

Boundary fluxes, upwelling, ecosystem & atmospheric feedbacks

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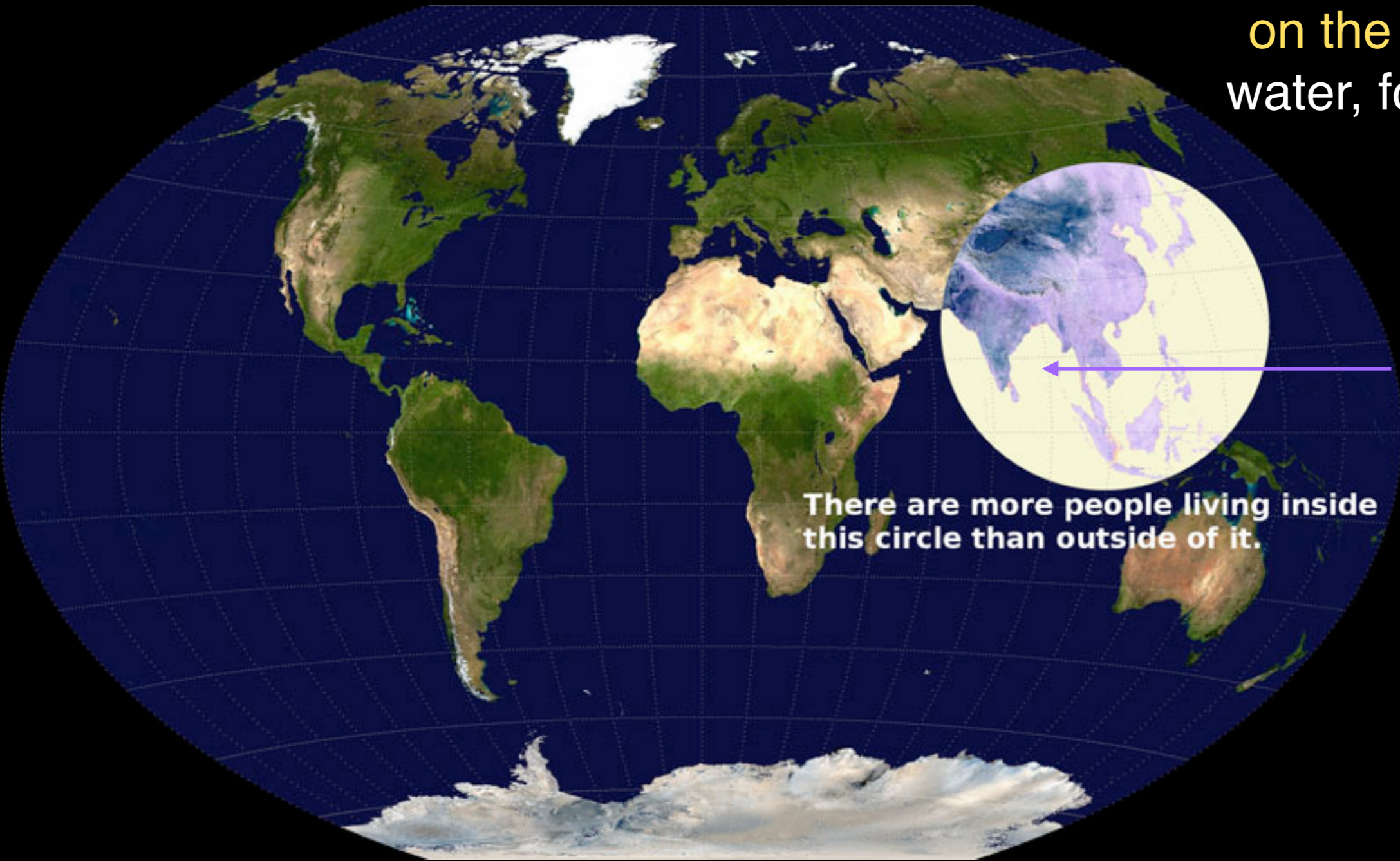
ASIRI

NASCar



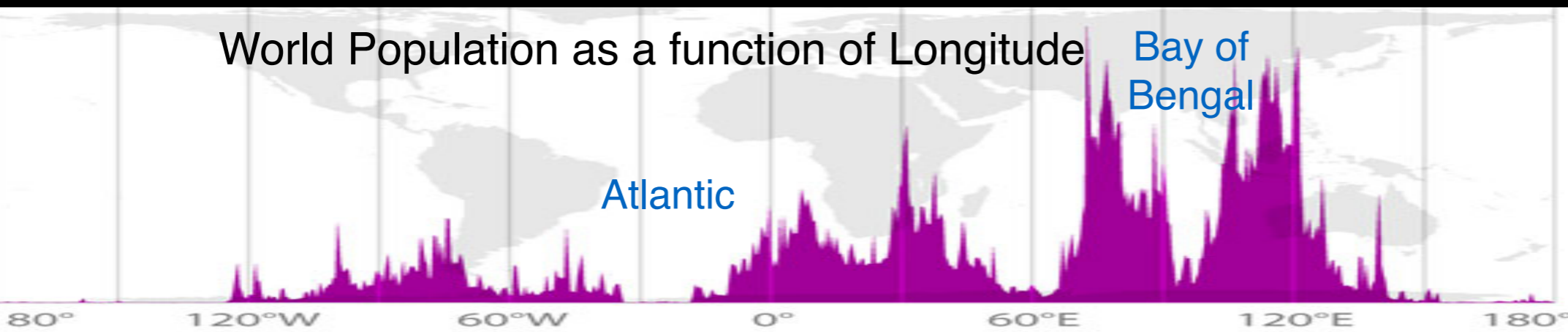
Indian Ocean's relevance

2.5 billion people depend on the Monsoon for water, food, economy

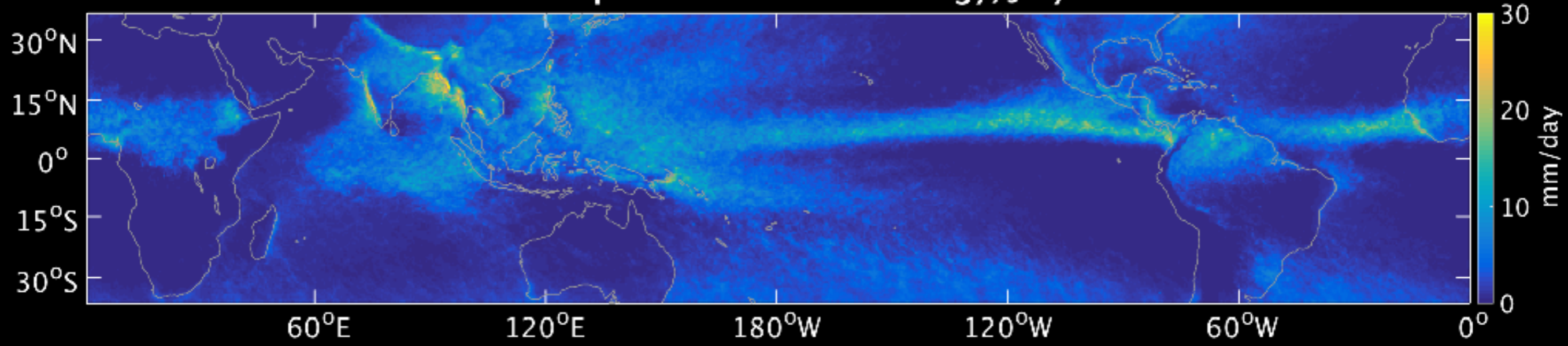


Bay of Bengal

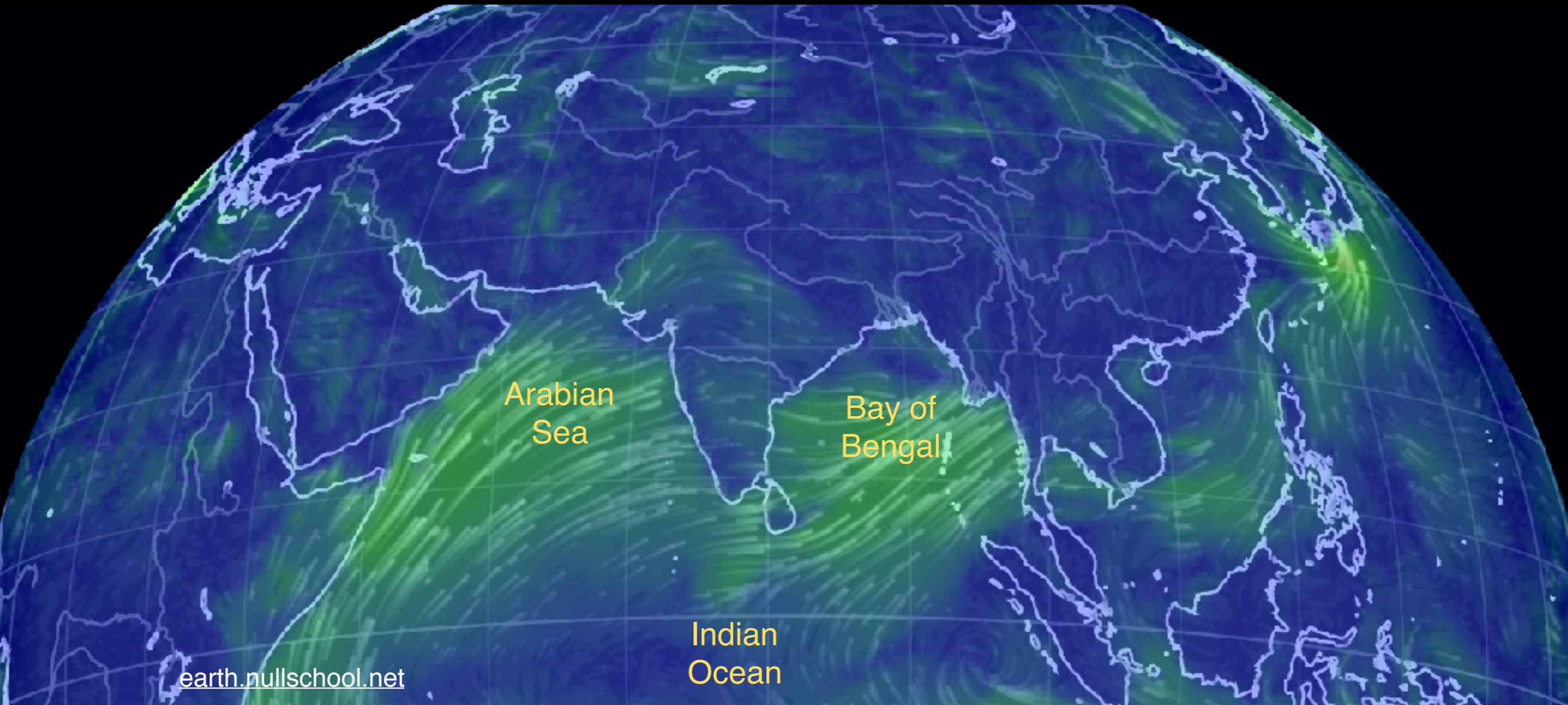
- Highest per capita impact of oceanic influence
- Largest human susceptibility to climate change.



TRMM Tropical Rainfall Climatology, July

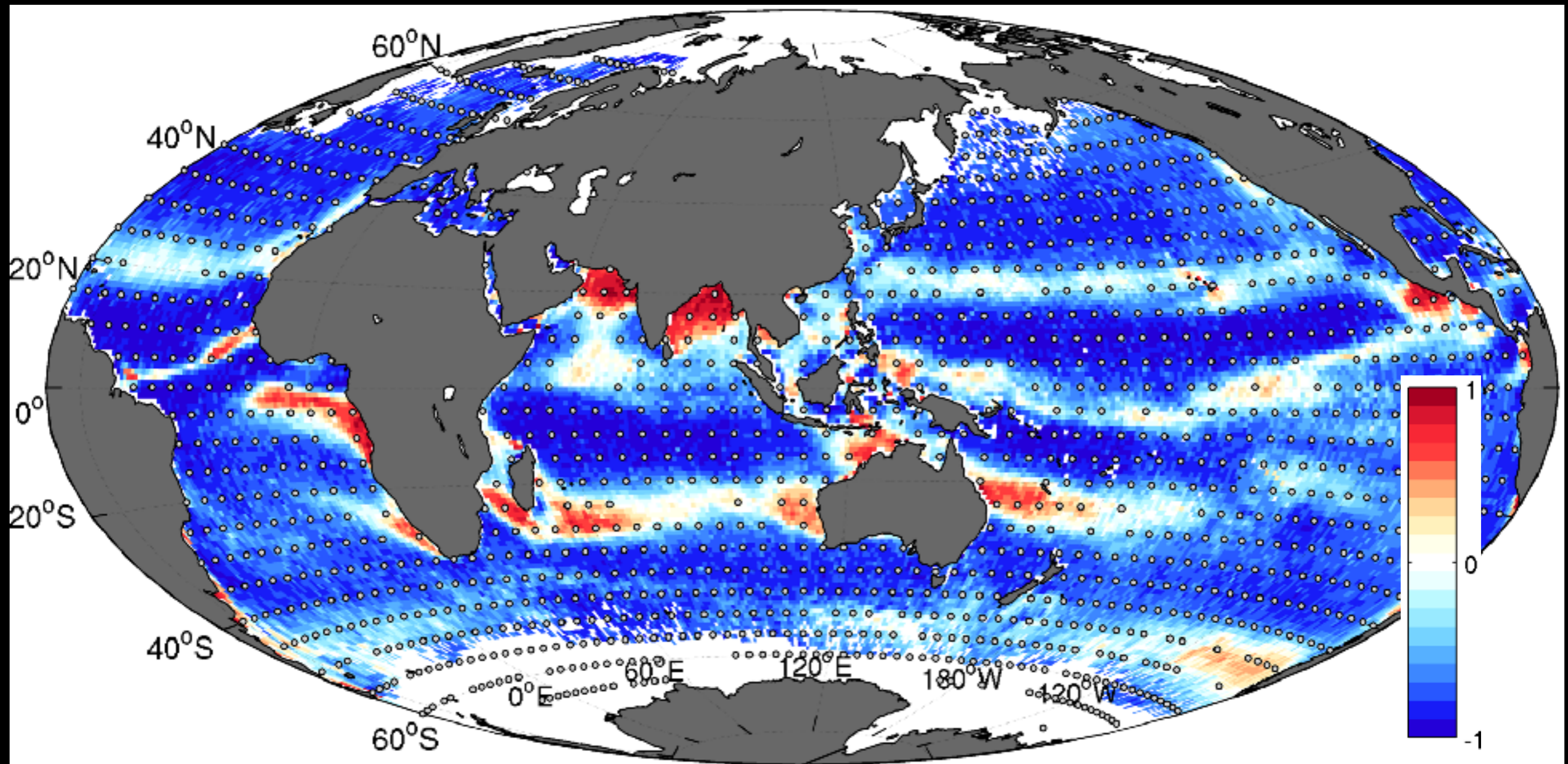


Summer Monsoon winds

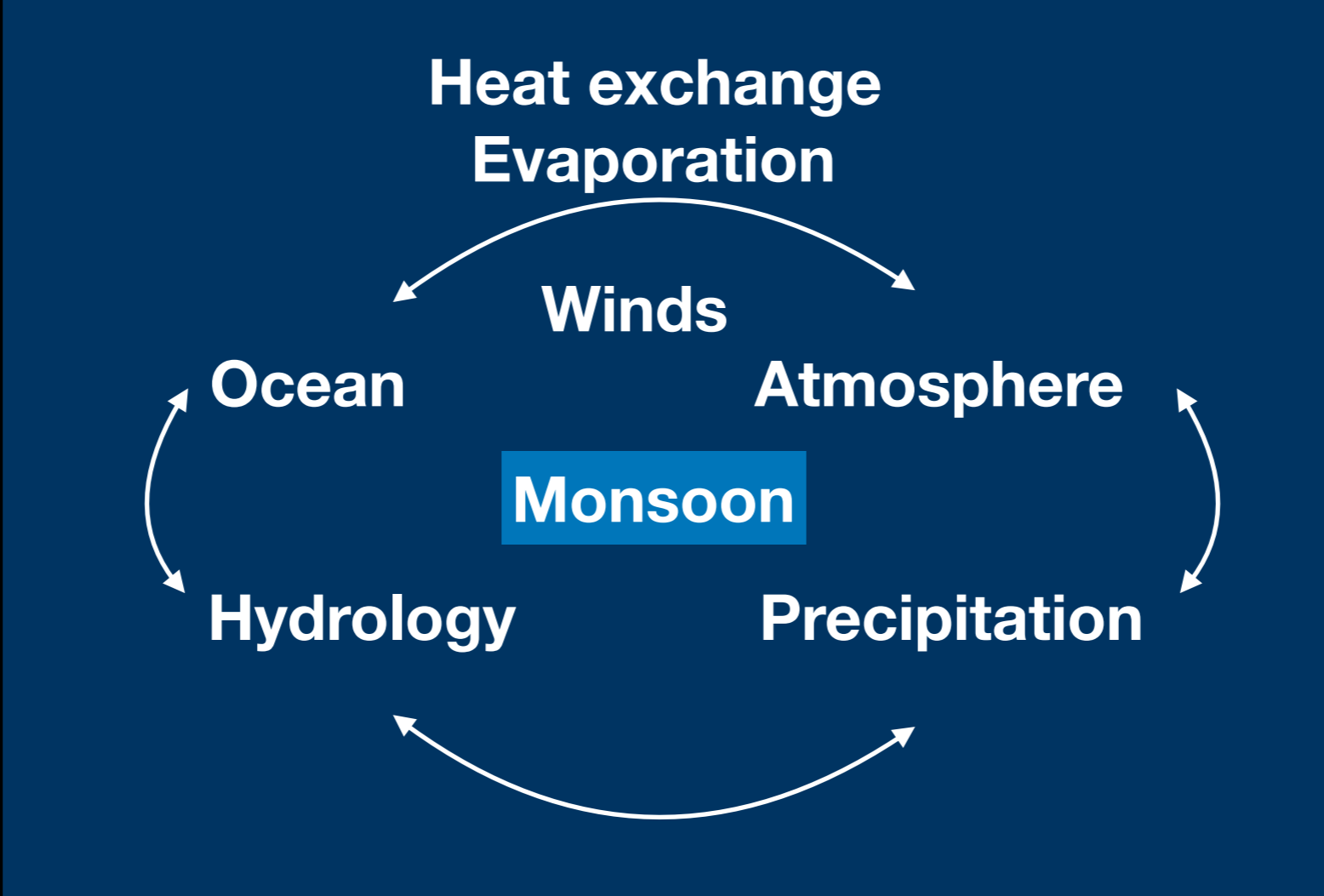


Intra-seasonal air-sea coupling

Correlation between 10-60 day SST and Wind Speed
in boreal summer; 2001-2009
QuikSCAT wind speed and NOAA OI SST



