Advanced School on Earth System Modelling & Workshop on Climate Change and Regional Impacts over South Asia

1. **Modeling Ocean Biogeochemistry**
2. **IITM-ESM and biophysical feedbacks in the Indian Ocean**

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What is ocean biogeochemistry?

Biology – micro-scale
Chemistry – organic and inorganic
Geology – interactions with solid Earth
Physical interactions
  Air-sea exchange; Particle settling rates;
  Advection, diffusion, mixing

Why include biogeochemistry in ocean models?

Carbon Cycle

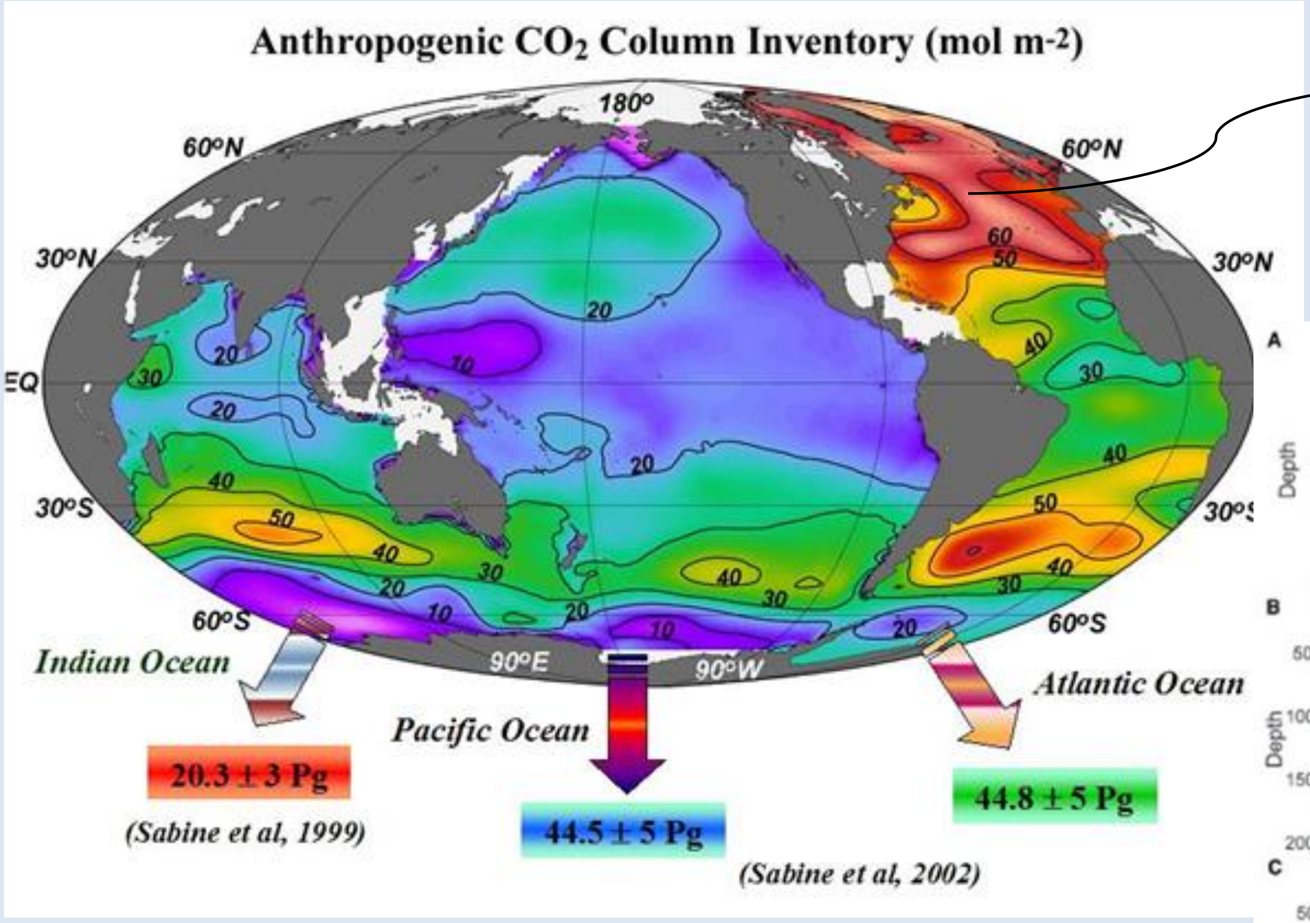
- Ocean carbon sink – past, present, future
- Glacial / interglacial change

Biophysical feedbacks

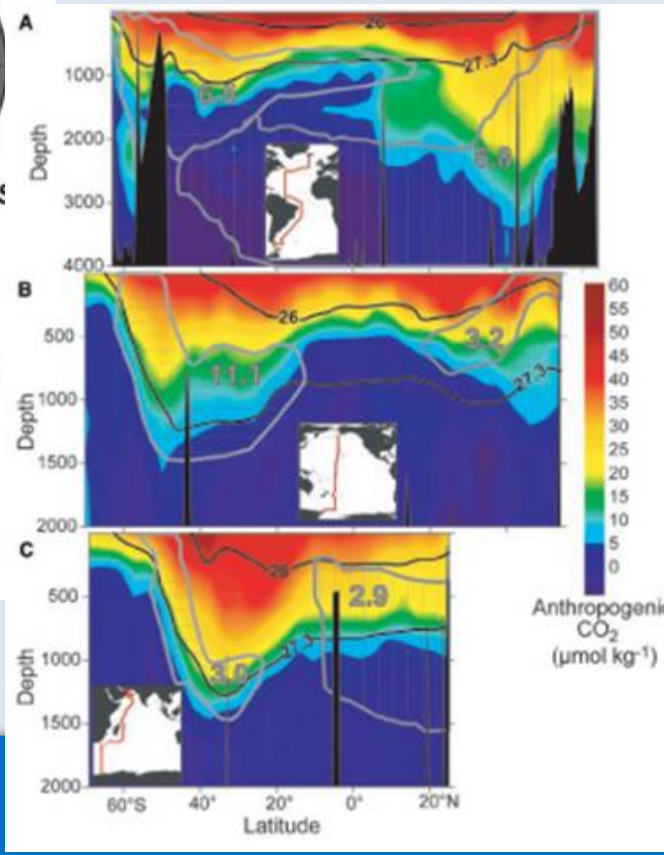
Trace gas emissions – Atmospheric chemistry

- e.g. Dimethyl Sulfide (DMS): CCN, emitted by phytoplankton, theorized climate feedbacks

Why include biogeochemistry in ocean models?



