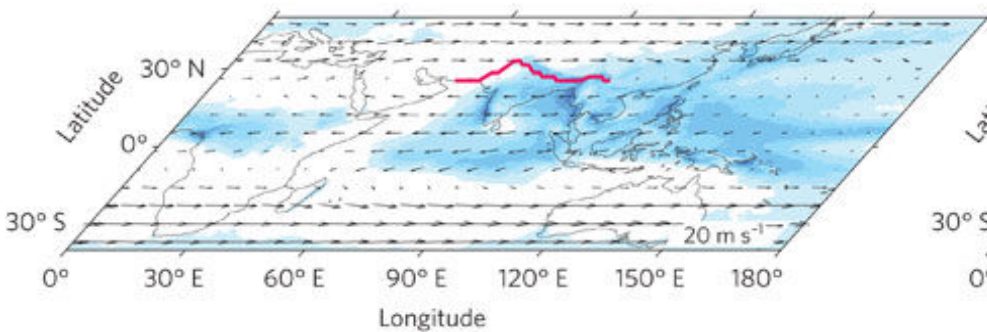
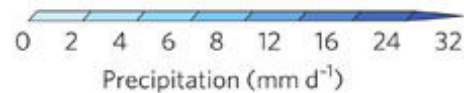
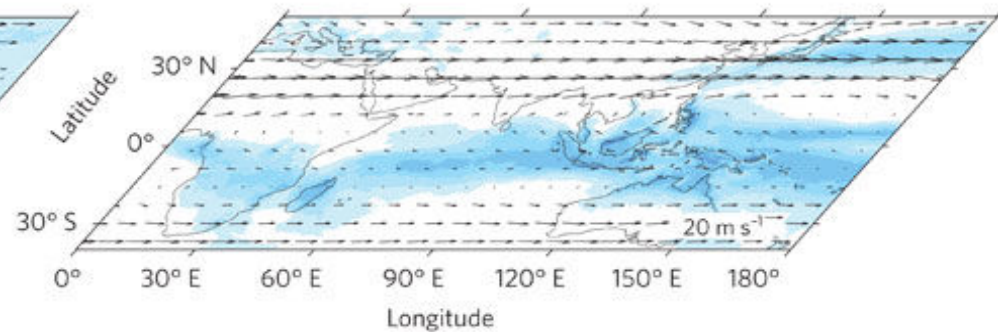


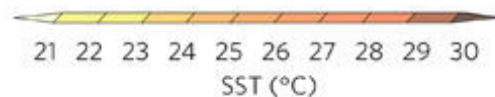
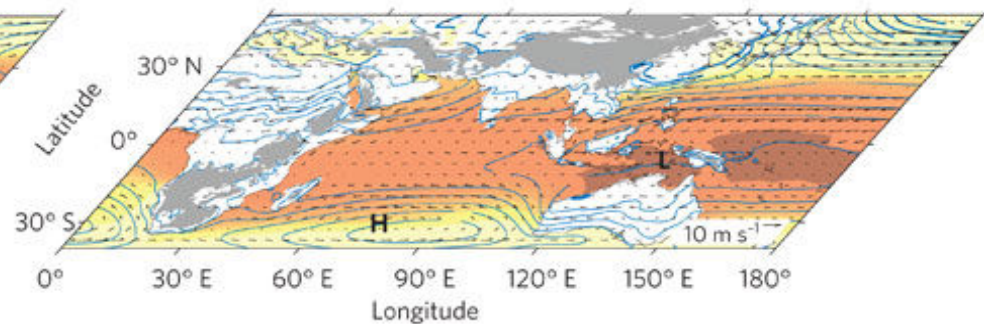
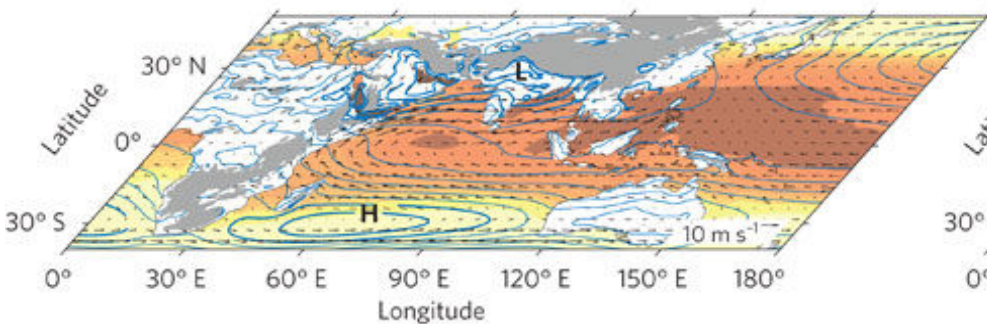
Boreal summer



