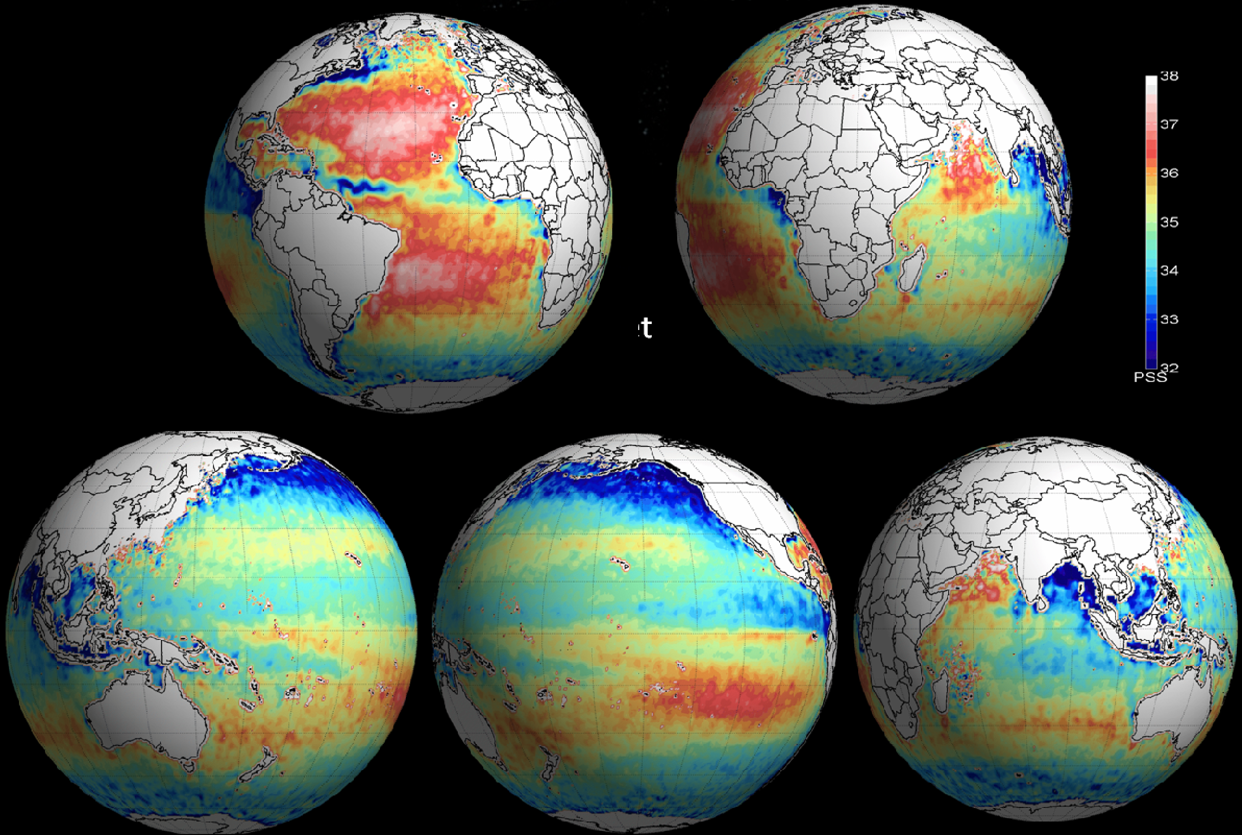
Sea Surface Salinity Satellite Monitoring & Oceanic Circulation



Nicolas Reul, SMOS Scientist (IFREMER)

2nd GlobCurrent User Consultation Meeting - 4-6 Nov. 2015

Outline

- ❑Sensors

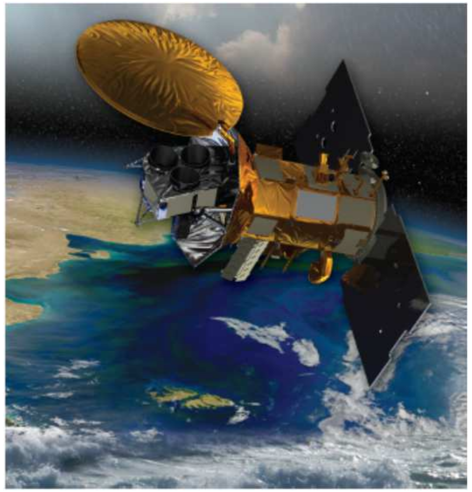
- ❑Tropical signals (river plume, freshpool, TIW) of mesoscale variability in frontal structures, eddies

- ❑ Meso-scale Western boundary currents (eddies)

Three Low-frequency Microwave radiometers providing ocean Surface Salinity monitoring capabilities since 2010

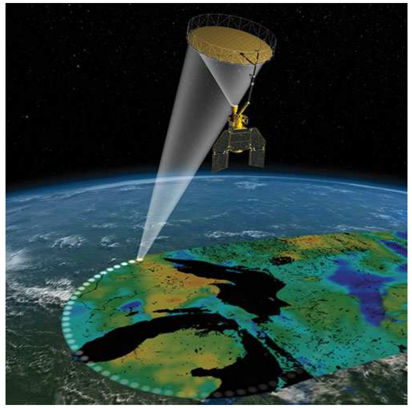
SMOS-ESA

Interferometric Radiometer
Frequency: 1.4 GHz L-band
Spatial Resolution: ~43 kms
Swath Width: ~1000 kms
Revisit time Equator: ~3 days
Incidence angles: 10°-60°
Fully polarimetric
Launched Nov 2009



Aquarius SAC-D/NASA

Real Aperture Radiometer
Frequency 1.4GHz C-band
Spatial Resolution: ~100 kms
Swath Width: ~300 kms
Revisit time Equator: ~7 days
Incidence angle: 40-50°
Linear polarizations
Launched july 2011
End of operation: may 2015

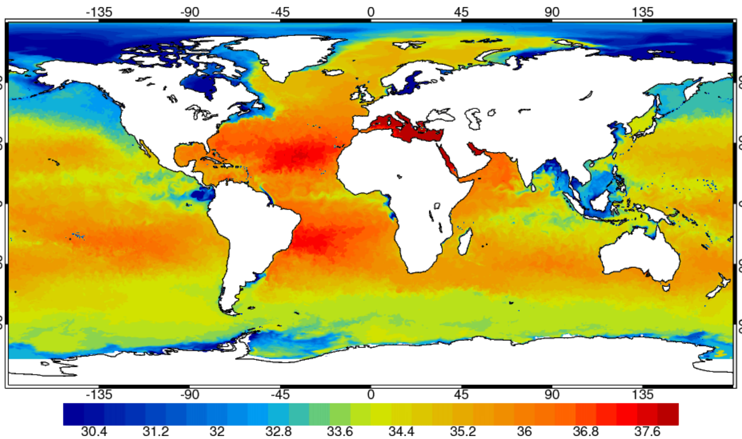


SMAP-NASA

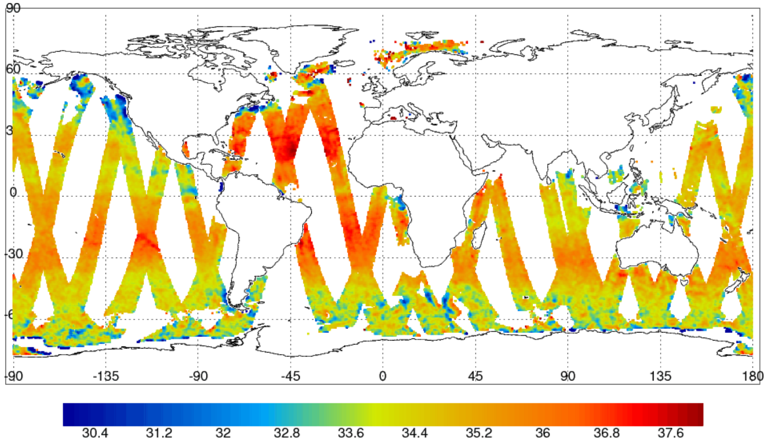
Real Aperture Radiometer
Frequency: 1.4 GHz L-band
Spatial Resolution: ~30 kms
Swath Width: ~1000 kms
Revisit time Equator: ~3 days
Incidence angle: 40°
Fully polarimetric
Launched Jan 2015

Daily SSS Sampling

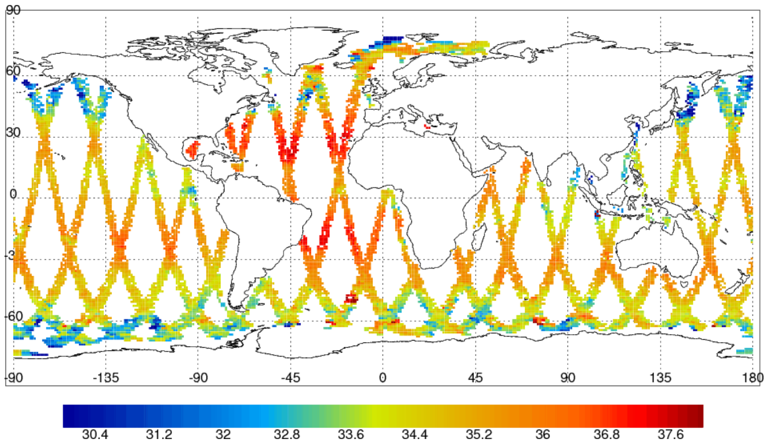
FOAM model



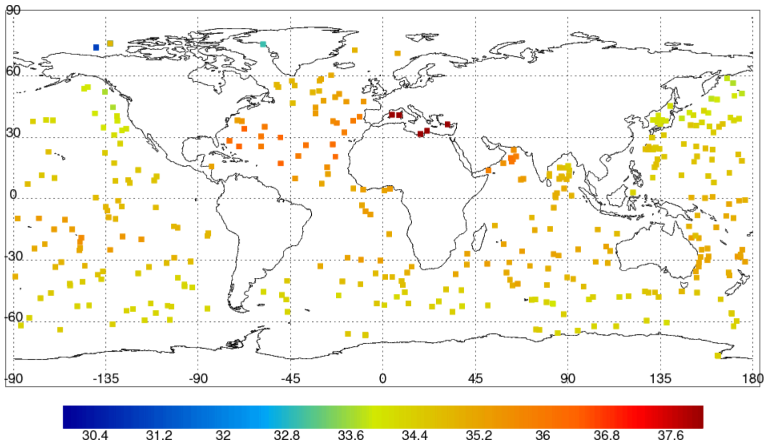
SMOS



Aquarius



Argo



Courtesy Mattiew Martin (UK Metoffice)

SSS as a passive tracer of circulation

Simple slab mixed layer

$$\frac{\partial S'}{\partial t} \approx \frac{S_0(E' - P')}{\bar{h}} - \bar{\mathbf{U}} \cdot \nabla S' - \mathbf{U}' \cdot \nabla \bar{S} - \frac{(\Gamma(w_e)(S - S_b))'}{\bar{h}} + \kappa \nabla^2 S'$$

Freshwater fluxes

Advection of salt
By surface currents
(Ekman+Geostrophic+…)

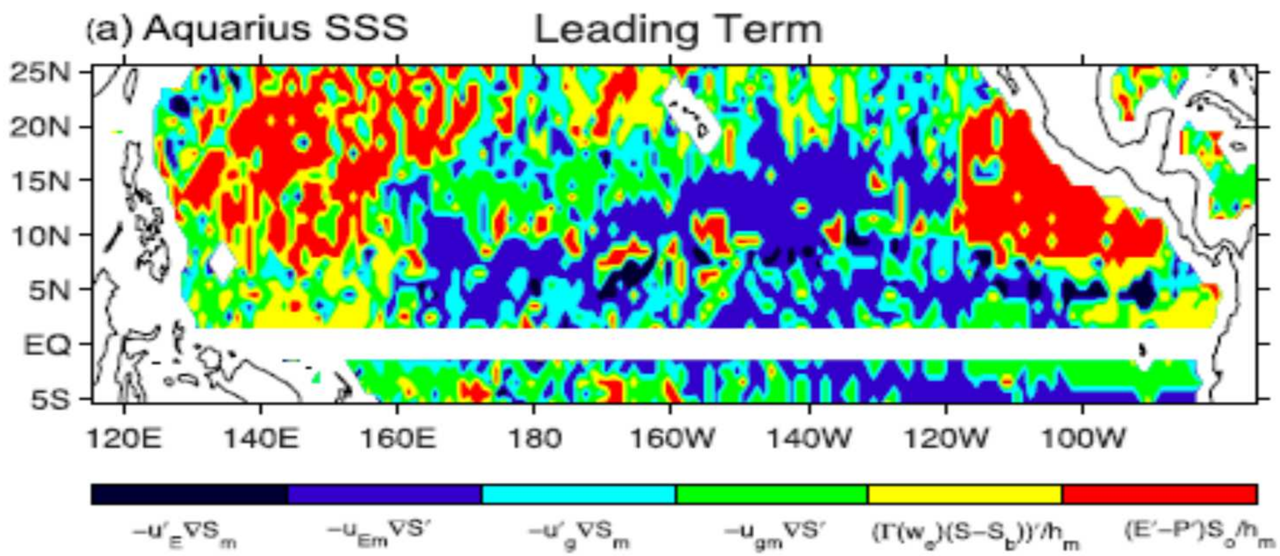
Ekman Pumping

Diffusion

Surface currents are responsible for the horizontal transport of ML salinity

Lisan Yu
(JGR, 2014
2015)

2 years of
data



Ekman

Geostrophy

SSS an active contributor of circulation

$$\rho(S,T) = \rho_o[1 + \beta S - \alpha T]$$

At the ocean surface, the buoyancy is given by:

$$b_s = -\frac{g}{\rho_o}\rho_s = -g[1 + \beta SSS - \alpha SST]$$

<u>Links between surface currents stream function and sea surface height in the geostrophic theory:</u>

For a horizontal flow (current) with velocity $\vec{u} \equiv (u, v)$, the stream function ψ is defined by: $\vec{u} = \nabla \times \psi$:

$$u = -\frac{\partial \psi}{\partial y}$$
$$v = \frac{\partial \psi}{\partial x} \qquad (1.3)$$

For a flow in geostrophic equilibrium, the sea-surface height η provides a direct estimation of the stream-function at the surface:

$$\psi_s = \frac{g}{f_o}\eta \qquad (1.4)$$

Links between stream function (surface currents) and surface buoyancy: the SQG theory

The surface quasi-geostrophy theory

Surface Buoyancy

$$\hat{\psi}_{surf}\left(\vec{k}, z\right) = \frac{\hat{b}_s\left(\vec{k}\right)}{Nk} exp\left(\frac{Nkz}{f_o}\right) \qquad \psi_s = \frac{g}{f_o}\eta$$

Current stream function

Given the relashionship (1.4) between sea-surface height and the stream function at the surface (z=0), from (1.8), one has a direct relation between SSH and surface buoyancy:

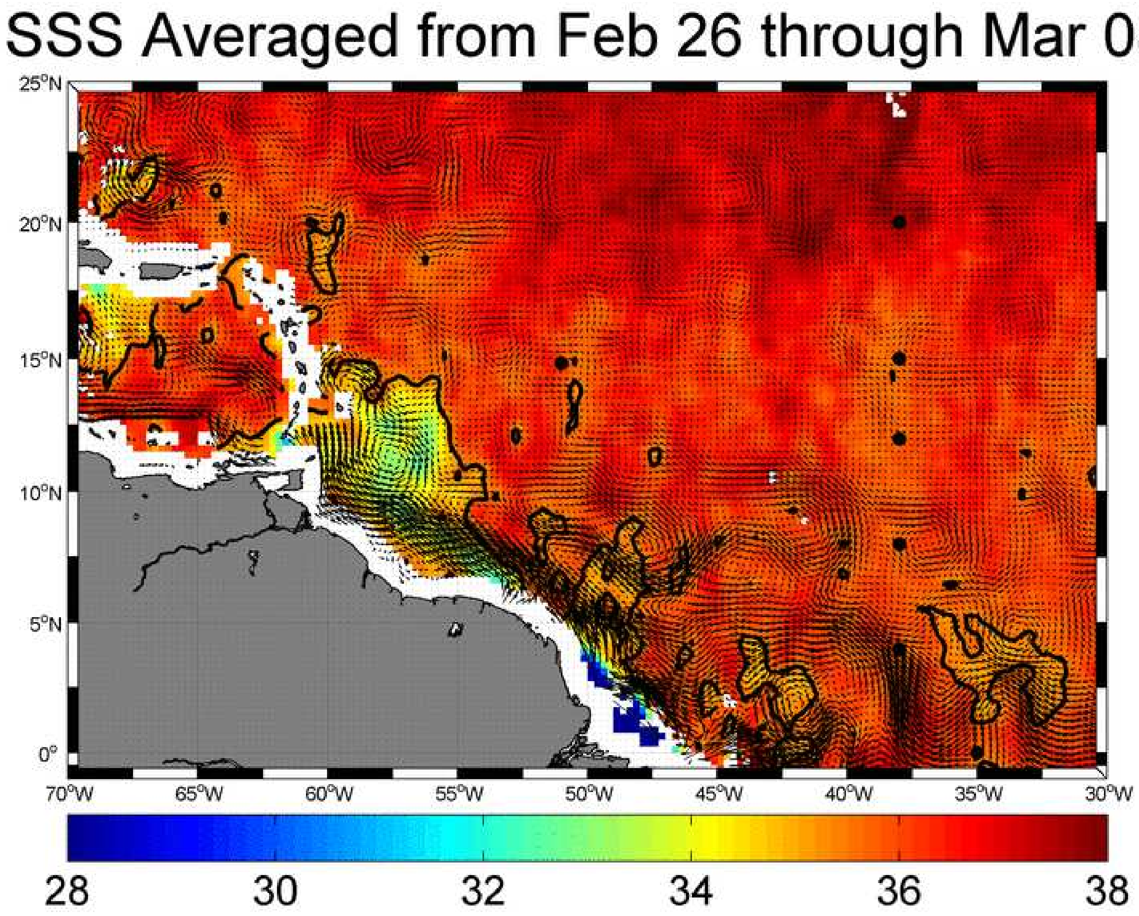
$$\hat{\eta}\left(\vec{k}\right) \approx \frac{f_o \hat{b}_s\left(\vec{k}\right)}{N_b g\ k} \qquad (1.9)$$

Surface Buoyancy (SSS & SST)

SSH (altimetry)

Tropical FreshPool Signals

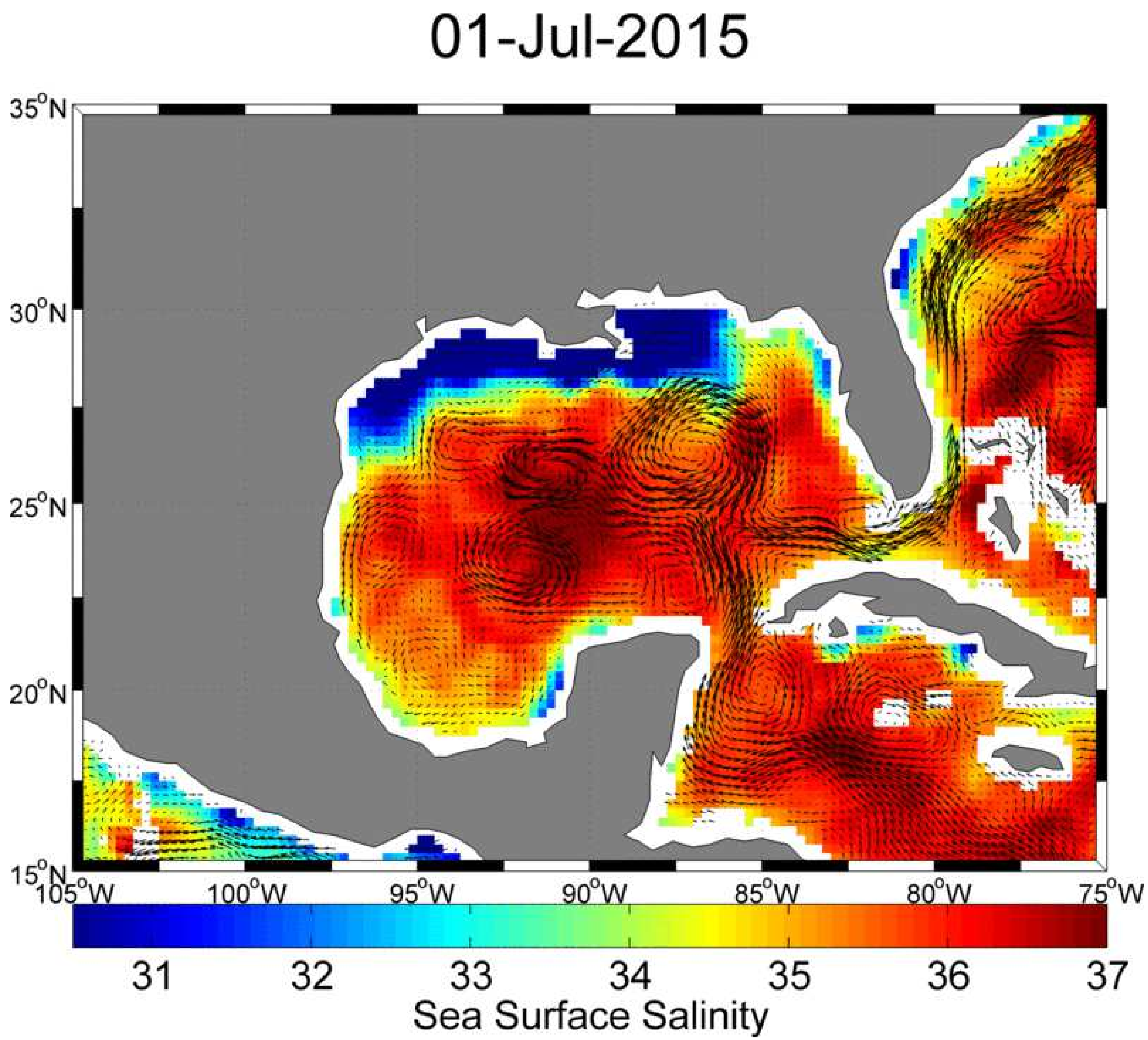
Monitoring Large Tropical River Discharges into the Ocean



