MARIE THARP LECTURE SERIES
FOR OCEAN RESEARCH | **NO.34**

GEOMAR

Prof. Dr. Marina Lévy

LOCEAN-IPSL, Sorbonne Université/CNRS/
IRD/MNHN, Paris, France

Online Seminar Wednesday, 16th December 2020, 11:00 a.m.

Do Small-scale Physical Processes matter for Marine Bio-geochemistry Responses to Anthropogenic Climate Change?

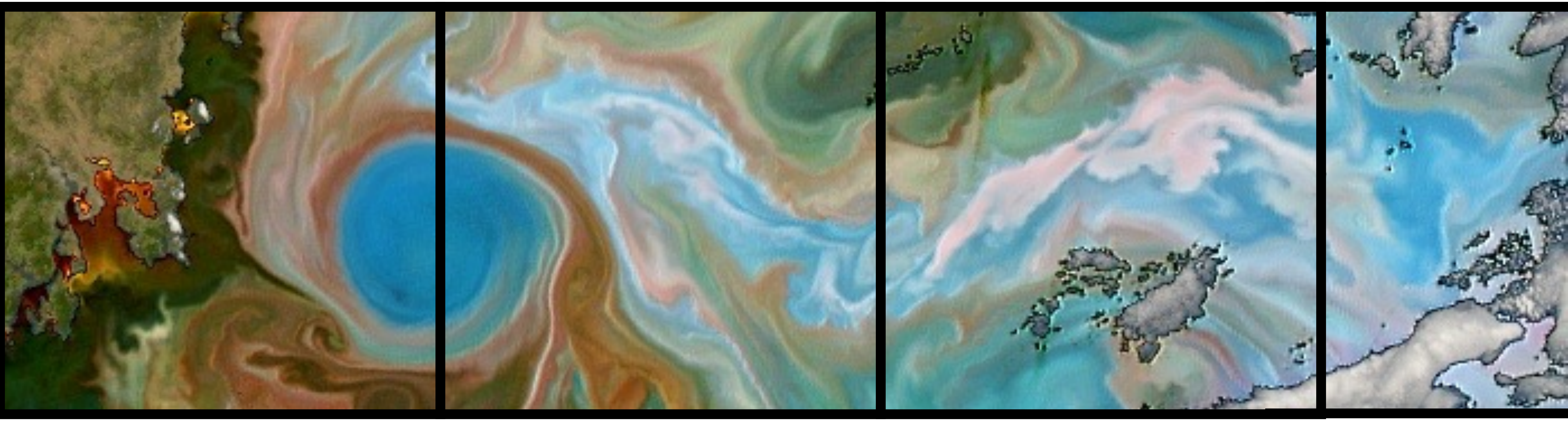
Do fine-scale physical processes matter for marine biogeochemistry responses to Climate Change ?

Marina Lévy

LOCEAN-IPSL, Sorbonne Université, Paris, France

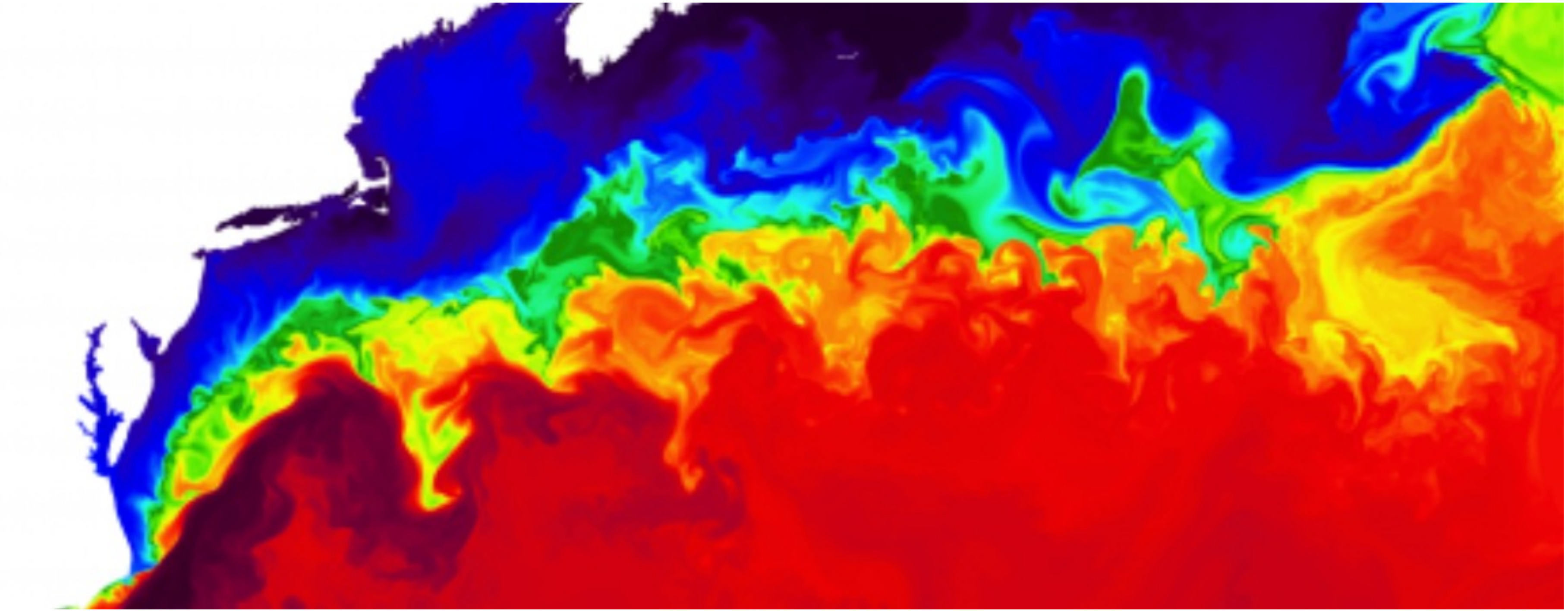
Surface Chla (Modis)

Lateral scales 1-50 km



Not explicitly accounted for in Earth System Models (ESM)
Sub-grid processes, parametrized

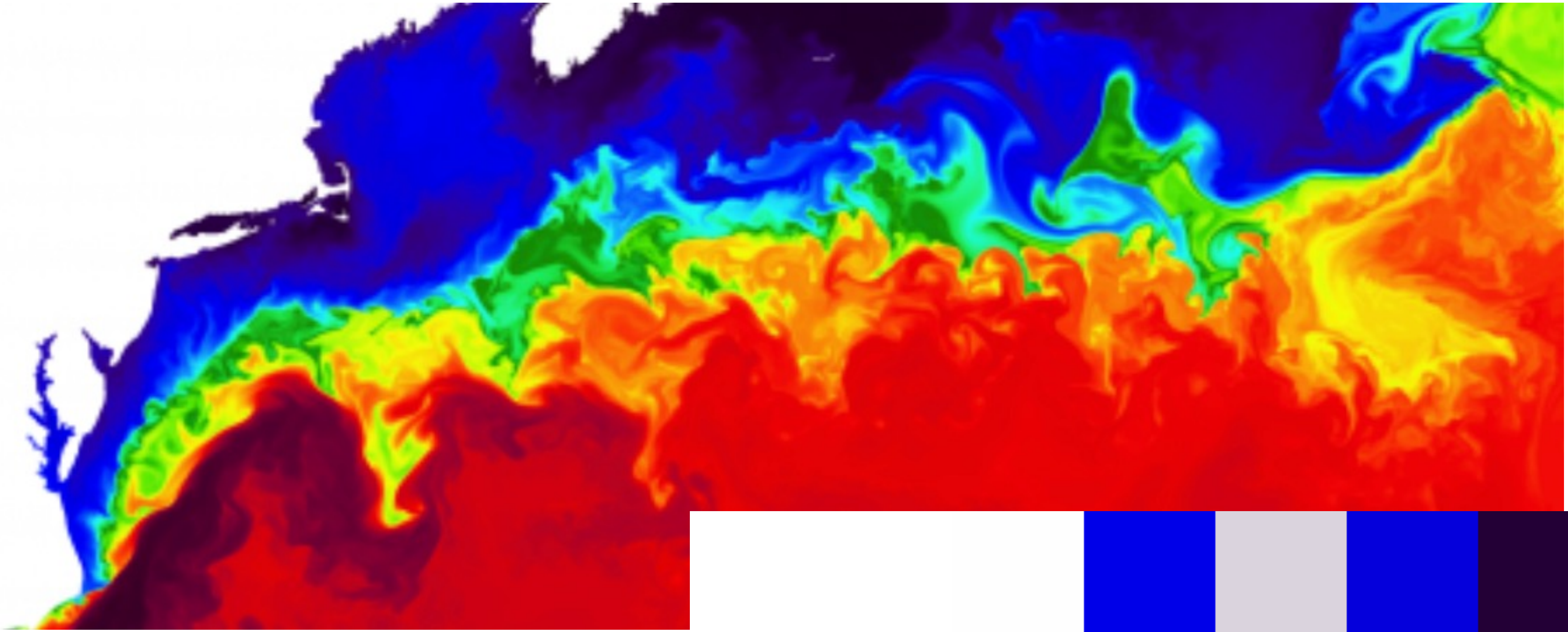
Fine resolution model simulation



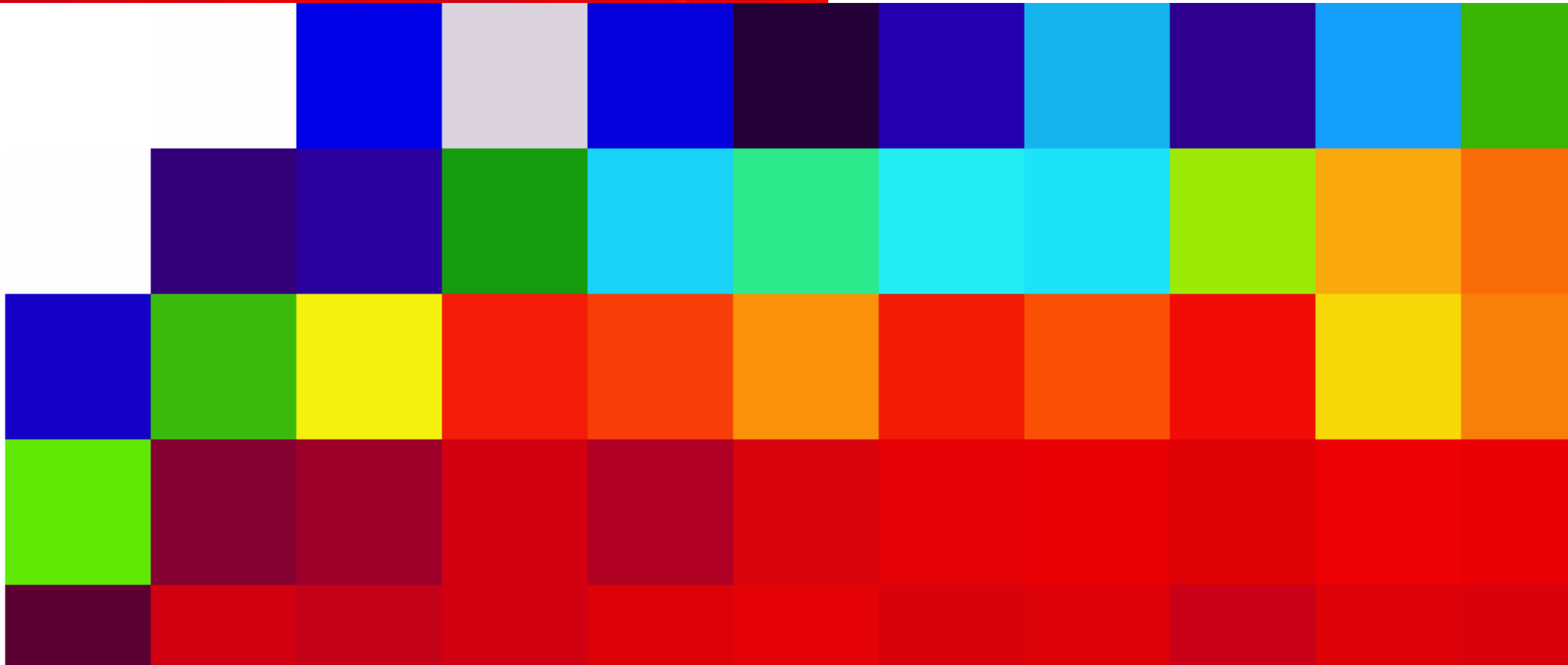
SST
Fine resolution grid
1/60°

© J-M Molines, MEOM
Ajayi et al. (2020)

