How eddies and wind modulate the OMZ in the Arabian Sea?

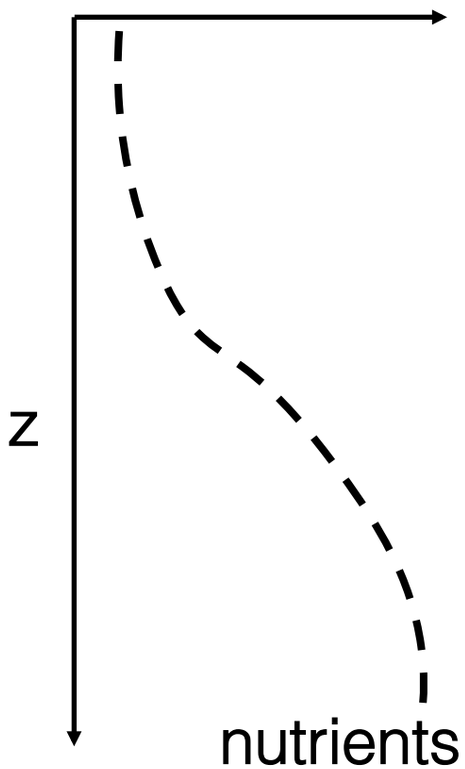
Marina Lévy
L. Resplandy, Keerthi, Parvathi
M. Lengaigne
O. Aumont, L. Bopp, V. Echevin, J. Vialard, S. Pous,
V. V. S. S. Sarma, and D. Kumar

Arabian Sea
Chlorophyll
Modis

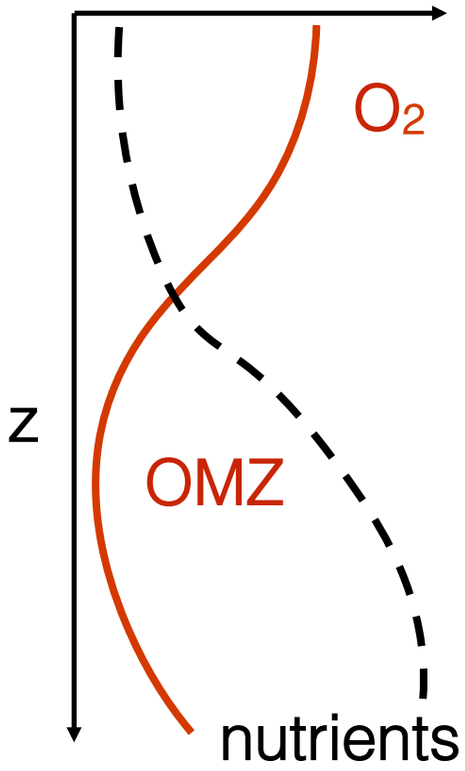
Oman

India

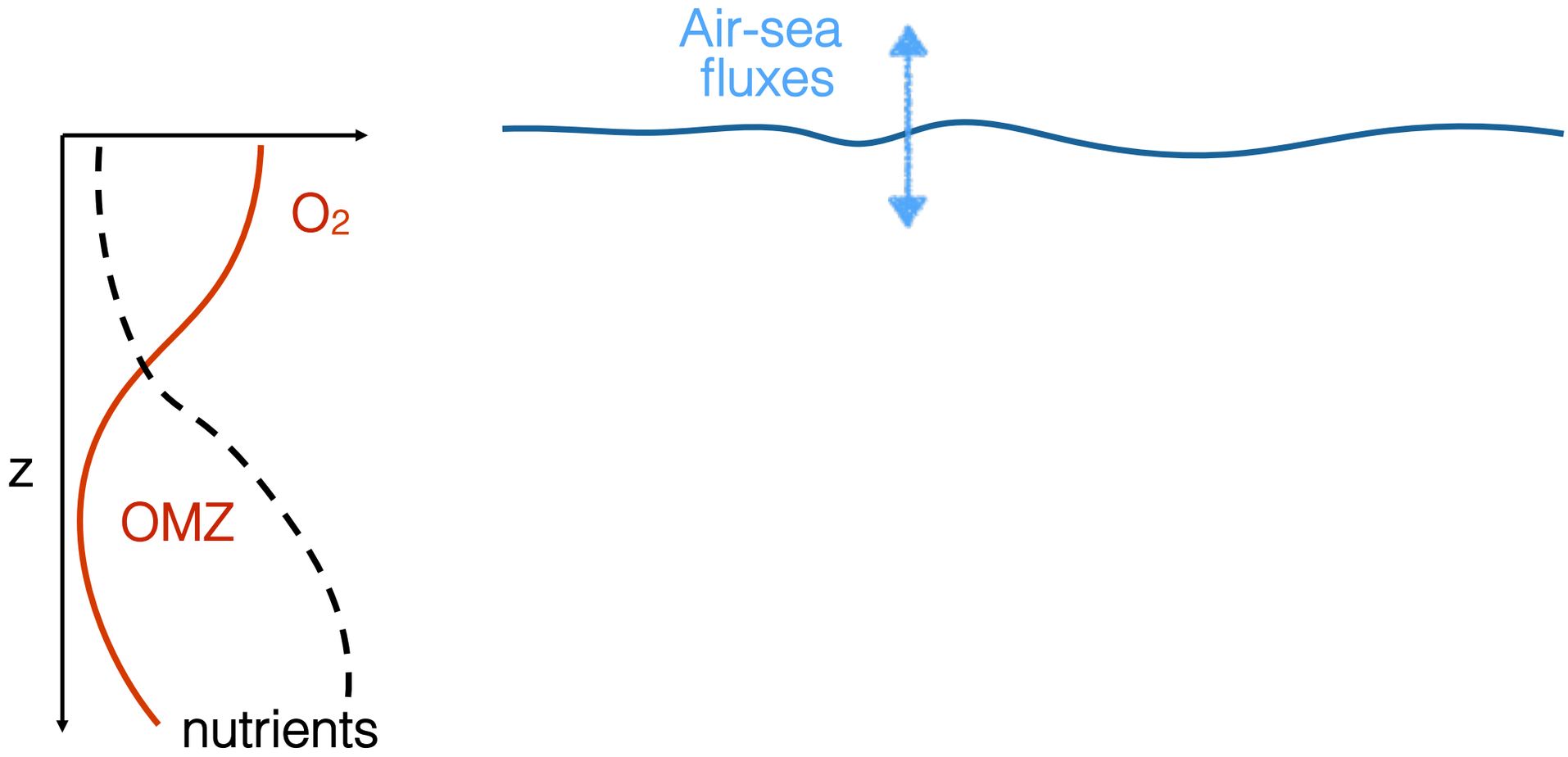
Processes impacting oxygen distribution in the ocean



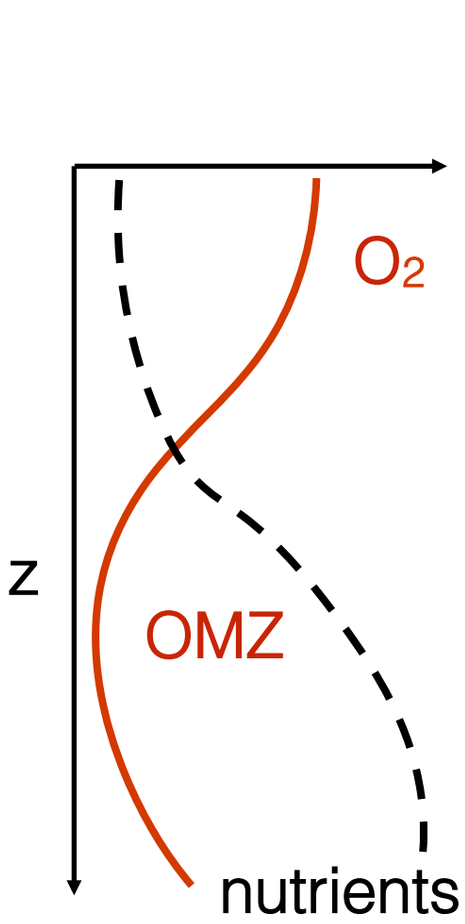
Processes impacting oxygen distribution in the ocean

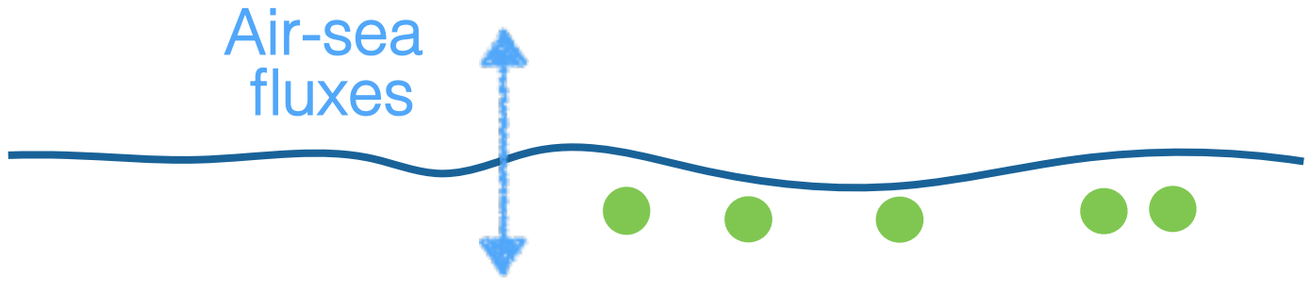


Processes impacting oxygen distribution in the ocean

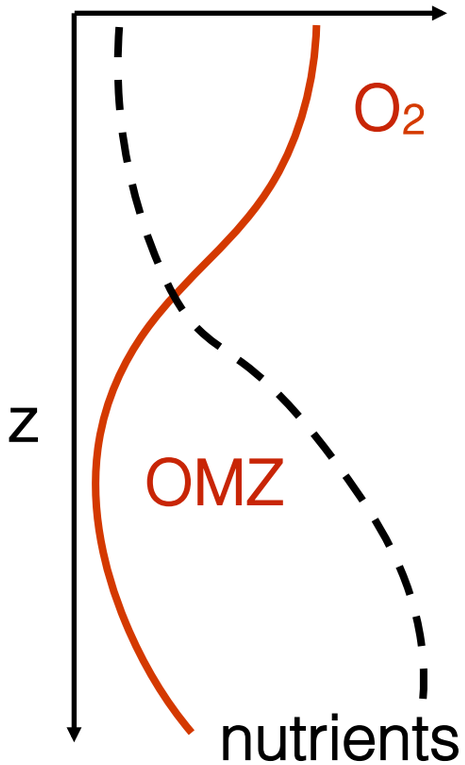


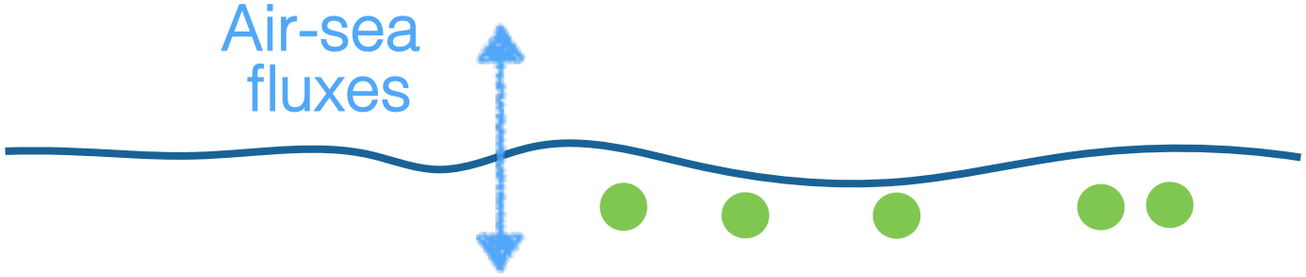
Processes impacting oxygen distribution in the ocean

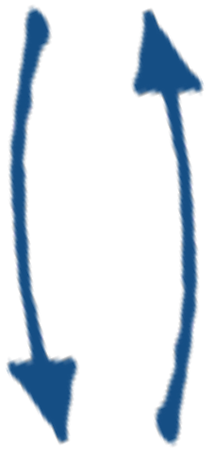




Processes impacting oxygen distribution in the ocean



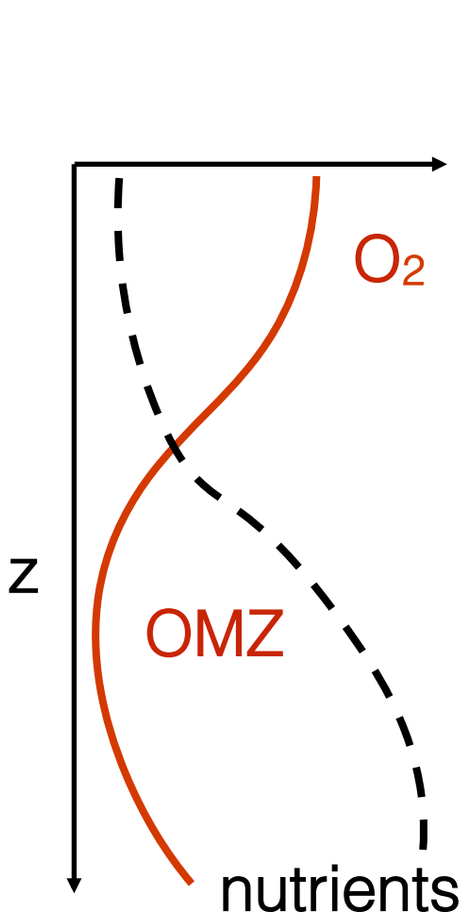


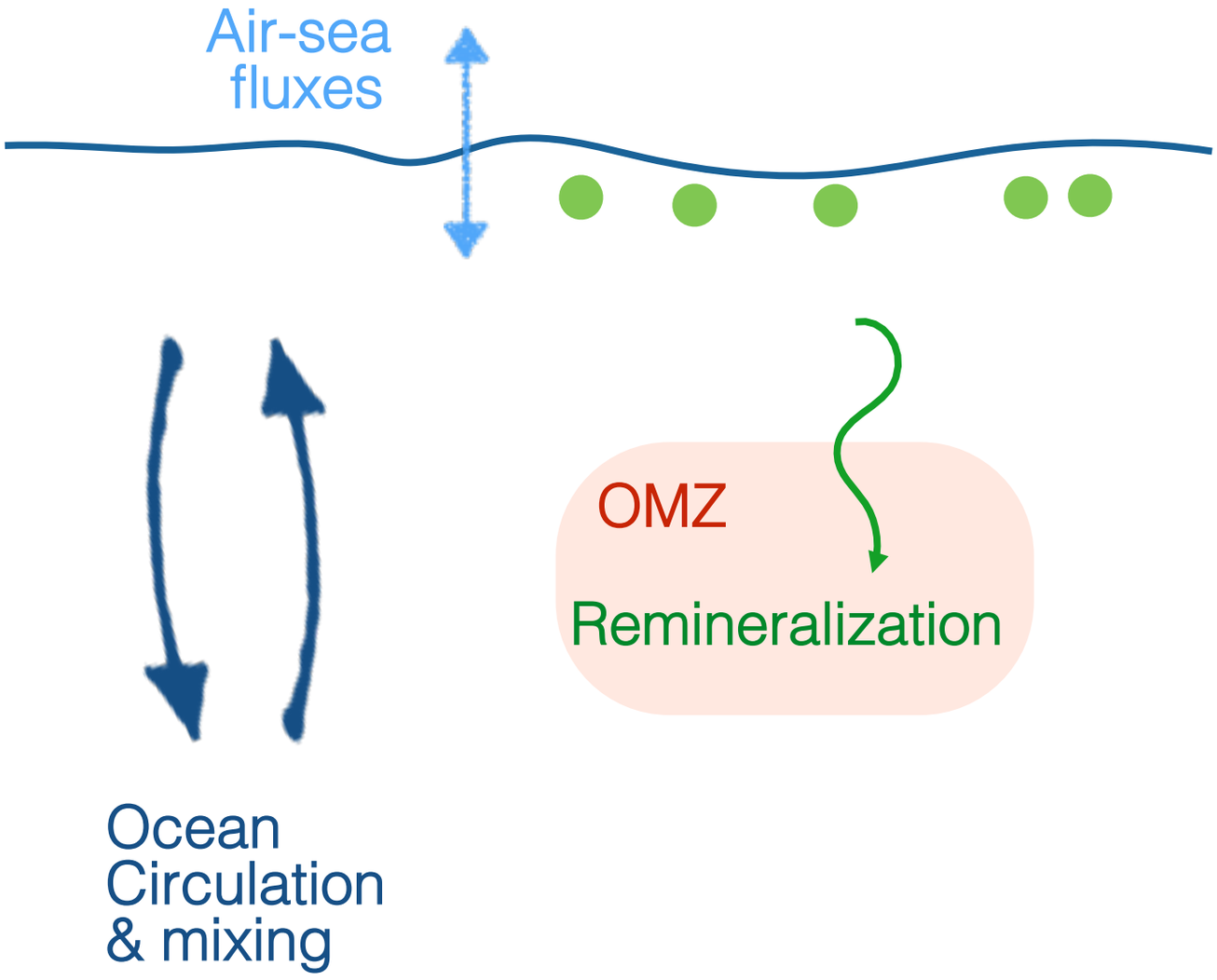


Ocean
Circulation
& mixing

Processes impacting oxygen distribution in the ocean

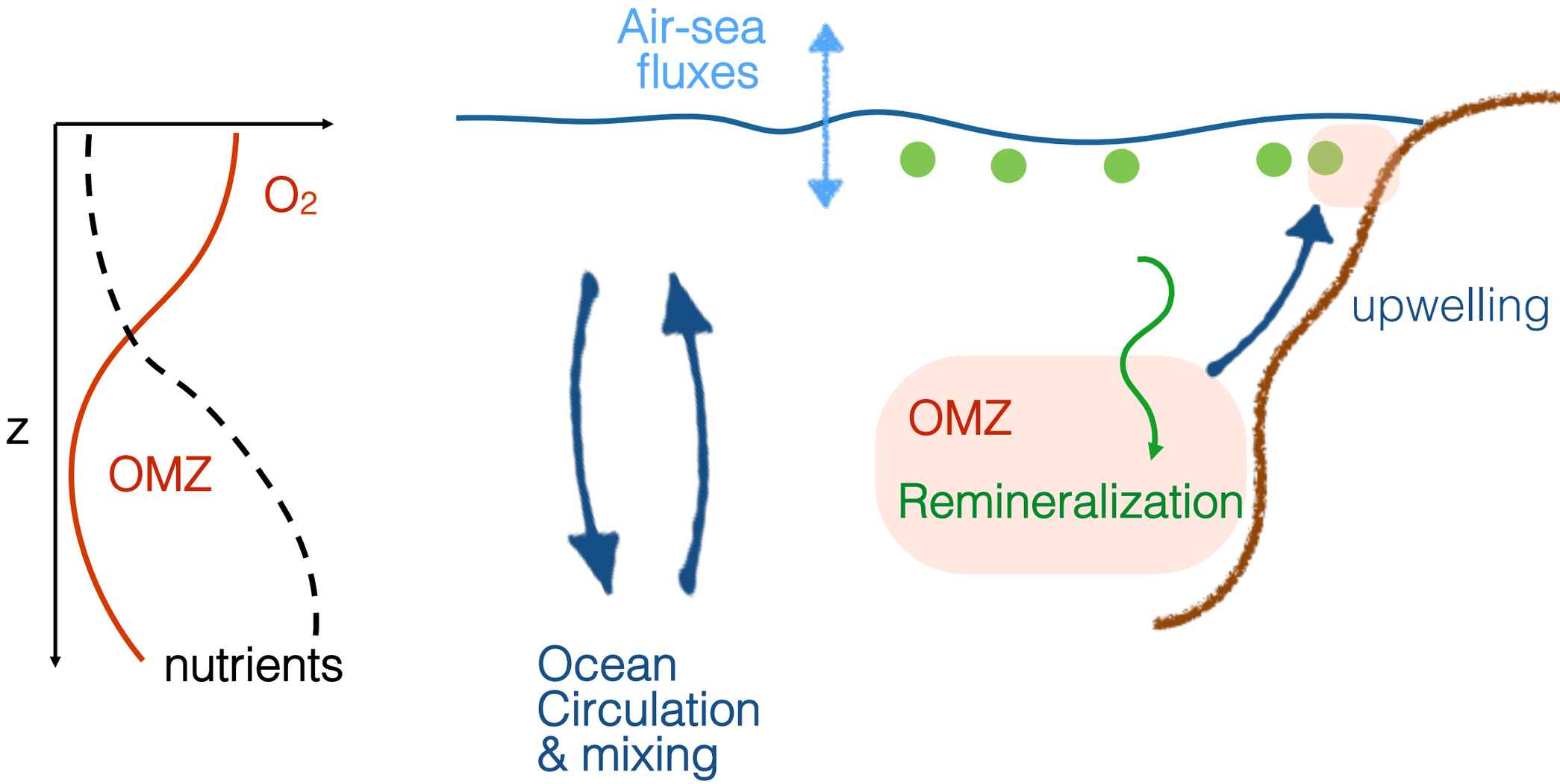
➢ low ventilation and intense biological production