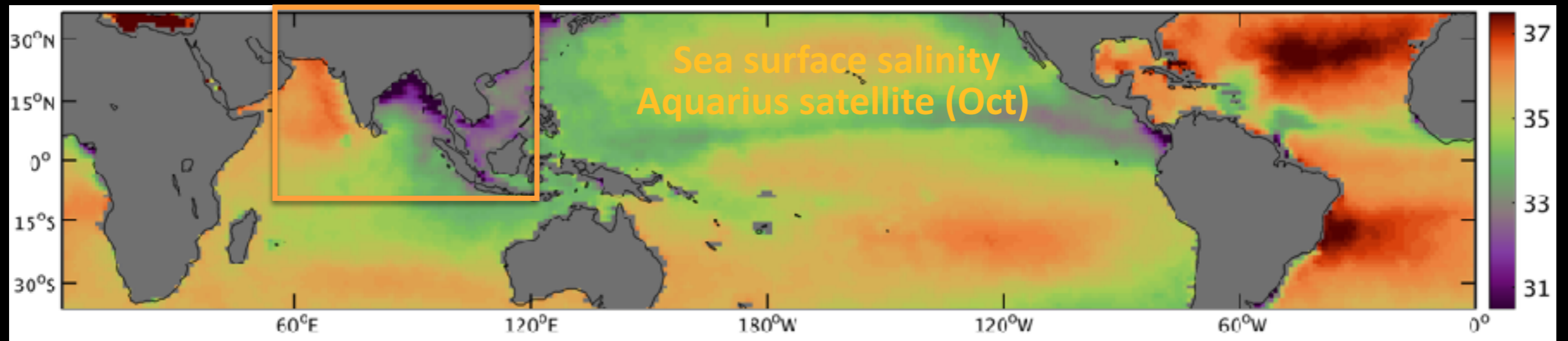
Negative Correlation: wind forcing the ocean
Positive Correlation: higher wind speed over warmer ocean



HYPOTHESIS

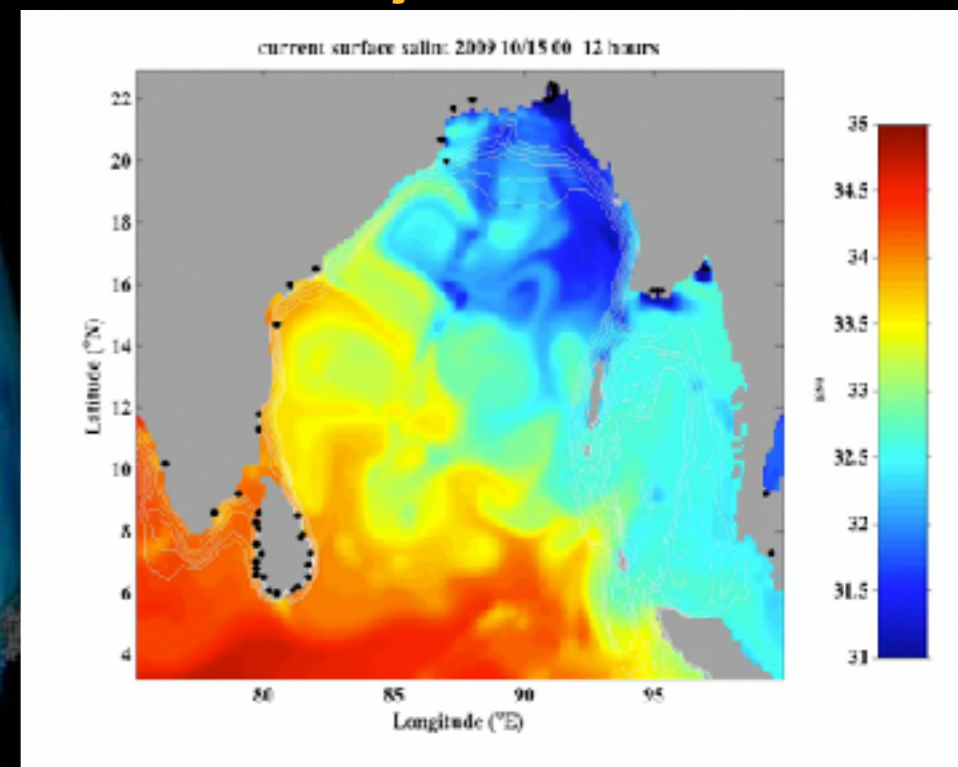
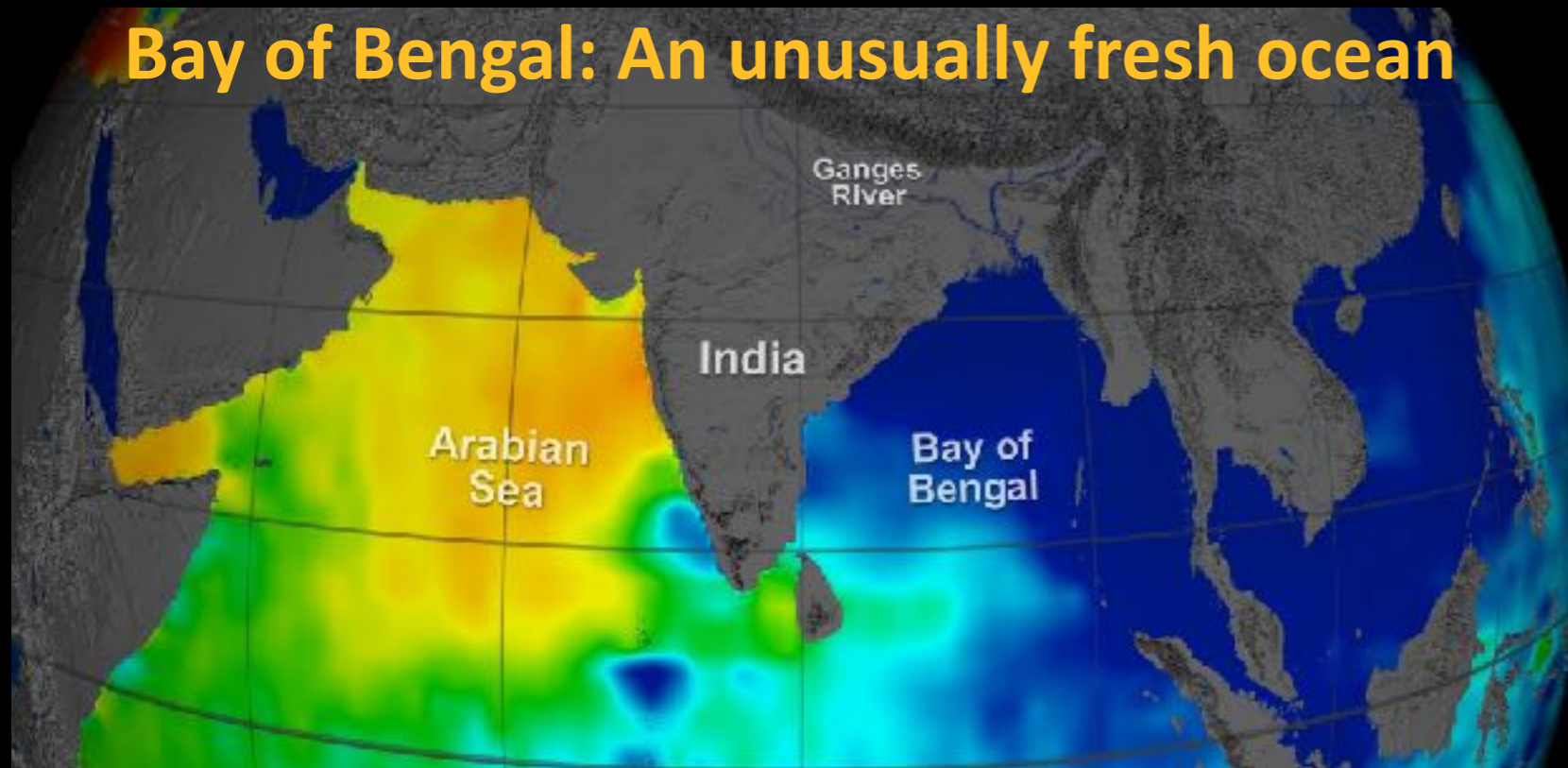
Freshwater input and salinity control on ocean density alters

- the upper ocean structure
- SST response
- effect of winds
- upwelling and mixing
- biogeochemistry
- phytoplankton productivity



