

SMOS and Aquarius Salinity Measurements and Validation in the Indian Ocean

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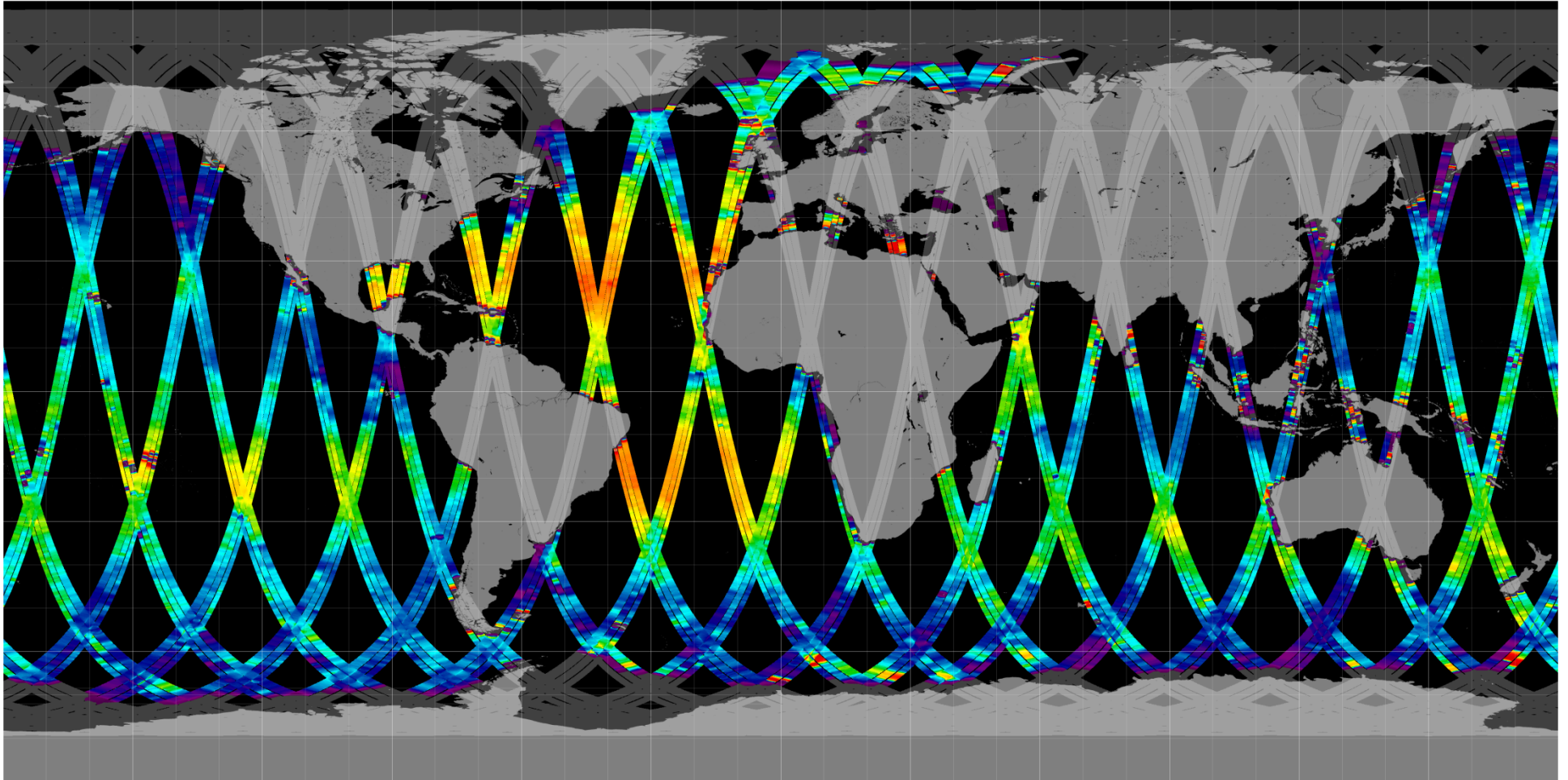
Dr. Ebenezer Nyadjro, NRC Postdoc at NOAA/PMEL

Clifford Felton, USC

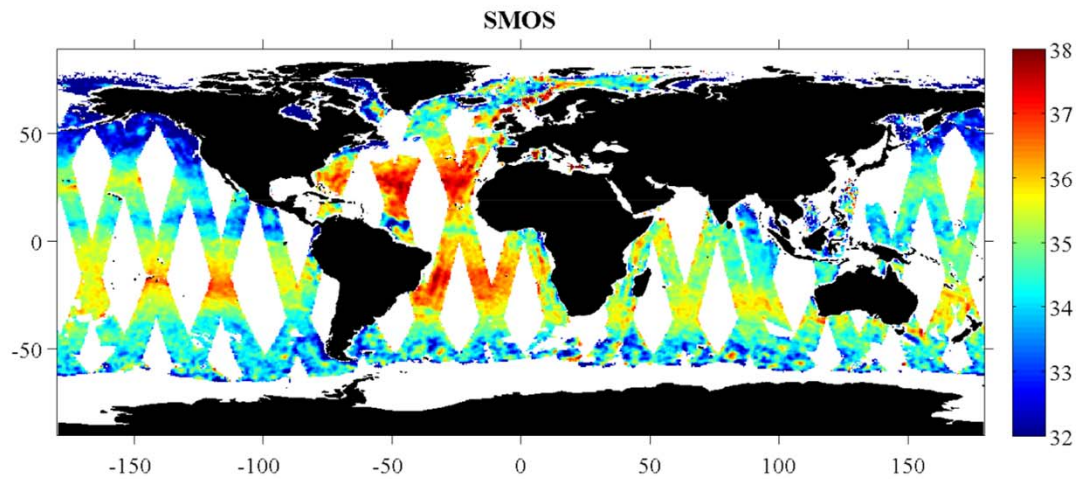
Outline

- ❖ Introduction
- ❖ Validation of SMOS/Aquarius-Daily/weekly/Monthly scale
- ❖ Validation of Box averages
- ❖ Comparison with RAMA moorings
- ❖ Salt Transports in the Indian Ocean
- ❖ Summary

Aquarius Daily Sea Surface Salinity

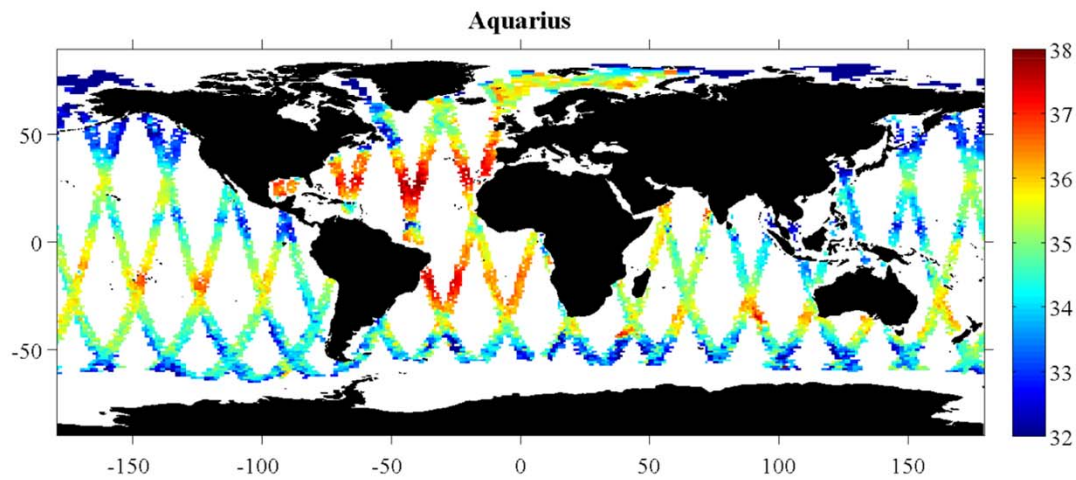


Aquarius & SMOS passes



SMOS

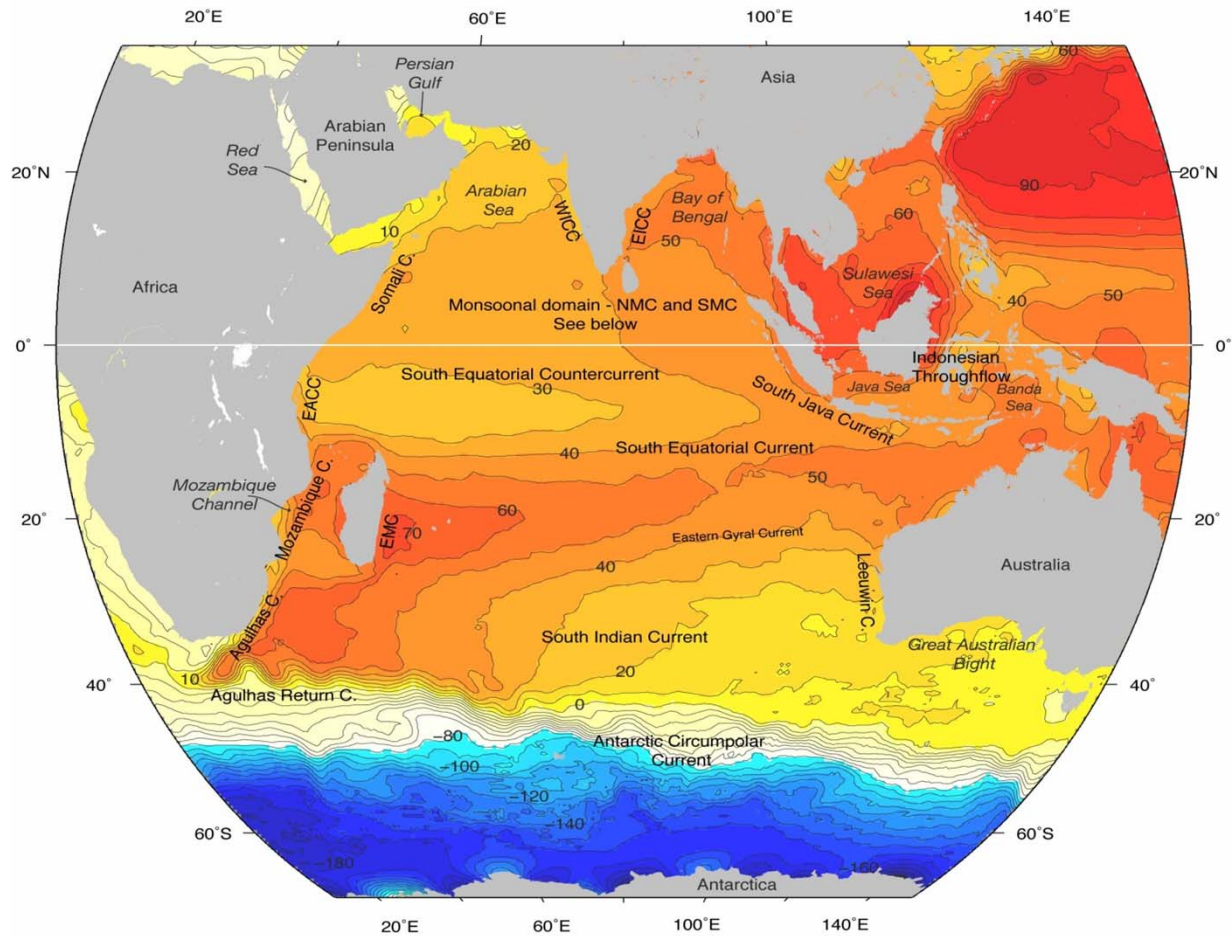
~1000 km Swath



Aquarius

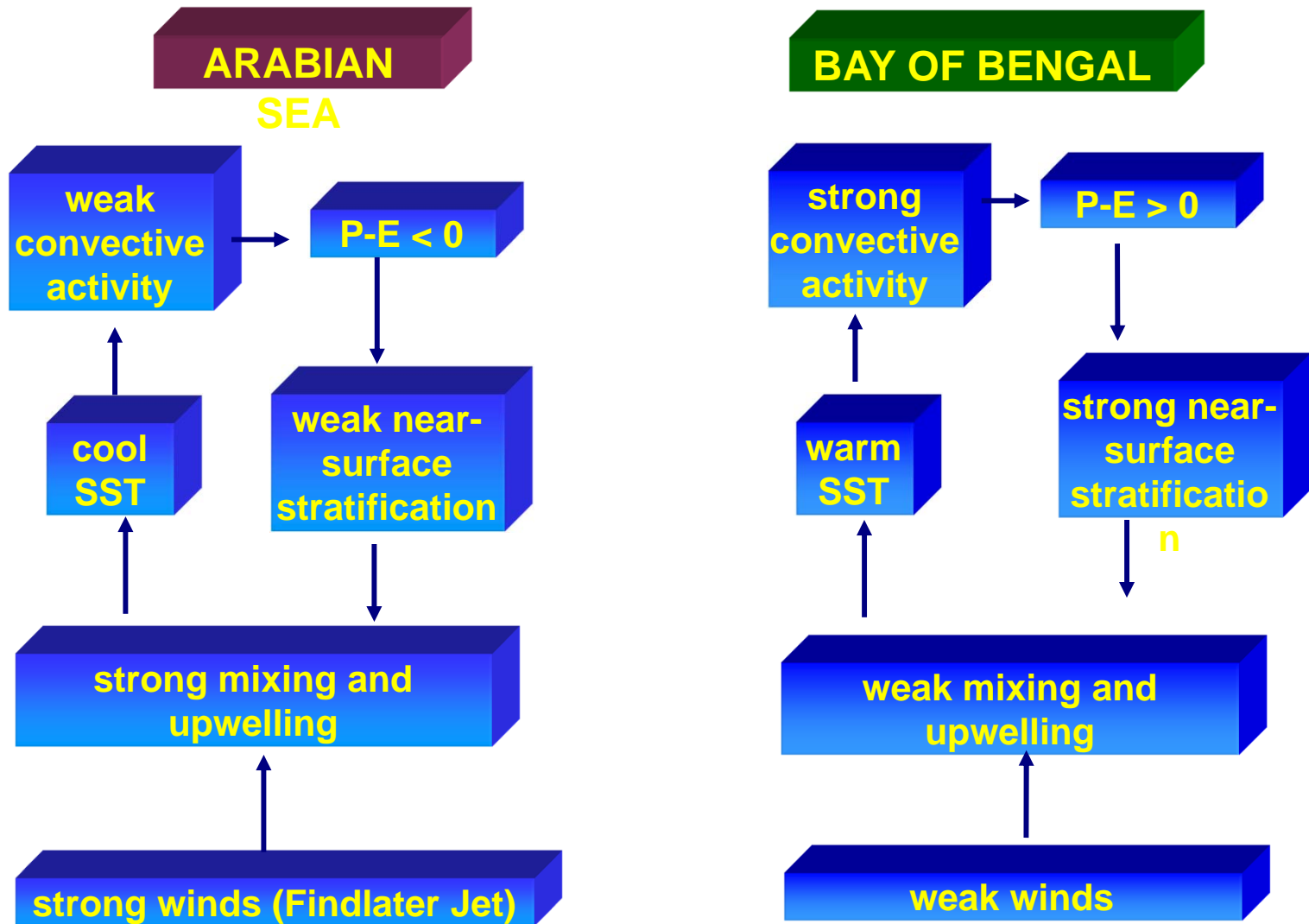
390 km Swath

Mean surface height and currents



Seasonal reversal of winds and currents impact salinity dynamics

North Indian Ocean



HYbrid Coordinate Ocean Model (HYCOM)

- High resolution: $1/12^\circ$
- Palk Strait opened in HYCOM
- Surface layer is mixed-layer
- Monthly river runoff (986 rivers); important for Bay of Bengal
- Used daily HYCOM outputs for 2009-present



