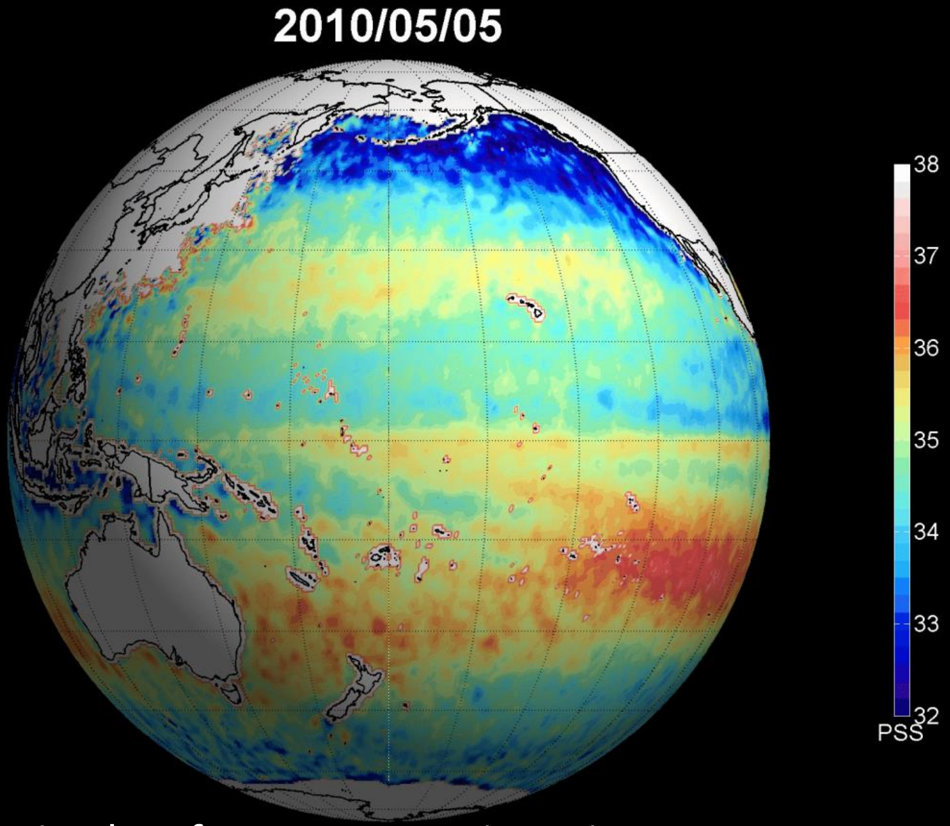
8 Years of Ocean Observations from SMOS satellite

An overview

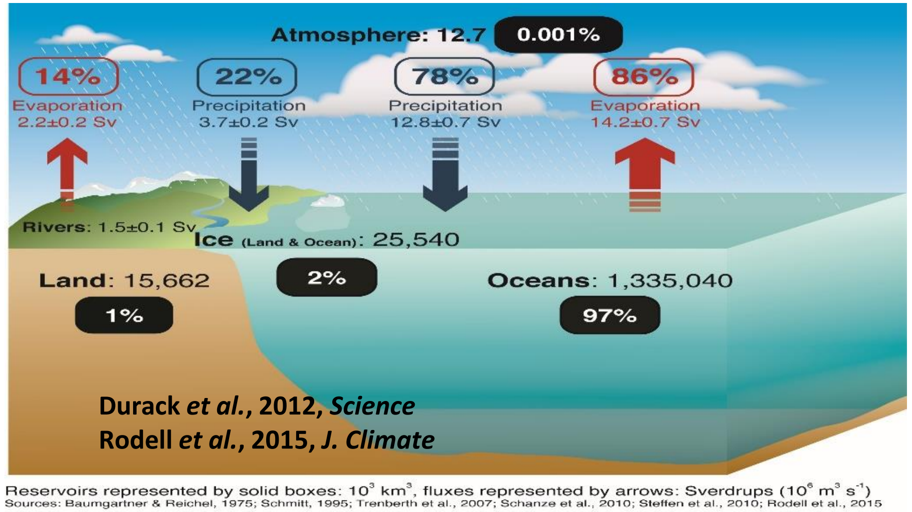
Nicolas Reul, IFREMER/LOPS
and the SMOS-OCEAN team



ECMWF/ESA workshop on using low frequency passive microwave measurements in research and operational applications, 4-6 Dec 2017

Why measuring sea surface salinity?
1- A tracer of freshwater fluxes and ocean circulation

- Insights into freshwater fluxes (precipitation, evaporation, runoff, freezing and melting of ice).Global oceans are the engine room of the **water cycle**
- **Ocean circulation**: advection and mixing



2- A strong influence on sea water density & Air-sea exchanges

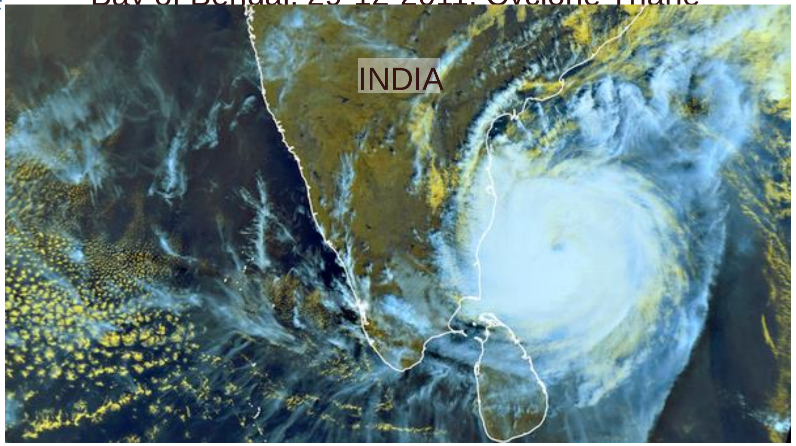
Salinity affects sea water density, which in turn governs **ocean circulation & air-sea exchanges:**

In cold waters (SST=2^{o}C), a **0.1 surface salinity increase** creates the same density change as **a 1^{o}C warming in temperature**

In the tropics (SST=2^{o}C), a **0.4 surface salinity increase** creates the same density change as **a 1^{o}C warming in temperature**

=>Large freshwater fluxes (river, rain) => strong haline stratification at the ocean surface => high SST => cyclones

Bay of Bengal, 29-12-2011, Cyclone Thane



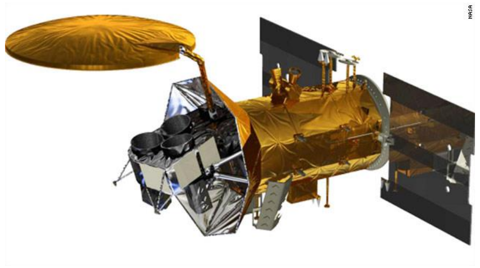
Status of Salinity from space from L-band radiometry

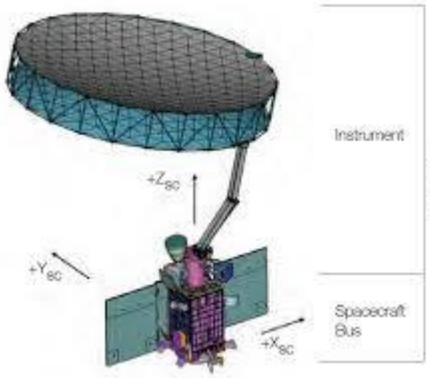
SMOS L-band ESA

Interferometric Radiometer
Spatial res~43 km (30-80 kms)
Swath~1500 km
Revisit-time~2-3 days
Incidence 0°-60°
Full polarization
Launched Nov 2009

Aquarius L-band

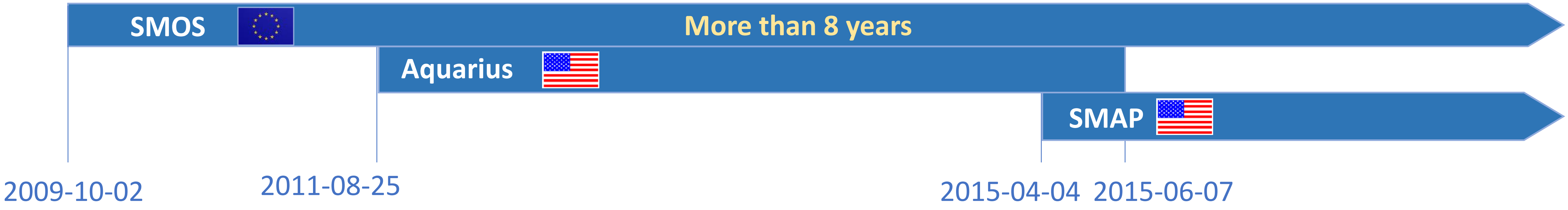
Argentina-USA collaboration (CONAE/NASA)
3 radiometers in the L-Band + 1 scatterometer
Spatial Res~100 km
Swath ~300 km
Revisit time~7 days
Incidence angle: 26°,34° and 40°
Full Polrization
Launched Aug 2011





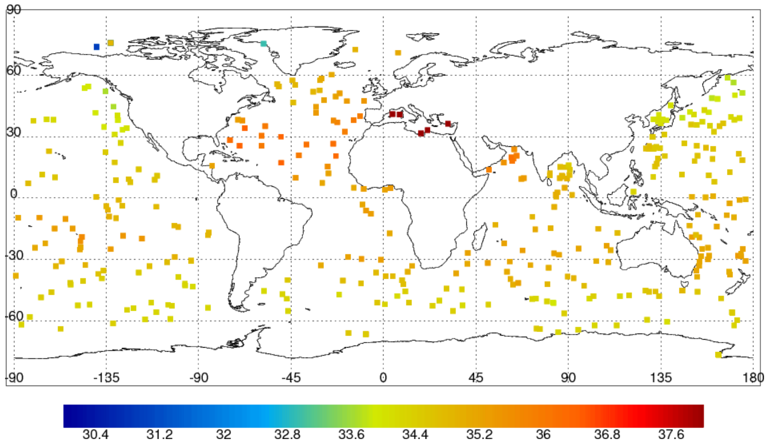
SMAP L-band

Soil Moisture ~~Active~~ Passive
Built at JPL
Radiometer+SAR
Spatial res~40 km
Swath~1000km
Revisit time ~2-3 days
Incidence angle 40°

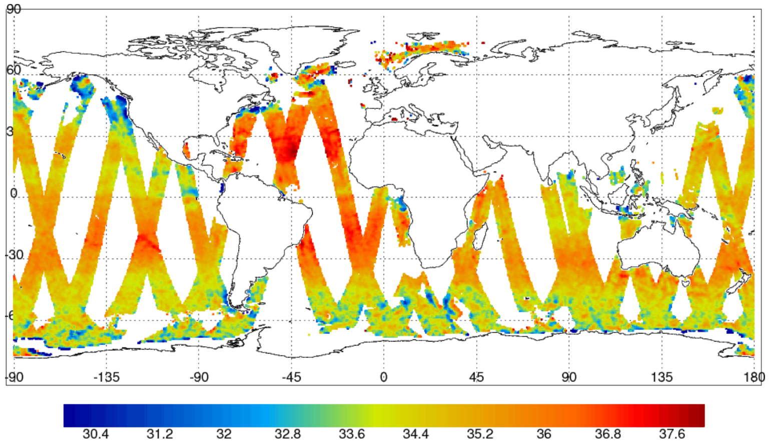


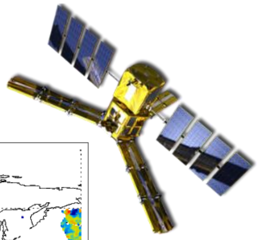
Spatial coverage & SSS variability

Argo over 1 day



SMOS over 1 day

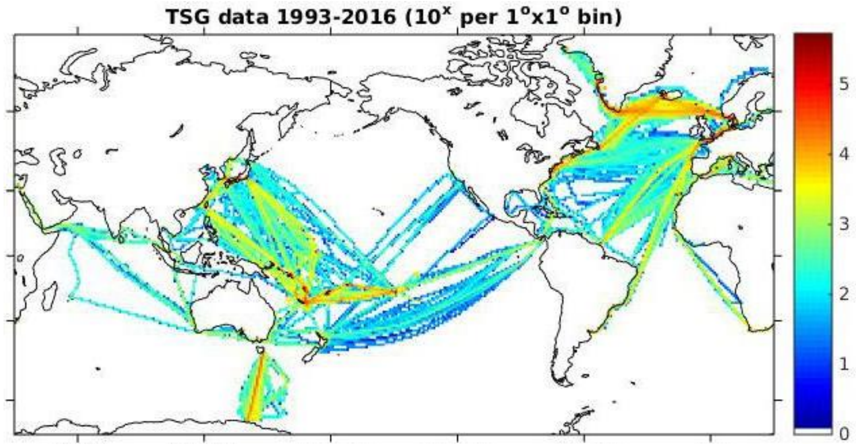




~50km resolution

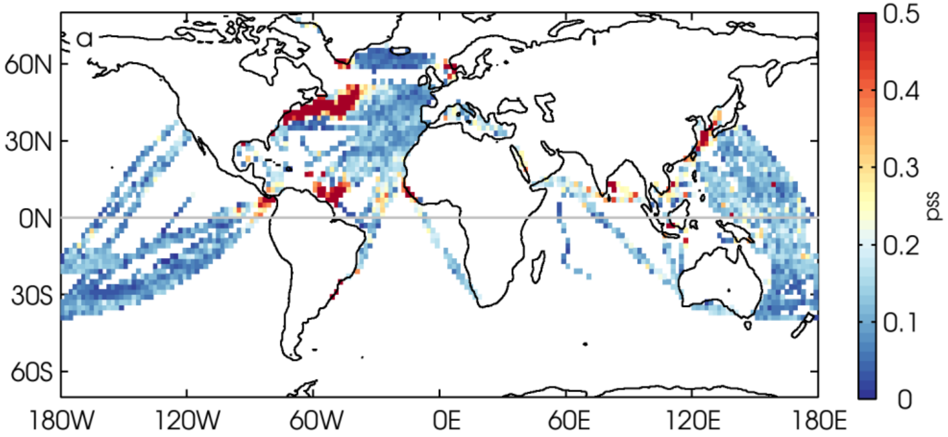
Revisit 3-5days

Ship data 1993-2016



DOI : 10.6096/SSS-LEGOS

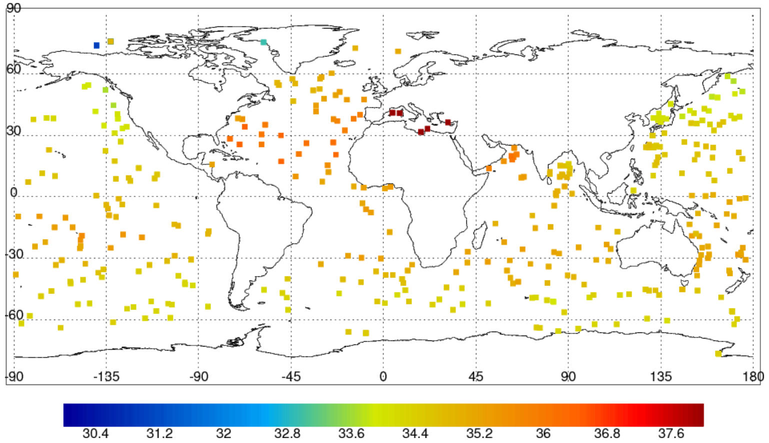
SSS variability from ship data in 100x100km^2



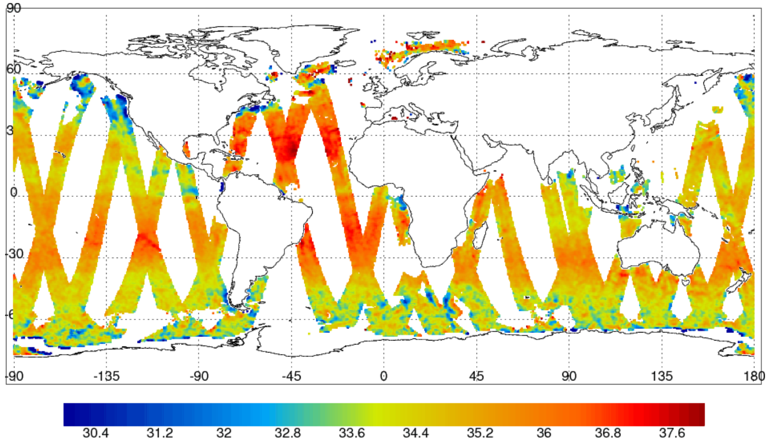
Boutin et al. BAMS 2016

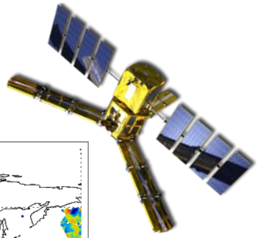
Spatial coverage & SSS variability

Argo over 1 day



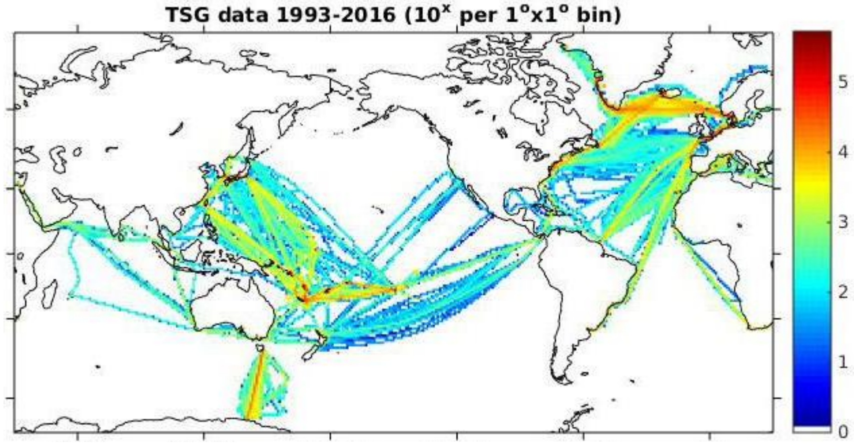
SMOS over 1 day



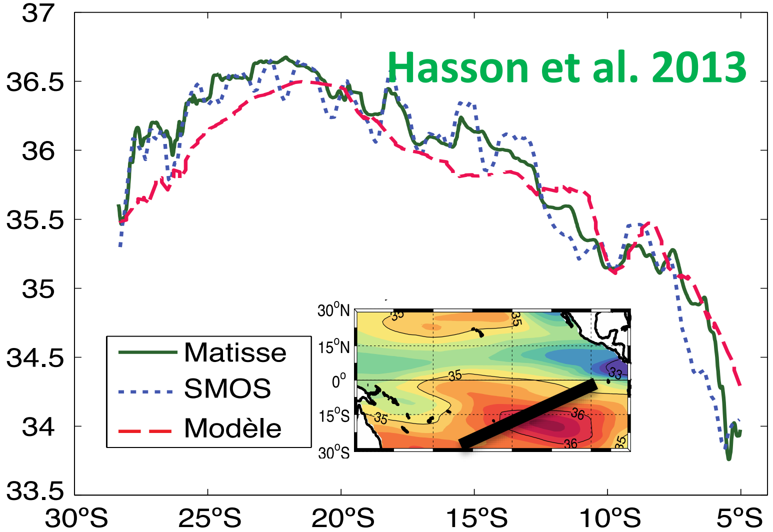


~50km resolution
Revisit 3-5days

Ship data 1993-2016



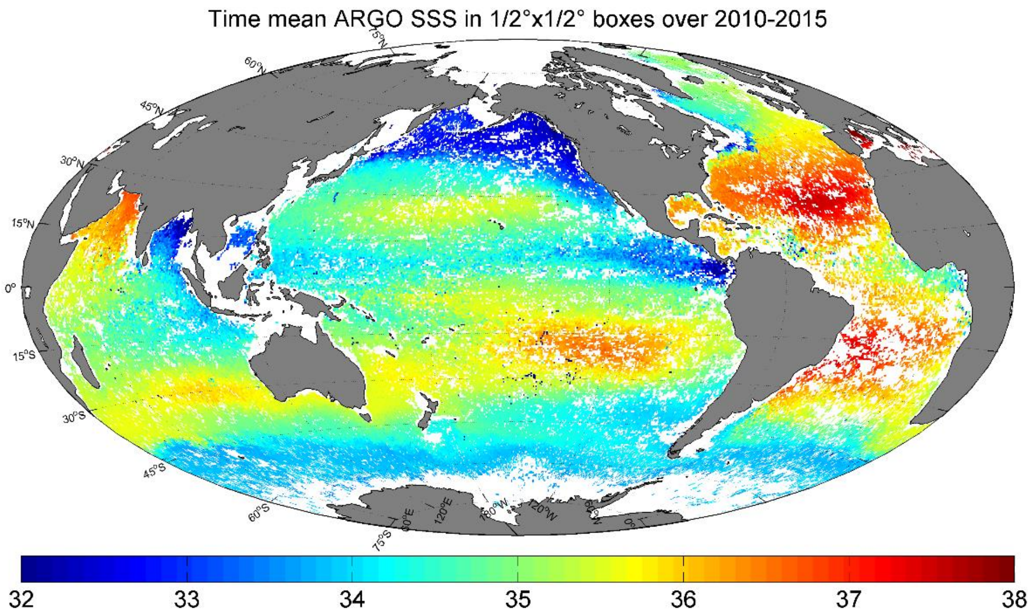
DOI : 10.6096/SSS-LEGOS

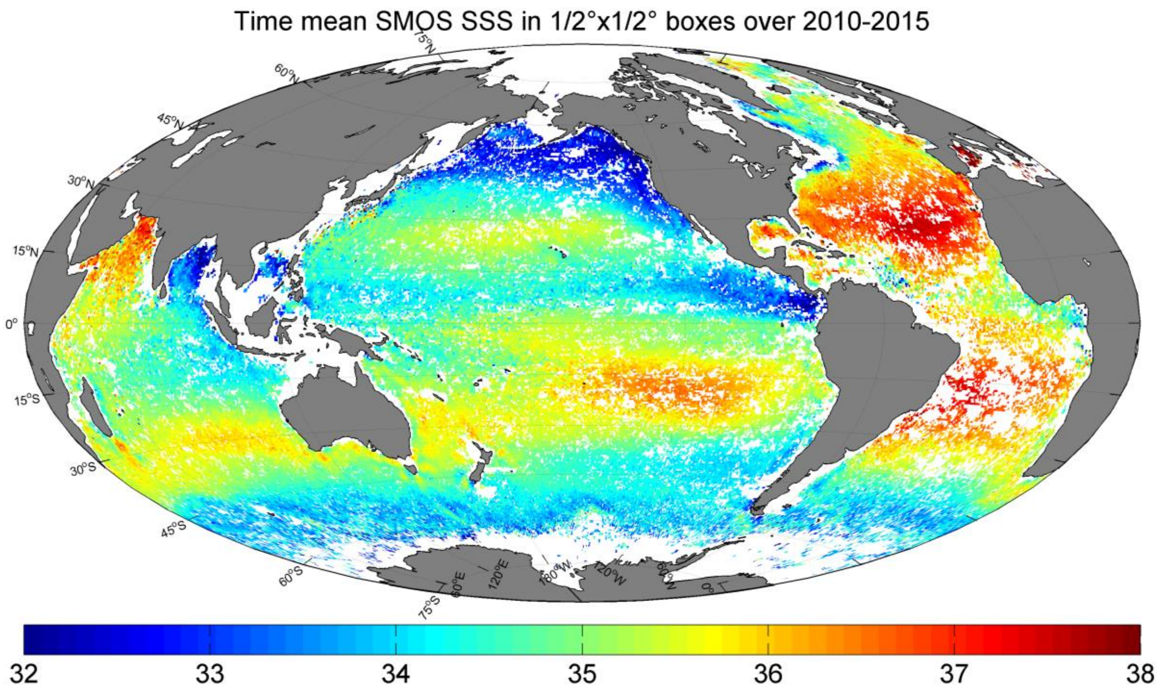


SMOS-TSG
mean= 0.22,
std = 0.32

New Zeland → Panama

Example among 16 transects (R/V Matisse, 20-27 février 2011)


Time mean ARGO SSS in 1/2°x1/2° boxes over 2010-2015
32
33
34
35
36
37
38


Time mean SMOS SSS in 1/2°x1/2° boxes over 2010-2015
32
33
34
35
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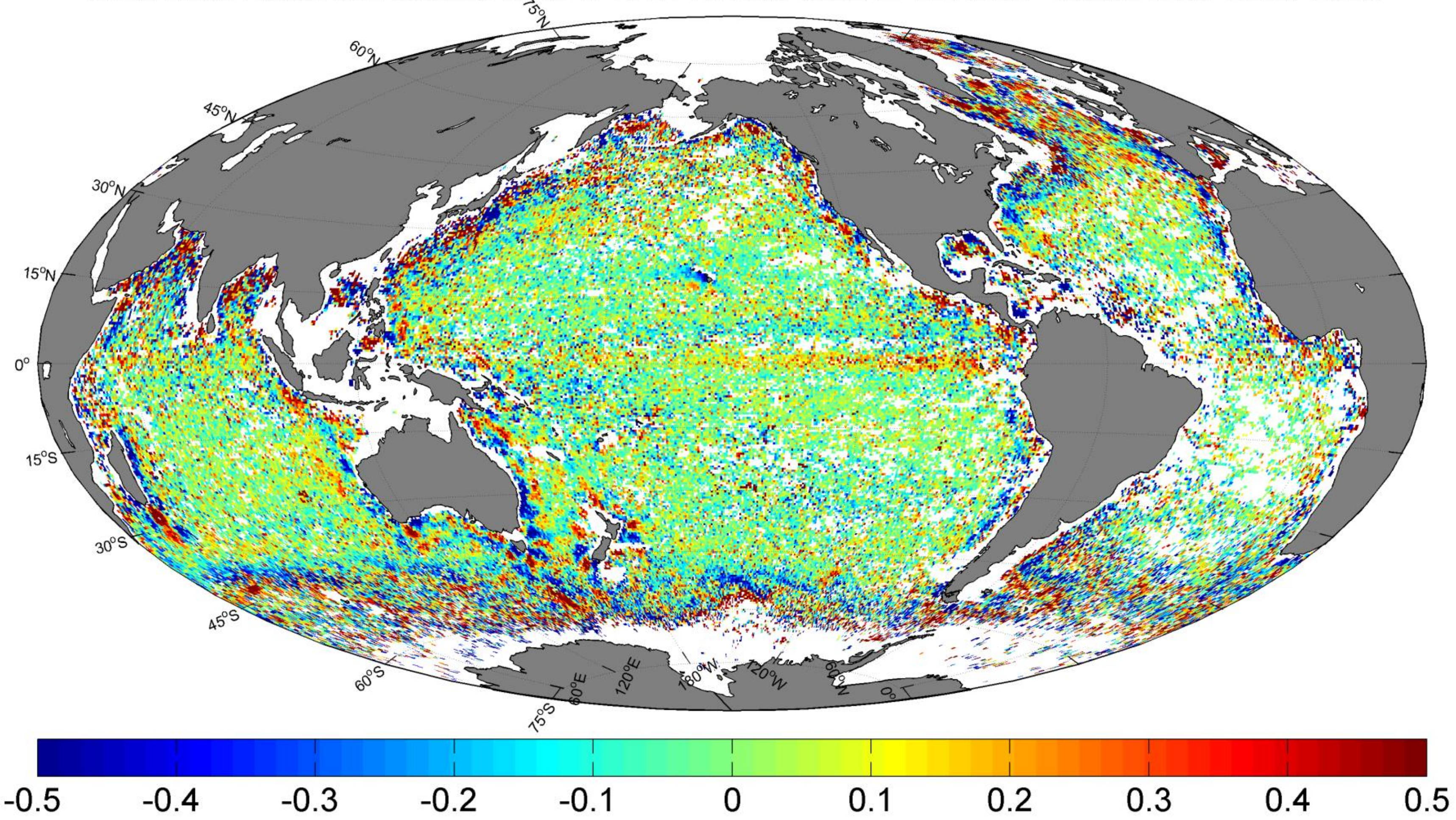
37
38

Time mean SSS diff: SMOS CEC-IFR L4-ARGO SSS in 1/2°x1/2° boxes over 2010-2015



Recent Progresses in SSS retrievals from SMOS data

- **At level 2 (swath SSS data):**

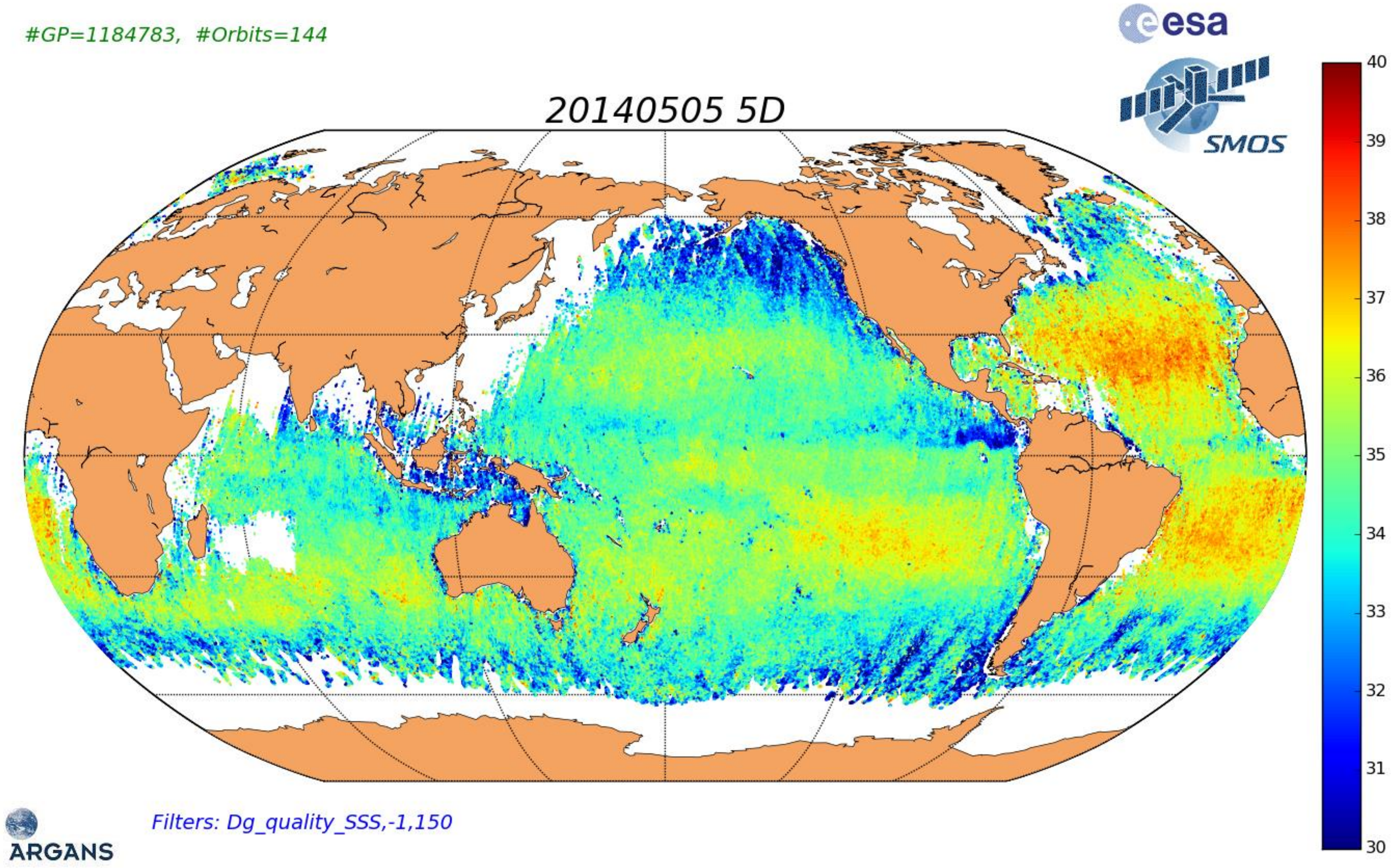
The **new Version 662 of the Level 2** Sea Surface Salinity data product is now available for the SMOS mission lifetime. It includes the following new contents:

- **From 3 SSS values** (previous versions) **to only 1 SSS value** in the product (I.e., roughness model 1)

- A new salinity product empirically **corrected for land-sea contamination (LSC)**

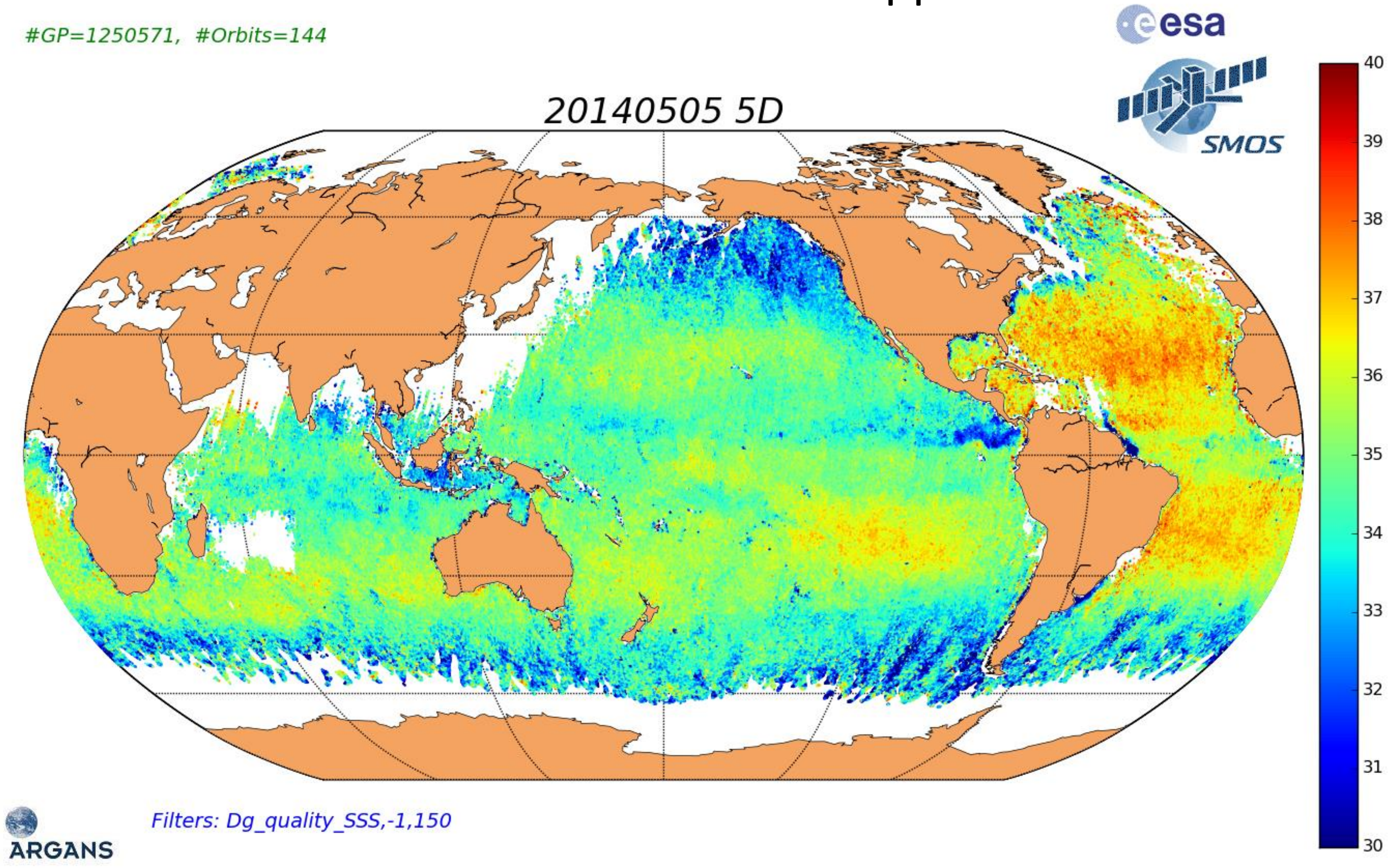
Recent Progresses in SSS retrievals from SMOS data

No land-sea correction



Recent Progresses in SSS retrievals from SMOS data

Land-sea correction applied

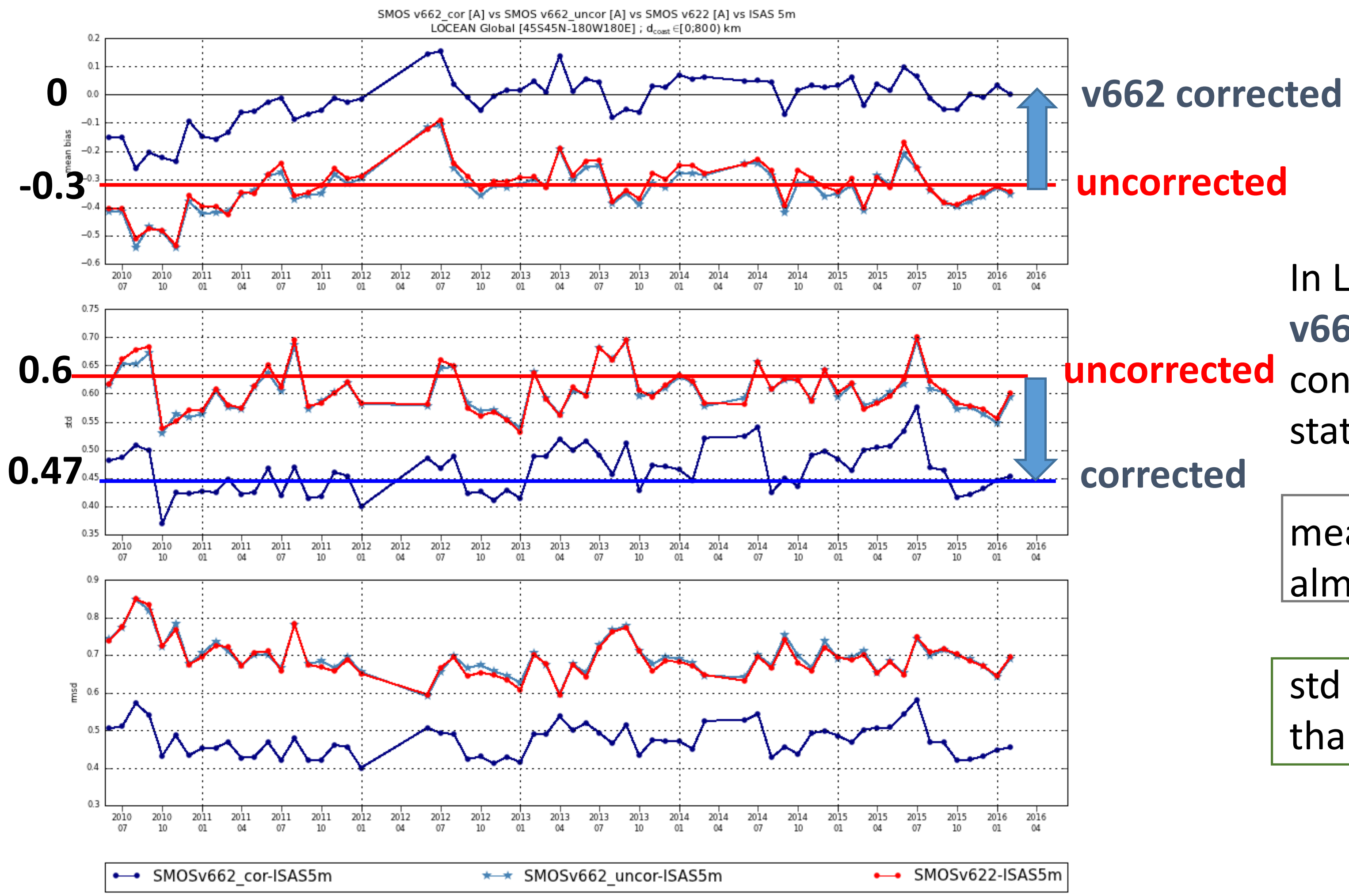


Land Sea Contamination
Validation Metrics for pixels with distances to coast<800km, Asc (Idem Desc)

Mean Difference SMOS-In Situ OA

Std

rmse



In LSC areas, for L3 pixel, **v662 corrected** consistently improves the statistics wrt v622:

mean abs bias almost null: 0.02 pss

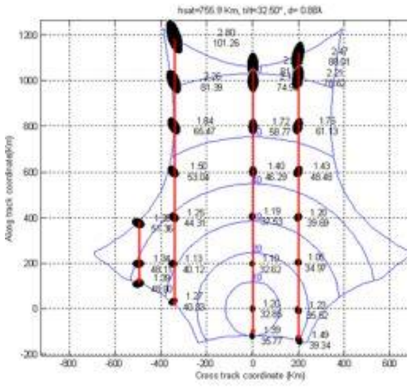
std decreases by more than 0.1 pss (std=0.47pss).