Processes impacting oxygen distribution in the ocean

➢ coastal anoxic events



Processes impacting oxygen distribution in the ocean

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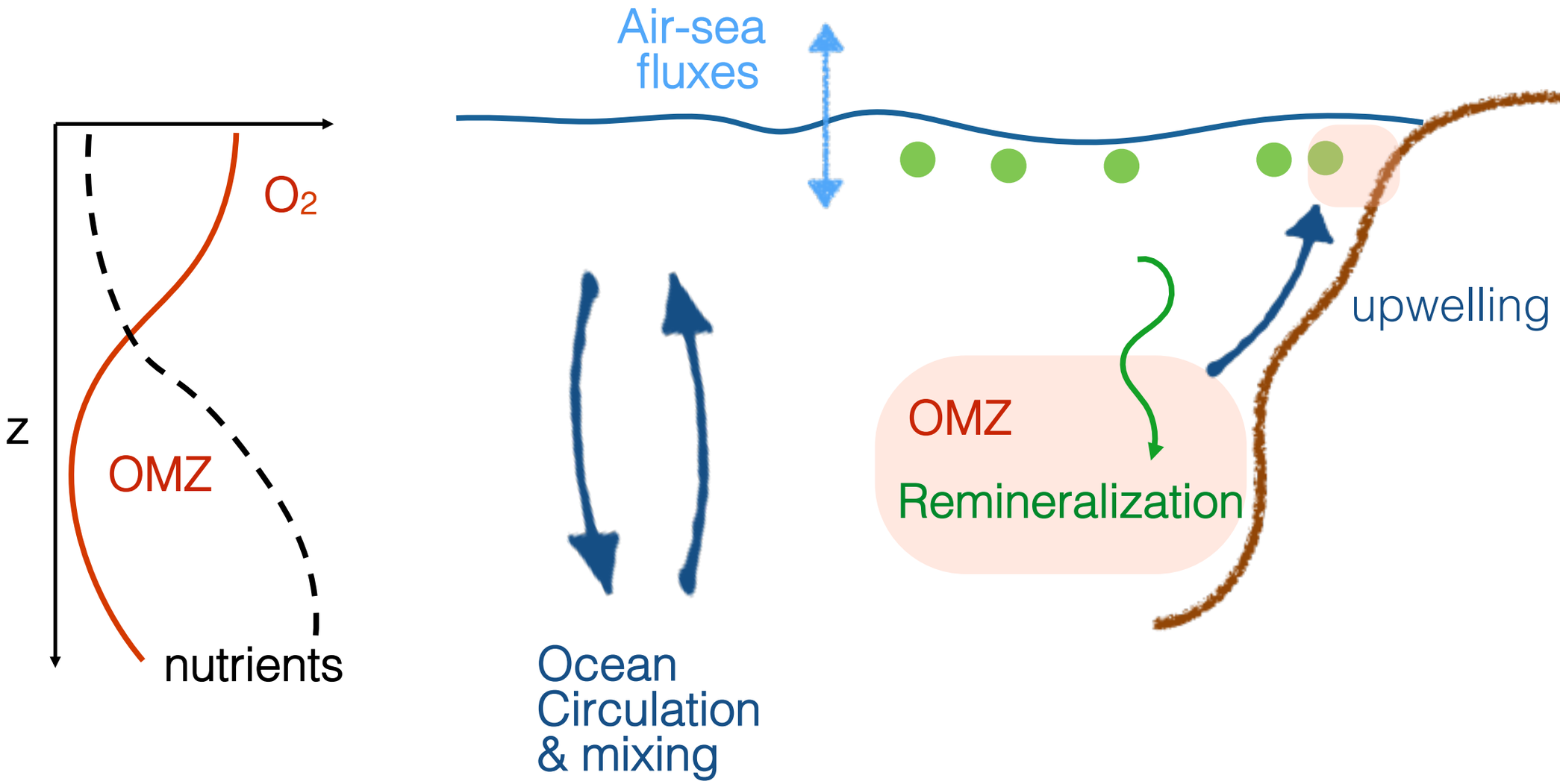
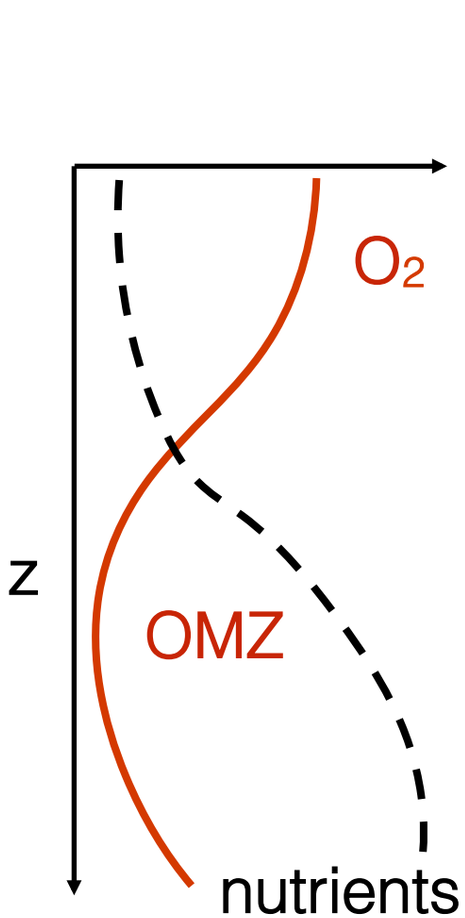
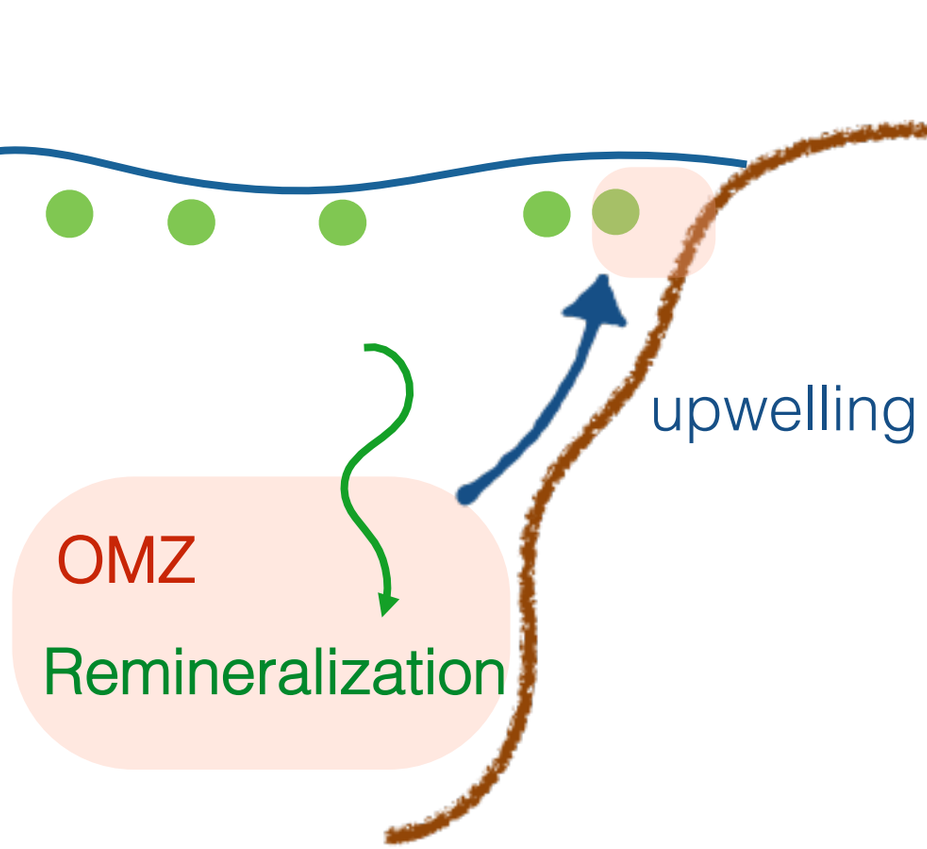


Processes impacting oxygen distribution in the ocean

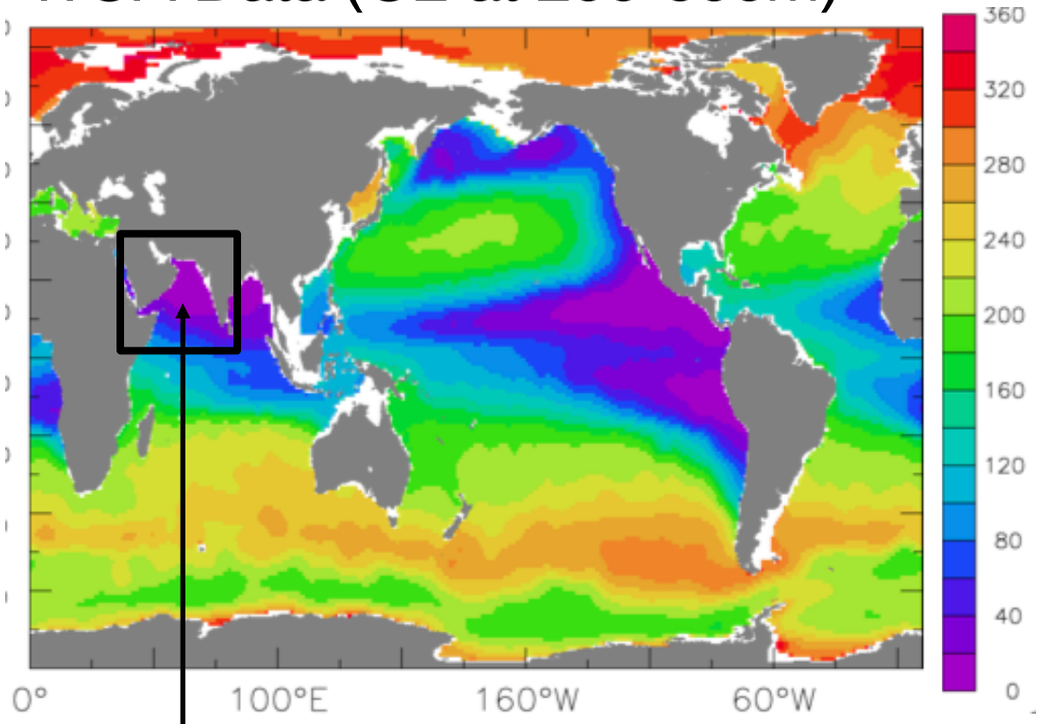
➢ Eddies and wind: affect PP, ventilation, transport





Context: oxygen minimum zone and climate change

WOA Data (O2 at 200-600m)

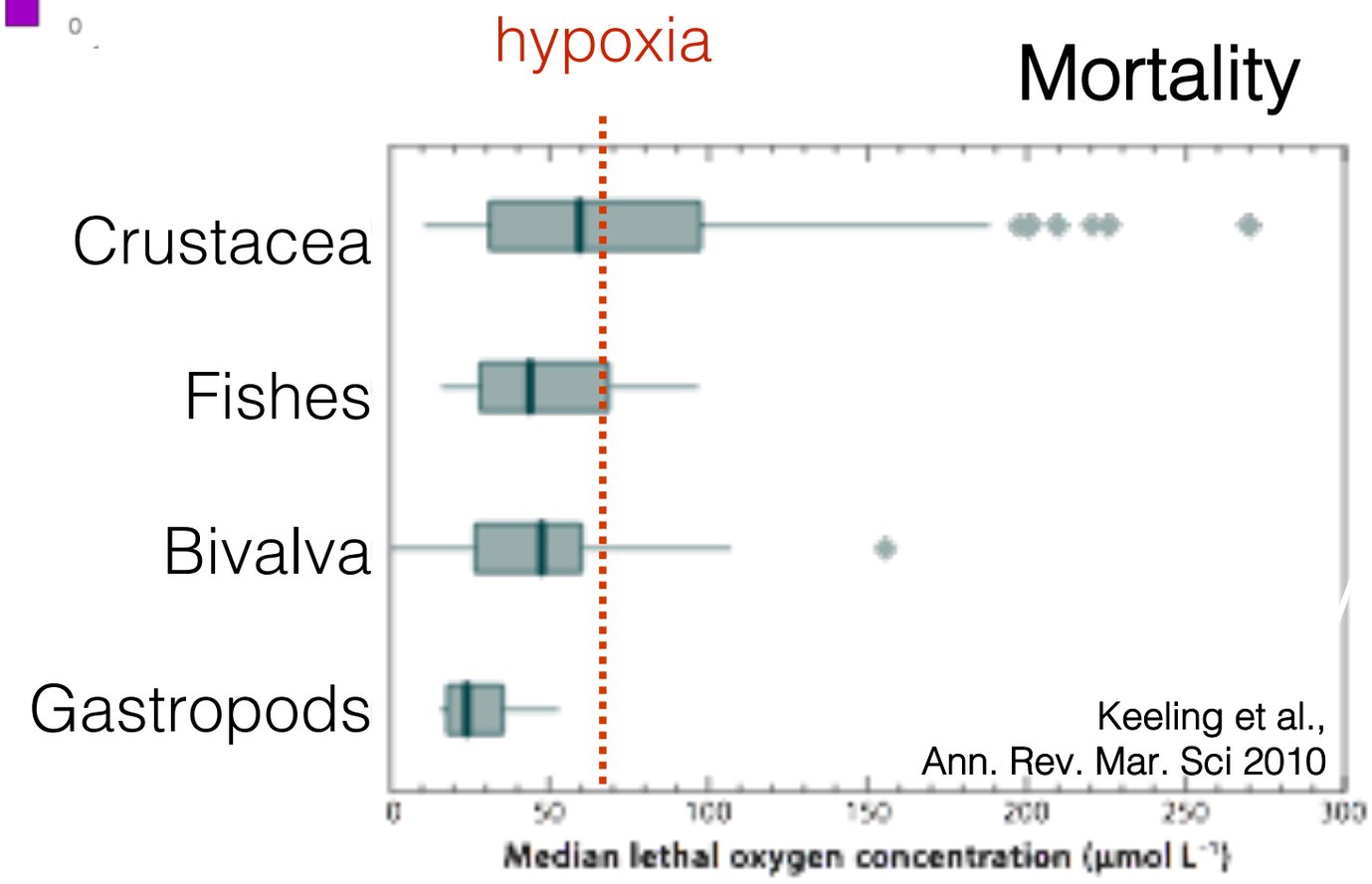


Bopp, Resplandy et al., Biogeosciences 2013

<20 mumol/L

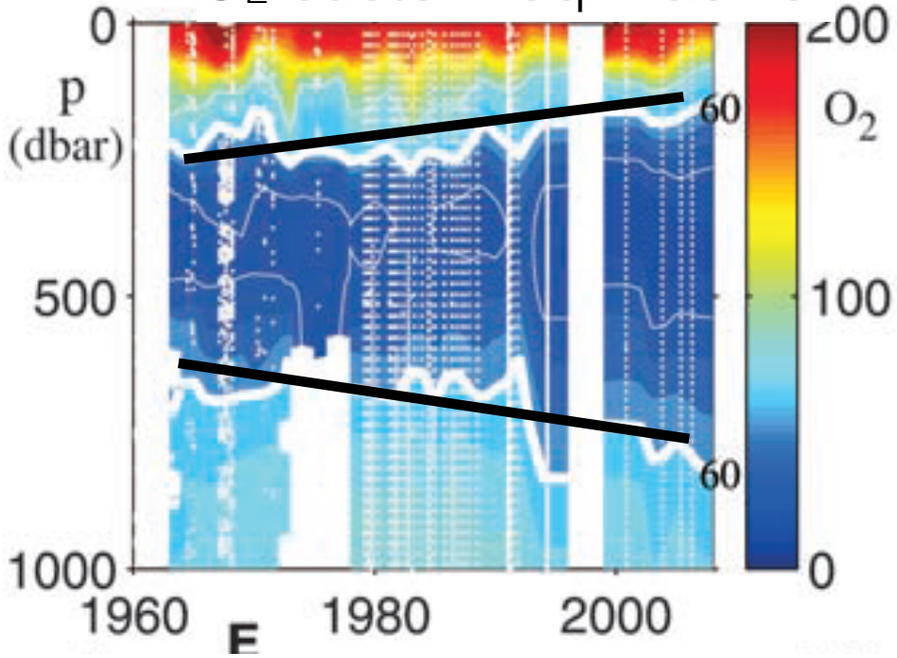
thickest oxygen minimum zone (OMZ) - 1000 m