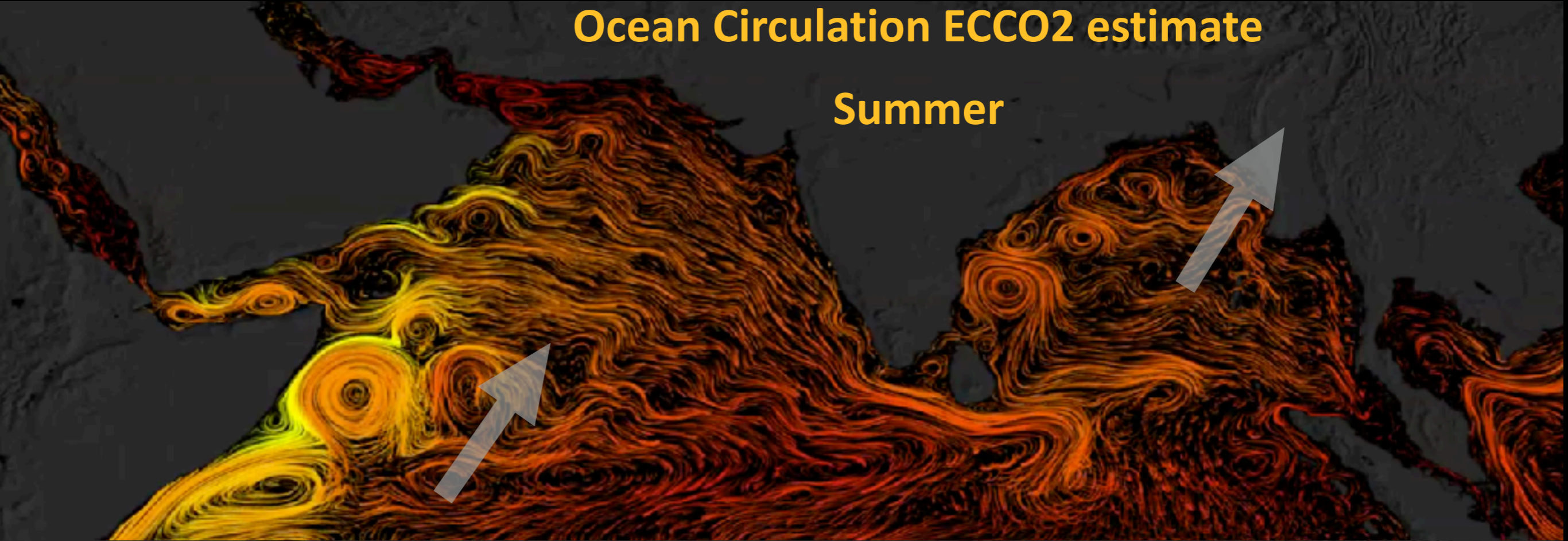
Salinity: NRL Model

Bay of Bengal: An unusually fresh ocean

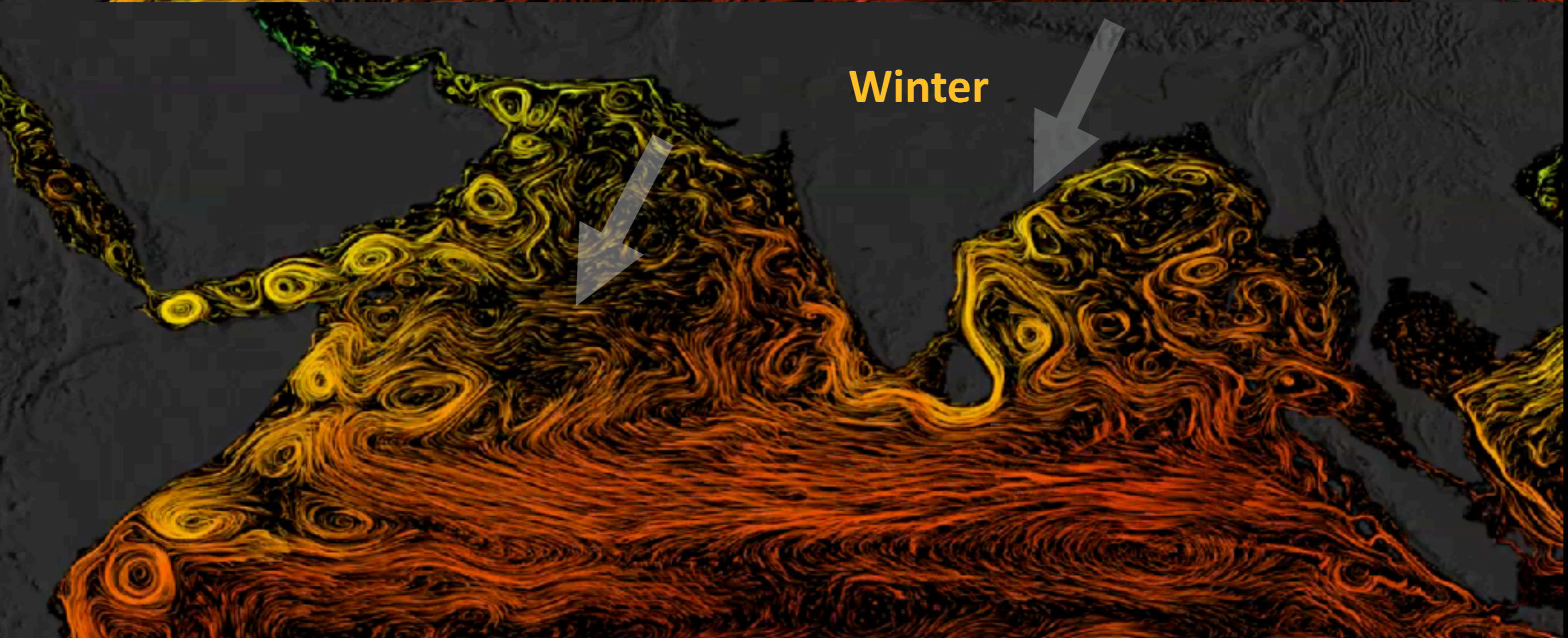


Ocean Circulation ECCO2 estimate

Summer



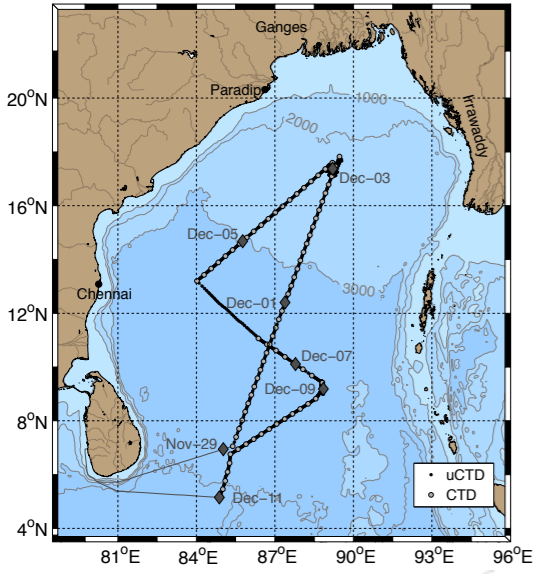
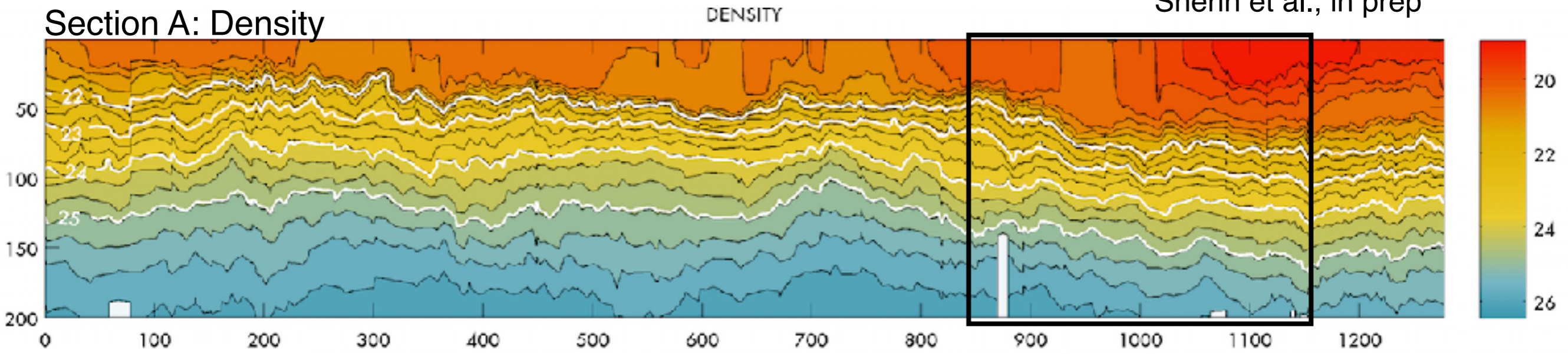
Winter



Underway CTD : upper 200 m sampled every ~3km
 80 CTD Profiles: Nitrate, oxygen, Chl, water sampling

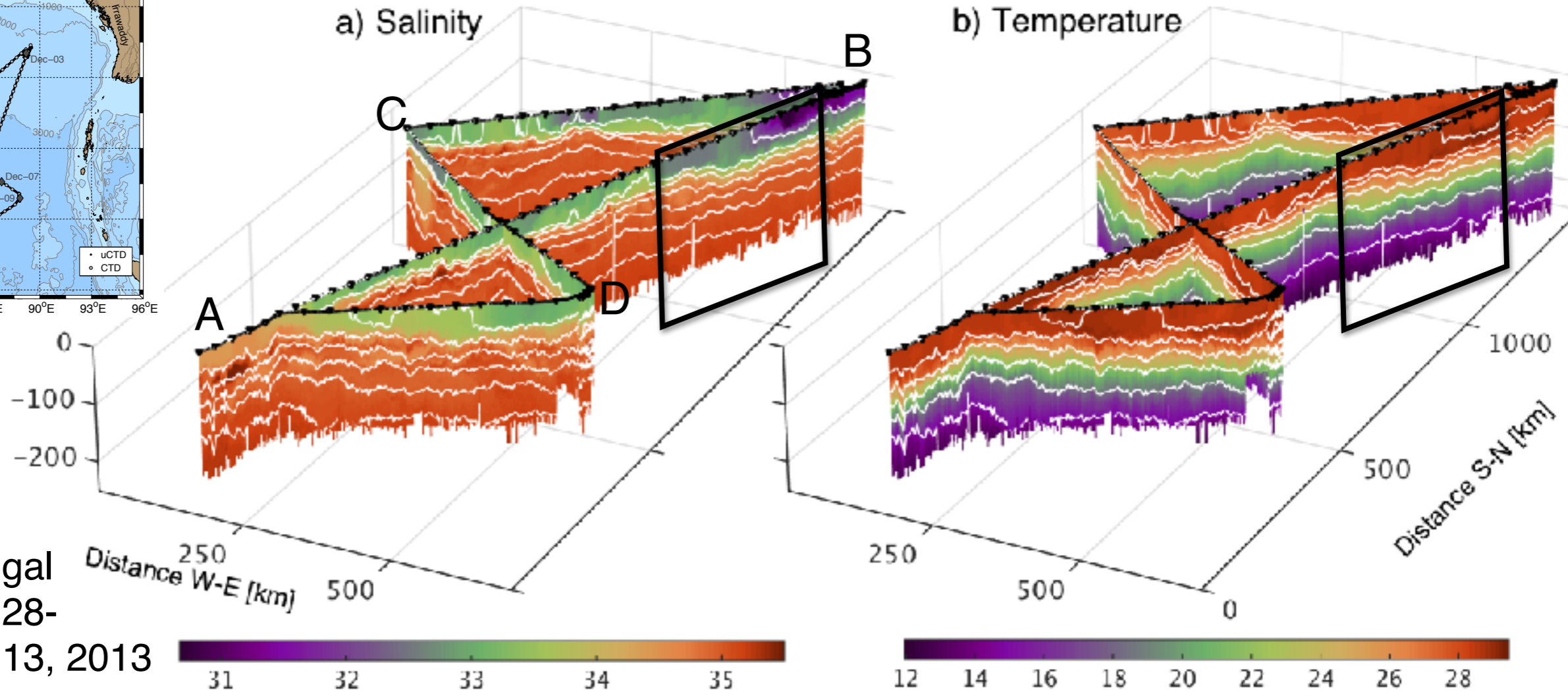
2013 ASIRI cruise
 Shroyer et al. in prep
 Spiro-Jaeger et al., in prep.
 Sherin et al., in prep

Section A: Density



a) Salinity

b) Temperature



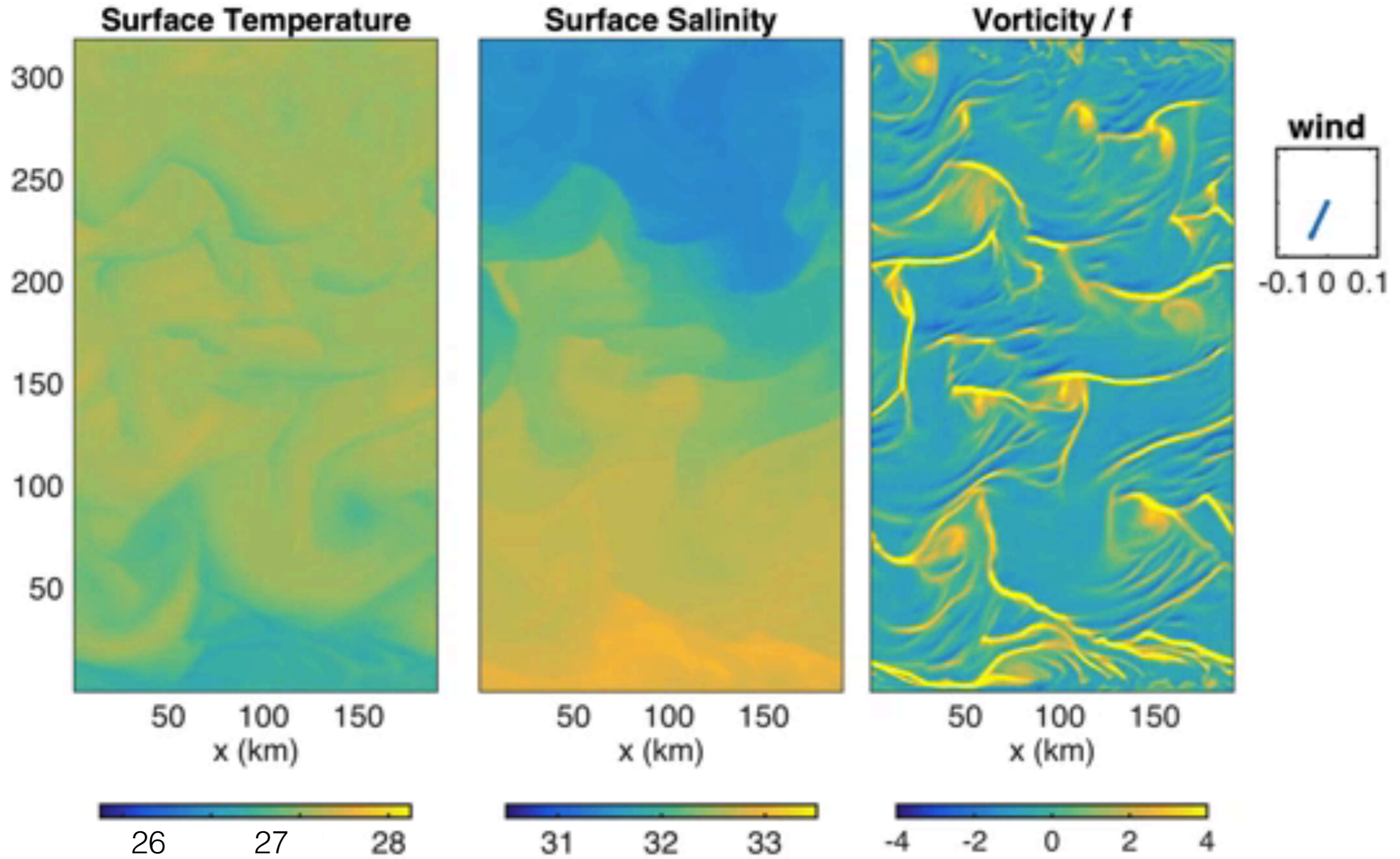
Bay of Bengal
 November 28-
 December 13, 2013

Process Modeling

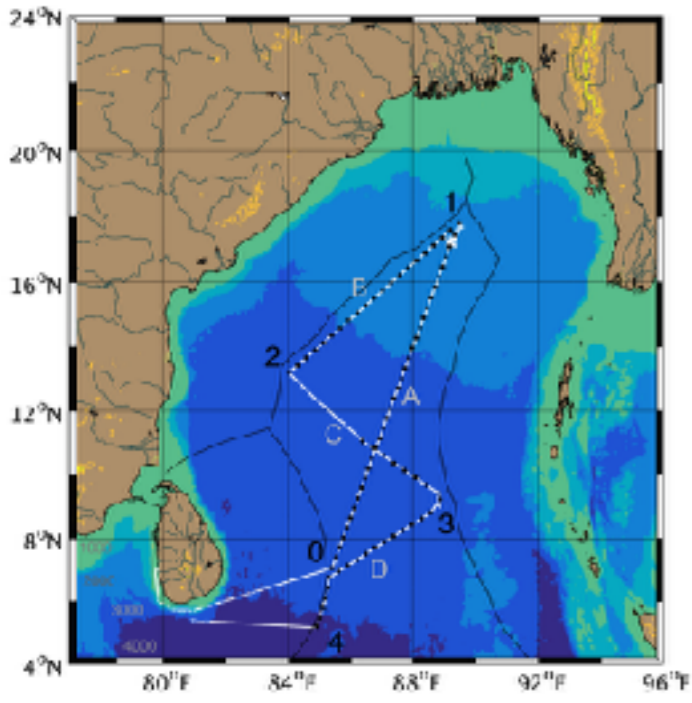
Initialize the model with a part of the ship section
Force with heat fluxes and winds from mooring (2014)

$L_x = 192$ km
 $L_y = 300$ km
 $dx = 1$ km
 $K_x = 0.3$ m²/s
 $K_z = 1e-6$ m²/s
below 30 m

Mean eddy transport is westward



ASIRI 2013 Leg 2

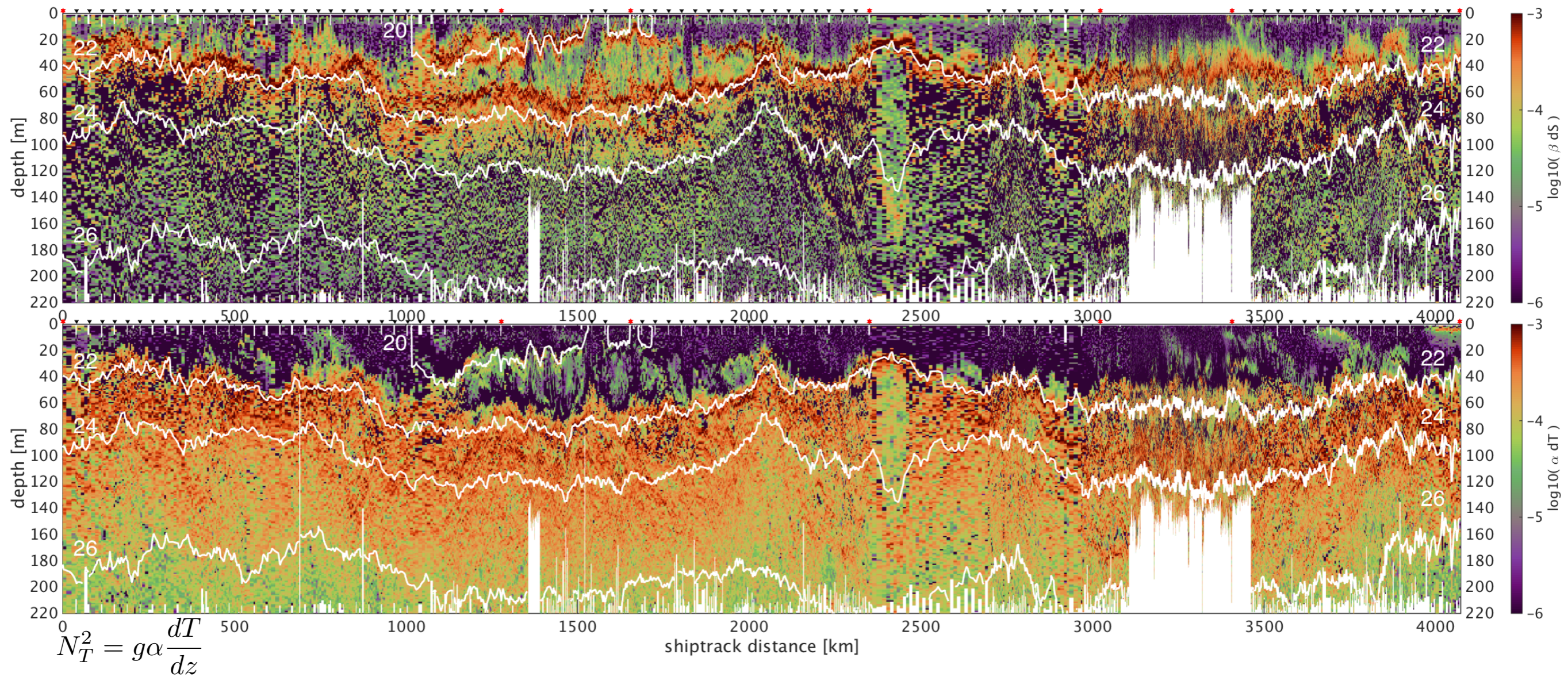
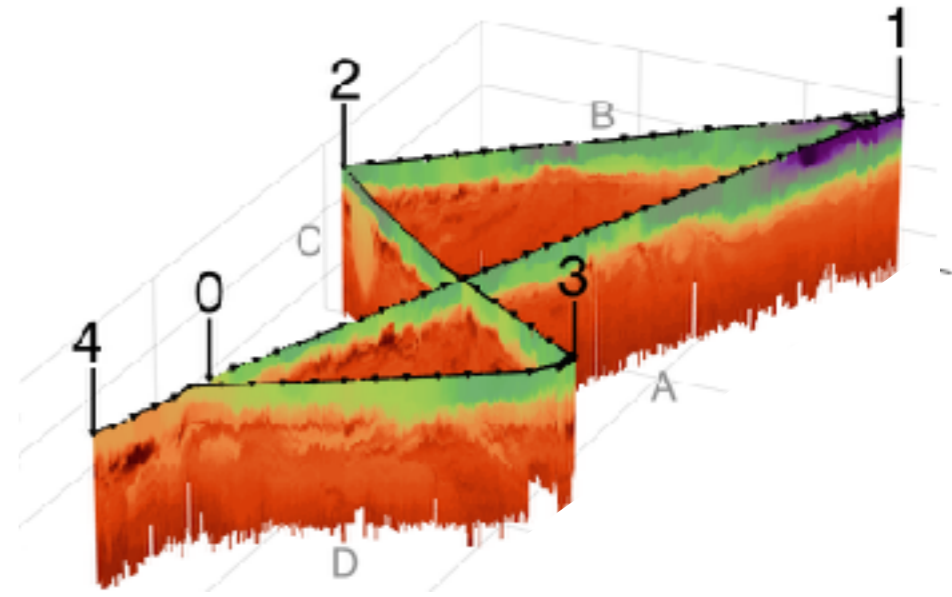