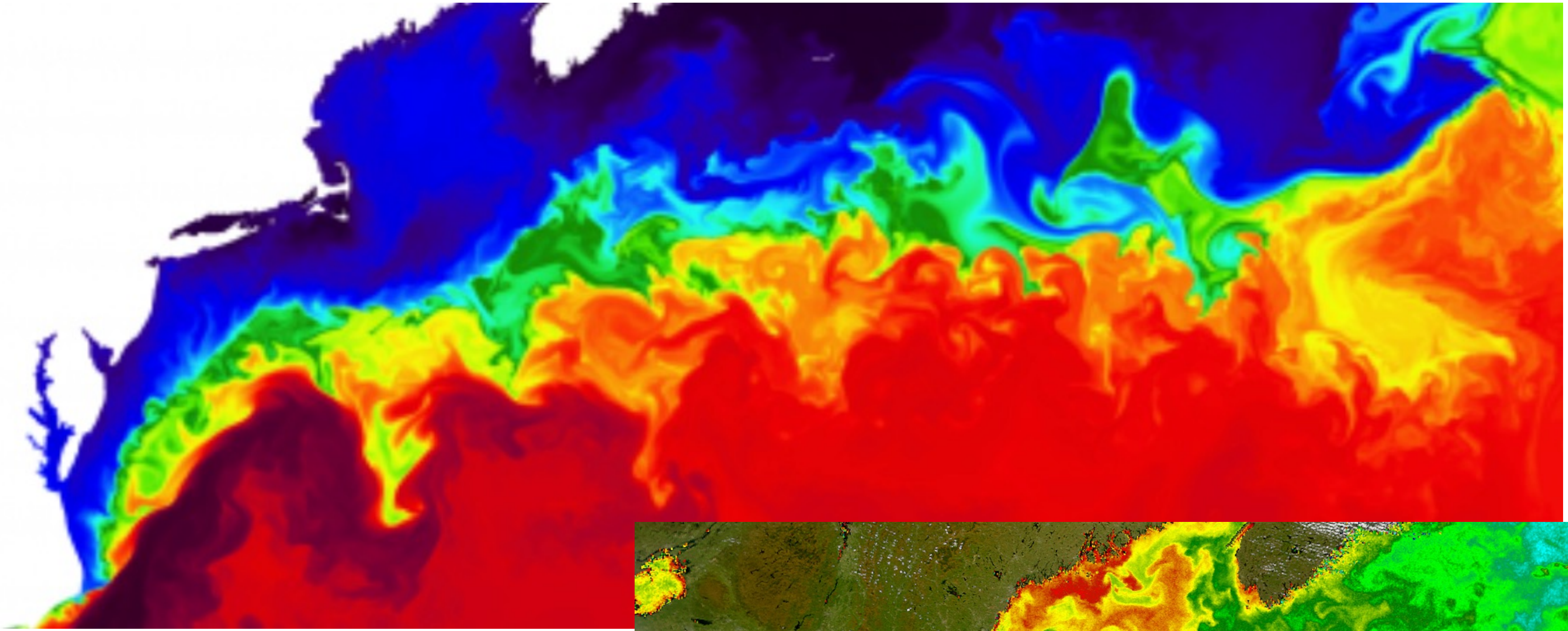
Emerge with increasing model resolution



SST
Fine resolution grid
1/60°

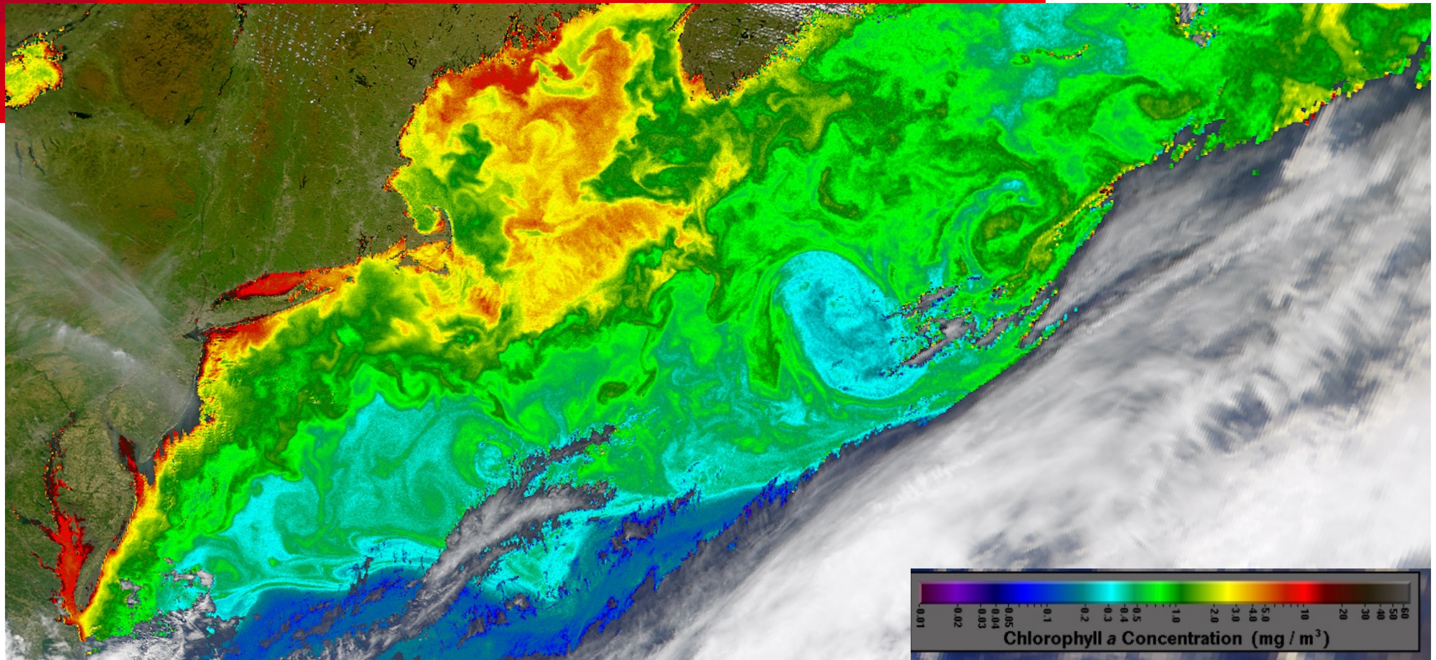


Coarse resolution grid
2°

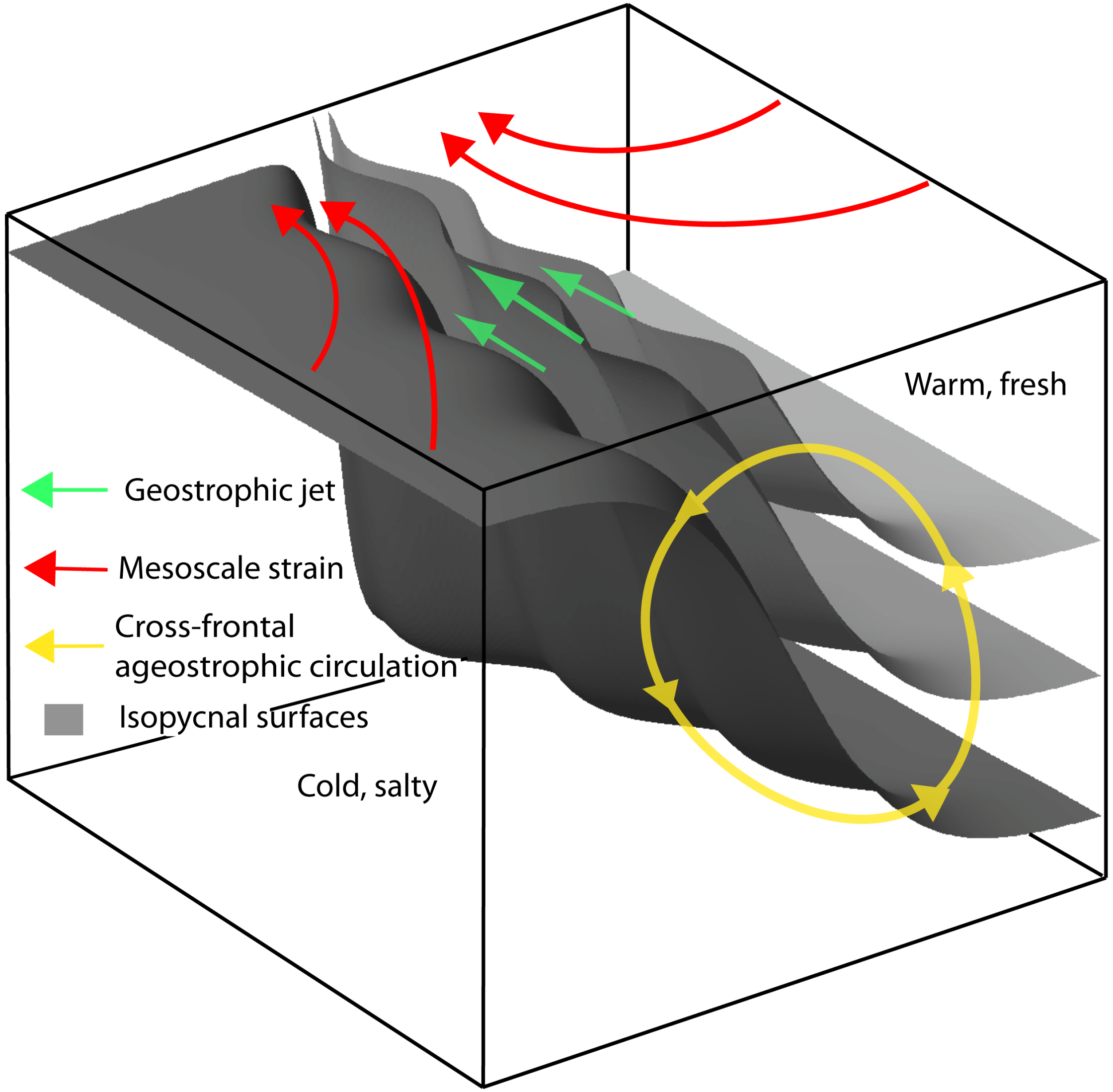


Fine resolution grid
1/60°

SeaWiFs image
11 May 2002
©NASA-GSFC



Local (sub-)mesoscales impact on biogeochemical budgets

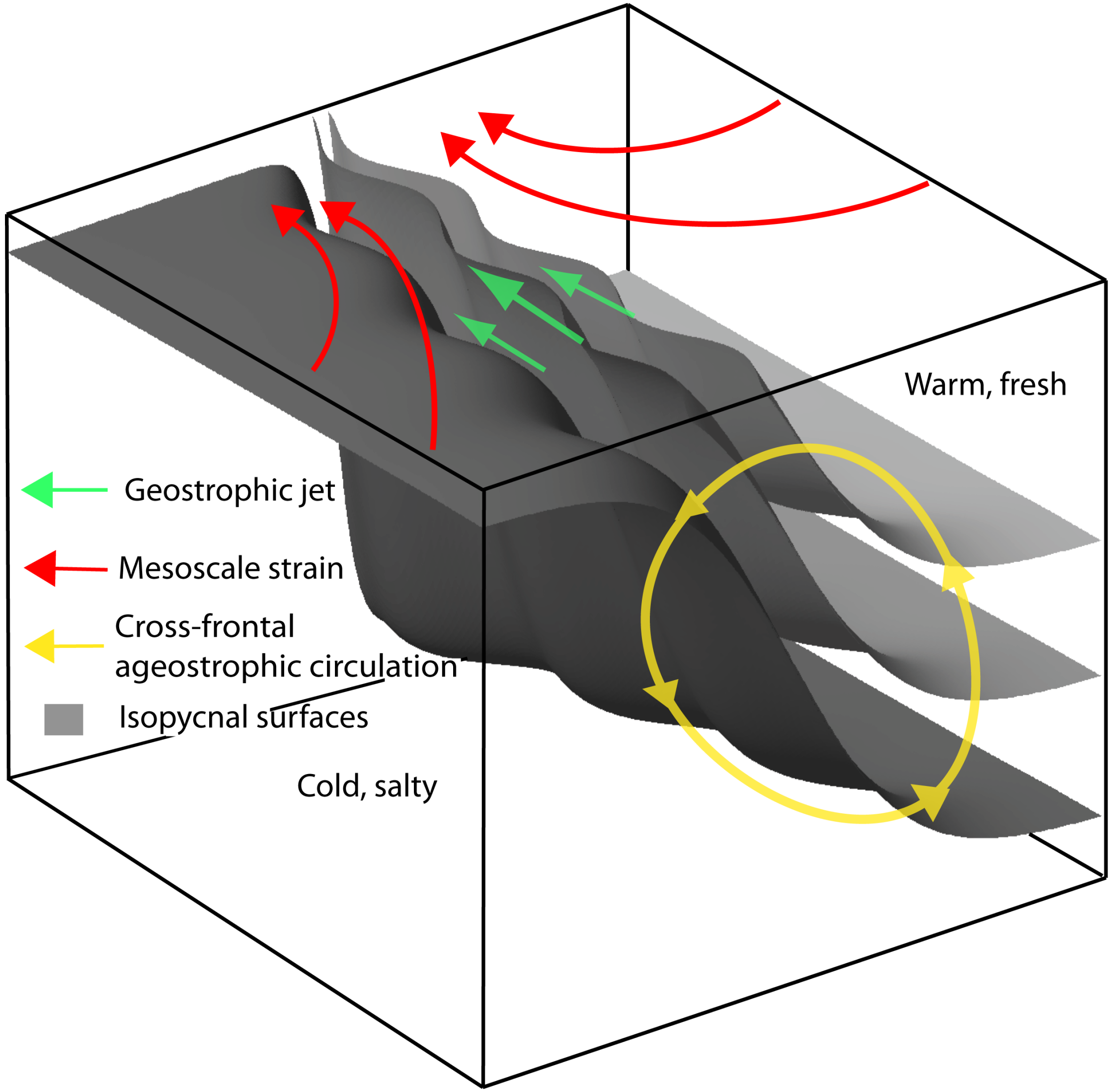


Strong vertical circulation over fronts:

- Transport of nutrients
- Subduction of oxygen
- Carbon export
- …

Levy et al, 2018

Local (sub-)mesoscales impact on biogeochemical budgets



Strong vertical circulation over fronts:

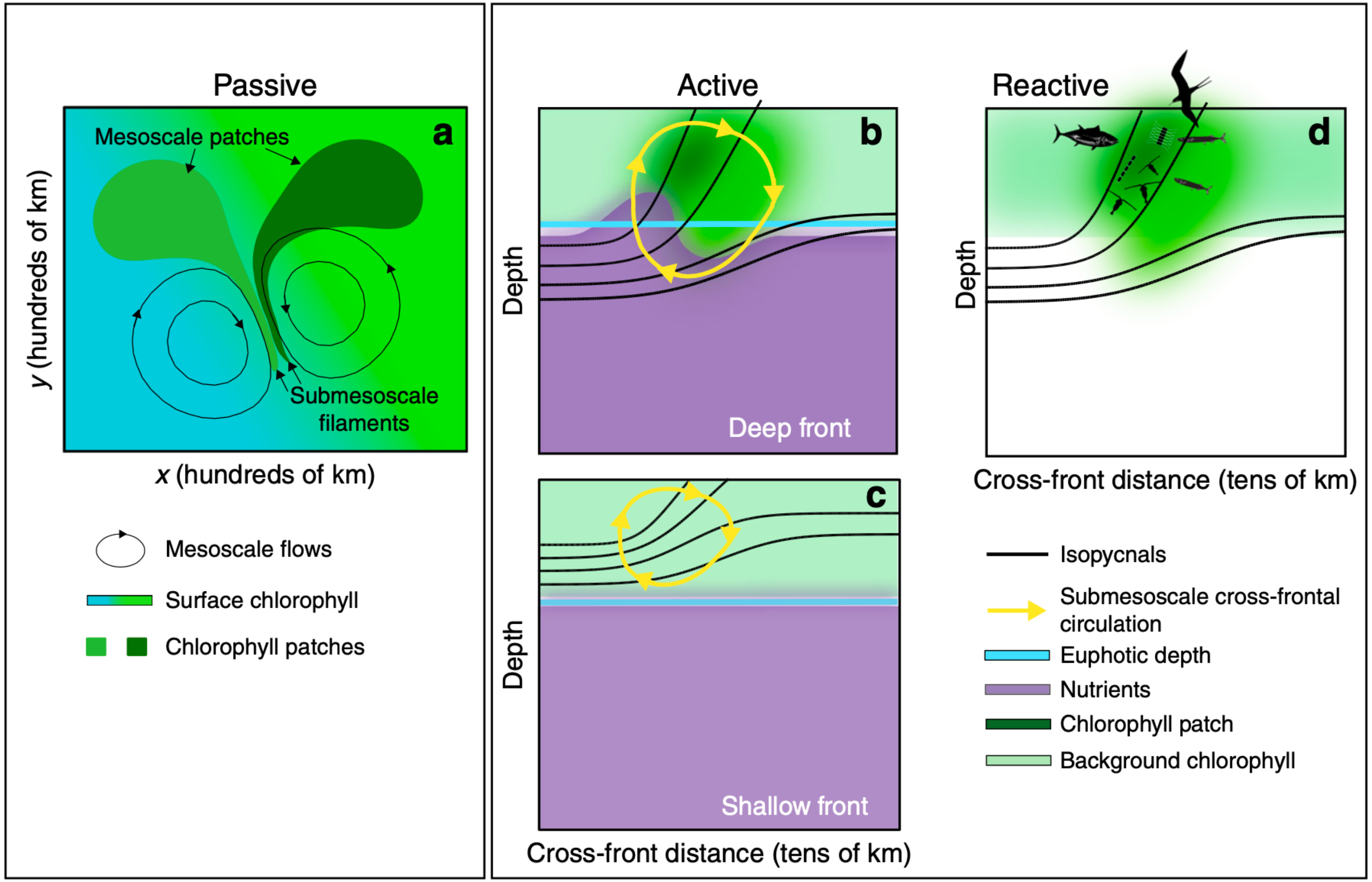
- Transport of nutrients
- Subduction of oxygen
- Carbon export
- …

Parametrization:

- GM: flatten large-scale isopycnals
- Redi: isopycnal diffusion

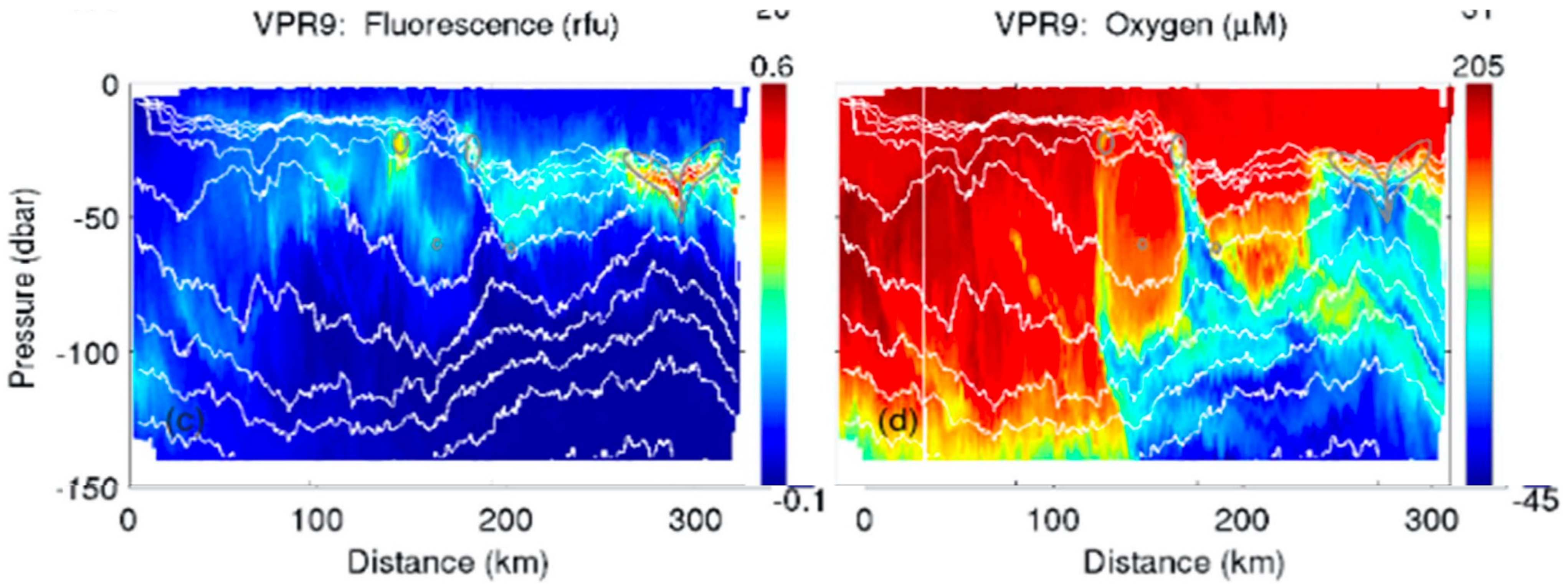
Levy et al, 2018

Local (sub-)mesoscales impact on biogeochemical budgets



Levy et al, 2018

Local (sub-)mesoscales impact on biogeochemical budgets

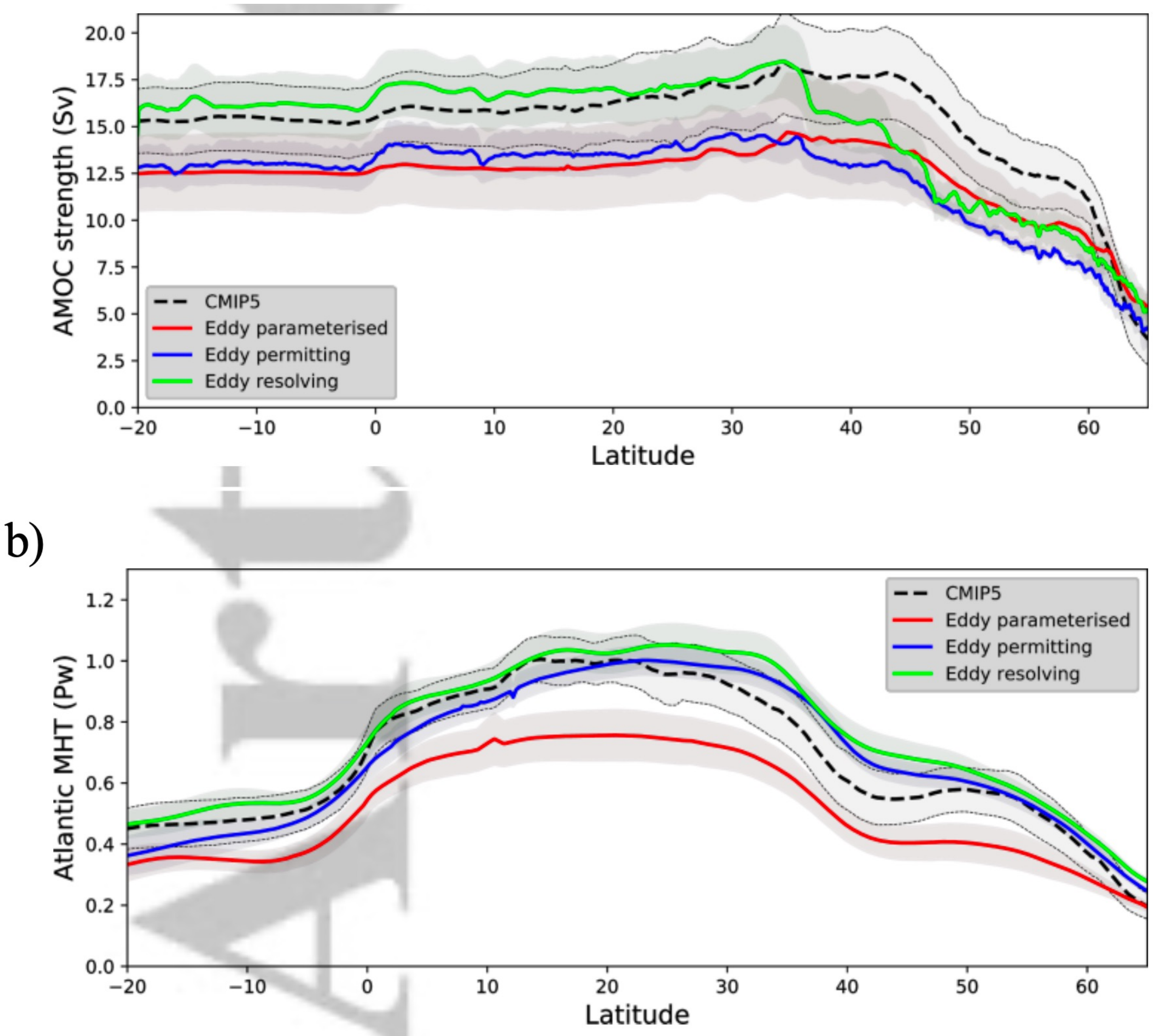


Lateral scales 1-50 km
Vertical scales 0-200 m

Towed VPR, Subtropical North Atlantic

Stanley et al. (2017)

Remote (sub-)mesoscales impact on biogeochemical budgets



Mean circulation affected by model resolution :

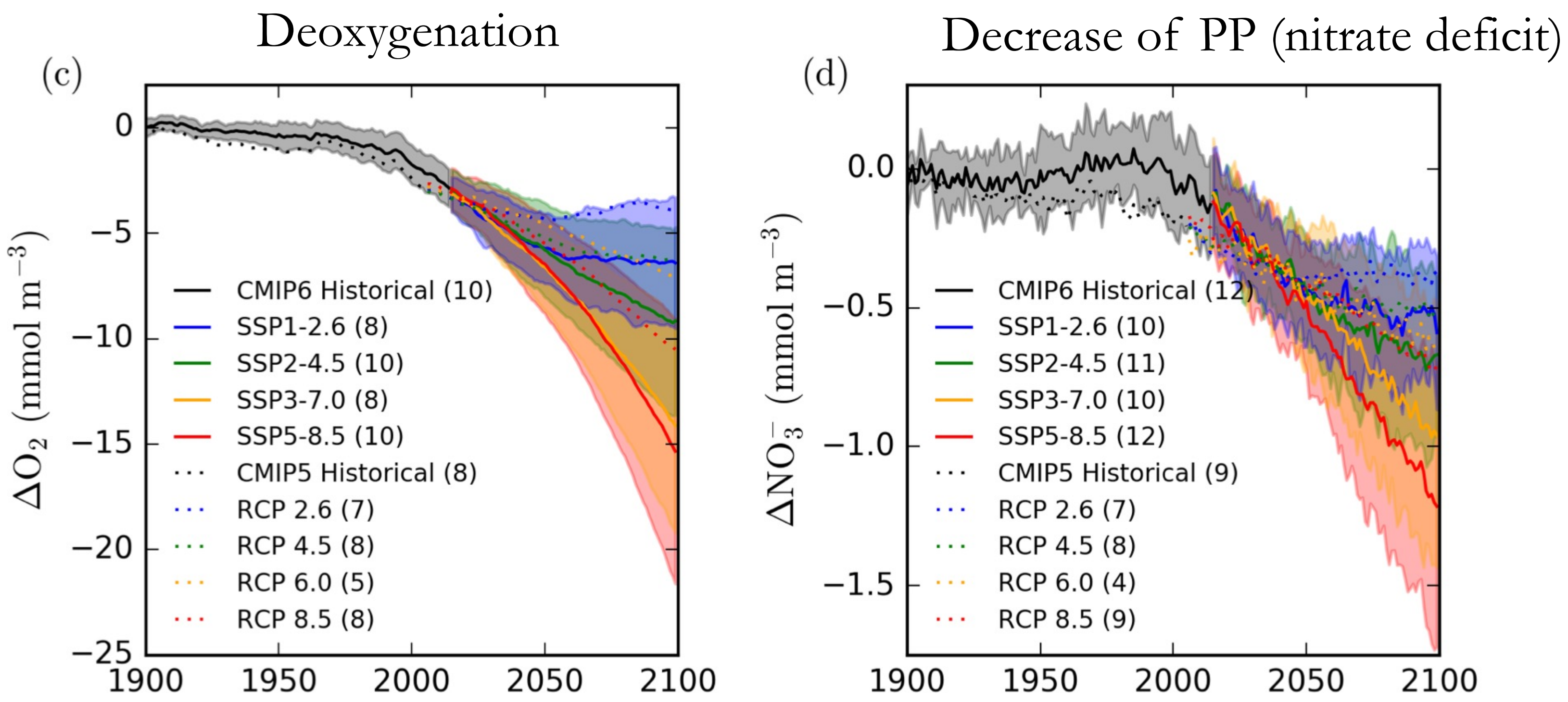
- AMOC
- Transport of heat

➢ Consequences on large-scale transport of nutrients, C, O_2

Hirschi et al. (2020)

Biogeochemical climate projections

Major threats

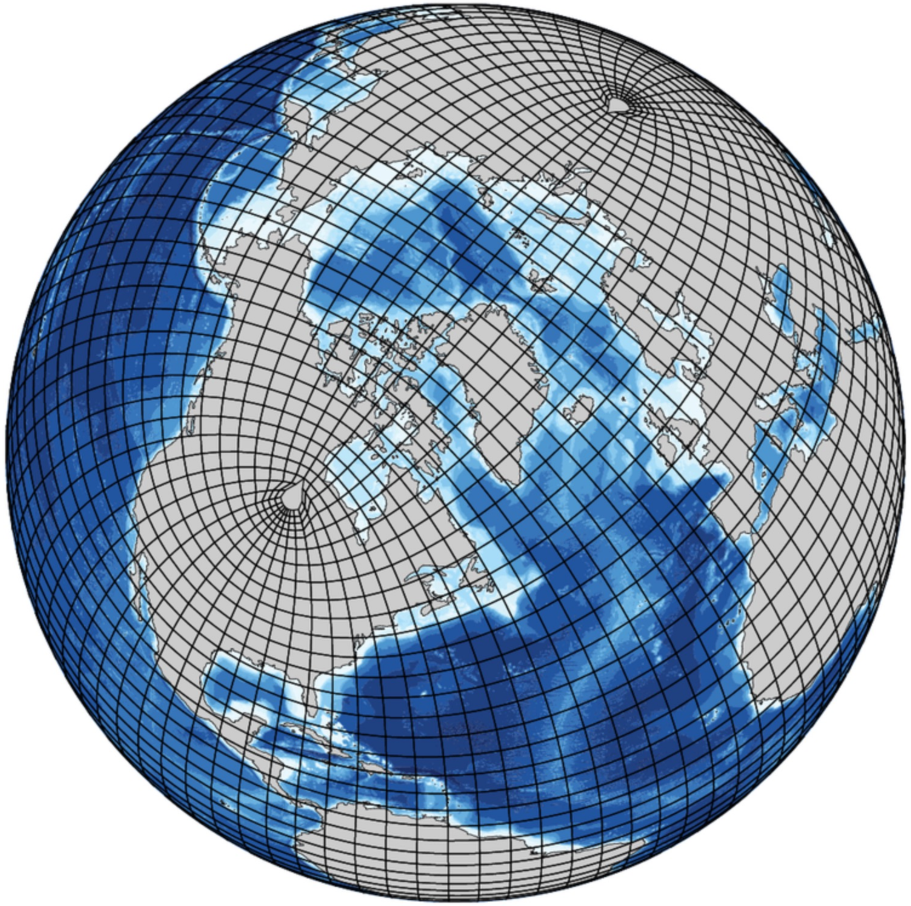


Kwiatkowski et al, 2020

Major uncertainties

- Emission scenario
- Model differences (parametrizations & numerics)

Are biogeochemical climate projections sensitive to these hidden features ?