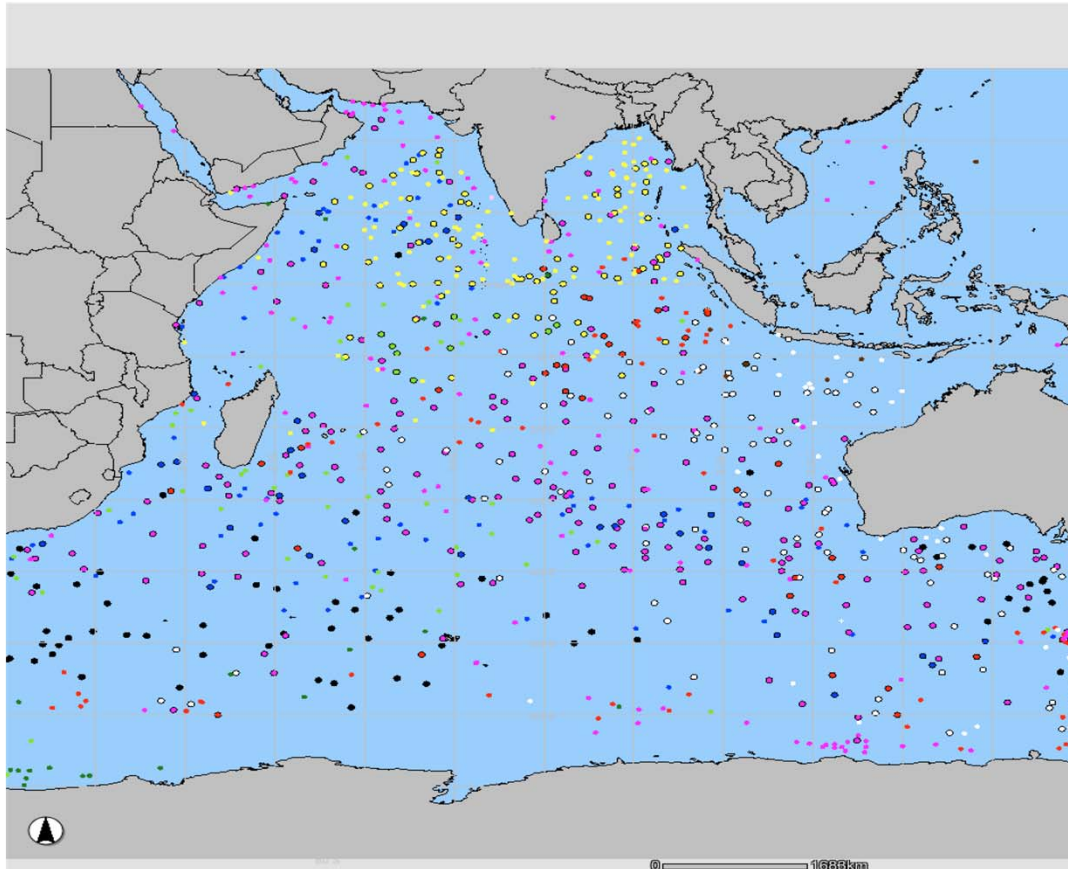
Palk Strait

Argo floats in the Indian Ocean

INCOIS- Argo Regional Center

ArcIMS Viewer

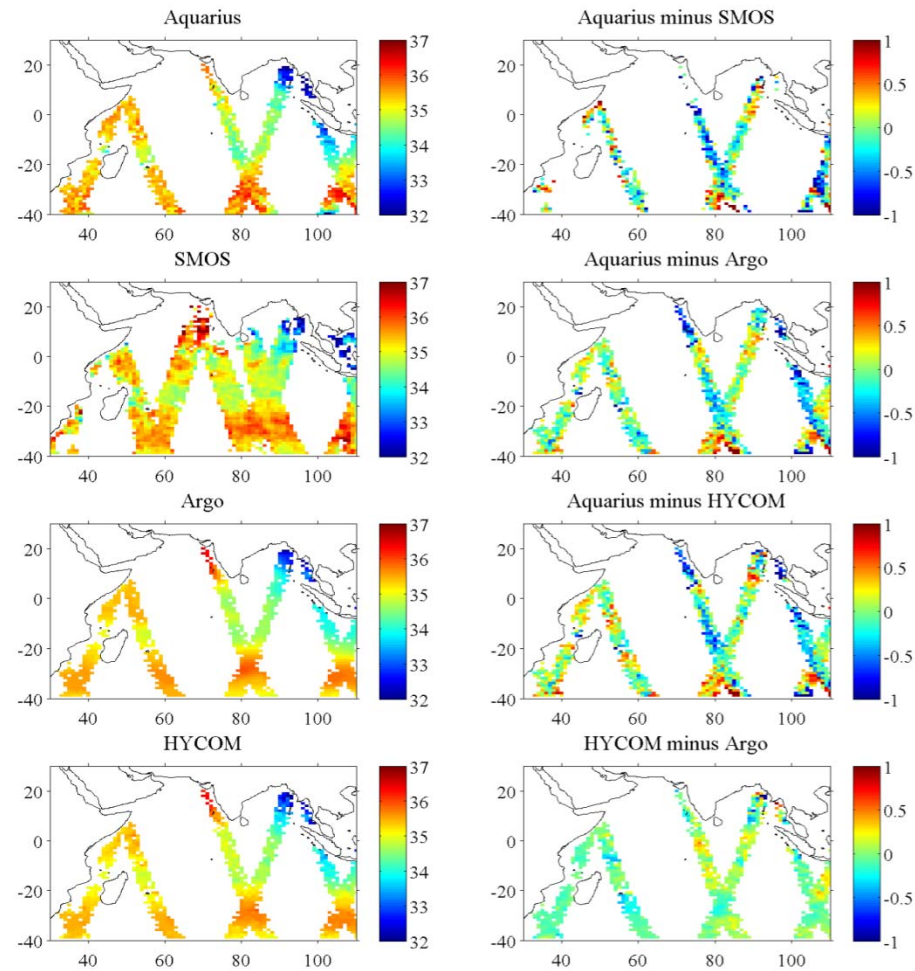
4/8/13 9:16 AM



Daily Sea Surface Salinity

Southwest Monsoon

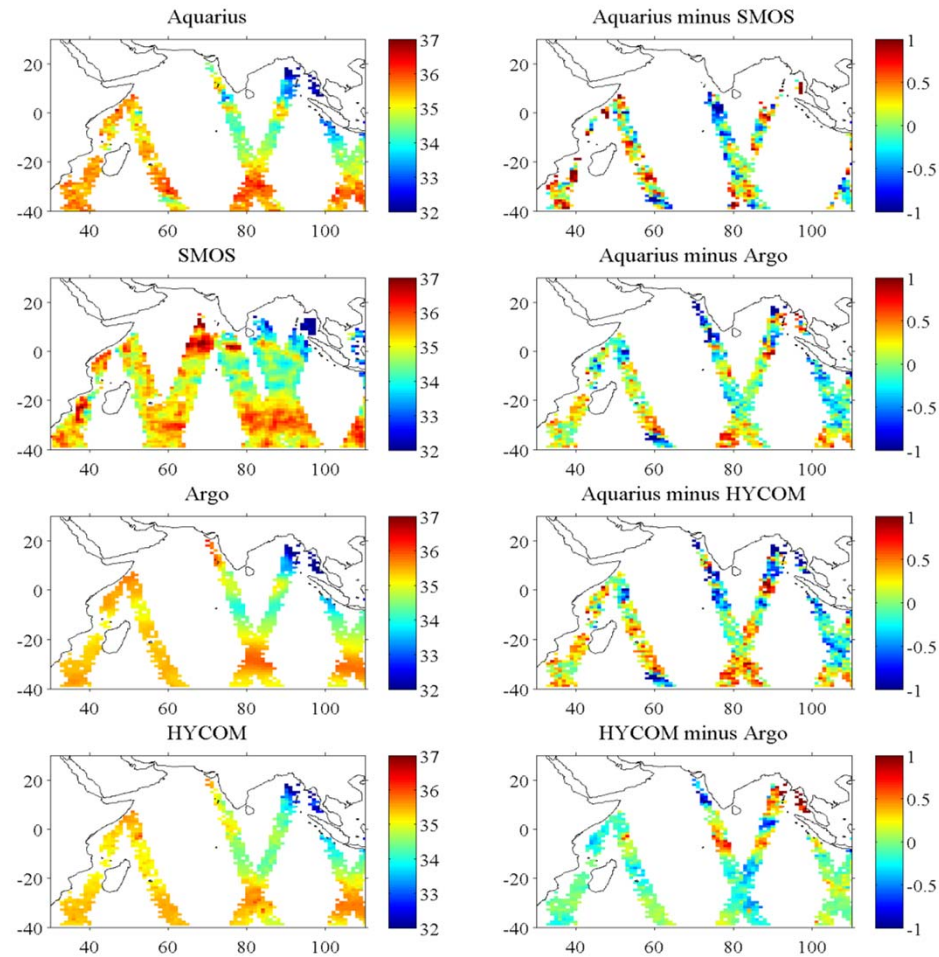
July 29, 2012



Daily Sea Surface Salinity

Northeast Monsoon

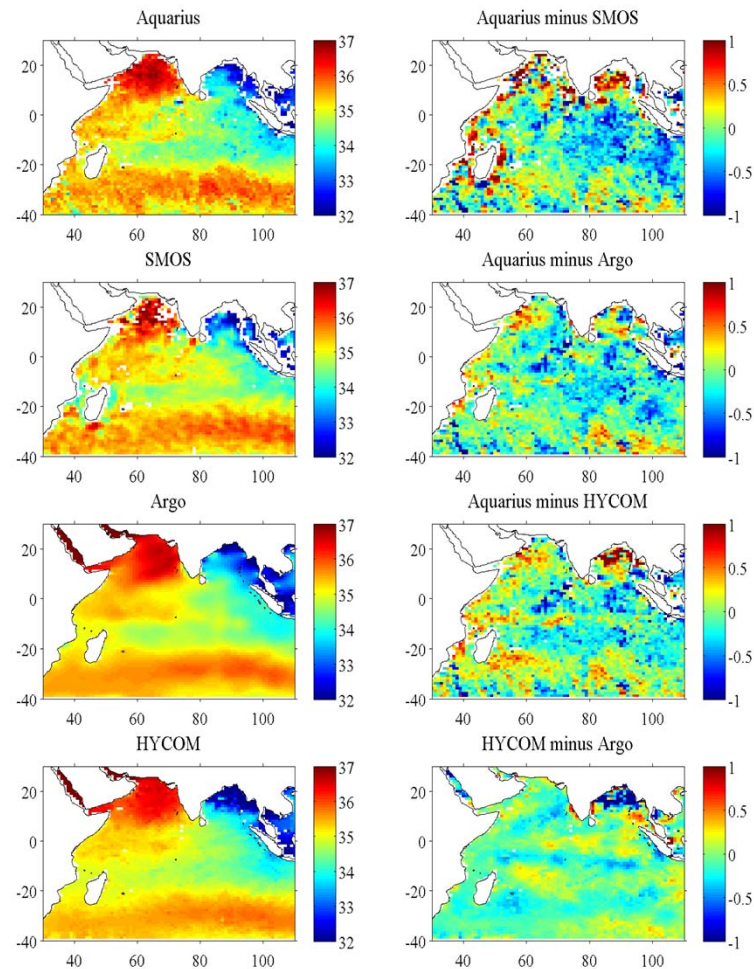
December 11, 2011



Weekly Sea Surface Salinity

Southwest Monsoon

July 4, 2012

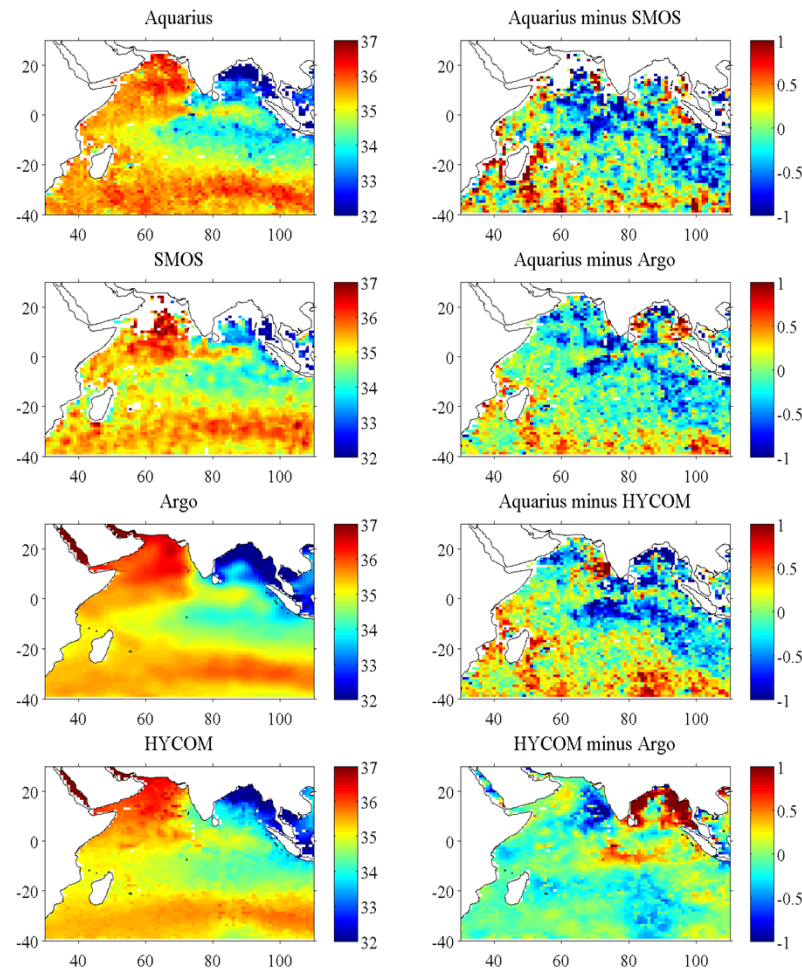


Large differences
along the coastal
regions

Weekly Sea Surface Salinity

Northeast Monsoon

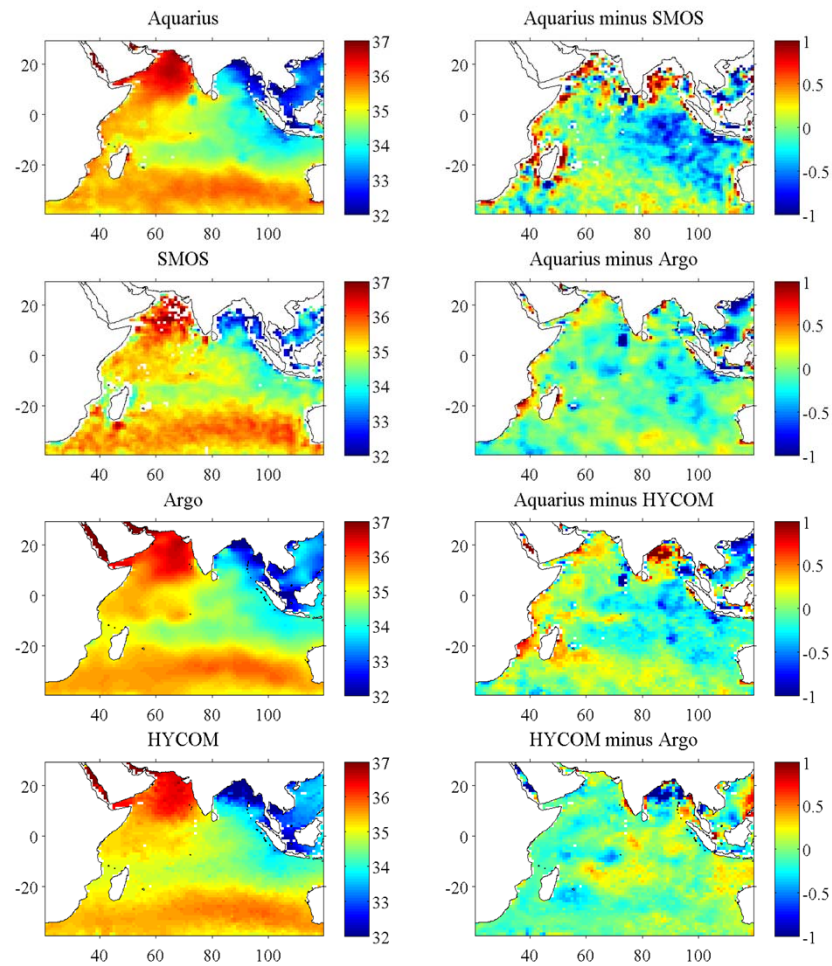
December 19, 2011



Monthly Sea Surface Salinity

Southwest Monsoon

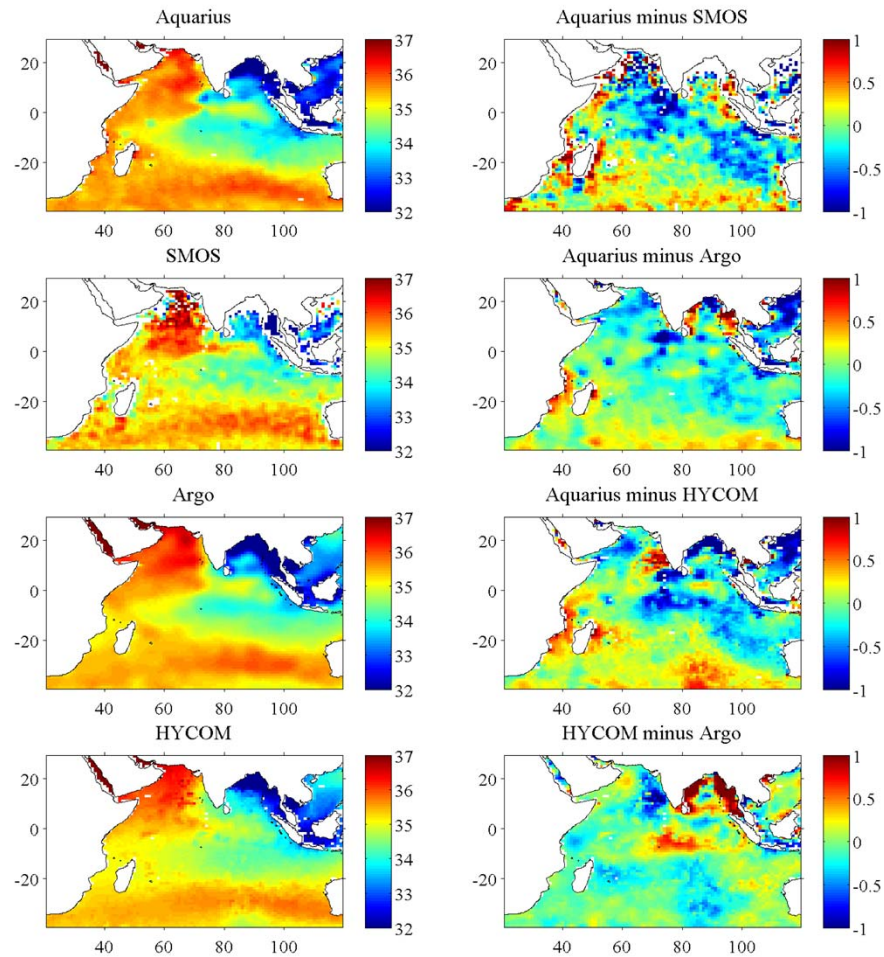
July, 2012



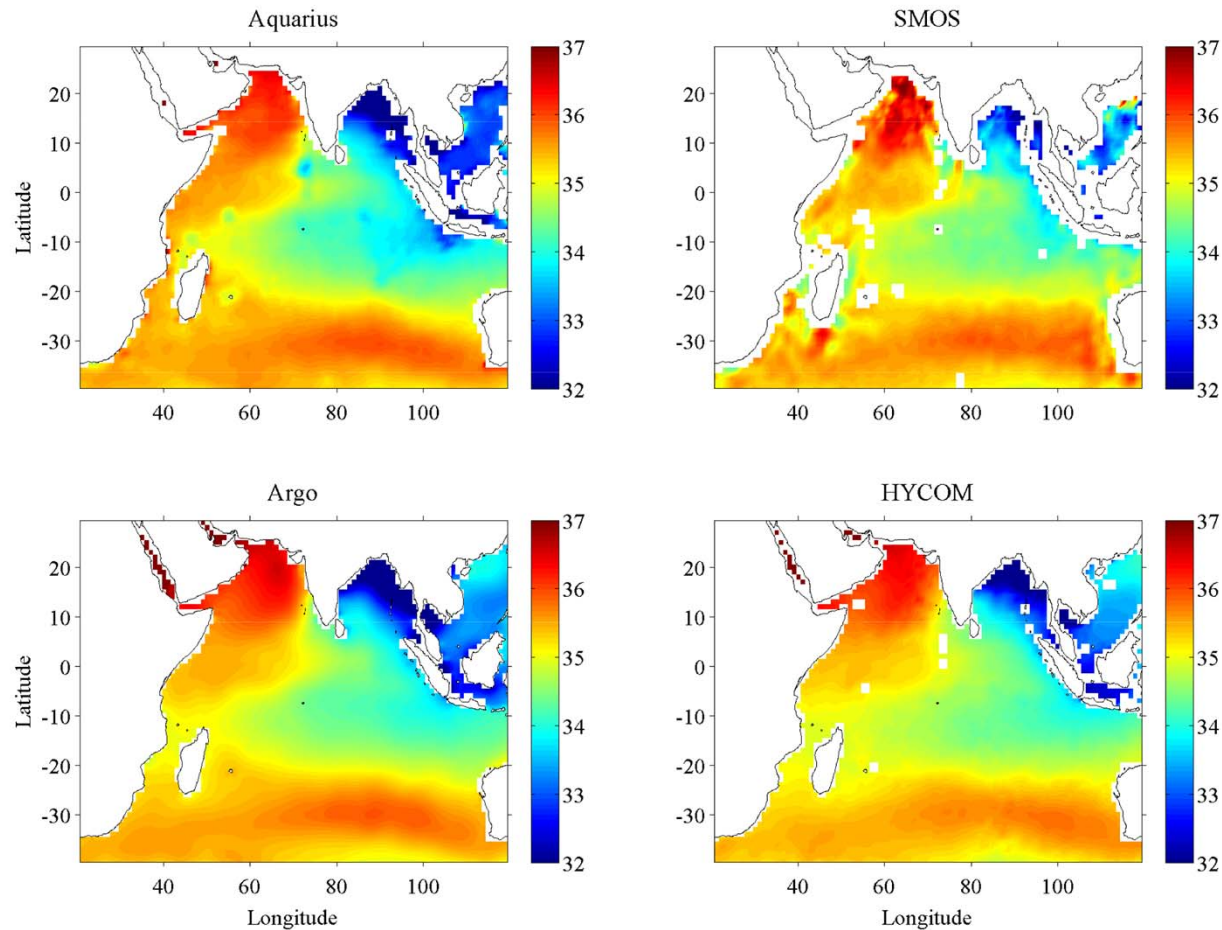
Monthly Sea Surface Salinity

Northeast Monsoon

December, 2011

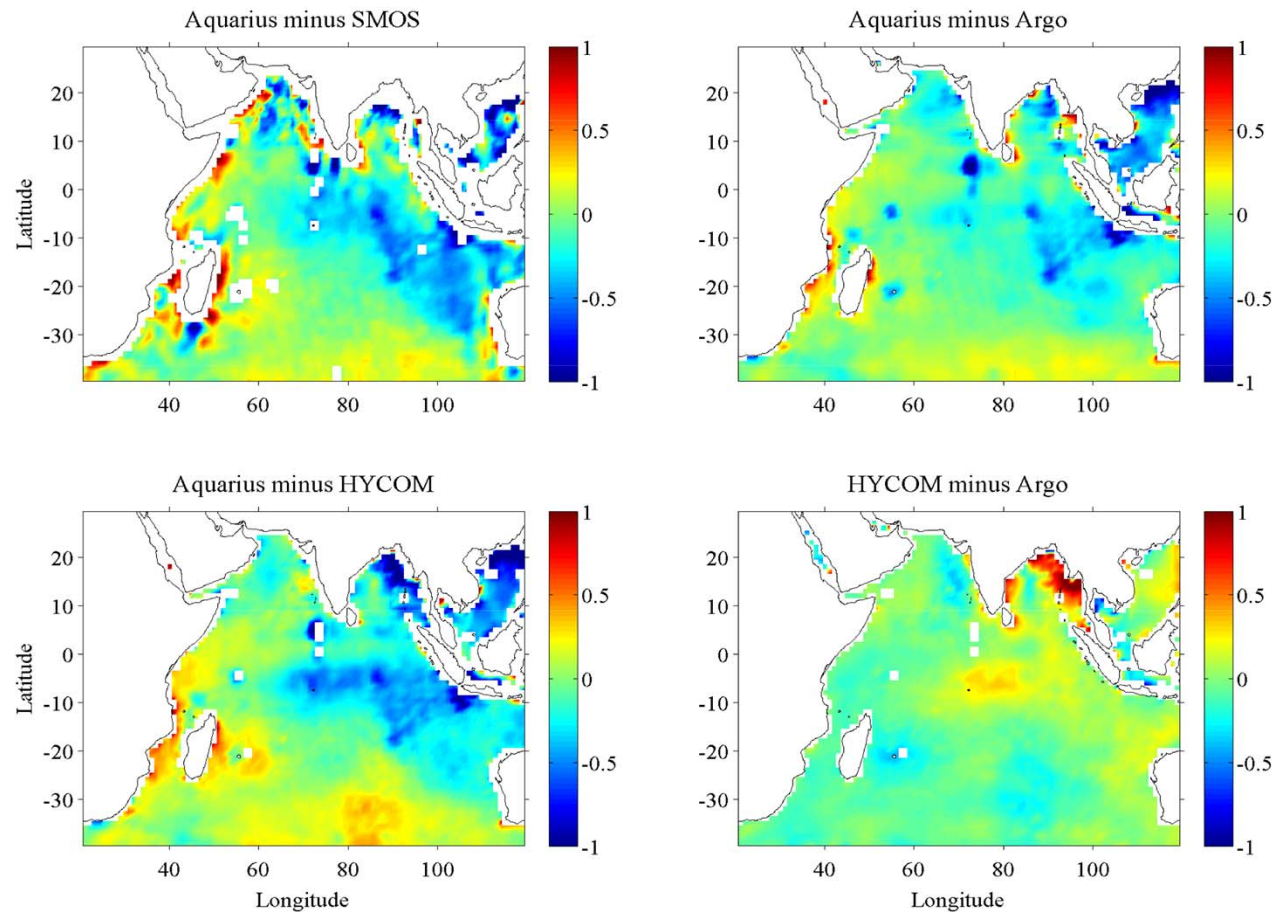


Annual Averages Sea Surface Salinity