bathes coasts of populated countries prone to eutrophication



Context: OMZ climate change vs. natural variability

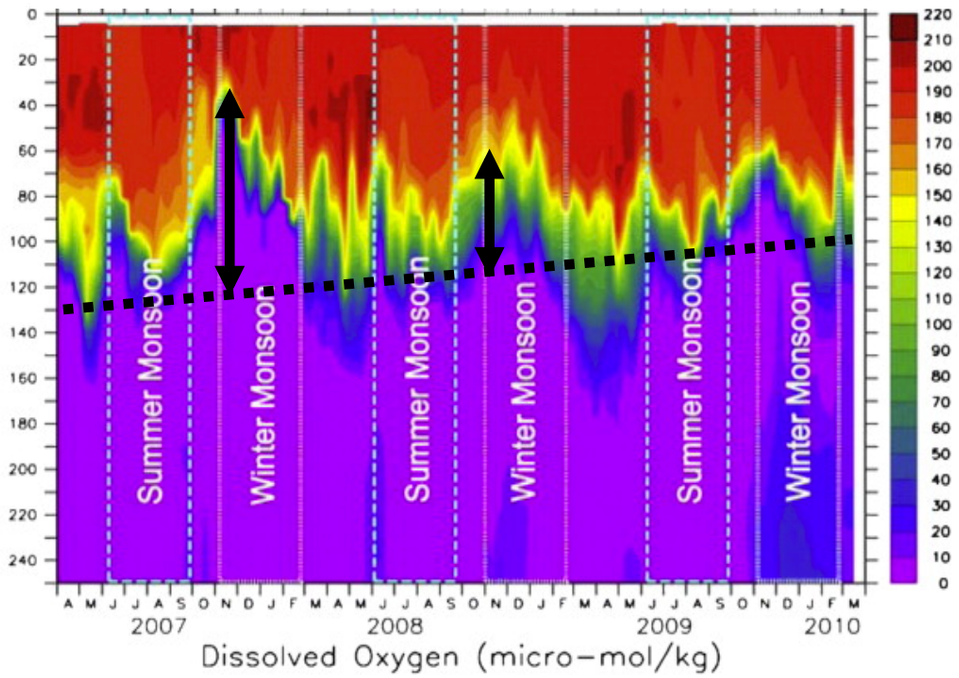
O_2 eastern eq. Pacific



Stramma et al., Science 2008

Increase in OMZ volume

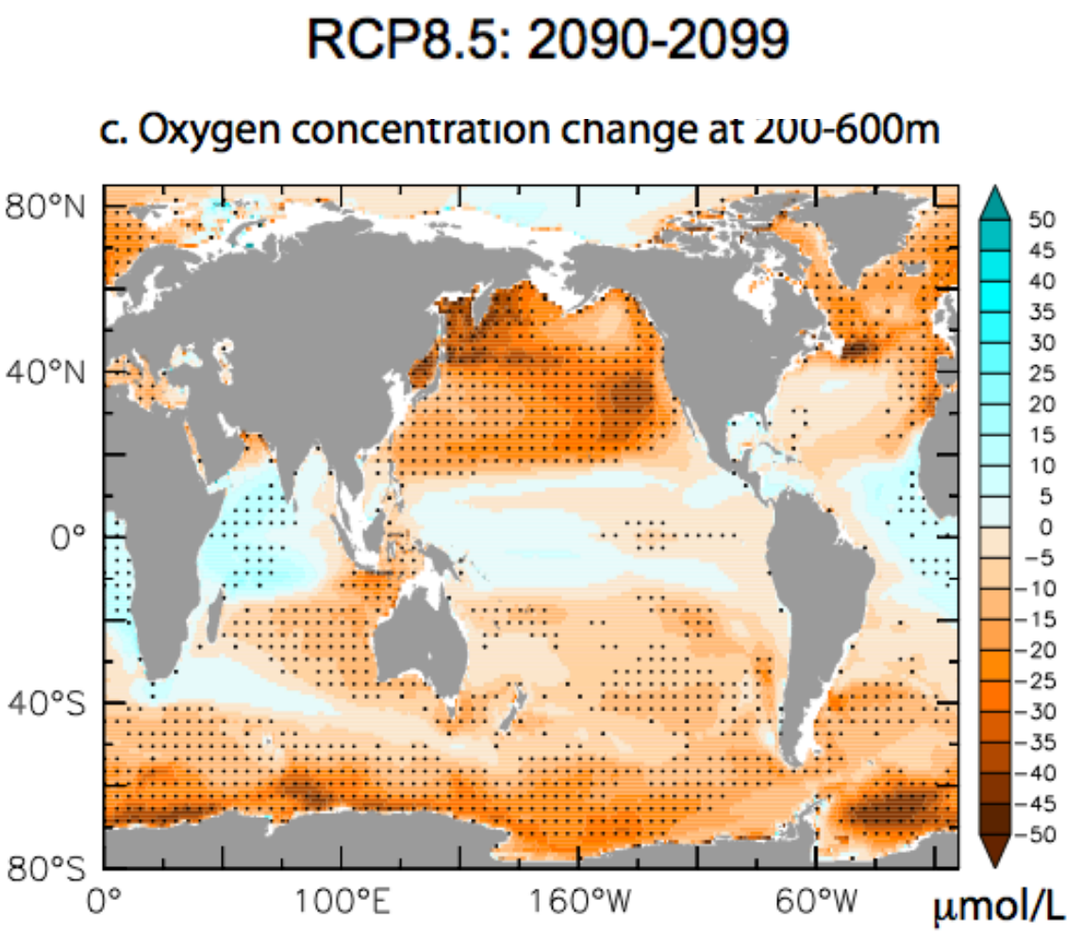
O_2 in Central Arabian Sea Argo float

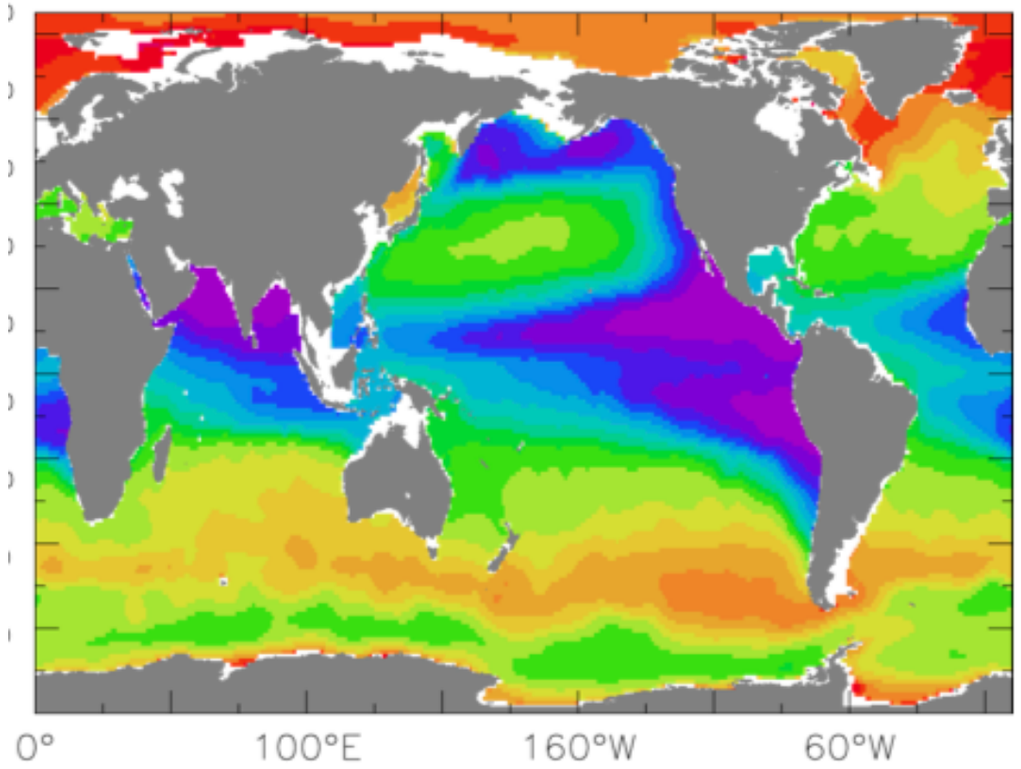


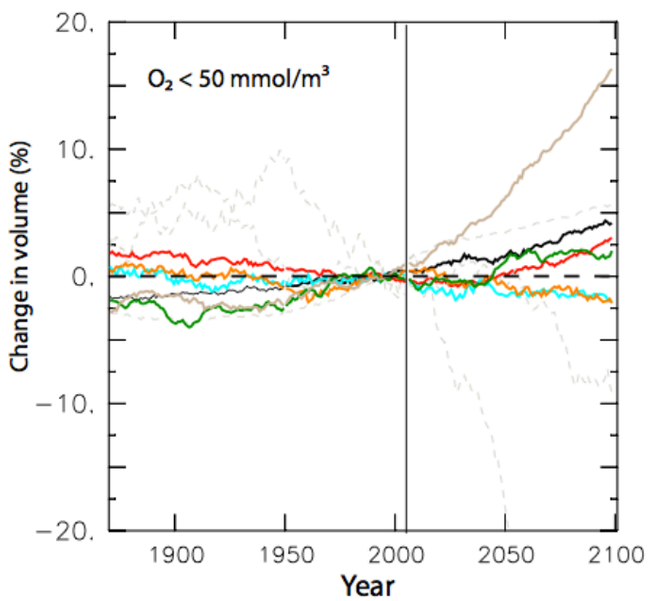
Prakash et al, Journal of Sea Res. 2012

No clear long term trend
Strong natural variability

Context: OMZ change in CMIP5 models





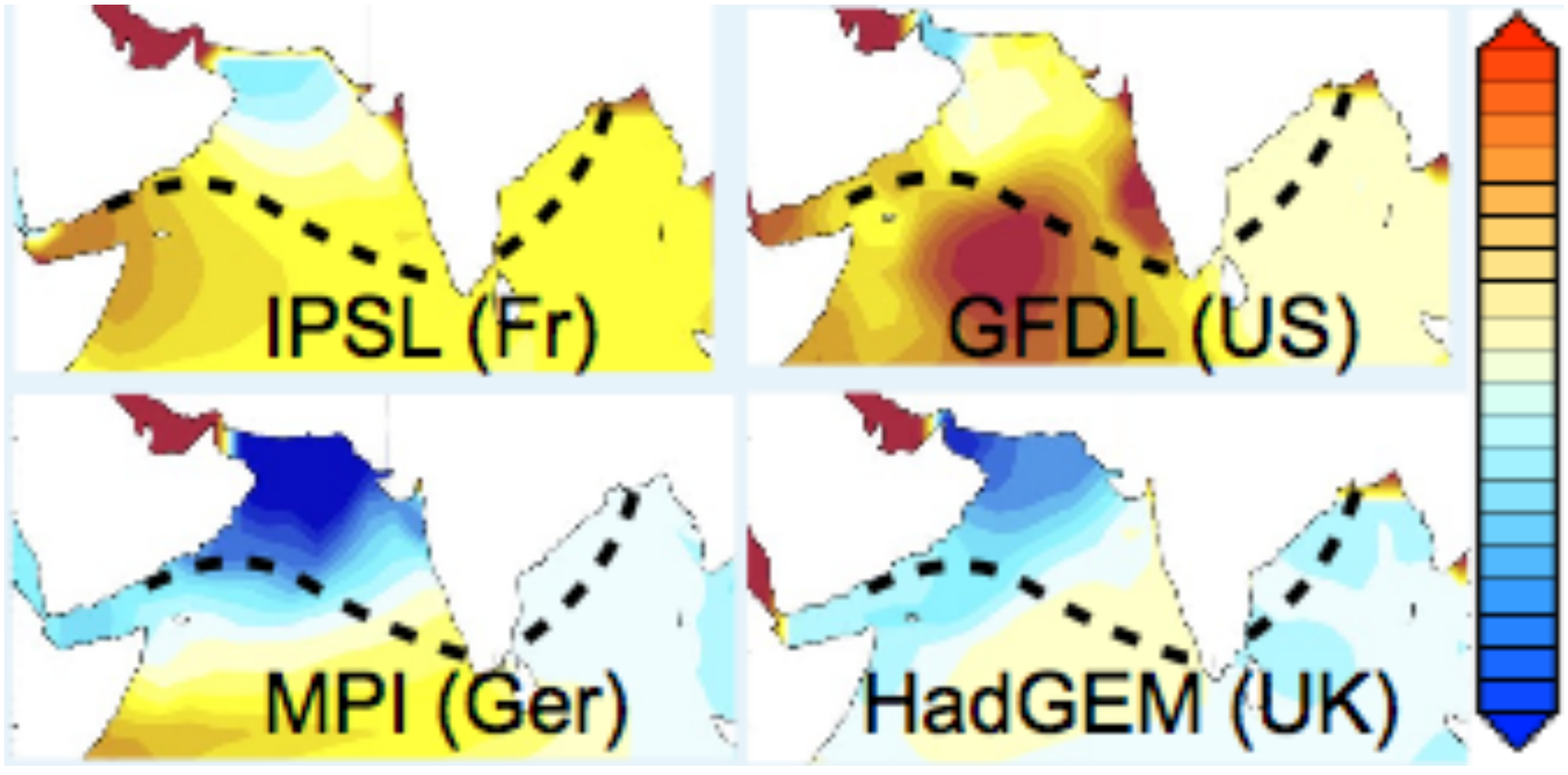


➢ large uncertainties in model projections

Bopp et al., 2013

Context: OMZ change in CMIP5 models

Disparate future predictions



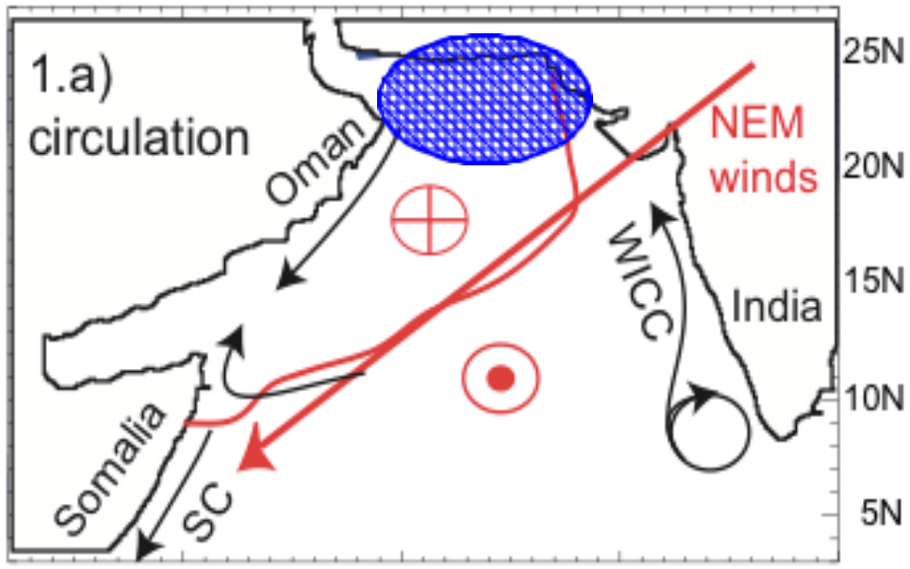
Bopp, Resplandy et al., Biogeosciences 2013

What regulates the OMZ in the Arabian Sea?

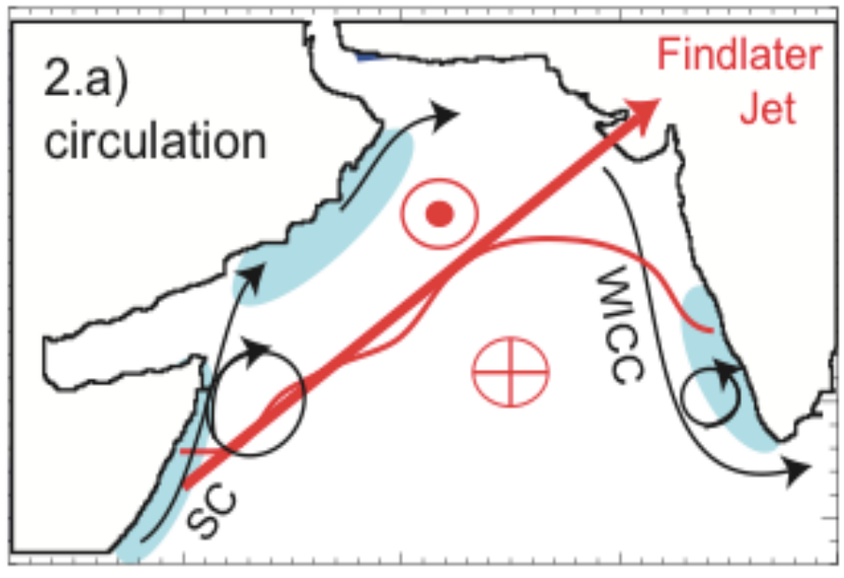
➢ 2 seasonal blooms forced by monsoonal circulation reversal

convection ~50-100 m

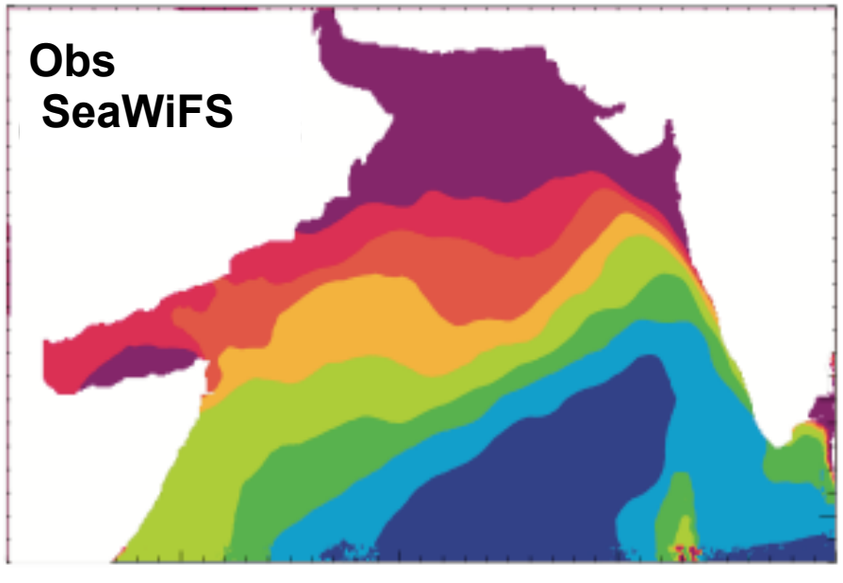
Winter (DJF)

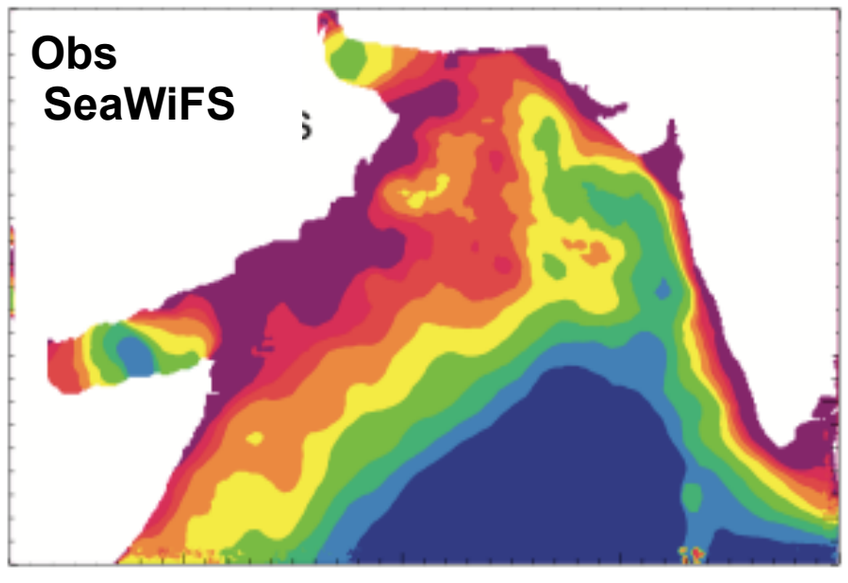


Summer (JJA)



3 upwelling systems

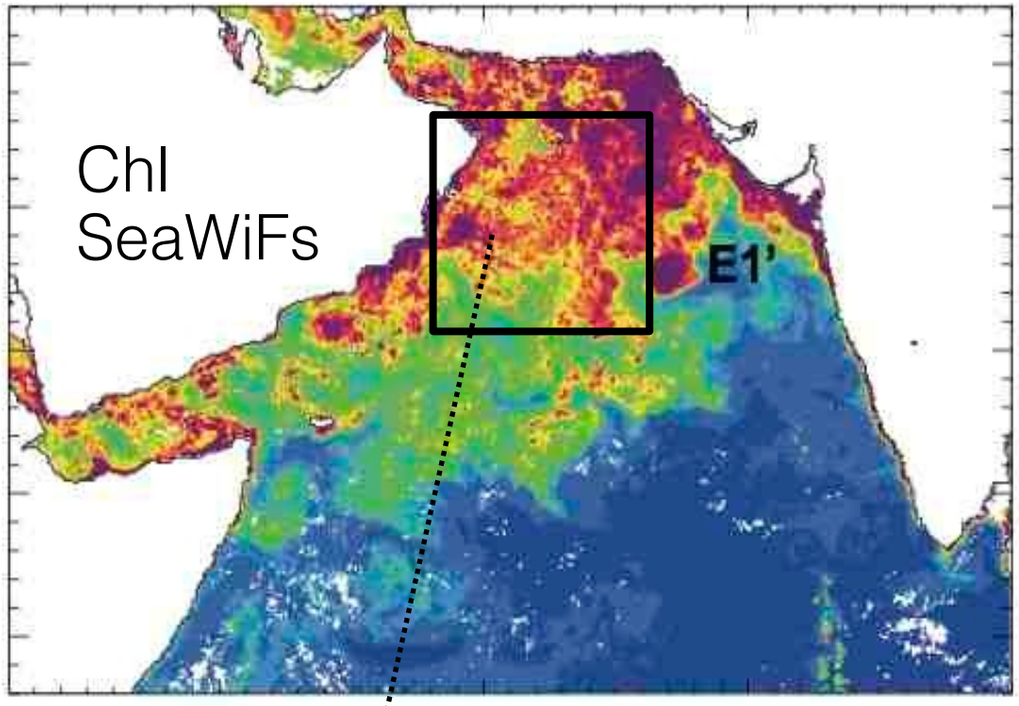




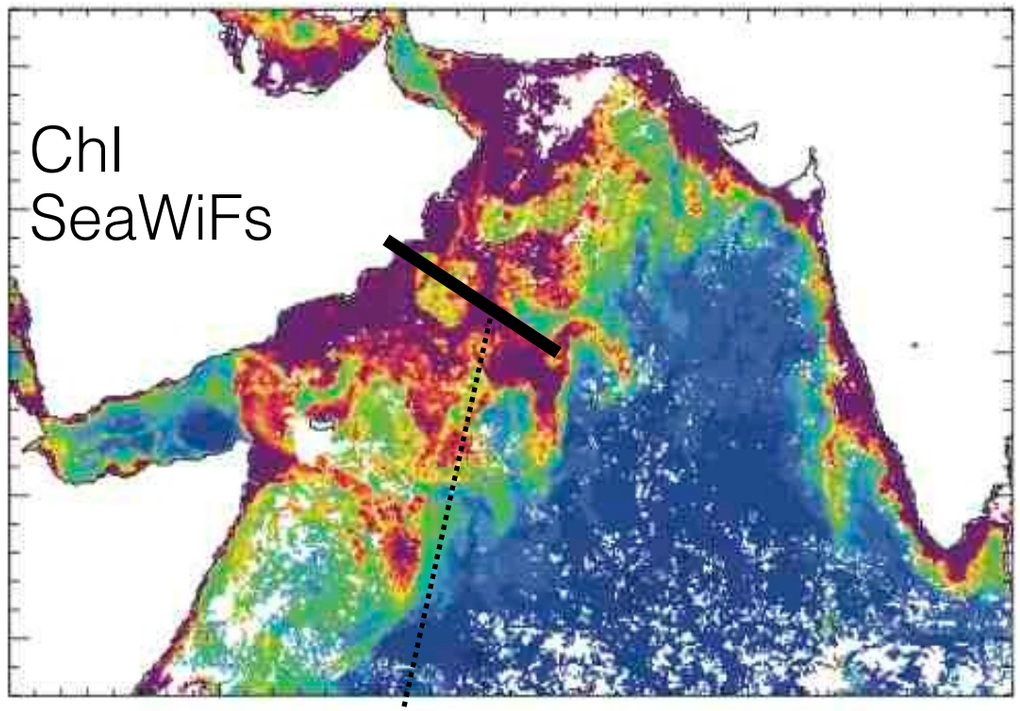
Resplandy et al., JGR 2012

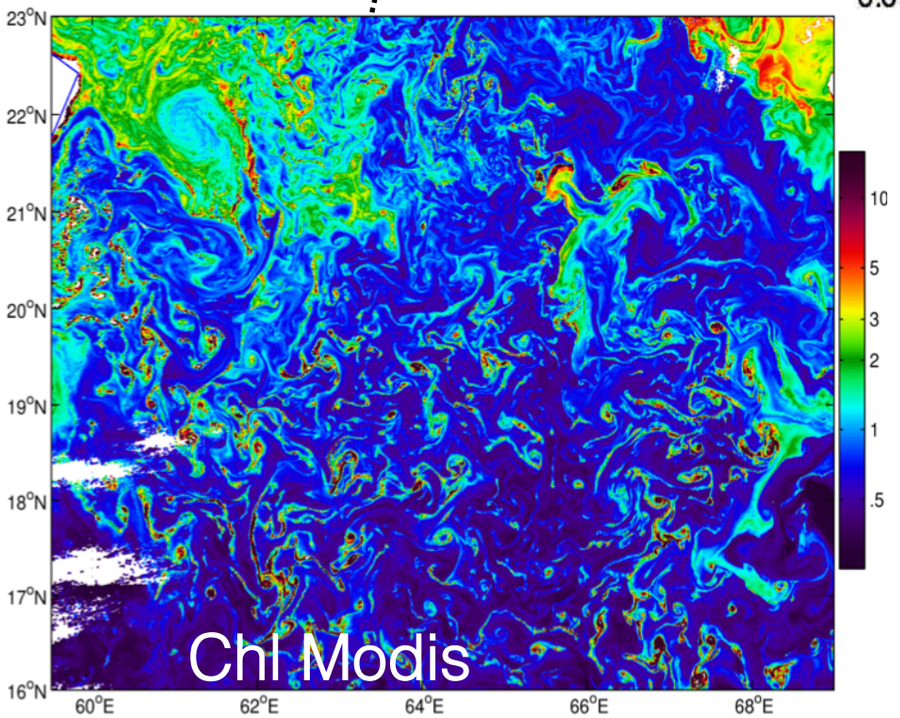
Modulation by sub-mesoscale in the Arabian Sea