Due to computational constrains

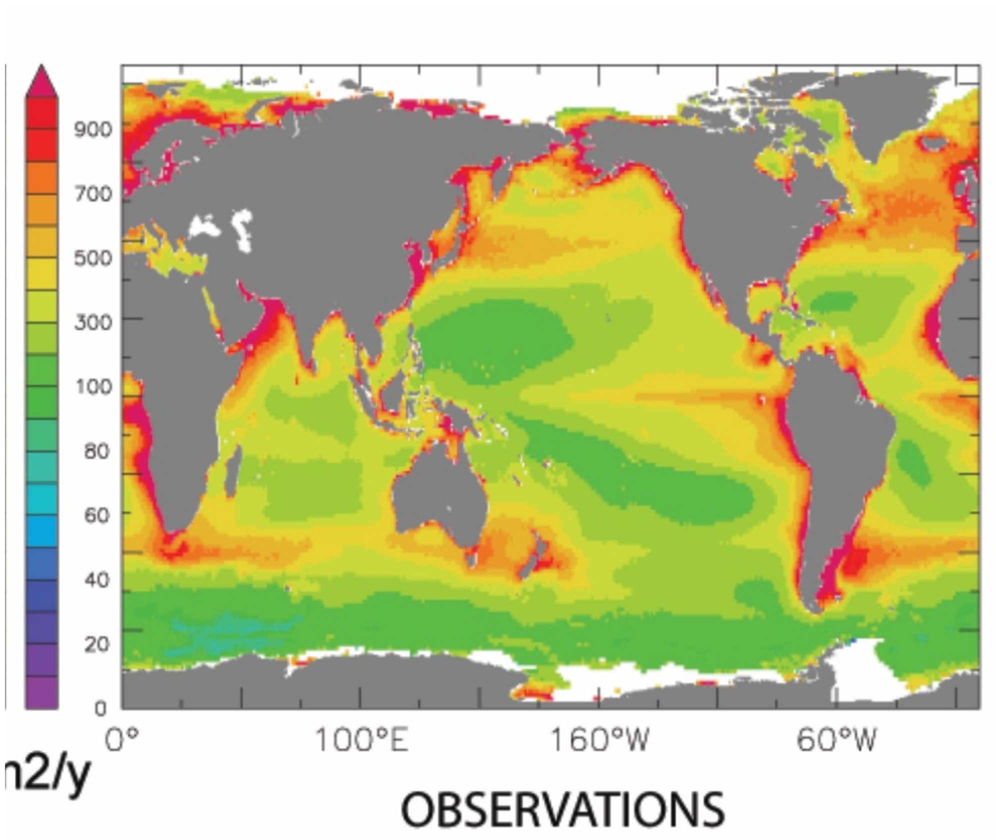
2° to 1/60°: 500,000 X more CPU time

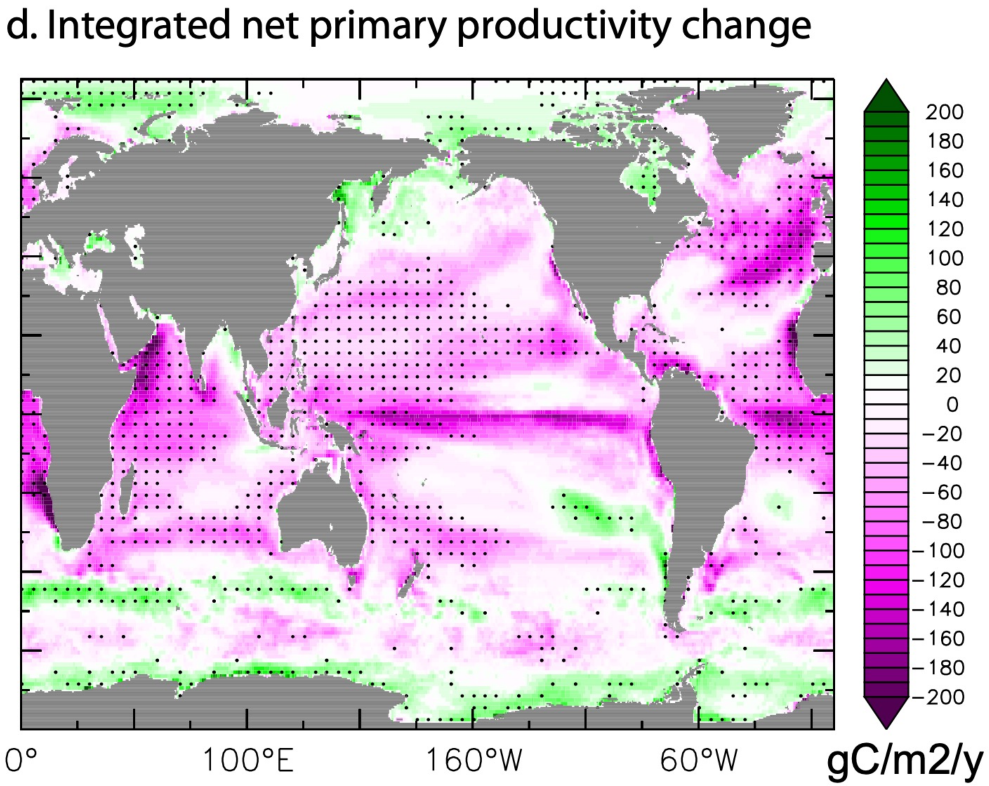
Outline

1. Reduction of primary production

2. Deoxygenation and volume of OMZ

Decrease of primary production

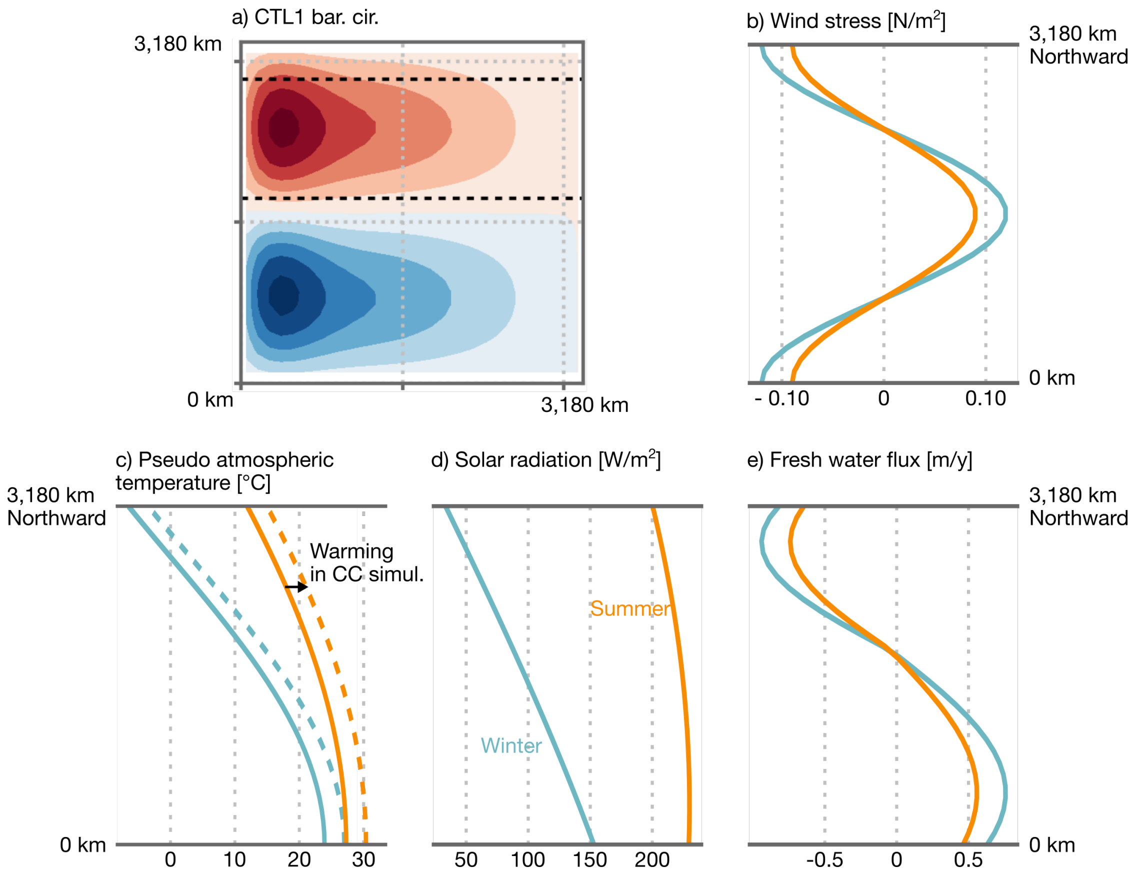




Bopp et al. (2013)

Attributed to increased stratification in response to warming of surface waters

Tool model



- Double-gyre system (NEMO OGCM) with biogeochemical model
- Domain of reduced size allows to carry long integrations at fine resolution
- Seasonal forcings
- Progressive warming (RCP8.5)

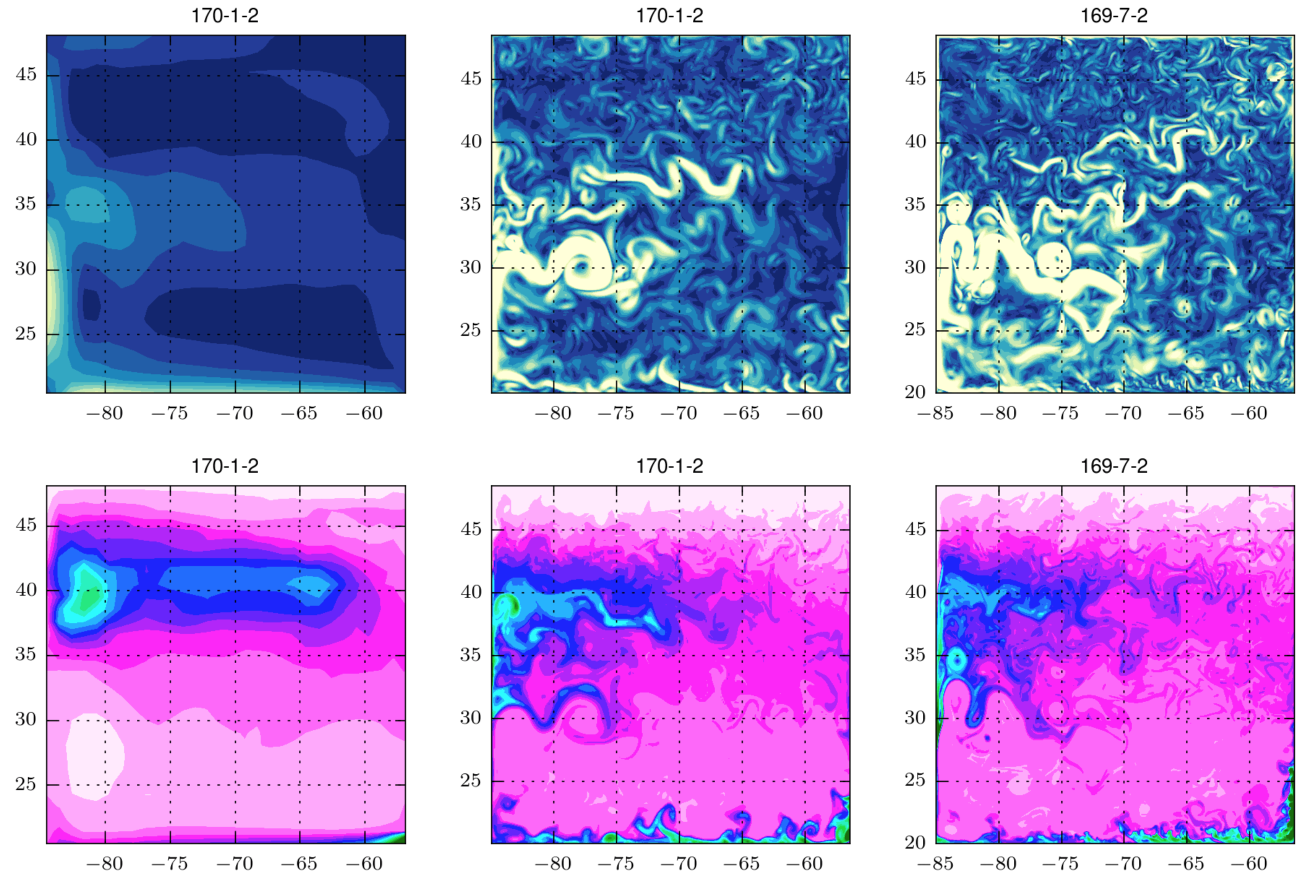
Couespel et al. (work in progress)

3 horizontal resolutions

1°~100 km | 1/9°~12 km | 1/27°~4 km

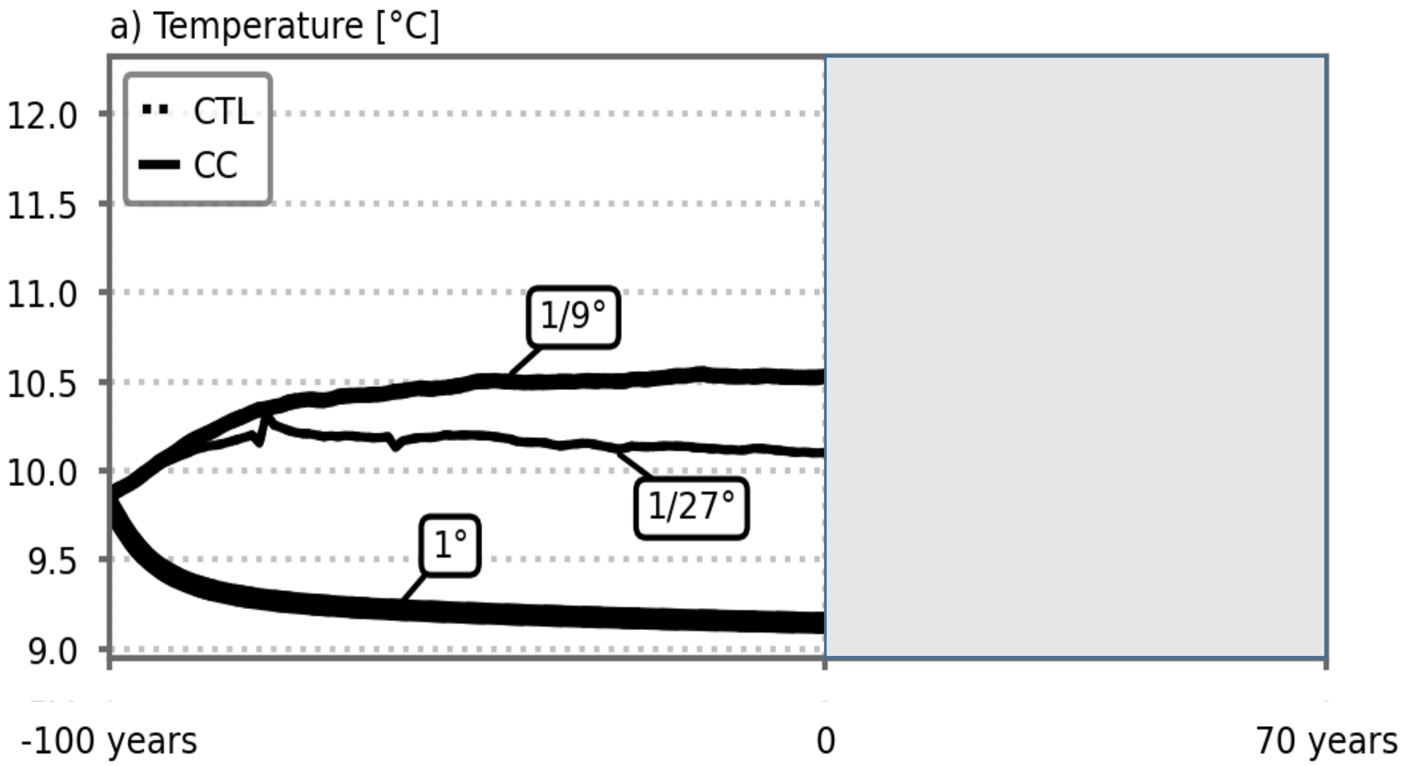
Surface speed

Phytoplankton at the surface



Emergence of (sub-)mesoscales with increasing model resolution

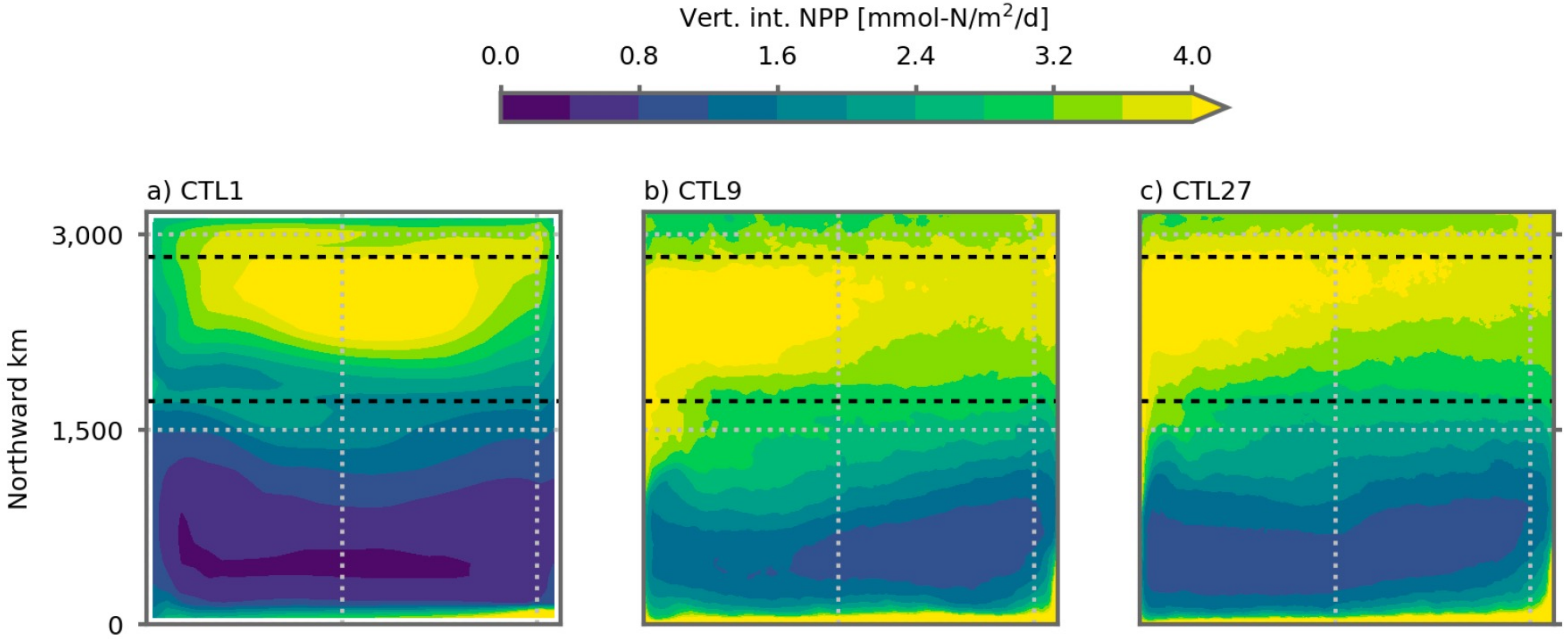
Historical simulation



- Different mean-state (remote effect)

