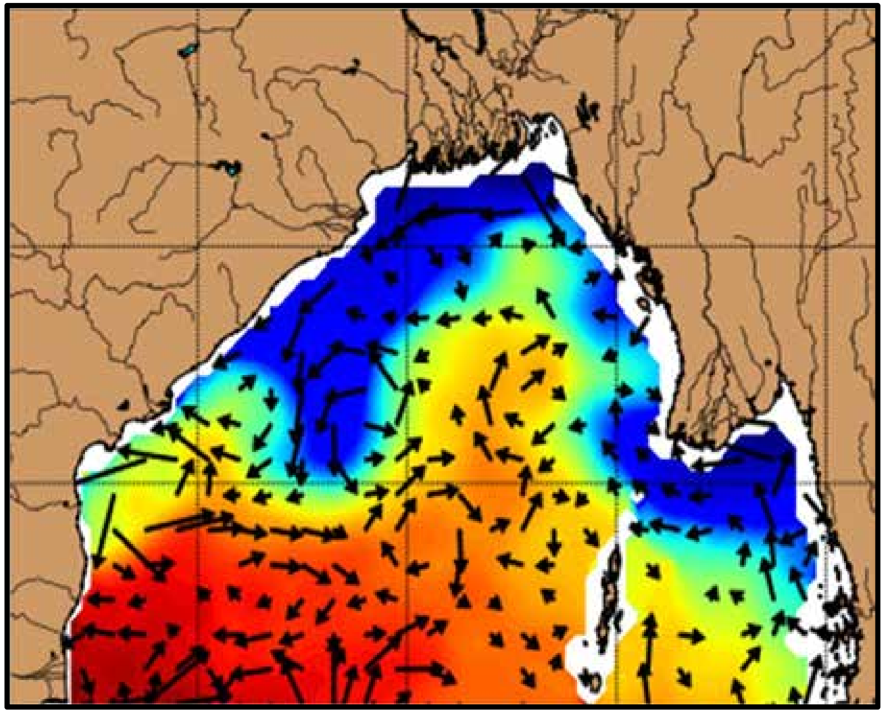
Jet Propulsion Laboratory
California Institute of Technology



Modulation of the Ganges-Brahmaputra river plume by the Indian Ocean Dipole and eddies inferred from satellite observations

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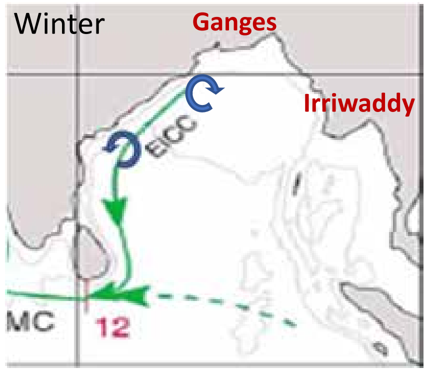
Motivations

Bay of Bengal (BoB) – challenging study region:

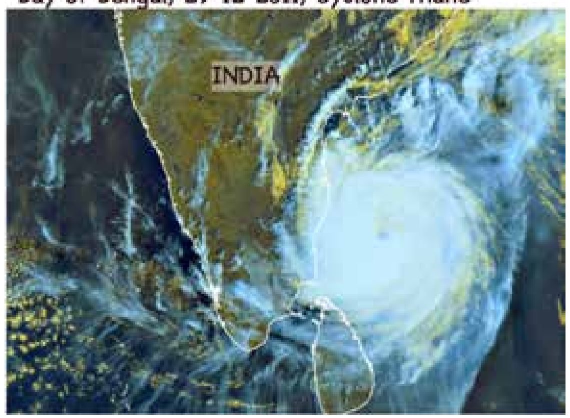
- Large variability:
  - River discharge (Ganges-Brahmaputra (GB))
  - Southwest monsoon
  - Eastern Indian Coastal Current (EICC) and eddies redistribute freshwater
  - Indian Ocean Dipole (IOD): interannual climate mode in the Indian Ocean similar to El Niño in the Pacific Ocean



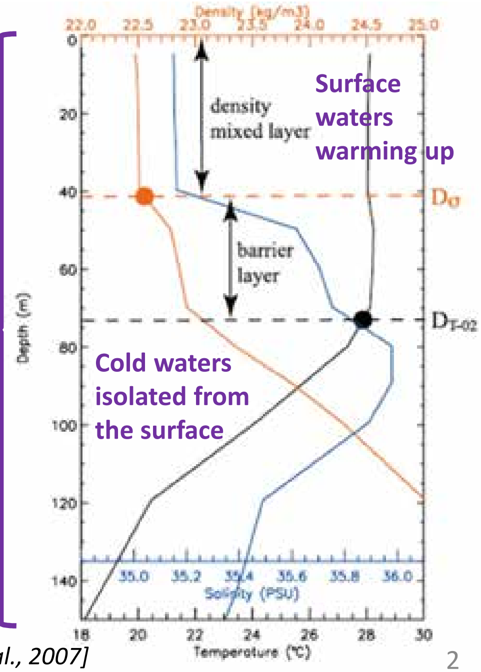
[Schott & McCreary, 2001]

- Importance for:
  - Impact on air-sea interactions (tropical cyclones, convection, rainfall) *[Sengupta et al., 2008; Shenoi et al., 2002]*
  - Impact on biogeochemistry and exchanges with the Arabian Sea *[Prasanna Kumar et al., 2002]*

