PKU – LSCE, Paris, 14th Nov 2013

From climate change to marine ecosystems with CMIP5 models: Multiple stressors, Decadal predictability, End-to-end ecosystem modelling

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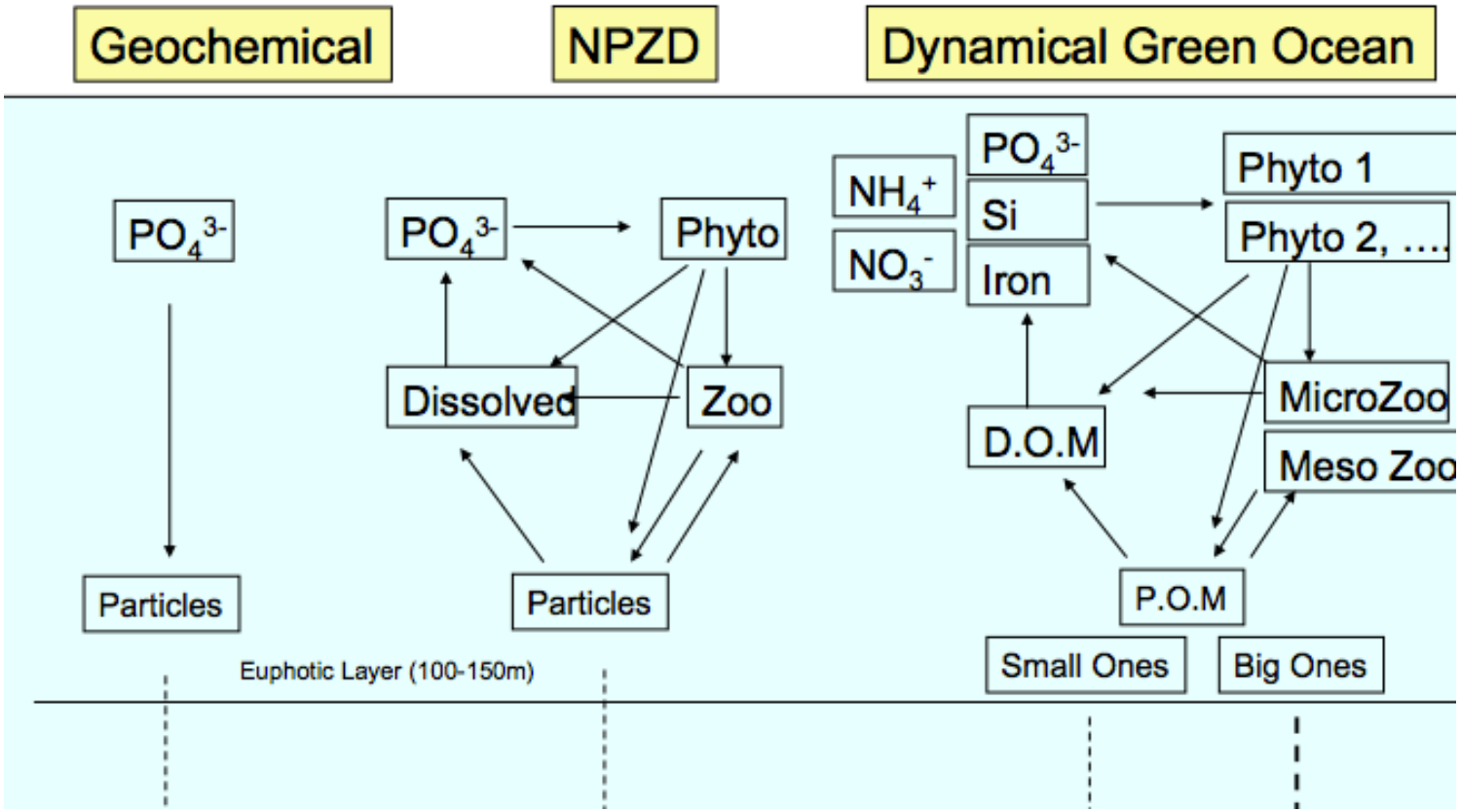
LABORATOIRE DES SCIENCES DU CLIMAT & DE L'ENVIRONNEMENT

