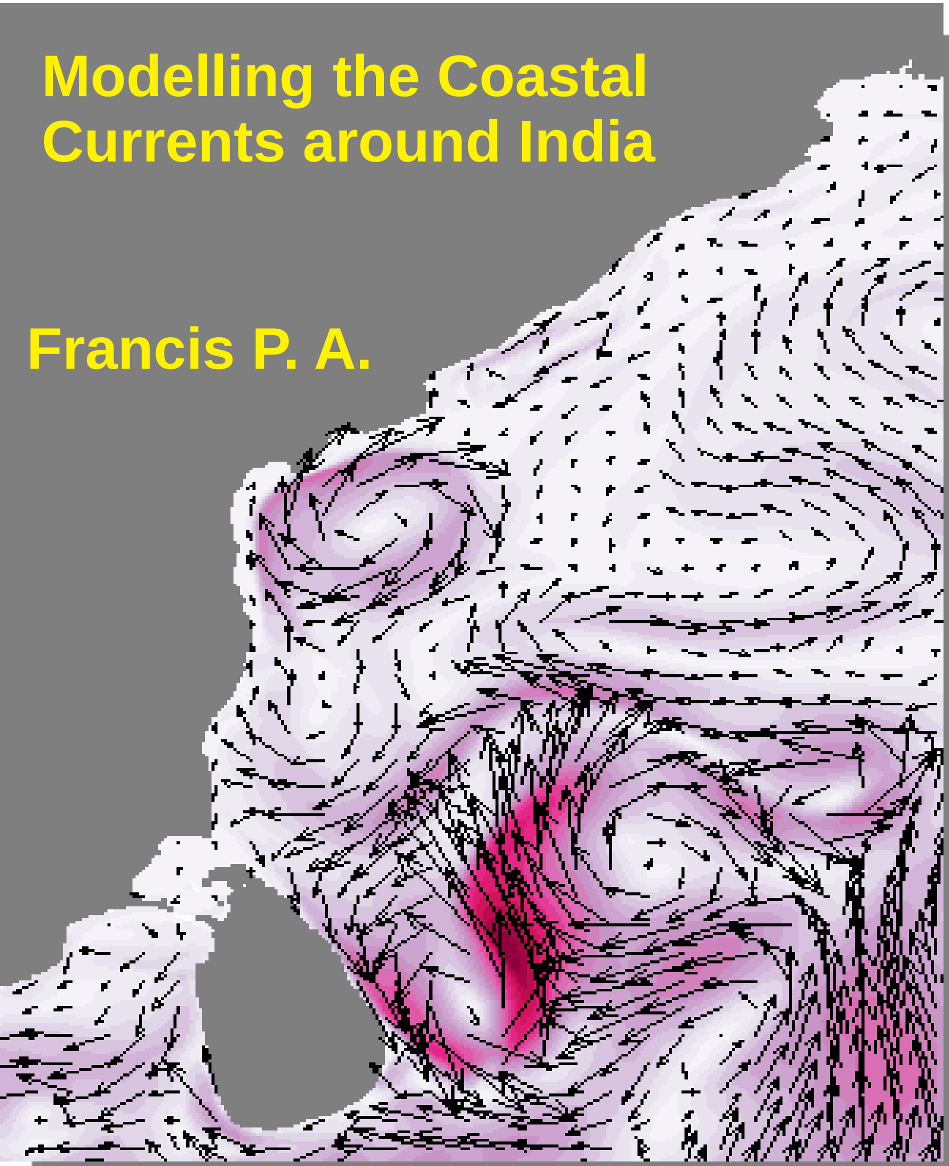
Modelling the Coastal Currents around India

Francis P. A.

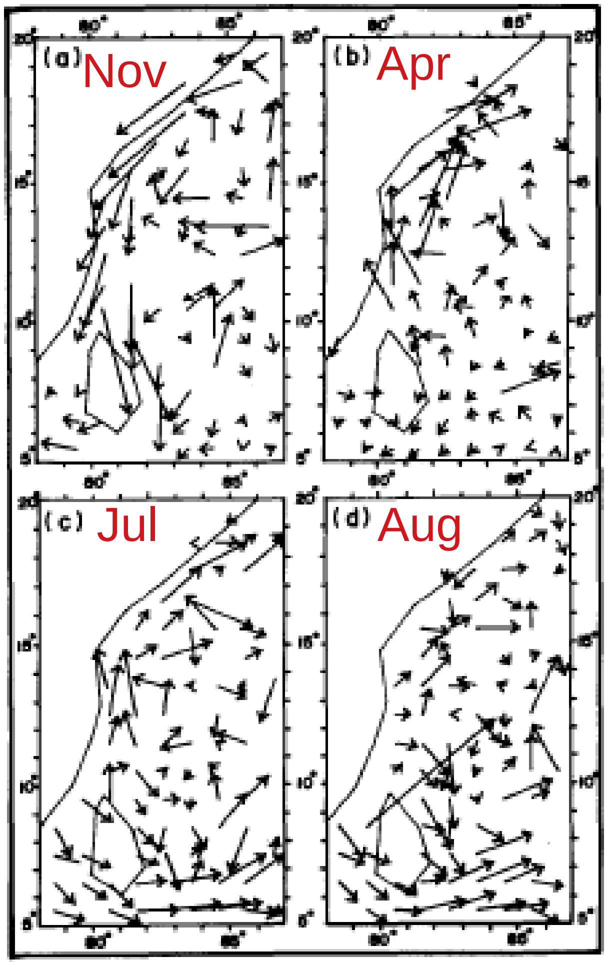


ITCOocean Webinar

Friday, 25th June 2021

Indian National Centre for Ocean Information Services
Ministry of Earth Sciences, Govt. of India
Hyderabad-500090

Earlier observations of western boundary currents in the Bay of Bengal



BoB circulation in the Cutler and Swallow (1984) ship drift data

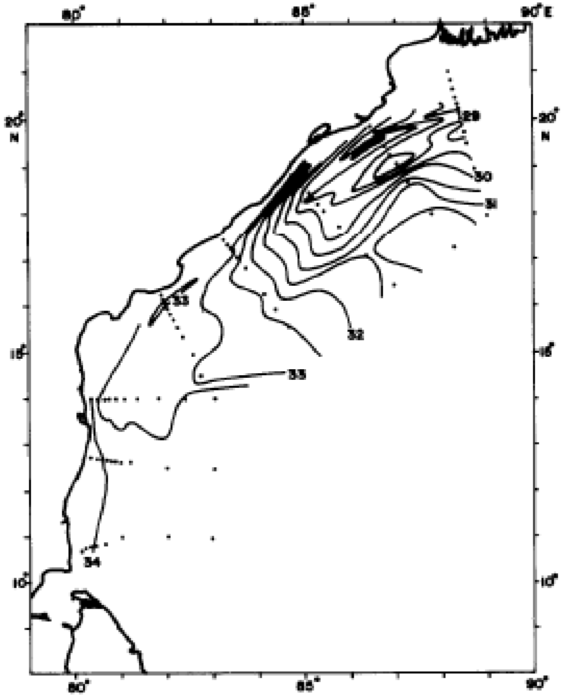
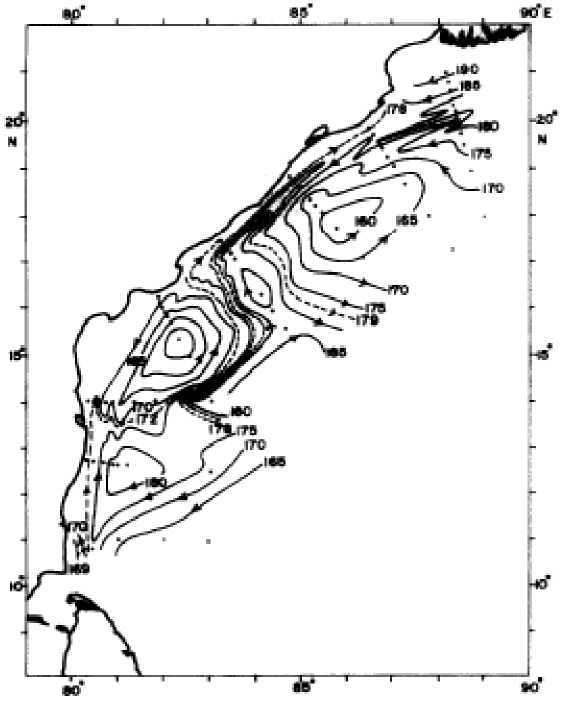


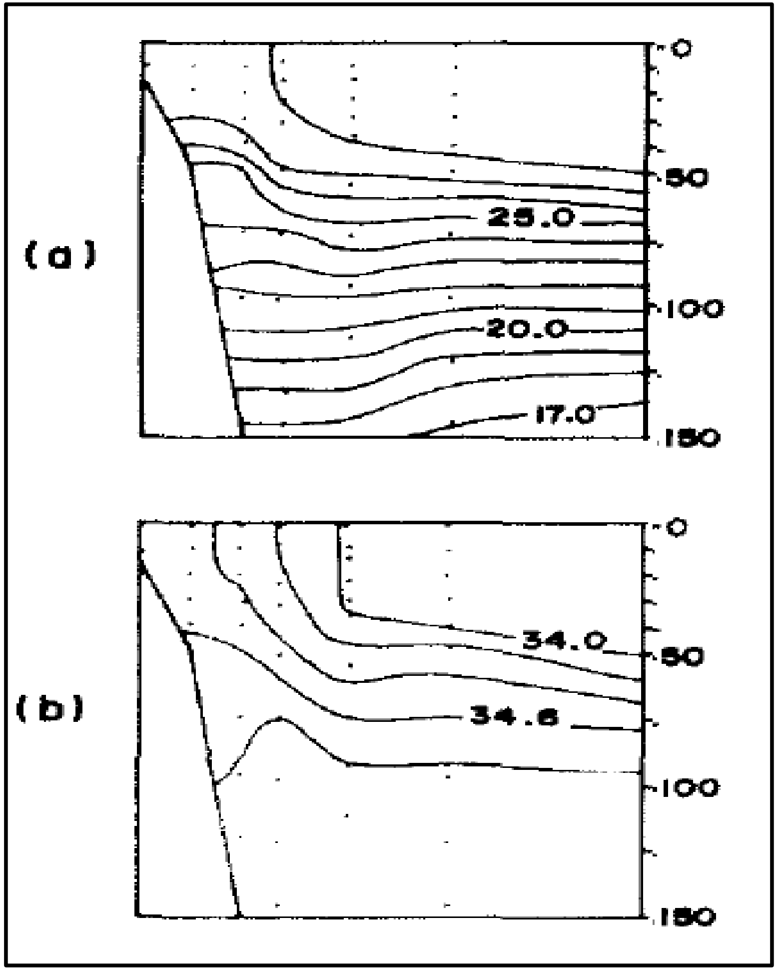
Fig. 6. Salinity (ppt) at the surface. Dots indicate station locations.



Surface salinity and dynamic topography observations

Shetye et al. 1991.

Longitude-Depth sections of temperature and Salinity near Chennai



From Shetye et al (1991)

Continental Shelf Research, Vol. 11, No. 11, pp. 1397–1406, 1991.
Printed in Great Britain.