largest intake

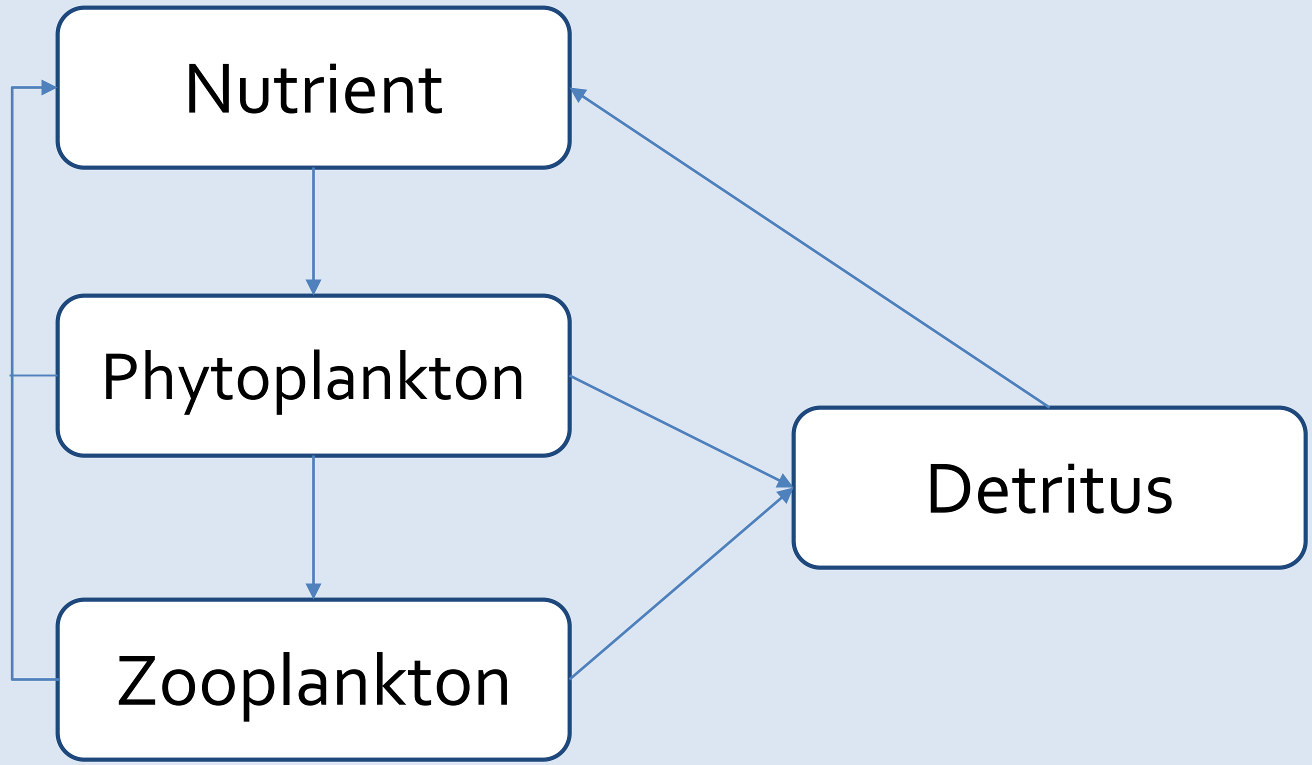


The ocean has absorbed about 50% of anthropogenic CO_2 emitted in last 200 yrs

Sabine et al., 2004

Simple ecosystem model for the lower trophic levels

NPZD model



Ecosystem complexity

There are ~20,000 of identified species of phytoplankton in 4 major groups

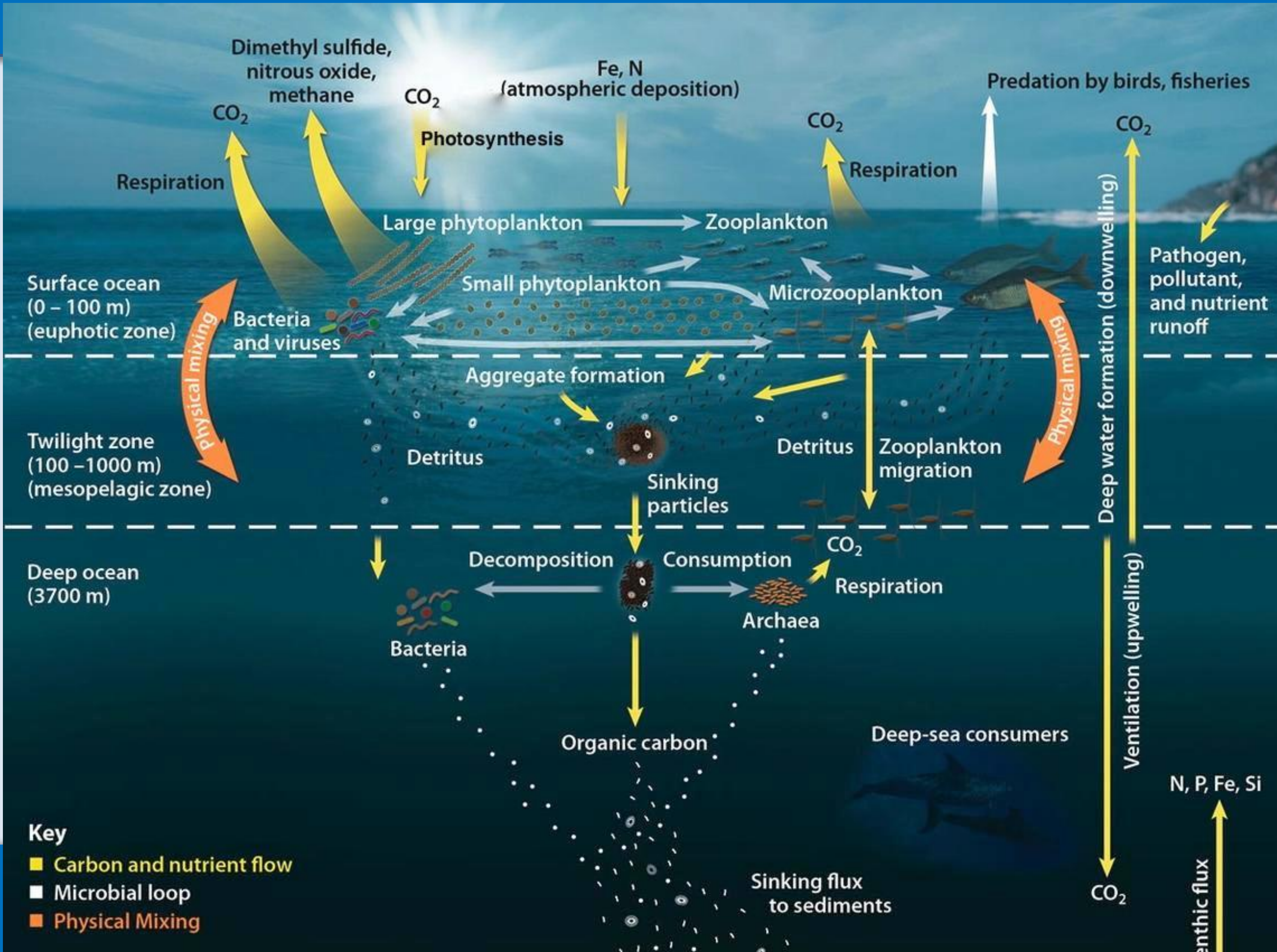
- Picoplankton
- Diatoms (silicate shells)
- Coccolithophorids (carbonate shells)
- Dinoflagellites

Zooplankton – also great variety

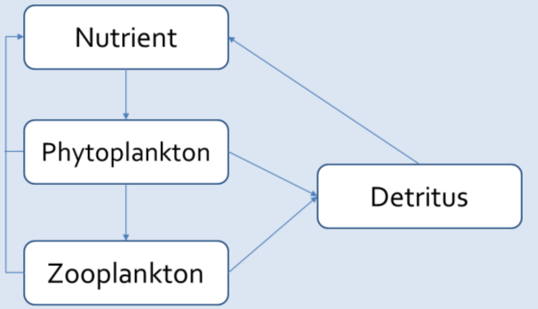
Much variability in key aspects

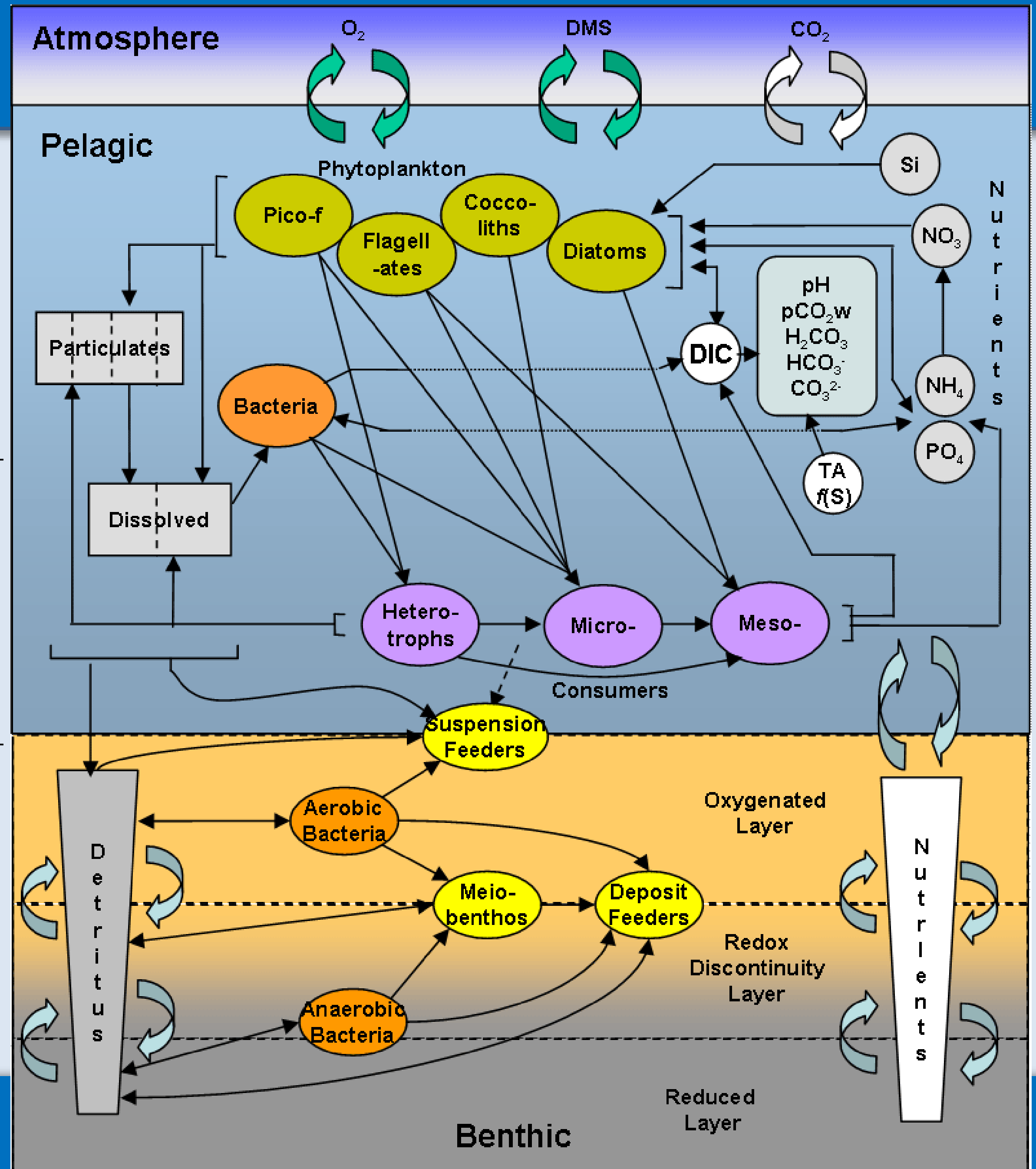
- Carbon to Nutrient, Carbon to Chlorophyll ratios
- Sinking velocities
- Growth rates, mortality rates, etc.

Biological Pump



Ecosystem model





Baretta et al, 1995

Ecosystem model

$$\frac{\partial Chl}{\partial t} = (\mu - L) * Chl - (s - w)\frac{\partial Chl}{\partial z} + \frac{\partial\left[K(\partial Chl / \partial z)\right]}{\partial z} \qquad (1)$$

$$\frac{\partial PON}{\partial t} = v * Chl - (s - w)\frac{\partial PON}{\partial z} + \frac{\partial\left[K(\partial PON / \partial z)\right]}{\partial z} - L * PON \qquad (2)$$

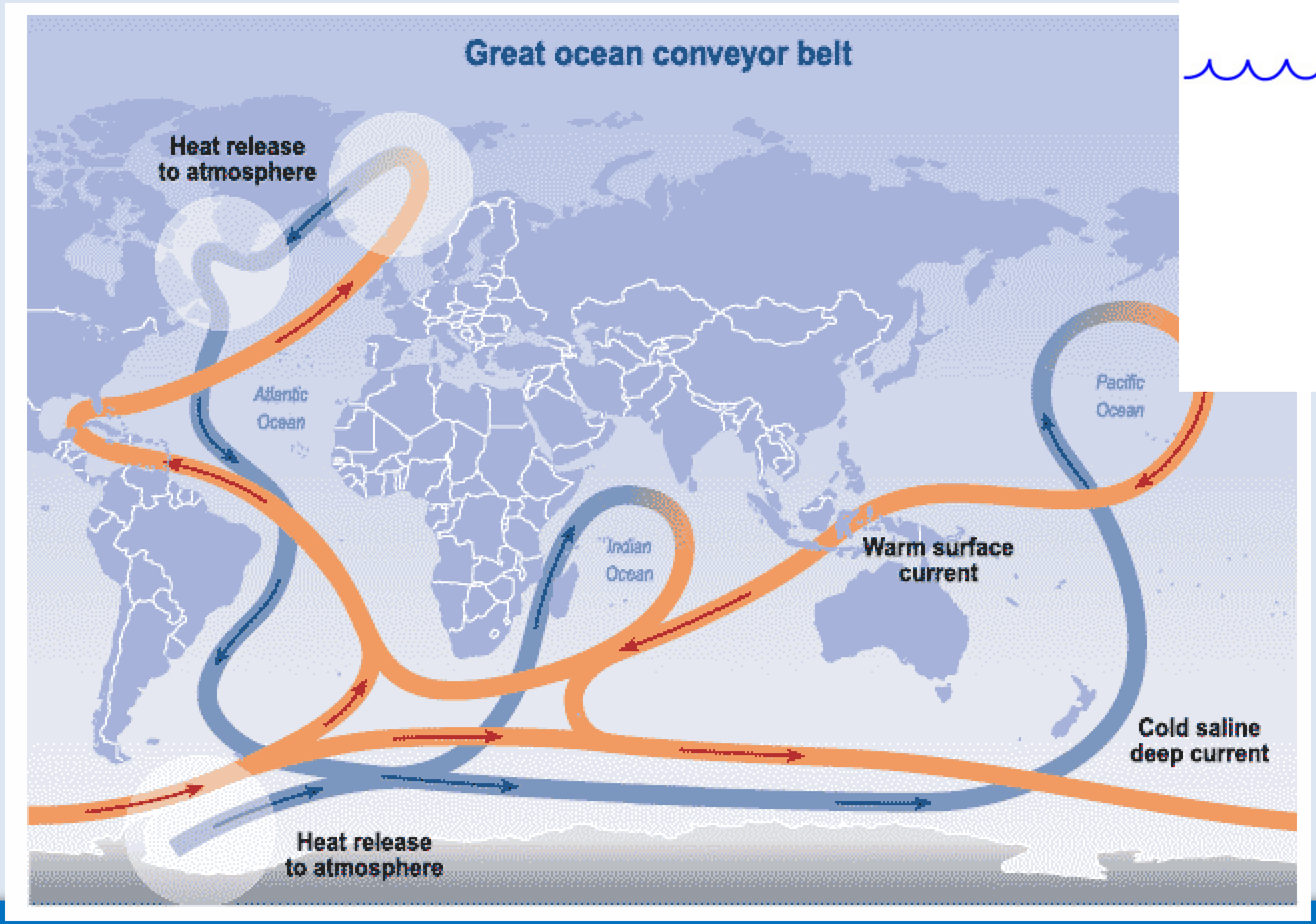
$$\frac{\partial N}{\partial t} = -v * Chl + w\frac{\partial N}{\partial z} + \frac{\partial\left[K(\partial N / \partial z)\right]}{\partial z} + r * L * PON \qquad (3)$$

