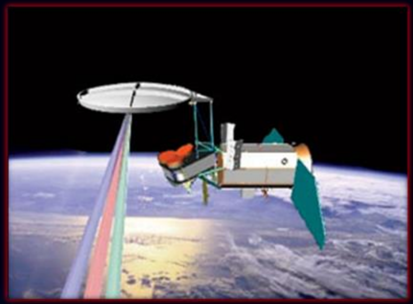
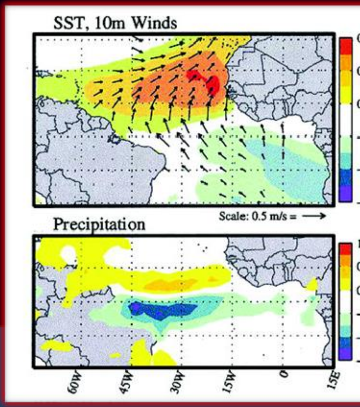
Satellite applications in tropical oceanography: perspectives from the Atlantic & Indian Oceans



Ebenezer Nyadjro

NRL/UNO



Collaborators:

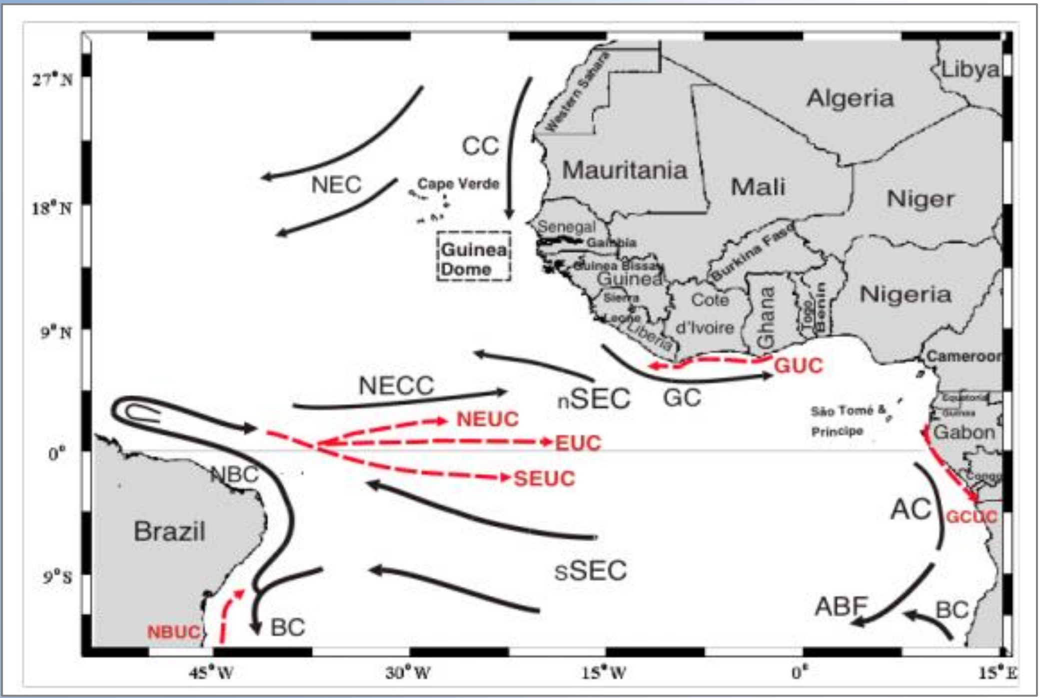
Dr. George Wiafe – University of Ghana

Dr. Subrahmanyam Bulusu – University of South Carolina

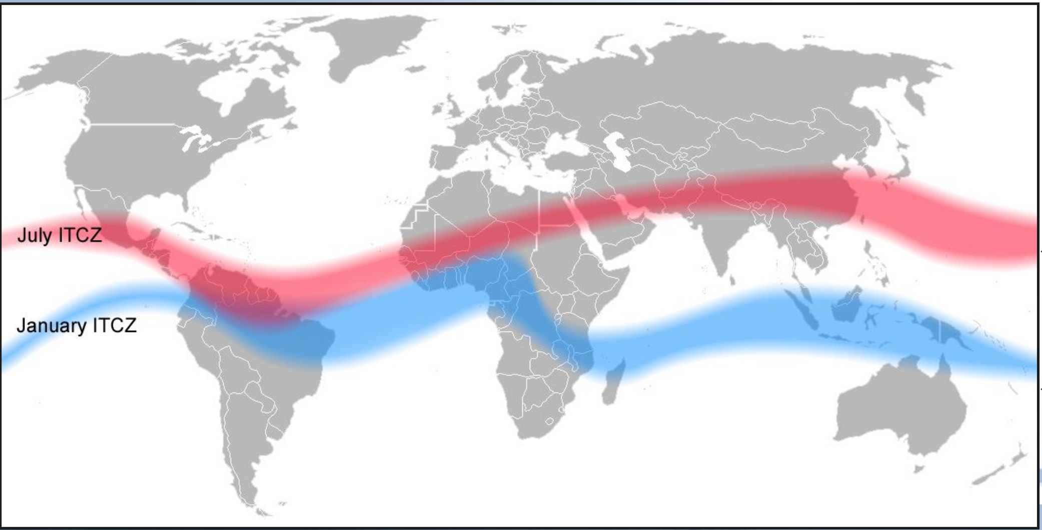
Gulf of Guinea Upwelling: satellite observations

(Wiafe and Nyadjro, IEEE GRSL 2015)

Background: Guinea Current



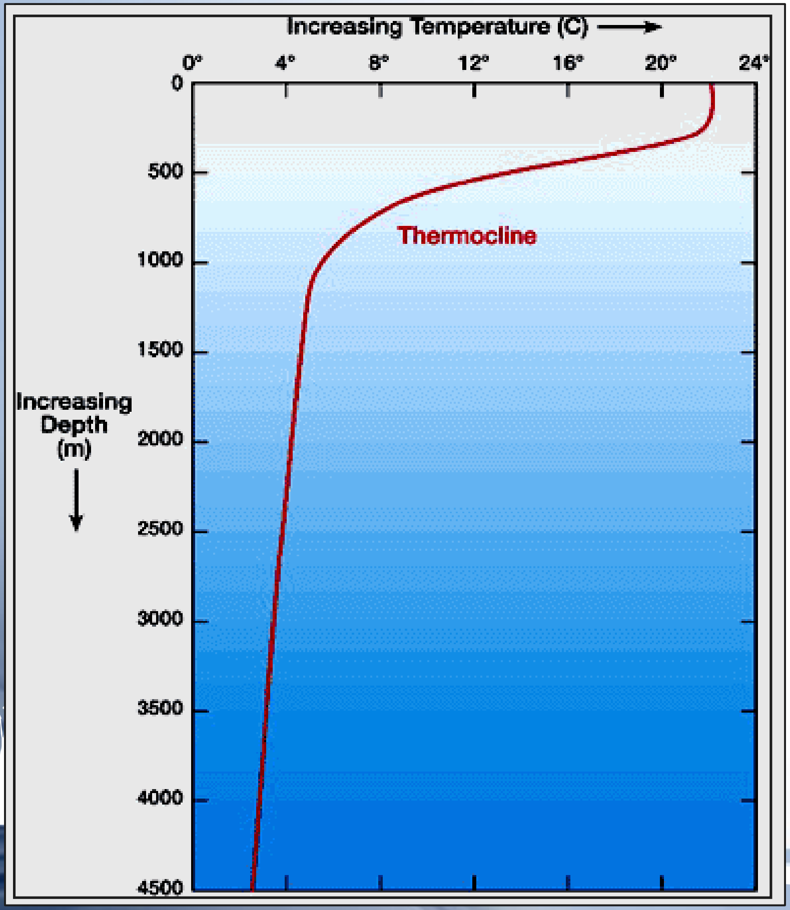
Muhammed, 2011

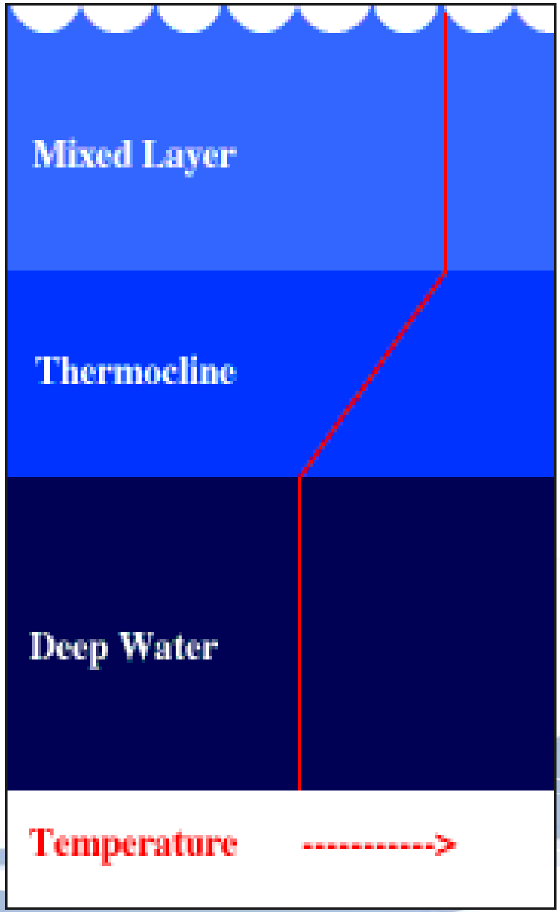


- ✓ GC: an eastern boundary current
- ✓ Current shear instability can cause TIW
- ✓ Climate system influenced by wind variability and ITCZ migration
- ✓ SE winds in summer
- ✓ Dry NE harmattan winds in winter

Background: Upwelling

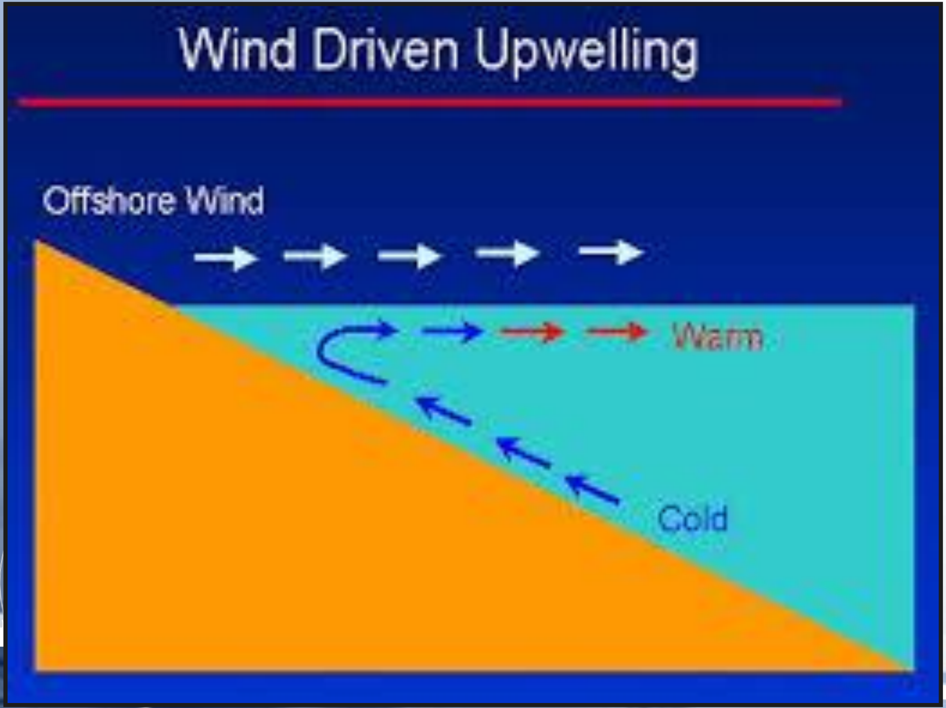
- Thermocline inhibits exchange of surface and subsurface waters.
- High nutrient-rich waters are locked up in subsurface waters.

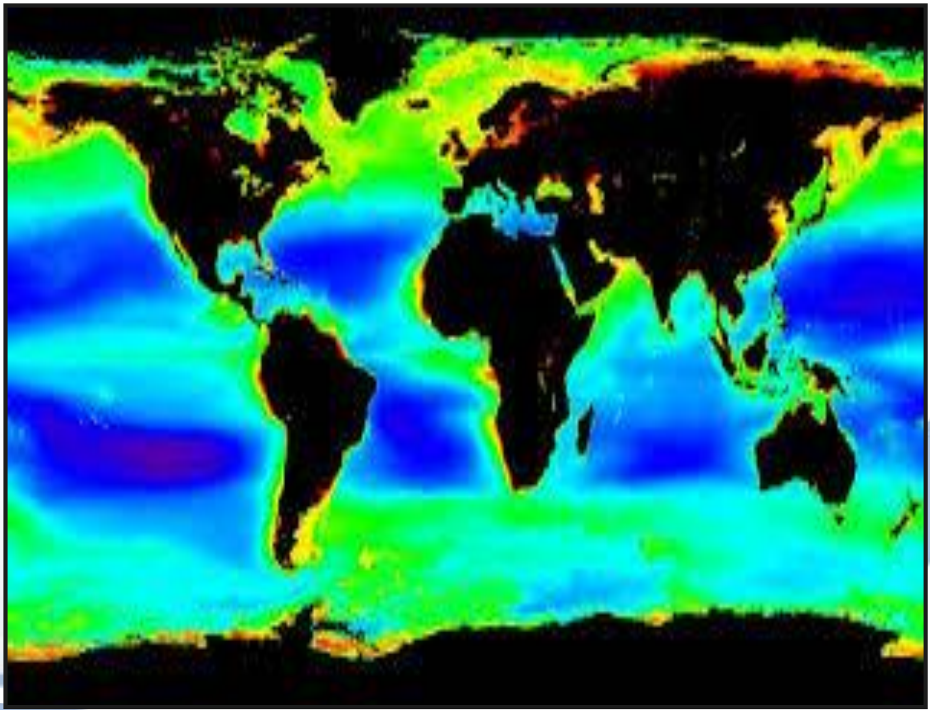




Background: Upwelling

- Cold nutrient-rich waters are brought into the surface ocean through upwelling.
- Indicators: low SST, low oxygen, high nutrients and increased primary productivity.

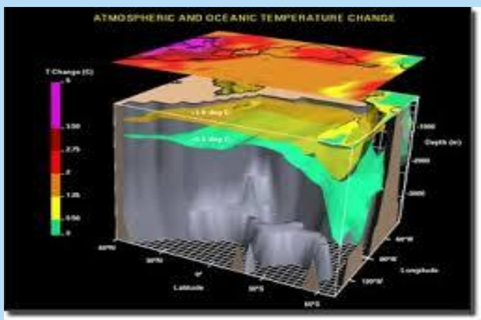


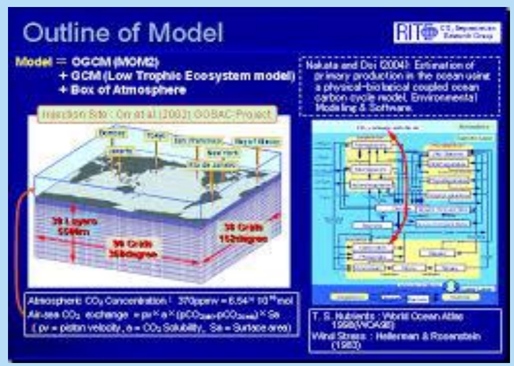


Background: Oceanographic Data Sources

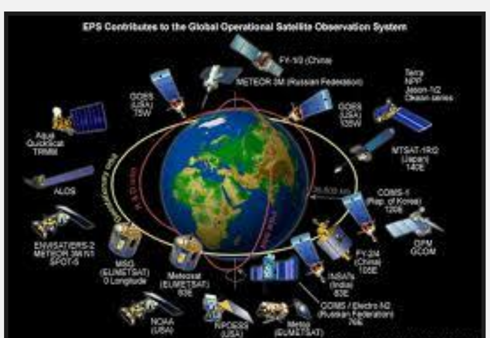
In-situ data:

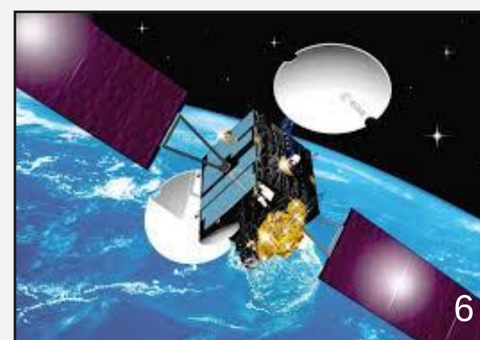
Modeling outputs:





Satellite data:





Research objectives:

- Study upwelling variability from satellite data
- Derive upwelling indexes
- Compare Ekman pumping and Ekman transport
- Understand remote contribution to GoG upwelling

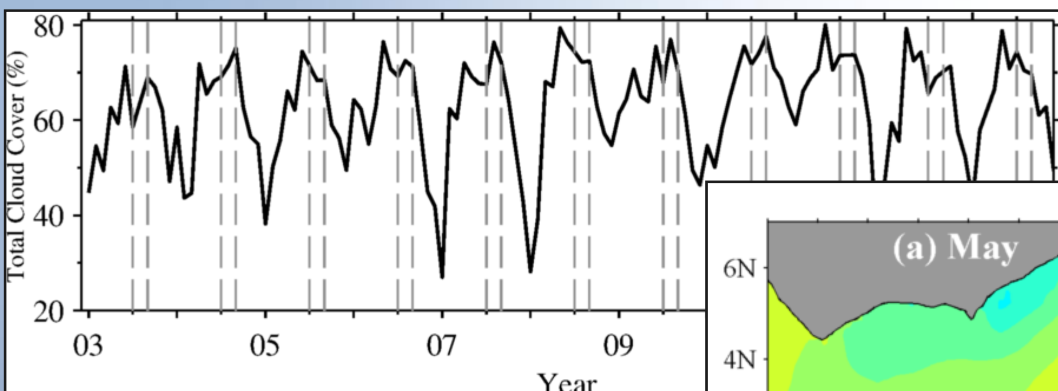
Data and Methods:

- NASA Multiscale Ultrahigh Resolution (MUR) SST analysis data set: 0.01°×0.01° (~1km×1km)