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



Water column highly stratified

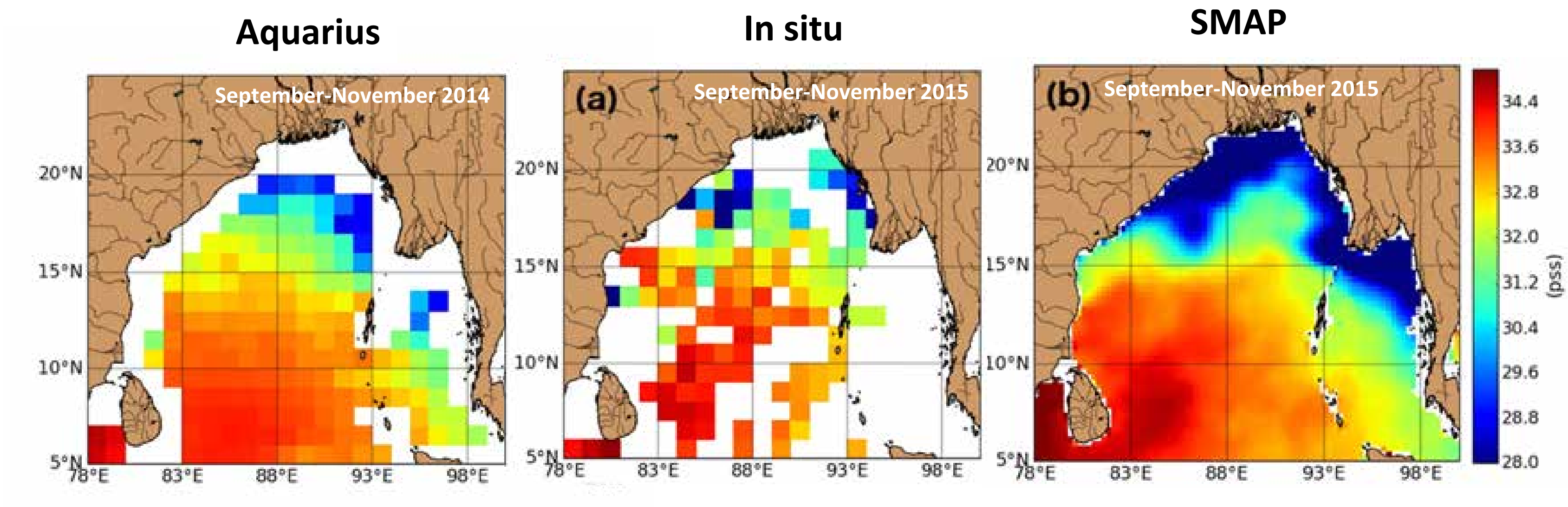


[De Boyer Montégut et al., 2007]

Context

Limitations in using SSS data from in situ and previous satellite missions

➡ SMAP SSS data now available since May 2015



Previous modelling studies: river plume interannual variability driven by the IOD and eddies *[Akhil et al., 2014]*

Can SMAP and altimetry data be used to study the interannual variability of the freshwater River plume and their forcing mechanisms?

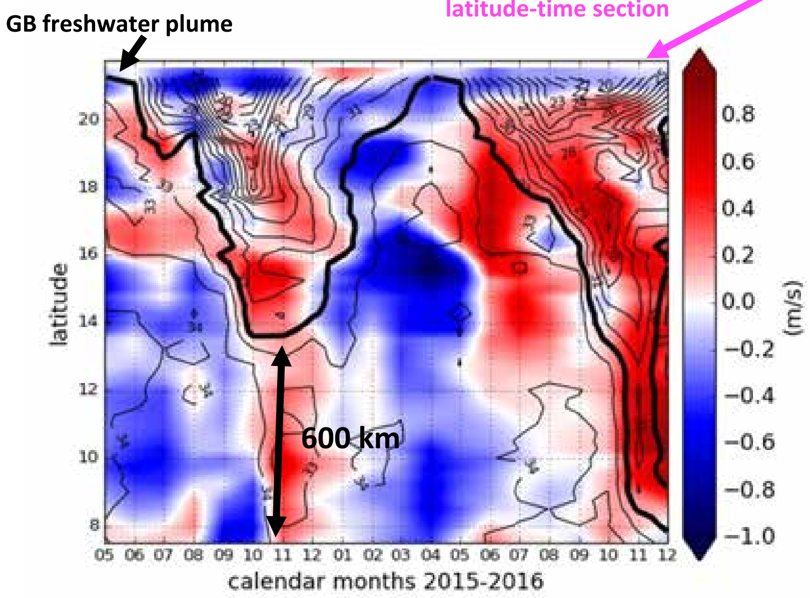
Data

- **SMAP SSS**: JPL Level 3 version 3 - 0.25° horizontal resolution, 8-day running mean (April 2015-December 2016)
- **Aviso Sea Level Anomaly (SLA)**: Level 3 - 0.25° horizontal resolution, daily (1993-2016)
- **Aviso currents**: Level 4 - 0.25° horizontal resolution, daily (1993-2016)