Density stratification due to

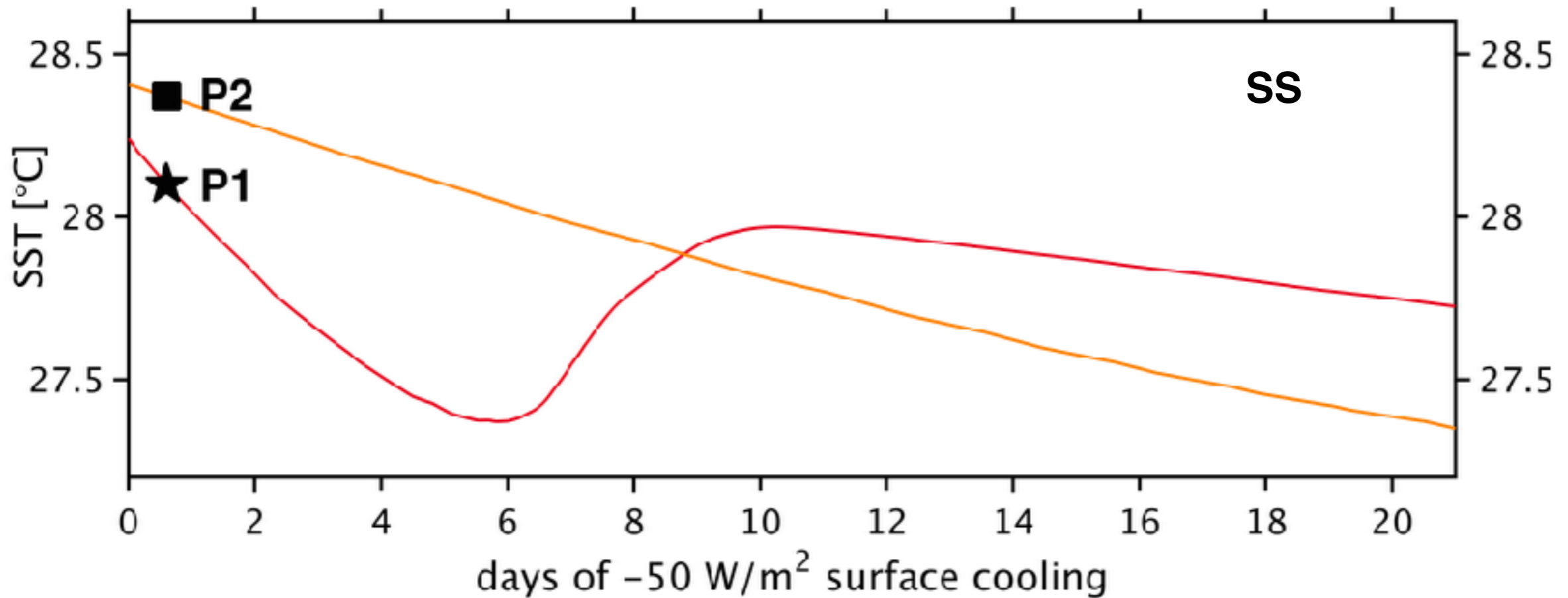
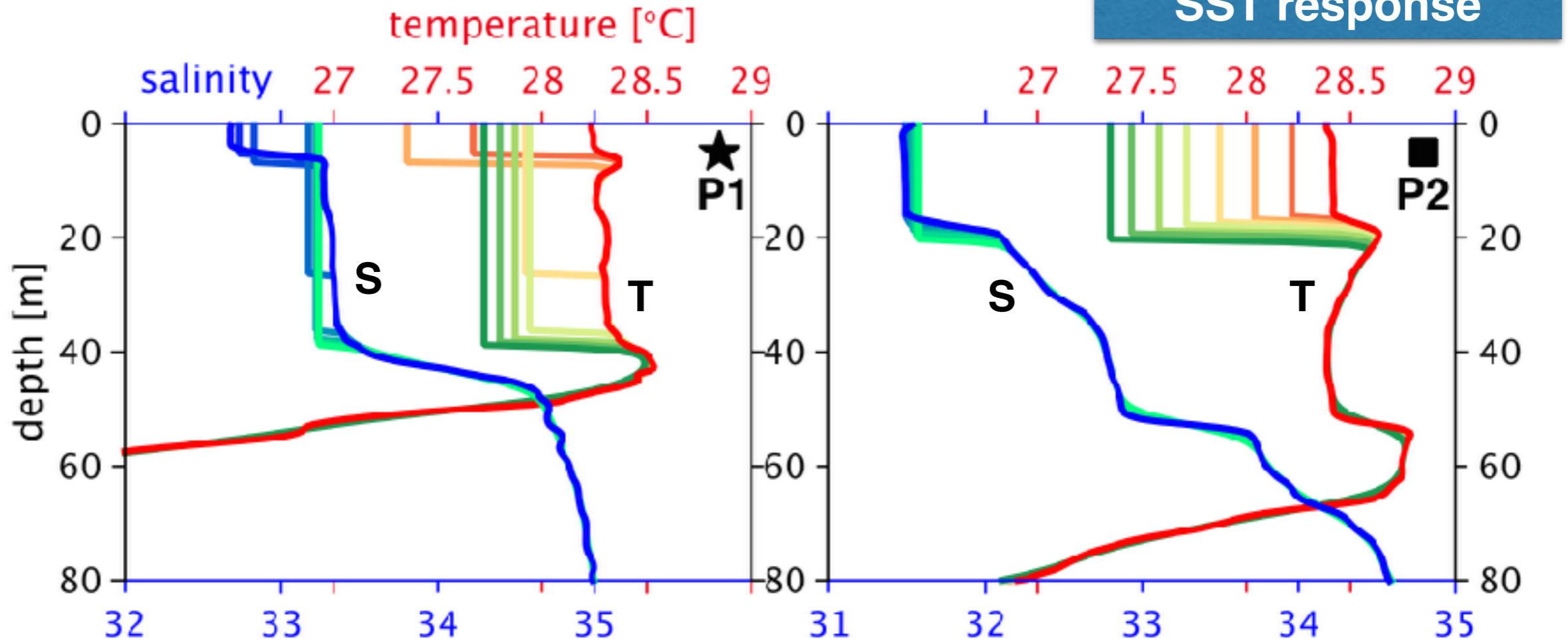
Top: Salinity $N_S^2 = -g\beta \frac{dS}{dz}$

Below: Temperature $N_T^2 = g\alpha \frac{dT}{dz}$

$$\Delta\rho = \alpha\Delta T - \beta\Delta S$$



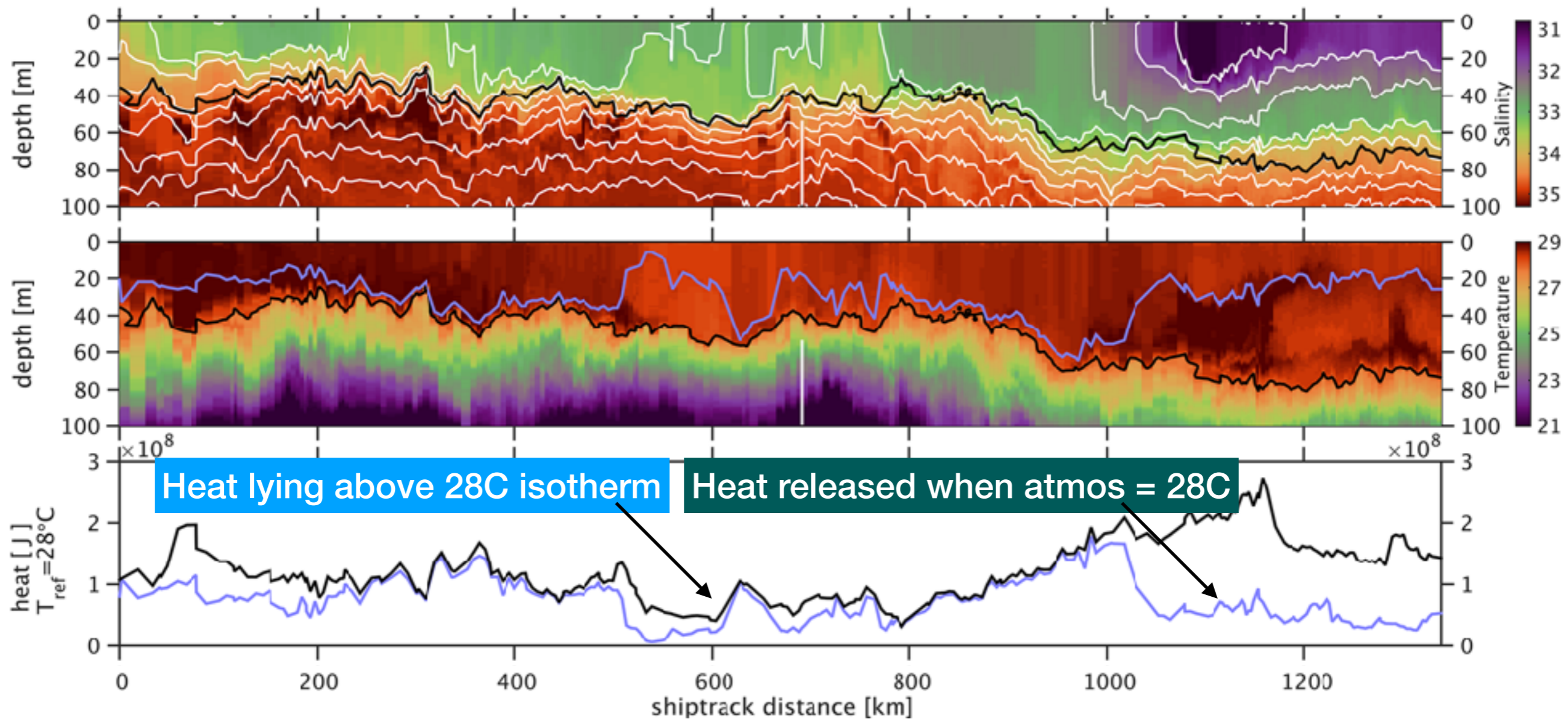
Role of freshwater on SST response



Role of freshwater Barrier Layer

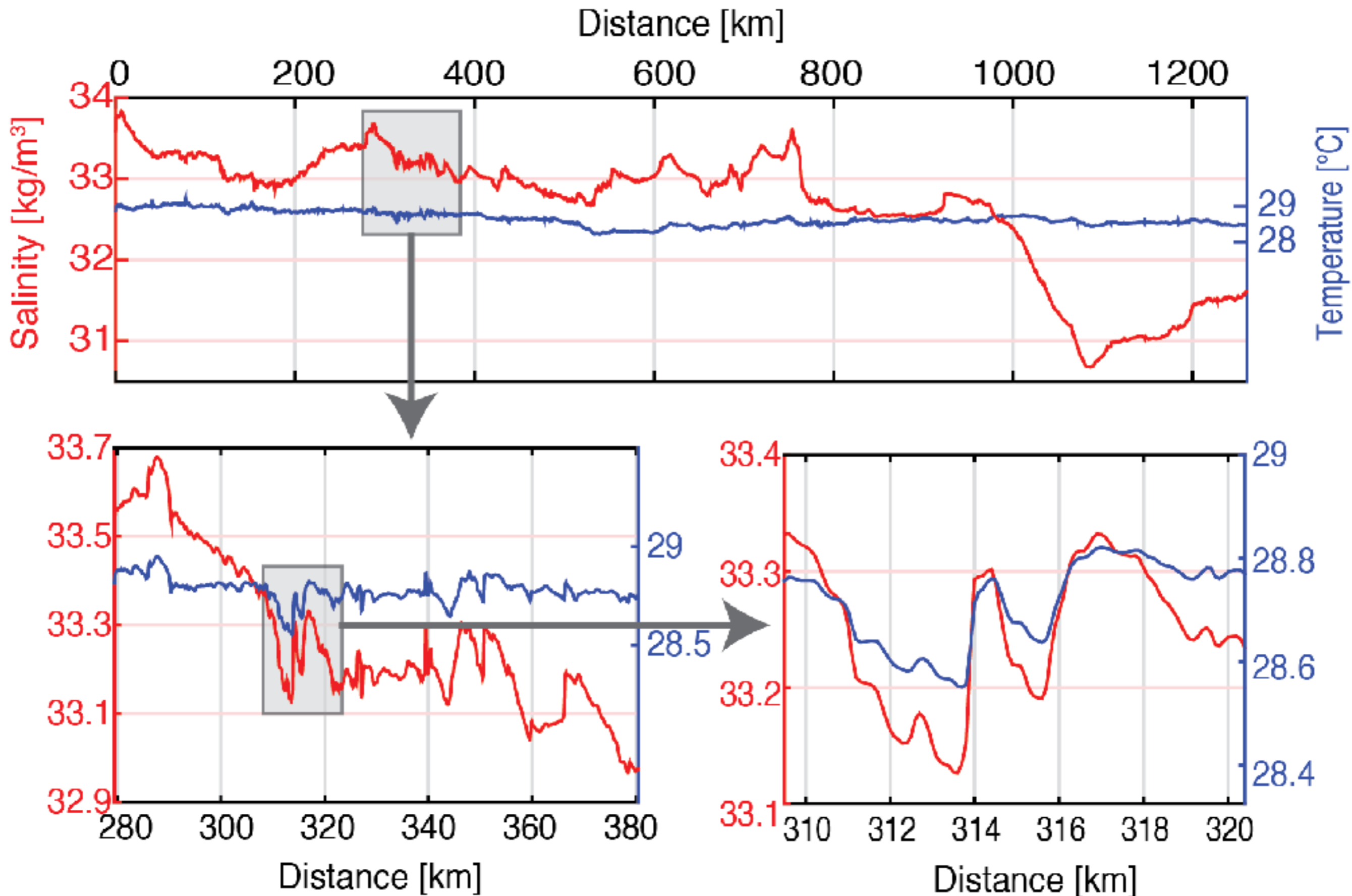
Difficult to extract heat from freshwater stratified ocean