Winter

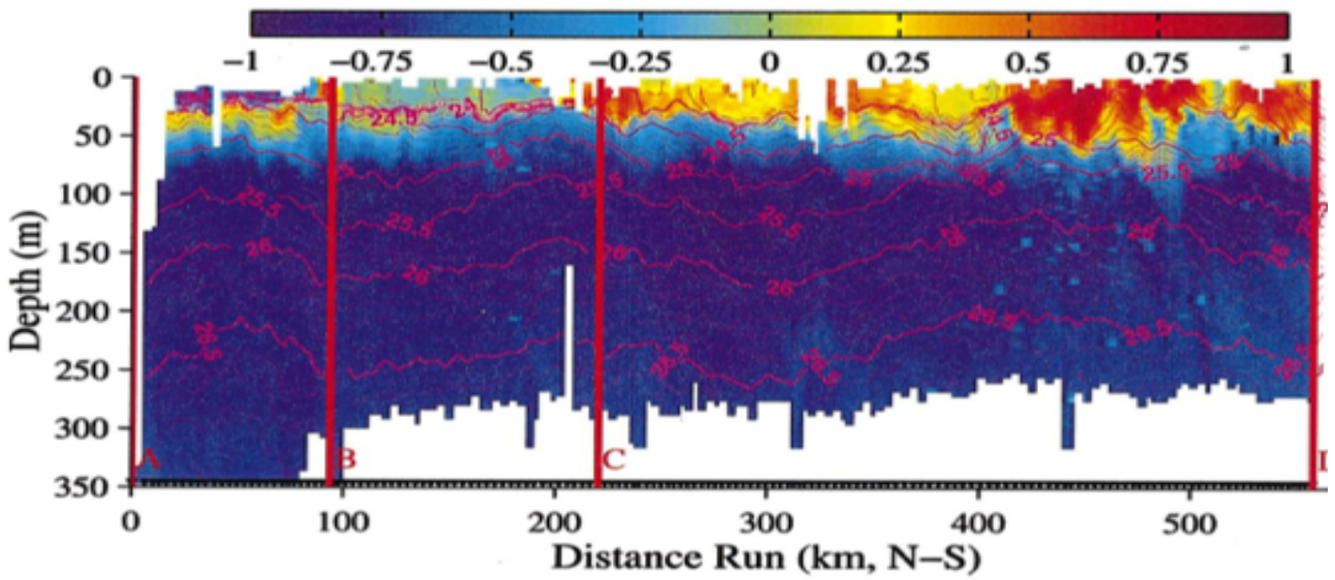


Summer

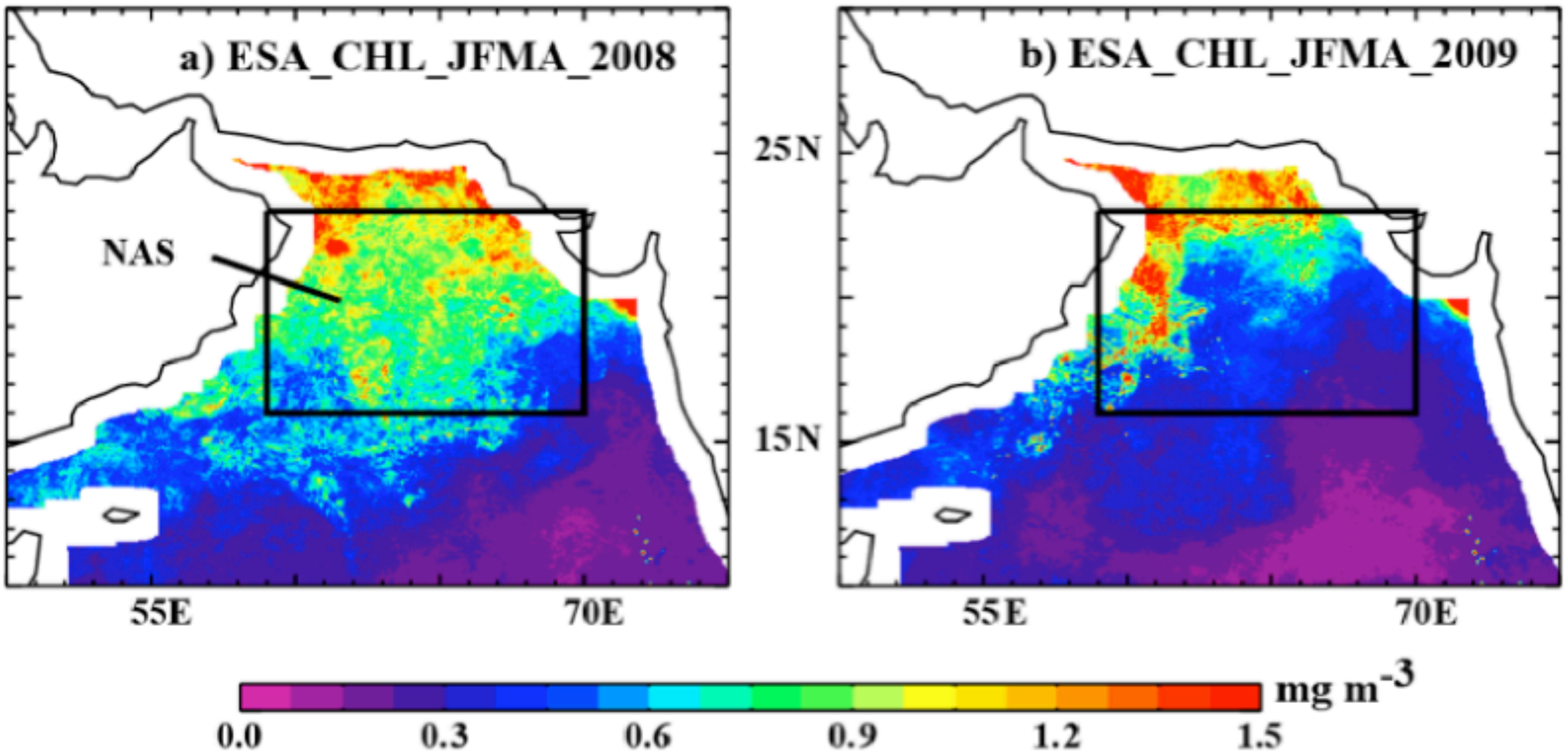




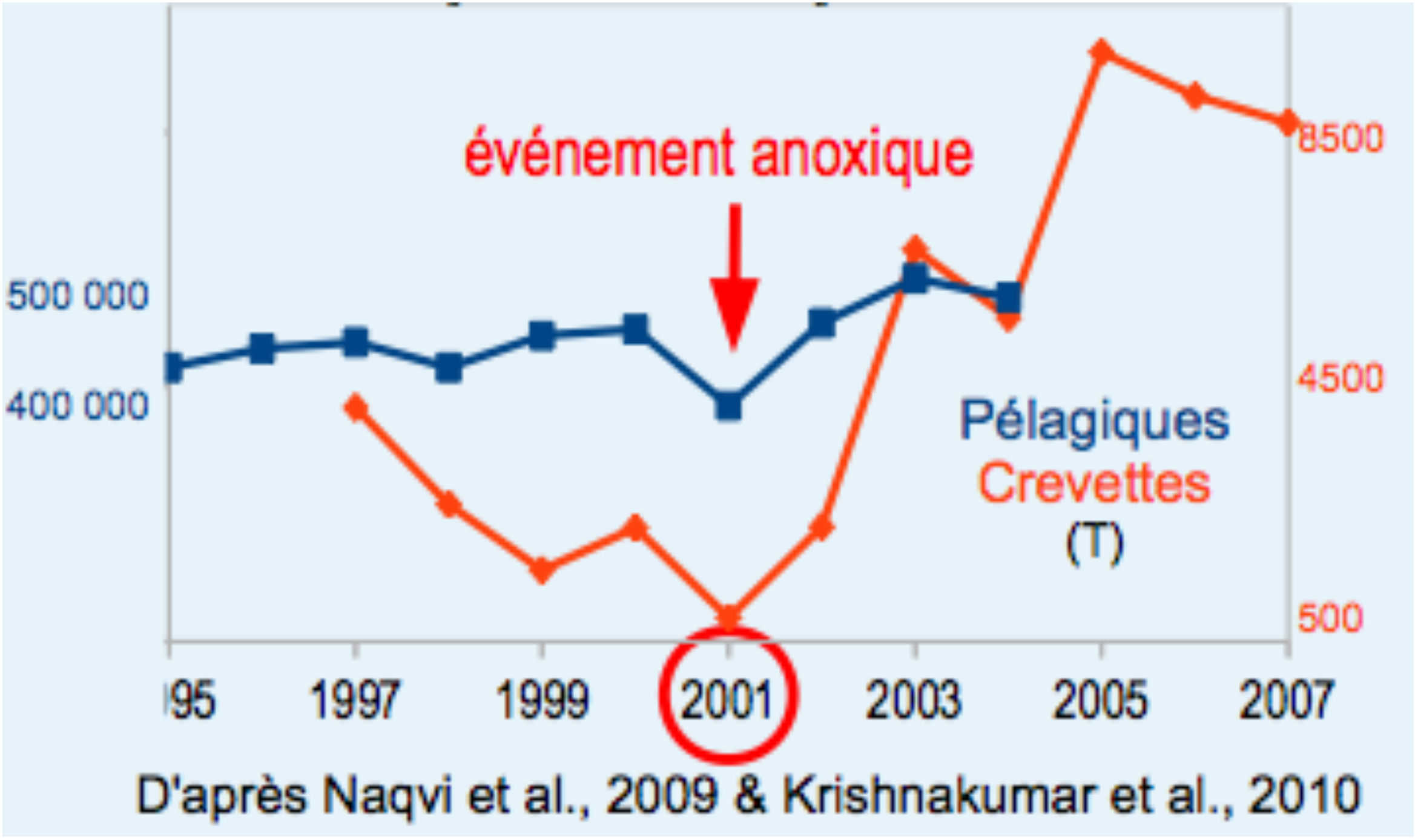
Chl in-situ (JGOFS 1995)



Strong inter-annual variability in winter bloom



Strong inter-annual variability of anoxic events



I. How do mesoscale eddies impact seasonal blooms?

II. What drives the inter-annual variability of the winter bloom

III. What drives the inter-annual variability of anoxic events

IV. How do mesoscale eddies impact the OMZ ?

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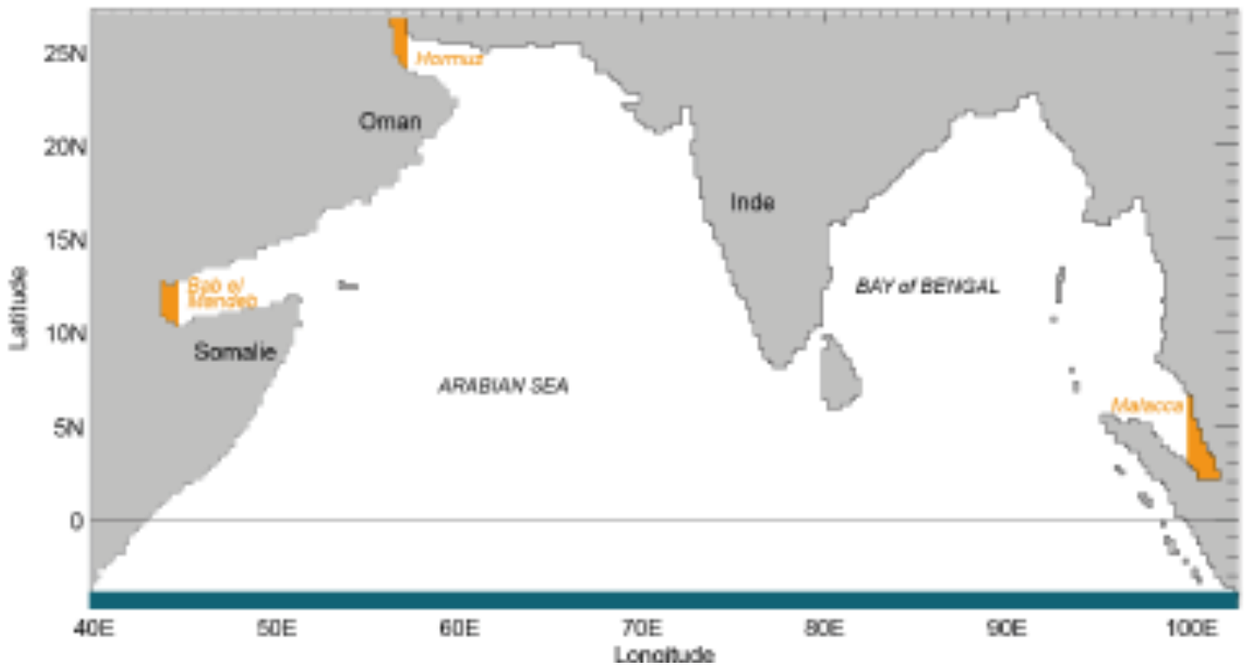
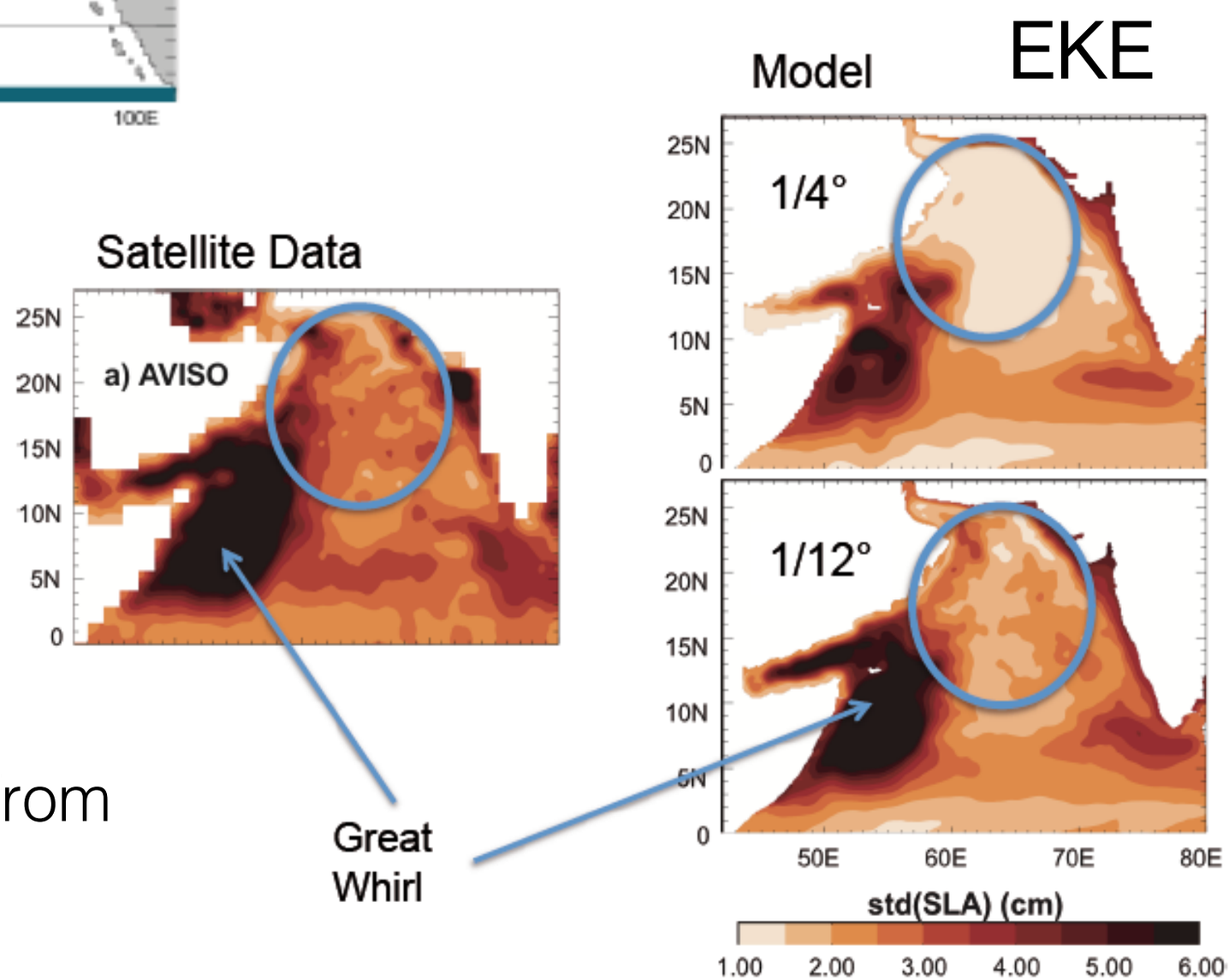
Strategy: high resolution bio-physical regional model



Resplandy et al., JGR 2011

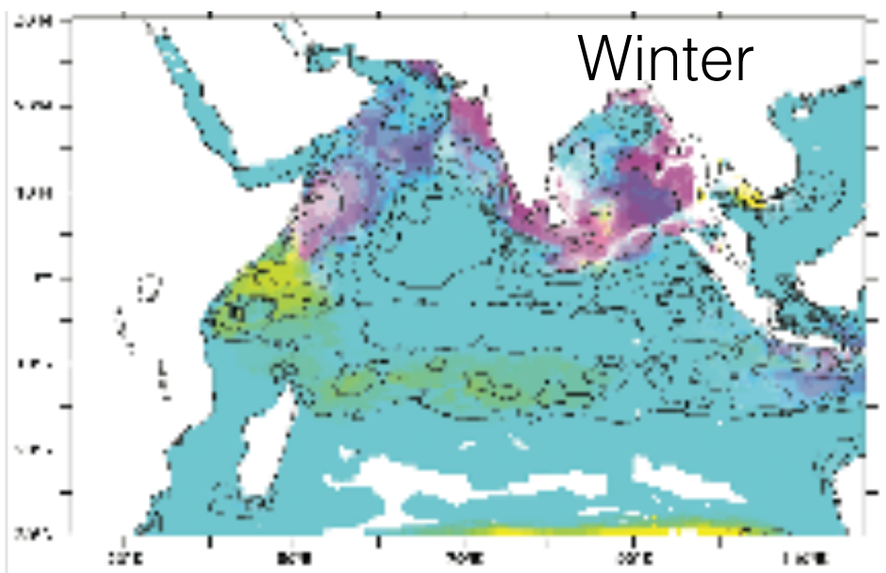
ocean physics NEMO
1/12° (~9 km)

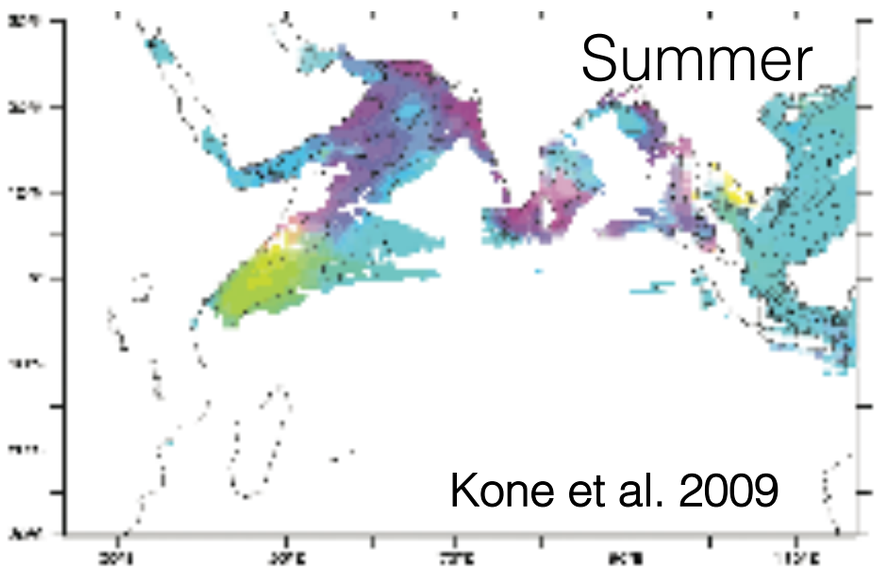
boundary & initial conditions from
1/2° model (Kone et al. 2009)