Reul et al., Surv. 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

Monitoring the Mississipi river Plume



Merged SMOS and SMAP SSS to form 3 days running mean SSS
SMAP SSS is a preliminary research product developed at IFREMER/ODL

Stommel's overturning gate mechanism (1993): intercation wind stress/sharp front

Initial presence of an Horizontal density gradient and a wind-driven shear layer

If upper wind-driven displacement is toward lower density: gravitational instabilities develop
⇒ Vertical mixing dominates,
Short-cutting horizontal exchanges

«Gate that open horizontal flux of the properties in the ML is closed »

If displacement is toward
higher density: vertical stratification
Little vertical mixing
Horizontal exchanges dominates
Gate is open

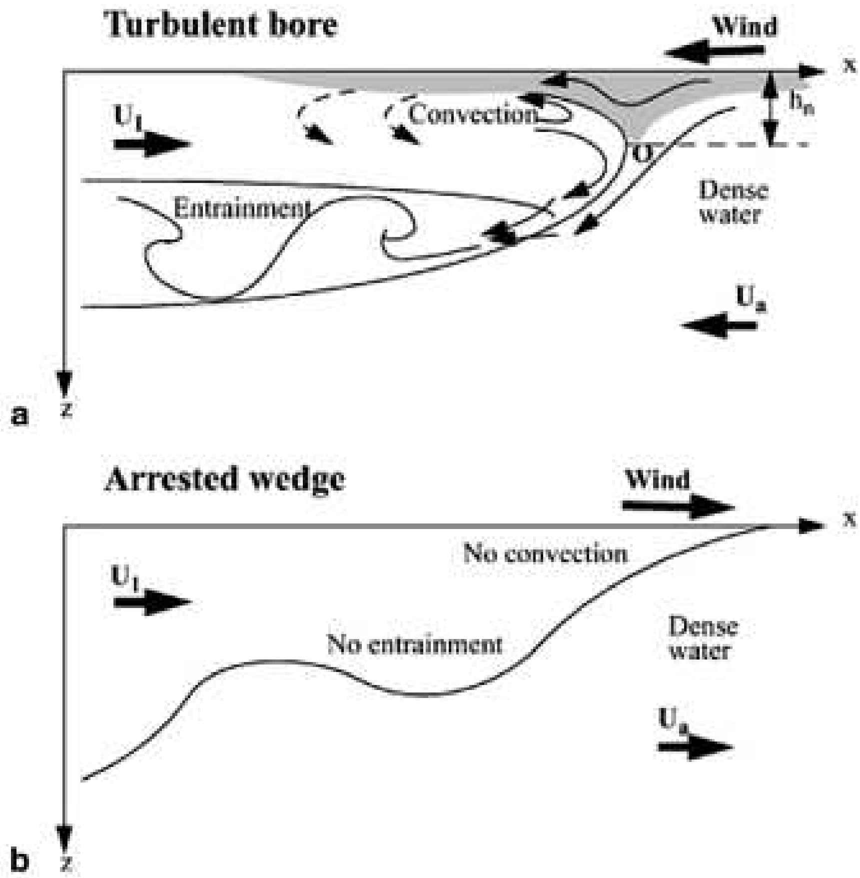


Fig. 5.36 Interaction of sharp frontal interface with wind stress: **a** Stommel's overturning gate is closed; **b** Stommel's overturning gate is opened. After Soloviev et al. (2002) with permission from Elsevier

Stommel's overturning gate mechanism (1993):

intercation wind stress/sharp front

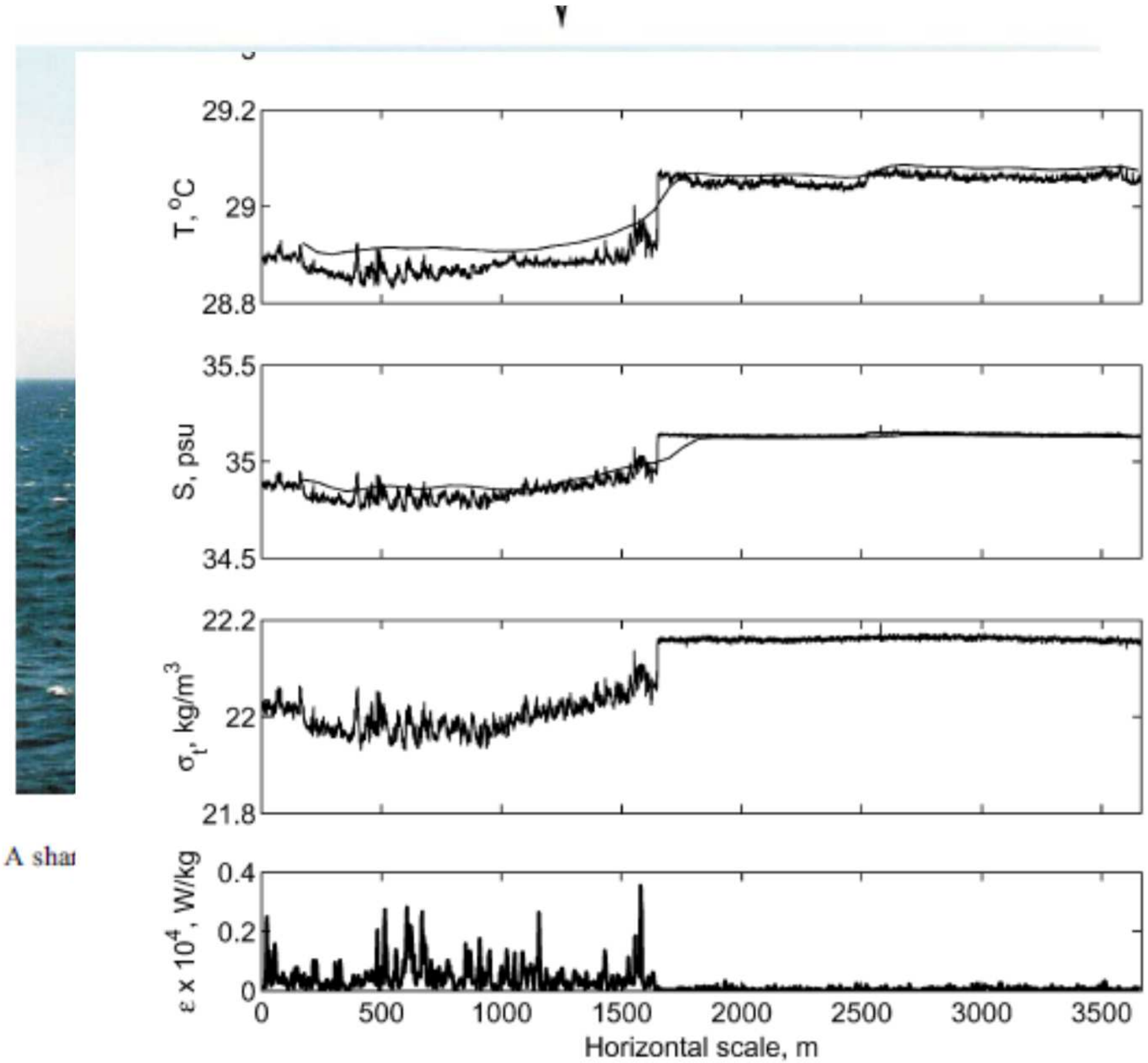
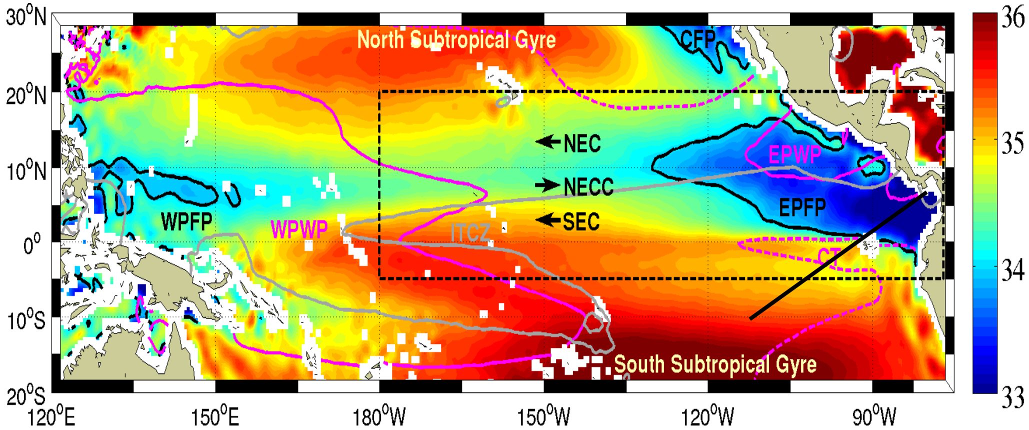


Fig. 1. A shar

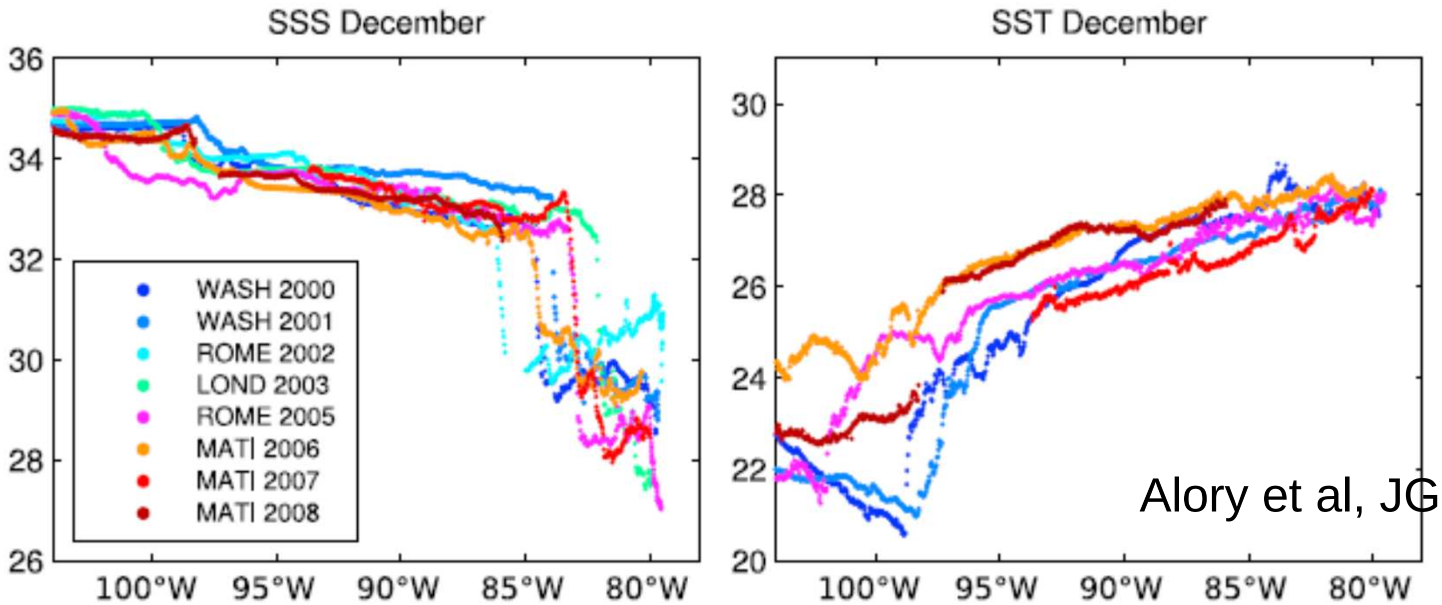
Soloviev et al., 2002

Eastern Pacific fresh pool (EPFP)



EPFP= Tropical surface water

(salinity<34)

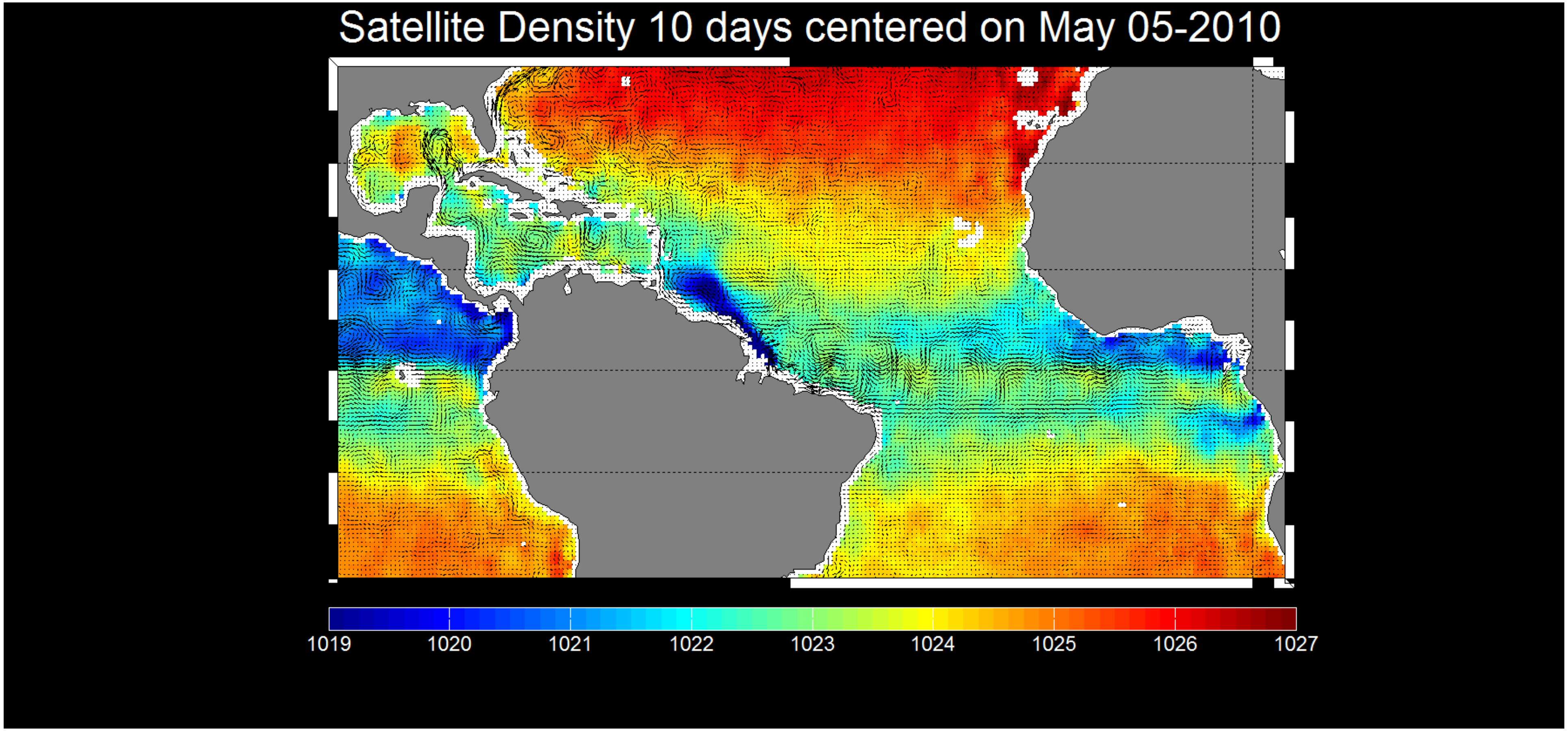


Alory et al, JGR, 2012

Figure 4. High-resolution SSS and SST transects collected from different Voluntary Observing Ships. The ship code and year of collect are given in the legends within the SSS figures.

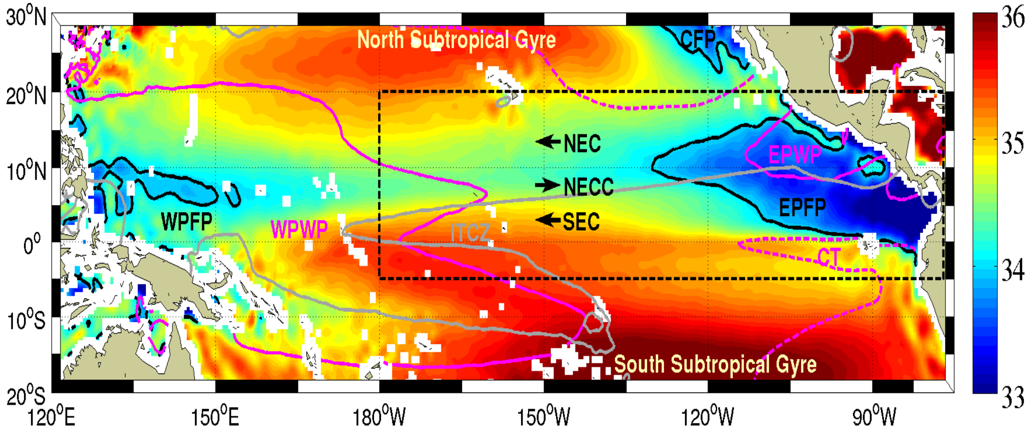
SSS and SST fronts are not systematically coincidents (in the Tropics in particular)

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

Eastern Pacific fresh pool (EPFP)



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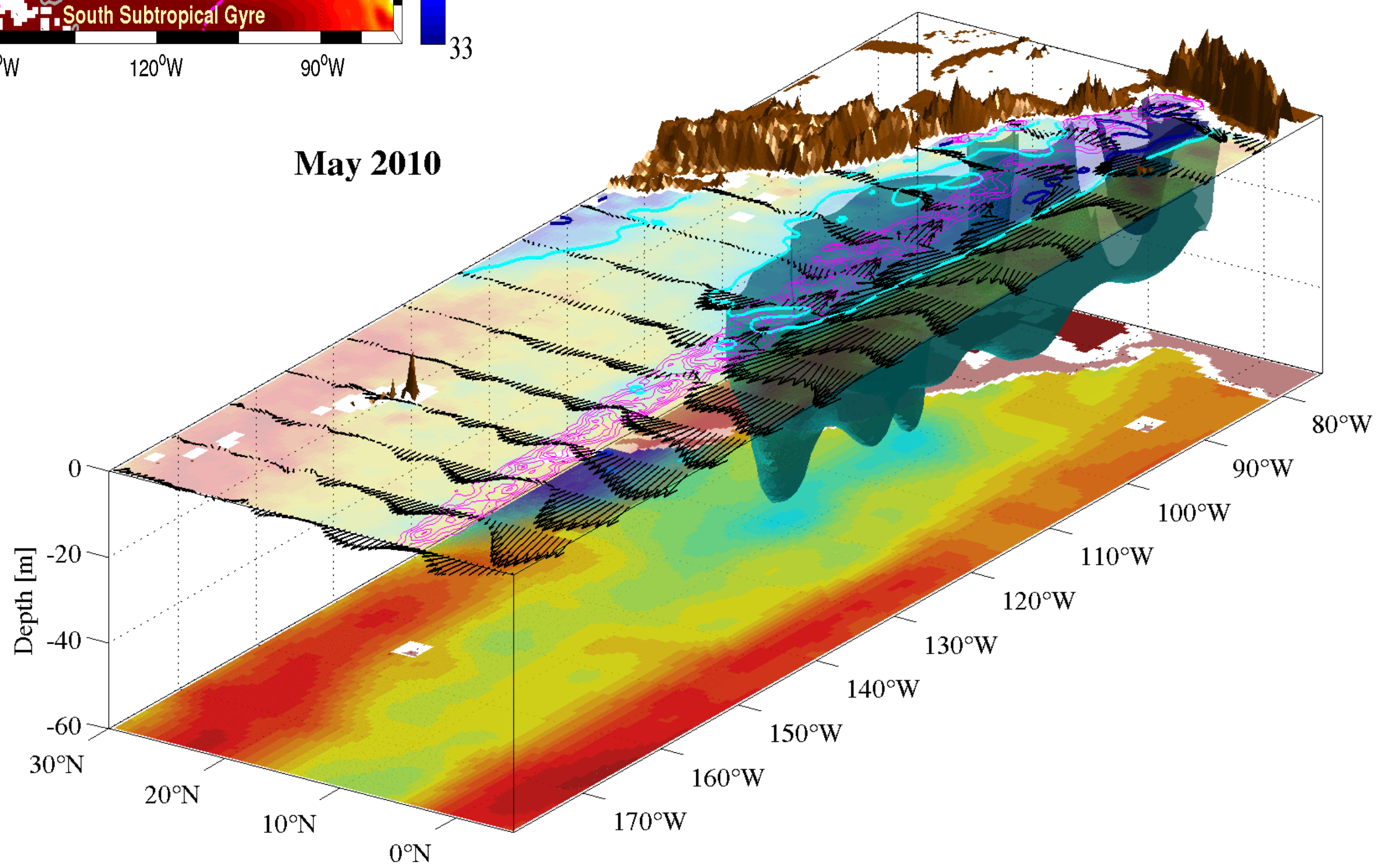
(salinity<34)