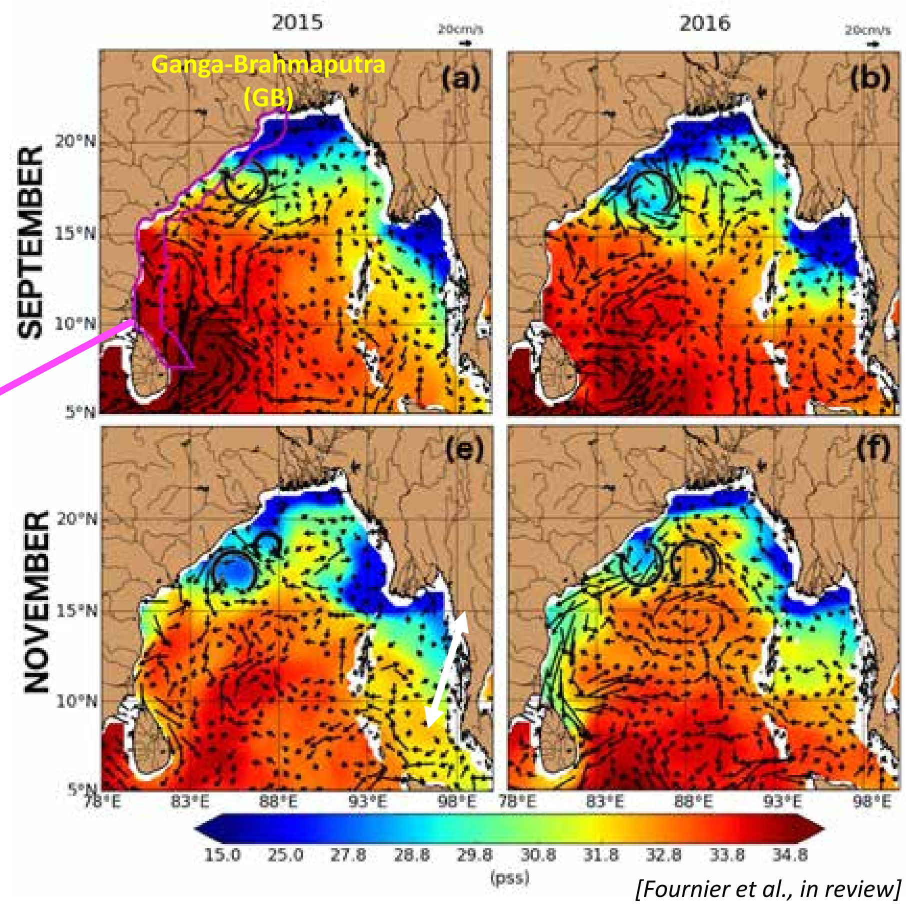
The freshwater plume extends further south in 2016 than in 2015

2015: freshwater plume confined north of 13°N - far weaker EICC

2016: freshwater plume extends further south to Sri Lanka
southward alongshore currents stronger especially south of 14°N



alongshore currents (colors) and SSS (contours) within 200 km of the eastern coast of India



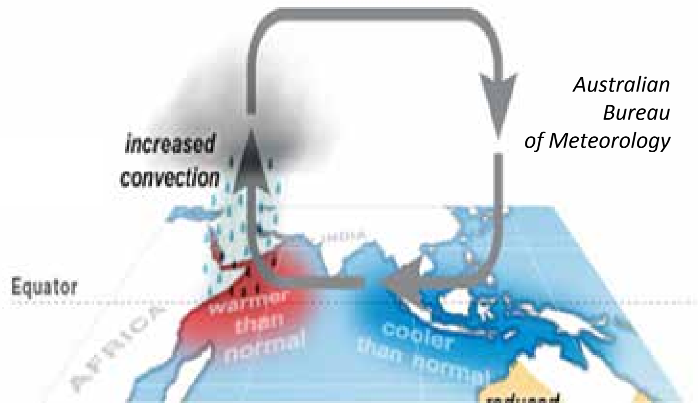
[Fournier et al., in review]

SMAP shows that the freshwater plume extends further south in 2016 than in 2015

CAUSES ?

The Indian Ocean Dipole

Indian Ocean Dipole (IOD):
- interannual climate mode in the Indian Ocean (similar to El Niño in the Pacific Ocean)
- peaks in fall
- lasts for ~6 months



Australian Bureau of Meteorology

During a **positive IOD**:

anomalous easterly equatorial winds

⬇

temperature gradient across the Indian Ocean equatorial and coastal upwelling Kelvin waves

