frontiers in Marine Science

REVIEW
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# Satellite Salinity Observing System: Recent Discoveries and the Way Forward

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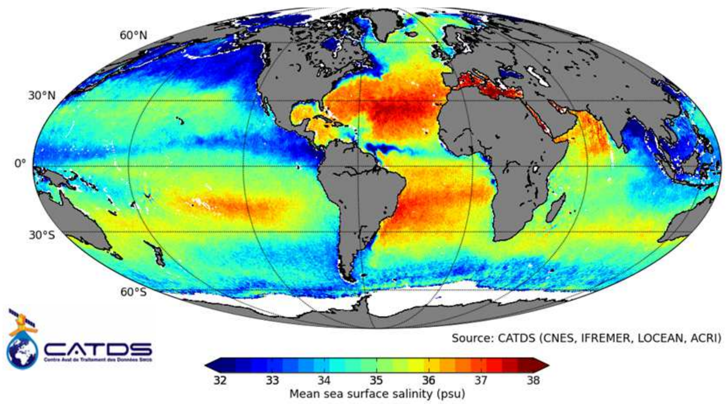
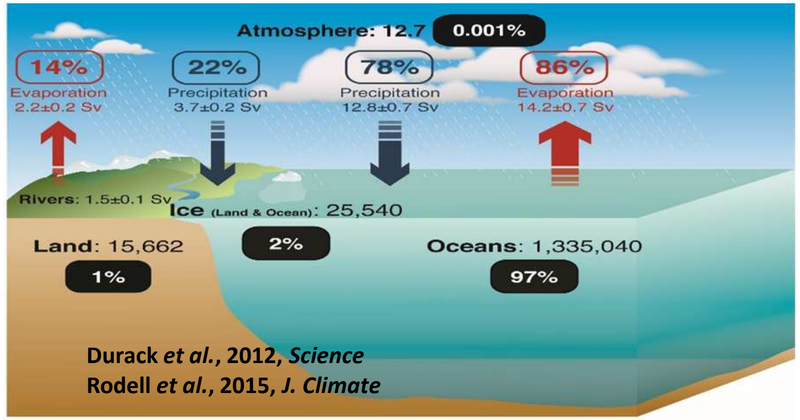
Contributions by the french community

SMOS SSS Septembre 2017



# Why measuring sea surface salinity?
# 1- A tracer of freshwater fluxes

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




Reservoirs represented by solid boxes: $10^3$ km$^3$, fluxes represented by arrows: Sverdrups ($10^6$ m$^3$ s$^{-1}$)
Sources: Baumgartner & Reichel, 1975; Schmitt, 1995; Trenberth et al., 2007; Schanze et al., 2010; Steffen et al., 2010; Rodell et al., 2015

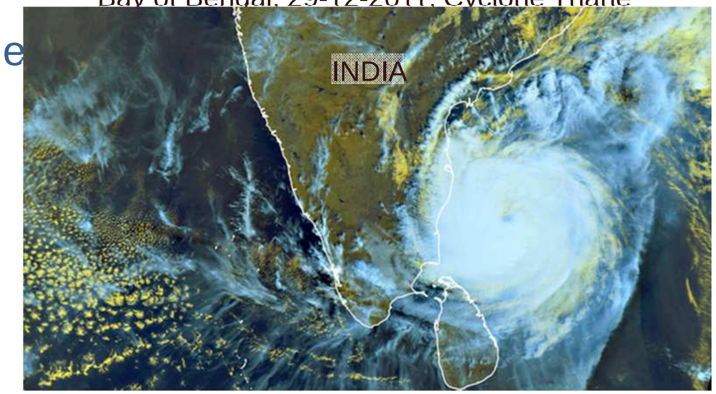
# 2- A strong influence on sea water density & Air-sea exchanges

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

In the tropics (SST=28$^{o}$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



# Salinity from space using L-band radiometry

**SMOS**
Soil Moisture and Ocean Salinity

ESA Earth Explorer (CNES PROTEUS platform)

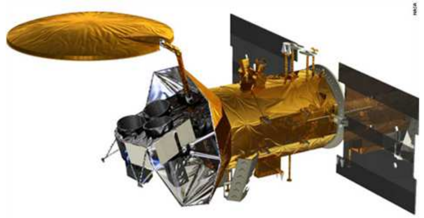
The first Interferometer for earth observation!

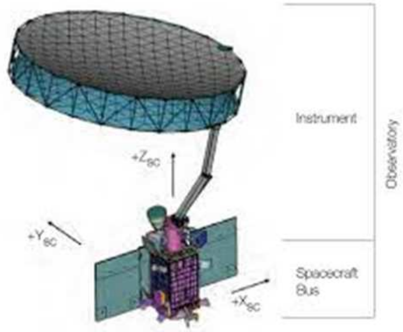
~43km resolution/ 3 day global coverage

**Aquarius**
Argentina-USA collaboration (CONAE/NASA)

3 radiometers + 1 scatterometer

~150 km resolution/ 7 day global coverage






**SMAP**
Soil Moisture ~~Active~~ Passive (NASA)

Radiometer

~40km resolution / 3 day global coverage

SMOS 10 years soon…

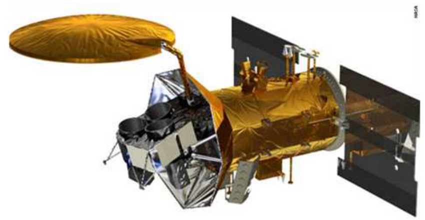
Aquarius Almost 4 years

SMAP 4 years

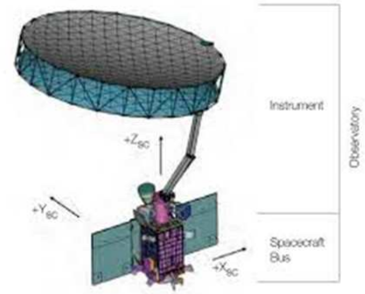
2010-01-01 2011-08-25 2015-04-04 2015-06-07

# Salinity from space using L-band radiometry

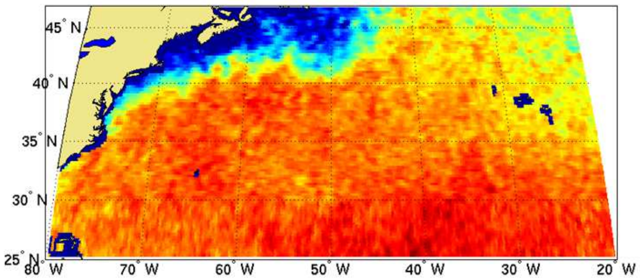
**SMOS**
Soil Moisture and Ocean Salinity
~50km resolution/ 7 day map

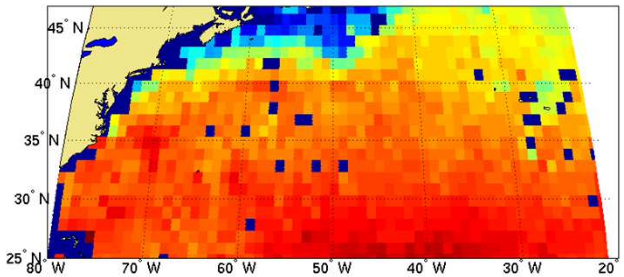


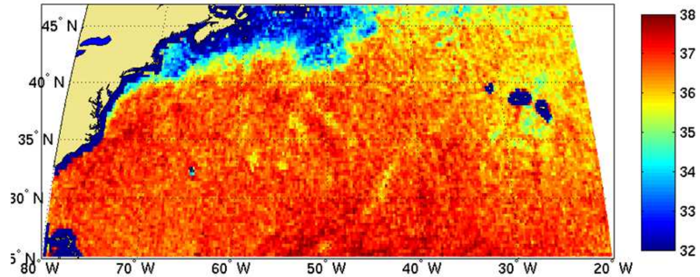
**Aquarius**
~150 km resolution/ 7 day map