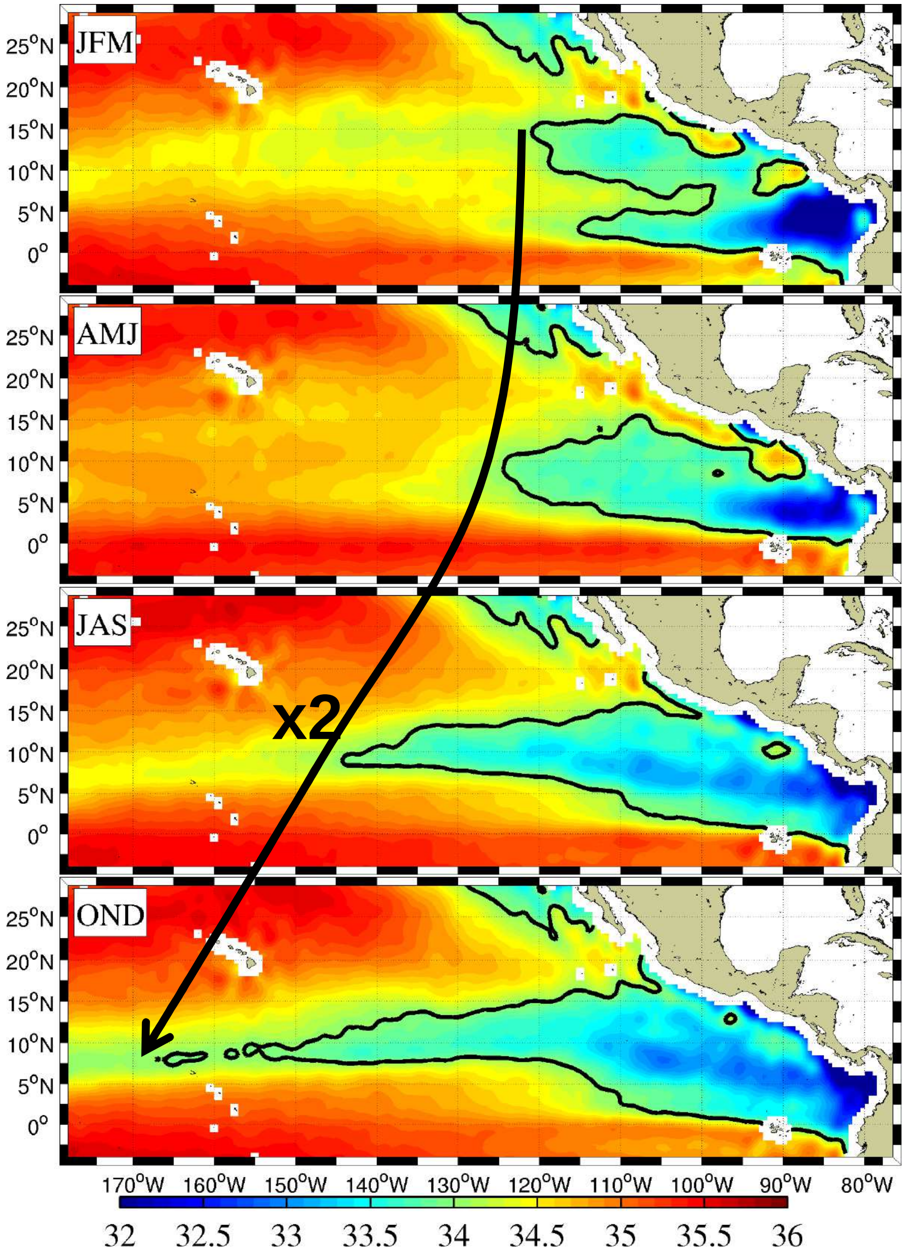
Data used:

- SMOS SSS
- ARGO salinity
- CMORPH precipitation
- OSCAR currents
- ASCAT wind stress

50 km, 7 Days

Guimbard, 2015

Seasonal SMOS SSS variability (2010-2014)



- Alory et al., 2012

Seasonal dynamics of the far eastern fresh pool (salinity<33) using TSG

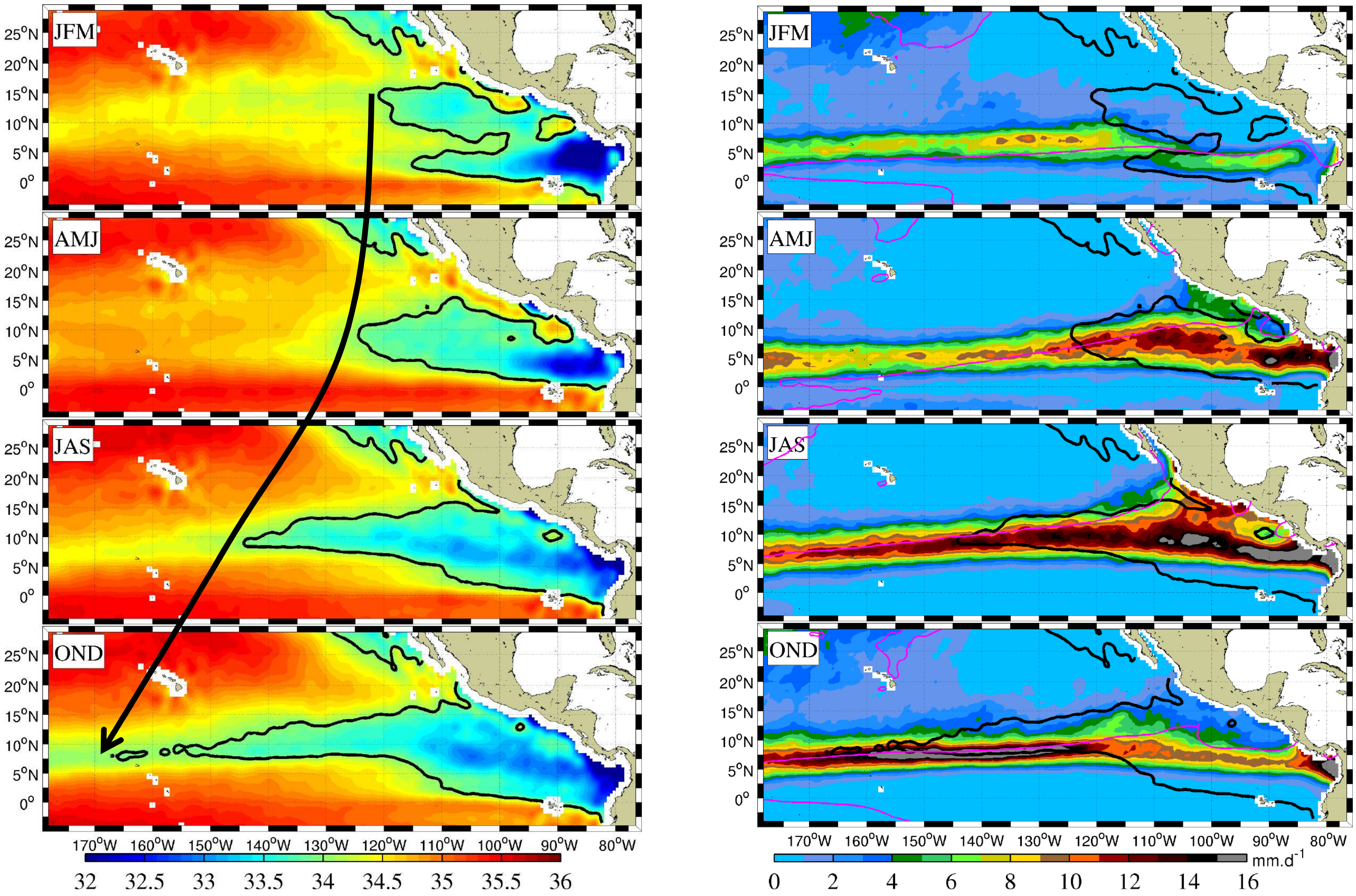
- Yu, 2015

Seasonal dynamics of the tropical salinity minima using Aquarius+Argo

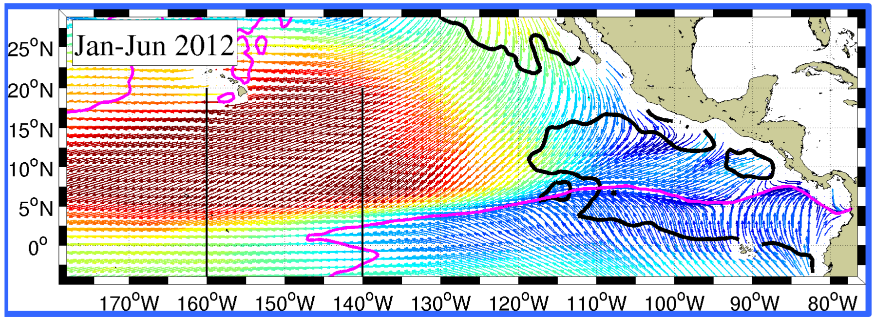
What are the main mechanism that drives the Fresh pool dynamics?

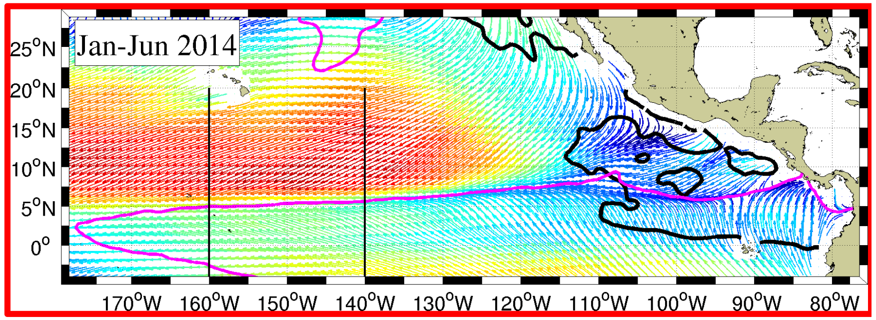
Intuitively: freshwater pool advection Westward ???

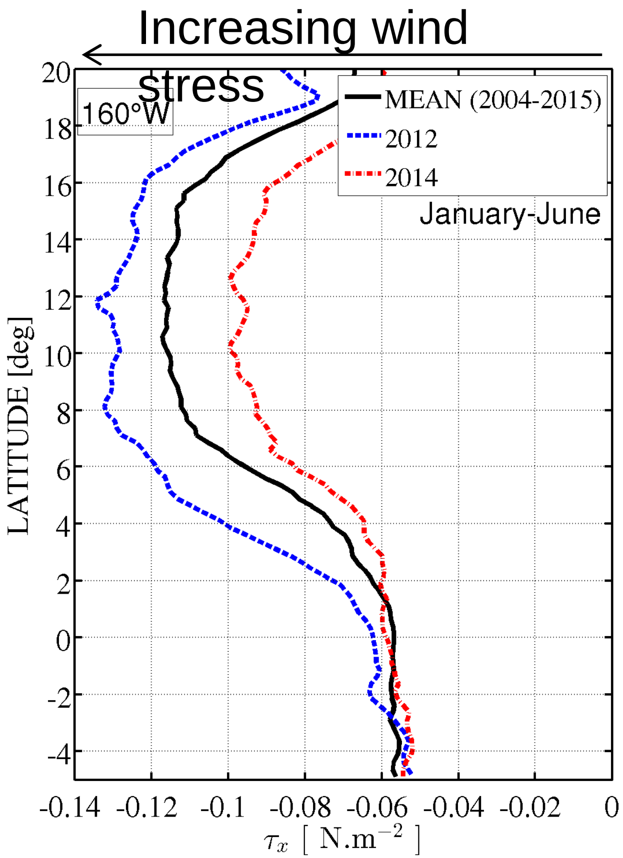
Seasonal SSS variability induced by precipitation



Physical mechanism: mean **<u>Zonal wind stress</u>** (January-June) comparison between 2012 and 2014



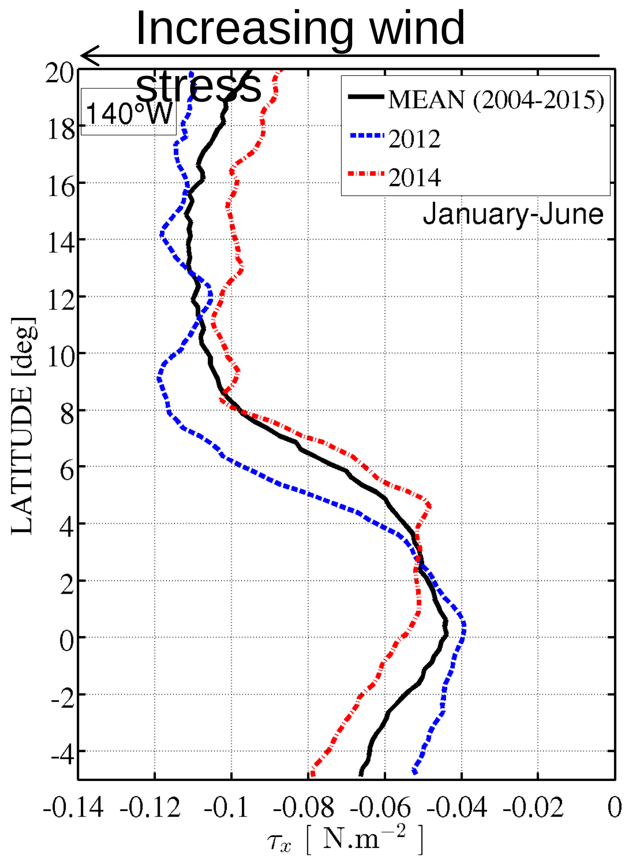




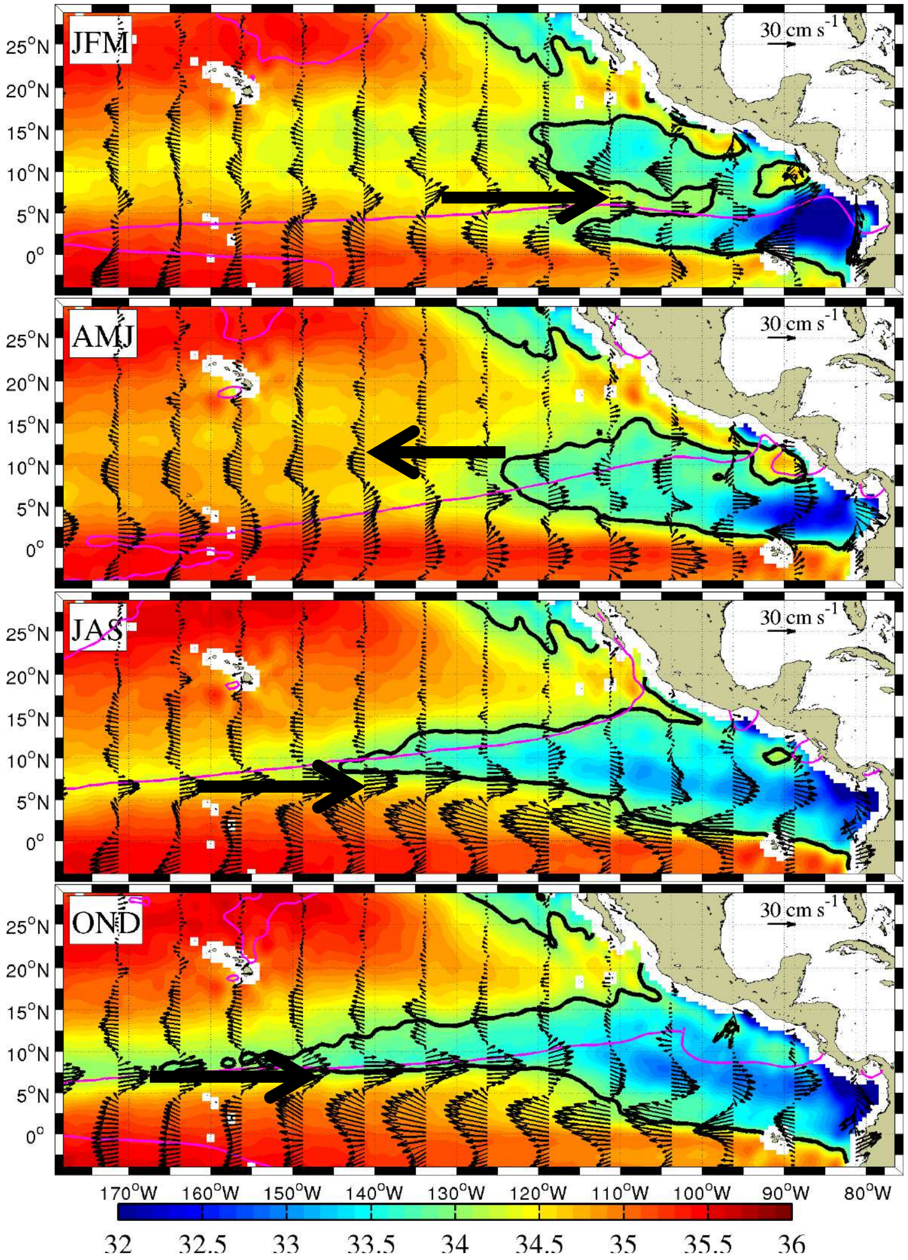
- Meridional Shift of the ITCZ
-> Southward in 2012

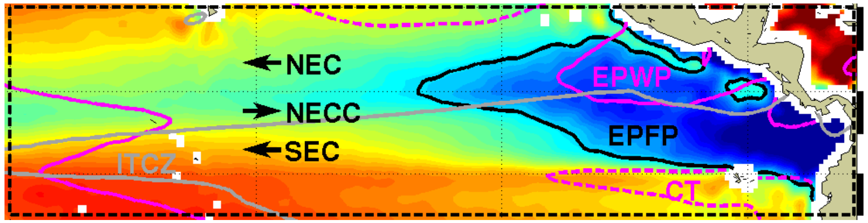
- Zonal Wind stress in 2014 is 20% lower than the 10 years average

- Zonal Wind stress in 2012 is 15% higher than the 10 years average



Seasonal SSS variability induced by currents





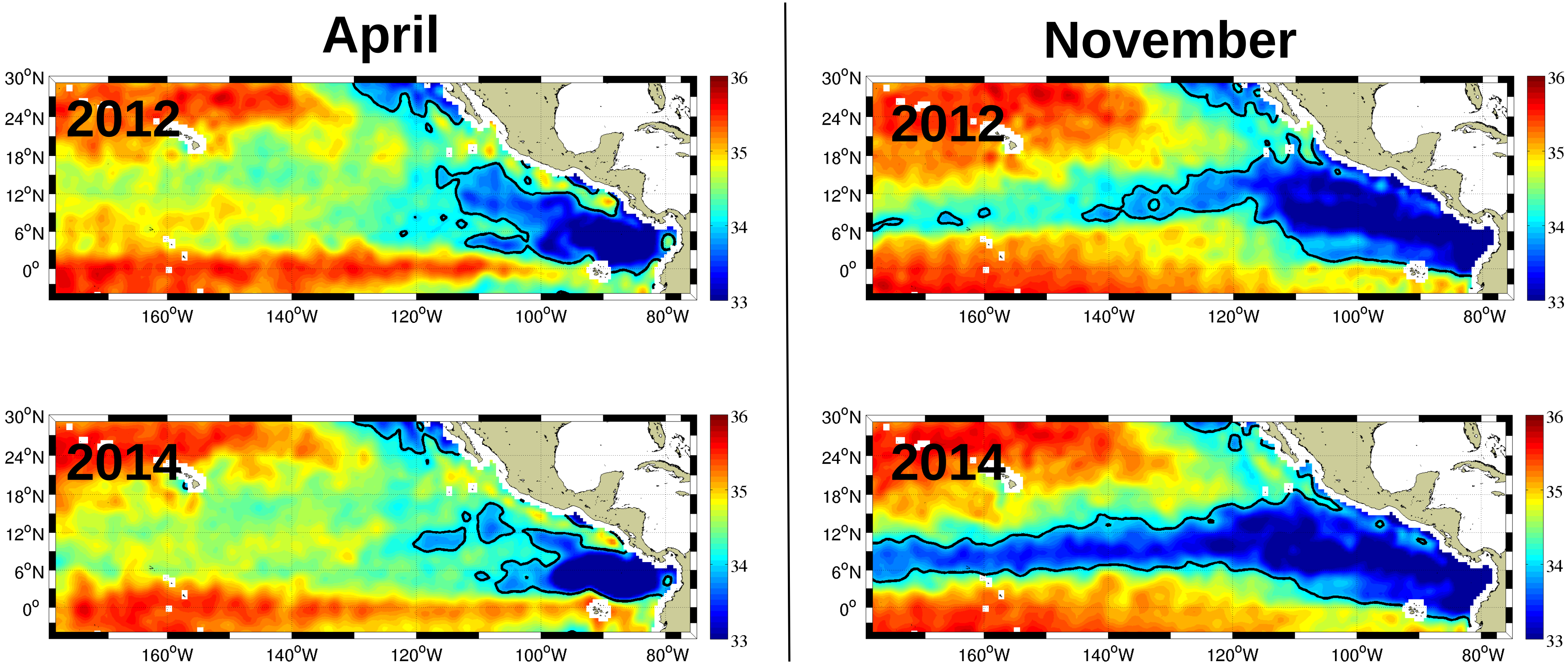
NEC = North Equatorial current
NECC = North Equatorial counter current
SEC = South Equatorial current

Intensification of the **NECC** and **SEC** in summer fall

Westward expansion of the pool against NECC eastward flow.