Boreal winter



Turner and Annamalai 2012

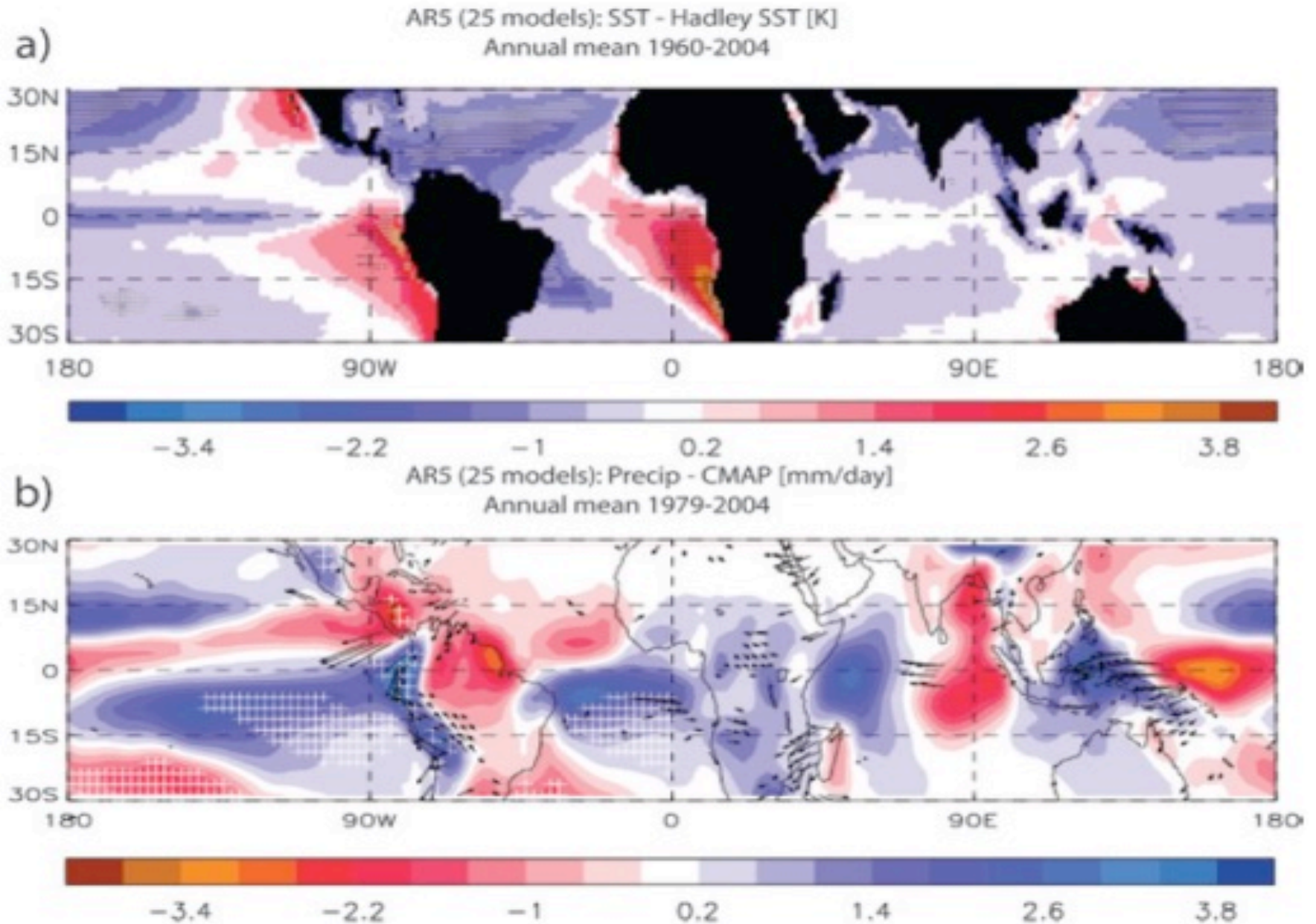


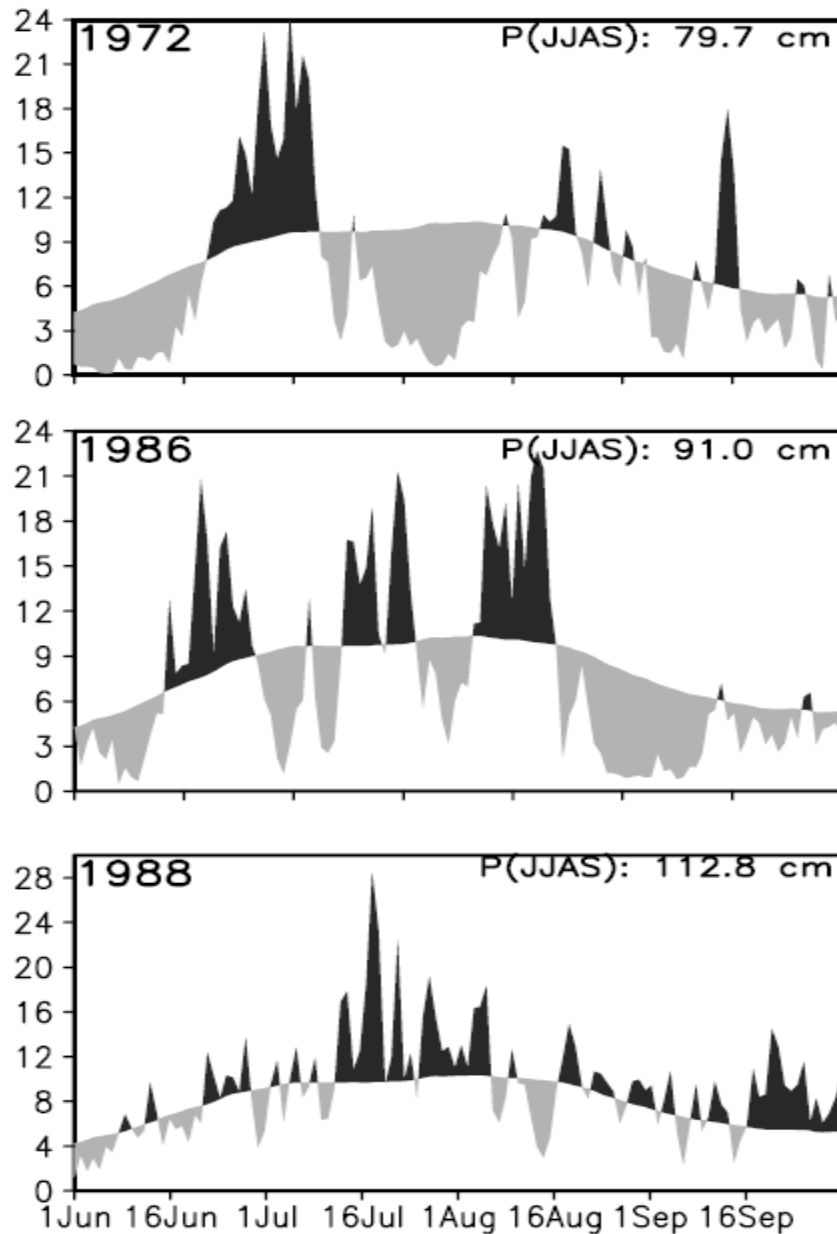
**Indian Ocean Response to the Monsoon has typically focused on winds and surface fluxes.**

**But the details of the ITCZ, monsoon onset and withdrawal may matter.**

**What about Integration of the fluxes by the Ocean and the MOC?**

# Mean SST and Precipitation Biases in the Indian Ocean are not indicative of model performance



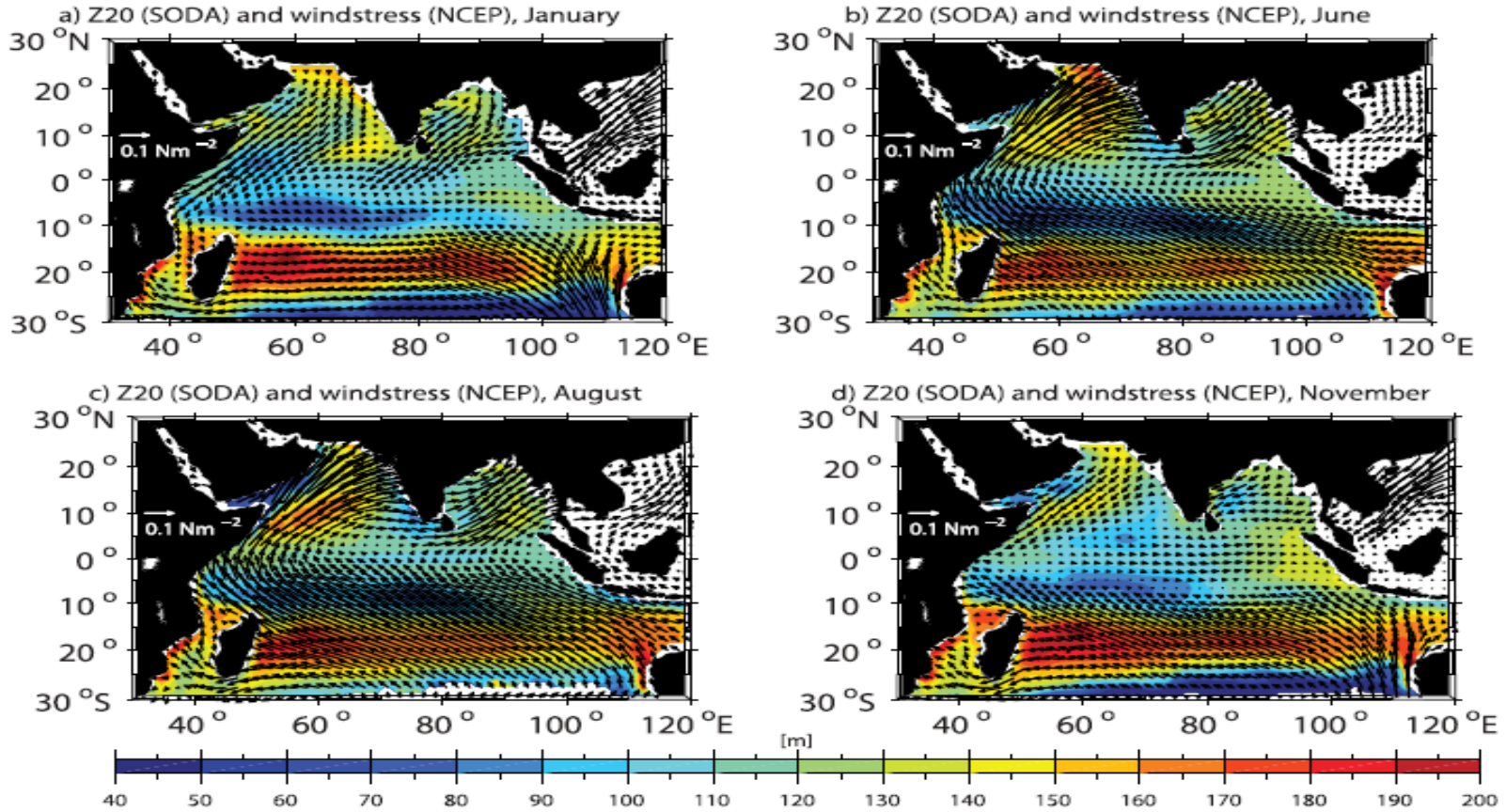


There have been shifts/trends in Onset, Withdrawal, Seasonal rainfall, Aerosols, and Teleconnections:

What is the Paradigm for Indian Ocean Response?

**Figure 2.2.** Daily rainfall (mm day<sup>-1</sup>) averaged over 72°E–87°E and 10°N–25°N based on station data over the Indian continent during the summer monsoon season for three years, 1972, 1986, and 1988. Departure from the mean annual cycle (shown as the envelope) are shaded. Seasonal mean rainfall for each year are also shown in the top-right corners.