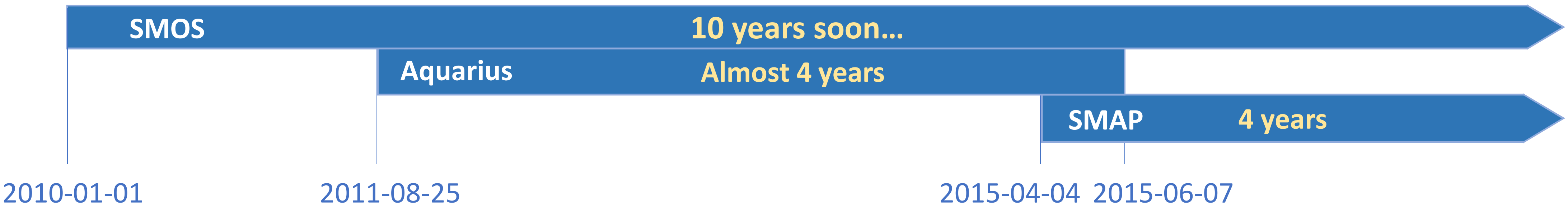



**SMAP**
Soil Moisture ~~Active~~ Passive (NASA)
~40km resolution / 7 day map



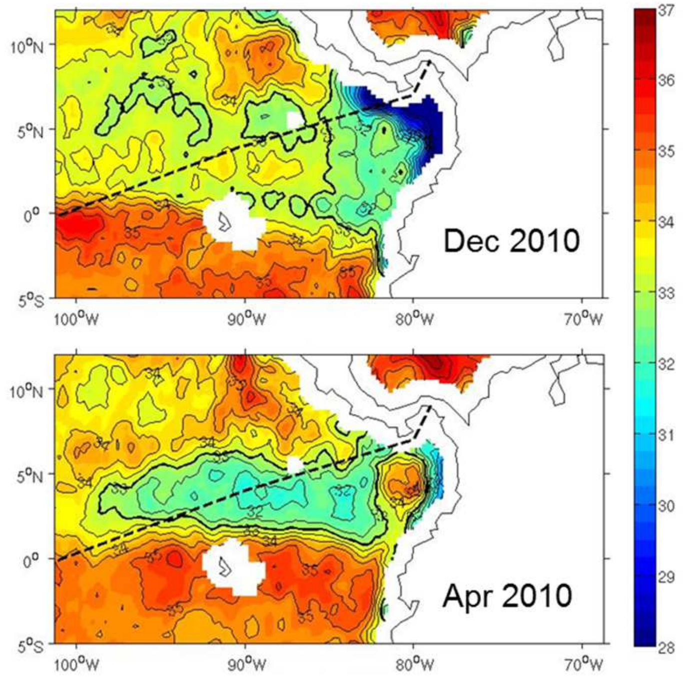
# SCIENTIFIC DRIVERS FOR SATELLITE SALINITY

- **IMPROVING KNOWLEDGE OF OCEAN CIRCULATION AND CLIMATE VARIABILITY**
- **OPENING THE WINDOW TO BETTER UNDERSTAND EARTH'S WATER CYCLE**
- **NEW OPPORTUNITIES IN MESOSCALE OCEANOGRAPHY**
- **SPACE-BASED OCEAN BIOGEOCHEMISTRY**

# Improving Knowledge of Ocean Circulation and Climate Variability:

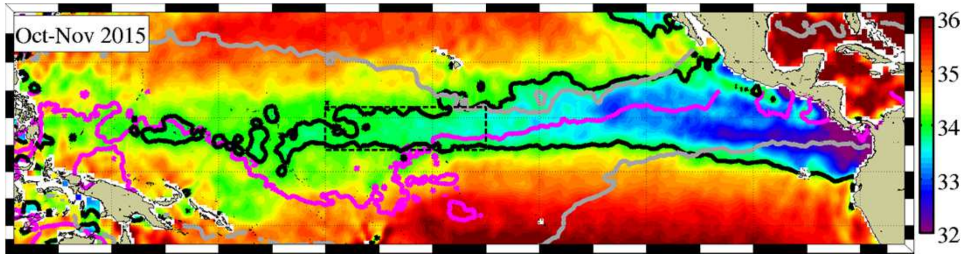
*New insight enabled by satellite SSS is the relationship between the largescale tropical fresh pools in the tropical Pacific with ENSO induced precipitation and oceanic transport associated with*

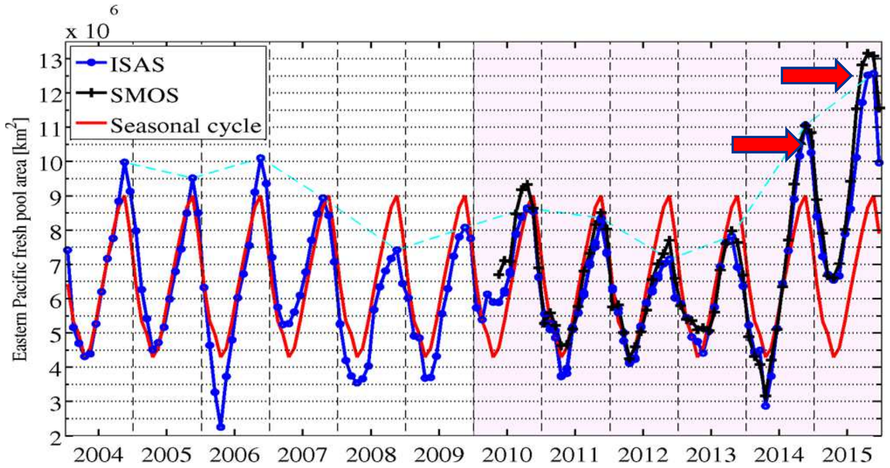
Fresh pool (eastern Pacific)




*Alory et al. 2012*

Larger extension of fresh salinities in the N tropical Pacific in 2015




*Brown et al 2015:*
*New insights of carbon parameters variability*
*Opposite effects of upwelling and dilution on pCO2*

Area of the East Pacific Tropical Fresh pool (SSS<34)
Nearly x 2 -3 during El-Nino 2014/2015

Guimbard et al. 2017

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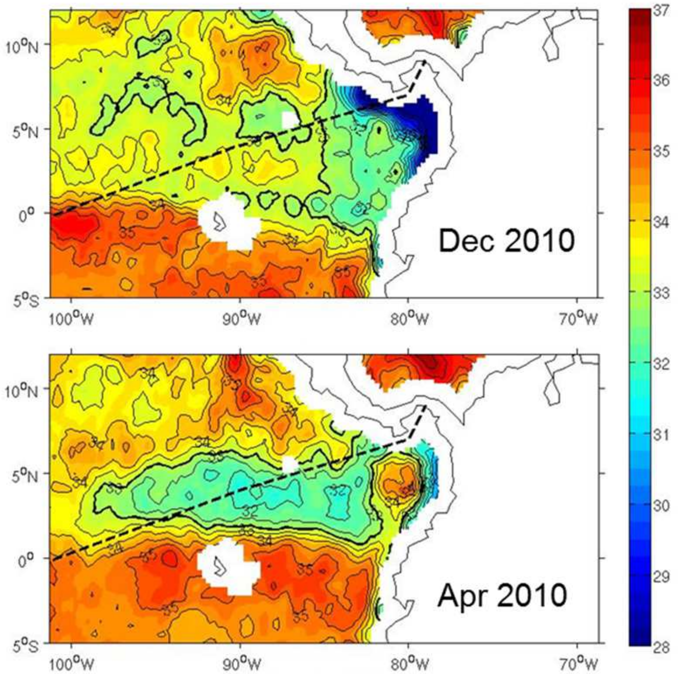