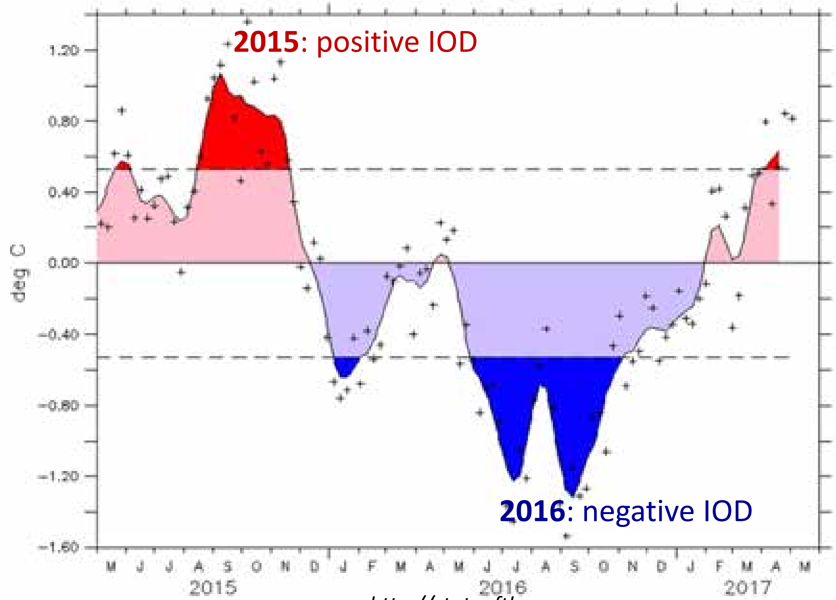
⬇

negative sea level anomaly (SLA) along the rim

⬇

anomalously weak EICC

Dipole Mode Index (DMI): reflects the IOD variability



http://stateoftheocean.osmc.noaa.gov

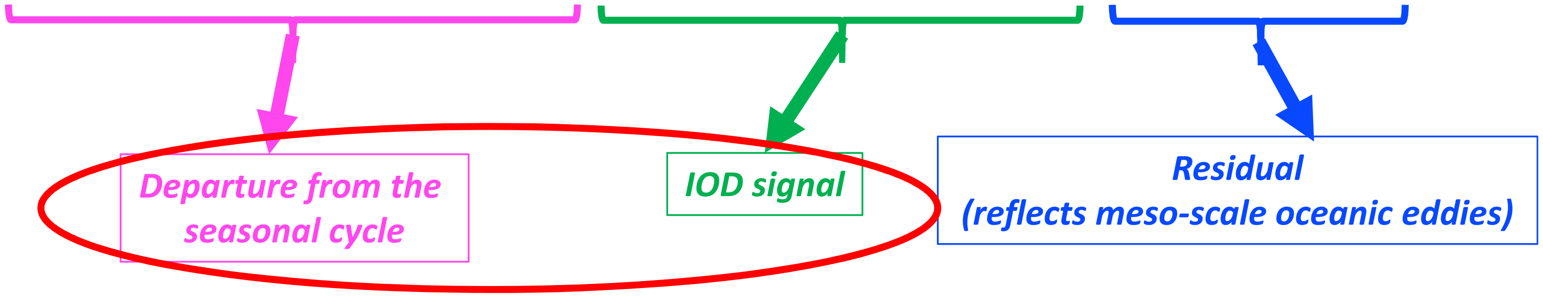
The Indian Ocean Dipole

Method: Lead-lag regression between ocean parameters and the 1993-2016 September-October-November DMI to study the effect of the IOD

$$SLA_{IOD} = IOD_{index}(year)*SLA(year,month)$$

$$current_{IOD} = IOD_{index}(year)*current(year,month)$$

$$SLA(year,month) - SLA_{SC}(year,month) = IOD_{index}(year)*SLA(year,month) + SLA_{RES}(year,month)$$



Altimetry: the negative IOD in 2016 caused a further south extension of the plume

2015

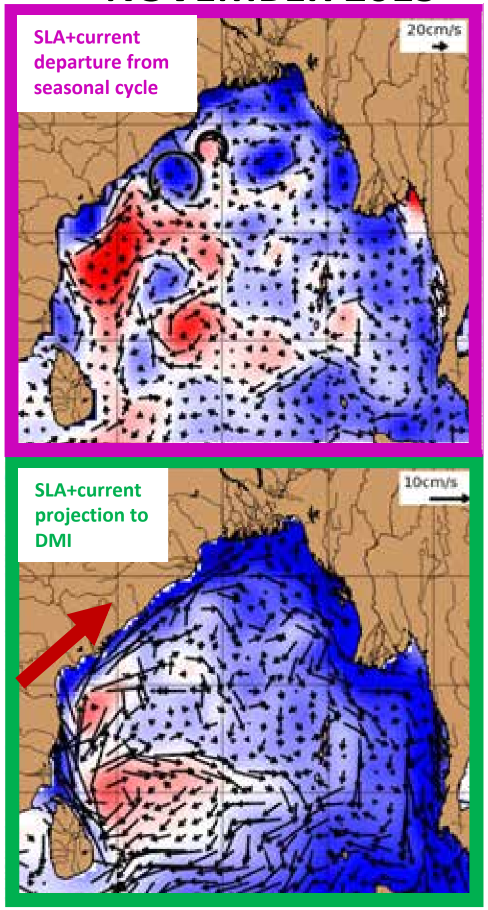
Negative SLA anomalies explained by the positive IOD

Strong northward current anomaly

⬇

anomalously weak southward EICC and freshwater transport

NOVEMBER 2015



2016

Positive SLA anomalies explained by the negative IOD

Strong current anomaly southward

⬇

anomalously strong southward EICC and freshwater transport

[Fournier et al., in review]

Altimeter data show that the negative IOD in 2016 caused a stronger southward current that carried the river plume 600 km further south

Meso-Scale Eddies affect the along-shore transport

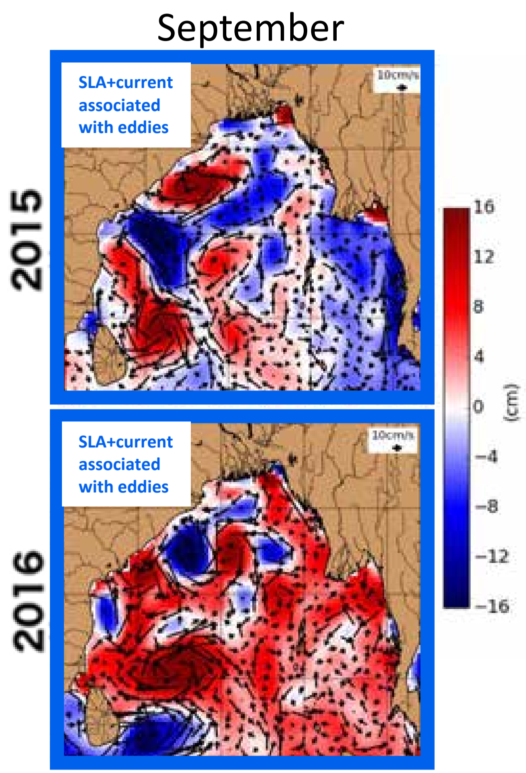
$$SLA(year,month) - SLA_{SC}(year,month) = IOD_{index}(year)*SLA(year,month) + SLA_{RES}(year,month)$$