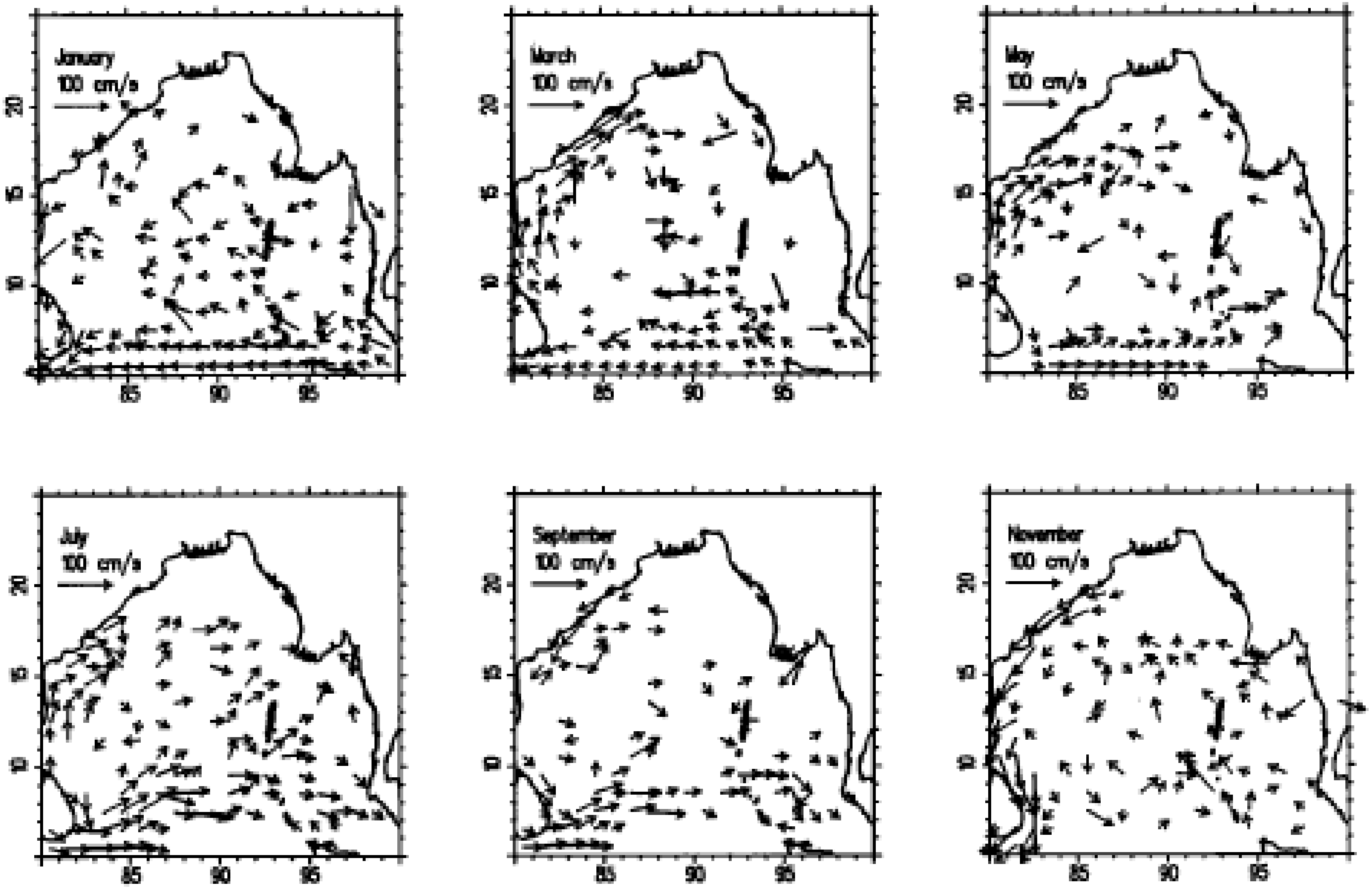
Wind-driven coastal upwelling along the western boundary of the Bay of Bengal during the southwest monsoon

S. R. Shetye,* S. S. C. Shenoi,* A. D. Gouveia,* G. S. Michael,* D. Sundar* and G. Nampoothiri*

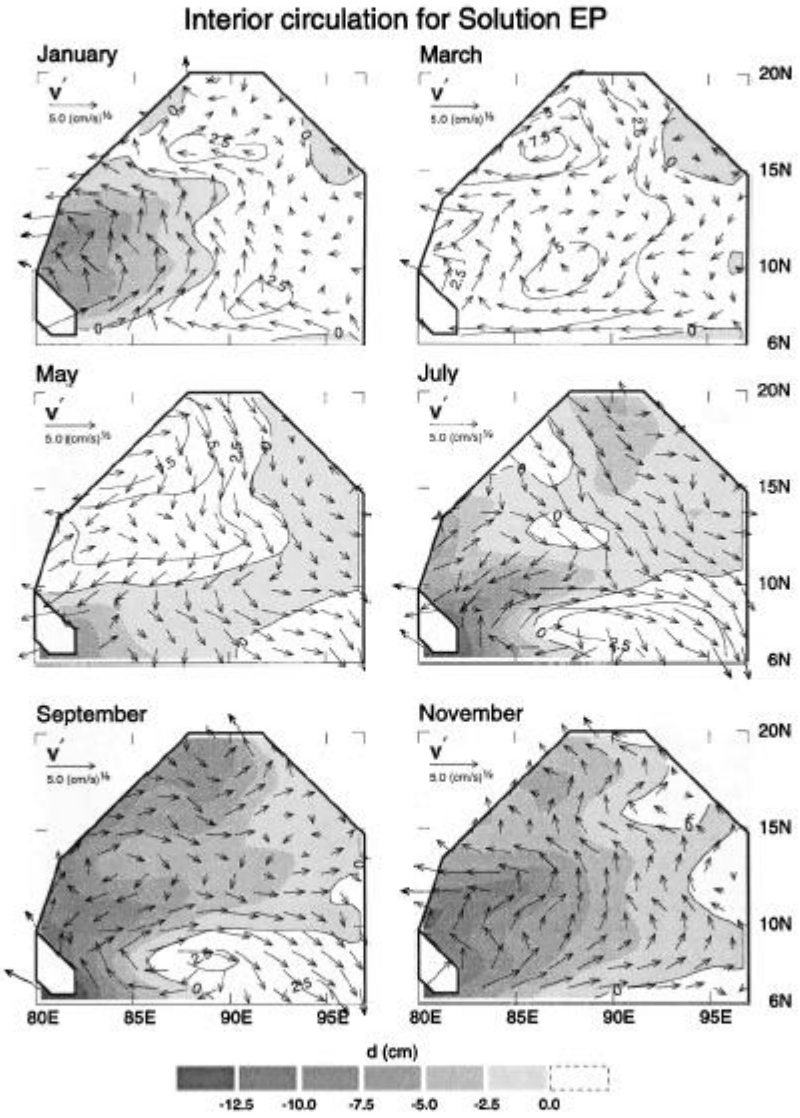
(*Received* 20 *August* 1990; *accepted* 30 *October* 1990)

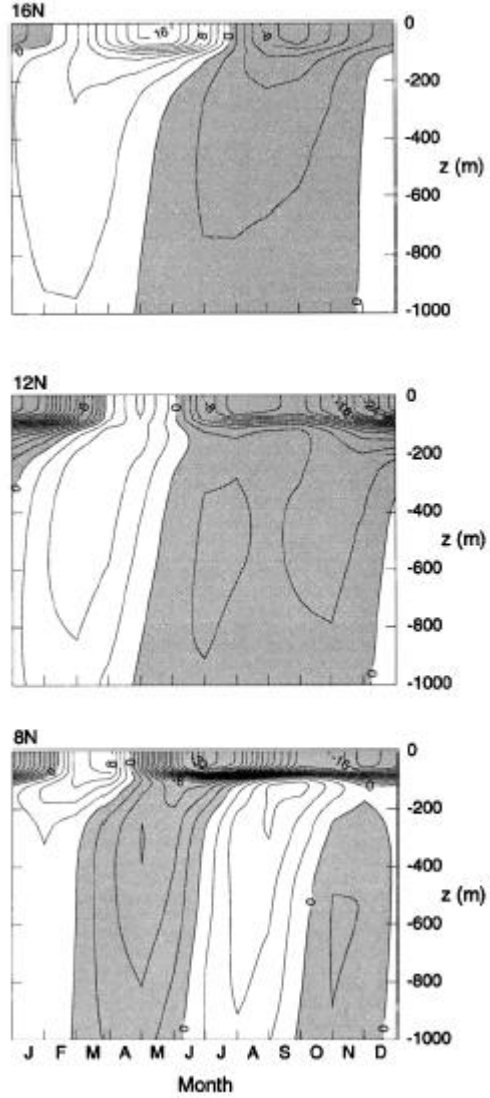
Abstract—A hydrographic survey during the southwest monsoon (July–August 1989) showed that along most of the western boundary of the Bay of Bengal, in an approximately 40 km wide band, isopycnals from depths up to about 70 m surfaced due to upwelling forced by local winds, in a fashion similar to that observed along eastern boundaries. Below the upwelling band there were often signatures of downwelling, suggestive of an undercurrent. There were no indications of a large-scale remotely forced western boundary current. Geostrophic velocity in the upwelling band was in the direction of the winds. The dynamic topography outside the upwelling band had cellular structures possibly indicating the presence of shelf waves with longshore wavelength of 400–500 km. The near-surface stratification was dominated by salinity, a consequence of high freshwater input to the Bay. The upwelling led to a coastward increase in salinity, except near the northern end where the freshwater influx from the Ganges and the Brahmaputra rivers overwhelmed other processes and gave rise to a freshwater plume offshore of the upwelling band. This plume moved equatorward against local winds.

Shetye et al. (1991) noted that below a depth of ~ 70m (at which signatures of upwelling were observed), often there were signals of downwelling, which indicate the presence of undercurrents.



Shankar et al. 1996



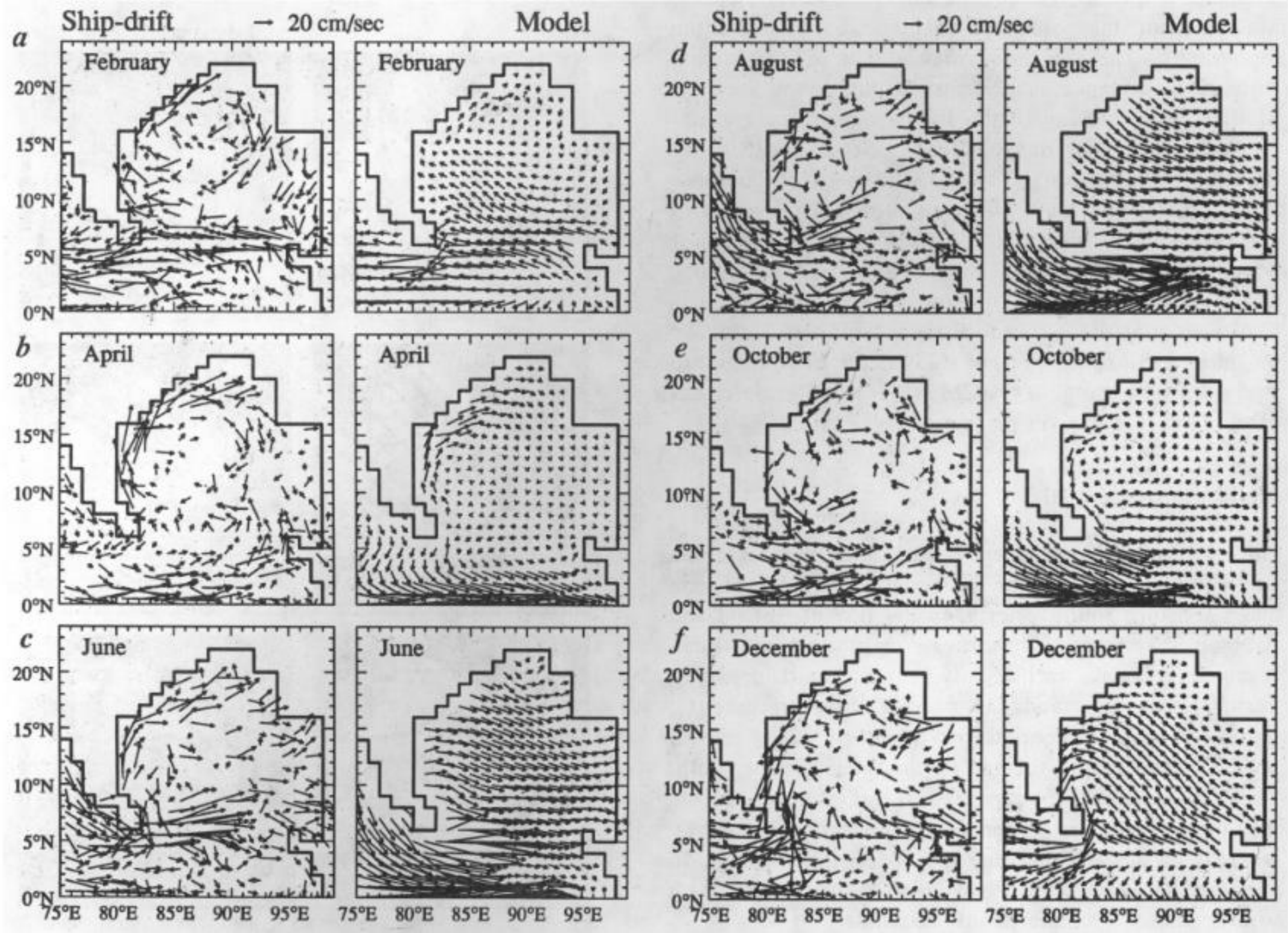


Shankar et al. 1996

McCreary et al. 1993
McCreary et al. 1996
Shankar et al. 1996
Potemra et al. 1996
Yu et al. 1996

Major objectives of these studies using numerical models (LCS) were to identify the forcing mechanisms of surface western boundary currents in the BoB.