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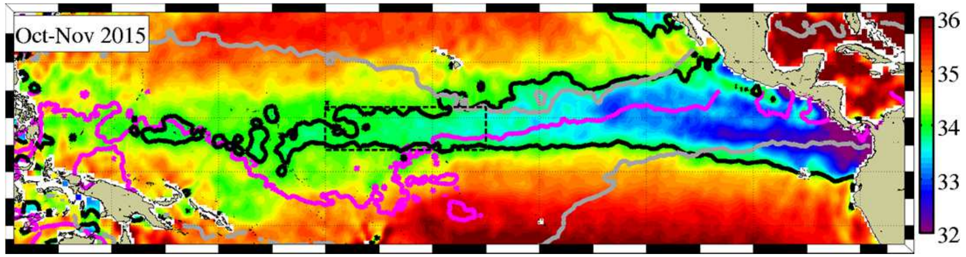
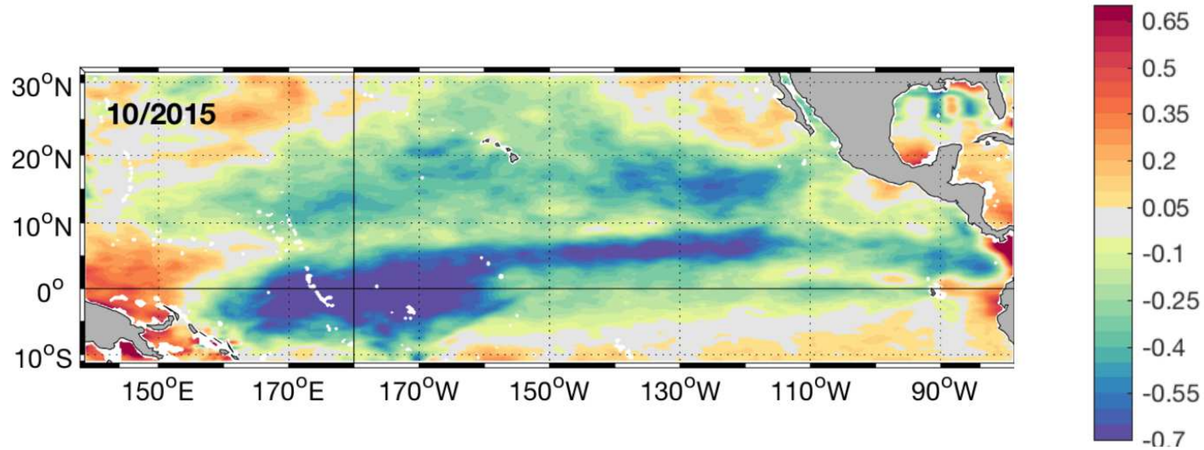



Sea surface salinity anomaly as a result of strong fresh water input (2014-2015) and surface current advection

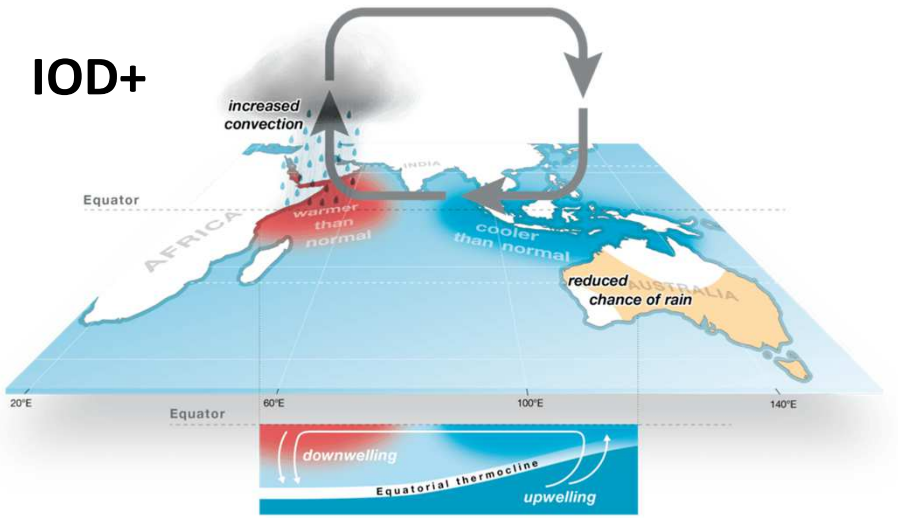
*Hasson et al. 2018*

# IMPROVING KNOWLEDGE OF OCEAN CIRCULATION AND CLIMATE VARIABILITY:

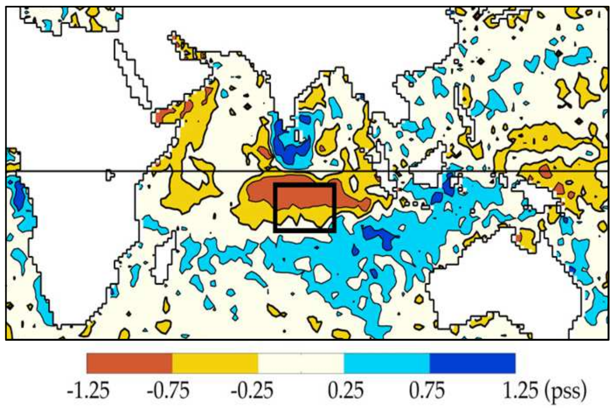
*help to characterize the structure of the Indian Ocean Dipole (IOD) (Durand et al., 2013)*

SSS signature of the Indian Ocean Dipole *('The El Niño of the Indian Ocean')*

**IOD+**



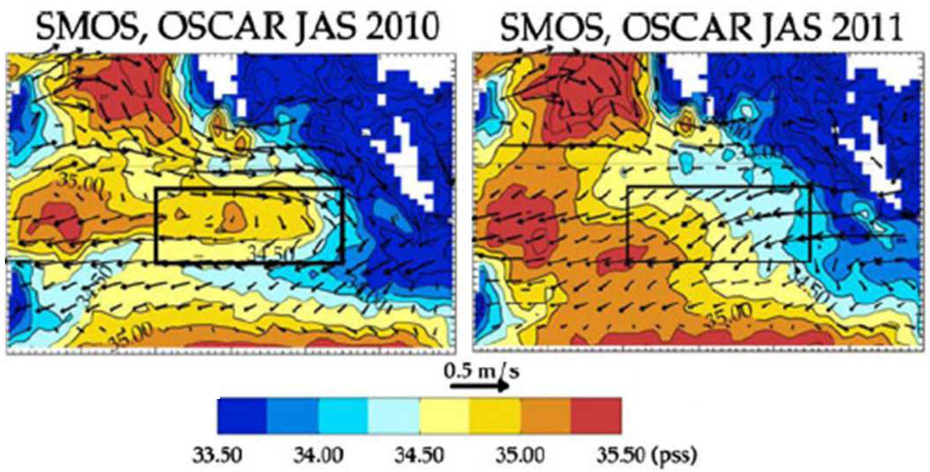

**SMOS Dec 2010 (IOD-) – Dec 2011 (IOD+)**




**Advection dominates**

Durand et al. (2013)

IOD-

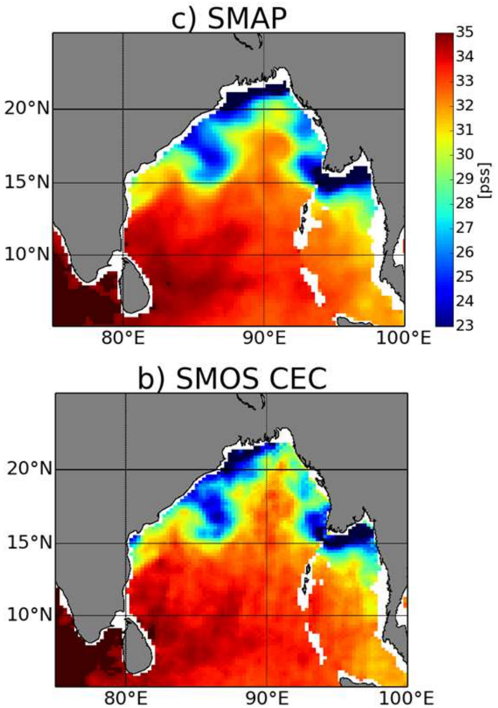



IOD+

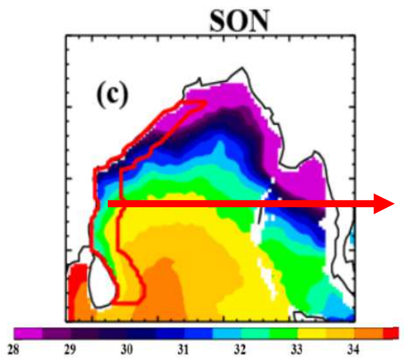
*Connecting the terrestrial and marine water reservoirs, with an aim to close the global balance of water fluxes and flows.*