L3 pixel stats, 45S-45N, Dcoast<800km, Asc			
	N	Mean bias	std
V662(corr)-ISAS	3797757	-0.0175	0.4734
V662(unc)-ISAS	3505079	-0.3336	0.6105
V622-ISAS	3282782	-0.3196	0.6135

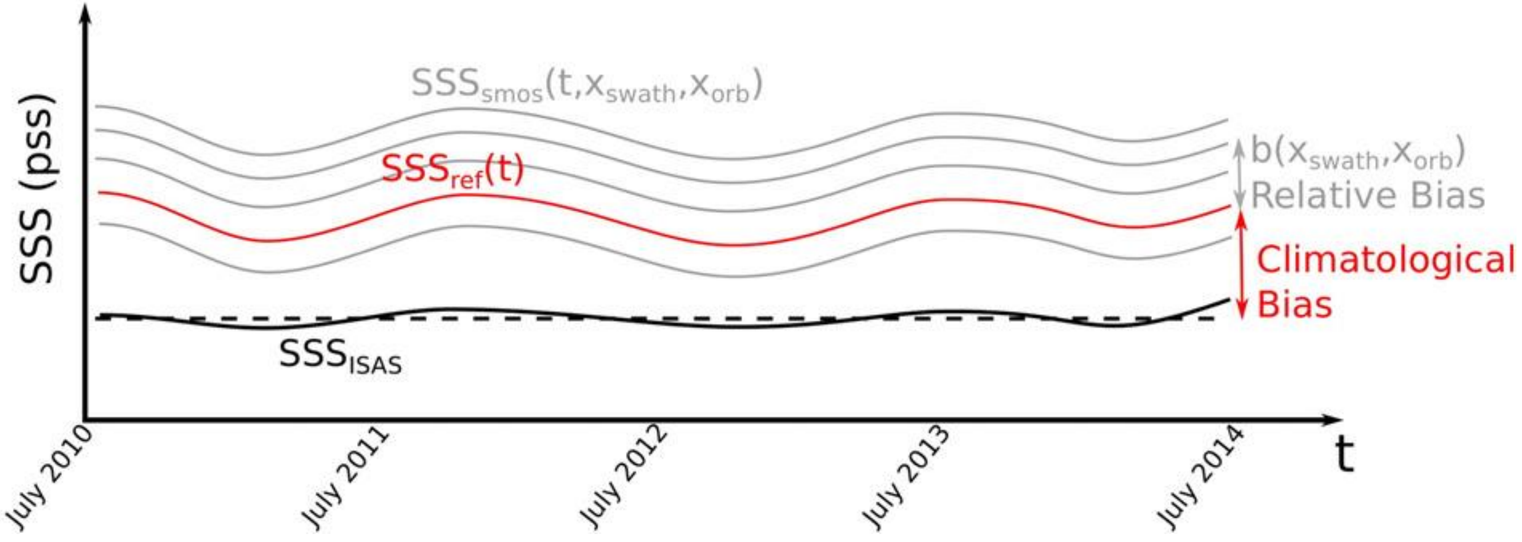
Recent Progresses in SSS retrievals from SMOS data

- A New (experimental) **salinity anomaly** product, currently based on WOA2009 climatology, and that **will be based on SMOS-data derived climatology in Level 2 v700**
- A New **scene-based filtering** algorithm to **mitigate** contamination from **RFI** and other sources (e.g., sun) based on the differences between brightness temperatures of successive snapshots
- A New **sun glint model** and sun brightness temperatures LUTs used as part of the forward model, and to set sun glint flags more accurately.
- **Roughness model 1** LUT has been **updated** , improving the estimation of forward model roughness brightness temperatures at wind speeds > 12 m/s.
- **TEC is now retrieved** from SMOS 3rd Stokes polarimetric measurements
- **Acard parameter** (proxy of dielectric constant) computed with LSC correction

Debiased Level 3/4 at CATDS (LOCEAN)



(a)



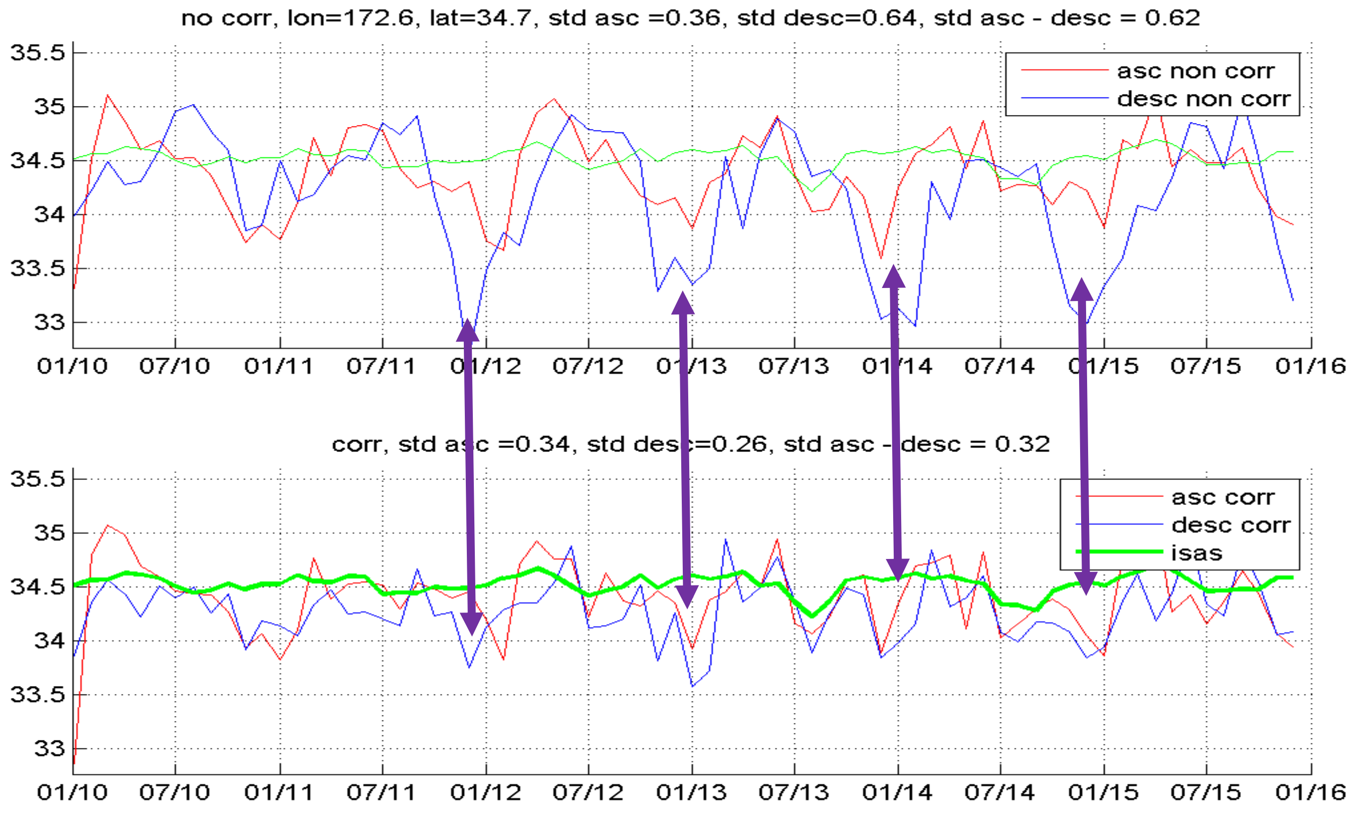
The method consist in auto-coherently correcting the relative-biases between SSS derived along each dwell lines. The SSS Ref is taken to be the center swath dwell line retrieved SSS

N. Kolodziejczyk et al. / Remote Sensing of Environment 180 (2016) 164–177

Debiased Level 3/4 at CATDS (LOCEAN)

Some elements of validation:
Comparisons of Ascending and Descending SSS with ISAS SSS in the northern Pacific Ocean

Reduction of latitudinal biases => Better agreement between ascending and descending orbits; more SSS variability seen by SMOS than ISAS



ACRI/LOCEAN

Debiased Level 4 at CATDS (IFREMER)

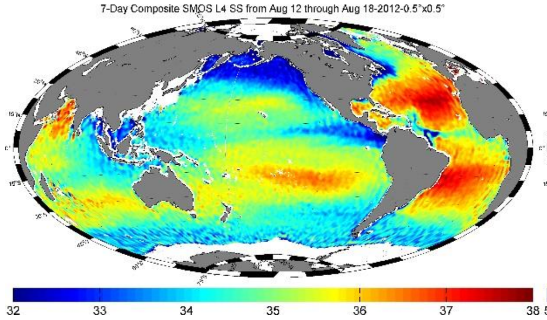
One Thematic product given weekly at 0.5°x0.5° including:

Weekly
0.5° res
Bias corrected using
Monthly ARGO OI
For scales > 10°x10°

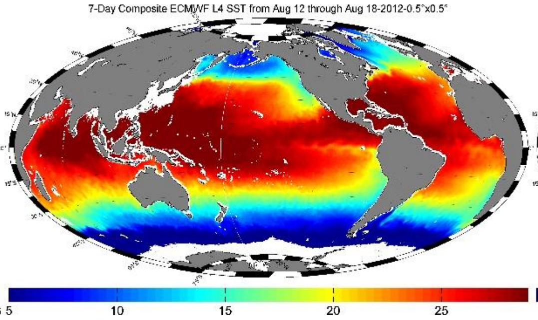
+

Thematic datasets

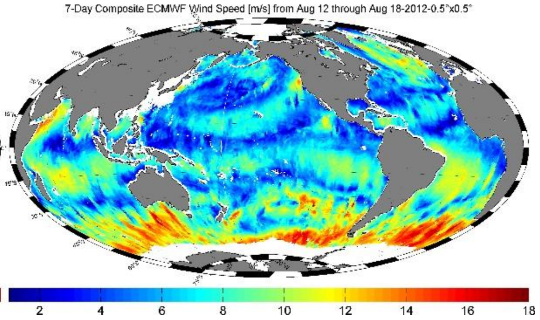
SSS SMOS



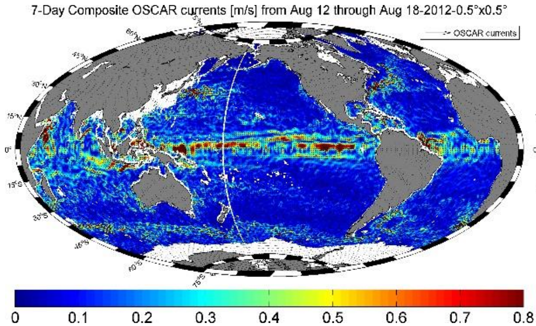
SST GHRSST



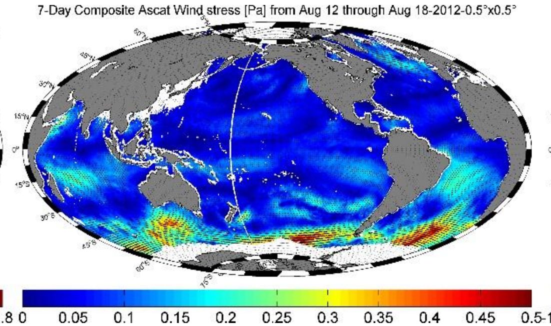
Wind ECMWF



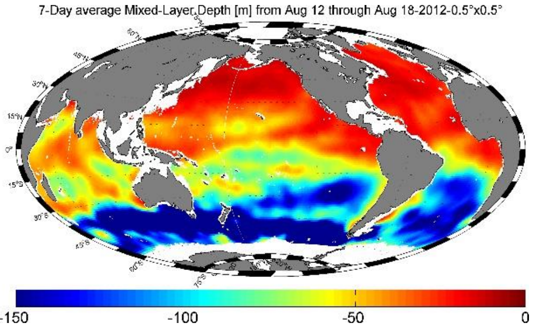
Currents Aviso



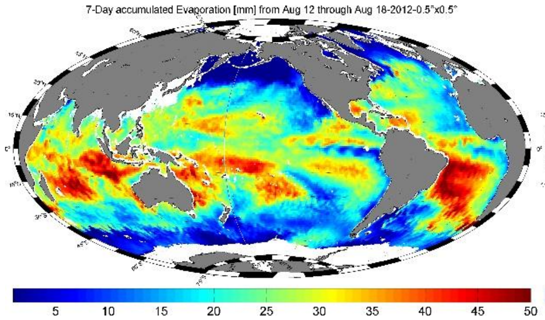
Wind Stress Ascat



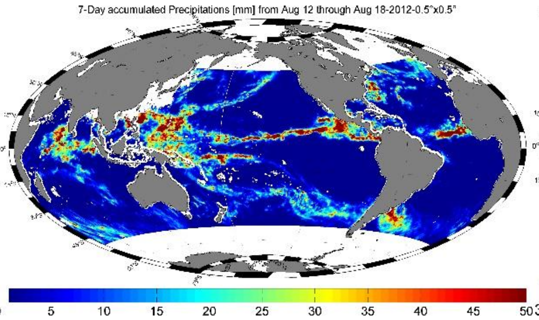
Mixed Layer Depth



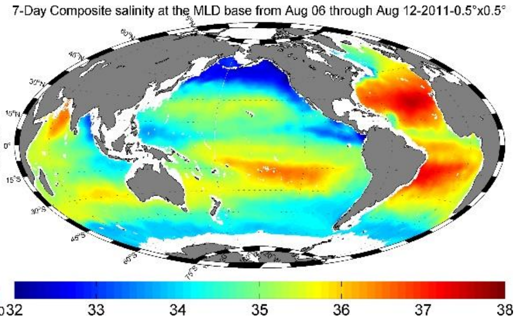
Evaporation OAFlux



Precipitation TRMM/GPM



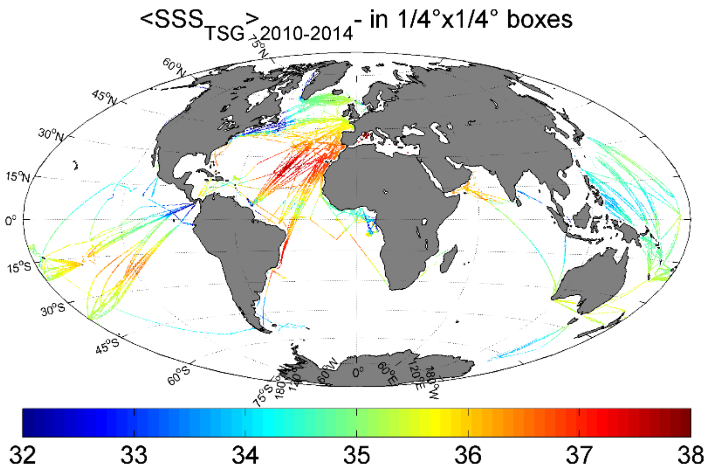
Salinity at base of MLD



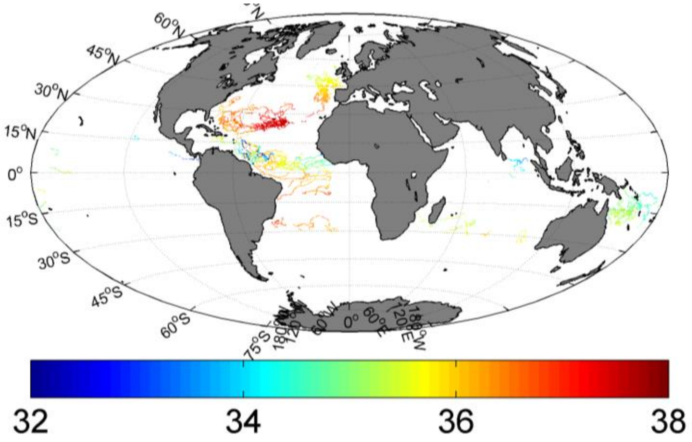
In Situ/ SMOS Match-Up Datasets at CATDS (IFREMER)

Match-ups with in situ data in each weekly products

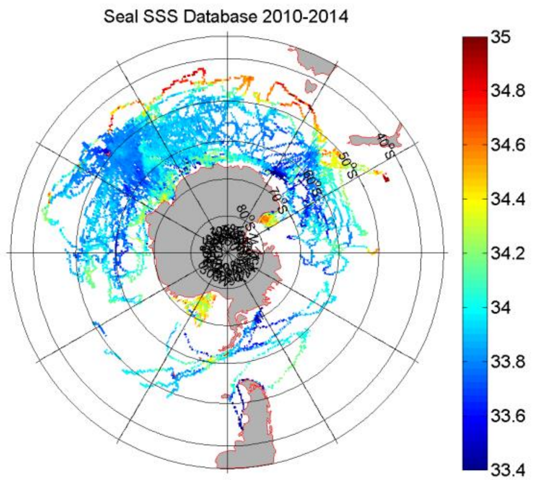
TSG



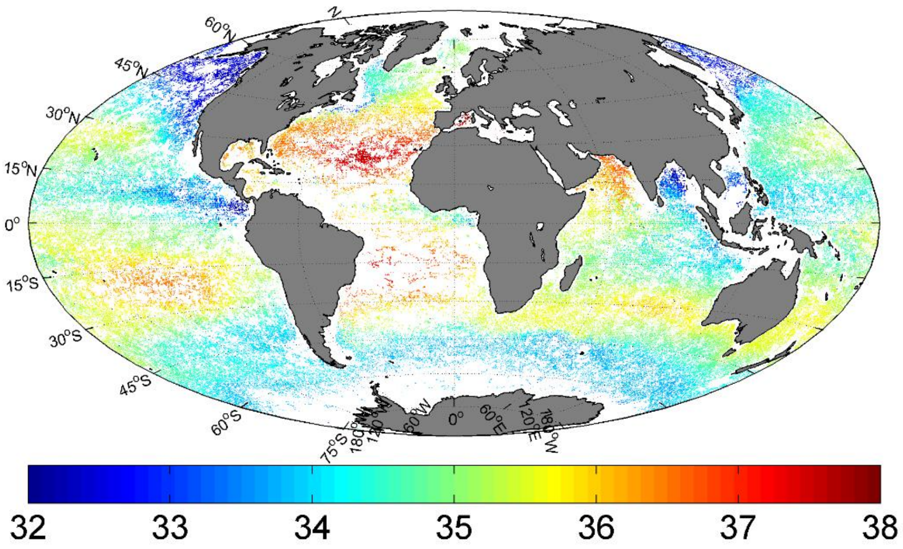
Surface Drifters



Equipped Sea Seals



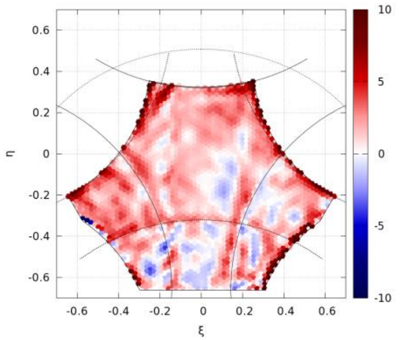
ARGO floats



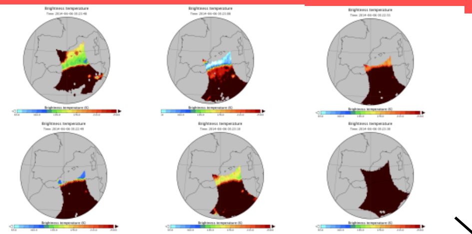
Non Bayesian retrieval & empirical debiasing at BEC

Bayesian retrieval

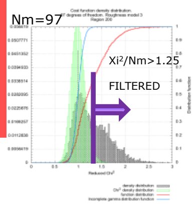
1 → OTT correction: constant antenna pattern (cannot correct scene-dependent biases)

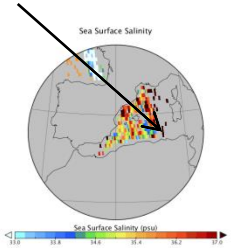


2 → Pre-filtering: (do not discard all the biased TBs)



3 → Combined cost function + Post-filter: Chi2p, etc (when one SSS is discarded, all the associated TBs (dwell line) are discarded)

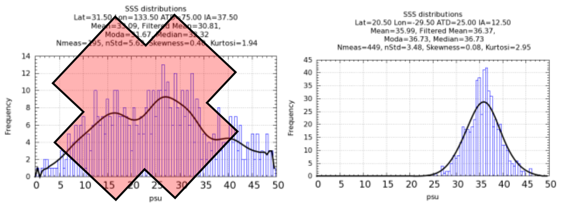




Debiased non-Bayesian retrieval

1 → Each TB gives one retieved SSS (no OTT correction)

2 → Three years of SSS are classified as function of location (lat-lon), position in the antenna (θ-xswath) and overpass direction



3 → We define filtering criteria and one representative value for each class (SMOS-based climatology)

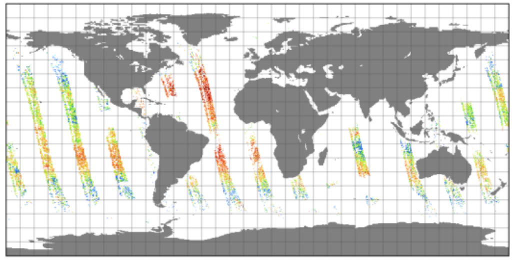
4 → We subtract the representative value from each SSS ⇒ SMOS-based anomaly

5 → Compute a L3 SMOS-based anomaly map and remove the global mean to each map

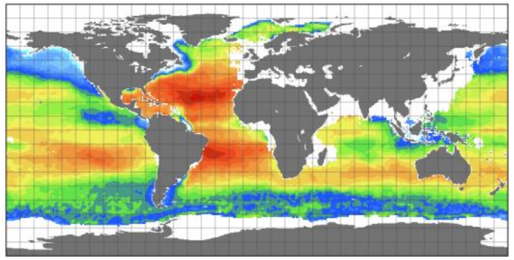
6 → Add annual Climatological SSS reference

Operational L3 & L4 products at BEC

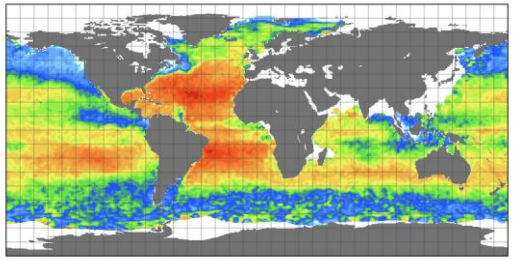
Operational global products (debiased Bayesian):



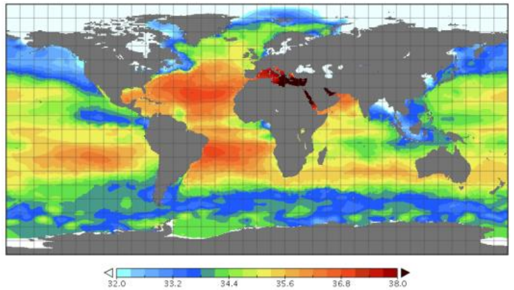
Daily gridded L2 map: This product is devoted to those users interested in working with L2 SMOS SSS data, but who are not familiar with the ESA standard format. Ascending & descending, separately, L2 SSS, of the same day in a regular cylindrical 0.25º grid and distributed in NetCDF files. *Accuracy:* low (about 1 psu)



Monthly binned L3 map: This product aims to final users who are interested in global, calibrated SMOS SSS maps mainly for climate applications. Binned products are served at a 1º grid for an averaged period of one month. *Accuracy:* high (about 0.2 psu).



Objectively analyzed L3 map: This product is thought for ocean modelers and, in particular, those interested in mesoscale activity. OA SSS maps are generated as 9-day averages of L2 data on a 0.25º grid, served daily. *Accuracy:* average (about 0.3 psu).

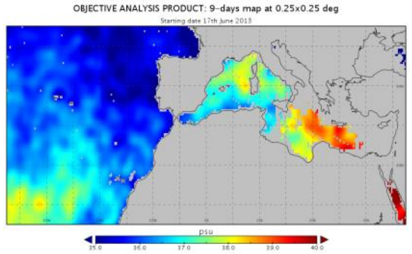


Data fused L4 maps: This product is addressed to those users requiring high spatial and temporal resolution. OSTIA daily SST maps at a 0.05º are used to increase the spatial and temporal resolution of the daily 9-day OA maps. Fusion parameters tuned to improve the fused product, as described in [Olmedo et al., 2016]. *Accuracy:* high (about 0.2 psu).

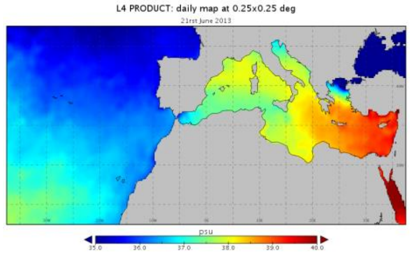
Experimental L3 & L4 products at BEC

Regional products, 2011-2013 (debiased non-Bayesian):

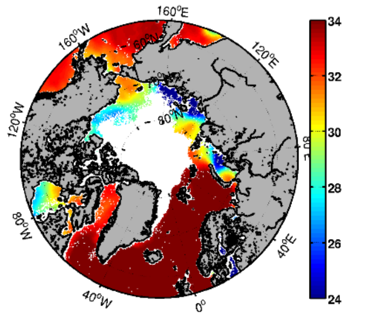
- **Mediterranean objectively analyzed L3 map**: OA L3 maps are generated as 9-day averages of L2 data on a 0.25º grid, served daily. OA paramenters tuned for the Mediterranean basin. *Accuracy:* average (about 0.3 psu). Significant biases (0.15-0.2 psu).



- **Data fused L4 maps:** Daily SSS maps at a 0.25º resolution. Fused with SSS climatology at data gaps. *Accuracy:* average (about 0.3 psu). Significant biases (0.10-0.15 psu).



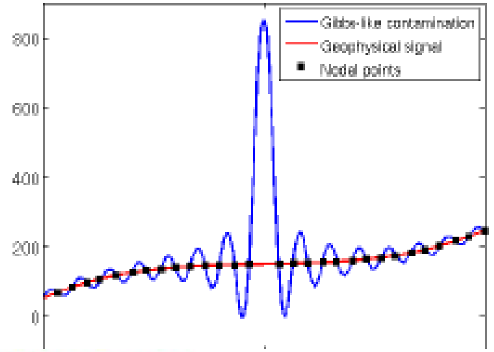
- **Arctic objectively analyzed L3 map:** OA L3 maps are generated as 9-day averages of L2 data on a 25-km polar grid, served daily. *Accuracy:* average (about 0.3 psu).



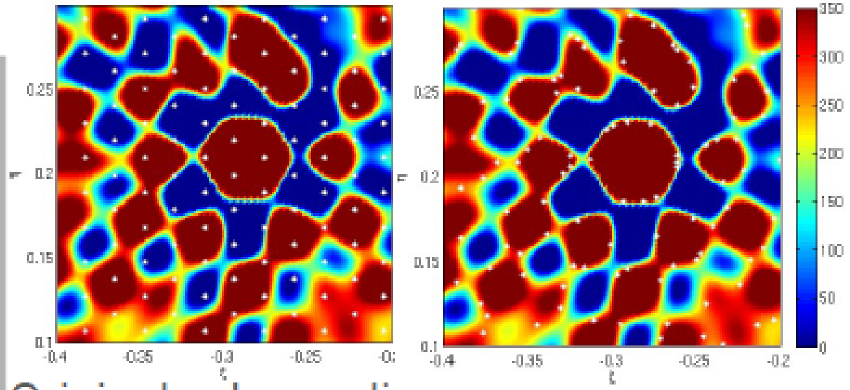
The Nodal Sampling is a new image reconstruction technique that mittigates Gibbs-like contamination produced by sharp transitions in TB scenes.

Hypothesis: ***The geophysical signal of interest varies relatively slow in space***

TB nominal values are replaced by the TB values at the Nodal points of an oversampled image



Gonzalez-Gambau, V., Turiel, A., Olmedo, E., Martinez, J., Corbella, I., and Camps, A. (2015) Nodal Sampling: A New Image Reconstruction Algorithm for SMOS. IEEE Transactions on Geoscience and Remote Sensing. doi: 10.1109/TGRS.2015.2499324. In press



Original subsampling (regular hexagonal grid

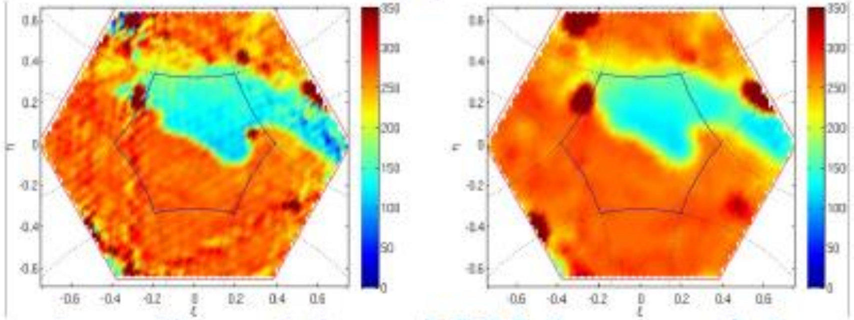
Final selection

Gonzalez-Gambau et al. IEEE TGRS, 2015

Nodal Sampling Technique from BEC

Reductions in the sidelobes and ripples are observed in the resulting images

Nominal



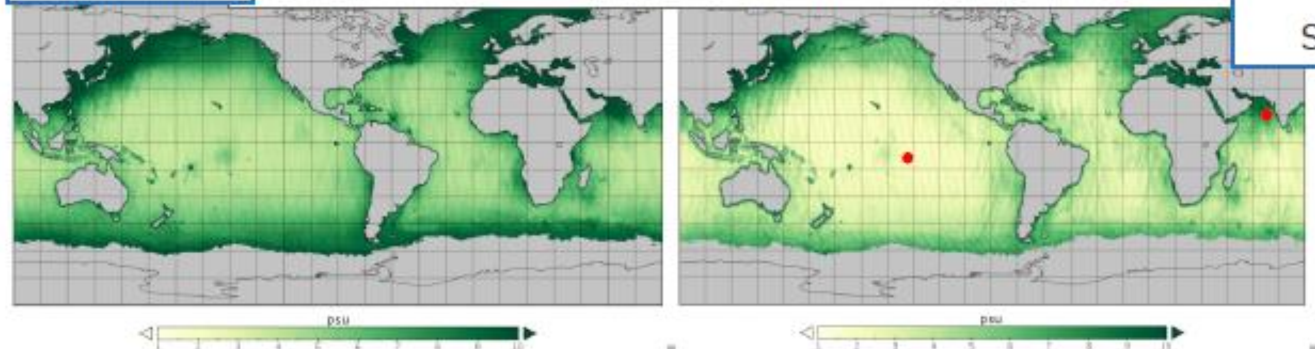
Nodal Sampling

Preliminary assessment on the retrieved SSS from nodal sampled TBs show a quality improvement in open sea regions

Std of a posteriori SSS distributions:
average error reduction using NS ~ 1.7 psu (25 %)

Nominal

Nodal Sampling

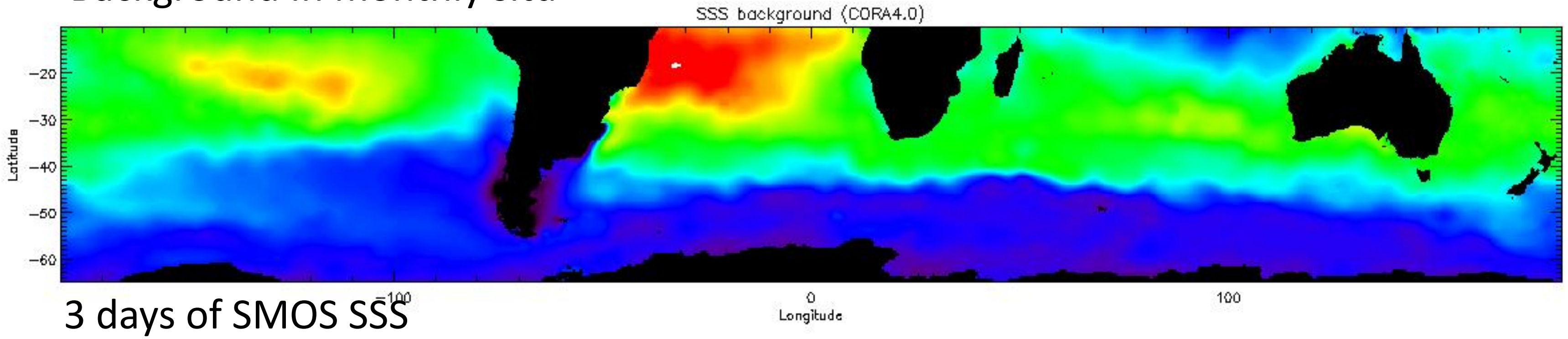


González-Gambau, V., Olmedo, E., Turiel, A., Martínez, J., Ballabrera, J., Portabella, M. and M. Piles. (2015). Enhancing SMOS brightness temperatures over the ocean using the nodal sampling image reconstruction technique. SMOS 5 years Special Issue Remote Sensing of Environment. doi: 10.1016/j.rse.2015.12.032. In press.

