Sea Surface Salinity Satellite Monitoring & Oceanic Circulation

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

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

- 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

(a) Aquarius SSS  Leading Term

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

At the ocean surface, the buoyancy is given by:

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

Links between surface currents, stream function and sea surface height in the geostrophic theory:

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

$$\vec{u} = \nabla \times \psi$$

$$u = -\frac{\partial \psi}{\partial y}$$
$$\nu = \frac{\partial \psi}{\partial x}$$

(1.3)

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

$$\psi_s = \frac{g}{f_o} \eta$$

(1.4)
Links between stream function (surface currents) and surface buoyancy: the SQG theory

The surface quasi-geostrophy theory

Surface Buoyancy

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

\[ \psi_s = \frac{g}{f_o} \eta \]

Current stream function

Given the relationship (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:

\[ \hat{\eta}(\vec{k}) \approx \frac{f_o}{N_b g} \hat{b}_s(\vec{k}) \]

SSH (altimetry) \quad Surface Buoyancy (SSS & SST)
Tropical FreshPool Signals
SMOS data now allow the regular monitoring of the seasonal & interannual variability in the discharge & advection of freshwater river plumes into the ocean.

Reul et al., Surv. Geophys., 2014
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): interaction 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
Stommel’s overturning gate mechanism (1993): intercation wind stress/sharp front

Soloviev et al., 2002
Eastern Pacific fresh pool (EPFP)

EPFP = Tropical surface water 
(salinity < 34)

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

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.

Alory et al, JGR, 2012
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)

EPFP = Tropical surface water
(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 **Zonal wind stress** (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 interannual variability?
Physical mechanism: mean \textbf{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

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:

\[ \frac{\text{SSS}(t) - \langle \text{SSS} \rangle}{\text{std} (\text{SSS})} \]

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

Yin et al., JGR 2014

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

SMOS SSS signal of Tropical Instability Waves

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))
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 altimeter-based streamfunction.
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
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?
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
Very good consistency between SSS & SSH, SLA patterns, particularly during 2 half 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 ($\text{sss} > 35.6 \Leftrightarrow \text{chl} < 0.1 \text{mg/m}^3$), particularly during the second half of the year

⇒ The aug-oct salty eddies are Chlorophyll poor structures in a significantly richer environment
Correlations
SSS/SLA
SST/SLA
\[ \rho(S,T) = \rho_o [1 + \beta S - \alpha T] \]

Smos SSS SST (GHRSSST)

Density anomaly fields (remove LF components)

+Sea Level anomalies from merged altimeter products (Aviso)

Contours:
Positive SLA (white)
Negative SLA (black)
\[ \hat{\psi}_{\text{surf}}(k, z) = \frac{\hat{b}_s(k)}{Nk} \exp \left( \frac{N k z}{f_o} \right) \]

\( \Rightarrow \) Retrieve surface currents from sat SSS & SST

If one assume SSS=35 and SST given by GHRSSST

Red are currents from surface density, Black arrows are altimeter derived ones
\[ \widehat{\psi}_{\text{surf}}(\vec{k},z) = \frac{b_s(\vec{k})}{Nk} \exp \left( \frac{Nkz}{f_0} \right) \]

\[ \Rightarrow \text{Retrieve surface currents from sat SSS & SST} \]

Now with SSS from SMOS and SST given by GHRSSST.
• 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)
In summer, eddy signature persistent on SSS, Chl but not on SST (air-sea exchange)

(Kolodziejczyk et al., JGR, 2014)
Conclusions & Perspectives

Surface currents are key modulators of SSS spatio-temporal variability: precise knowledge of the latter is a pre-requisite 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