Satellite salinity retrieval along the coast is challenging

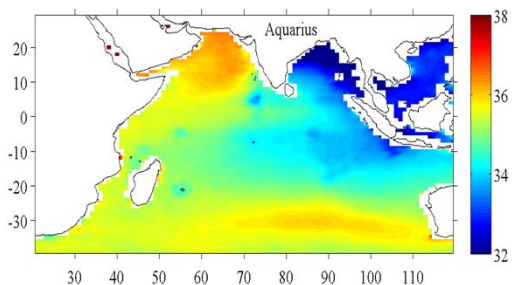
Annual Averages Sea Surface Salinity Differences



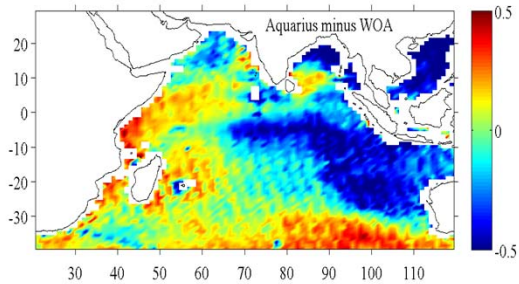
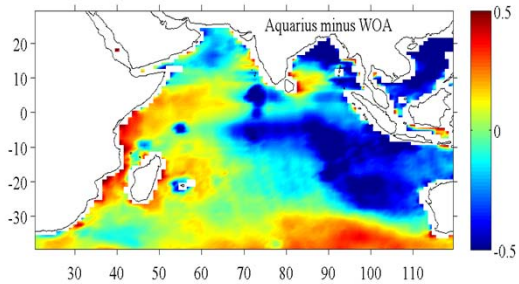
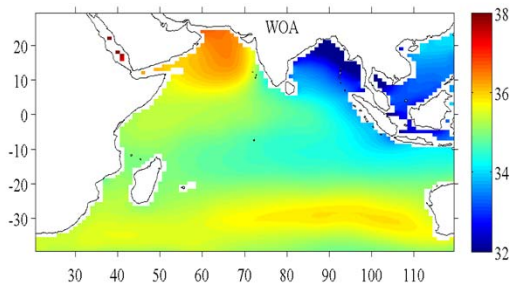
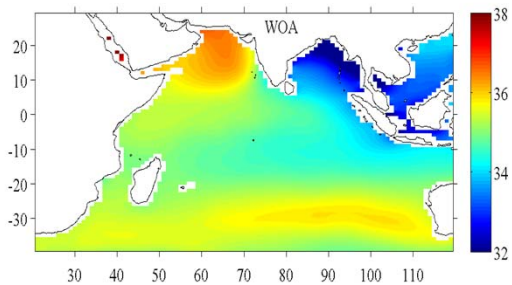
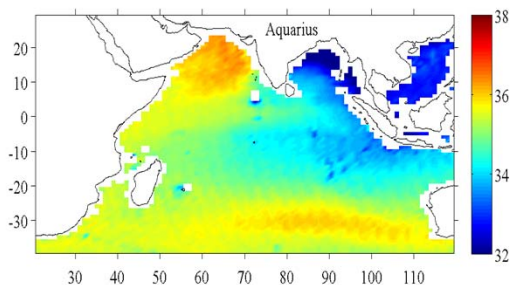
Aquarius is able to resolve salinity closer to coast than SMOS

Comparison of Aquarius with WOA09

Aquarius-SCIM



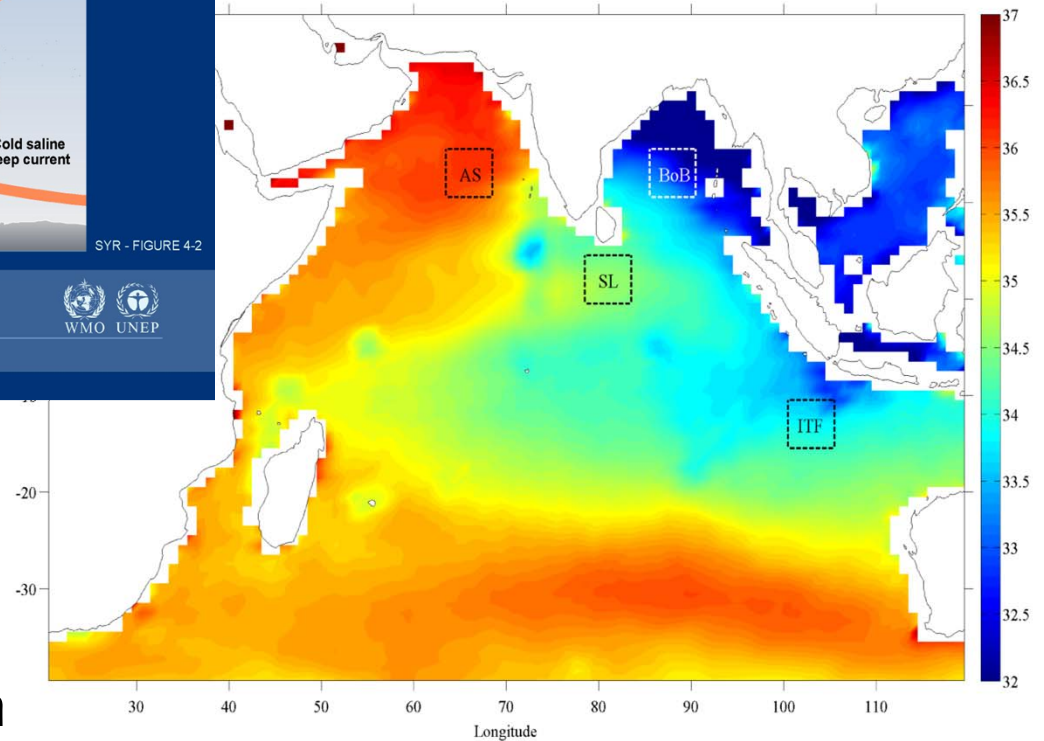
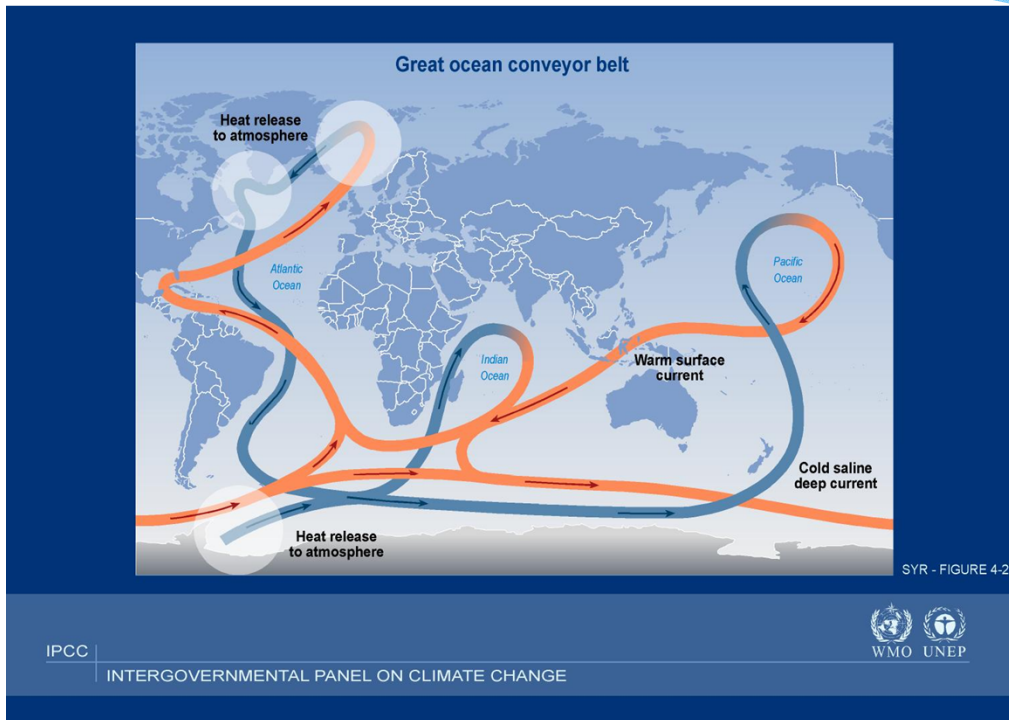
Aquarius-SCI



Key points

- Averaging (weekly/monthly) of satellite salinity minimizes error
- Retrieval of salinity near coastal regions need improving
- Satellite derived salinity is able to capture the Sea Surface Salinity pattern in the Indian Ocean

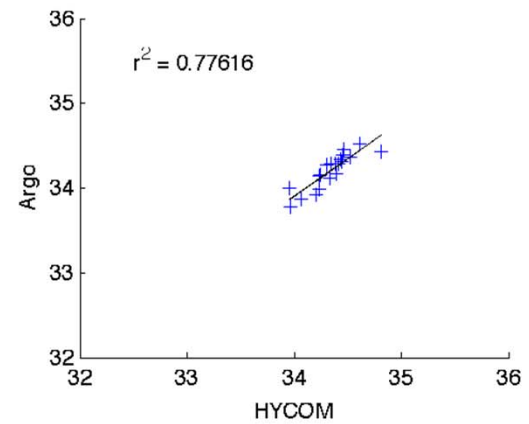
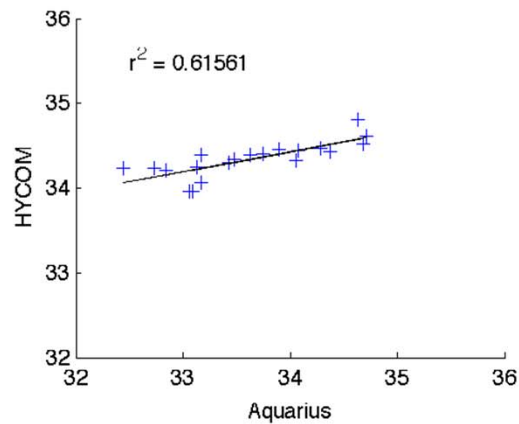
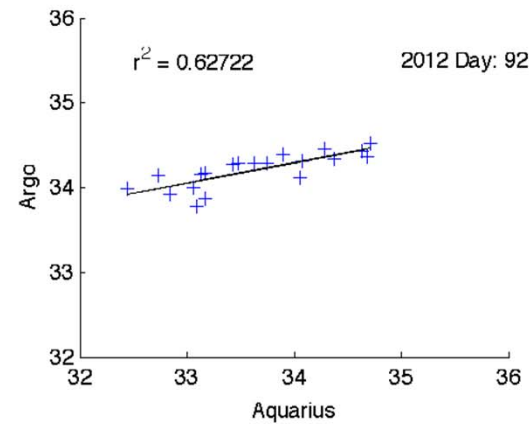
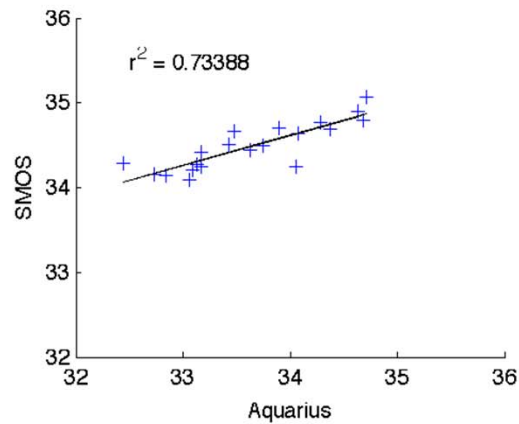
Box Average



