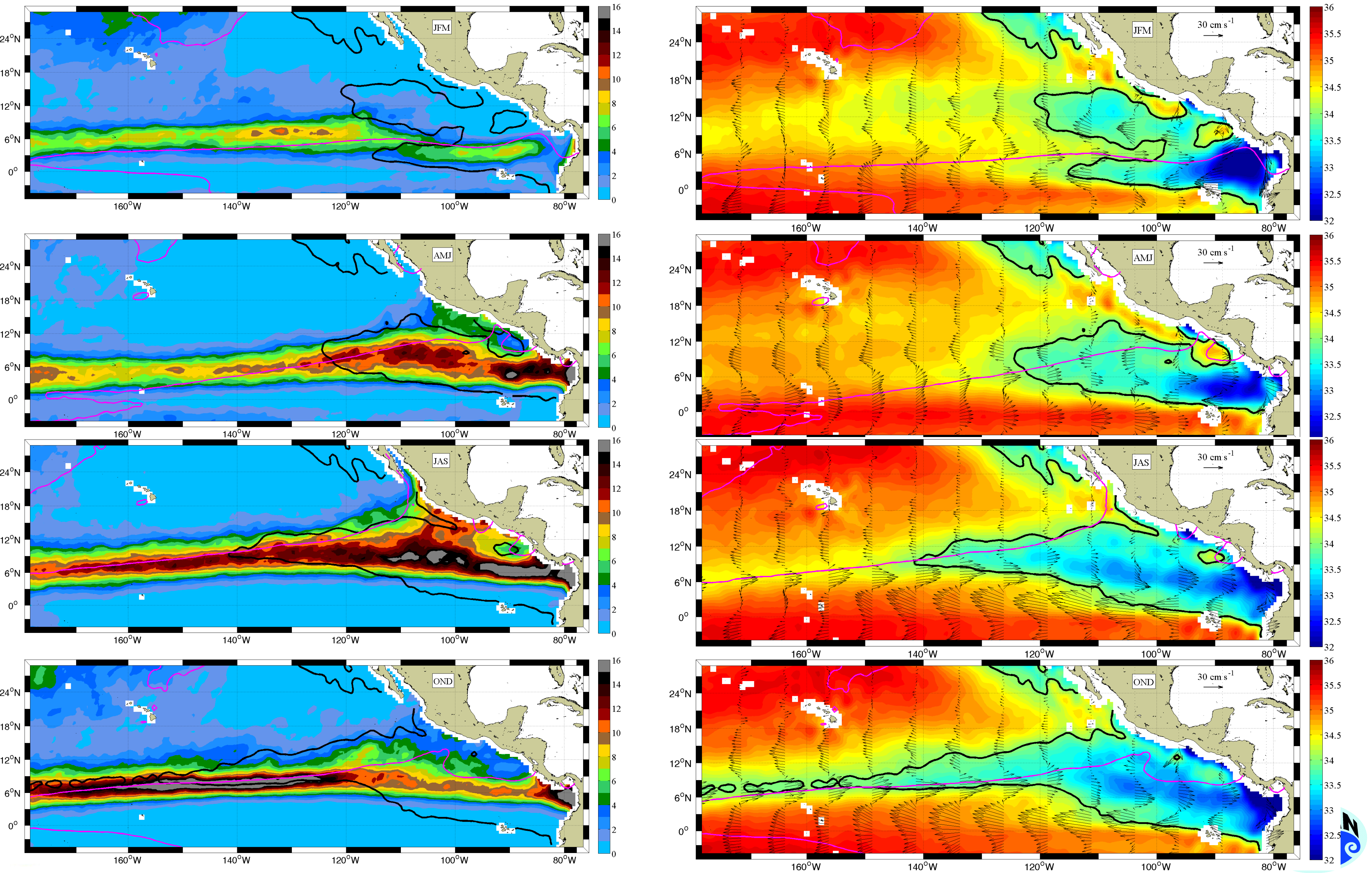
-0.18 pss/ mm/hr
r = -0.5



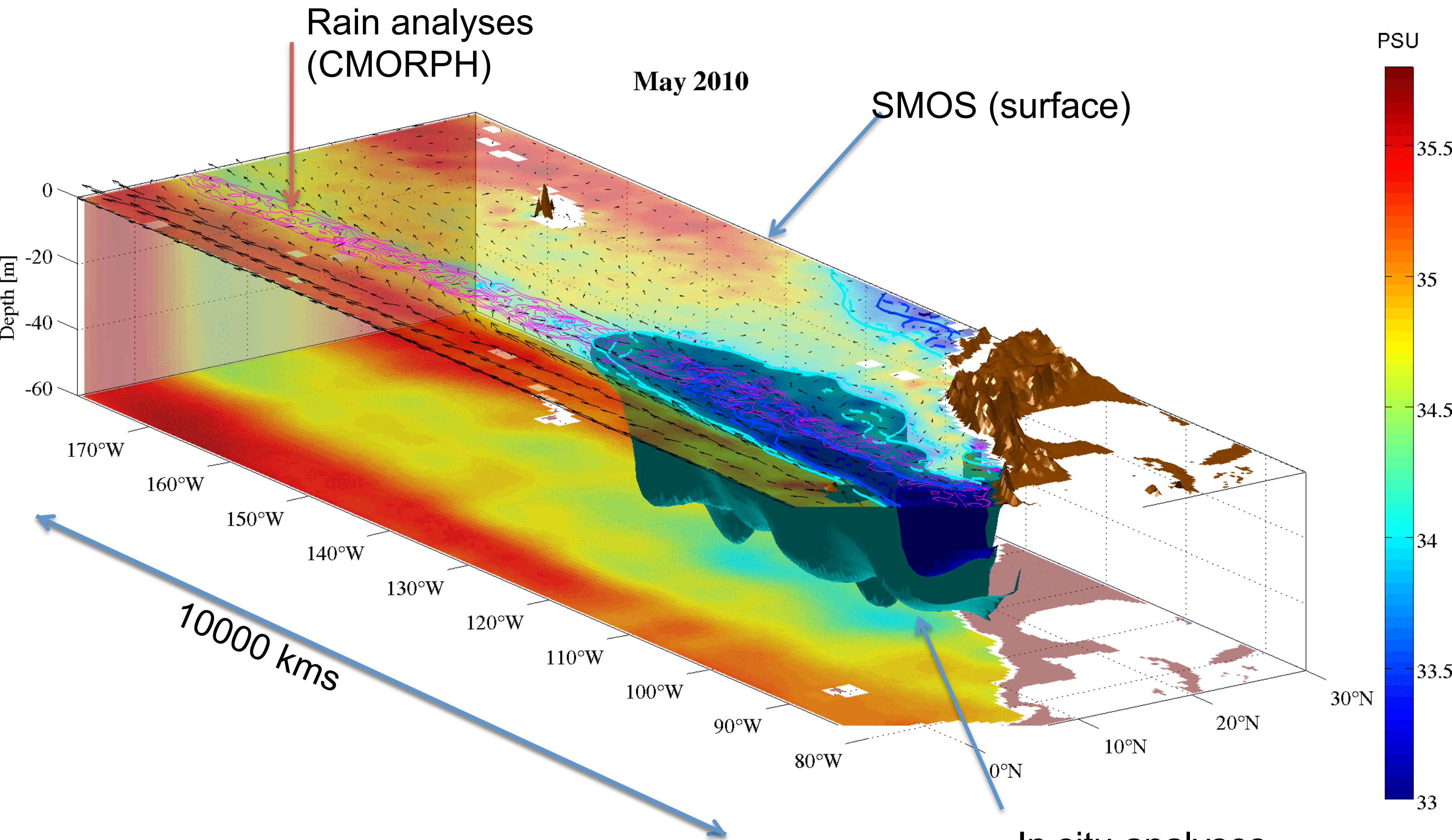
In SW Pac :
-0.22 pss/mm/hr
r = -0.5

Boutin et al, JGR, 2014

Eastern Pacific Freshpool & 3D monitoring of the pool



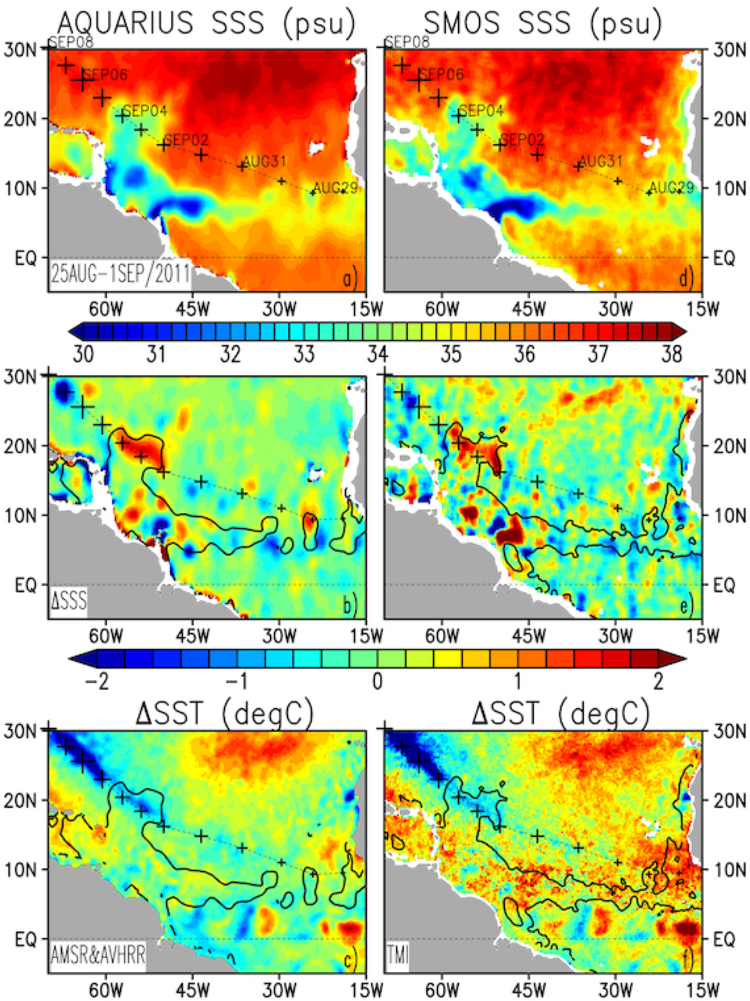
Eastern Pacific Freshpool & 3D monitoring of the pool



See S. Guimbard's talk

- Air-Sea Interactions (hurricanes & Barrier Layers, upwellings)