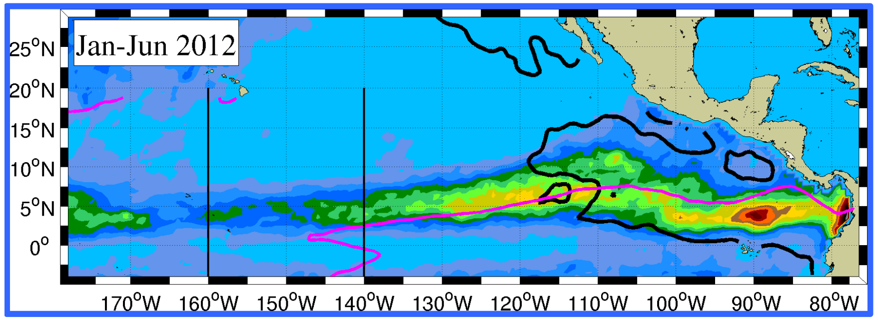
Surface ocean currents role not clear

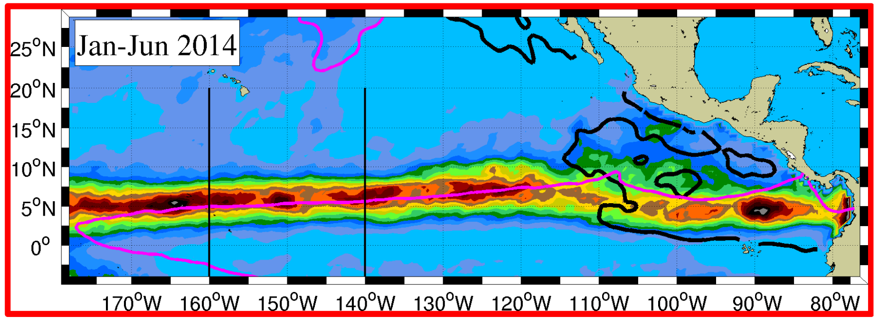
The Fresh pool interannual variability between 2012 and 2014: Monthly average SSS from SMOS

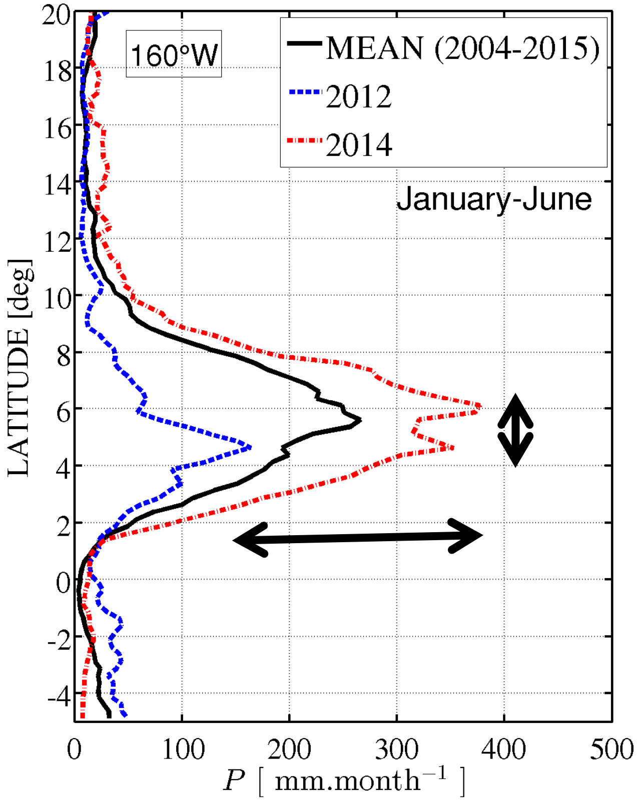


What physical mechanisms govern this SSS internnual variability?

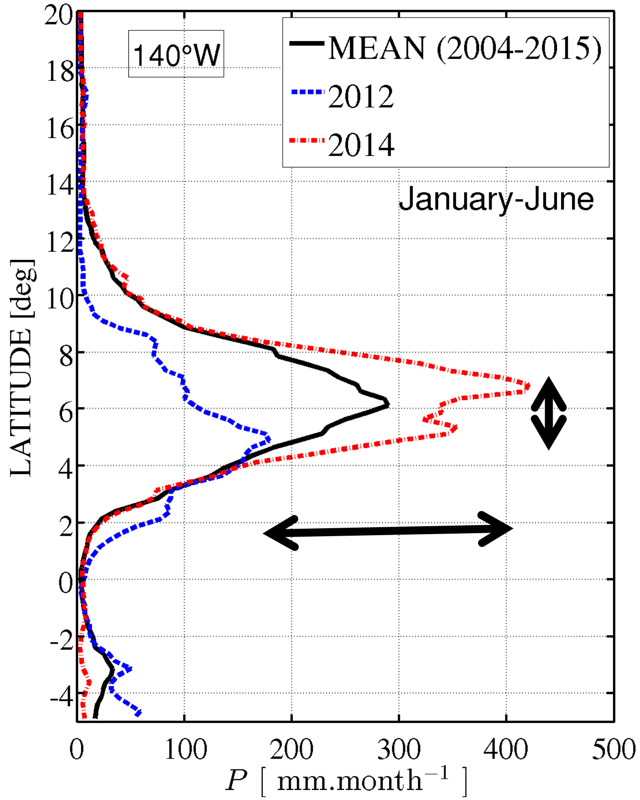
Physical mechanism: mean **precipitation rate** (January-June) comparison between 2012 and 2014



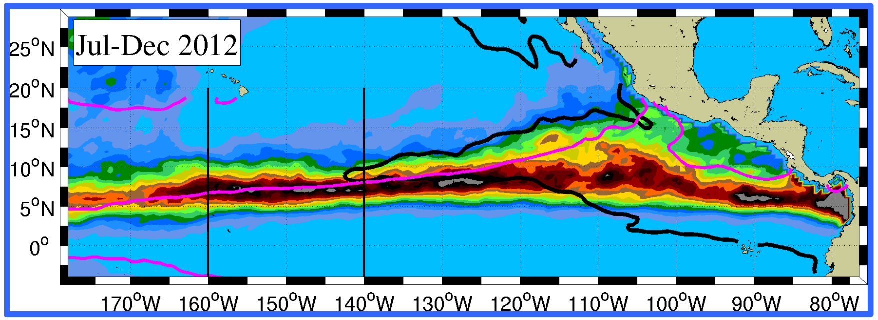


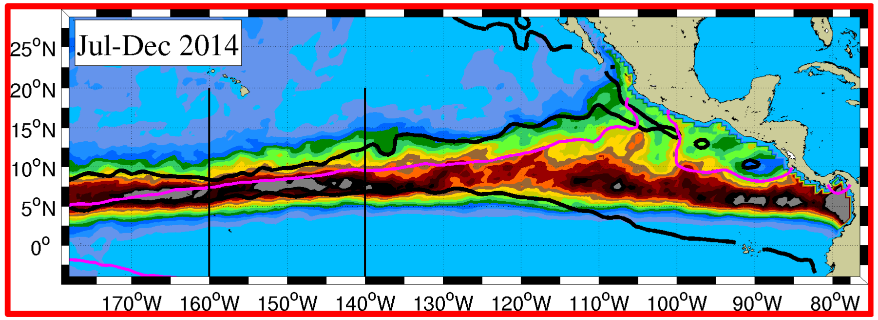


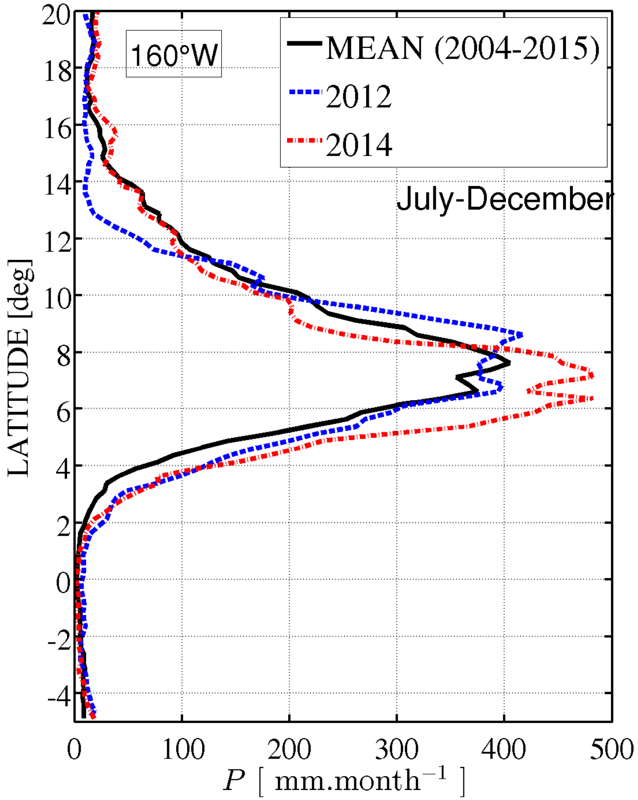
- Southward shift (~150 km) of the max of precipitation in 2012
- Precipitation rate is 40 % lower in 2012 and 25% higher in 2014 than the 10 years average.



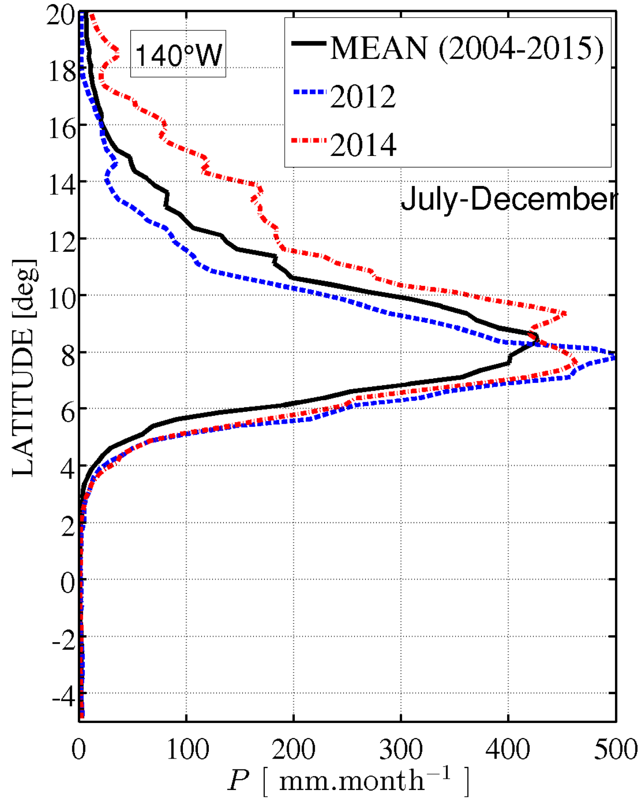
Physical mechanism: mean **precipitation rate** (July-December) comparison between 2012 and 2014



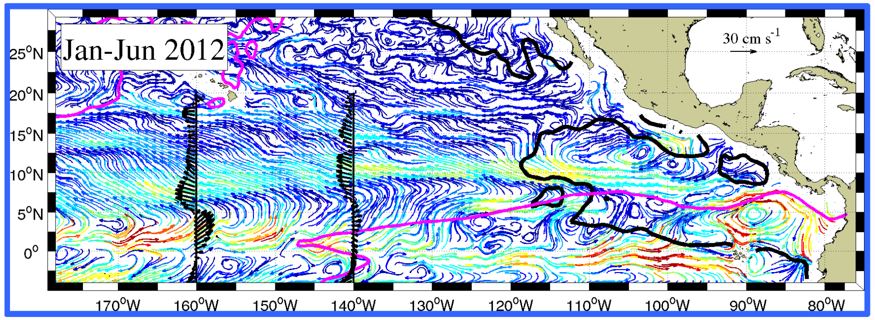


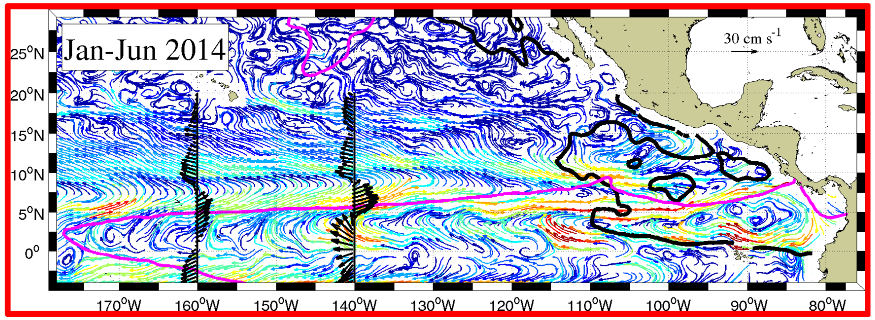


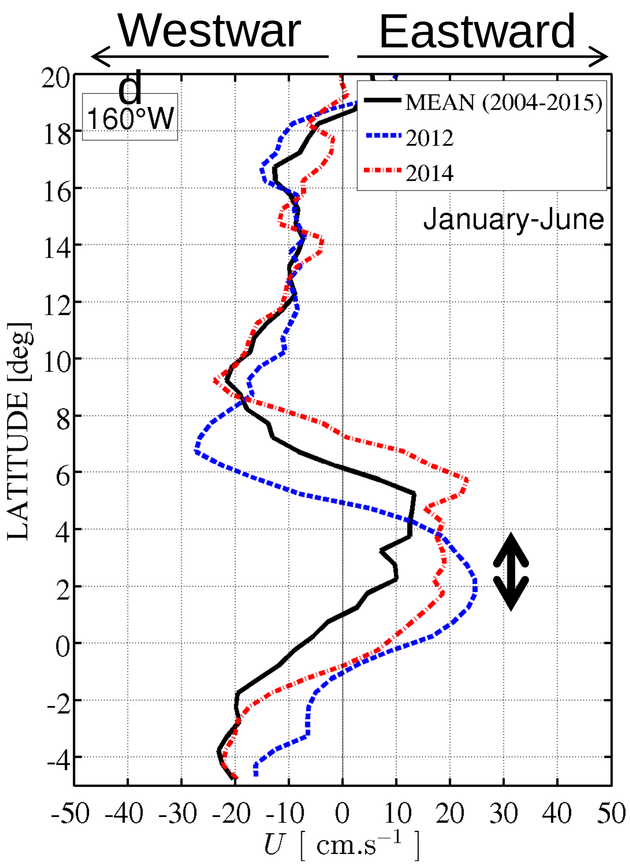
- Southward shift of the max of precipitation in 2012 has been reduced
- Precipitation rate is 20% higher in 2014 than the 10 years average.



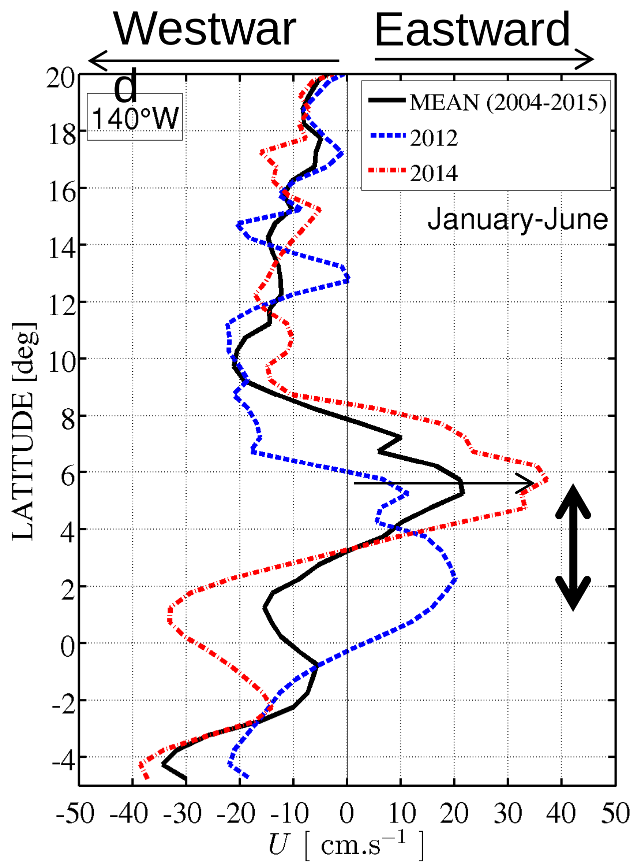
Physical mechanism: mean **Zonal currents** (January-June) comparison between 2012 and 2014



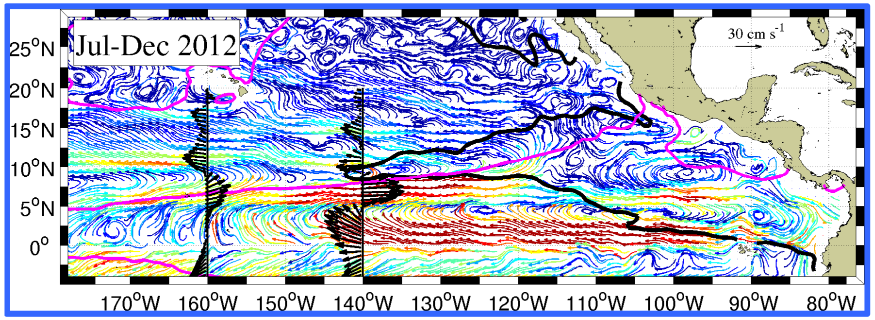


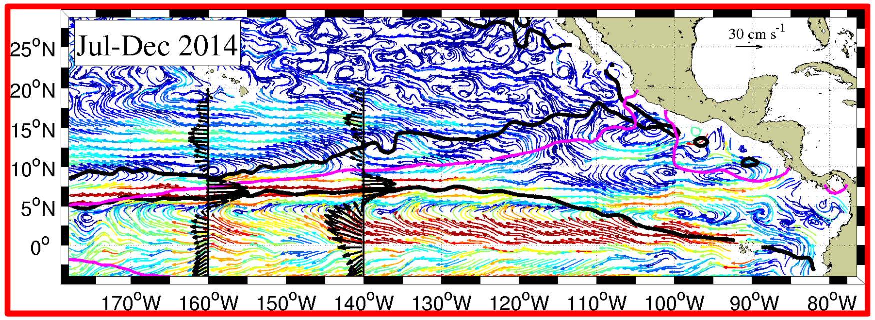


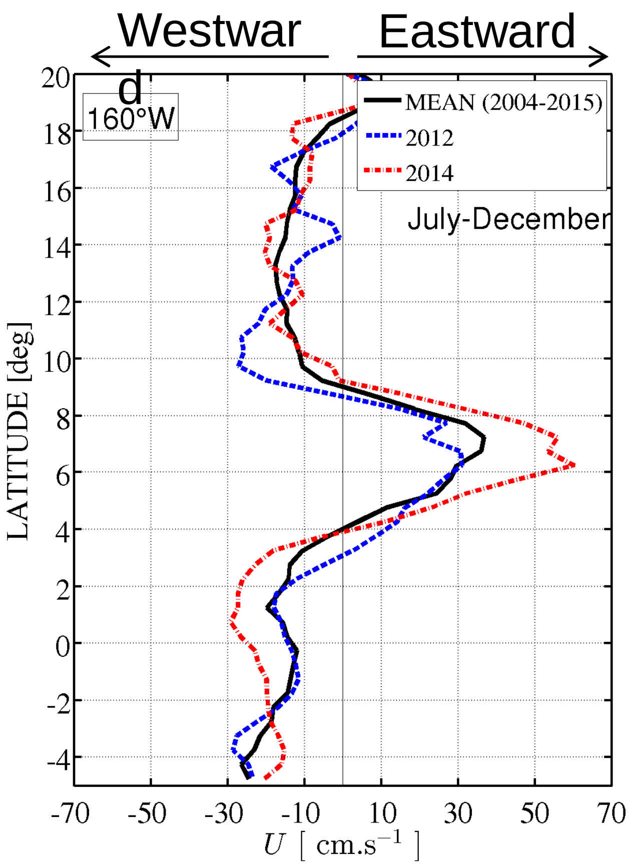
- Southward shift (~200km) of the NEC,NECC & SEC in 2012
- Intensified NECC in 2014 (x2)



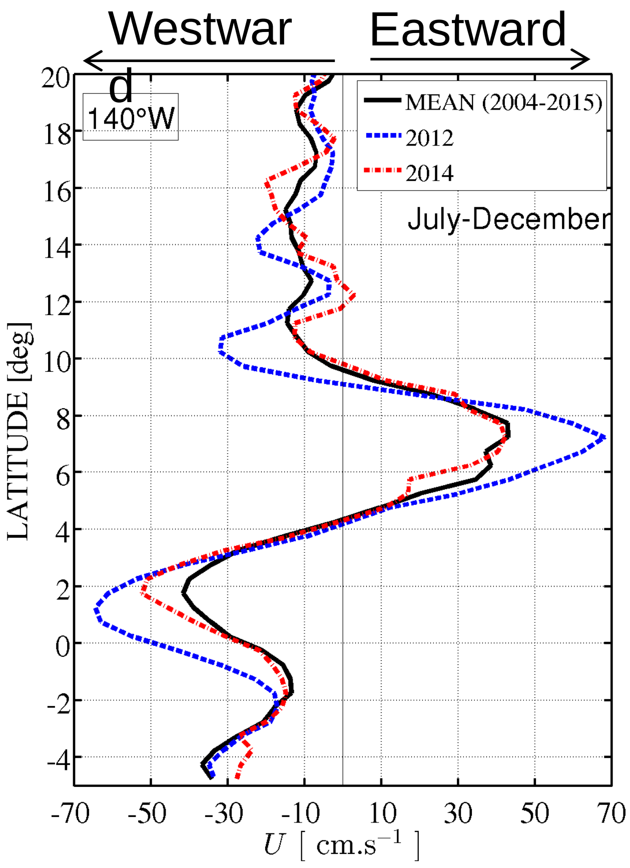
Physical mechanism: mean **Zonal currents** (July-December) comparison between 2012 and 2014