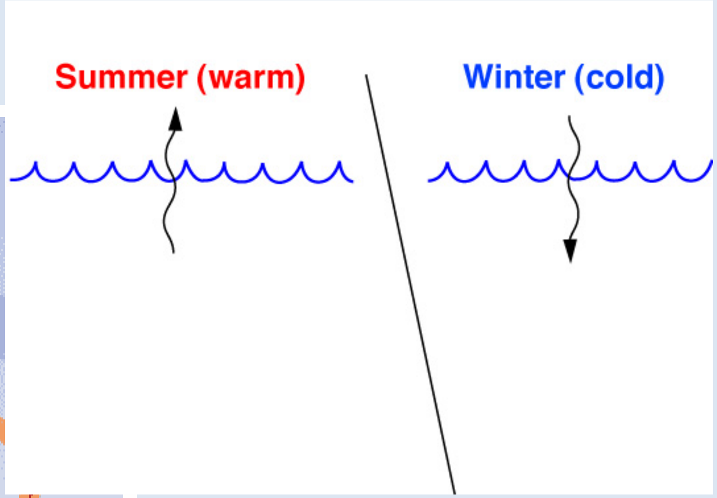
where

μ: specific growth rate, a function of the internal nutrient concentration and PAR
L : specific loss rate
s: phytoplankton sinking rate
w: upwelling velocity
K: turbulent vertical eddy-diffusion coefficient
v: specific uptake-rate
r: recycling efficiency

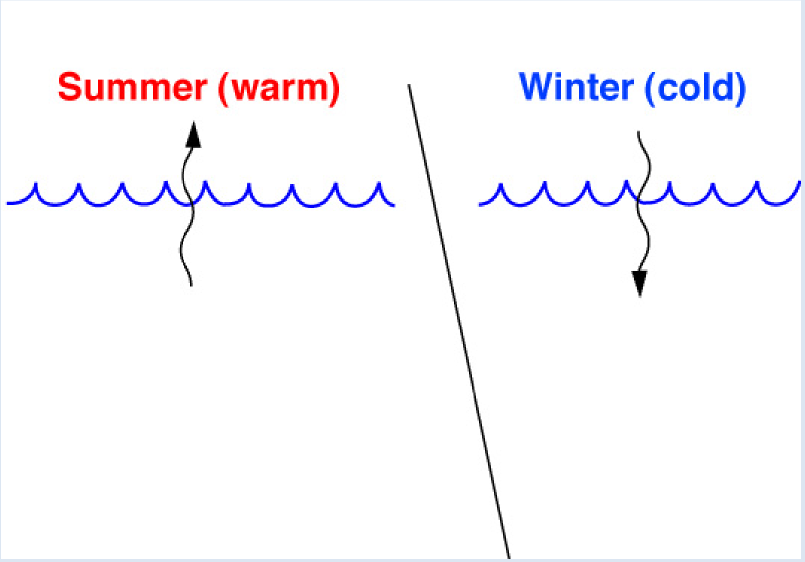
Solubility pump: dissolved, inorganic carbon

1. thermohaline circulation
2. solubility = inverse function of seawater temperature