- Coastal Kelvin waves
- Equatorial Forcing
- Interior Bay forcing

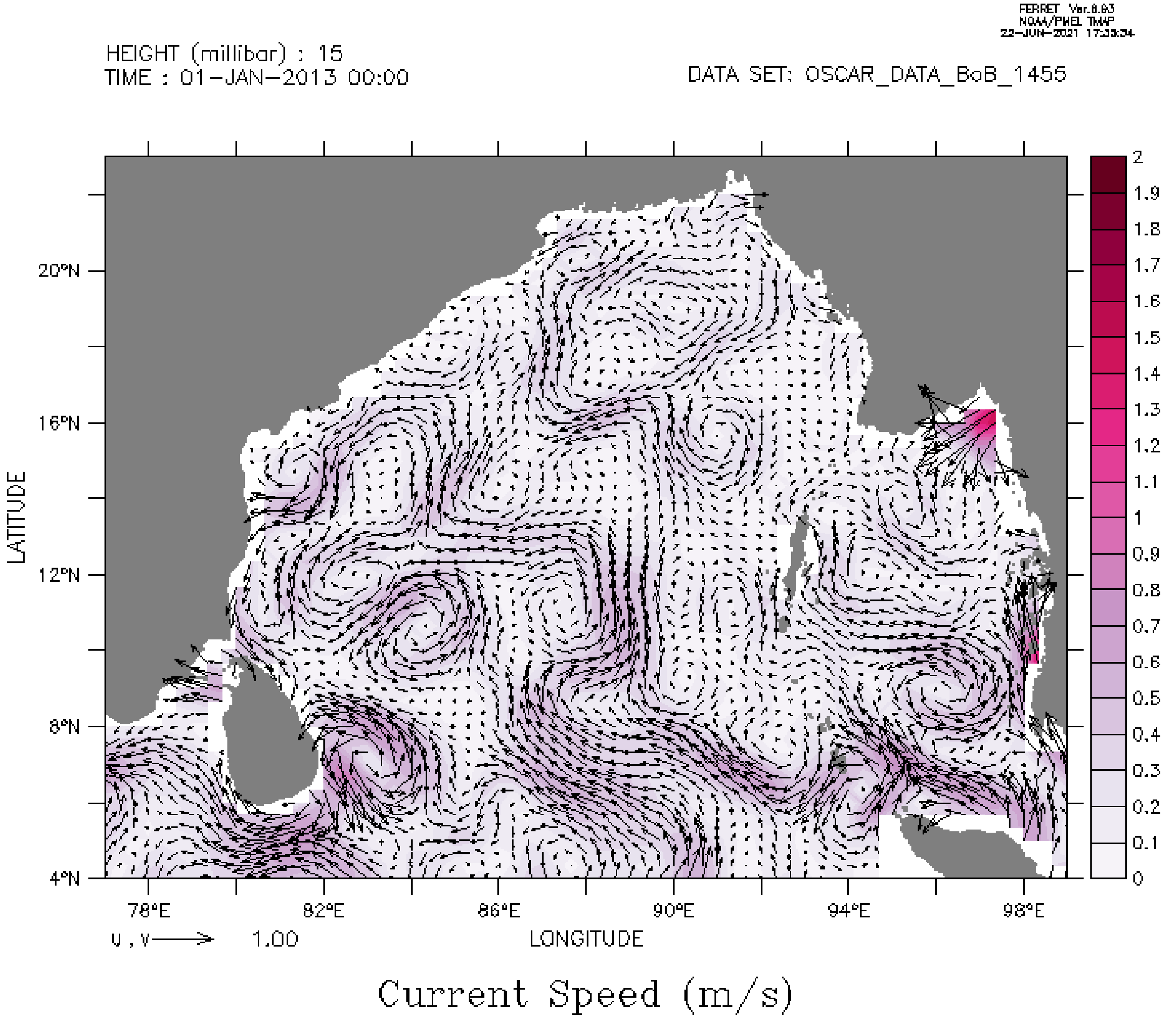


First ever application of OGCM in Indian Ocean was by Vinayachandran et al. 1996

Objective of this study was to identify the relative importance of different forcing mechanisms identified using pervious studies.

- Coastal Kelvin waves
- Equatorial Forcing
- Interior Bay forcing

BoB Circulation (OSCAR)



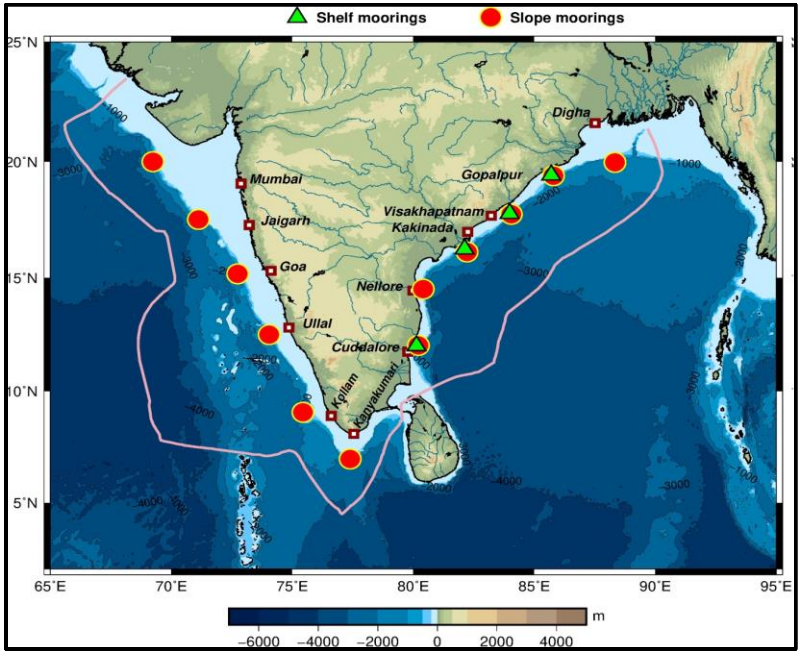
Earlier modeling studies on coastal currents off the east coast of India during 1990’s were primarily to identify the relative roles of different forcings of EICC and understand their relative importances.

Focus of oceanographic research shifted to equatorial Indian Ocean after the discovery of Indian Ocean Dipole in 1997.

Studies on the coastal circulation, including the EICC revived after 2010 mainly due to

1. Availability of continuous observations (ADCP, HF Radar)
2. Requirements of operational ocean services
3. Enhanced capability in the coastal modeling

Locations of ADCP installations in the Indian coastal waters

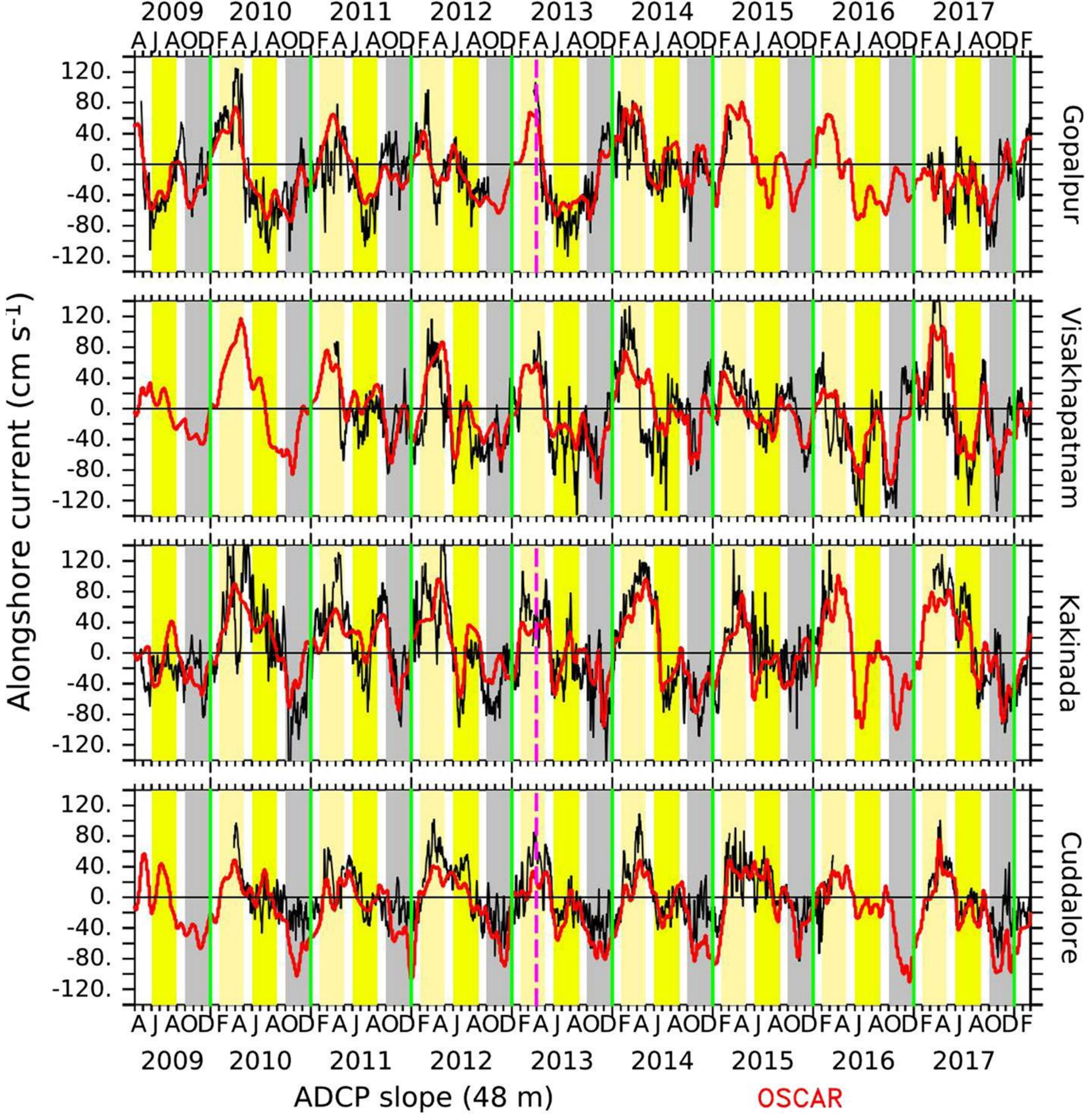


Source: INCOIS Annual Report 2017-18

- INCOIS and CSIR-NIO initiated a significant (and very challenging) programme to systematically measure the vertical structure of high-frequency coastal currents in the Indian coastal waters using a series of Acuostic Dopler Current Profilers (ADCPs).
- Initially pairs of ADCPS (one on shelf and another on slope were deployed at several carefully chosen locations in the east and west coast of India. Later, due to operational reasons, the shelf ADCPs are restricted to only 4 locations
- Availability of contiuous data from these ADCPs triggered a series of research on the coastal circulation around India, including its variation in space and time, its teleconnections with processes in the far away oceans, internal tides, etc.

Some important publications are:

Mukherjee et al (2018), Mukherjee et al (2017), Mukherjee et al (2014), Mukherjee et al (2013), Prakash et al (2012), Shenoi (2009), Subheesh et al (2016), Jithin et al (2017), Jithin et al (2019), etc..



Surface current observations in the slope region along the east coast of India.

OSCAR currents also represent the variation in the slope currents reasonably well, except in the very high-frequency part.

Annual cycle is prominent.

ADCP observations show very high-frequency variation in the surface currents.

Simulation of the high-frequency variation is the new challenge for the modelers.