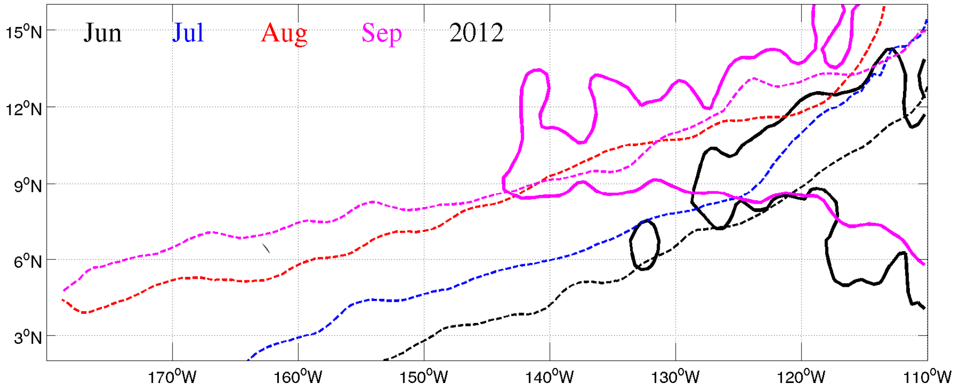


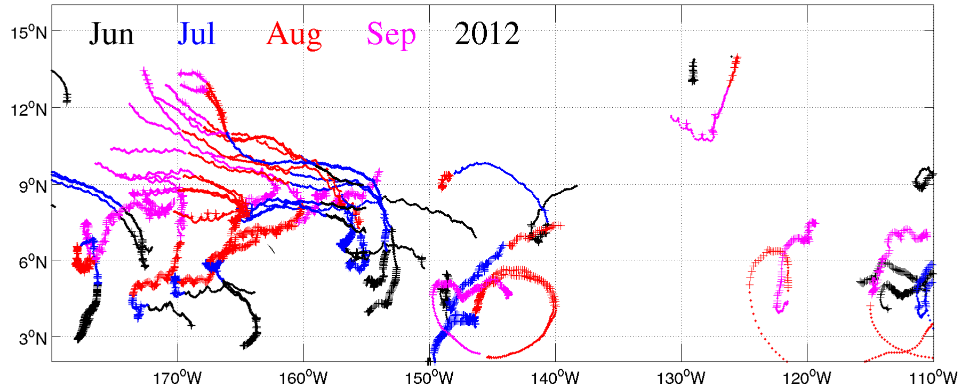


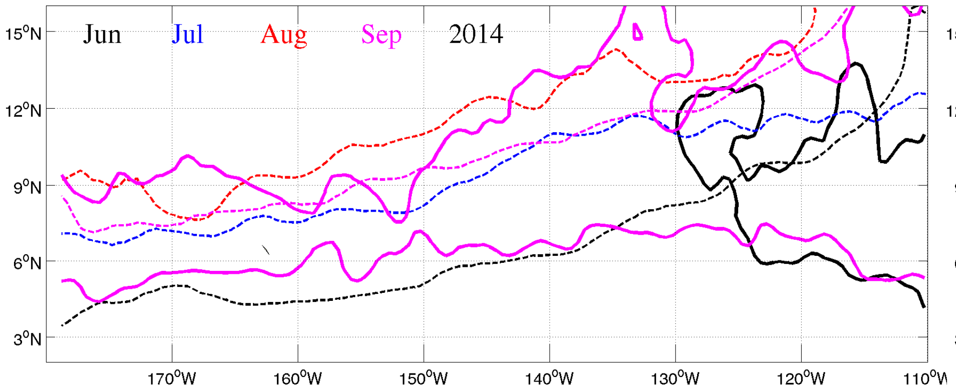
- no more southward in 2012
- Intensified NECC in 2014 at 160ºW
- Intensified NECC in 2012 at 140ºW

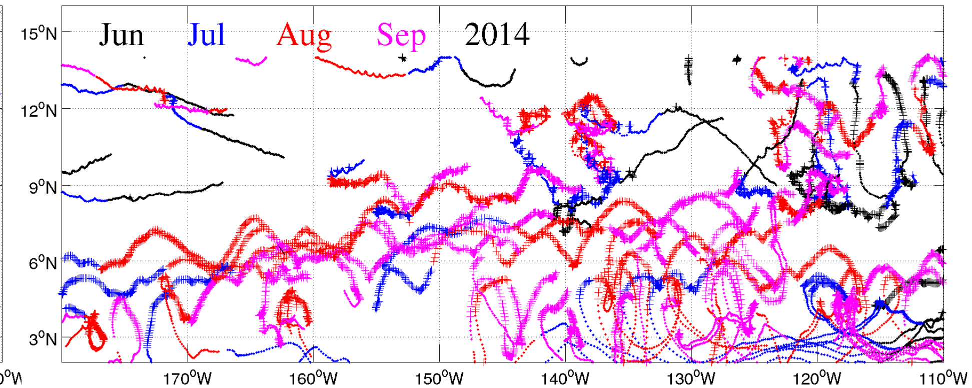


Intraseasonal salinity variability







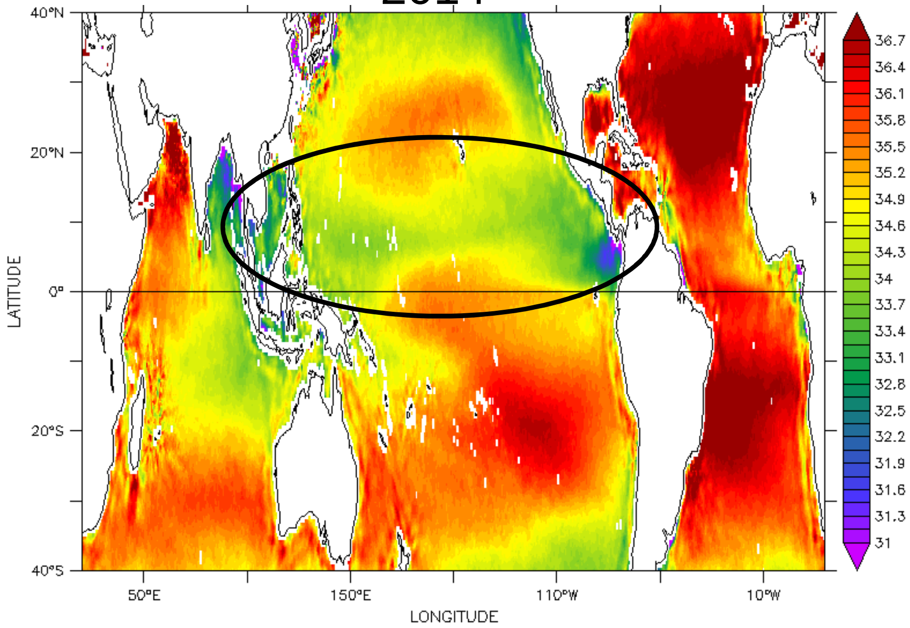


Fresh water pool extent

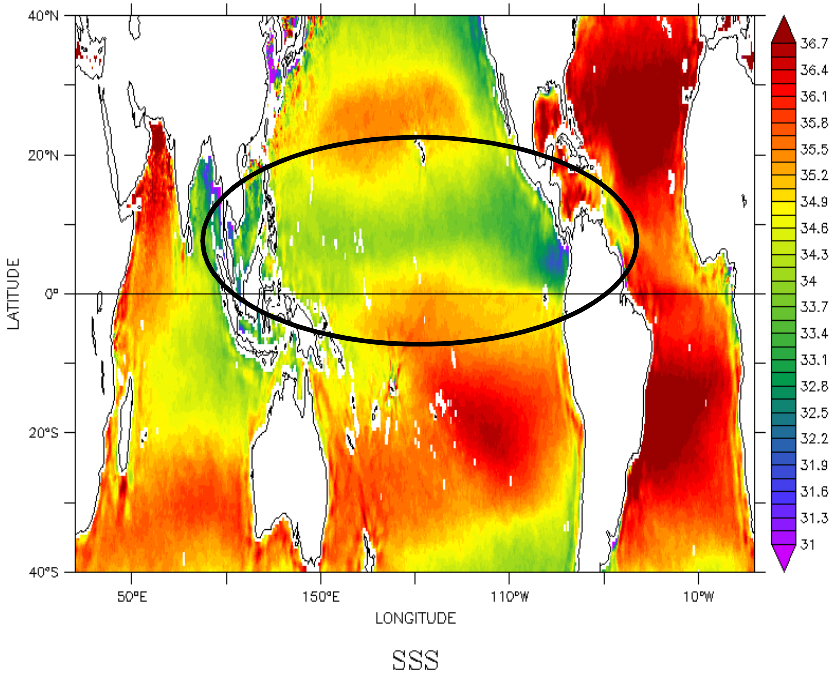
Drifter trajectories

SMOS « sees » an intense freshening in the Tropical Pacific during El-Nino 2014-2015

2014

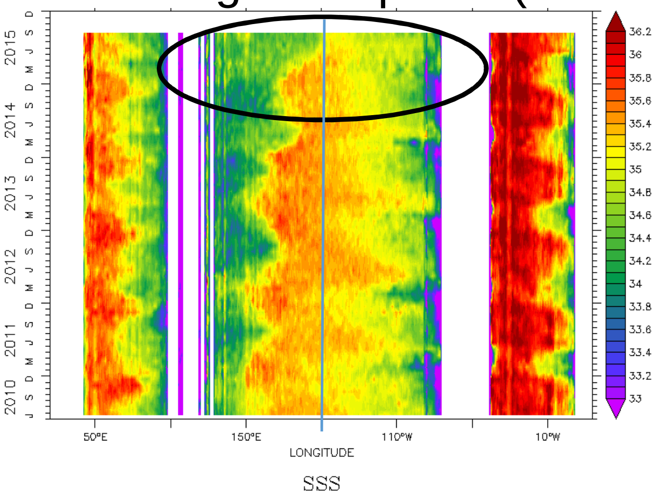


2015



SSS along the equator (2°S-2°N)

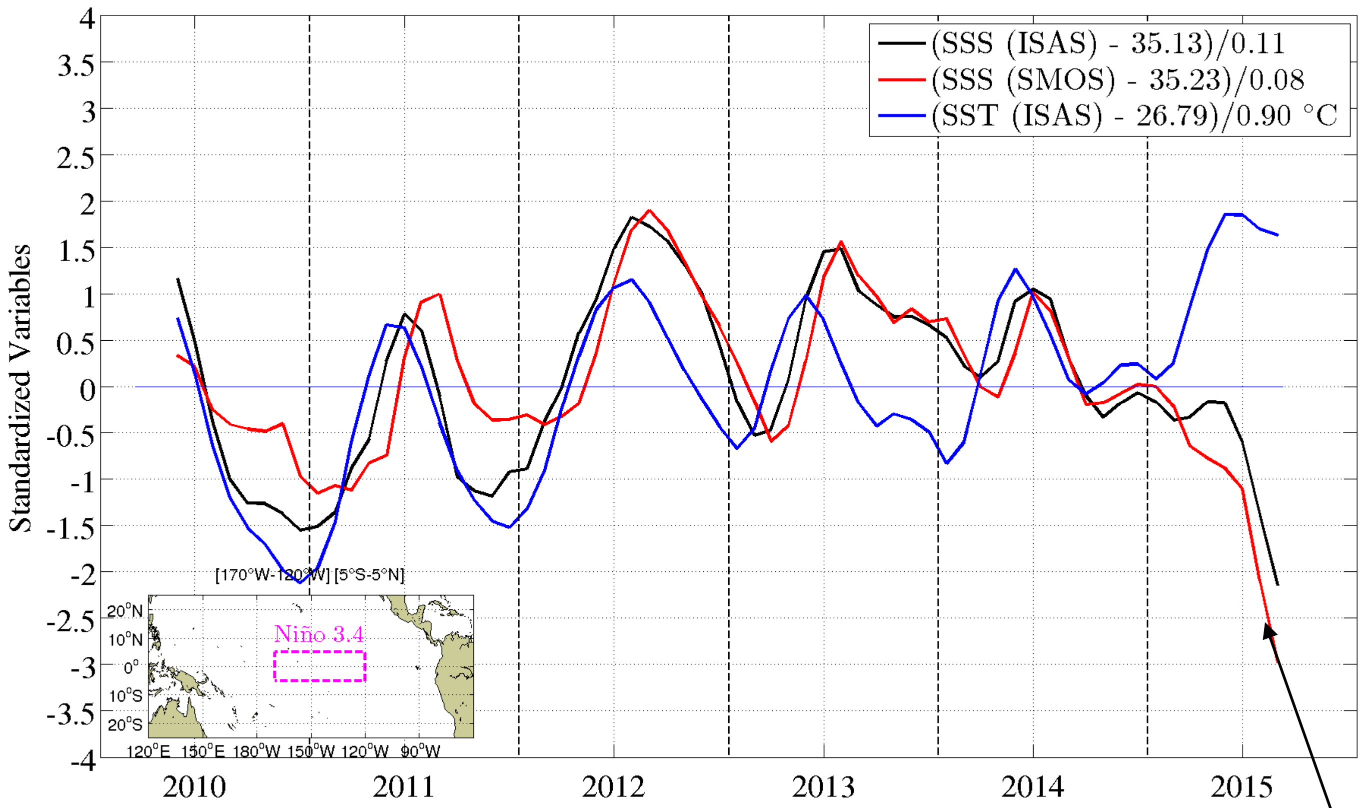
2015
2014
2013
2012
2011
2010



- Fresher SSS in the N tropical Pacific In 2015 with significant Extension of the western and eastern freshpools towards the dateline

Guimbard, Reul, Maes, in prep (2015)

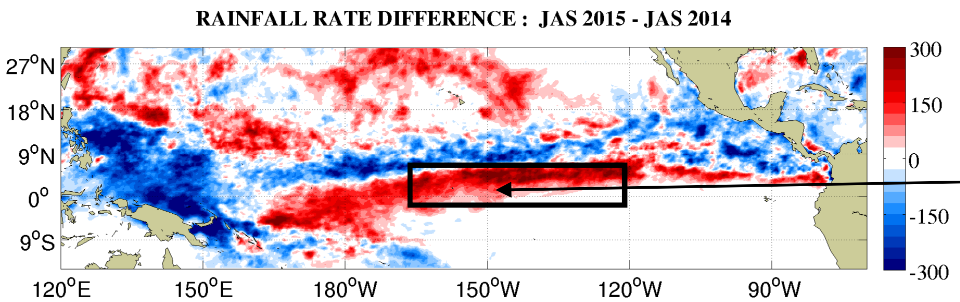
SMOS « sees » an intense freshening in the Tropical Pacific during El-Nino 2014-2015



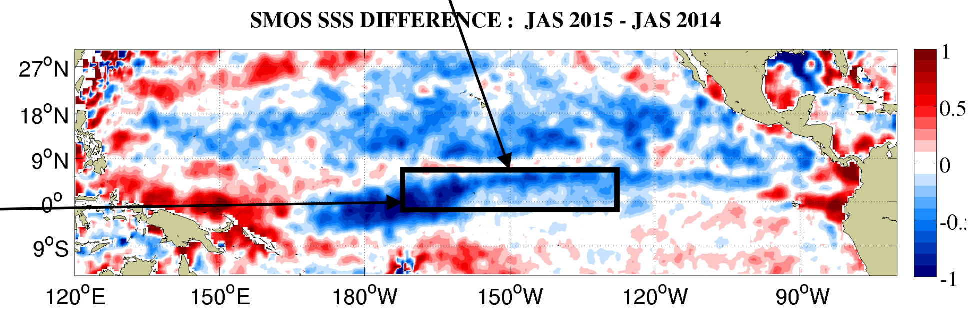
Index NiNo 3.4:
[SSS(t)-<SSS>]/ std (SSS)

Very significant Signature of El-Nino in SSS Signal of the central Pacific

⇒ Dominated by Excess Precipitation

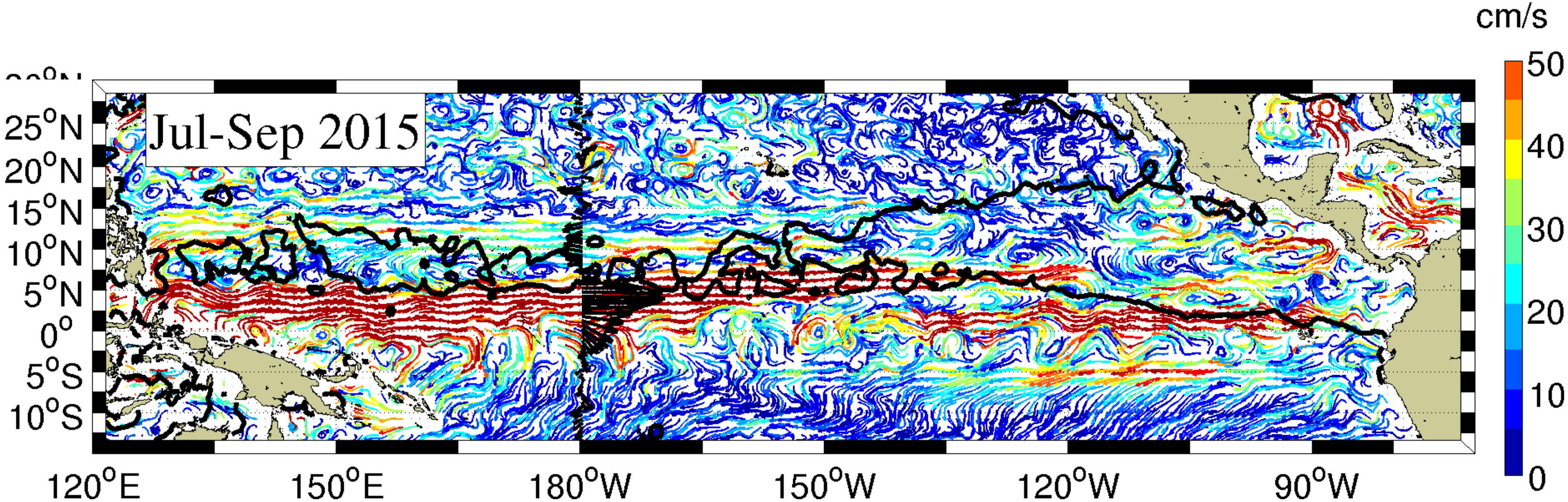


More Precip (CMORPH) in 2015 than 2014

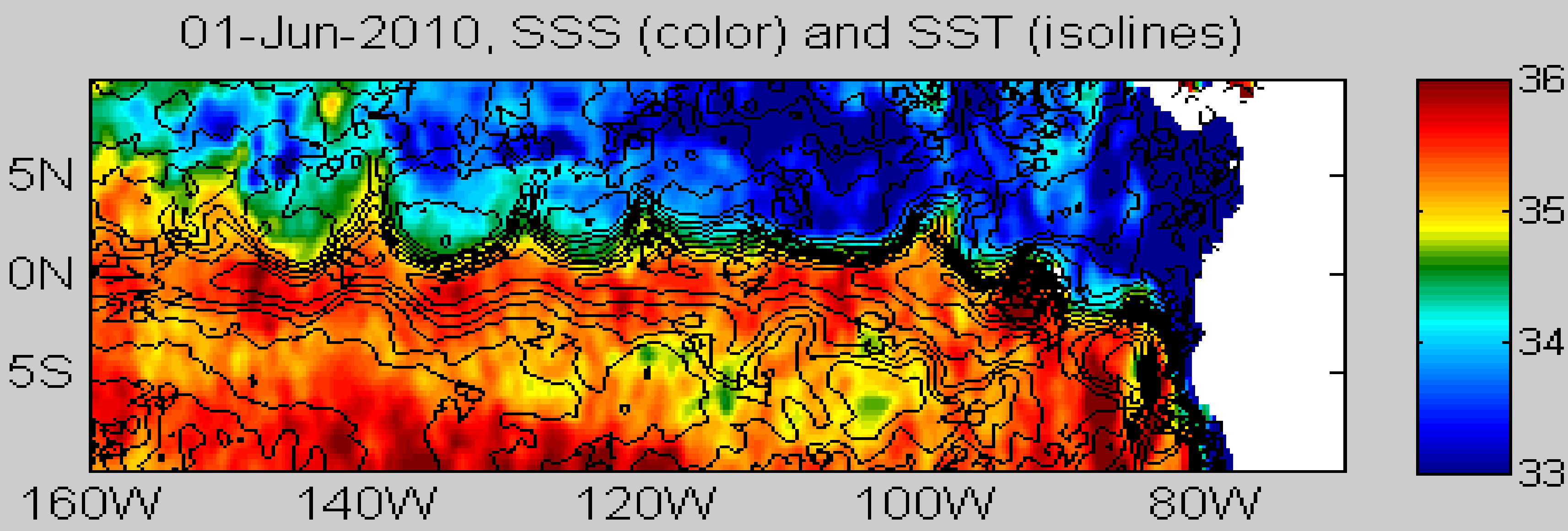


Fresher SSS (SMOS) in 2015

Very significant intensification of Pacific Equatorial Currents (NECC, NEC) during the 2015 El-nino
=> Impact on oceanic water cycle (advection, BL)



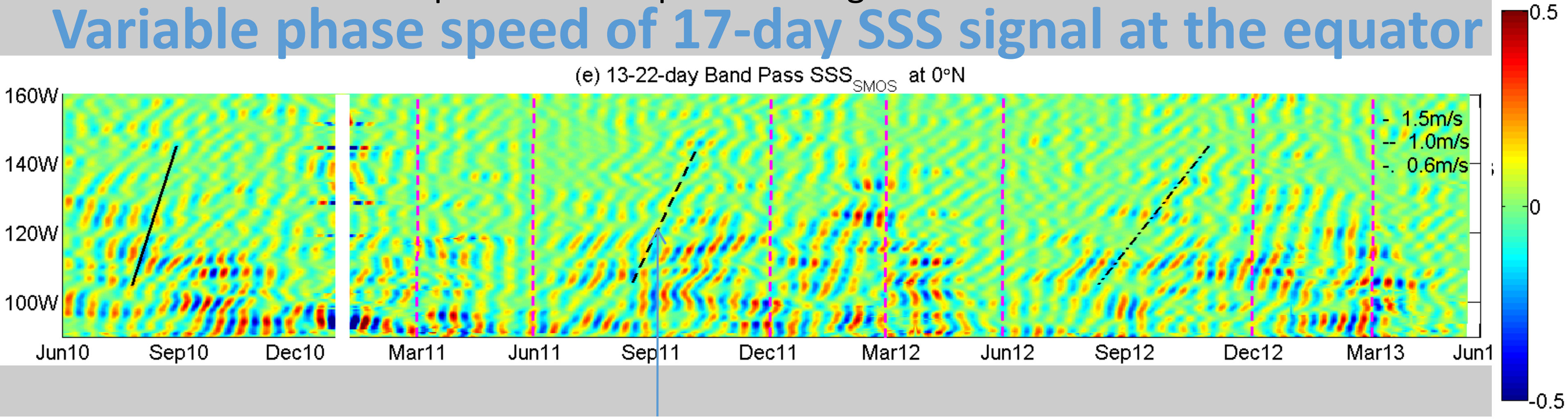
SMOS SSS signal of Tropical Instability Waves