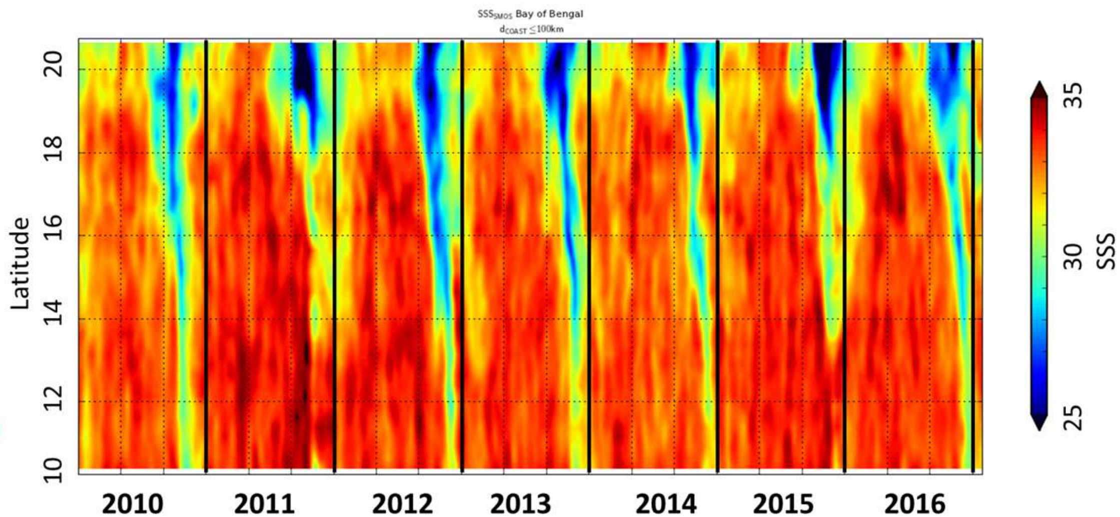
# Bay of Bengale: 'the river in the sea'

Gange + Brahmaputra => The 'river in the sea' Seen by SMOS




*Boutin et al. 2018*




*Akhil, Vialard et al, in prep.*

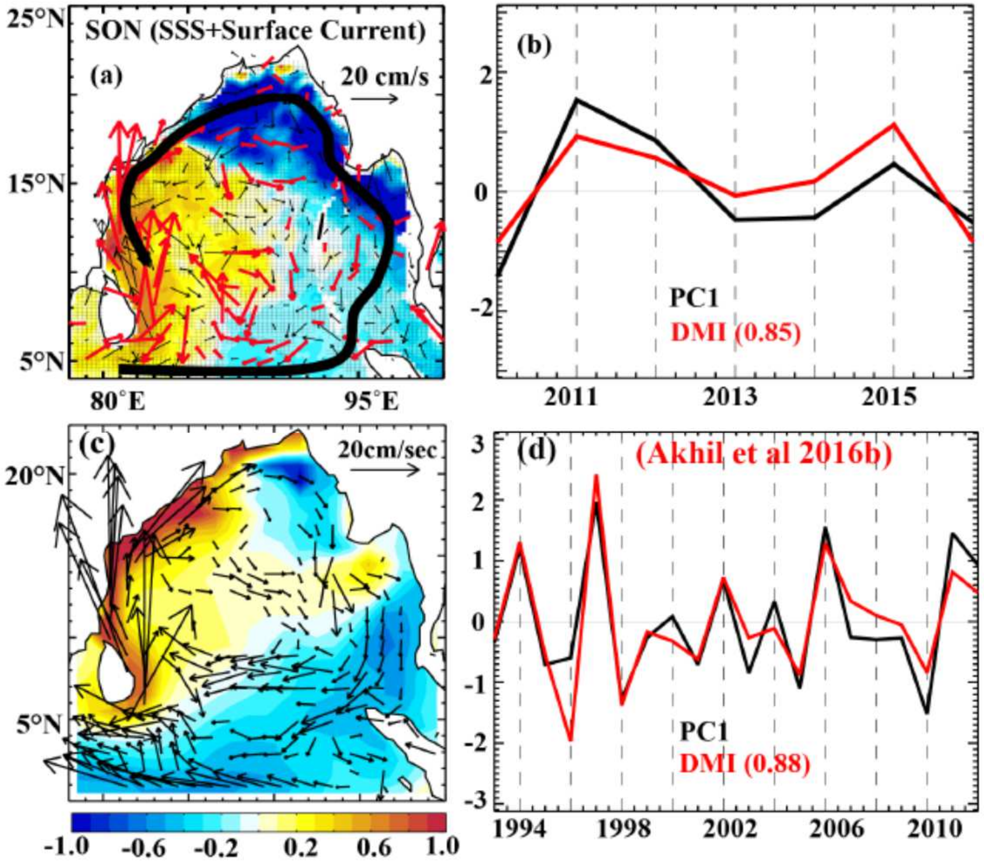
# Bay of Bengale: 'the river in the sea'

Gange + Brahmaputra => The 'river in the sea' Seen by SMOS

INTERANNUAL VARIABILITY

**SMOS**

**Model**




Consistent leading pattern of interannual SSS variability associated with the IOD

**Driving processes**

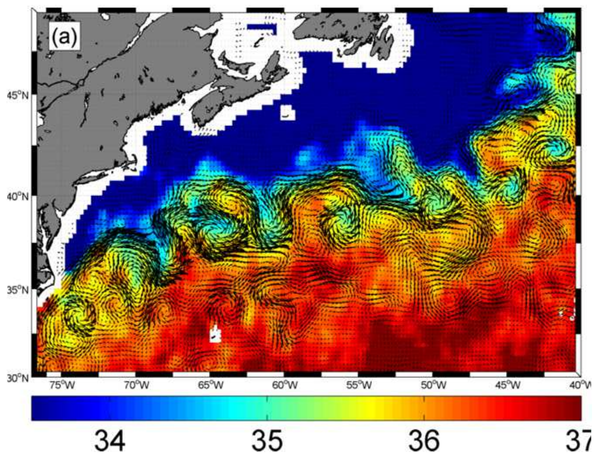
**IOD+➔ equatorial easterlies ➔ Equatorial downwelling Kelvin wave ➔ Coastal downwelling Kelvin wave ➔ weaker EICC ➔ Ganges plume extends less southward ➔ SSS' > 0**

*Akhil, Vialard et al. , in prep*

# New Opportunities in Mesoscale Oceanography:

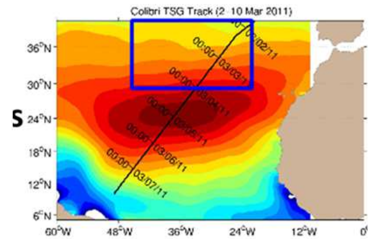
***A tremendous advantage of satellite SSS observations is their synoptic view of oceanic mesoscale haline features associated with fronts and eddies** .The capability to systematically sample 40– 100 km scales every 4 days is unachievable by other salinity observing platforms.*
*Redefinition of **the role of salinity in density variability, thermohaline circulation, and in the energy balance of the upper ocean**.*