Mukherjee et al. 2020

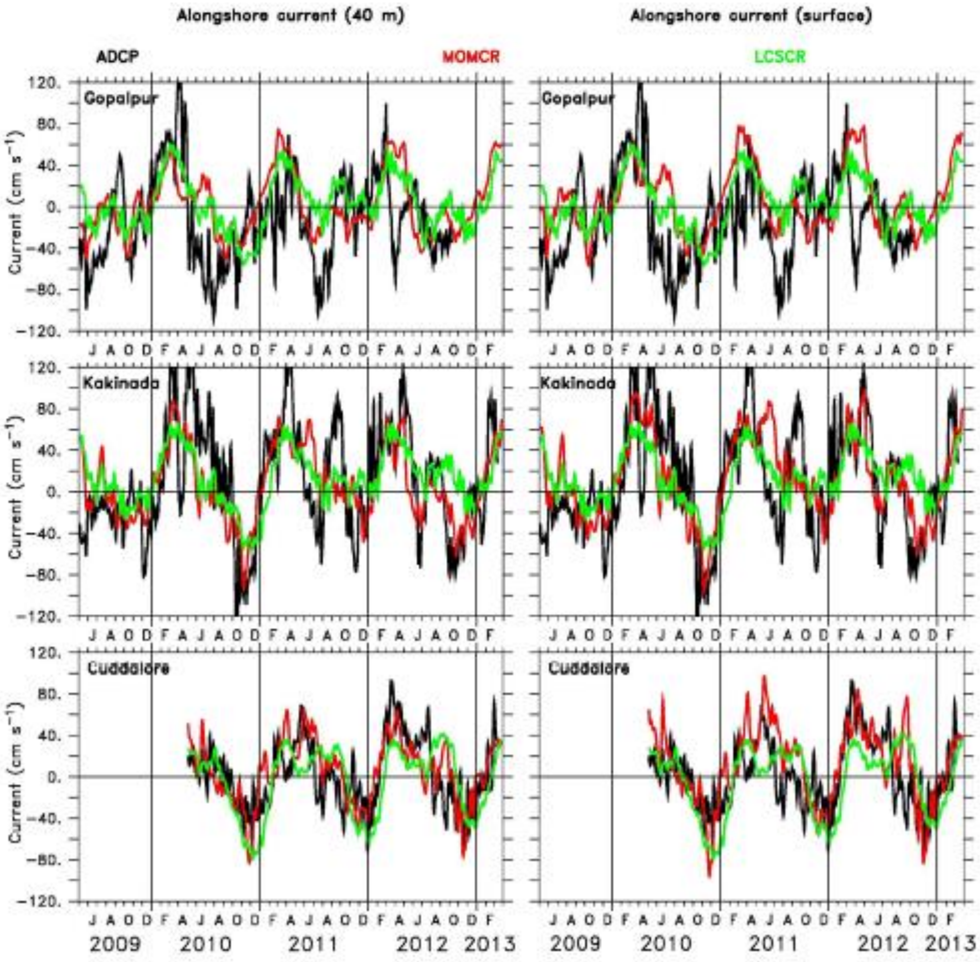
Clim Dyn (2018) 50:3949–3980
DOI 10.1007/s00382-017-3856-x

Numerical simulation of the observed near-surface East India Coastal Current on the continental slope

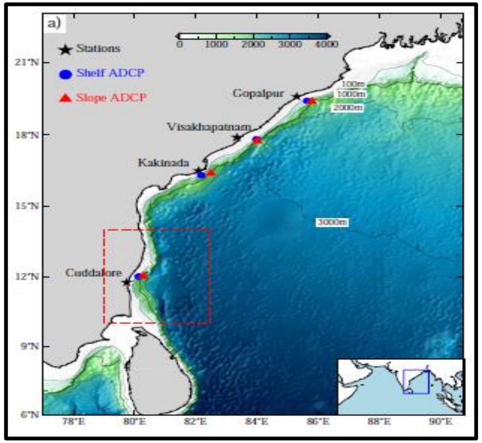
A. Mukherjee[1,2] · D. Shankar[2] · Abhisek Chatterjee[1,2] · P. N. Vinayachandran[3]

Received: 10 January 2017 / Accepted: 7 August 2017 / Published online: 22 August 2017

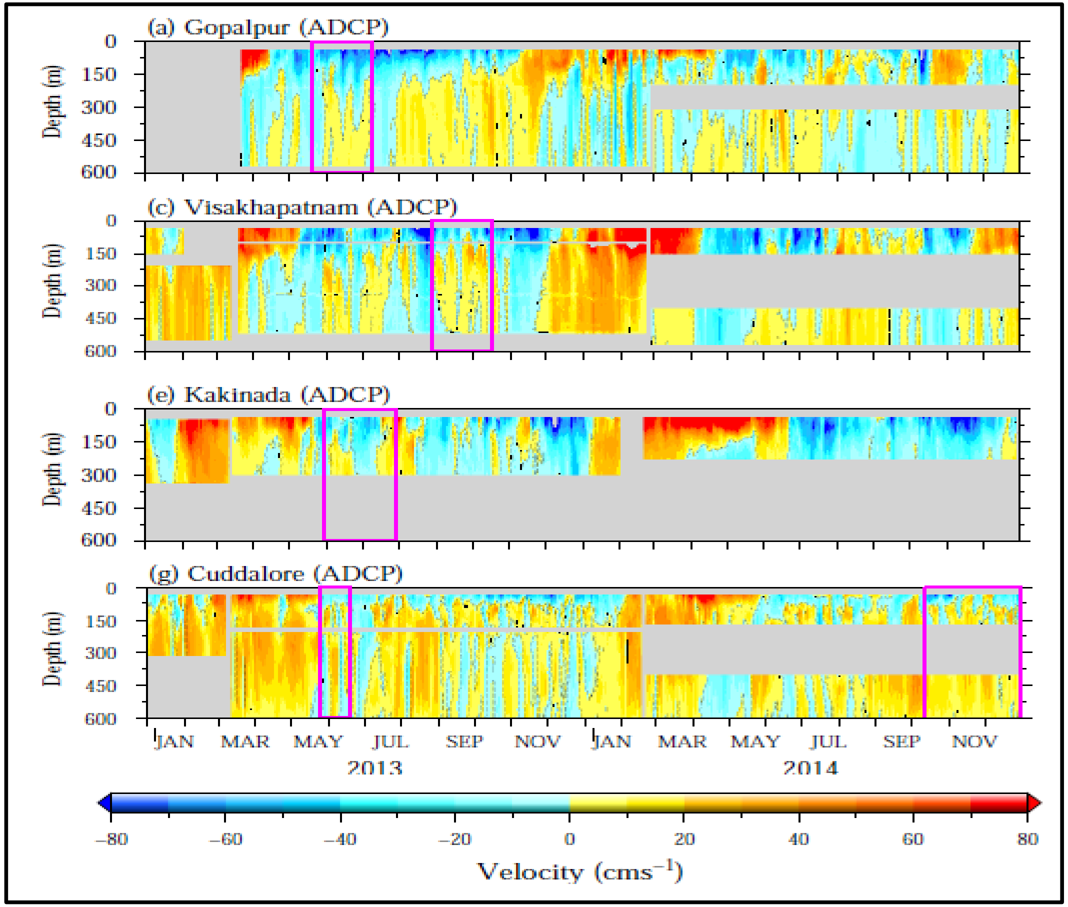
- Compared the performance of LCS and MOM4p1 in simulating the variability of EICC in different timescales.
- Despite being a linear model, LCS could simulate the annual cycle of EICC very well.
- Both LCS and MOM4p1 had difficulties in simulating the higher frequency variability in EICC.



During 2013-14



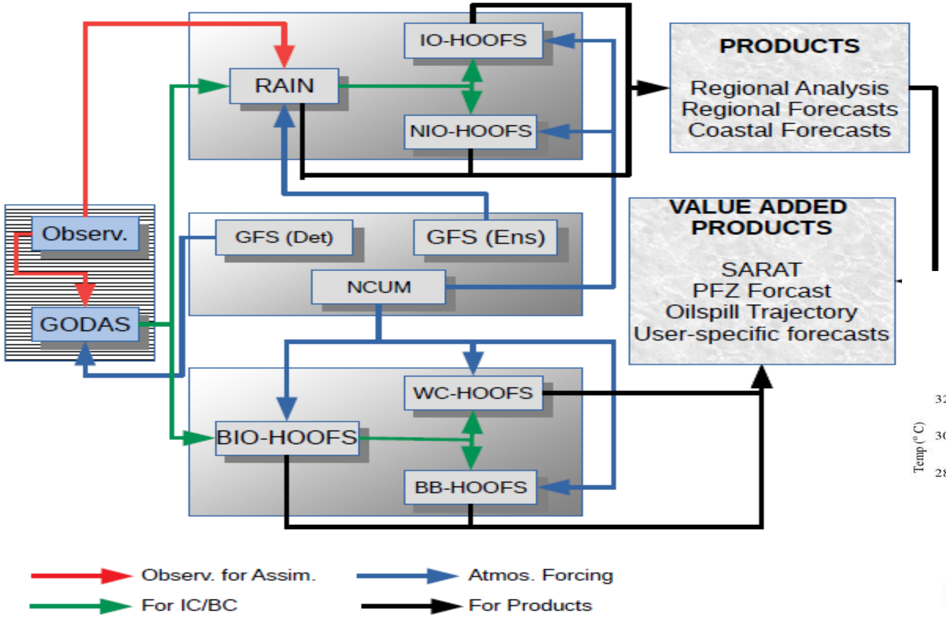
- Apr/May-Nov/Dec: Equatorward surface currents
- Dec/Jan-Mar/Apr : Poleward surface currents
- Transitions from equatorward to poleward and reverse happen progressively from north to south.
- Undercurrents are prominent off-Cuddalore, but not completely absent in other locations.

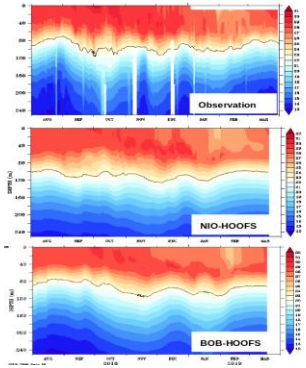


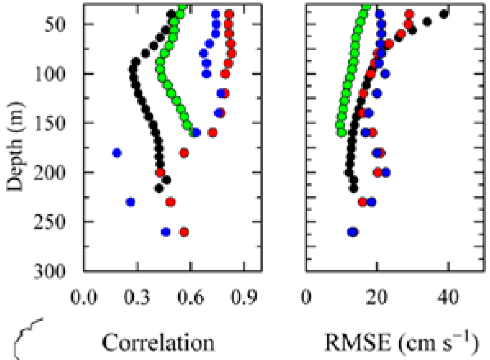
(Francis et al. Ocean. Dyn. 2020)

High-resolution Operational Ocean Forecast and reanalysis System for the Indian Ocean

Different components of HOOFS

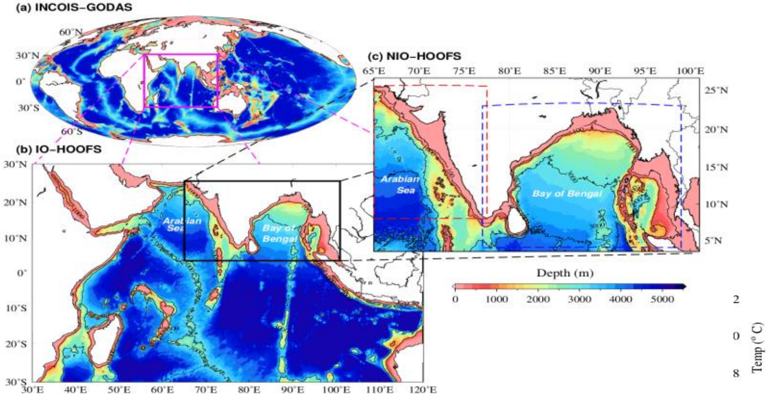


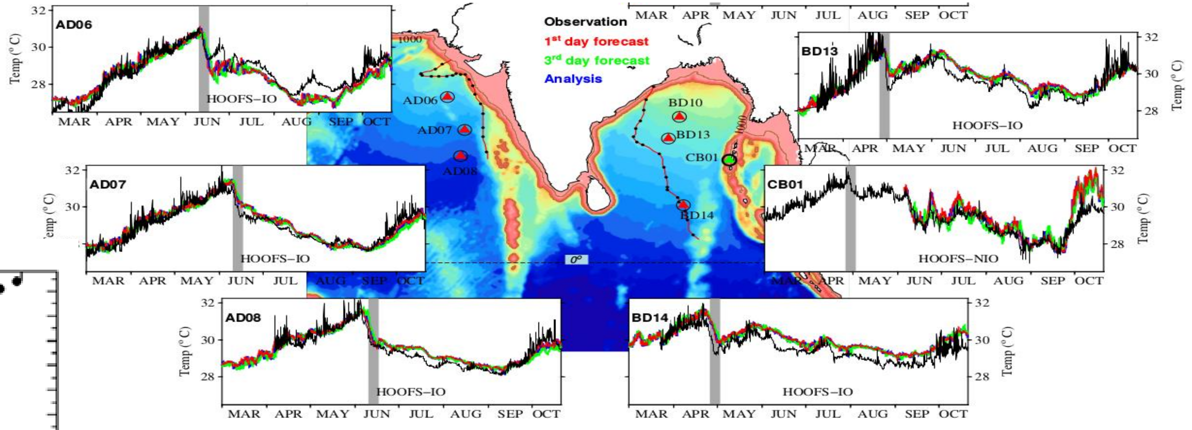


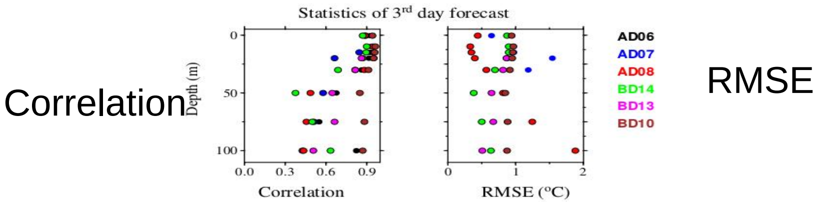


Francis et al., BAMS (2020)