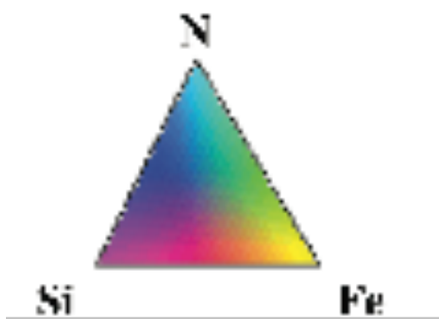


Strategy: high resolution bio-physical regional model

Diatom nutrient limitation



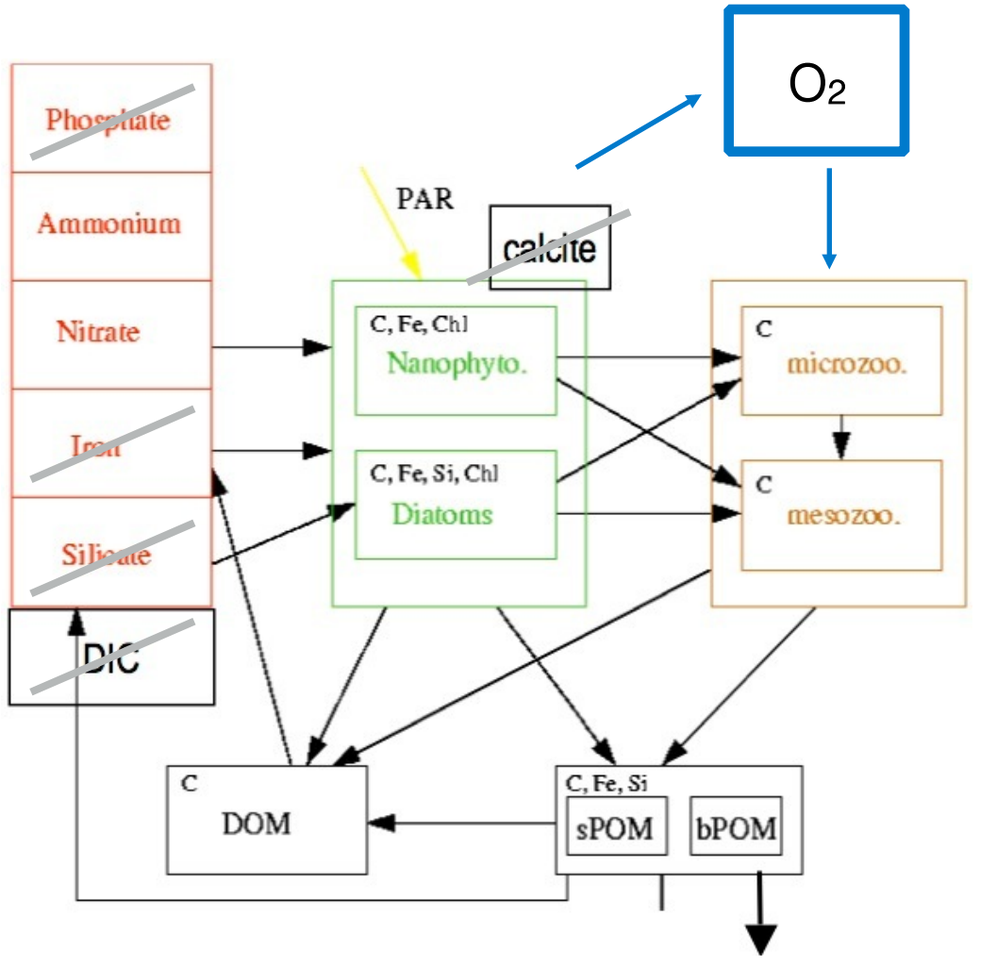




Biogeochemical module PISCES

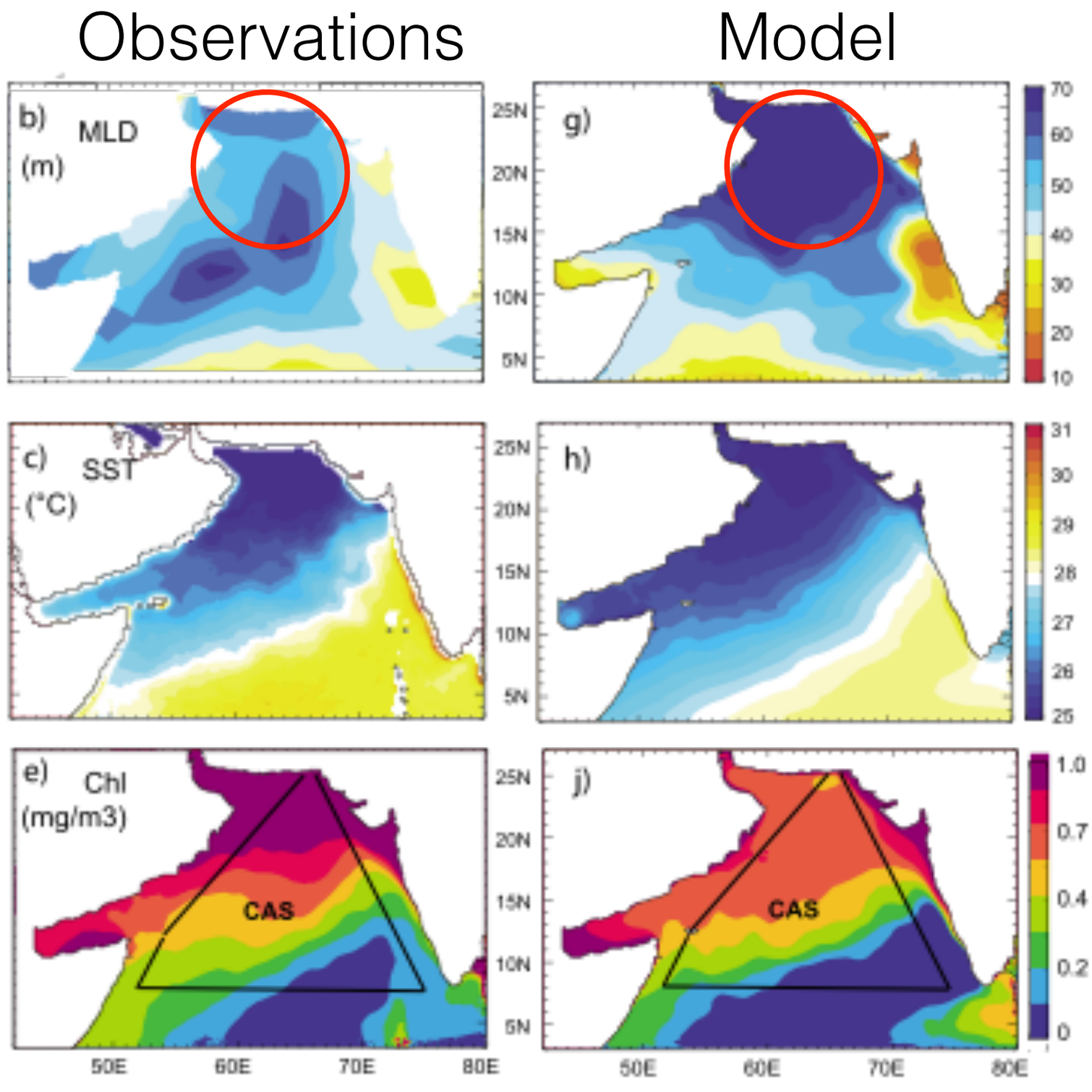
24 => 16 compartments

simplified from iron, phosphate & calcite



I. Impact of mesoscale on seasonal blooms

Winter mean



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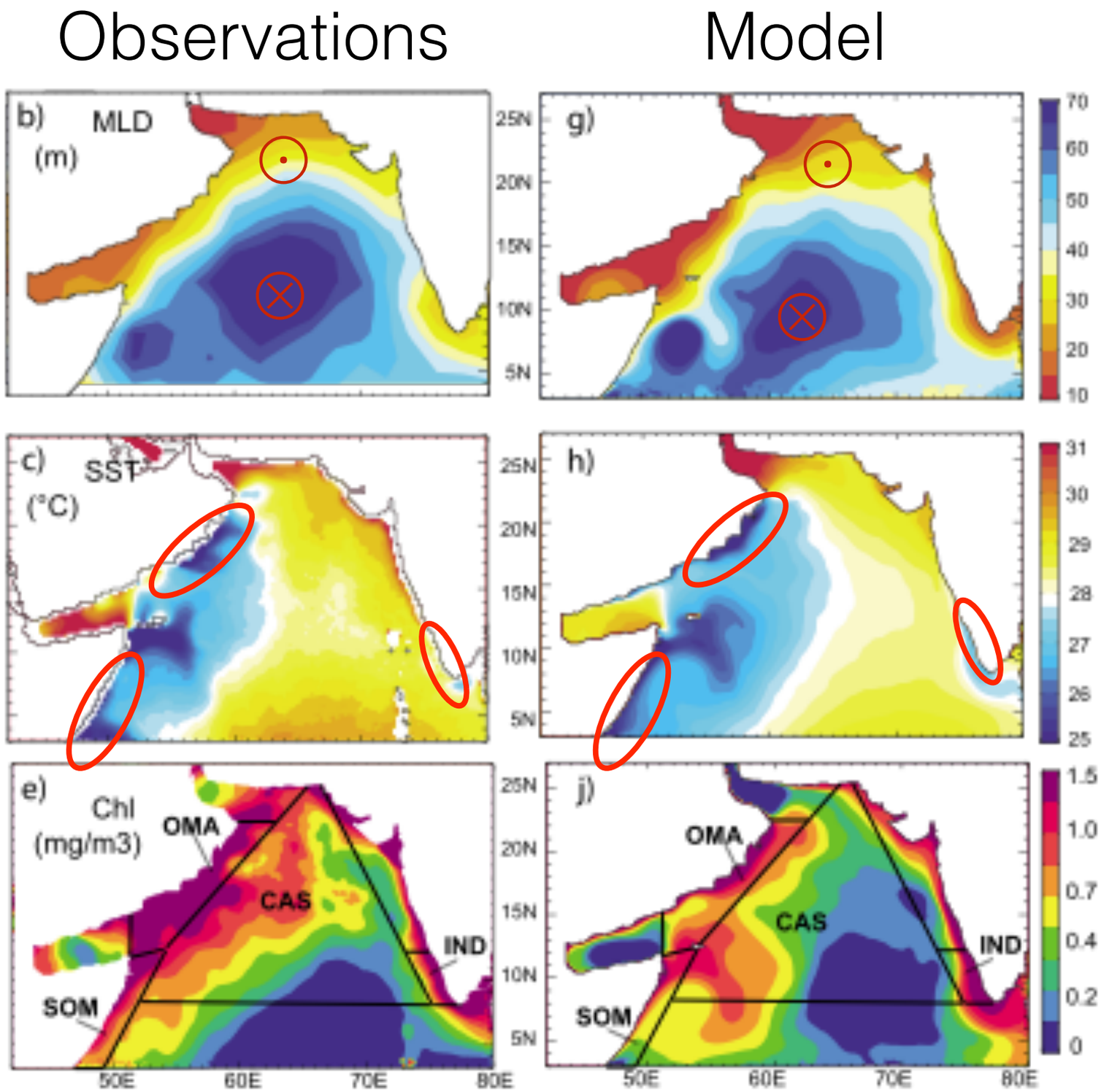


Biogeochemistry very sensitive to model shortcomings

I. Impact of mesoscale on seasonal blooms

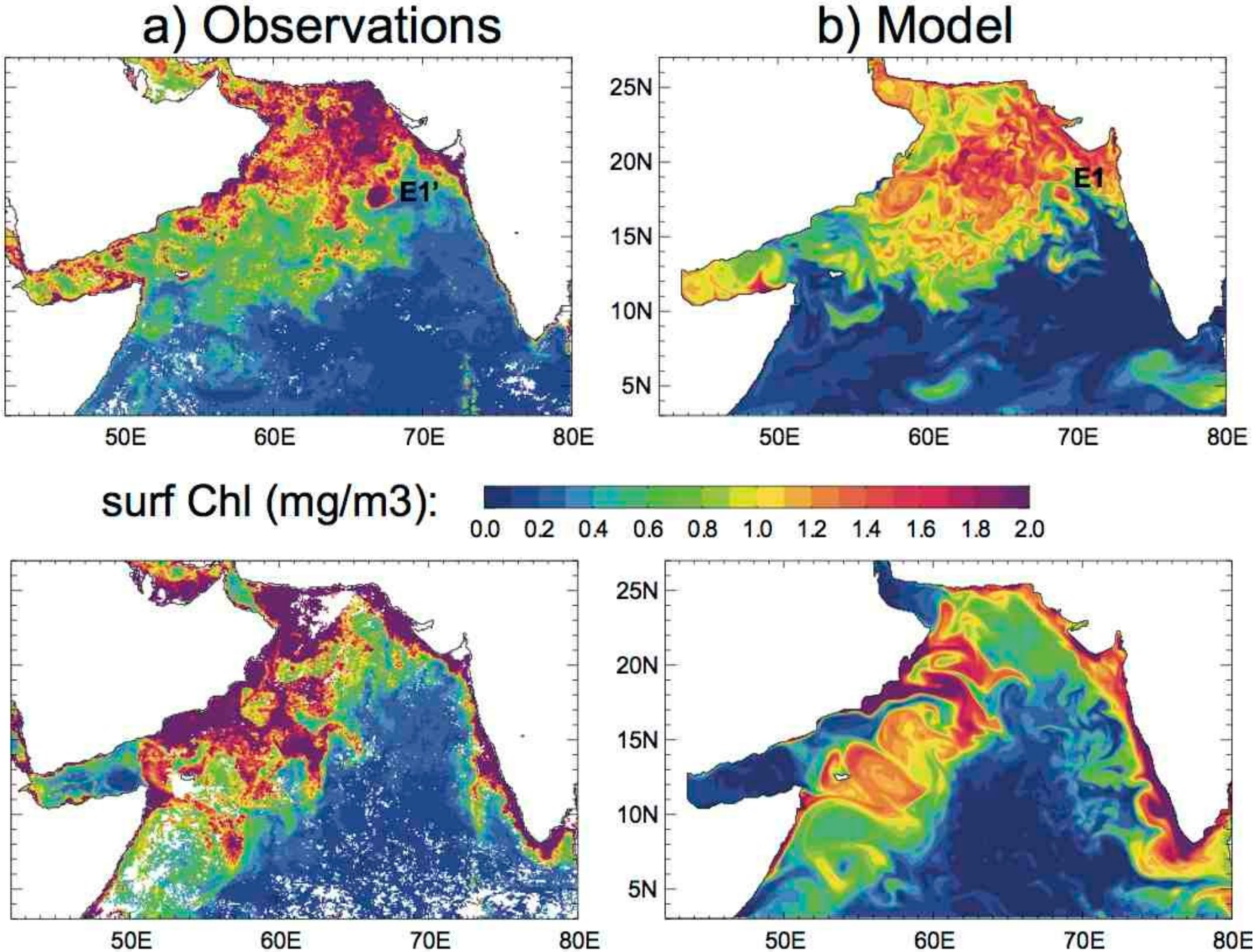
Table 1. Annual Integrated PP Over the Arabian Sea in Model Simulations[a]

Estimates	Method	PP ($gC.m^{-2}$)
This study	biophysical model 1/12°	185
Kawamiya and Oschlies [2003]	biophysical model 1/3°	70
Behrenfeld and Falkowski [1997]	Chl satellite-based	153
Antoine et al. [1996]	Chl satellite-based	184

I. Impact of mesoscale on seasonal blooms

Winter snapshot

Summer snapshot



Resplandy et al., JGR 2011

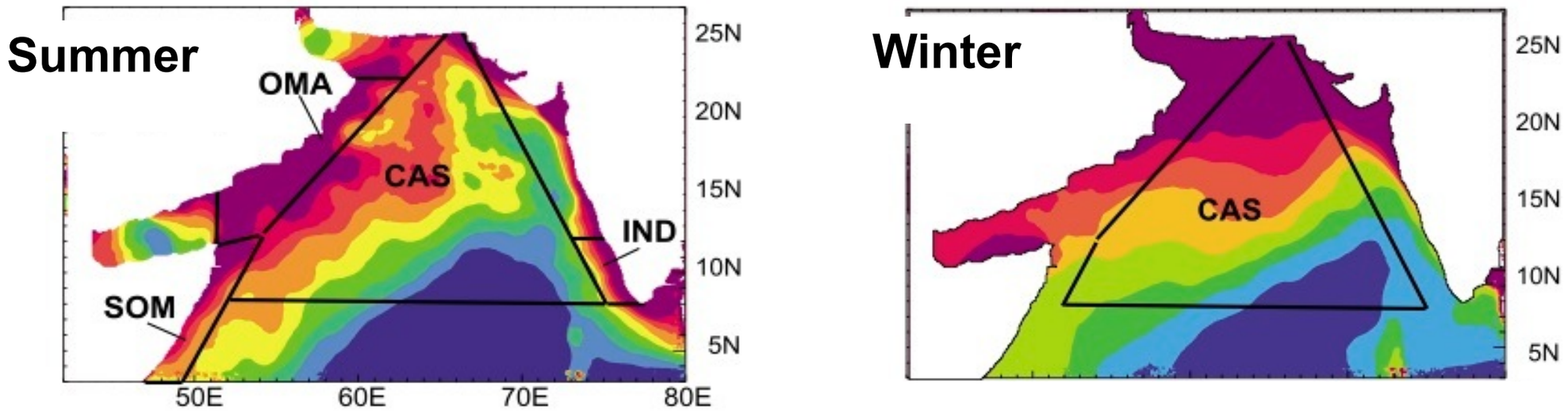
I. Impact of mesoscale on seasonal blooms

➢ Limiting nutrient budget

$$\partial N/\partial t = \underbrace{\text{lateral advection} + \text{vertical advection}} + \text{vertical mixing} + \text{Bio sources/sinks}$$

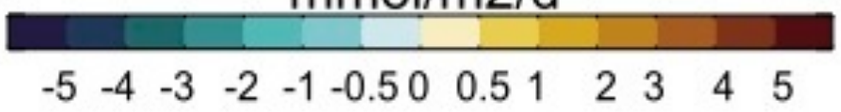
advection = Mean + Eddy

➢ Budget over blooming regions: 0-80 meters

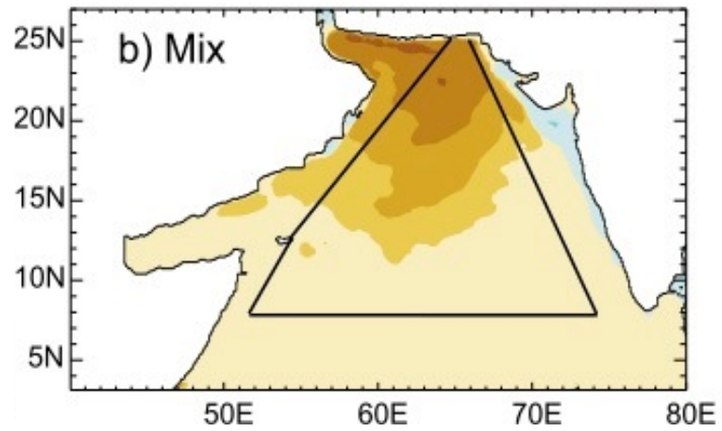


I. Impact of mesoscale on seasonal blooms

Winter

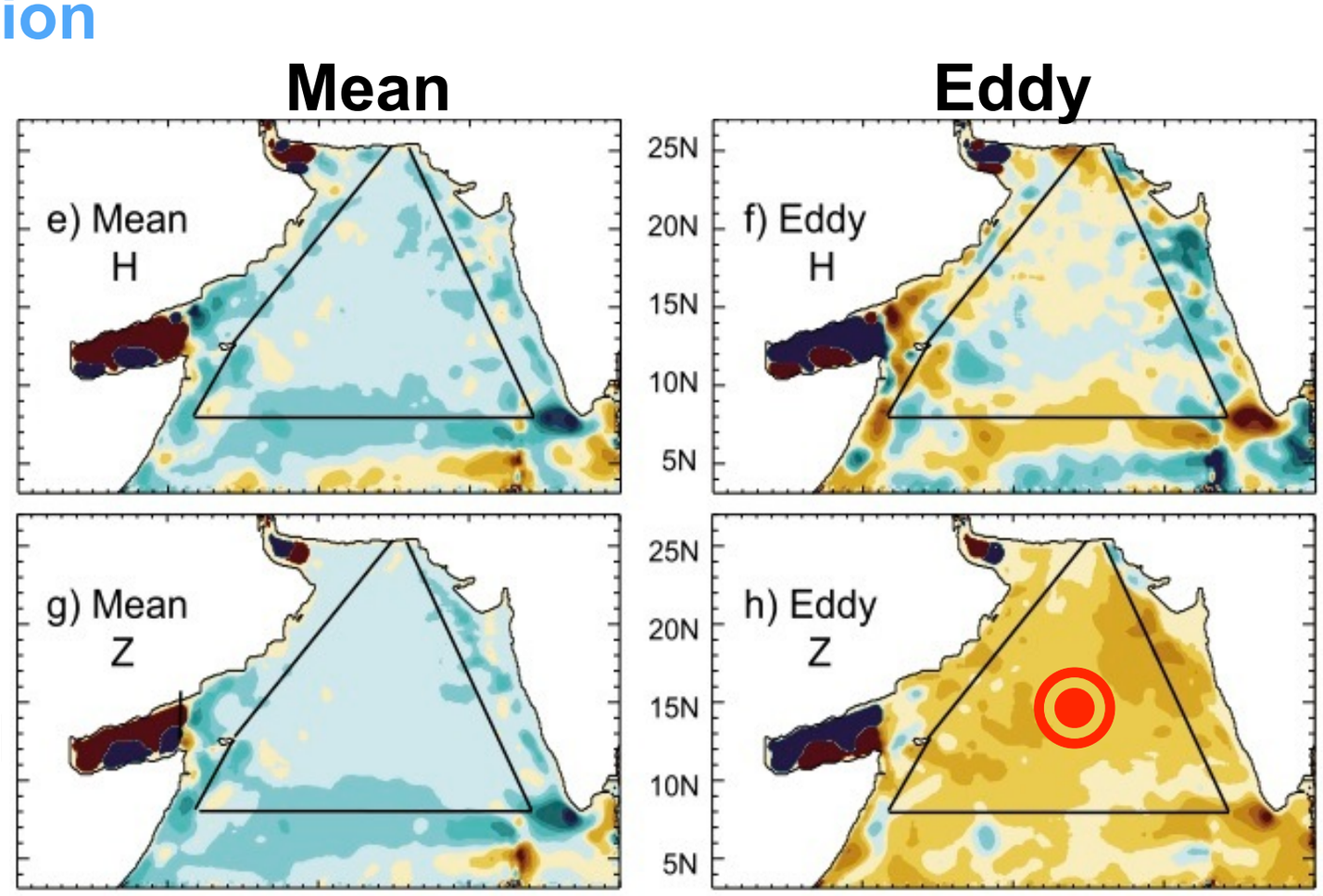


vertical mixing



➢ Major input by **vertical mixing**

advection

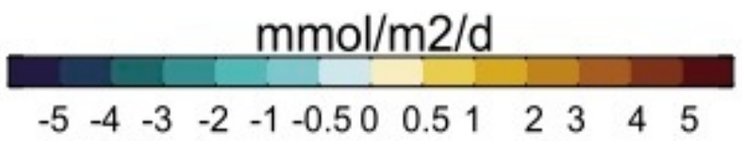


➢ Crucial role of **eddy vertical advection** in Central Arabian Sea (40-50%)