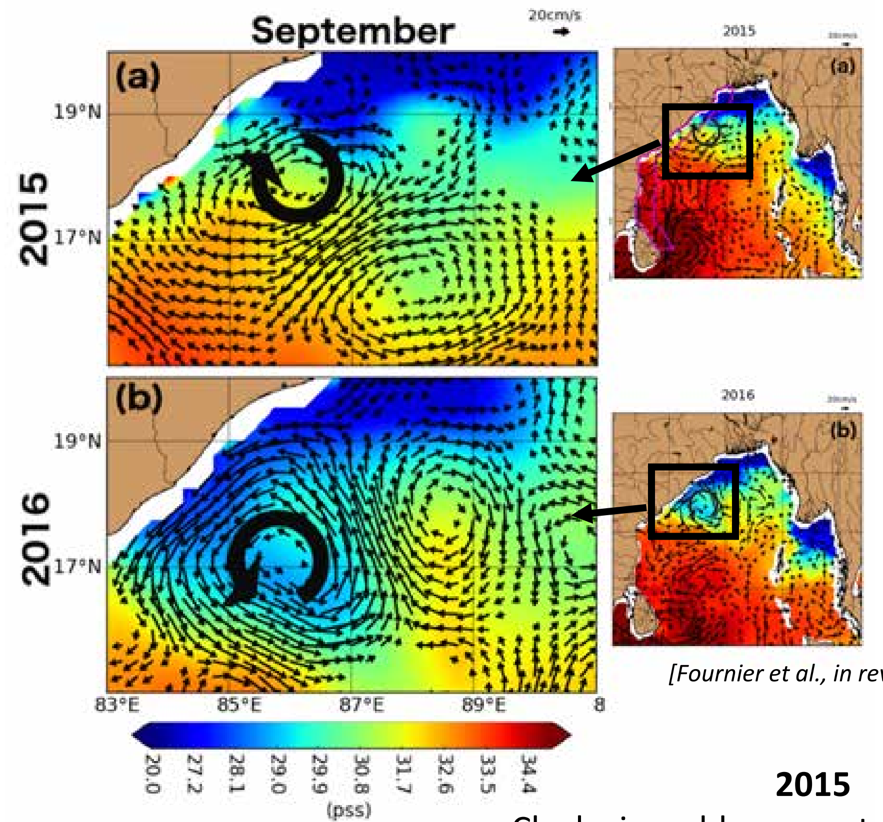
Departure from the seasonal cycle

IOD signal

Residual (reflects meso-scale oceanic eddies)

Meso-Scale Eddies affect the along-shore transport





[Fournier et al., in review]

Altimeter and SMAP data show mesoscale eddies affecting the along-shore transport

Good correspondence between independent datasets (currents and SSS)

2015
Clockwise eddy prevents the southward transport of the freshwater plume

2016
Counter clockwise eddy carries freshwater plume southward

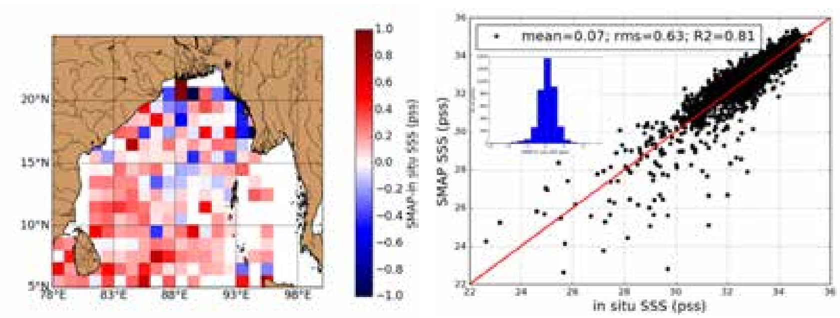
Summary

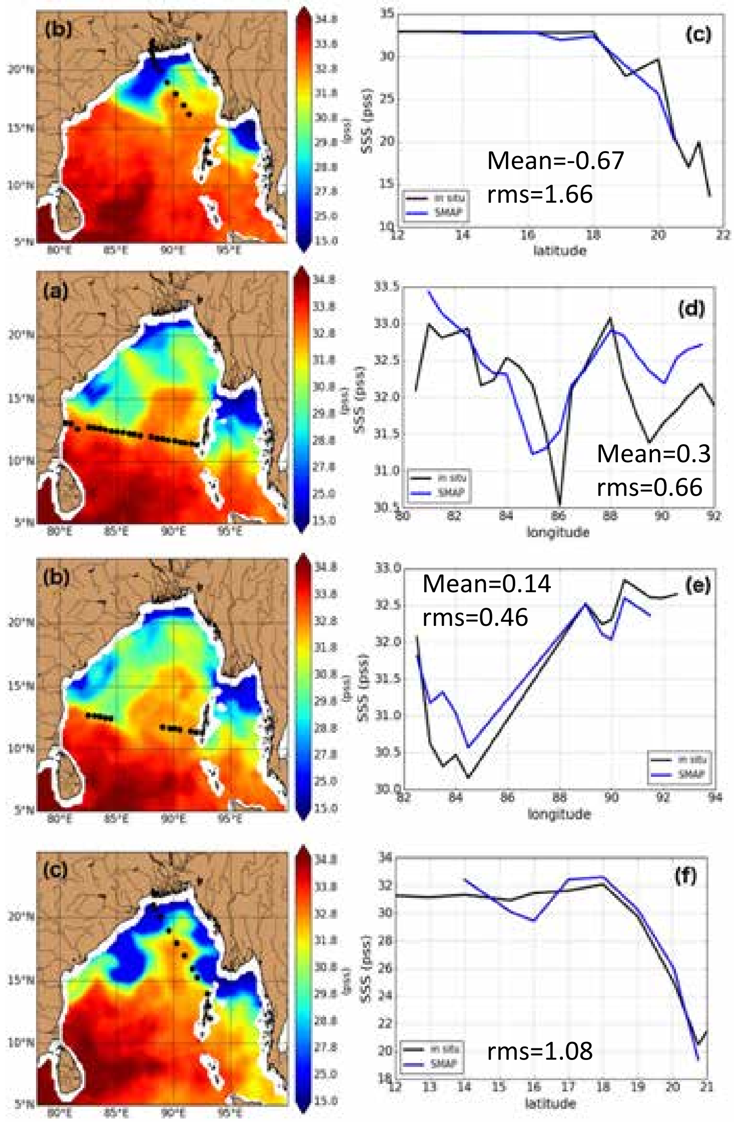
- SSS from SMAP along with altimetry data (SLA and currents) provide unprecedented views of this peculiar "river in the sea" feature from intraseasonal to interannual timescales
- The good correspondence in the synergistic use of SSS and altimetry, two independent datasets, shows that SMAP SSS well captures mesoscale features such as eddies
- Remote forcing associated with the negative IOD in the fall of 2016 caused a stronger EICC and "river in the sea" that extended approximately 600 km further south than that in 2015
- Mesoscale eddies induced meandering of this plume, exporting freshwater away from the coast
- Importance for improving our understanding on the exchange of freshwater with the Arabian Sea, biogeochemistry and air-sea interactions