Introduction

The new generation of Earth System Models in CMIP5 includes more complex ocean biogeochemical components



Introduction

- The new generation of Earth System Models in CMIP5
  includes more complex ocean biogeochemical components

- Recent climate-change simulations for CMIP5 / IPCC-AR5 now available
  and include long-term as well as near-term (decadal) simulations (Taylor et al. 2009)

Introduction

- The new generation of Earth System Models in CMIP5 includes more complex ocean biogeochemical components

- Recent climate-change simulations for CMIP5 / IPCC-AR5 now available and include long-term as well as near-term (decadal) simulations (Taylor et al. 2009)

Outline of my talk

- Projections of multiple stressors of ecosystems (T, pH, NPP, O_2) in the 21st century

  Bopp et al. BG 2013

- Decadal predictability of biogeochemistry / ecosystems (Tropical Pacific)

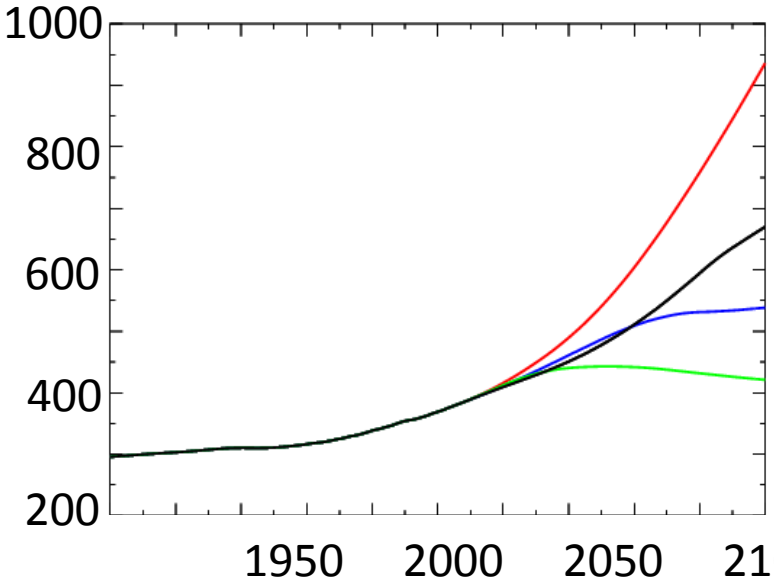
  Séférian et al. in rev

- Towards end-to-end marine ecosystem modelling

  Lefort et al. in prep

Multiple Stressors

Use of the "new" Representative Concentration Pathways Scenarios (RCPs)



RCP8.5 : CO_{2atm} = 936 ppm in 2100

RCP6.0: CO_{2atm} = 670 ppm in 2100

RCP4.5: CO_{2atm} = 538 ppm in 2100

RCP2.6: CO_{2atm} < 450 ppm

(CMIP5, Taylor et al. 2009)

… and of simulations performed with the most recent generation of Earth System Models