**Figure 1.** Monsoon wind stress fields from the 1990–1998 National Centers for Environmental Prediction (NCEP) [Kalnay *et al.*, 1996] climatology (vectors) and depths of 20°C isotherm (Z20) from Simple Ocean Data Assimilation (SODA) (mean for 1992–2001, color shaded) for (a) January, (b) June, (c) August, and (d) November.

Schott *et al.* 2009

- **Mixed Layer – Thermocline Interactions? BGC – Ecosystem Responses?**
- **Summer vs Winter Blooms. Eddies, Biological vs Solubility Pumps**
- **Subsurface Chl-Max? What happens during IODZM events? Surfacing of SCM or new species?**
- **Iron Limitation? Aerosols and Iron fertilization?**

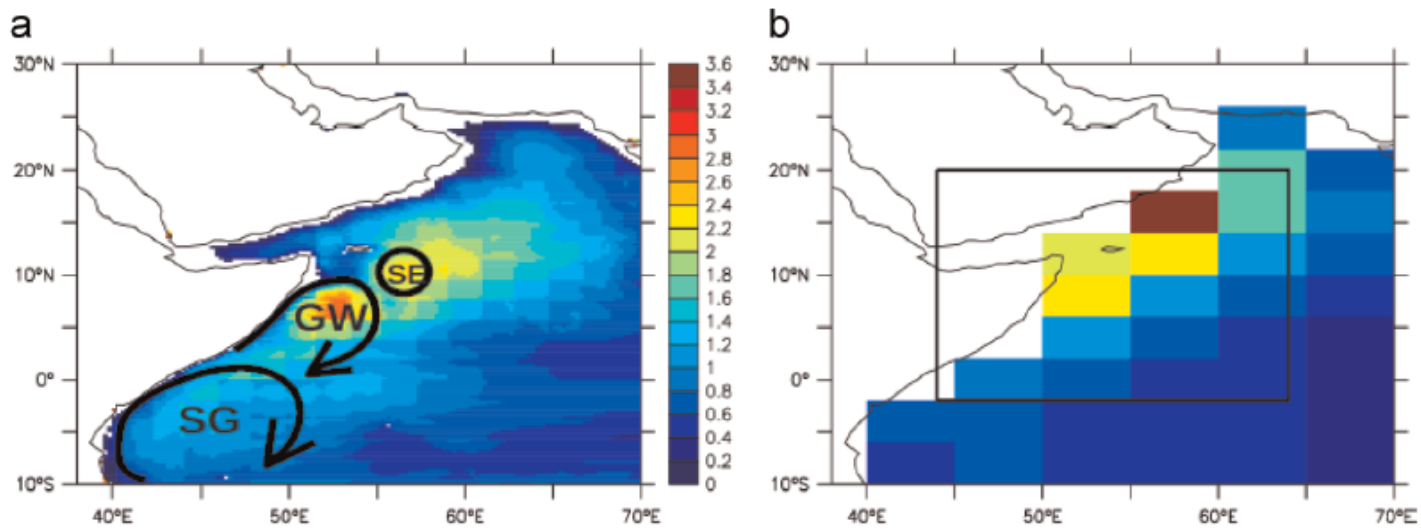


Fig. 1. (a) Annual mean sea-to-air CO<sub>2</sub> fluxes from the model (1992-1997) and (b) from the observations of Takahashi et al. (2009). Units are in mole m<sup>-2</sup> yr<sup>-1</sup>.

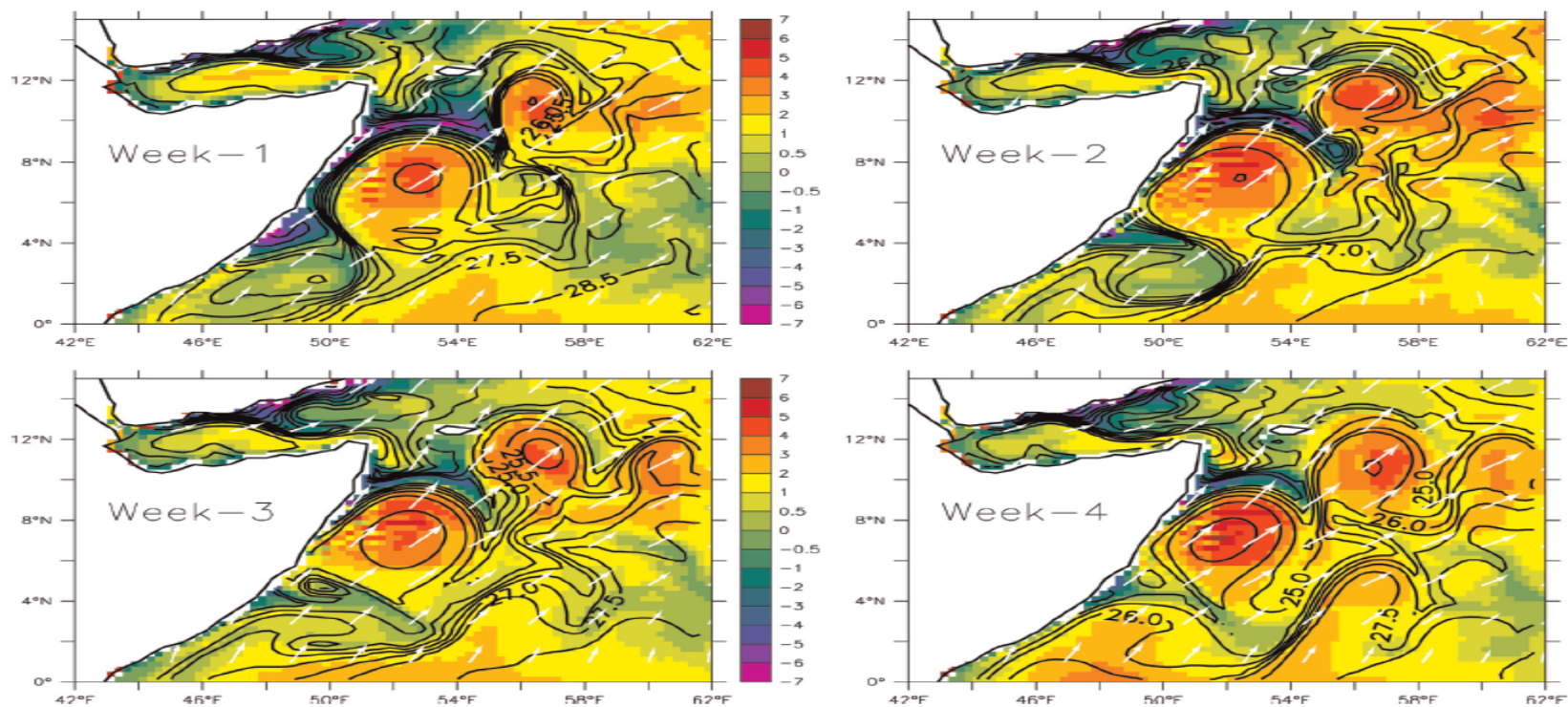
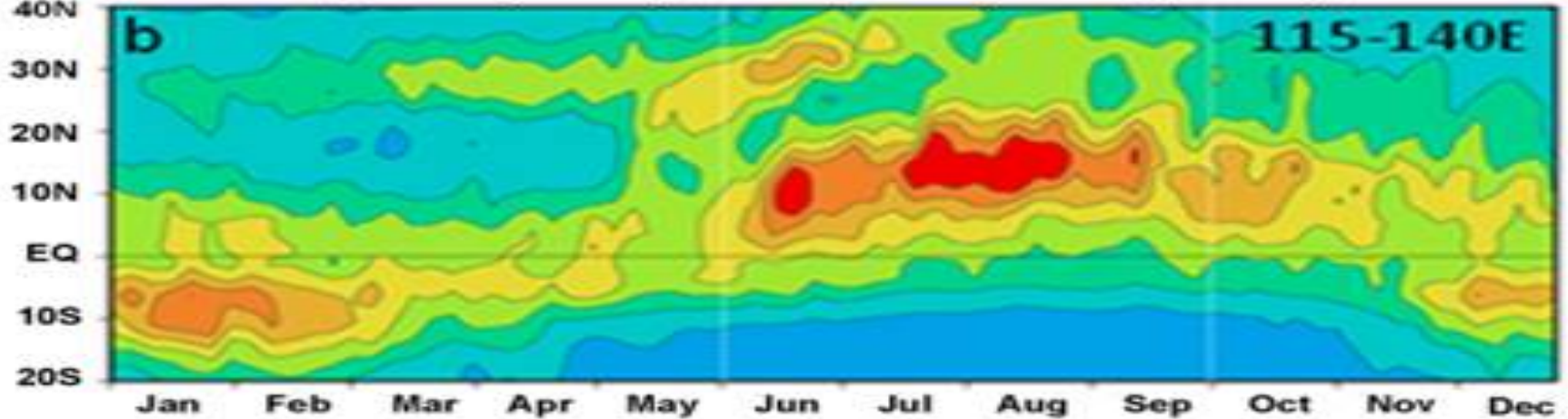
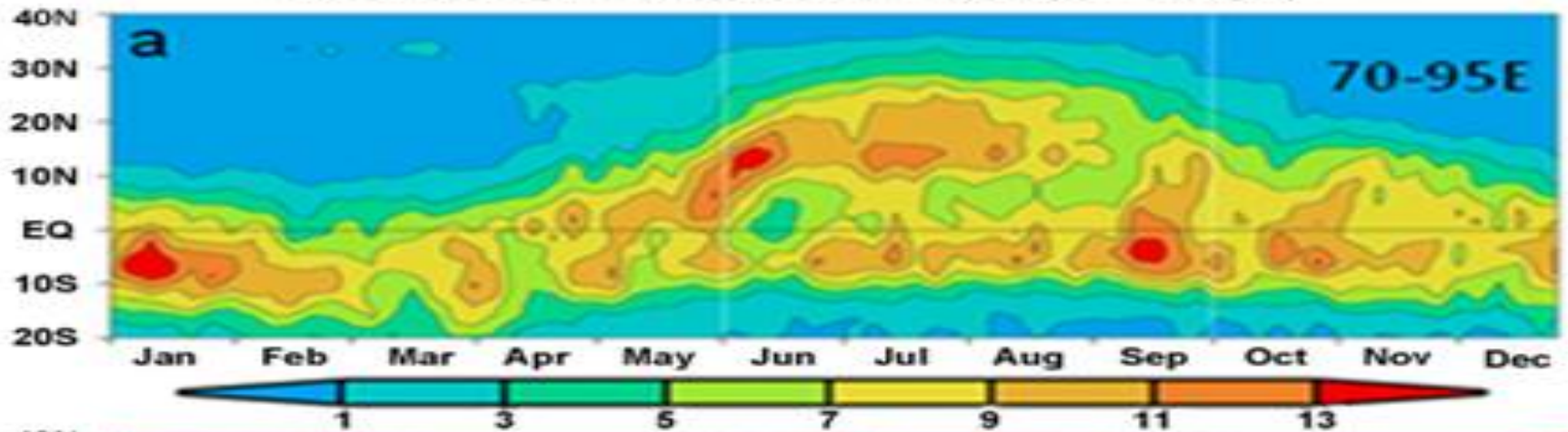