SMAP SSS validation in the Bay of Bengal (BoB)

In-situ salinity:

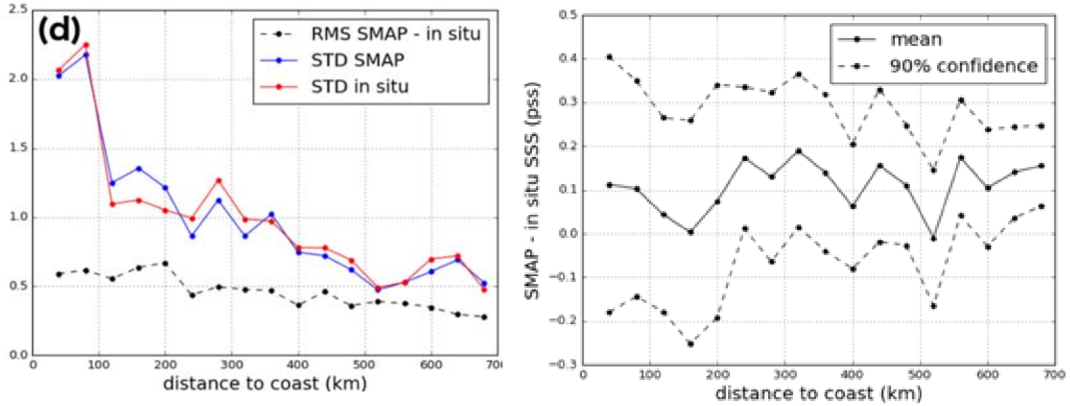
- WOD09 (April 2015-December 2016)
- NIO bucket samples - bimonthly basis along transects





- Good agreement
- Strong gradients along transects well captured by SMAP
- Differences larger near the coast
- Differences could be explained:
    - strong near-surface stratification
    - spatiotemporal sampling differences
    - land contamination

SMAP SSS validation in the Bay of Bengal (BoB)

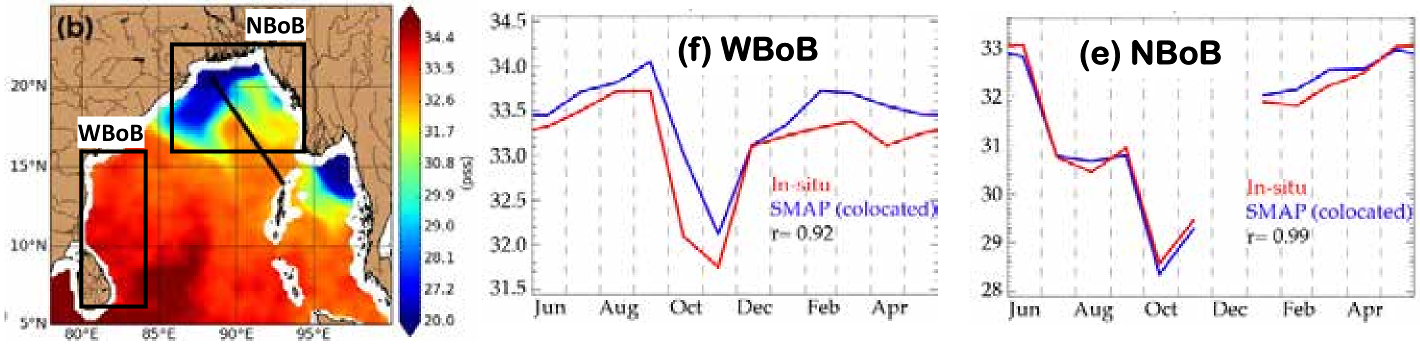


- SMAP - in situ RMSD as a function of the distance to the coast:
  - slightly larger within 200 km of the coast (~0.6) than offshore (~0.4)
  - always smaller than the STD of the SMAP or in situ SSS signals (2 to 4 times smaller within 200 km of the coast)

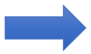
- Similarly, the SMAP ~0.1 bias does not increase within 200 km of the coast

➡ SMAP is accurate enough to monitor the large salinity signals within 100-200 km of the coast in the BoB