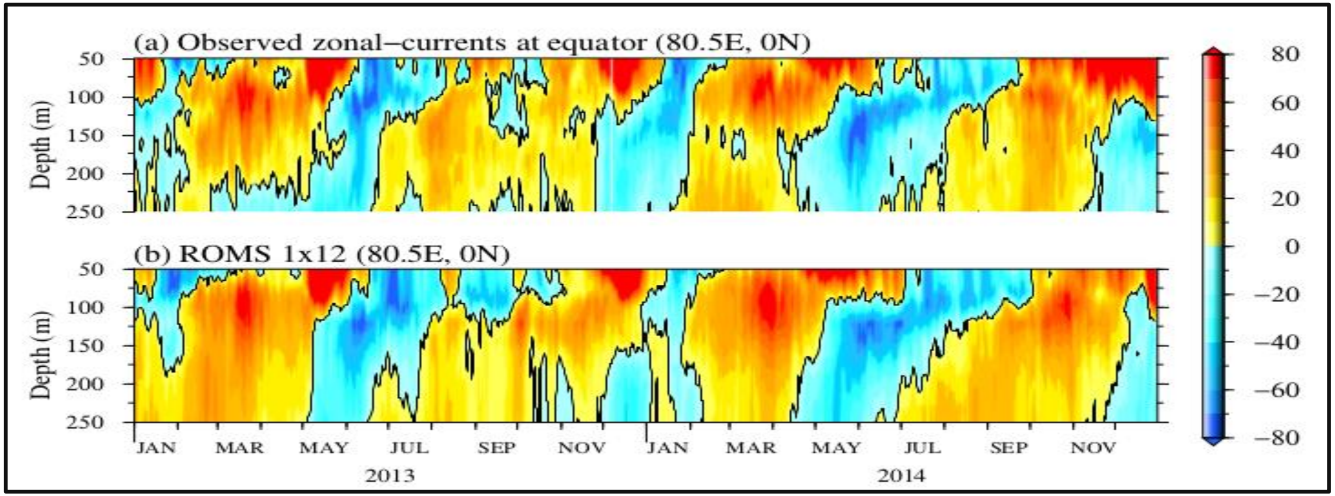
Domain of different models used in HOOFS







Time-depth section of zonal currents at 80.5ºE, EQ
Observation (top) and model simulation (bottom)



Model : Regional Ocean Modeling System (ROMS3.6)

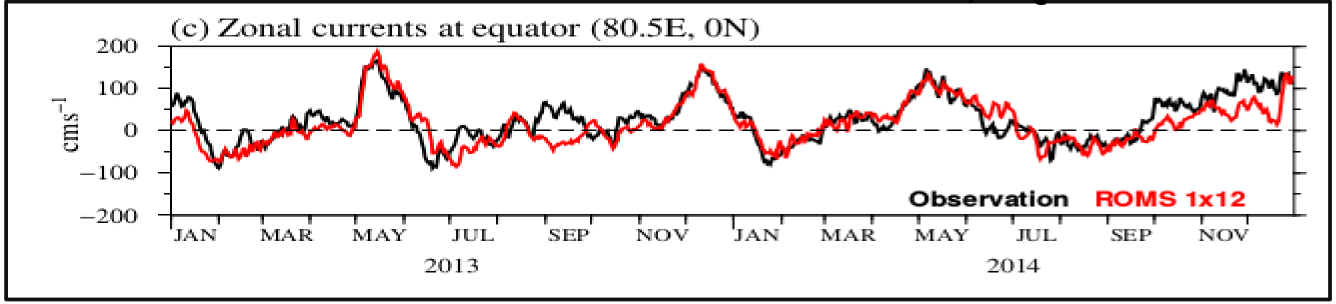
Domain : Indian Ocean

Resolution : 1/12 degree

Forcing : NCMRWF

Effy et al (2020)

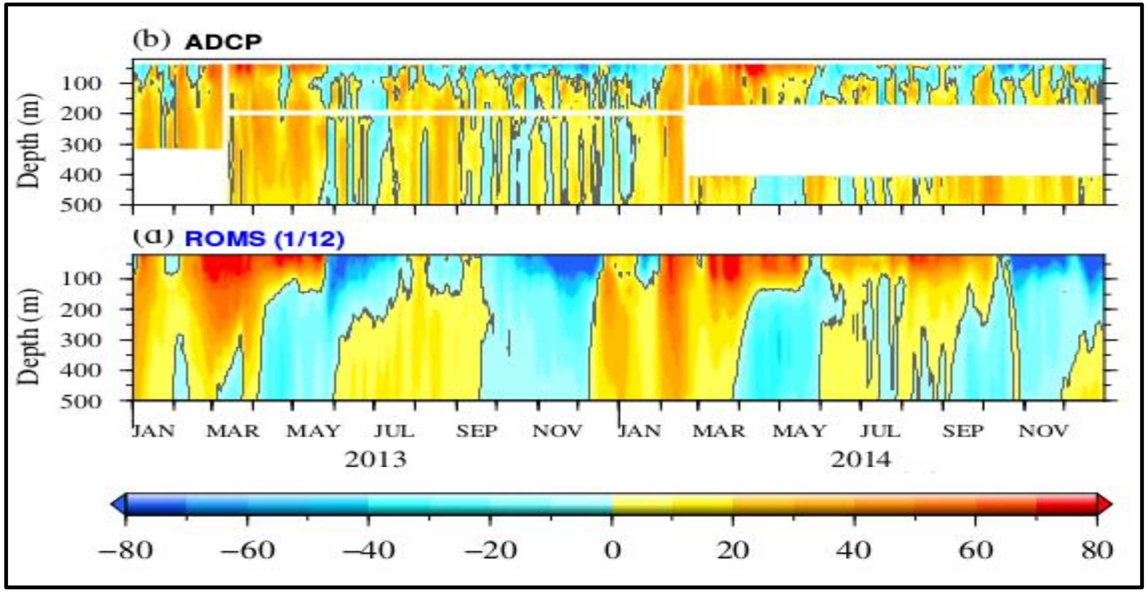
Surface zonal currents at 80.5ºE, EQ



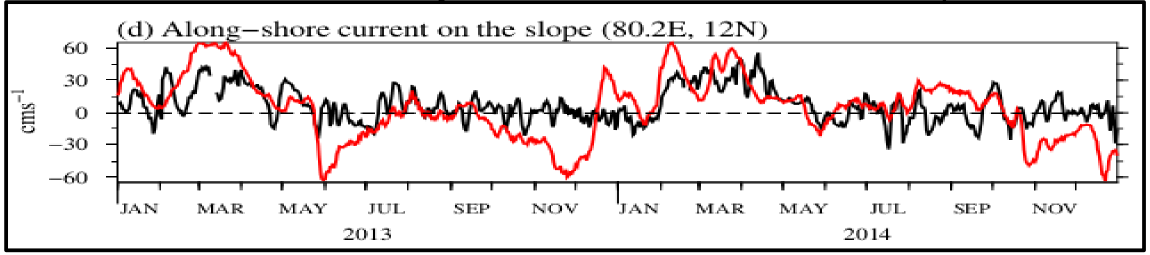
From Jithin et al (2019)

- State-of-the art Ocean model simulate the circulation in deep ocean with very good accuracy.
- Even the subsurface features are well simulated by the model

Time-depth section of zonal currents at slope off-the coast of Cudallore Observation (top) and model simulation (bottom)



Surface alongshore currents at 80.5ºE, 12N



From Jithin et al (2019)

Model : Regional Ocean Modeling System (ROMS3.6)

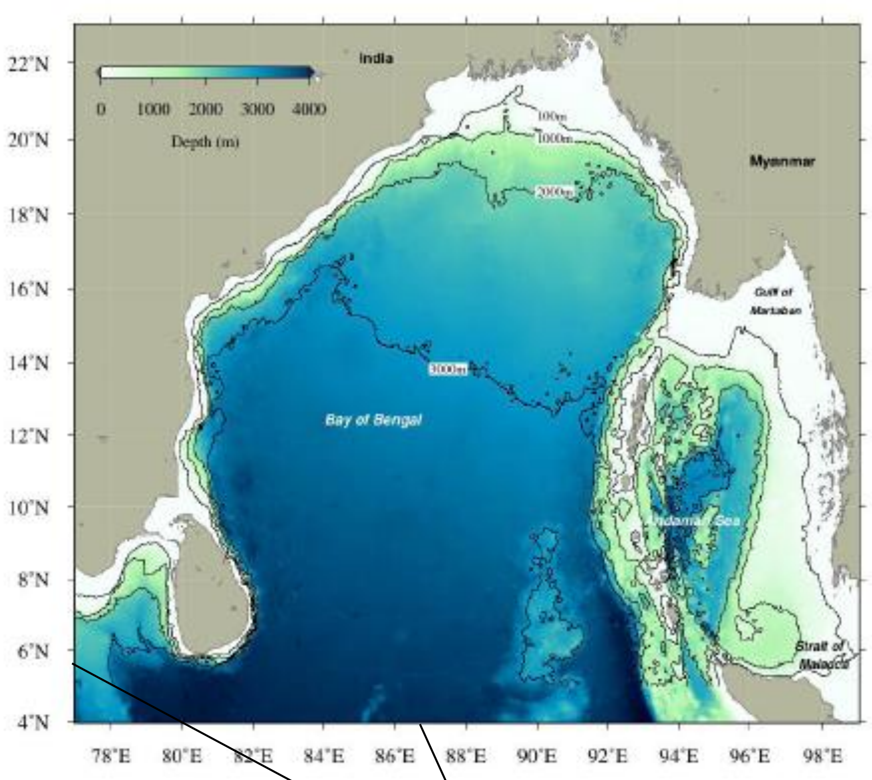
Domain : Indian Ocean

Resolution : 1/12 degree

Forcing : NCMRWF

Effy et al (2020)

- However, the model has difficulty in simulating the observed variation in the coastal circulation



Model- Regional Ocean Modeling System (ROMS)

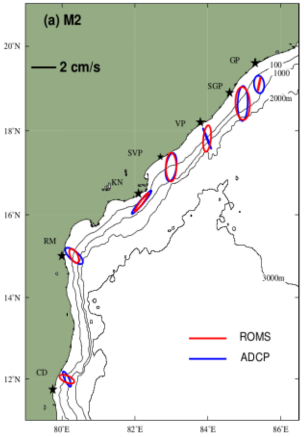
Horizontal resolution : 1/48 deg (2.25 km)

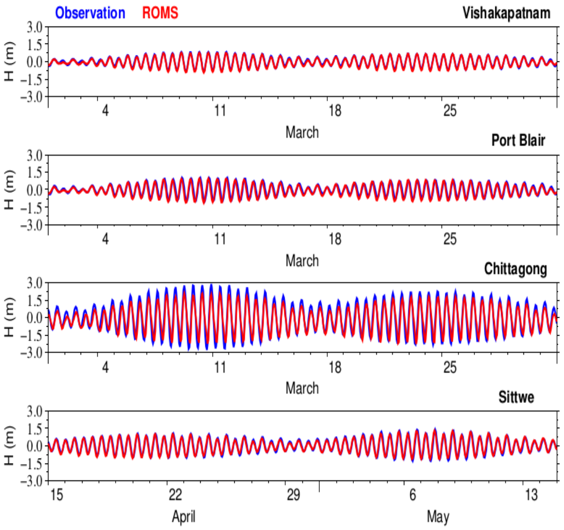
Vertical resolution : 40 sigma levels

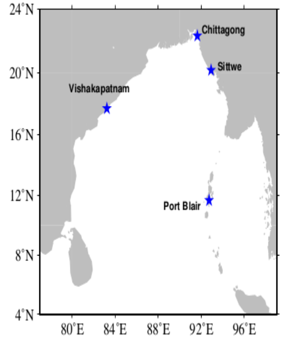
Physics options :

- KPP mixing scheme,
- Bulk aerodynamic formulation for flux computaton,
- 10-constituent tidal forcing,
- realistic daily boundary conditions in the south and west