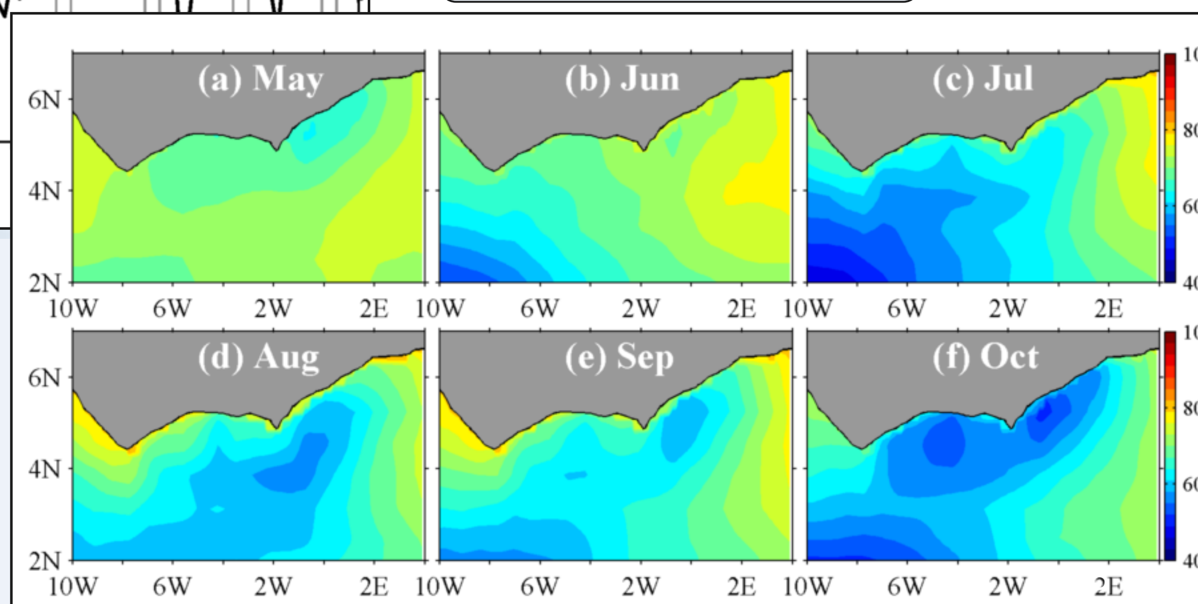
- Data is merged:

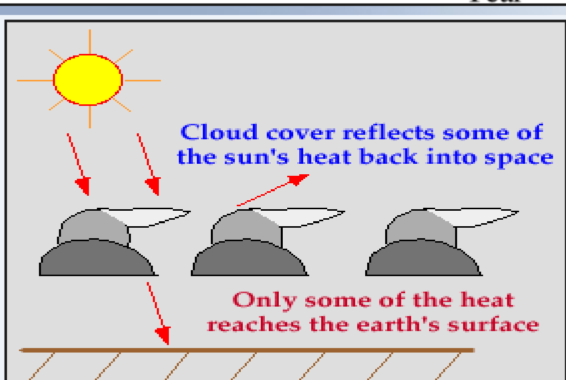
  (a) high spatial resolution IR: AVHRR & MODIS

  (b) weather-tolerant microwave: AMSR-E



Cloud coverage





Data and Methods:

- NASA Multiscale Ultrahigh Resolution (MUR) SST analysis data set: $0.01^{\circ}\times0.01^{\circ}$ (~1km×1km)
- Data is merged:
  - (a) high spatial resolution IR: AVHRR & MODIS
  - (b) weather-tolerant microwave: AMSR-E
- AVISO SSHA: $0.25^{\circ}\times0.25^{\circ}$
- QSCAT winds: $0.25^{\circ}\times0.25^{\circ}$

$$\boldsymbol{\tau} = \rho_a C_d \,|\,\mathbf{U}\,|\,\mathbf{U}$$

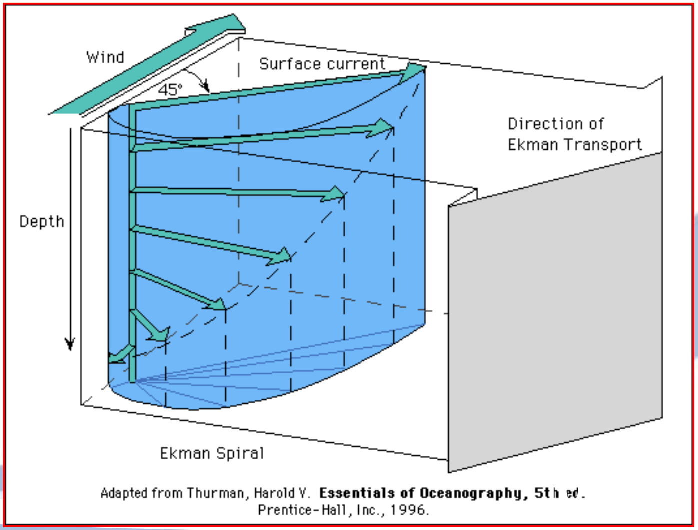
Data and Methods:

Ekman transport: $$\mathbf{M} = \frac{\boldsymbol{\tau}}{\rho_o f}$$ units = $m^2\, s^{-1}$

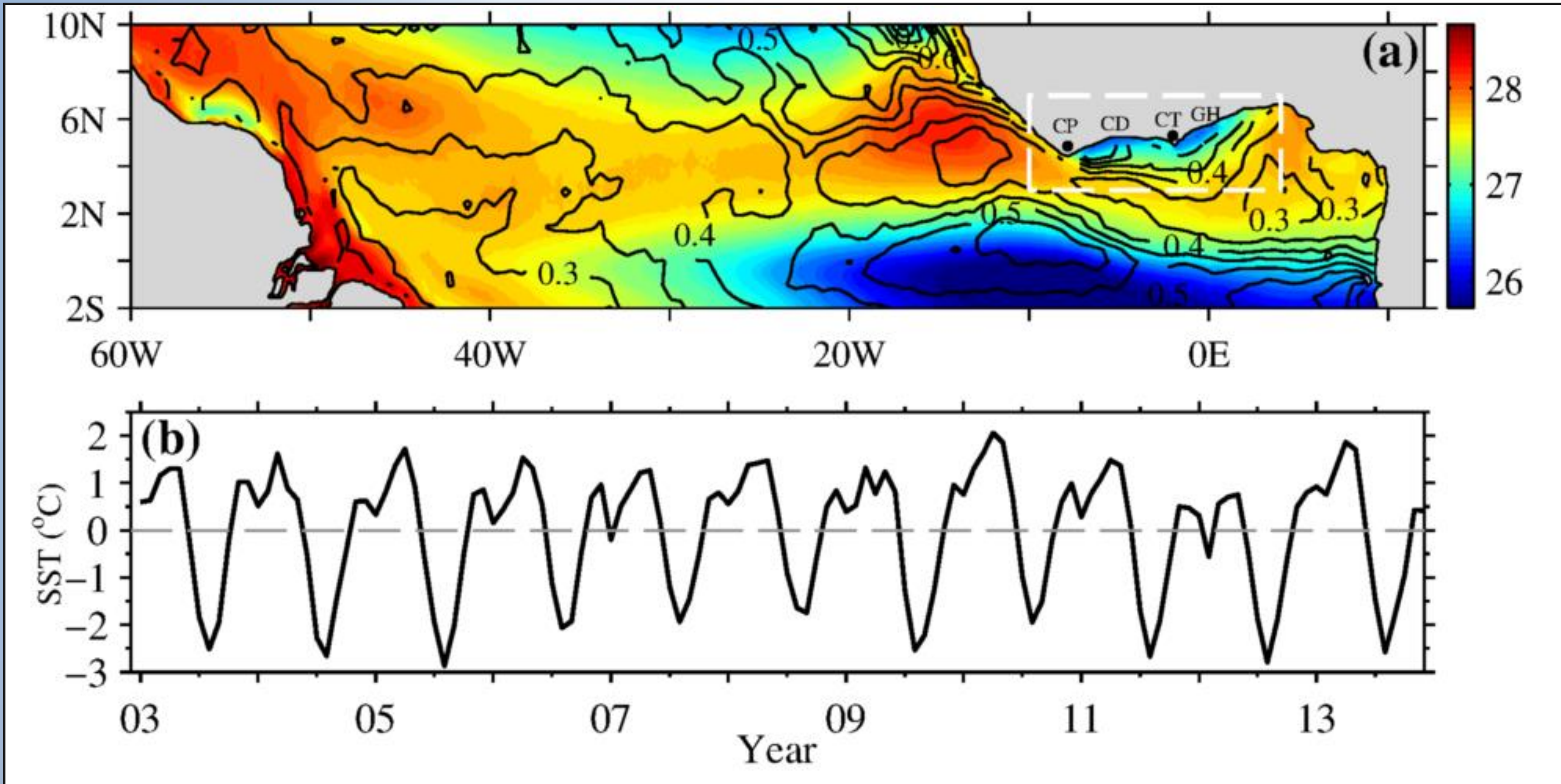
Ekman pumping velocity: $$w_e = \frac{1}{\rho_o f} \nabla \times \boldsymbol{\tau}$$ units = $m\, s^{-1}$

Compare the two: **M**/R; R~70-100 km

Upwelling Index: UI_{ET} and UI_{SST}

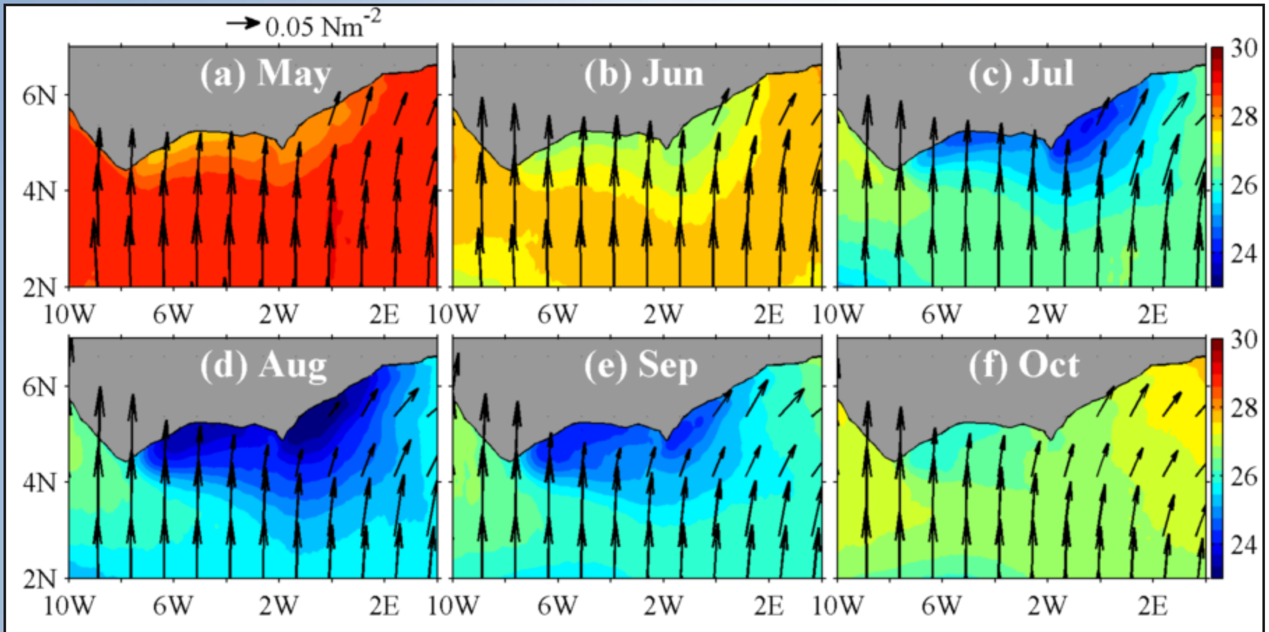


Results:



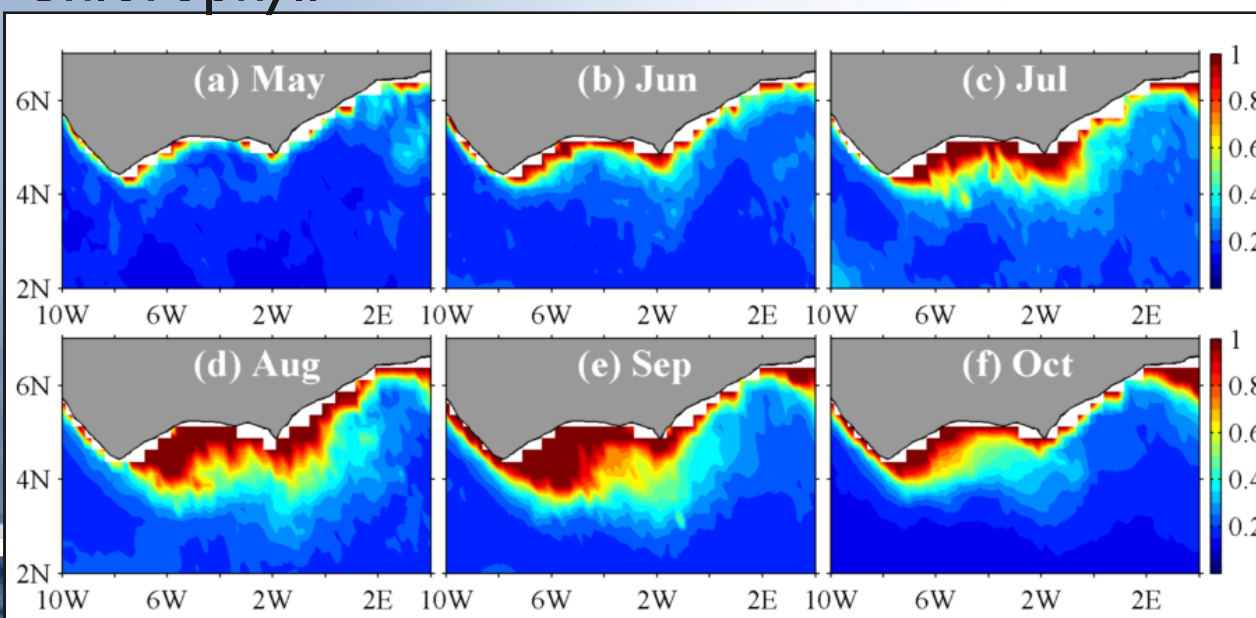
- 2 types of upwelling: equatorial and coastal
- Minor upwelling: typically 3 weeks; between December-March
- Major upwelling: July-September
- Significant variability in the NW GoG

SST, Winds



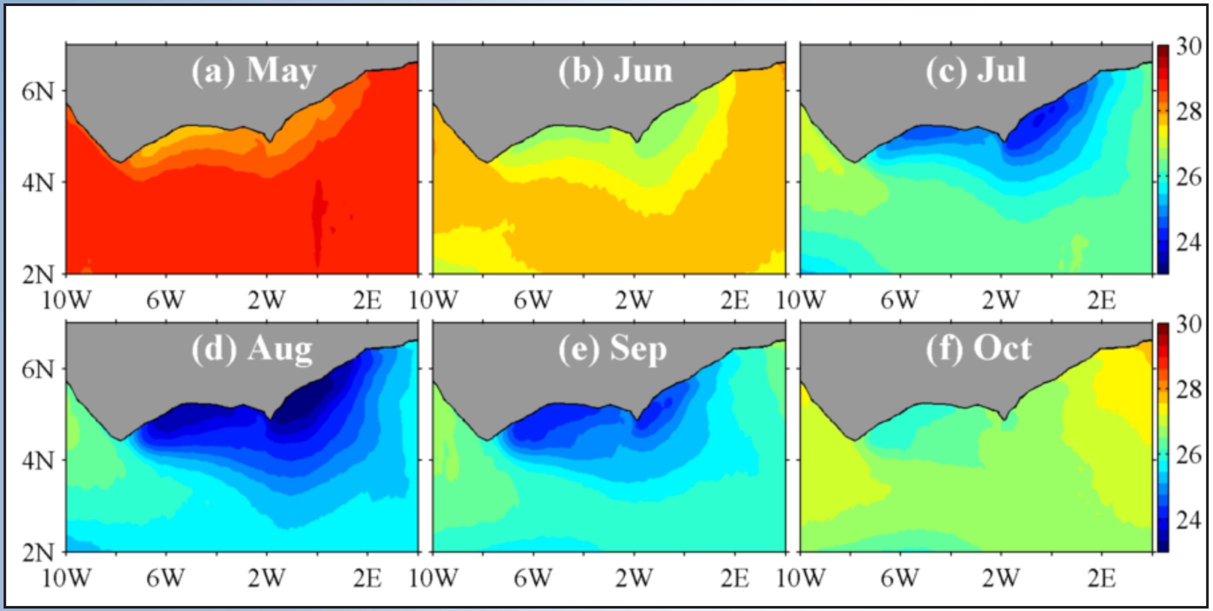
- Strong summer wind stress
- Non-favorable winds west of 2°W
- Western low SST from other regions??

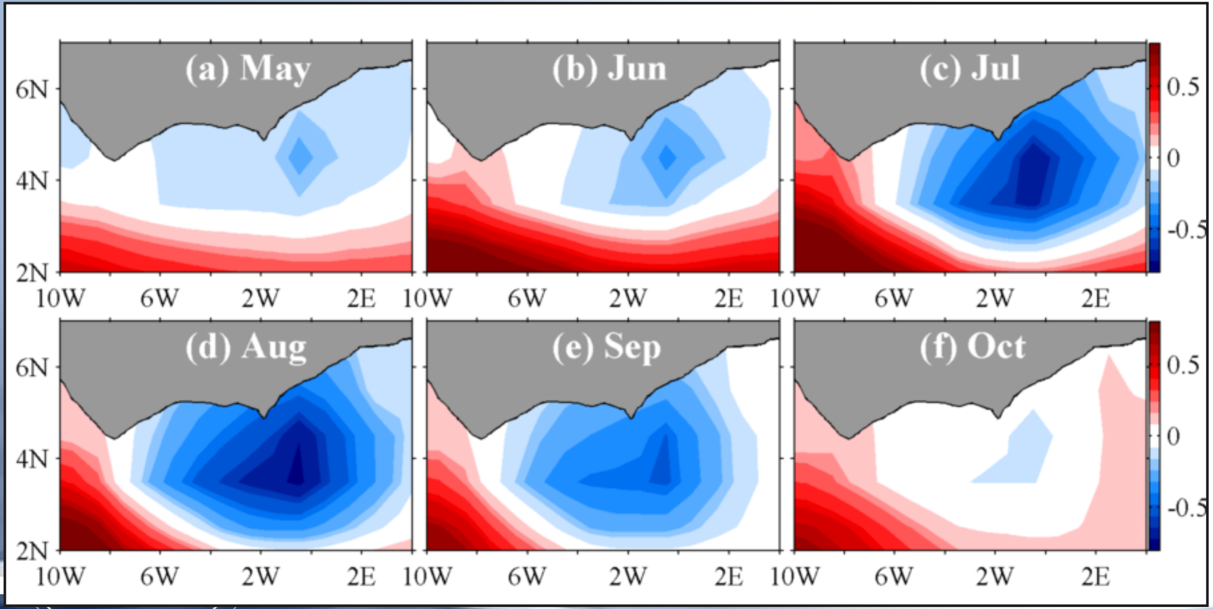
Chlorophyll



- Chl captures upwelling variations
- Offshore spreading of upwelling cell
- Potential for varying dynamics in the area