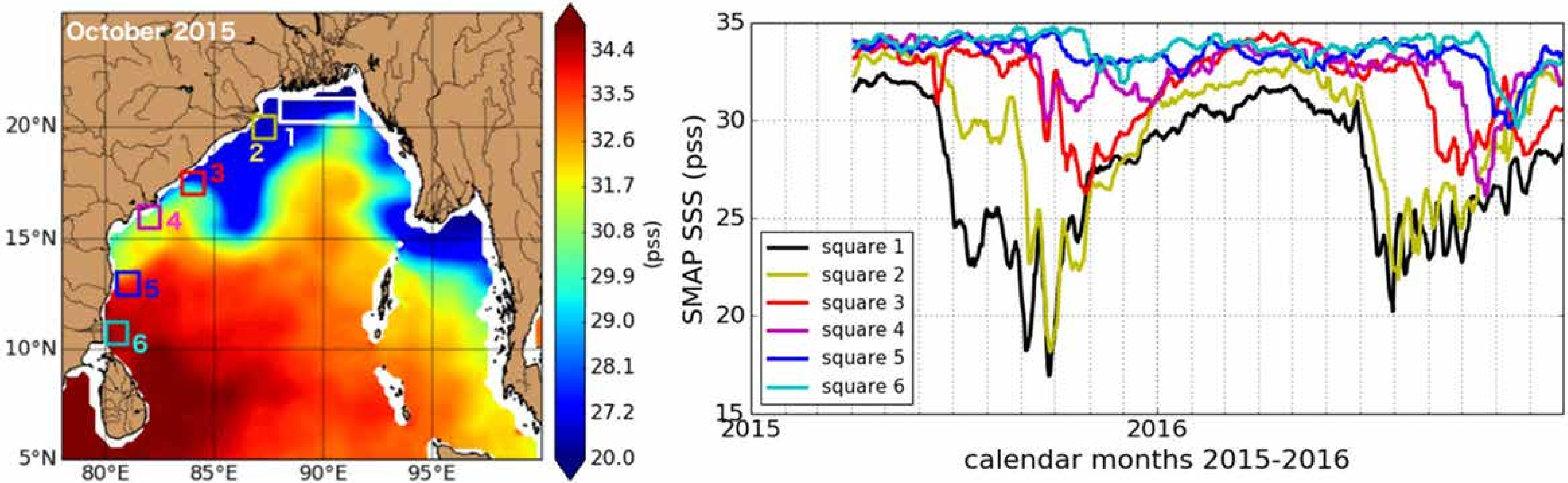
SMAP SSS validation in the Bay of Bengal (BoB)



Excellent comparison between in situ and collocated SMAP data

 SMAP captures the large-scale signals

The freshwater plume extends further south in 2016 than in 2015



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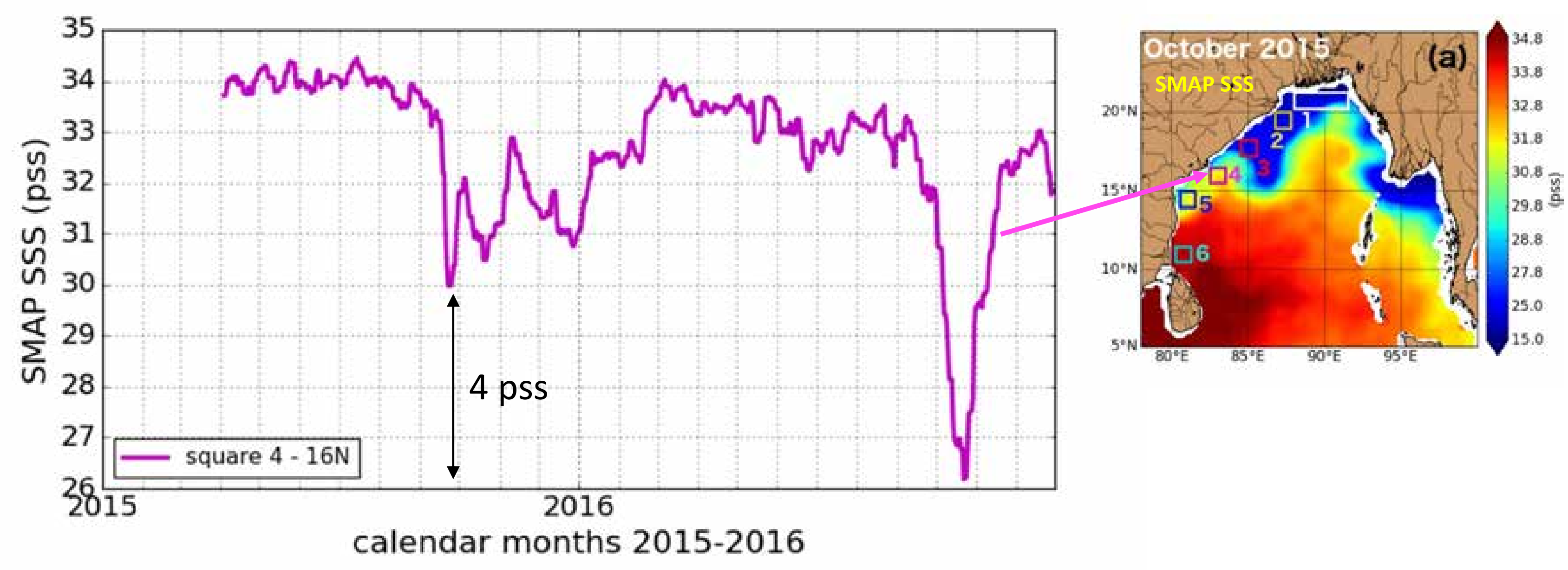
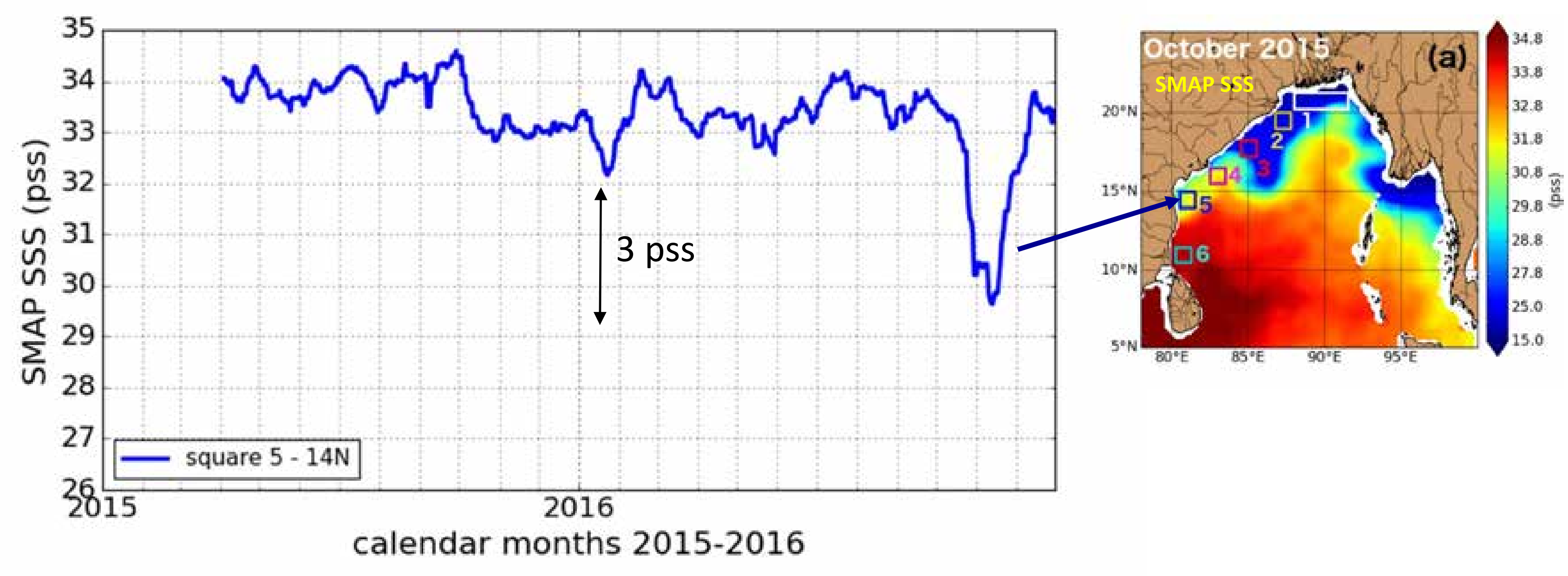