Forcing: NCMRWF atmospheric analysis



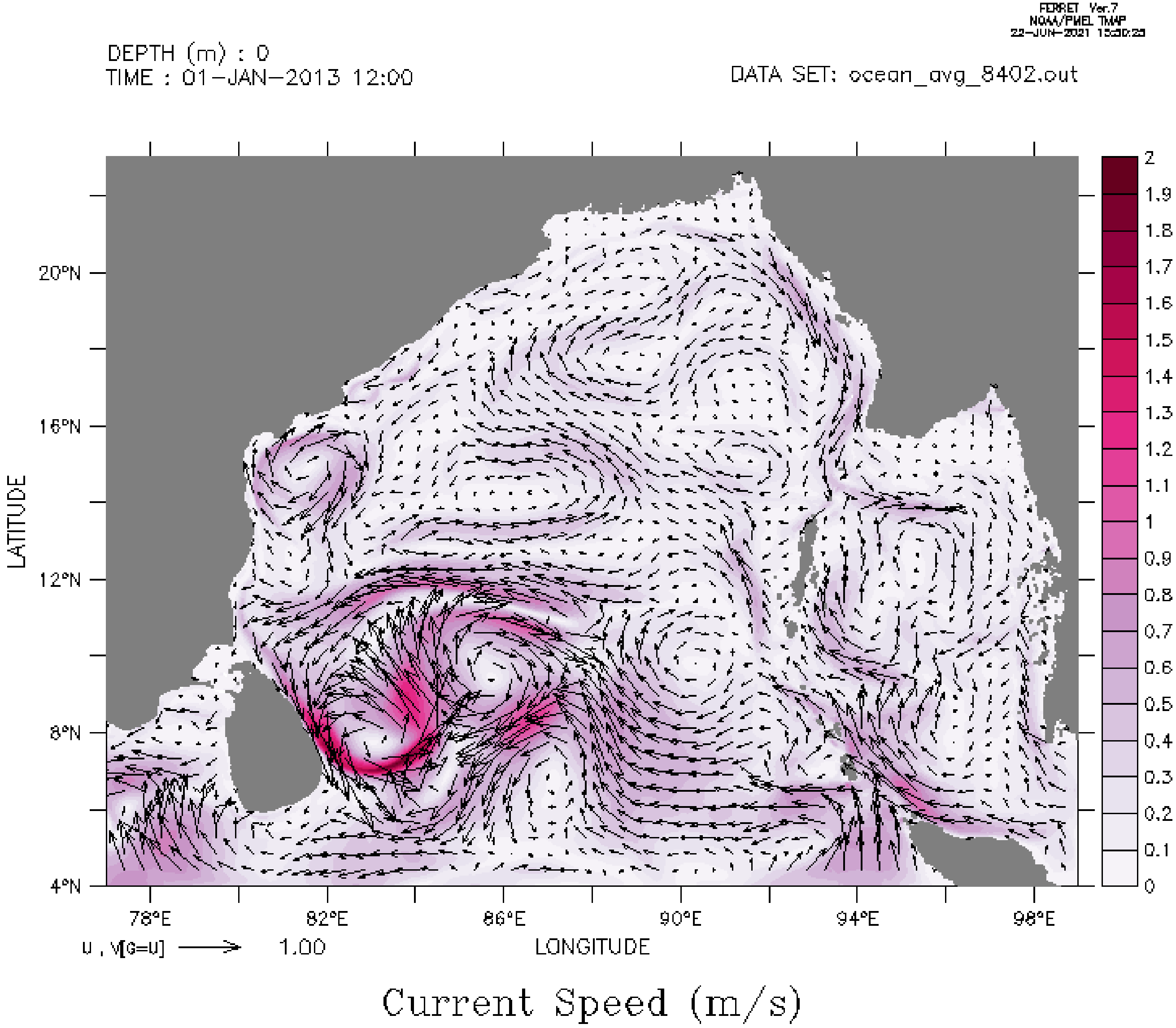




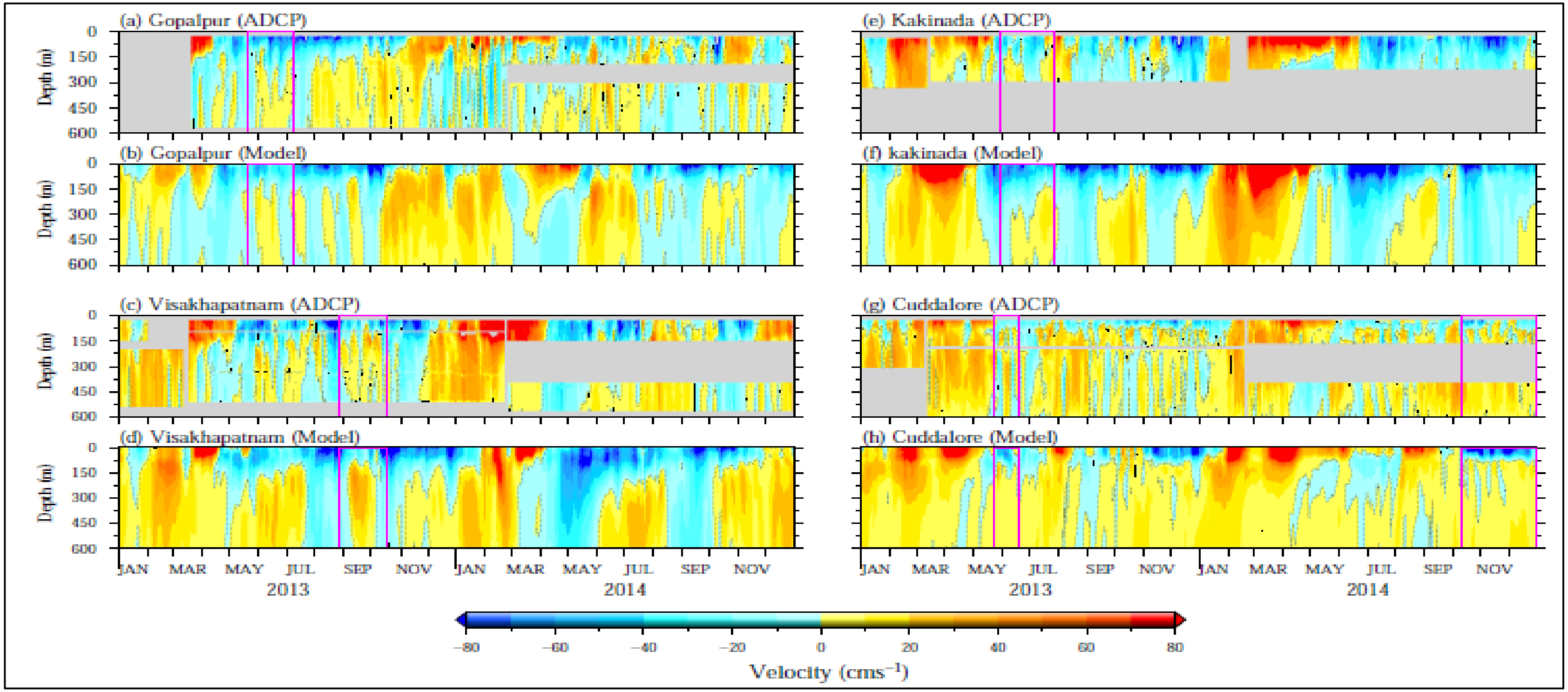
Tracer/momentum boundary conditions and initial condition are extracted from daily mean values of ROMS (1/12 degree) configuration for Indian Ocean Basin

Since the model is meant for coastal application, it is fined tune to simulate the barotropic and baroclinic tidal circulation accurately, in addition to the subtidal circulation.

BoB Circulation (ROMS)



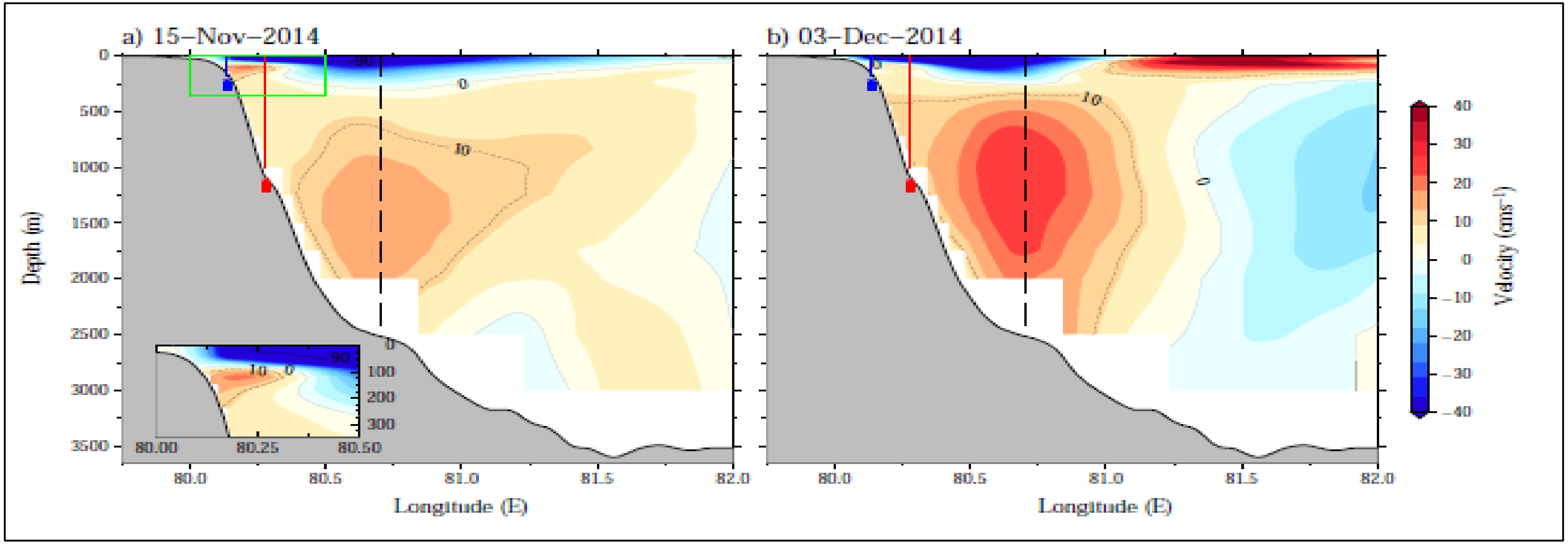
Variation of alongshore currents with depth (model simulations and observation)



- Very high resolution configuration of ROMS could simulate the observed variation in the alongshore currents with better accuracy.

- Hence these simulations are extremely useful for studying the structure and dynamics of EICC.

Longitude-Depth section of alongshore currents at 12oN (off-Cudallore) on 15th November 2014 & 4th December 2014.

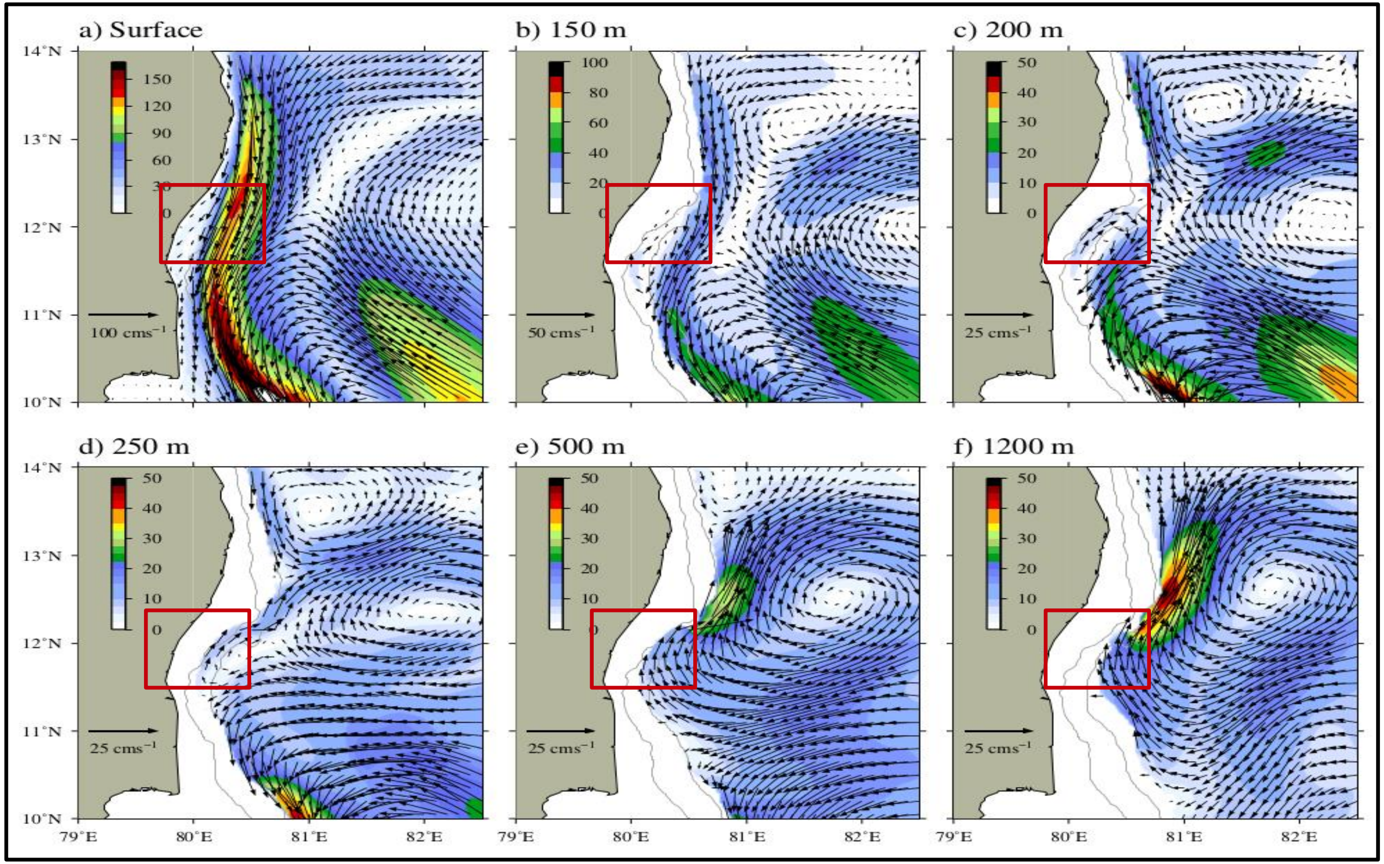


- Very strong equatorward alonshore flow in the surface (with core of the flow slightly away from the coast)