Upwelling indexes

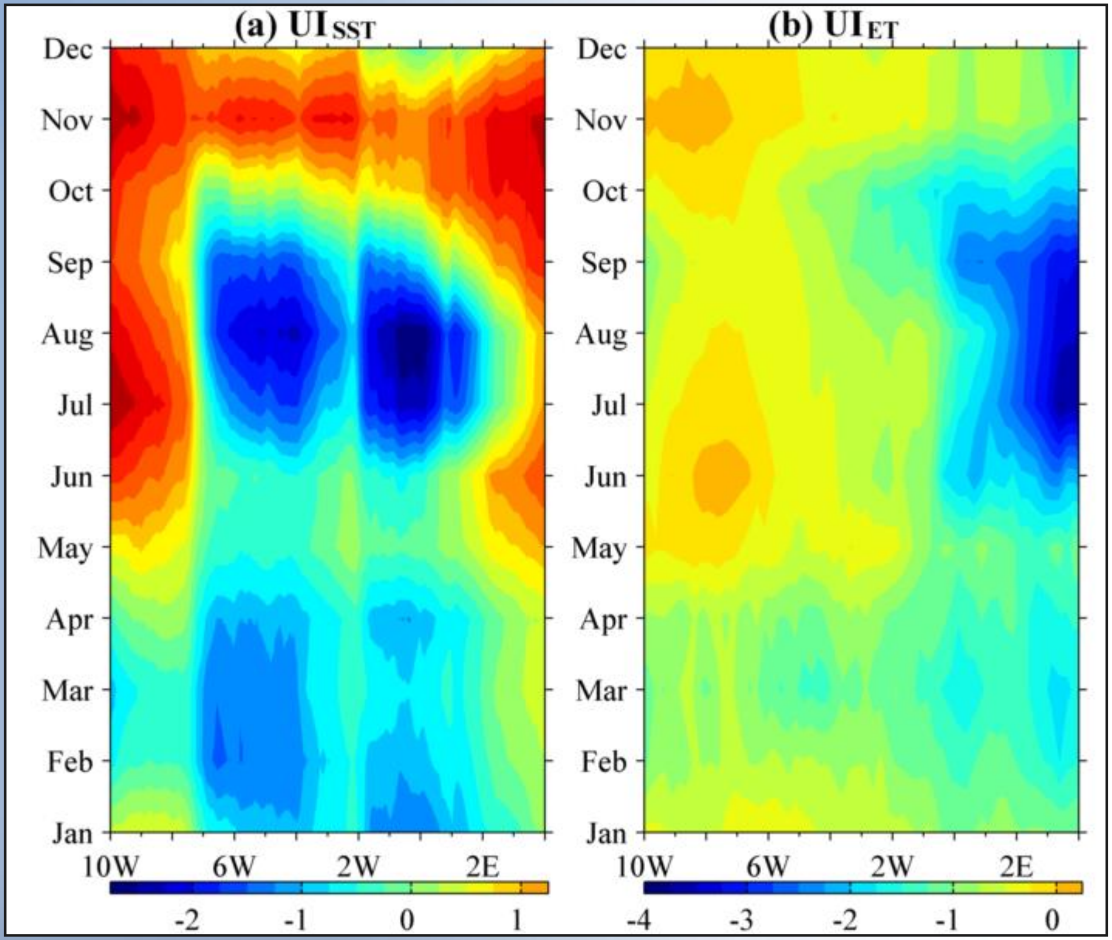


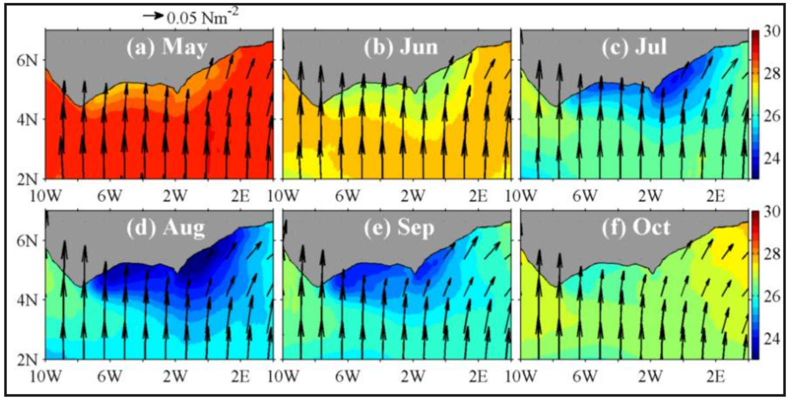


SST meridional gradient

- UI_{SST}: coastal minus offshore SST

Upwelling indexes

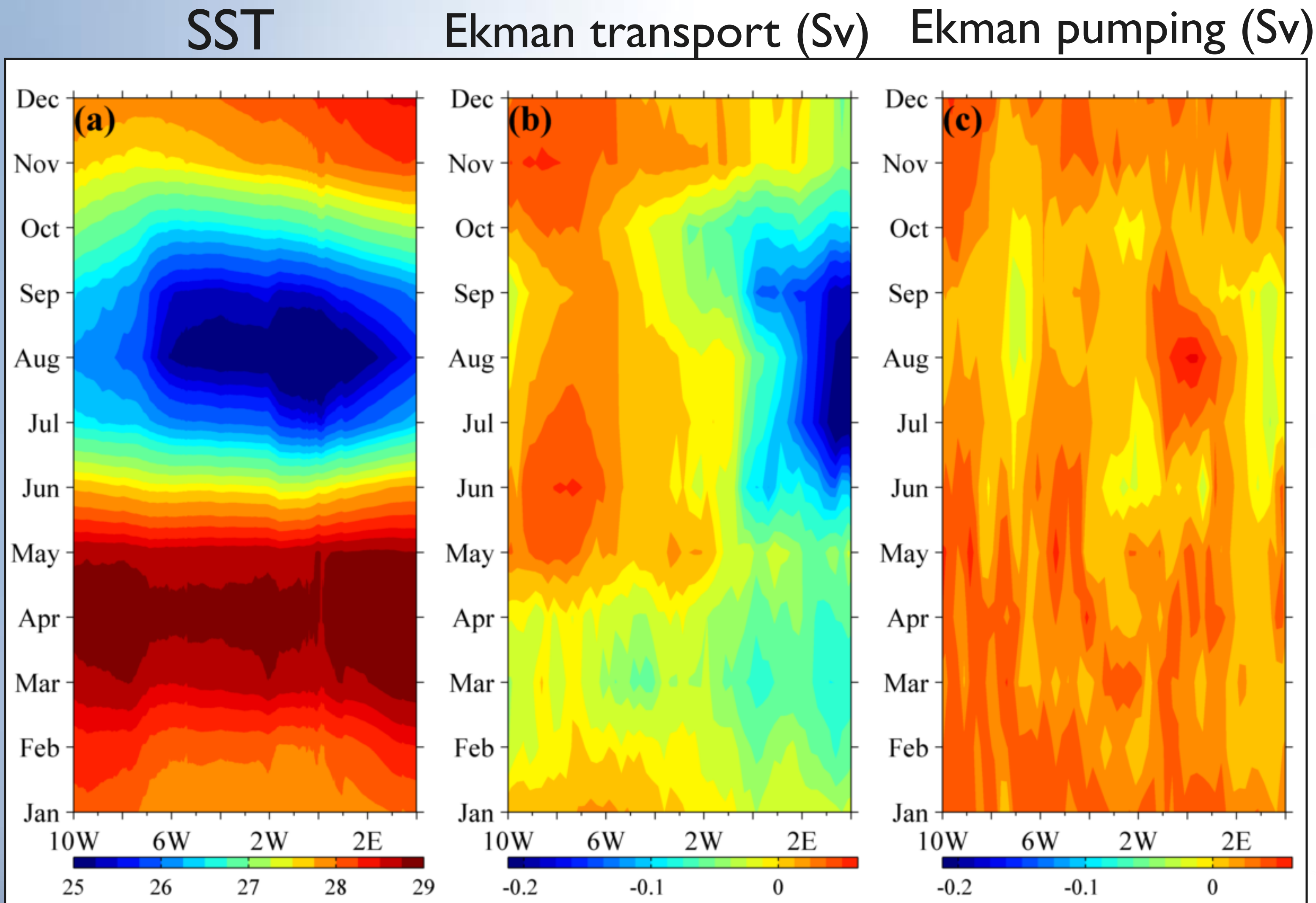




- UI_{SST} captures well the upwelling variability
- UI_{ET} suggests several upwelling periods
- UI_{ET} has assumptions
- UI_{ET} issues around capes

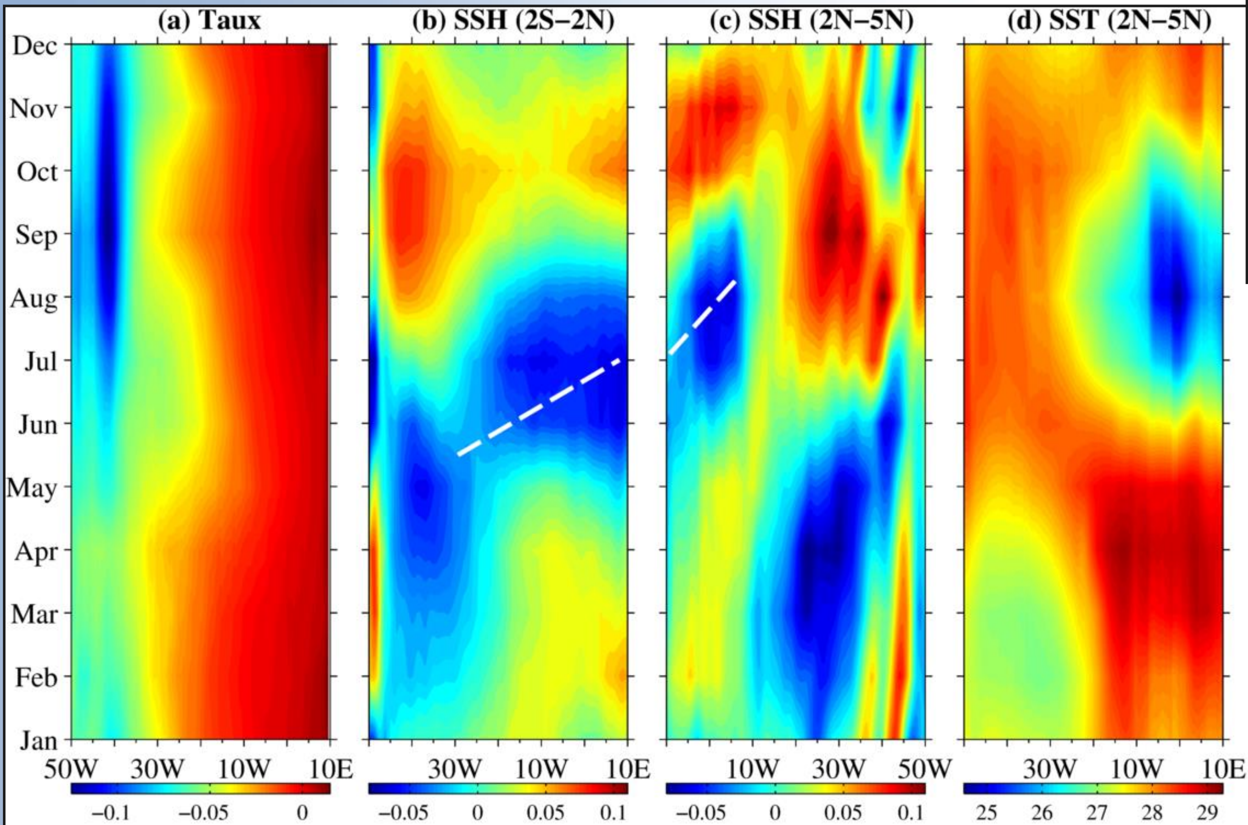
✓ Temporal match between UI_{SST} and UI_{ET}

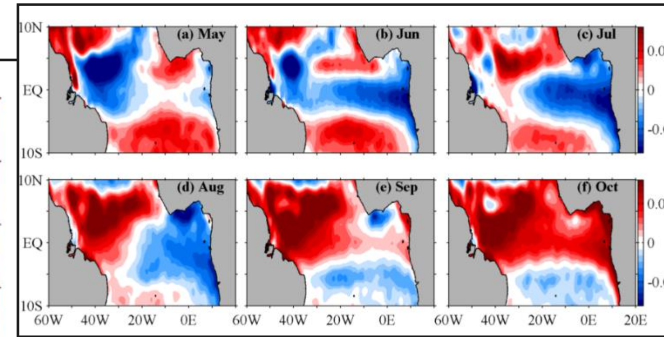
✓ Spatial mismatch between UI_{SST} and UI_{ET}



- Ekman transport more important than Ekman pumping
- Positive wind stress curl east of Cape Three point
- Evidence of remote contribution

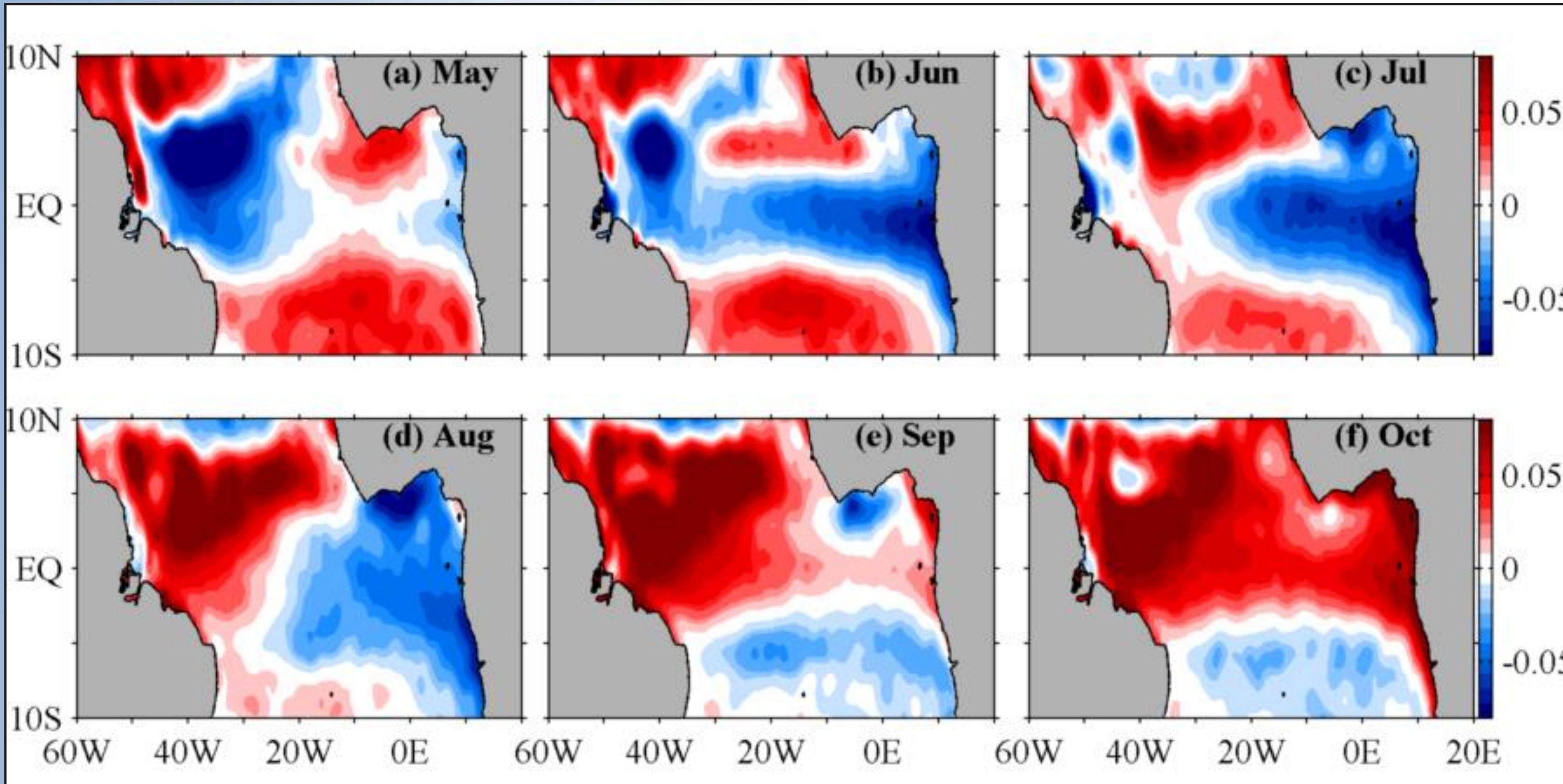
Remote contribution





- Westward winds in west; warm volume water in west
- Pressure gradient balances wind stress
- Winds excite Kelvin waves; reach east by July
- Waves shoal thermocline in east; low SSHA; upwelling

Remote contribution



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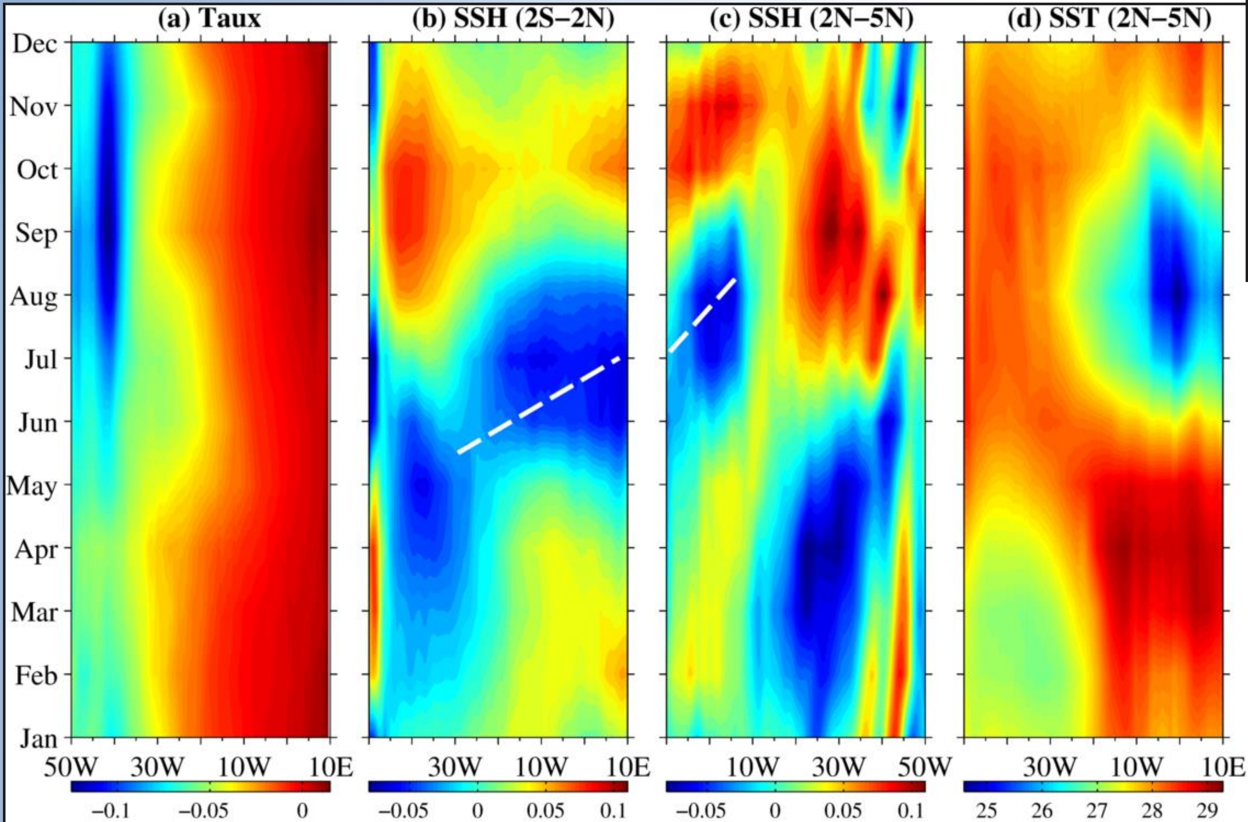

