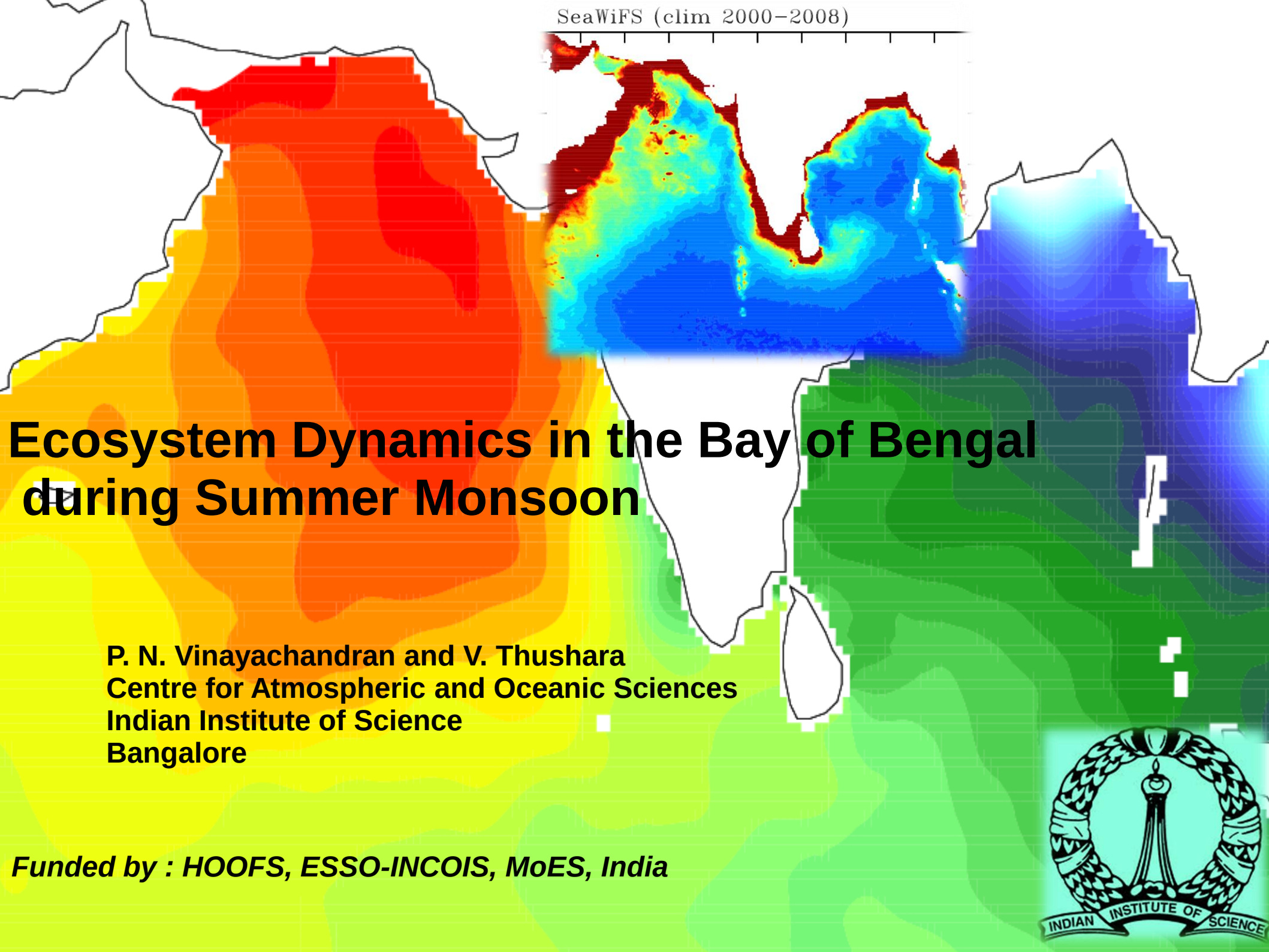
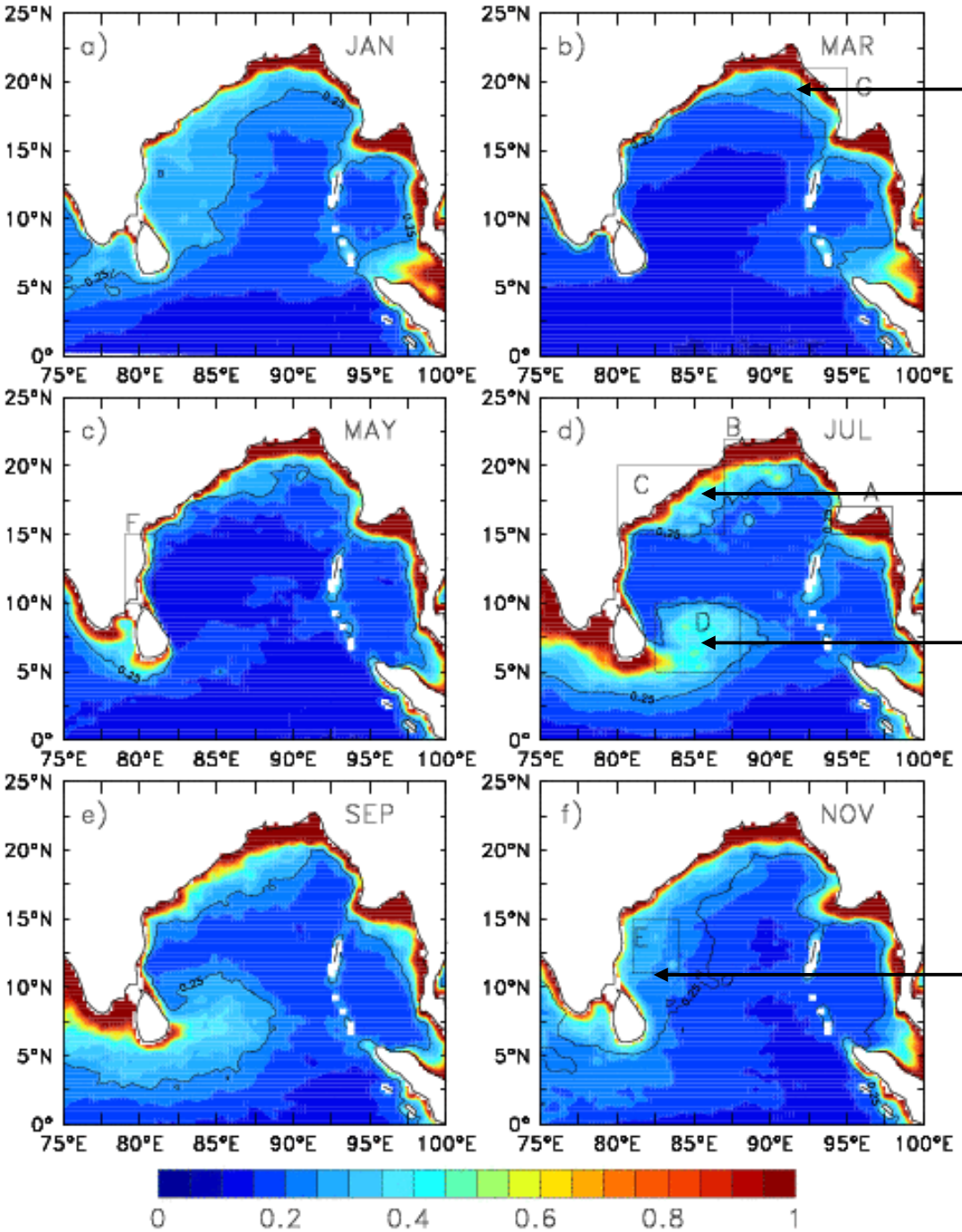


Ecosystem Dynamics in the Bay of Bengal during Summer Monsoon

P. N. Vinayachandran and V. Thushara
Centre for Atmospheric and Oceanic Sciences
Indian Institute of Science
Bangalore

Funded by : HOOFS, ESSO-INCOIS, MoES, India

Productive regions in the Bay of Bengal



1. River mouths

2. Northwestern Bay of Bengal (southwest monsoon)

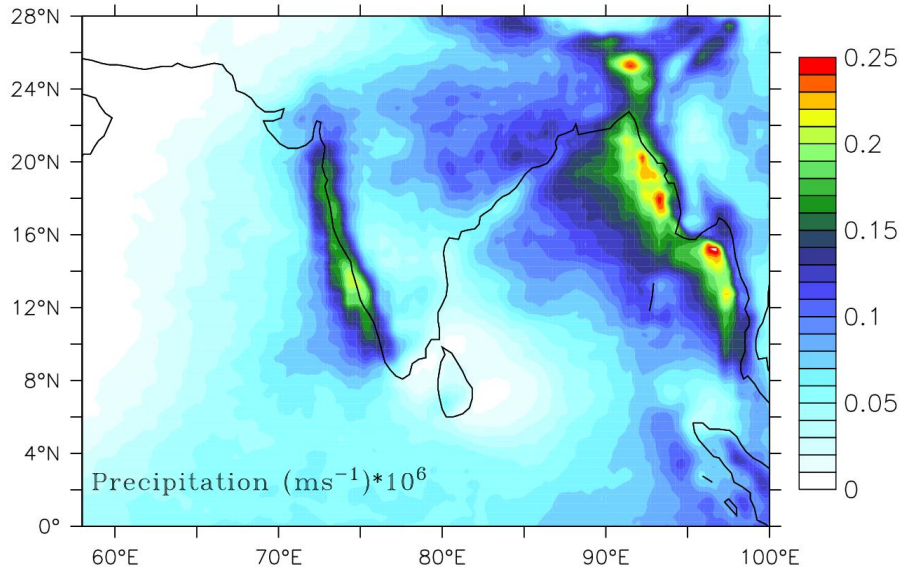
3. Around Sri Lanka (southwest monsoon)

4. Southwestern Bay of Bengal (northeast monsoon)

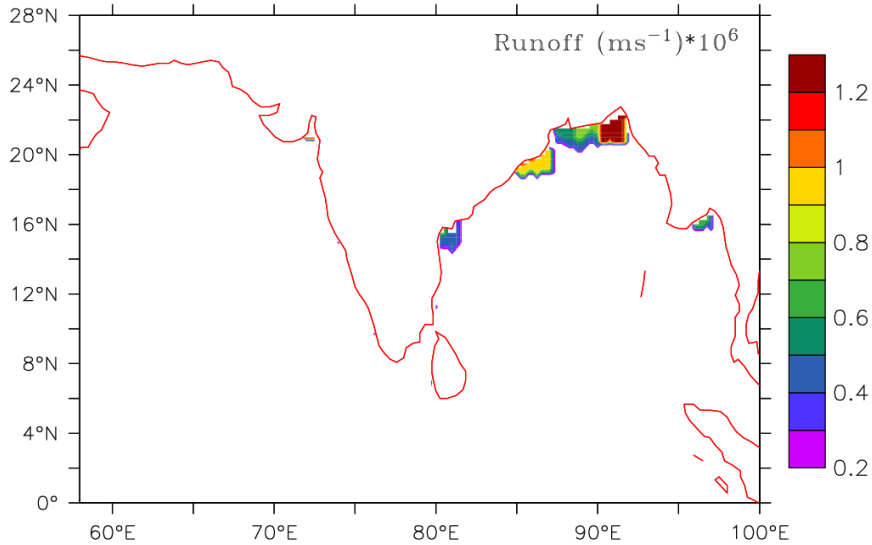
Vinayachandran, 2009 (AGU Book Chapter)

Large freshwater influx

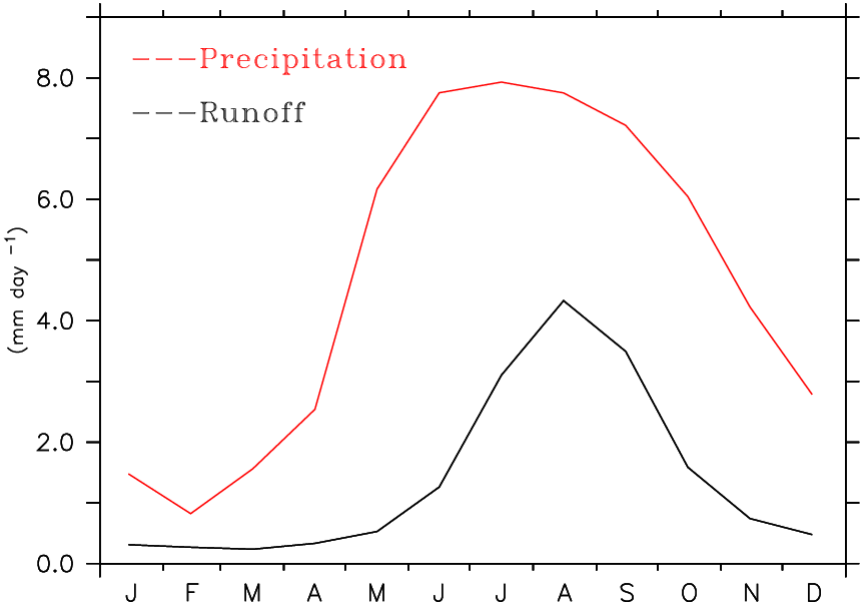
Precipitation (TRMM climatology, JJAS)