Fig. 5. Week-1 through 4 evolutions of air-sea CO<sub>2</sub> fluxes (color), SST (contour) and surface winds (vectors) over Somali region shown as an example from 1992



## Mean 5-day Precipitation Rate (mm day<sup>-1</sup>)

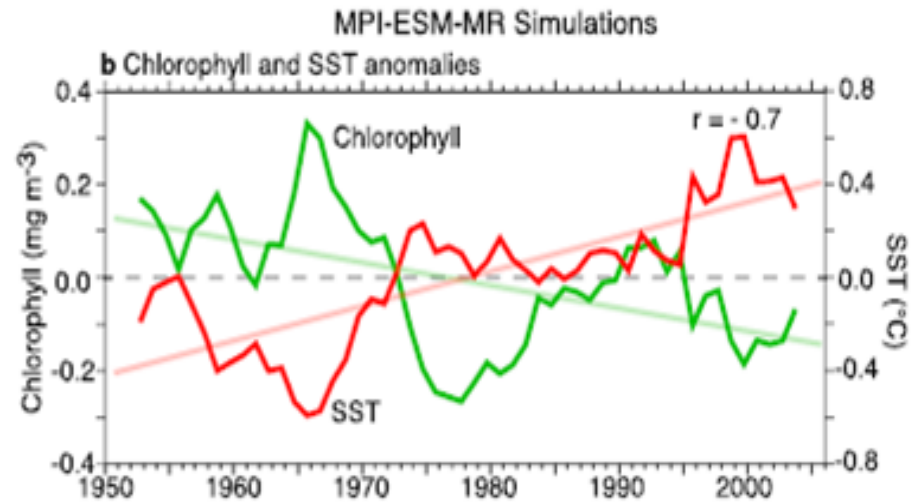
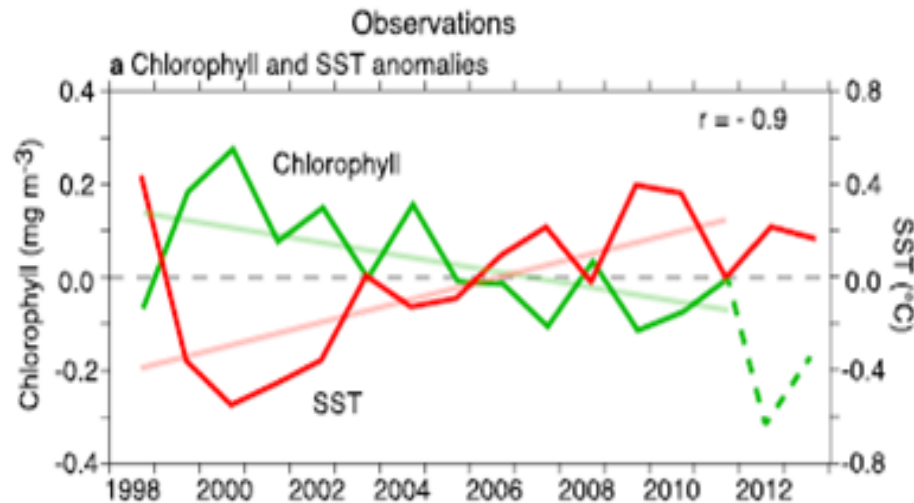
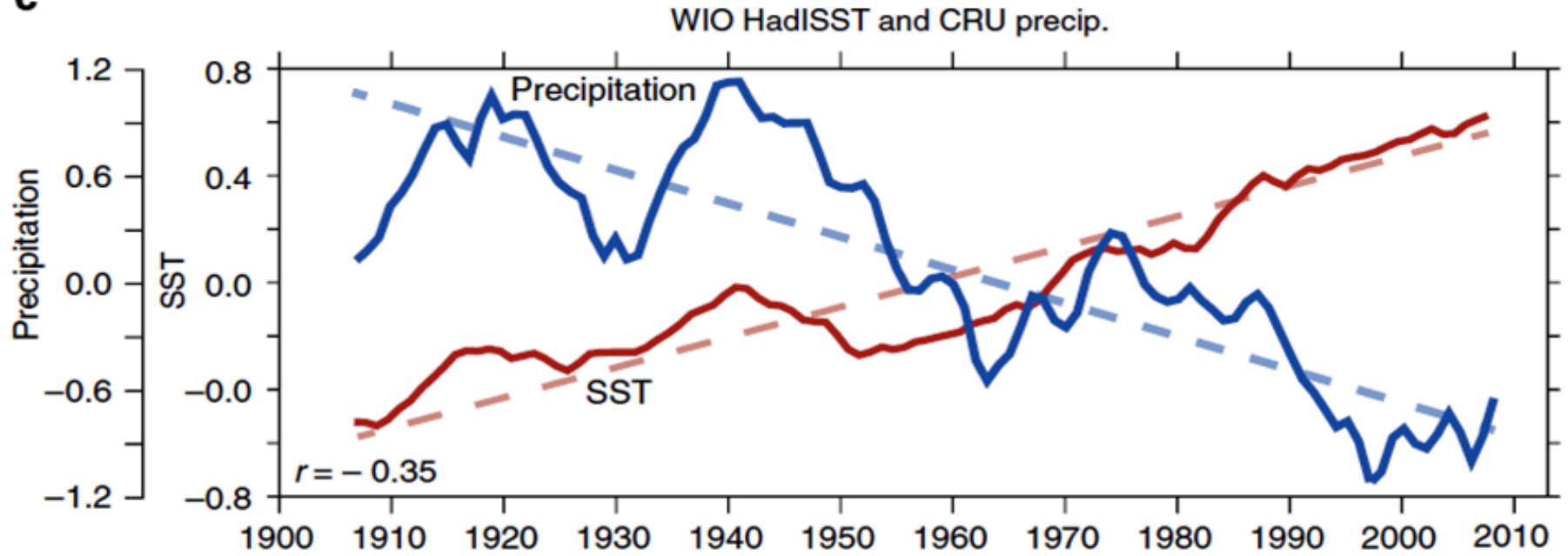


WMO

- BGC-Ecosystem and Monsoon Interactions: Local and Remote Forcings
- Land-Ocean Competition for Precipitation: Impact of Freshwater Forcing
- BGC-Ecosystem response to MJOs, MISOs, Onset, Withdrawal, Depressions
- Ocean's Role in ITCZ – Energy constraints?