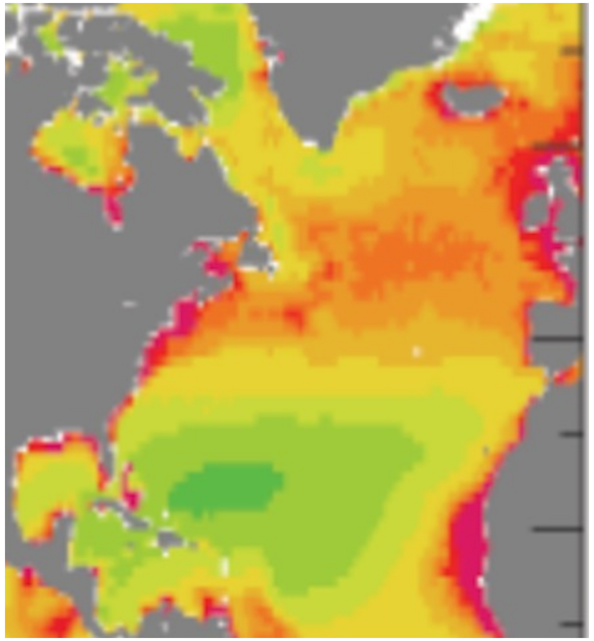
Levy et al. (2010, 2012)

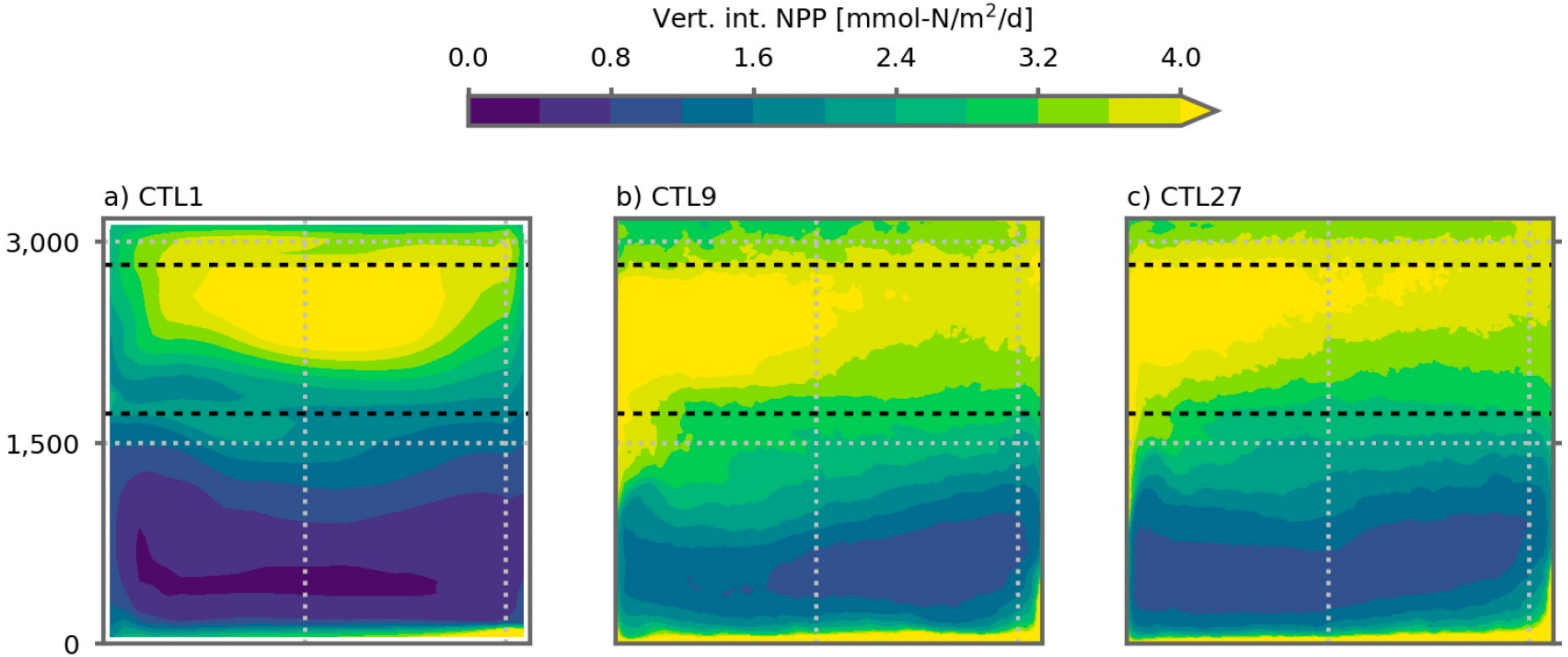
Historical simulation



Levy et al. (2010, 2012)

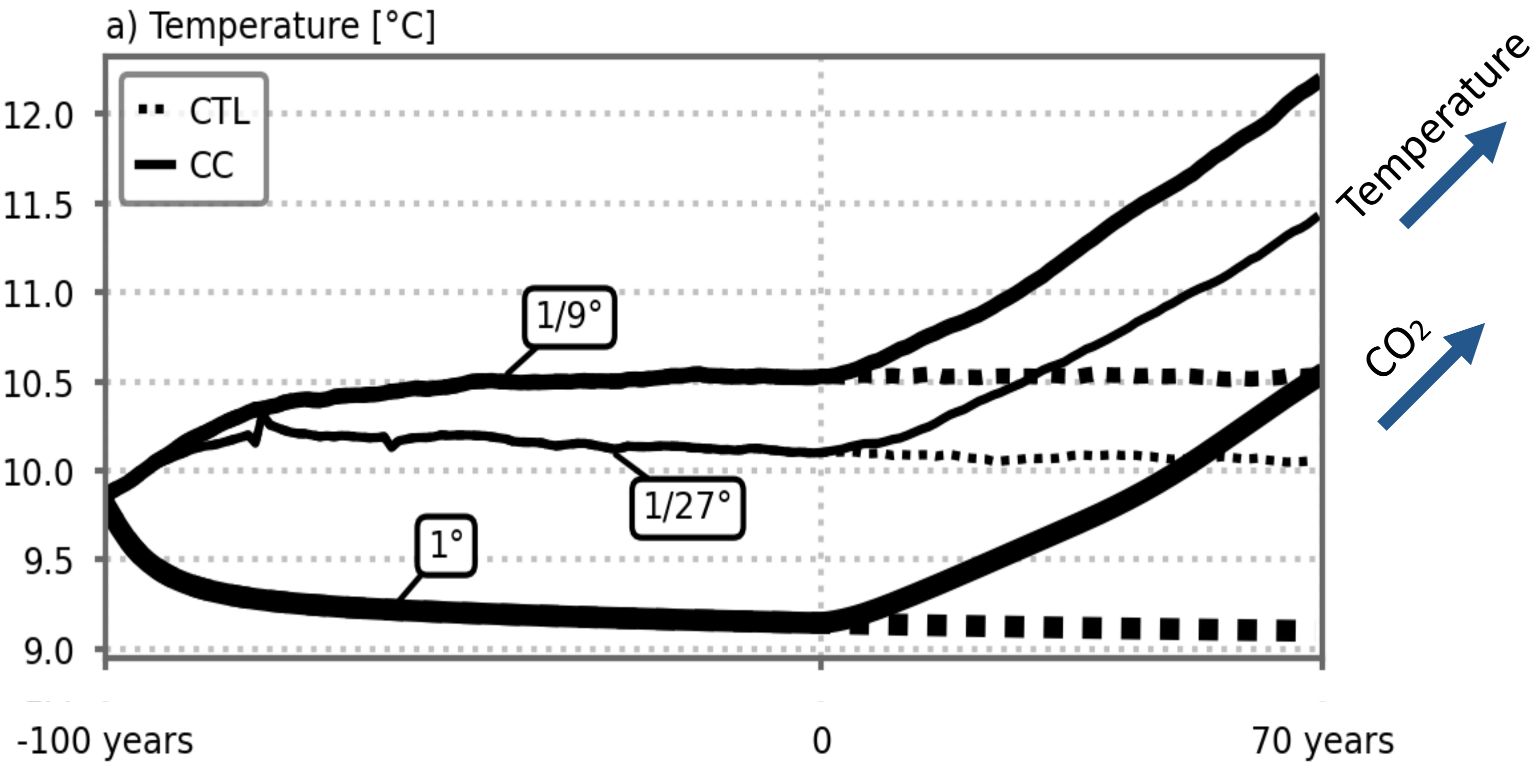
Historical simulation





Levy et al. (2010, 2012)

Climate change simulation



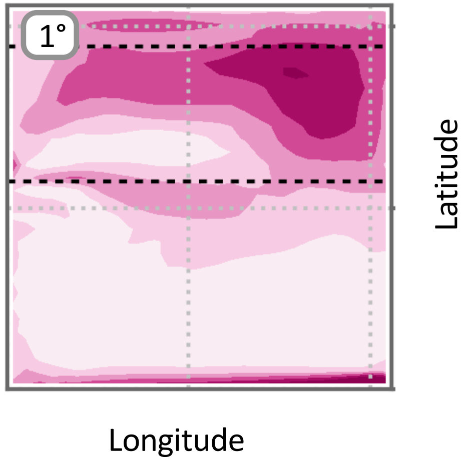
+ 3°C in 70 years

+1% CO_2 / year

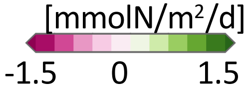
➢ Different projections

Couespel et al. (work in progress)

PP decline

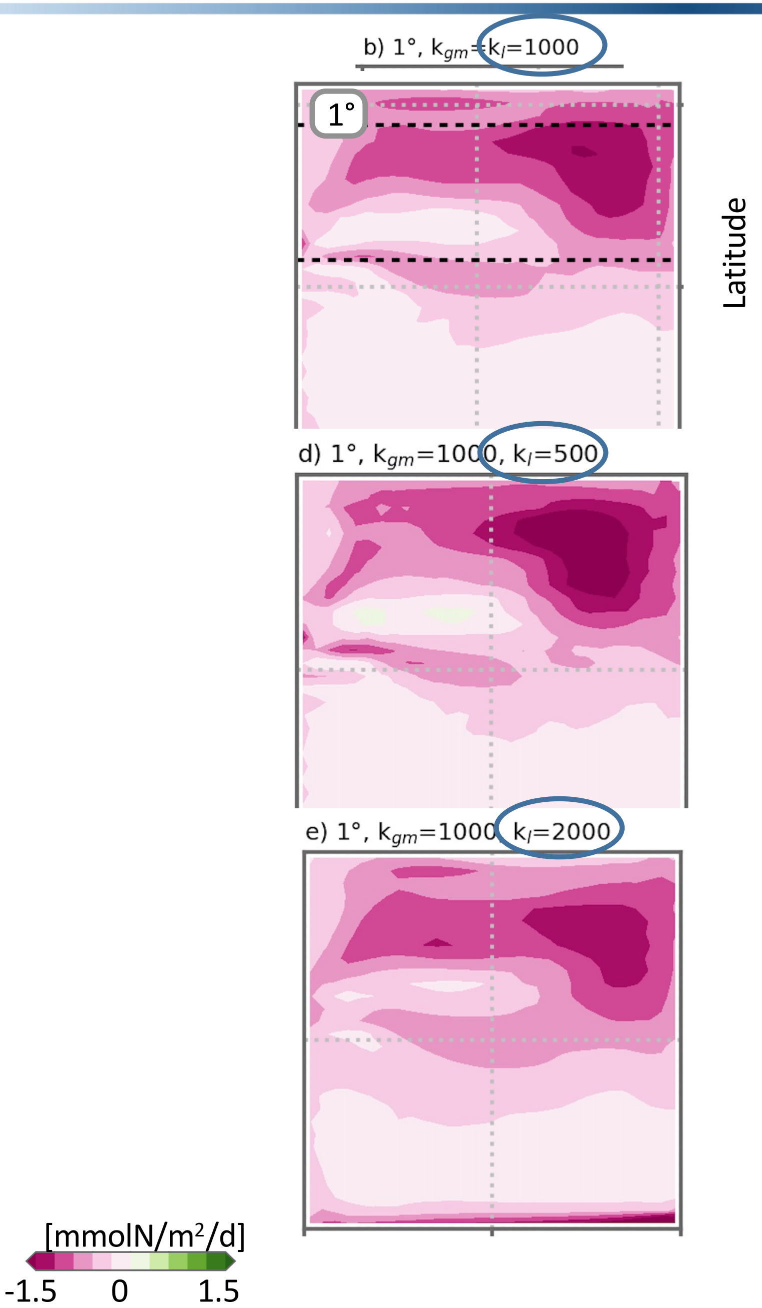


- Strong PP decline at 1° in the northern gyre



Couespel et al. (work in progress)

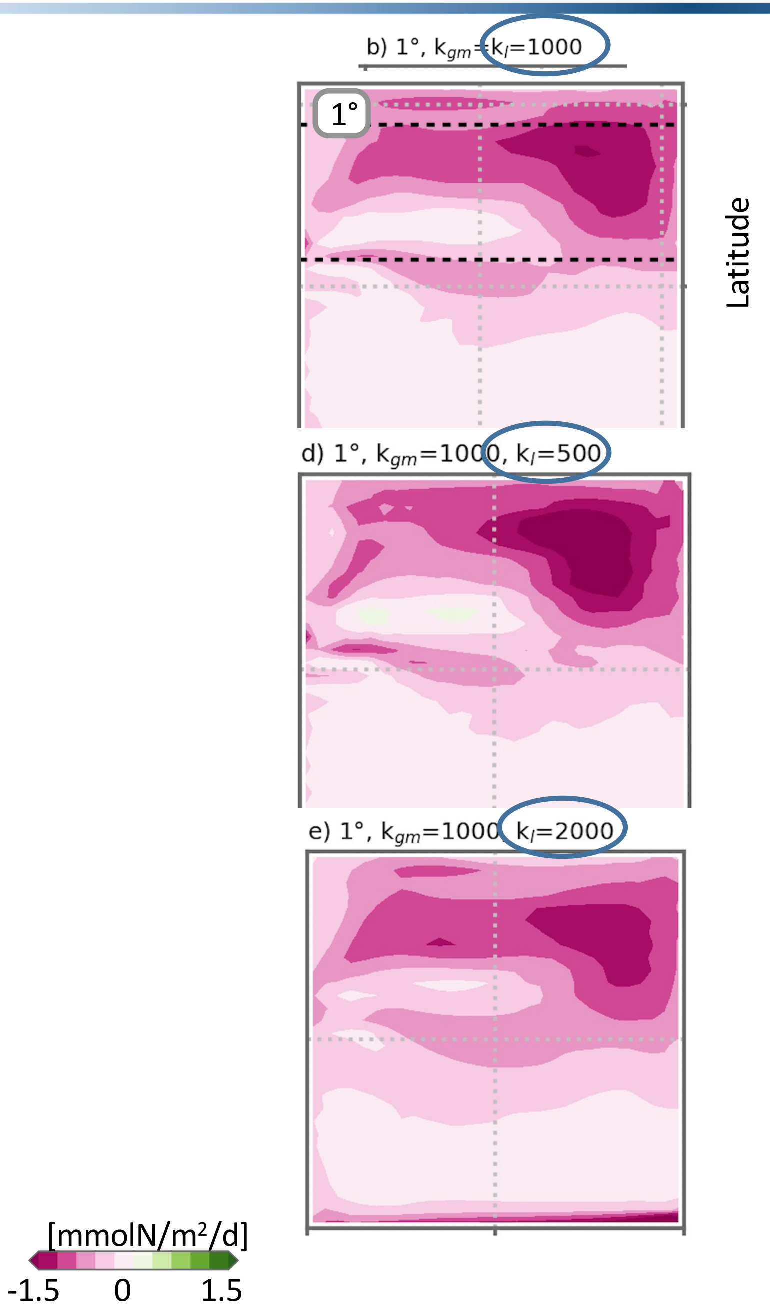
PP decline



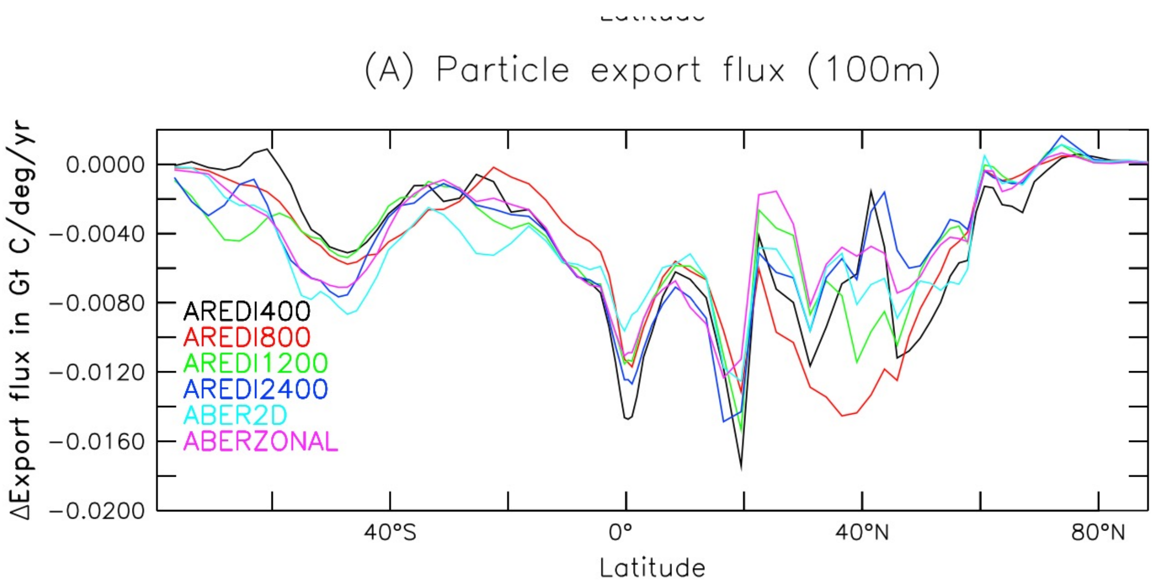
- Strong PP decline at 1° in the northern gyre
- Weakly sensitive to Aredi coefficient

Couespel et al. (work in progress)

PP decline



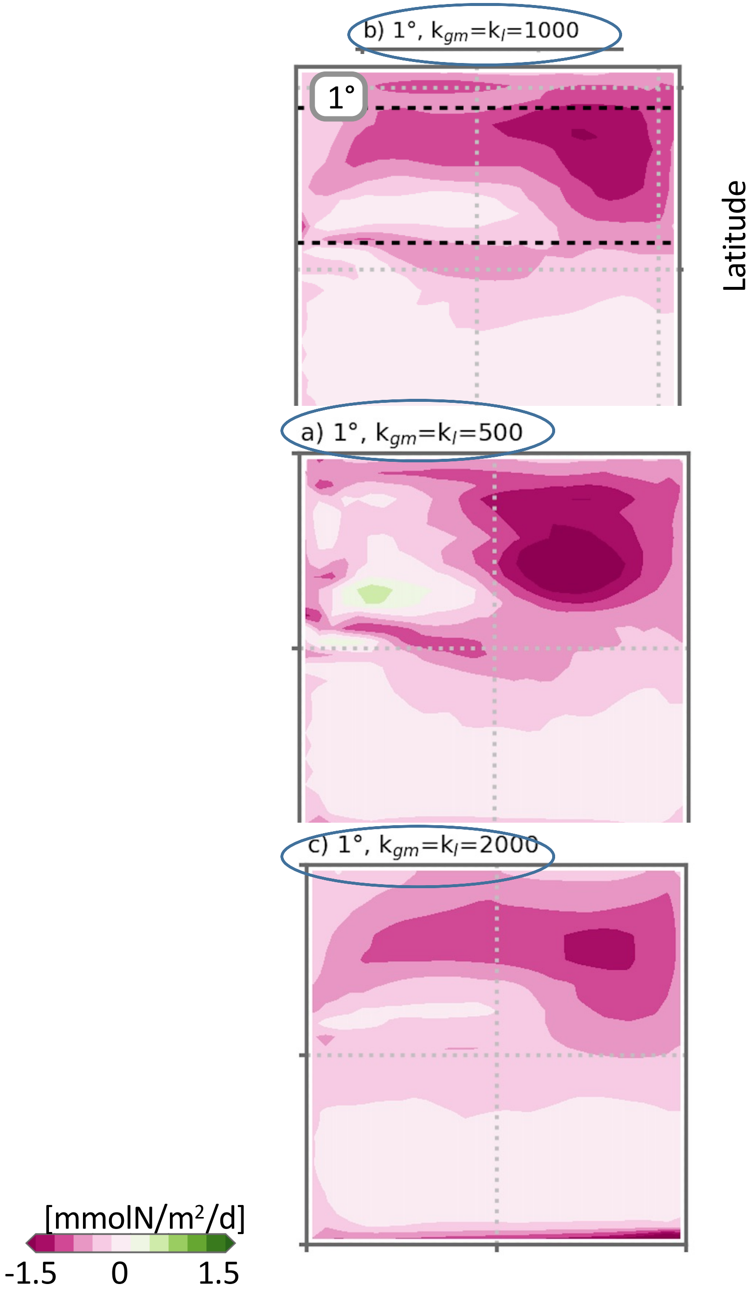
- Weakly sensitive to Aredi coefficient



(B) Change in Export Production 40−140 yrs after CO_2 doubling

Bahl et al. (2019)