Boxes chosen to reflect SSS dynamics in the Indian Ocean

Daily Pass correlation

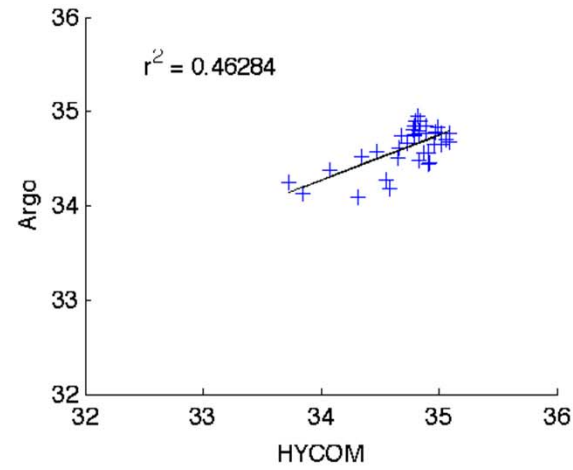
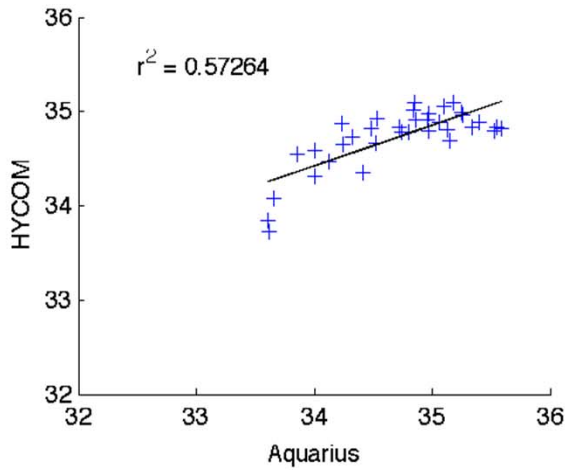
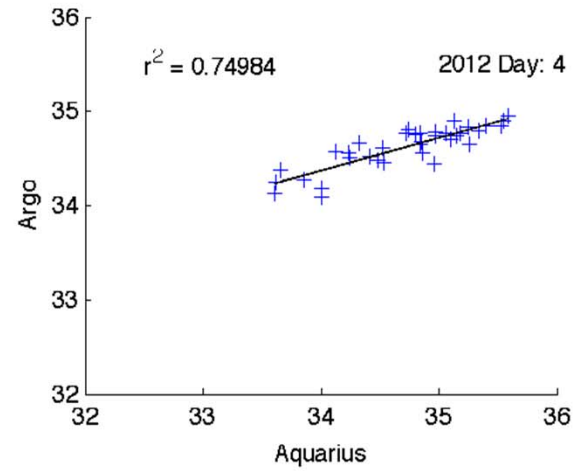
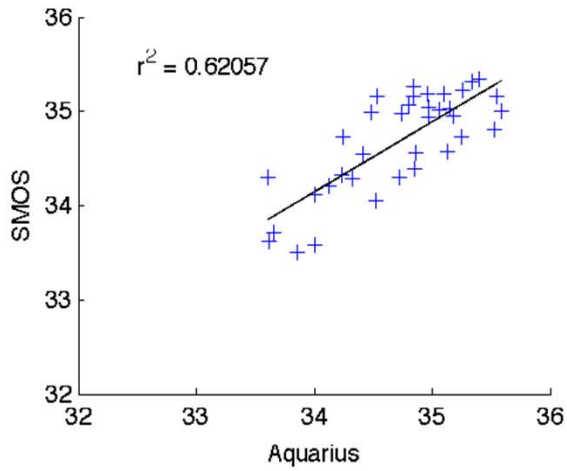
ITF Region



High correlation between SMOS and Aquarius

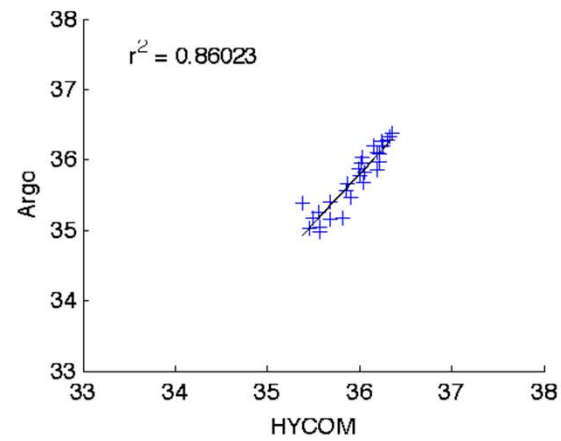
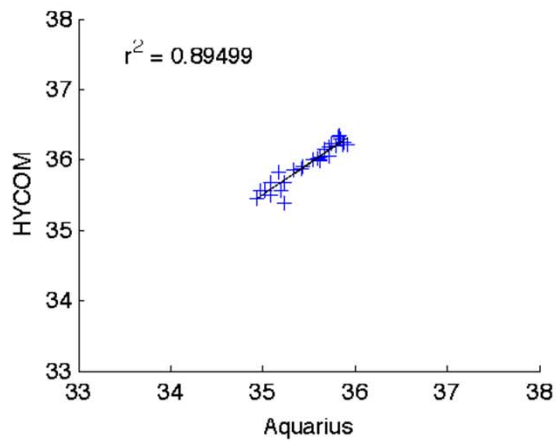
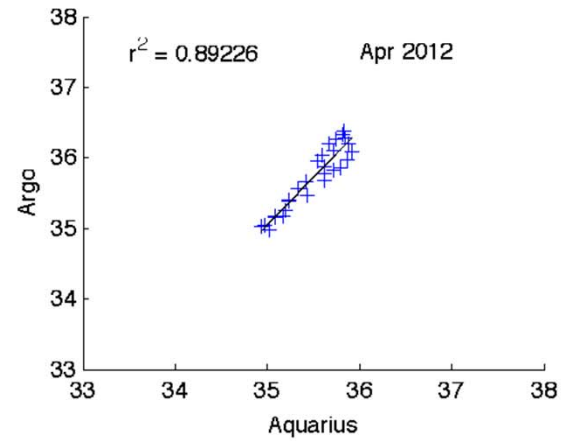
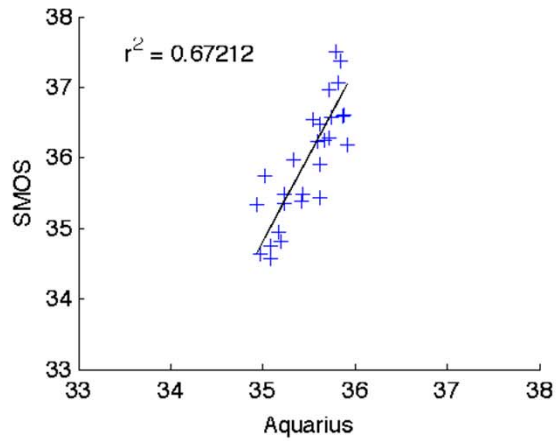
Weekly Passes correlation

SL Region



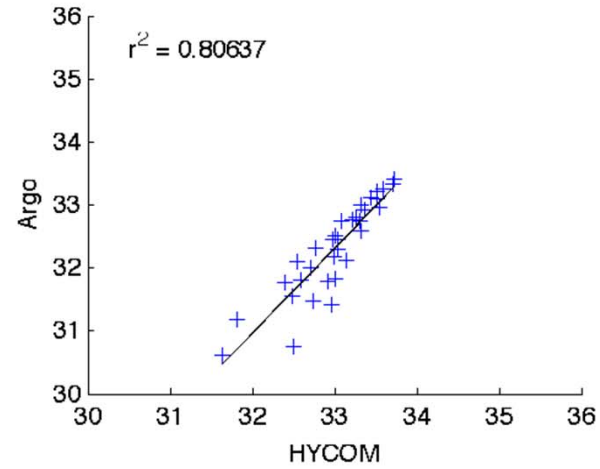
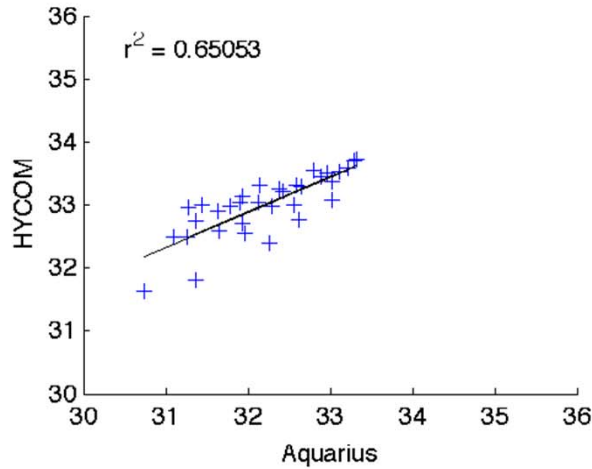
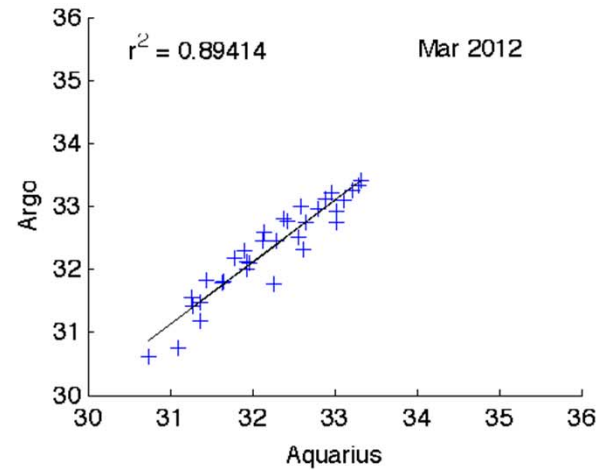
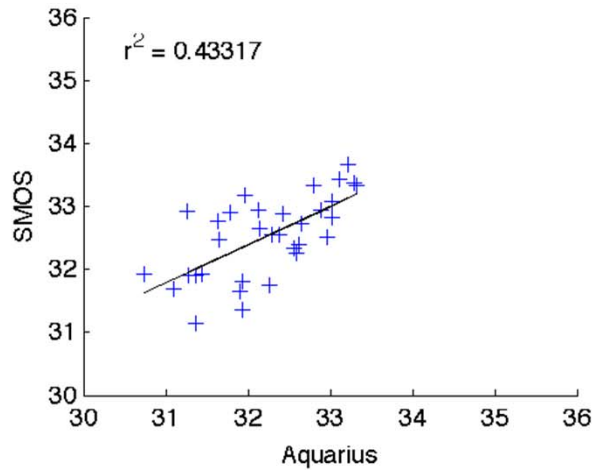
Monthly Passes correlation

AS Region

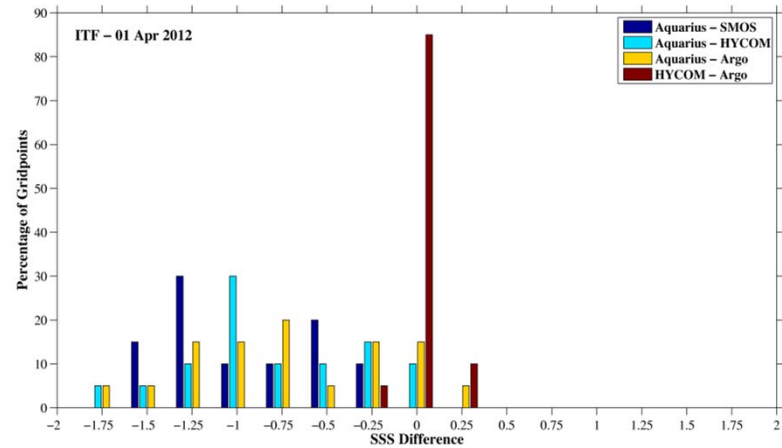
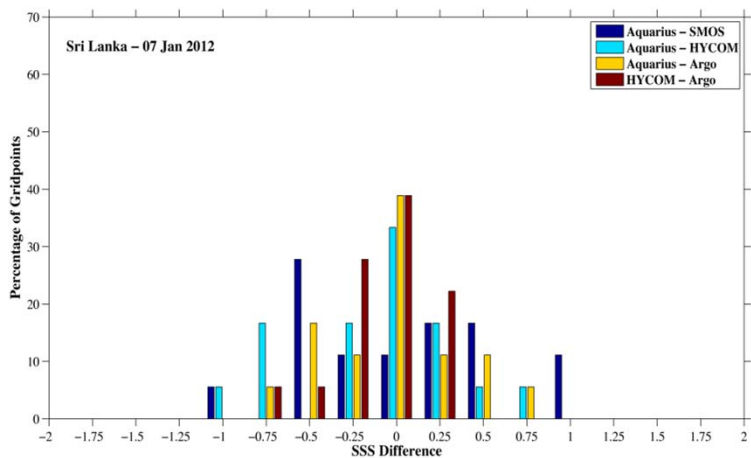
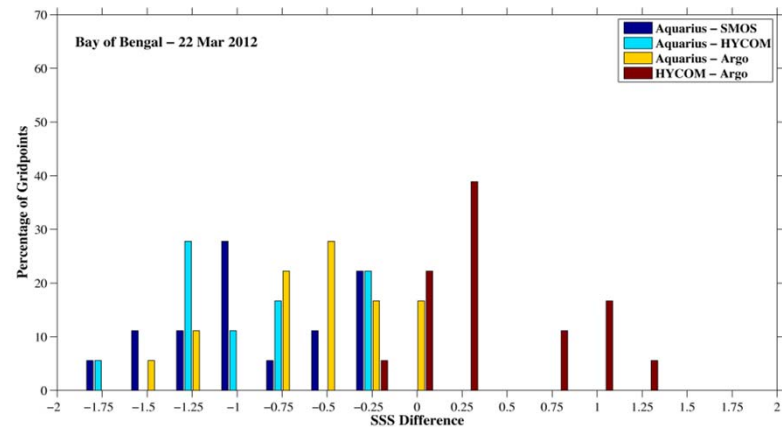
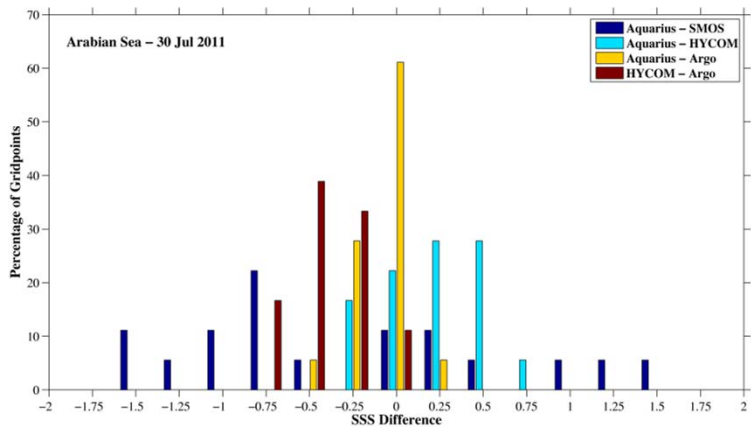