Haline wake of Hurricanes in the Amazon plume & Impact on Intensification

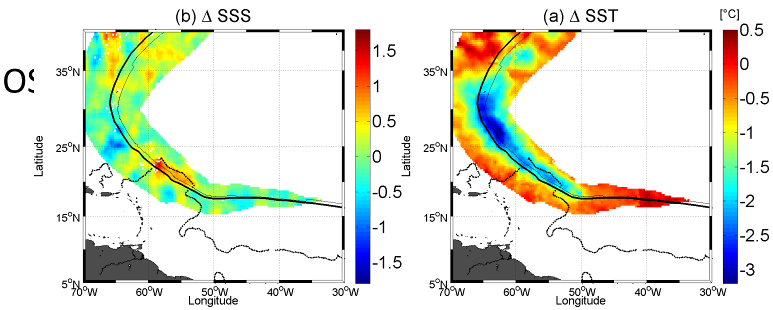


AQUARIUS and SMOS SSS before hurricane Katia (2011). Crosses are the hurricane daily position.

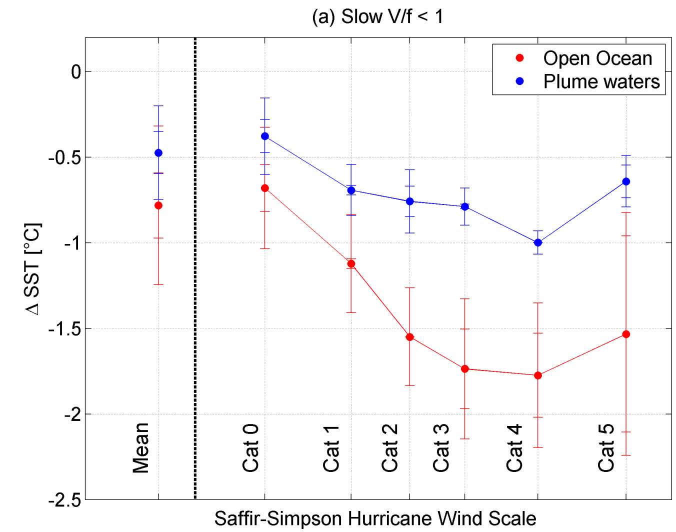
SSS differences after minus before the hurricane passage. 35 psu contour before the passage of Katia is overlain.

SST differences after minus before the hurricane passage.