Fall 2016:

- the freshening southward progression more visible
- 2 to 4 pss lower SSS at 16°N, 14°N and 11°N

The freshwater plume extends further south in 2016 than in 2015



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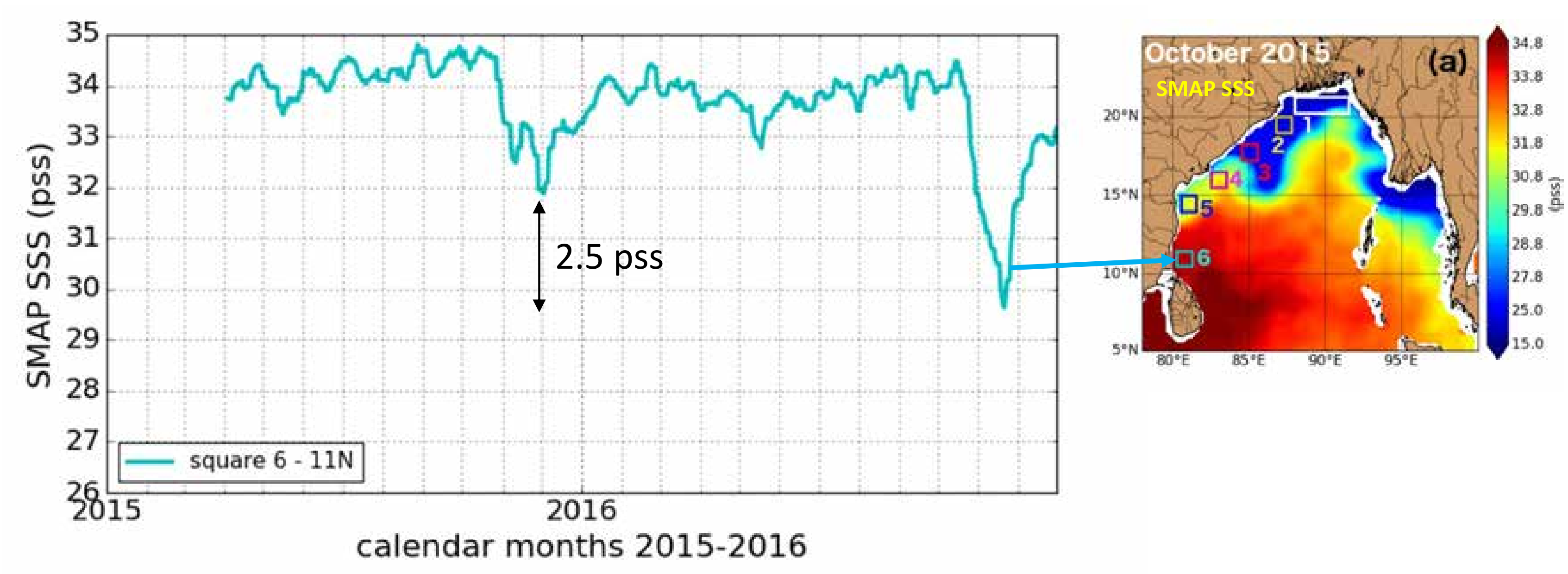

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