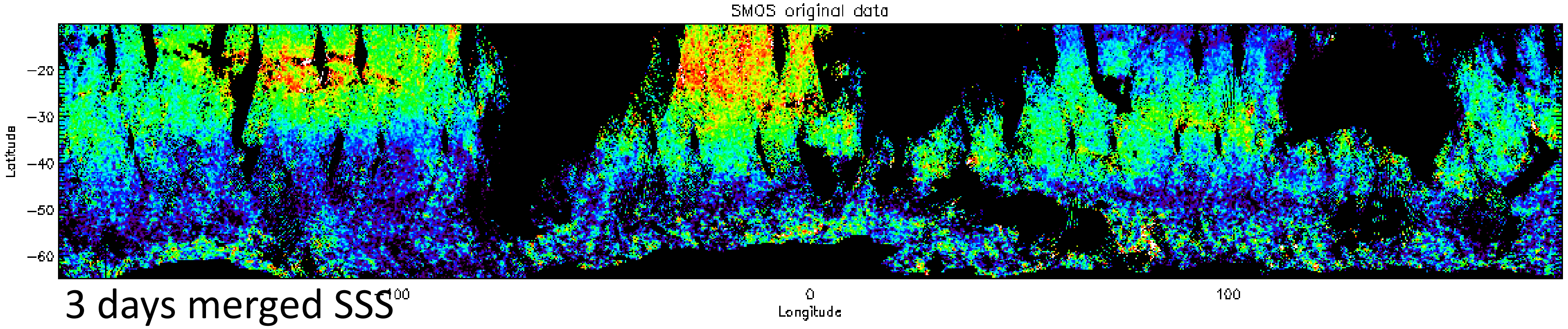
SMOS-B

Objective analysis In situ & SMOS

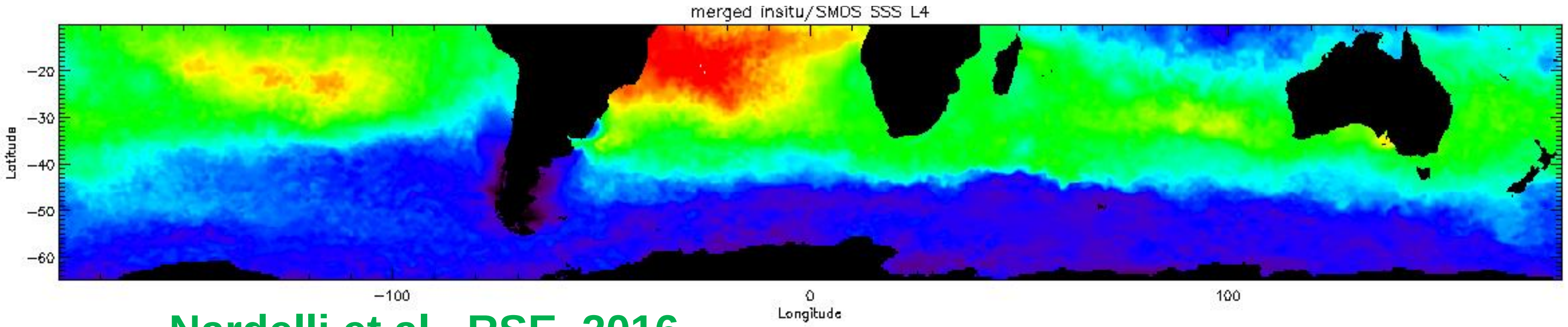
Background In monthly situ



3 days of SMOS SSS



3 days merged SSS



Nardelli et al., RSE, 2016

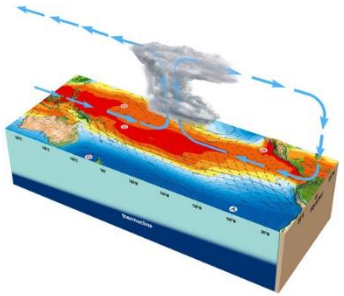
Applications over ocean

- **Large Scale Climate indexes**
  - Detection and monitoring of Large scale SSS anomalies related to climate fluctuations - ENSO and IOD (LOCEAN, IFREMER, IRD, Univ. Maryland)
- **Ocean circulation and modelling**
  - Characterizing mesoscale variability of SSS (and density) in frontal structures, eddies (IFREMER, LOCEAN, JPL)
  - Monitoring key oceanic thermohaline circulation processes: Gulf Stream (IFREMER)
  - T/S Diagrams and water masses formation (ESA)
  - Detecting Tropical Instability Waves - TIW (LOCEAN, JPL)
  - Monitoring of planetary waves - Rossby (NOC)
  - Assimilating SMOS in OGCM (Univ. Hamburg, Mercator, UK MetOffice)
- **Air-Sea (or Land-Sea) interactions**
  - Monitoring freshwater river plumes (JPL, IFREMER, Univ. of Maryland)
  - Detecting Upwelling and barrier layers (LEGOS, IFREMER)
  - Monitoring precipitation-induced signals (LOCEAN, Univ. Washington, NUIG)
  - Characterizing SSS variability in high evaporation/precipitation zones (SPURS and SPURS-2 experiments)
- **Marine Biology / Biogeochemistry**
  - Ocean Acidification (Univ. Exeter, PML, IFREMER)
- **Numerical Weather Prediction**
  - Hurricane/storm tracking and intensity forecasting (IFREMER, UK MetOffice)

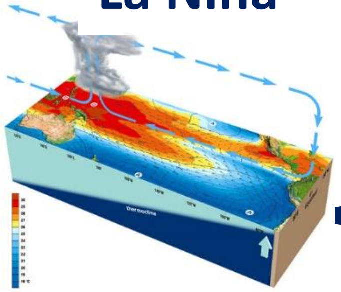
Large scale climate variability:
SSS & ENSO in the Equatorial Western Pacific (Warm & Fresh Pool)

Signatures of ENSO in SMOS SSS at the Equator (2°S-2°N)

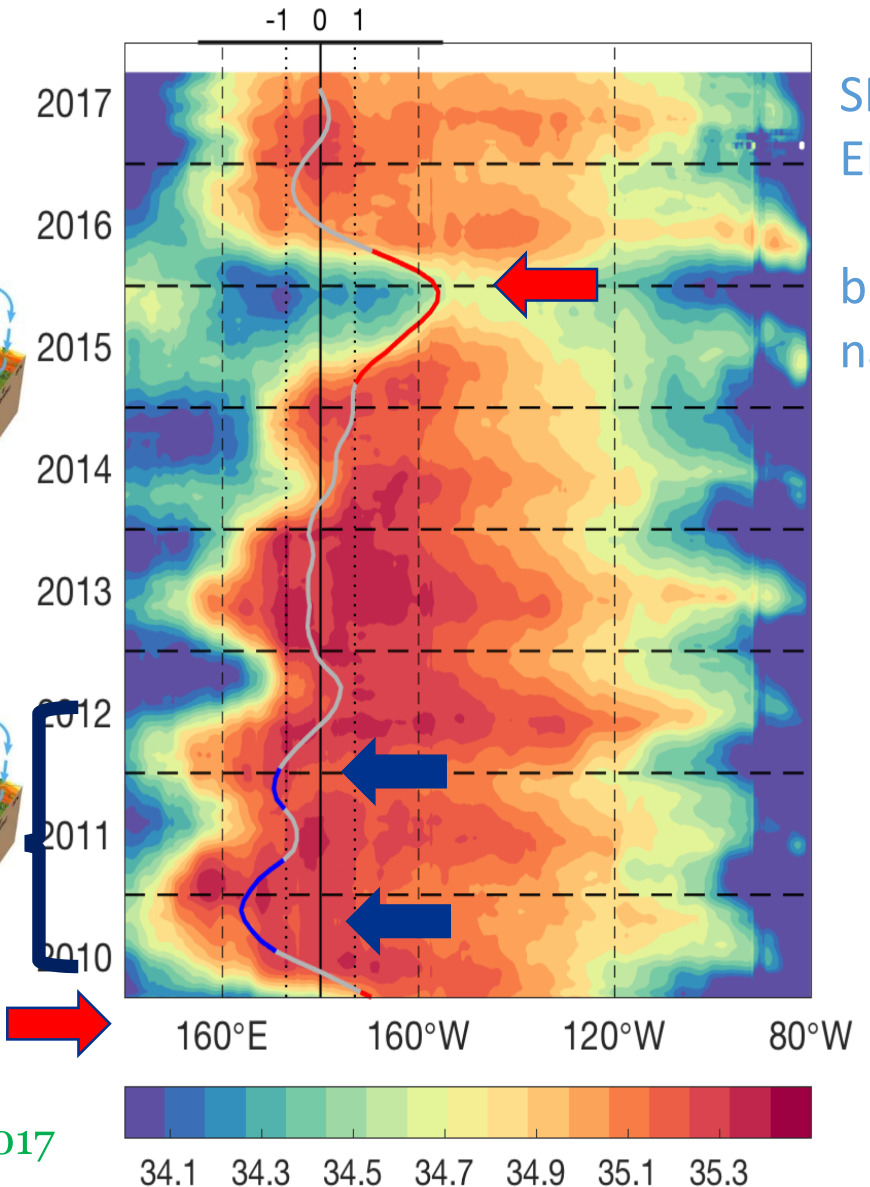
El Niño



La Niña



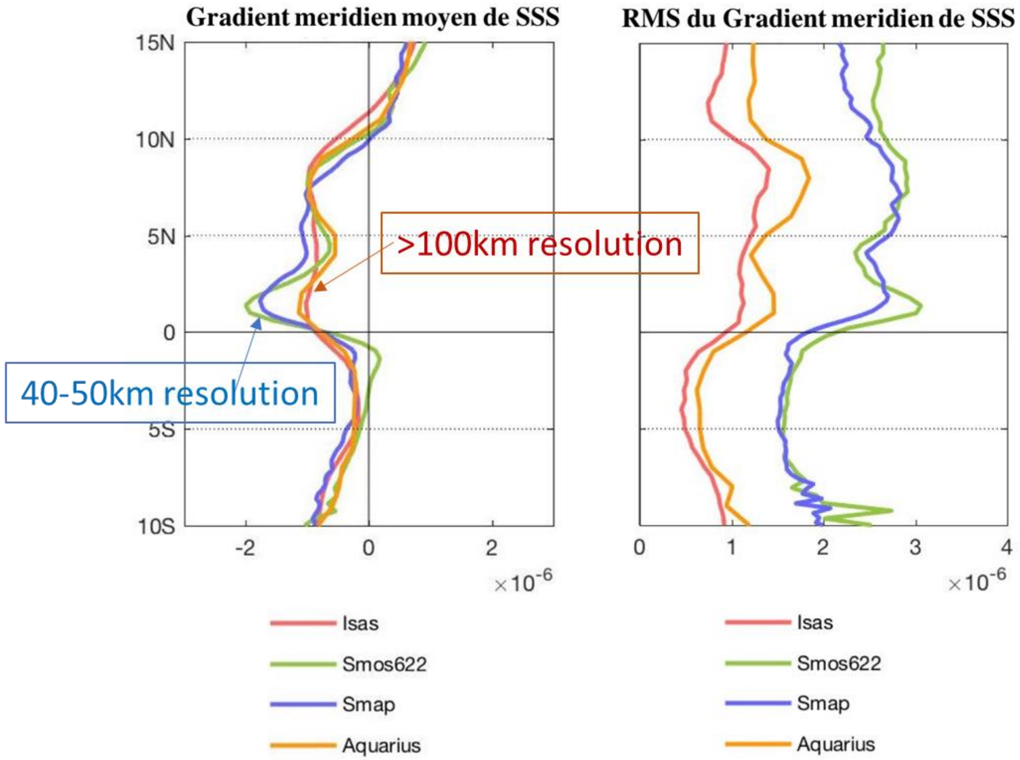
El Niño



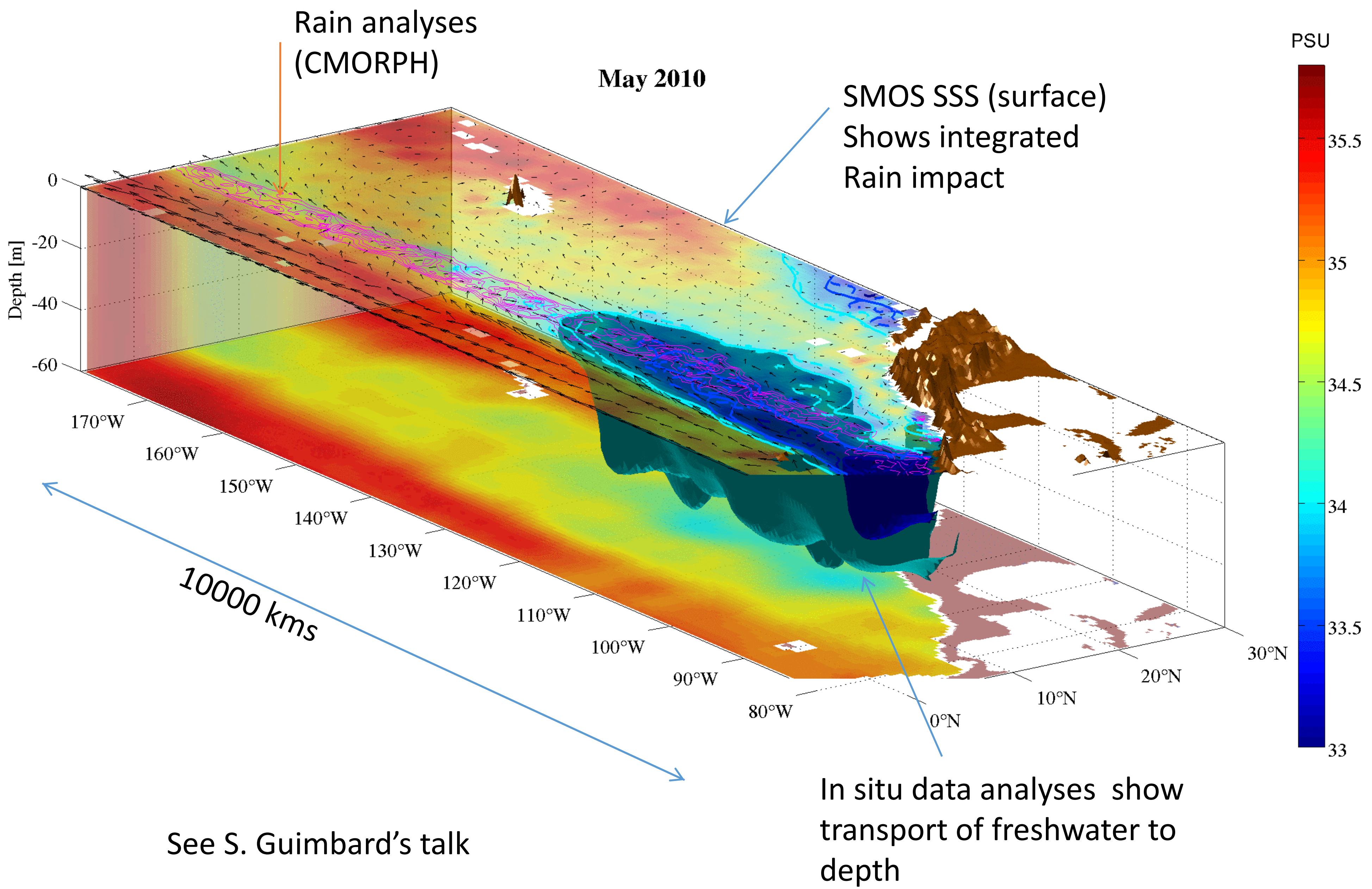
Hasson et al. 2017

SMOS is the only L-band radiometer which sampled a complete ENSO cycle

but large diversity of El Niño events and important to monitor narrow zonal currents => need to continue SMOS SSS monitoring

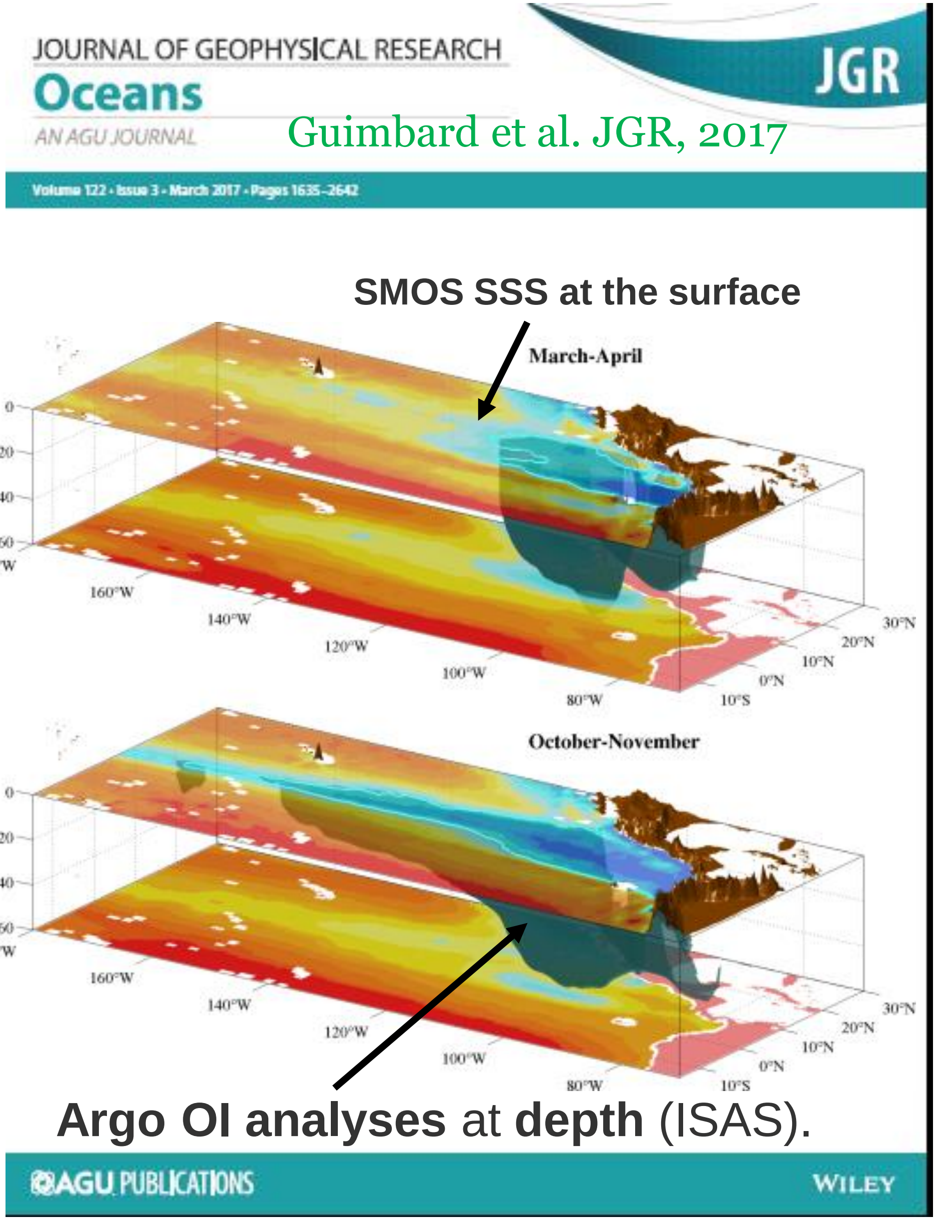


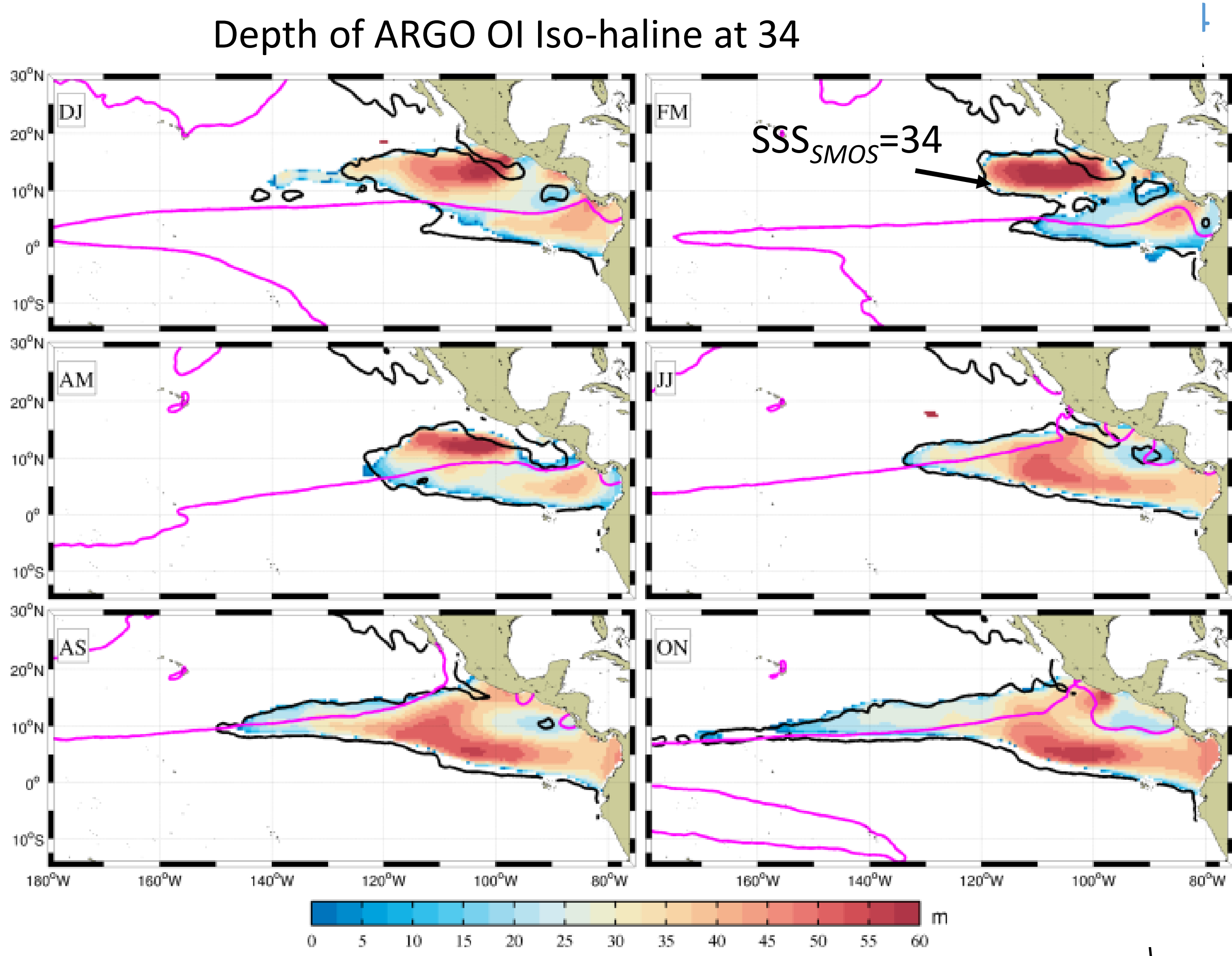
Eastern Pacific Freshpool & 3D monitoring of the pool



See S. Guimbard's talk

Large scale climate variability:
SSS & ENSO in the North Eastern tropical Pacific



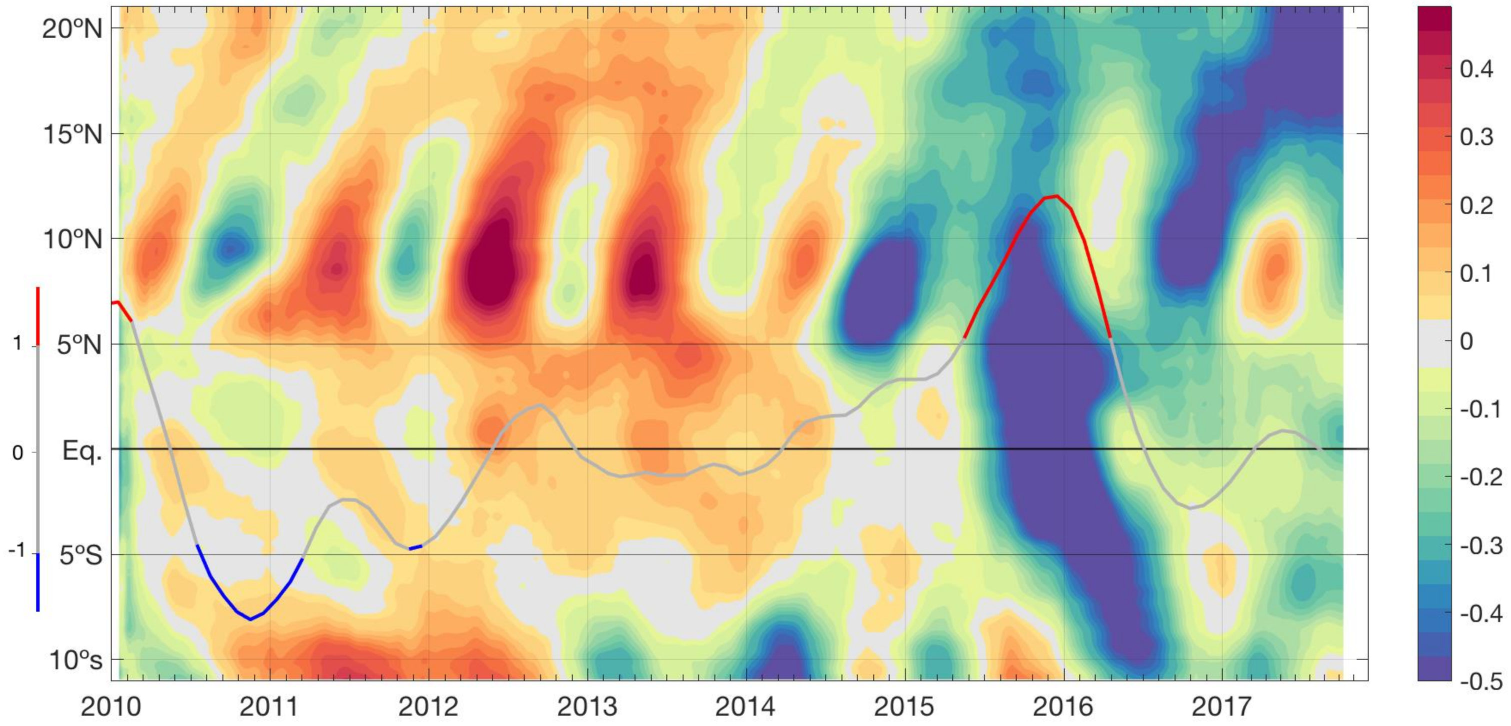


Area of the East Pacific Tropical Fresh pool (SSS<34)

Nearly x 2 during last El-Nino 2014/2015

SMOS sees a ~10% more extended pool than ARGO OI in fall 2015

SMOS SSS in the central Pacific (150-170W) (L3Q SMOS/CATDS)

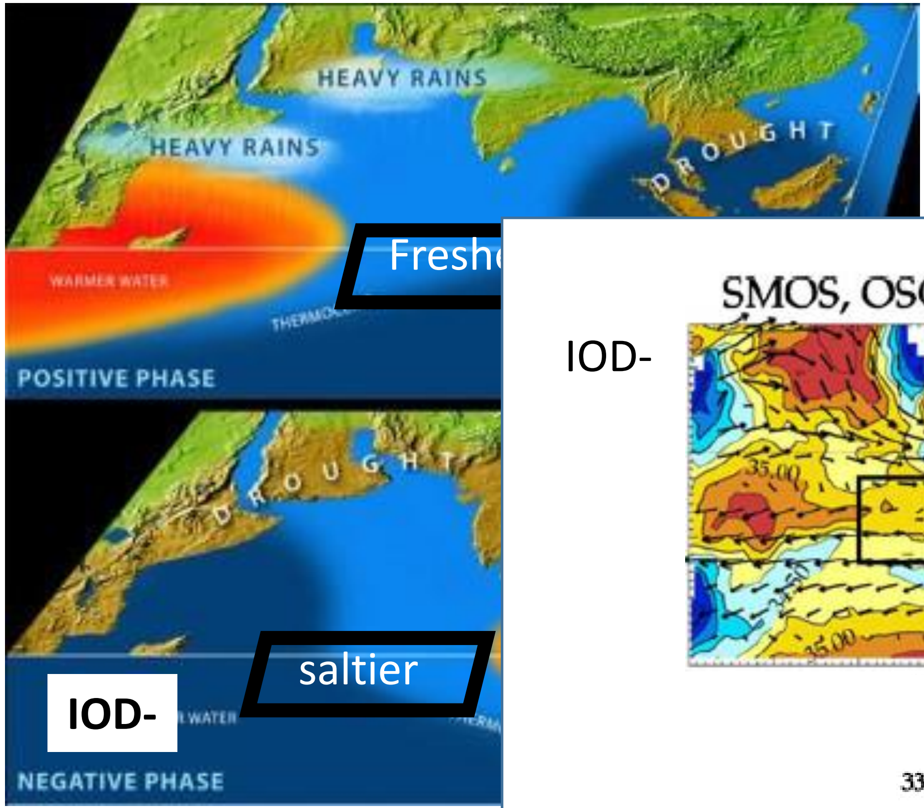


SMOS SSS reveals poleward pathways of equatorial anomalies as shown for the 2011 La Niña and for the 2014-2015 El Niño events

Caption: 2010-2017 latitude-time plot of SMOS SSS anomalies produced by the CEC-LOCEAN averaged between 150º and 170ºW. The NINO3.4 index is displayed on top, centered on the equator, blue during La Niña and red during El Niño
https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/nino34.long.anom.data.

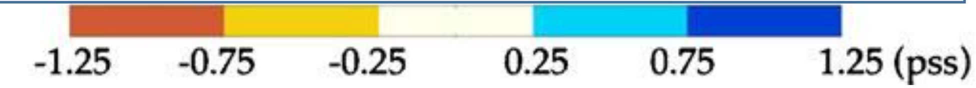
Hasson et al. 2017

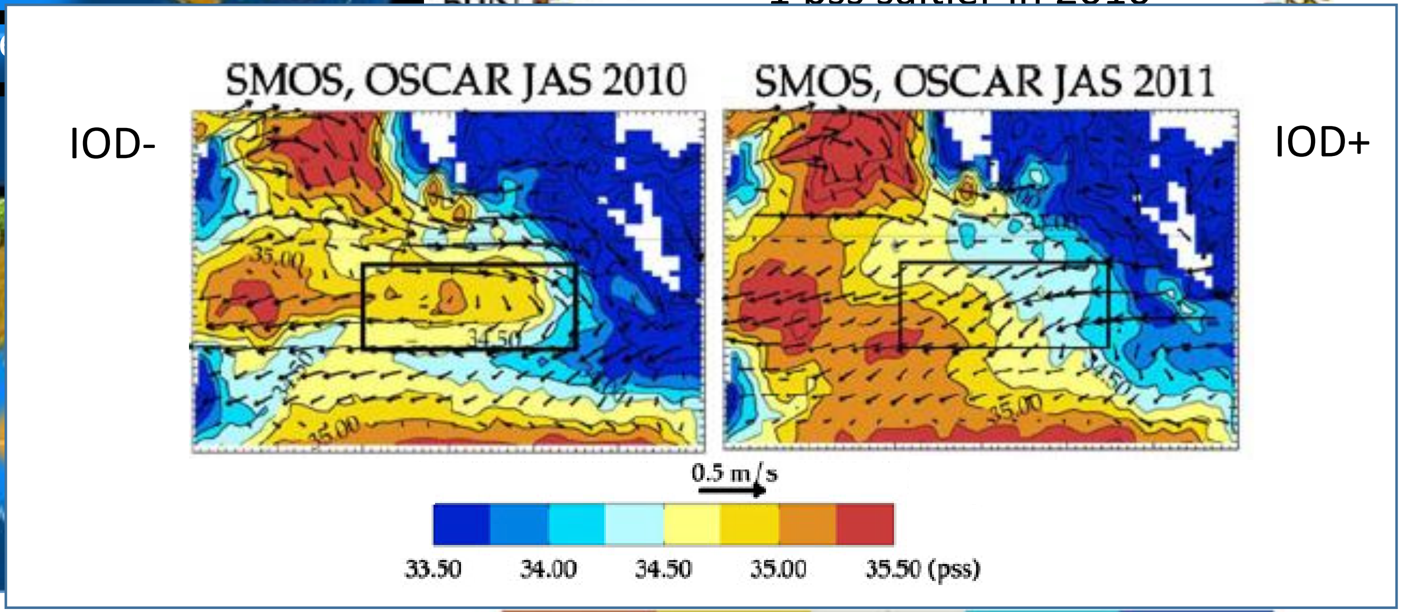
Large scale climate variability in the tropical Indian Ocean: SSS & the Indian Ocean Dipole (The "El-Niño of the Indian Ocean')

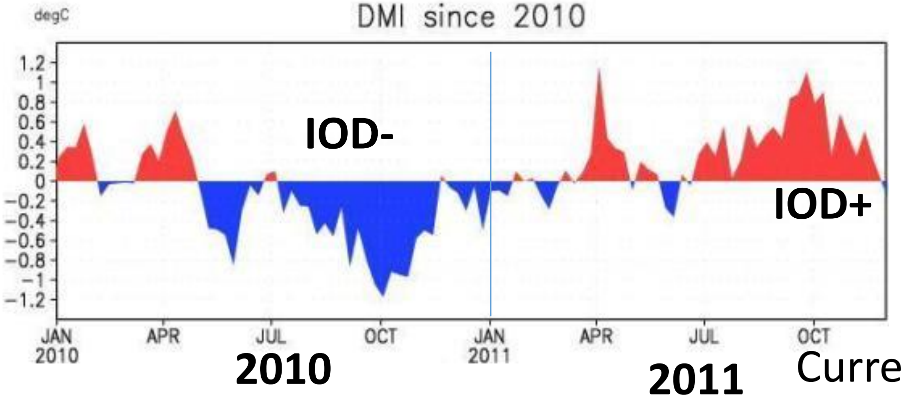


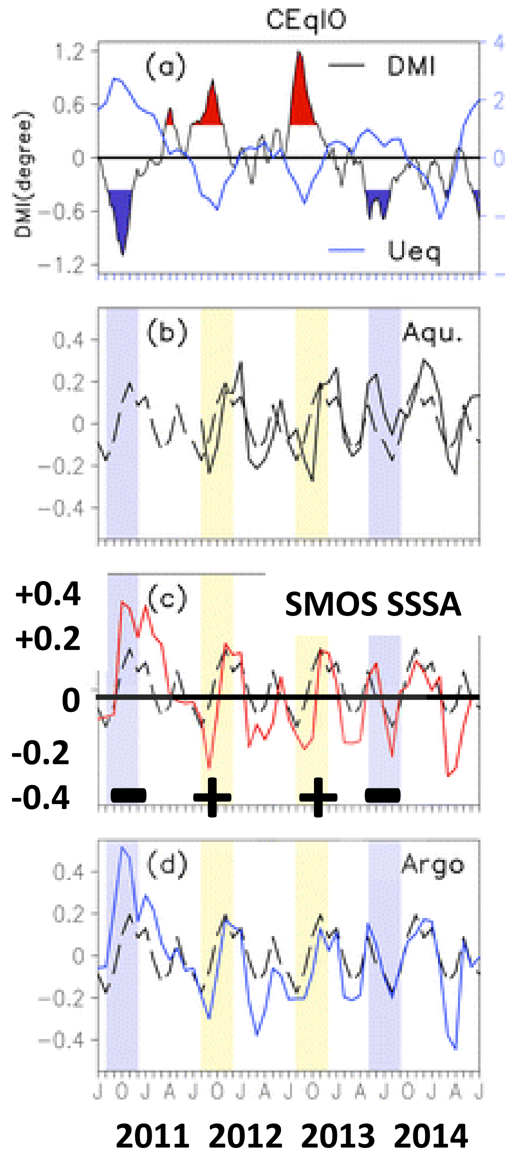
SMOS SSS anomalies

Dec 2011 (IOD+) – Dec 2010 (IOD-)









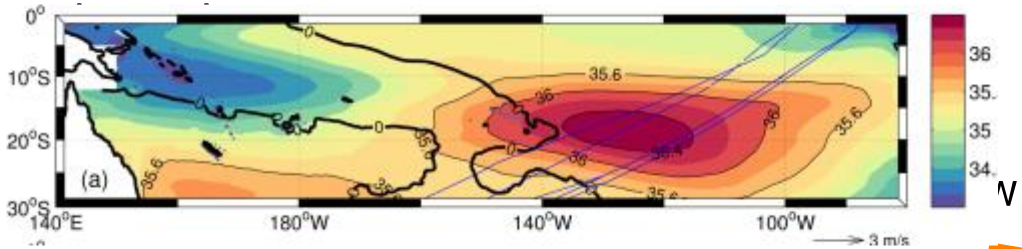
Durand et al. Ocean Dyn. (2013)
Nyadjro and Subrahmanyam, IEEE GRSL, (2014)
Nyadjro and Subrahmanyam, RSE, (2016)

Current Advection of fresh water plays an important role

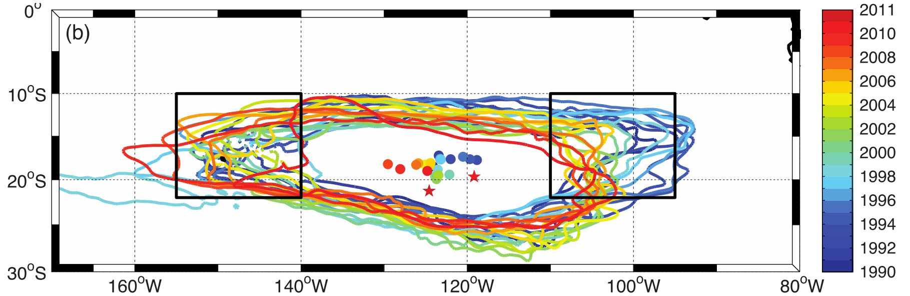
Du & Zhang, Jclim, (2015)

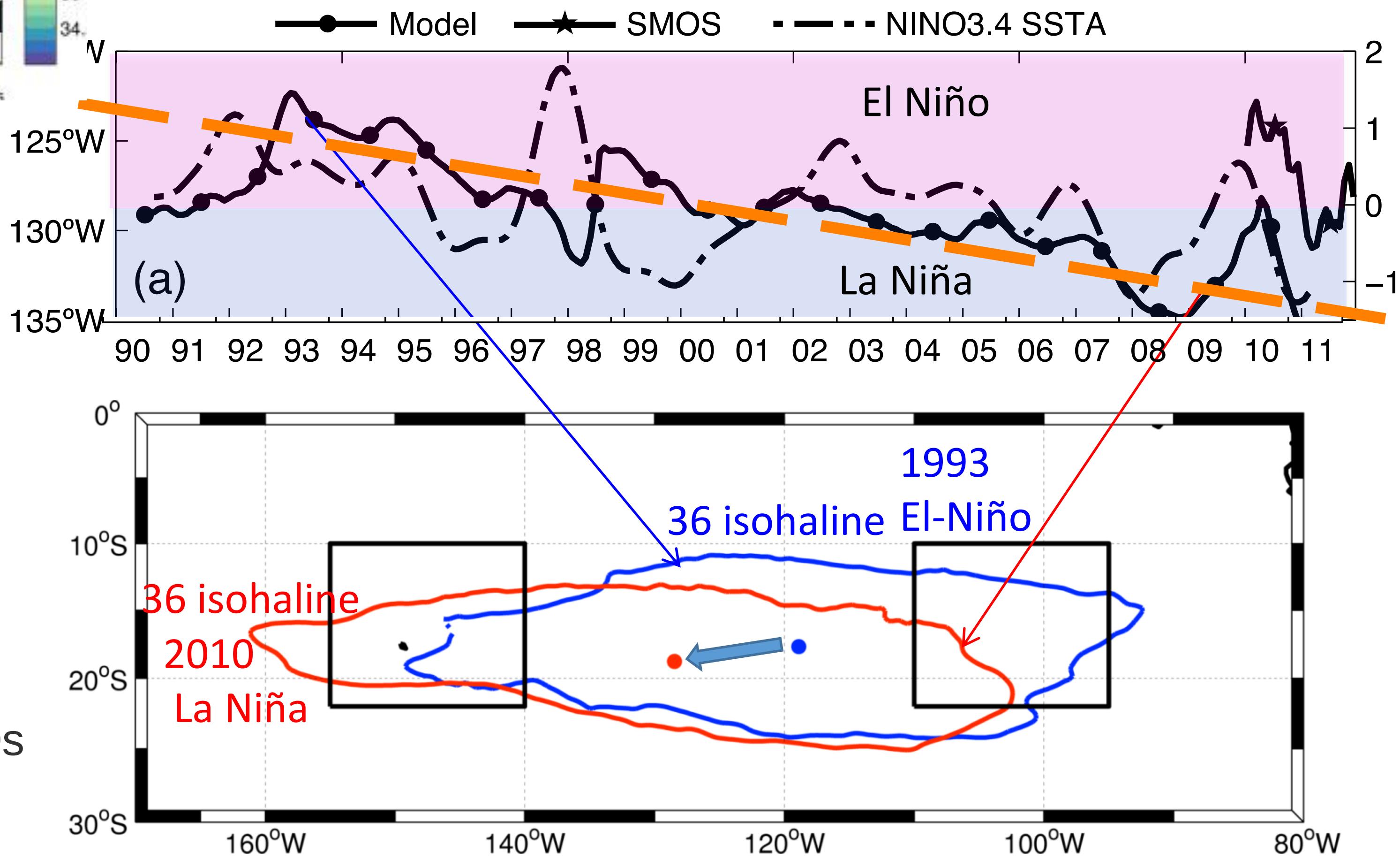
Large scale climate variability in the South Pacific Ocean: SSS maximum interannual osillations

SSS variability associated to **Pacific** Decadal Oscillation ?