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

Higher Latitudes

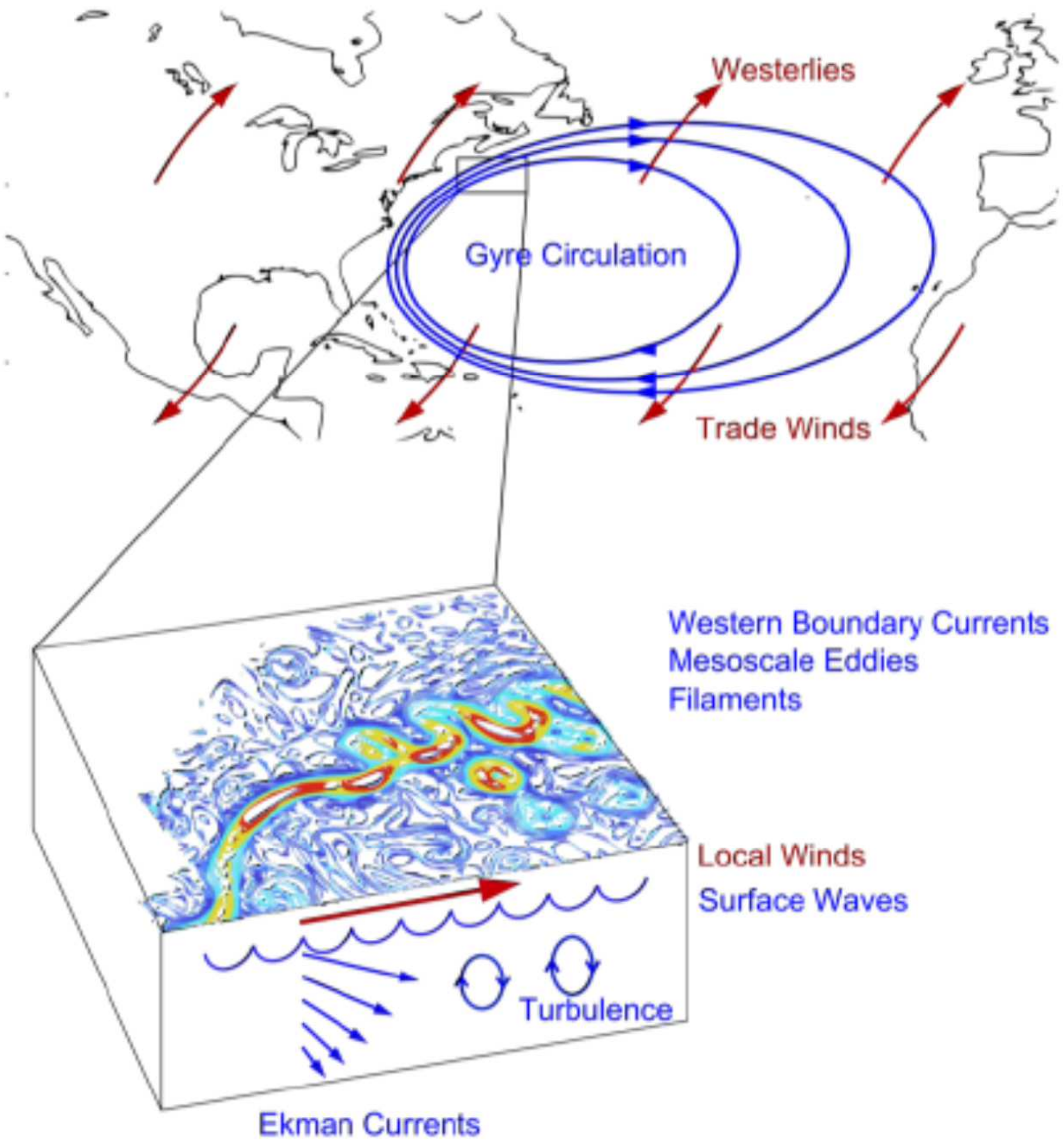
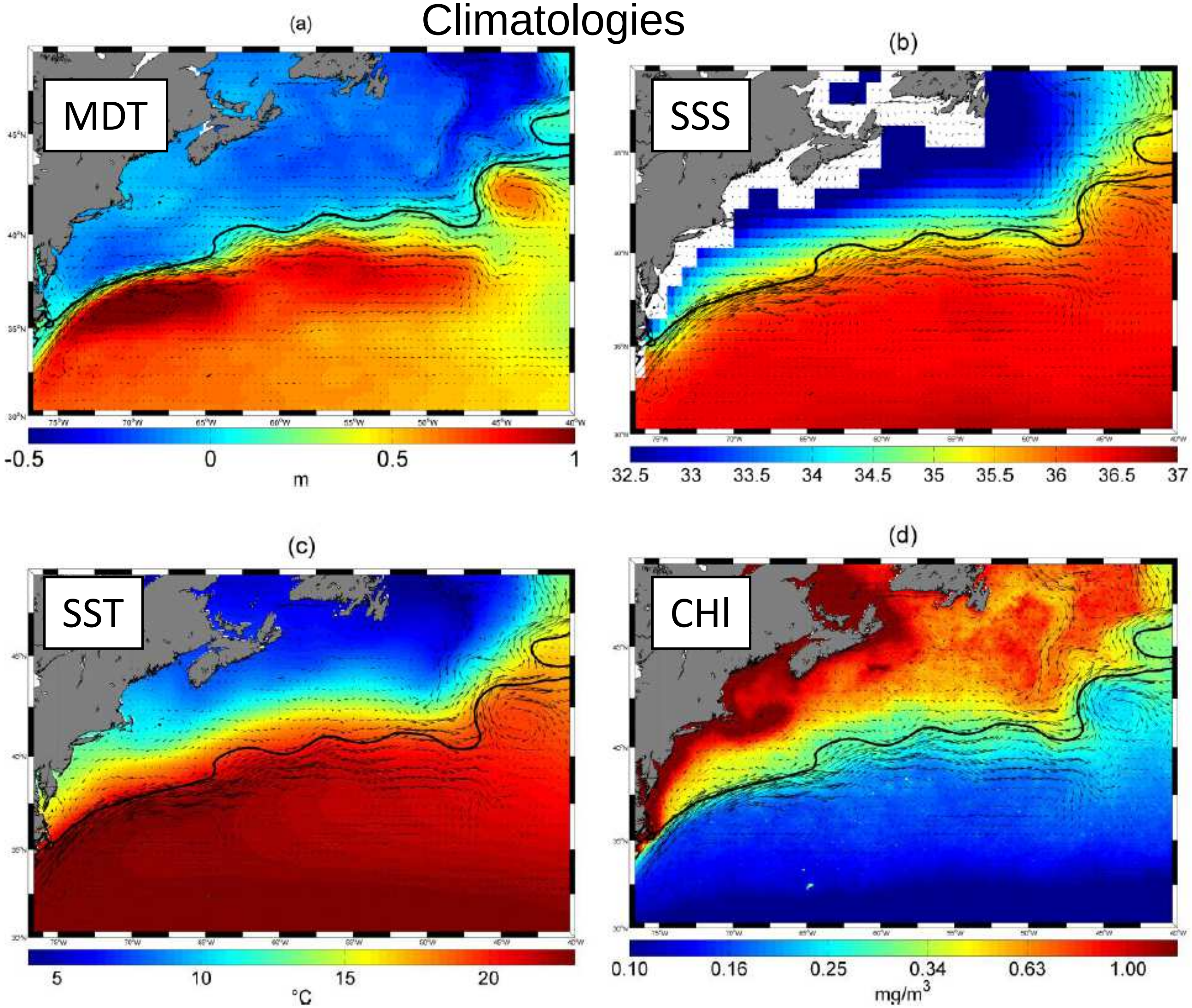


Figure 6.1: Schematic of near-surface currents focused on the western boundary current of the Gulf Stream (Image source: Kathleen Dohan (Earth and Space Research, Seattle))

Climatologies

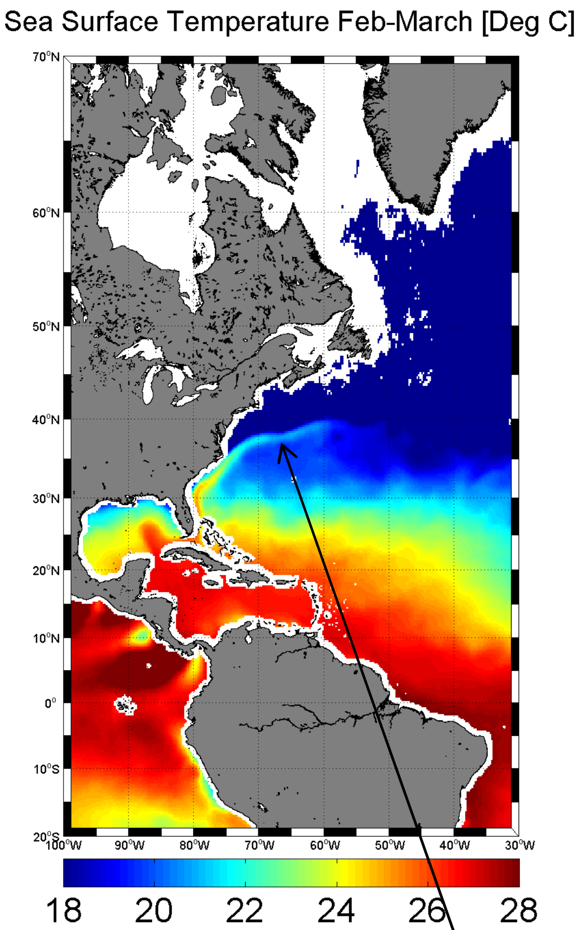


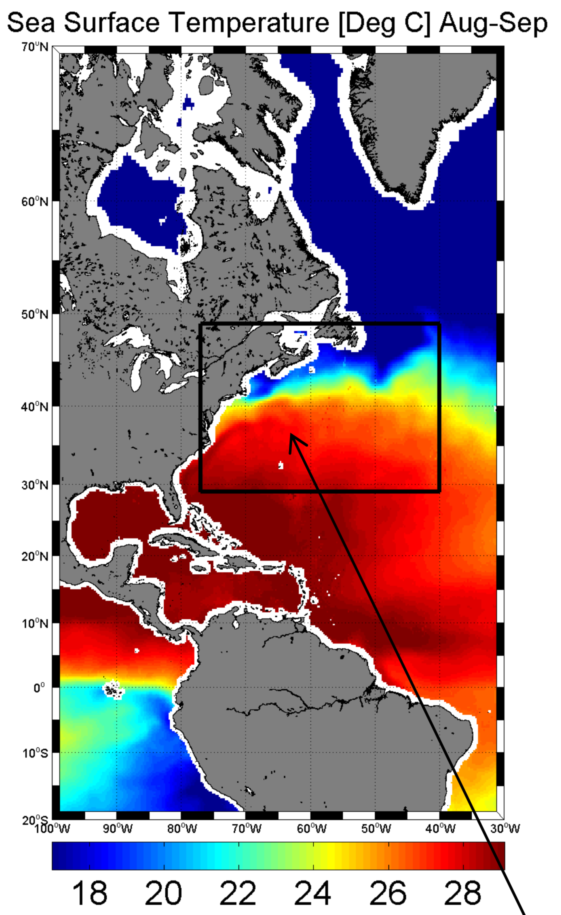
Large scale
Strong
Frontal
Boundaries
⇒SSH
⇒SSS
Zonal Gradients> 5 pss/10
⇒SST
⇒Chl

Figure 2: *Climatologies of (a) the Mean Dynamic Topography (color) and geostrophic currents (arrows) (Rio, 2009); (b) World Ocean Atlas SSS; (c) Pathfinder SST (Casey) and (d) SeaWIFS 1997-2007 Chlorophyll. The black curve extending across the North Atlantic is the separating streamline estimated from the steady atltimer-based streamfunction.*

smos+ sos

support to science element



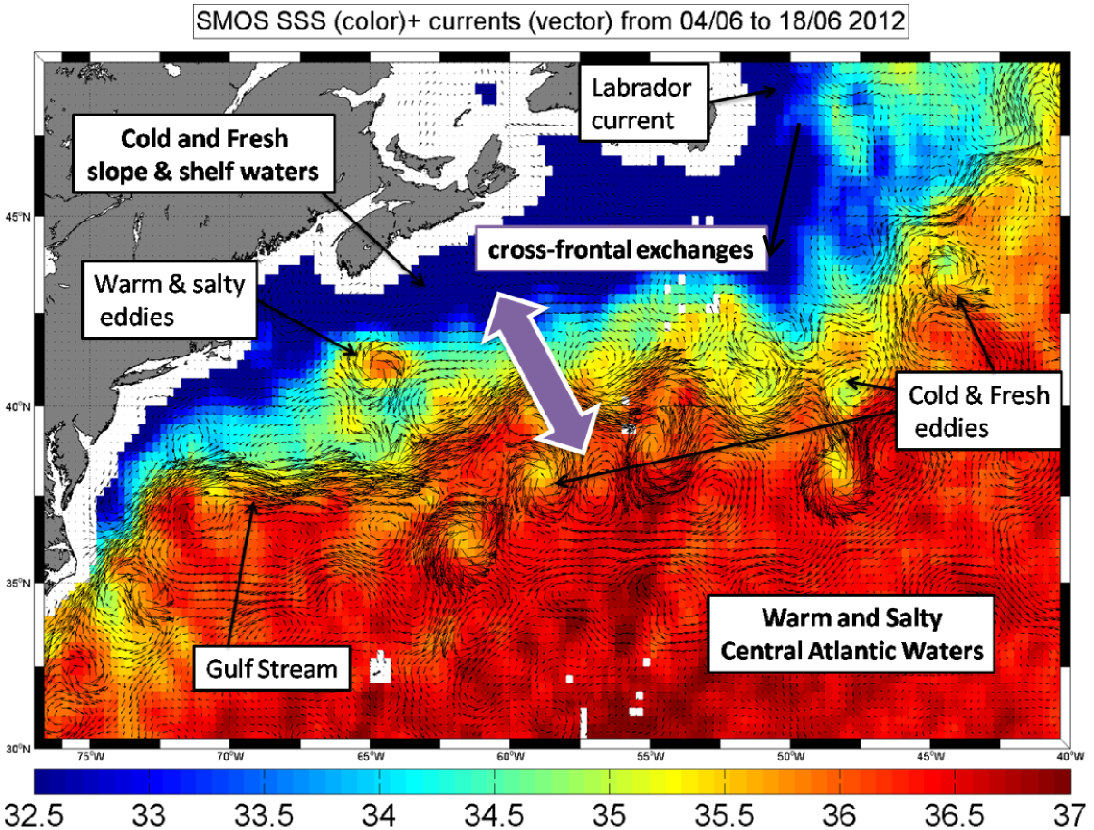


Winter: **contrasting warm tropical waters advected into the North Atlantic by the Gulf stream**

Summer : **the surface warmed up all around the Gulf stream boundaries smearing the current signal**

⇒More difficult to detect the Gulf stream path
In Summer than in Winter from thermal satellite imagery

Reul et al;
GRL, 2014



Sketch explaining the ocean circulation features in this area

Questions:

1) Is SMOS able to track Near-Surface Transport Pathways of salt in the North Atlantic Ocean ?

⇒Looking for Throughput from the Subtropical to the Subpolar Gyre

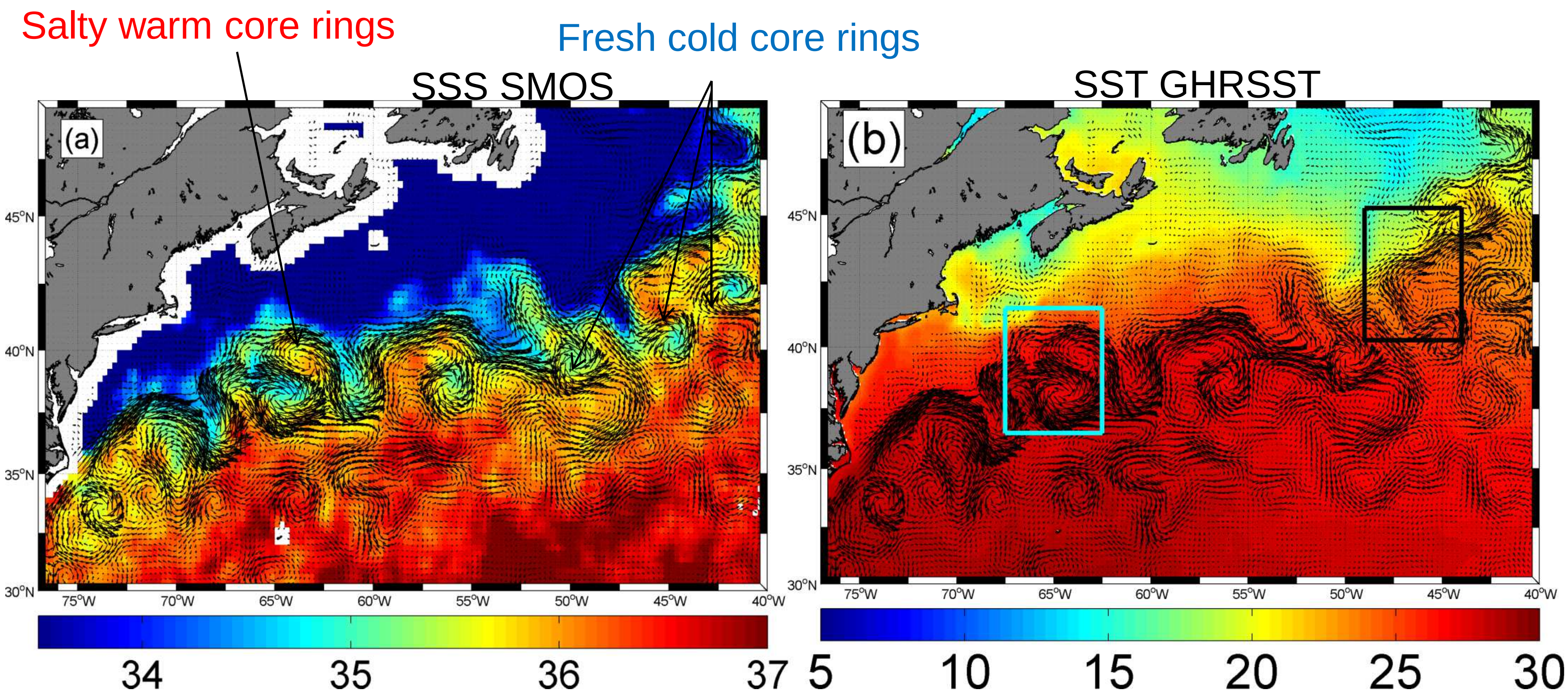
2) How SMOS data complement SST & SSH informations to better track meso-scale features and improve surface current estimates ?

3) What accuracy of SMOS products at moderate to low SSTs ?

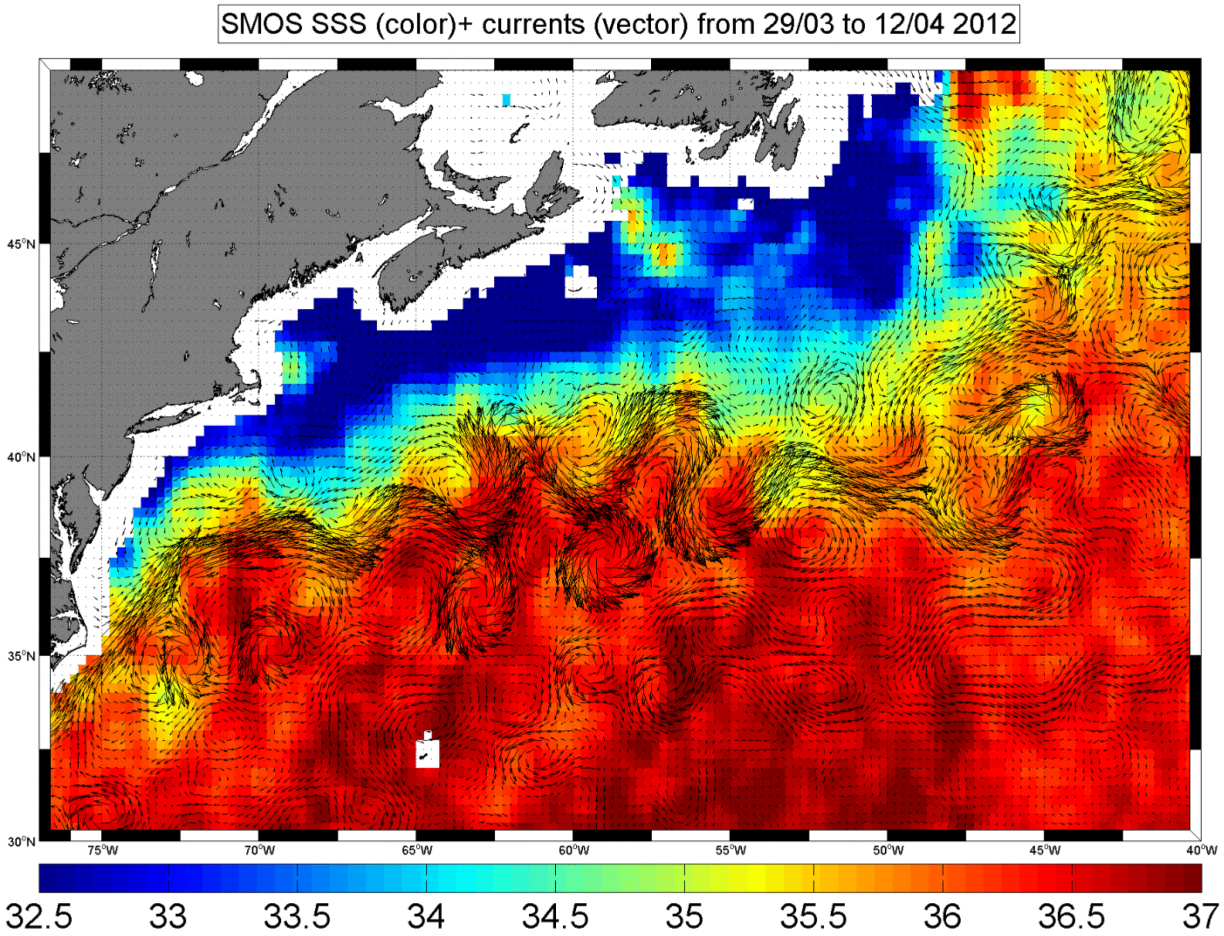
4) Can SMOS data be used to better monitor biological productivity ?

Summer signatures of SSS/SST over the gulf stream

Meso-scale structure Detection



During formation and in the early stages of their existence, Gulf Stream rings are detectable by infrared and microwave thermal satellite imagery. Young rings are revealed directly because of the cold (warm) surface water at the core and the surrounding ring of warm (cold) Gulf Stream (slope) water. However, cold-core rings that have existed throughout a summer usually are no longer evident from surface temperature observations, since the upper mixed layer has been heated by the sun.