PP decline

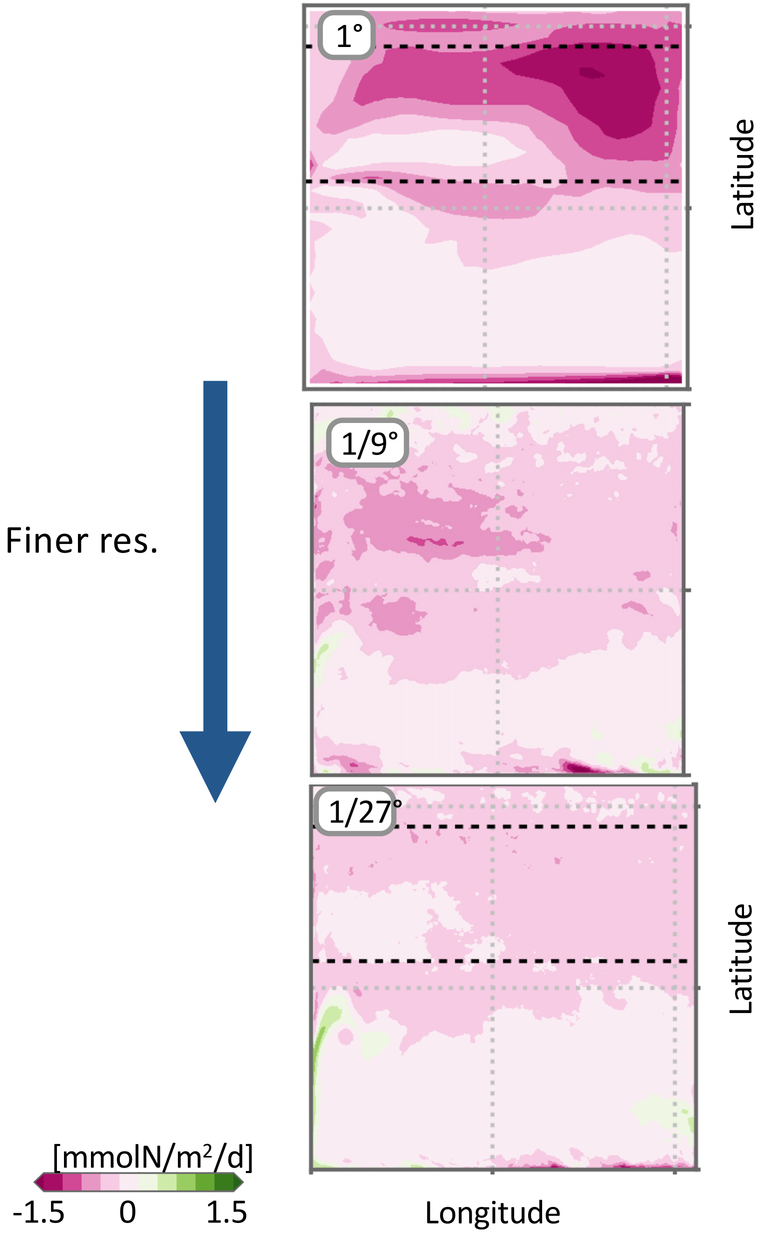


- Strong PP decline at 1° in the northern gyre

- Weakly sensitive to GM coefficient

Couespel et al. (work in progress)

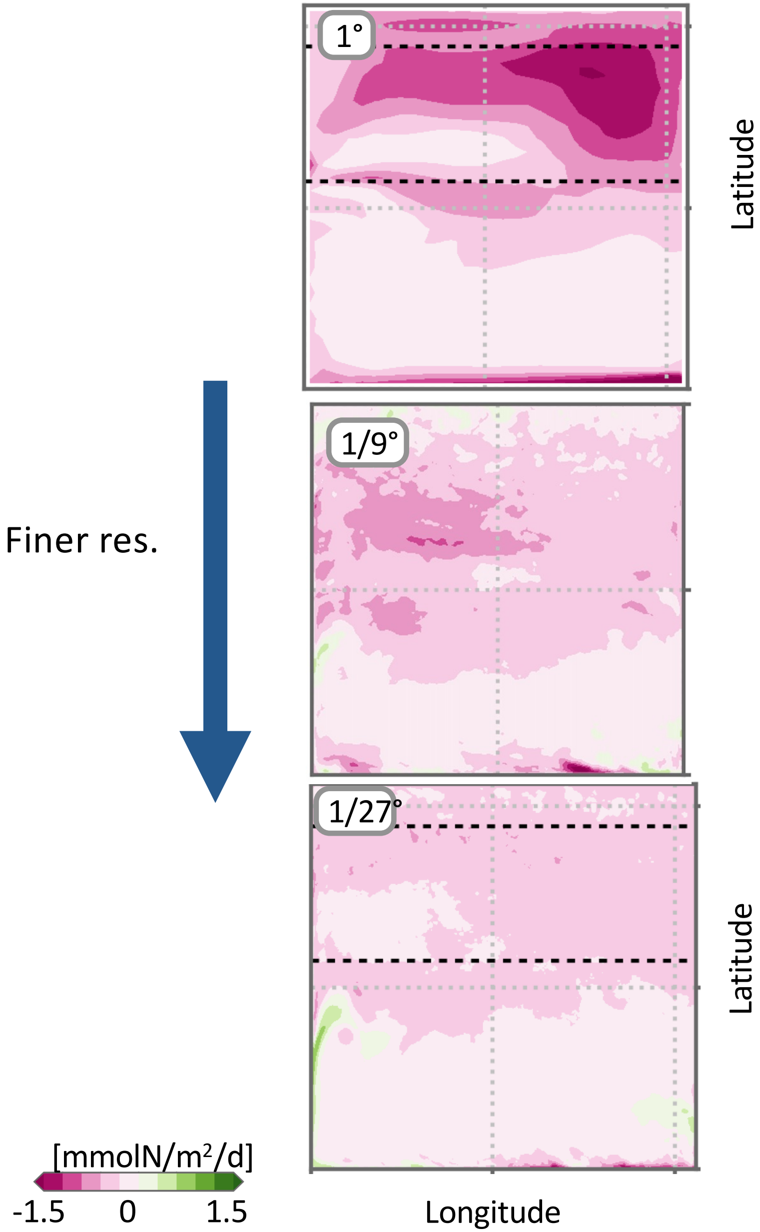
PP decline

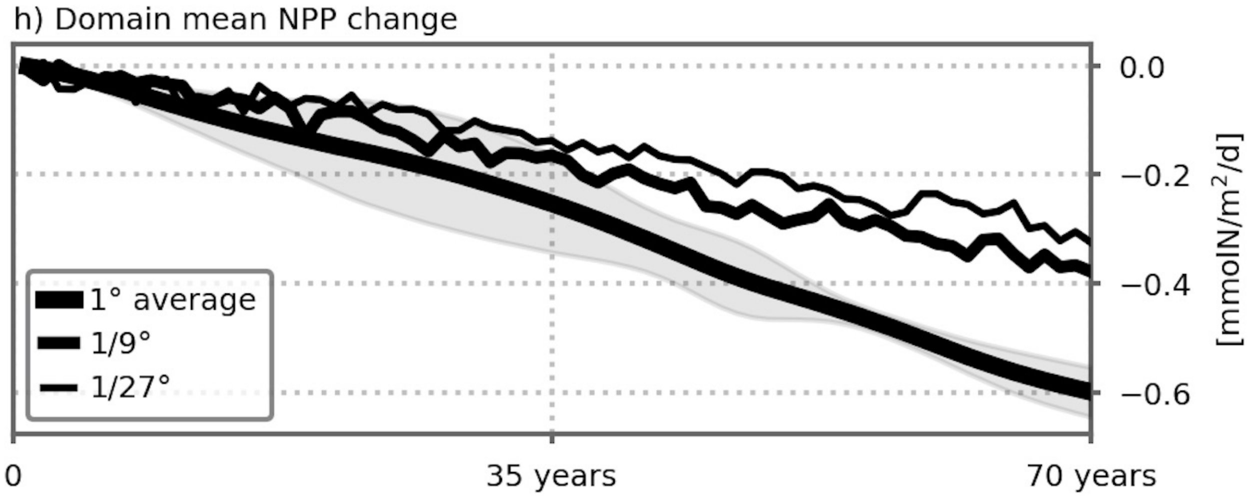


- PP decline strongly attenuated at 1/9° and 1/27°
- Decline halfed at 1/27°

Couespel et al. (work in progress)

PP decline

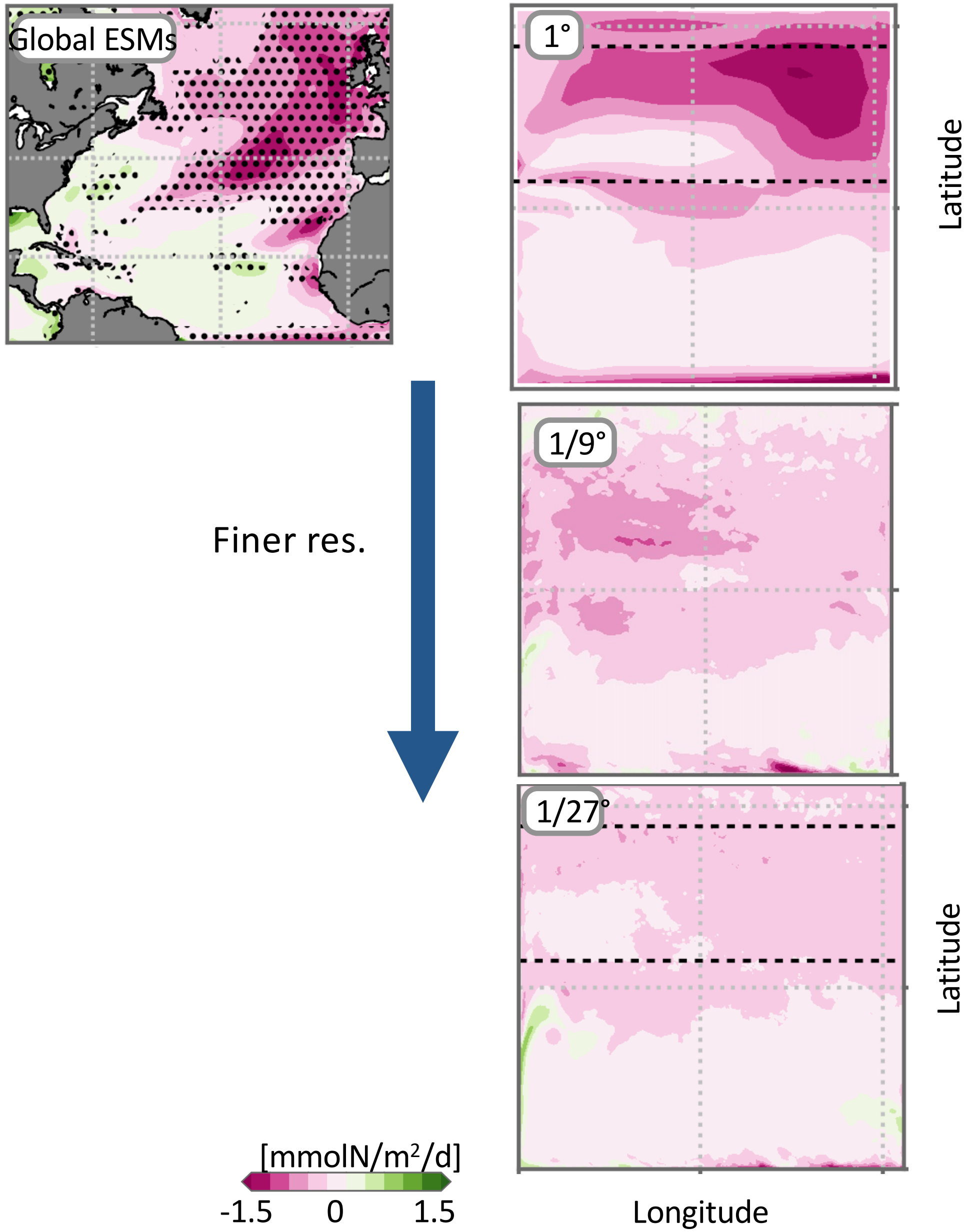


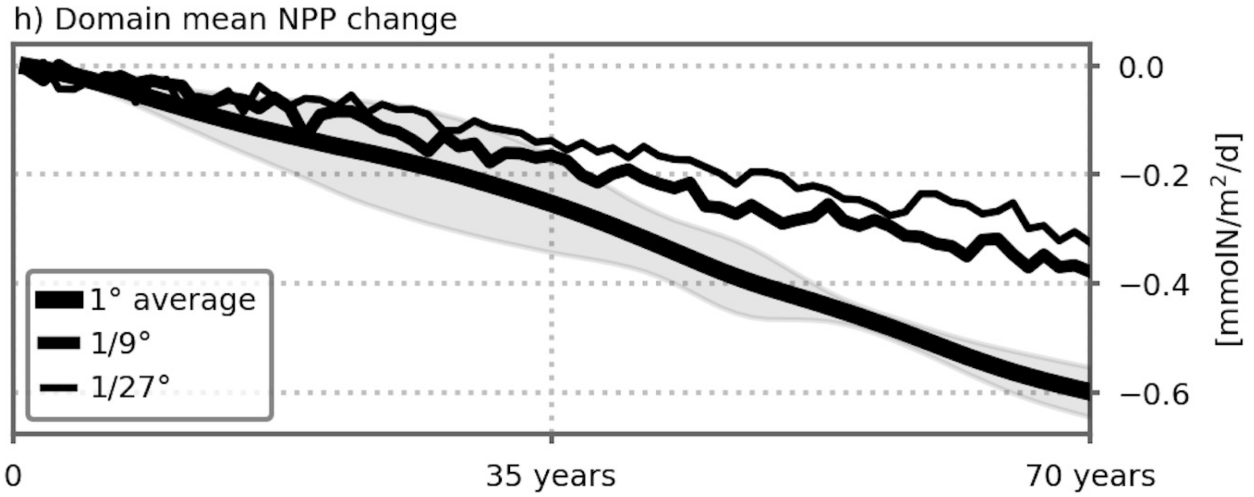


➢ Difference between resolutions larger than spread related to ocean parametrization

Couespel et al. (work in progress)

PP decline

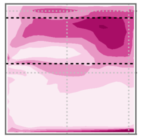


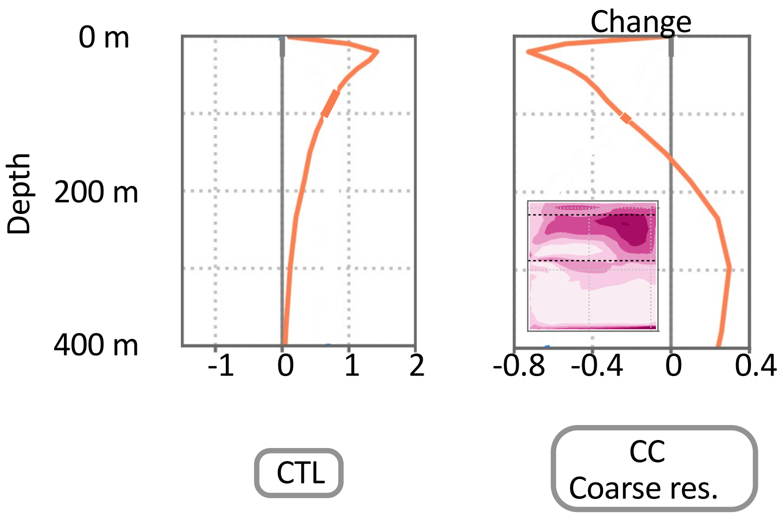


- Difference between resolutions larger than spread related to ocean parametrization
- Magnitude of decline at 1° similar to ESMs

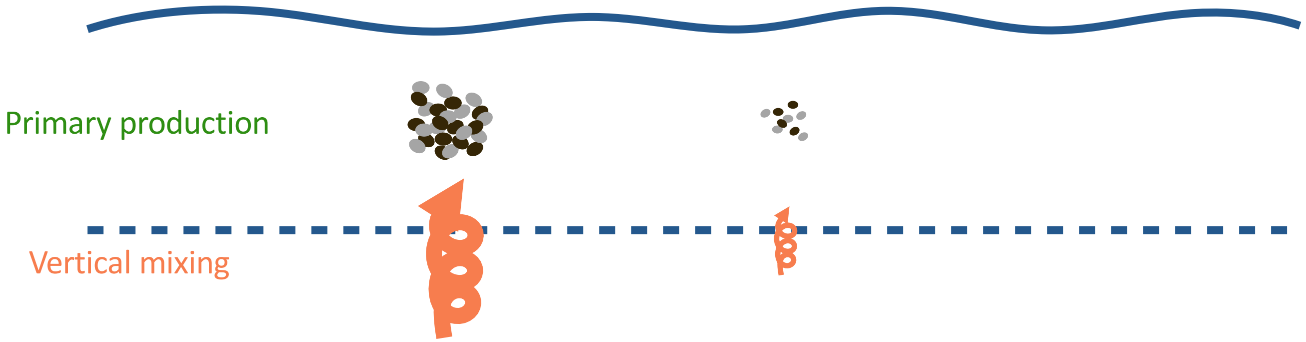
Couespel et al. (work in progress)

Decline in NO_3 supplies

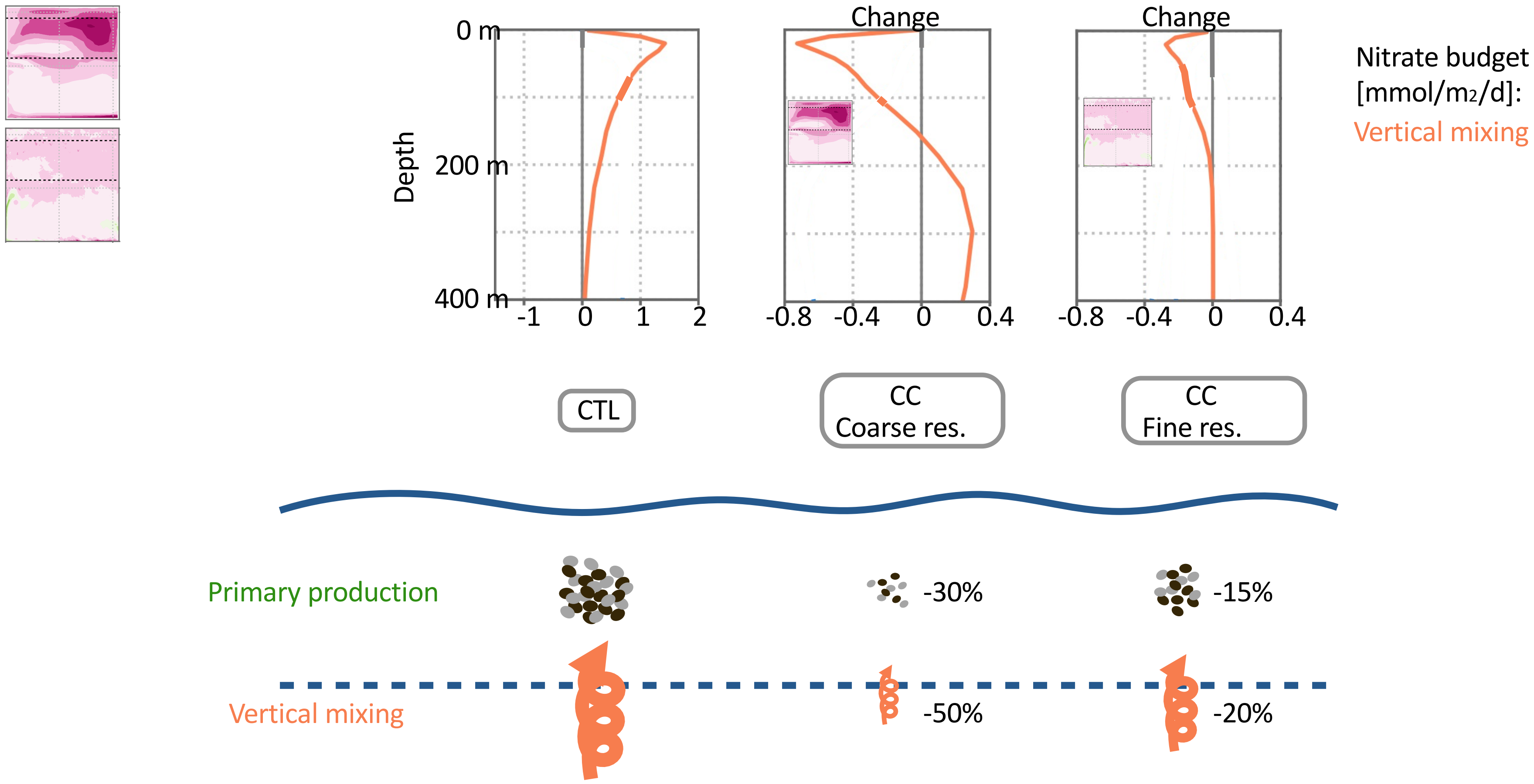




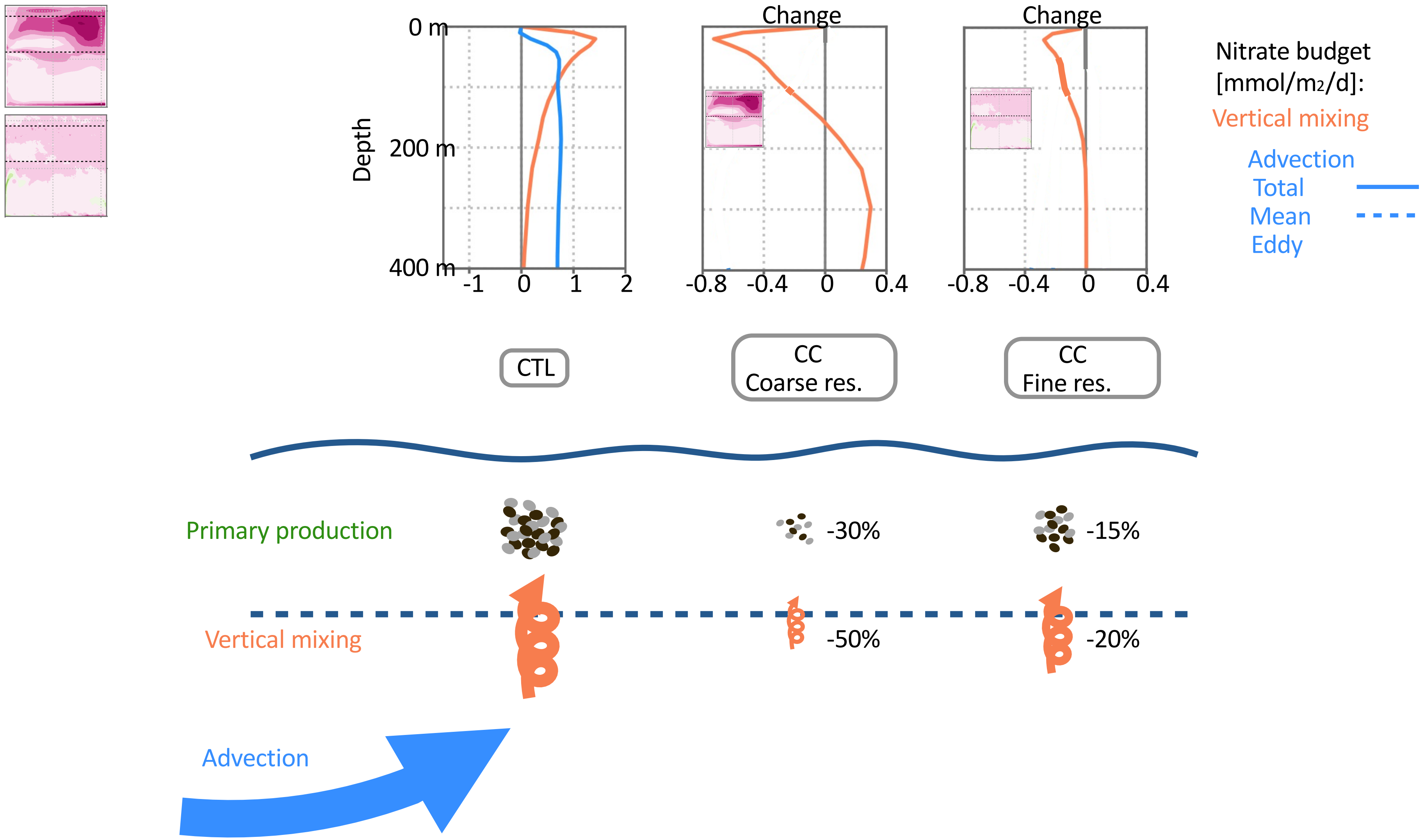
Nitrate budget
[mmol/m_2/d]:
Vertical mixing