Resplandy et al., JGR 2011

I. Impact of mesoscale on seasonal blooms

Summer

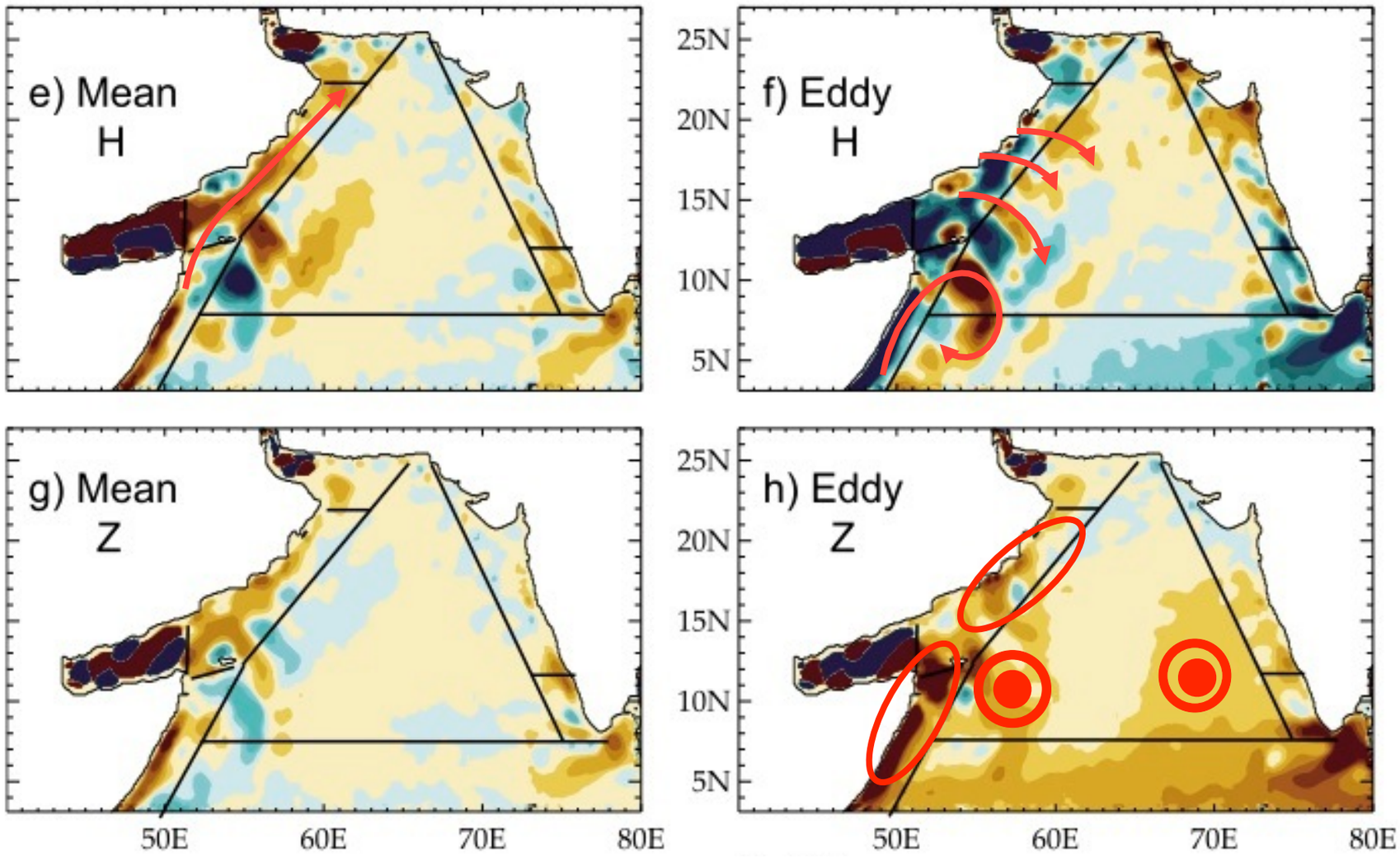


Advection

Mean **Eddy**

lateral

vertical



Central AS: **eddy advection** (50-70%)

Resplandy et al., JGR 2011

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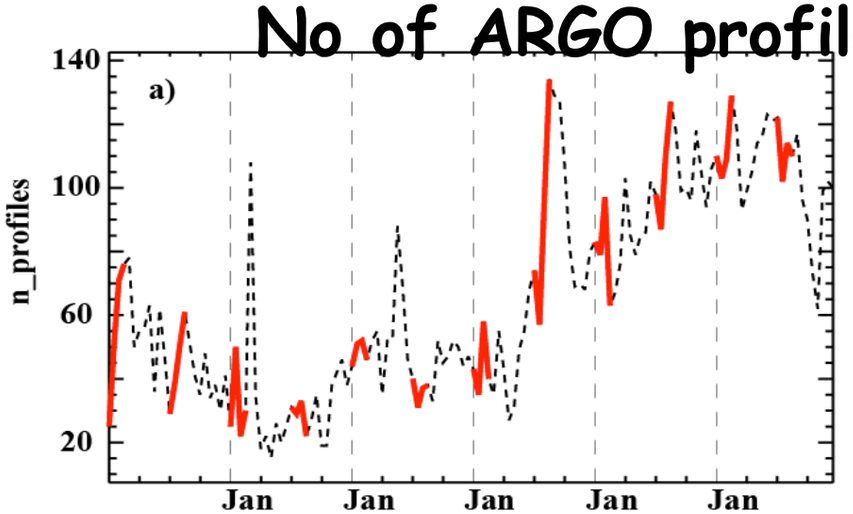
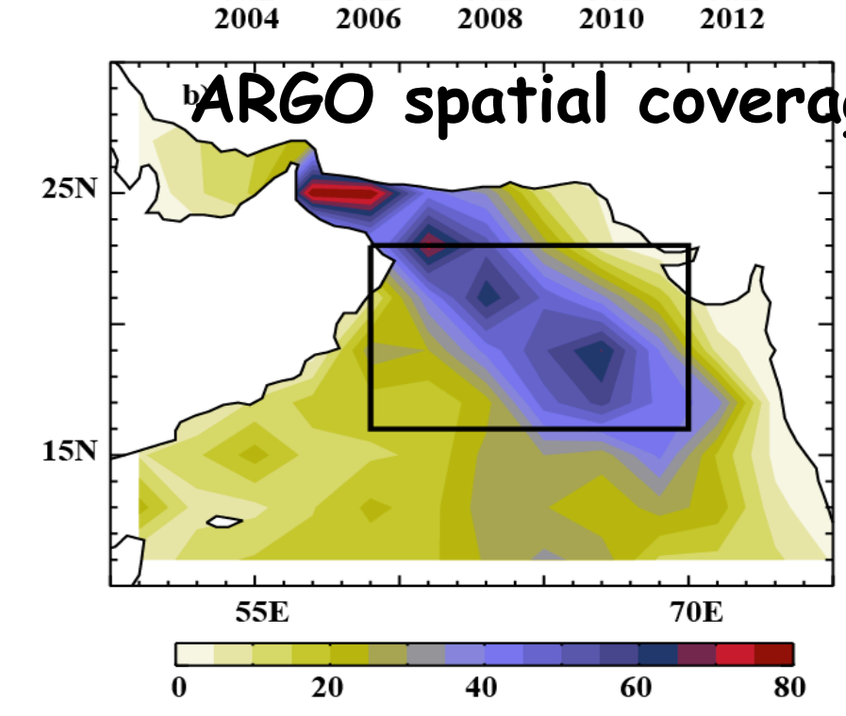
Method

Argo observations for MLD and thermocline depth

Ocean color Chl time series: 1998 to 2013

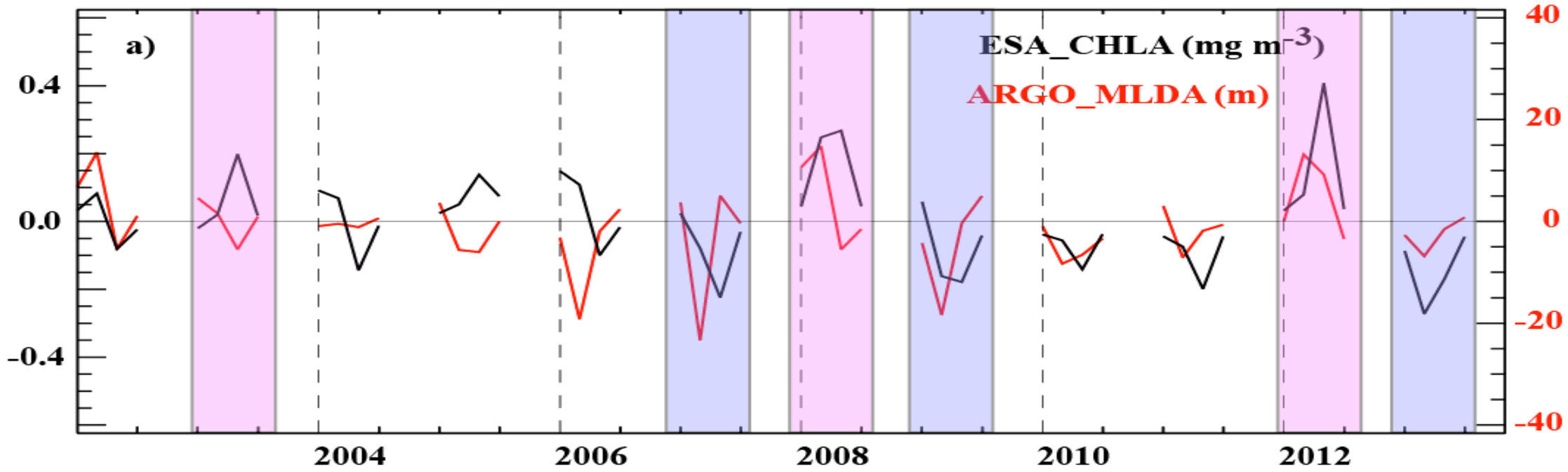
Bio-OGCM of the Arabian Sea





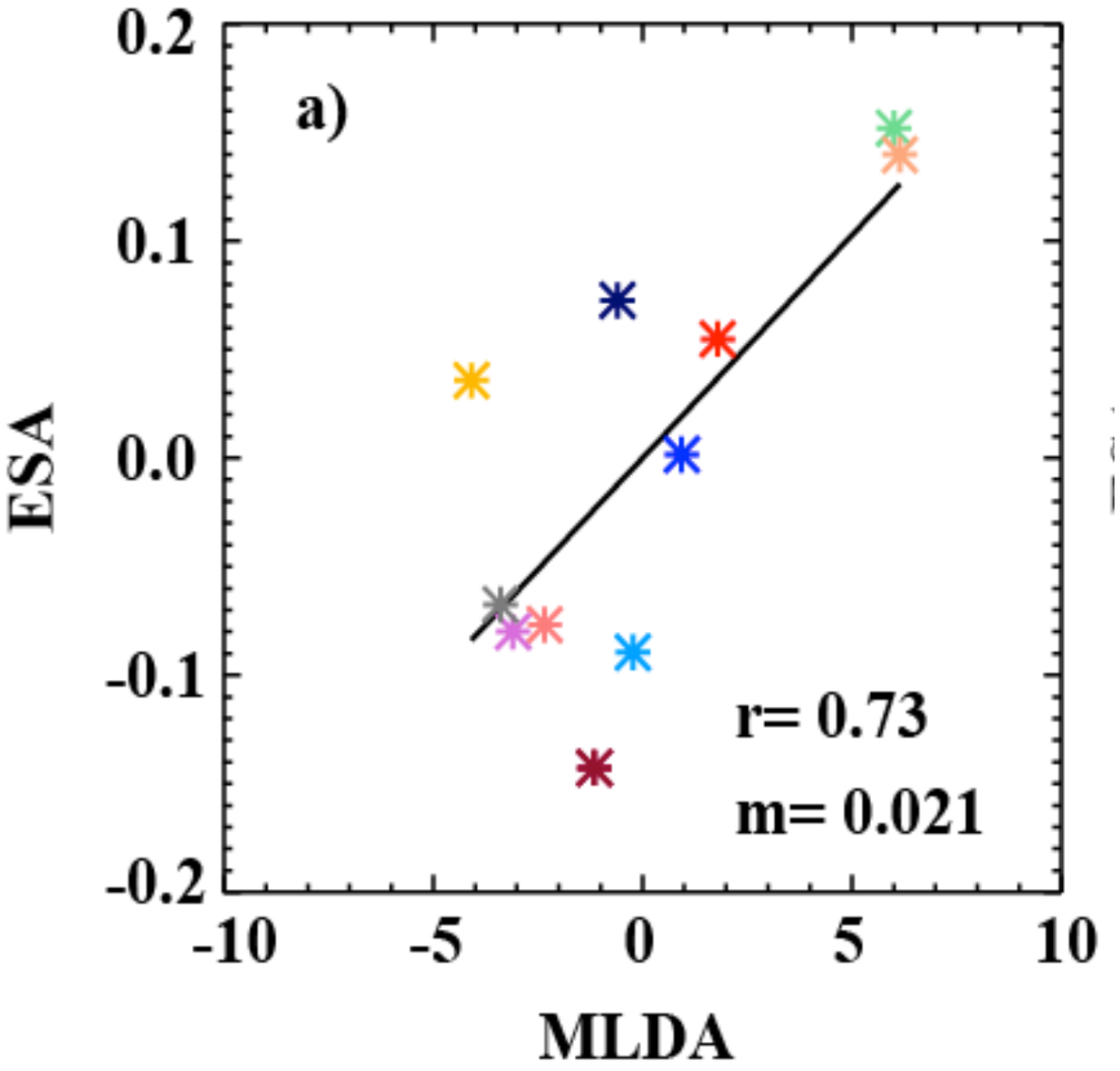
Keerthi M G, Matthieu Lengaigne, Jerome Vialard, Parvathi V, C de Boyer Montegut, in preparation

CHL and MLD anomalies at intra-seasonal timescales

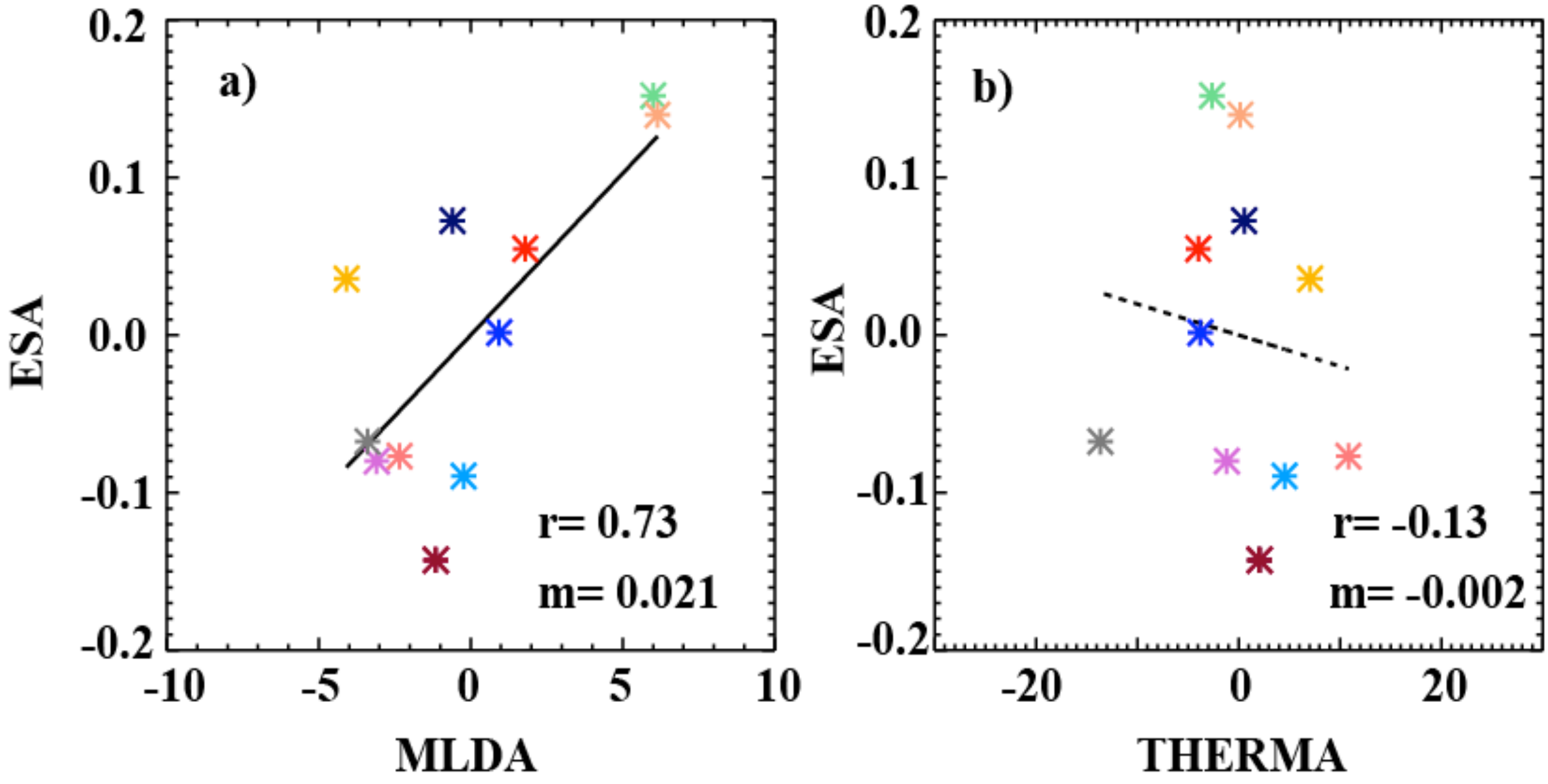


More Chl when deeper MLD

CHL response to MLD variability at non seasonal timescales



2003.2004.2005.2006.2007.2008.2009.2010.2011.2012.2013


a)
b)
ESA
MLDA
THERMA
0.2
0.1
0.0
-0.1
-0.2
-10
-5
0
5
10
-20
20
r= 0.73
m= 0.021
r= -0.13
m= -0.002
2003.2004.2005.2006.2007.2008.2009.2010.2011.2012.2013

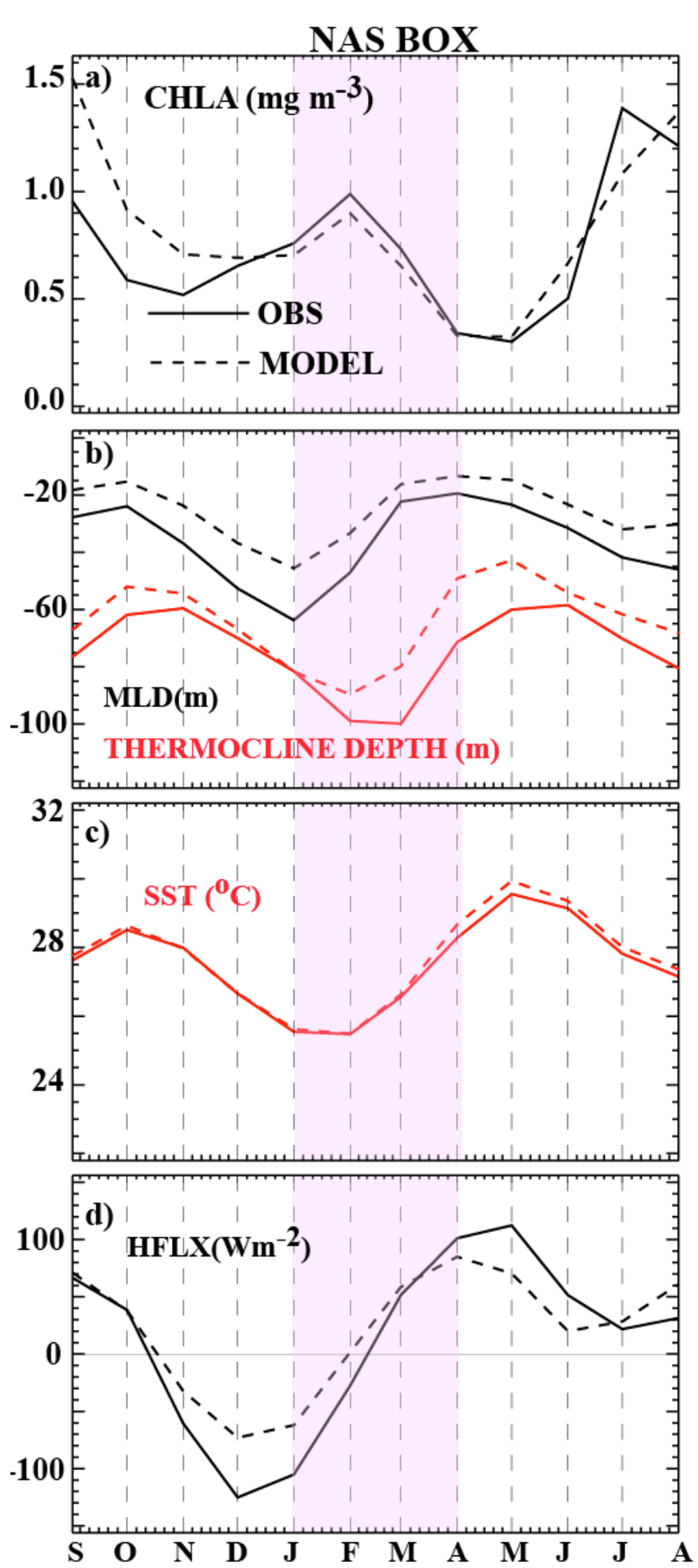
Model Analysis

MODEL: NEMO-PISCES coupled physical-biogeochemical *OGCM*: Regional ¼° configuration for Indian Ocean