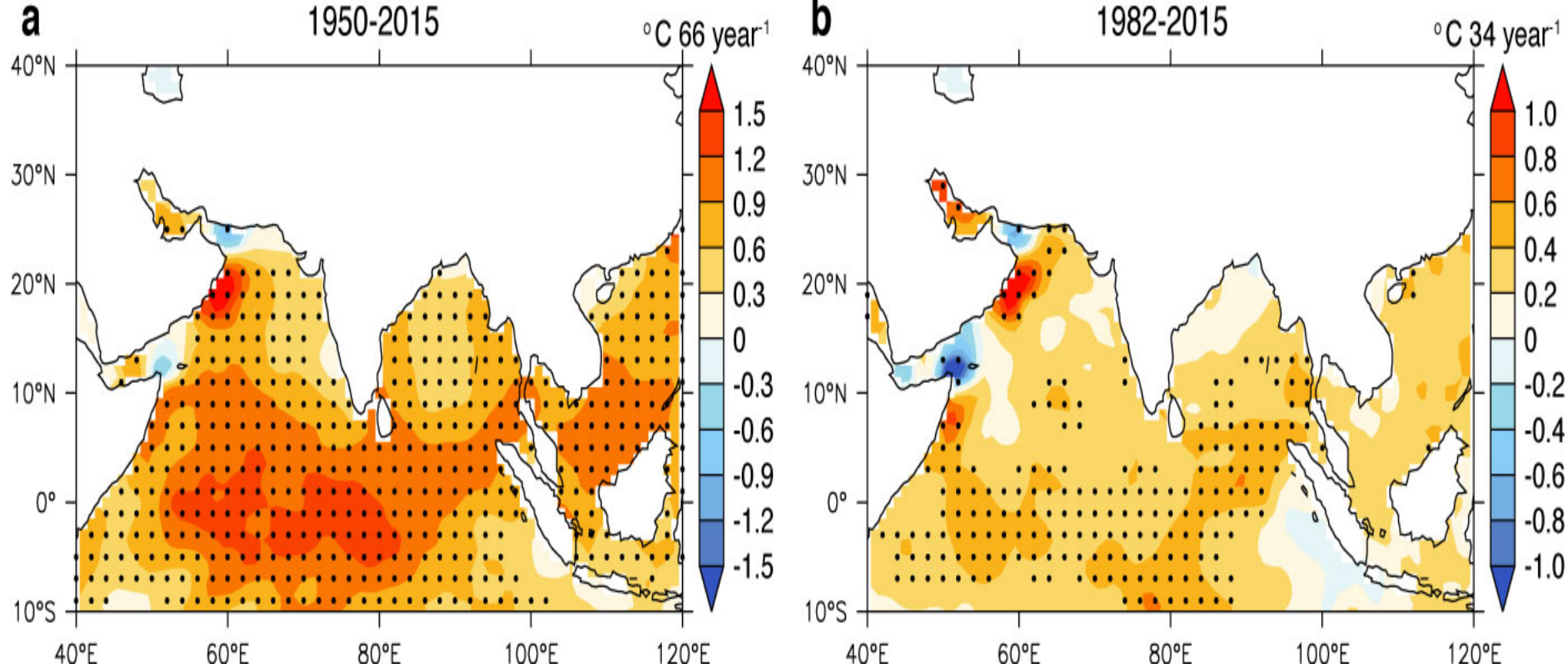
# Trends or Regime Shifts? Onset, Withdrawal, Length of Rainy Season

**c**



## Warming NOT Spatially Uniform

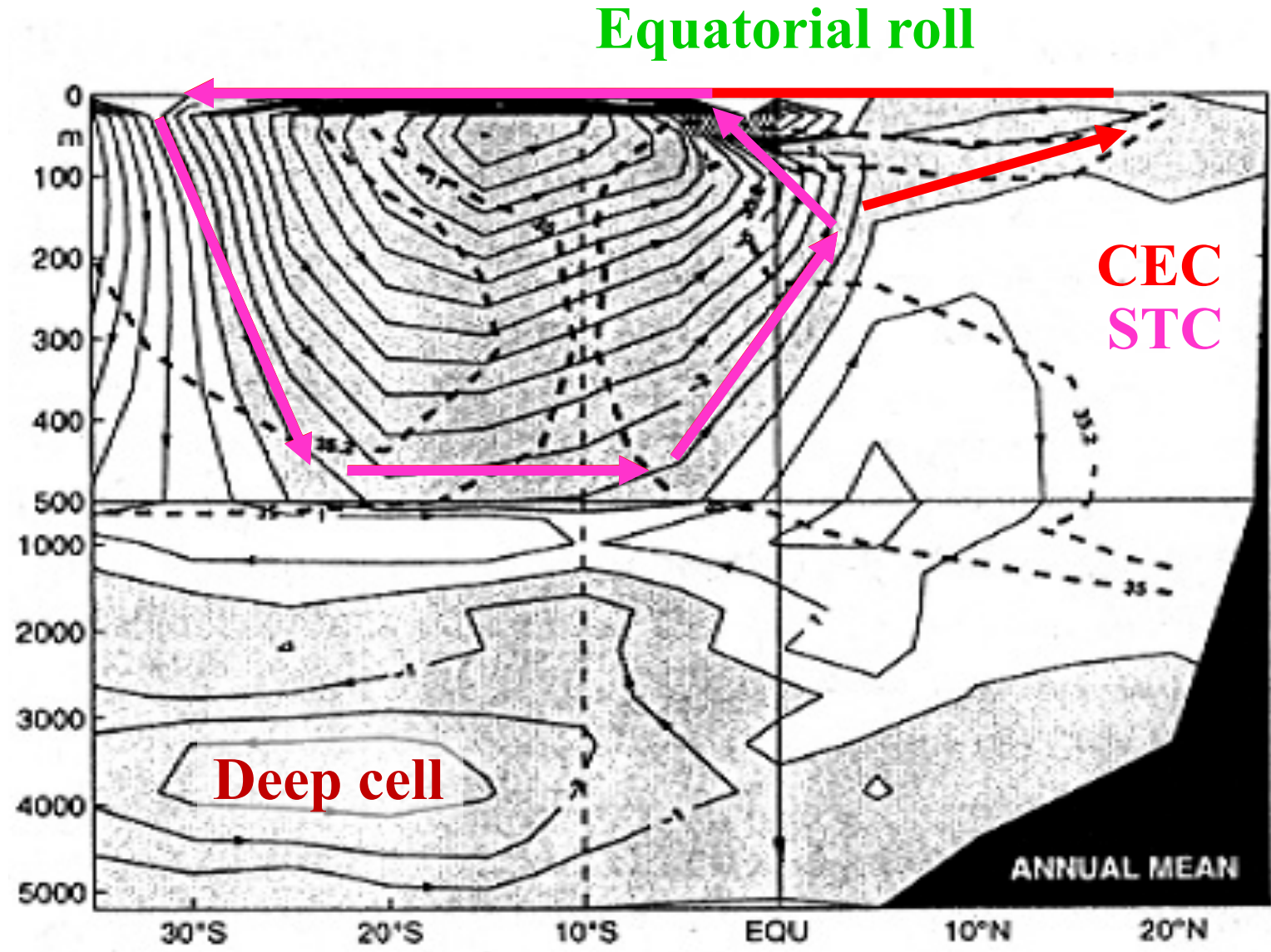
### Sea surface temperature trends



- **Pattern of Warming: BoB vs Arabian Sea – BGC and Ecosystem?**
- **Wind trends not so obvious. P and E Trends? Land vs Ocean?**
- **Upper Ocean Structure? Diurnal-to-Decadal Timescales**
- **ITF? Warming Hiatus? MOC?**
- **Failure of CMIP5 models: historical trends and projections**