River runoff (SAGE climatology, JJAS)



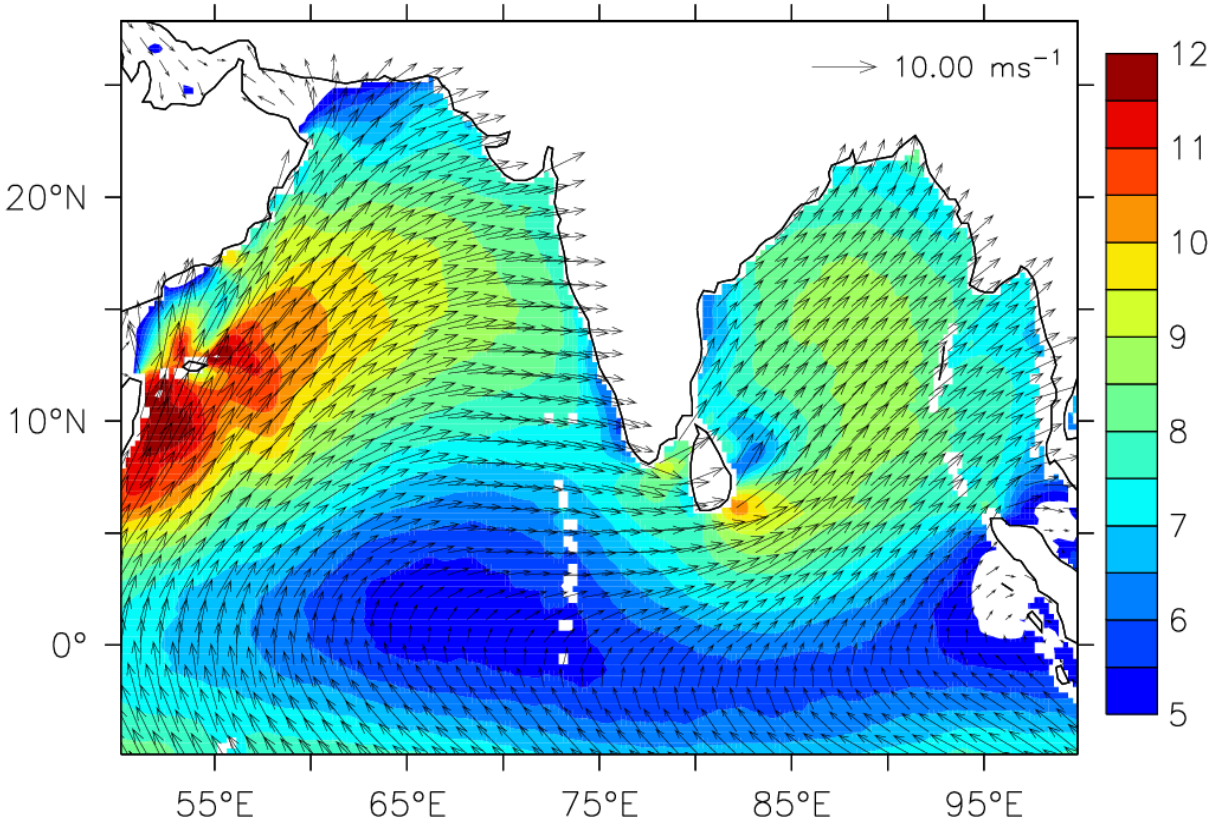
- River discharge ~ 1560 km^3 year^{-1}
- Precipitation - evaporation ~1100 km^3 year^{-1}
- Excess freshwater ~ 2600 km^3 year^{-1}

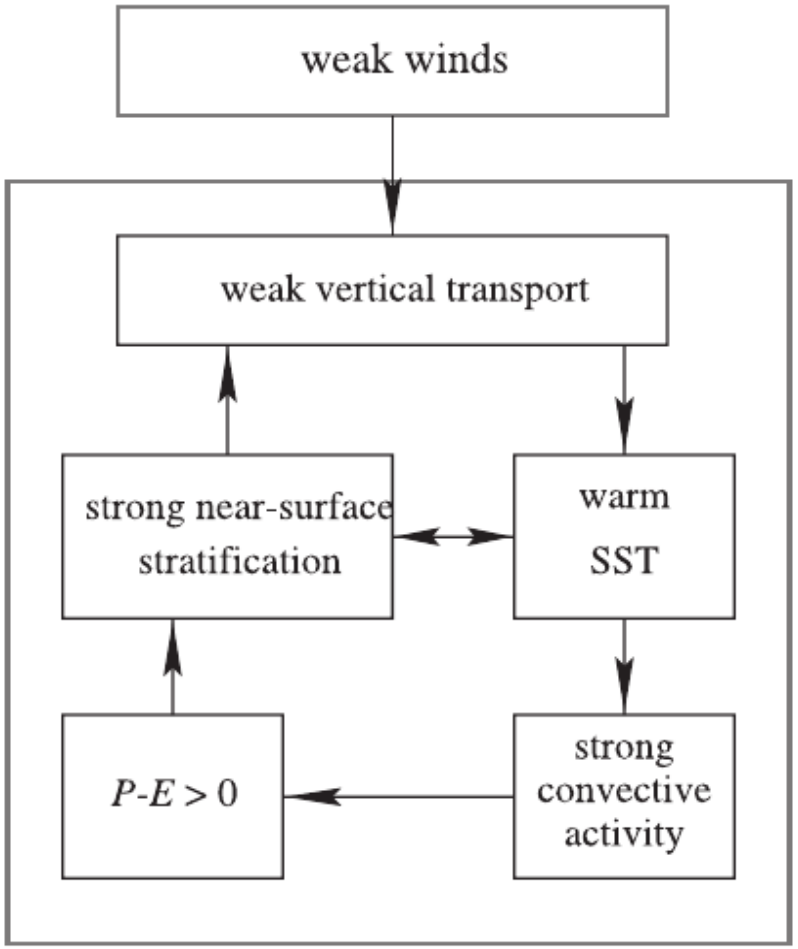


Monthly climatology of precipitation and runoff averaged over 80E:100E and 5N:23N

Weak winds

Wind speed (QuikSCAT climatology, JJAS)