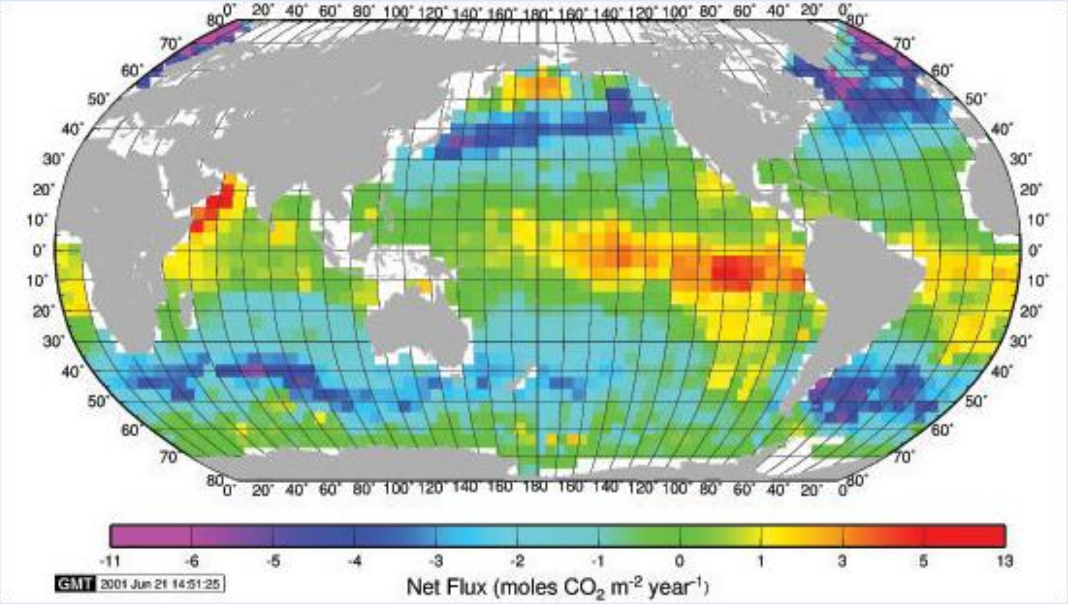




Temperature influence on Carbon fluxes

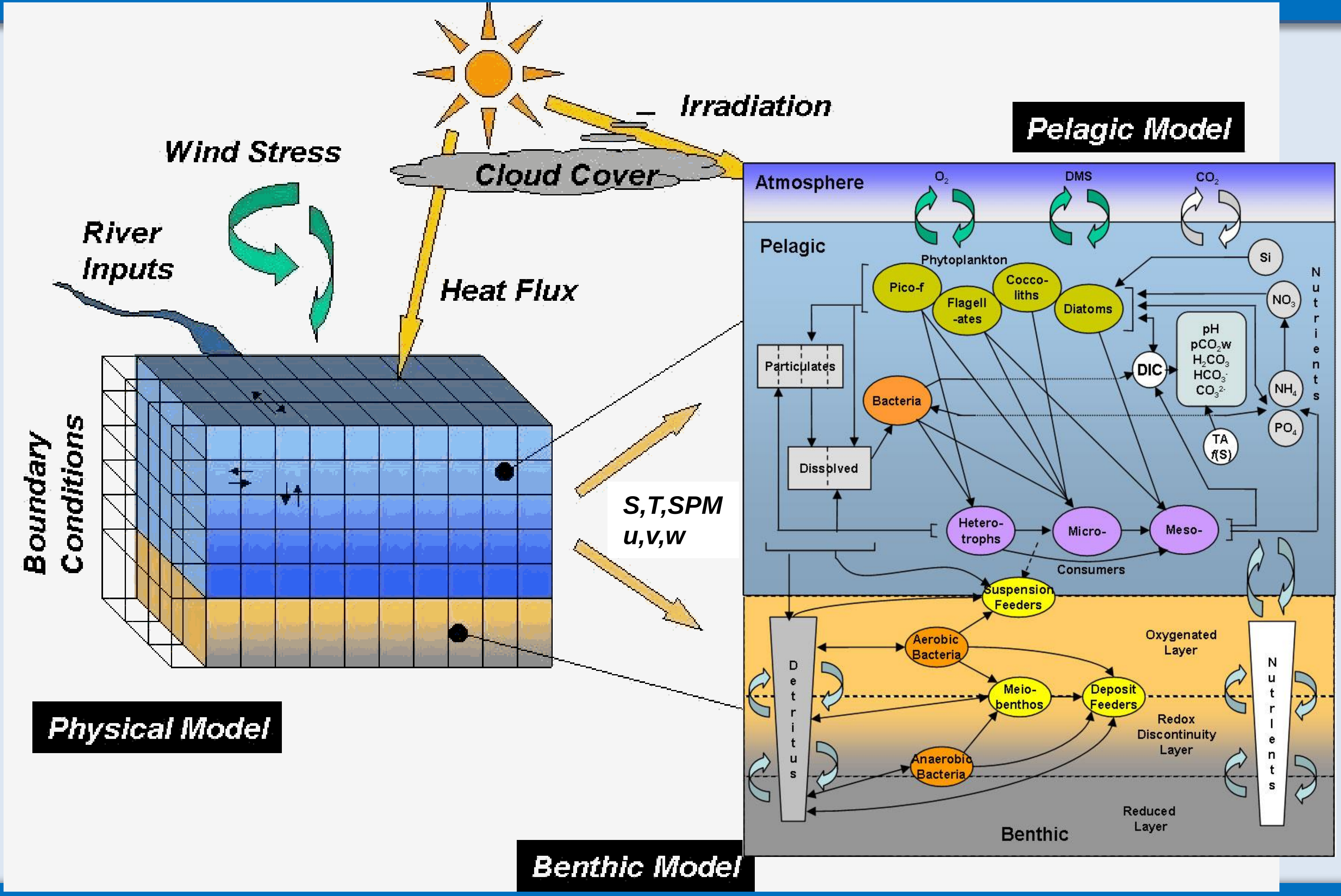


Mean sea–air CO_2 flux



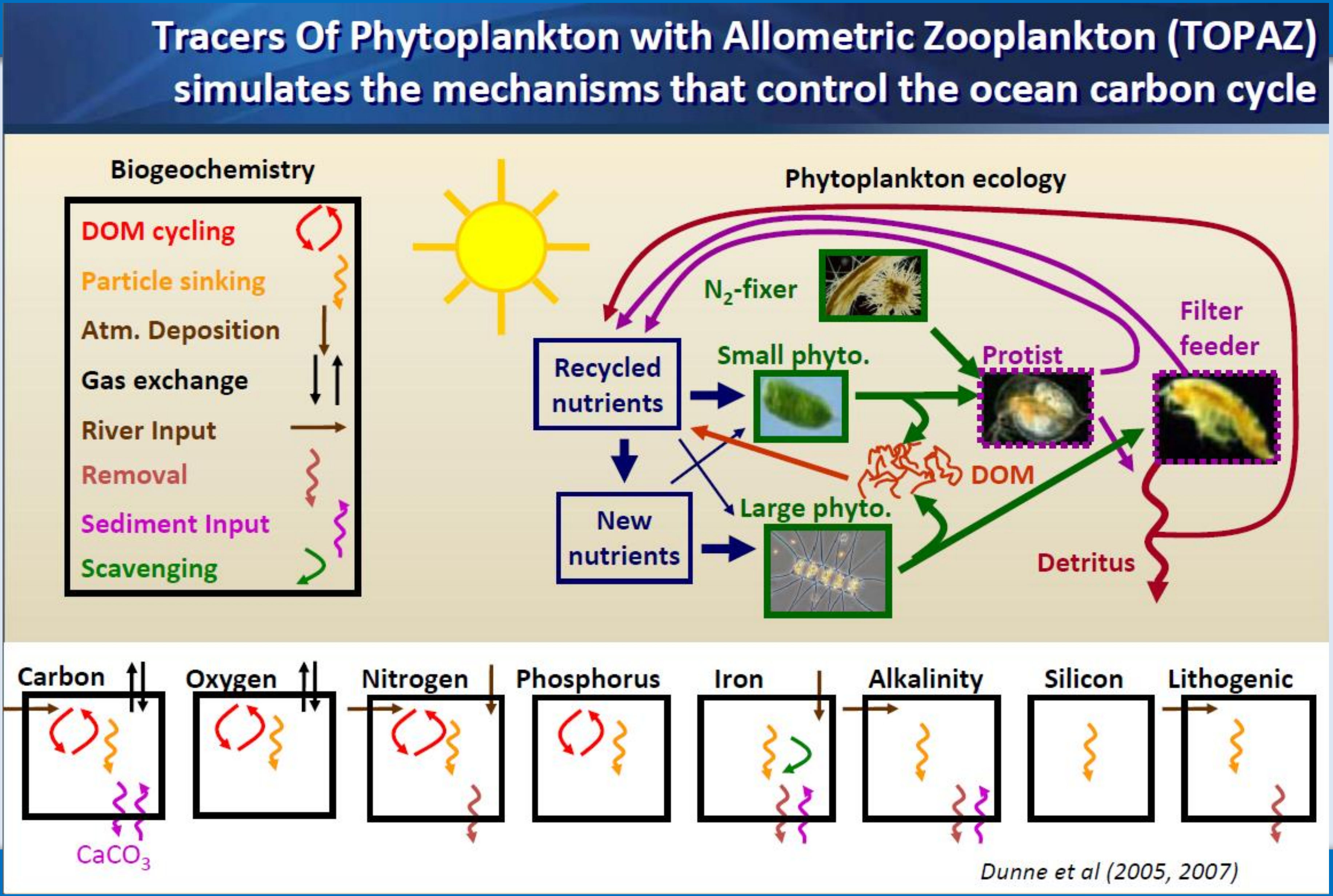
Sabine et al., 2004

Conceptual coupled Physical-Ecosystem model



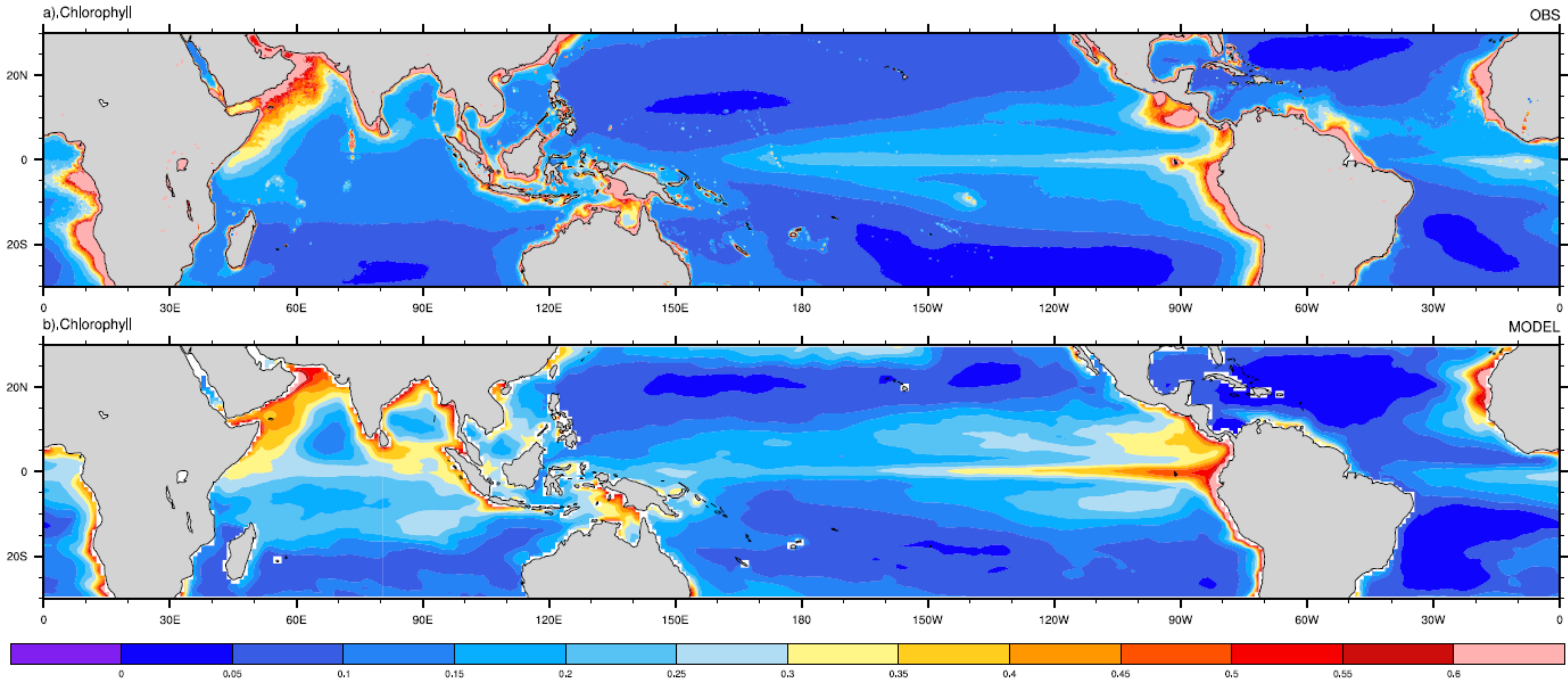
Baretta et al, 1995

TOPAZ in IITM-ESM

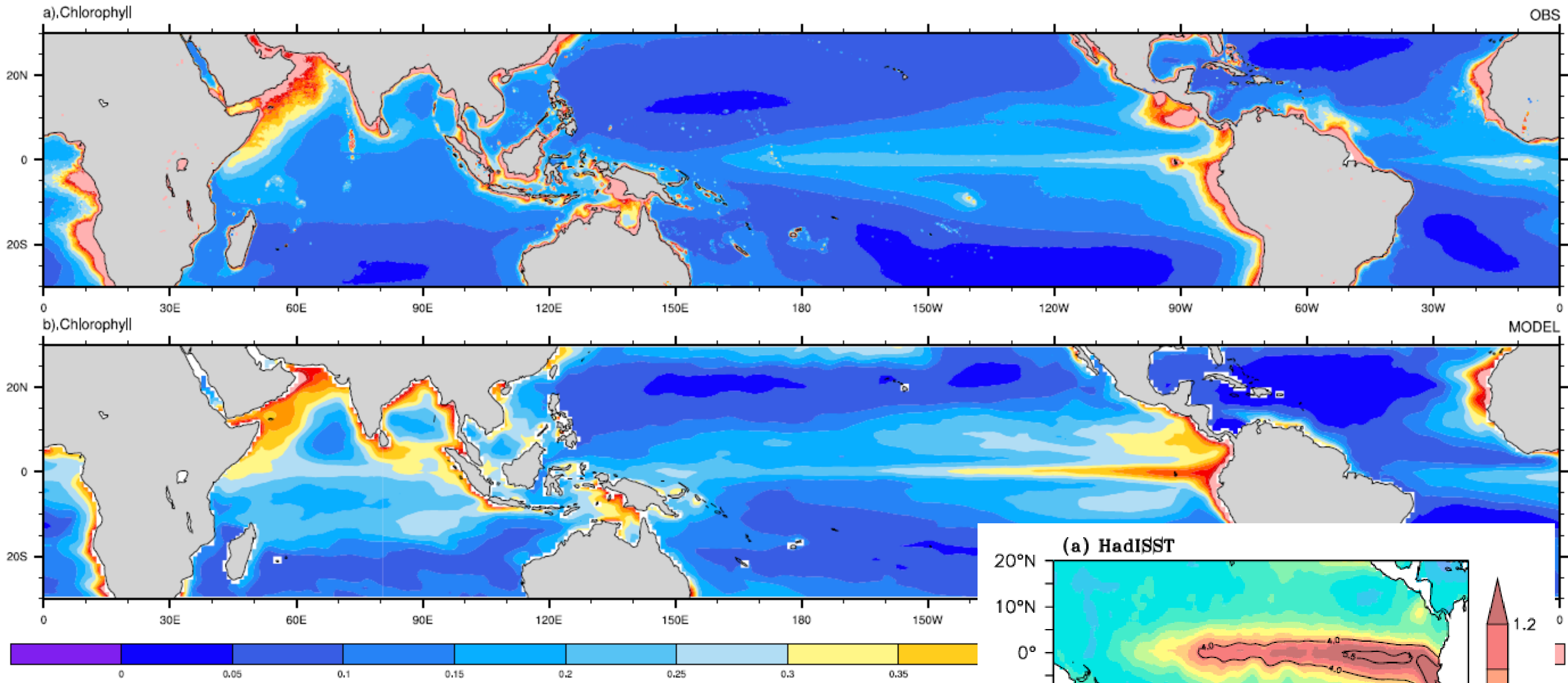


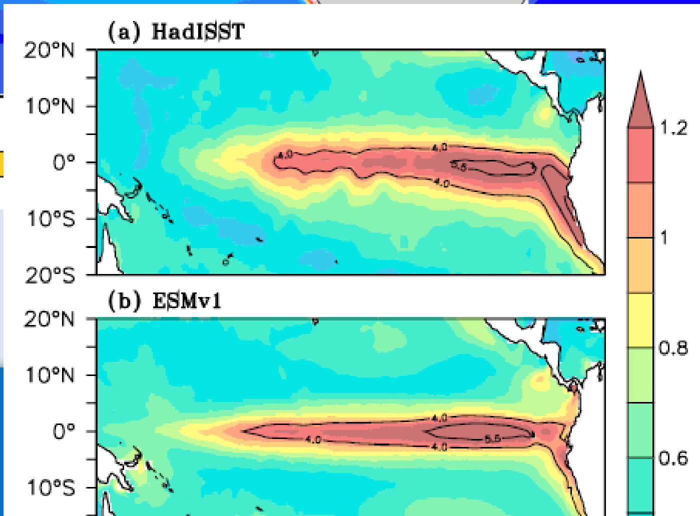
Dunne et al., 2005, 2007

TOPAZ in IITM-ESM
Summer Chlorophyll simulations

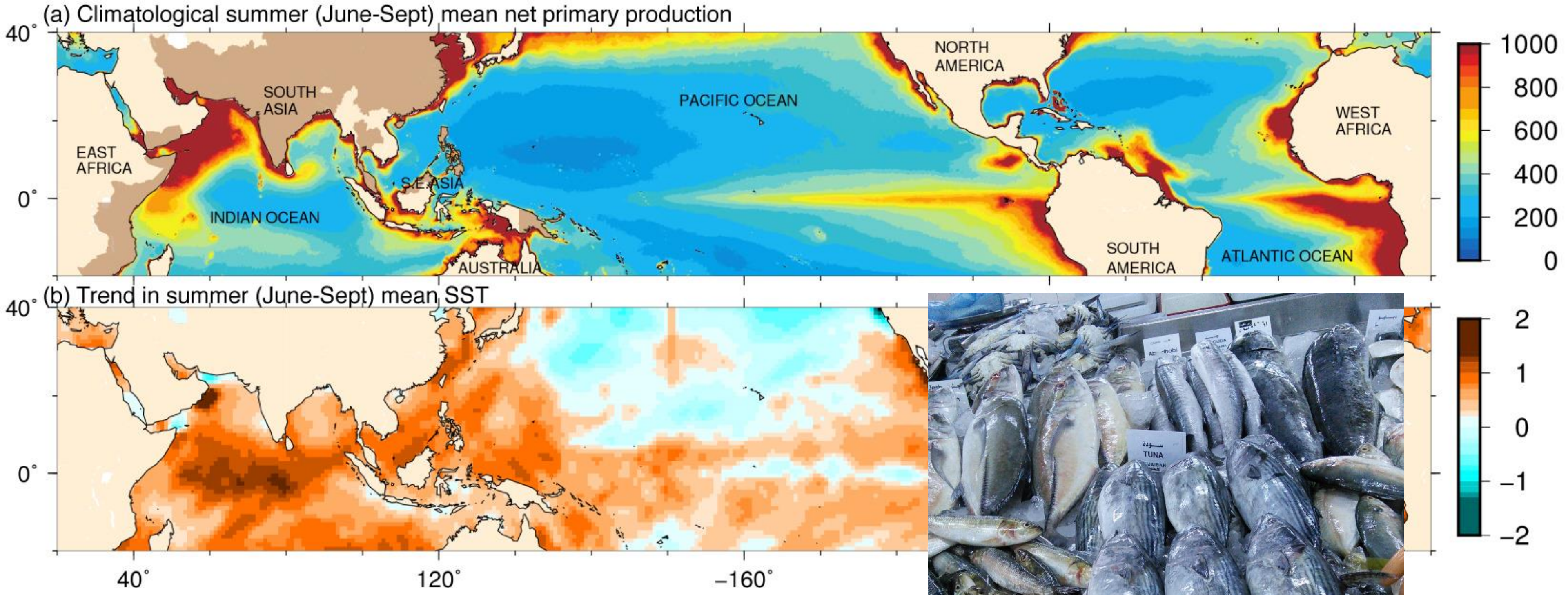


TOPAZ in IITM-ESM
Biophysical feedbacks important





Warming – Marine Primary Production
western Indian Ocean is a highly productive region…



Tuna

Roxy et al. *GRL*, 2016

Warming – Marine Primary Production
Earlier studies suggest an increase in WIO NPP

Studies have suggested an decrease in chlorophyll and marine primary production in the tropical oceans, due to rising SSTs.