- Strong subsurface flow (poleward) with its core below 500m depth

- Distinct poleward subsurface flow with peak around 100-200m depth

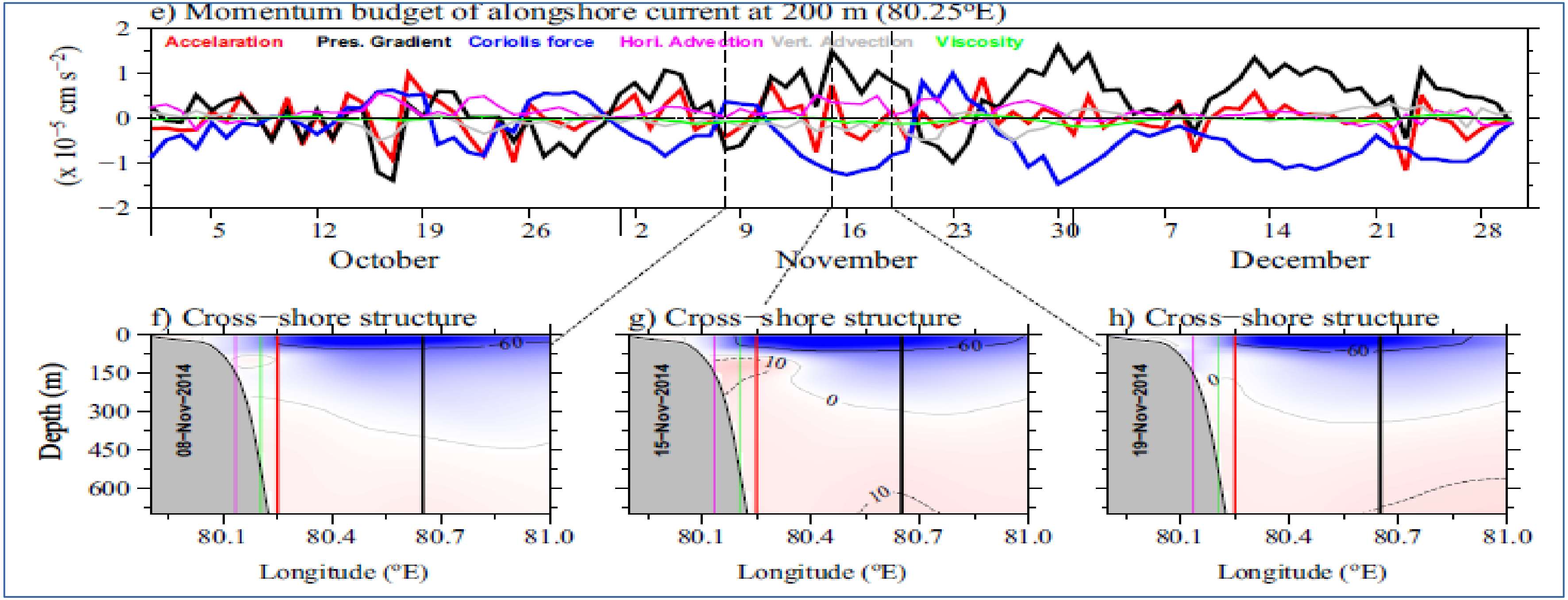
Spatial pattern of circulation off the coast of Cudallore in different levels on 4th December 2014 (model simulation)



Important features of coastal circulation off-Cudallore

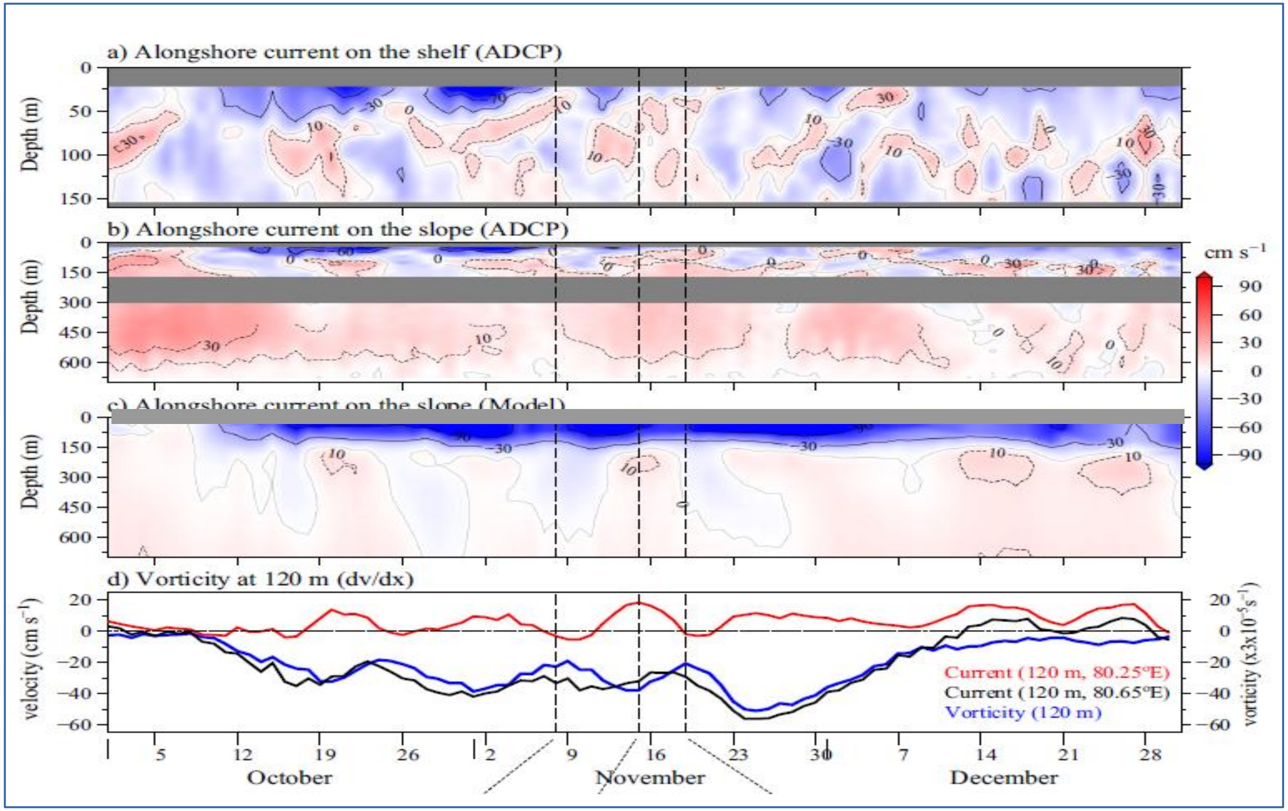
- Very strong equatorward alonshore flow in the surface
- Formation of a small-scale anticyclonic circulation to the west of EICC at 150m.
- Bifurcation of EICC at 200m and strengthening of subsurface anticyclonic circulation.
- Subsurface anticyclonic flow near the coast merges with largescale anticyclonic flow at 250m.
- Strong poleward flow below 500m associated with subsurface anticyclone

Momentum budget of alongshore current at 200m



Cross-shore structure of alongshore current at 12^{o}N

Time-depth section of alongshore flow off-Cudallore during Oct-Dec 2014

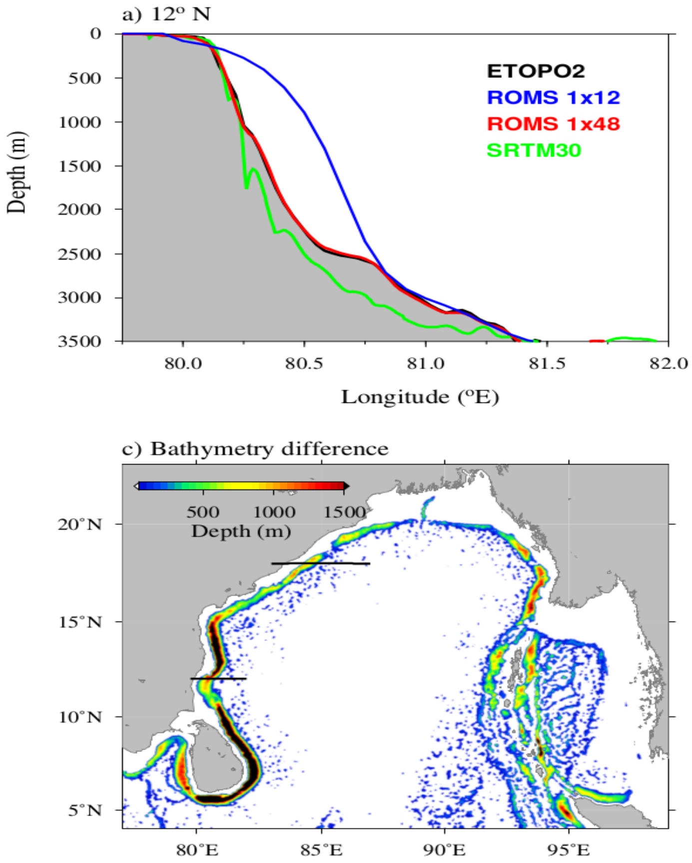


Timeseries of alongshore currents (120m) at 12^{0}N, 80.25ºN (red) & 12^{0}N, 80.65ºN (blue) and zonal gradient of alongshore currents (black, relative vorticity) during Oct-Dec 2014

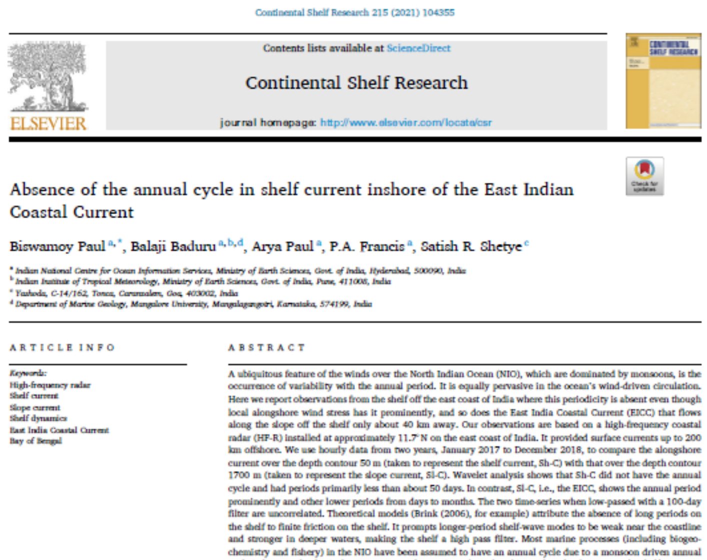
- Strong intraseasonal variatoin in surface EICC.
- Intraseasonal variation in subsurface is strong between 100-250m
- Subsurface poleward flow (which is associated with small-scale eddies intensify followed by the intensification of surface equatorward flow.
- Relative vorticity closely follows the alongshore equatorward flow away from the coast.
- Anticyclonic flow setup to the onshore side of the core of the EICC

Why such undercurrents are missing in a low resolution model?