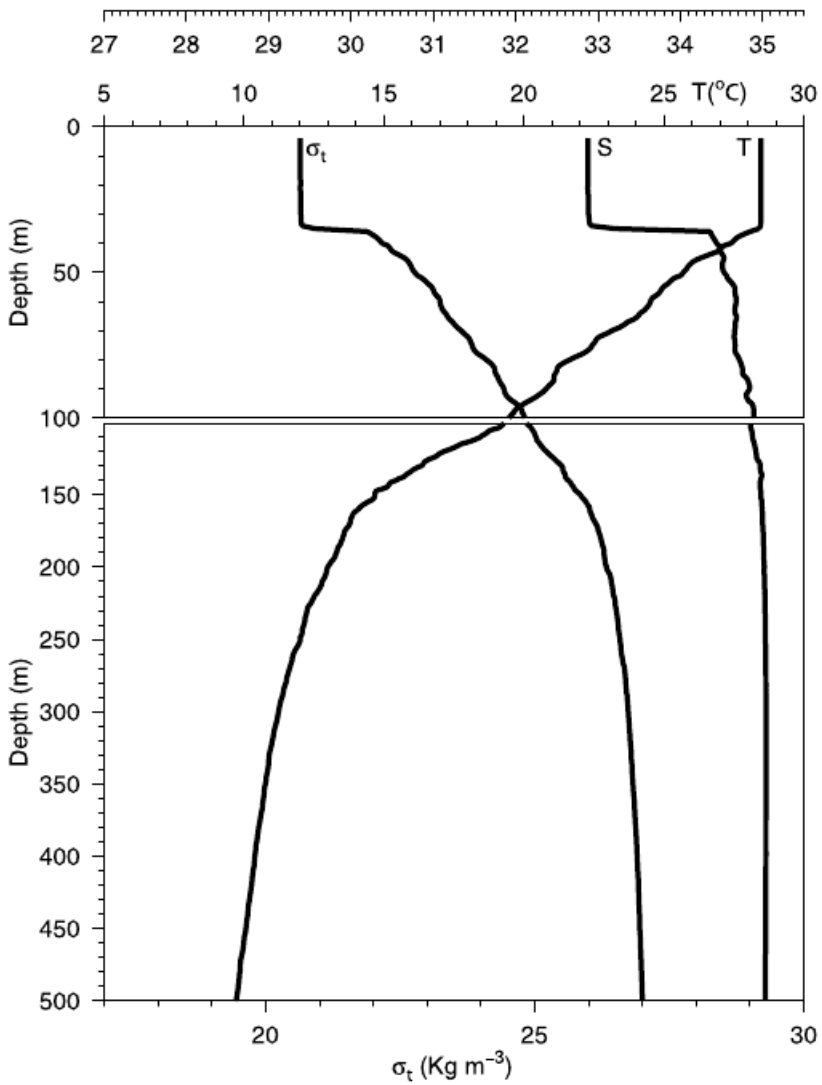




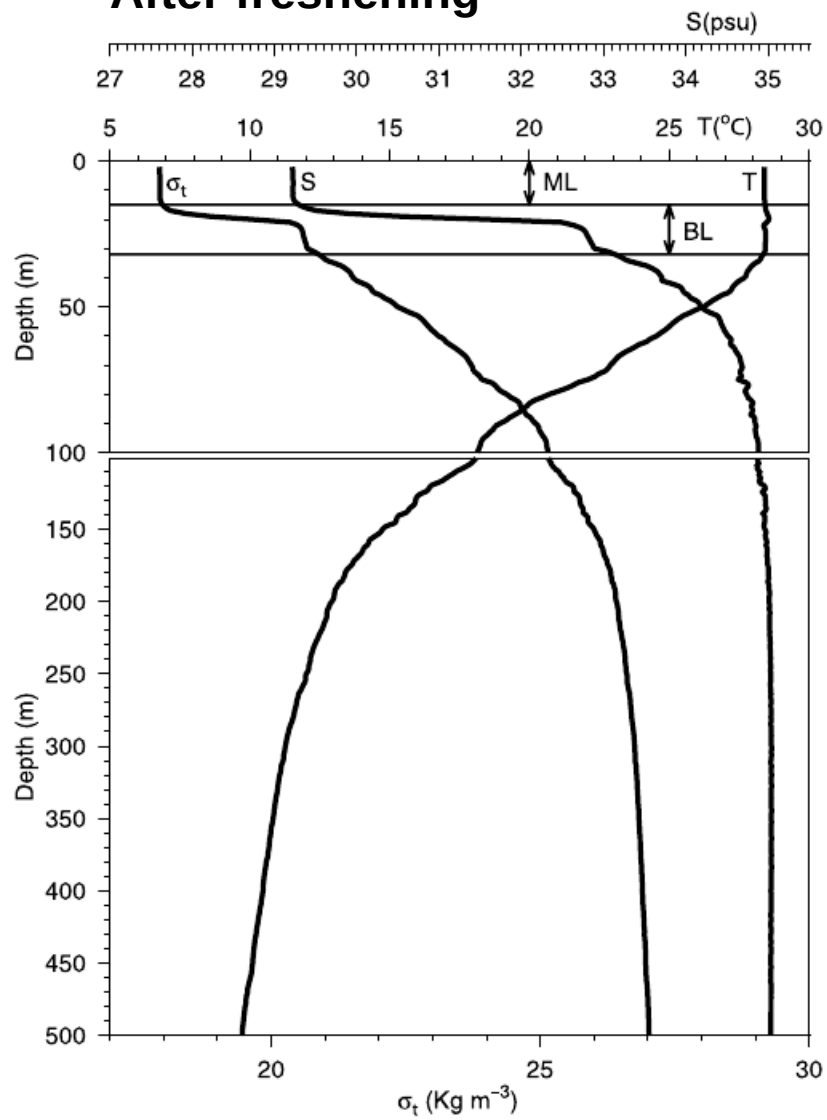
Shenoi et al., 2002, JGR

Barrier layer formation

Before freshening

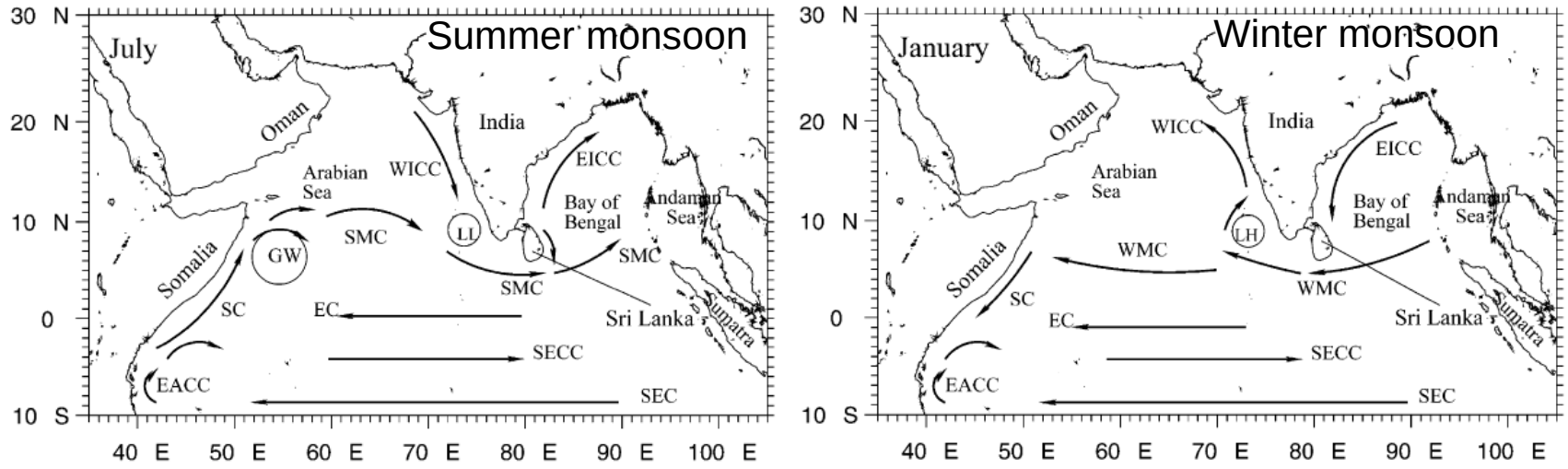


After freshening



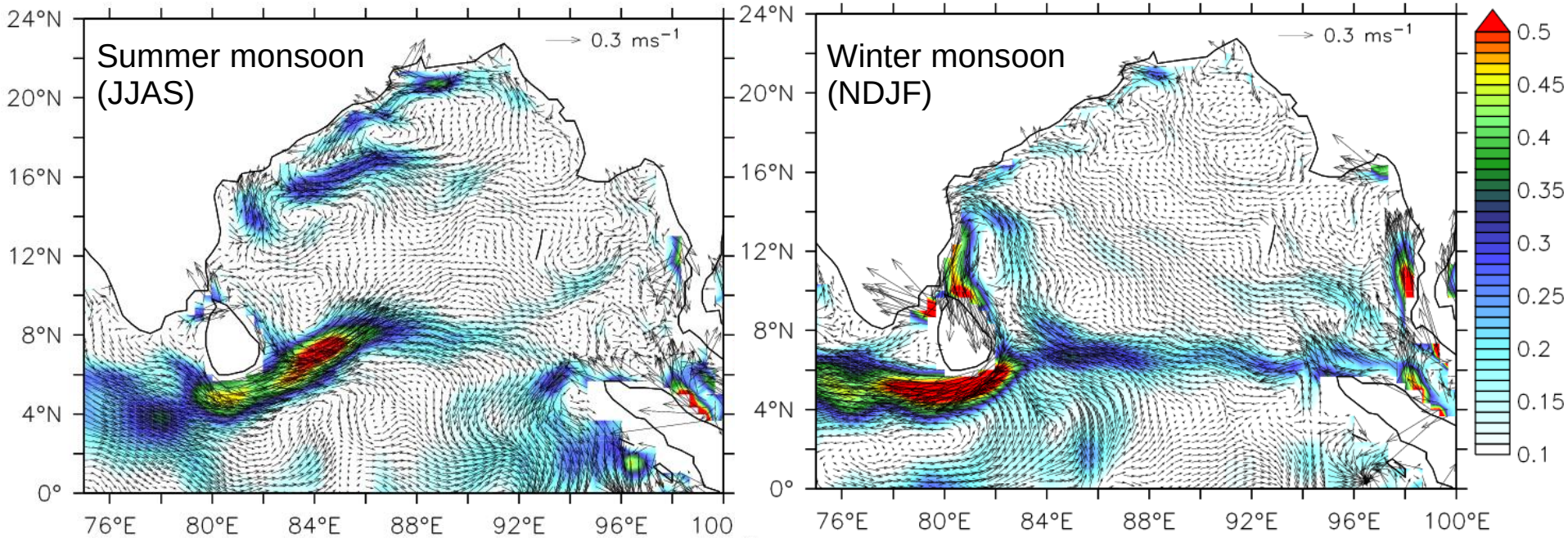
Vinayachandran et al., 2002, JGR

Seasonally reversing circulation controlled by local and remote effects



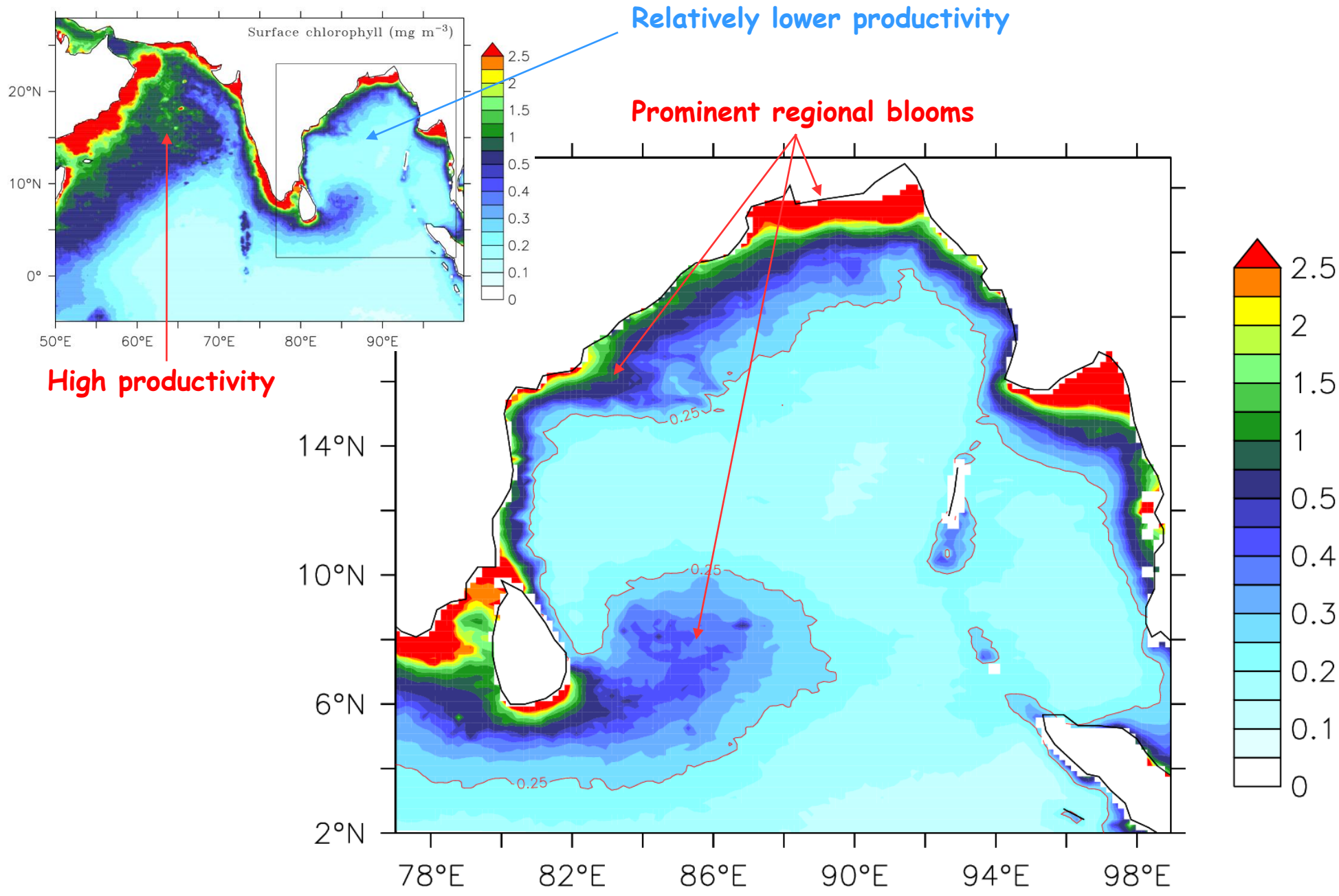
Shankar et al., 2002

Surface currents of the bay (OSCAR climatology)

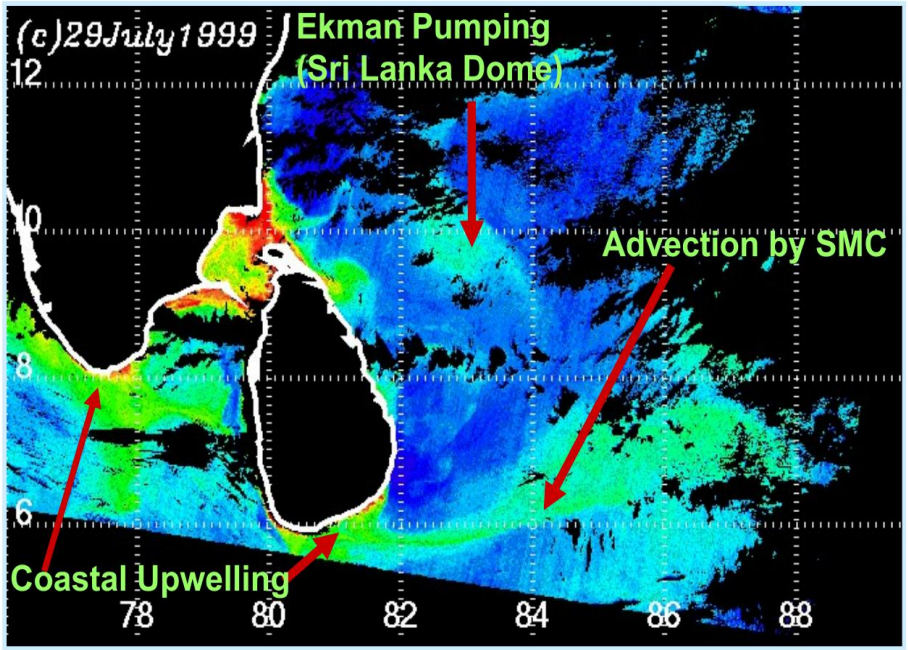


Biological productivity

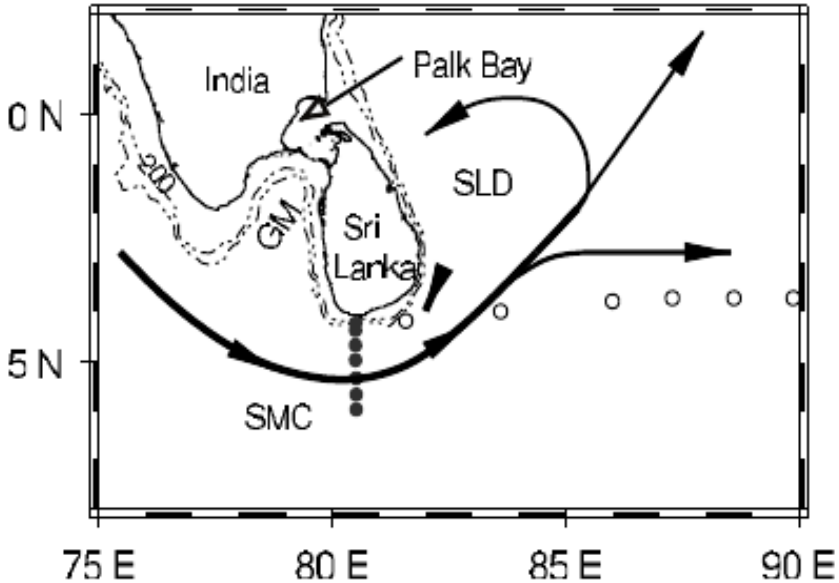
Surface chlorophyll (SeaWiFS, 2000-2008 climatology, JJAS)



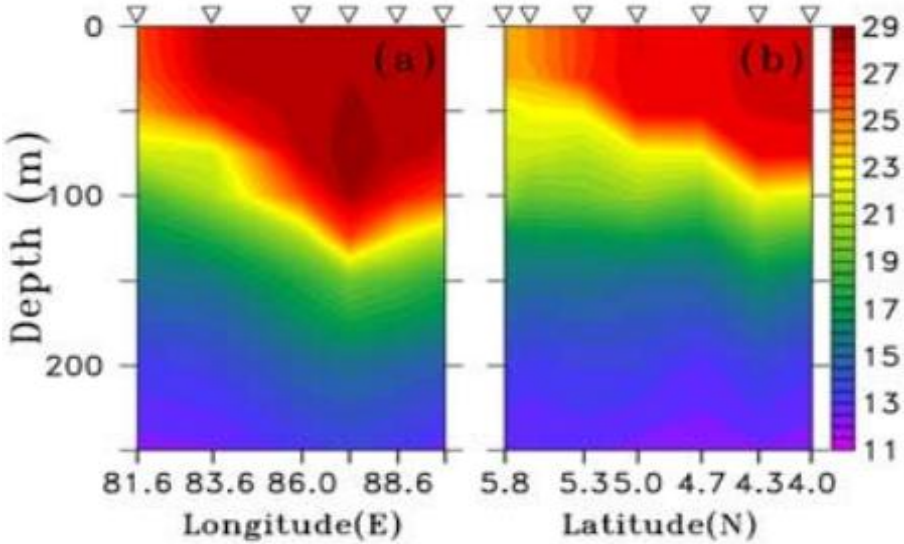
Bloom dynamics around Sri Lanka (summer monsoon)



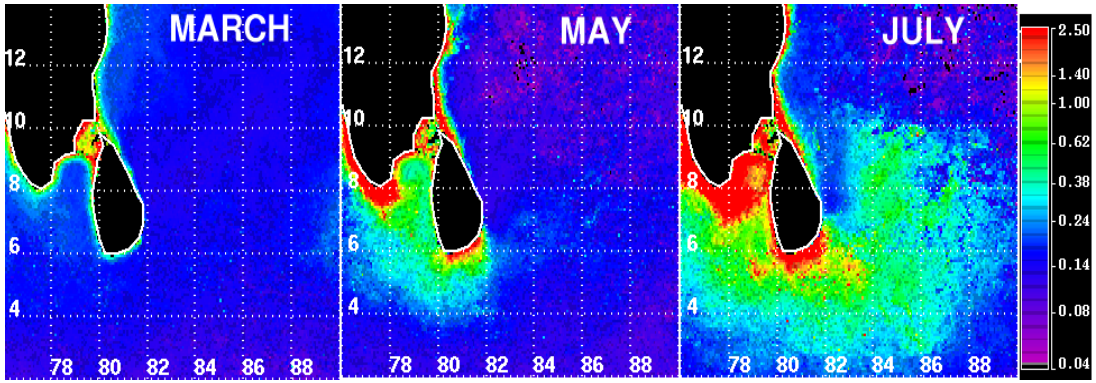
Chlorophyll around Sri Lanka from IRS-P4 OCM.