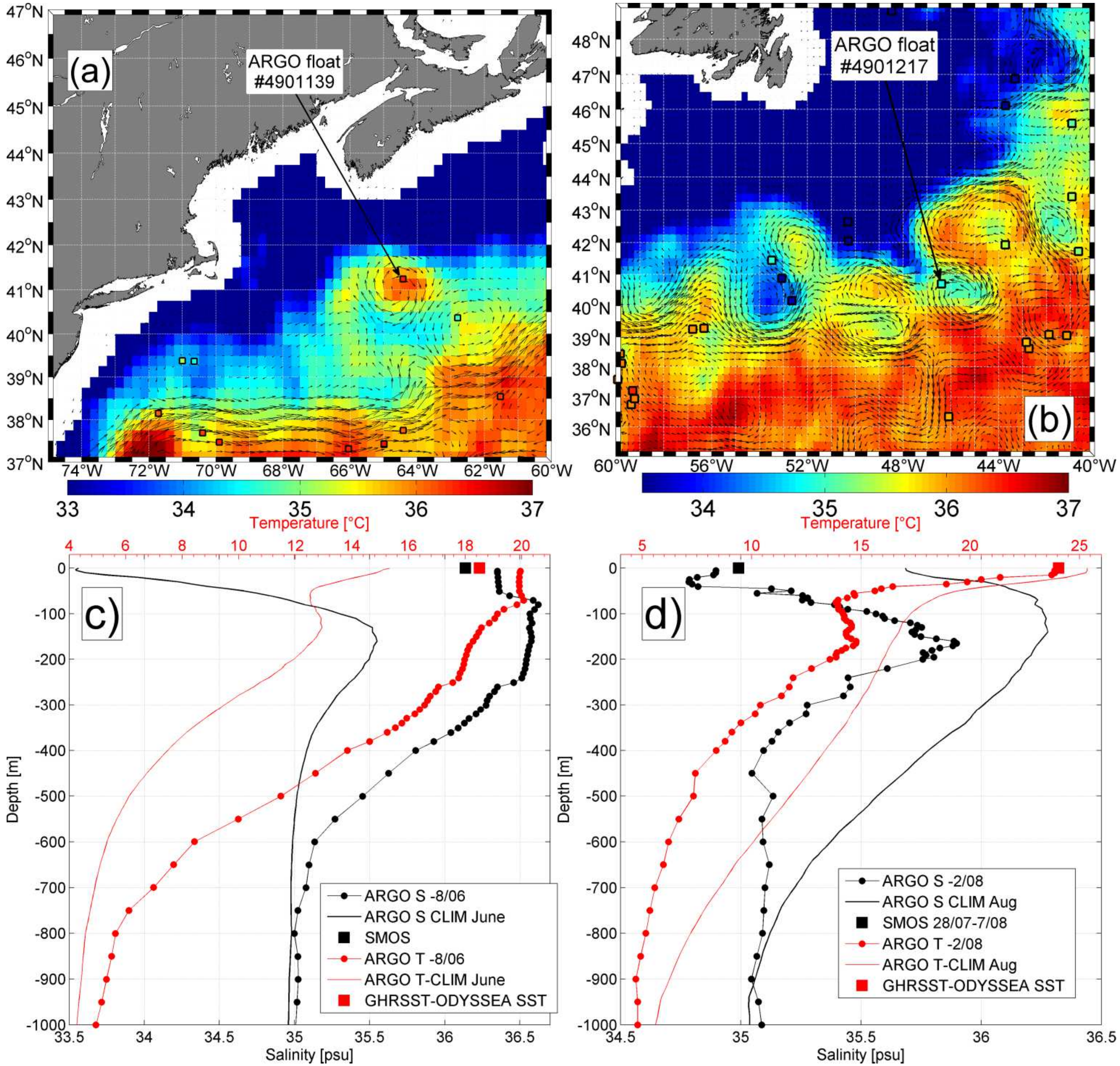


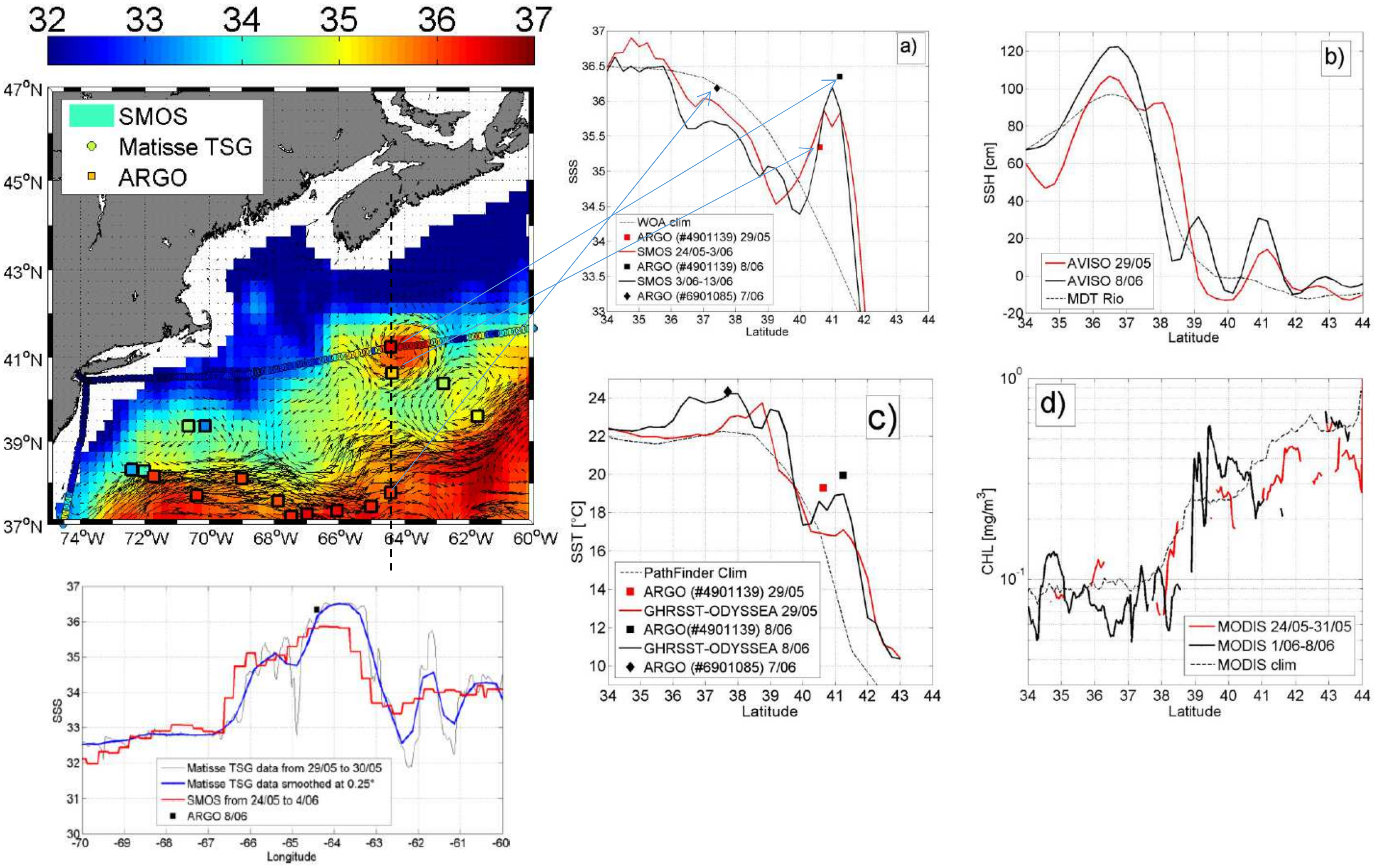
SMOS running 10-days average + OSCAR currents interpolated daily at 0.25°

Animation available at:

http://www.ifremer.fr/naiad/salinityremotesensing.ifremer.fr/gulfstream_smos.gif

SMOS versus In situ detection of the ring structures





SMOS
Matisse TSG
ARGO
a)
WOA clim
ARGO (#4901139) 29/05
SMOS 24/05-3/06
ARGO (#4901139) 8/06
SMOS 3/06-13/06
ARGO (#6901085) 7/06
SSS
Latitude
b)
AVISO 29/05
AVISO 8/06
MDT Rio
SSH [cm]
Latitude
c)
PathFinder Clim
ARGO (#4901139) 29/05
GHRSST-ODYSSEA 29/05
ARGO(#4901139) 8/06
GHRSST-ODYSSEA 8/06
ARGO (#6901085) 7/06
SST [°C]
Latitude
d)
MODIS 24/05-31/05
MODIS 1/06-8/06
MODIS clim
CHL [mg/m^3]
Latitude
Matisse TSG data from 29/05 to 30/05
Matisse TSG data smoothed at 0.25°
SMOS from 24/05 to 4/06
ARGO 8/06
SSS
Longitude

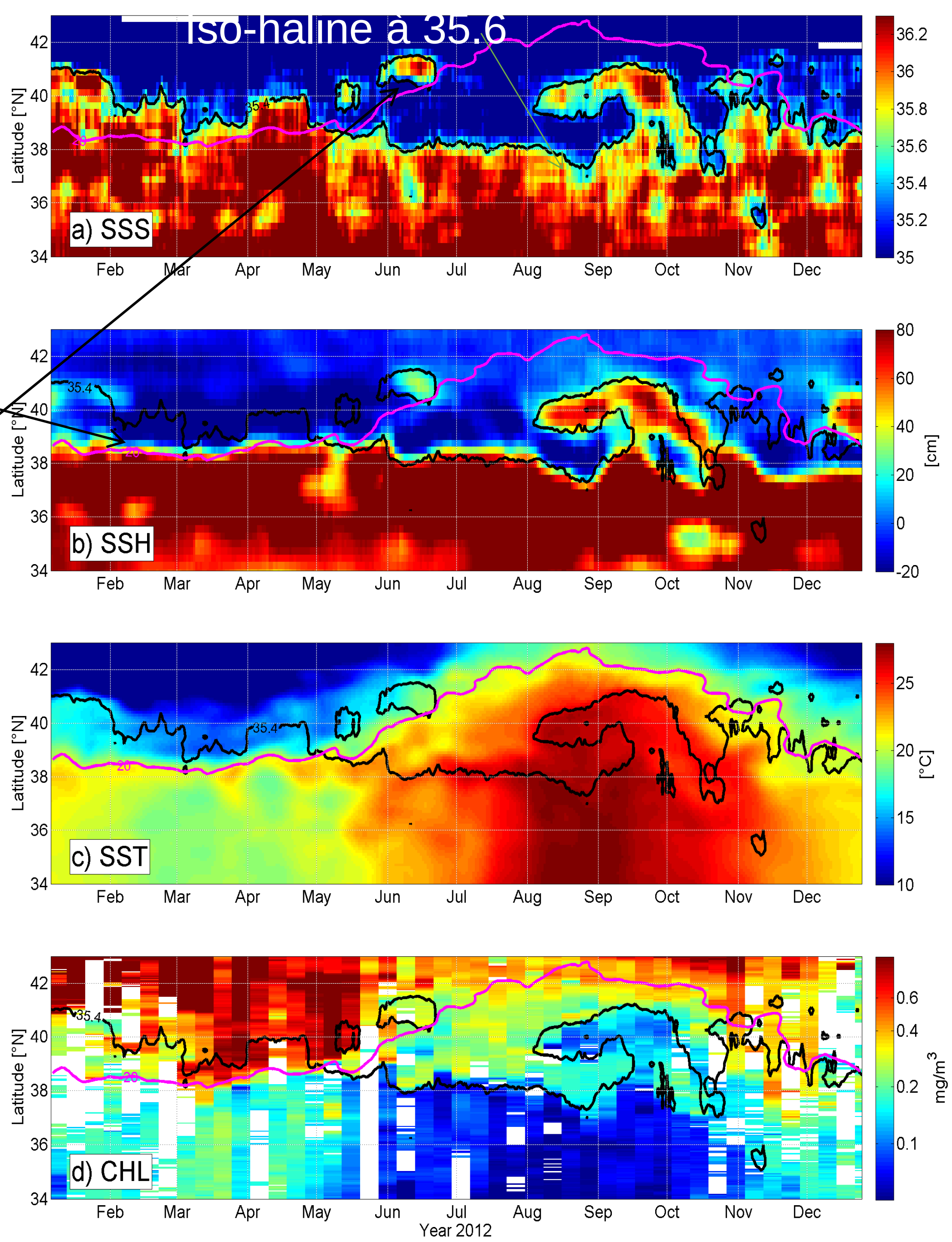
Very good consistency Between SSS & SSH, SLA patterns, particularly during 2half of the year (june-Oct)

SST better tracer of SLA than SSS from jan-May

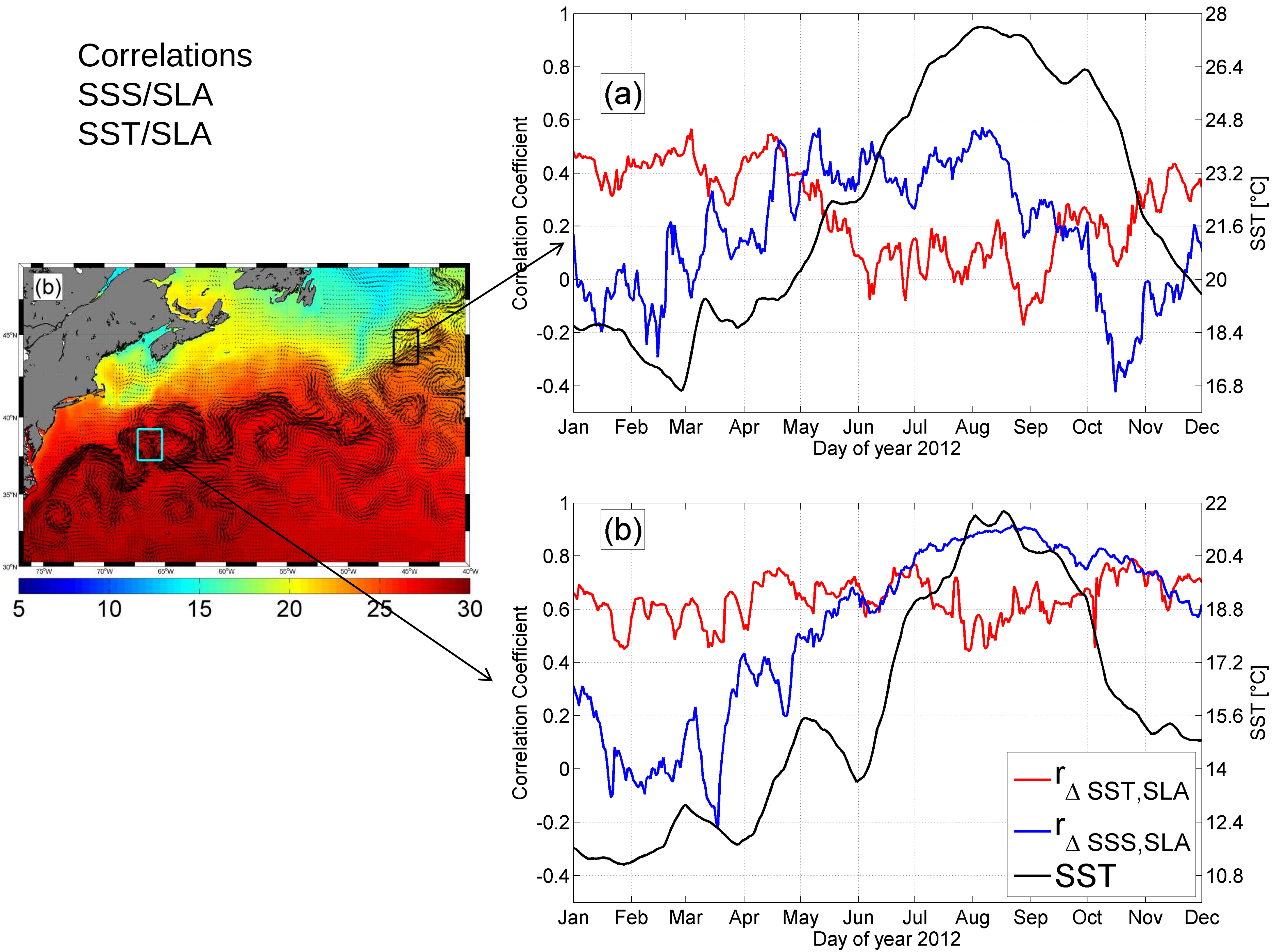
First salty eddy in June does not exhibit an apparent
Strong SST anomaly, nor a significant Chl anomaly

The spread of the chlorophyll poor waters (from the subtropical gyre) is strongly related to the north-south oscillations of the 35.6 halocline (sss > 35.6⇔ chl <0.1 mg/m3), particularly during the second half of the year

⇒The aug-oct salty eddies are Chlorophyll poor structures in a signifcantly richer environment



Correlations
SSS/SLA
SST/SLA



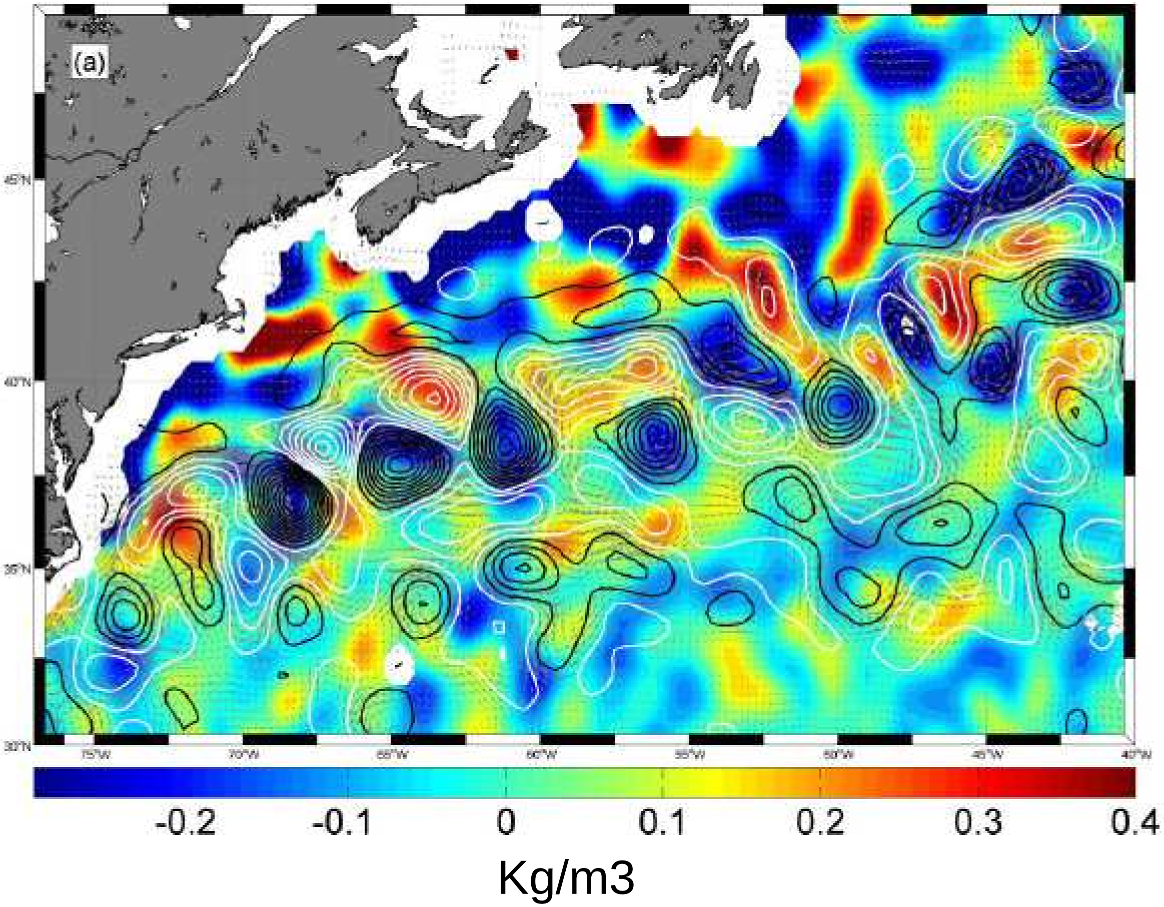
Smos SSS

SST (GHRSST)

$$\rho(S,T) = \rho_o[1 + \beta S - \alpha T]$$

Density anomay fields
(remove LF components)

+Sea Level anomalies from merged altimeter products (Aviso)