Barycenters of 36 isohalines:
★ SMOS
● Modèle

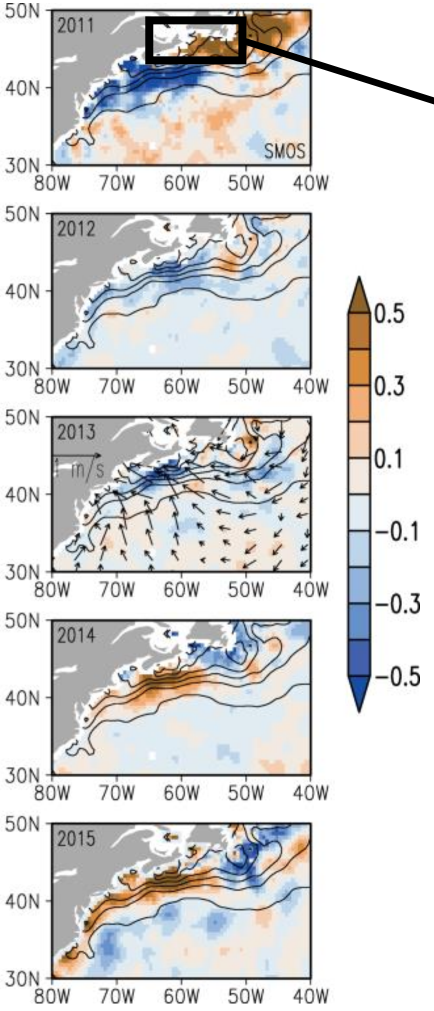




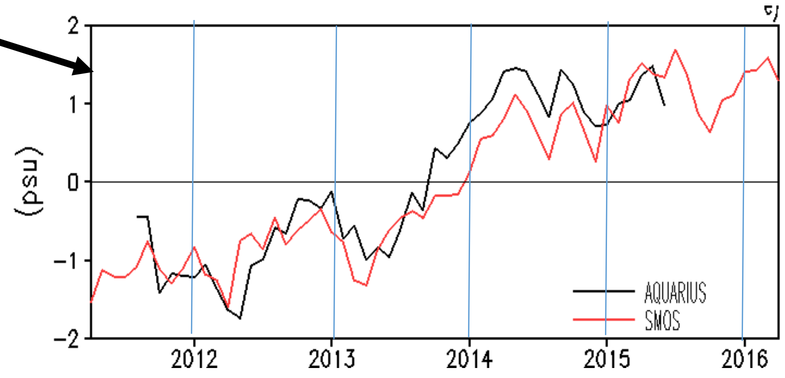
Low frequency westward shift of the barycenter of 1400 km from the mid 1990s to the early 2010s
links to the El Nino Southern Oscillation
PDO phenomena ?

Hasson et al. (2013)

Large scale climate variability:
Interannual surface salinity on Northwest Atlantic shelf



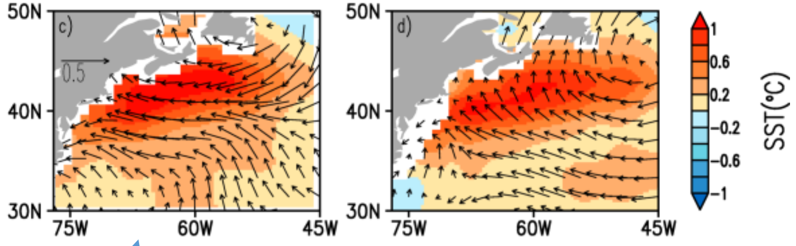
SMOS SSS Data (2011-2015)

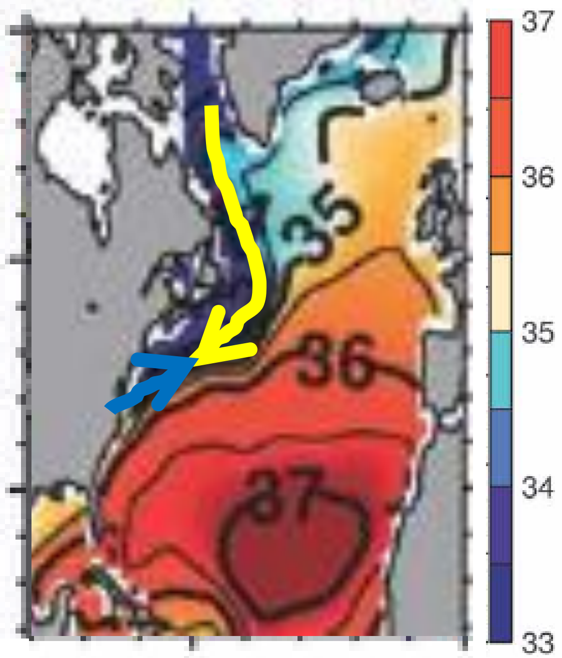


- **SSS increased by ~2 between 2011 & 2015** in a large region on **Northwest Atlantic shelf**, north of the Gulf Stream

- Source is a change in the **wind** & **Ekman Transport** which limited freshwater inputs from North by Southwestward flowing currents along the coasts

Anomalous easterly-southeasterly winds and Ekman transport





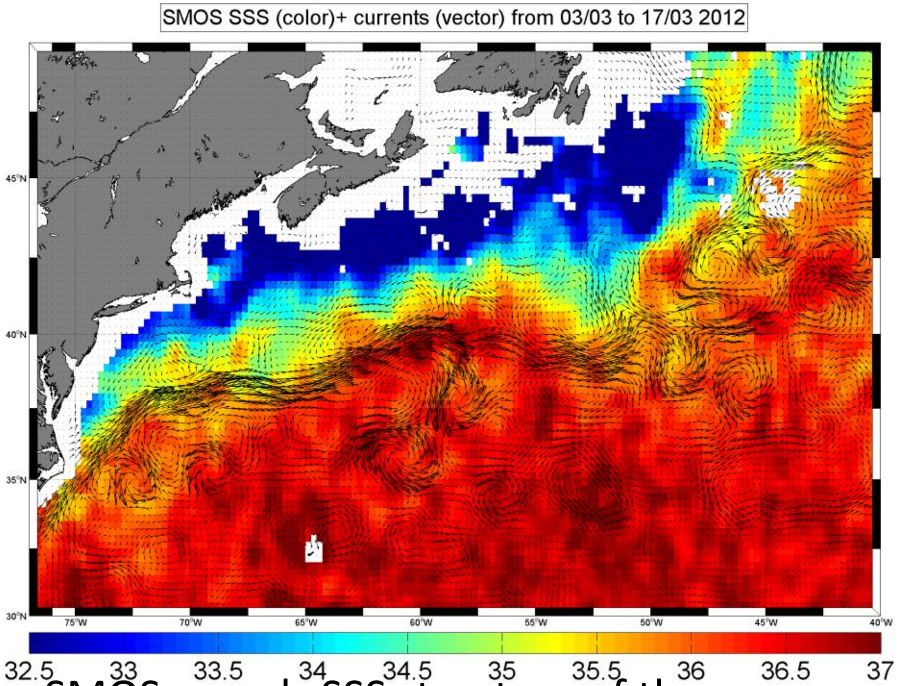
Grodsky et al., JGR, 2017

Monitoring SSS variability at Meso-scale

- Eddies
- Propagative large-scale planetary waves
- Fronts

Eddies in the Gulf Stream

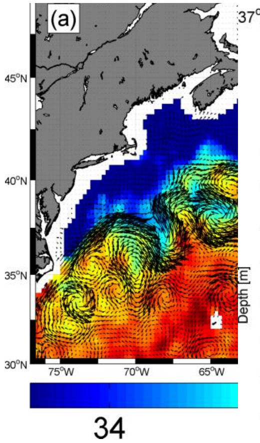
N. Reul et al. GRL 2014

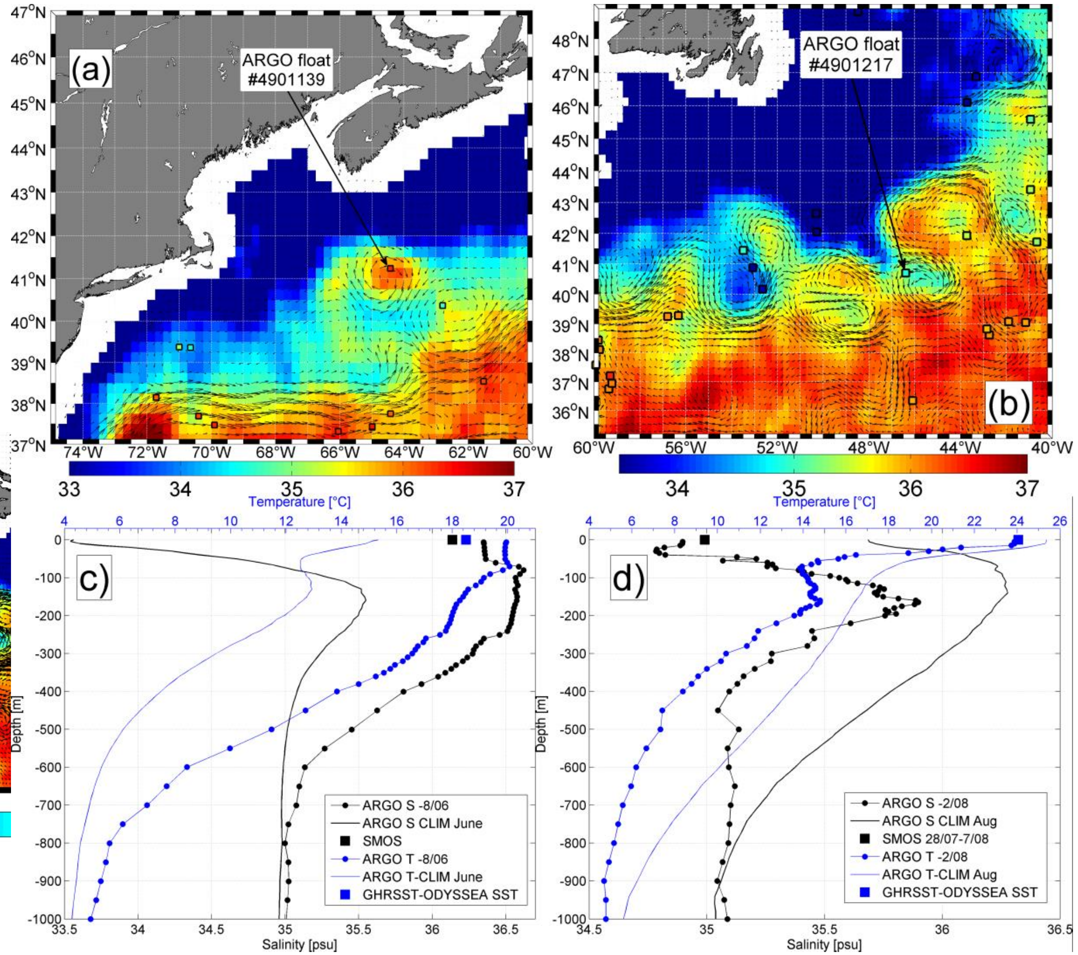


- SMOS reveals SSS structure of the Gulf Stream with an unprecedented space and time resolution

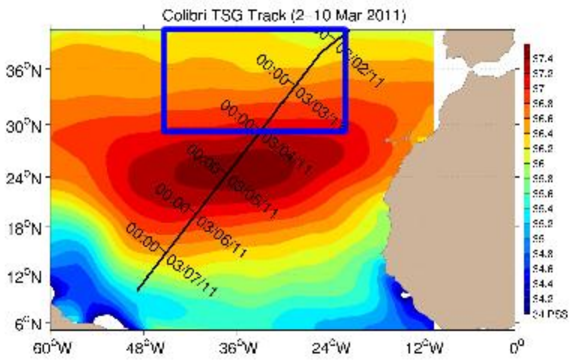
- Cold/fresh Core rings are much better captured by SSS than by SST during summer.

- Perspective : Surface salt-transport estimates by Eddies Subtropical⇔Subpolar Gyres

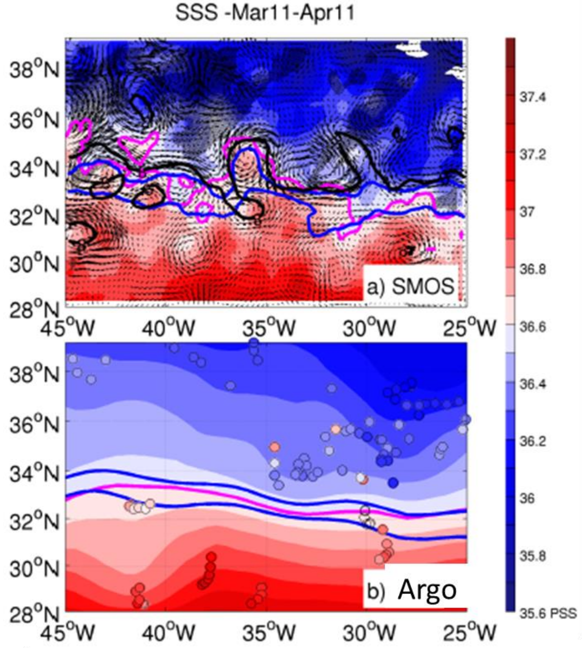


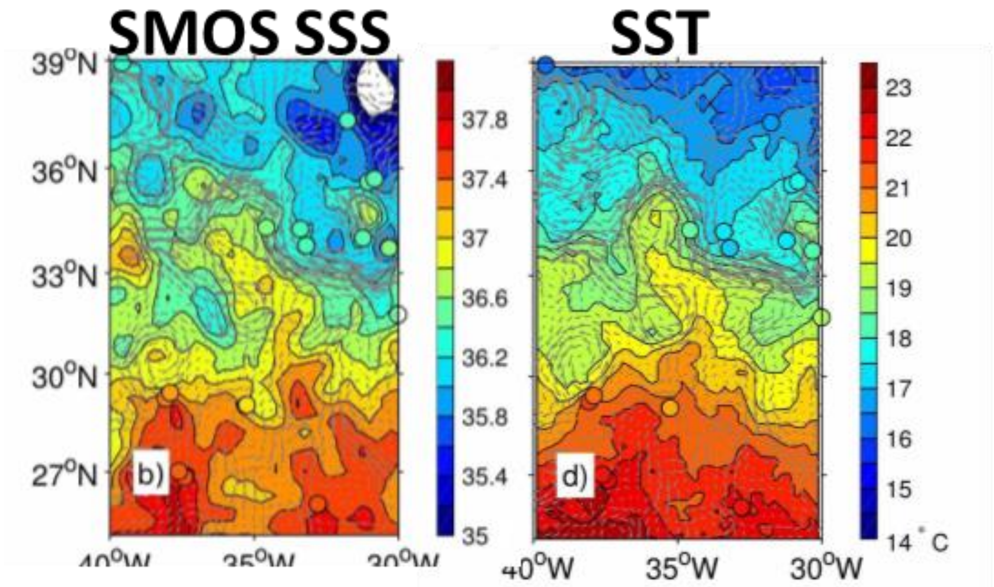


Eddies in the Azores Front/current



End of winter in the Azores Front/current – Temperature-salinity compensated structures

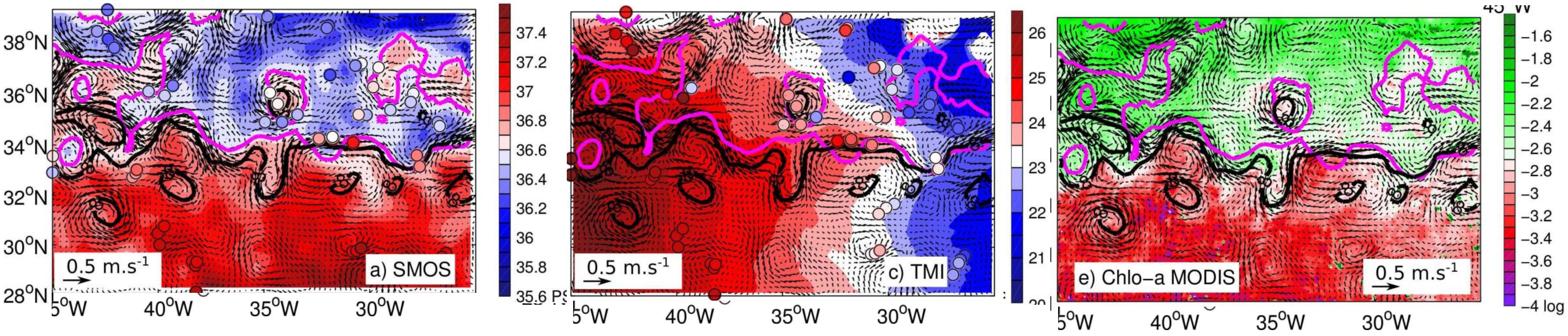




Kolodziejczyk et al., JGR, 2015

Isohaline 36.6
Vorticity 8 10^{-5} s^{-1} (core of current)

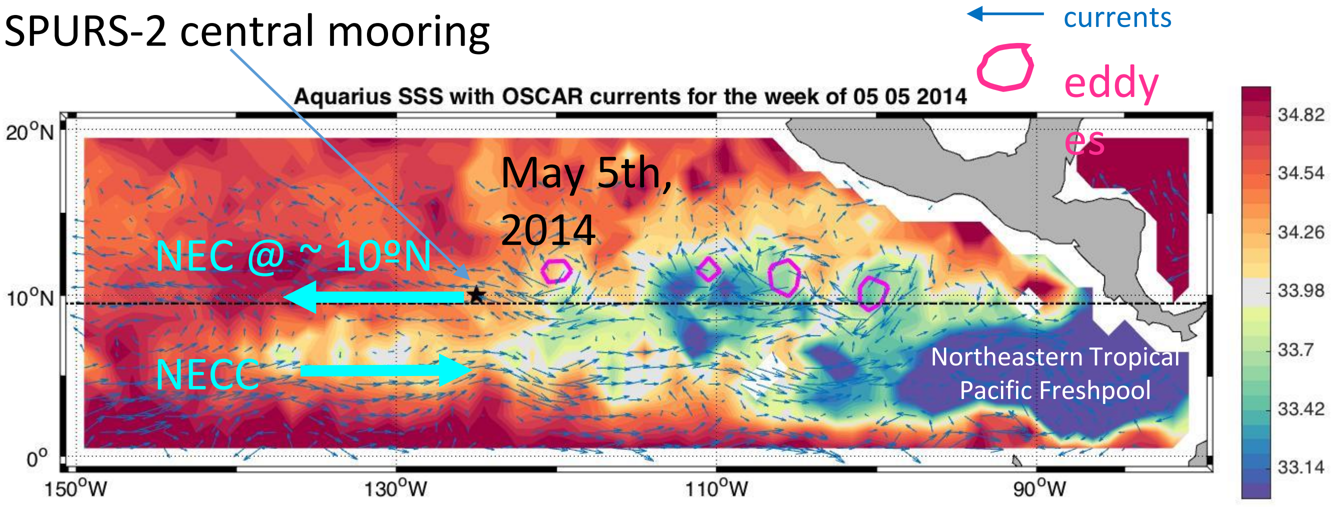
In summer, temperature very different from salinity structures. S and Chl structures very consistent



Propagative features: eddies in the North tropical Pacific

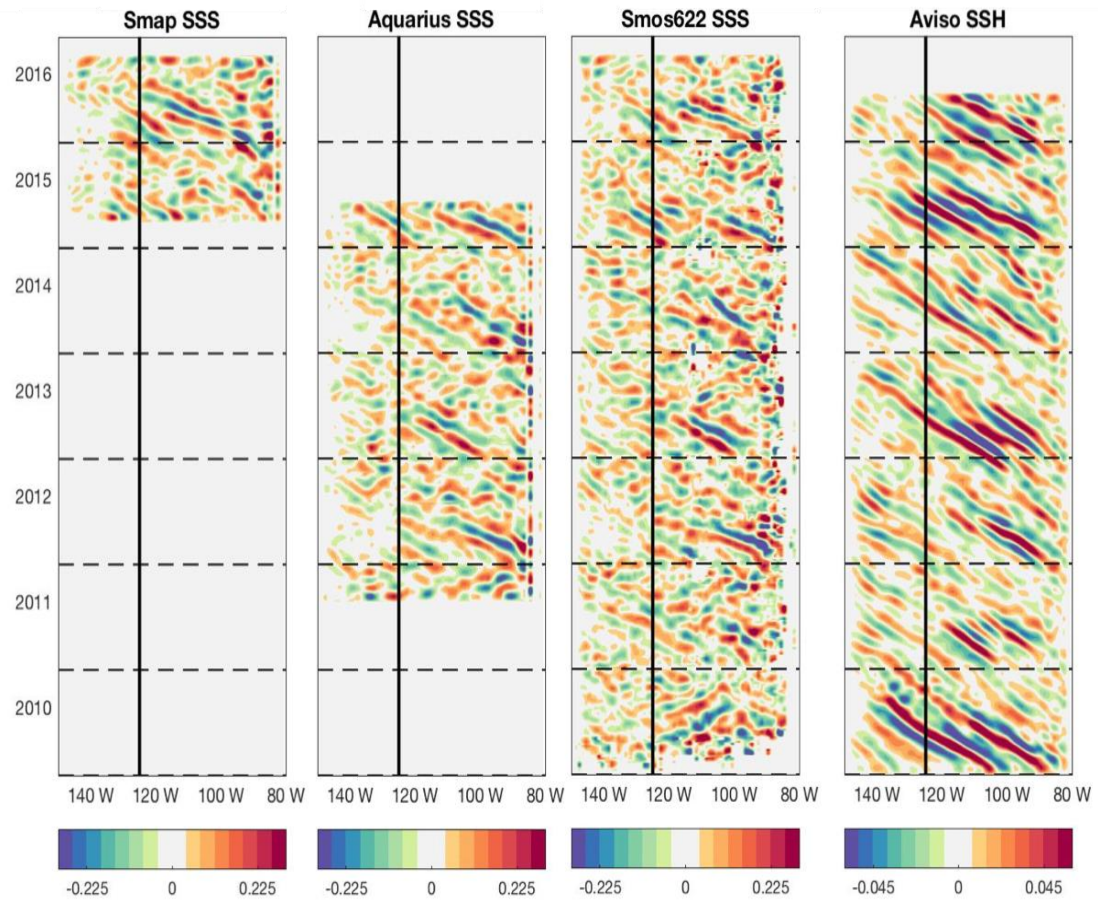
Eddies transport heat, mass and may interact with the atmosphere (possible retroactions, e.g. wind…): never regularly sampled SMOS resolution allows to track them

OBSERVED SSS – May 2014



- Westward propagation evident in all observed fields.
- Seasonal and interannual variation

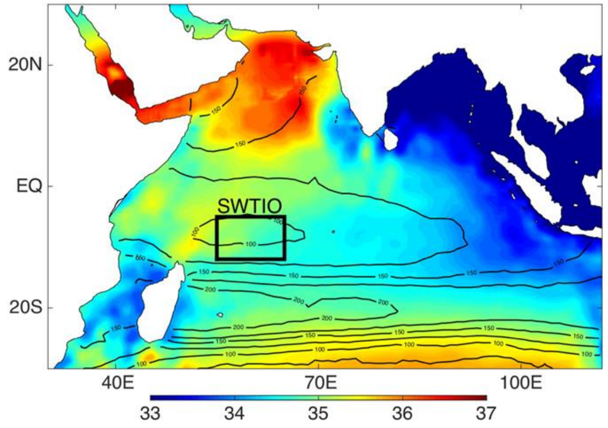
50-180d ANOMALIES at 10ºN



Hasson et al., ocean science, 2016

Ongoing studies to better characterize the eddies and their interaction with the atmosphere (LEGOS, LOCEAN)

Propagative features: Planetary waves in the Indian Ocean

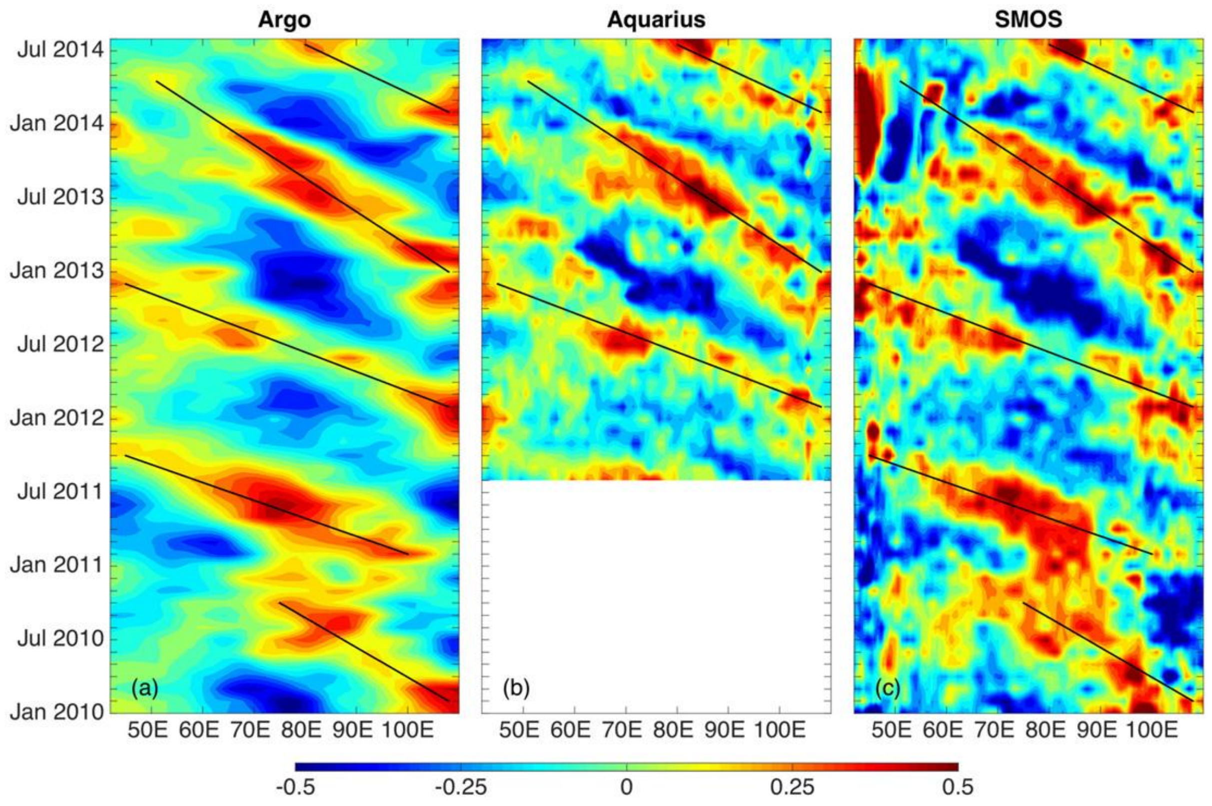


Climatology of SMOS salinity 2010–2014

Southwest tropical Indian Ocean (SWTIO) shows westward moving salty Rossby waves

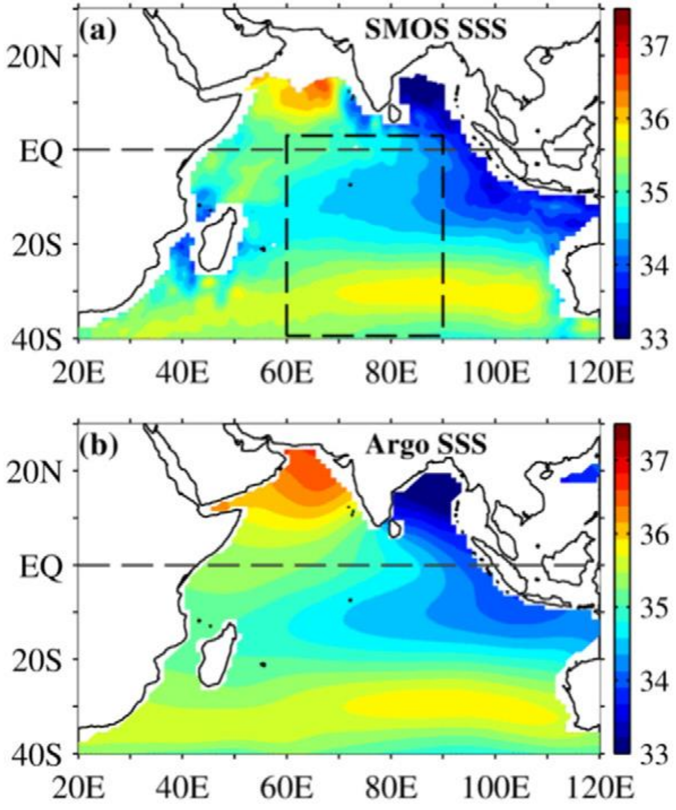
Aquarius and SMOS produce Barrier Layer Thickness estimates that are greater than Argo by 10–20m on average.

=> Implication for Asia Monsoon

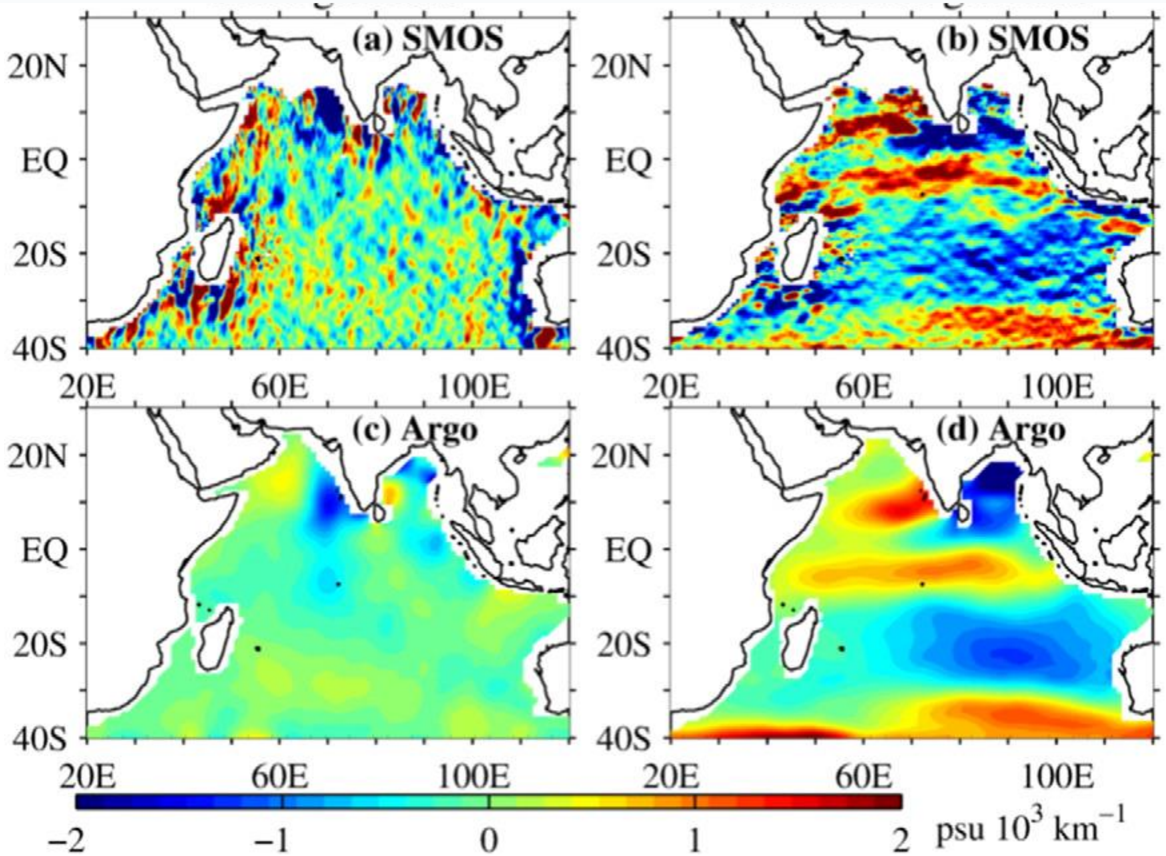


D'Addezio, & Subrahmanyam,RSE (2016)

Fine scales: salinity fronts in the Indian Ocean



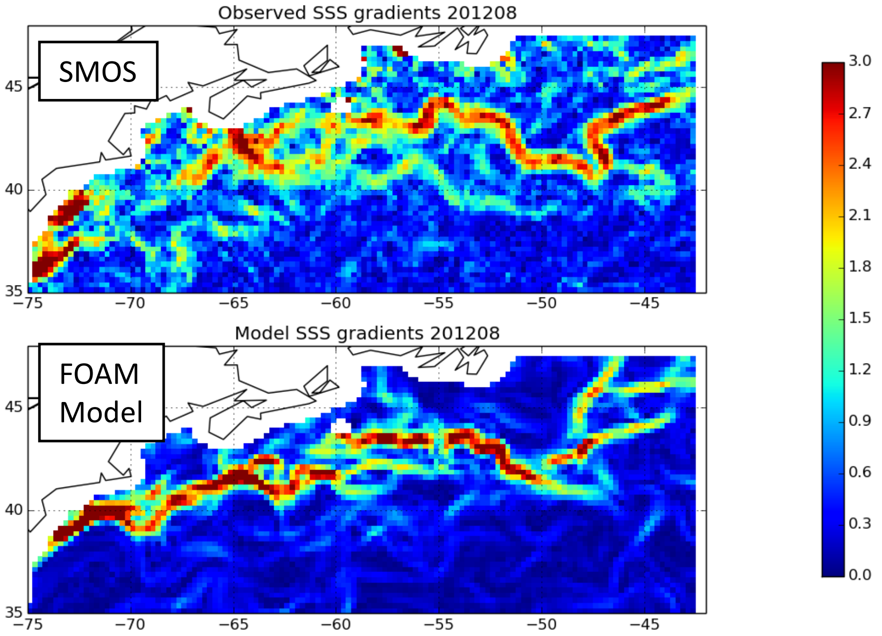
- ❑ Occurrence and variability of Indian Ocean SSS fronts from SMOS
SMOS captures SSS fronts with relatively strong magnitude compared to Argo.
- ❑ Indian Ocean SSS fronts influenced by ITCZ, ocean currents
- ❑ **Indian Ocean Dipole influences the dynamics of SSS** fronts.



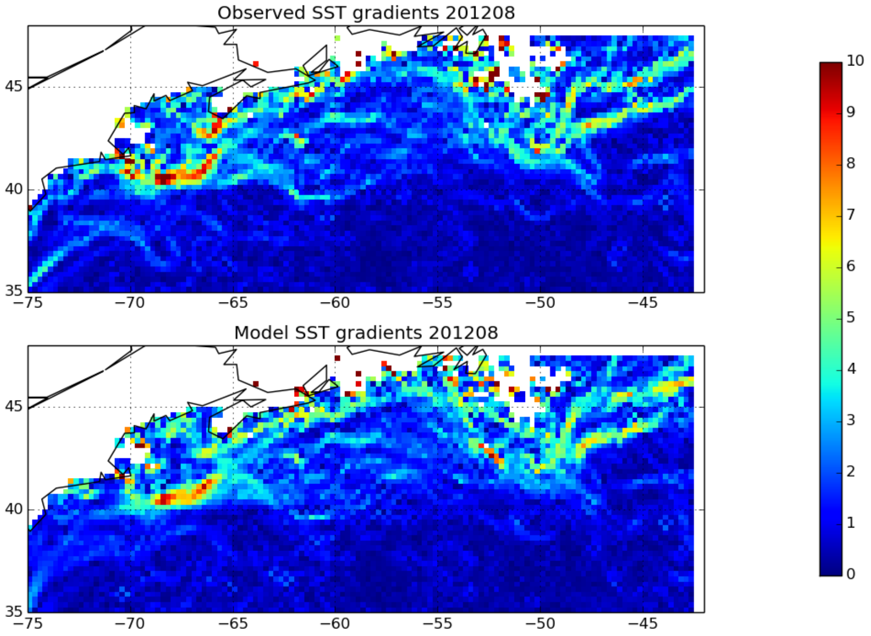
Nyadjro et al.,RSE (2016)

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

SSS horizontal gradients



SST horizontal gradients



- **SSS fronts agree well between FOAM 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**

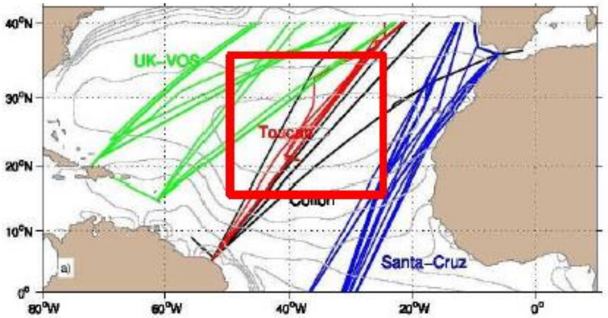
Martin, RSE, 2016 (UK Metoffice)

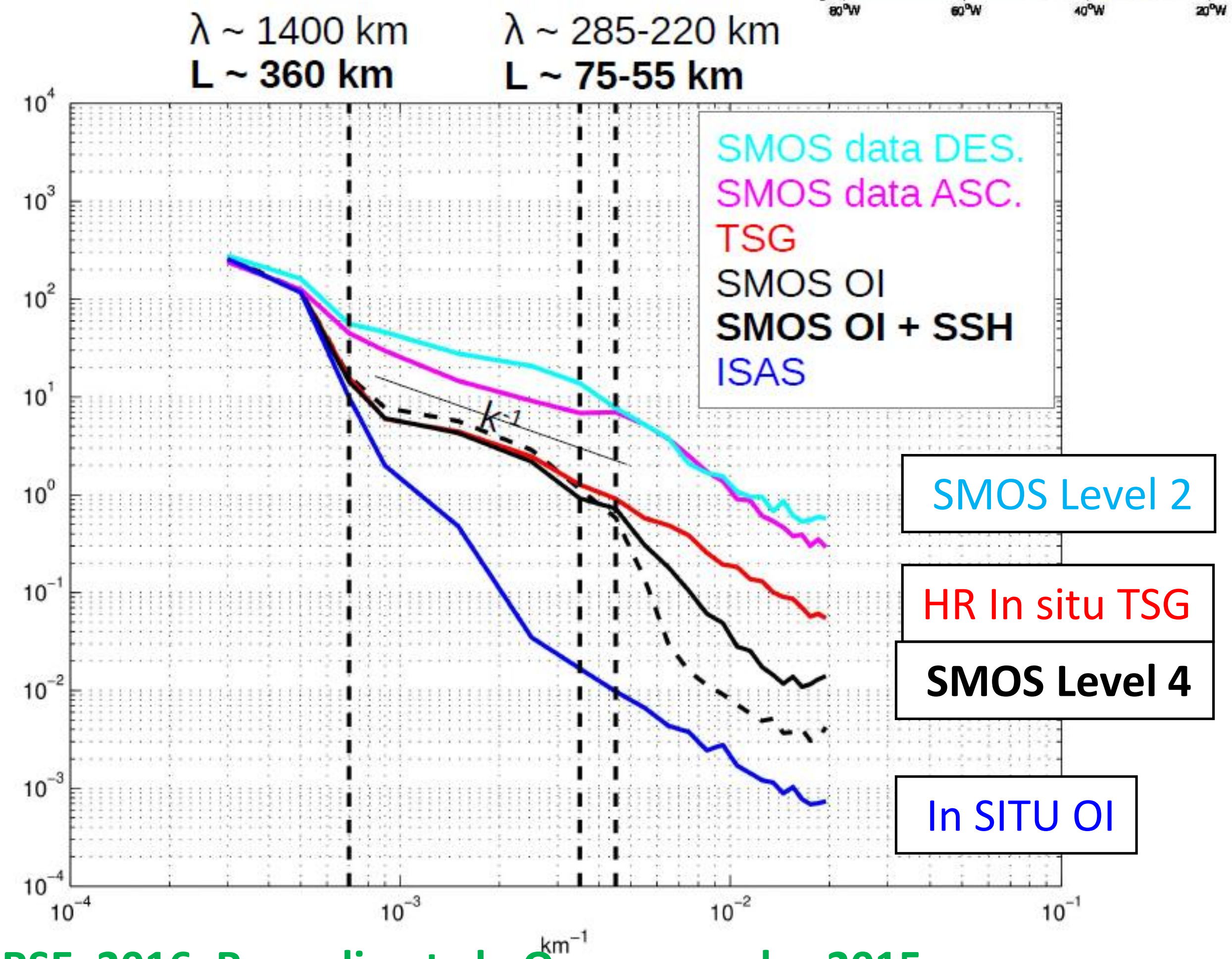
SMOS « sees » the Meso-scale SSS variability down to ~100-50 km