Vinayachandran et al., 2004, GRL

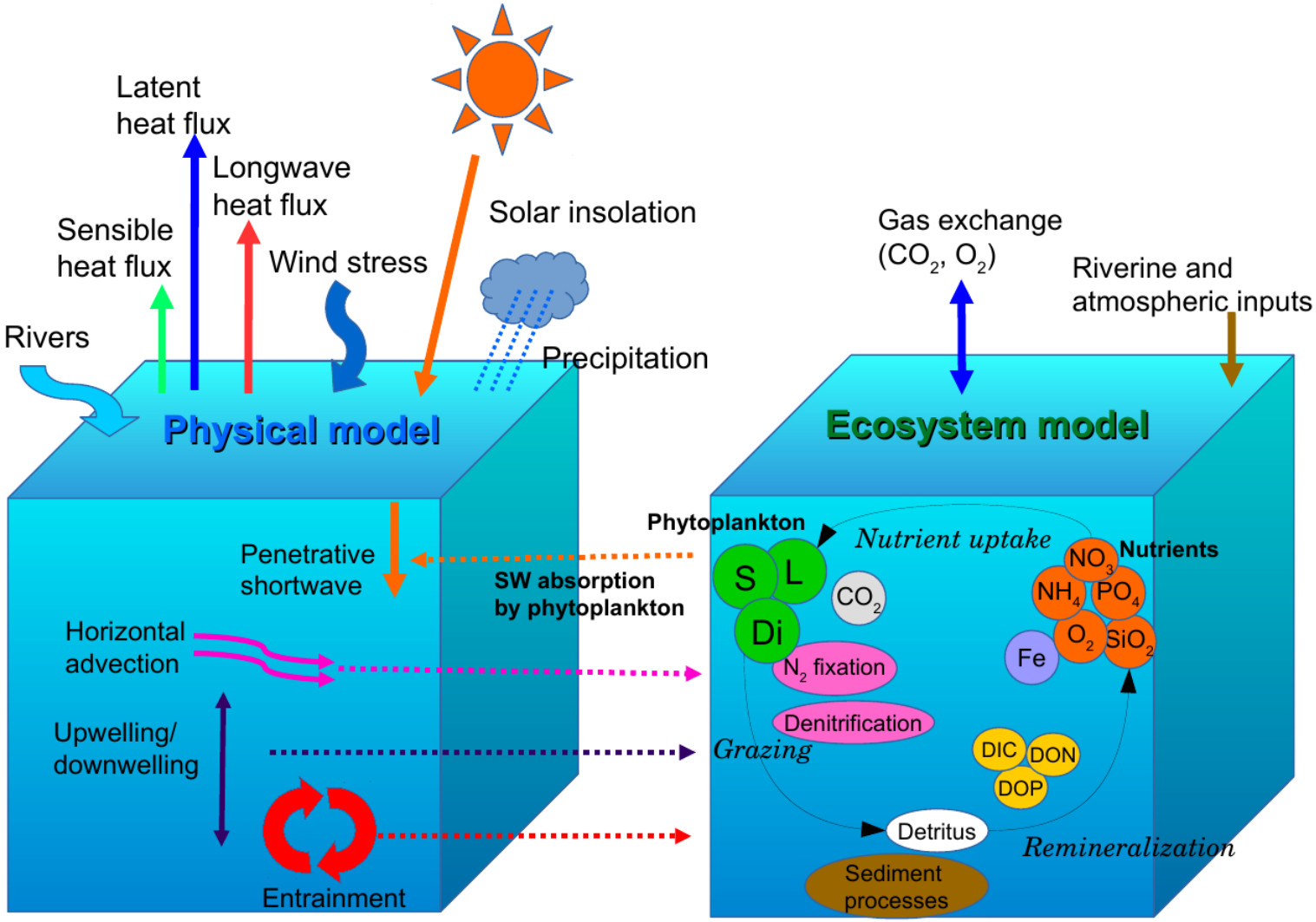


Vertical sections of temperature



Coupled physical-ecosystem models

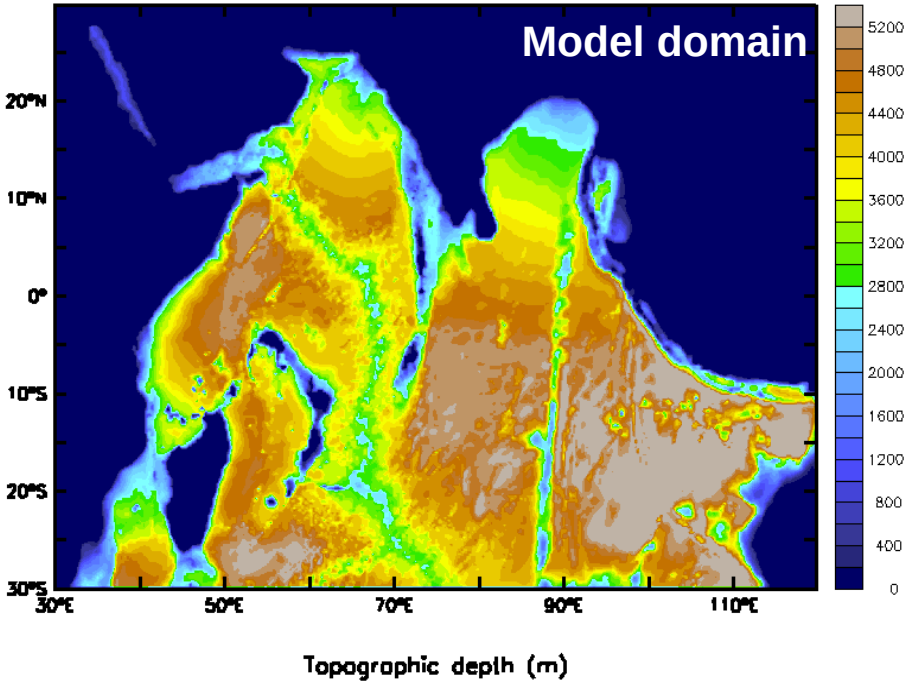
- **MOM4P1–TOPAZ**
- **ROMS–bio Fennel**



Schematic representation of oceanic processes and bio-physical interactions in MOM4P1-TOPAZ coupled physical-ecosystem model.

GFDL Modular Ocean Model (MOM4P1)

- Domain: 30°E - 120°E, 30°N – 30°S
- Horizontal resolution: 0.25° X 0.25°
- Z-coordinate (40 vertical levels; 5m resolution in the top 60m)
- Horizontal mixing - Chassignet and Garaffo (2001)
- Vertical mixing - Large et al. (1994)
- Shortwave parameterization - Morel and Antoine (1994)



Tracers of Phytoplankton with Allometric Zooplankton (TOPAZ) *(Dunne et al., 2010)*

- Includes 25 tracers
- 3 groups of phytoplankton
  - small, large and diazotrophs
- cycles of C, N, P, Si, Fe, O_2 and lithogenic materials
- includes gas exchange, atmospheric deposition, nitrogen fixation, denitrification, river inputs and sediment processes
- co-limitation of light, temperature, macronutrients and iron

$$\mu = \frac{P^{\mathrm{C}}_{\mathrm{max}}}{1+\zeta} e^{kT} \min(\mathrm{Lim_N}, \mathrm{Lim_P}, \mathrm{Lim_{Fe}}) \times \mathrm{Lim_{Irr}}$$

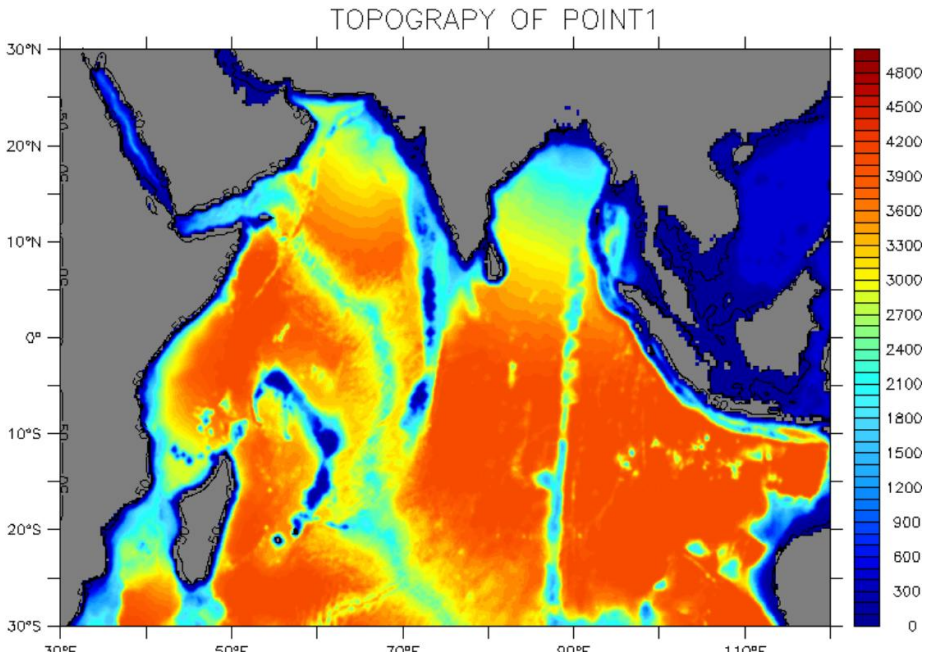
μ - growth rate of phytoplankton
$P^{\mathrm{C}}_{\mathrm{max}}$ - maximum carbon assimilation rate
ζ - cost of biosynthesis
k - Eppleys temperature coefficient
T - temperature
$\mathrm{Lim_{N,P,Fe,Irr}}$ - limitation terms

Regional Ocean Modeling System (ROMS)

- Domain: 30E to 120E and 30S to 30N
- Horizontal resolution: 25 km
- 40 vertical levels with finer resolution,

within the upper few meters.

- free surface, terrain following
- Horizontal mixing - Smagorinsky
- Vertical mixing - KPP



Bio-Fennel model *(Fennel et al. 2006)*

- Includes phytoplankton, zoo-plankton, chlorophyll, large and small detritus, NO3 and NH4.

- initialized with traces of NO3 taken from WOA 2005.

- Remaining biological variables are initialized to a constant value of 0.1 mmol N m-3 all over the domain.