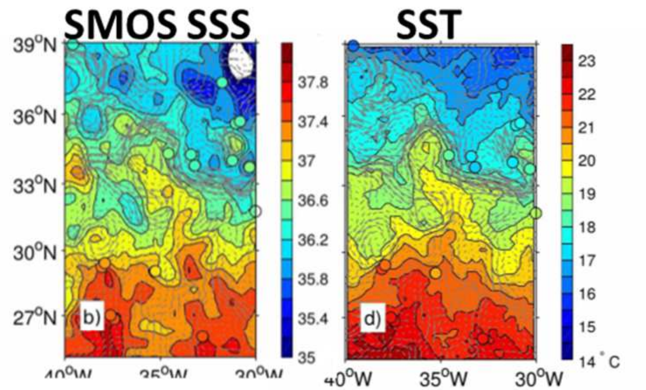
▪**SSS structure of the Gulf Stream** with an unprecedented space and time resolution




*Reul et al. 2014*

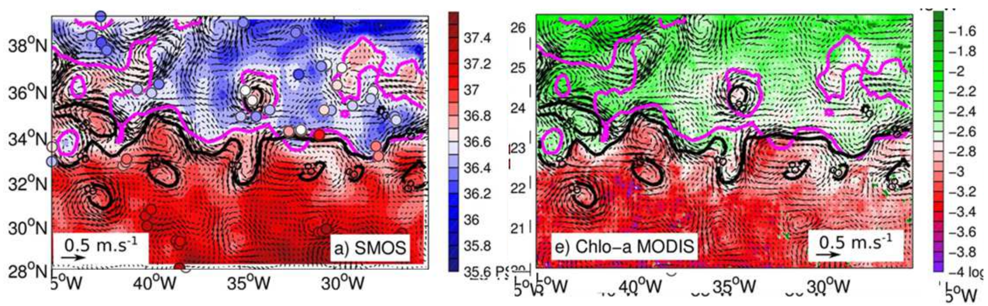
**End of winter in the Azores Front/current – Temperature-salinity compensated structures**




*Kolodziejczyk et al. 2015*

**In Summer, S and Chl structures very similar**

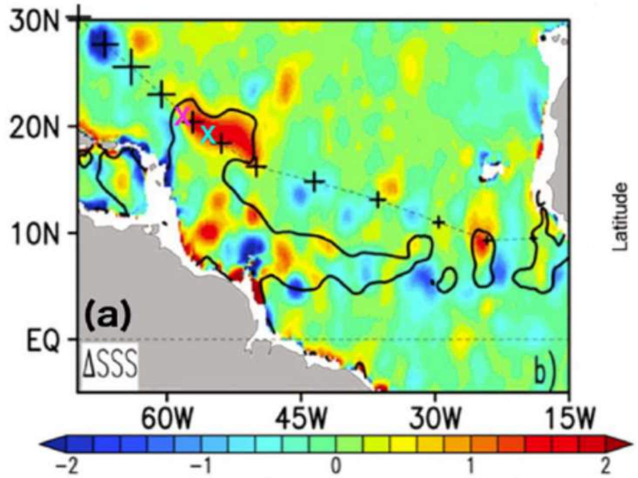


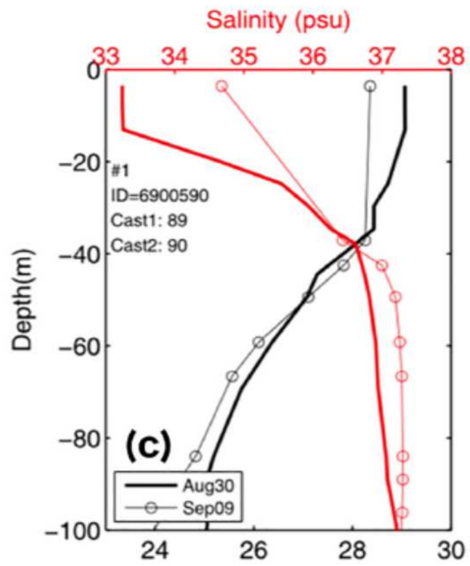
# APPLICATION DRIVERS FOR SATELLITE SALINITY

- **Hurricane Monitoring**
- **Inferring Rainfall Over the Oceans**
- **Ocean Forecasting on the Horizon / Toward Better ENSO Forecasting**

## HURRICANE MONITORING :

*Satellite SSS measurements are able to capture haline wakes that form after hurricane passage, particularly in regions where upper-ocean stratification is driven by salinity.*
*By analyzing hundreds of storms in the Atlantic Ocean' …Grodsky et al., 2012; Reul et al., 2014, ….*
*study* ***the effect of barrier layers***
***on hurricane intensification, emphasizing the role of salinity stratification in mixed-layer dynamics' and air-sea exchanges****.*

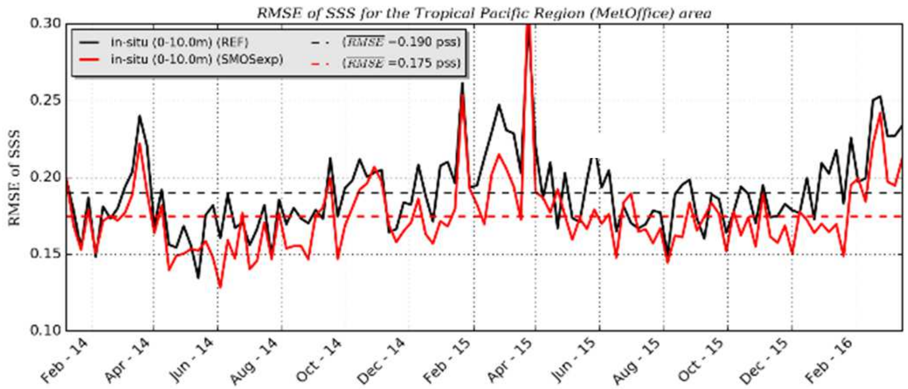


# OCEAN FORECASTING ON THE HORIZON:

*Although, at the moment, no ocean forecasting systems assimilate satellite SSS data operationally, there have been a number of efforts to develop schemes to do so by investigating the SSS data's impact on the ocean analyses and forecast. For example, as part of the ESA SMOS-NINO15 project….*

In Mercator-Ocean model, after assimilation 8% reduction in RMSD compared to near-surface Argo salinity data in the tropical Pacific (12% and 6% in the tropical Atlantic and tropical Indian Ocean respectively).