Comparison with TSG

→ Power Spectra

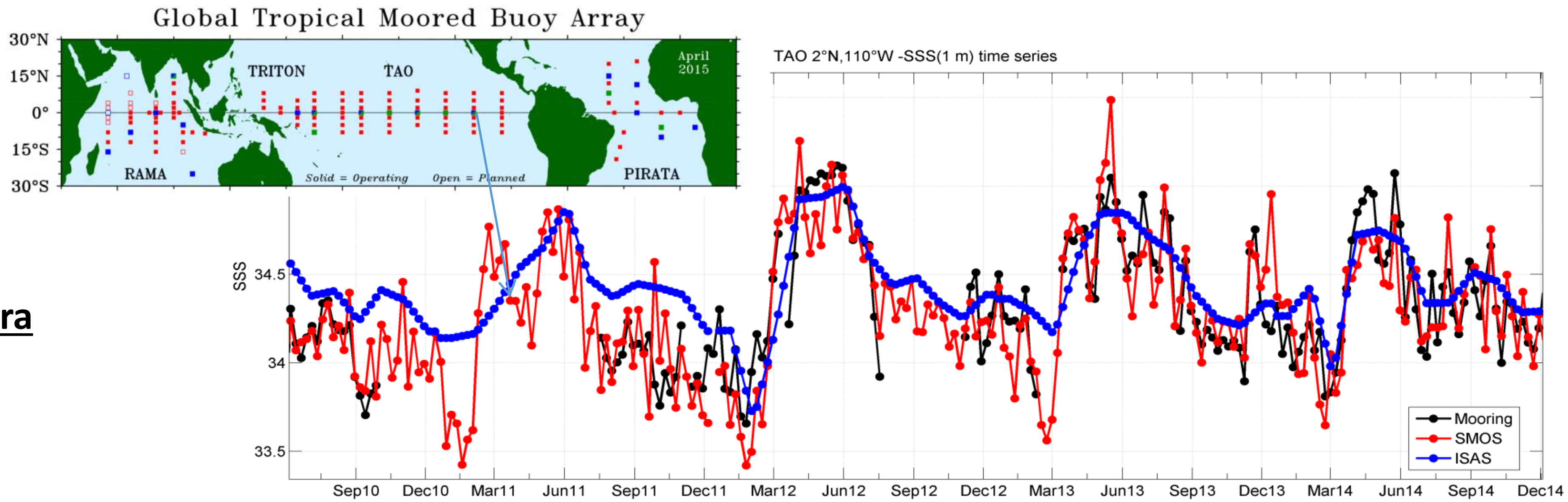
→ 32 TSG section (Colibri & Toucan)





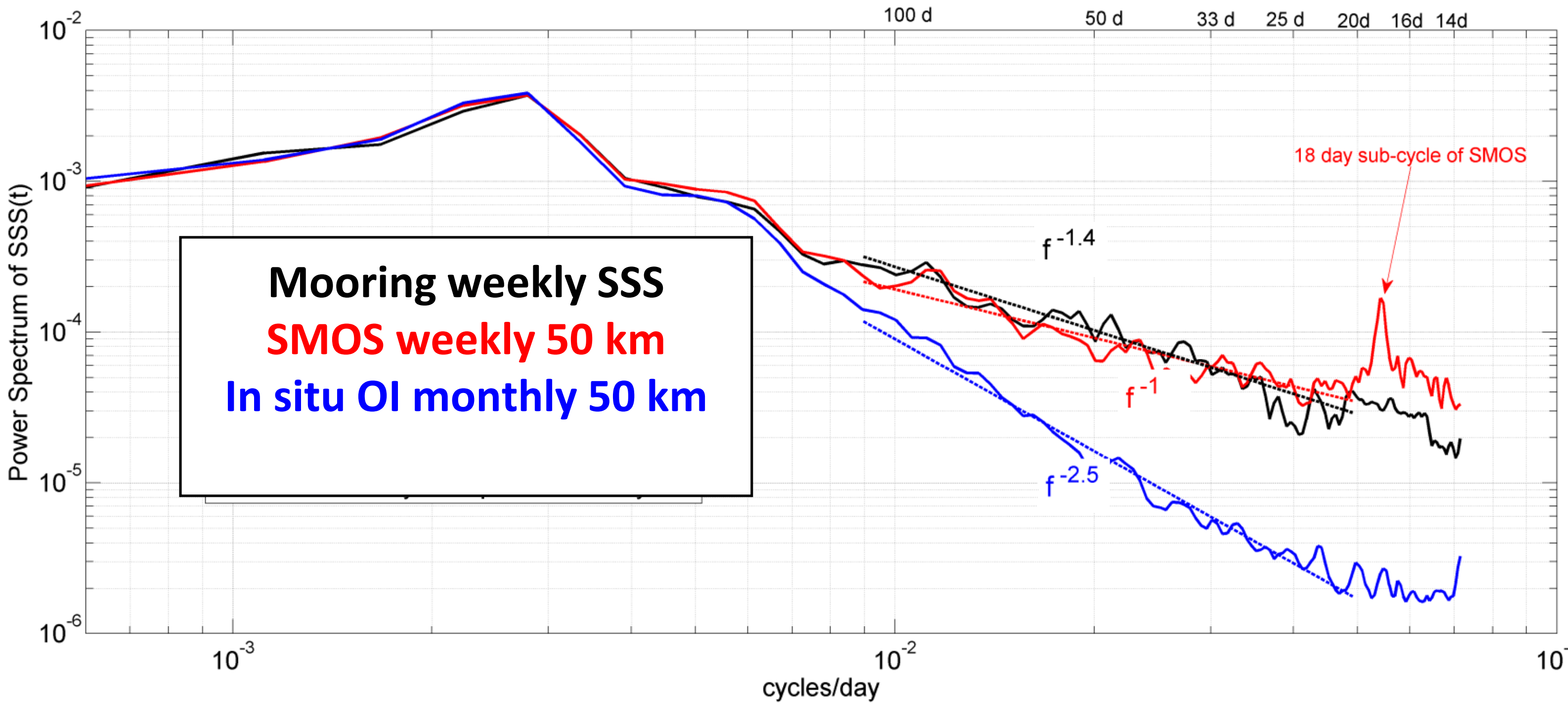
Kolodziejczyk et al., RSE, 2016, Reverdin et al., Oceanography, 2015

Temporal Spectra At Moorings



Can be done at
Any virtual location

Relevant SMOS SSS variability down to ~18 days



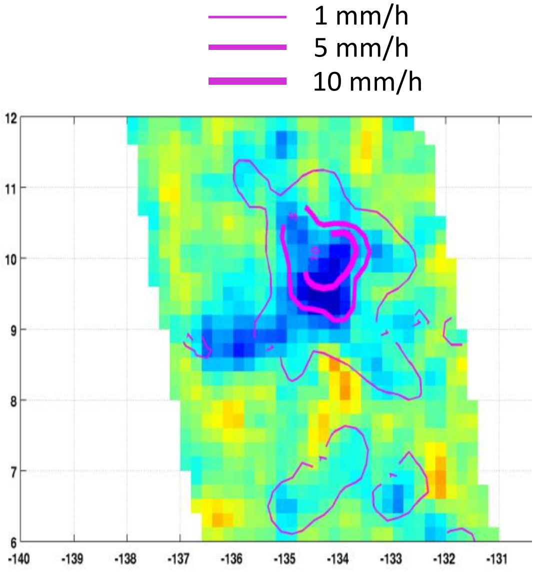
Freshwater Flux Monitoring

- SSS as a ‘rain gauge’ ?
- River plume

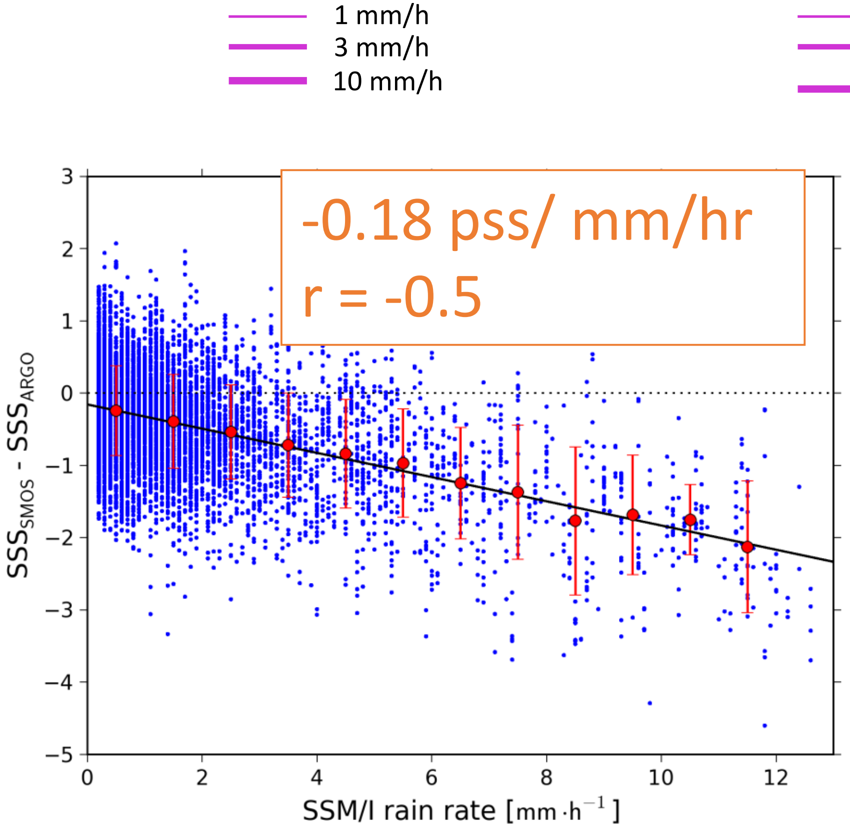
Impact of rain on SMOS SSS

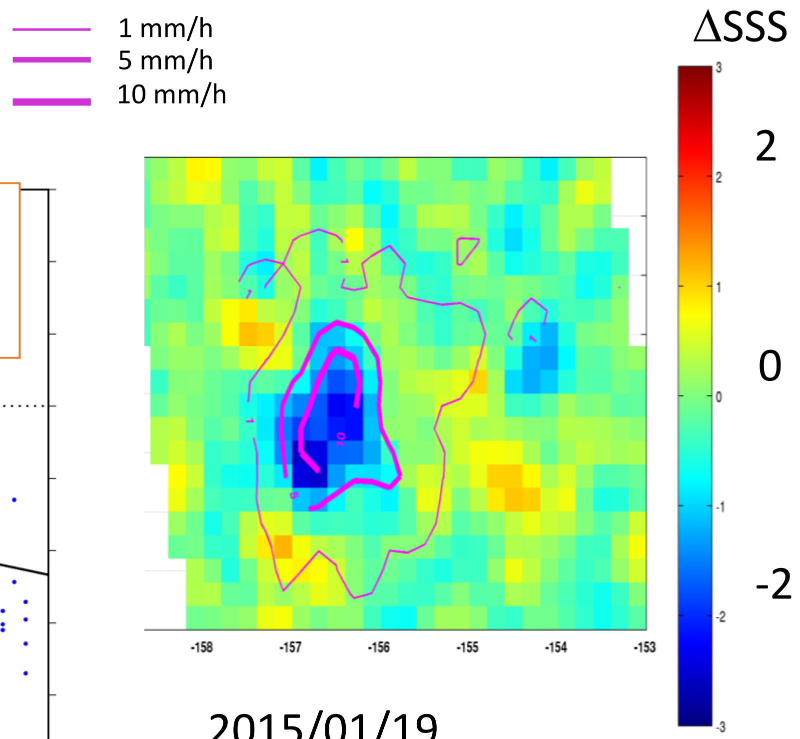
Boutin et al. (2013, 2014)

- Satellite rainfall and SMOS freshenings (ΔSSS) are closely correlated at local scale and short temporal scale (<30mn)



2015/11/05

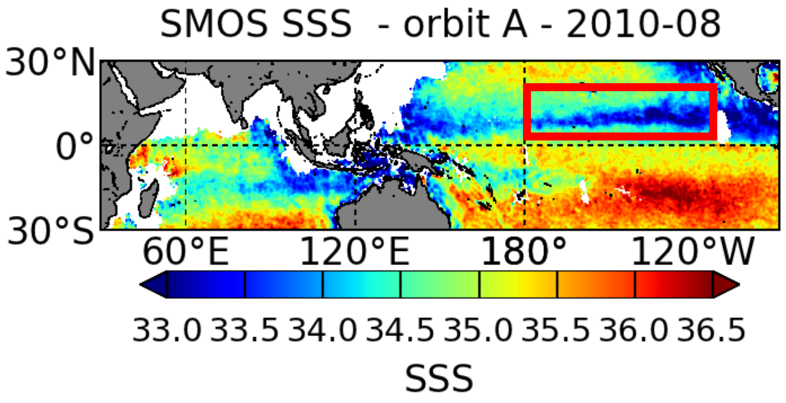




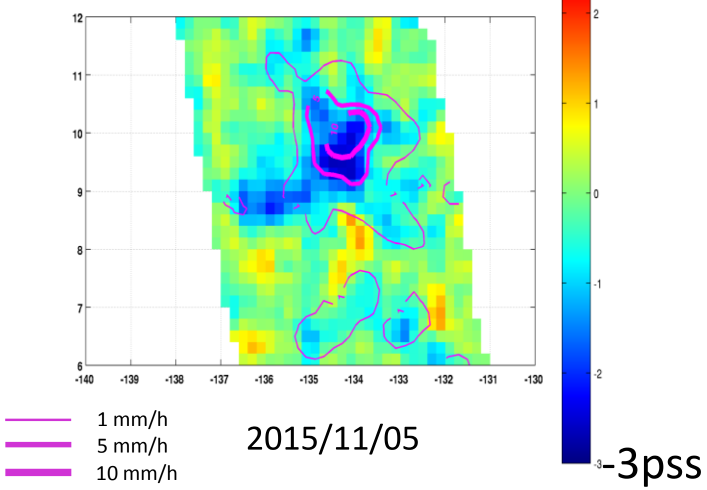
2015/01/19

Satellite radiometer records salinity in the first top cm: an information not accessible by ARGO measurement => surface salinity stratification and rain events

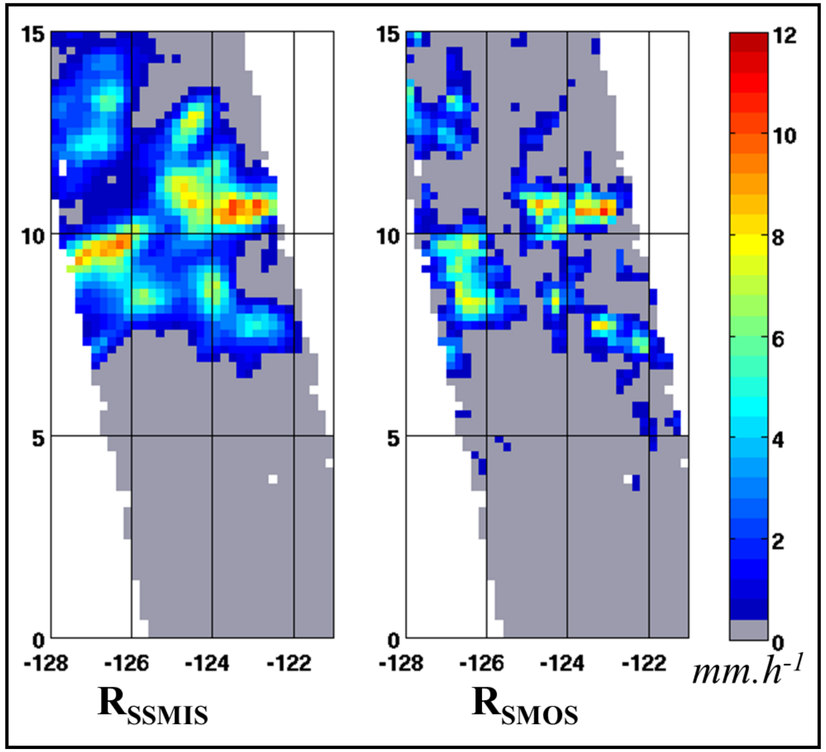
Precipitation estimates from SMOS SSS



SMOS SSS anomaly and SSMI rain rates



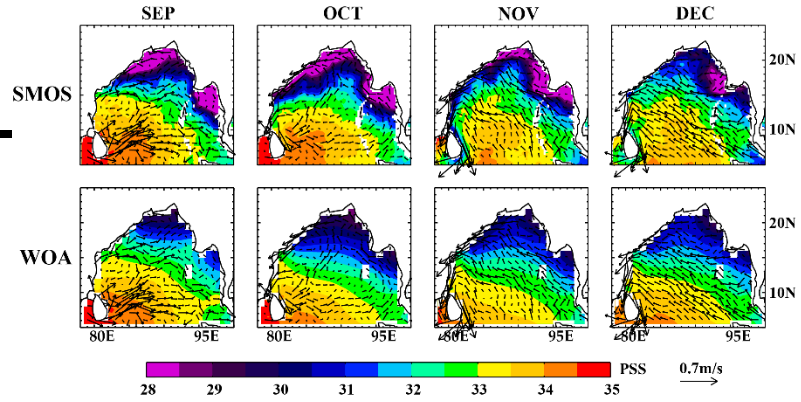
- Satellite rainfall and SMOS SSS freshenings are closely related at local scale and short temporal scale (<30mn) => SMOS retrieved 'instantaneous' rain rate



In rainy areas, **instantaneous SMOS rain rate complement spatio-temporal coverage of rain monited by microwave radiometry (GPM constellation)** !

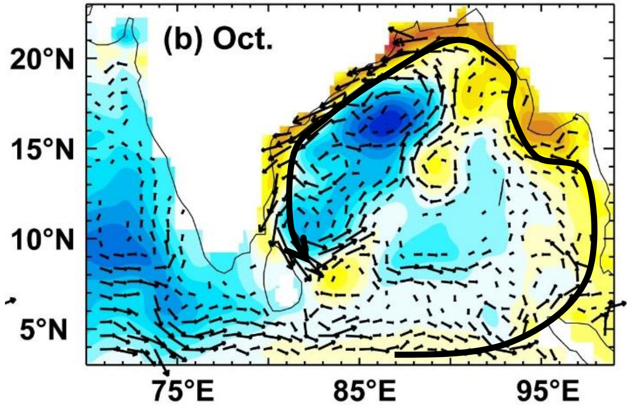
Boutin et al. 2013, 2014; Supply et al. 2017

Bay of Bengal: ‘the river in the sea’

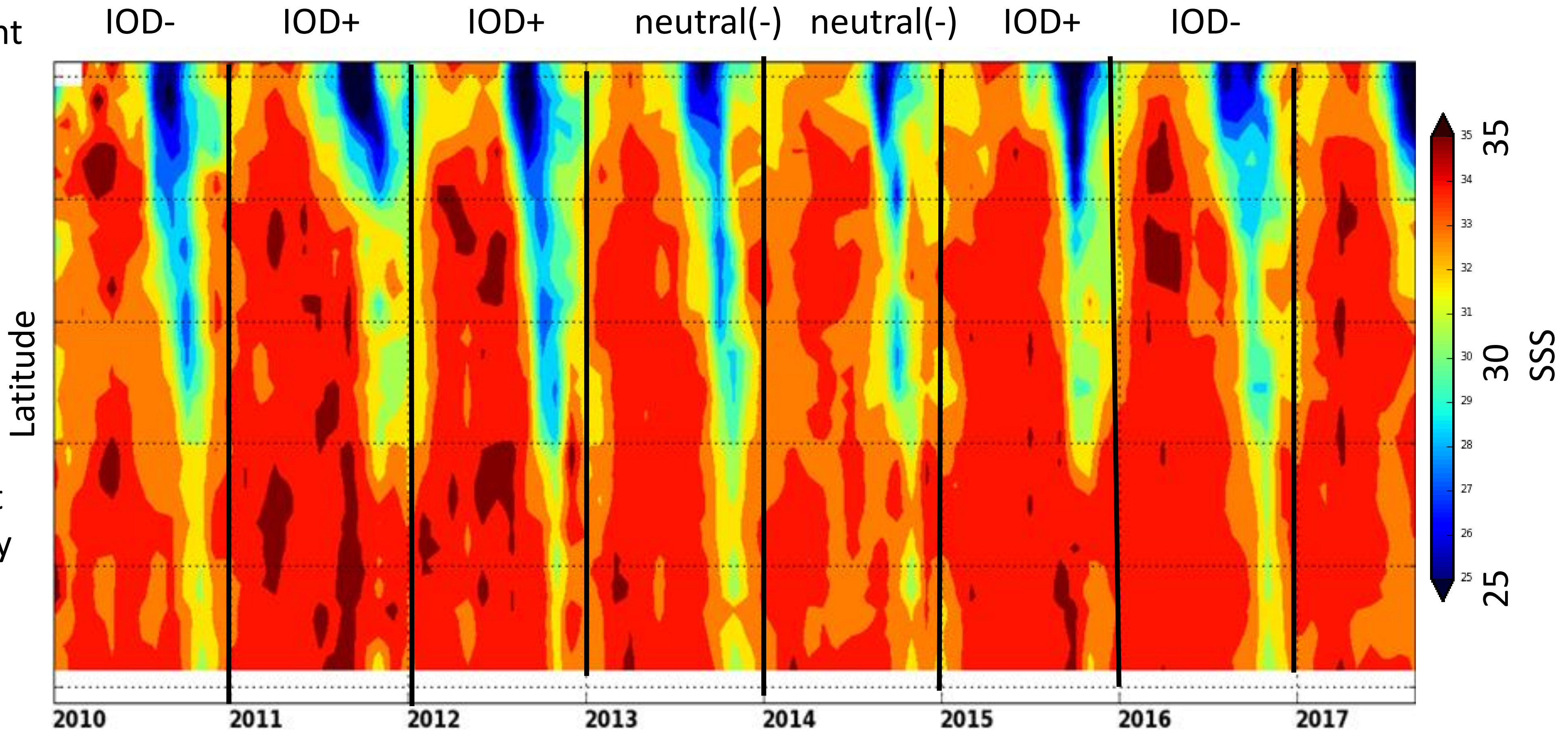


Gange + Brahmaputra => The ‘river in the sea’
Seen by SMOS.
Model studies suggest an Interranual variability linked to Indian Ocean Dipole (variable advection) (Akhil et al. 2016): we see it with SMOS

East India Coastal Current



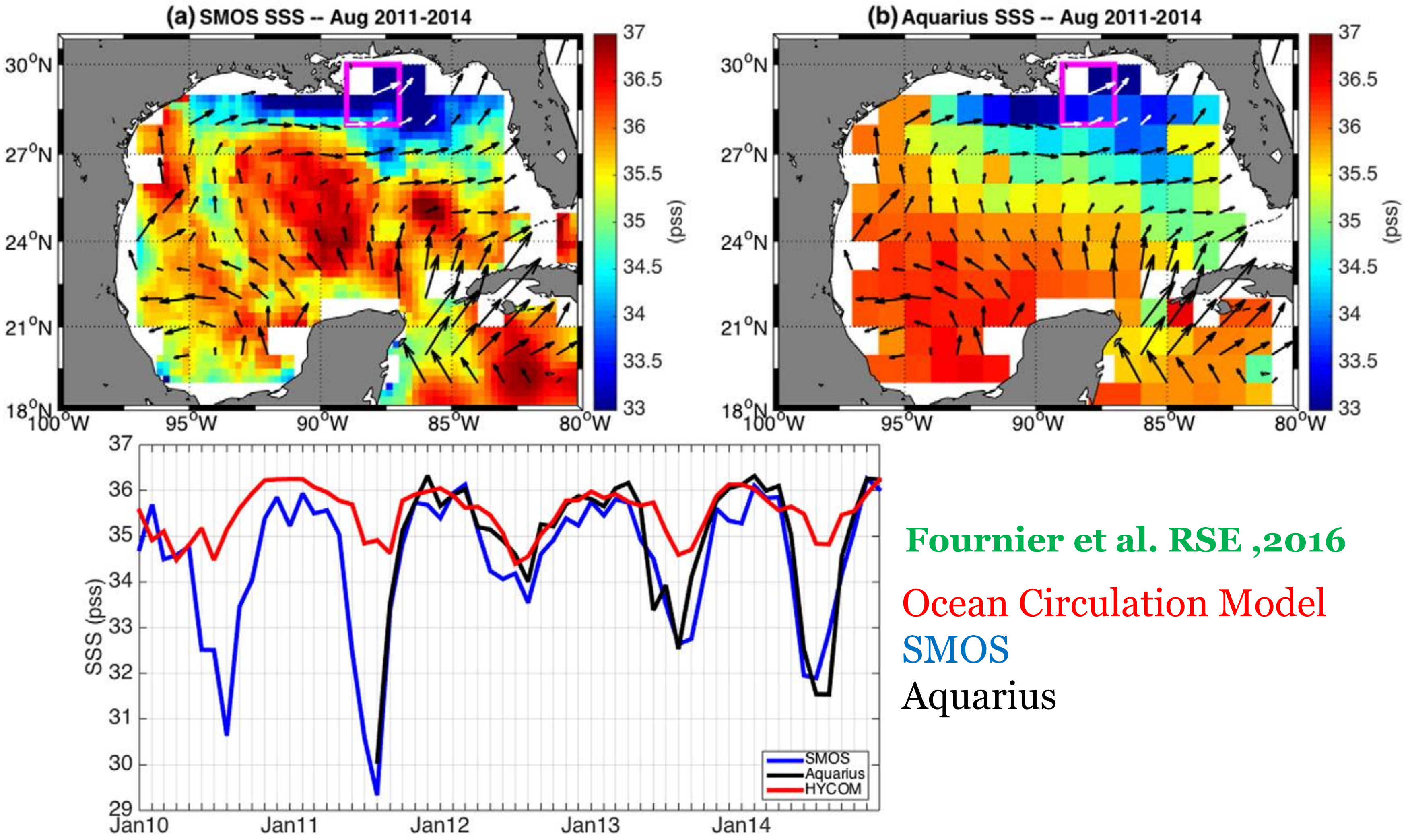
In situ cannot capture the very strong SSS gradient along the coast.



SMOS data revealed
that EICC transport
the fresh
river water along the coast
With interannual variability
Related to IOD

Vialard, Akhil, Marchand et al. 2017

Freshwater plumes: the Mississipi river plume

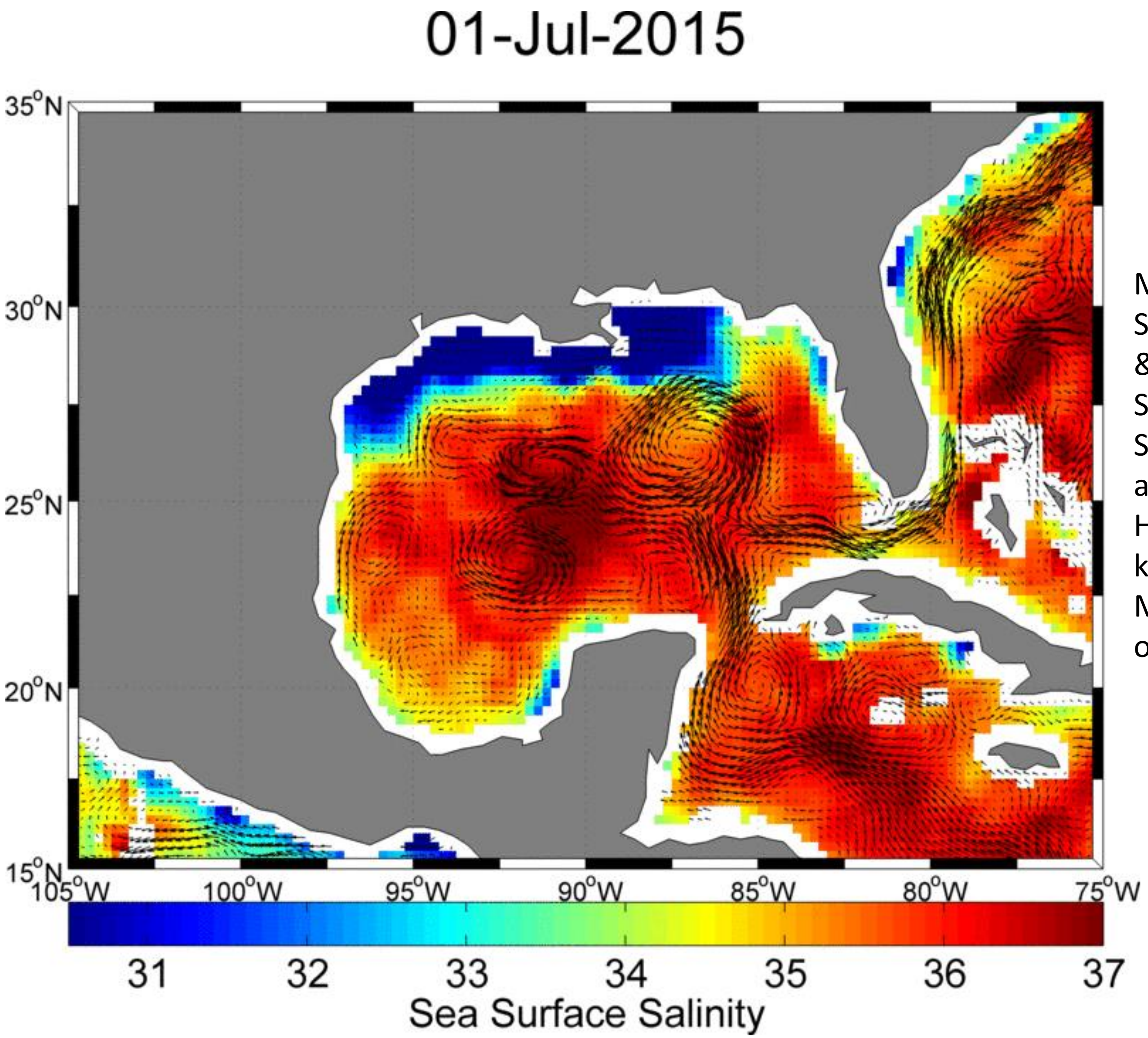


Fournier et al. RSE ,2016

Ocean Circulation Model
SMOS
Aquarius

- Observations of seasonal & interannual SSS changes in Mississippi and River plume
- Interannual SSS can be as large as seasonal SSS anomalies in Mississippi River plume.
- River discharge is the major forcing, evaporation–precipitation plays a minor role
- Significant implications to ocean modeling/forecast and hypoxic zone monitoring

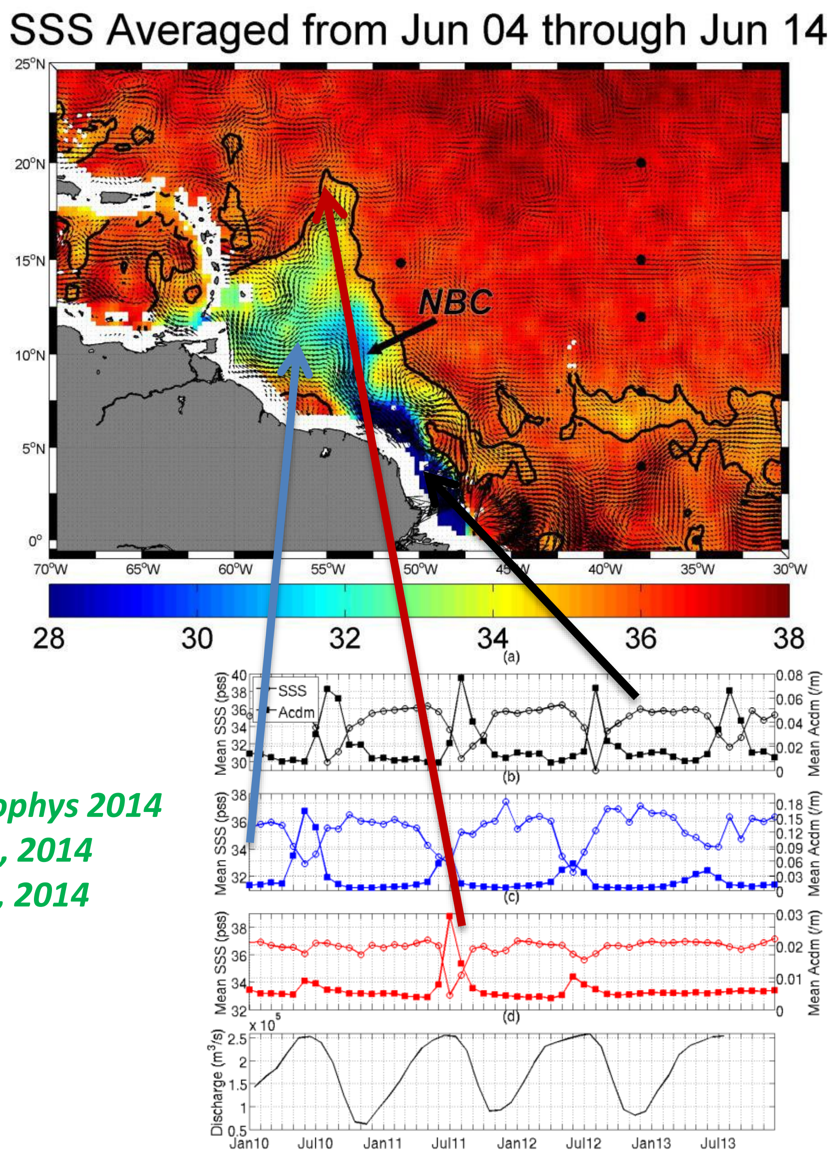
Monitoring the Mississipi river Plume

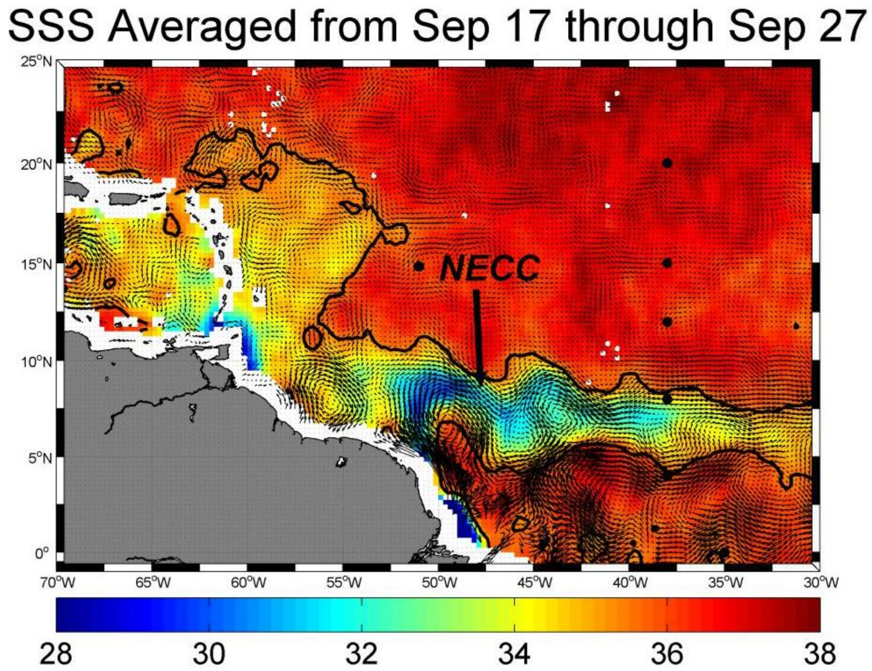


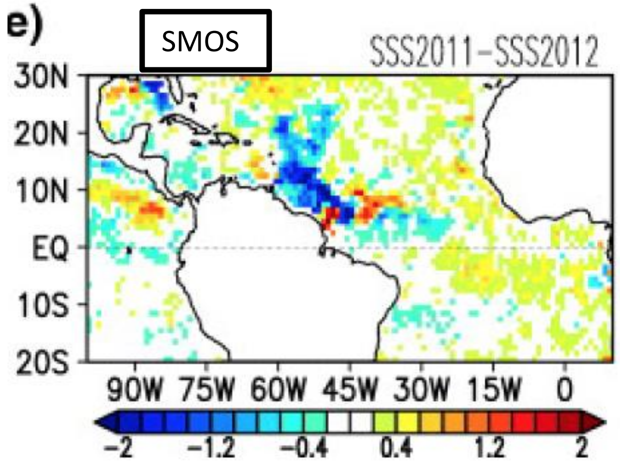
Merged SMOS & SMAP SSS allows High res (3 days, 40 km) Monitoring of meso-scale SSS

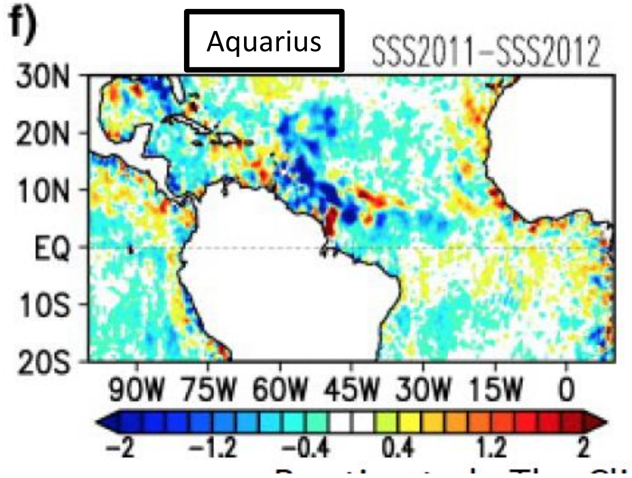
Merged SMOS and SMAP SSS to form 3 days running mean SSS

Amazon River plume monitoring









Reul et al., Rev Geophys 2014
Fournier et al., JGR, 2014
Grodsky et al., RSE, 2014