1D numerical experiment: Set surface temperature to 28 deg C

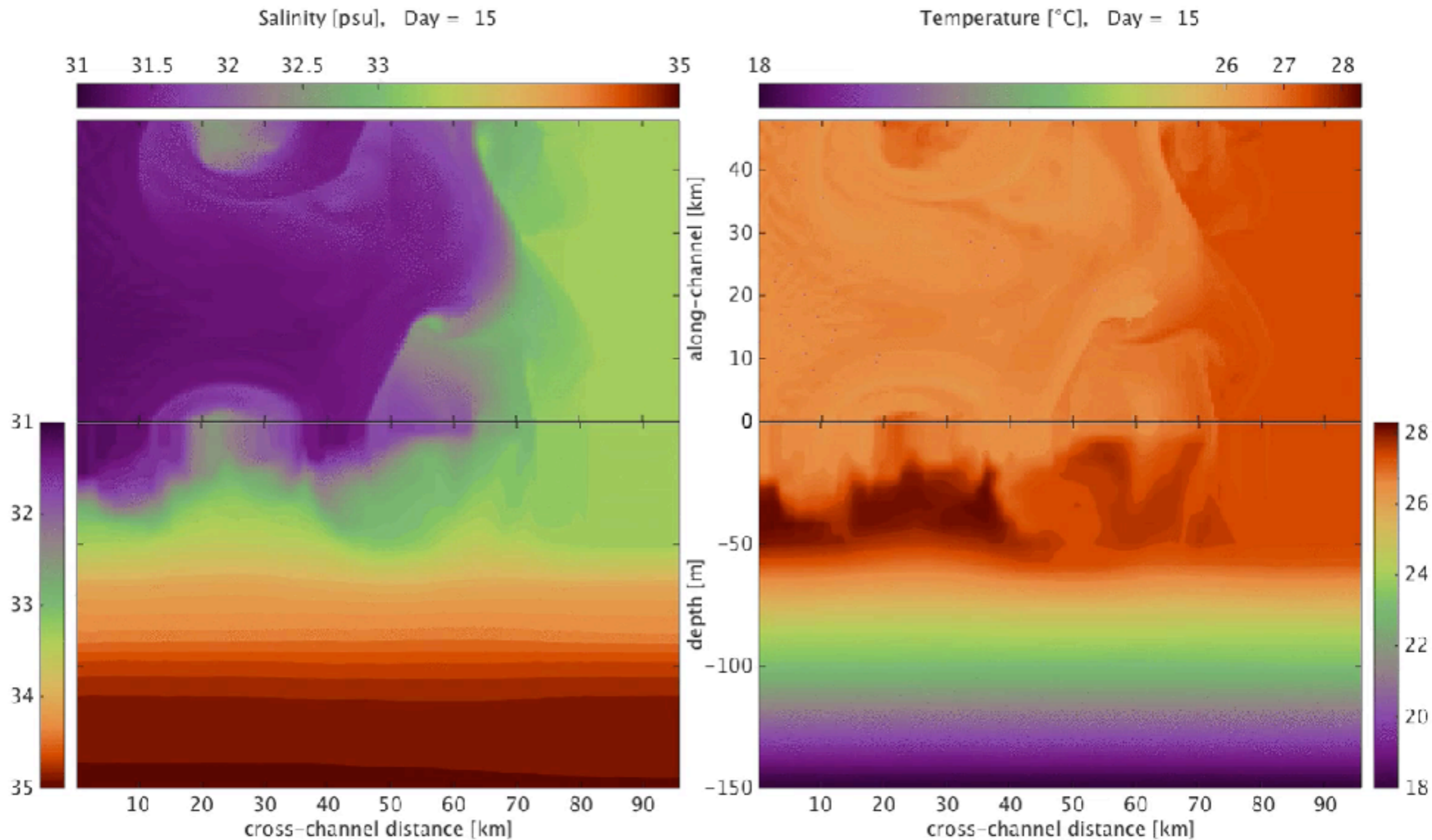


Submeso-scale-selective compensation of fronts

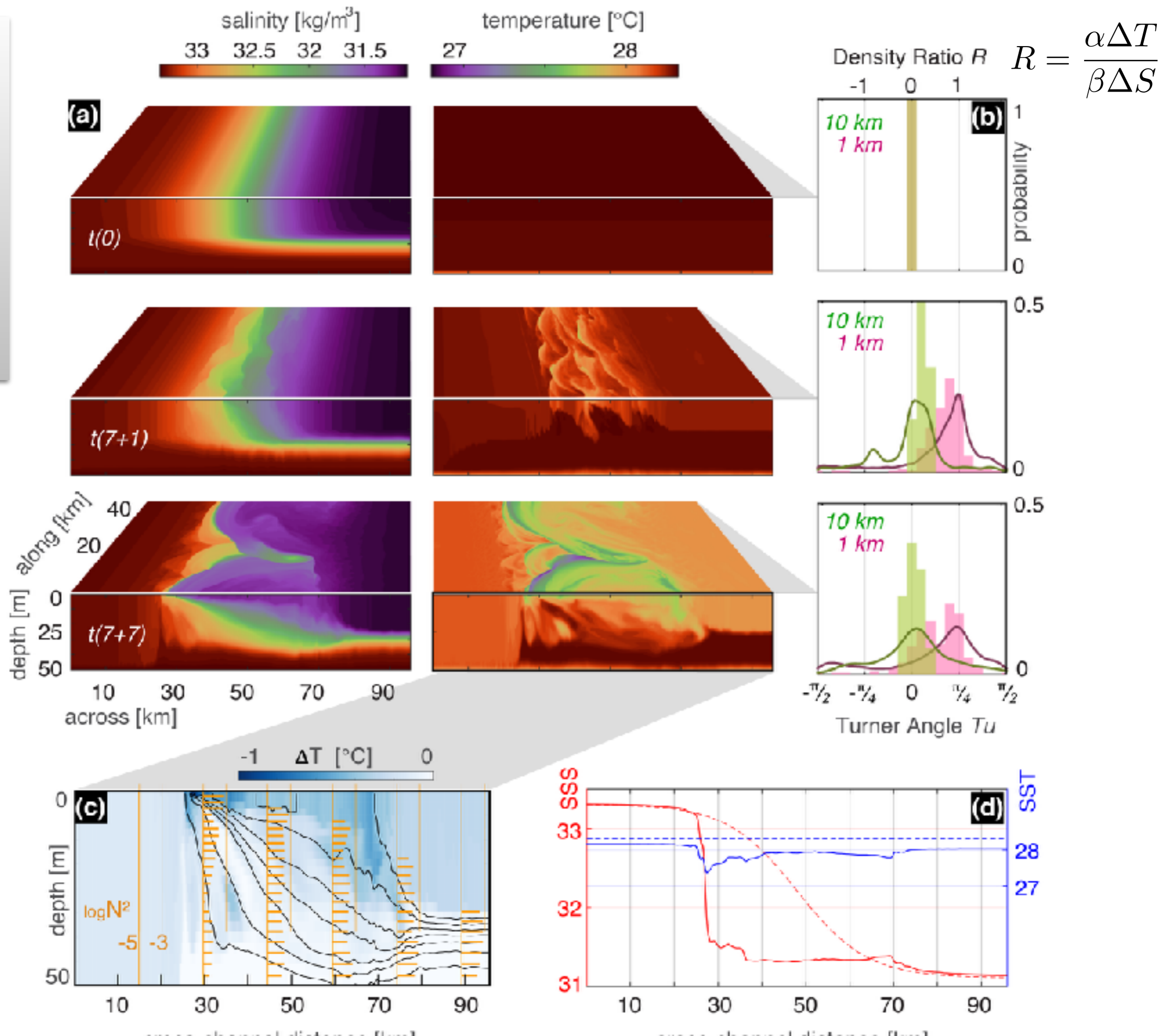
Spiro Jaeger & Mahadevan (in review)