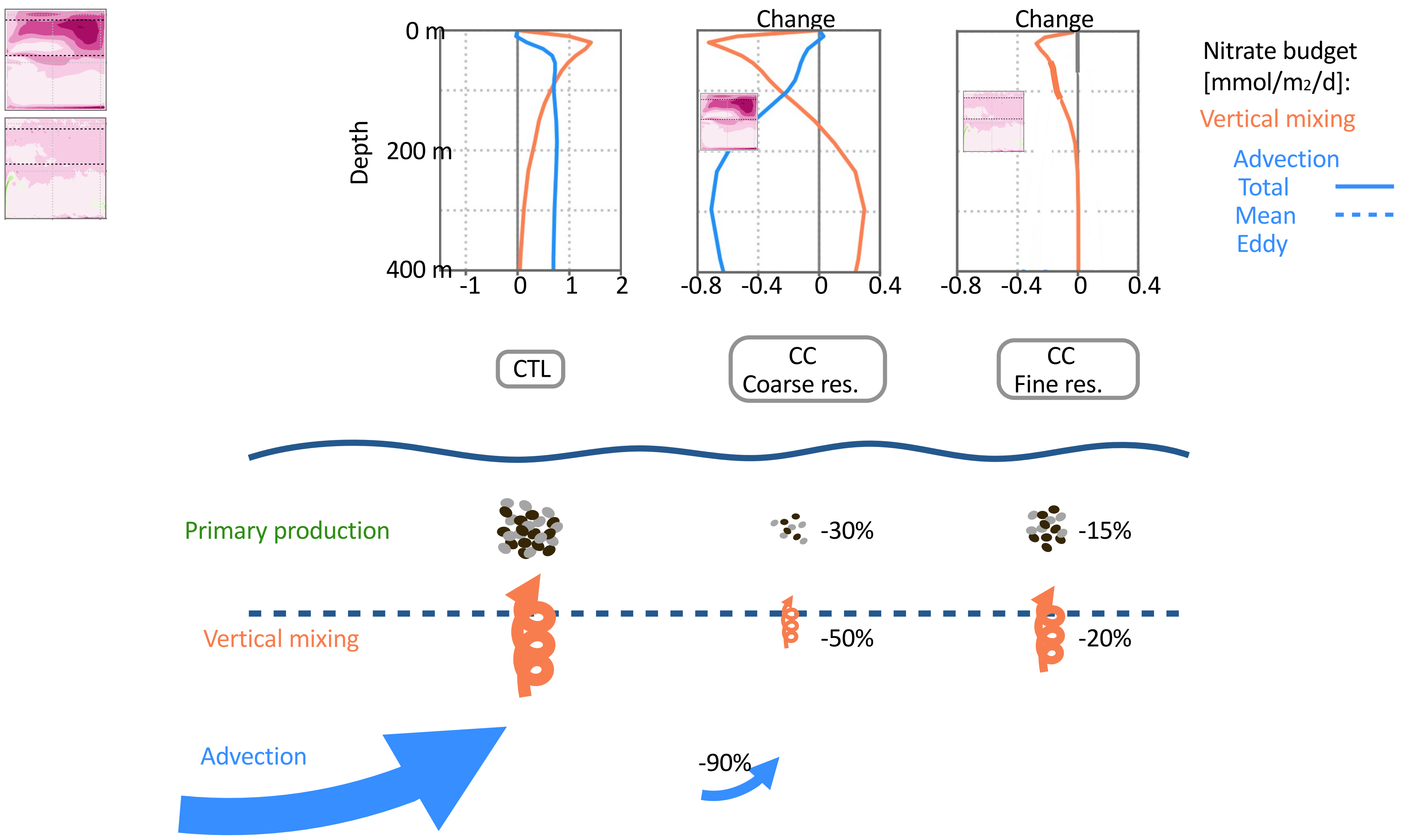
Decline in NO_3 supplies



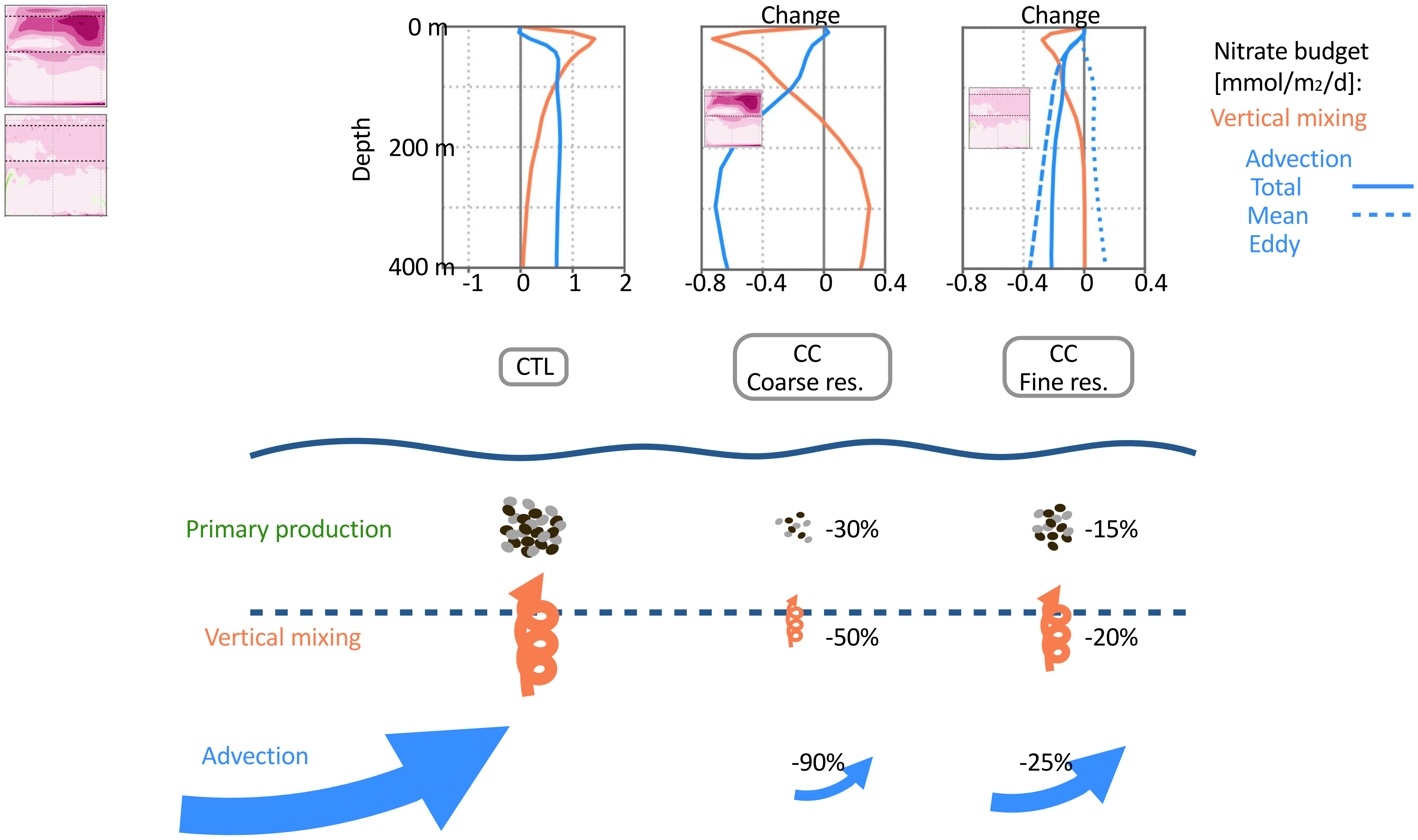
Decline in NO_3 supplies



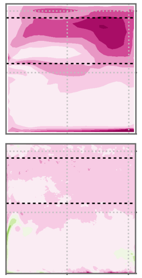
Decline in NO_3 supplies

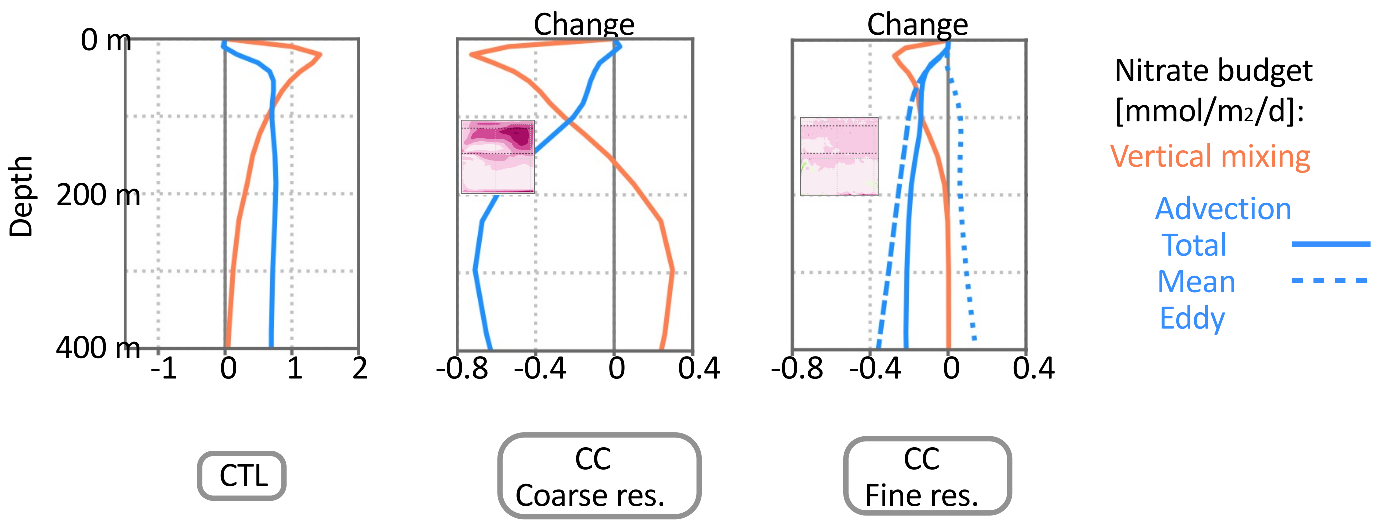


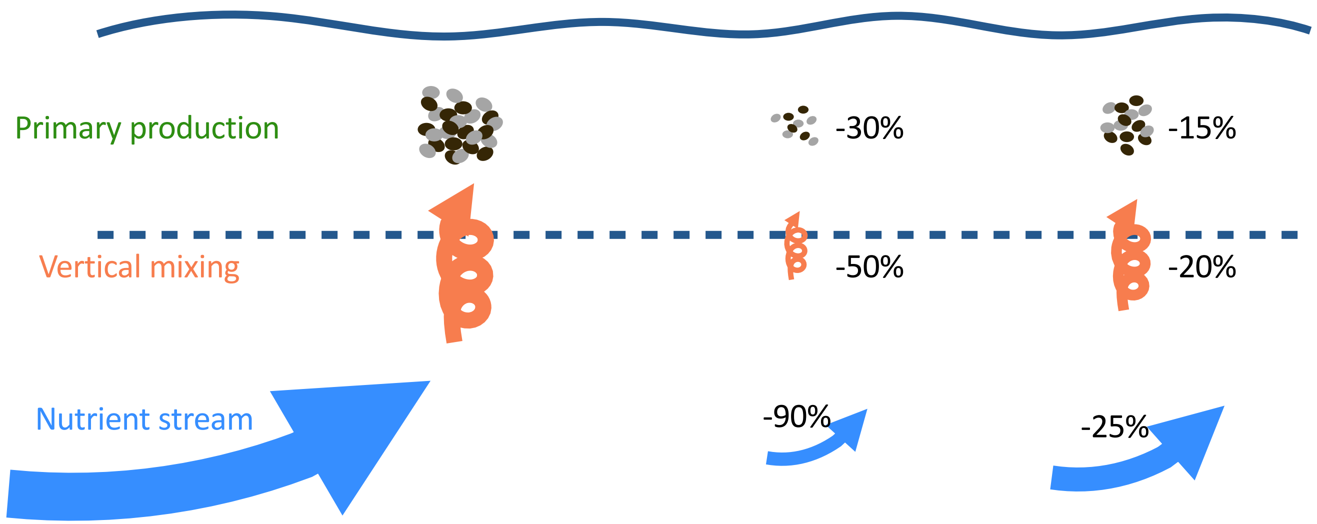
Decline in NO_3 supplies



Decline in NO_3 supplies





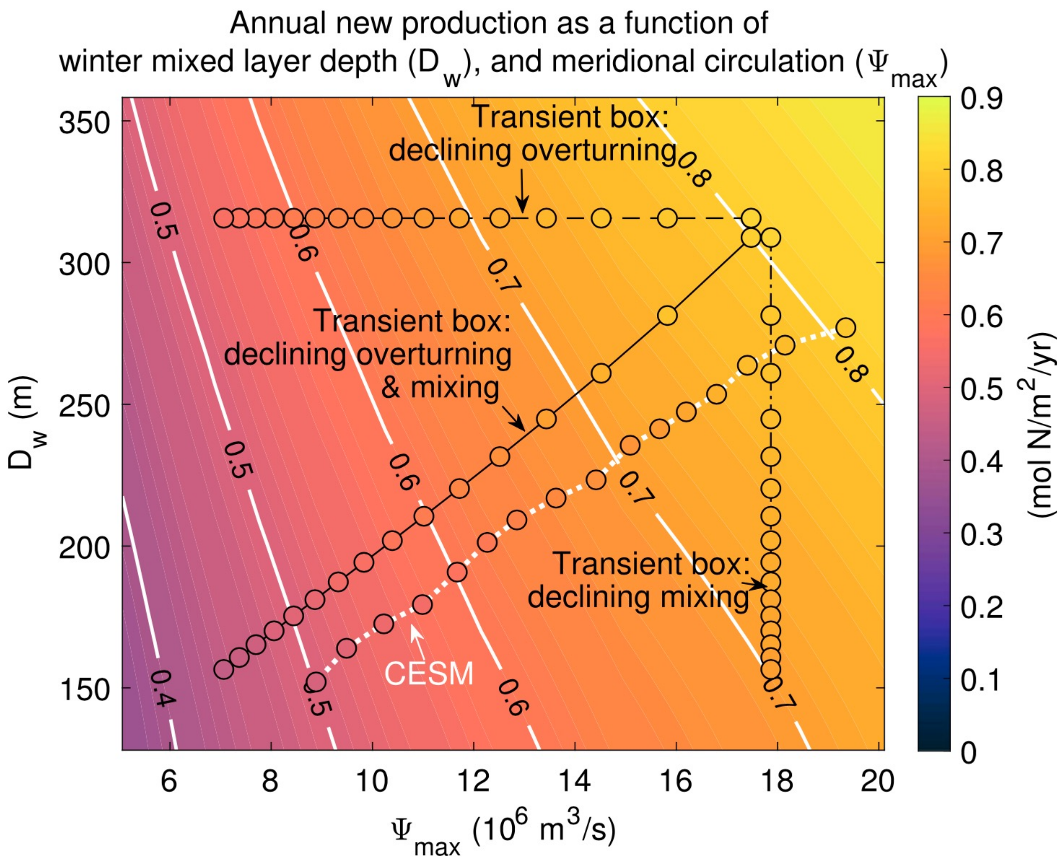


Williams et al. (2006)

Whitt (2019, 2020)
Tagklis et al. (2020)
Slow down NS

Couespel et al.