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

Gulf of Guinea: Niger & Congo signature

ISAS SMOS-OI-75km SMOS debias_v2

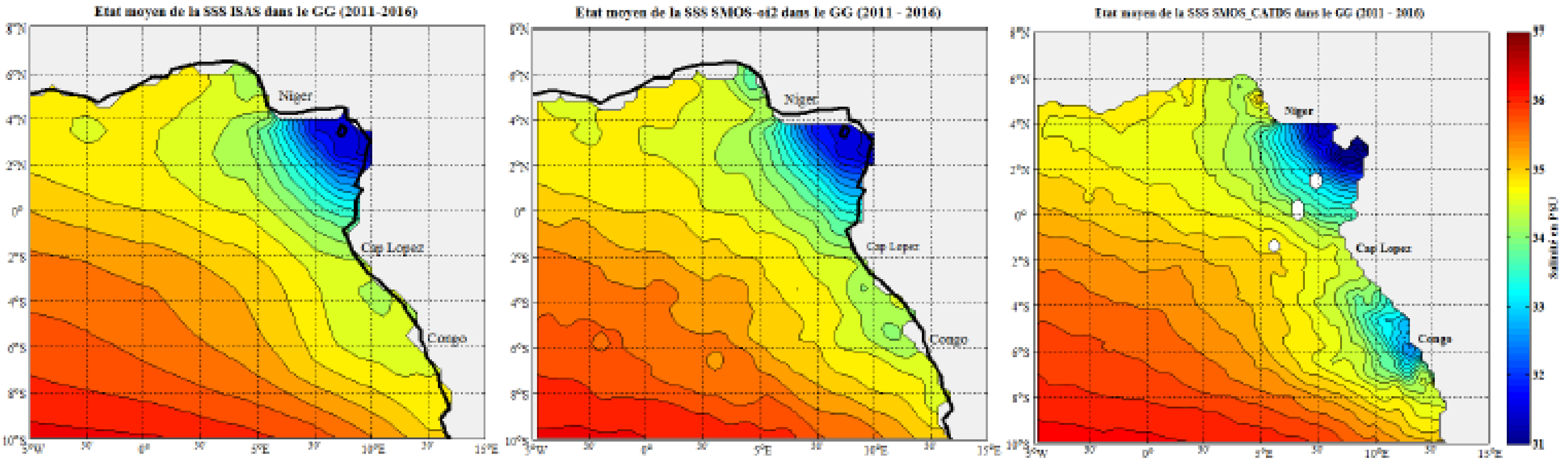
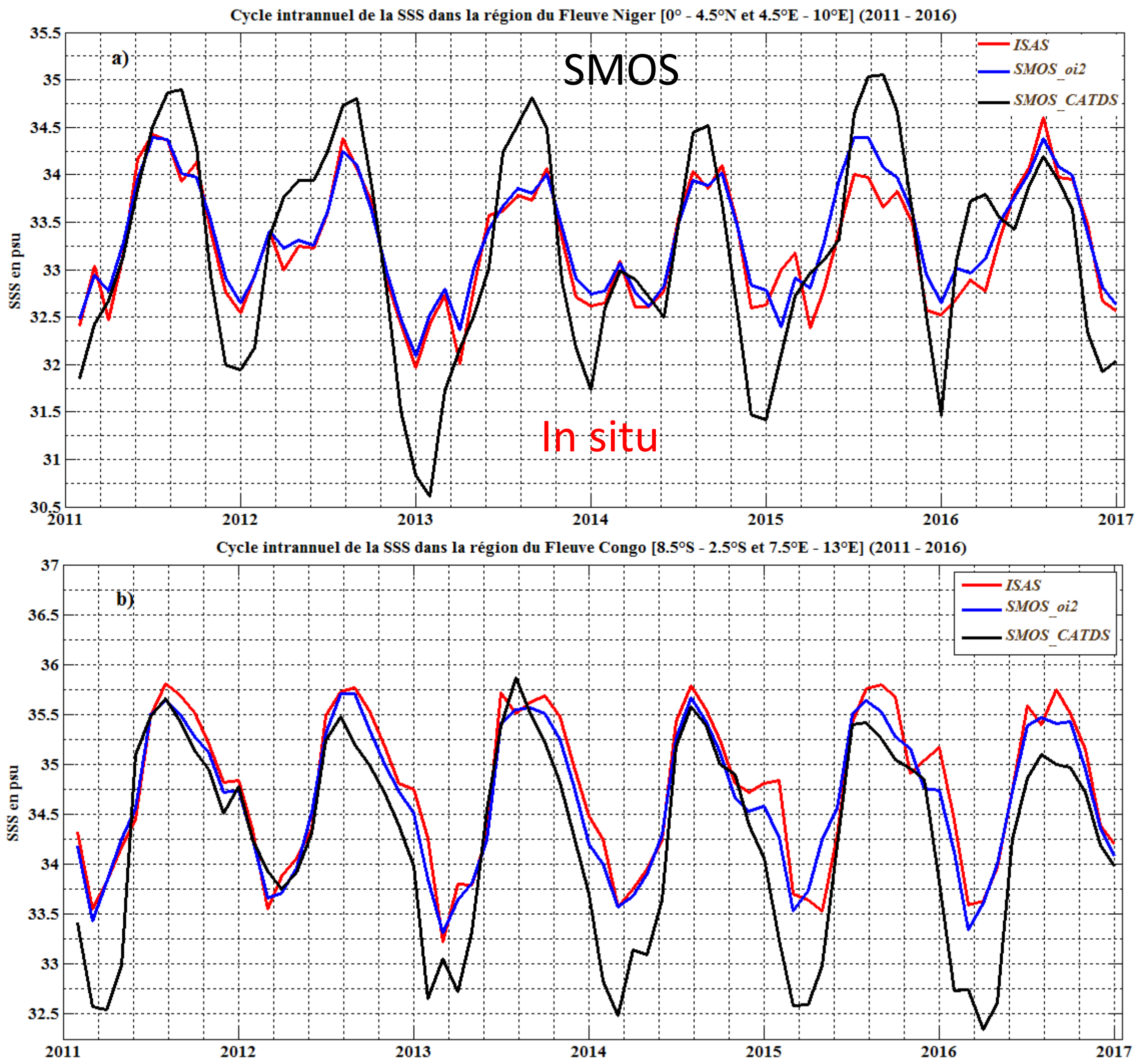


FIGURE 3.4 – *Etat moyen de la SSS dans le GG : ISAS (à gauche), SMOS-oi2 (au milieu), SMOS_CATDS (à droite)*

N.B. Version de SMOS-OI à 75km

O.J. Houndegnonto (N. Kolodziejczyk, LOPS)

Gulf of Guinea: Niger et Congo signature
Interannual variability



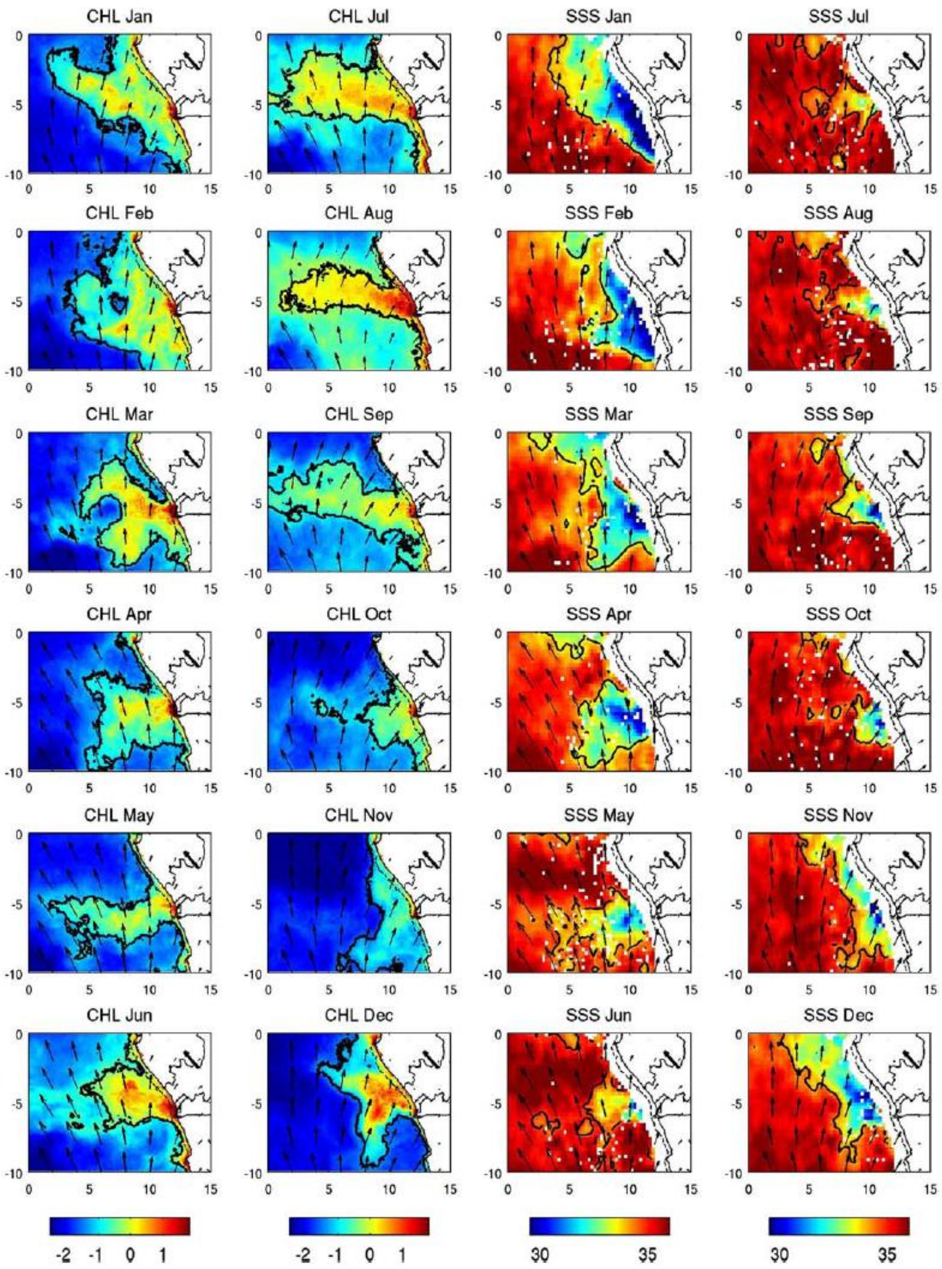
Niger

Congo

SMOS SSS at 1cm depth show fresher
SSS than most in situ data at ~5m depth
In these large river plumes

Stage O.J. Houndegnonto (N. Kolodziejczyk, LOPS)

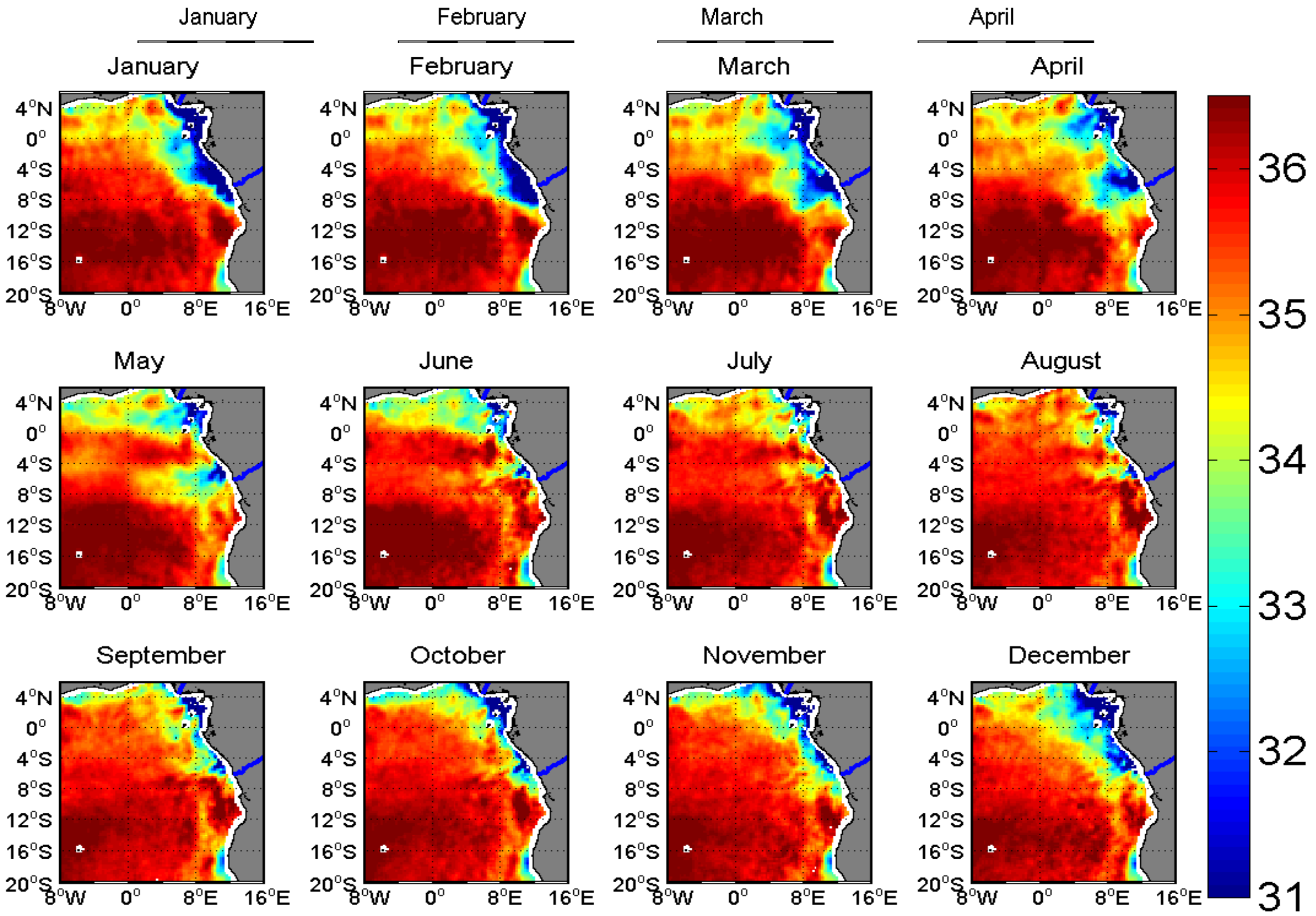
Correlation SSS-chlorophyll within the Congo river Plume



- ❑Dispersal and dynamics of the Congo plume studied from satellite data products
- ❑Salinity from the SMOS mission reveals seasonal strength And behaviour of plume
- ❑Negative salinity–chlorophyll correlations across 500 km2 zone west of river mouth
- ❑Main plume axis oriented northwest, or west–southwest, 400–1000 km from river mouth
- ❑Dynamics controlled by wind forcing, wind driven currents and fresh water discharge

Hopkins et al., RSE, 2013

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

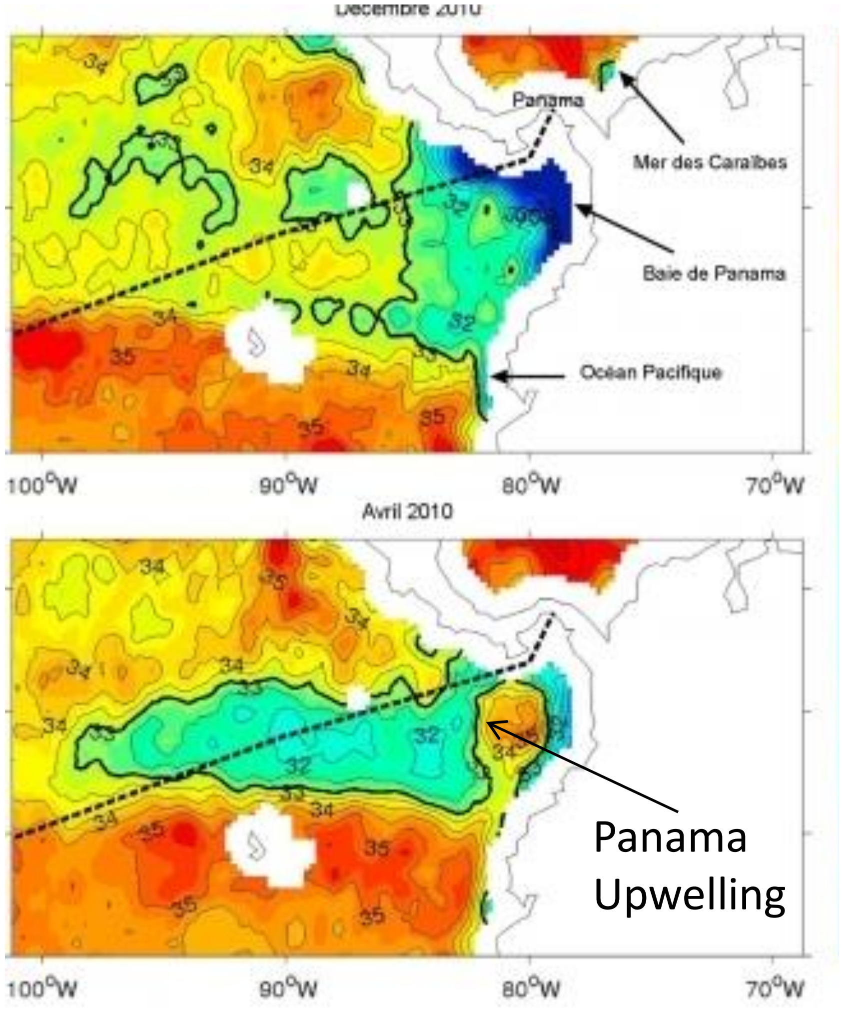
SMOS data now allow the regular monitoring of the seasonal & interannual variability in the discharge & advection of freshwater river plumes into the ocean

SSS & Air-Sea Interactions

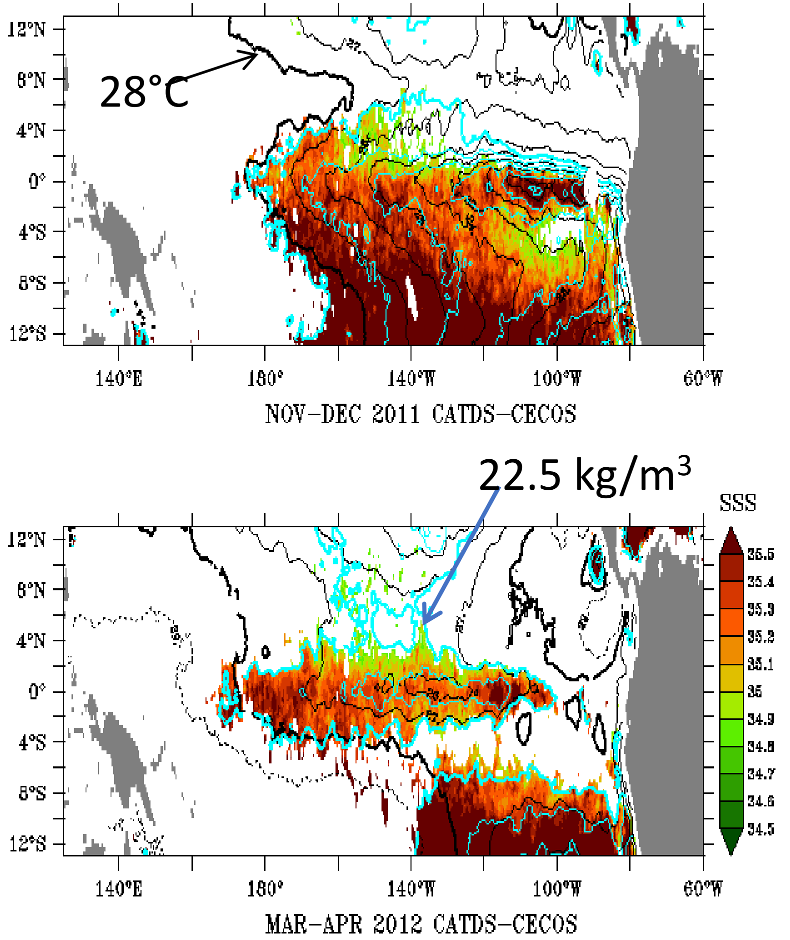
- Equatorial Upwellings
- Tropical Cyclone Interactions with River plume & BL

SSS upwelling off Panama and Equatorial Upwelling in the Pacific

SMOS



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



Alory et al, JGR, 2012

Maes et al., Geoscience Let, 2014

SSS signature of the Equatorial upwelling: Atlantic

The Atlantic Cold Tongue (ACT) shows a maximum in surface salinity 1 month ahead of the SST minimum associated with the equatorial upwelling.

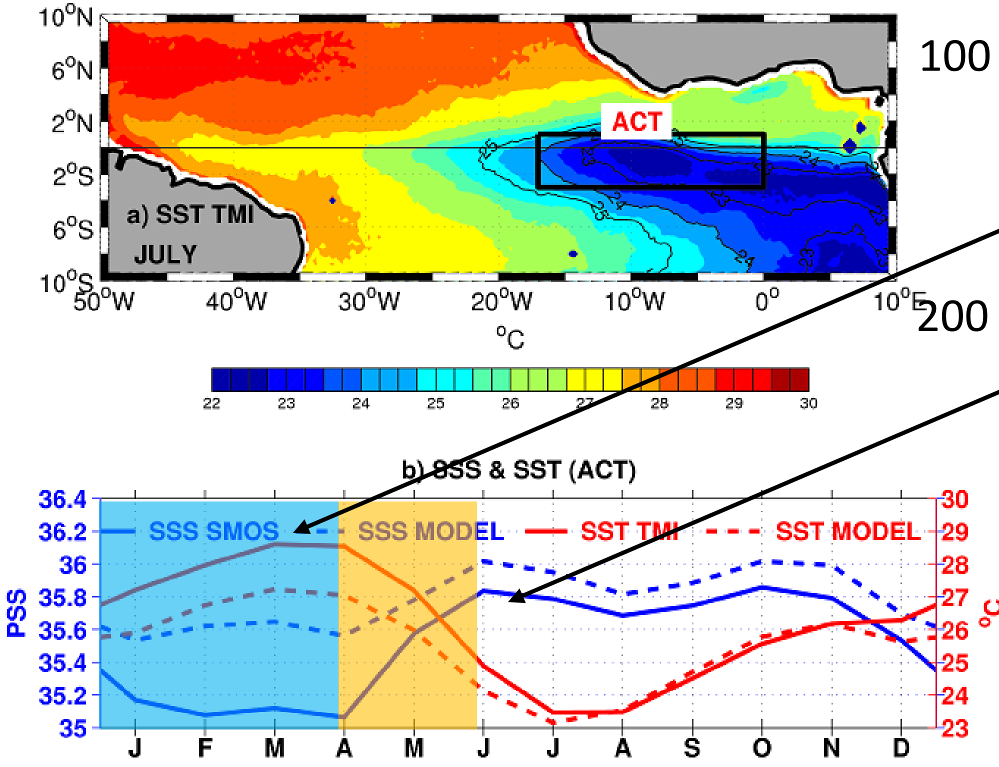
Combining SMOS SSS, model and in situ data the mechanism responsible for this observation was found to be the erosion of the salty core of the Equatorial Undercurrent

SSS might help better forecasting of the West African Monsoon rainfall [*Okumura and Xie*, 57 2004; *Caniaux et al.*, 2011; *Brandt et al.,* 2011]

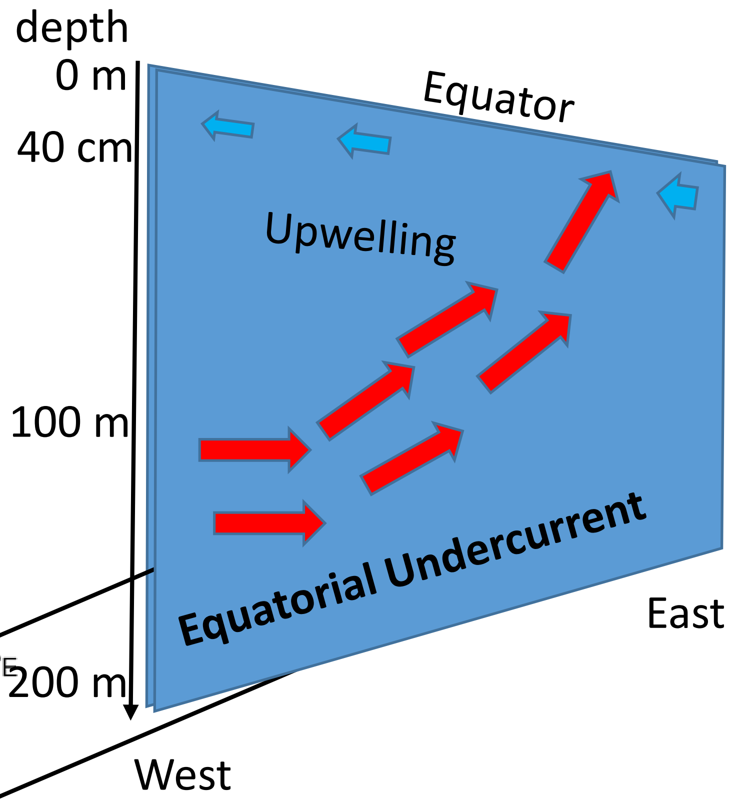
SSS plays a role in the regional climate

Da Allada et al., 2013, 2014

SSS seasonal cycle in the Equatorial Upwelling (SMOS + model)



Da Allada et al., 2017

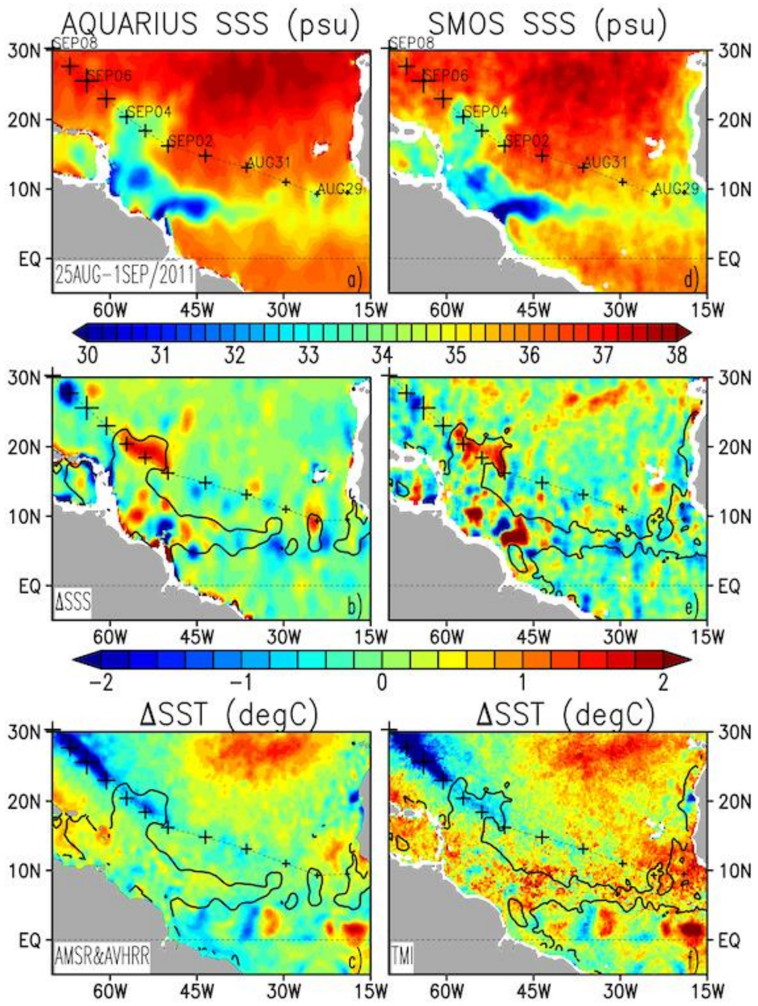


Pluie

Upwelling

Advection: S ↓ toute l'année

Haline Wake of Hurricanes in the Amazon Plume & stratification Impact on hurricane Intensification

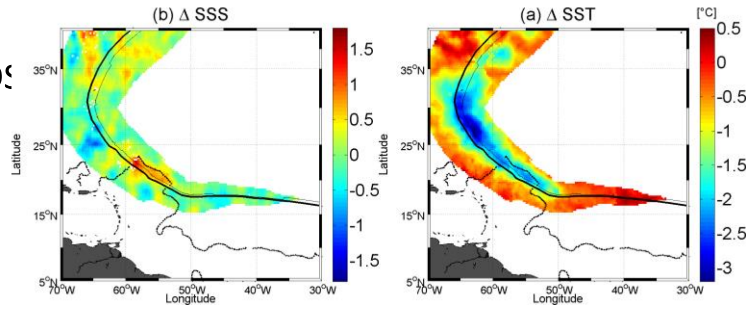


AQUARIUS and SMOS SSS before hurricane Katia (2011). Crosses are the hurricane daily position.

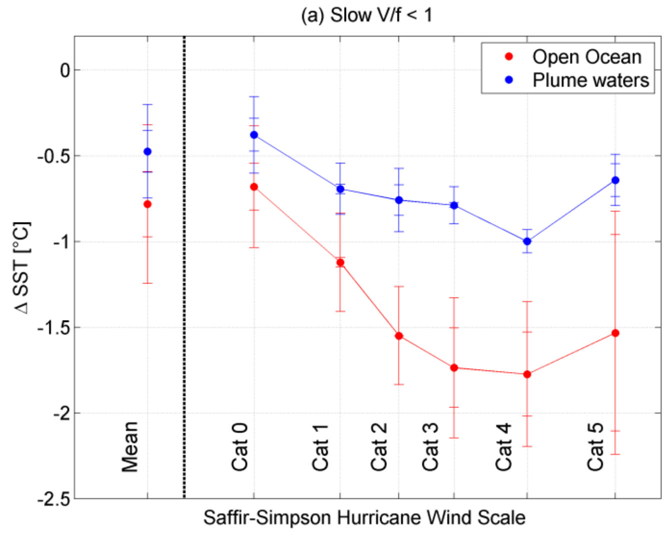
SSS differences after minus before the hurricane passage. 35 psu contour before the passage of Katia is overlain.

SST differences after minus before the hurricane passage.

Grodsky et al., GRL, 2012



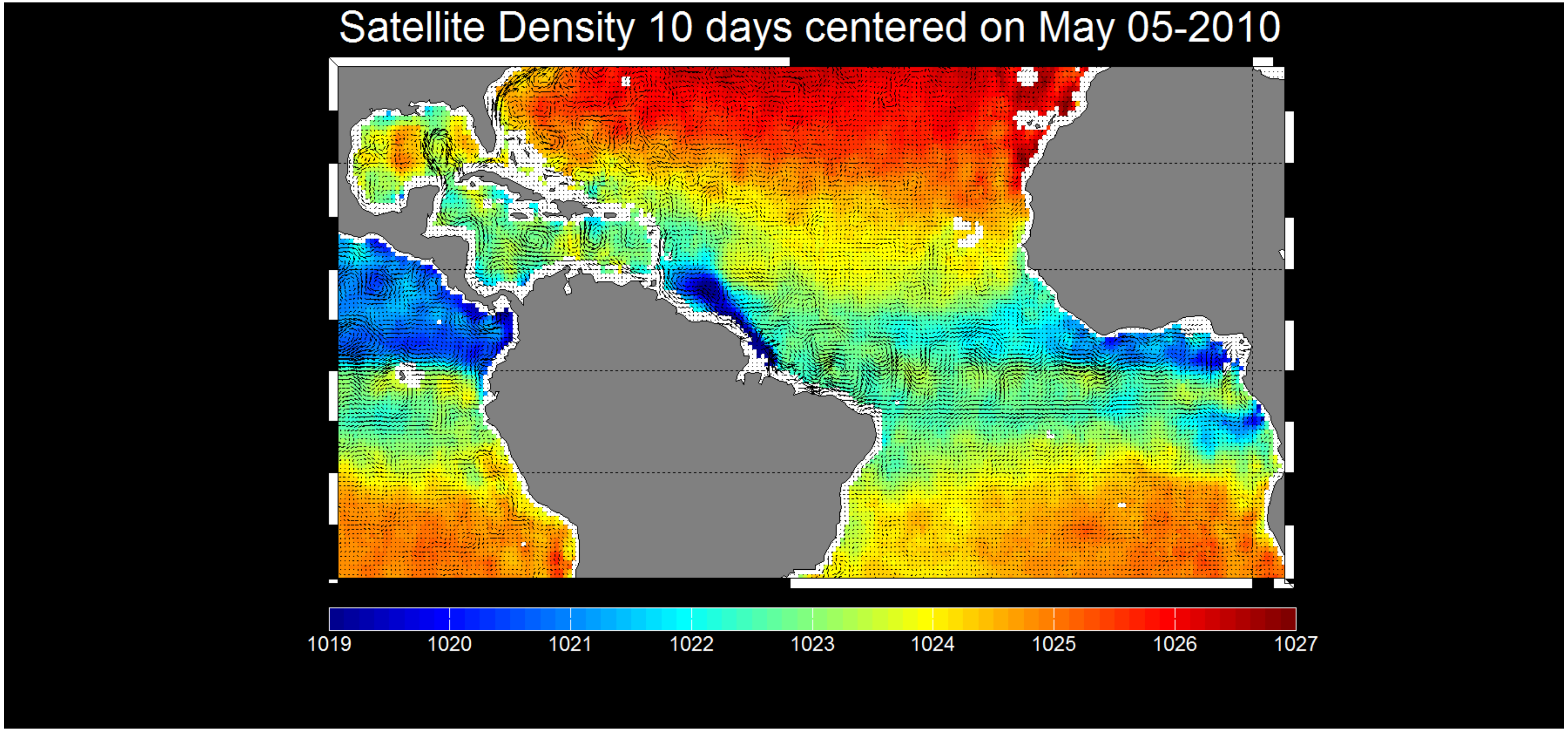
SSS & SST differences after minus before hurricane Igor passage (2010).



Reduced SST cooling over halocline driven stratification

Reul et al. (2014, JGR)

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

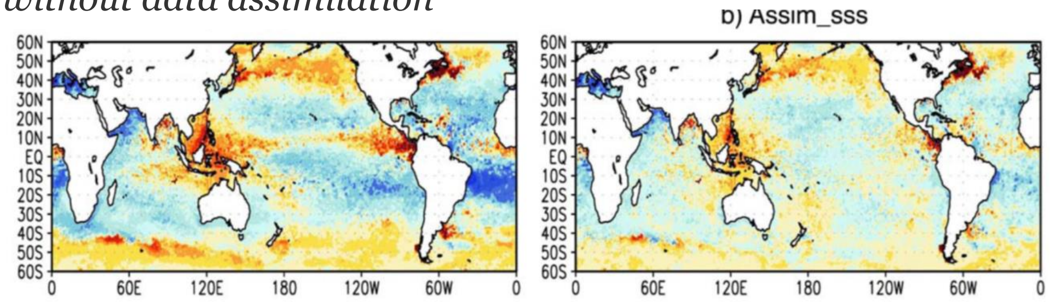
SMOS SSS data assimilation

The complementary role of SMOS sea surface salinity observations for estimating global ocean salinity state

Mean Bias Model-ARGO

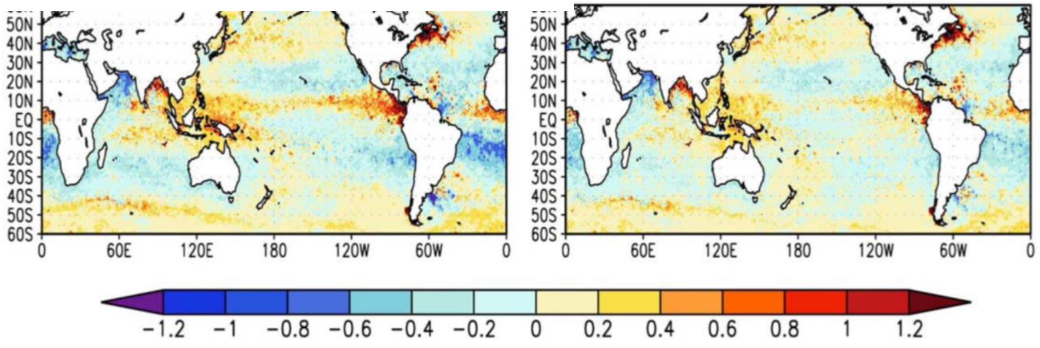
Model without data assimilation

Model with only SMOS data assimilation



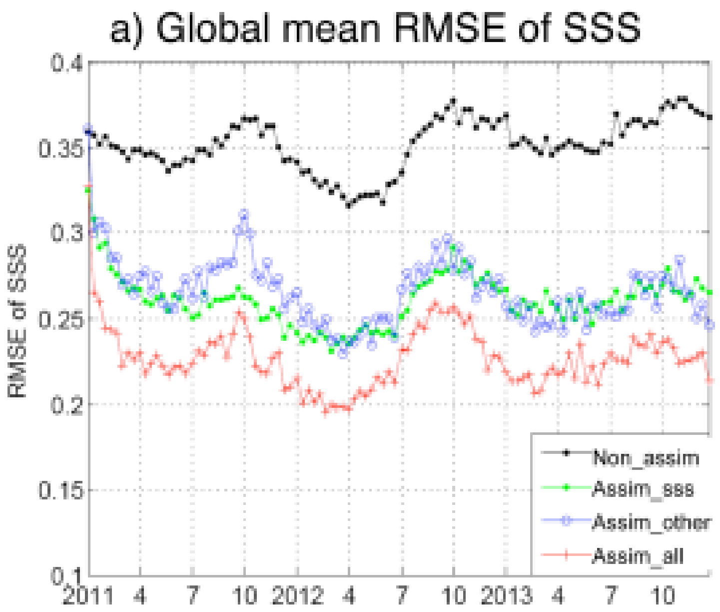
Model with SST, SLA, and T/S assimilation but no SMOS

Model with SST, SLA, T/S and SMOS SSS



Lu, et al (2016), , J. Geophys. Res. Oceans

Time series of the root-mean-square error of the modeled SSS field compared with the Argo data for the four experiments from 2011 to 2013.



Model without data assimilation

Model with SMOS data assimilation

Model with SST, SLA, and T/S assimilation but no SMOS

Model with SST, SLA, T/S and SMOS SSS

First results of a SMOS data assimilation experiment with the CMEMS Mercator Ocean forecasting system

smos+ niño15

support to science element

CLS, Met Office and Mercator Océan

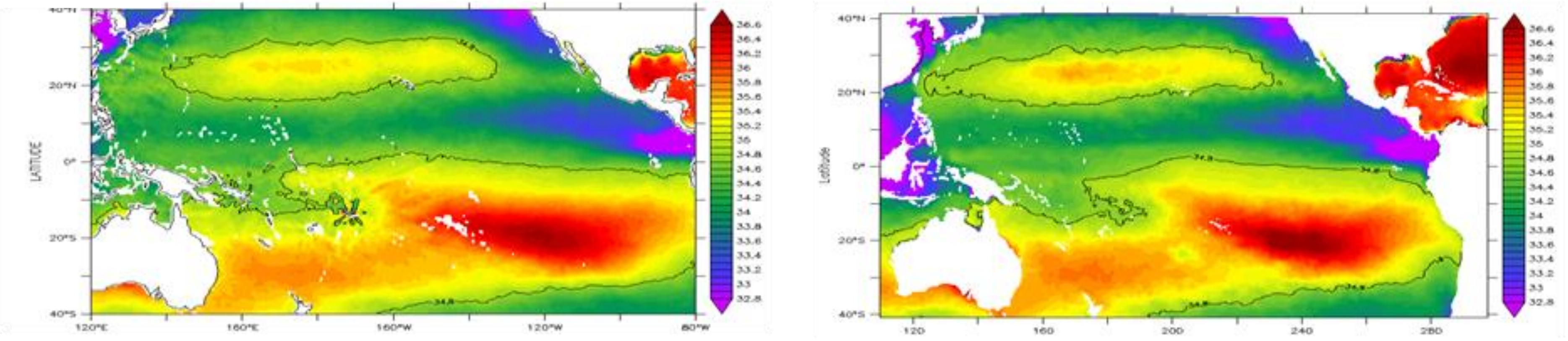


Figure 1: Mean 2015 SSS from: SMOS Observations (left) and ¼° Mercator Ocean reanalysis (right).