Monthly Passes correlation

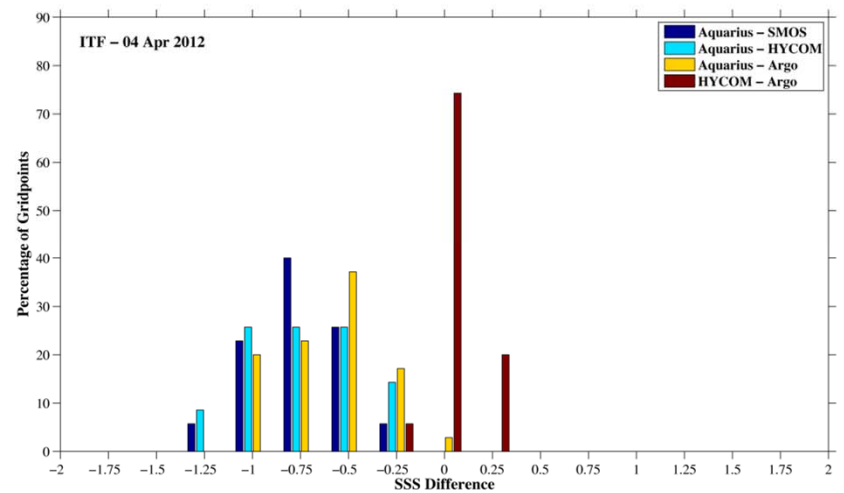
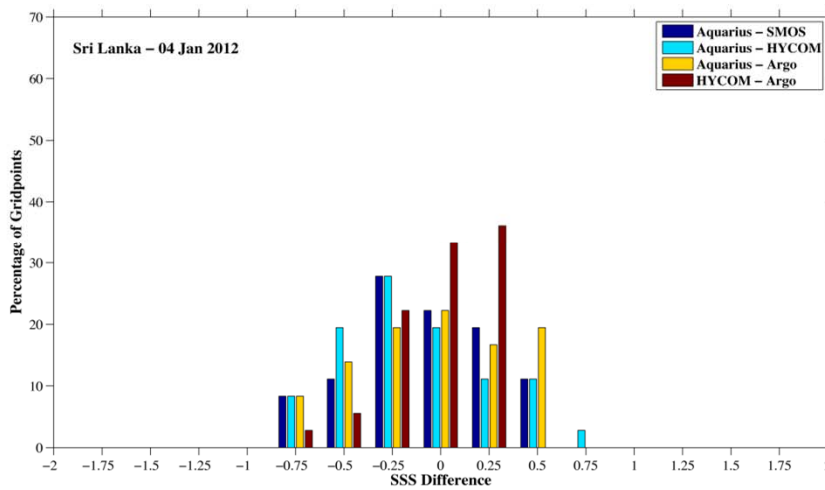
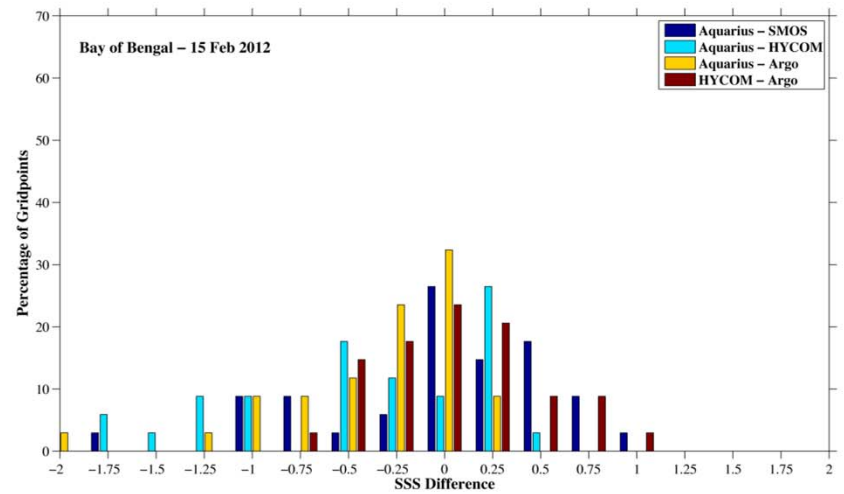
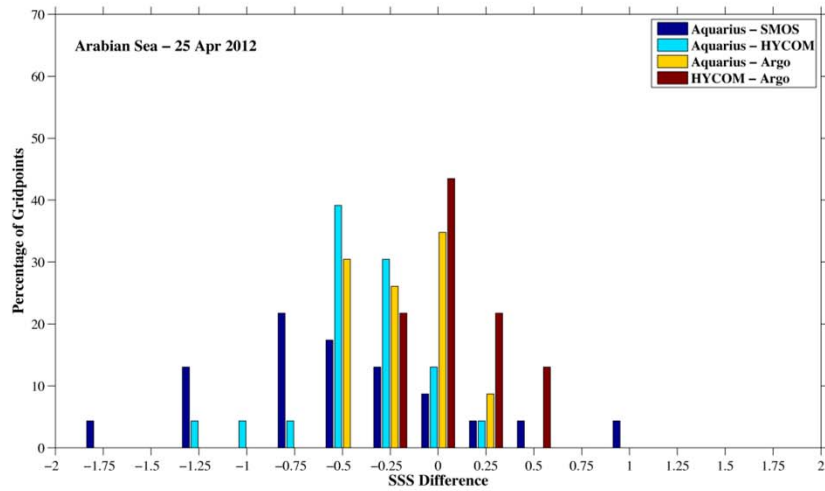
BoB Region



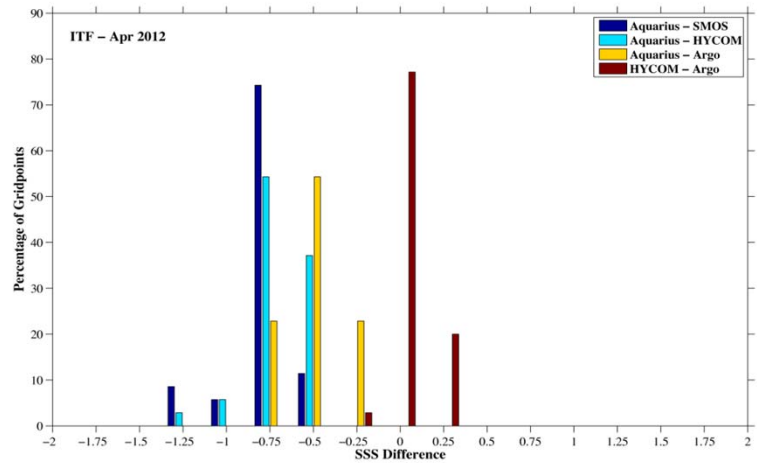
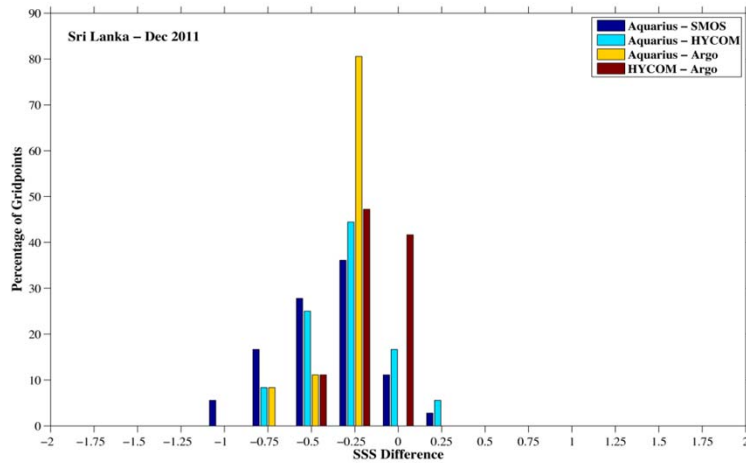
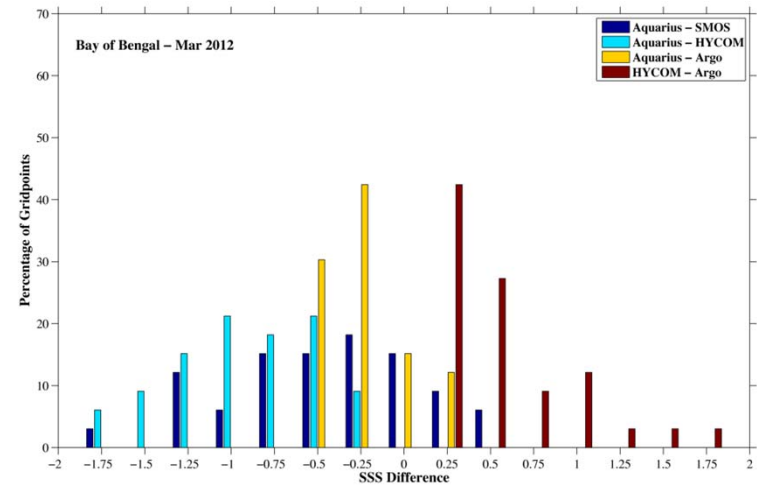
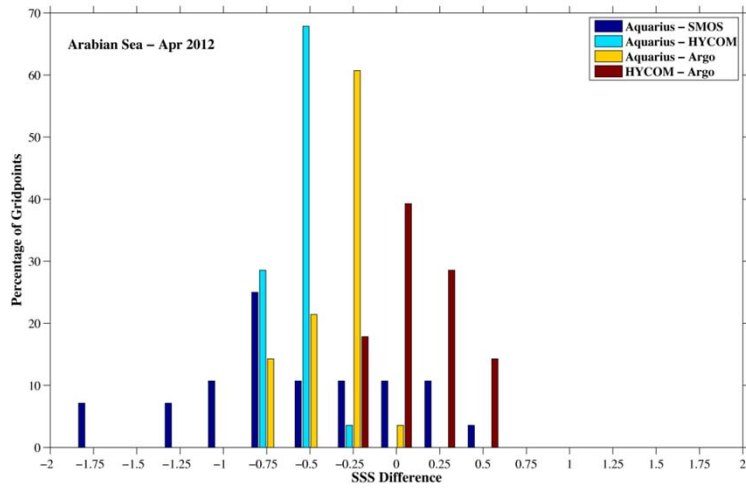
Daily Box Histograms



Weekly Box Histograms



Monthly Box Histograms



Box Average Differences

Arabian Sea			
Salinity Differences	Daily	Weekly	Monthly
Aquarius - SMOS	-0.06	-0.12	-0.16
Aquarius - HYCOM	0.32	-0.02	0.00
Aquarius - Argo	-0.02	-0.19	-0.16
HYCOM - Argo	-0.34	-0.16	-0.15

Bay of Bengal			
Salinity Differences	Daily	Weekly	Monthly
Aquarius - SMOS	-0.70	-0.04	-0.10
Aquarius - HYCOM	-0.50	-0.28	-0.26
Aquarius - Argo	-0.24	-0.26	-0.21
HYCOM - Argo	0.26	0.02	0.05

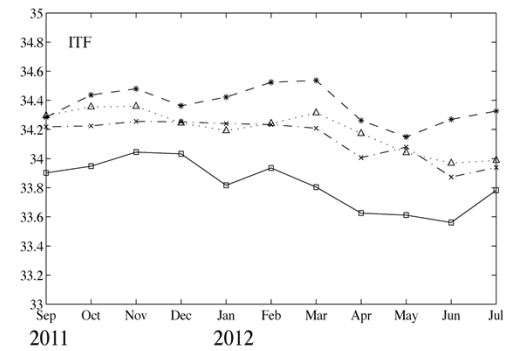
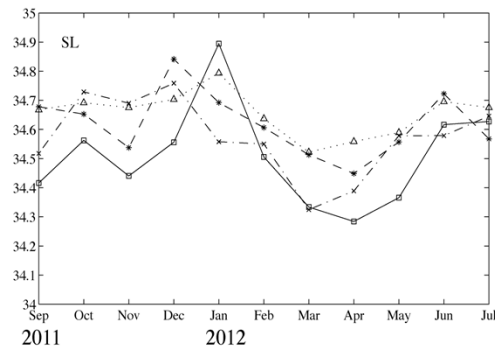
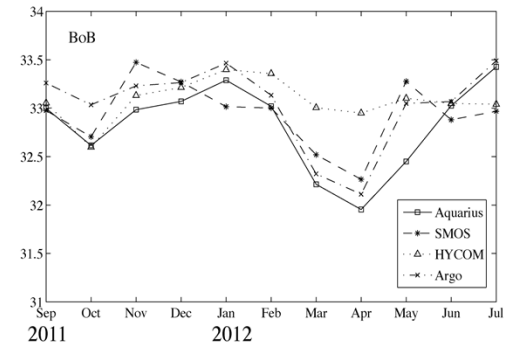
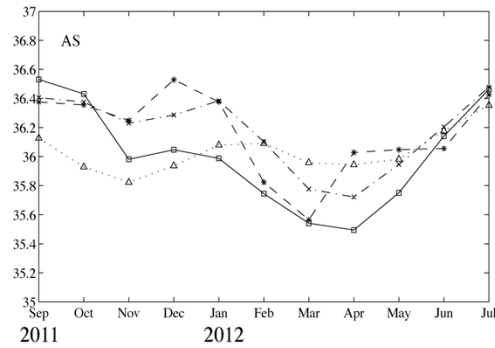
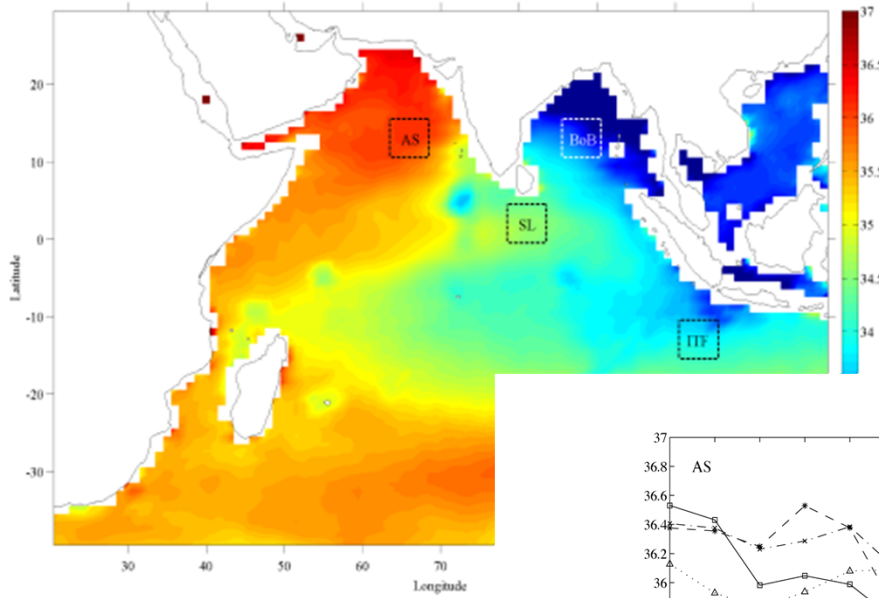
Sri Lanka			
Salinity Differences	Daily	Weekly	Monthly
Aquarius - SMOS	-0.11	-0.05	-0.11
Aquarius - HYCOM	-0.06	-0.10	-0.15
Aquarius - Argo	0.02	-0.02	-0.07
HYCOM - Argo	0.07	0.08	0.08

Indonesian Throughflow			
Salinity Differences	Daily	Weekly	Monthly
Aquarius - SMOS	-0.57	-0.55	-0.54
Aquarius - HYCOM	-0.34	-0.39	-0.37
Aquarius - Argo	-0.33	-0.38	-0.32
HYCOM - Argo	0.00	0.01	0.06

Key points

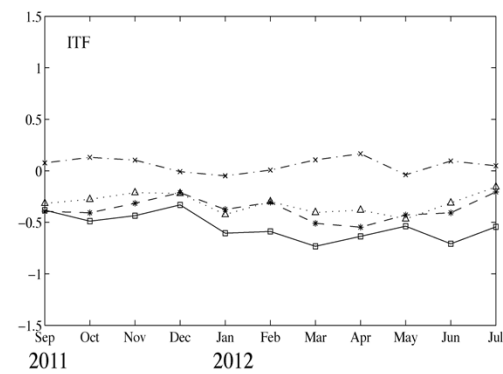
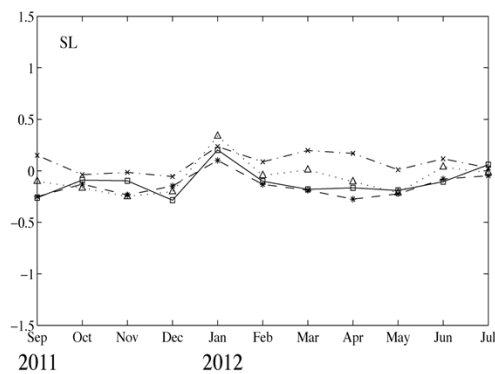
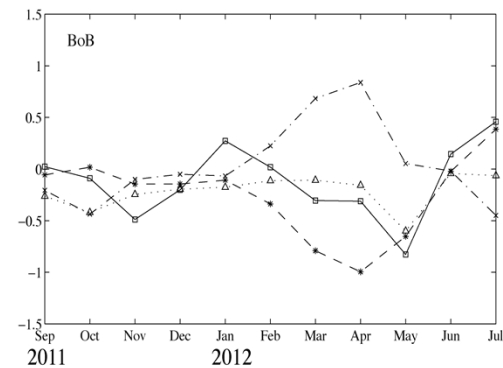
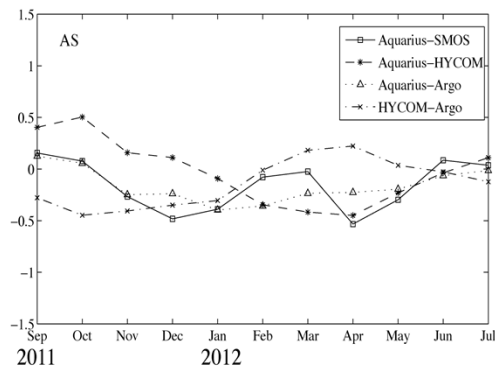
- Correlations between SSS products in the box average regions are encouraging
- Monthly averaging of SSS improves on accuracy