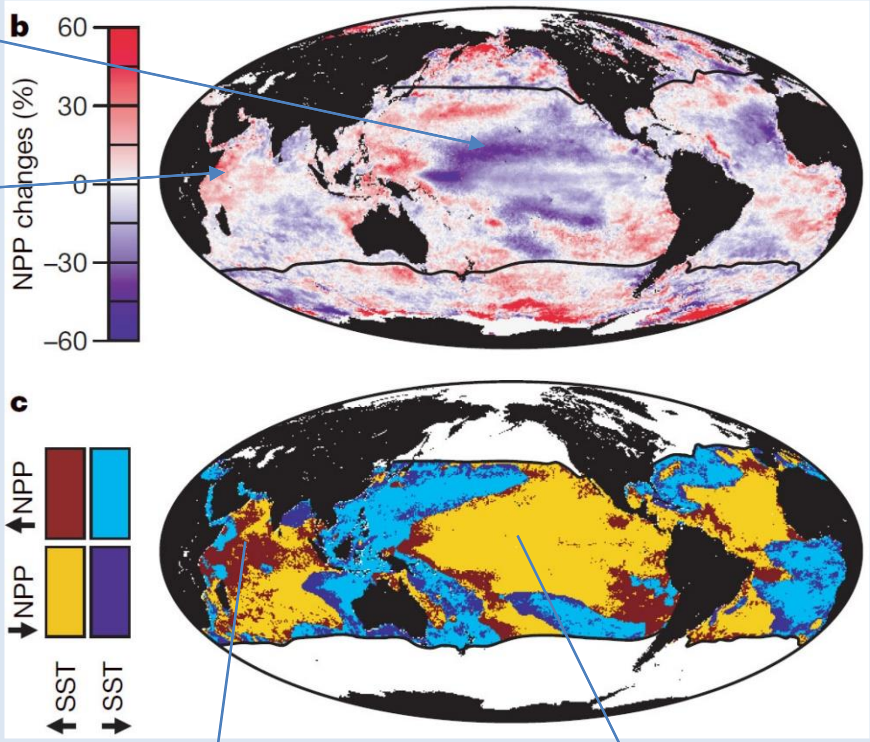
However, the chlorophyll changes in the WIO suggested an increasing trend.

Goes et al. 2005: Increase of more than 350% in summer plankton biomass in the WIO, driven by strengthening monsoon winds (1997–2004).

Gregg et al. 2005: Second largest increase (37%) in Chl among the open oceans, in WIO (1998–2003).

50–60 years of data is required to detect a trend above the natural variability. For tropical regions (WIO) it can be shorter (20—30 years) (Henson et al. 2010, Beaulieu et al. 2013)

Behrenfeld et al. *Nature*, 2006



Red: NPP increase with SST increase

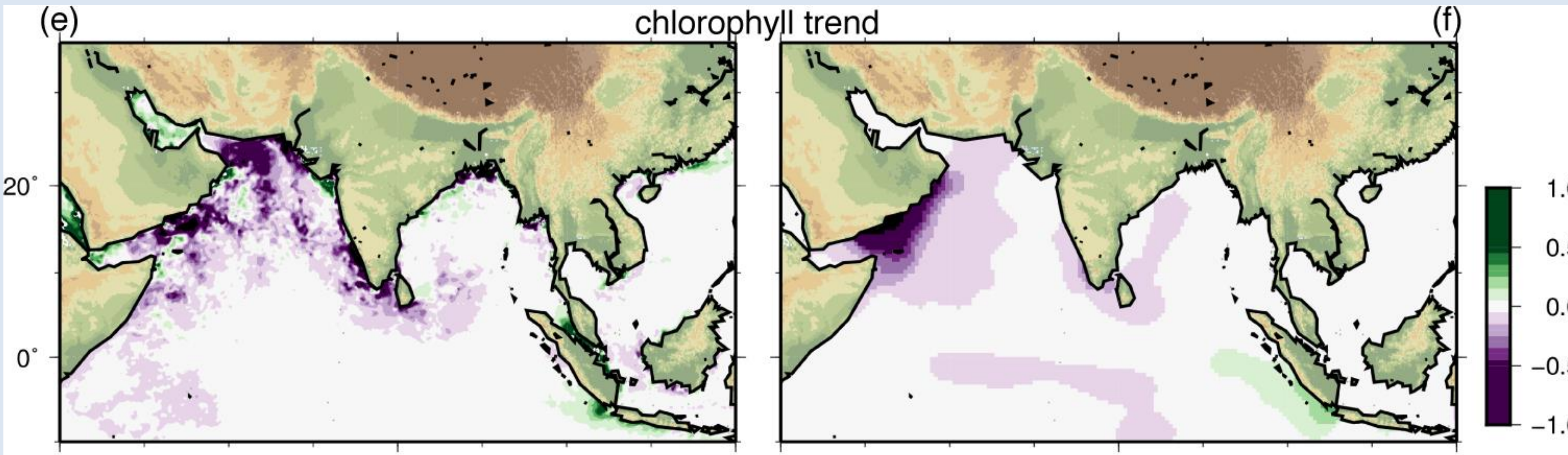
Yellow: NPP decrease with SST increase

Goes et al. *Science*, 2005; Gregg and Rousseaux, *JGR*, 2005
Behrenfeld et al. *Nature*, 2006

Reduction in Marine Primary Production
Chlorophyll trends in observations and simulations