Grodsky et al., GRL, 2012



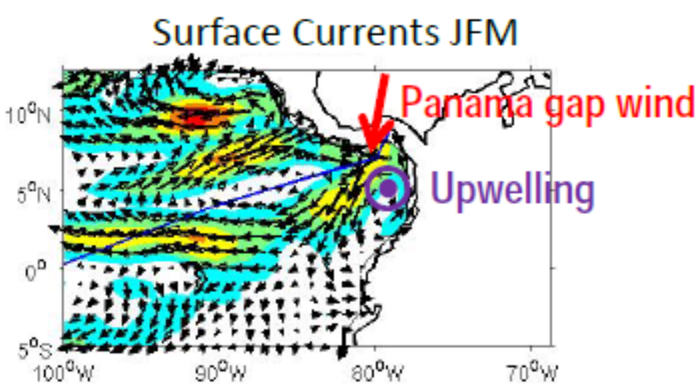
SSS & SST differences after minus before hurricane Igor passage (2010).



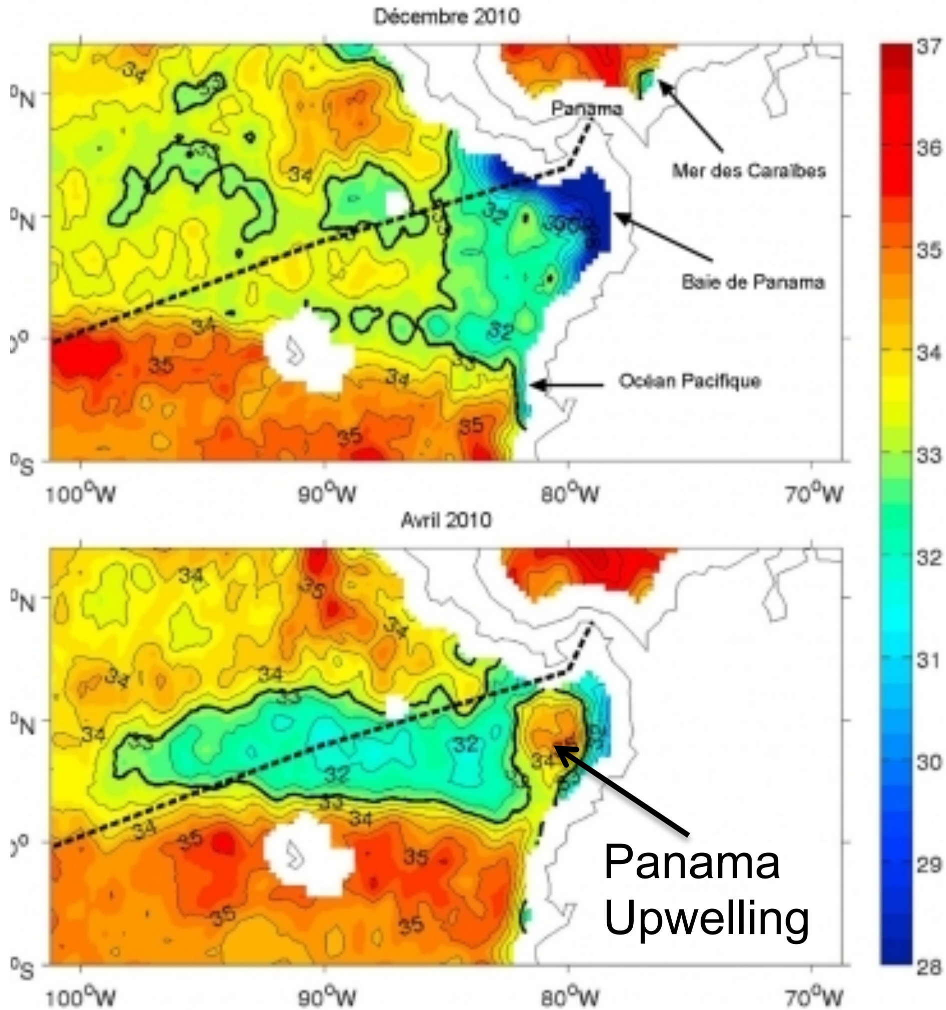
Reduced SST cooling over halocline driven stratification

Reul et al. (2014, JGR)

SSS signal of the Panama Upwelling



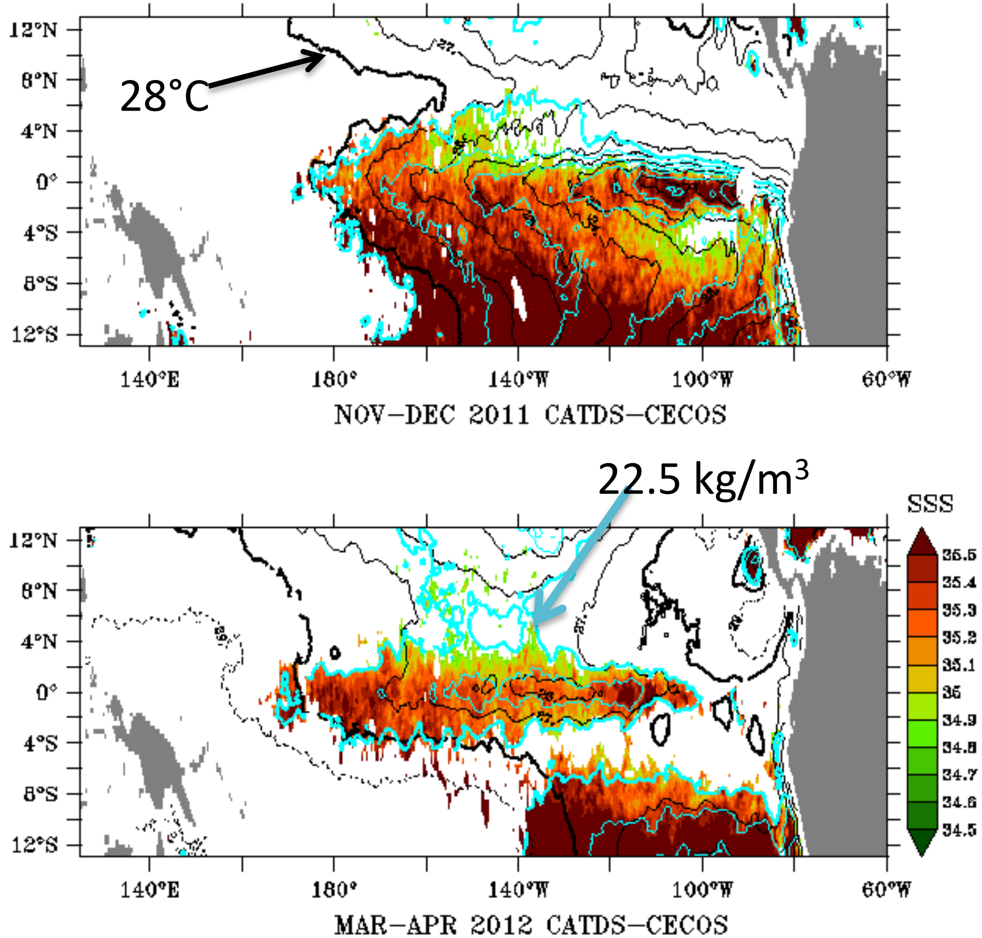
SMOS

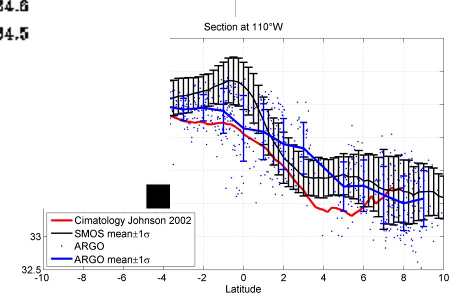


Alory et al, JGR, 2012

The SSS signature of the Pacific Equatorial Cold Tongue as revealed by SMOS

New use of a water density criterion to characterize the cold tongue seasonal cycle