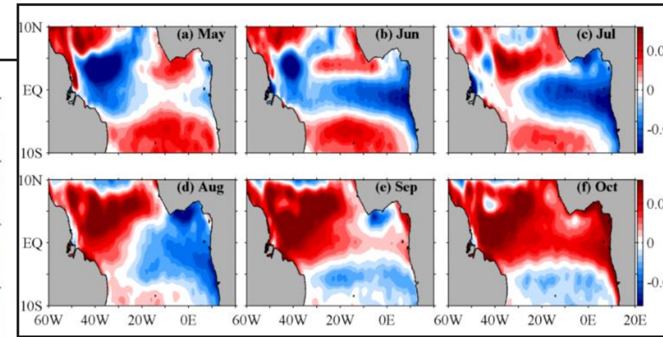

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Summary

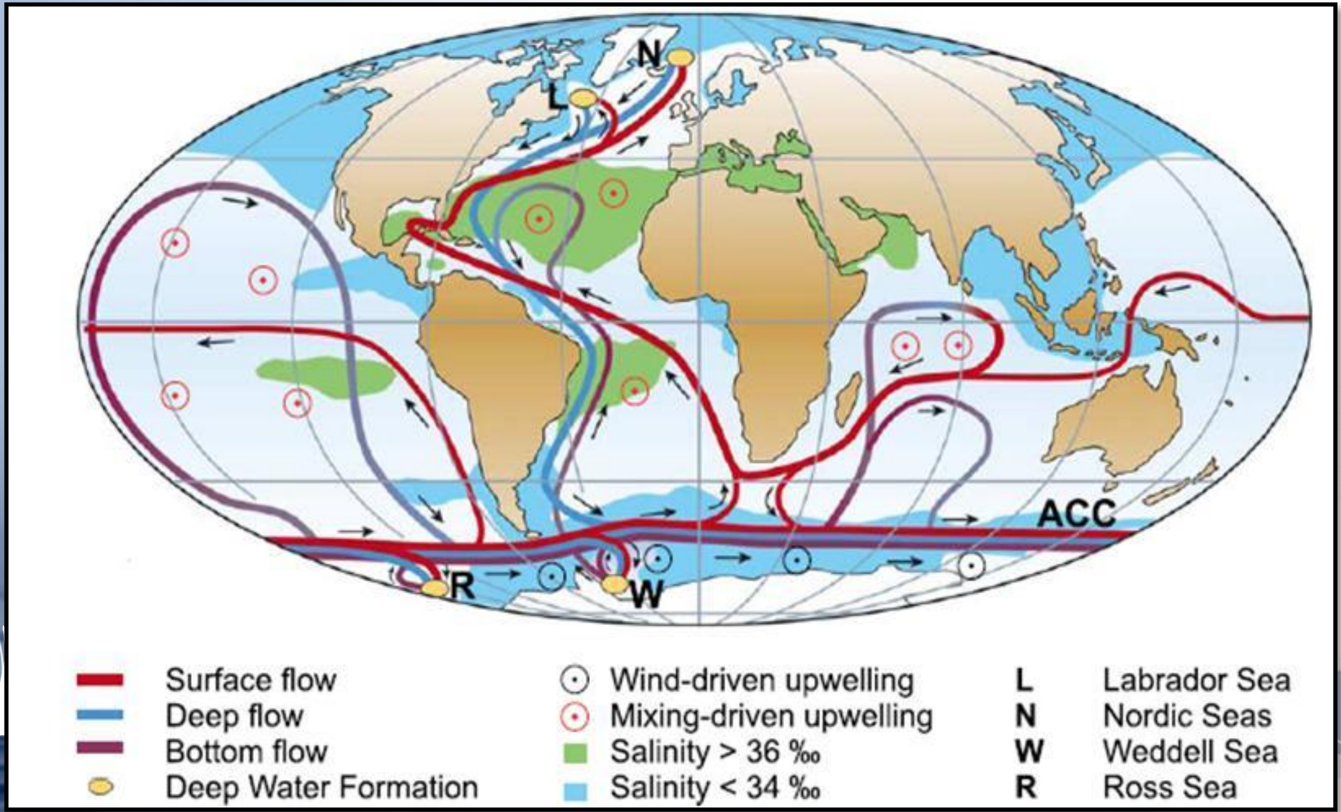
- Satellite data resolves SST near coast
- Finer spatial information from satellite vrs. in-situ data
- Ekman transport contributed more to upwelling than Ekman pumping
- Remote contribution is important
- Kelvin waves enhance upwelling in NW GoG

Satellite observations of Indian Ocean salinity

(Nyadjro and Subrahmanyam, IEEE GRSL 2014)

Importance of salinity

- ✓ density/water mass
- ✓ ocean circulation
- ✓ hydrological cycle
- ✓ air-sea interaction



Schmitz, 2005

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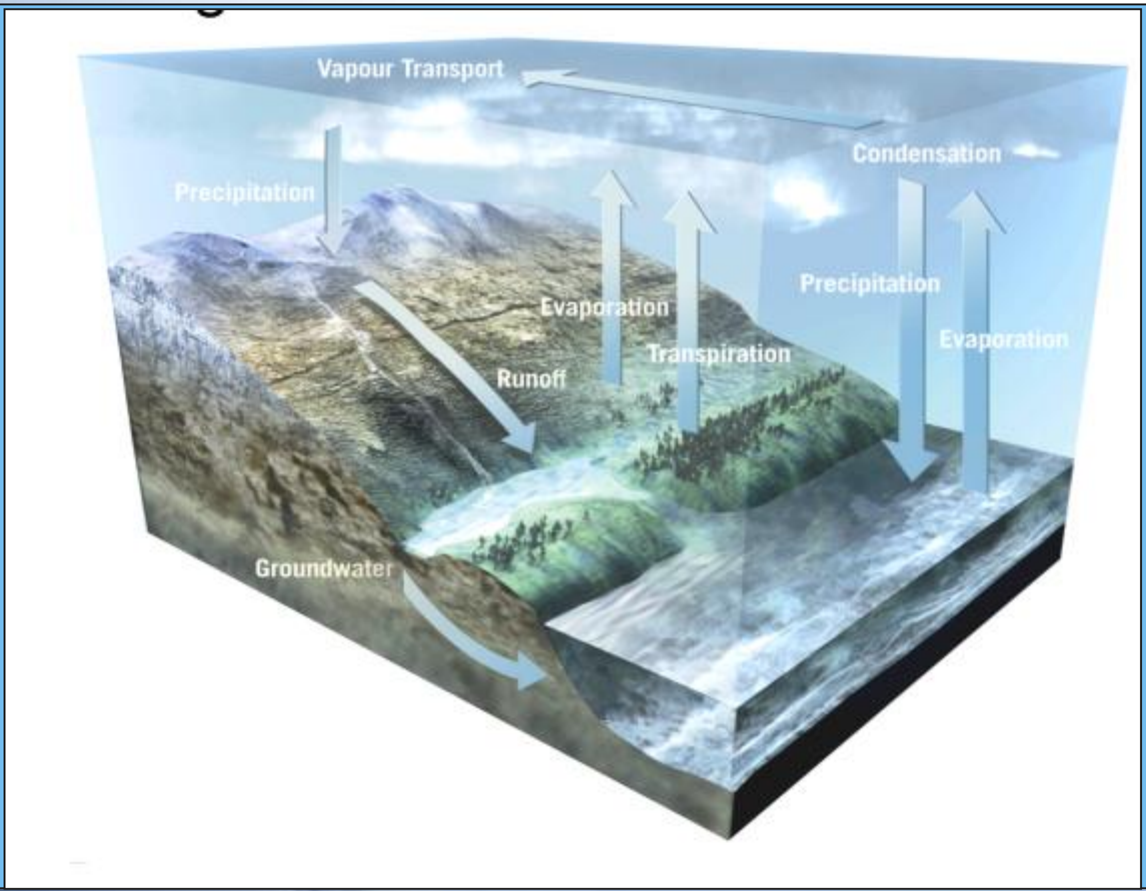
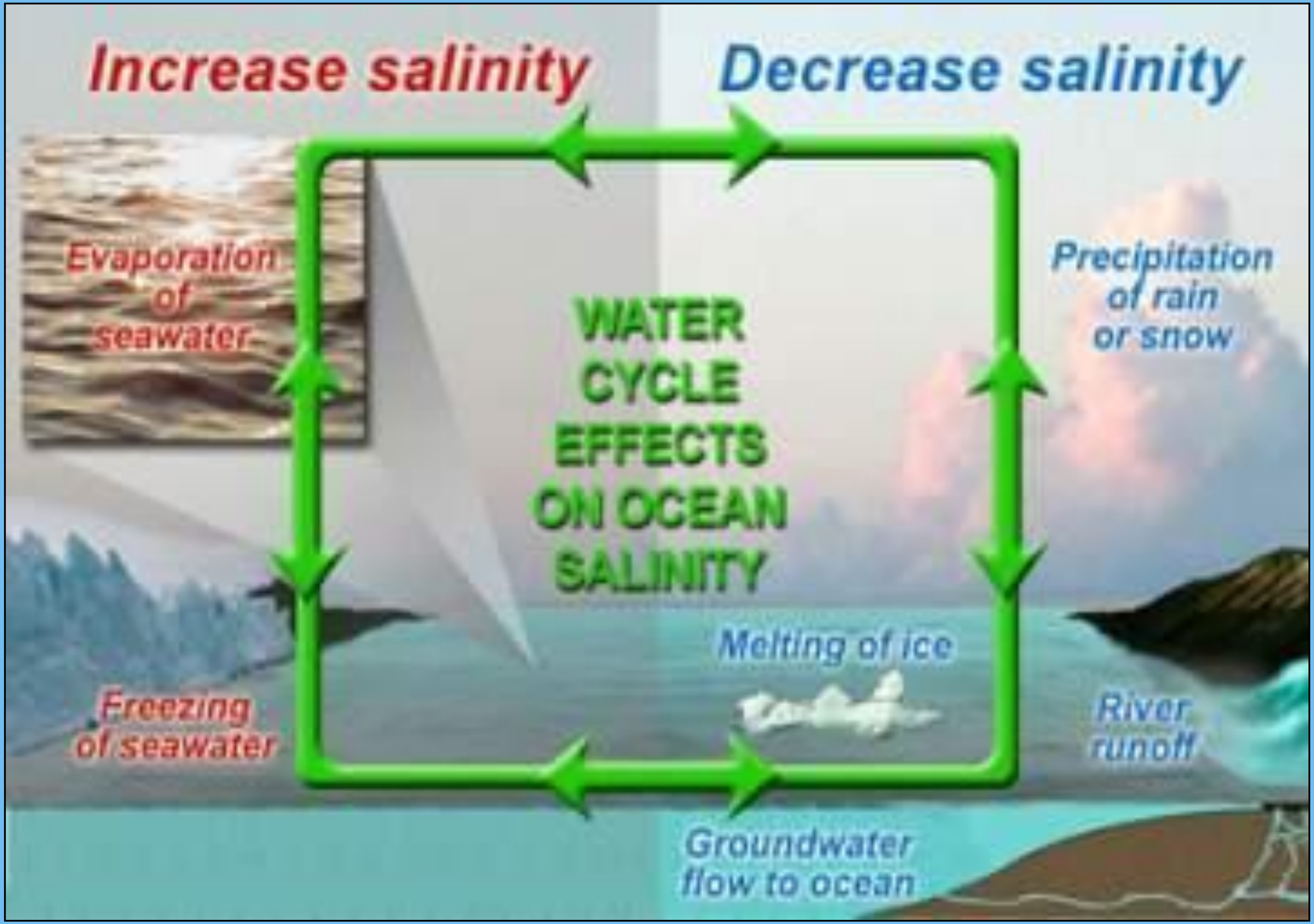
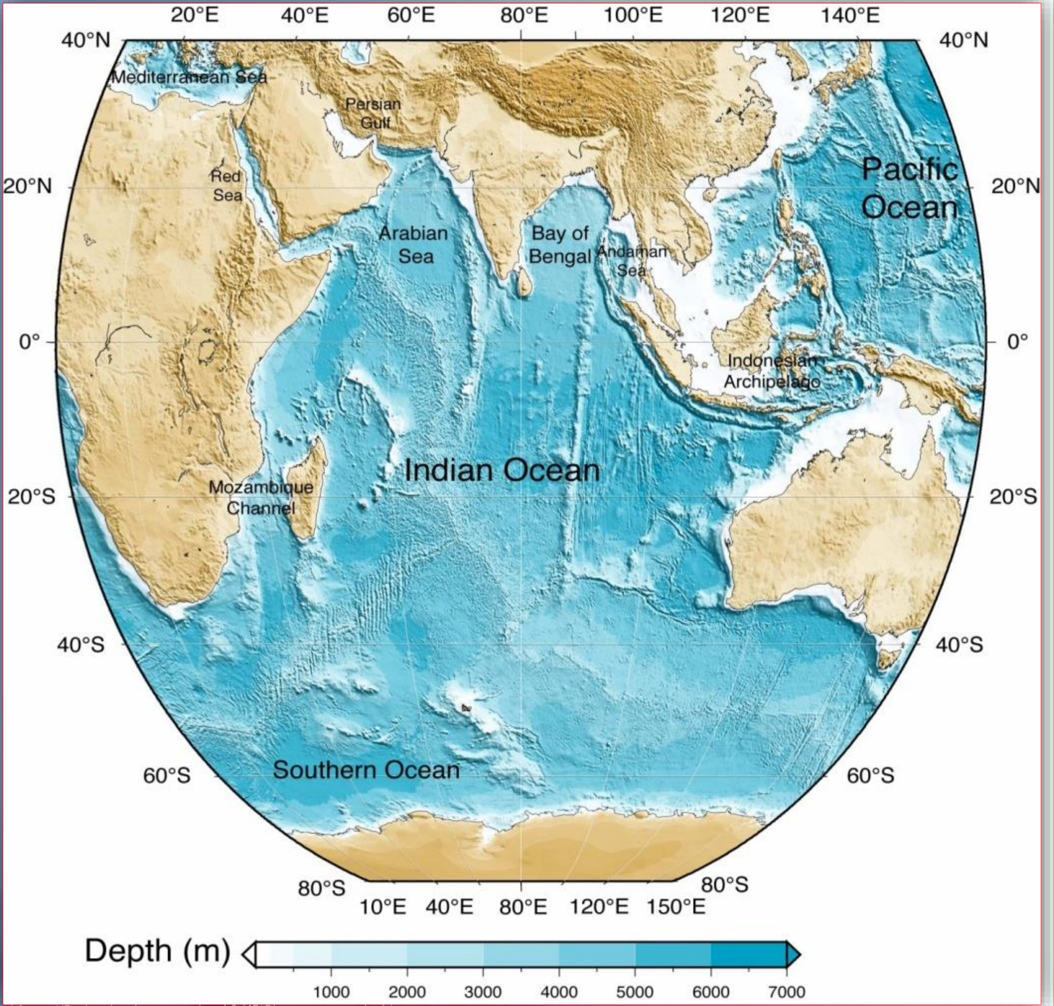


Importance of salinity



OCEAN SALINITY AND CLIMATE: link between the water cycle and the ocean circulation

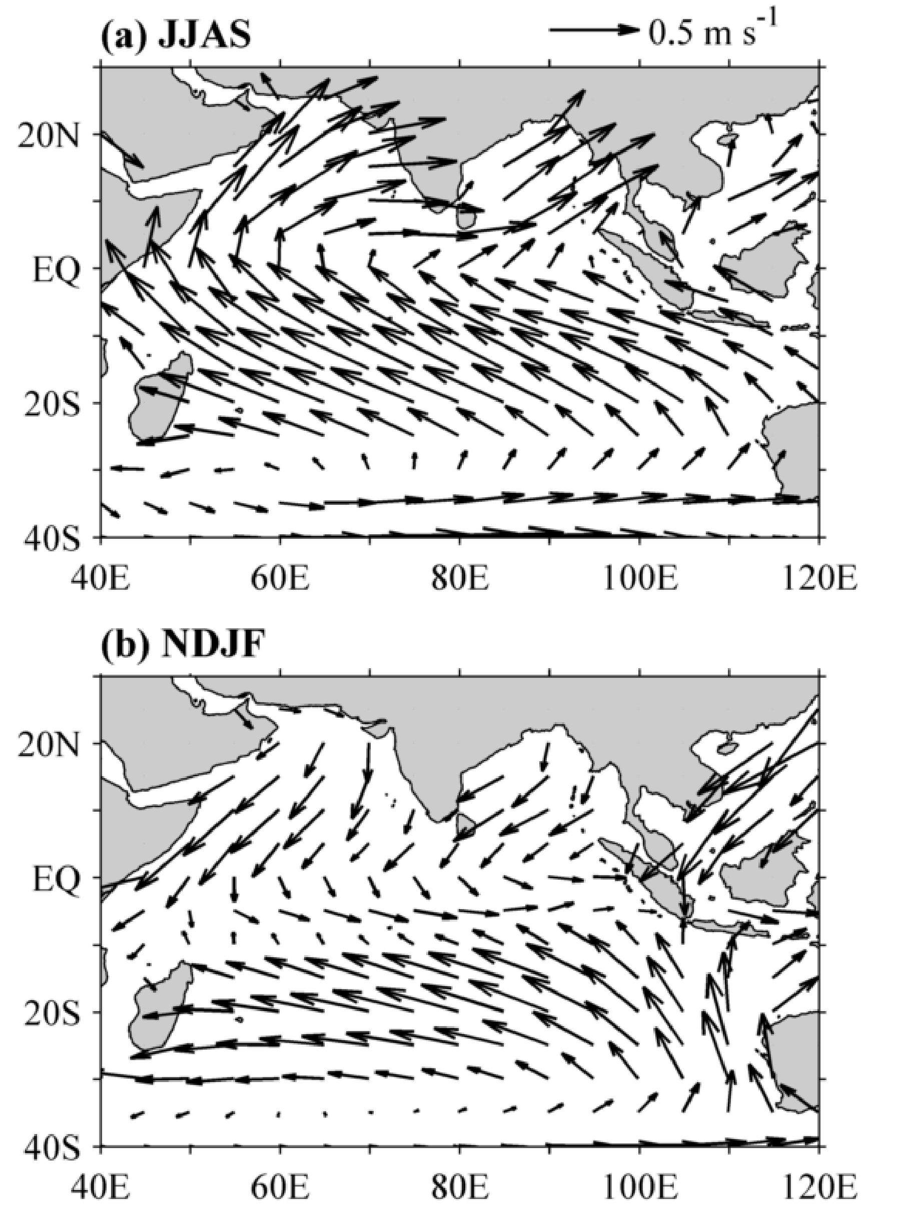
The Indian Ocean



Indian Ocean sea floor. Han et al. 2011

- Several basins & ridges
- Northern basin – no connection to any open oceans
- Pacific Ocean and the ITF – warm, fresh water
- Seasonal reversal of winds and currents
- Southwest monsoon: June -Sept
- Northeast monsoon: Nov-Feb