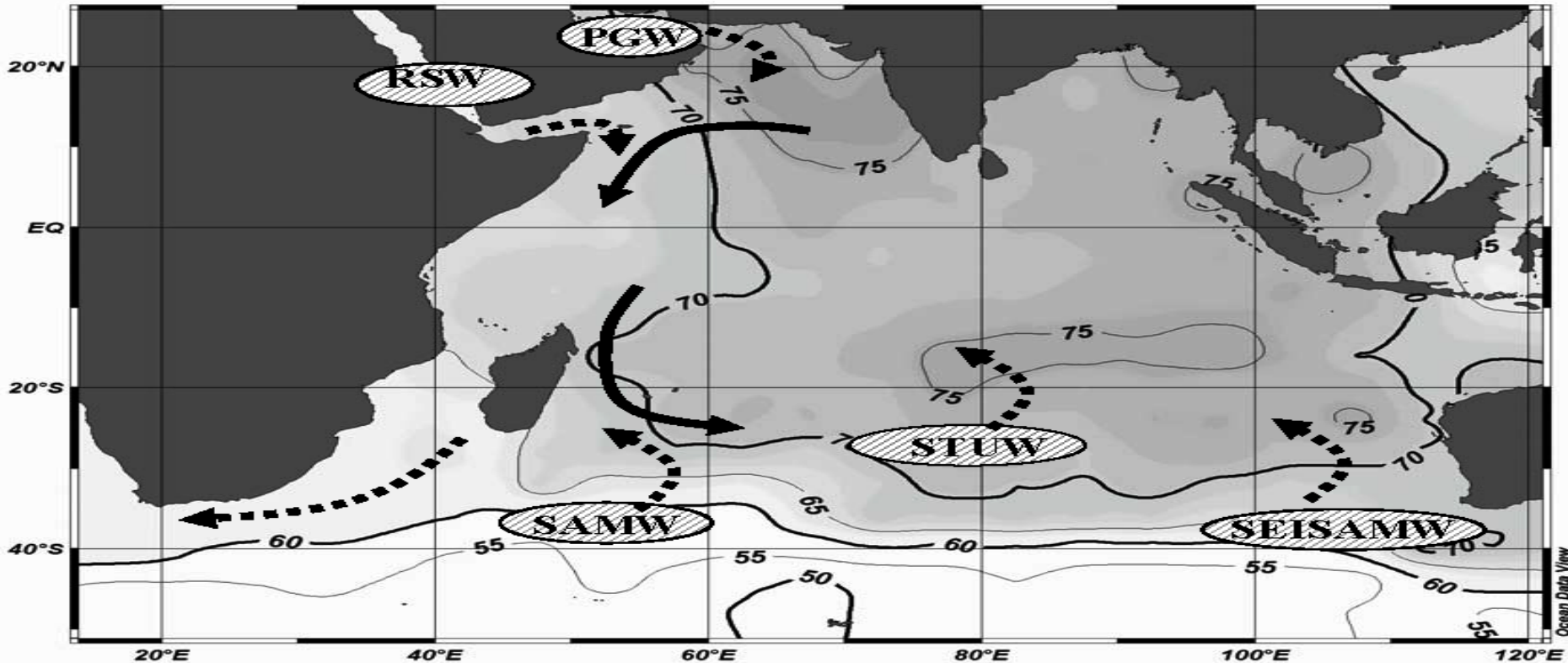


# Meridional stream function from an IO GCM (Stolen from Jay)



Garternicht and Schott (1997)

# Flushing timescales? Integral Constants?



- DOC and MOC; Warming, Stratification, DOC and Nutrients.
- DOC and AOU.
- ITF, MOC, DOC.
- ITF, MOC and IO Warming

# Microbes? Food web? Disease Pressure?

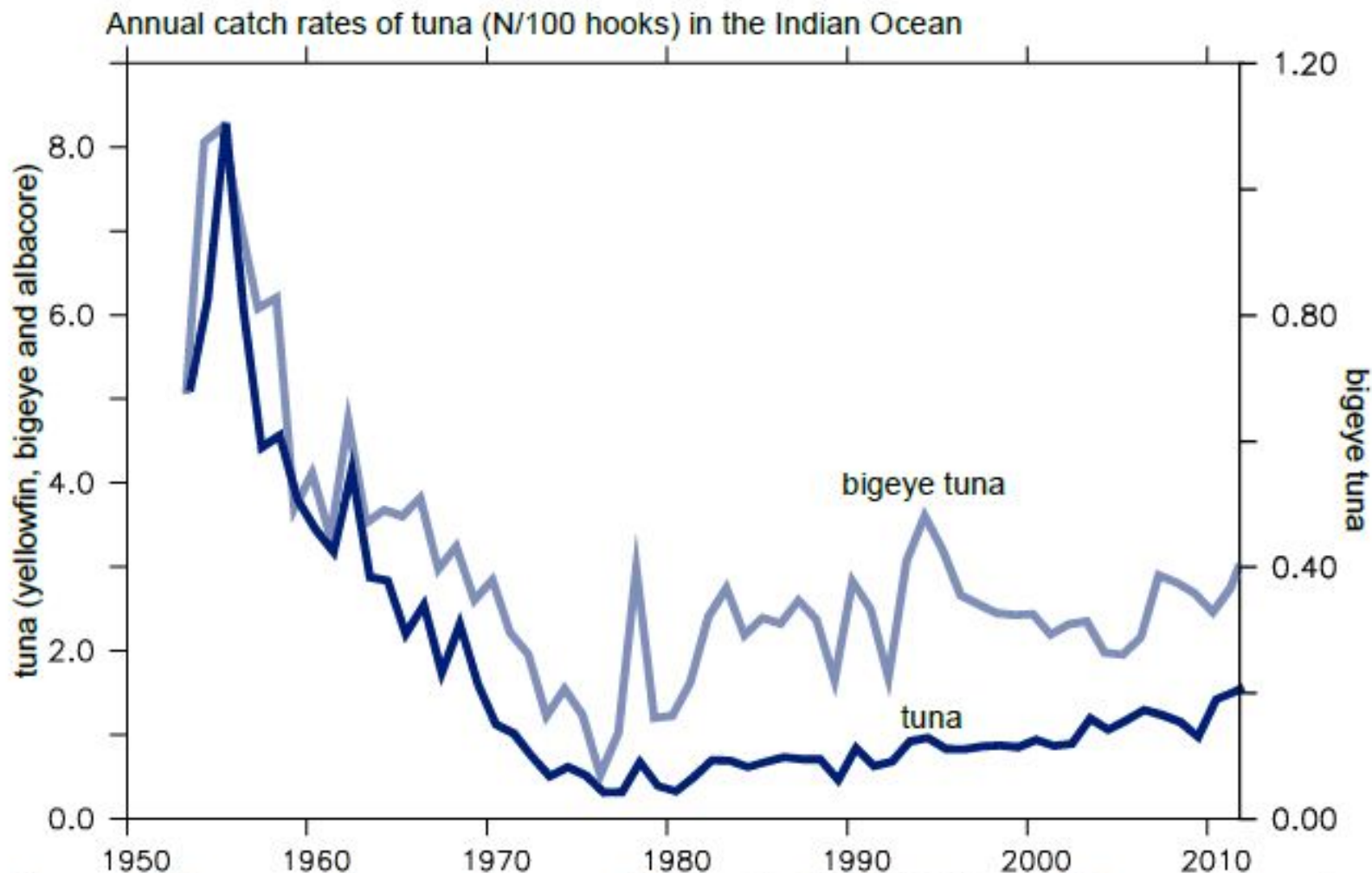


Figure 4: Tuna catch rates shows a decline by 50-90% during the past decades.