Box Average in the Indian Ocean



Box Average in the Indian Ocean

Differences

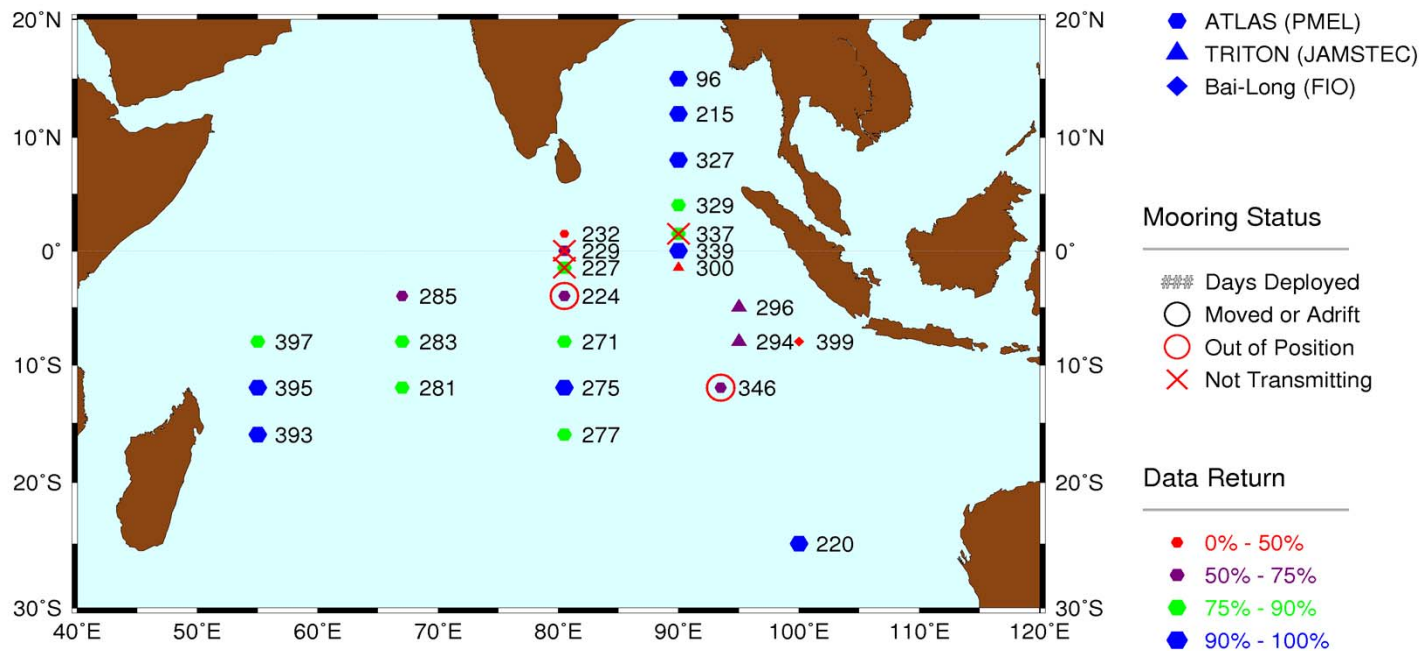


Larger differences occur in the Bay of Bengal

Comparison with RAMA Moorings

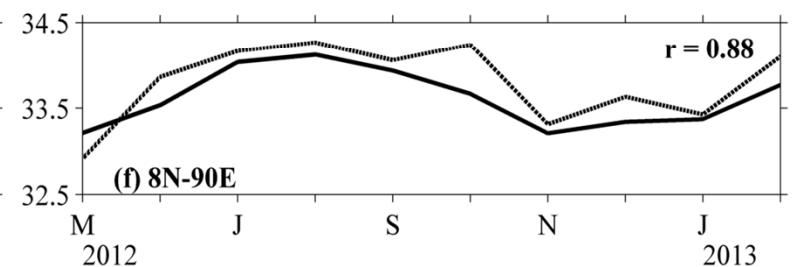
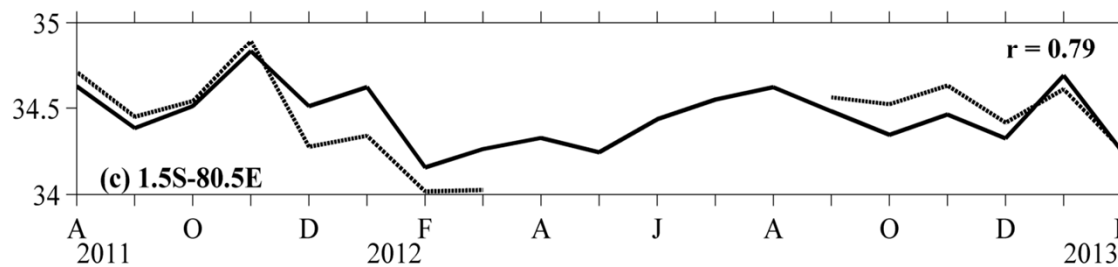
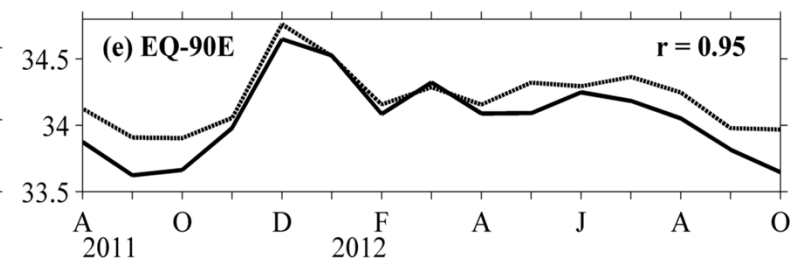
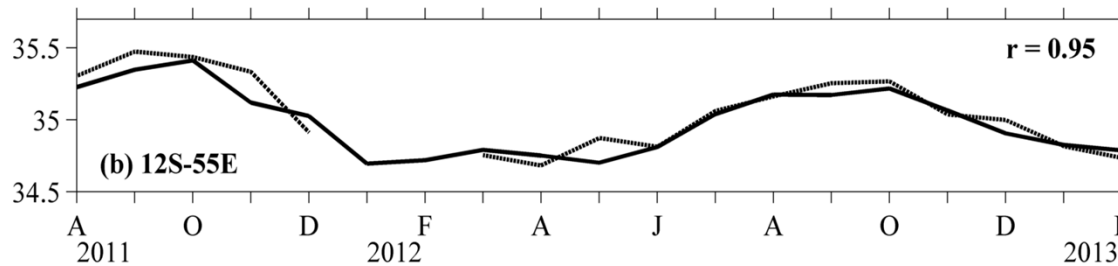
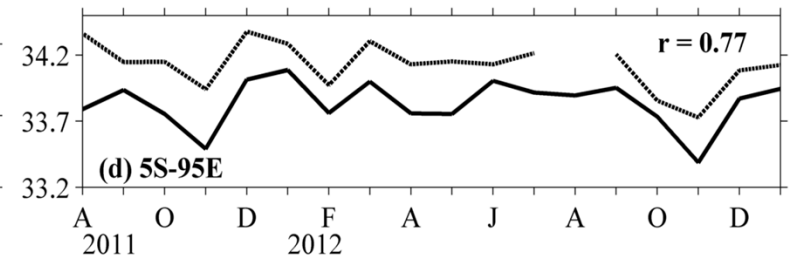
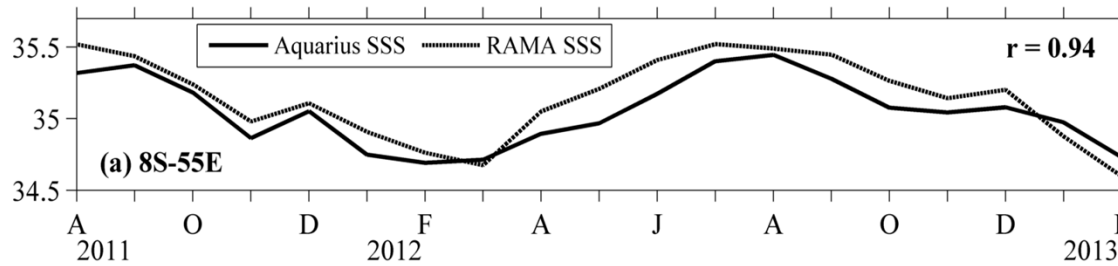
Status of Presently Deployed RAMA Moorings

Updated Apr 05, 2013



(Click Mooring Symbol for Summary)

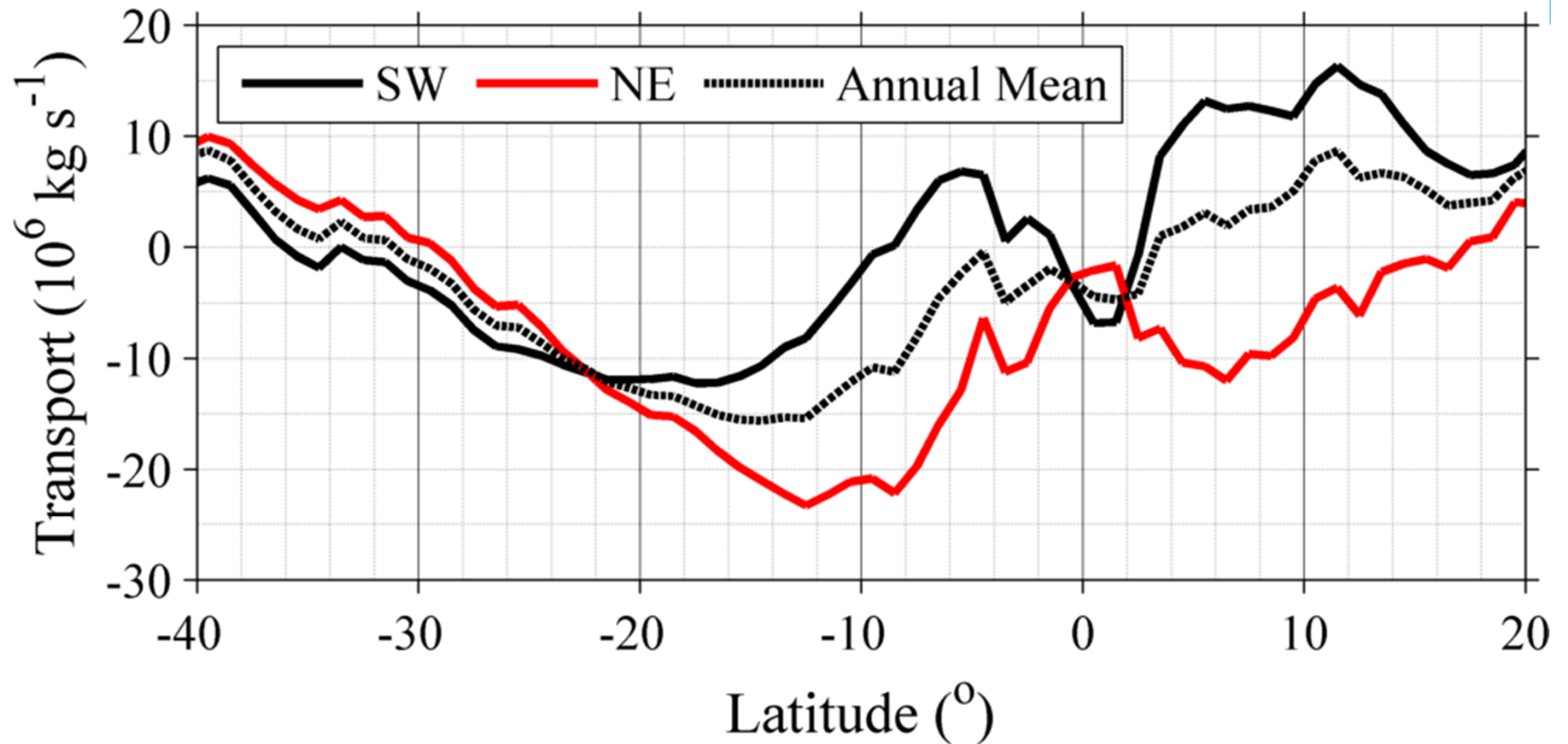
Comparison with RAMA Moorings



Key points

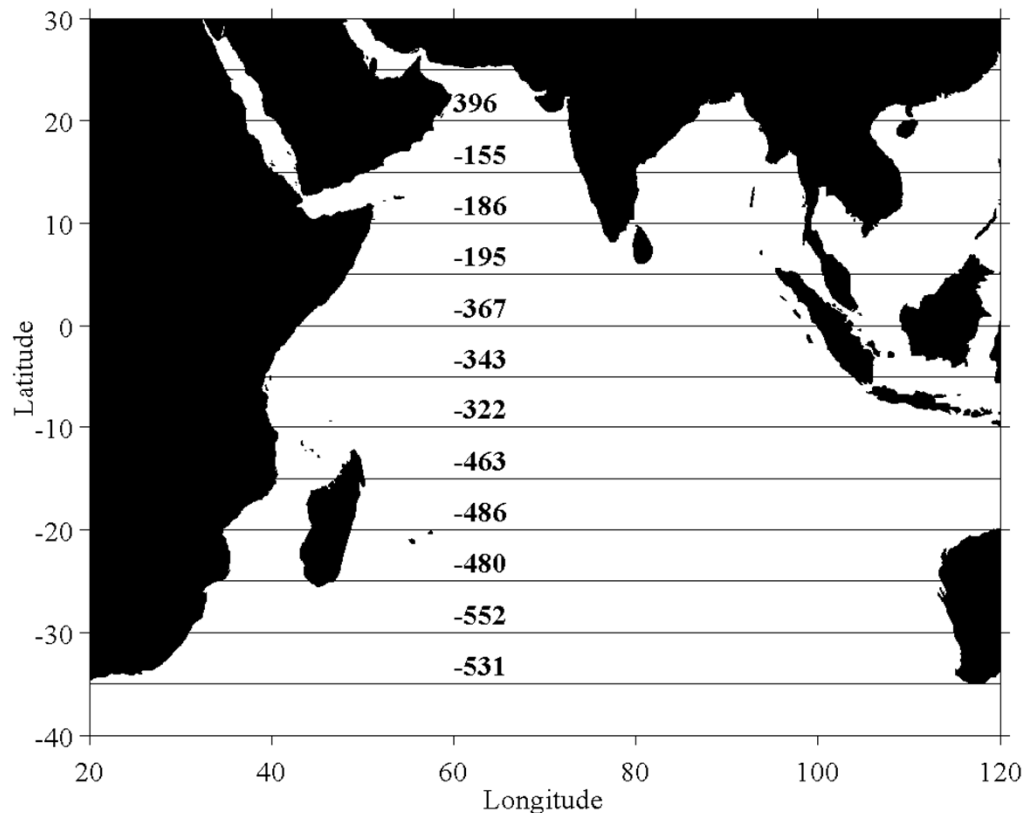
- Box averages show larger differences in the northern Indian Ocean
- Strong correlations between Aquarius and RAMA SSS.

Aquarius Meridional Salt Transport



Larger differences between SW and NE transport occur within ± 15 degree of the equator

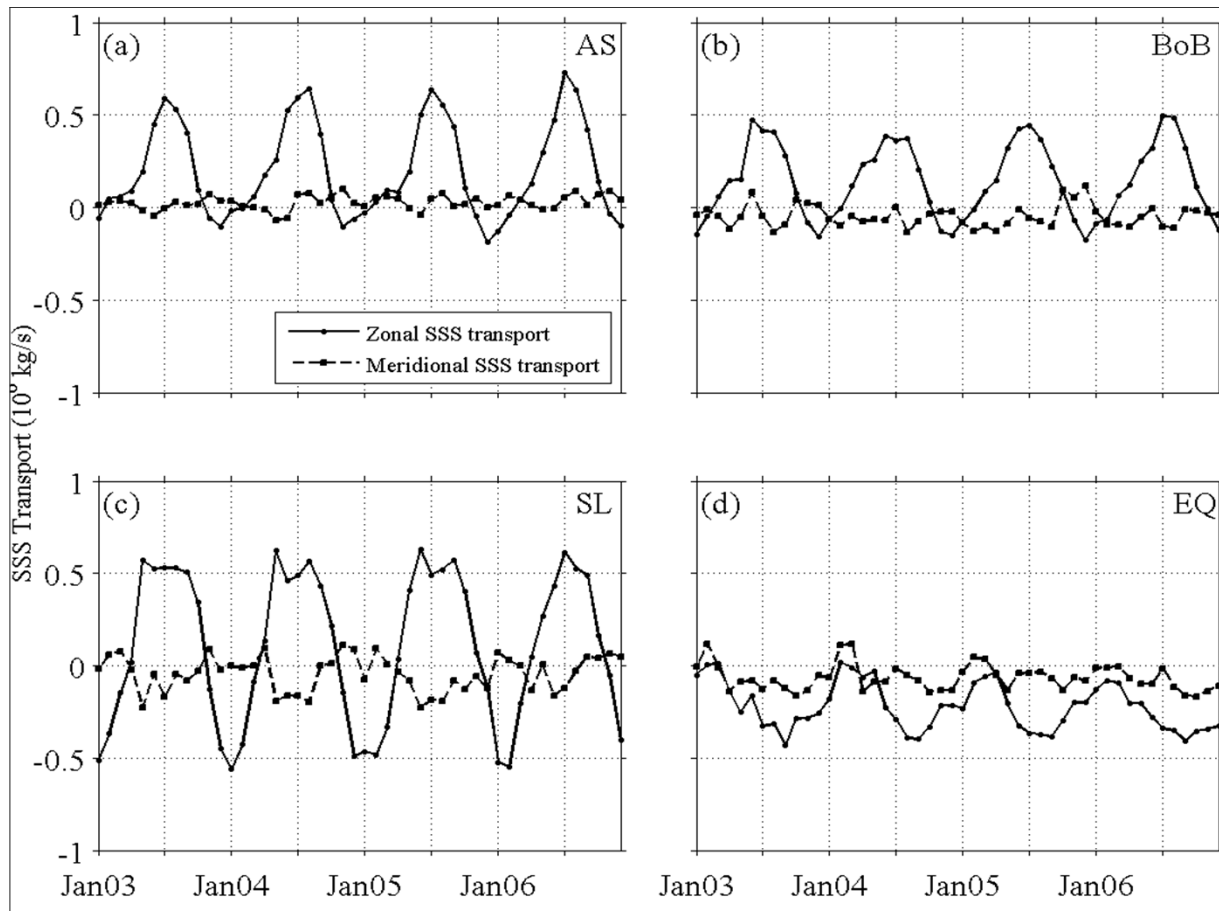
Annual mean net meridional salt transport