The Indian Ocean



Monsoon winds

- Several basins & ridges
- Northern basin – no connection to any open oceans
- Pacific Ocean and the ITF – warm, fresh water
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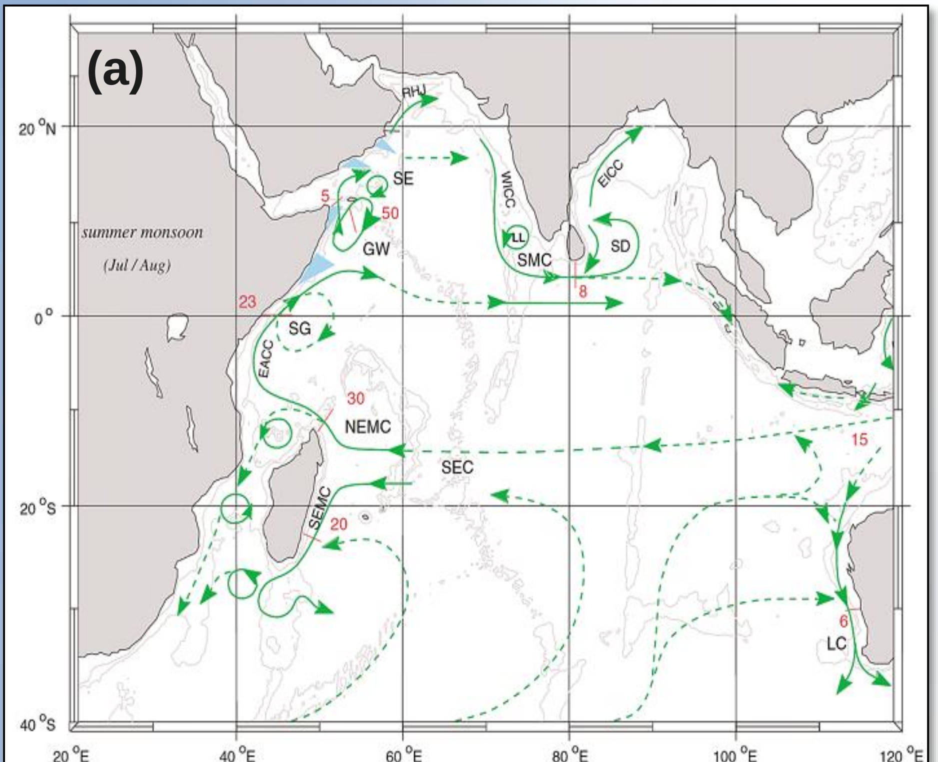
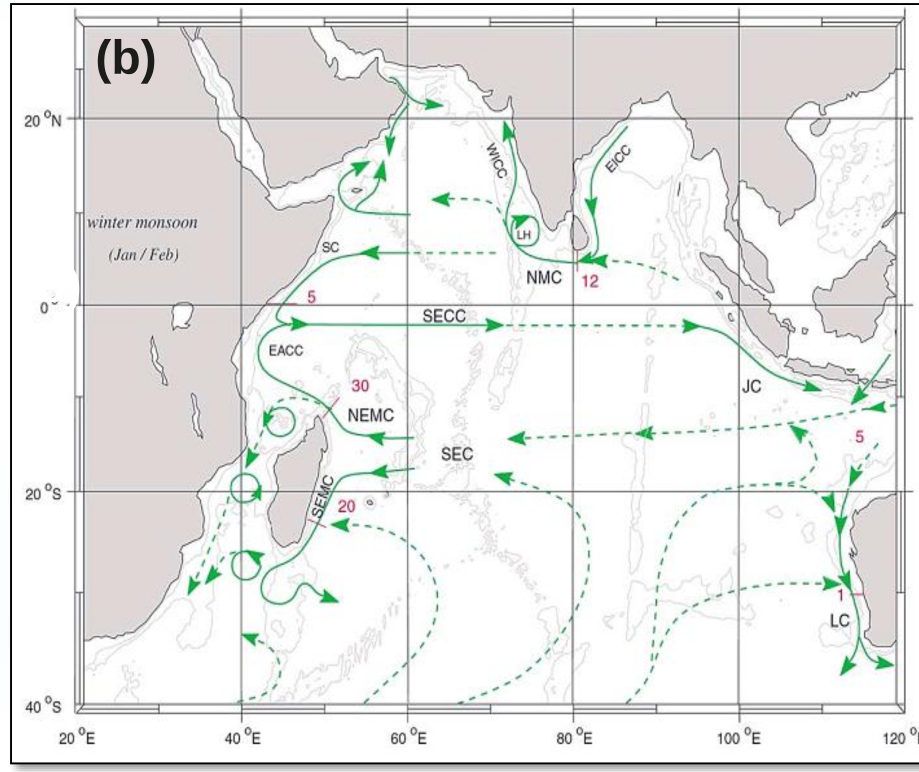
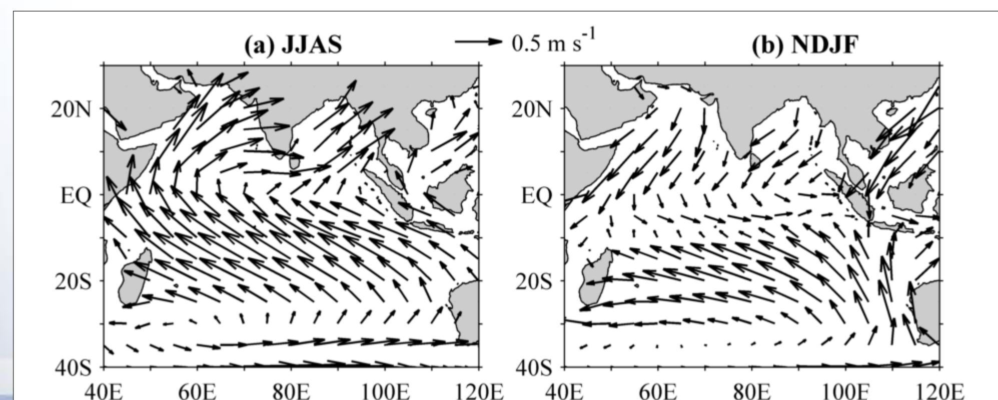
Current patterns in the Indian Ocean





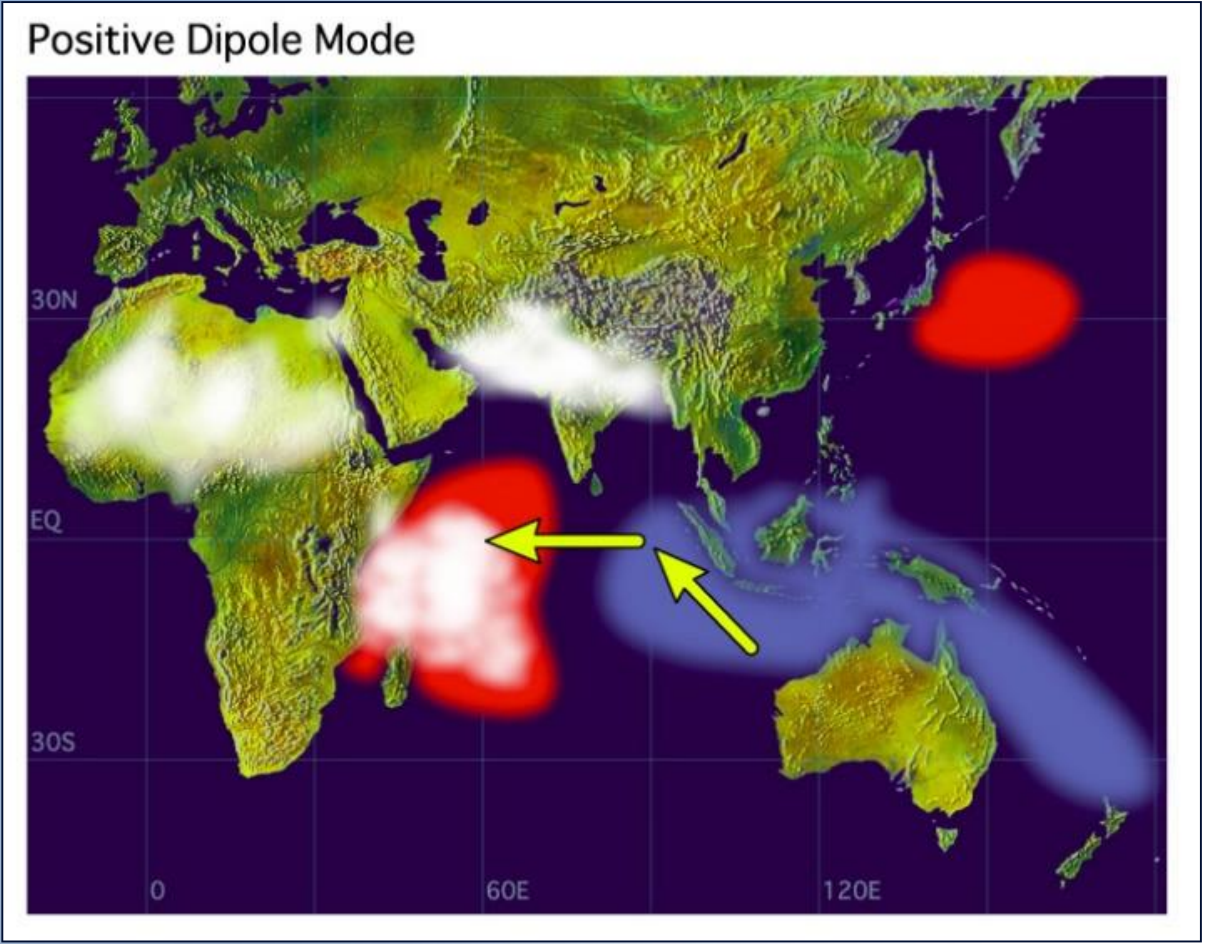
A schematic representation of Indian Ocean currents during (a) the Southwest monsoon and (b) the Northeast monsoon (Schott and McCreary 2001).



Objectives

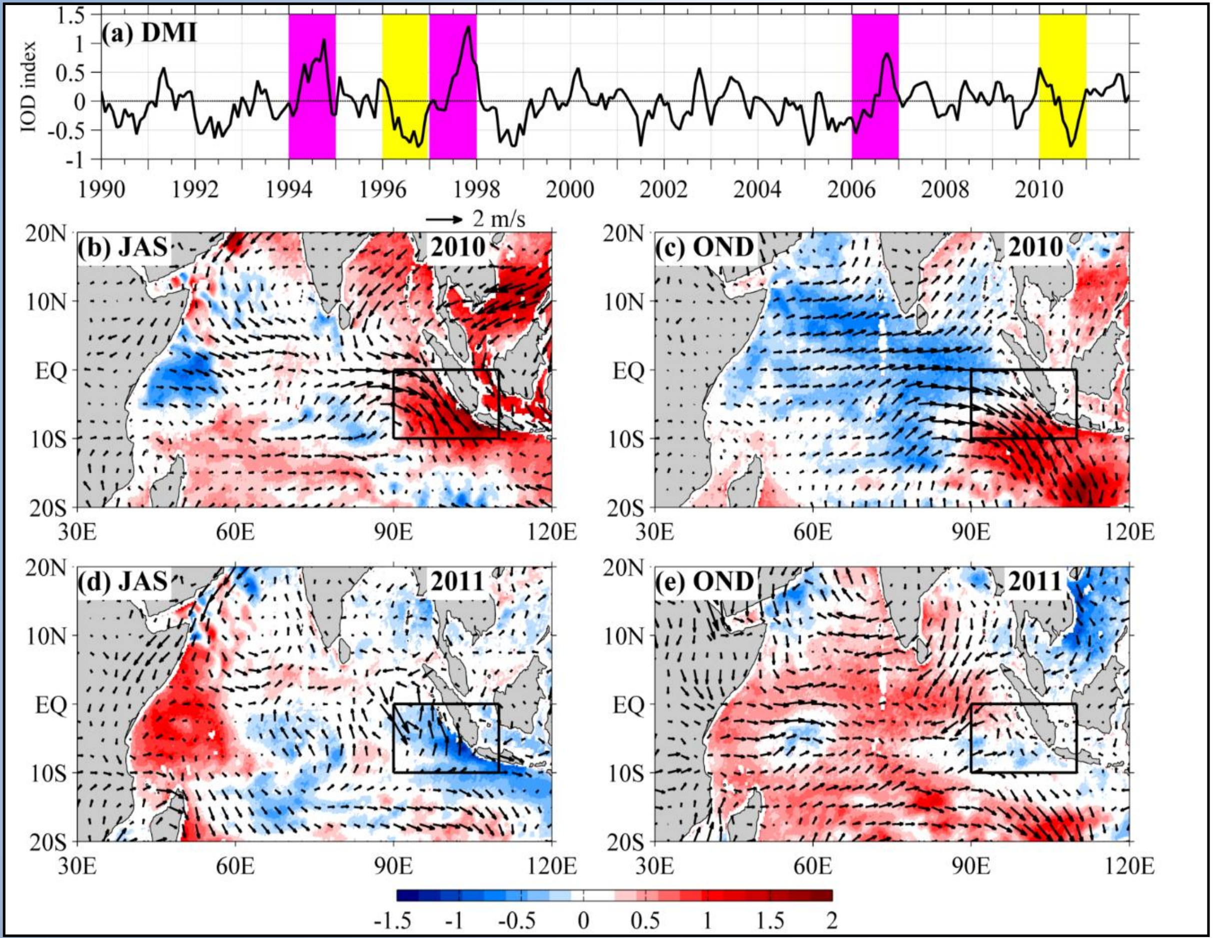
- Validation of satellite salinity in the Indian Ocean
- Examine salinity variability during IOD
- Quantify the salinity budgets in Central Equatorial and Eastern Indian Ocean regions

Indian Ocean Dipole (IOD)



- Positive IOD: High SST in west and low SST in east
- Negative IOD: Low SST in west and high SST in east
- IOD peaks in SON
- El Nino: easterly winds weaken; warm Pacific waters move westward

Indian Ocean Dipole (IOD)



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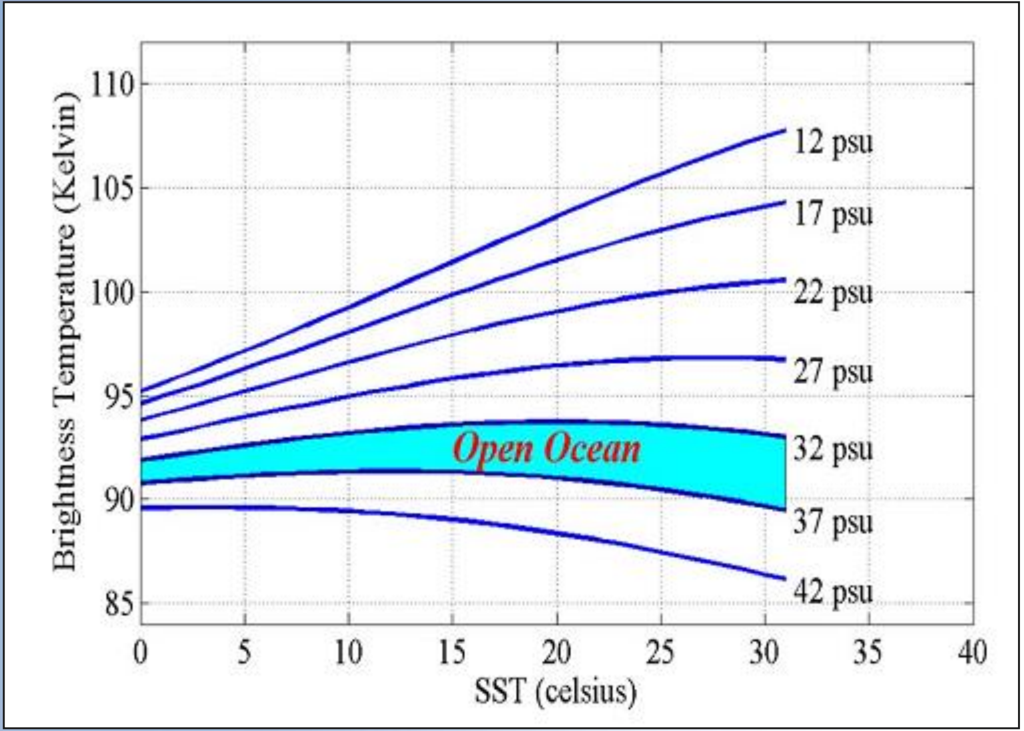
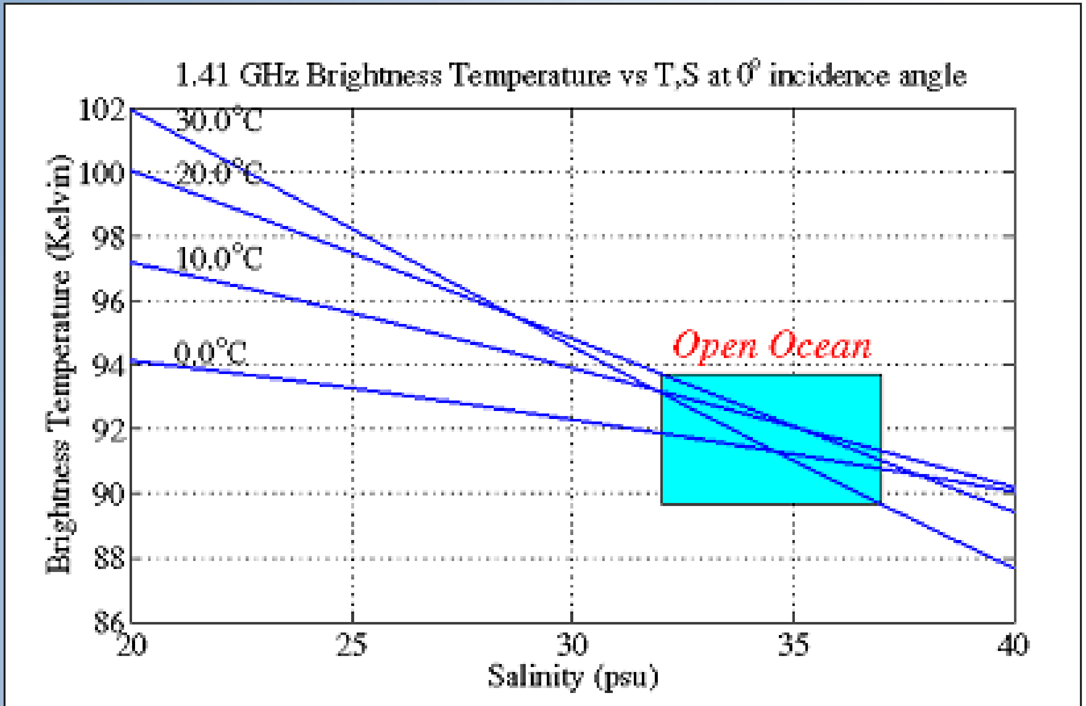
The Technology



Dependence of T_B at nadir with SST and SSS [*Camps et al.*, 2003]

- L-Band microwave (passive) radiometer
- 1.4 GHz
- Radiometer measures the brightness temperature (T_b)

- T_b is linked to salinity through the dielectric constant of the sea water via its emissivity, e:
- $$T_b = eT$$
- This is then linked to the Klein-Swift model (1977) & retrieval algorithms to obtain SSS



The Technology

T_b = $e\,T$

e = Emissivity

T = Physical Temperature

e = function (freq, S, T)

= $1 - R^2$

= $1 - [(1-\sqrt{\varepsilon})/(1+\sqrt{\varepsilon})]^2$

(normal incidence)

ε = Relative Dielectric Constant

= ε(freq, S, T)