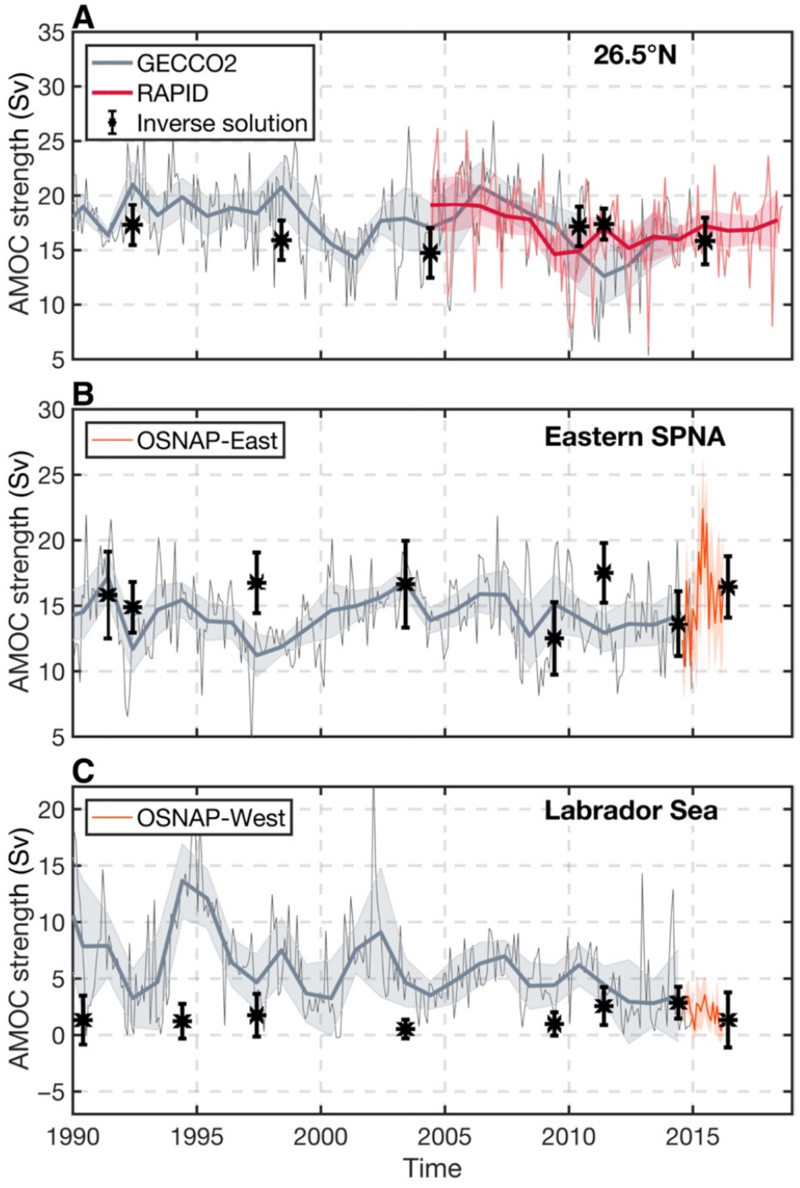
NO_3 stream intensity linked to AMOC strength

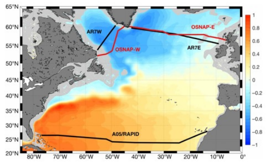


AMOC

Whitt and Jansen (2020)

Relative stability of the AMOC





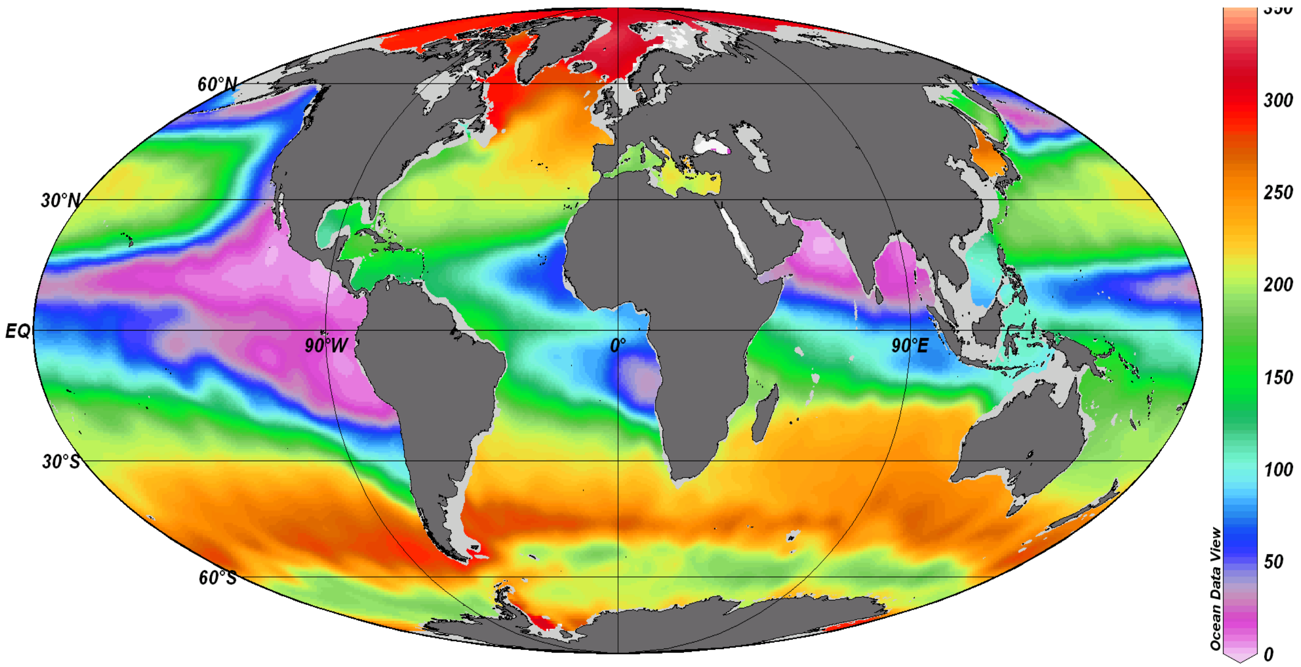
Fu et al. (2020)

Impact of resolution on projected PP decline

- Attenuated PP decline at fine resolution with our tool model
- Tool model results suggest overestimated PP decline in ESMs
- Small local eddy effect small, remote eddy compensation effects
- Calls for better understanding of the role of eddies in the transport response to CC

Couespel et al. (work in progress)

Impact of resolution on Oxygen Minimum Zone

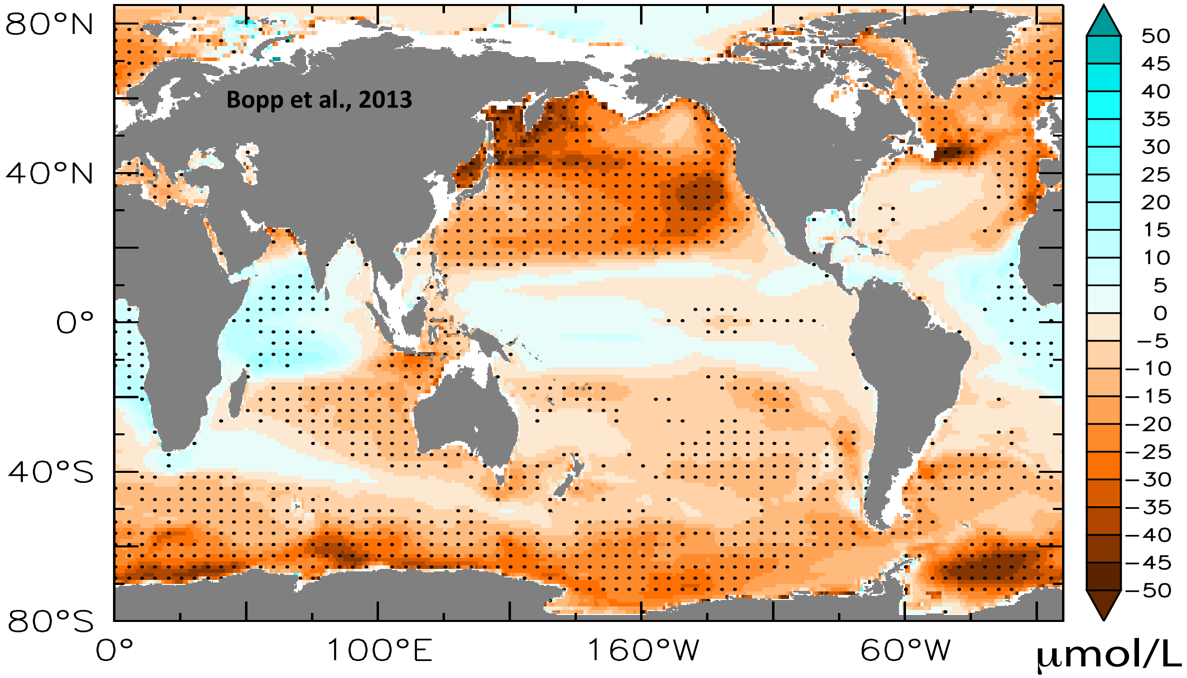


(μmol l^{-1})

Oxygen at 400 m (WOA)

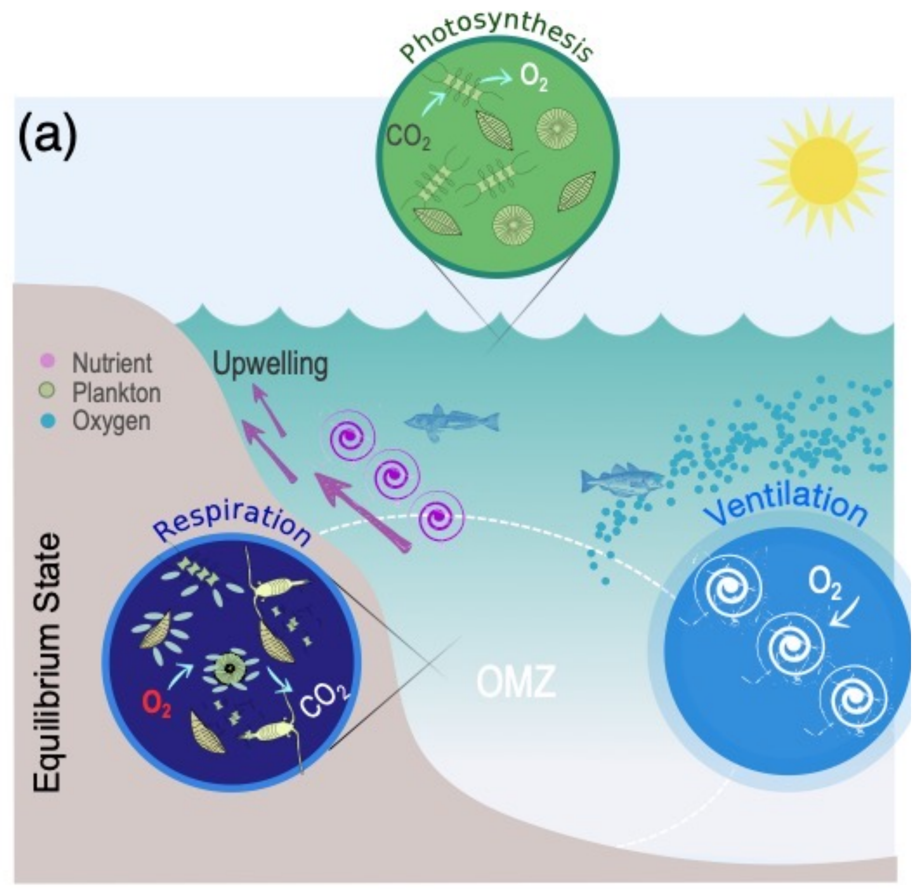
Will OMZ expand or shrink ?

Change in O2 between 400-1000m by 2100



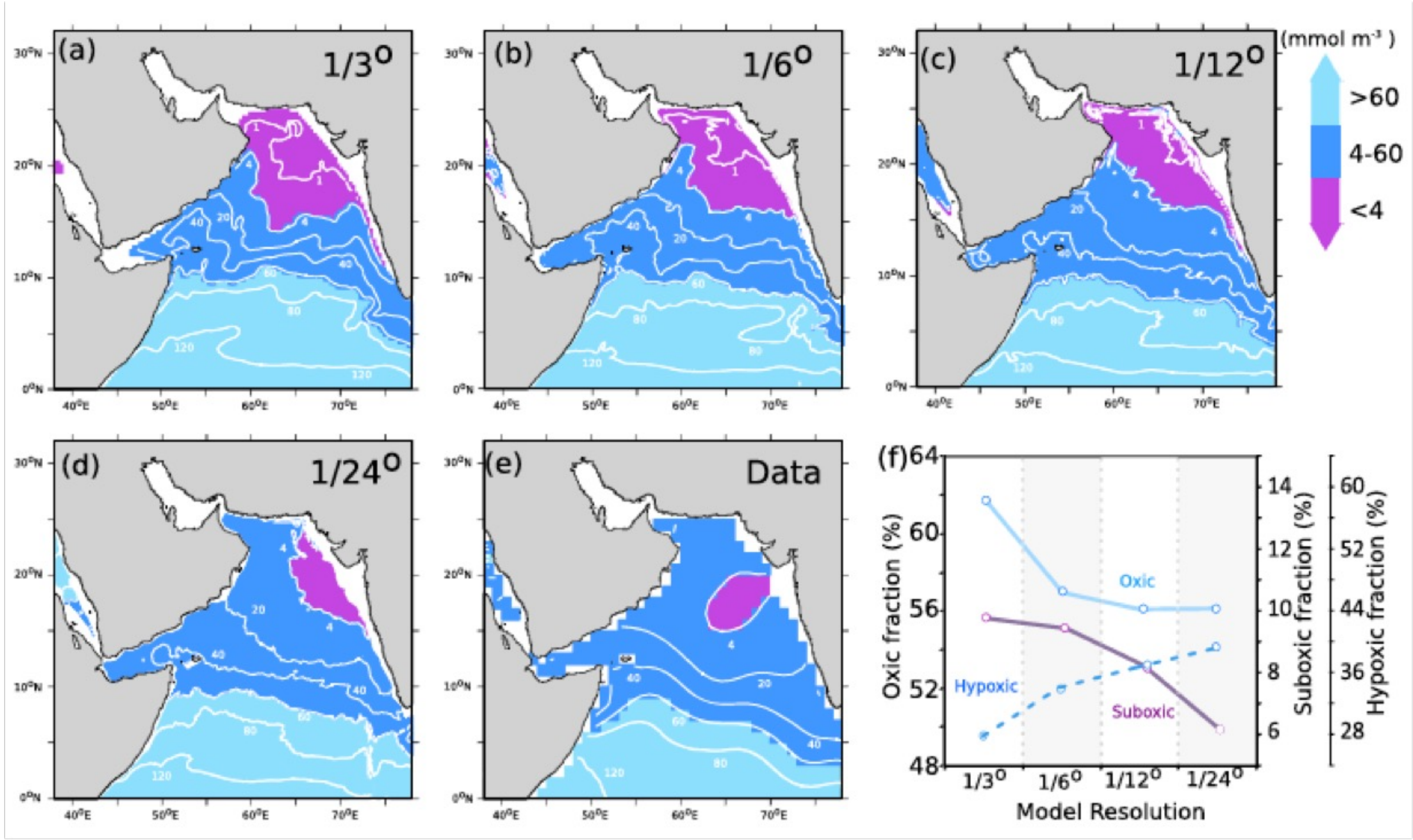
- 50% of global deoxygenation due decreased O_2 solubility
- Decreased ventilation balanced by decreased respiration
- O_2 trend is largely uncertain in tropical regions where OMZ are located

OMZ at equilibrium



- Shadow zones, below major upwelling systems
- Balance between respiration and ventilation
- Ventilation largely due to eddies:
  90% in the Arabian Sea OMZ (Resplandy et al., 2012)

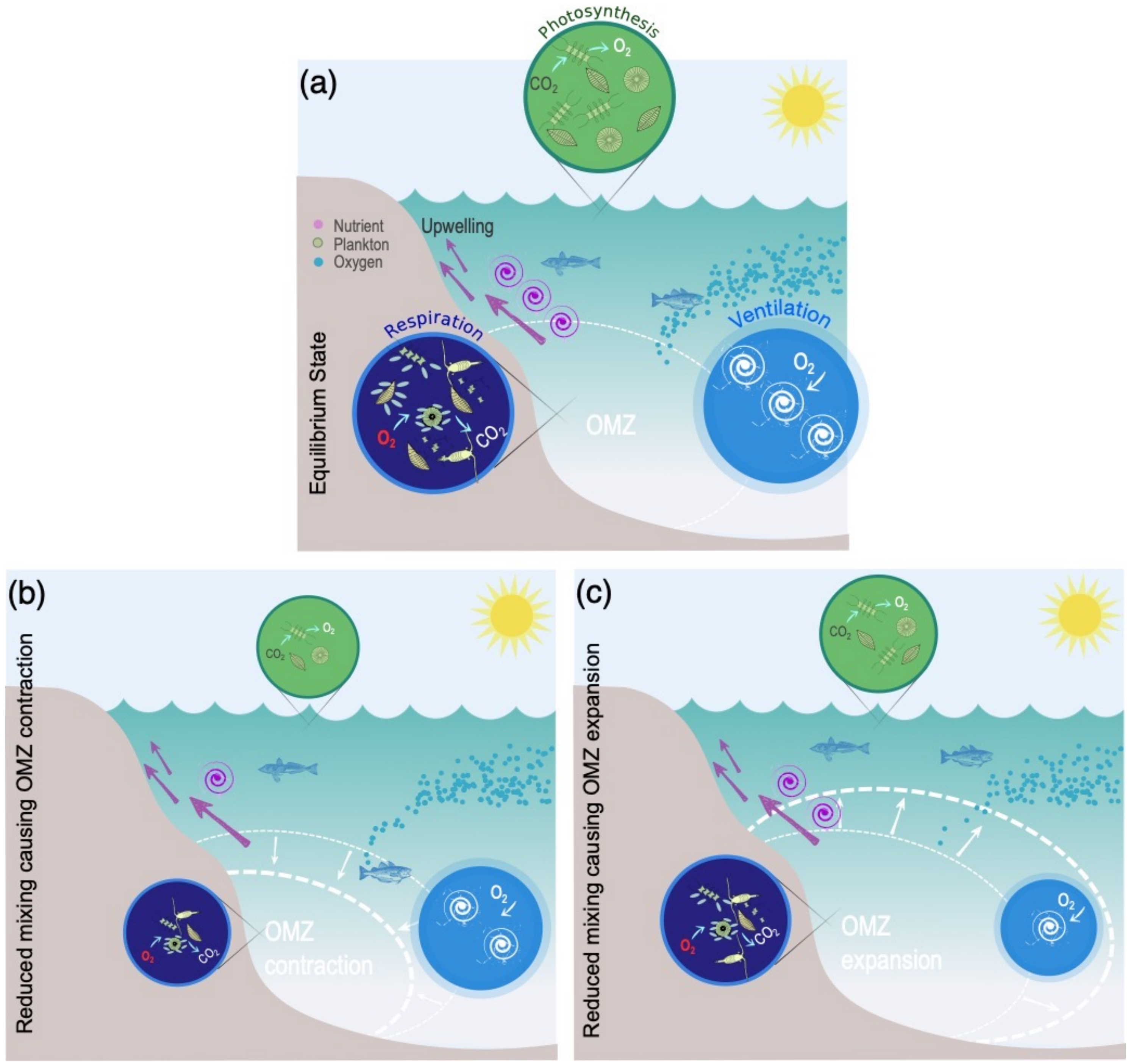
Arabian sea OMZ at equilibrium



- More realistic OMZ with fine-resolution model
- Shrinking of suboxic volume
- Expansion of hypoxic volume

Lachkar et al., 2016

Climate Change



Less ventilation : less O2
Less productivity: more O2

Outcome depends on respective decrease of each

Levy et al., accepted

Arabian Sea downscalling experiments

- Regional model of the North Indian Ocean (ROMS-NPZD)
- Forced by atmospheric reanalyses + climate change anomaly from CMIP5
- 1/3° - 1/6° - 1/12°