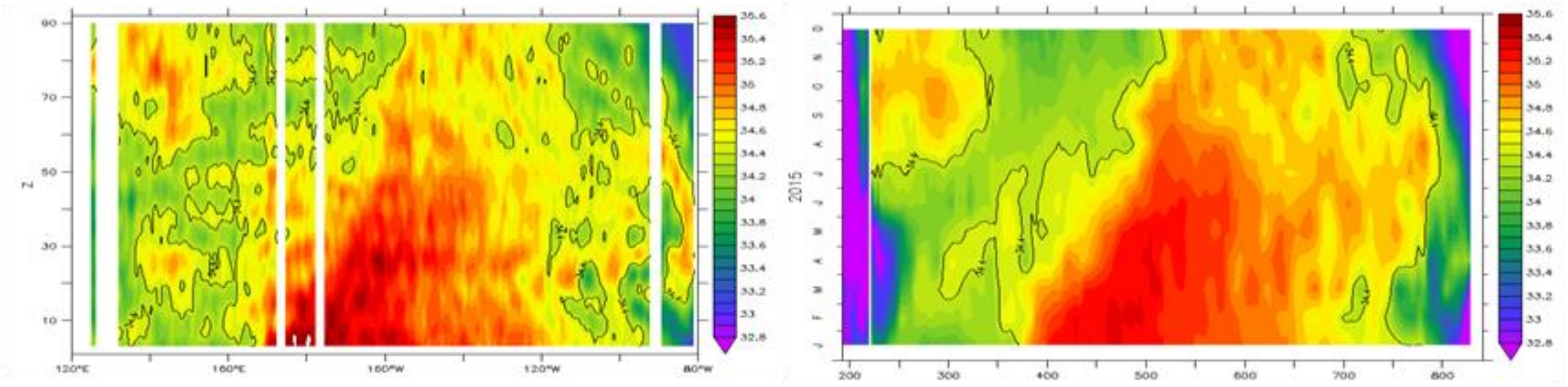


Figure 2: Time evolution of the equatorial surface salinity in 2015: SMOS Observations (left) and ¼° Mercator Ocean reanalysis (right).

Courtesy, Benoit Tranchant, CLS

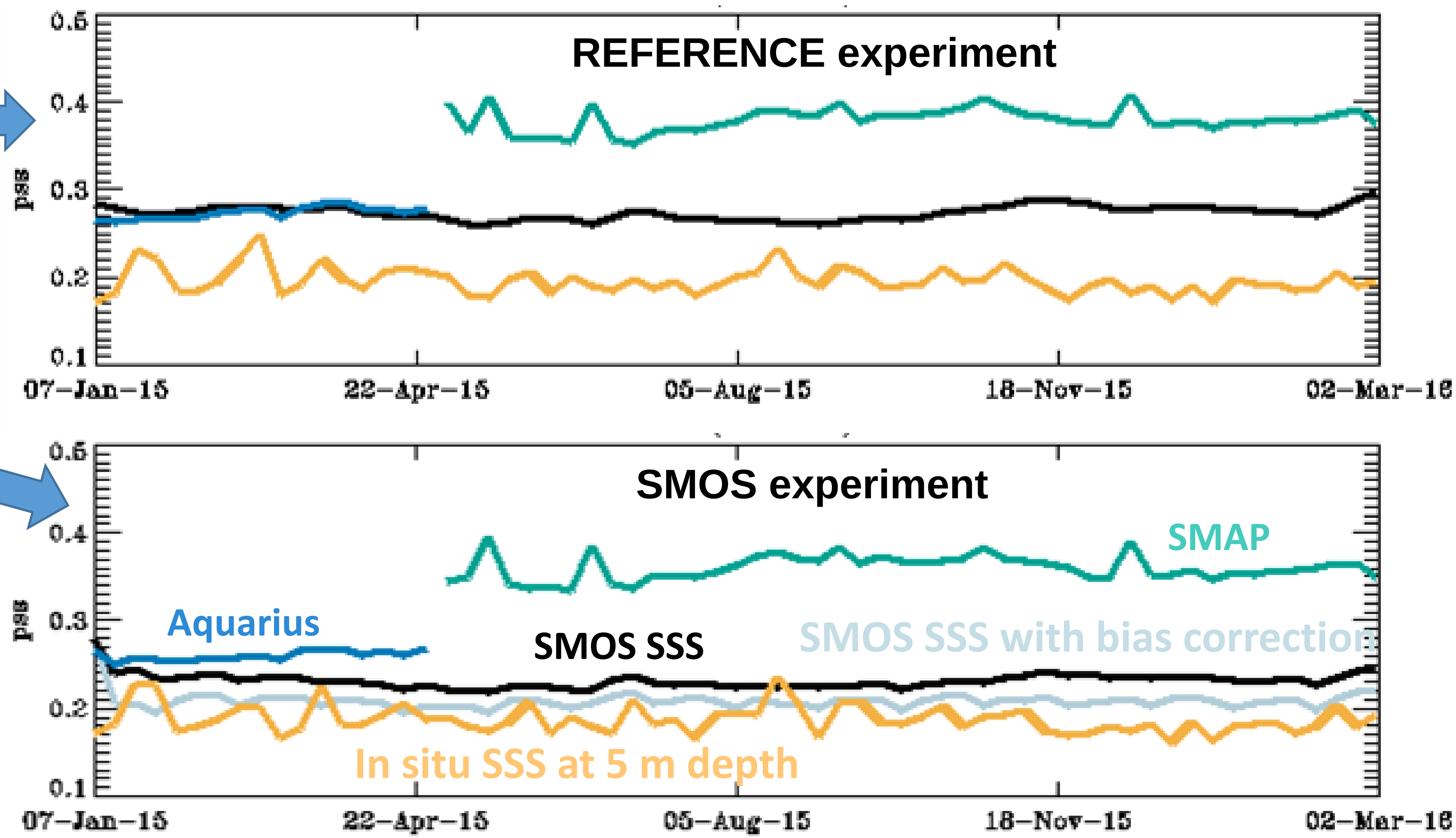
Results from

First results of a SMOS data assimilation experiment with the CMEMS Mercator Ocean forecasting system

1) Reference experiment with the data assimilation of the current network (SLA, SST, in-situ T/S profiles) but no SSS assimilation

and

2) SMOS experiment with the data assimilation of SSS from SMOS after bias correction (18-day products sampled at 25km res) (grey curve)



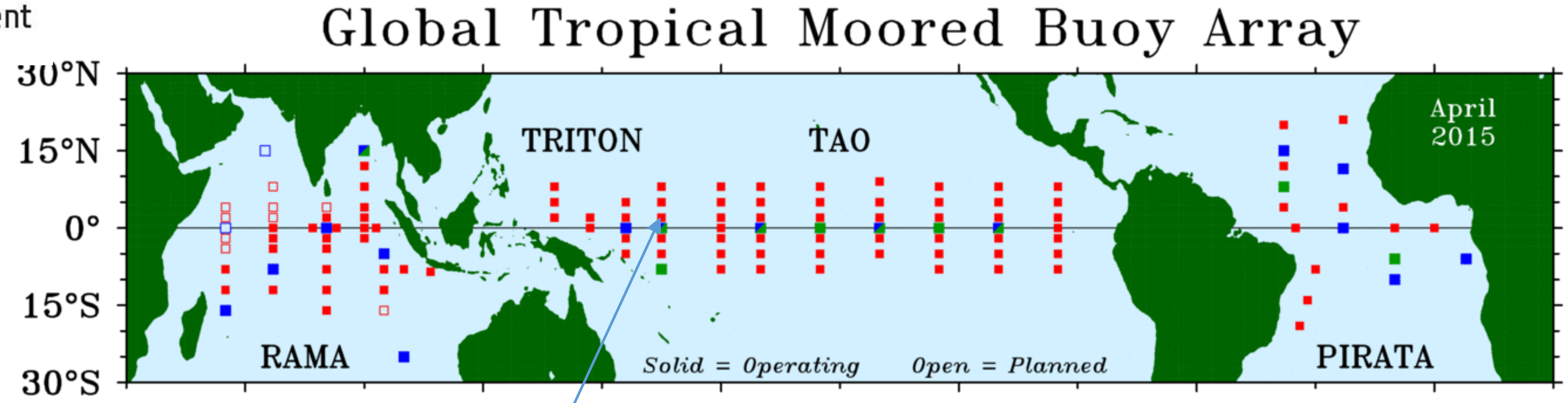
RMS **of SSS innovation (pss) averaged over the global domain for the REFERENCE (top) and SMOS (bottom) experiments from January 2015 to March 2016.**

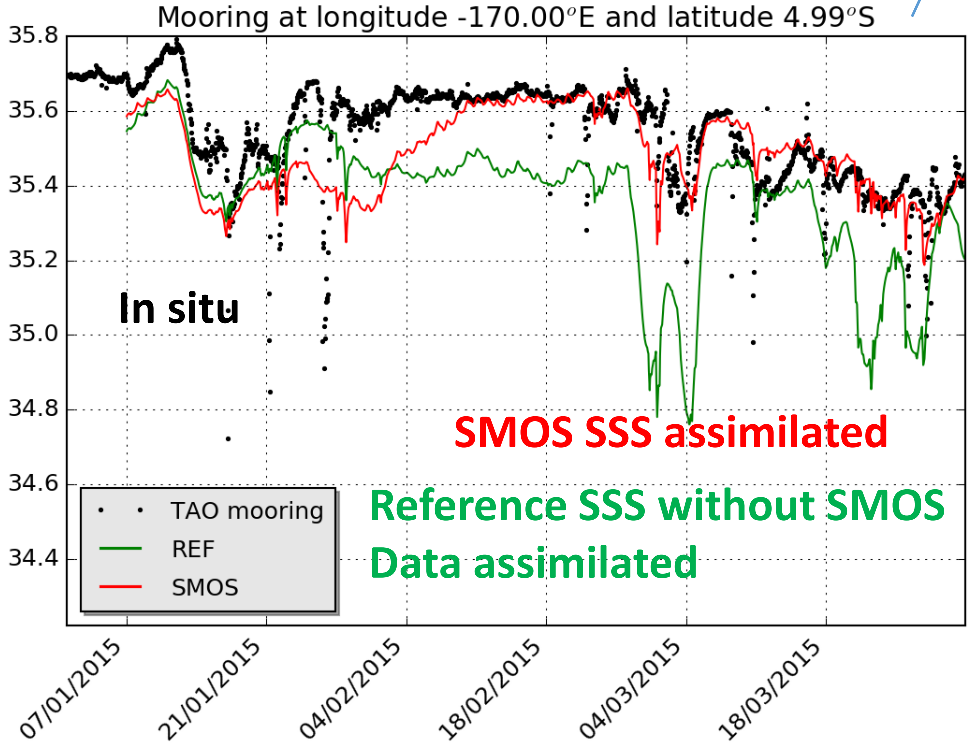
The assimilation of SSS allows for a significant reduction (**up to 25%**) of the rms for all SSS products (the assimilated SSS (grey) is close to the rms of in situ innovation (orange)

Courtesy, Benoit Tranchant, CLS

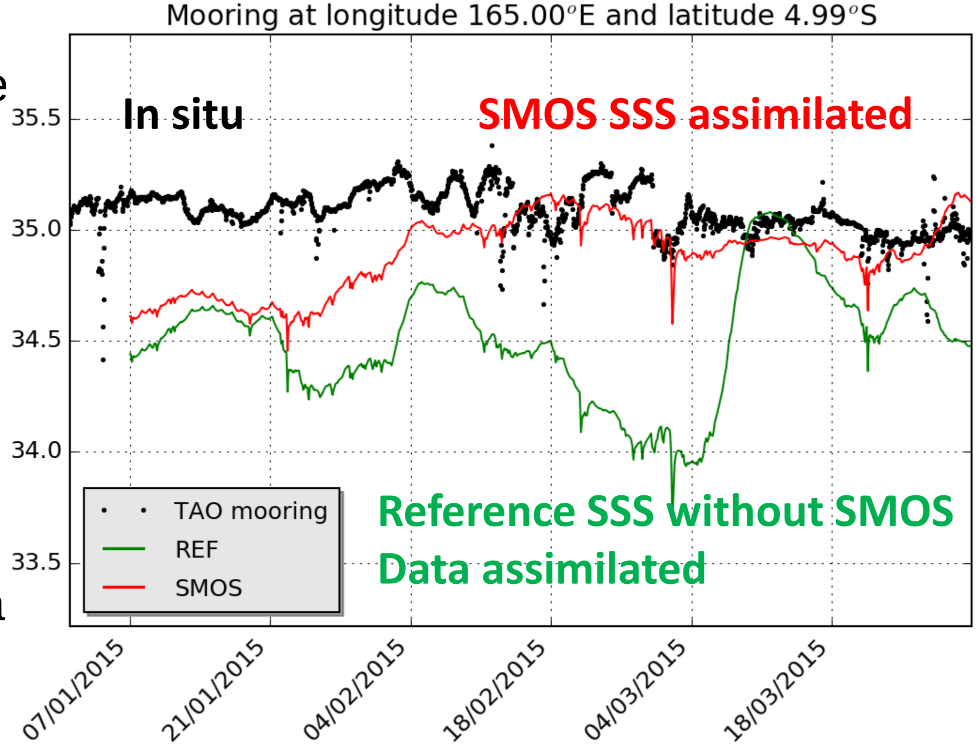
smos+ niño15
support to science element

First results of a SMOS data assimilation experiment with the CMEMS Mercator Ocean forecasting system





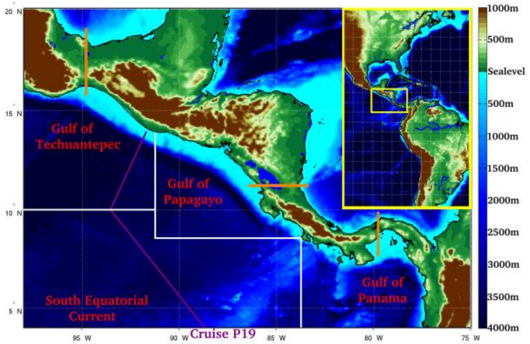
The TAO moorings have not been assimilated (data withdrawal) and can be considered as independent data. The comparison to two different experiment (REFERENCE and SMOS) with the TAO SSS (1 m below the sea water) shows that assimilation of satellite SSS data can be efficient



Courtesy, Benoit Tranchant, CLS

New insights of pCO_2 variability in the tropical eastern Pacific Ocean using SMOS Salinity

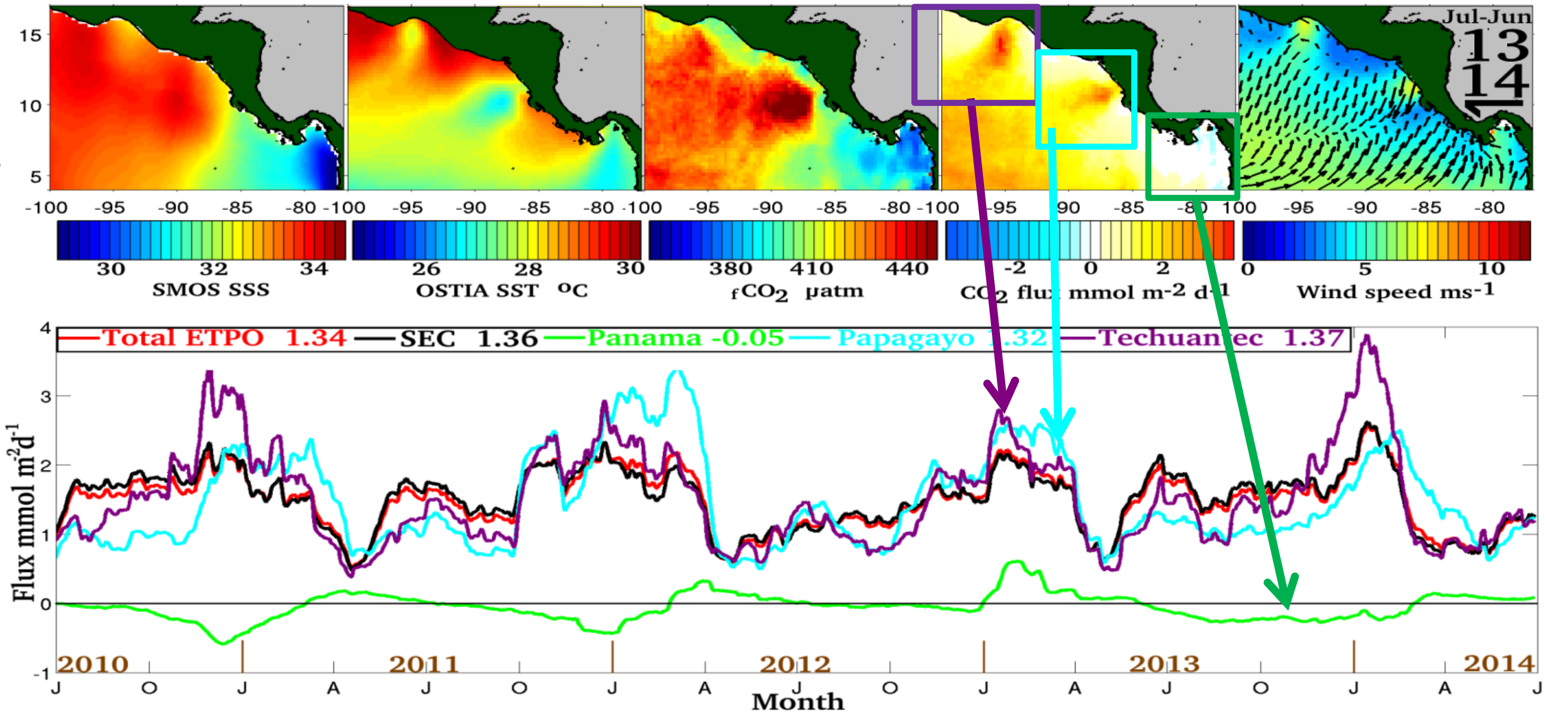
C W Brown, J Boutin, L Merlivat, LOCEAN Paris



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.**

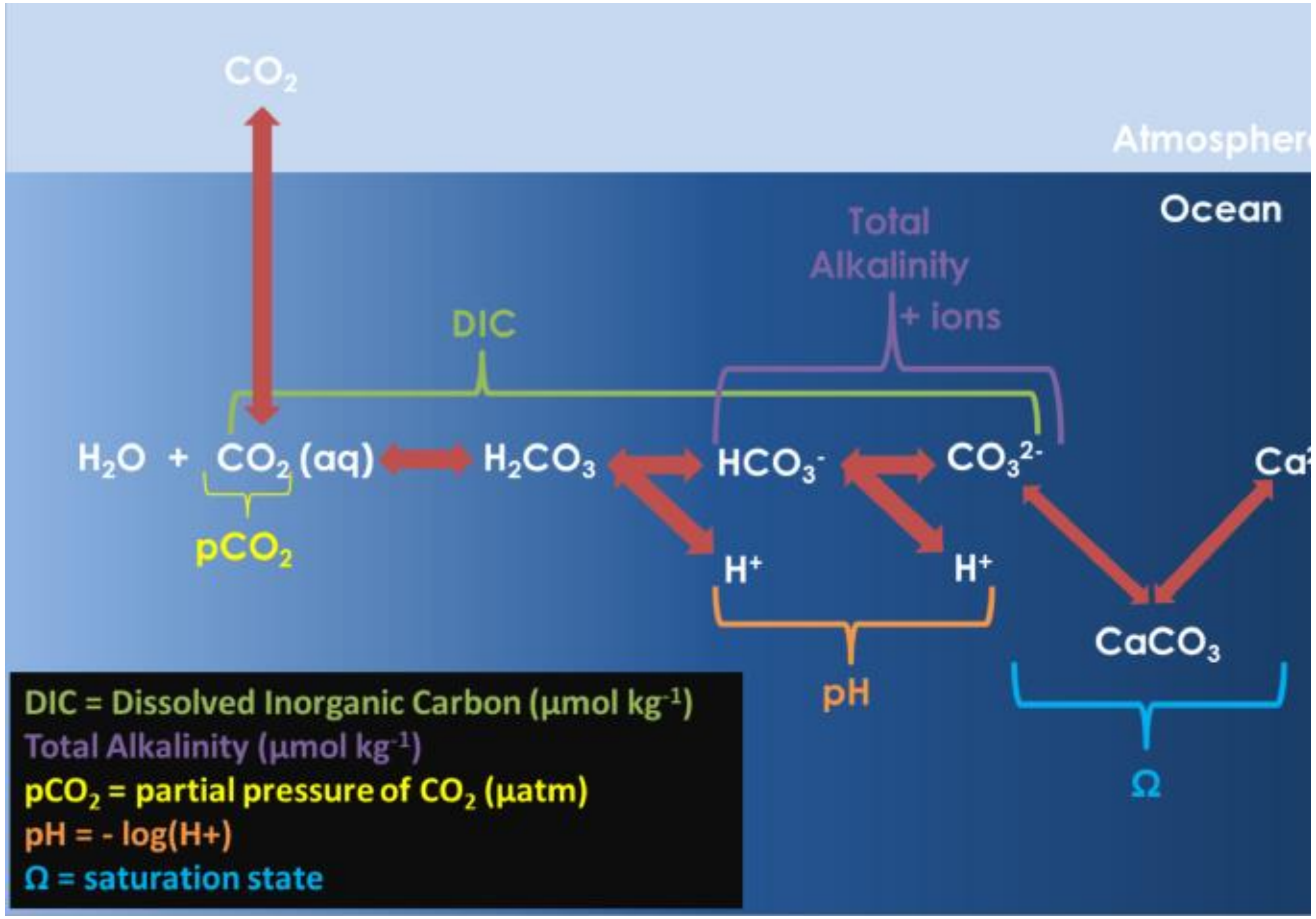
The synergistic use of SMOS SSS, together with satellite SST, precipitation and wind allows the first spatio-temporal mapping of pCO2 in certain dynamic regions and to distinguish atmospheric CO2 signatures from subsurface injection at the surface

(here the coastal upwellings along the Pacific coasts of central America)



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

Impact of SSS on Bio-chemistry (carbonate cycle)



Four key components of Oceanic carbonate cycle:

1) Dissolved Inorganic carbon

2) Total Alkalinity

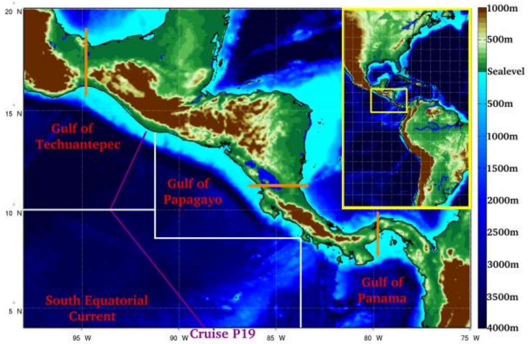
3) PH

4) Co2 fugacity (pCo2)

In principle, knowledge of any two of these four is sufficient to solve the carbonate system equations. However, overdetermination, the process of measuring at least three parameters, is advantageous.

New insights of pCO_2 variability in the tropical eastern Pacific Ocean using SMOS Salinity

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



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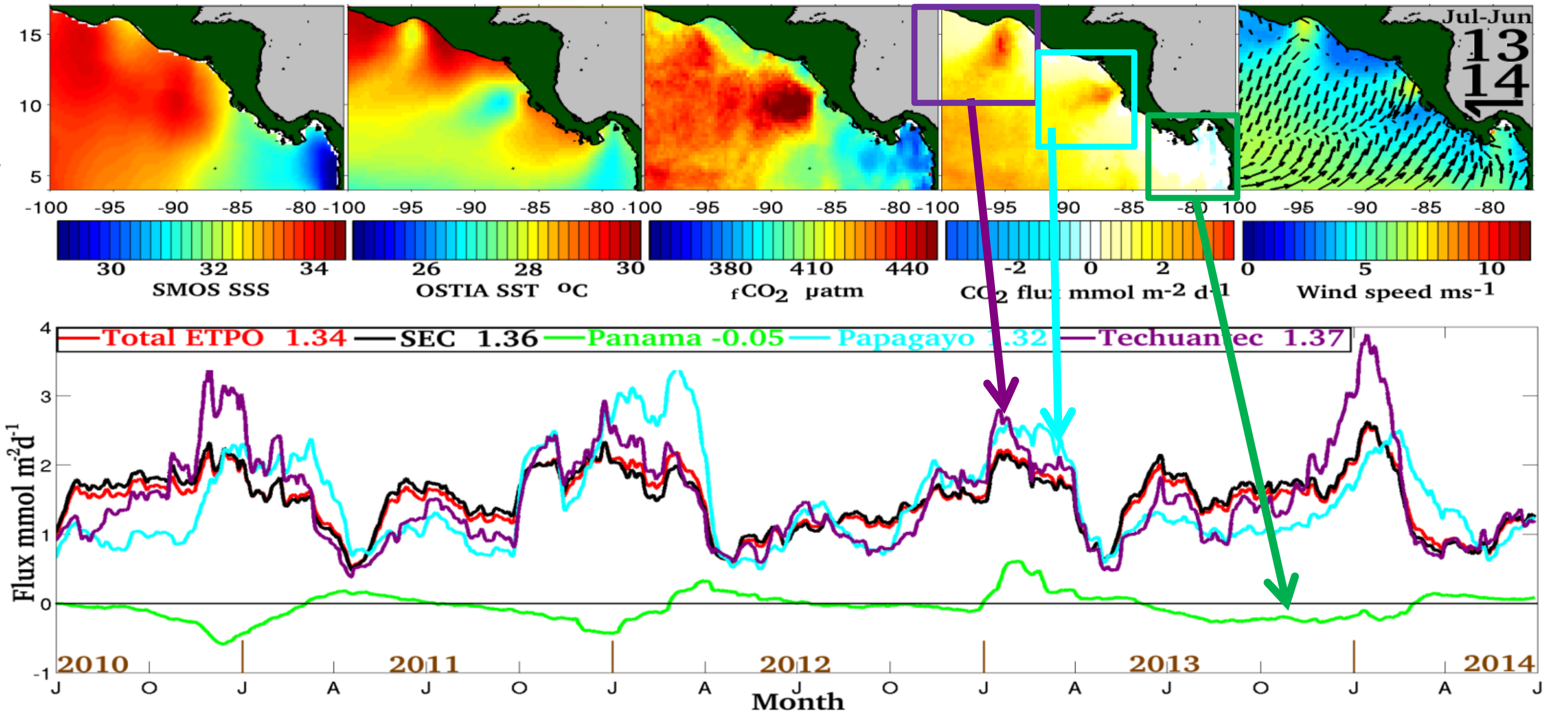
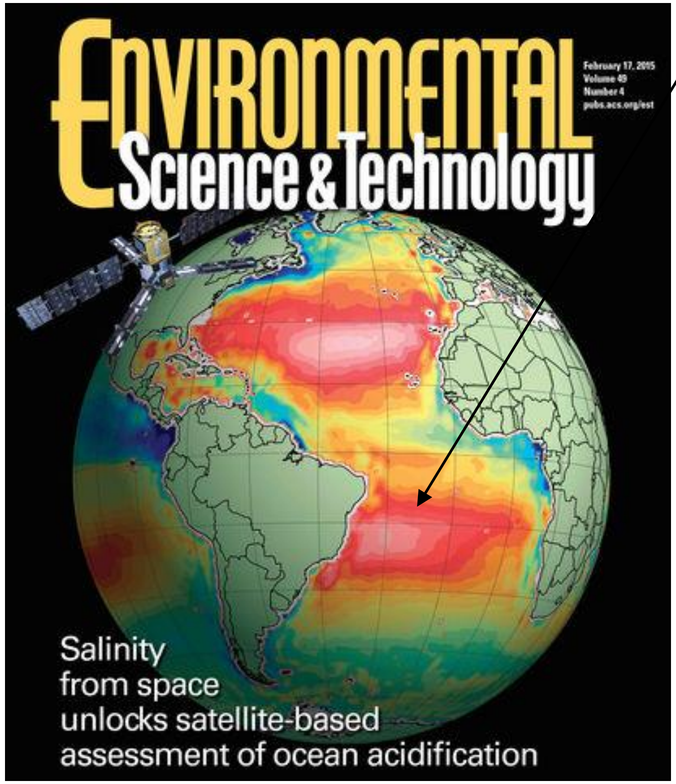


Brown et al. Biogeoscience, 2016

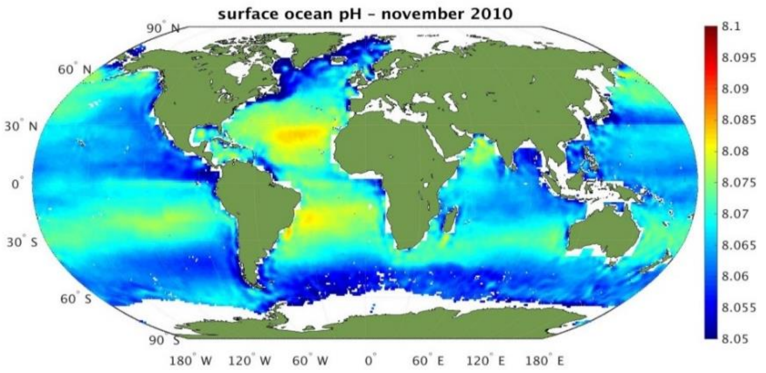
Biogeo-chimie à partir de la SSS SMOS data: cycle des carbonates

Spaceborne data estimation of alcalinity:

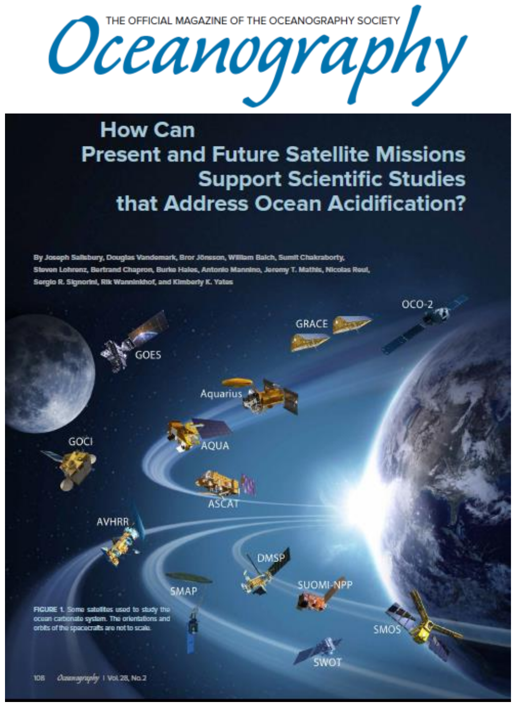


Land et al., *Environmental Science & Technology*, 2015

- First Estimation of **Total Alcalinity A_T** of surface water from spaceborne measurements of SSS & SST:
- **A_T** =Funct(SSS,SST) (lee et al 2006)
  SSS,SST = SMOS CATDS, GHRSST
- **A_T** little impacted by biological processes
- **A_T** strongly correlated with SSS
- First-ever estimates of EO-based **global surface ocean pH using SMOS SSS, satellite SST & ocean color**
- **Help defining future mission concepts to monitor ocean acidification**



First-ever estimates of EO-based global surface ocean pH. (credits: ESA/R. Sabia)



Salisbury et al., *Oceanography*, 2015

50-100 km/weekly to monthly

Accuracy of ±0.2 pss SSS⇔ ±10-15 µmol^{-1} **A_T**

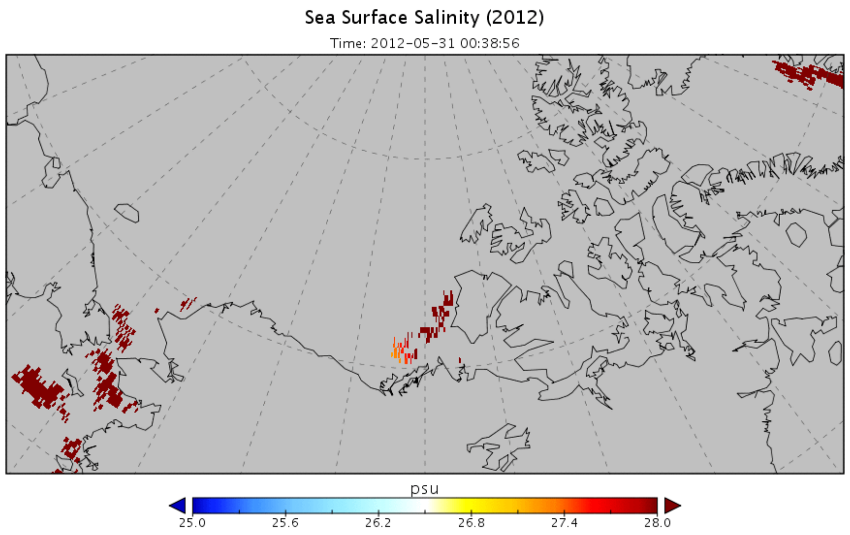
SMOS data allows a global monitoring of **A_T**

Particularly in intense mixing zones (river plumes, current fronts)

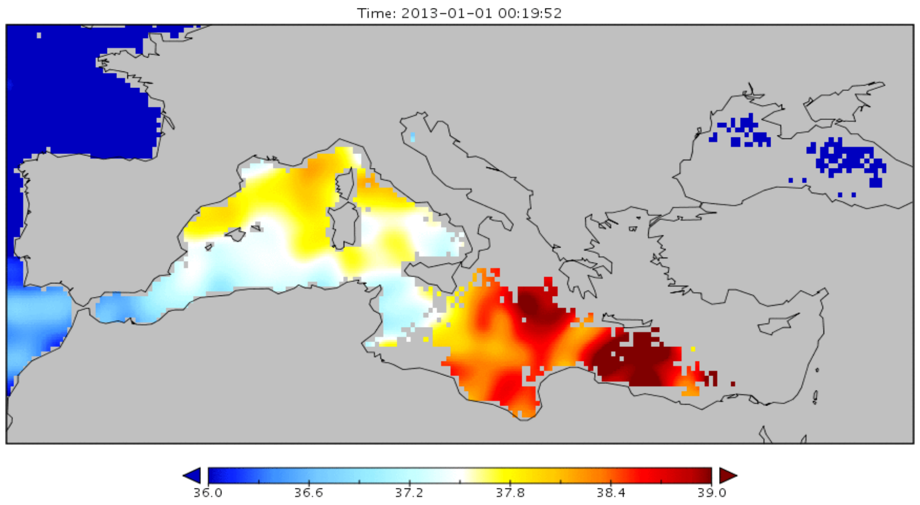
New challenges

New non-Bayesian algorithms and empirical de-biasing techniques

Upcoming product: Arctic SSS



SSS retrievals in the Mediterranean Sea



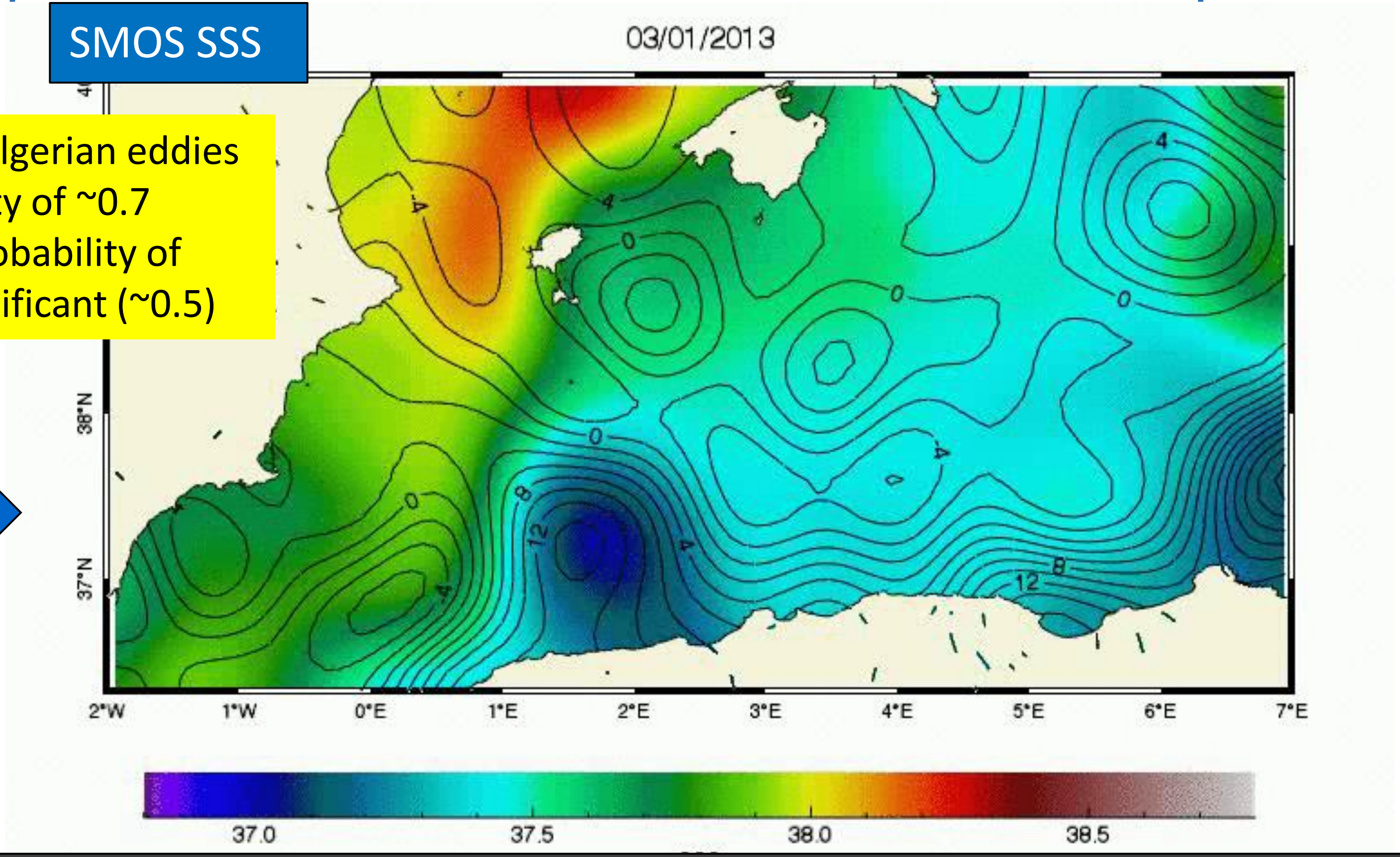
E. Olmedo, J. Martínez, A. Turiel, J. Ballabrera-Poy, M. Portabella, "Enhanced retrieval of the geophysical signature of SMOS maps", accepted in Remote Sensing of Enviroment

Improvements in the SSS retrieval
+
Improvements in multifractal fusion techniques

SMOS SSS

In winter we detect Algerian eddies with a probability of ~0.7
In summer the probability of detection is not significant (~0.5)

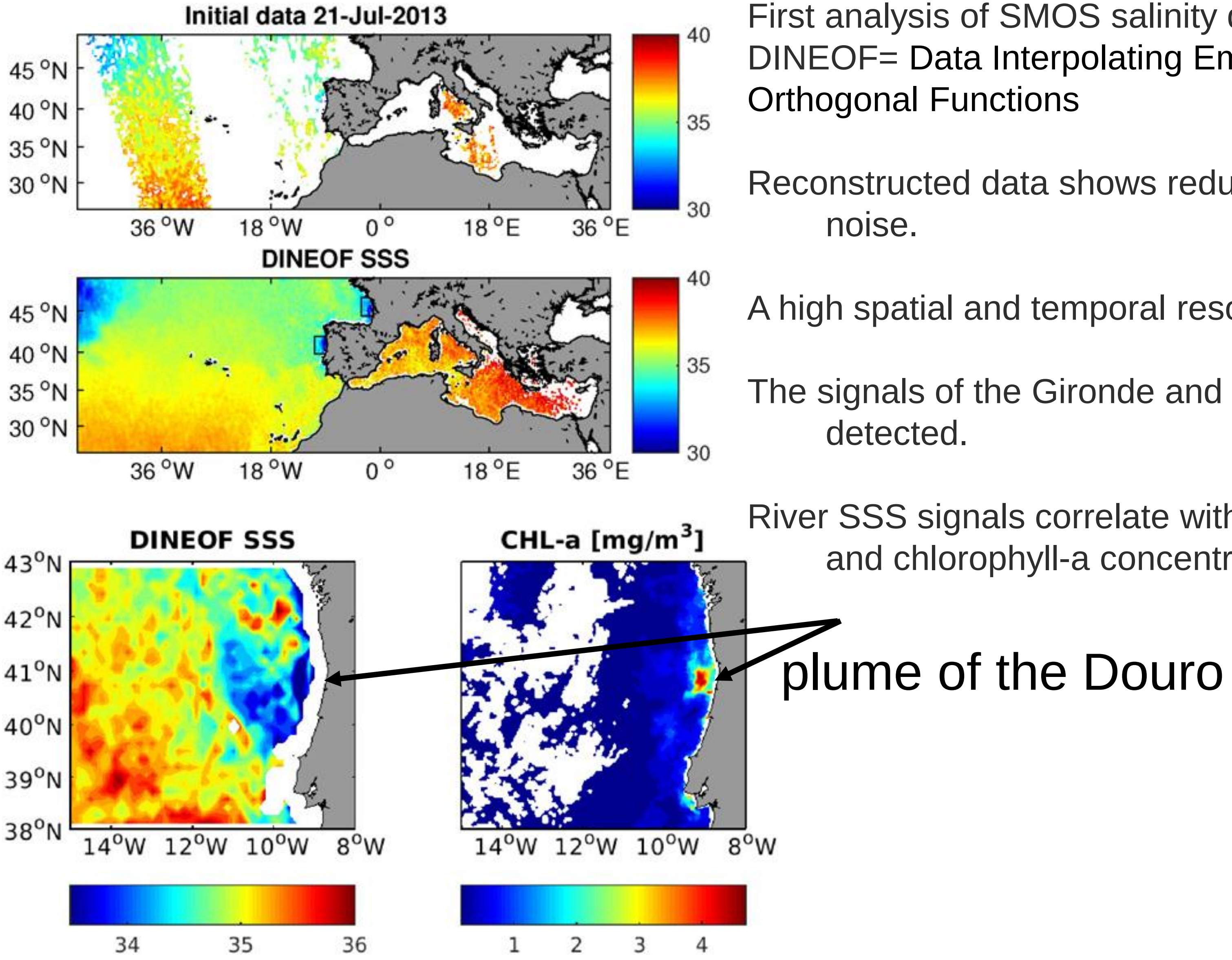
Contour lines SSH AVISO



J. Isern-Fontanet, E. Olmedo, A. Turiel, J. Ballabrera-Poy, E. Garcia-Ladona “Retrieval of eddy dynamics from SMOS Sea Surface Salinity measurements in the Algerian Basin (Mediterranean Sea)” under review in Geophysical Research Letters

Towards Application in challenging zones

Med and European Seas with Dineof



First analysis of SMOS salinity data using DINEOF= Data Interpolating Empirical Orthogonal Functions

Reconstructed data shows reduced error and noise.