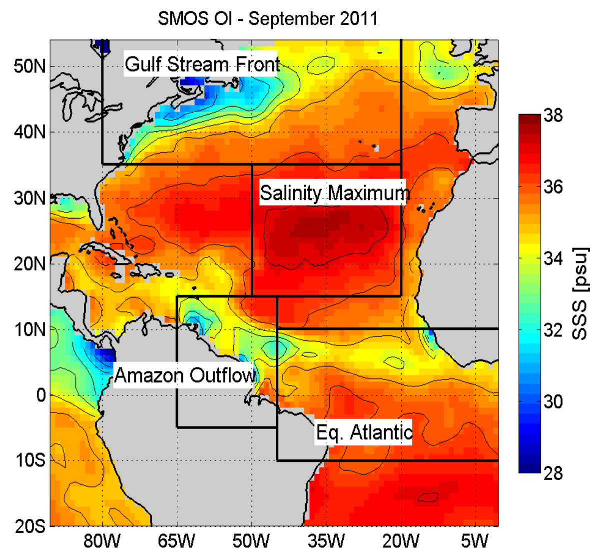
Maes et al., Geoscience Let, 2014

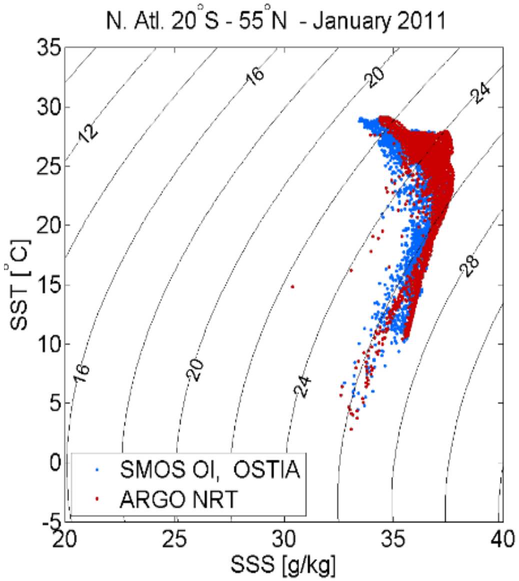
- Temperature-Salinity diagrams
- Thermo-haline circulation/surface density

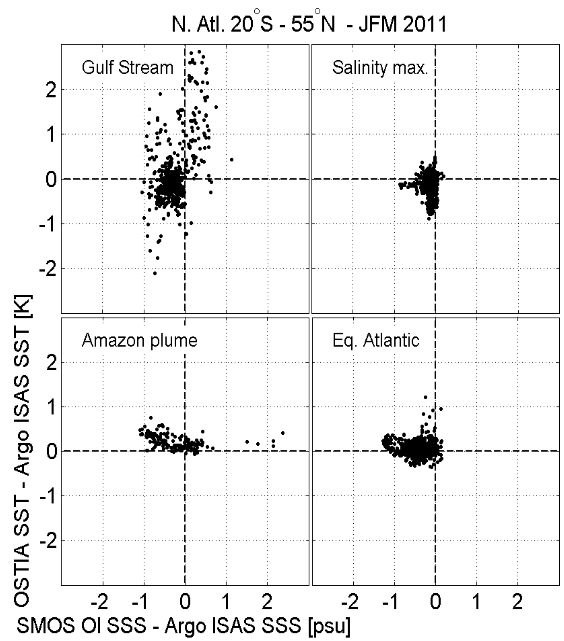
Routinely monitoring SSS-SST diagrams

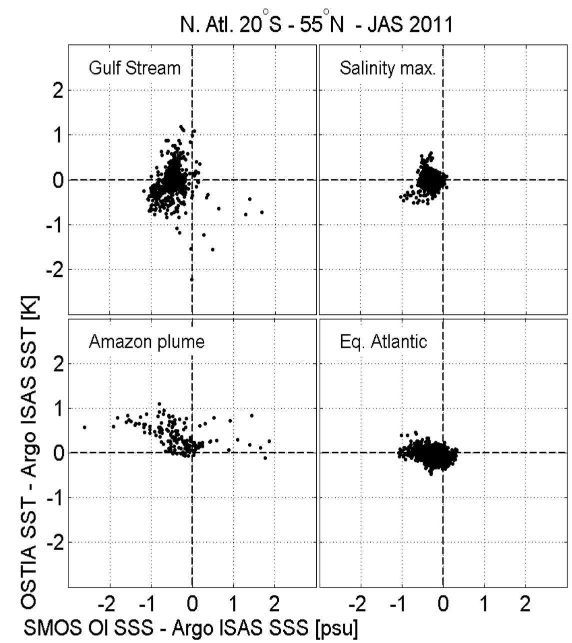
1. Generating routinely satellite-derived surface T-S diagrams, obviating the lack of extensive sampling of the surface open ocean
2. Displaying the T-S diagrams variability and the distribution/ dynamics of SSS, altogether with SST and the relative density with respect to in-situ measurements