-150 W/m² cooling: 18-days process study ocean model

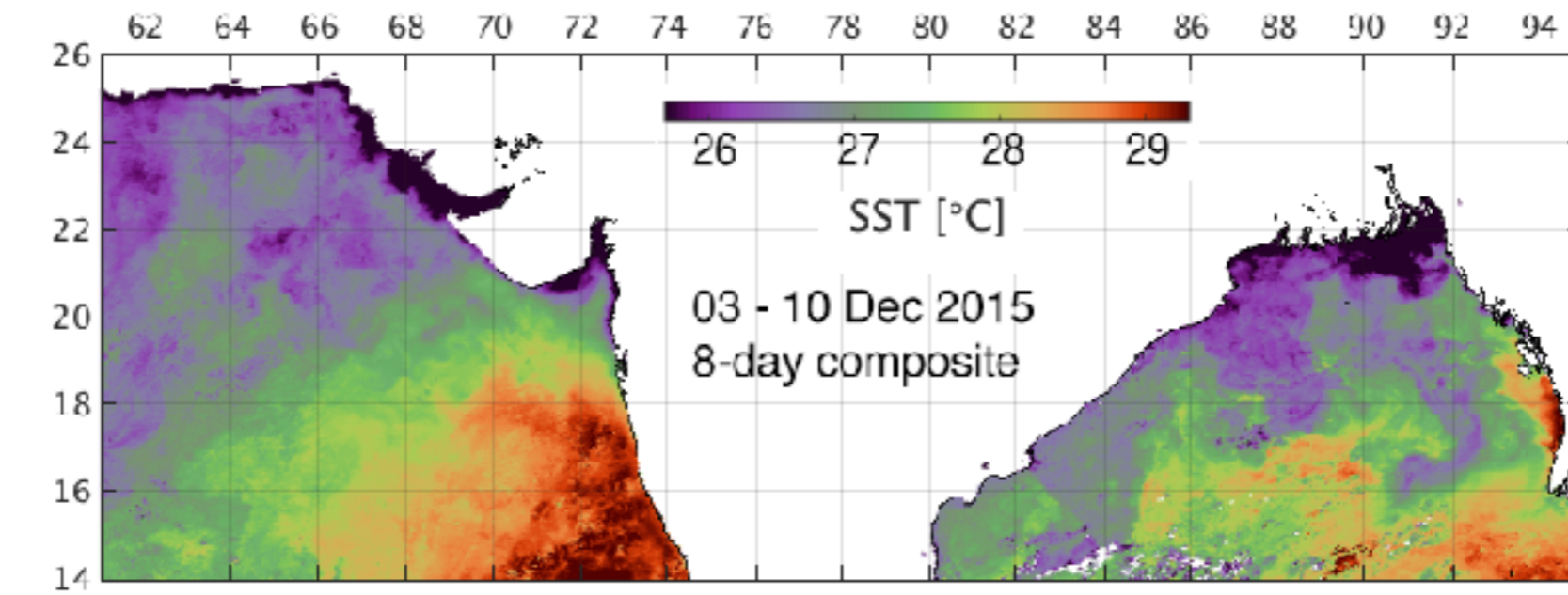


Uniform cooling of a shallow salinity front

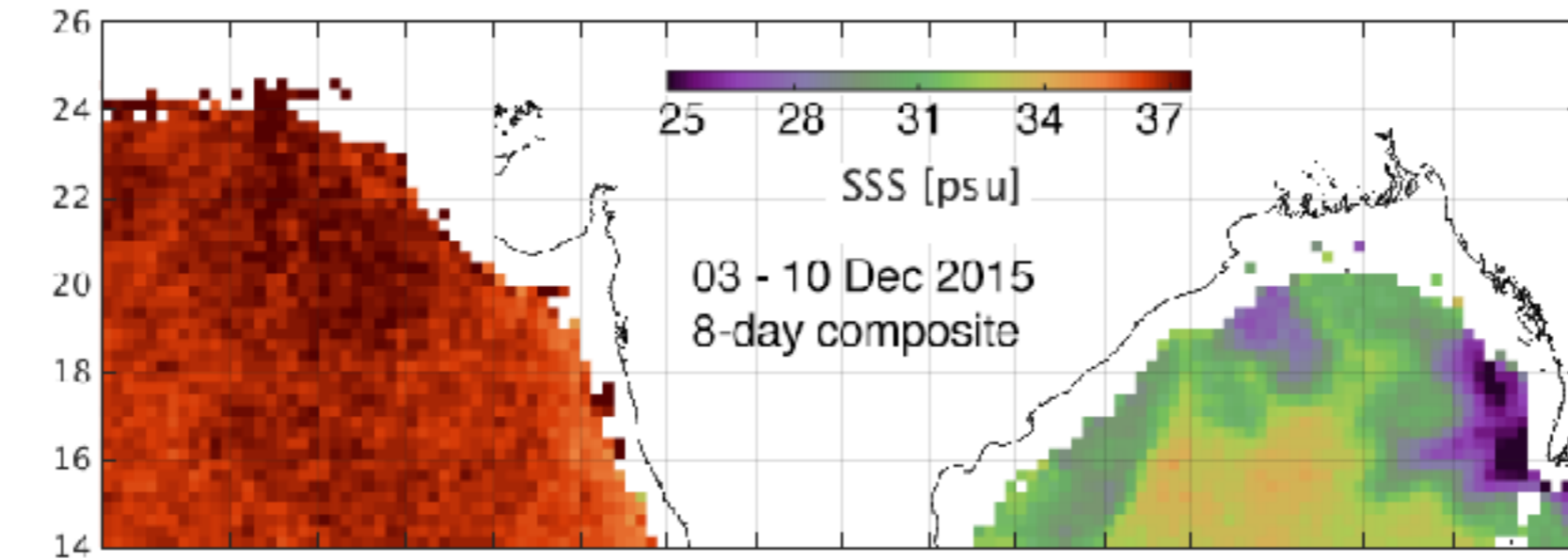


WINTER

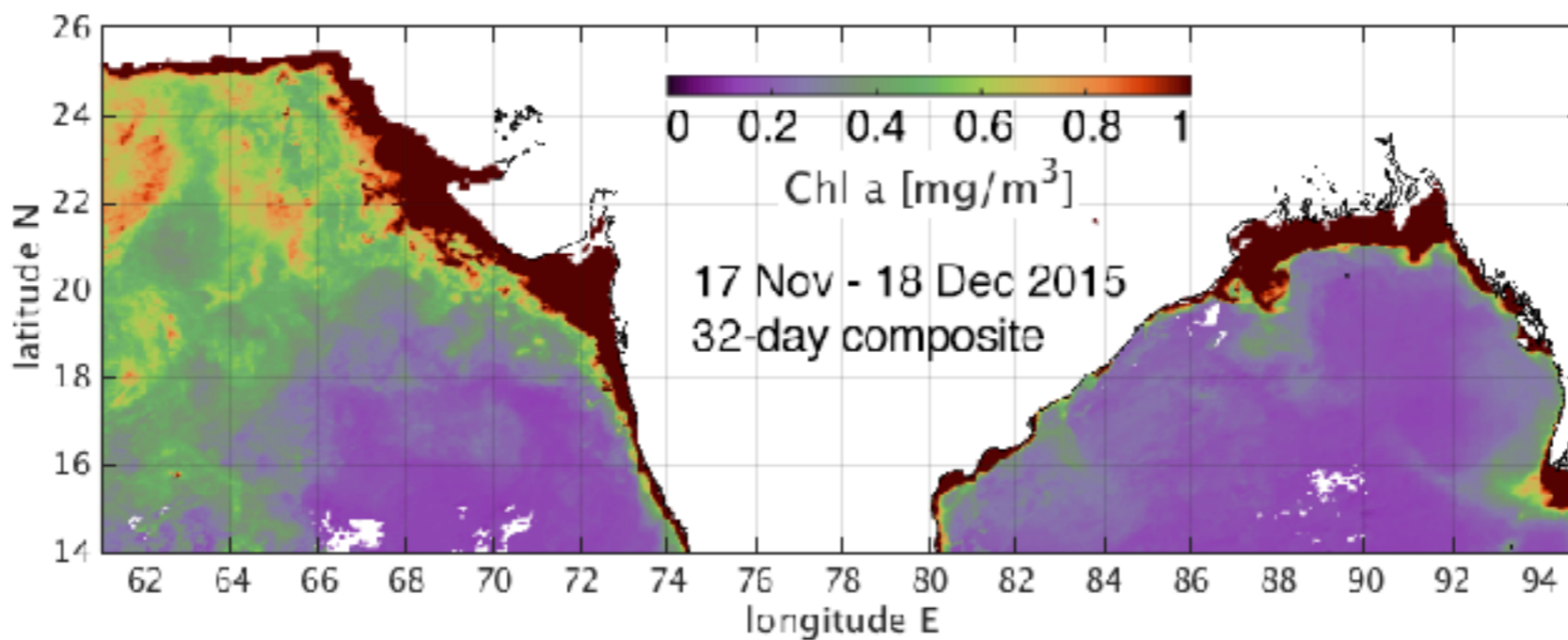
SST

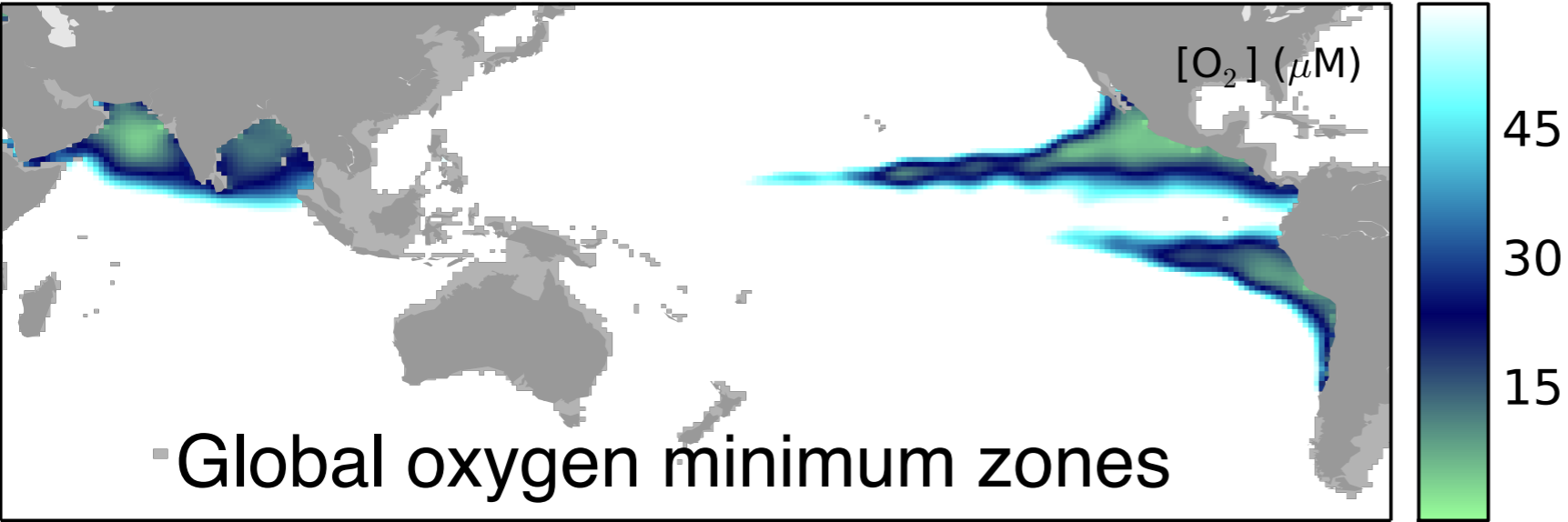


SSS



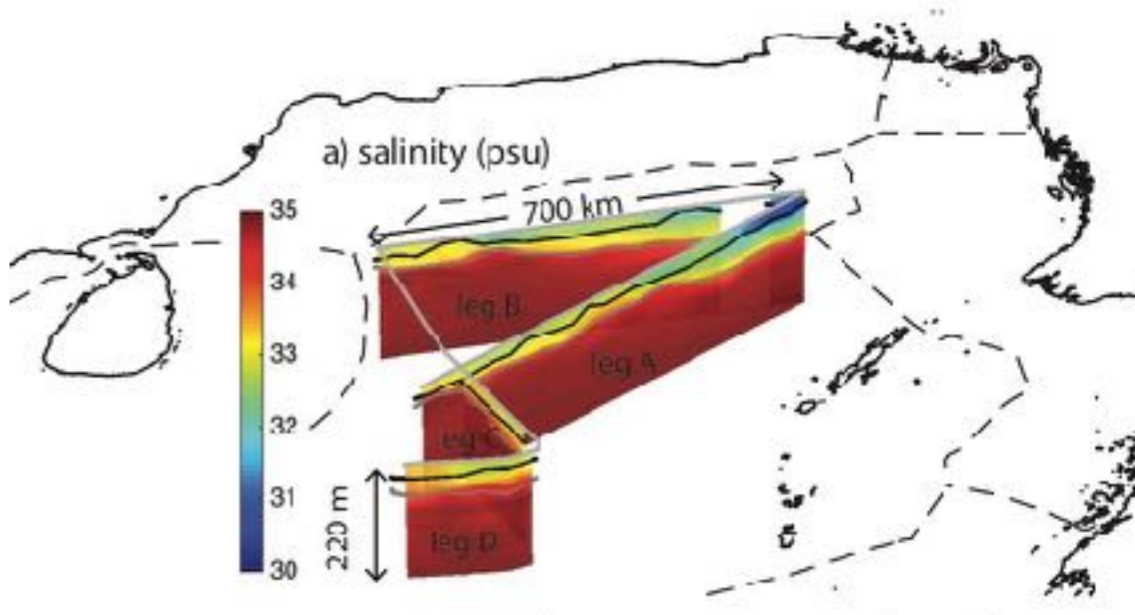
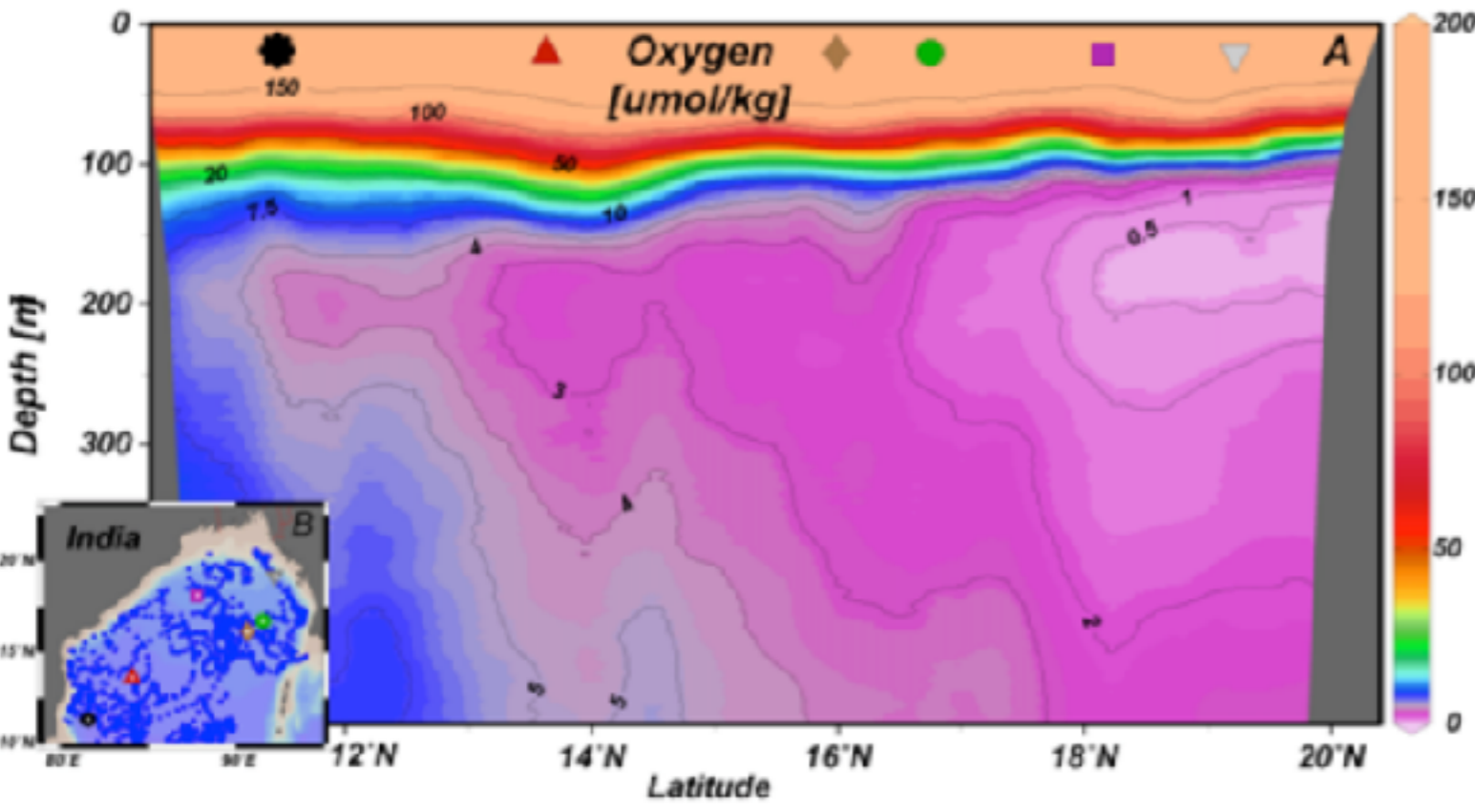
CHL





The Northern Indian Ocean is one of the major OMZs of the world.

Unusually strongly stratified!



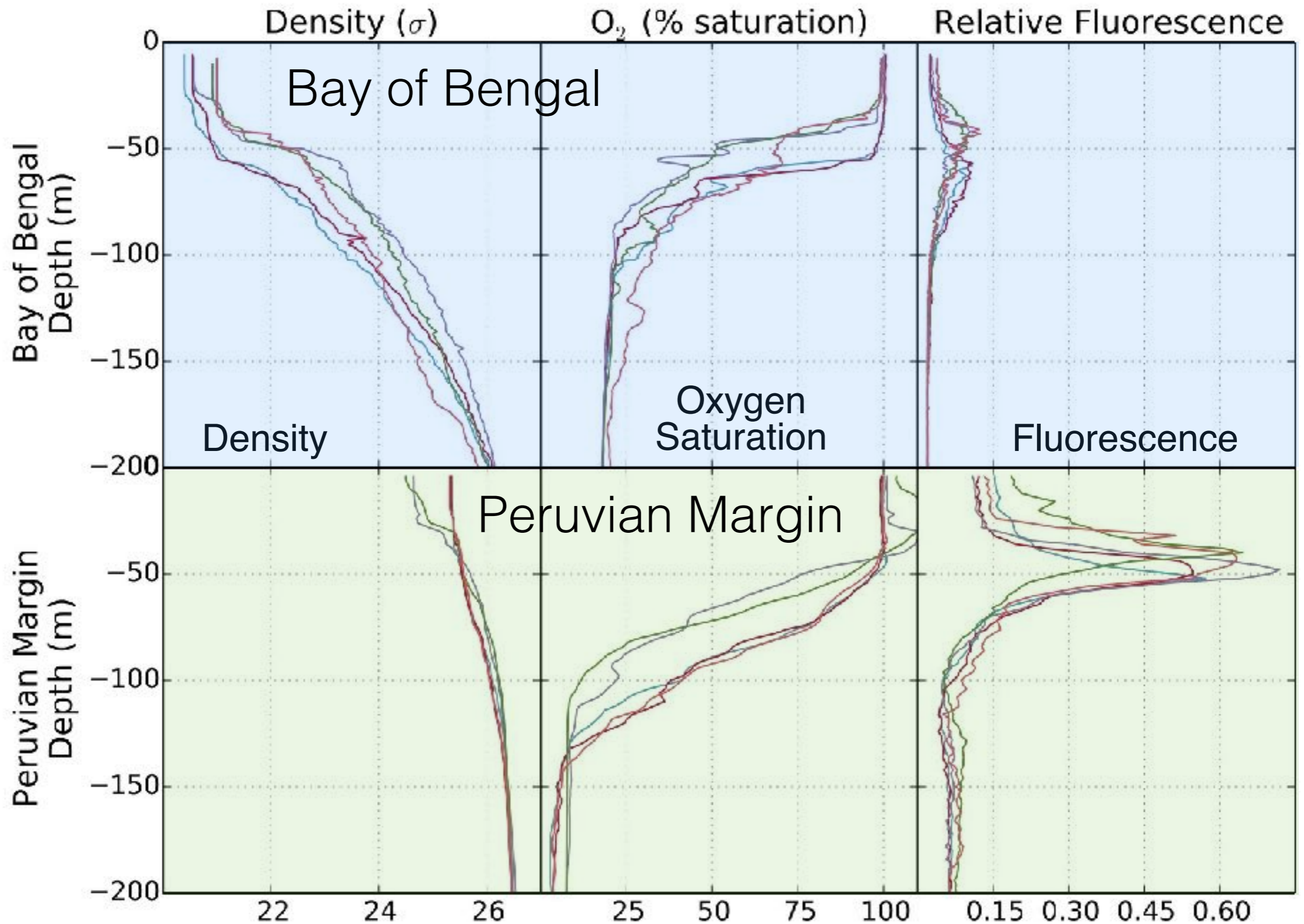
2013 ASIRI cruise

Oxygen from ARGO in the Bay of Bengal (Figure courtesy Eric D'Asaro)

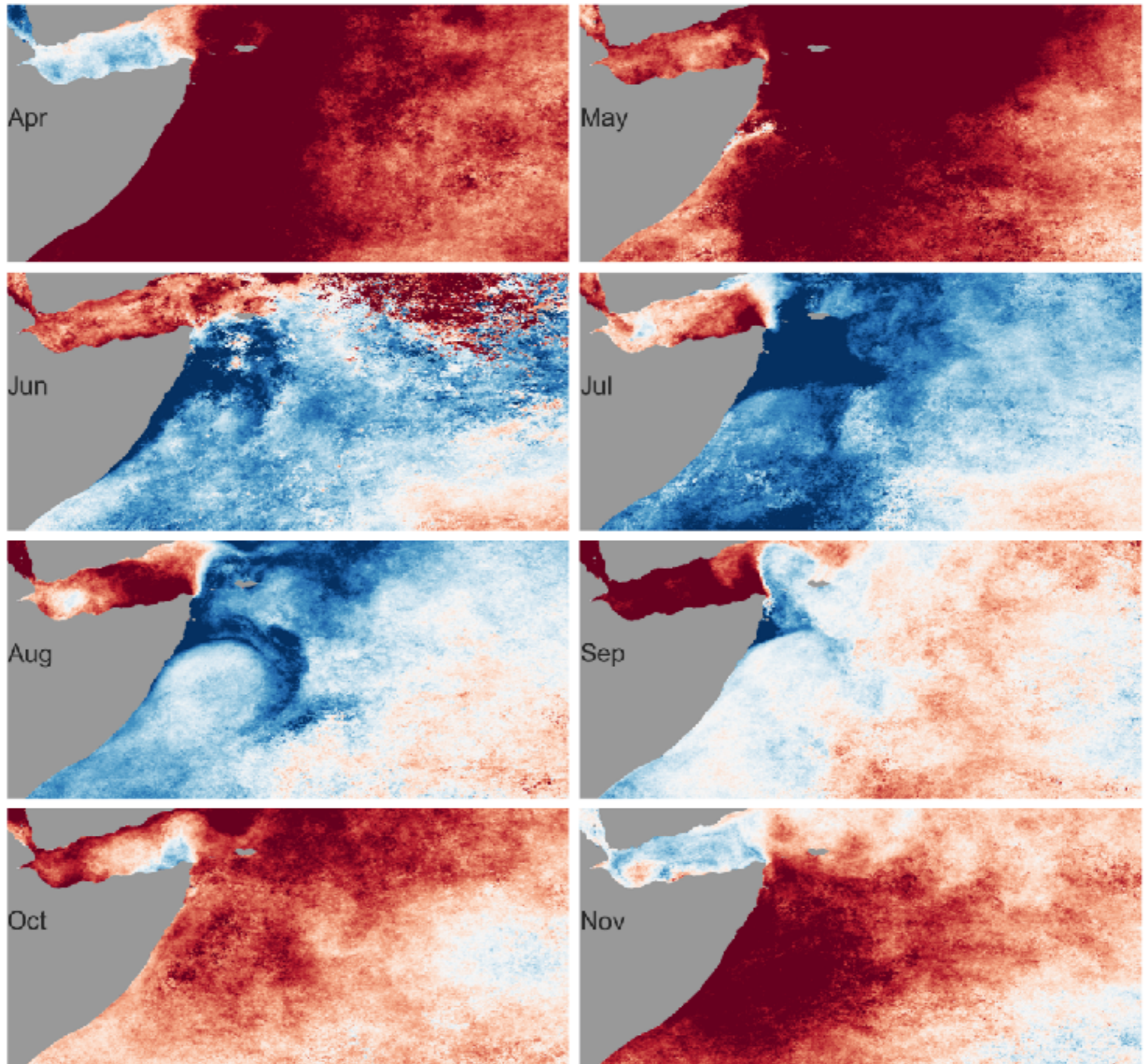
Wijesekera et al., BAMS, 2016

But, the Bay of Bengal differs from the Eastern Pacific OMZs

It exists in spite of low productivity due to high vertical density stratification