Tranchant et al. 2019

## Impact on TIW activity

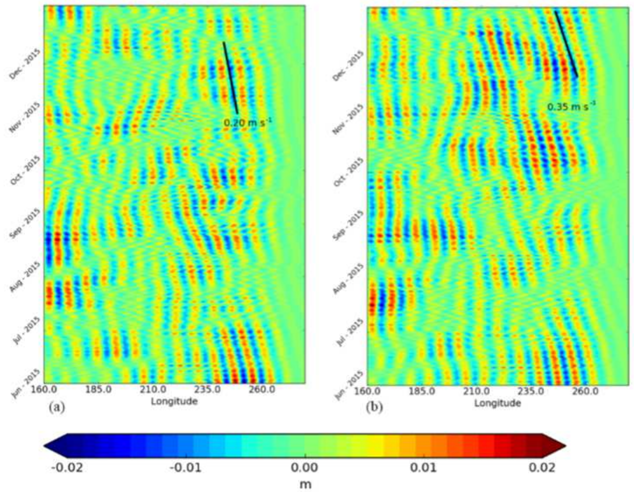


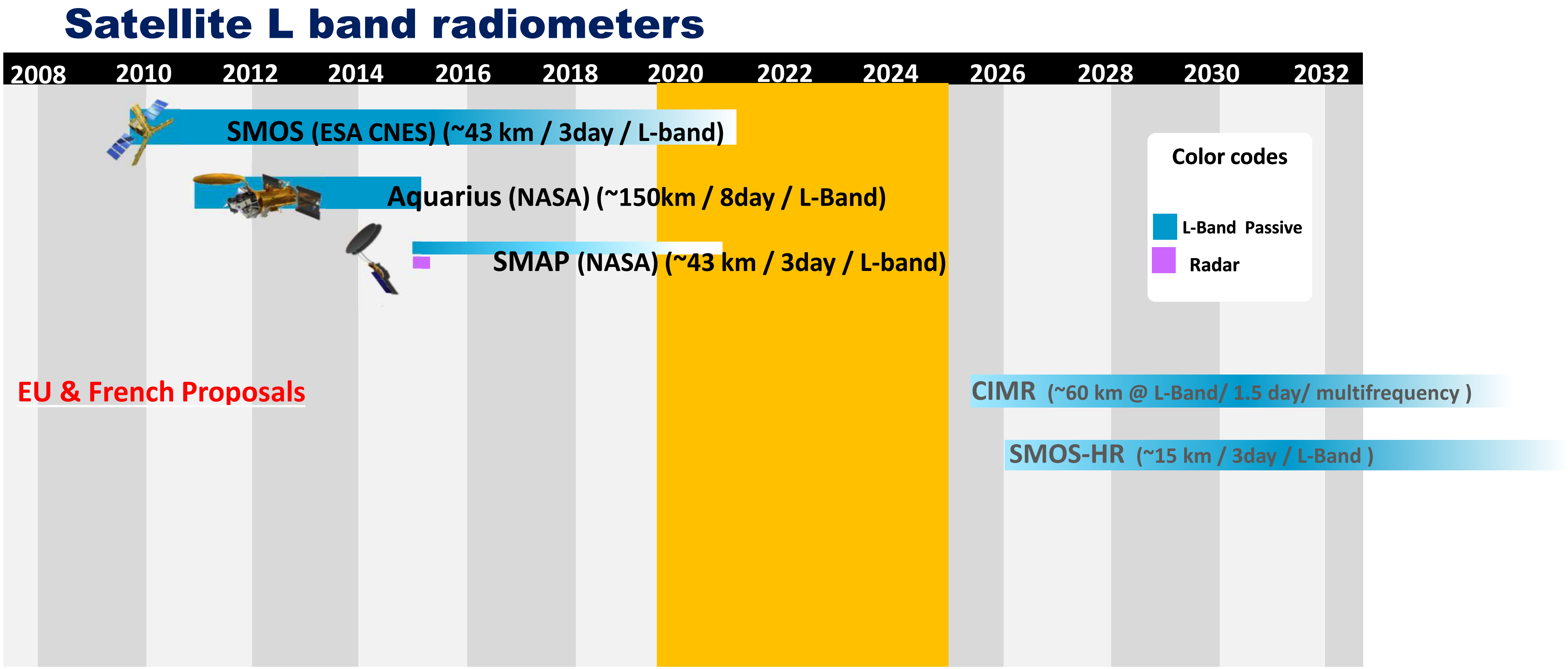

**Figure 14.** Hovmöller diagram of 28–40-day (33 days) band-passed SSH anomalies at 4° N referenced to the temporal annual mean of June–December 2015 for the REF experiment **(a)** and for the SMOSexp experiment **(b)**. The propagation speeds of 0.20 and 0.35 $m\,s^{-1}$ (solid lines) are representative of the propagation speed for the 28–40-day bands.

# OPPORTUNITY FOR INTEGRATION

- **COMPLEMENTING THE IN SITU SALINITY NETWORK**
  - to interpret in situ observations during field experiments
  - to verify the spatial extent of various ocean features (river plumes, eddies, ENSO anomalies…)
- **SYNERGIES WITH OTHER SATELLITE MEASUREMENTS**
  - SST, currents, ocean color, precipitation, wind speed (air-sea fluxes)
- **IMPROVING THE SATELLITE SSS ERROR BUDGET FOR MORE MEANINGFUL INTEGRATION**
  - Sampling (different spatial & temporal sampling by in situ and satellite sensors) and Observational error (in situ and satellite 'instrumental' uncertainties)
  - Necessary to assess a 'realistic' satellite mission accuracy

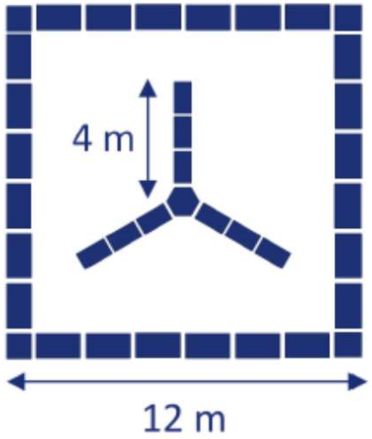
# LOOKING AHEAD

- **THE NEED FOR CONTINUITY**
- **THE NEED FOR ENHANCEMENT**
  - Accuracy – Reducing Uncertainties:
    - Improve technology, retrieval algorithms, RFI filtering
    - High latitudes
  - Resolution – Monitoring Mesoscale Features
  - Coverage – Better Sampling of Coastal Oceans
- **OVERALL STRATEGY FOR NEXT DECADE**
  - **CIMR** Simultaneous Measurements by Multiband Radiometers => SSS, SST, wind
  - **SMOS-HR** Monitor SSS at 25-km spatial resolution or less, to get similar resolution to SST & wind


Satellite L band radiometers
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
SMOS (ESA CNES) (~43 km / 3day / L-band)
Aquarius (NASA) (~150km / 8day / L-Band)
SMAP (NASA) (~43 km / 3day / L-band)
Color codes
L-Band Passive
Radar
EU & French Proposals
CIMR (~60 km @ L-Band/ 1.5 day/ multifrequency )
SMOS-HR (~15 km / 3day / L-Band )

# From SMOS to SMOS-HR

**SMOS**



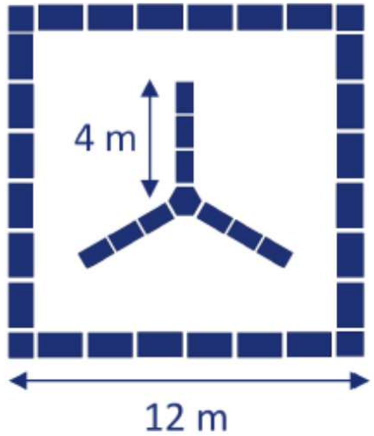

**SMOS-HR**


N. Rodriguez-Fernandez(1) et al.

(1) CESBIO, Toulouse, France
(2) CMLA, Cachan, France
(3) CNES, Toulouse, France
(4) Airbus Defence and Space, Toulouse, France
(5) LOCEAN, Paris, France
(6) IGE, Grenoble, France
(7) IsardSat, Barcelona, Spain

# From SMOS to SMOS-HR

**SMOS**




**SMOS-HR**


Phase 0 study at CNES by CESBIO and AIRBUS DS: successfully finalized in May 2019

Interferometer with larger antenna array than SMOS => resolution ~15km (10km at nadir)

RFI filtering at instrument level (Sub frequency bands) (SMOS: no RFI filtering)

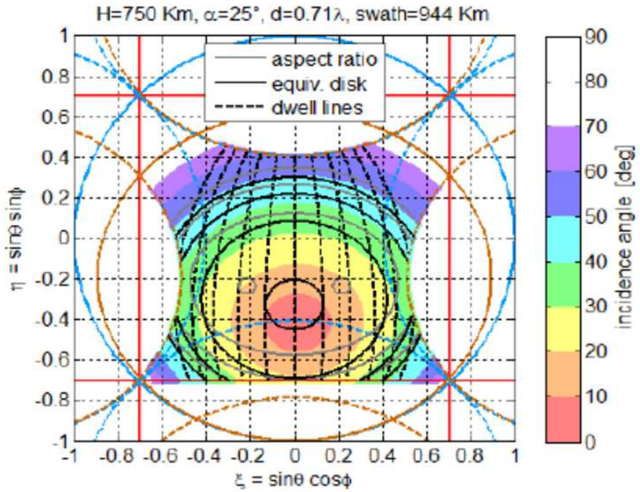
Spatial frequency spacing: 0.7 $\lambda$ (reduce aliasing) (SMOS: 0.87 $\lambda$)