A high spatial and temporal resolution is kept.

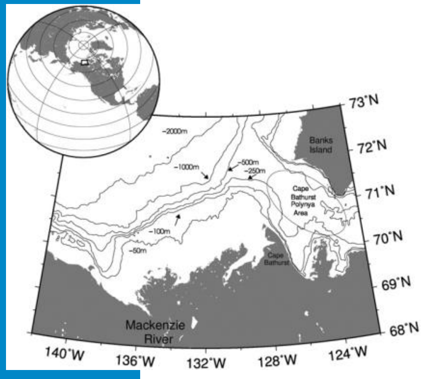
The signals of the Gironde and Douro rivers are detected.

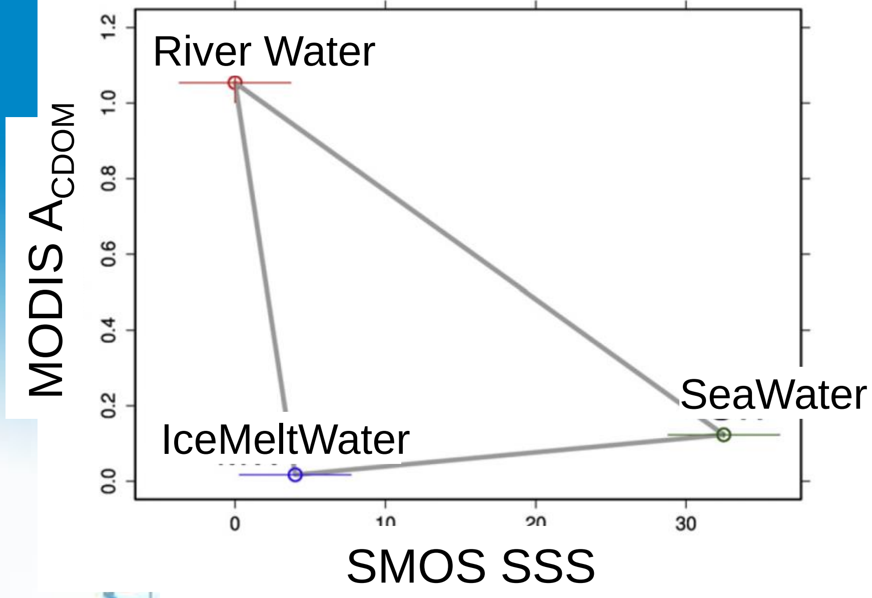
River SSS signals correlate with river discharge and chlorophyll-a concentration data

Alvera-Azcárate et al.,

RSE, 2016

Arctic Ocean:
SMOS + Ocean color





A new algorithm for discriminating water sources using satellite data for Arctic Ocean.
Fractions of water sources can be discriminated with the associated uncertainties from space. measurements

Matsuoka et al., RSE, 2016

July 2010 | July 2012

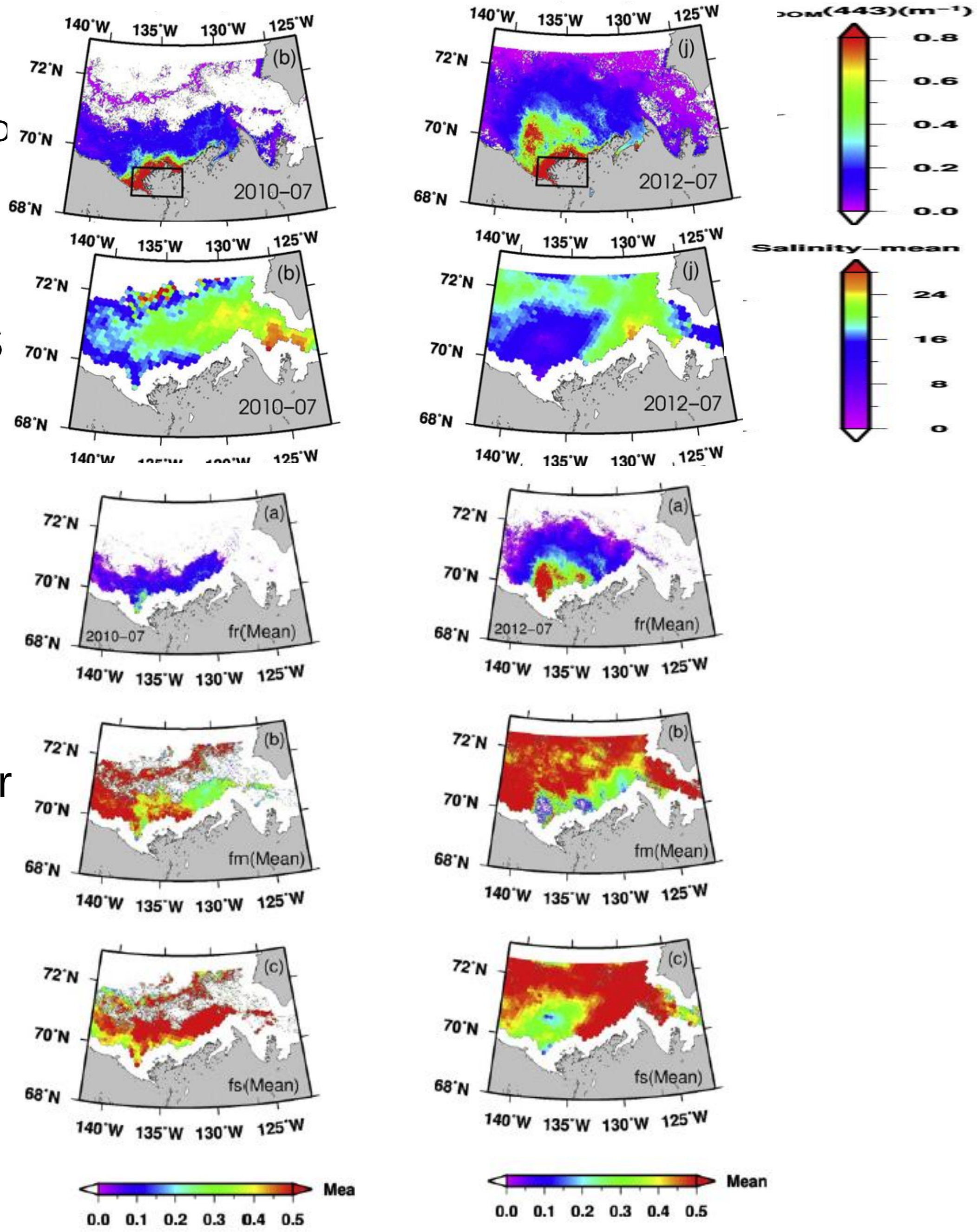
MODIS A_{CDOM}

SMOS SSS

RiverWater fraction

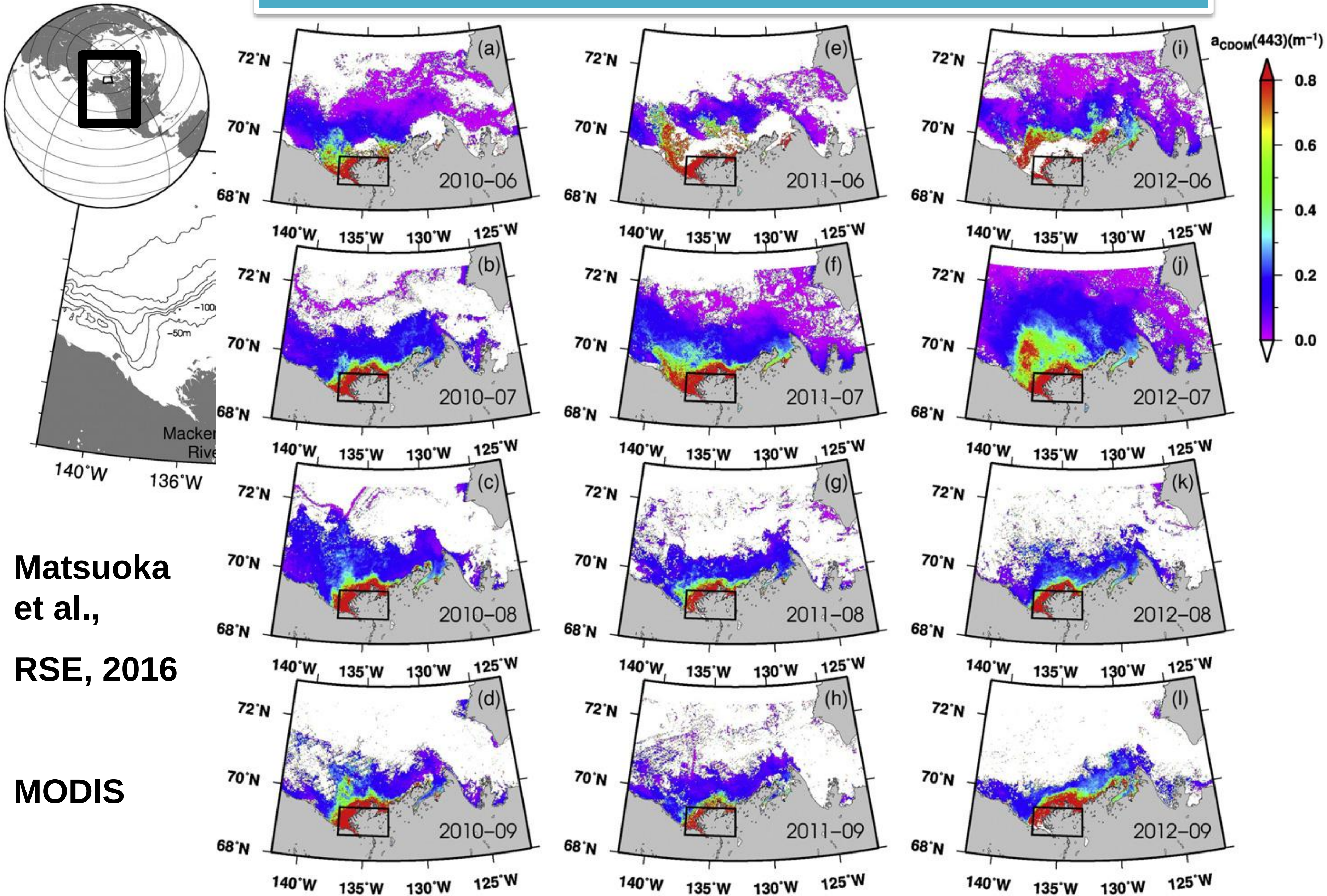
Ice Meltwater fraction

Sea water fraction



Towards Application in challenging zones

Synergies Color/SSS SMOS in southern Beaufort Sea



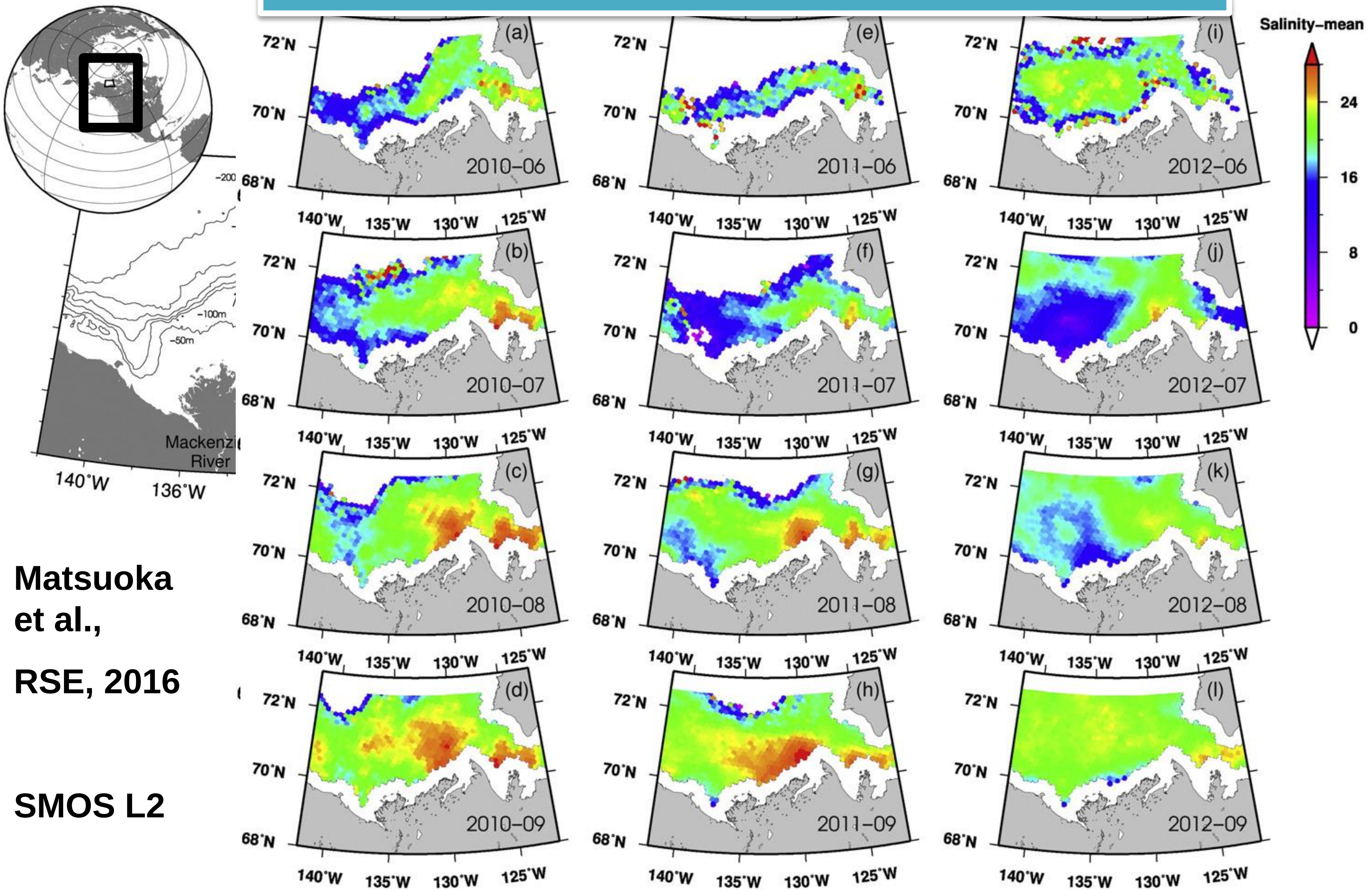
Matsuoka et al.,

RSE, 2016

MODIS

Towards Application in challenging zones

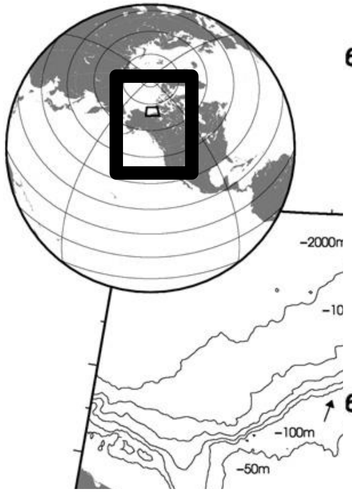
Synergies Color/SSS SMOS in southern Beaufort Sea



Matsuoka et al.,

RSE, 2016

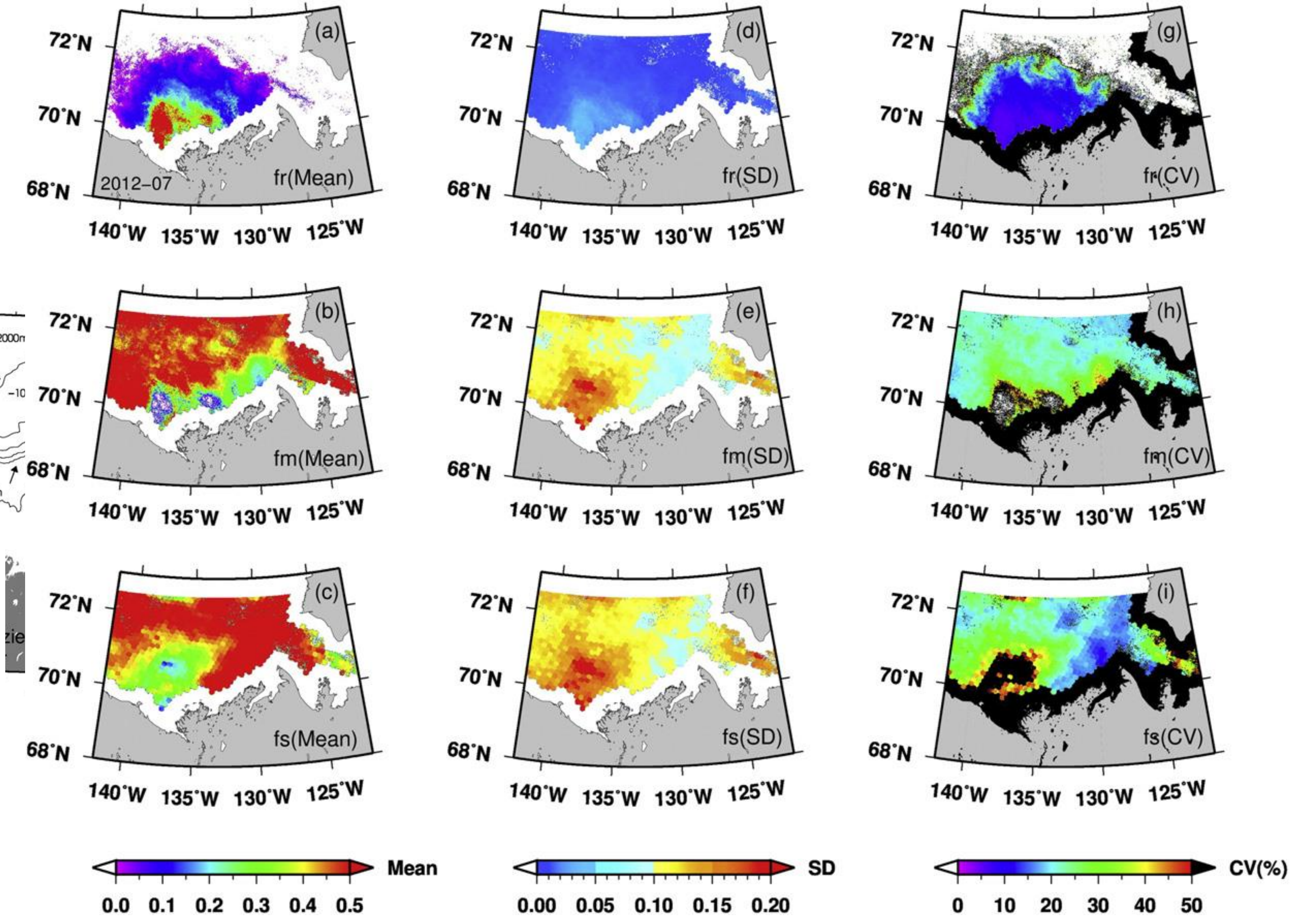
SMOS L2



Matsuoka et al.,

RSE, 2016

Classes of seawater, ice meltwater, and river water



A new algorithm for discriminating water sources using satellite data is presented for Arctic Ocean.

Fractions of water sources can be discriminated with the associated uncertainties from space.

The satellite approach is complimentary to in situ discrimination.

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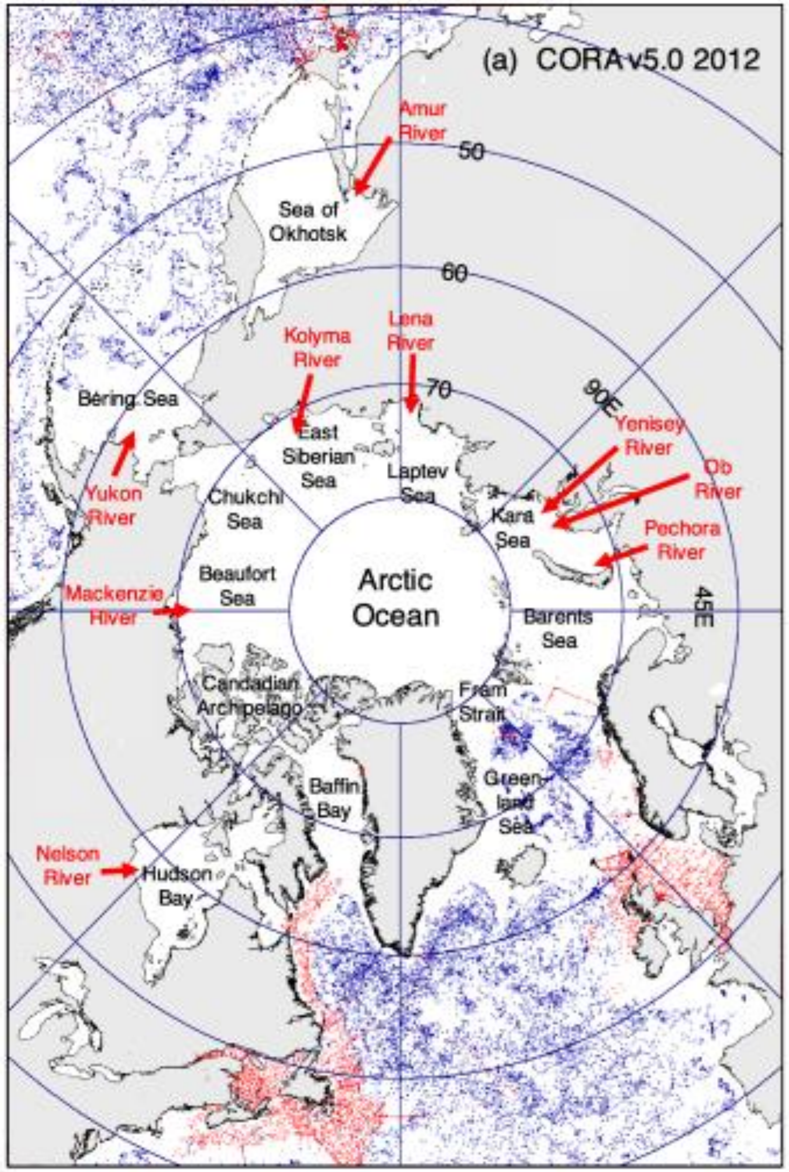
Research Article

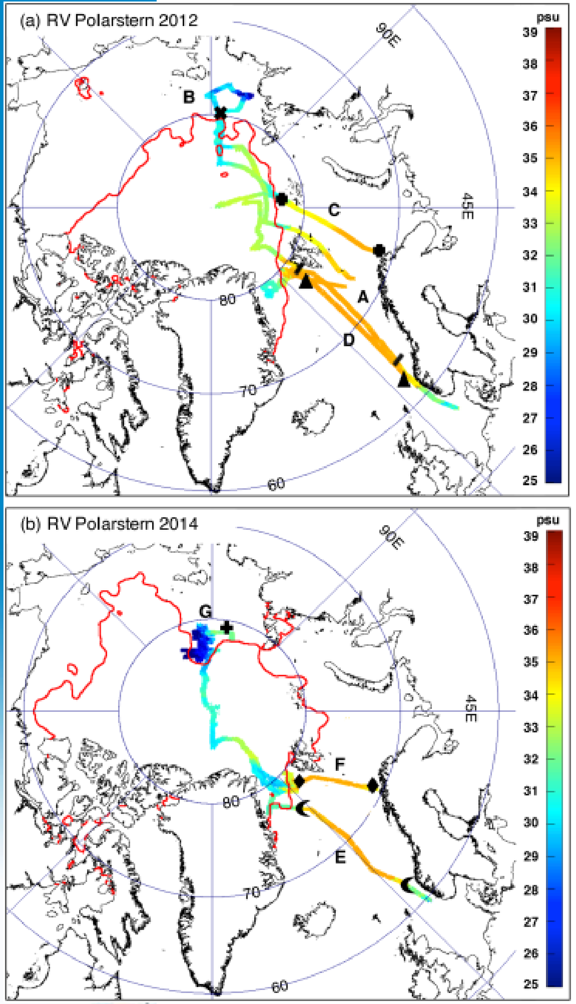
Satellite observed salinity distributions at high latitudes in the Northern Hemisphere: A comparison of four products

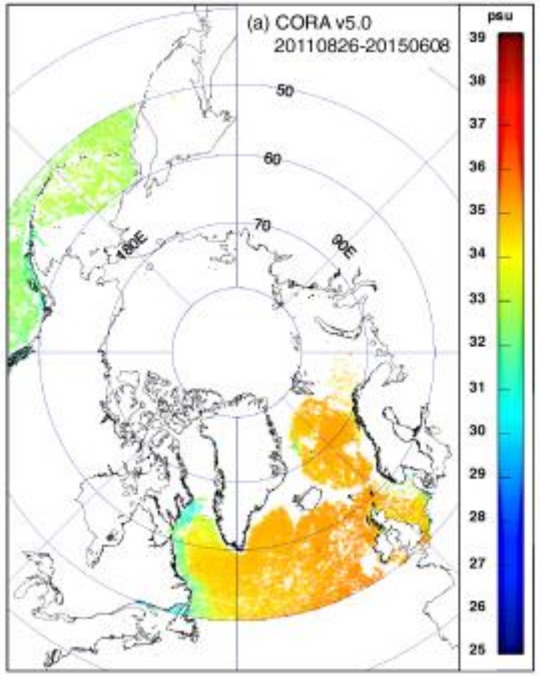
Cynthia Garcia-Eidell, Josefino C. Comiso, Emmanuel Dinnat, Ludovic Brucker

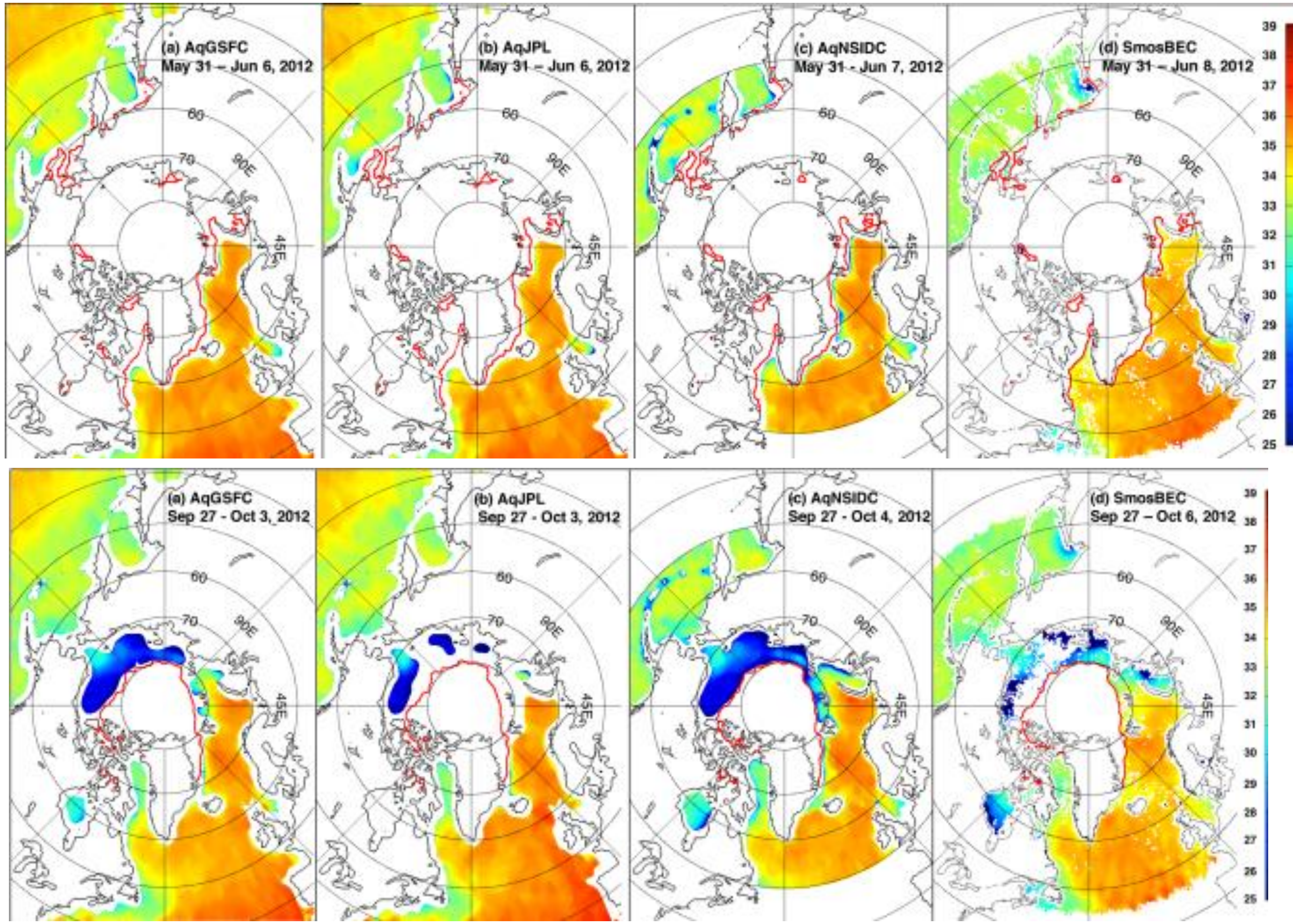
First published: 23 September 2017 Full publication history

In the polar regions where spatial and temporal changes in sea surface salinity (SSS) are deemed important, the data have not been as robustly validated because of the paucity of in situ measurements.



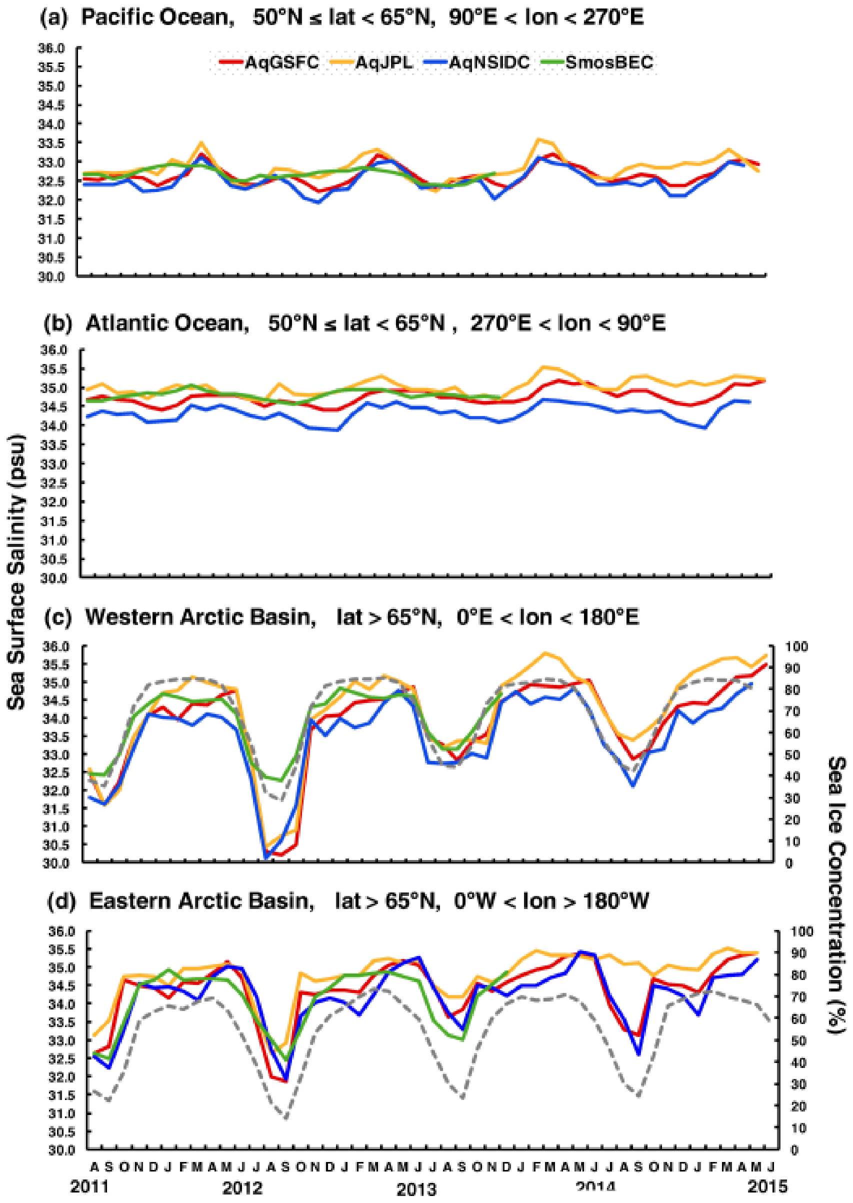






The RMS errors when compared with CORA5.0 data are 0.412, 0.487, 0.465 and 0.323 psu for the AqGSFC, AqJPL, AqNSIDC and SmosBEC products, respectively.

SSS remote sensing in polar seas



Spaceborne observations capture the seasonality and interannual variability of SSS in the Arctic with reasonably good accuracy

SUMMARY

SMOS mission provides unique spatio-temporal monitoring of SSS for more than 8 years.

Need to continue the SSS monitoring from space

⇒Synoptic monitoring of SSS at 50km resolution provides new constraints for a better understanding and modelling of the water cycle, ocean circulation, air-sea exchange, biogeochemistry

⇒New applications in challenging zones (High latitude & Closed Seas) are emerging thanks to new algorithm developments

See more in JGR-Ocean 2014 special issue "Early Scientific Results from the Salinity Measuring Satellites Aquarius/SAC-D and SMOS“ and in RSE 2016 SMOS special issue

PERSPECTIVES

- Continue the monitoring of large scale climate anomalies (ENSO, IOD, North Atlantic etc...) and analyse the origin of the anomalies (multi sensors analysis, sensibility studies with ocean models)
- Multi-sensors analysis (SMAP, SWOT, CFOSAT…)
- Owing to the recent progresses in correcting land-sea contamination new applications are planned in coastal areas, related to river discharges, coastal currents.. (e.g. Bay of Bengal, China Sea, Mississippi etc..) => relation to soil moisture anomalies
- Assimilation in models (ESA funded Nino15 study, CCI salinity and High winds)
- Improvement in image reconstruction (Gibbs2) + hourly ECMWF wind speeds should permit to improve quality of SMOS SSS at high latitude (better land-sea and ice-sea contamination correction) => monitoring of high latitude (e.g. ice melting (see next slide), water masses formation…)
- Development of PI-MEP and CCIs