# Back Up Slides

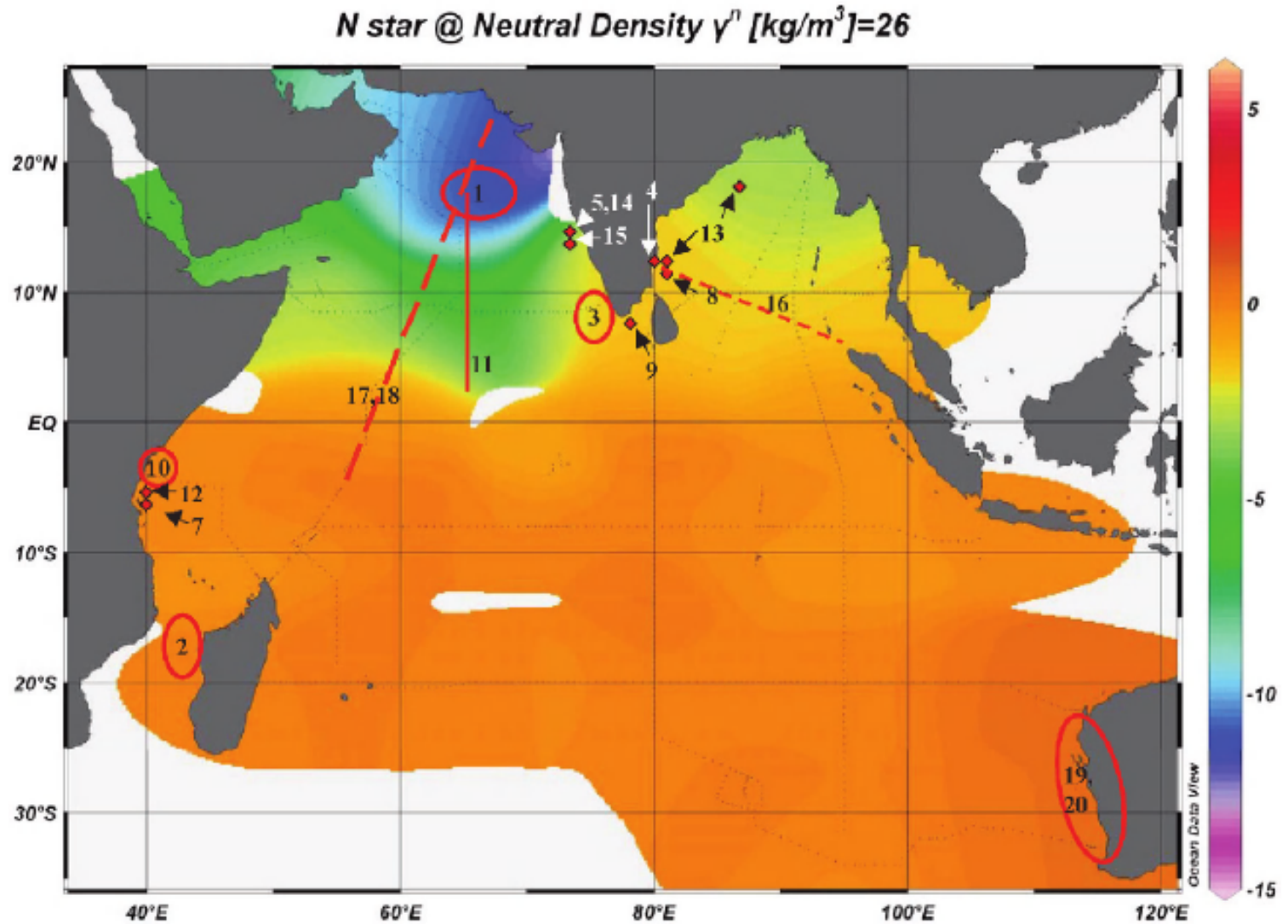
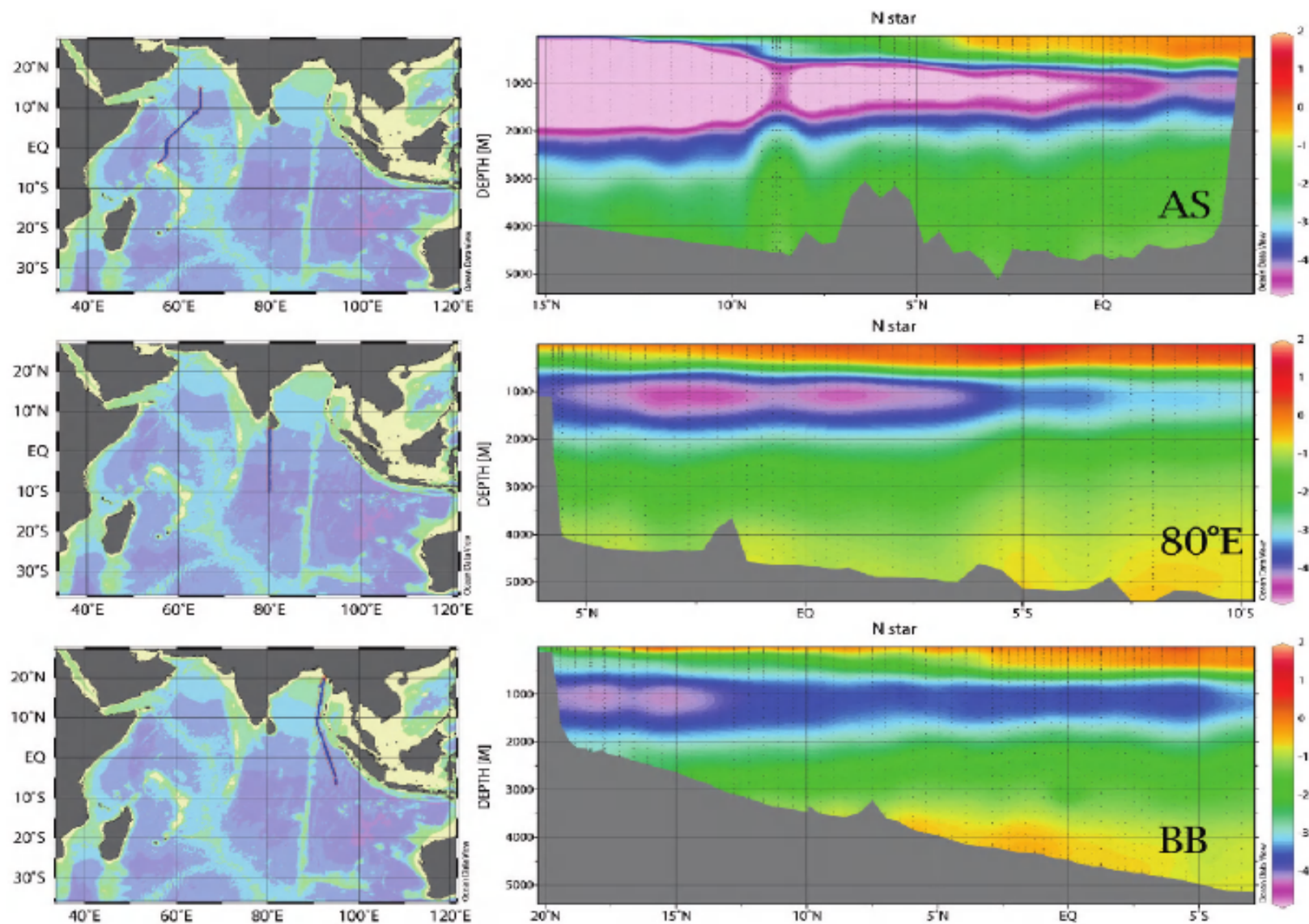


Plate 1. Distributions of  $N^*$  on the  $26 \text{ kg m}^{-3}$  neutral density surface with study locations indicated (see Table 1). Plotted using Ocean Data View (R. Schlitzer, 2008, available at <http://odv.awi.de/>) and WOCE Indian Ocean data.



**Plate 2.** Meridional plots of  $N^*$  ( $\mu\text{M}$ ) in the western IO including the Arabian Sea, the central IO along  $80^\circ\text{E}$  and south of India, and in the eastern IO including the Bay of Bengal (BB) (note the different latitudinal spans for the two basins). Plotted using Ocean Data View (R. Schlitzer, 2008, available at <http://odv.awi.de/>) and WOCE IO data.