Effective Alias Free FOV: 920km (0° tilt); revisit in 3 days

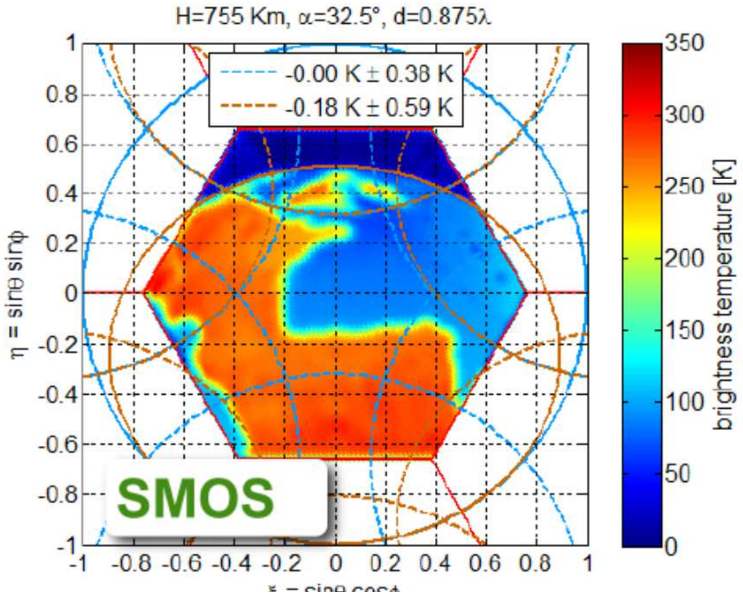
Radiometer uncertainty: ~twice better than SMOS/SMAP at @40km equivalent resolution