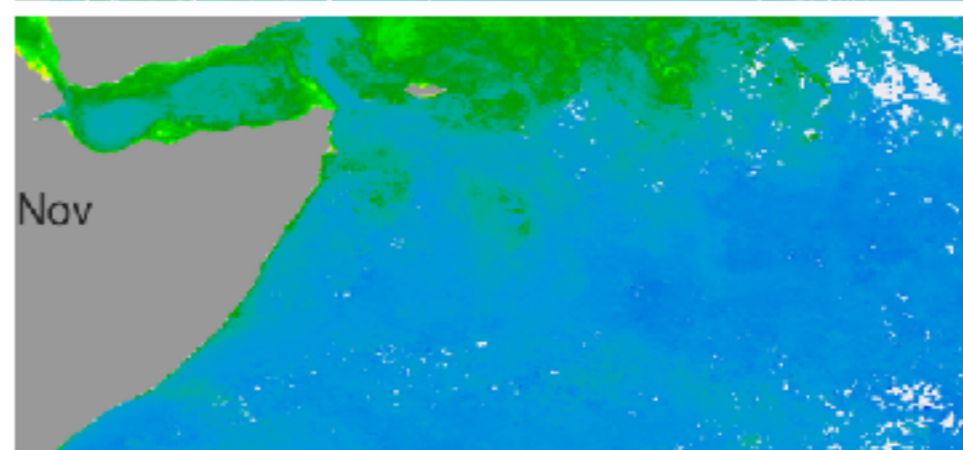
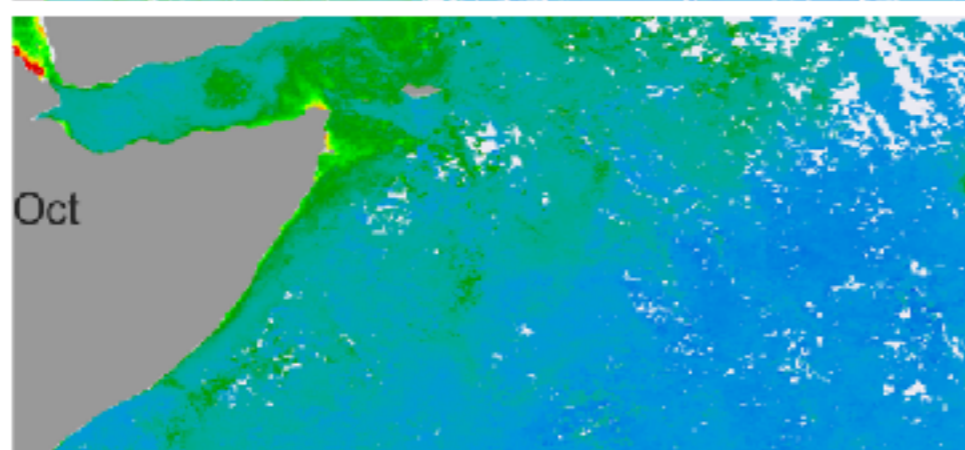
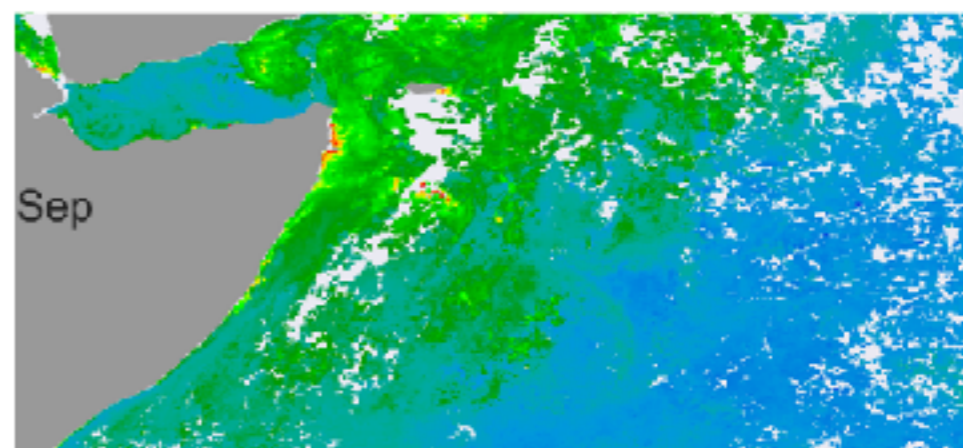
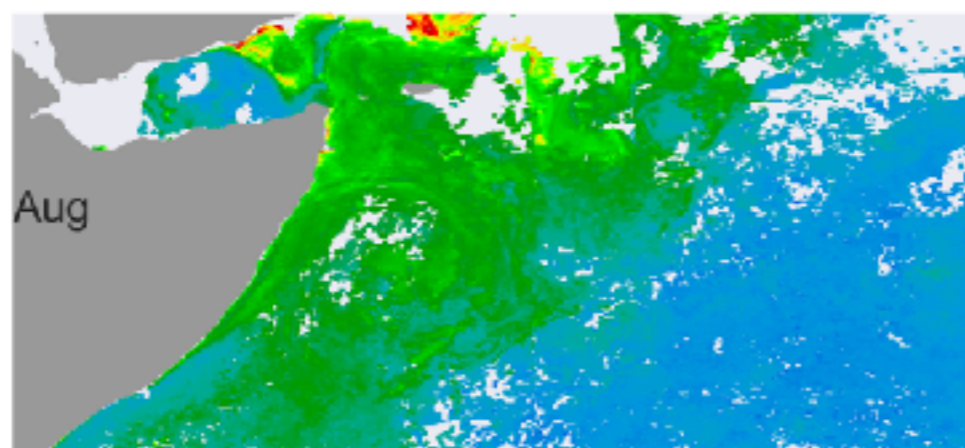
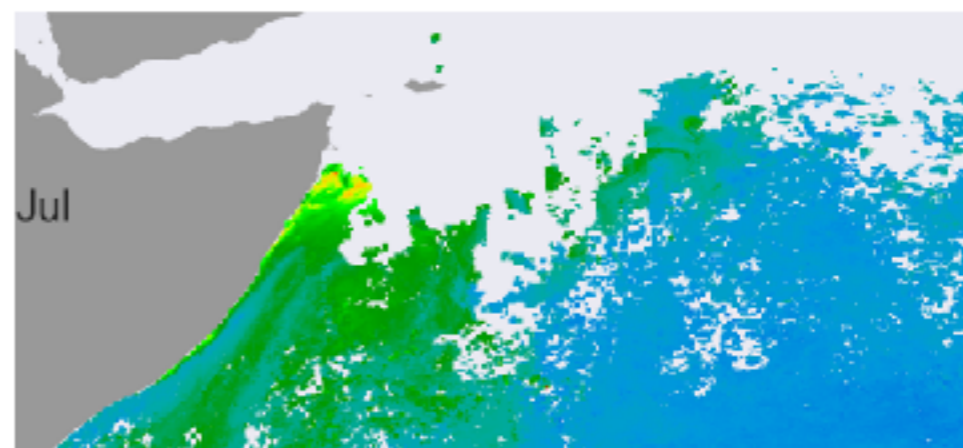
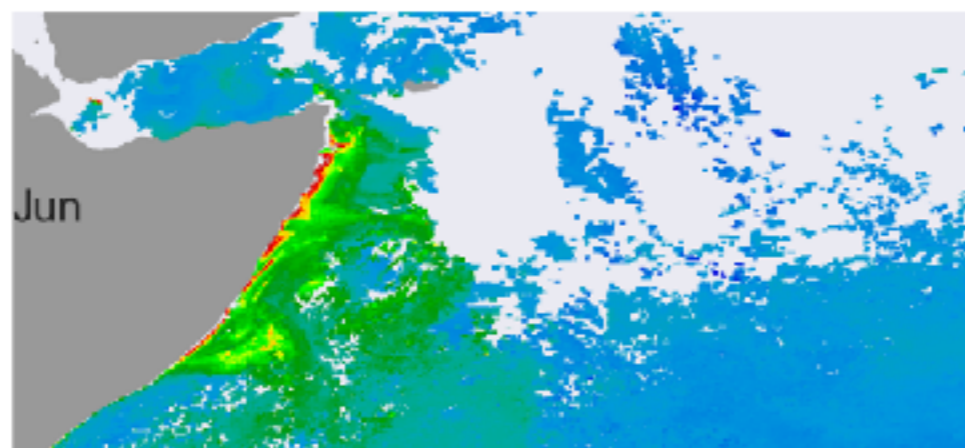
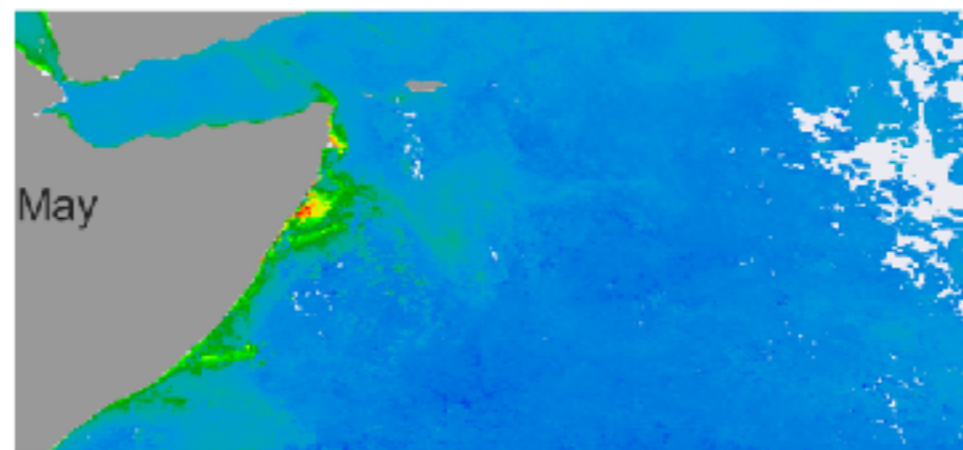
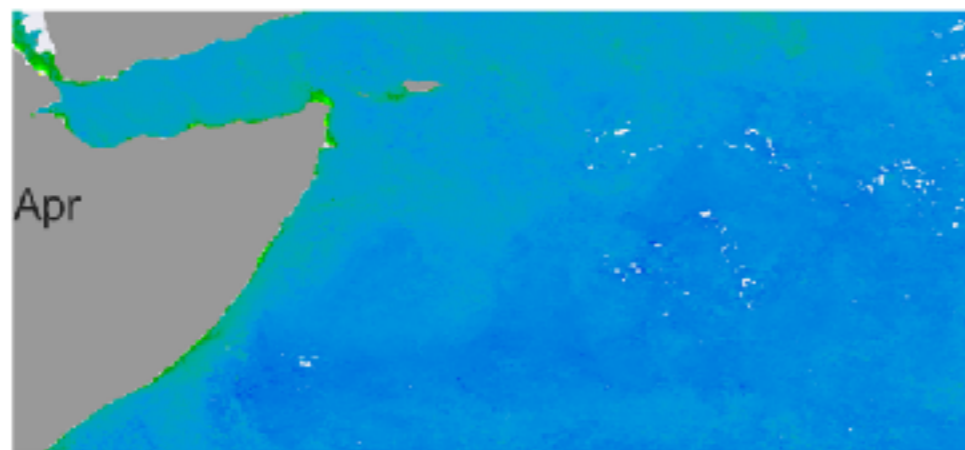
2015 monthly
SST
Anomaly
from annual
mean
based on 4 km
daily MODIS
data



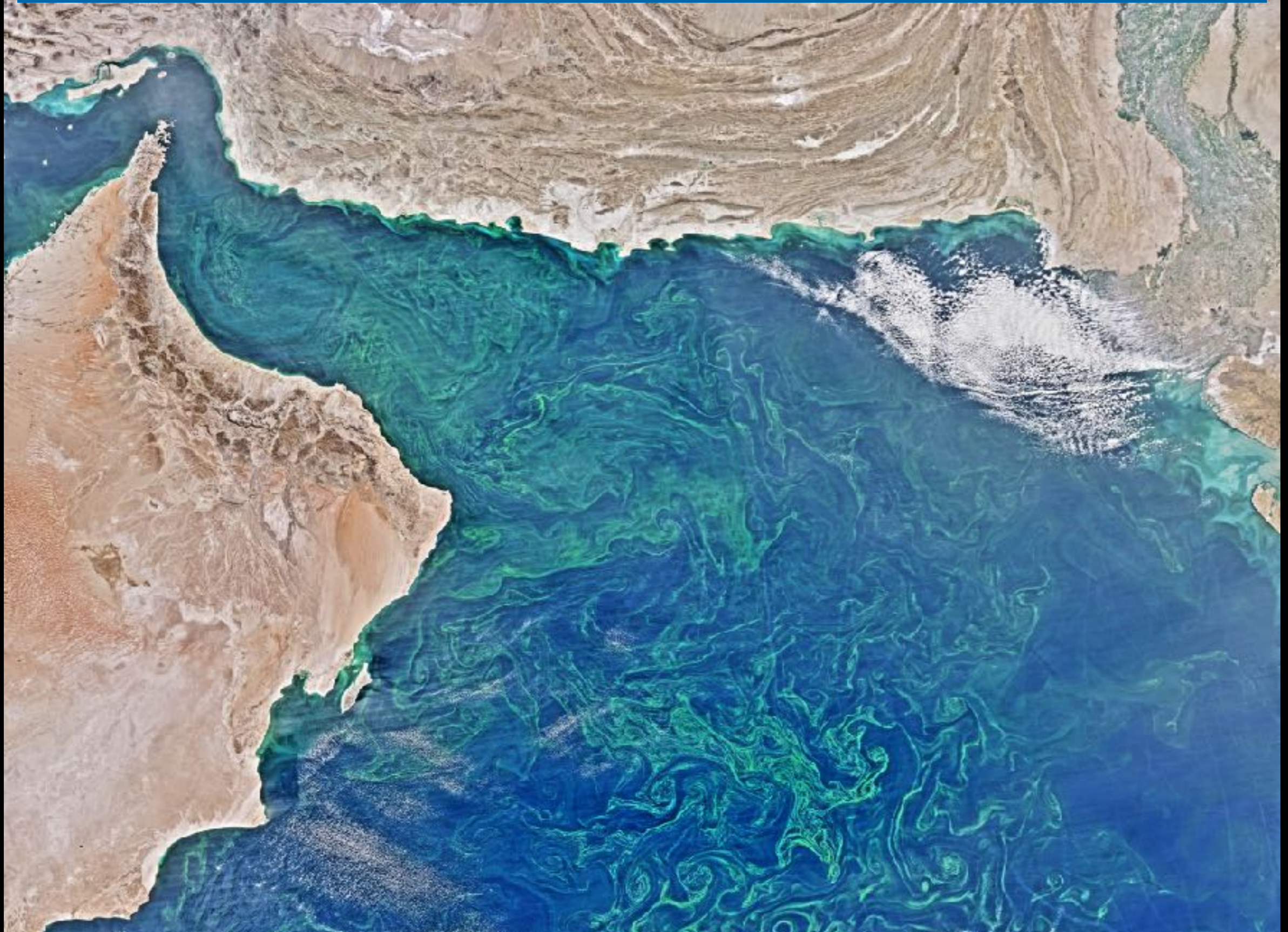
2015 monthly
Chlorophyll
log scale

4 km daily
MODIS data

$0.1 - 50 \text{ mg m}^{-3}$



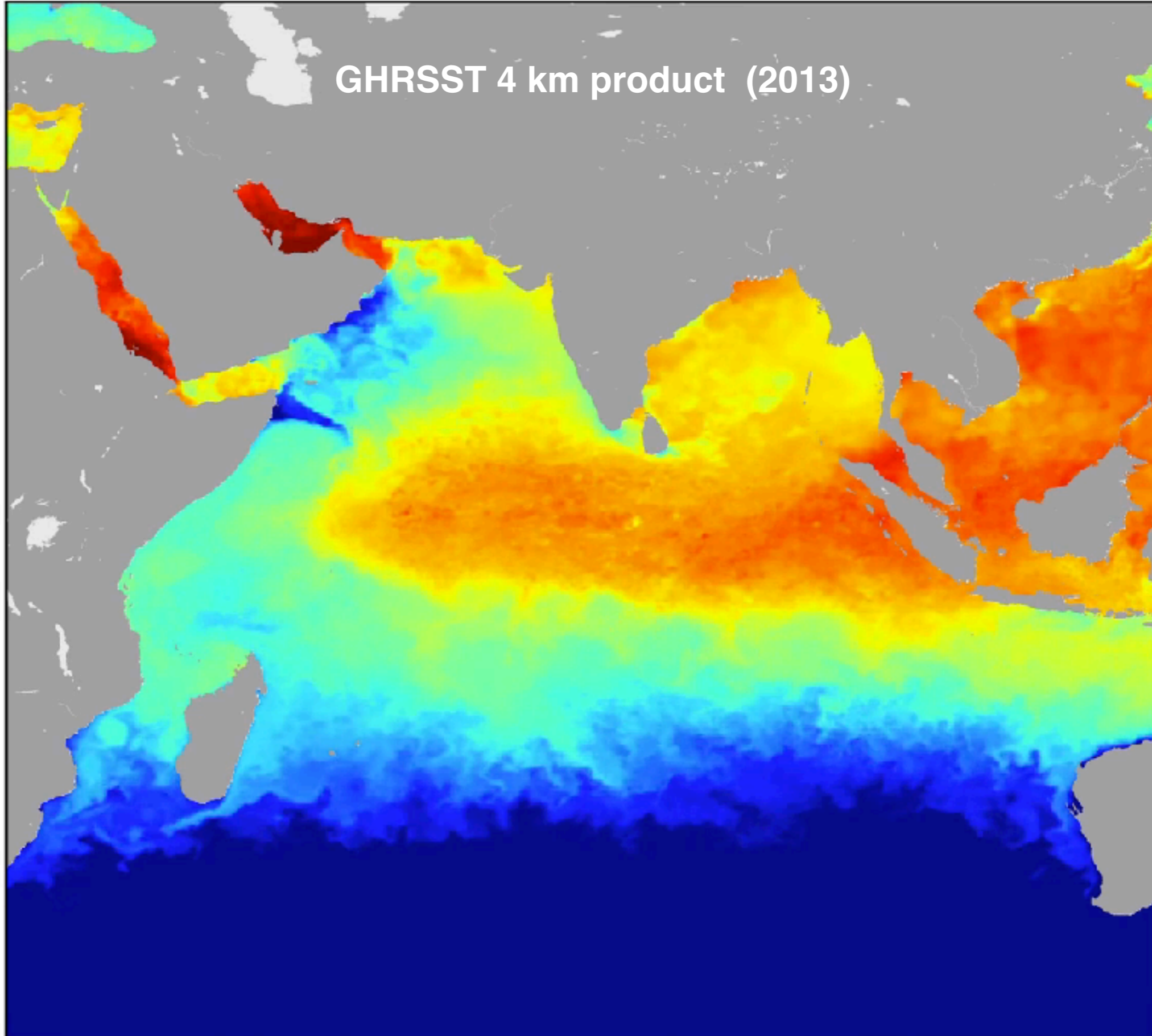
February 14, 2015, from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite



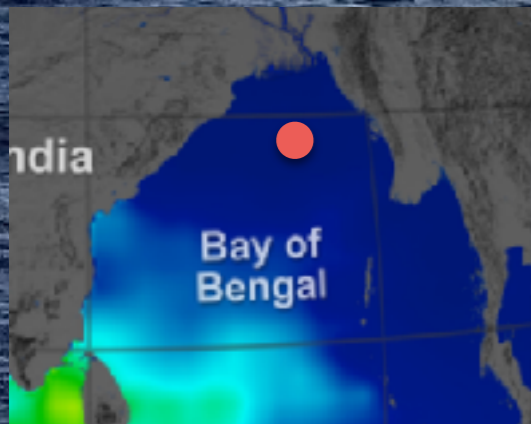
2013-08-02 00:00

**SUMMER
SST**

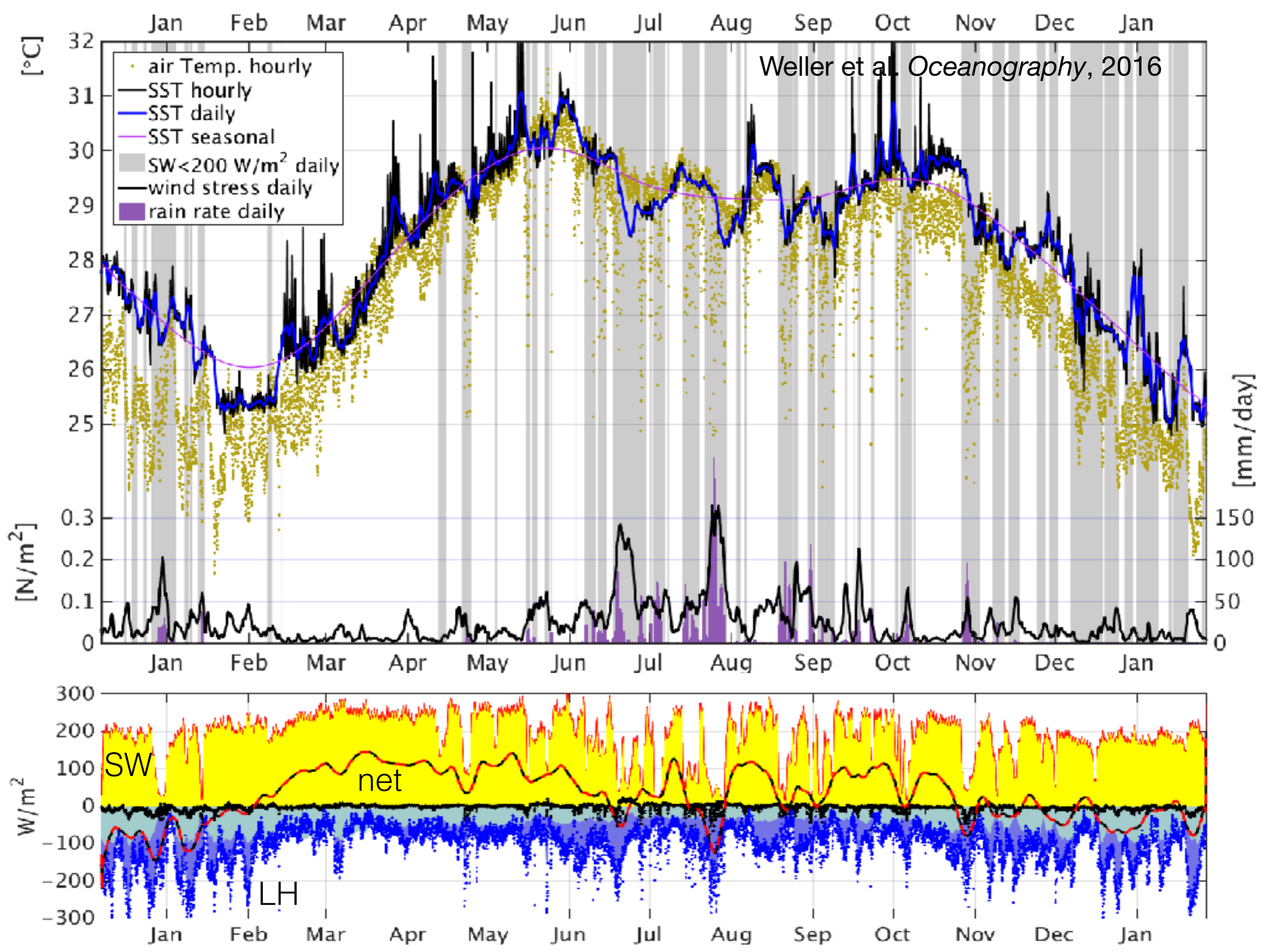
GHRSSST 4 km product (2013)



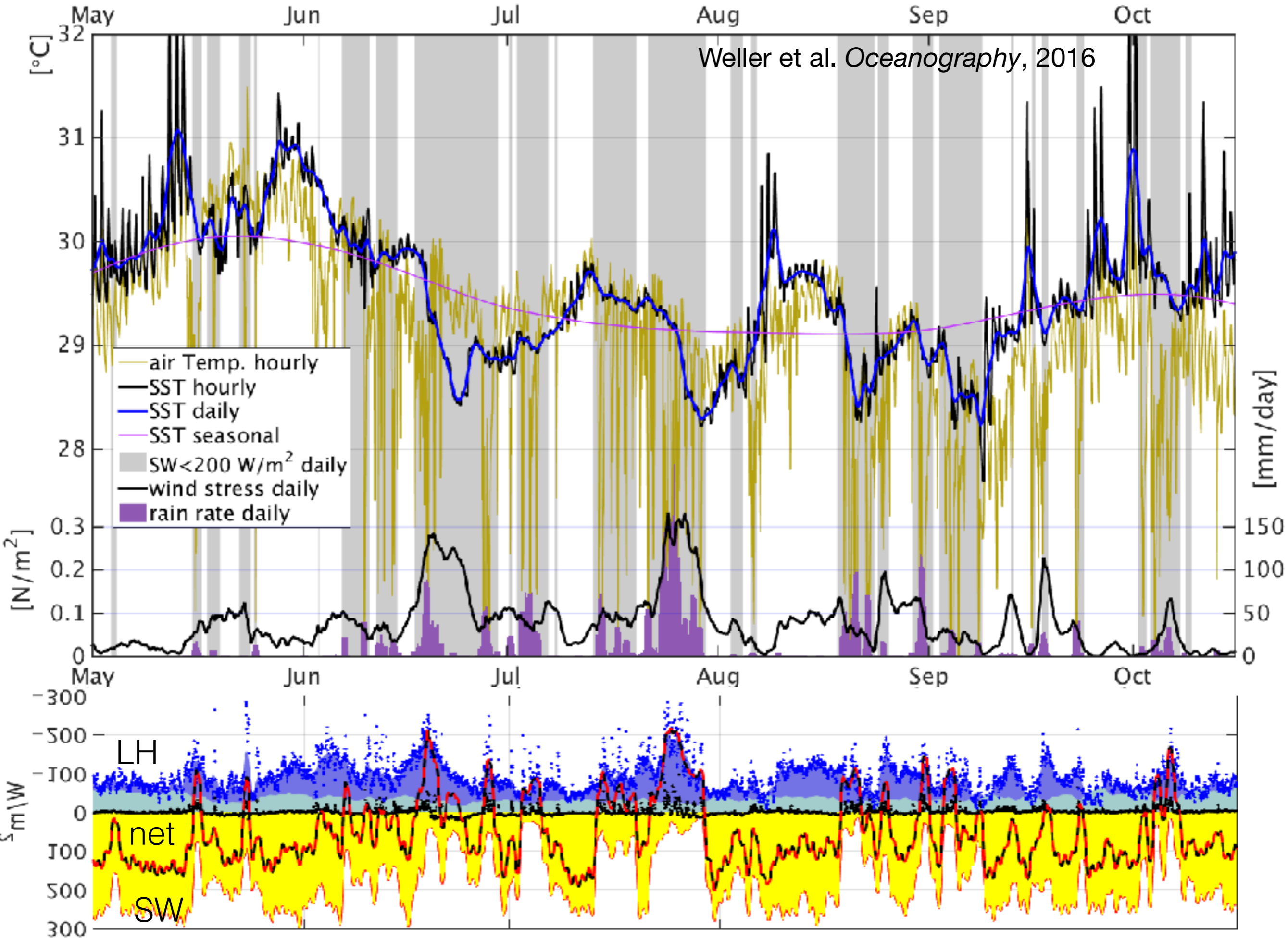
Bob Weller, Tom Farrar (WHOI)
Debasis Sengupta, M. Ravichandran, R. Venkatesan (India)



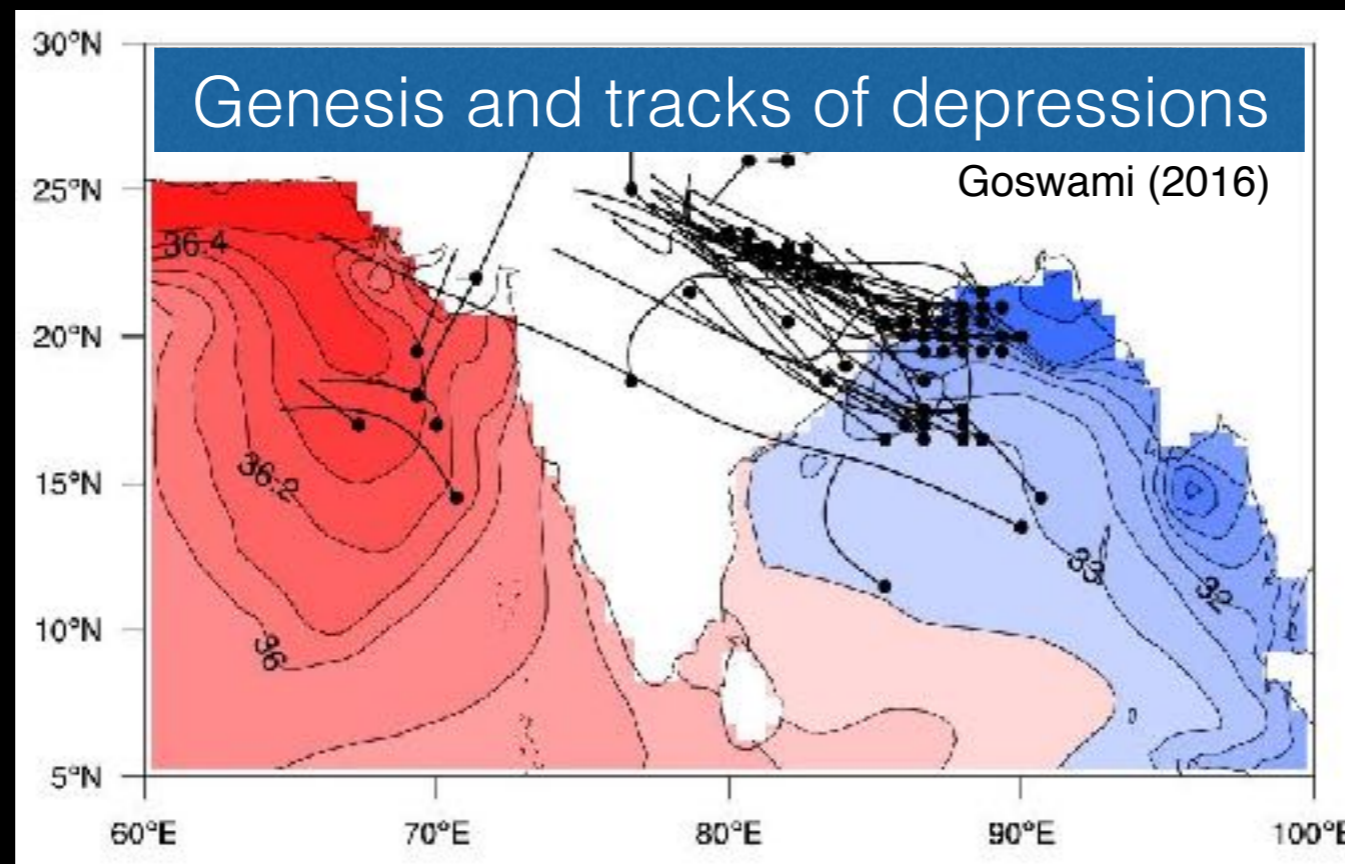
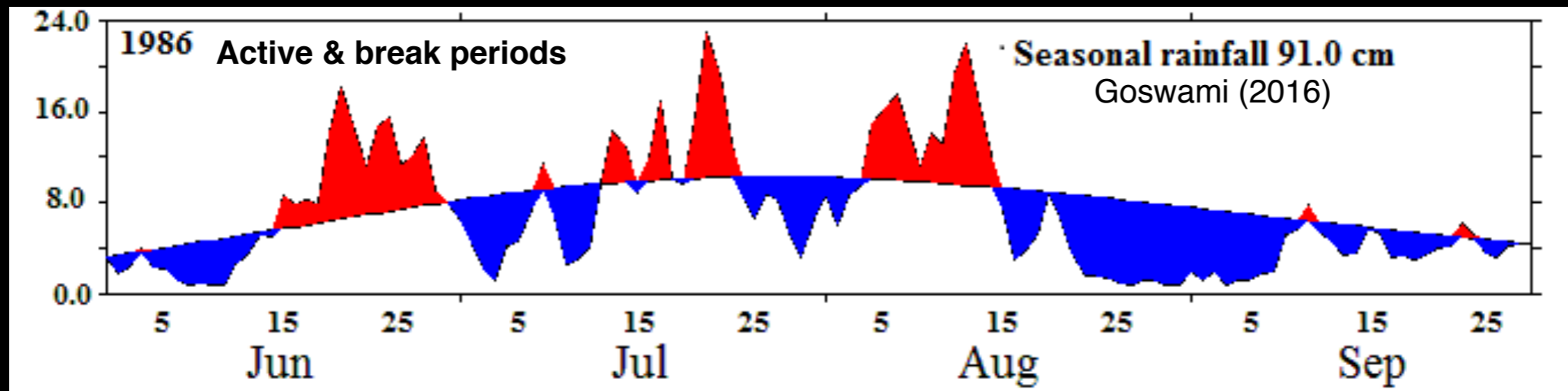
- WHOI Mooring at 18N in 2015-16, Indian mooring 2017
- Surface and upper ocean structure. Air-sea flux estimates
- Sustained measurements in a changing ocean



Weller et al. *Oceanography*, 2016



Monsoons: A challenge for prediction



Coupled forecast models - a common problem

- Sea surface is too cool, stratification weak
- Intra-seasonal variability not captured

Ocean needs to be better represented

Summary



- The northern Indian Ocean is unique in the way the atmosphere and ocean interact creating the monsoons.
- The freshwater from the monsoon has a feedback on this interaction
- Salinity exercises control on the density in this Bay of Bengal, altering
 - the SST response
 - response to wind stress
 - upwelling and mixing
 - biogeochemistry
 - phytoplankton productivity

Sea surface salinity
Aquarius satellite (Oct)