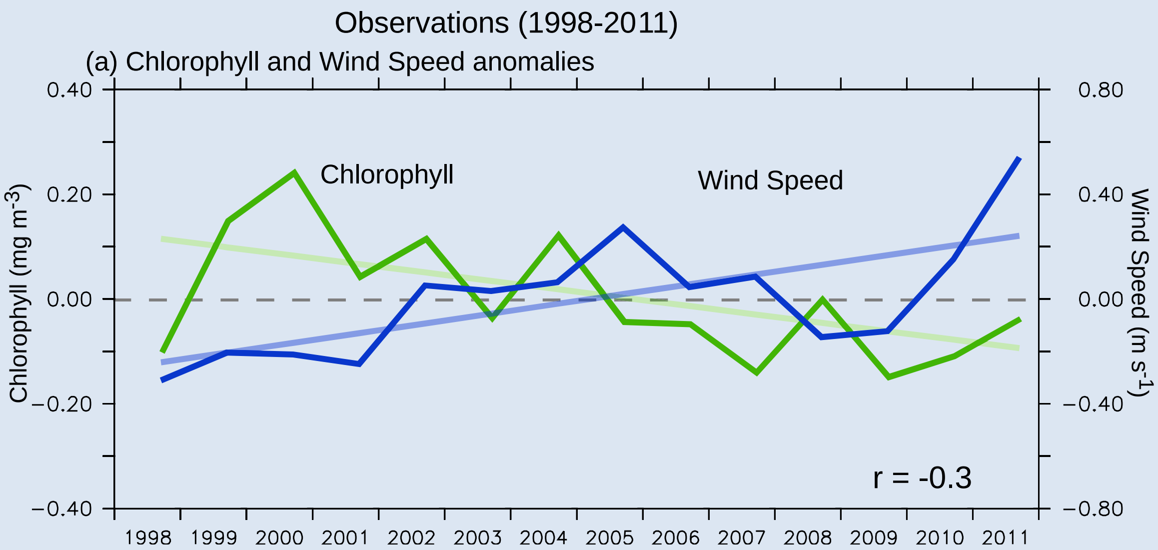
Observations: Merged Satellite
(SeaWiFS, MODIS, and MERIS)
1998 - present (~ 17 years)

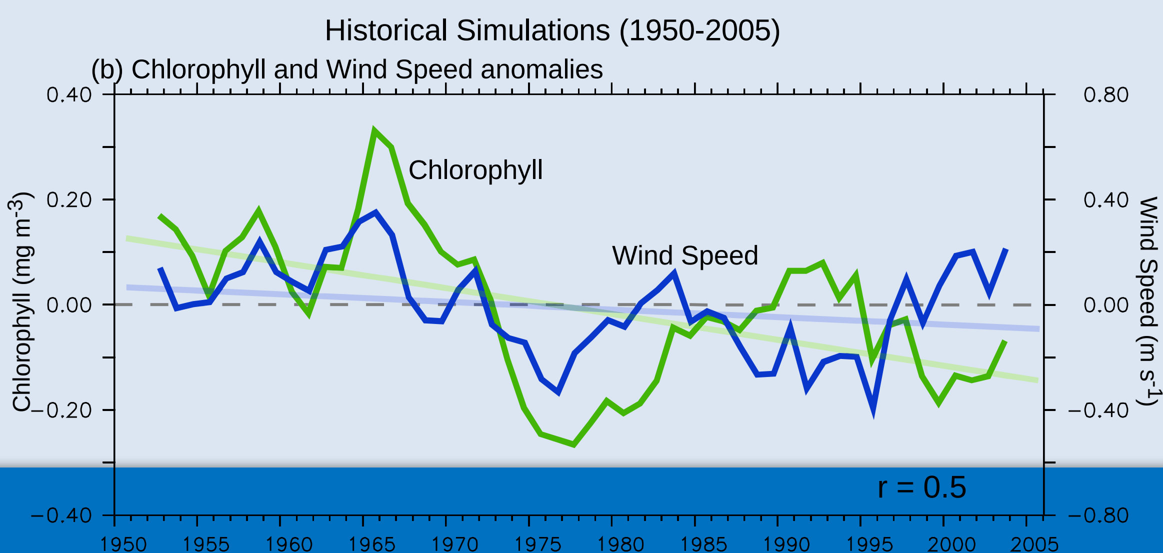
Historical Simulations:
(Best of CMIP5: MPI-ESM-MR)
1950–2005 (56 years)



20–30% reduction in marine primary productivity over the western Indian Ocean

Long-term changes in winds over WIO are minor - Minimal role on the chlorophyll trends



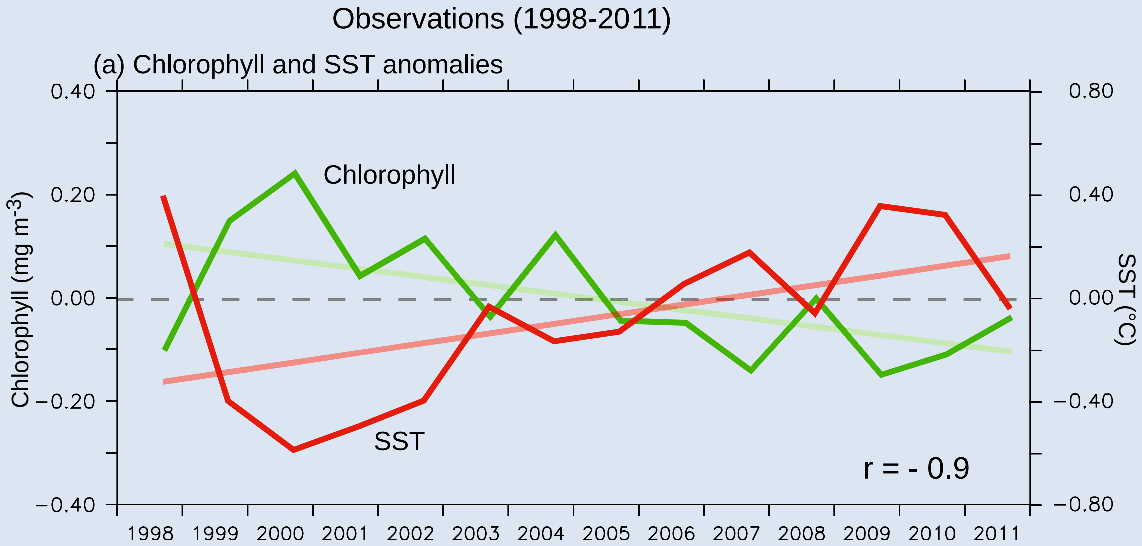


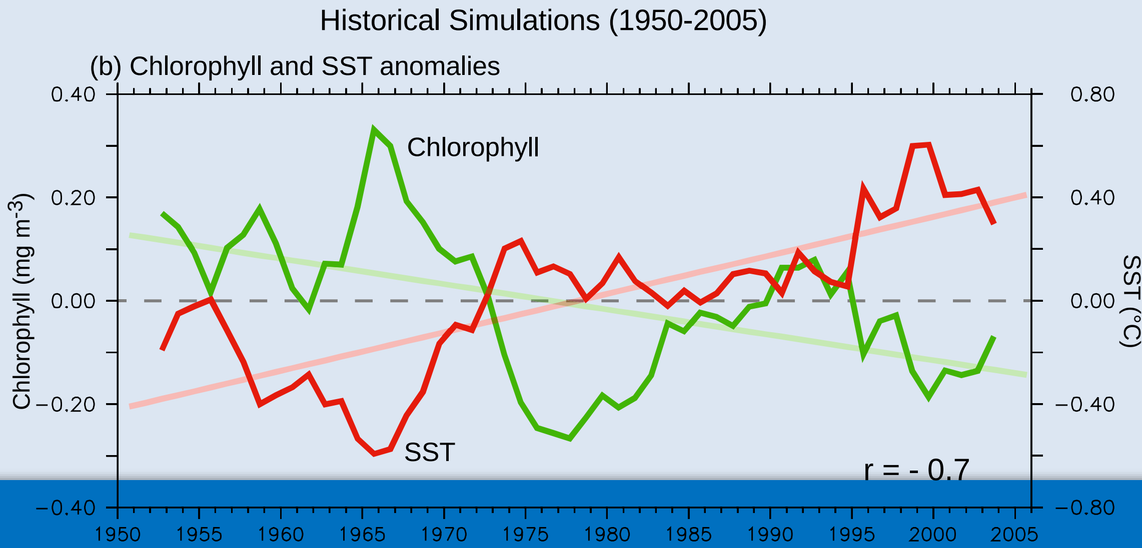
Wind speed anomalies over the western Indian Ocean indicate an increase in wind speed in the recent two decades

However, the long−term changes over the same region is only about 0.2 m s^{-1} − changes which are minor compared to an SST trend of 0.6C during the same period.

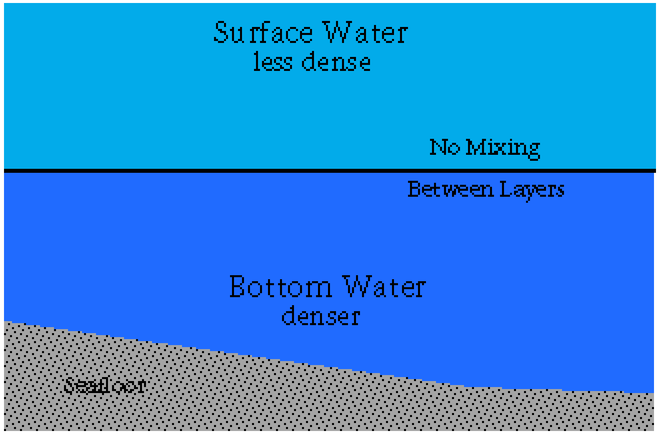
Correlation indicates a a minimal role of the changing winds

Warming stratifies the ocean - and suppresses the mixing of nutrients from the subsurface, reducing chlorophyll