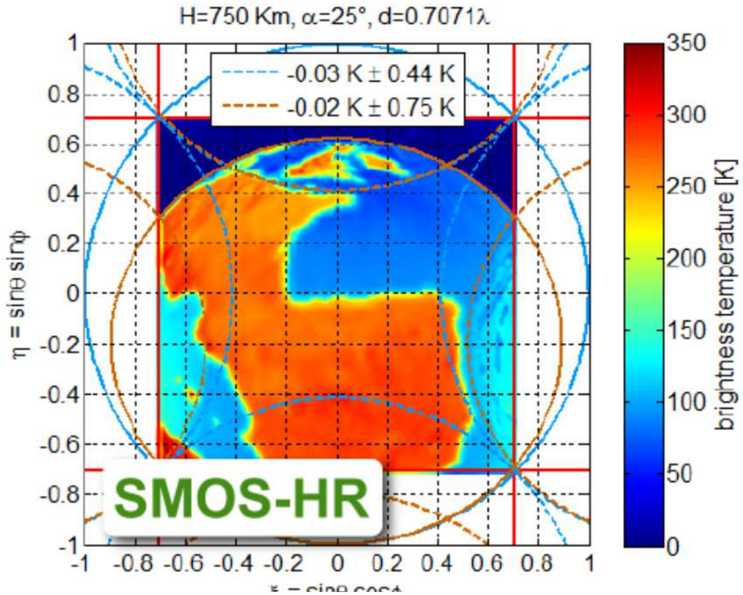
# SMOS-HR: FOV and comparison to SMOS

**SMOS HR field of view and incidence angles**



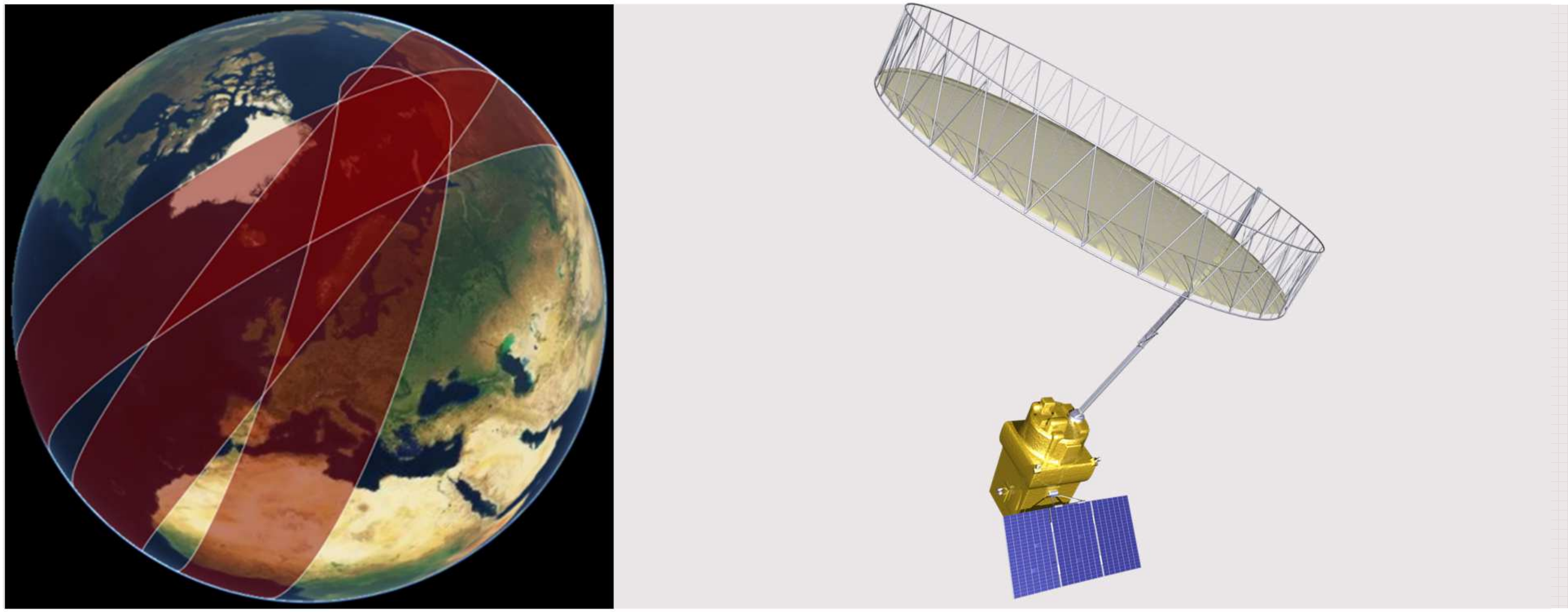

E. Anterrieu




**Higher resolution => much closer to coasts, reduced SSS noise (at fixed resolution)**

# CIMR mission Status
# Copernicus Ice Monitoring Radiometer

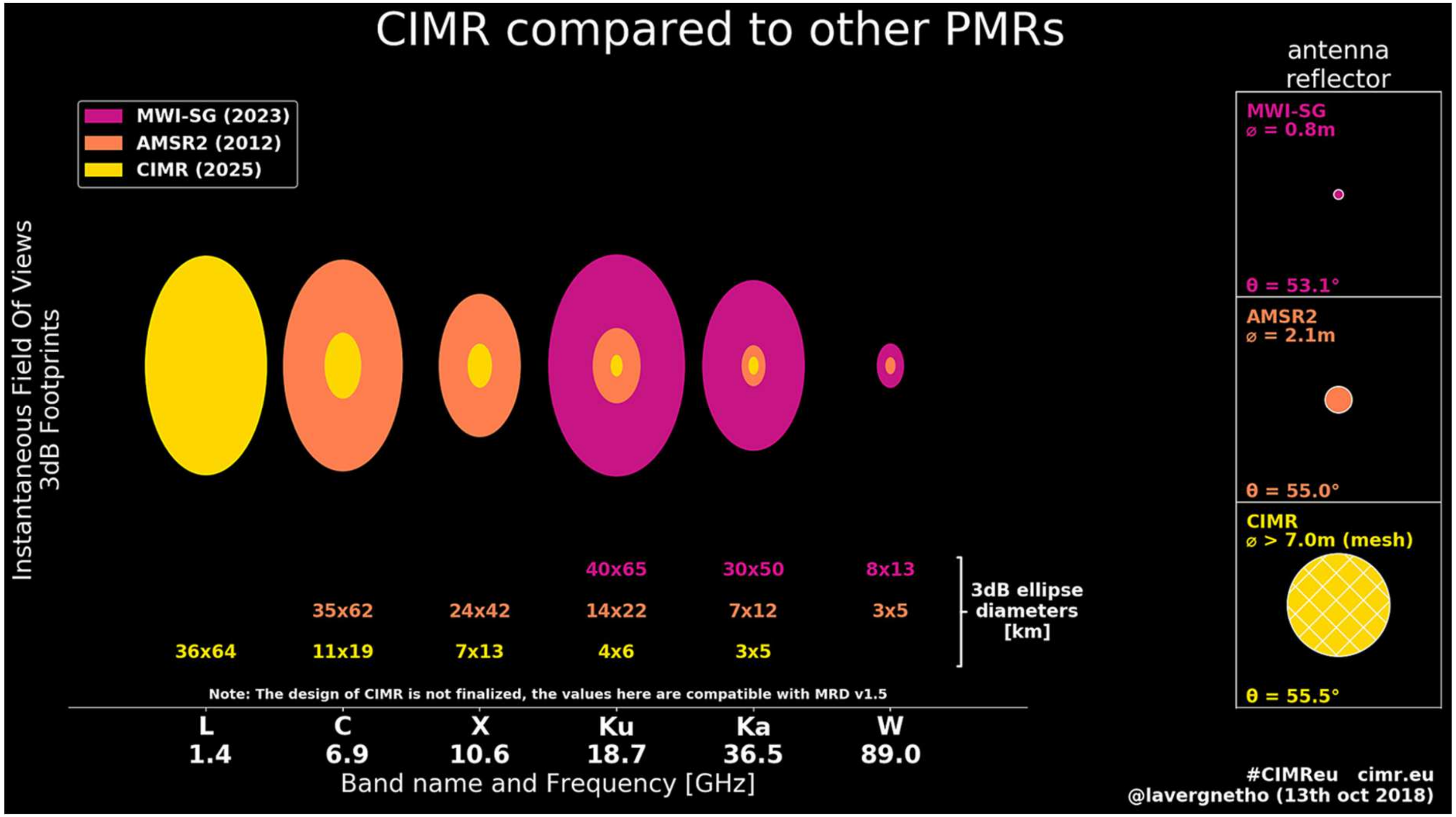


Nicolas Reul, with contributions from EU/ESA CIMR Mission Advisory Group

- One of the 6 High Priority Candidate Missions for the Expansion phase (>2025) of the Sentinels.
    - Currently under a definition study (Phase B1) until Aug 2019

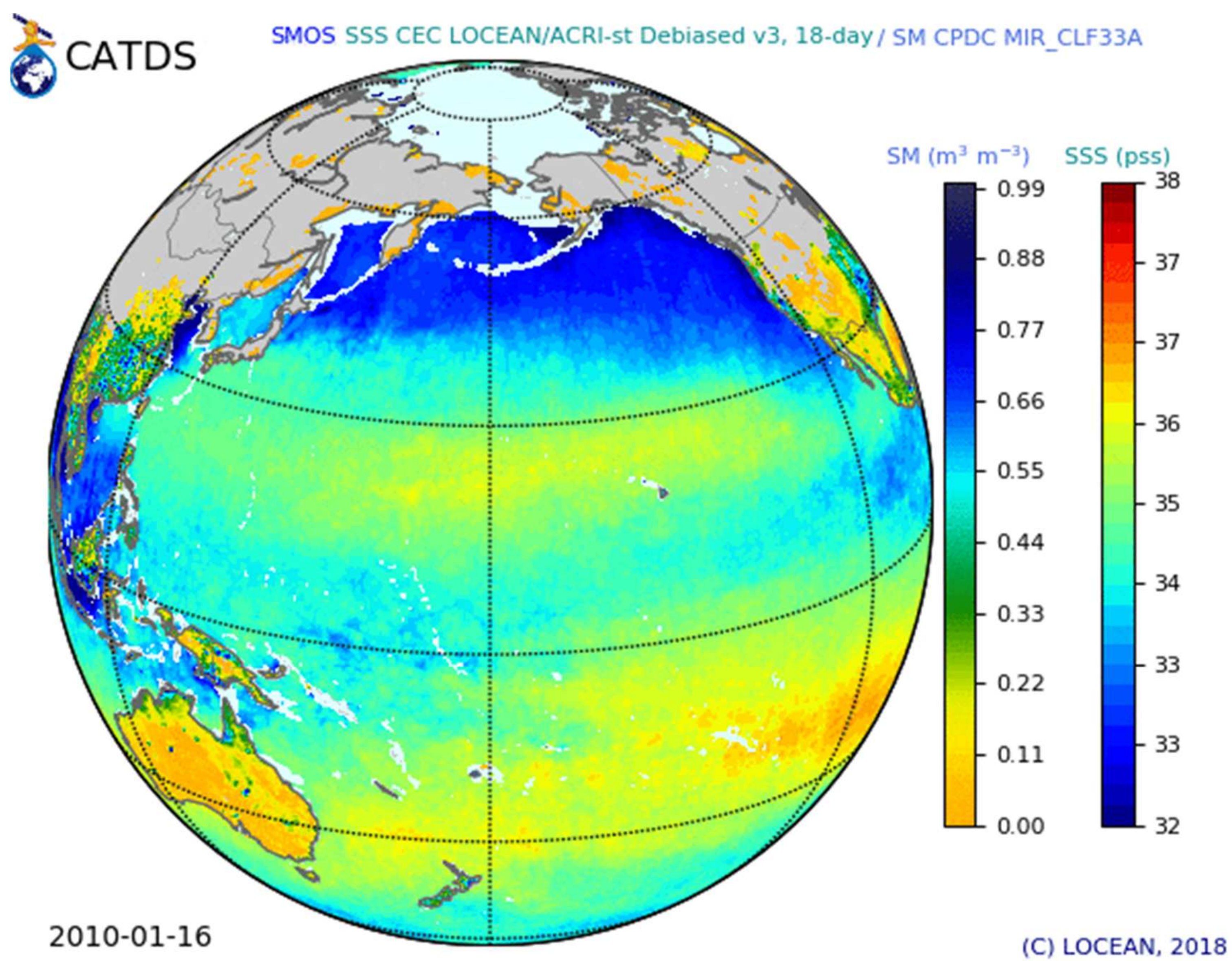
## CIMR mission

# Channel selection



# Summary

- Intermediate spatial resolution at L-band (30x60km) between SMOS (~av 43 km) , SMAP (39 x 47 km) & Aquarius (~150 km) but:
  - ~1900 km wide-swath
  - Large L-band footprints overlaps
  - Reduced radiometer uncertainties (NEDT~0.3 K)
  - On board radiometer RFI filtering
- CIMR has L, C, X, Ku and Ka bands so we can develop new approaches for SST, Salinity and high wind speed retrievals: in this respect CIMR is unique


CATDS
SMOS SSS CEC LOCEAN/ACRI-st Debiased v3, 18-day / SM CPDC MIR_CLF33A
SM (m³ m⁻³)
0.99
0.88
0.77
0.66
0.55
0.44
0.33
0.22
0.11
0.00
SSS (pss)
38
37
37
36
35
34
33
33
32
2010-01-16
(C) LOCEAN, 2018