- NO3 is prescribed at the open boundaries of the domain

Model forcings	**MOM4P1-TOPAZ**	**ROMS-bio_Fennel**
Radiation Air temperature Humidity Surface pressure	ERA-INTERIM (3-hourly)	NCEP (6-hourly)
Winds	ERA-INTERIM (3-houry) merged with QuikSCAT (daily)	QuikSCAT (daily)
Precipitation	TRMM(daily)	TRMM(daily)
River discharge	SAGE (monthly climatology)	Fekete et al. (monthly climatology)

Initial conditions

Temperature, salinity and nutrients – WOA09

Boundary conditions

Northern and western boundaries - no-slip, no normal flow, no-flux

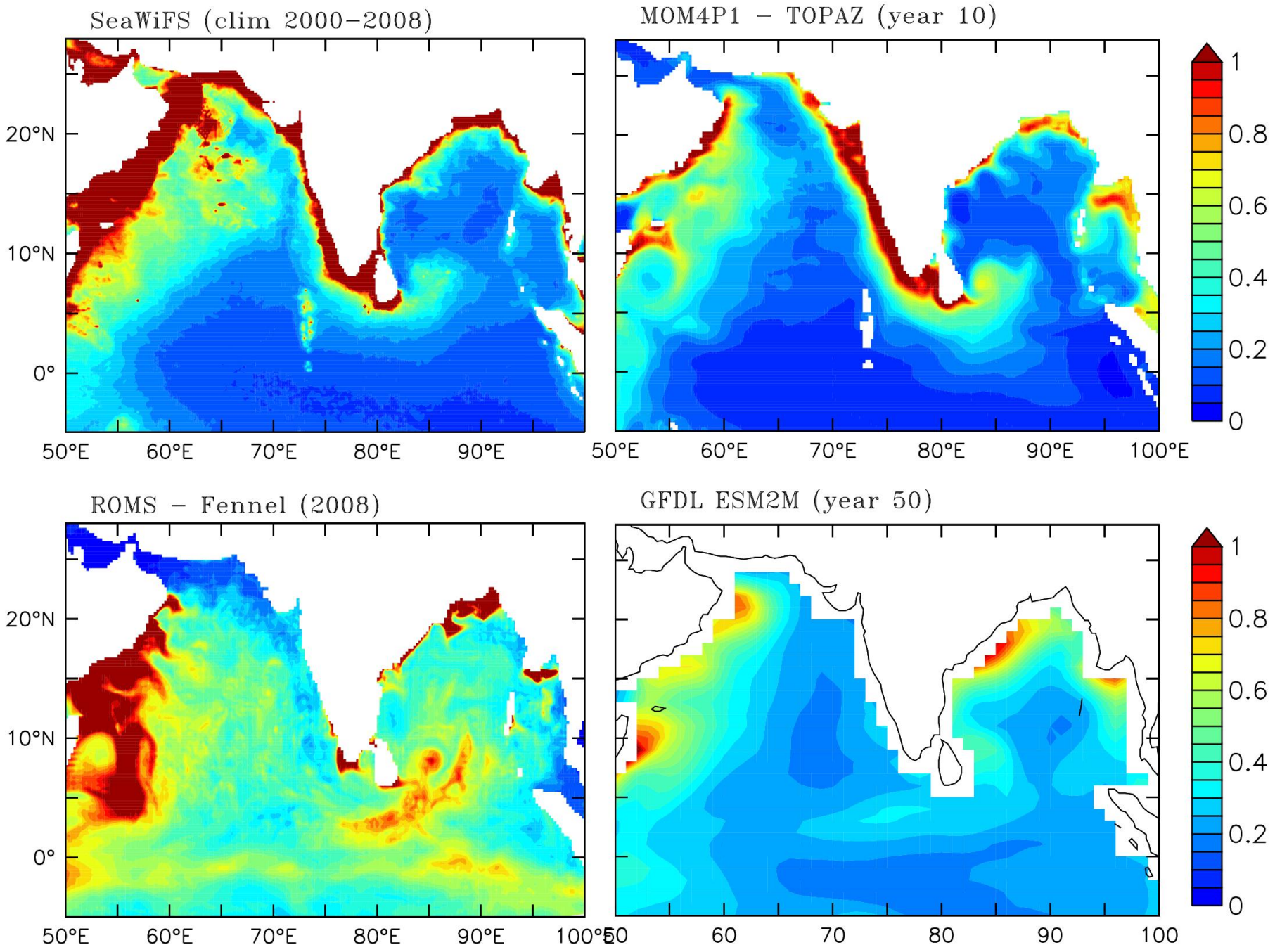
Eastern and southern boundaries - sponge layer

Spin up

Physical model - 10 years

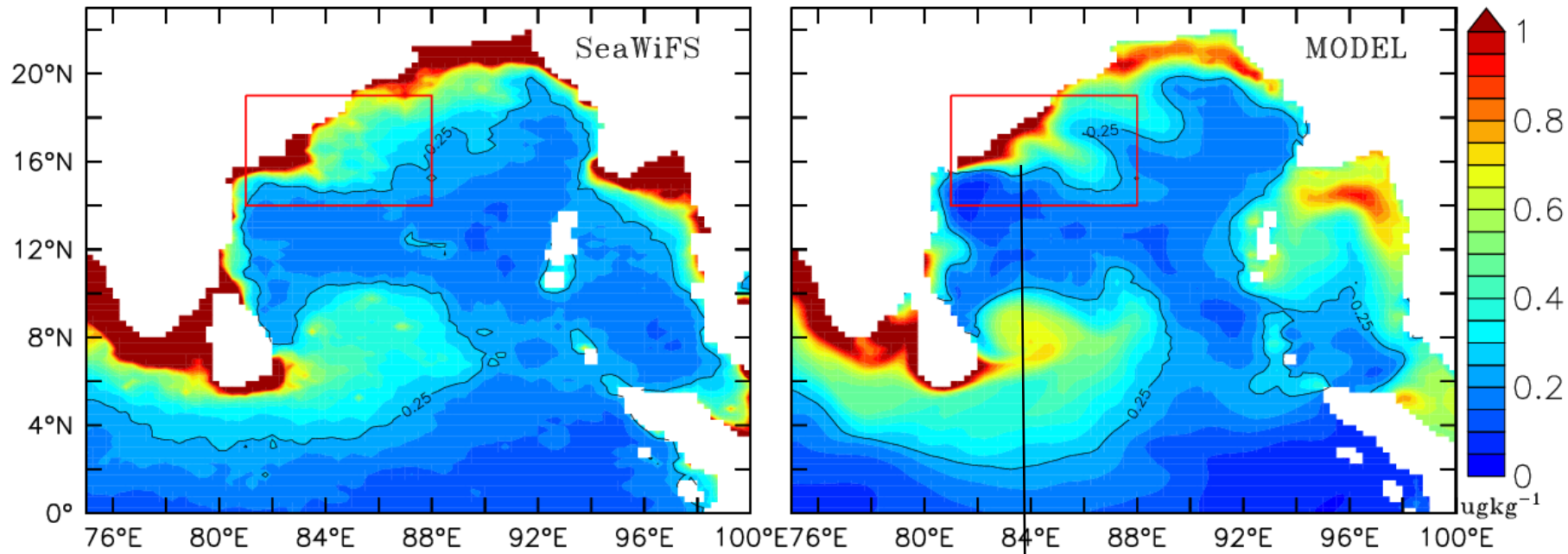
Coupled physical-ecosystem model - 10 years

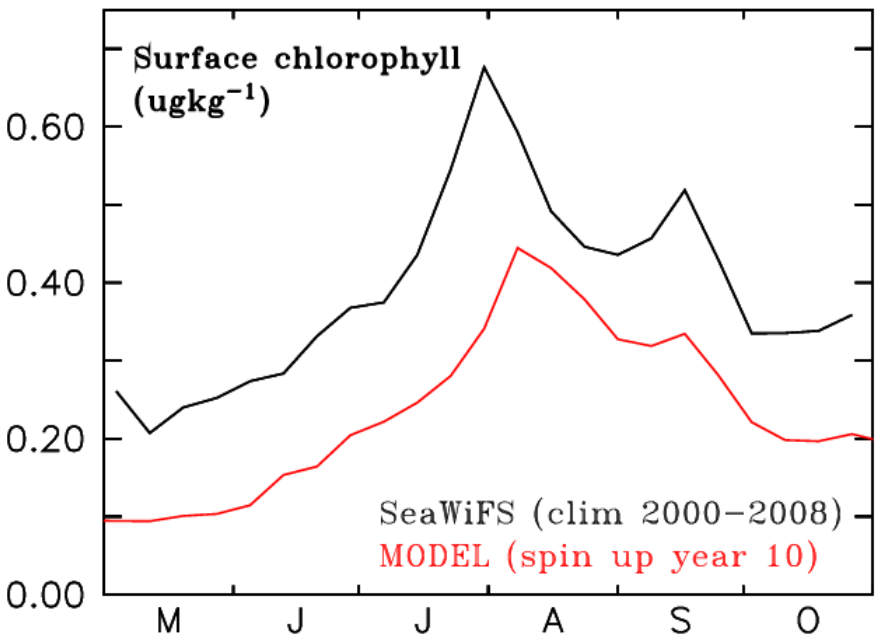
Surface chlorophyll (mg m^{-3}): Observations and simulations (July)



Summer blooms in the Bay of Bengal (MOM4P1-TOPAZ)

August



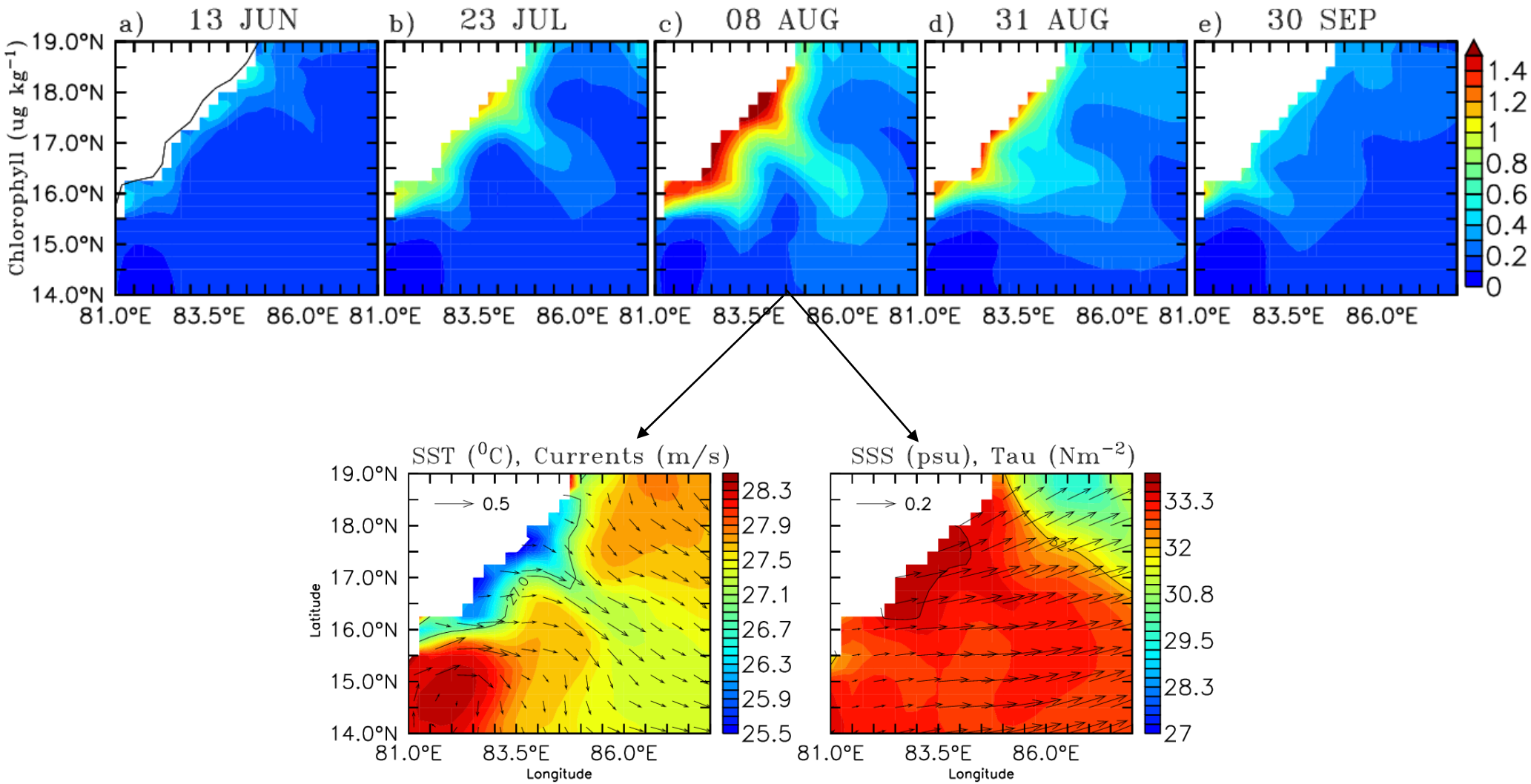


Northwestern bay

- *Prominent blooms during the summer monsoon*
- *Major fishing zones including Kakinada and Vishakhapatnam*