Sabia et al., JGR, 2014, SMOS-Aquarius special issue

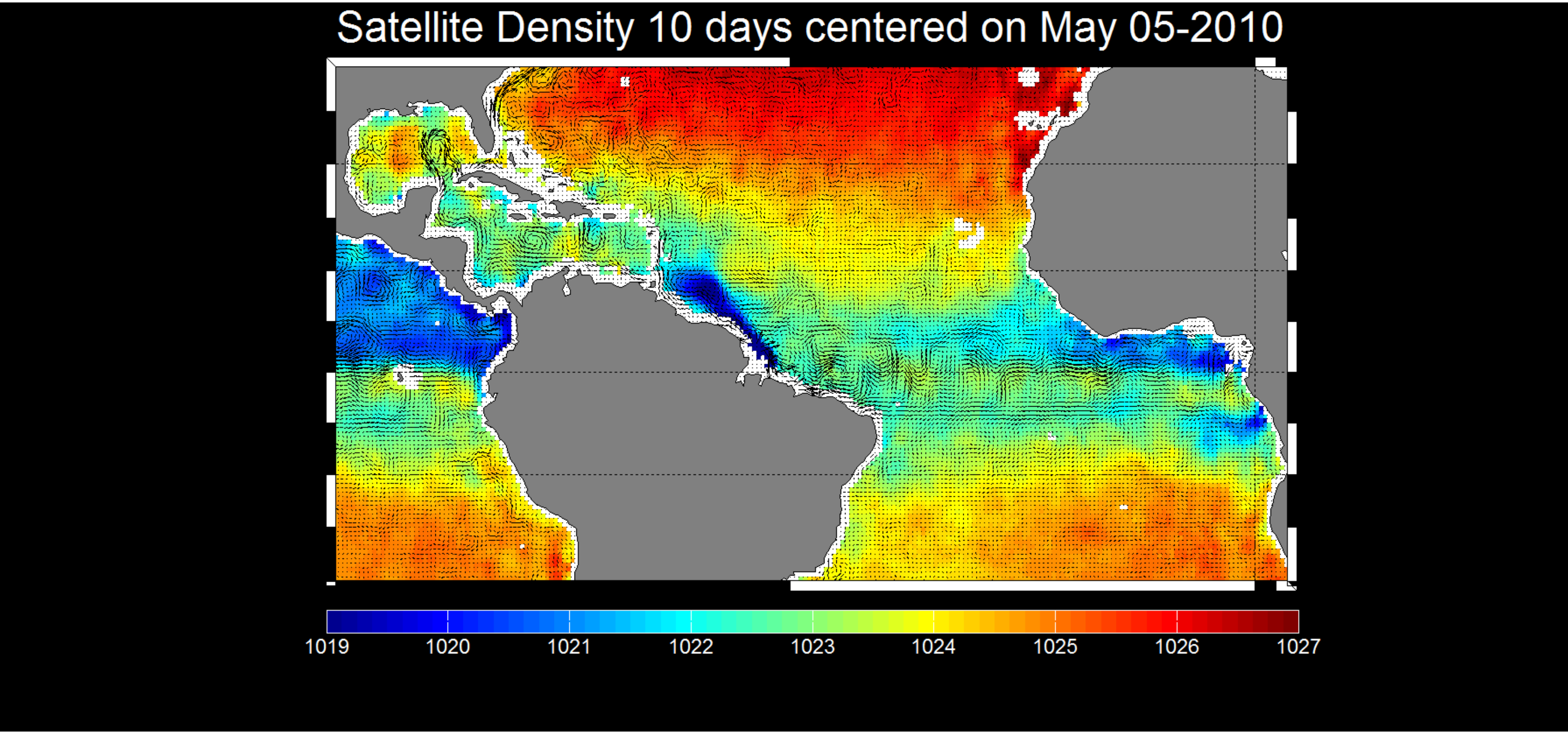








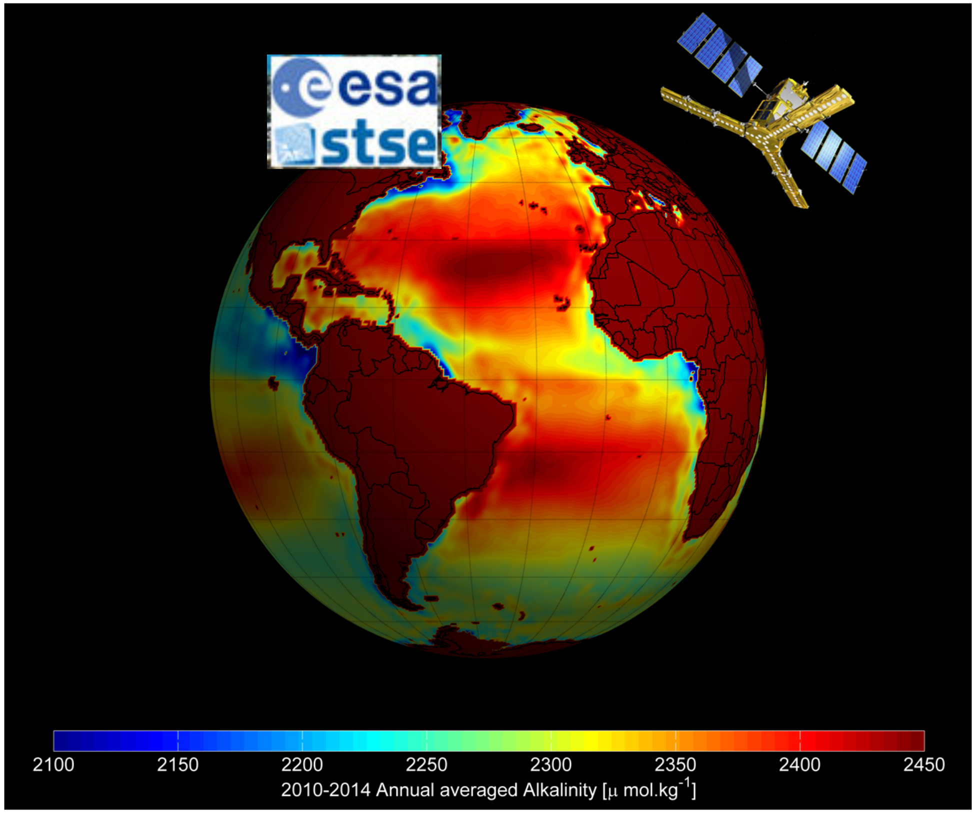
Monitoring surface density variability (50 km/10 days) from satellite SSS & SST



First time mapping of Satellite Sea surface Density variability
made possible thanks to SMOS SSS=> key for thermo-haline circulation

- Bio-Chemistry

SSS used in synergy to monitor ocean Alkalinity



Land et al., *Environmental Science & Technology,* 2015

Alkalinity=function(SSS,SST)
(Lee et al, 2006)