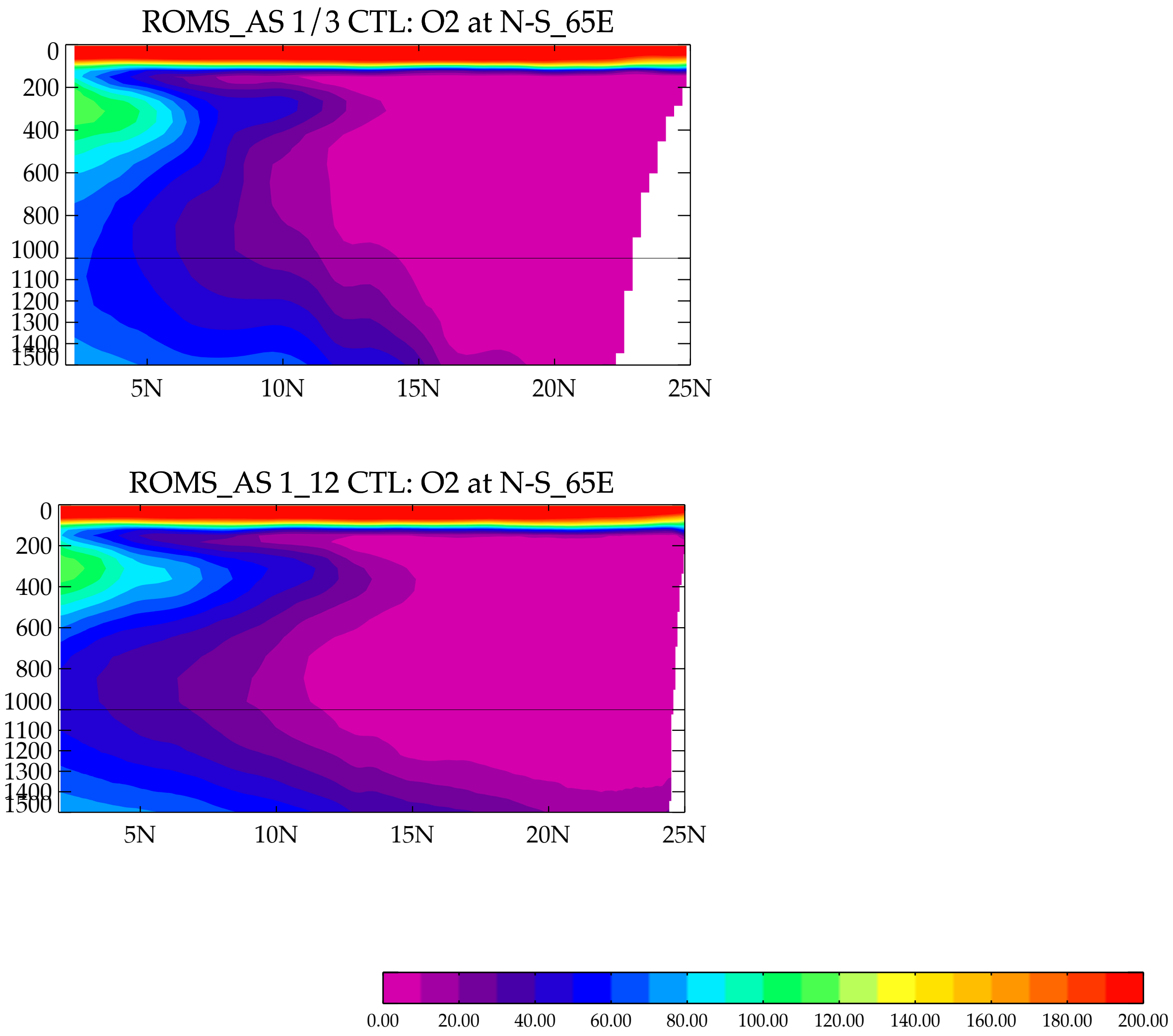
Parvathi et al., work in progress

Arabian Sea downscalling experiments

Control Experiments

1/3°

1/12°



- Smaller OMZ at 1/12°

Parvathi et al., work in progress

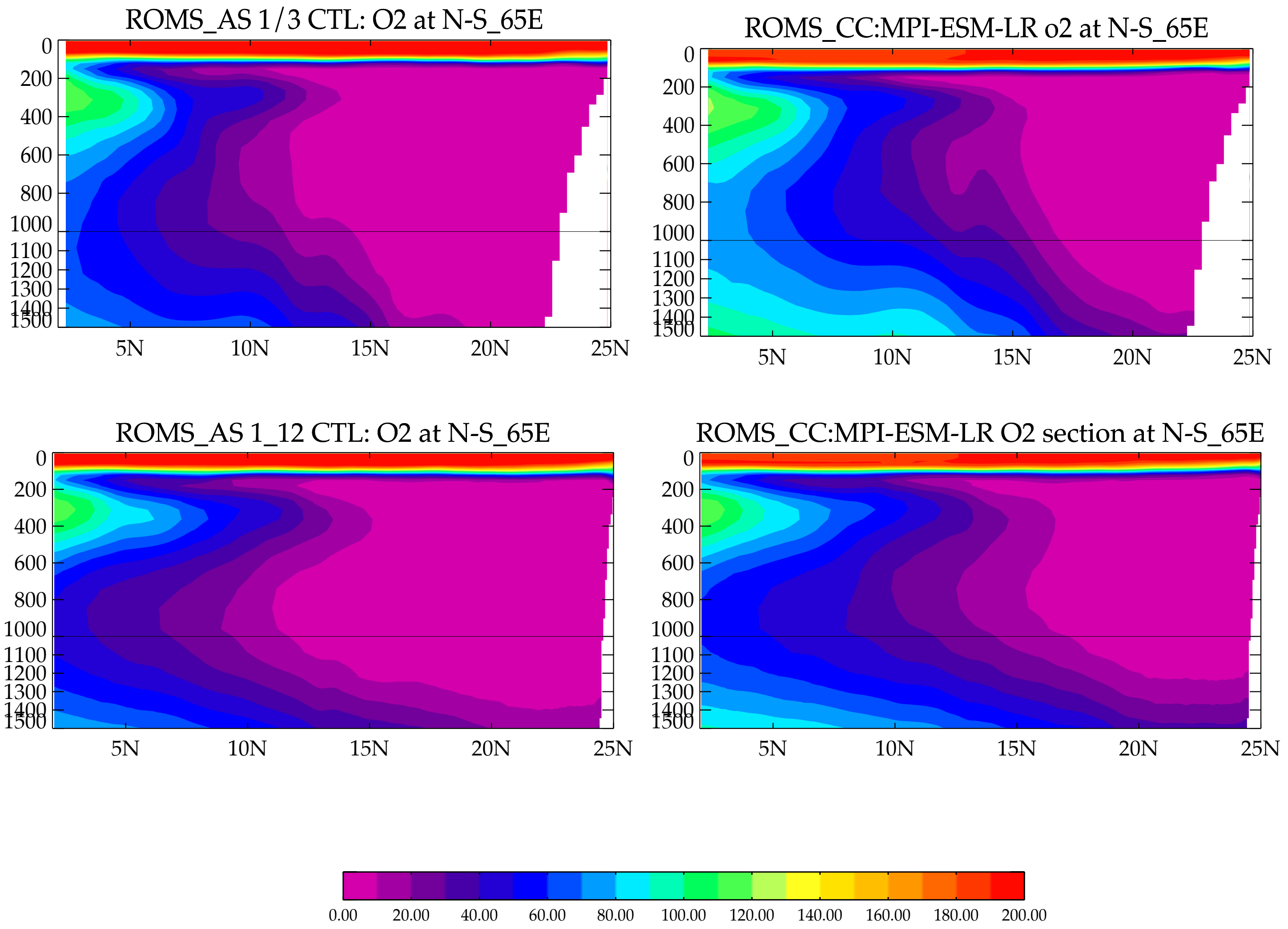
Arabian Sea downscalling experiments

Control Experiments

Climate Change Experiments

1/3°

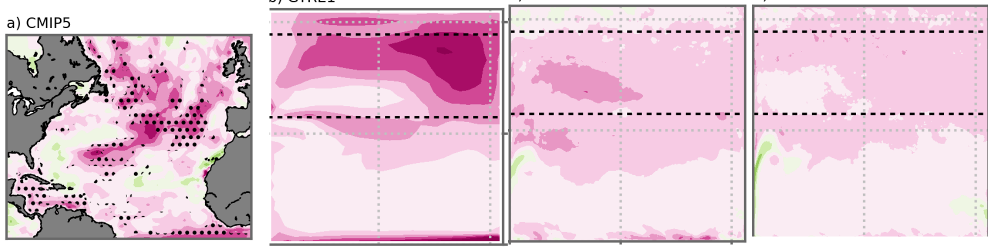
1/12°



- Shrinking of the OMZ with CC
- Decrease in PP > decrease in ventilation
- Similar decrease of the suboxic volume (-50%) for both simulations

Parvathi et al., work in progress

Key Messages

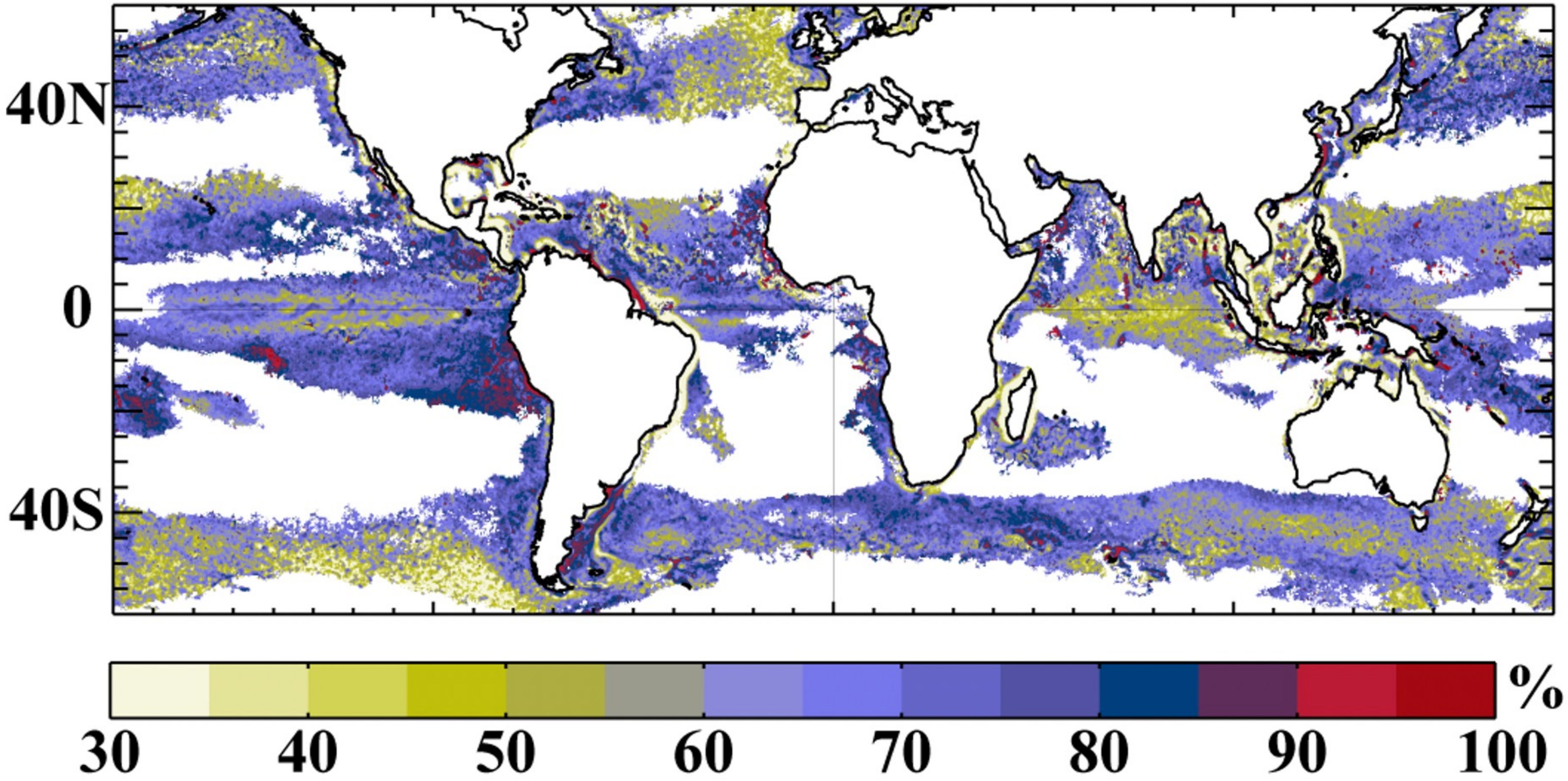


1. Possible stabilizing effect of (sub-)mesoscales on biogeochemical responses to climate change deserve further investigation by the community

2. Calls for improved parametrizations validated against quantities important for biogeochemistry

Widespread impact

% of Total Chla variance represented by sub-seasonal events of spatial scale < 100 km



Lateral scales 1-50 km
Vertical scales 0-200 m
Temporal scales < 100 days

Keerthi et al. – Work in progress

Outline

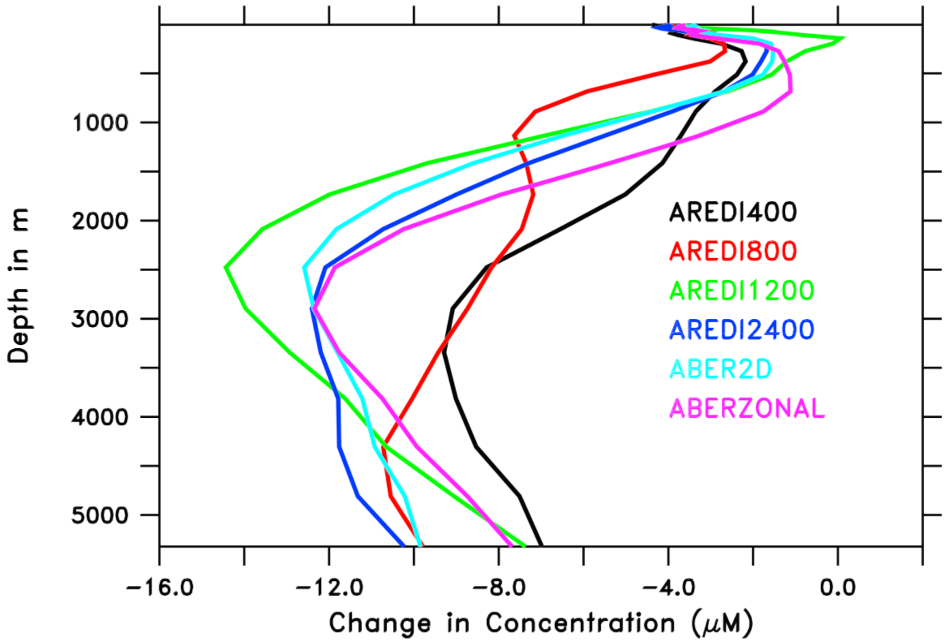
1. Biogeochemical climate projections: sensitivity to mixing
2. Reduction of primary production: sensitivity to model resolution
3. Deoxygenation and volume of OMZ: sensitivity to model resolution

Evaluation of uncertainties

1. Inter-model comparison: CMIP spread
2. Sensitivity to parametrizations of (sub-)mesoscale dynamics
3. Sensitivity to explicit inclusion of (sub-)mesoscale dynamics

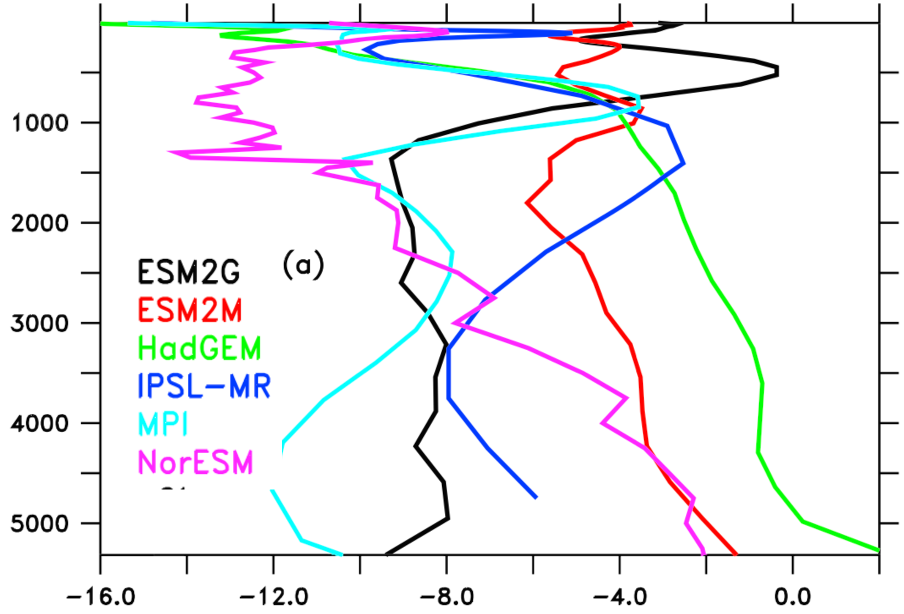
Parametrization of lateral mixing

Deoxygenation: CM2Mc model, varying eddy diffusivity



(C) ΔGlobal mean O_2, JHU runs

Deoxygenation : CMIP5 model ensemble



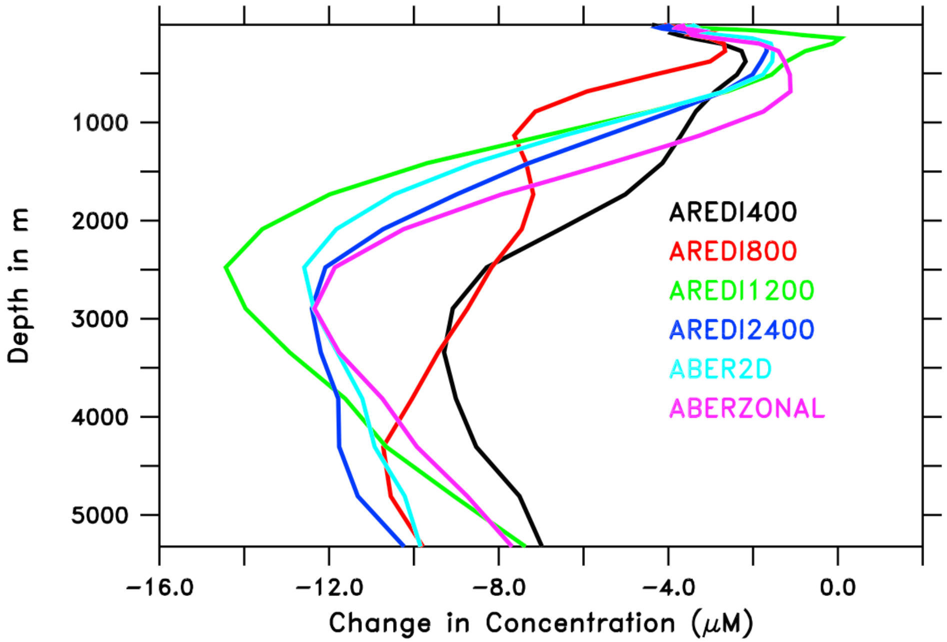
(C) ΔO_2, CMIP5 Model, 1pct Runs

Bahl et al. (2019)

➢ CMIP model spread is partly related to uncertainties in eddy parametrization

Parametrization of lateral mixing

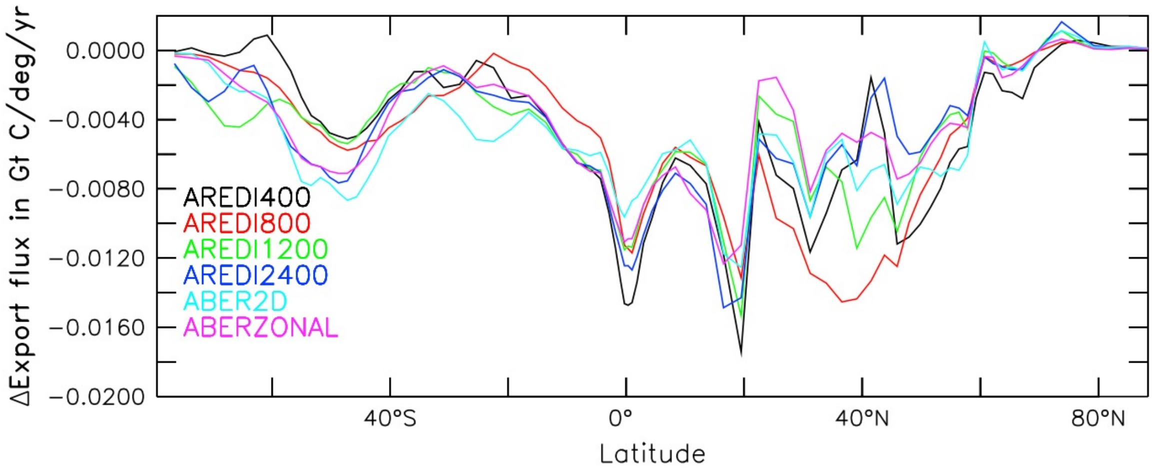
Deoxygenation



(C) ΔGlobal mean O_2, JHU runs

Decrease in Export

(A) Particle export flux (100m)



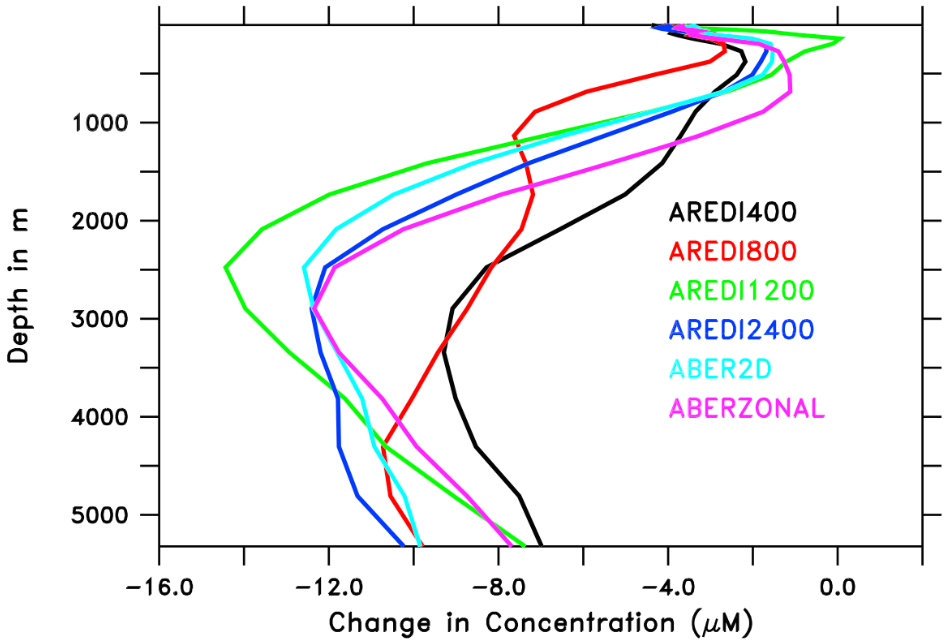
(B) Change in Export Production 40−140 yrs after CO_2 doubling

Bahl et al. (2019)

CM2Mc model, sensitivity to eddy diffusivity Aredi

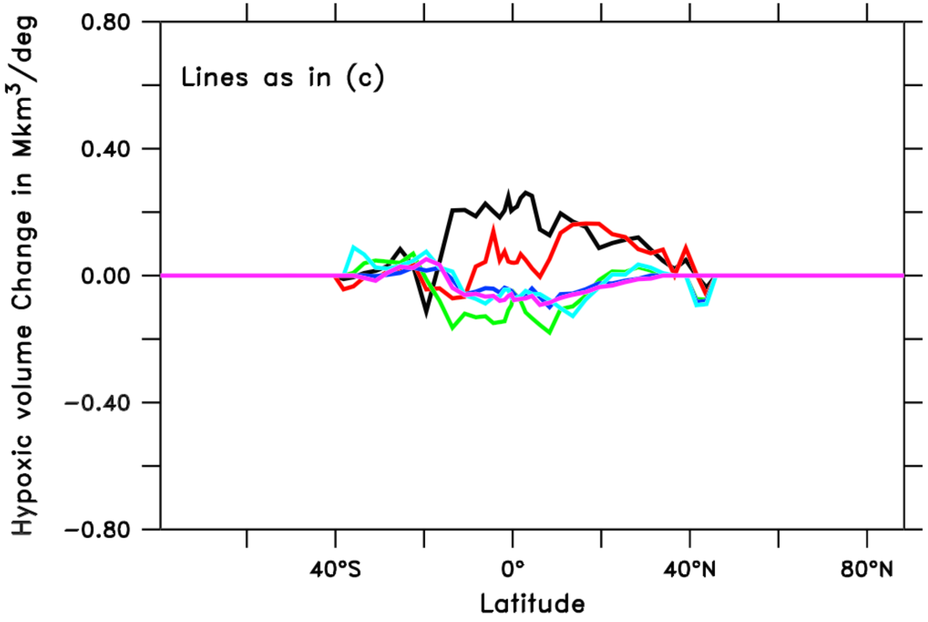
ESM with parametrized eddy mixing

Deoxygenation



(C) ΔGlobal mean O_2, JHU runs

Oxygen Minimum Zones



(D) ΔHypoxic volume

Bahl et al. (2019)

- ➢ OMZ may expand or shrink depending on mixing coefficient