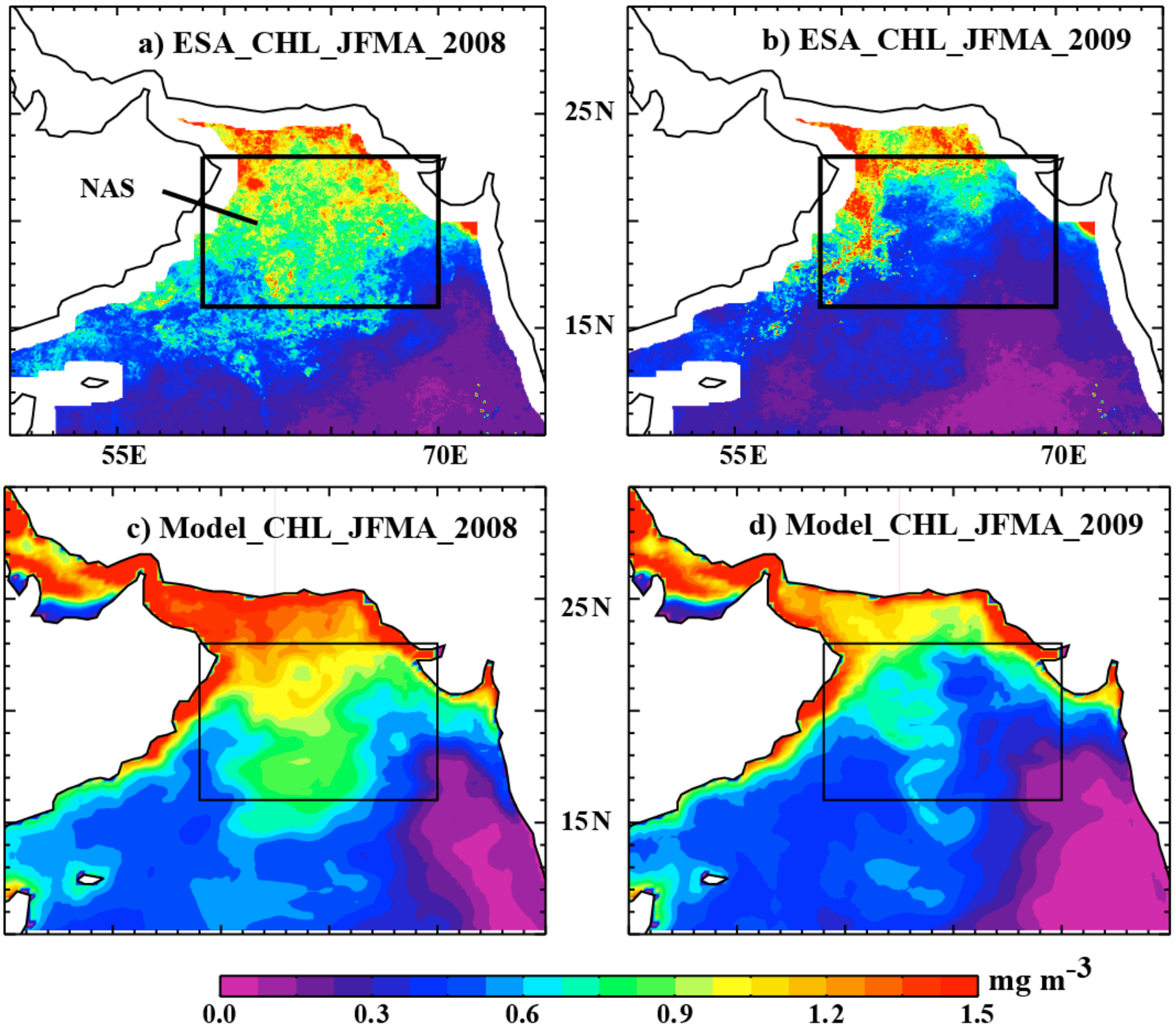
SIMULATION:

NEMO NIO (1960-2012) :

- Regional configuration installed at CSIR-NIO
- Interannual forcing from DFS4.3

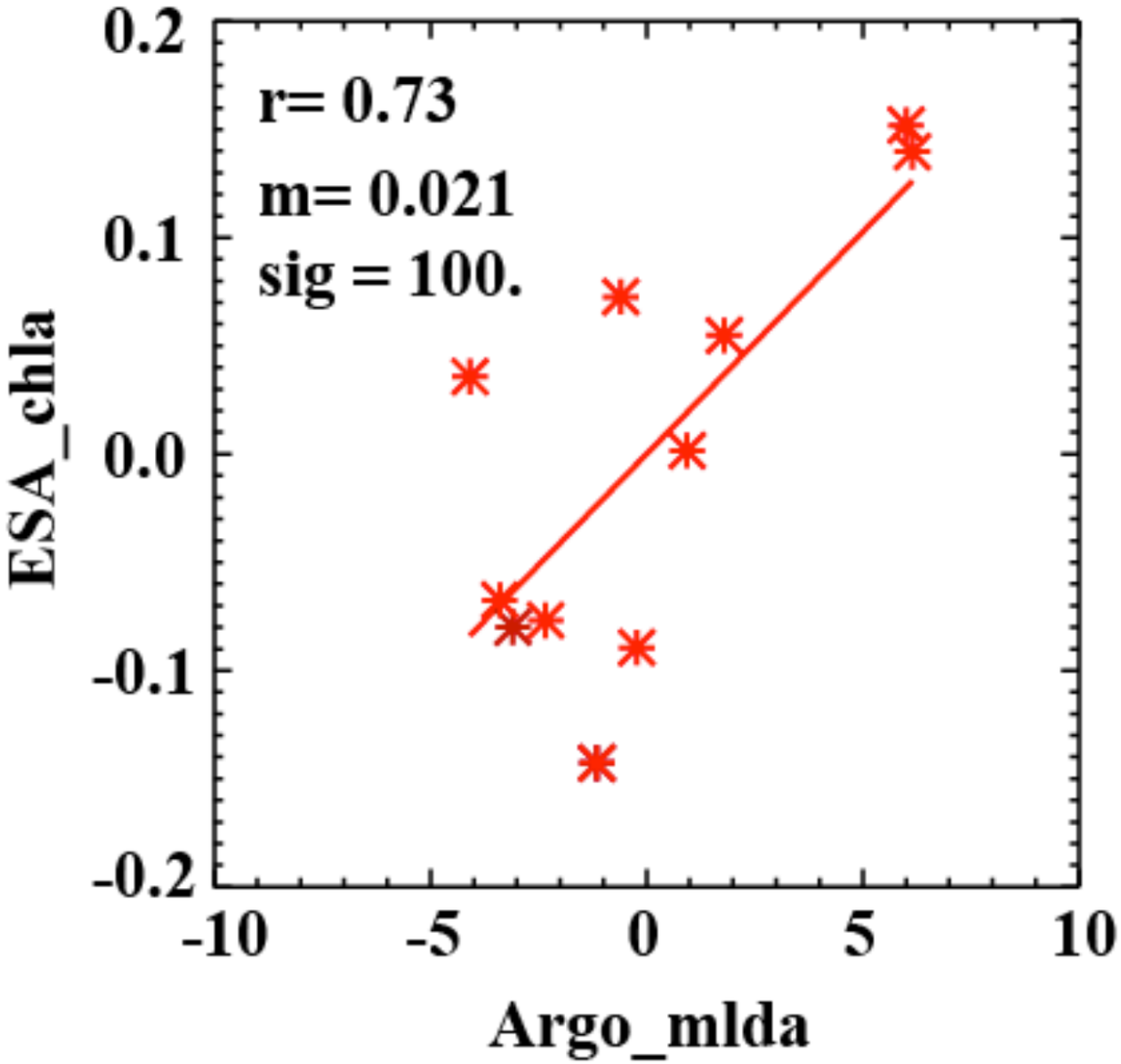


Model evaluation (Interannual)

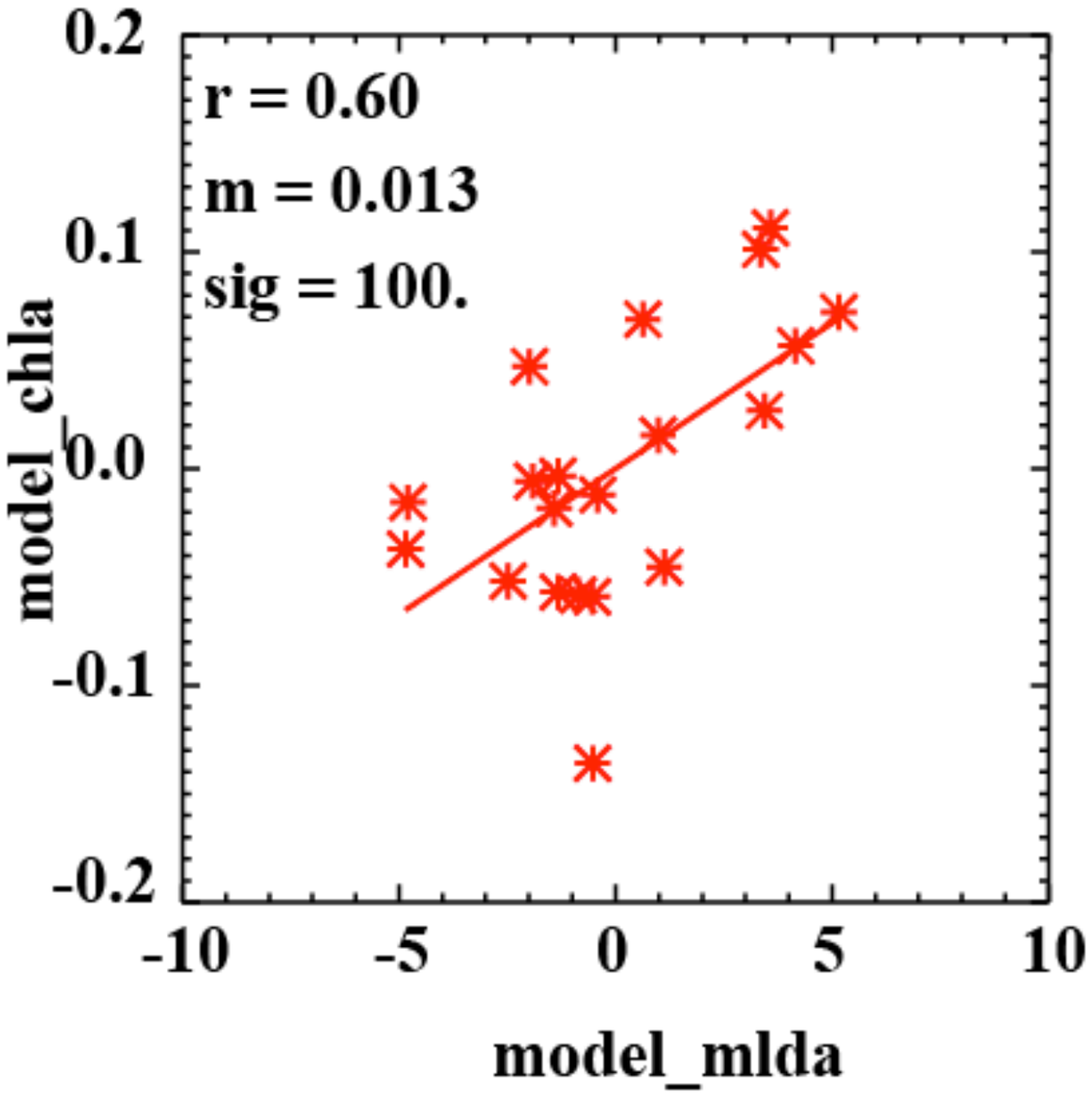


- Model captures the strong bloom in 2008 and weaker bloom in 2009

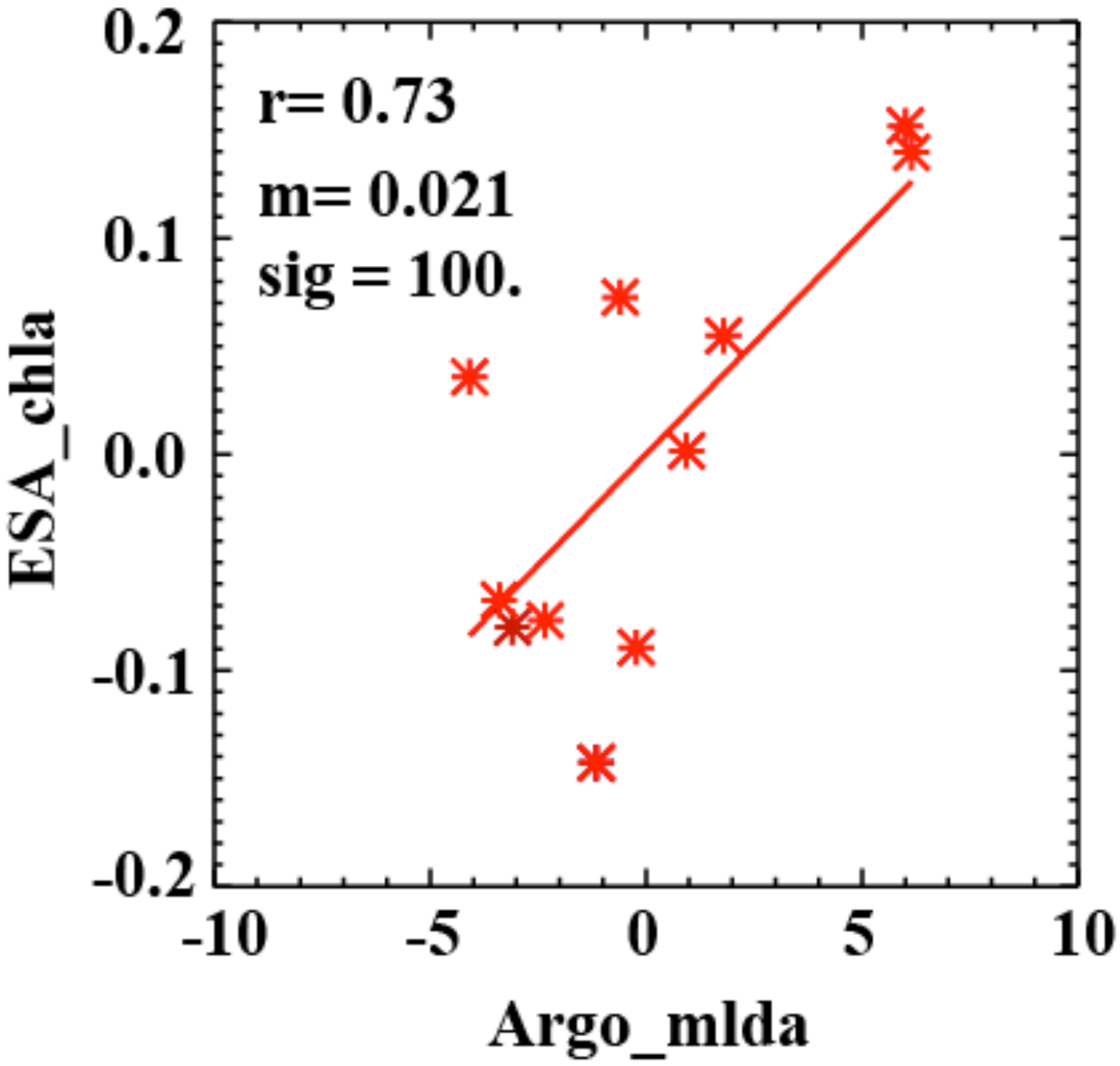
Observations



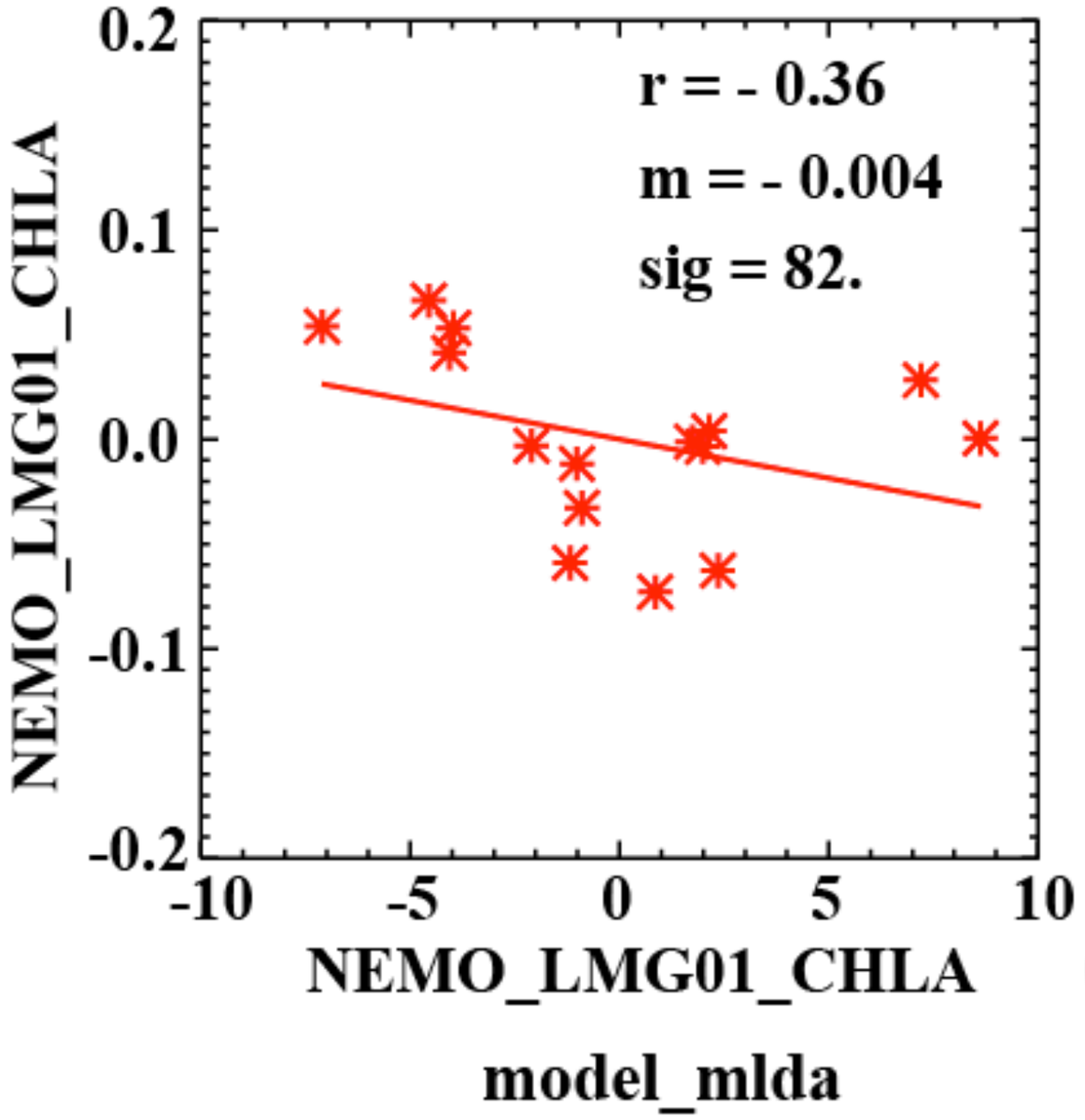
Model



Observations



Model



I. How do mesoscale eddies impact seasonal blooms?

II. What drives the inter-annual variability of the winter bloom

III. What drives the inter-annual variability of anoxic events

IV. How do mesoscale eddies impact the OMZ ?

Method

Ocean Model (NEMO-PISCES)

- Physical model (NEMO) coupled with a biogeochemical component (PISCES)