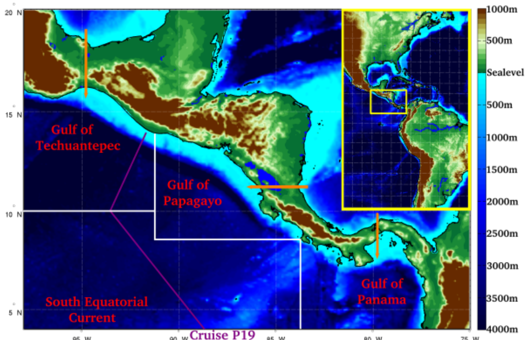
Lee et al. (2006) A_T***algorithms:***
Regionally variable slope and intercept parameters (see Lee et al. [2006] for details) for the following algorithm:

$$A_T = a + b(SSS - S) + c(SSS - S)^2 - d(SST - T) + e(SST - T)^2$$

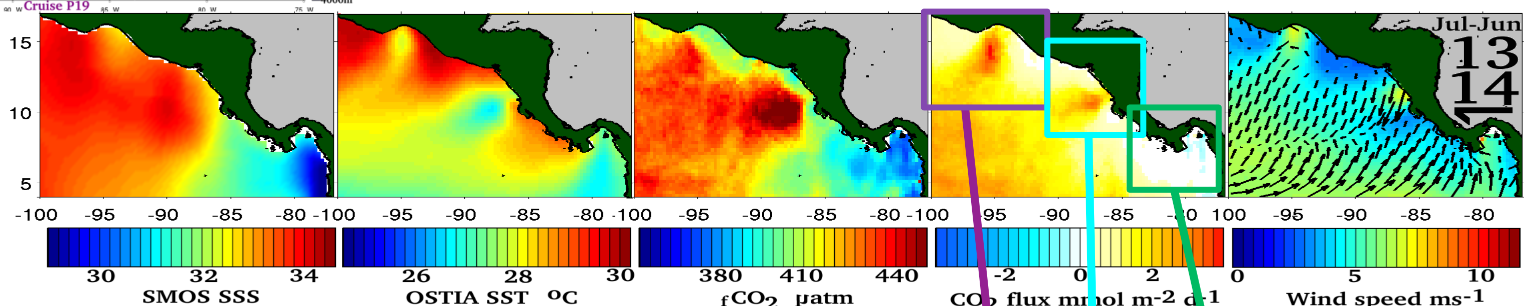
Salinity data are key for assessing the marine carbonate system, and new space-based salinity measurements will enable the development of novel space-based ocean acidification assessment. As the carbon cycle is dominantly controlled by the balance between the biological and solubility carbon pumps, innovative methods to exploit existing satellite sea surface temperature and ocean color, and new satellite sea surface salinity measurements, are needed and will enable frequent assessment of ocean acidification parameters over large spatial scales.

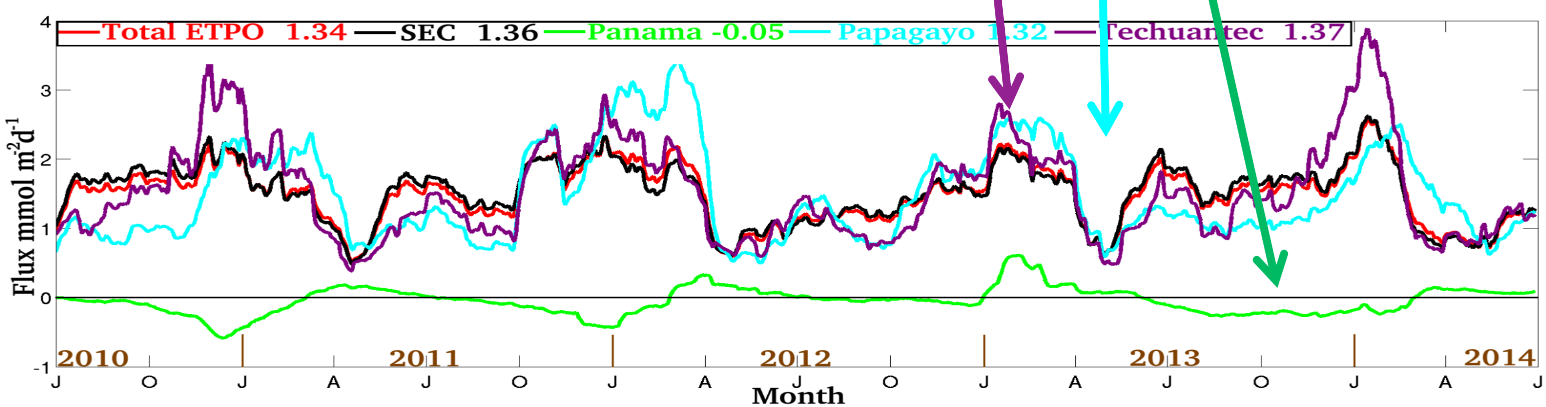
New insights of pCO₂ variability in the tropical eastern Pacific Ocean using SMOS Salinity

C W Brown, J Boutin, L Merlivat, LOCEAN Paris



A quantitative analysis of the opposite effects **of local upwellings and rainfall** on the variability of surface ocean CO_2 partial pressure and of the **air-sea CO_2 flux.**



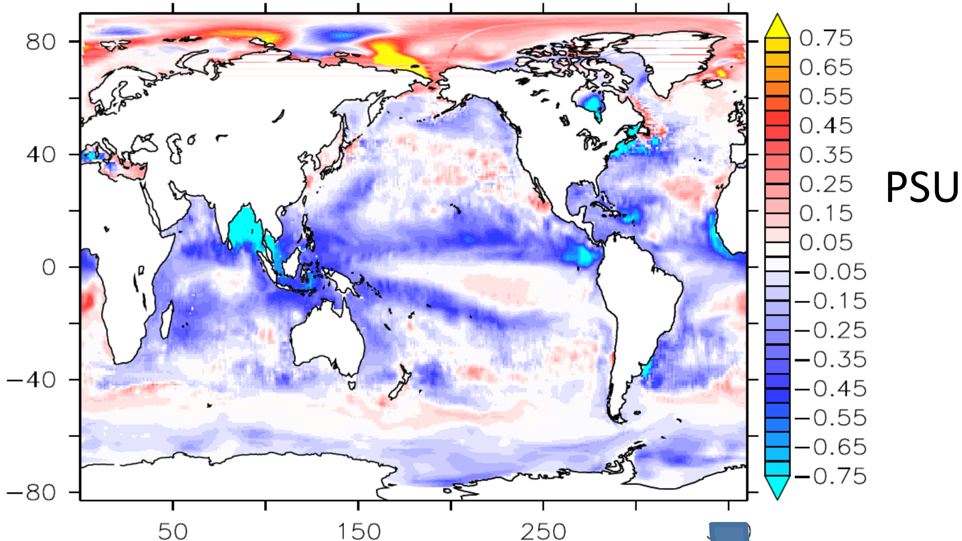


Brown et al. 2015, New insights of pCO_2 variability in the tropical eastern Pacific Ocean using SMOS SSS, Biogeoscience Discussion.