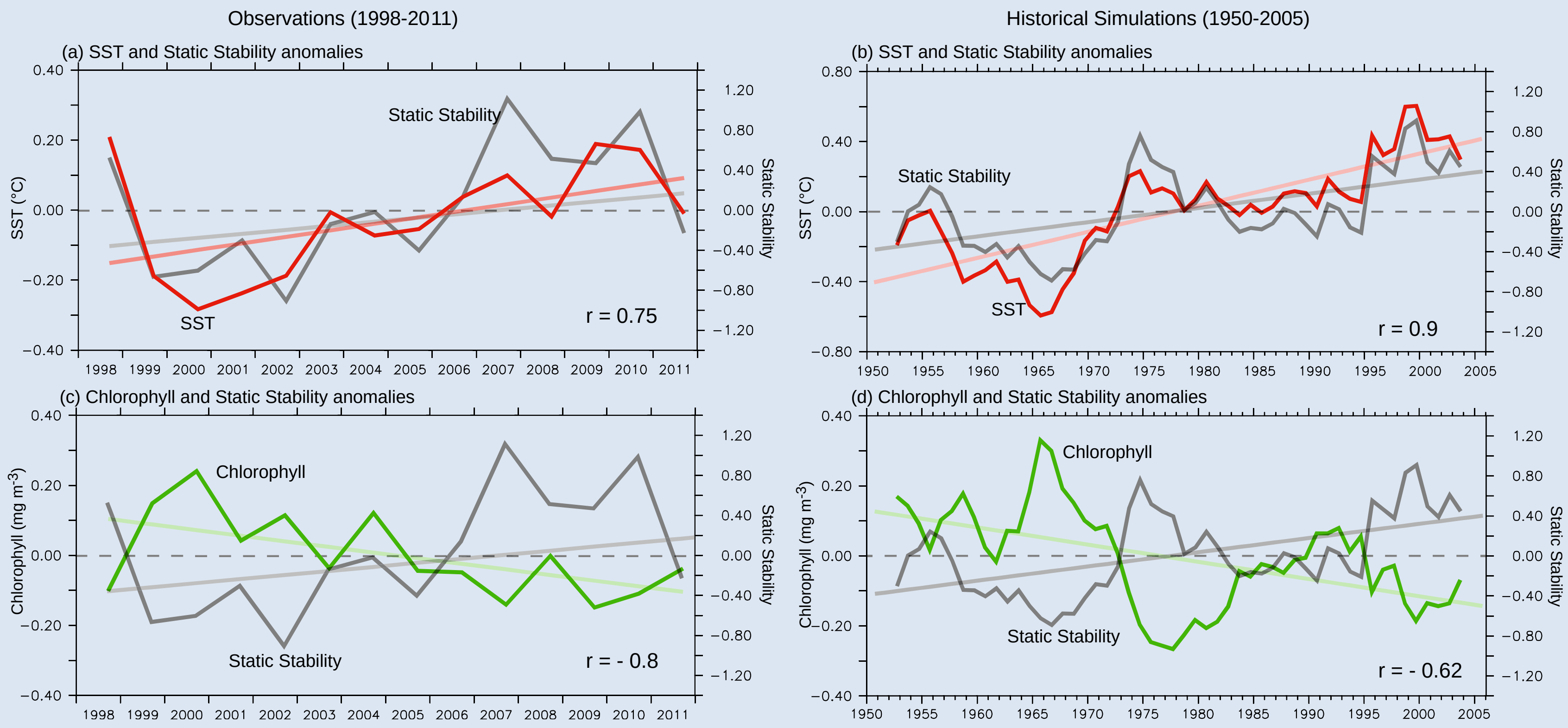
stratification



Stratification - No mixing between water layers

Warming stratifies the ocean - and suppresses the mixing of nutrients from the subsurface, reducing chlorophyll

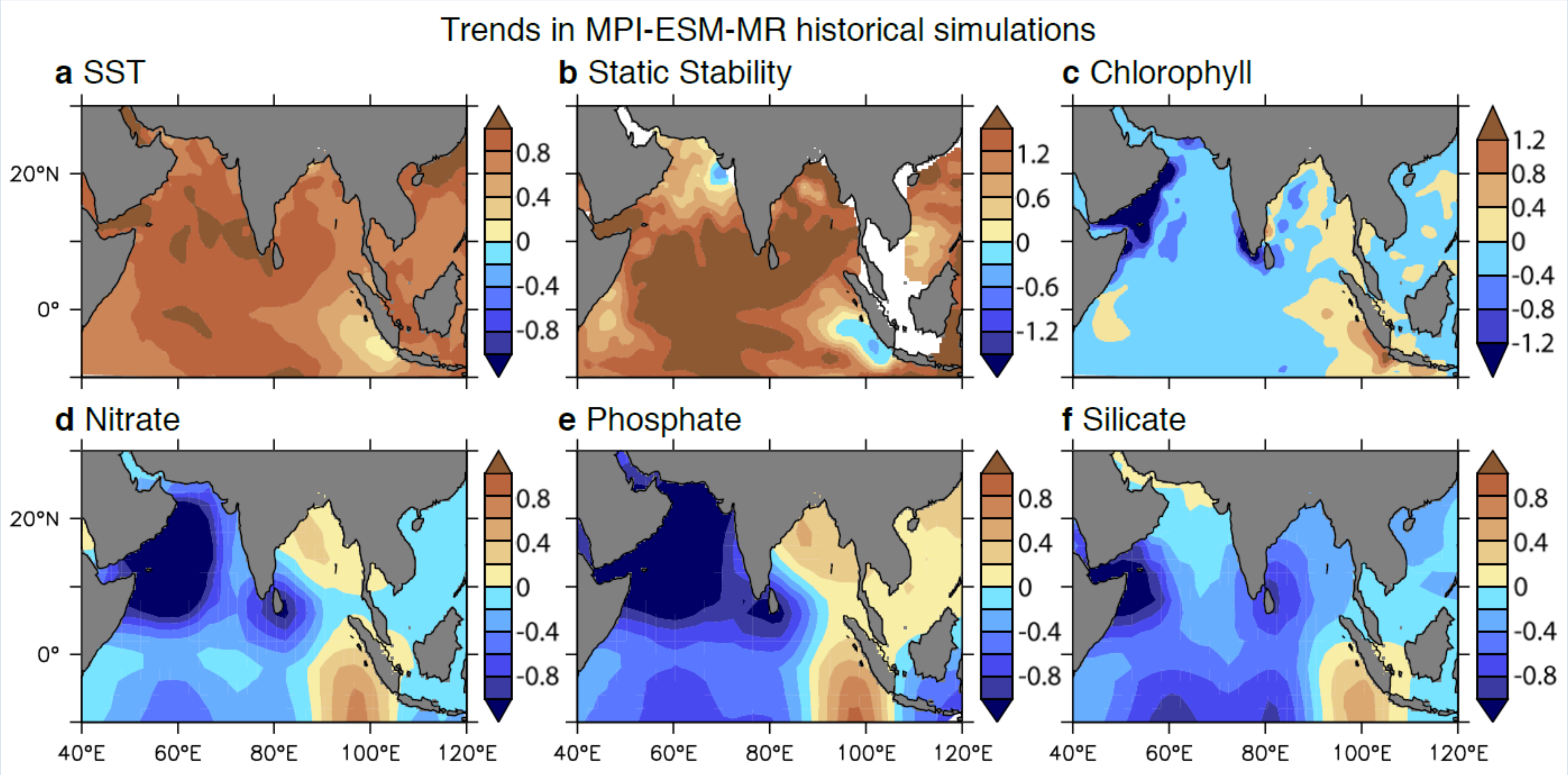
Enhanced stratification due to increasing SST



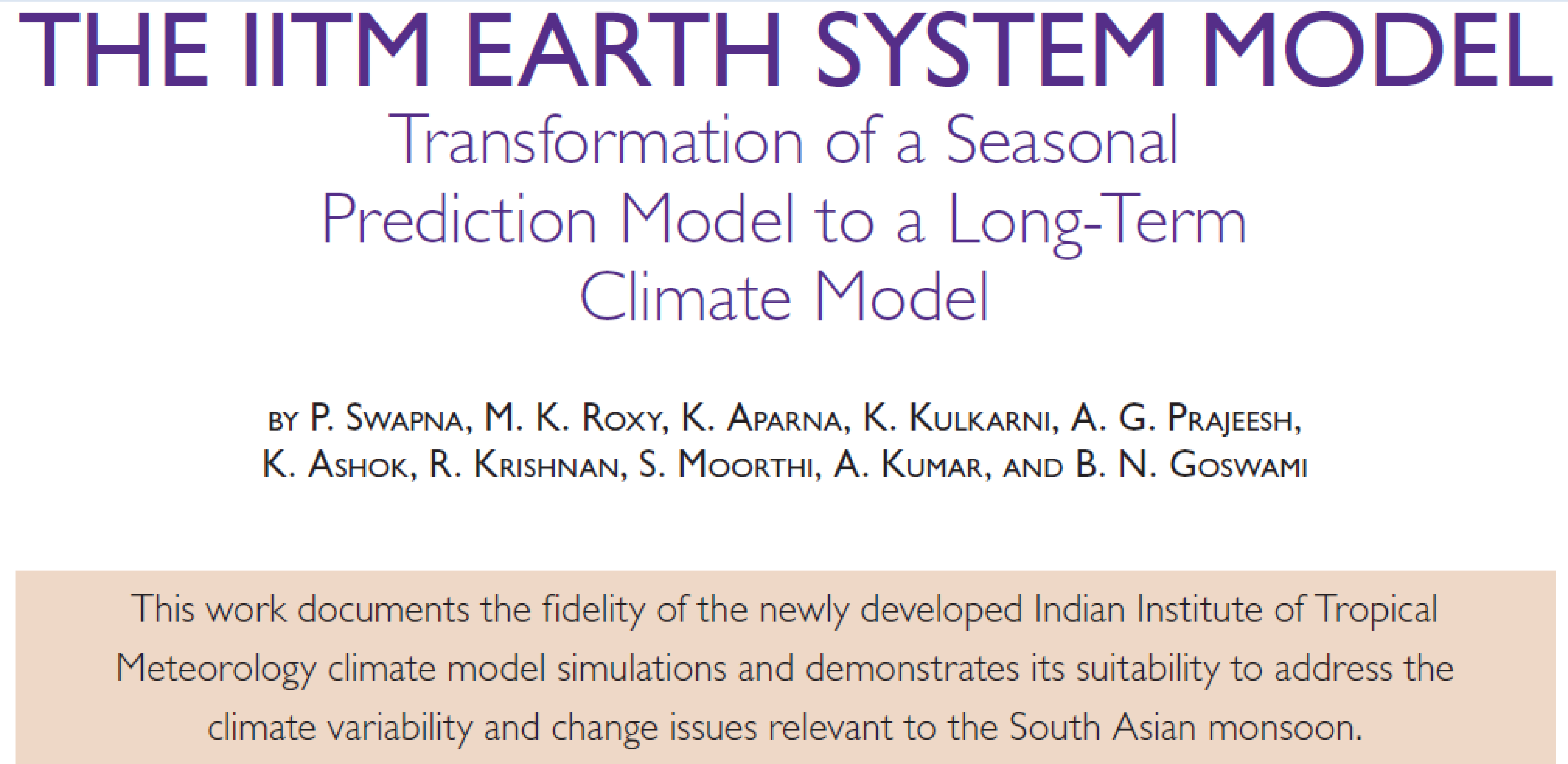
Stratification highly correlated to the reduction in Chlorophyll

Warming stratifies the ocean - and suppresses the mixing of nutrients from the subsurface, reducing chlorophyll

Nitrate, Silicate and Phosphate shows significant reduction over the same region where chlorophyll trend is negative



Earth System Model for South Asia for Future Climate Projections



THE IITM EARTH SYSTEM MODEL
Transformation of a Seasonal Prediction Model to a Long-Term Climate Model