Comparison of Model Topography with observation



Difference between the
topography in
1/12 and 1/48 grids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Absence of the annual cycle in shelf current inshore of the East Indian Coastal Current

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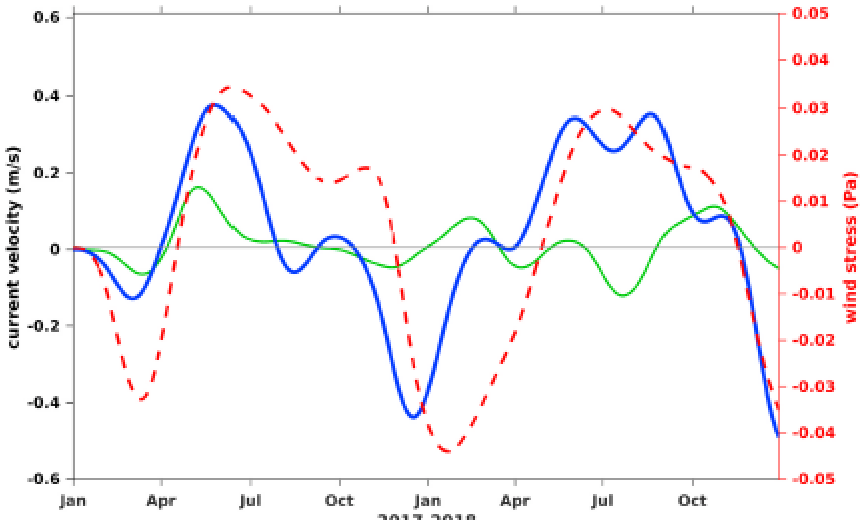
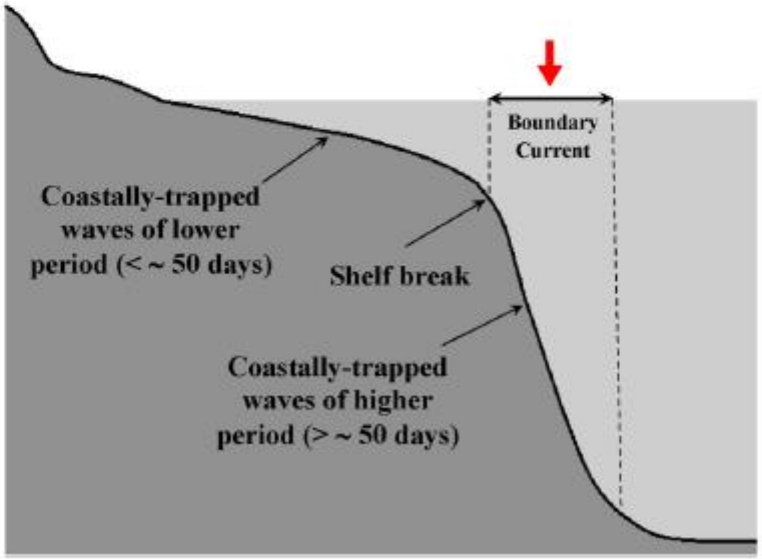
Shelf current
Slope current
Shelf dynamics
East India Coastal Current
Bay of Bengal

ABSTRACT

A ubiquitous feature of the winds over the North Indian Ocean (NIO), which are dominated by monsoons, is the occurrence of variability with the annual period. It is equally pervasive in the ocean's wind-driven circulation. Here we report observations from the shelf off the east coast of India where this periodicity is absent even though local alongshore wind stress has it prominently, and so does the East India Coastal Current (EICC) that flows along the slope off the shelf only about 40 km away. Our observations are based on a high-frequency coastal radar (HF-R) installed at approximately 11.7°N on the east coast of India. It provided surface currents up to 200 km offshore. We use hourly data from two years, January 2017 to December 2018, to compare the alongshore current over the depth contour 50 m (taken to represent the shelf current, Sh-C) with that over the depth contour 1700 m (taken to represent the slope current, Sl-C). Wavelet analysis shows that Sh-C did not have the annual cycle and had periods primarily less than about 50 days. In contrast, Sl-C, i.e., the EICC, shows the annual period prominently and other lower periods from days to months. The two time-series when low-passed with a 100-day filter are uncorrelated. Theoretical models (Brink (2006), for example) attribute the absence of long periods on the shelf to finite friction on the shelf. It prompts longer-period shelf-wave modes to be weak near the coastline and stronger in deeper waters, making the shelf a high pass filter. Most marine processes (including biogeochemistry and fishery) in the NIO have been assumed to have an annual cycle due to a monsoon driven annual



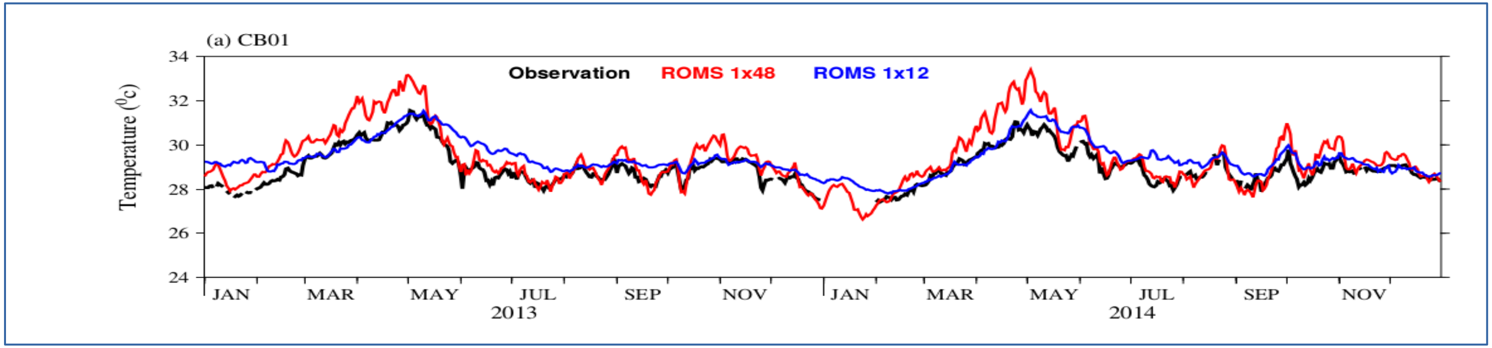
Low-passed (100-day Butterworth filter) current on the slope (Sl-C, thick blue line), on the shelf (Sh-C, thin green line), and wind stress (dashed red line) on the east coast (10◦N to 21◦N).



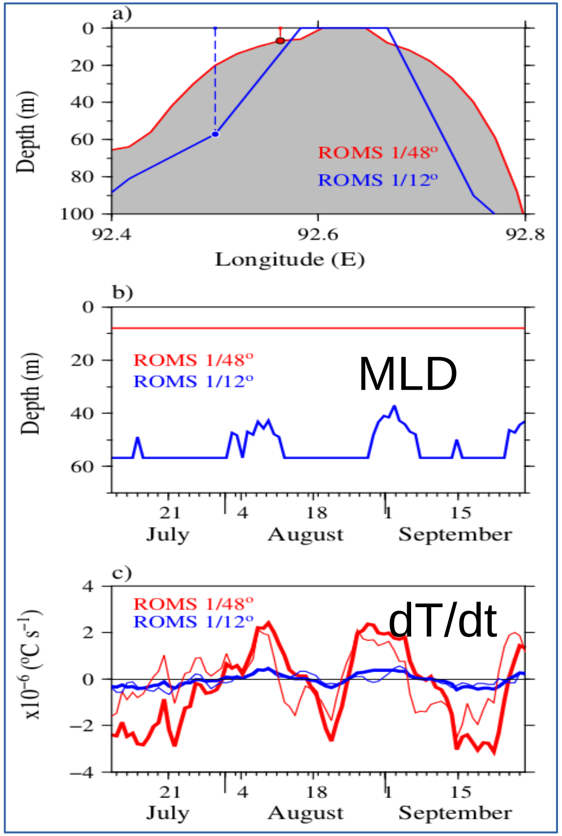
The region near the coastline serves as a high pass filter supporting only a shorter period motion.

Similarly, the region in the offshore edge of the shelf becomes a low-pass filter.

Variation of temperature 3m depth in observation, ROMS 1/48 and ROMS 1/12



CB01 (11° 35´·33N., 92° 35´·77E)



- Variation of temperature is better simulated by the highresolution model compared to the lower resolution configuration.
- There is a considerable difference in the depth of ocean at the buoy location between the model configurations.
- Since the water depth in 1/48º ROMS as shallow as 10 m, temperature responds to variation in Net Heat Flux quickly.
- The MLD in 1/12º model is significantly deep, the net heat flux get distributed over a larger depth compared to 1/48º model and hence the variation in temperature is relatively less.

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Virtual Special Issue - CORE-II

An assessment of the Indian Ocean mean state and seasonal cycle in a suite of interannual CORE-II simulations

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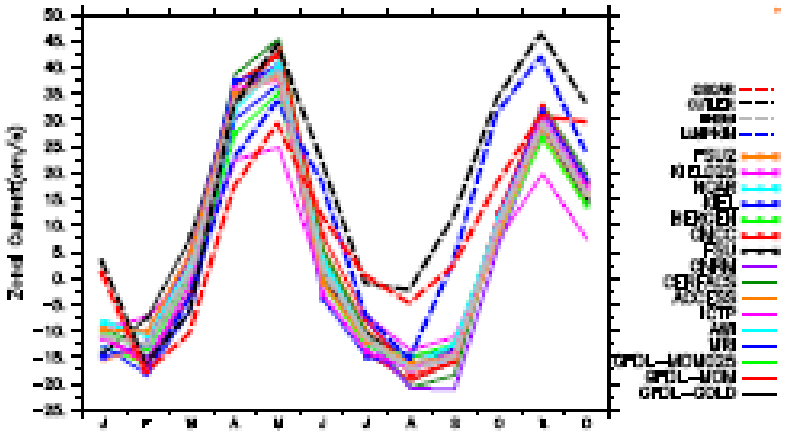
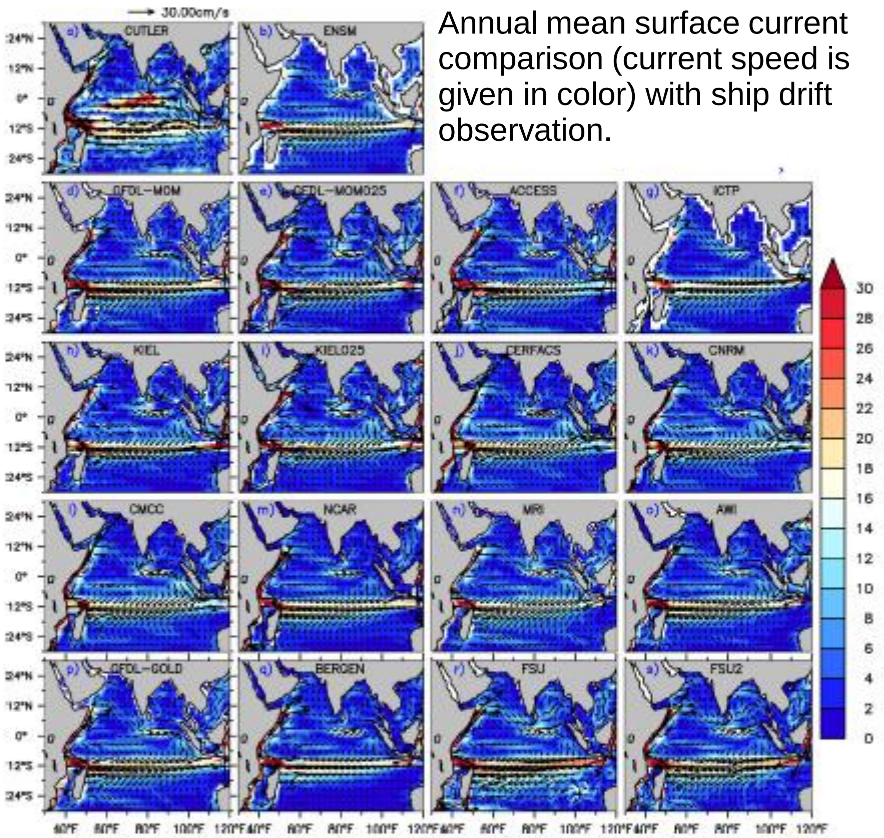


Fig. 24b. Seasonal cycle of zonal currents at the WJ location [55–80°E, 2.5°S – 2.5°N] averaged over 0 – 15 m depth from CORE-II simulations and observations (CUTLER, OSCAR, LUMPKIN).



Annual mean surface current comparison (current speed is given in color) with ship drift observation.

“Refinement in model horizontal resolution does not significantly improve simulations.”- Rahman et al. (2020)

This result holds true for open ocean simulations, but certainly can not generalize when coastal circulations are considered.

Concluding remarks

1. State of the art circulation models can simulate the shorter-term variation in the coastal circulation with a fairly good accuracy.

2. Part of the high-frequency variation of undercurrents off Cudallore could be associated with meso-scale circulation below the surface

3. High-resolution circulation models may not be improving the simulations of open ocean circulation features, but certainly improves the simulations of coastal circulation

4. Accurate representation of bathymetry is very critical in the simulation of coastal circulation.

Thank You,

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