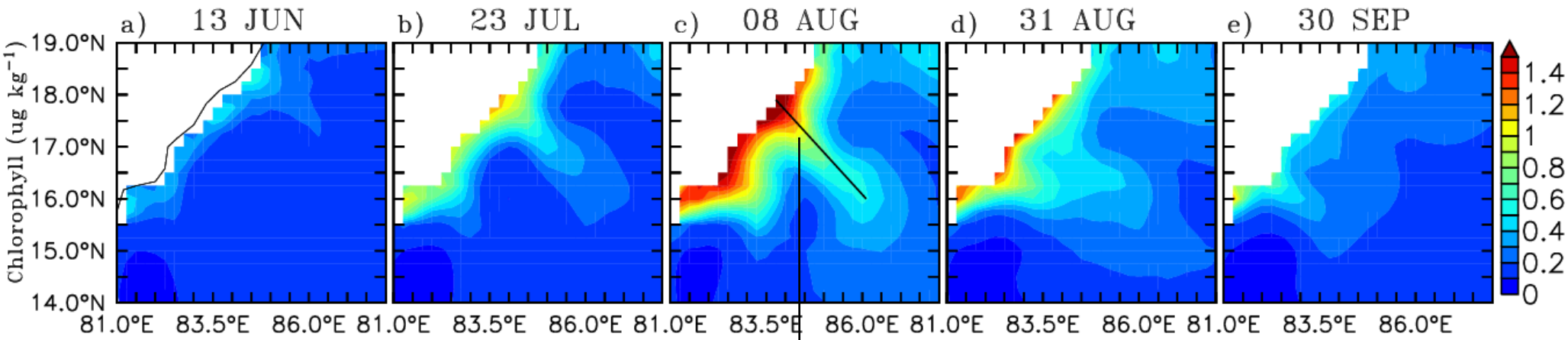
Thushara & Vinayachandran, JGR, 2016

Evolution of the summer bloom in the northwestern bay

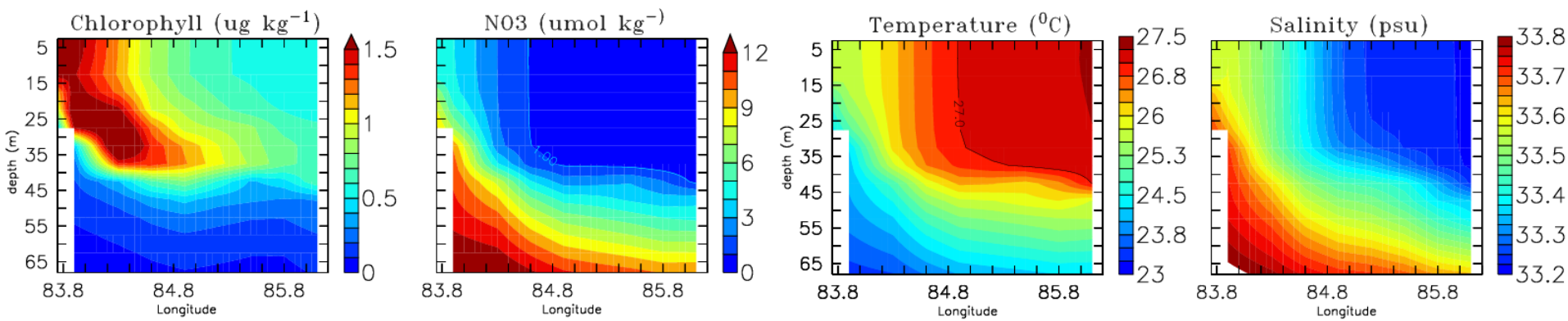


- The bloom develops close to the coast and spreads offshore.
- The bloom region is characterised by colder and saltier waters.

Evolution of the summer bloom in the northwestern bay

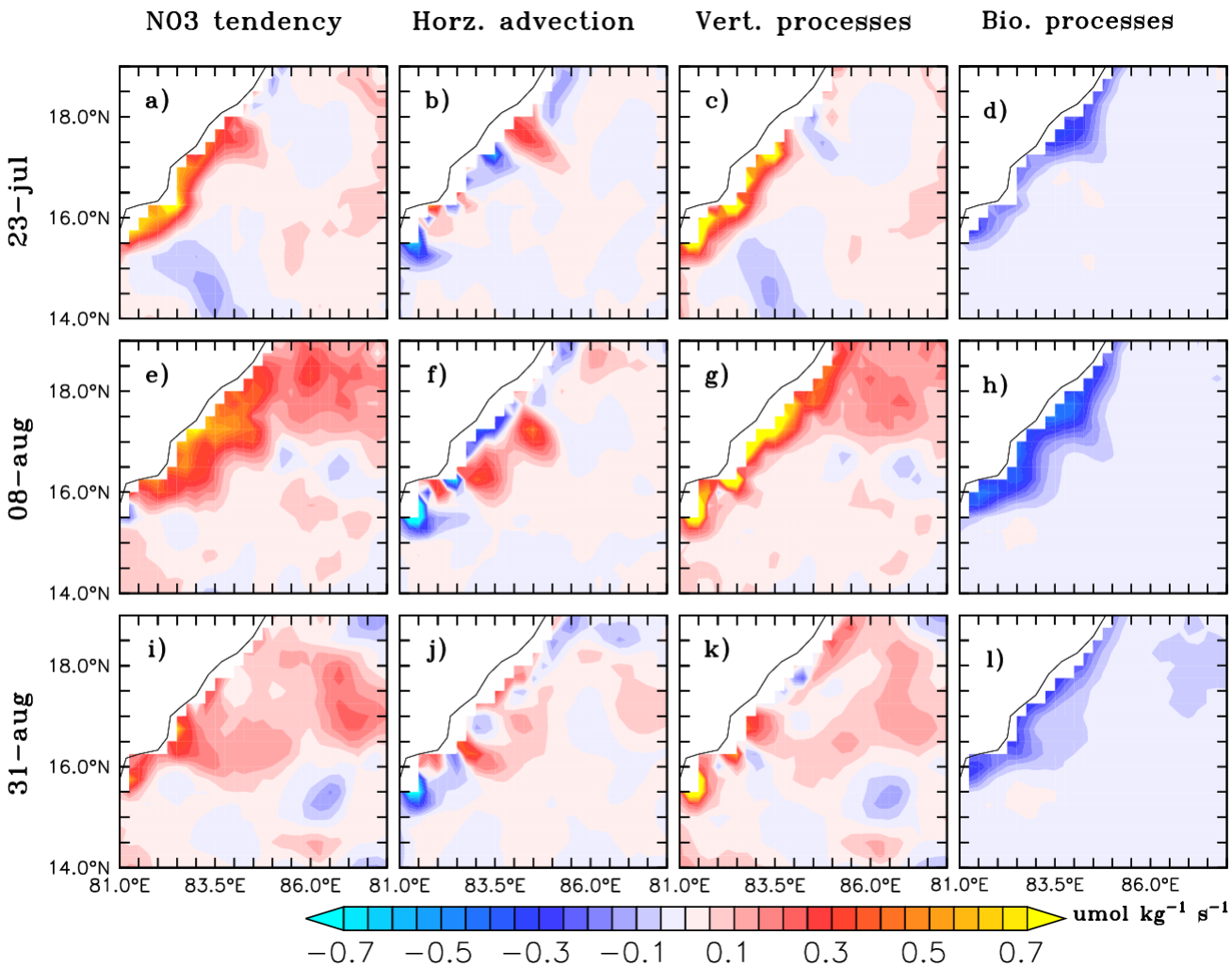


Vertical sections along the transect

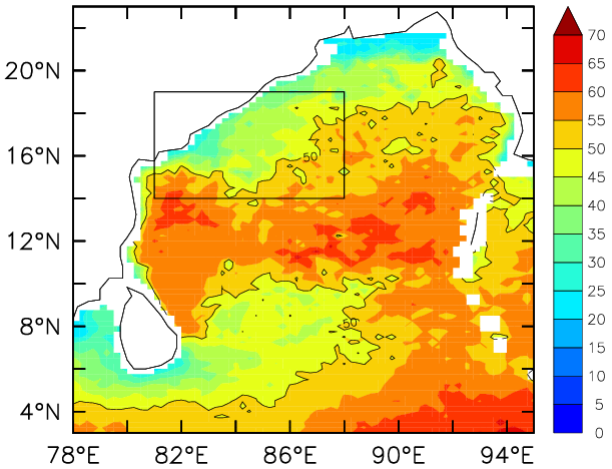


- Upwelling signals close to the coast.
- Shoaling of temperature, salinity and nitrate isopleths in the region of bloom.

Nitrate budget for the euphotic layer



Euphotic layer depth: depth of 1 Wm^{-2} irradiance



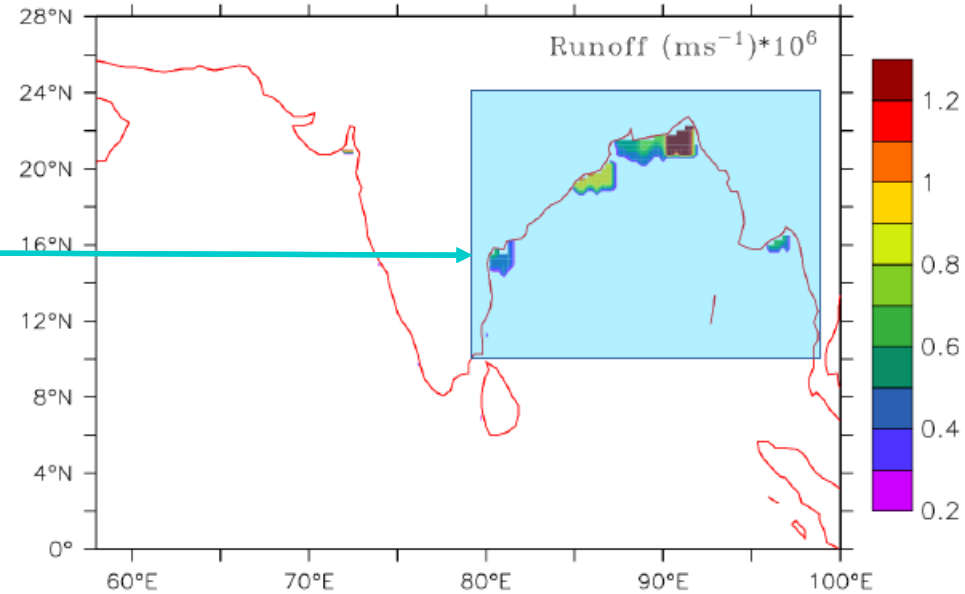
- Nutrient supply to the surface layers is largely controlled by the vertical processes.
- Horizontal advection transports upwelled nutrients from coastal to offshore regions.
- Biological processes reduce nutrient concentration (mainly through phytoplankton uptake).

Role of freshwater and wind stress forcings

Model sensitivity experiments

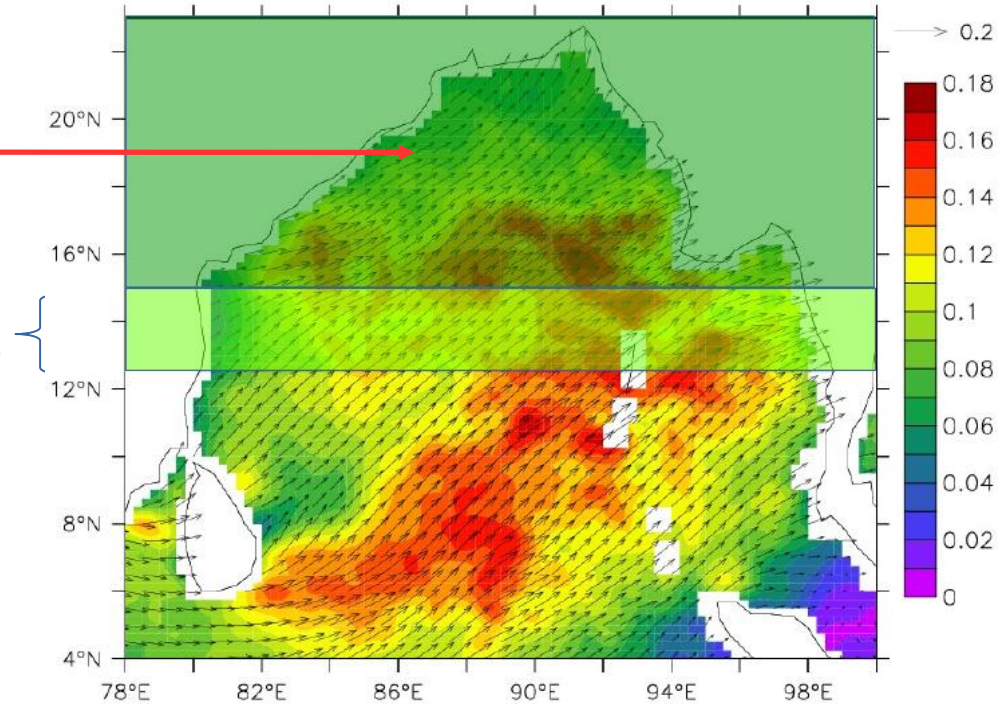
NORIV

- Switched off the rivers of Bay of Bengal



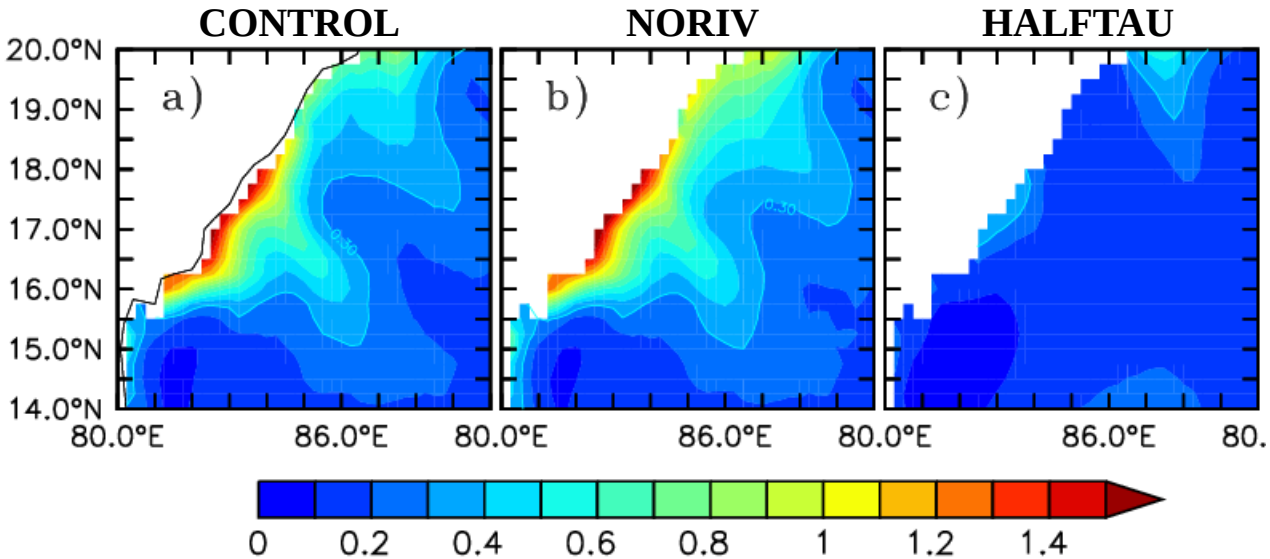
HALFTAU

- Reduced the wind stress forcing by 50% north of 15°N in the bay
- Ramping for 10 grid points south of 15°N