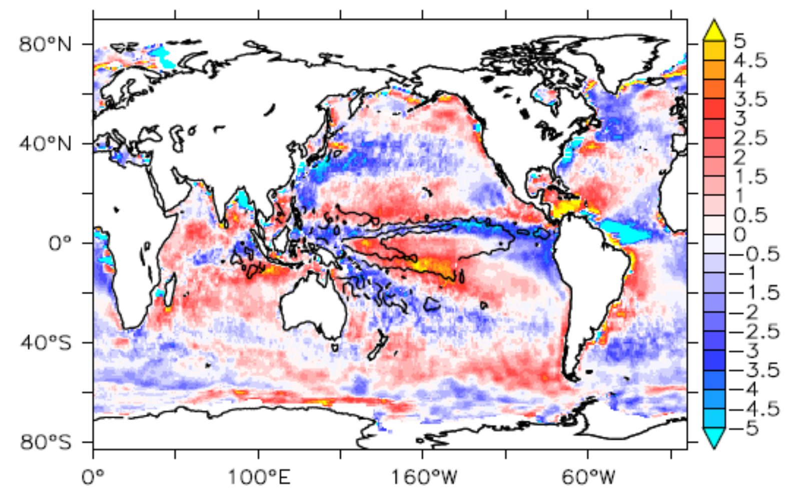
- Ocean Circulation Modeling

Testing the impact of assimilating satellite SSS data

Surface salinity difference
(SMOS assimilated minus not assimilated)
(2010–2011 mean)



Change in E-P (mm/d)



GECCO2/MIT ocean circulation Model
A. Köhl, University of Hamburg, 2014

Major impact in high precipitation & river runoff zones

First tests => importance of careful caracterization of errors and mixed layer physics

Köhl et al., (2014) **Impact of assimilating surface salinity from SMOS on ocean circulation estimates, JGR. Oceans**

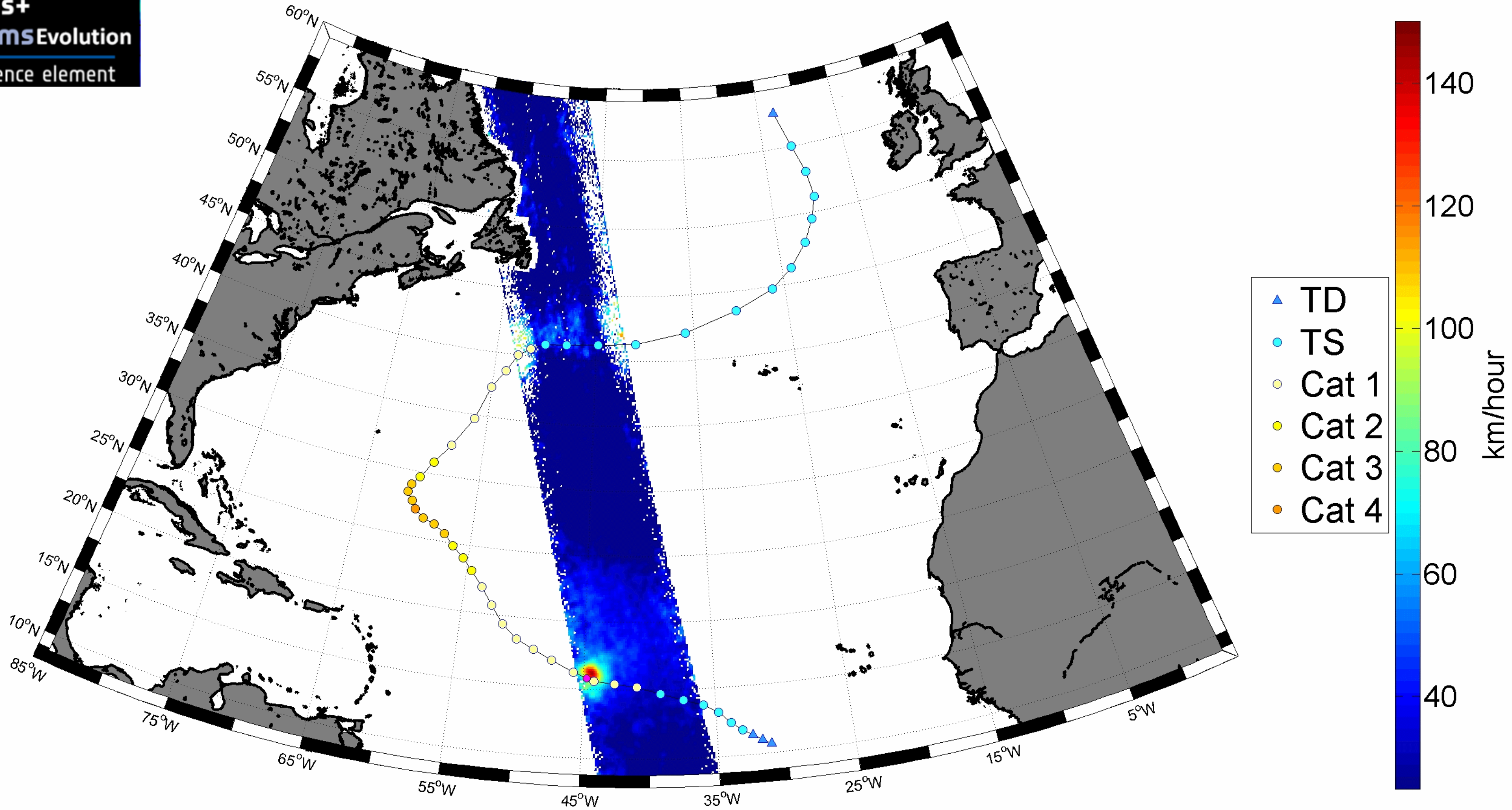
❑High-Surface wind remote sensing

Surface Wind Speed Monitoring in Tropical Cyclones

Atmosphere is almost transparent to L-band radiation
SMOS offer a unic opportunity to **monitor ocean surface properties in extreme wind conditions** for which scatterometry & passice microwave at higher frequencies are inadequate

smos+ stormsEvolution support to science element

Hurricane Danielle-2010/08



SMOS Wind speed -2010/08/24 at -08:09 UTC

Reul et al, JGR, 2012

Summary

- SMOS have brought significant new understanding to intraseasonal variability in the ocean associated with mesoscale eddies & TIWs that are important to ocean dynamics, climate variability, and biogeochemistry.

- SMOS SSS demonstrates complementarity with other observing systems (e.g., SST & SSH, CHl, in situ).

- Demonstrate the ability to monitor the path of large tropical river waters In the ocean & the links with ocean color

- Clearly detected freshening signals associated with high precipitation zones (rain gauge ?)

- New views on air-sea interactions processes such as upwellings and hurricane interacations with fresh-pool barrier layers

- New views on the short space & time scales of the bio-chemistry of the carbonate system (pCO2, alkalinity..)