Salt transport ($\times 10^6$ kg/s)

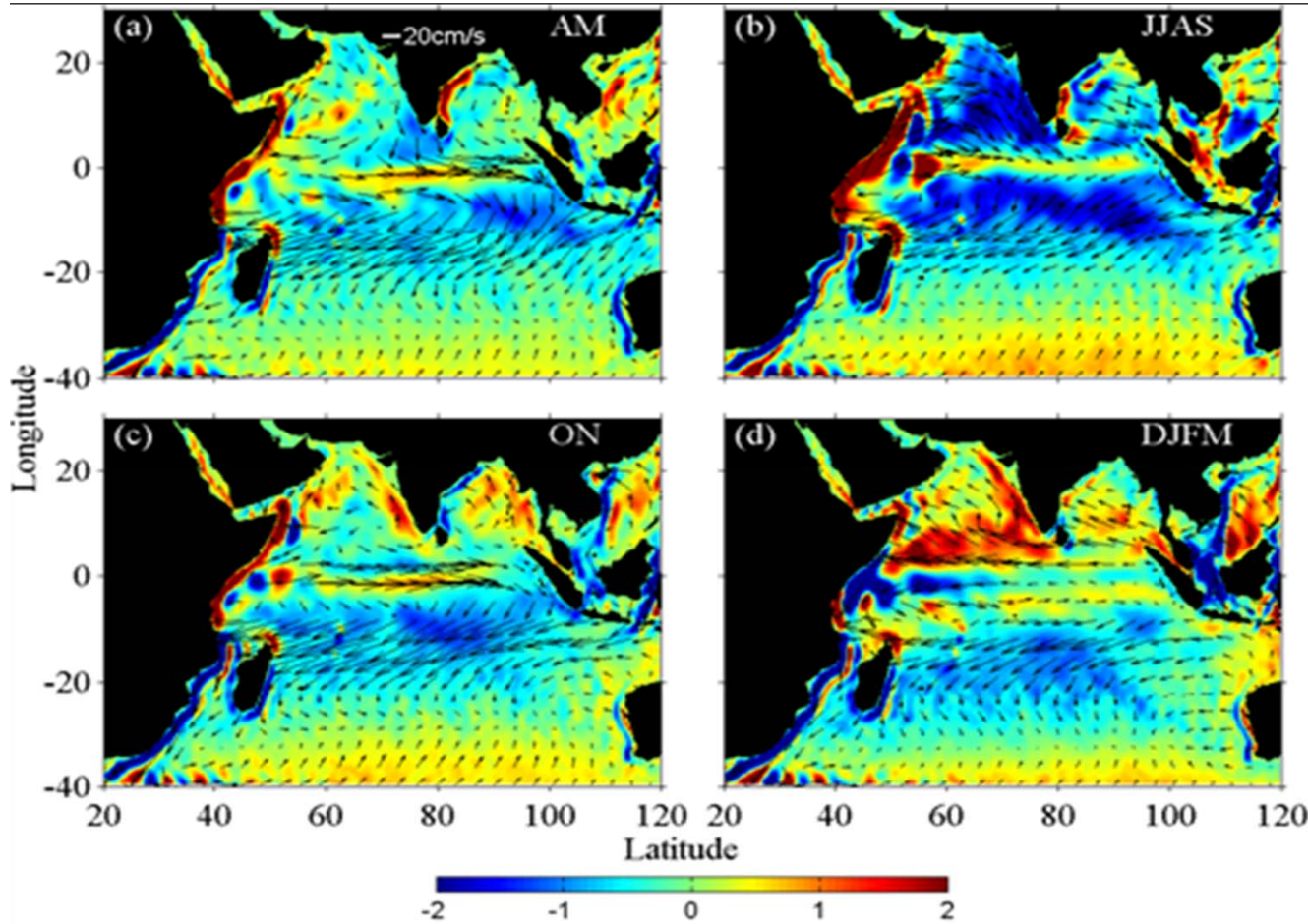
- Net transport is southward except 20° N
- transport increases southward
- Indian Ocean is a net exporter of salt

Near-surface salt transport



- zonal transport higher than meridional transport
- transport minimal in S. Indian Ocean.
- strongest transport along SL region.

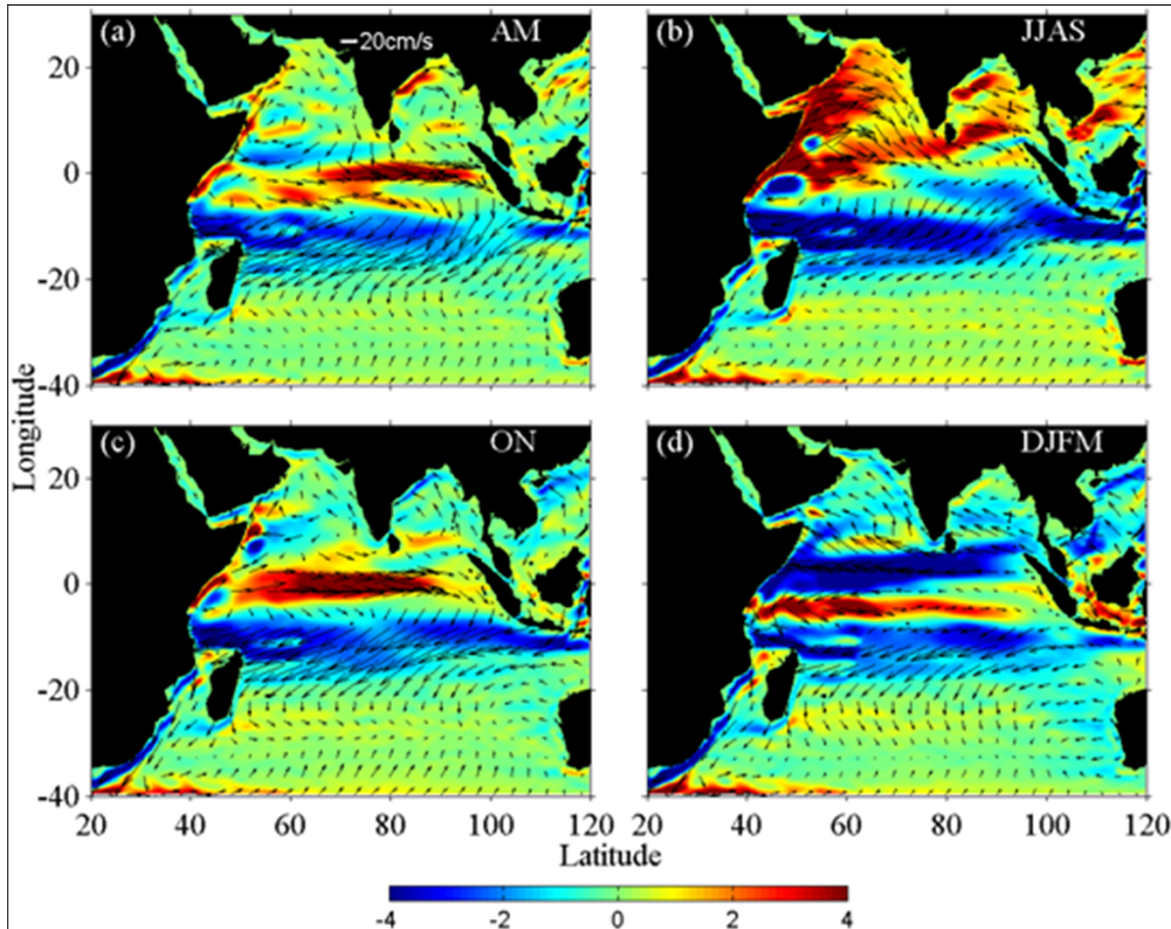
Mean Meridional Near-Surface Salt Transport



- Seasonal reversals of transport more pronounced in NIO
- Reversals strong along Somali Current, eastern AS and western BoB

$\text{Kg m}^2 \text{s}^{-1}$

Mean Zonal Near-Surface Salt Transport

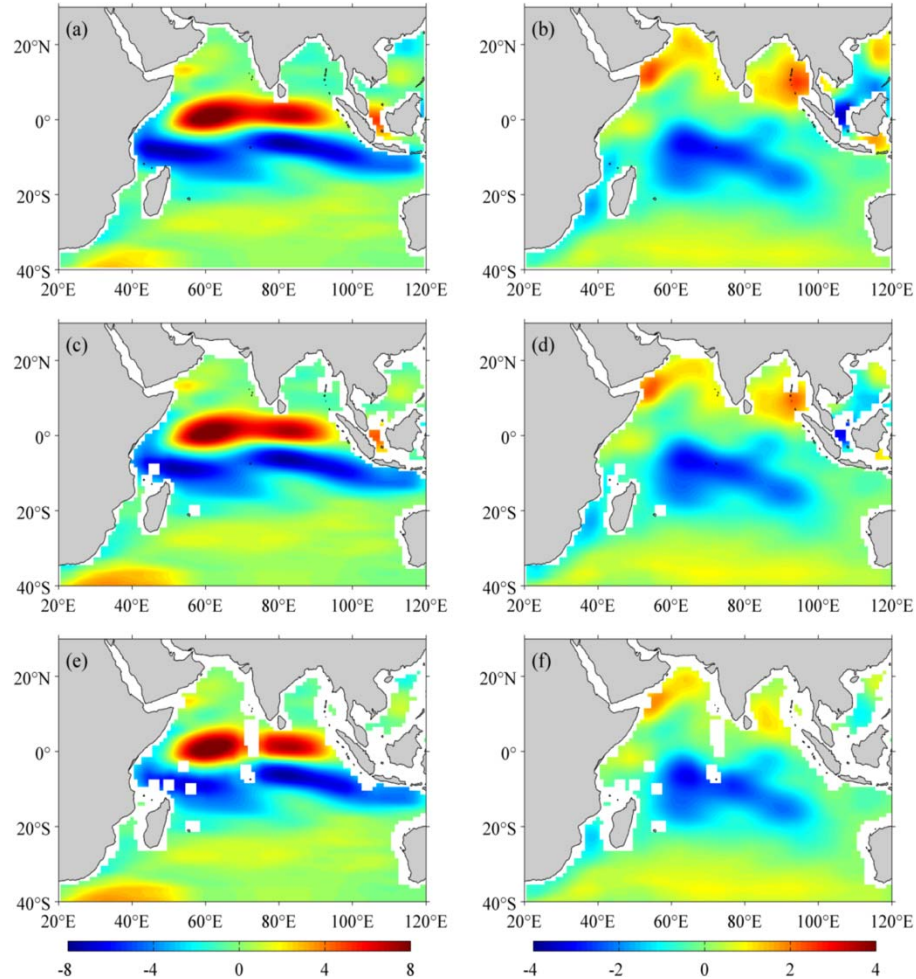


$\text{Kg m}^2 \text{s}^{-1}$

- zonal transport higher than meridional transport
- effects of Wyrтки jets seen along the equator in May and October
- year-round transport along 5° S - 15° S due to SEC