Role of freshwater and wind stress forcings

Surface chlorophyll from control and sensitivity experiments

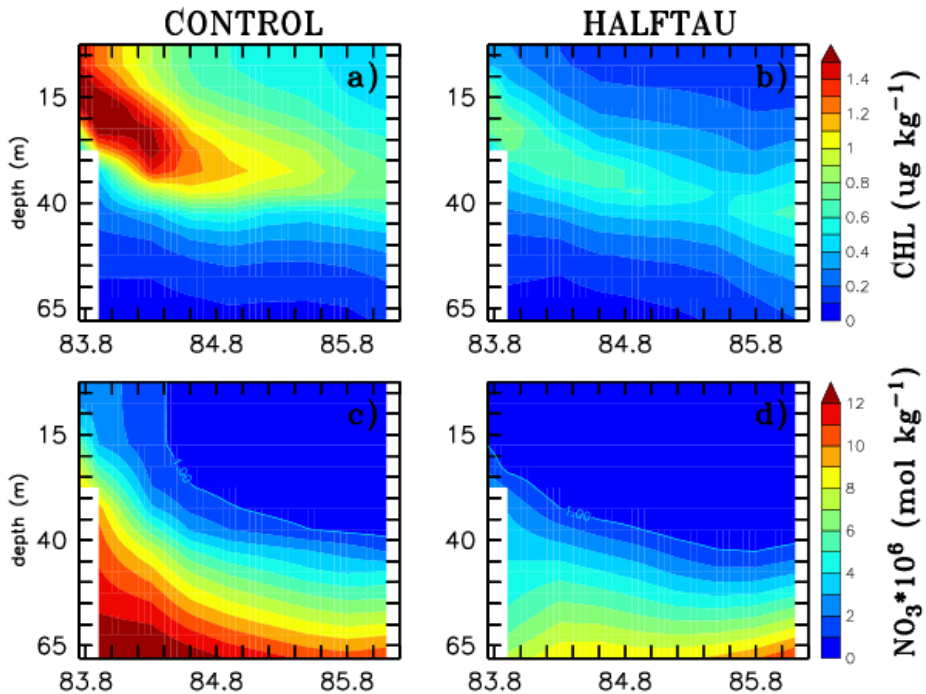


CONTROL : main run

NORIV : switched off BoB runoff

HALFTAU : wind stress reduced by 50%

Vertical sections of chlorophyll and nitrate



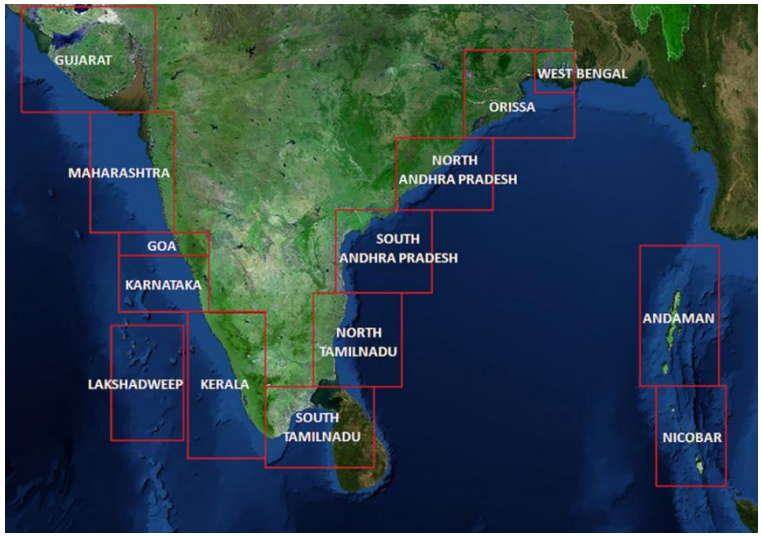
- Productivity remains largely unaffected by the freshwater discharge.
- Reduced wind stress weakens the coastal upwelling of nutrients, resulting in a significant reduction in productivity.

Summary

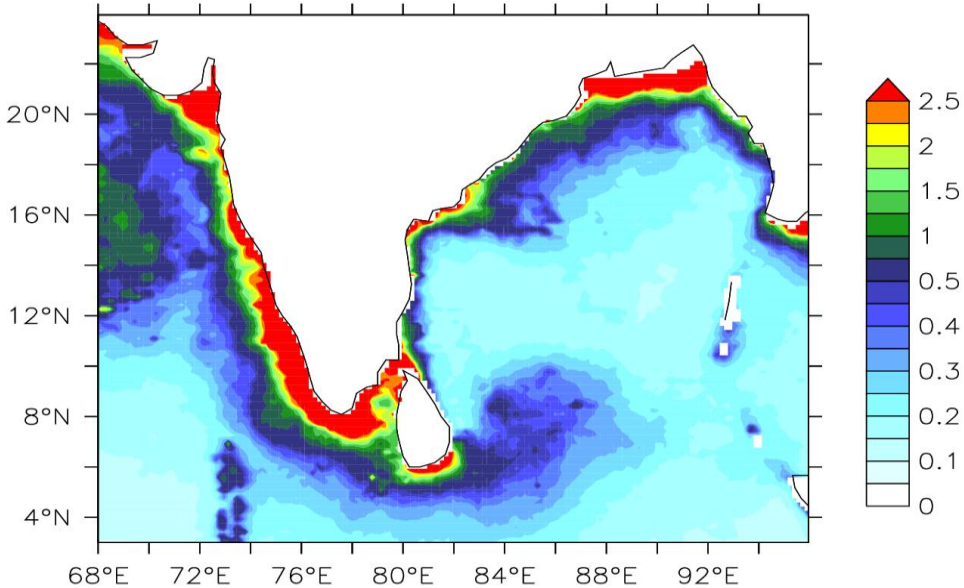
- **Prominent regional bloom in the north-western Bay of Bengal during summer.**
- **MOM4-TOPAZ combinations is able to reproduce the bloom.**
- **Dominant role of upwelling driven by coastal along-shore winds.**
- **The bloom is largely unaffected by river runoff.**

Implications to fisheries?

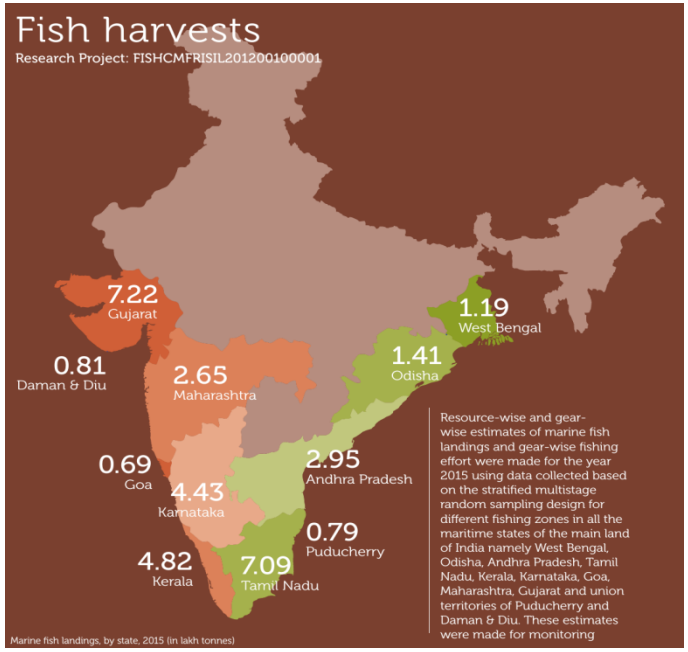
Marine fisheries in India



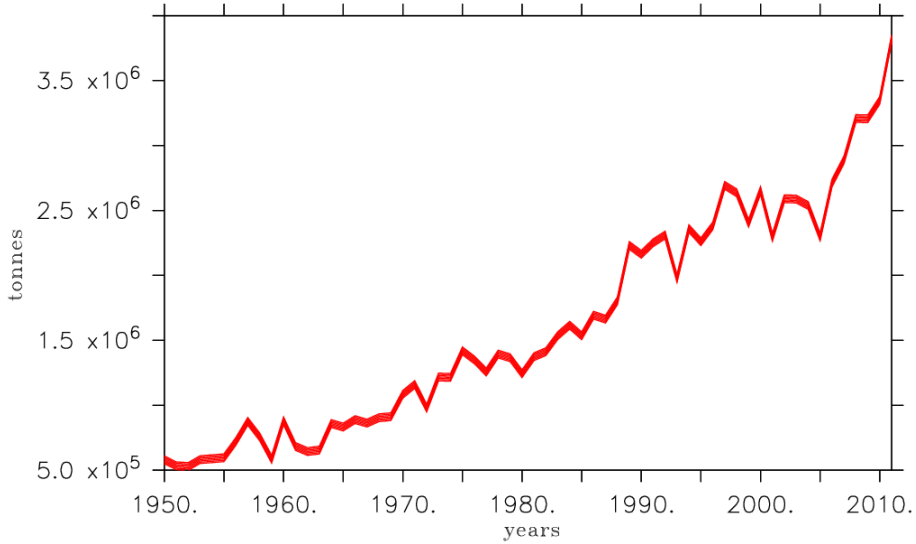
Potential Fishing Zone (ESSO-INCOIS)



Summer monsoon (Jul-Aug) blooms around India (SeaWiFS climatology for 2000-2008)

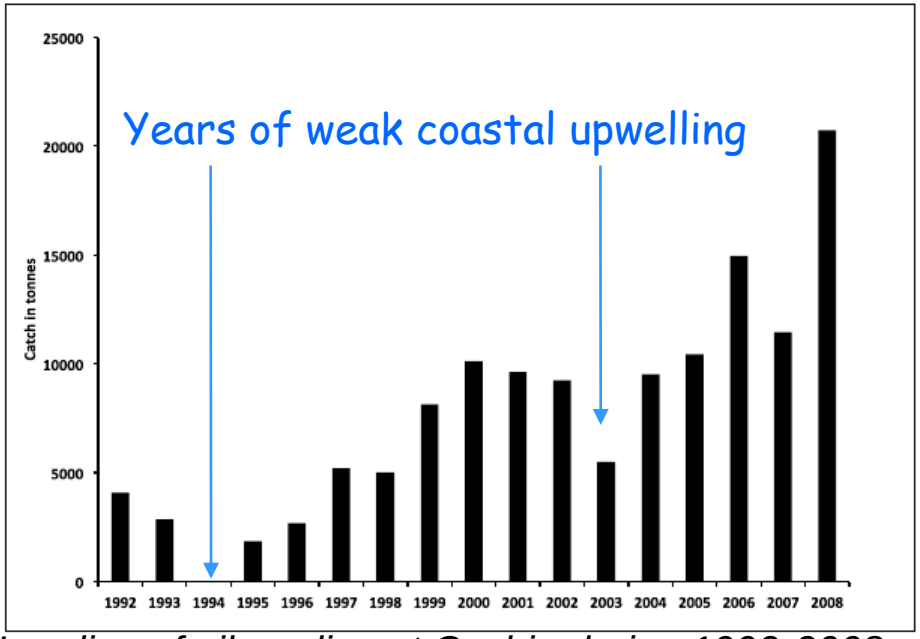


Marine fish landings (in lakh tonnes), by state for 2015 (CMFRI Annual Report 2015-16)