- Regional configuration installed at CSIR-NIO

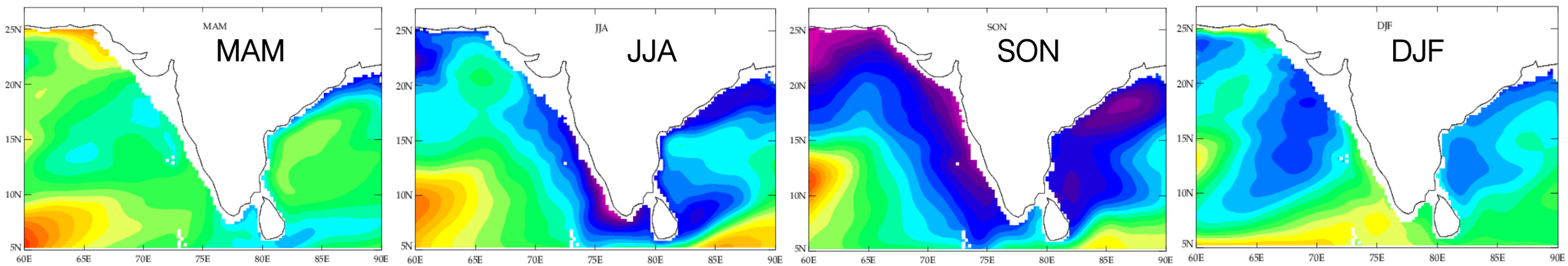
- 0.25 X 0.25 spatial resolution

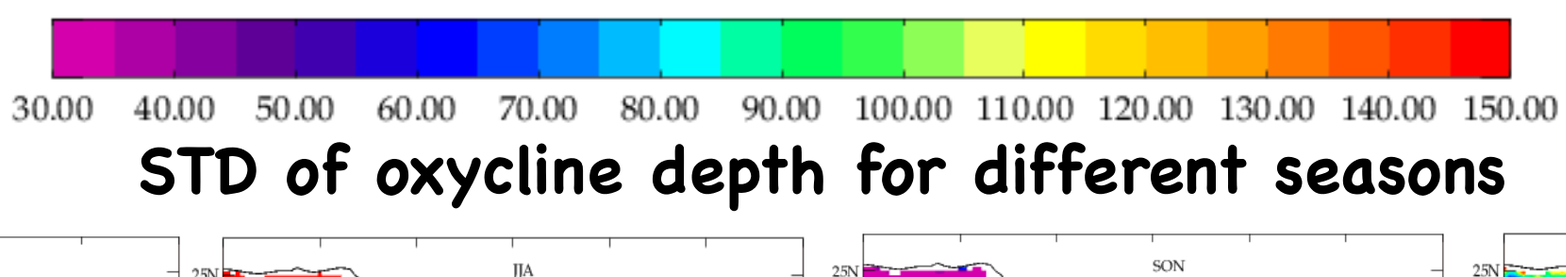
- Interannual forcing from DFS4.3: 1960-2012

V. Parvathi[1], I. Suresh[1], S. Neetu[1], M. Lengaigne[1,2], L. Resplandy[3], C. Ethé[2], J. Vialard[2], O. Aumont[2], H. Naik[1], SWA. Naqvi

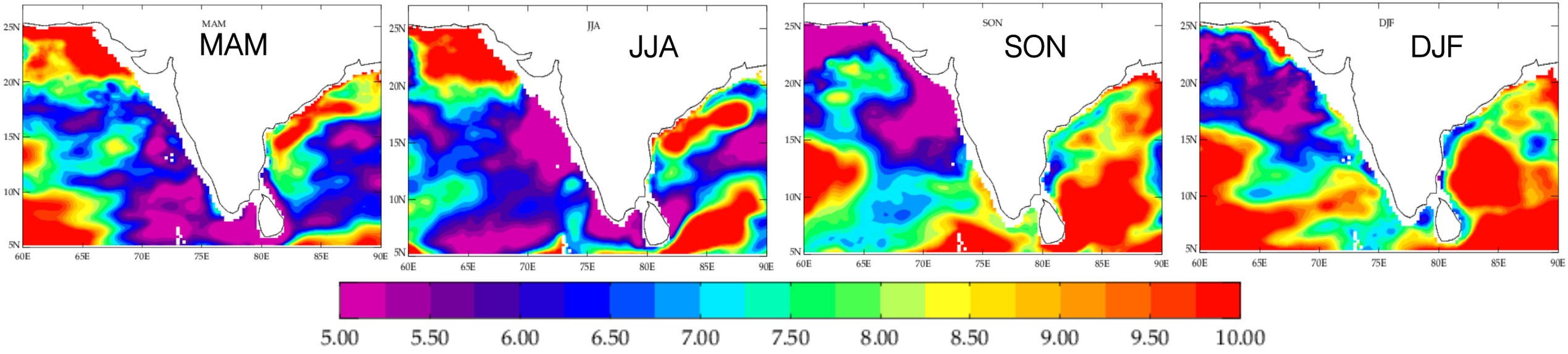
Results

Mean oxycline depth (D100) for different seasons



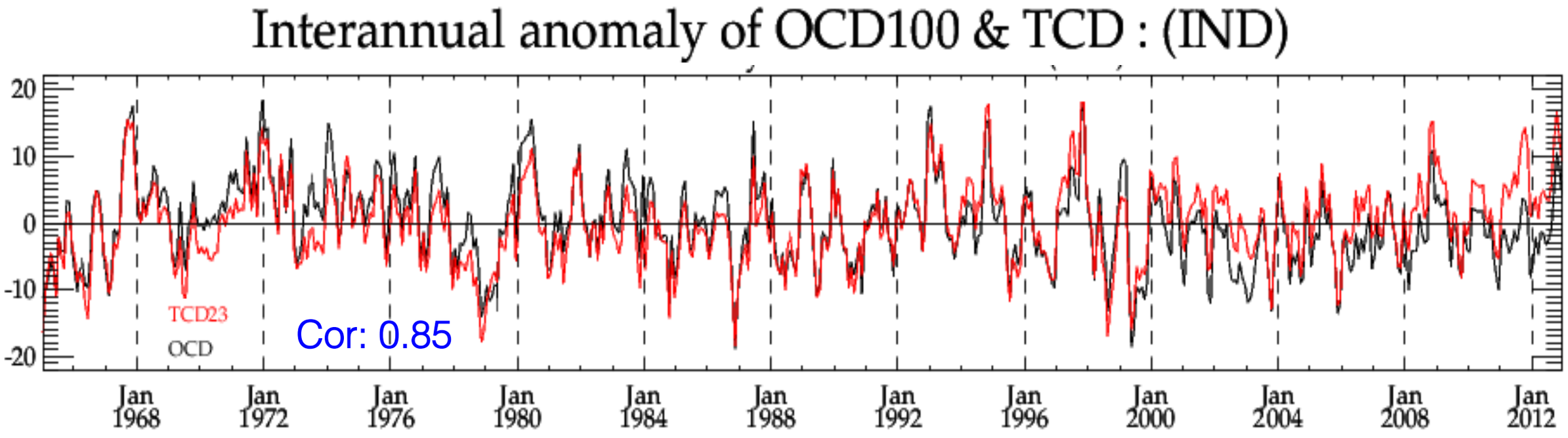


STD of oxycline depth for different seasons



Shallowest oxycline and maximum variability along WCI during SON, which is the time of coastal hypoxia!!

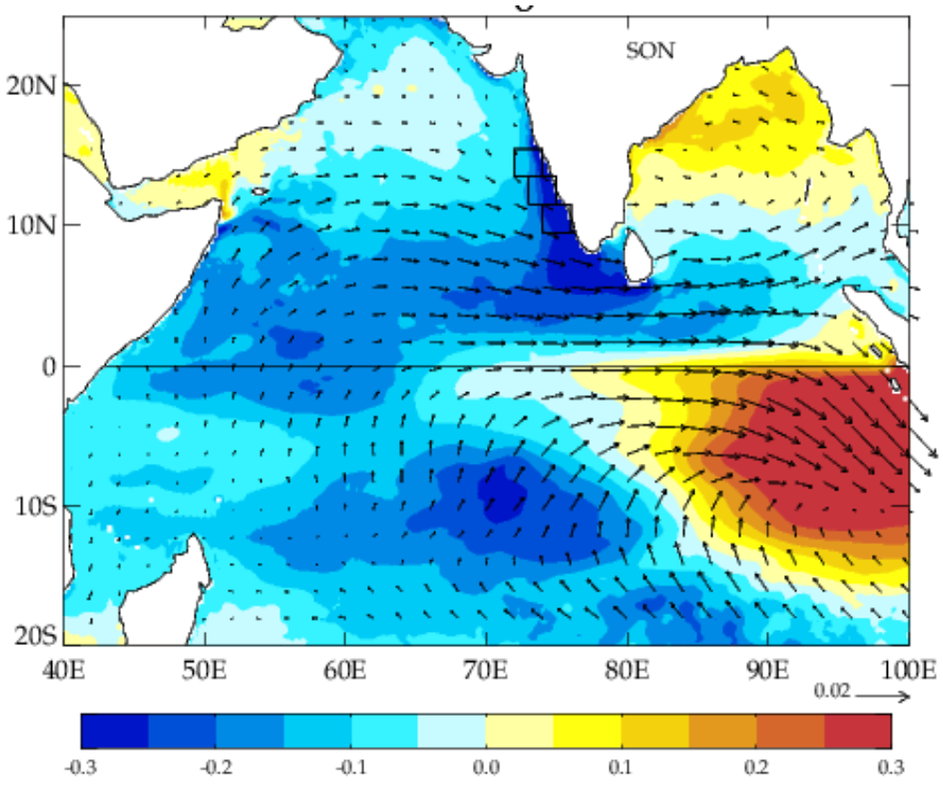
Results



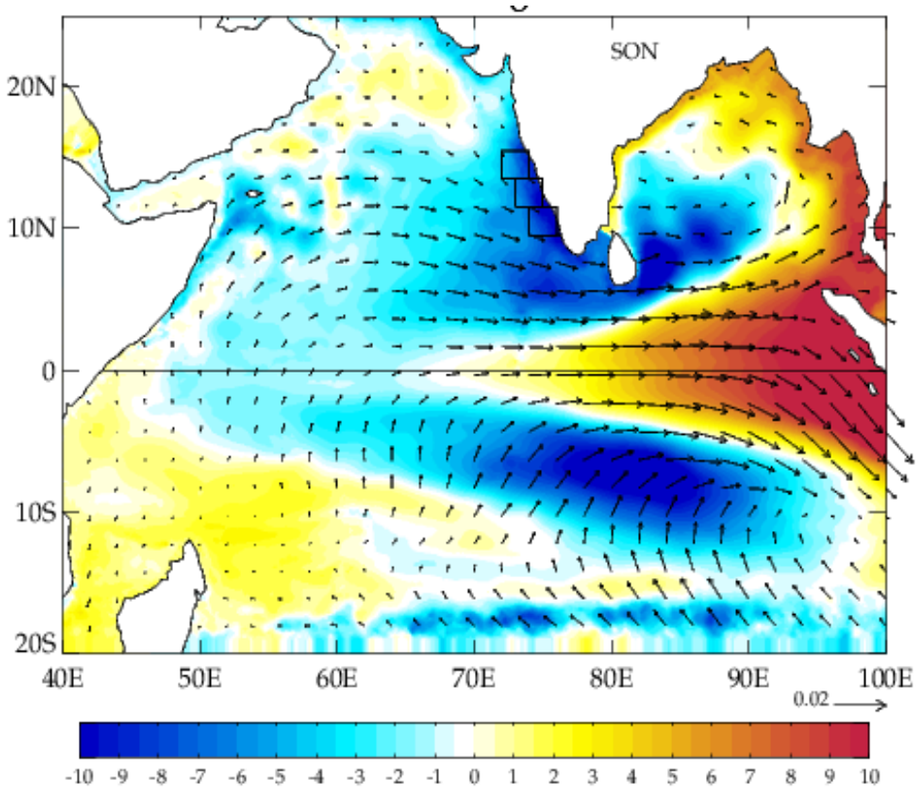
➢Tight relationship between thermocline and oxycline suggesting a physical control on oxygen variability

Results

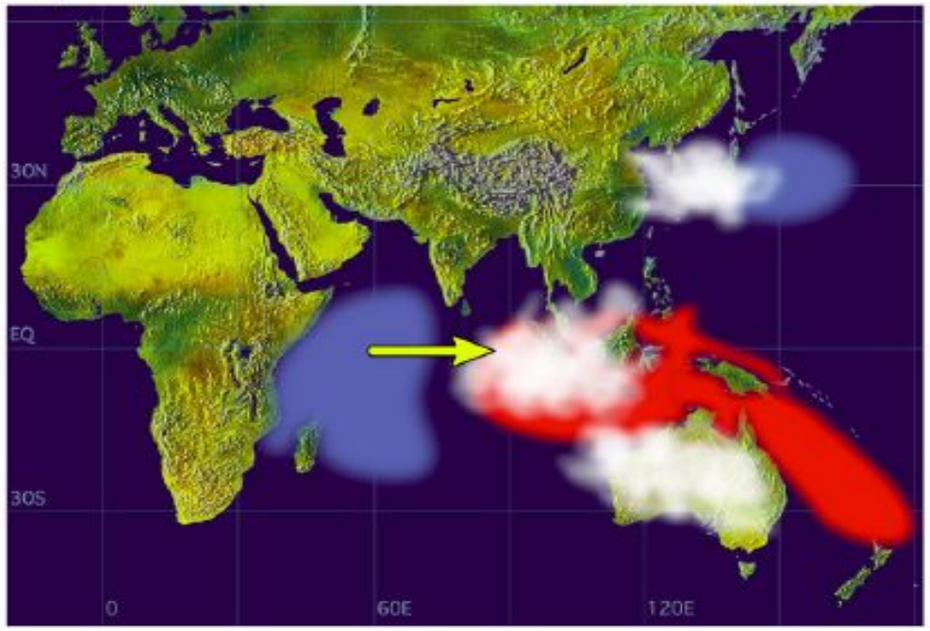
SST & wind pattern at Interannual time-scale



TCD & wind pattern at Interannual time-scale



Negative Dipole Mode



- Typical pattern of SST/Winds during SON => IOD

- Typical thermocline/Oxycline pattern during SON => main mode controlling interannual variability of DO along WCI is IOD

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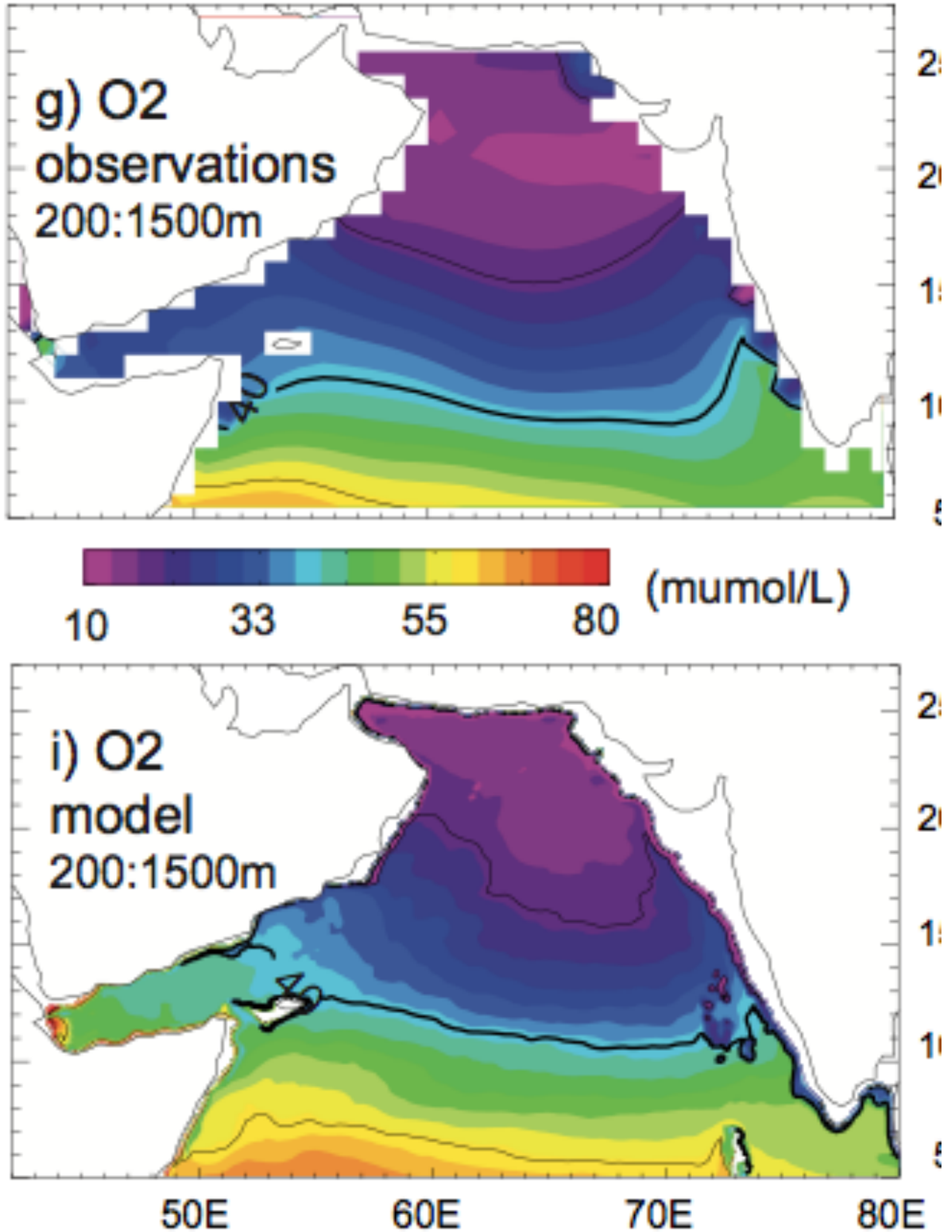
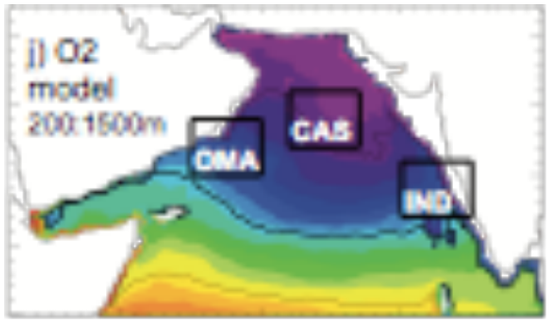
Impact on OMZ ventilation



Impact on OMZ ventilation

Resplandy et al., Biogeosciences 2012

Total

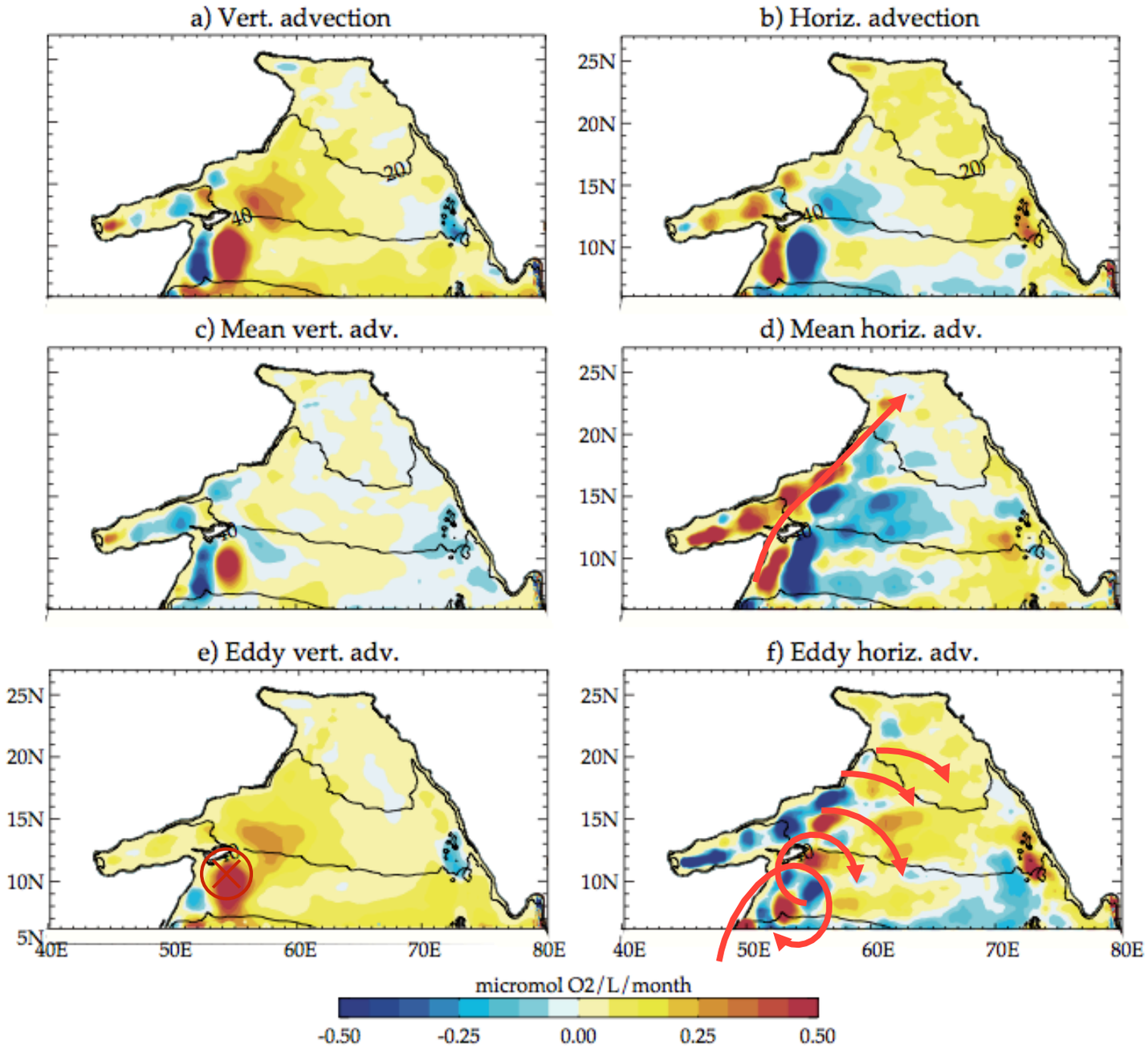


Mean

Eddy

Vertical

Horizontal



Oxygenation of the OMZ by eddy vertical and lateral advection

Conclusions

Mesoscale strongly modulate:

- Productivity in the central AS
- the strength of the OMZ

Interannual variability due to

- wind events
- Indian Ocean Dipole

Need of more long-term observations ..
limitation in temporal coverage (~10 years)

=> interannual - decadal & long term variability ??