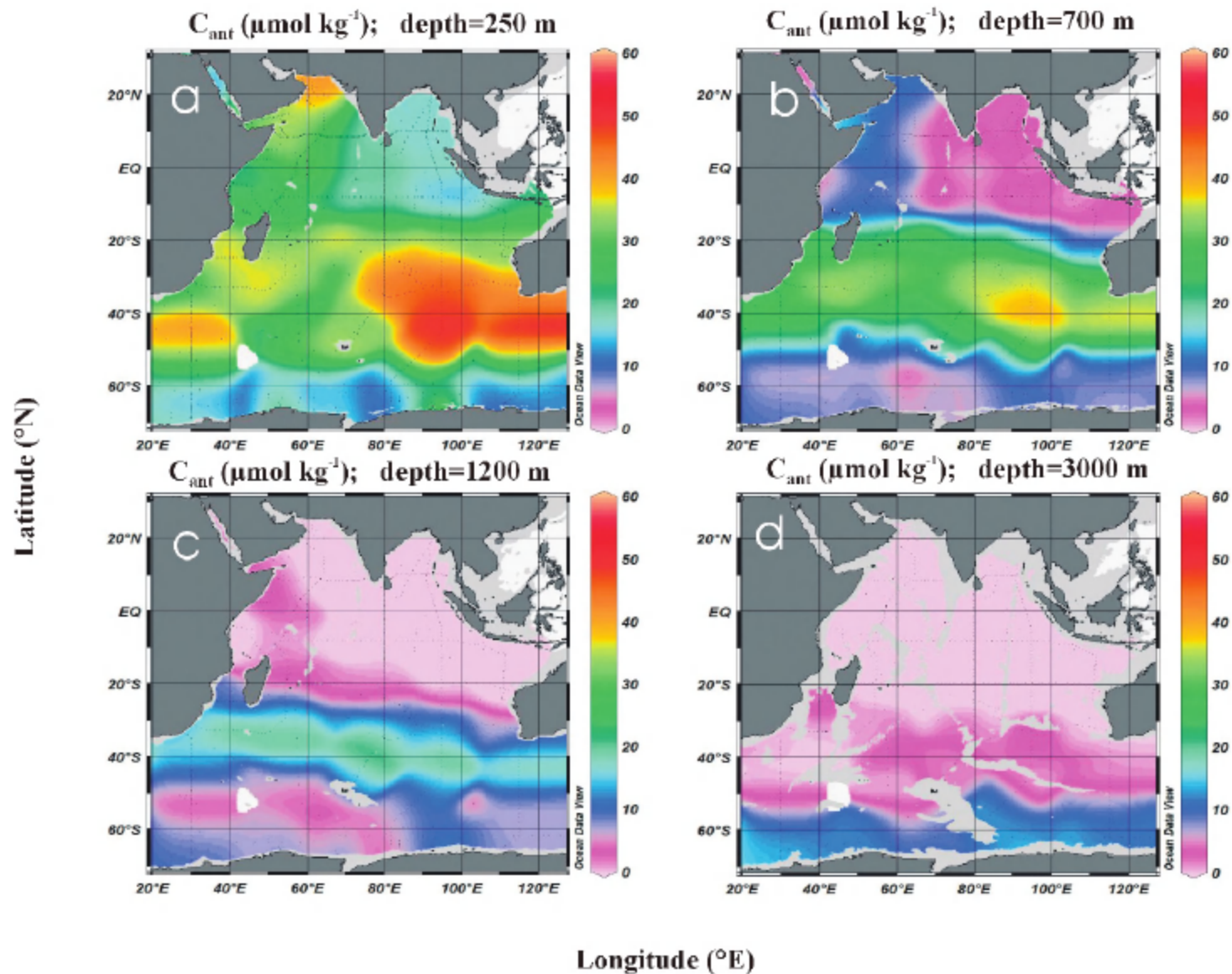
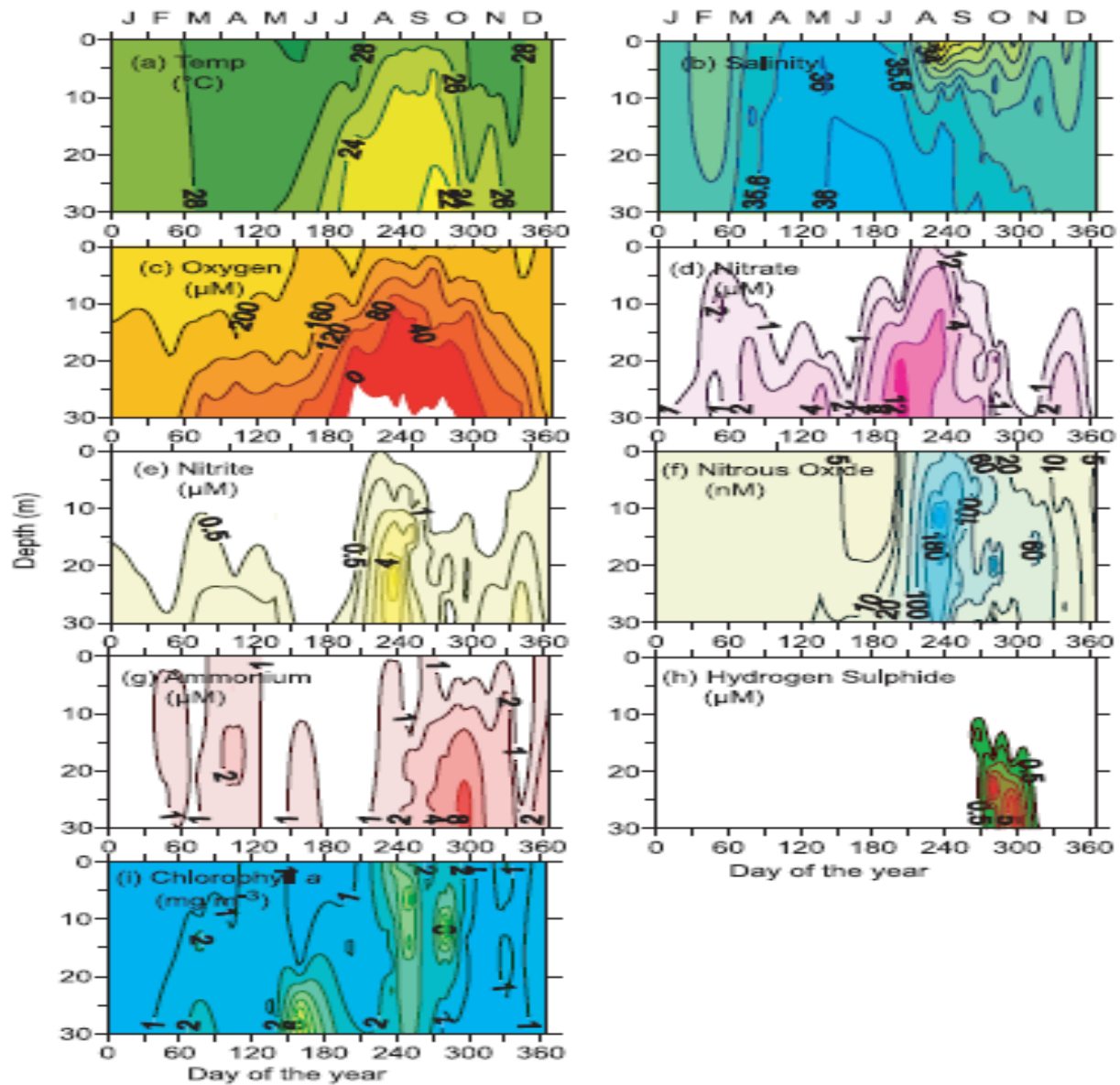


Plate 1. Anthropogenic CO<sub>2</sub> distribution in the Indian Ocean calculated by the TrOCA method at (a) 250, (b) 700, (c) 1200, and (d) 3000 m depth.



**Plate 2.** Monthly/fortnightly averaged records showing annual cycle of (a) temperature, (b) salinity, (c) oxygen, (d–g) inorganic nitrogen species, (h) hydrogen sulfide, and (i) chlorophyll *a* at the Candolim Time Series (CaTS) site (15°31'N, 73°39'E) based on observations from 1997 to 2006.