- New capability to monitor surface wind speed in extreme conditions of Tropical cyclones

- A major strength of satellite SSS relative to in-situ SSS is the ability
  - to estimate spatial gradient, which is critical to the studies of eddy-mean flow interaction and related air-sea interaction.
  - To estimate and "interfacial SSS", proxy of ocean-atmosphere water fluxes
  - To provide in synergy with SST a first view of the surface density variability (thermo-haline circulation)

Future Challenges

- ❑ Data quality homogenization (Land sea contamination, RFI & drift, cold Seas)
- ❑ Multi-sensor synergies (SMOS-Aquarius-SMAP)
- ❑ Ocean Modelling Impact

Some SMOS publications 2014-2015

- Brown, C. W., J. Boutin, and L. Merlivat (2015), New insights of pCO2 variability in the tropical eastern Pacific Ocean using SMOS SSS, *Biogeosciences Discuss.*, *12*(6), 4595-4625, doi:10.5194/bgd-12-4595-2015.
- Fournier Severine, Chapron Bertrand, Salisbury Joseph, Vandemark Douglas, Reul Nicolas Comparison of spaceborne measurements of sea surface salinity and colored detrital matter in the Amazon plume. Journal of Geophysical Research - Oceans IN PRESS. http://dx.doi.org/10.1002/2014JC010109.
- Kolodziejczyk, N., O. Hernandez, J. Boutin, and G. Reverdin (2015), SMOS salinity in the subtropical north Atlantic salinity maximum. Part II: Horizontal thermohaline variability, J. Geophys. Res. Oceans, 120, 972–987, doi: 10.1002/2014JC010103.
- Land P., Shutler J. Findlay H., Girard-Ardhuin F., Sabia R., Reul N., Piolle J.F., Chapron B.,Quilfen Y., Salisbury J., Vandemark D., Bellerby R., Bhadury P. (2015). Salinity from space unlocks satellite-based assessment of ocean acidification. *Environmental Science & Technology*, 49(4), 1987-1994. http://dx.doi.org/10.1021/es504849s
- Boutin, J., N. Martin, G. Reverdin, S. Morisset, X. Yin, L. Centurioni, and N. Reul (2014), Sea surface salinity under rain cells: SMOS satellite and in situ drifters observations, *Journal of Geophysical Research: Oceans*, *119*(8), 5533–5545, doi: 10.1002/2014JC010070.
- Grodsky S., G. Reverdin, J. Carton and V. Coles, 2014. Year-to-year salinity changes in the Amazon Plume: contrasting 2011 and 2012 Aquarius/SACD and SMOS satellite data. Remote Sensing of Environment,140 (2014) 14–22, doi: 10.1016/j.rse.2013.08.033.
- Hasson, A., T. Delcroix, J. Boutin, R. Dussin, and J. Ballabrera-Poy (2014), Analyzing the 2010–2011 La Niña signature in the tropical Pacific sea surface salinity using in situ data, SMOS observations, and a numerical simulation, Journal of Geophysical Research: Oceans, 119(6), 3855-3867, doi:10.1002/2013JC009388.
- Maes C., N. Reul, D. Behringer, and T. O'Kane (2014), The salinity signature of the equatorial Pacific cold tongue as revealed by the satellite SMOS mission, *Geoscience Letters*, 1:17 doi: 10.1186/s40562-014-0017-5.
- Reul N., S. Fournier, J. Boutin, O. Hernandez, C. Maes, B. Chapron, G. Alory, Y. Quilfen, J. Tenerelli, S. Morisset, Y. Kerr, S. Mecklenburg and S. Delwart (2014a), Sea Surface Salinity Observations from Space with SMOS satellite: a new tool to better monitor the marine branch of the water cycle, *Surv in Geophys*, 35:681–722, doi:10.1007/s10712-013-9244-0.

Some SMOS publications 2012-2014

- Reul, N., B. Chapron, T. Lee, C. Donlon, J. Boutin, and G. Alory (2014b), Sea surface salinity structure of the meandering Gulf Stream revealed by SMOS sensor, *Geophys. Res. Lett.,* 41, doi:10.1002/2014GL059215
- Reul, N., Y. Quilfen, B. Chapron, S. Fournier, V. Kudryavtsev, and R. Sabia (2014c), Multisensor observations of the Amazon-Orinoco river plume interactions with hurricanes, *Journal of Geophysical Research: Oceans*, 119(12), 8271-8295, doi: 10.1002/2014JC010107.
- Yin, X., J. Boutin, G. Reverdin, T. Lee, S. Arnault, and N. Martin (2014), SMOS Sea Surface Salinity signals of tropical instability waves, Journal of Geophysical Research: Oceans, 119(11), 7811-7826, doi:10.1002/2014JC009960.
- Boutin, J., N. Martin, G. Reverdin, X. Yin and F. Gaillard (2013), Sea surface freshening inferred from SMOS and ARGO salinity: Impact of rain, *Ocean Science, 9*, 183-192, doi: 10.5194/os-9-183-2013.
- Durand Fabien, Alory G., Dussin R., Reul N. SMOS reveals the signature of Indian Ocean Dipole events. Ocean Dynamics, 2013.
- Hasson, A., T. Delcroix, and J. Boutin (2013), Formation and variability of the South Pacific Sea Surface Salinity maximum in recent decades, Journal of Geophysical Research: Oceans, 118(10), 5109-5116, doi:10.1002/jgrc.20367.
- Hopkins, Jo; Lucas, Marc; Dufau, Claire; Sutton, Marion; Stum, Jacques; Lauret, Olivier; Channelliere, Claire. 2013 Detection and variability of the Congo River plume from satellite derived sea surface temperature, salinity, ocean colour and sea level. *Remote Sensing of Environment*, 139. 365-385. 10.1016/j.rse.2013.08.015
- Maes C., B. Dewitte, J. Sudre, V. Garçon, and D. Varillon (2013) : Small-scale features of temperature and salinity surface fields in the Coral Sea, *Journal of Geophysical Research: Oceans*, 118, 5426–5438, doi: 10.1002/jgrc.20344.
- Grodsky, S. A., N. Reul, G. Lagerloef, G. Reverdin, J. A. Carton, B. Chapron, Y. Quilfen, V. N. Kudryavtsev, and H.-Y. Kao (2012), Haline hurricane wake in the Amazon/Orinoco plume: AQUARIUS/SACD and SMOS observations, Geophysical Research Letters, 39(20), L20603, doi:10.1029/2012GL053335.
- Alory, G., C. Maes, T. Delcroix, N. Reul, and S. Illig (2012), Seasonal dynamics of sea surface salinity off Panama: The Far Eastern Pacific fresh pool, *J. Geophys. Res.*, 117, C4, doi:10.1029/2011JC007802.