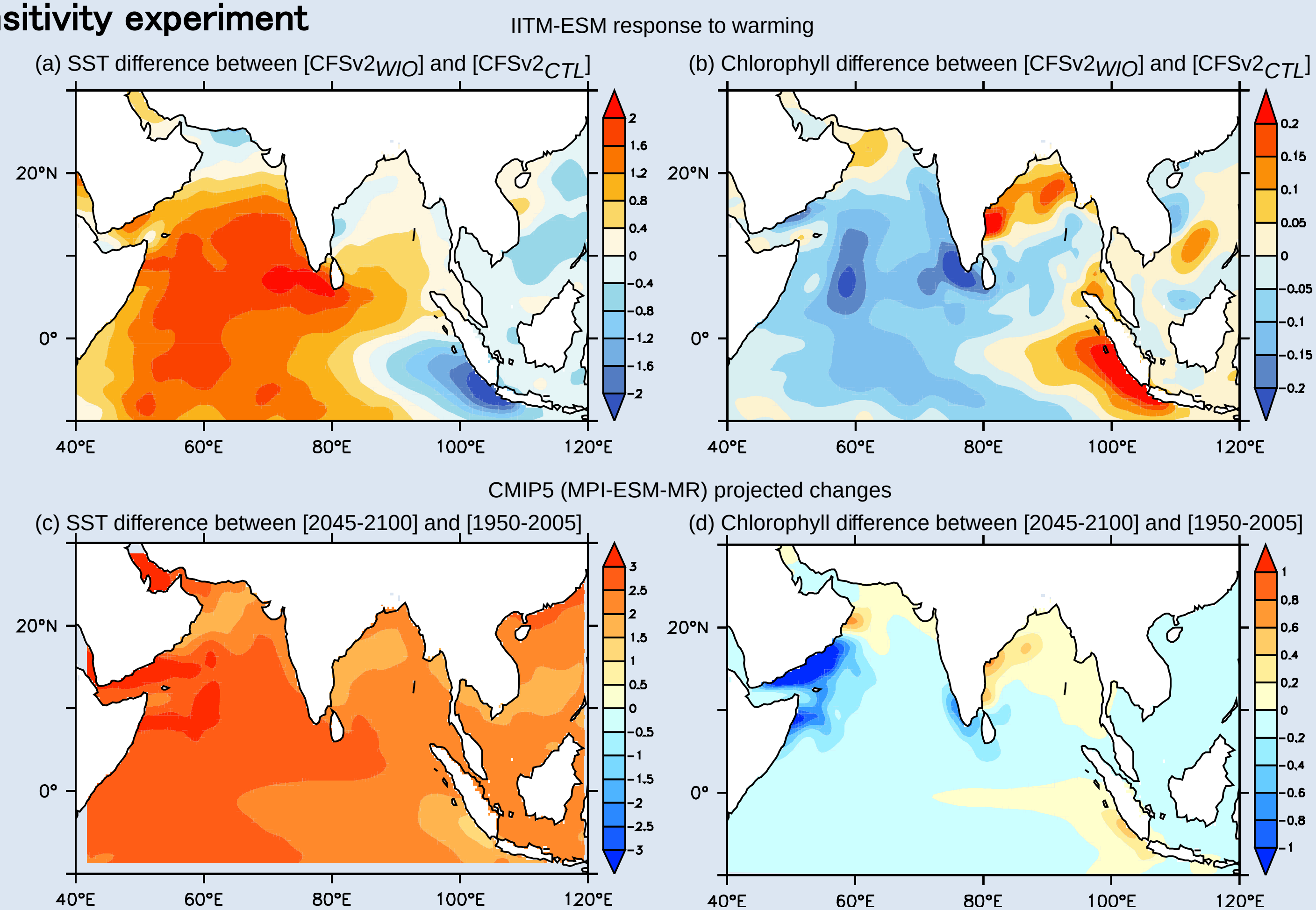
BY P. SWAPNA, M. K. ROXY, K. APARNA, K. KULKARNI, A. G. PRAJEESH, K. ASHOK, R. KRISHNAN, S. MOORTHI, A. KUMAR, AND B. N. GOSWAMI

This work documents the fidelity of the newly developed Indian Institute of Tropical Meteorology climate model simulations and demonstrates its suitability to address the climate variability and change issues relevant to the South Asian monsoon.

Swapna et al. *BAMS*, 2015

IITM – Earth System Model
- response to western Indian Ocean warming

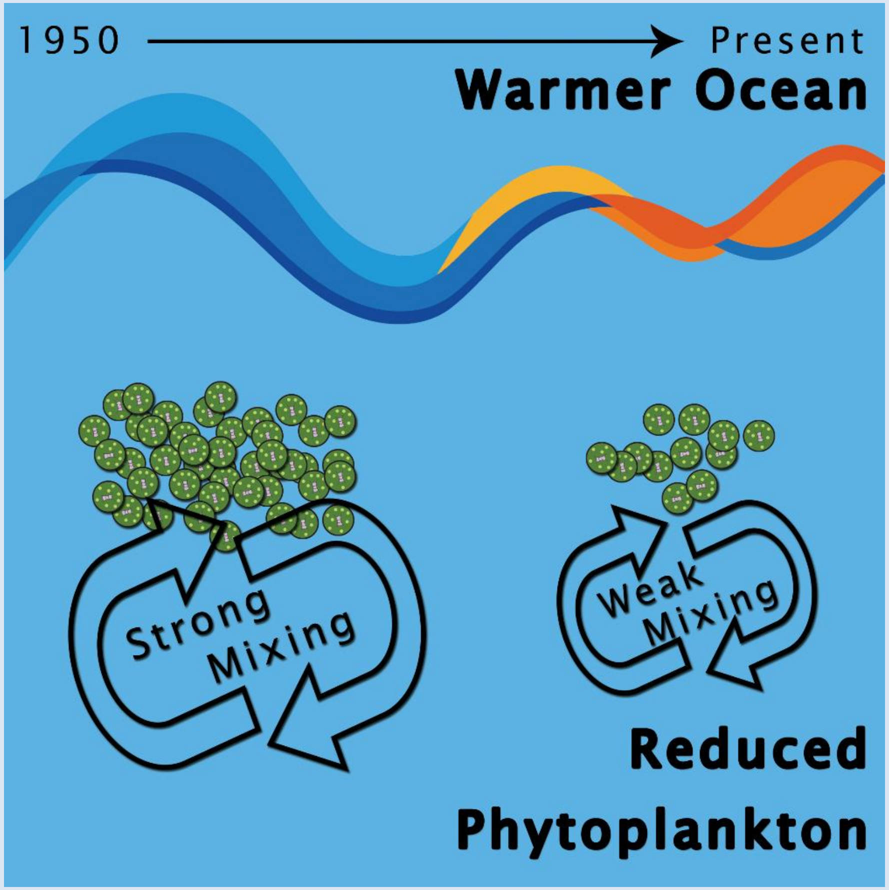
IITM–ESM sensitivity experiment



CMIP5 future projections

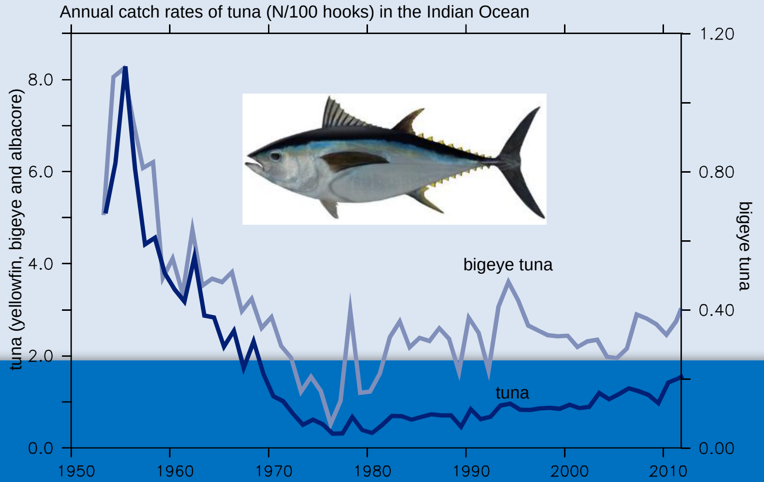
Roxy et al. *GRL*, 2016

Warming Ocean, Reduced Marine Productivity



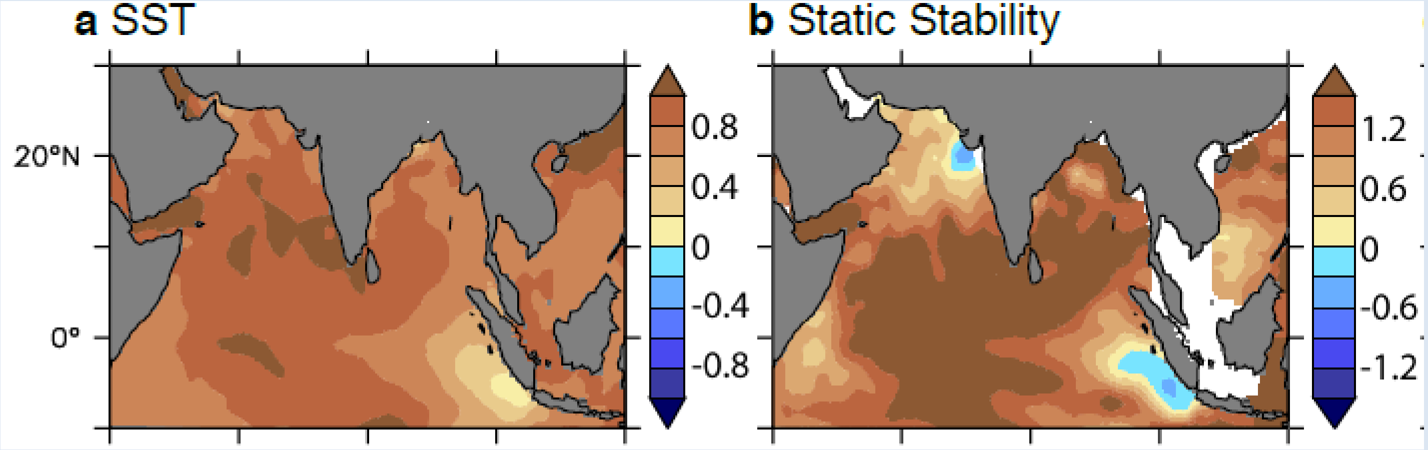
Future?
CMIP5 future projections suggest further warming of the Indian Ocean. Will the phytoplankton decrease further?

Is Indian Ocean turning into an ecological desert?
Along with the stress from fisheries industries… reduced plankton might increase the fish stress



Roxy et al. *GRL*, 2016

Missing links - asymmetry in the warming



Identify and separate dynamics/processes leading to surface and subsurface warming