- T_b is linked to salinity through the dielectric constant of the sea water via its emissivity, e:
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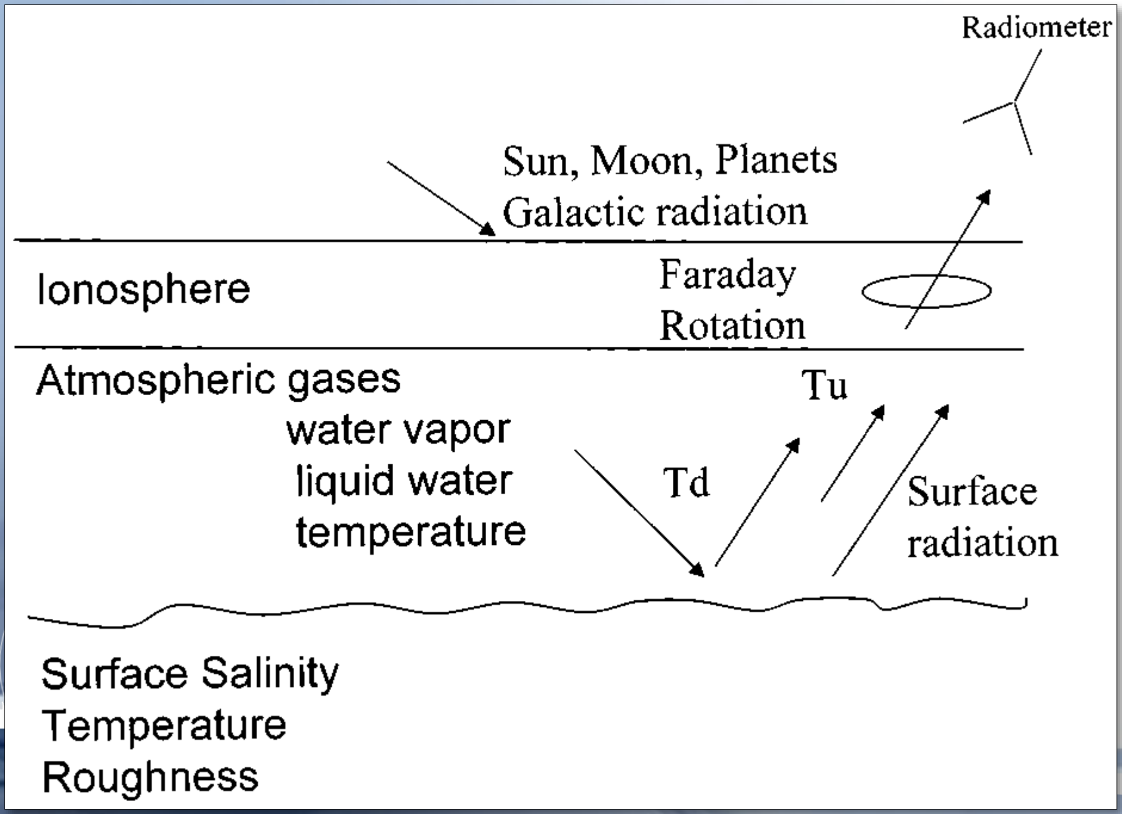
The Technology

Error sources:

- solar reflection
- atmospheric oxygen
- galactic noises
- SST
- wind speed (sea surface roughness)

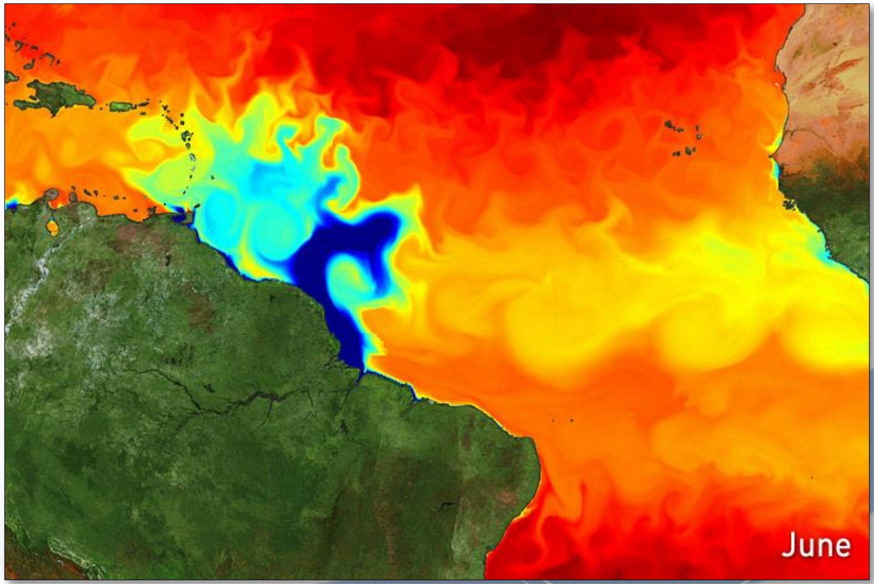


Geophysical sources that influence the microwave radiation from sea surface [*Yueh et al.*, 2001]

Soil Moisture and Ocean Salinity (SMOS)

- Launched on 2 November 2009
- Soil moisture (SM) and ocean salinity (OS)
- Resolution : 1-3 days & 45 km
- Accuracy of 0.1 psu/ 30 days/200 km

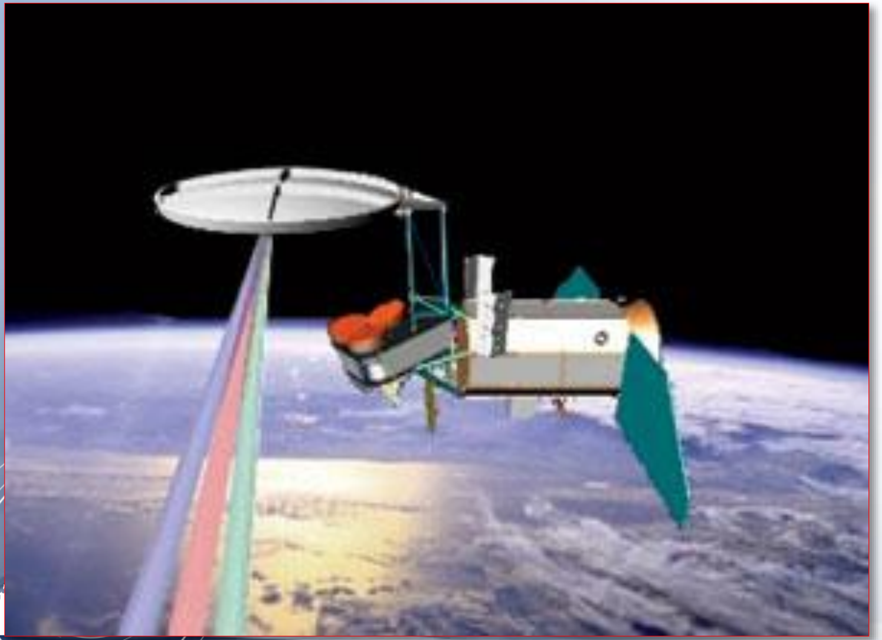
The SMOS satellite



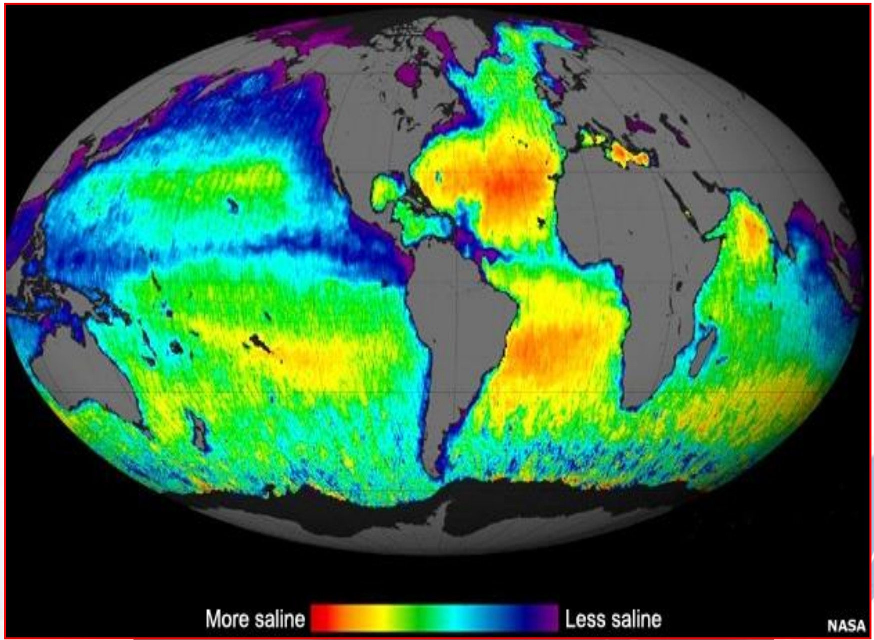
Amazon freshwater plume from SMOS

Aquarius

- NASA & CONAE; launched10 June 2011; died June 2015
- MWR-ocean wind & direction, rain, sea ice
- NIRST – SST; 3 bands
- Resolution: 7 days & 150 km
- Accuracy: 0.2 psu/30 days/150 km

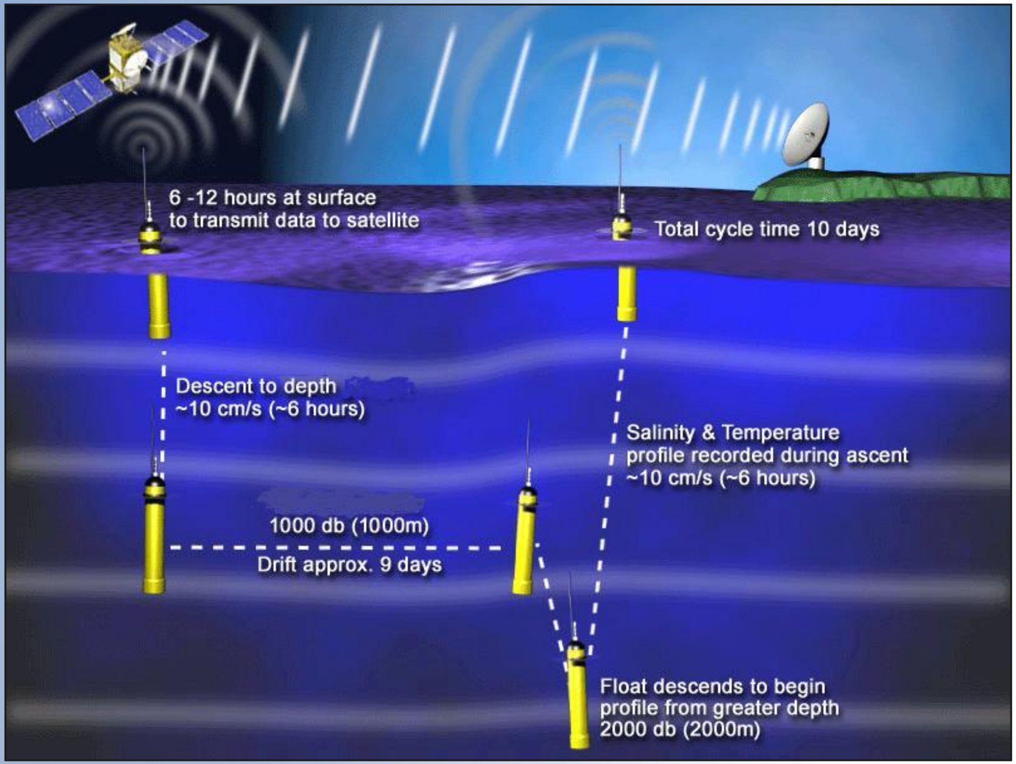


Aquarius satellite in orbit

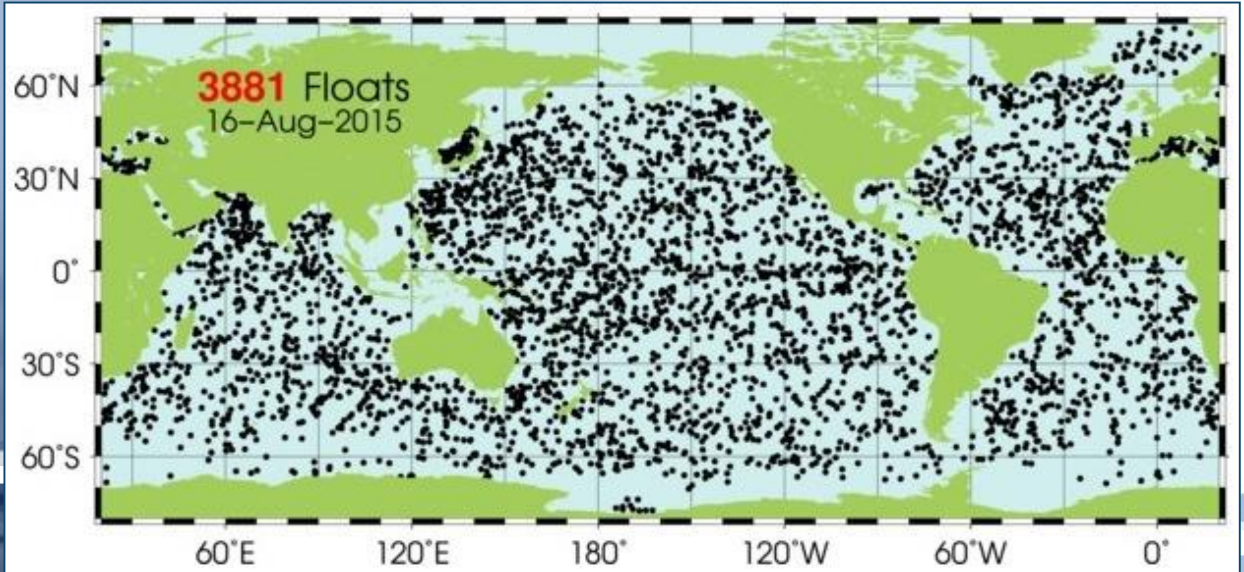


Aquarius global mean SSS

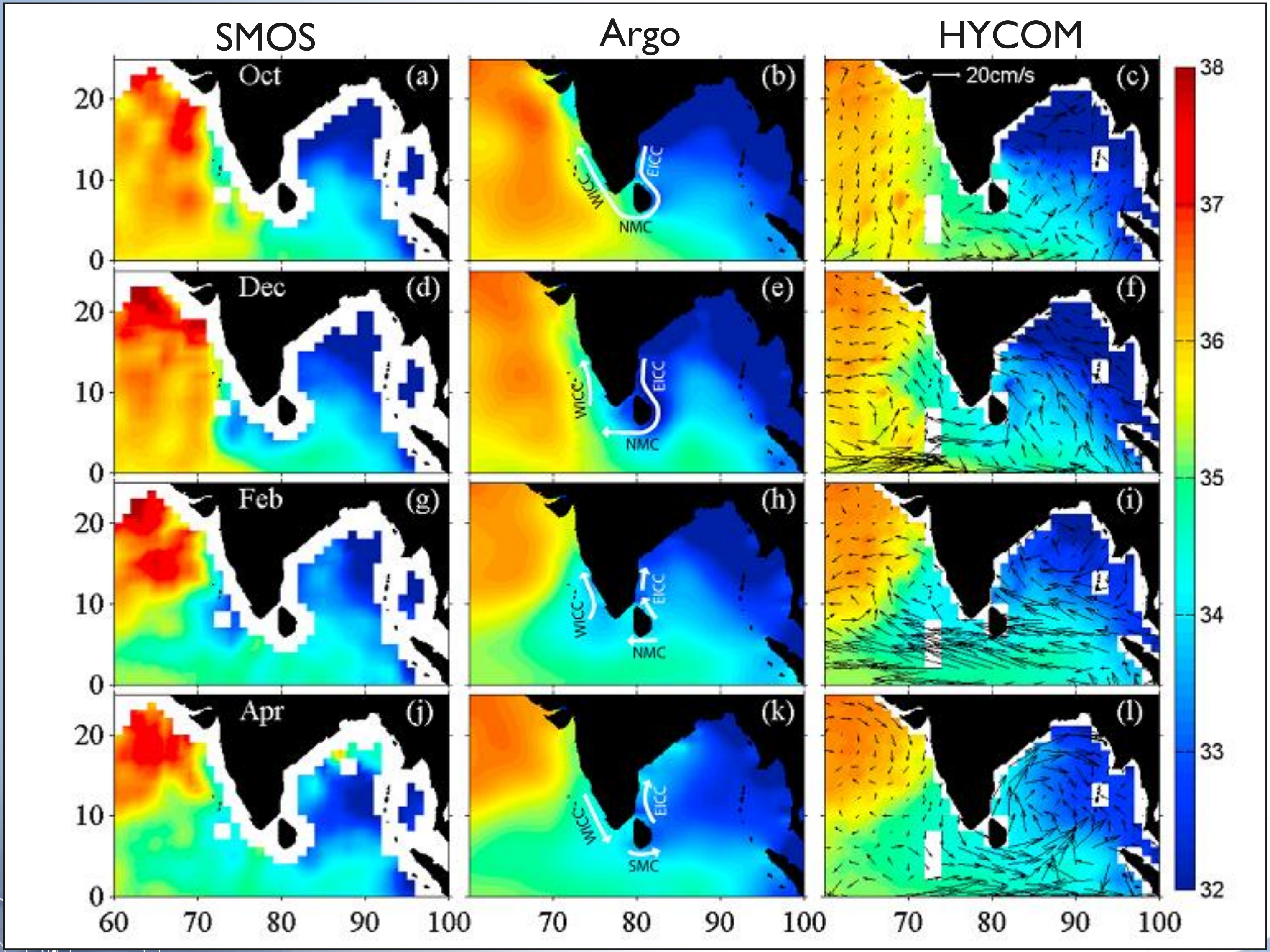
Argo float data



Argo is a global array of more than 3,800 free-drifting profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean.