Mean Salt Transport October-November, 2011

Nyadjro et al., RSE, 2013



Argo

SMOS

Aquarius

$\text{Kg m}^2 \text{s}^{-1}$

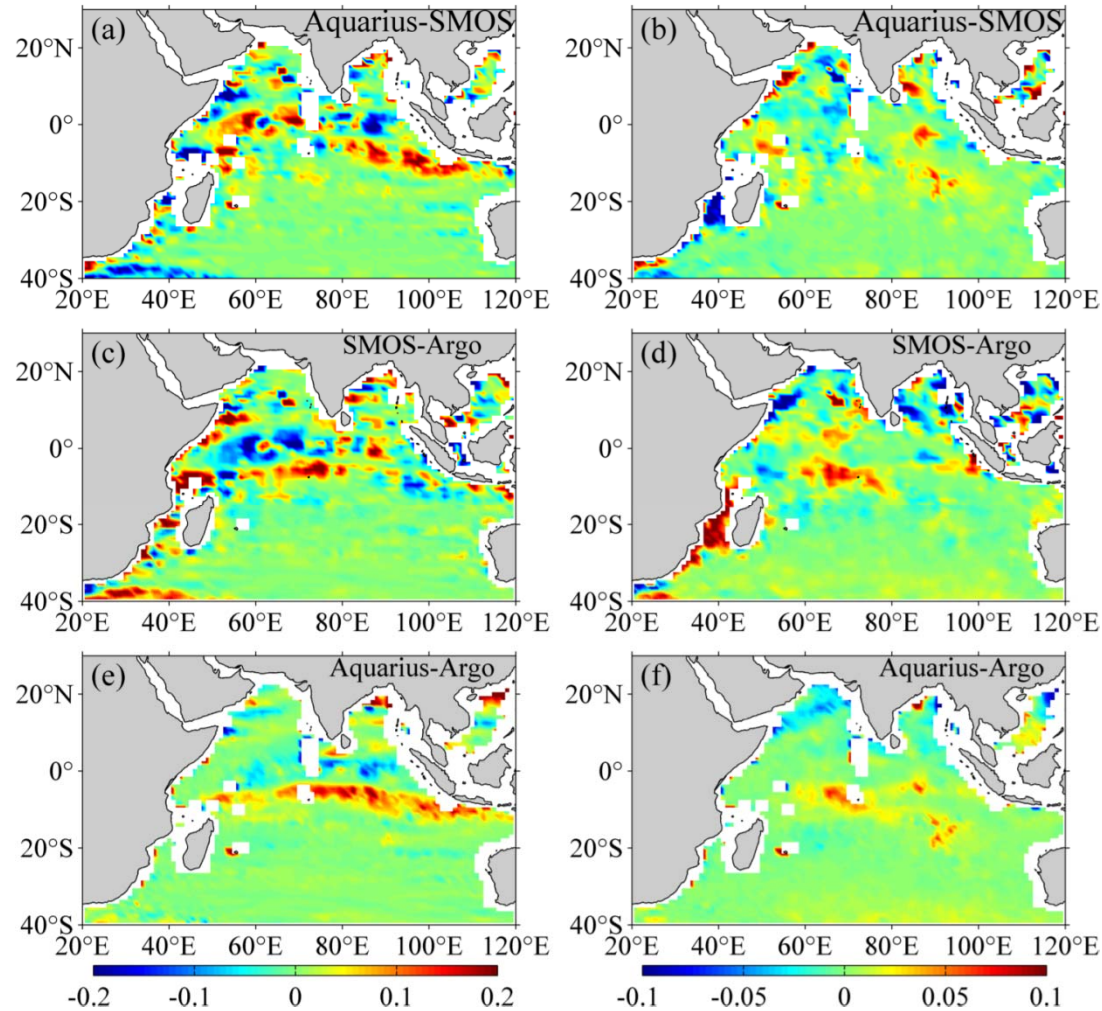
Zonal

Meridional

Mean Salt Transport October-November, 2011

Differences

Nyadjro et al., RSE, 2013

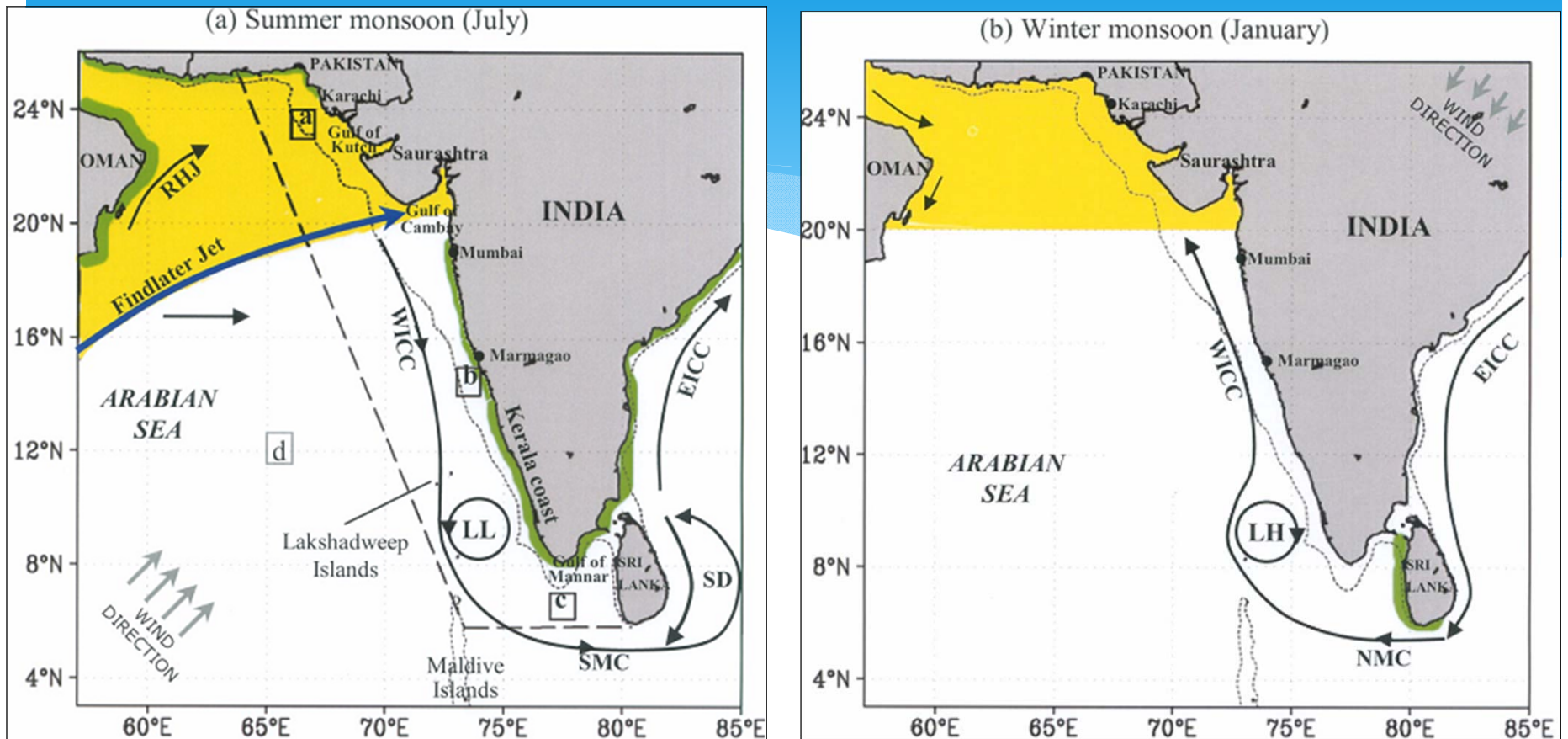


$\text{Kg m}^2 \text{s}^{-1}$

Zonal

Meridional

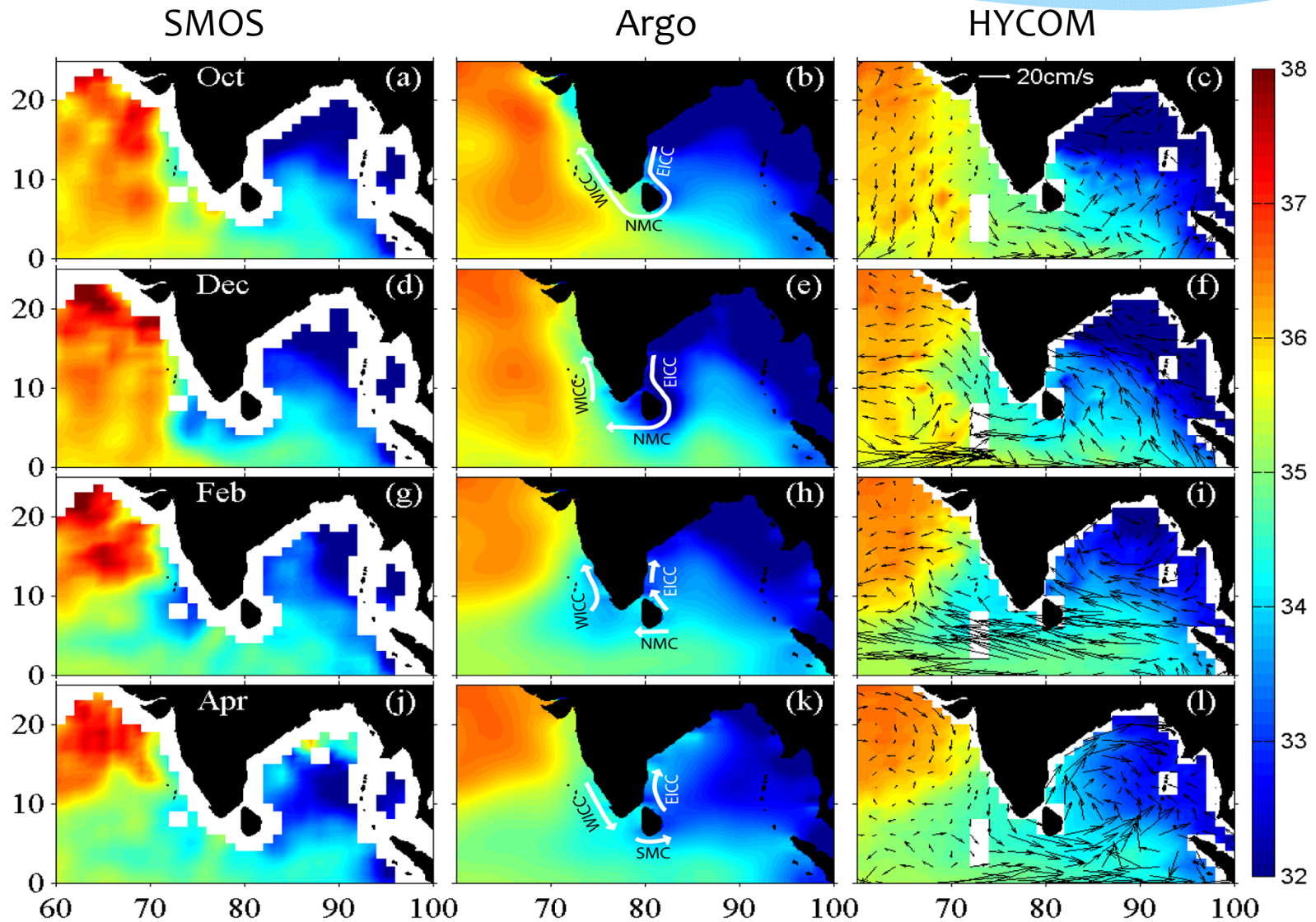
The Southeastern Arabian Sea (SEAS)



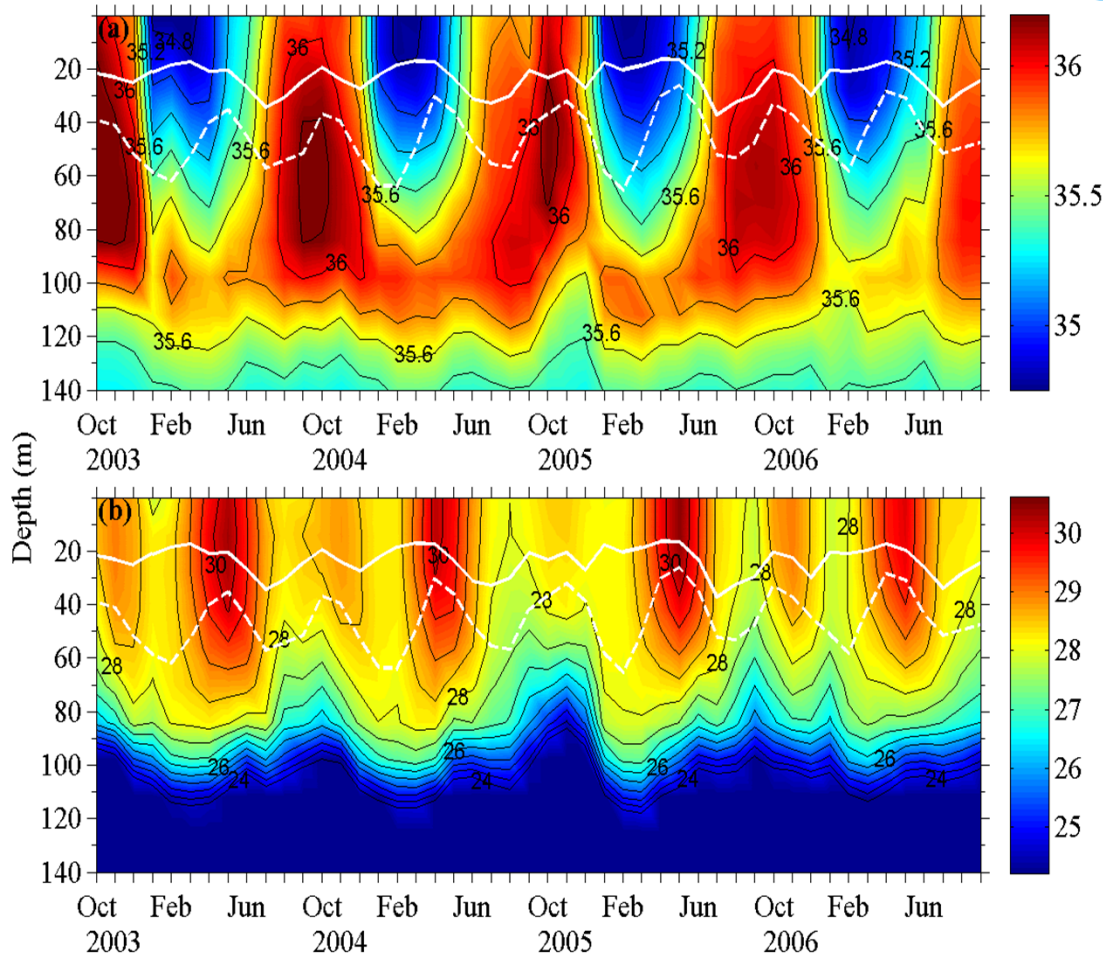
(Source: Luis and Kawamura, 2004)

- SW monsoon: strong SW winds, surface cooling, heat loss, Lakshadweep Low
- NE monsoon: weak NE winds, Lakshadweep High

Sea Surface Salinity variations in the SEAS



Salinity and temperature variations in the SEAS



- average depth of warm pool is 40 m.
- two temperature warm cores; April-May, October-December
- low saline (<34) water in top 60 m between December-June
- Higher salinity (~36) occur below 70 m between July-November.

Depth-time section of Argo

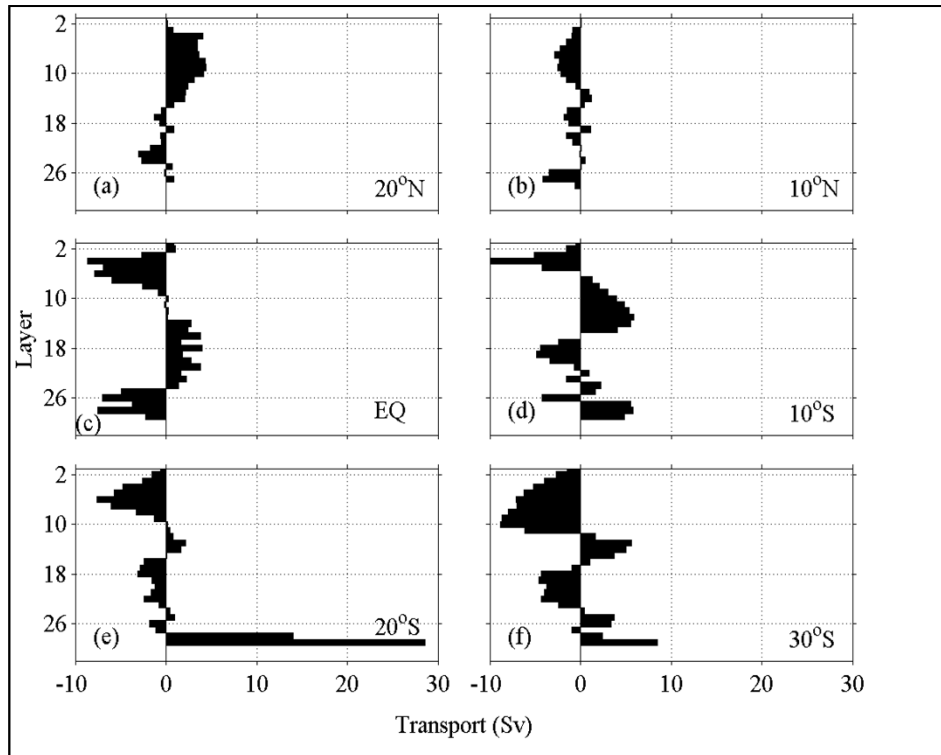
(a) salinity and (b) temperature

MLD- solid white lines, Isothermal layer-dashed white line

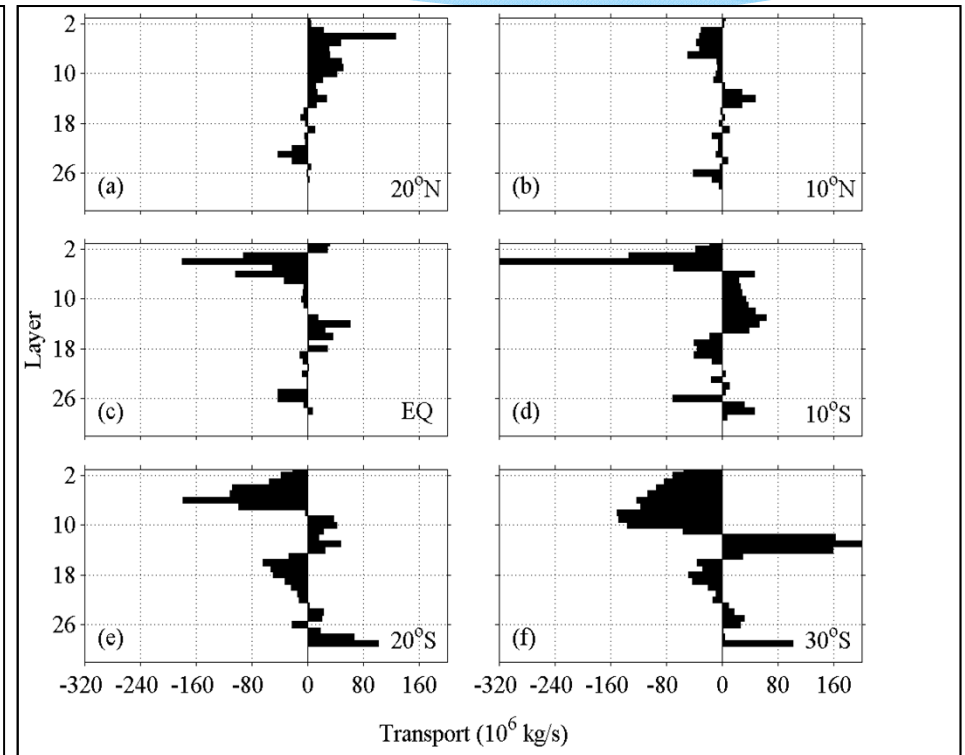
Summary

- SMOS and Aquarius are able to show the broad patterns of SSS
- Spatio-temporal averaging of data reduces error.
- Retrieval is however a challenge in the coastal regions
- Meridional salt transport is enhanced during the monsoon seasons.
- Salt transport derived from satellites captures the influence of Wyrcki jets in the equatorial region.
- SMOS data is erratic in the northern Indian Ocean due to Radio Frequency Interferences (RFI) and land-ocean contamination
- Anomalous salt transport driven by changes in velocity rather than salinity fluctuations in the North Indian Ocean
- We need more cal/val in the Indian Ocean. Argo float (STS floats) data will aid remedy to the above issues and improve the quality of satellite data.

Depth variation of volume and salt transport



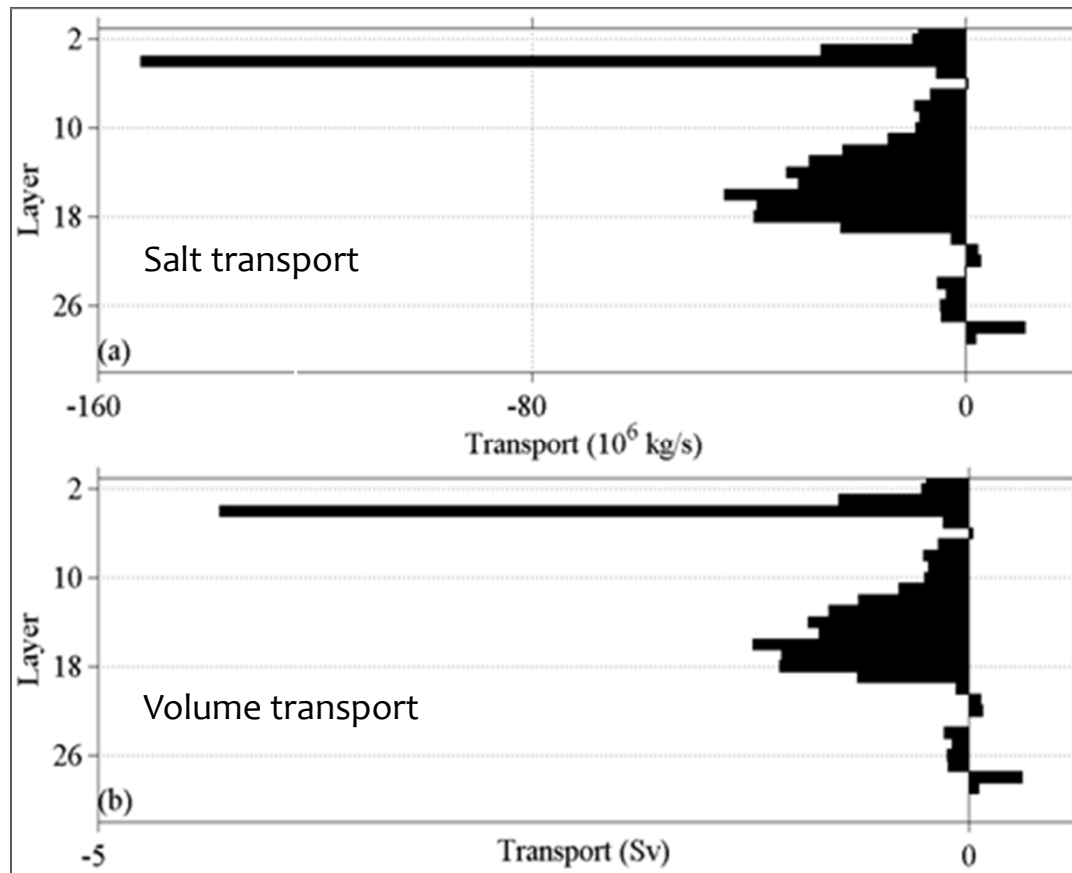
Volume transport



Salt transport

- transport is southward in surface depths
- transport is northwards in deeper waters

ITF Salt and Volume transports



- ITF goes as far as Somali region
- This study: 14.4 Sv of water and 512×10^6 kg/s of salt into Indian Ocean.
- Other studies : Piola and Gordon (1984): 14 Sv; Godfrey (1989) 12 Sv.