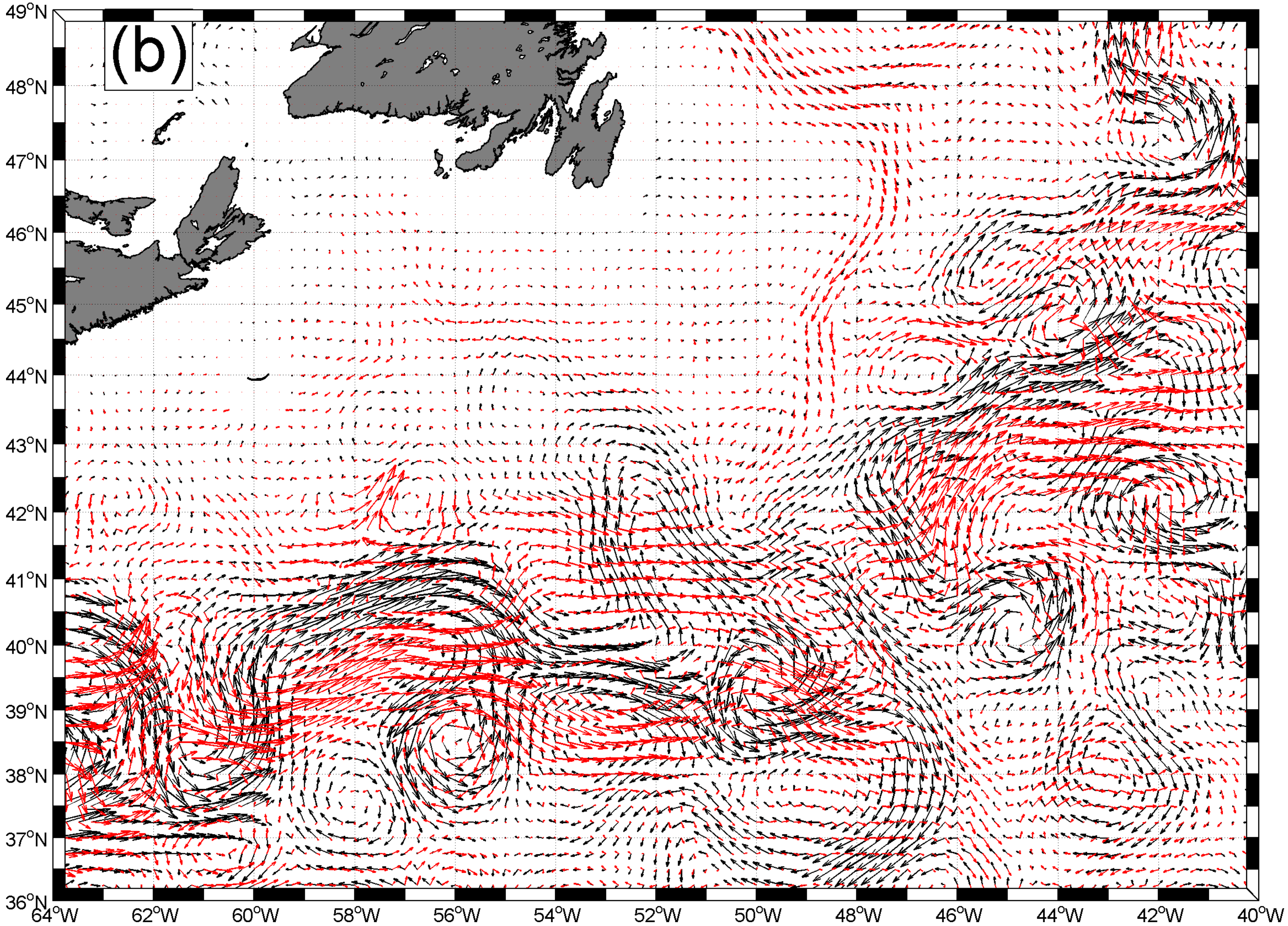
Contours:

Positive SLA (white)
Negative SLA (black)

$$\hat{\psi}_{surf}(\vec{k},z) = \frac{\hat{b}_s(\vec{k})}{Nk} exp\left(\frac{Nkz}{f_o}\right)$$

=> Retrieve surface currents from sat SSS & SST

If one assume SSS=35 and SST given by GHRSST

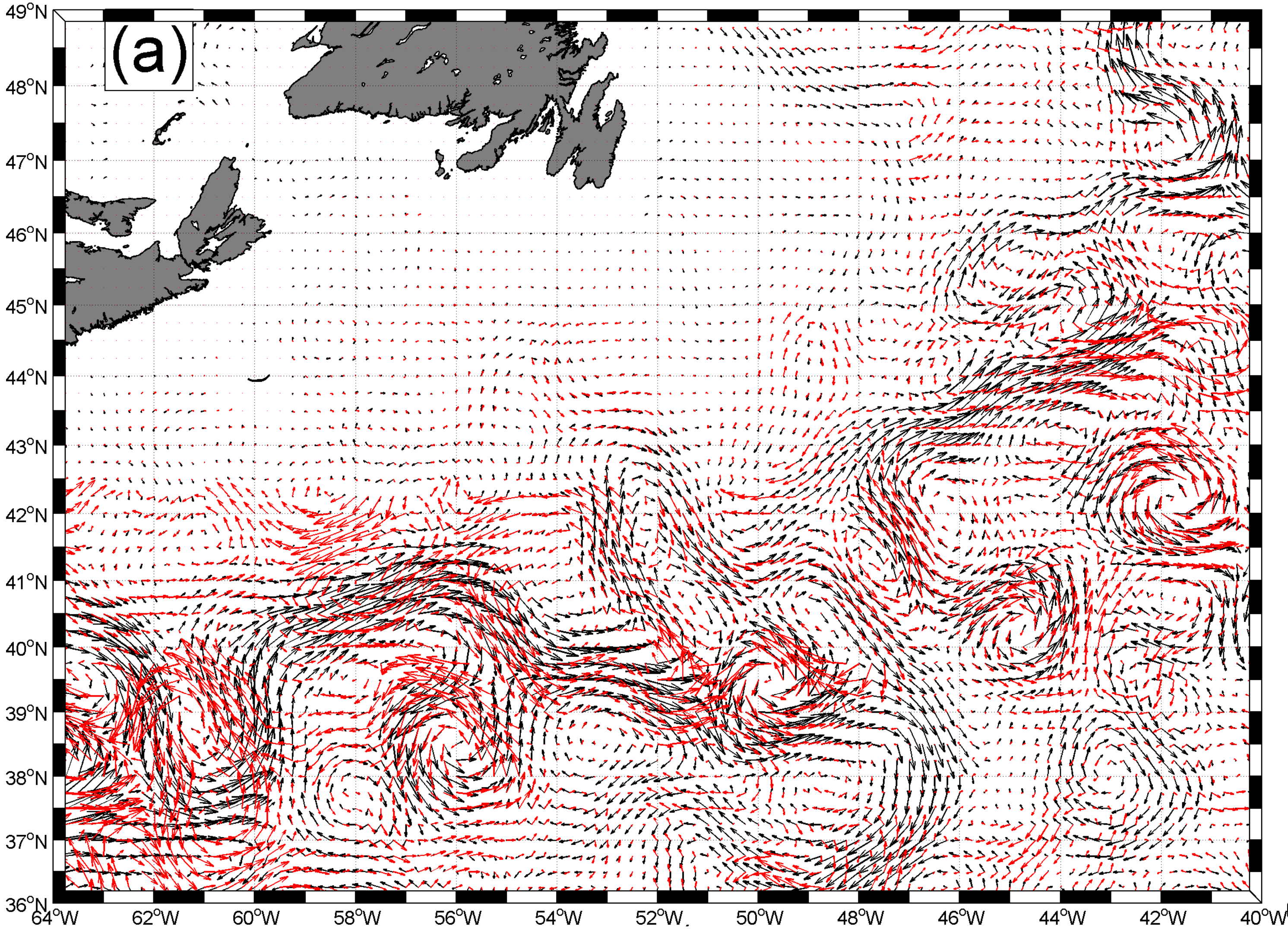


Red are currents from surface density, Black arrows are altimeter derived one

$$\hat{\psi}_{surf}\left(\vec{k},z\right)=\frac{\hat{b}_s\left(\vec{k}\right)}{Nk}exp\left(\frac{Nkz}{f_o}\right)$$

=> Retrieve surface currents from sat SSS & SST

Now with SSS from SMOS and SST given by GHRSST

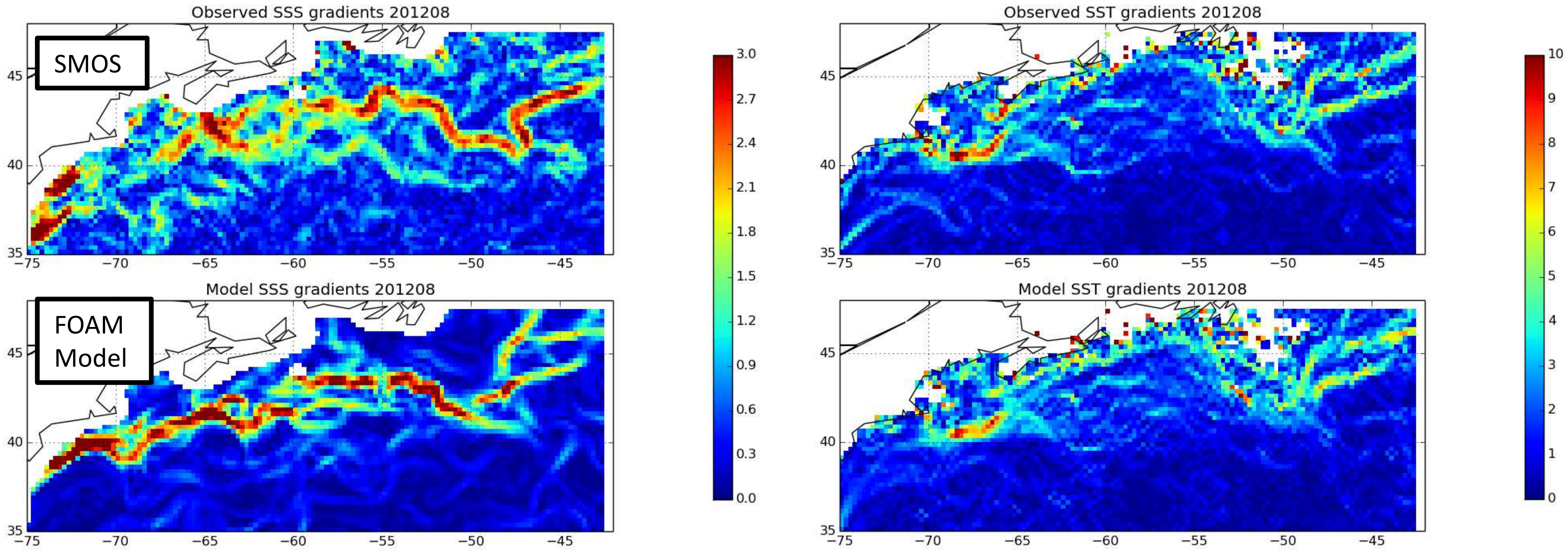


ed ones

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

SSS horizontal gradients

SST horizontal gradients

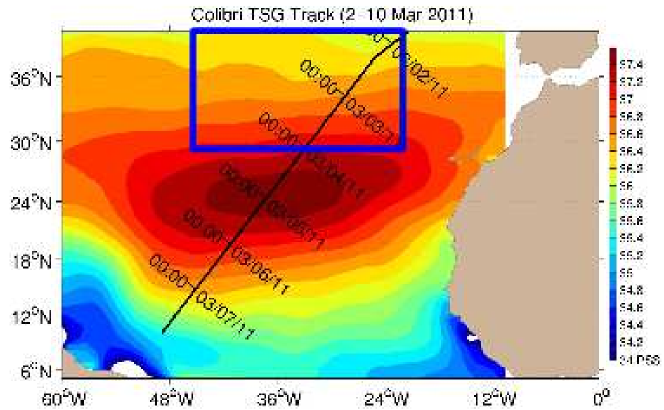


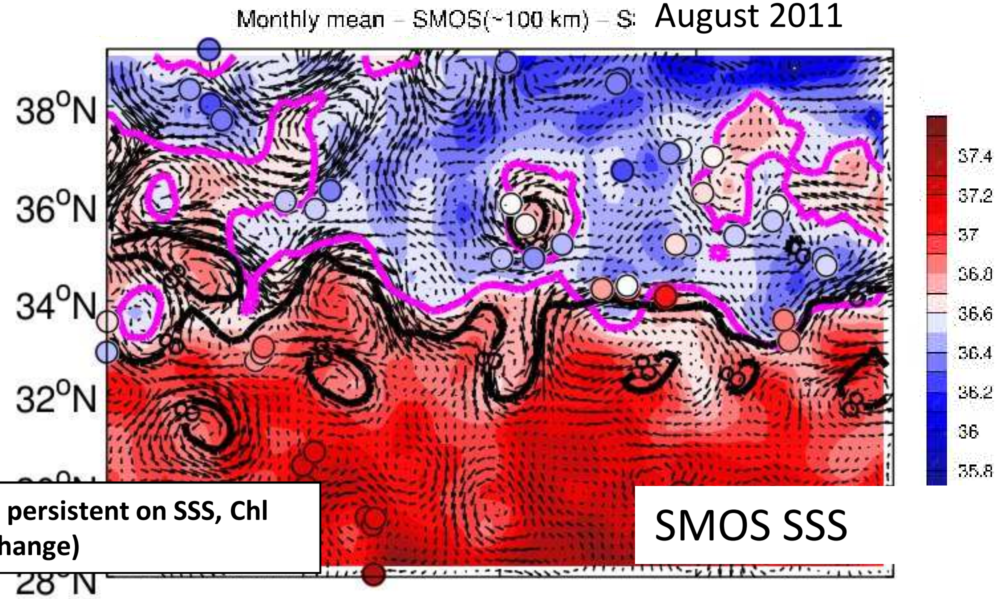
- SSS fronts agree well between model and SMOS observations
- However, SMOS data shows a frontal structure in the main part of the GS which the model doesn’t represent. Who is right ?
- Surface warming has masked the underlying structures in SST in summer, SSS comes as a natural complement to SST & SSH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

M. Martin (UK Metoffice)

Azores current/Front Example

August 2011

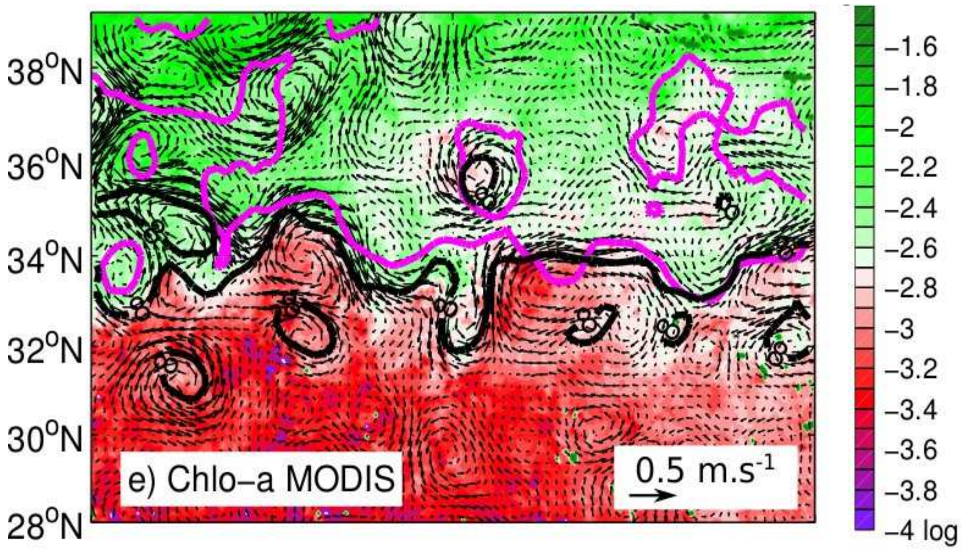


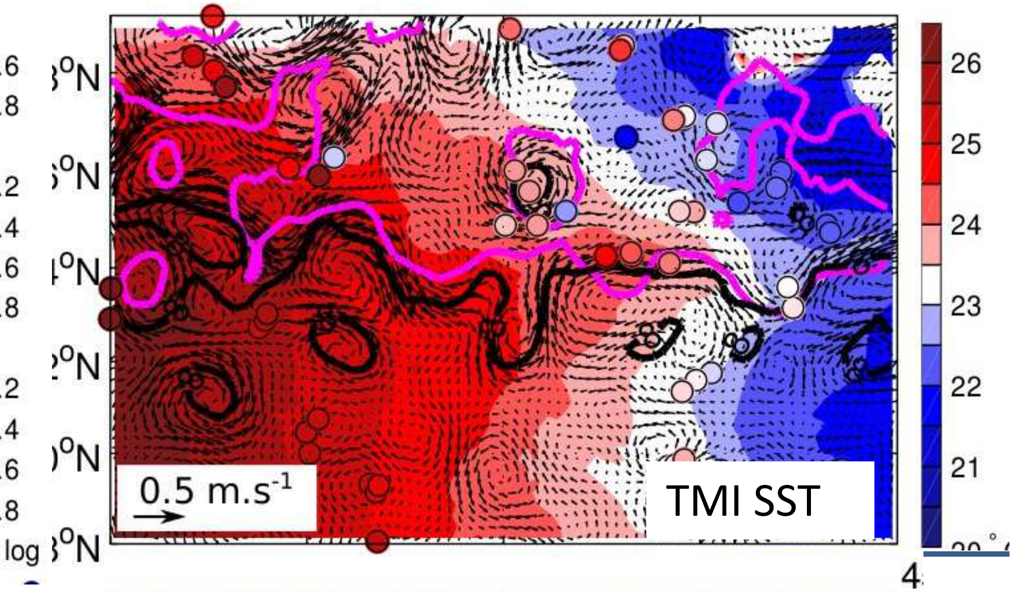


SMOS SSS

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

MODIS Chl





TMI SST

(Kolodziejczyk et al., JGR, 2014)

Isohaline 36.6

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

Conclusions & Perspectives

Surface currents are key modulators of SSS spatio-temporal variability: precise knowledge of the latter is a pre-requisit to oceanic freshwater cycle characterization

SSS (e.g. discharge from river) can act as a « passive » tracer of surface circulation

SSS, by modifying density with SST, changes the air-sea interaction to open, or, close Exchanges of horizontal properties:

large scale example were shown but higher resolution currents will certainly benefit from SSS data

SSS is less rapidly reacting to atmospheric forcing than sst, particularly in non rainy seasons (e.g. summer over the GS) => complement SST

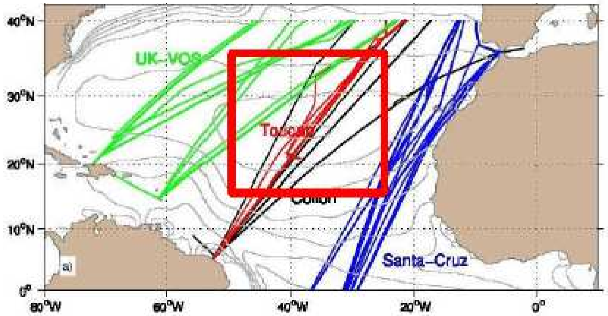
In areas and season where SSS dominates surface buoyancy, SSS can help improve Oceanic currents estimates (intermediate time sampling in between altimeter passes)

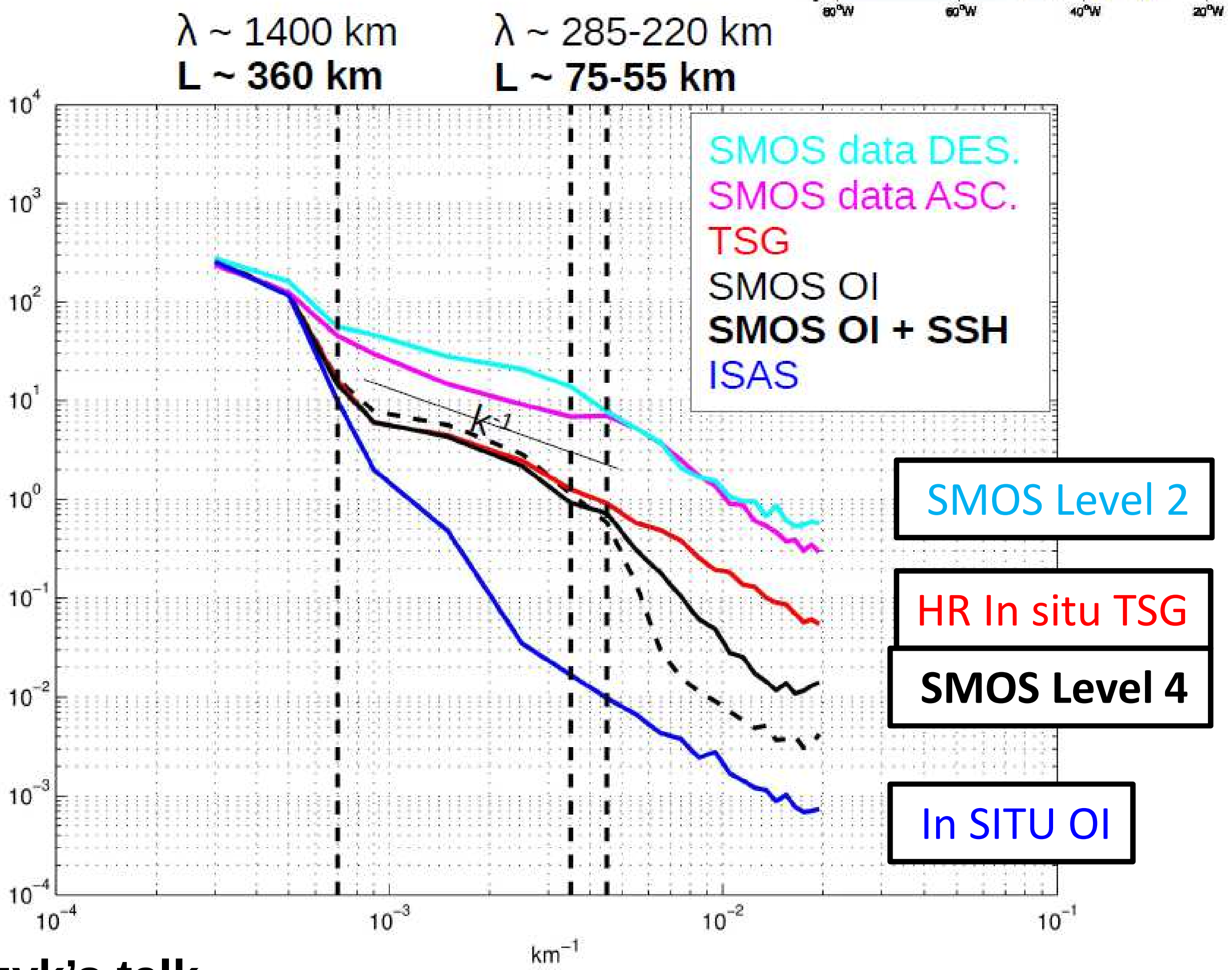
SMOS « sees » the Meso-scale SSS variability down to ~100-50 km

Comparison with TSG

→ Power Spectra

→ 32 TSG section (Colibri & Toucan)





See N. Kolodziejczyk's talk