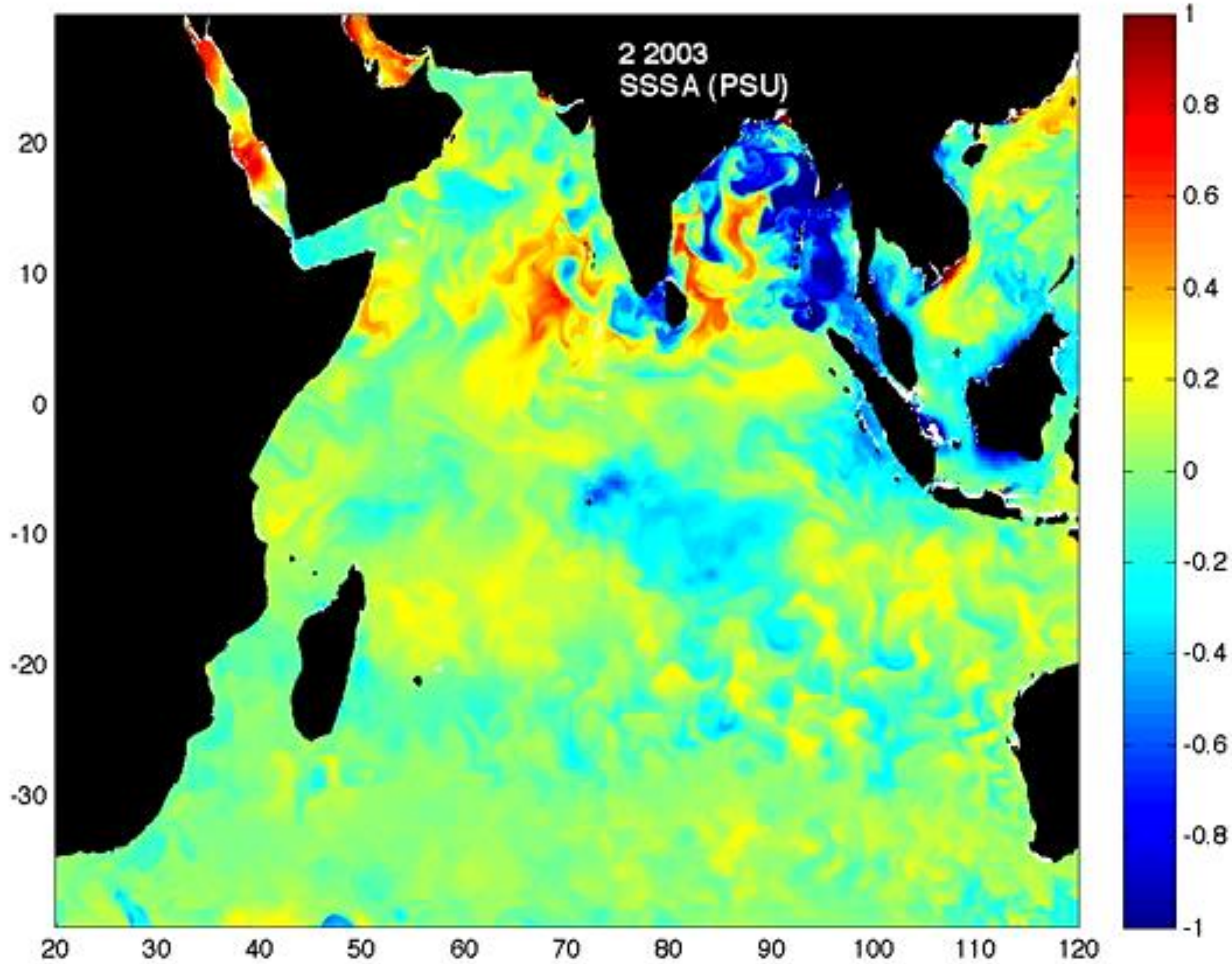


Indian Ocean Salinity



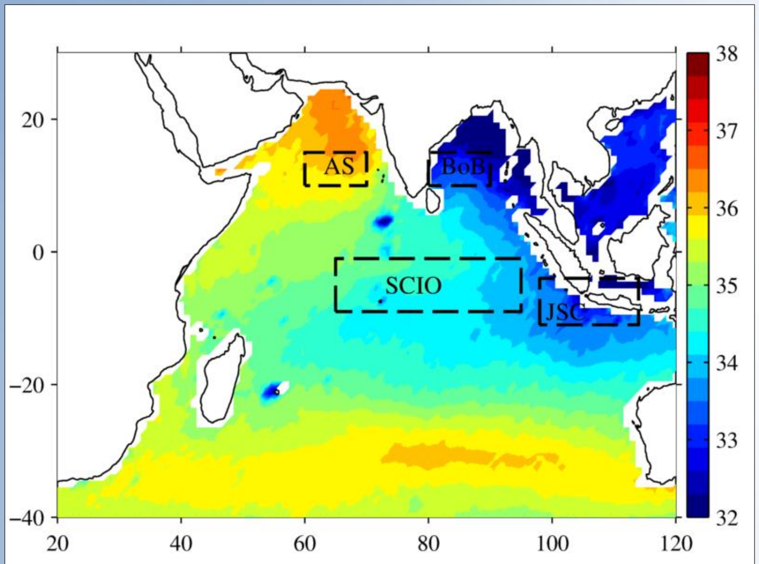
- SSS in the northern Indian Ocean is highly variable

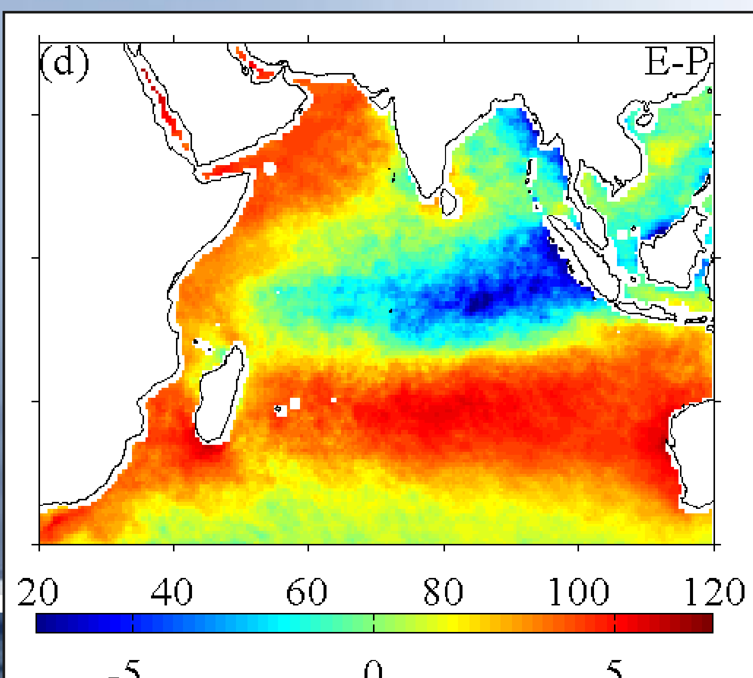
Indian Ocean Salinity

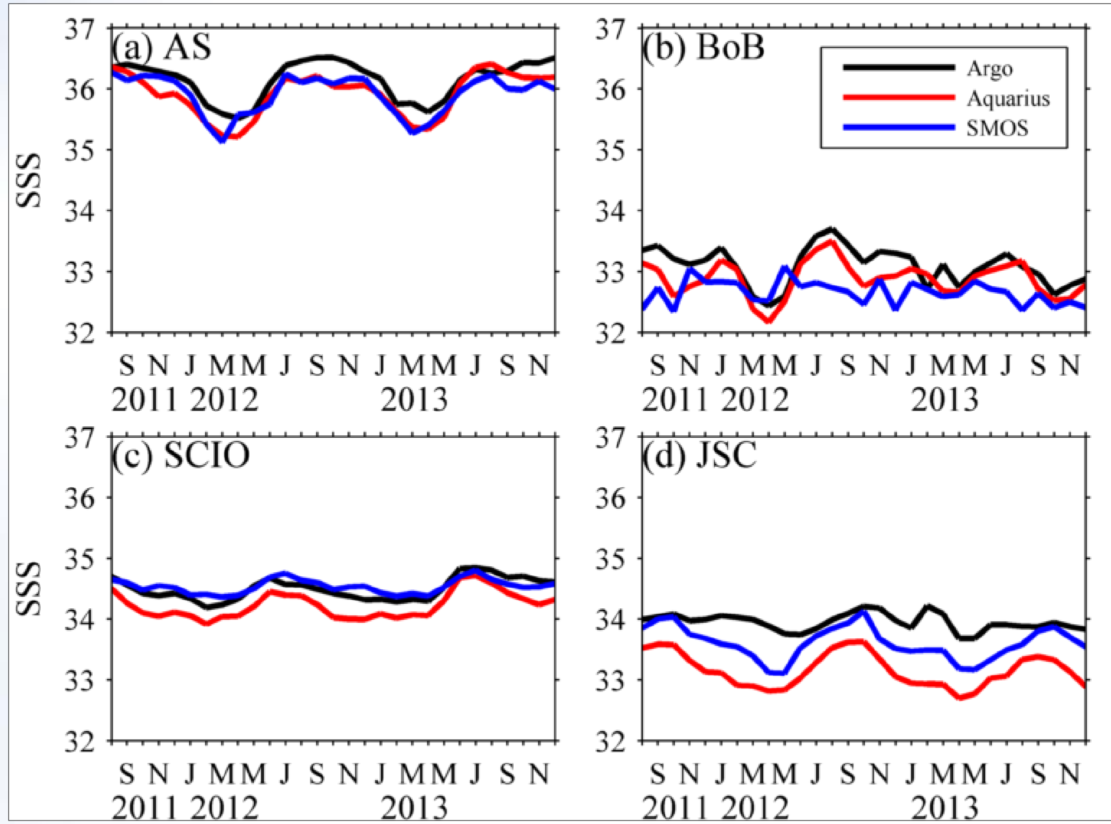


- SSS in the northern Indian Ocean is highly variable

Data

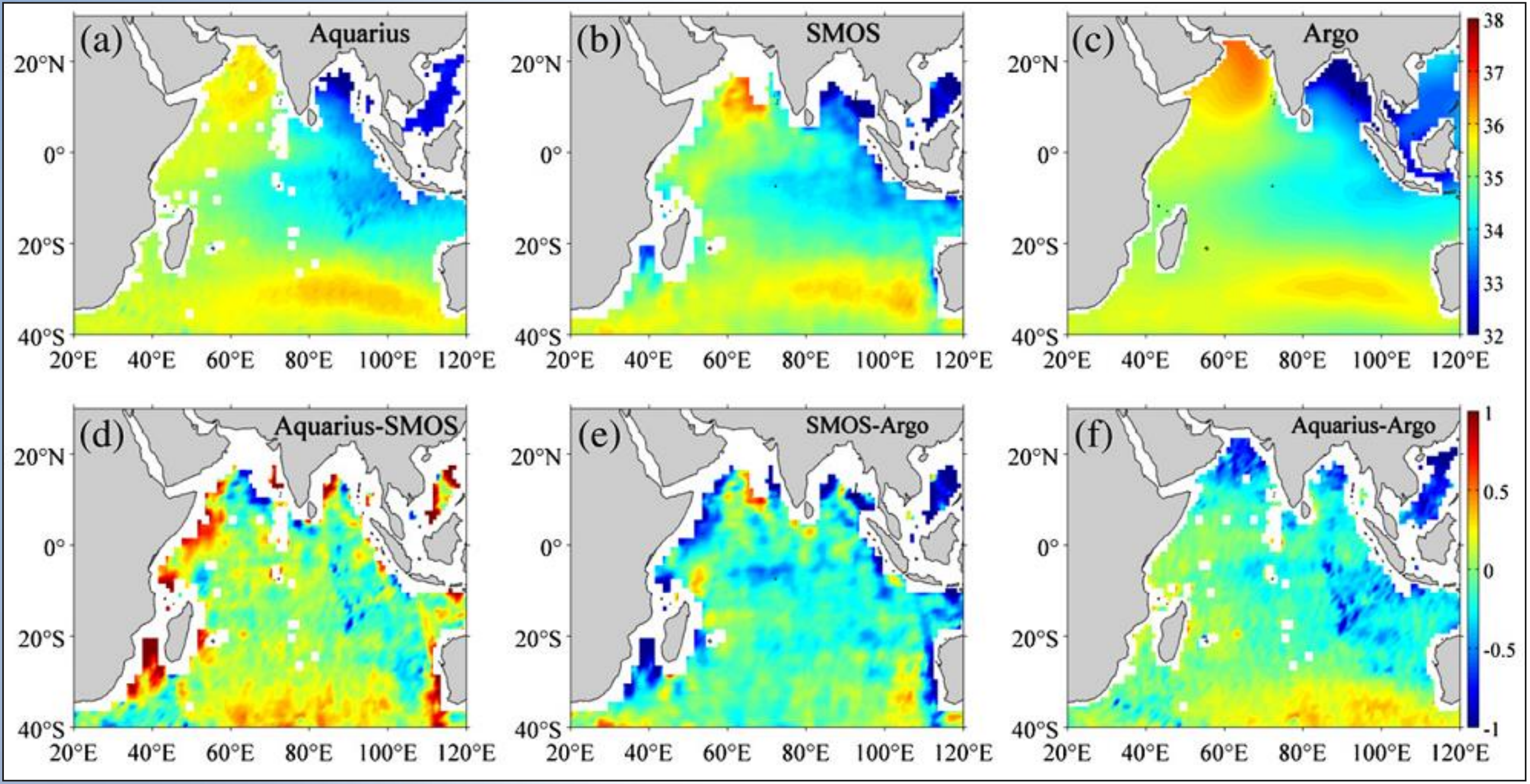






- Relatively good comparison b/t data sets
- Challenges in high precipitation regions
- Satellites more reliable in S. Indian Ocean than N. Indian Ocean
- Effects of land-ocean contamination; RFI

Data



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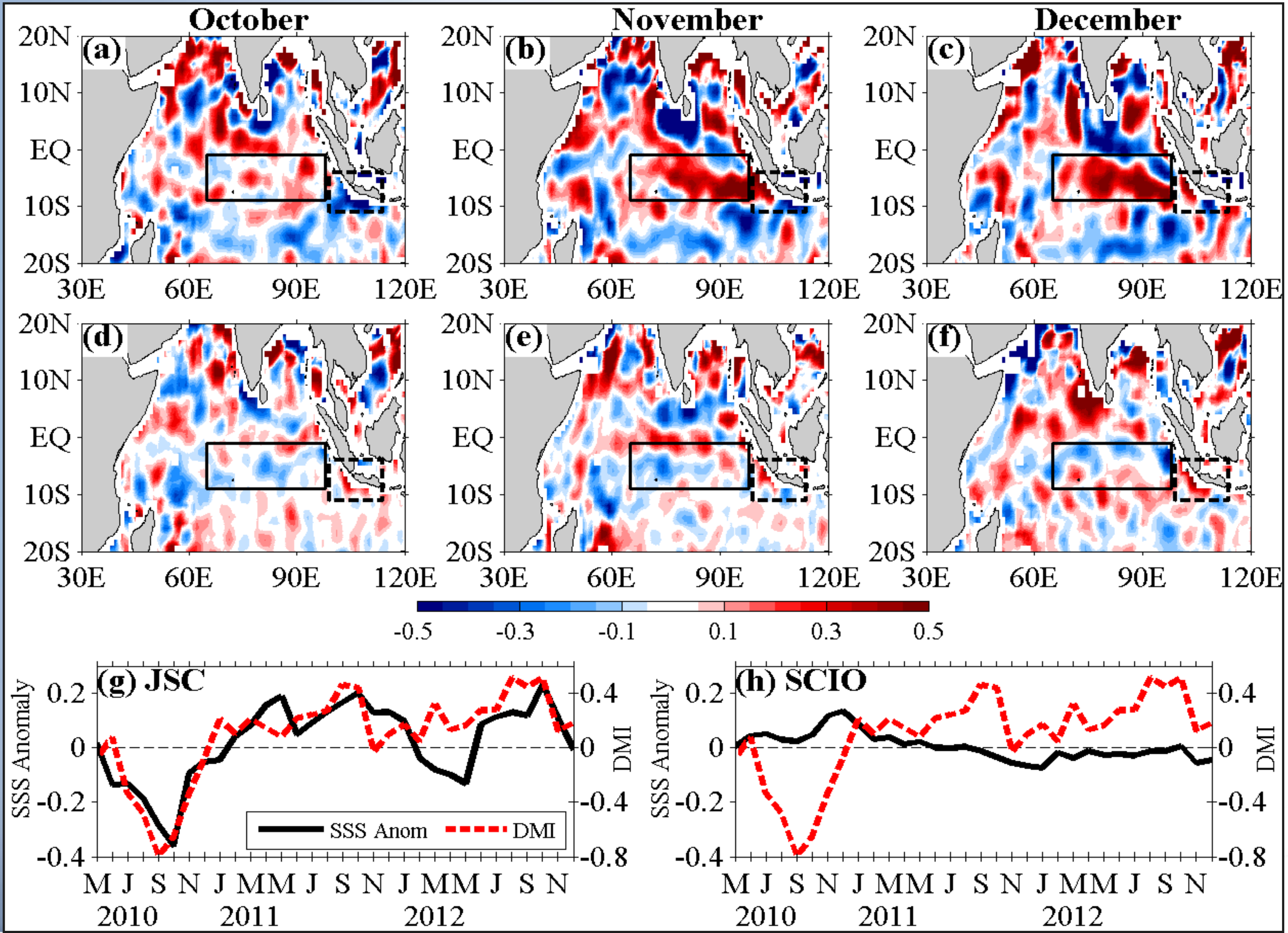
Satellite SSS and the IOD



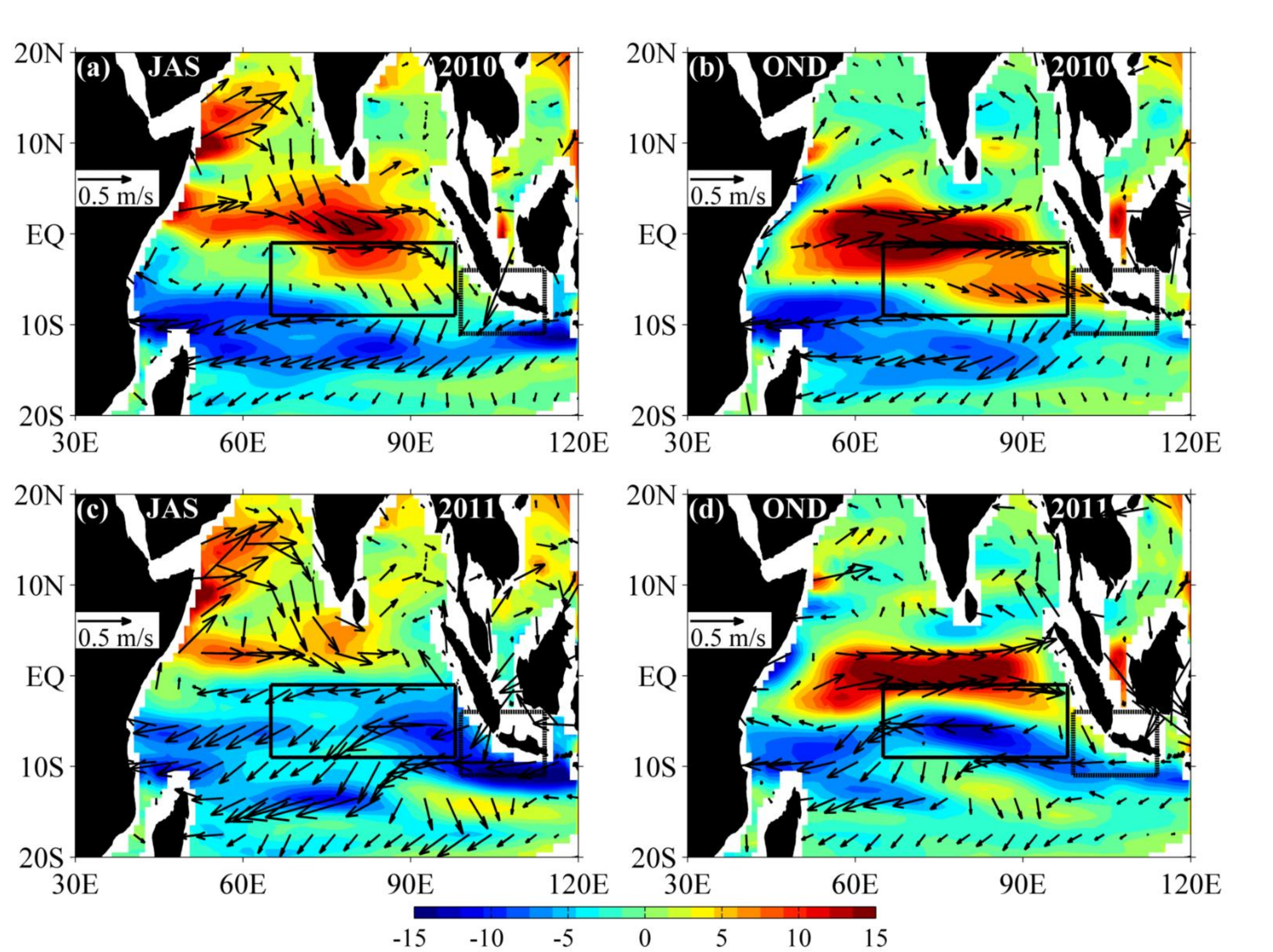
2010

2011

- SMOS able to capture SSS pattern during IOD events
- Lower than usual SSS observed in Java-Sumatra during SON 2010