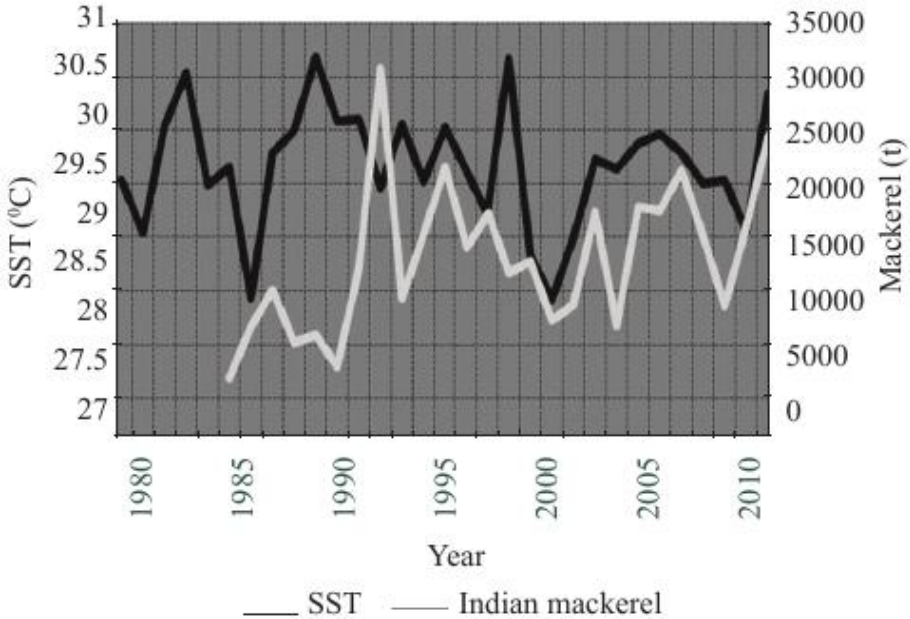
Estimated Marine Fish Landings in India (1950-2011, annual mean) (CMFRI)

Fisheries response to oceanic conditions

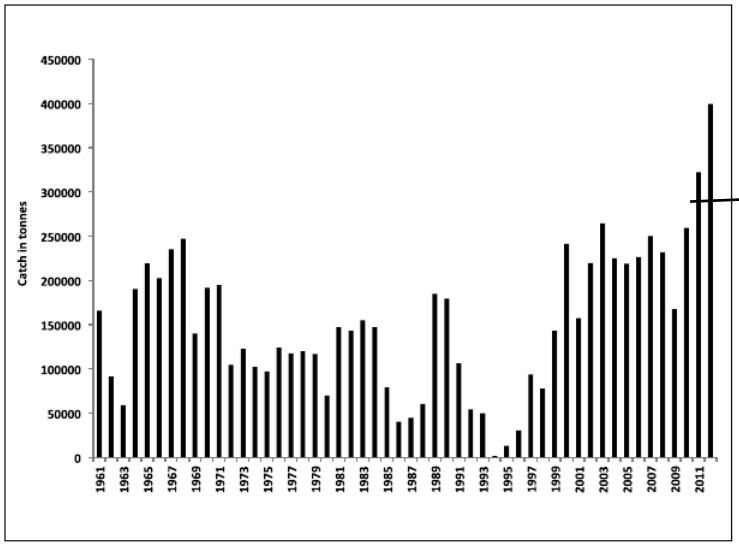


Landing of oil sardine at Cochin during 1992-2008 (Kripa et al., 2015)

Increase in fish catch with SST rise



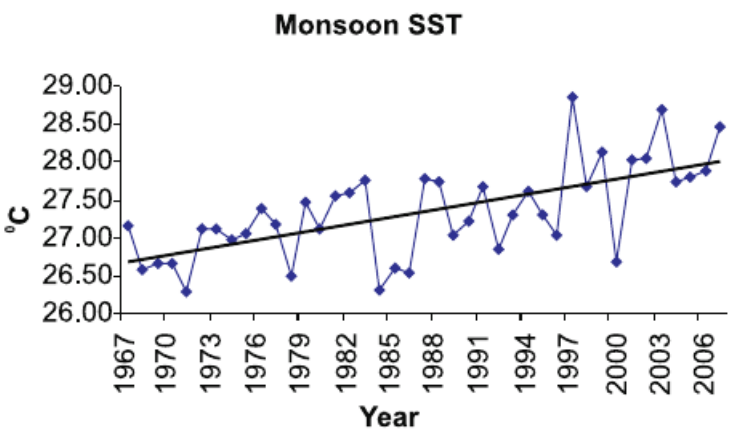
Catch of Indian Mackerel vs. SST along the Tamilnadu coast (Kizhakudan et al., 2014)

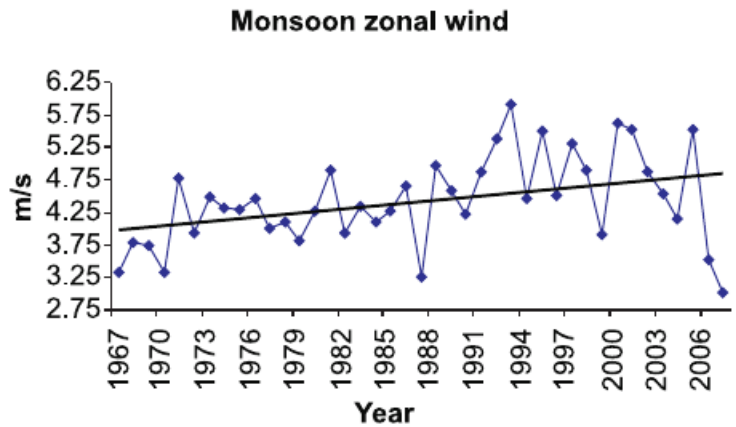


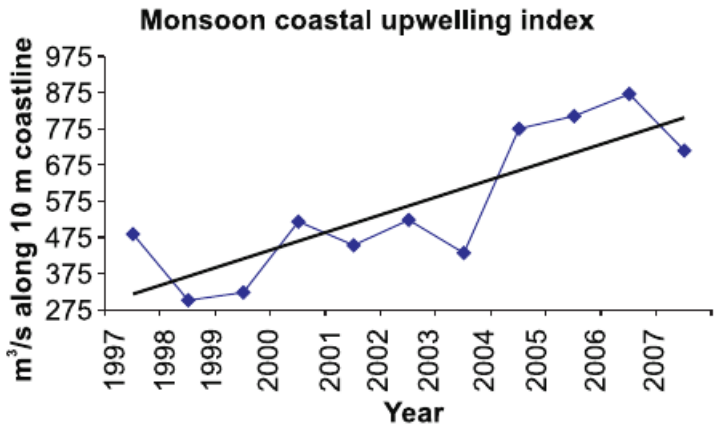
Increased fish landings - linked to global warming?

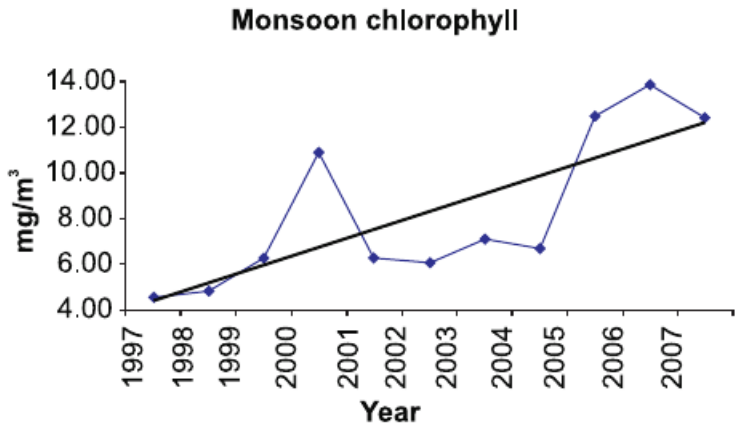
Oil sardine landings of Kerala during 1961-2012 (Kripa et al., 2015)

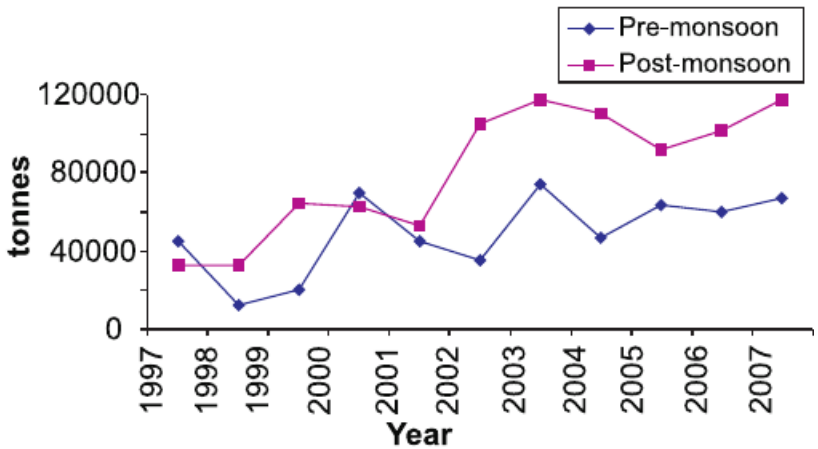
Interannual changes in fisheries off the Kerala coast





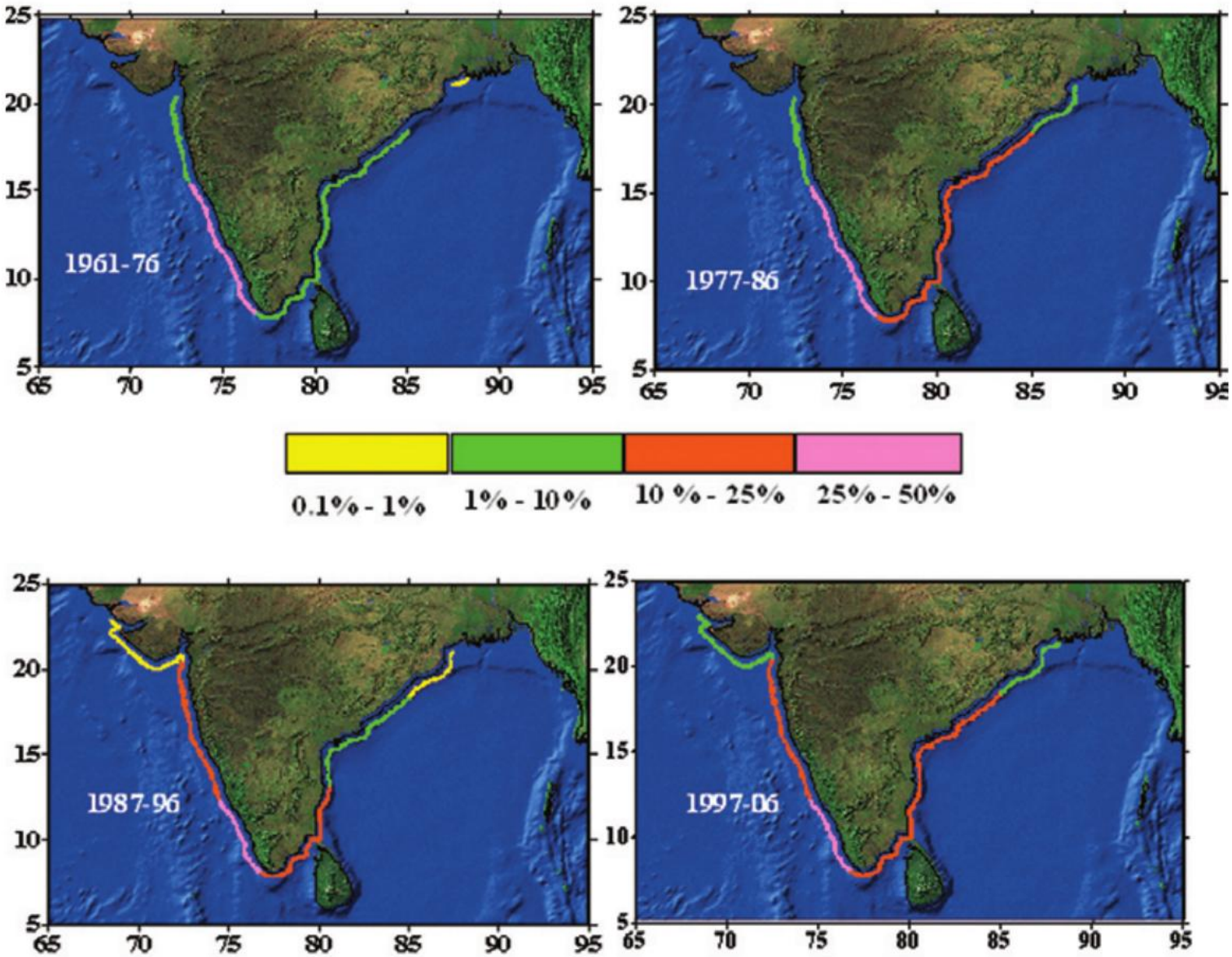






Oil sardine landings of Kerala during 1997-2007
(CMFRI Annual report, 2009-2010)

Extended distribution of fisheries in response to climate change



Extended distribution of Indian Mackerel towards northern latitudes in response to SST rise (CMFRI Annual report, 2007-2008).


Thank you