- Higher than usual SSS in the central EqIO during 2010
- Differences in SSS due to advection, E, P

Satellite SSS and the IOD

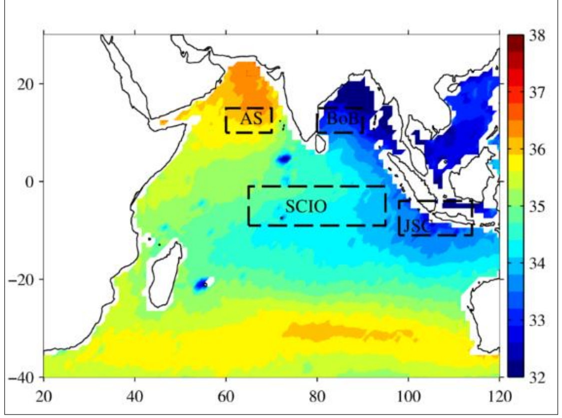


Salt flux

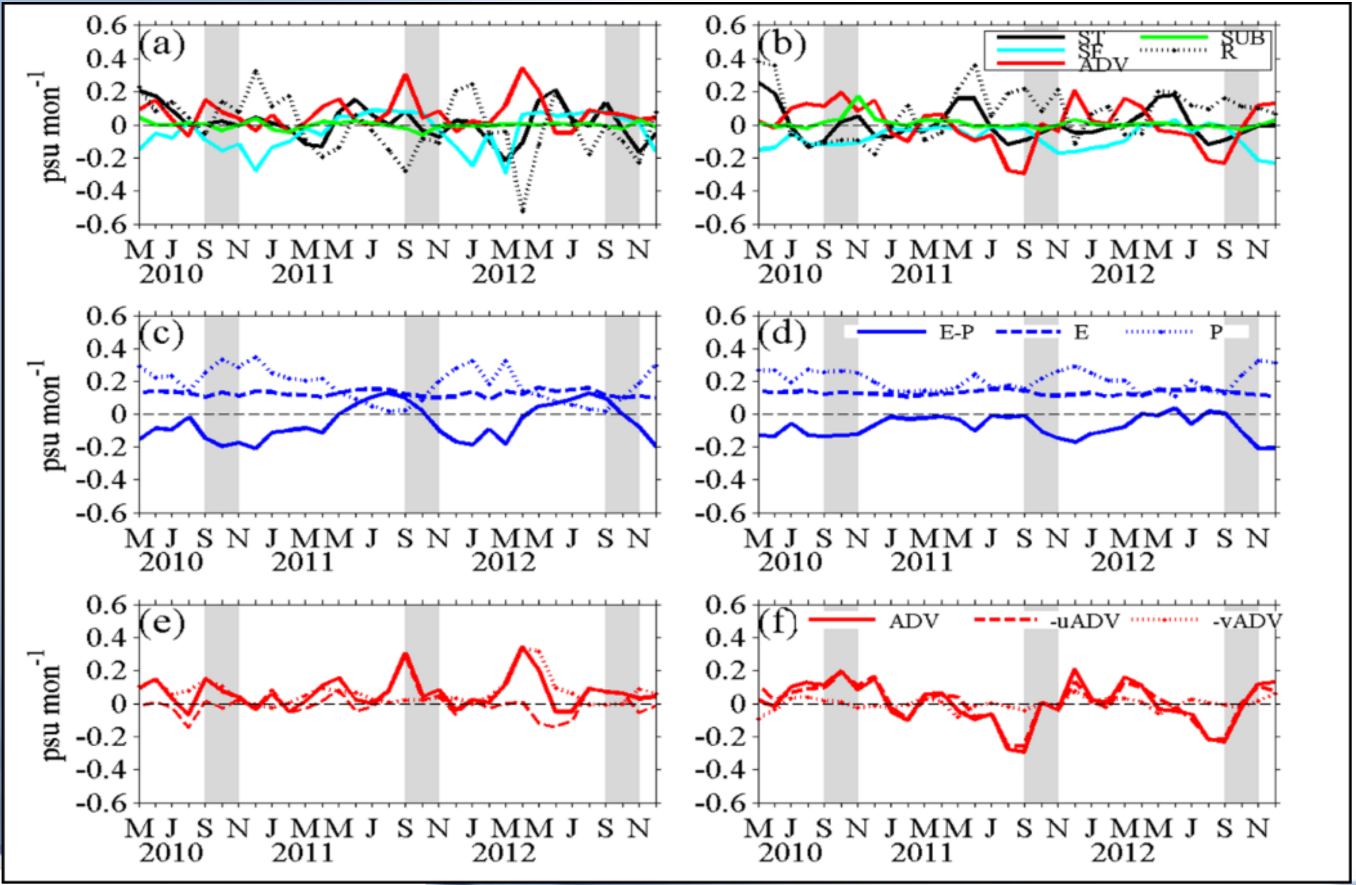
- Currents bring high SSS from AS into the central EqIO
- This is absent in a normal year.
- The high SSS is able to reach the eastern coast
- This does not however lower SSS in the east as there is also high ppt and FW from the ITF

Salt budget estimated from:

$$\frac{\partial S}{\partial t} = S\frac{(E-P)}{h} - u\frac{\partial S}{\partial x} - v\frac{\partial S}{\partial y} - w\frac{\partial S}{\partial z} + R$$



JSC region: salinity tendency dominated by advection and surface freshwater forcing terms



SON 2010: net positive salt advection; negative SSS anomaly however

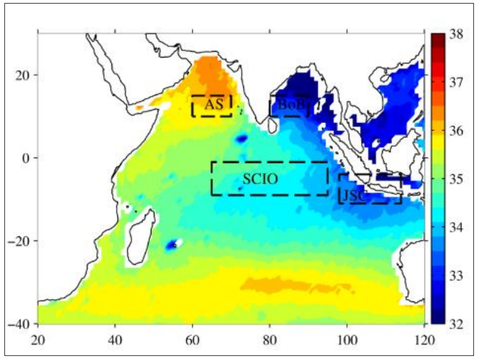
Higher precipitation than evaporation

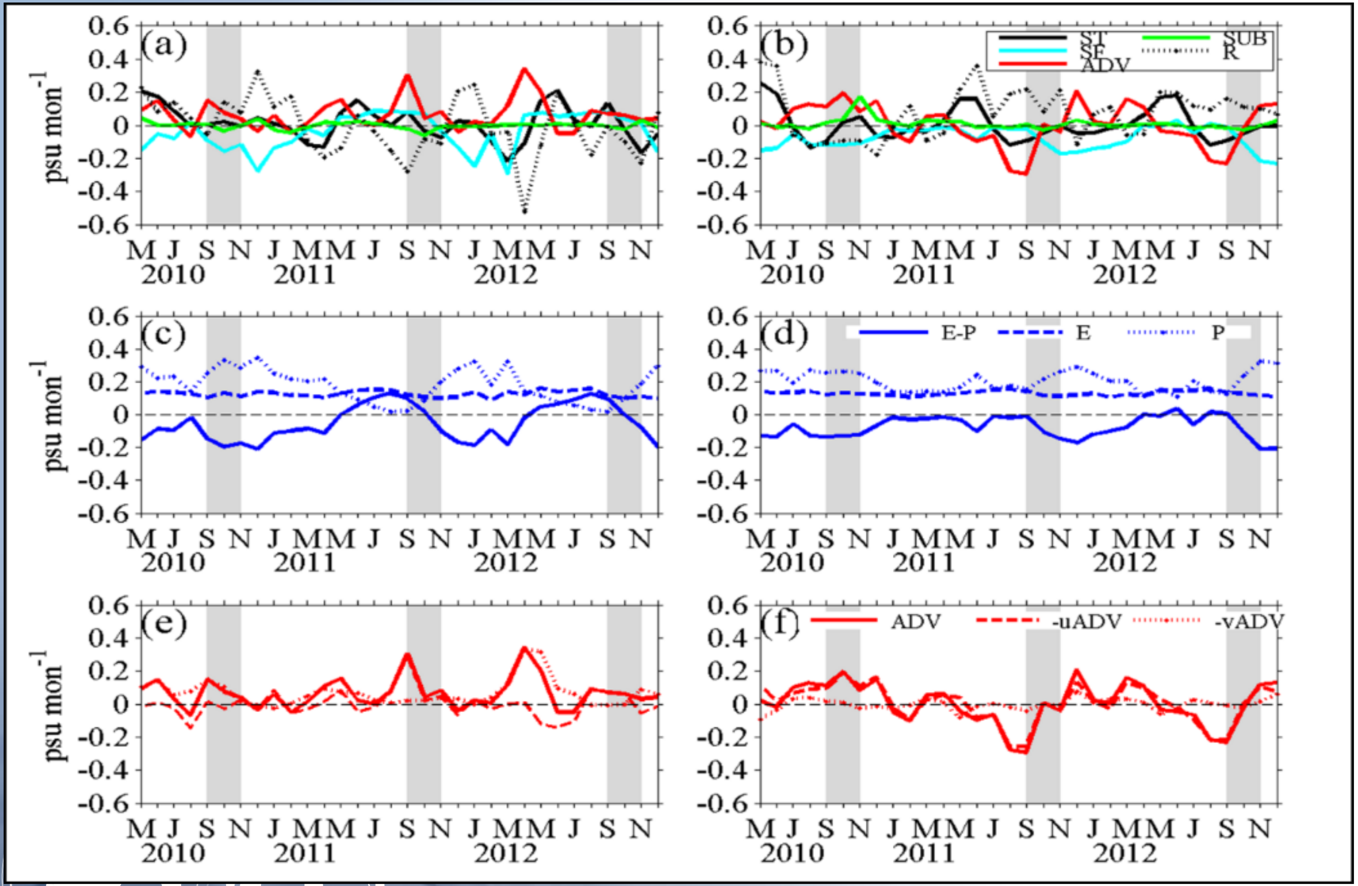
SON 2011/12: SFW relatively lower; higher SSS anomalies

Salt budget terms averaged in the boxes for (left panel) JSC and (right panel) SCIO

SCIO region: salinity tendency dominated by advection and surface freshwater forcing terms

Increased zonal advection bring high saline waters from west.





SON 2010: lower ppt; higher *SUB* term

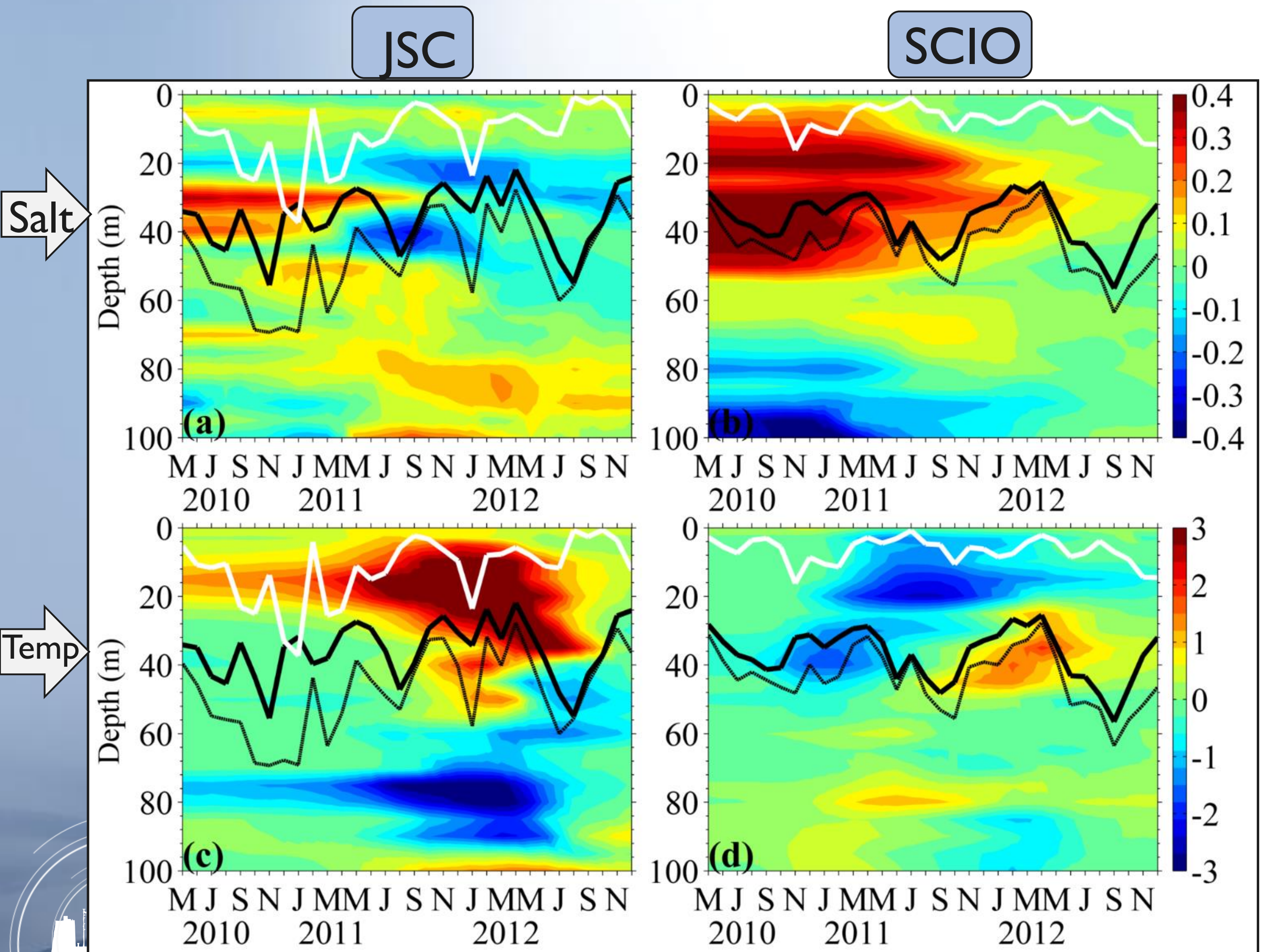
2011/12: advection reverses to be westward;

This brings less saline waters from Pacific Ocean

Salt budget terms averaged in the boxes for (left panel) JSC and (right panel) SCIO

JSC: during SON 2010, barrier layer thickens; MLD deepens;

Thermocline however also deepens due to elevated temperatures; suppresses upwelling of subsurface salt

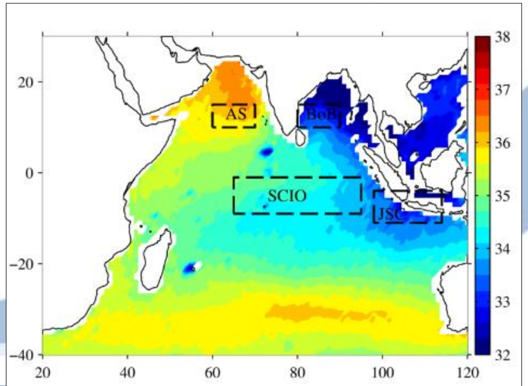


Argo salinity anomalies (a) and (b), Argo temperature anomalies (c) and (d) averaged in the boxes for (left panel) JSC and (right panel) SCIO. ILD (dashed black line), MLD (solid black line), and BLT (solid white line); BLT=ILD-MLD

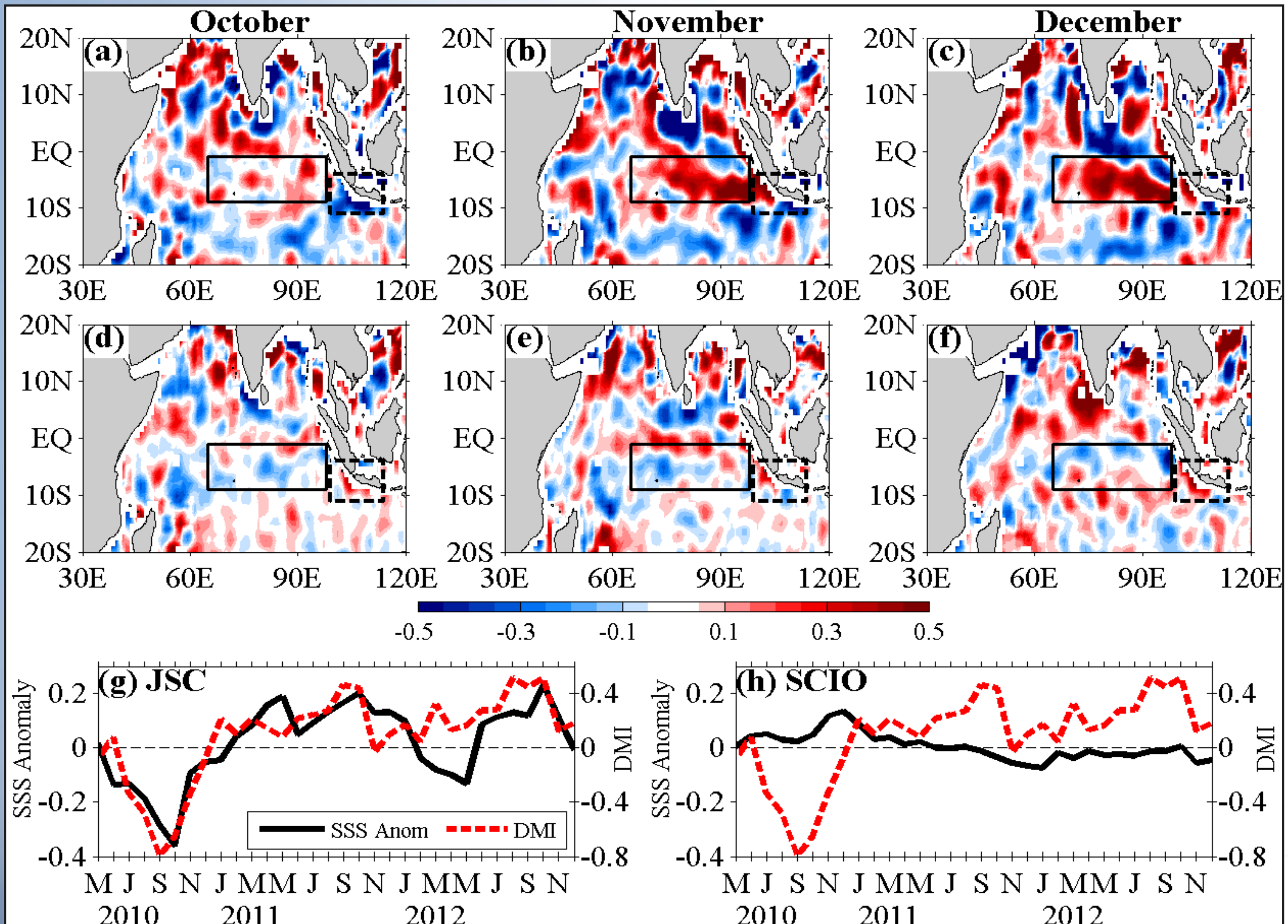
Opposite scenario in SCIO:

thermocline shoals,

favors upwelling of more saline sub-surface waters into surface waters



Satellite SSS and the IOD



2010

2011

- SMOS able to capture SSS pattern during IOD events
- Lower than usual SSS observed in Java-Sumatra during SON 2010

- Higher than usual SSS in the central EqIO during 2010
- Differences in SSS due to advection, E, P

Thank you