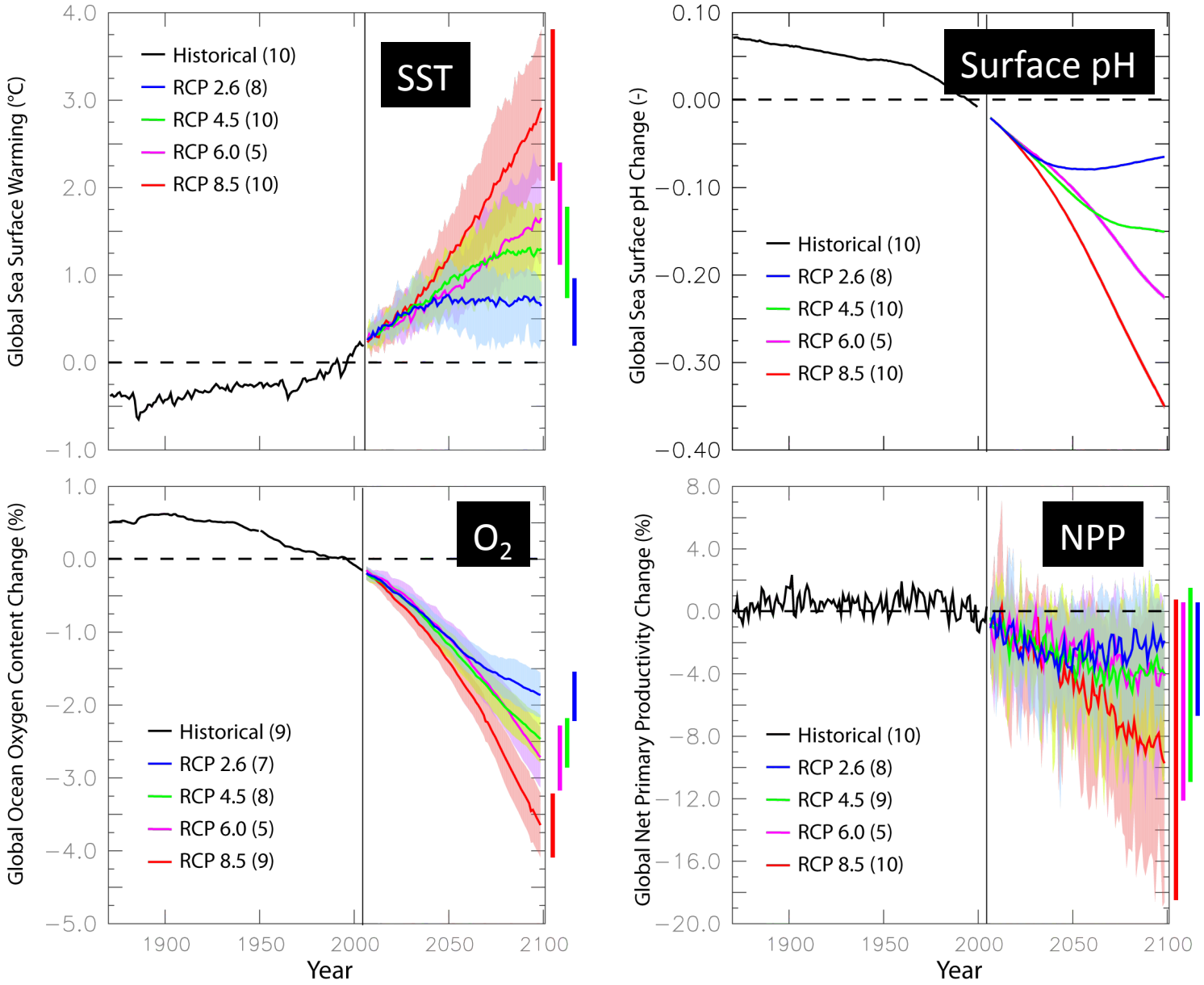
10 models:

- CCSM1-BGC (Lindsay et al. 2013)
- CMCC-ESM (Cagnazzo et al. 2011)
- GFDL-ESM2G (Dunne et al. 2012)
- GFDL-ESM2M (Dunne et al. 2012)
- HadGEM2-ES (Collins et al. Jones et al. 2011)
- IPSL-CM5A-LR (Dufresne et al. 2013)
- IPSL-CM5A-MR (Dufresne et al. 2013)
- MPI-ESM-LR (Giorgetta et al. 2013)
- MPI-ESM-MR (Giorgetta et al. 2013)
- NorESM1 (Bentsen et al. 2012)

Multiple Stressors

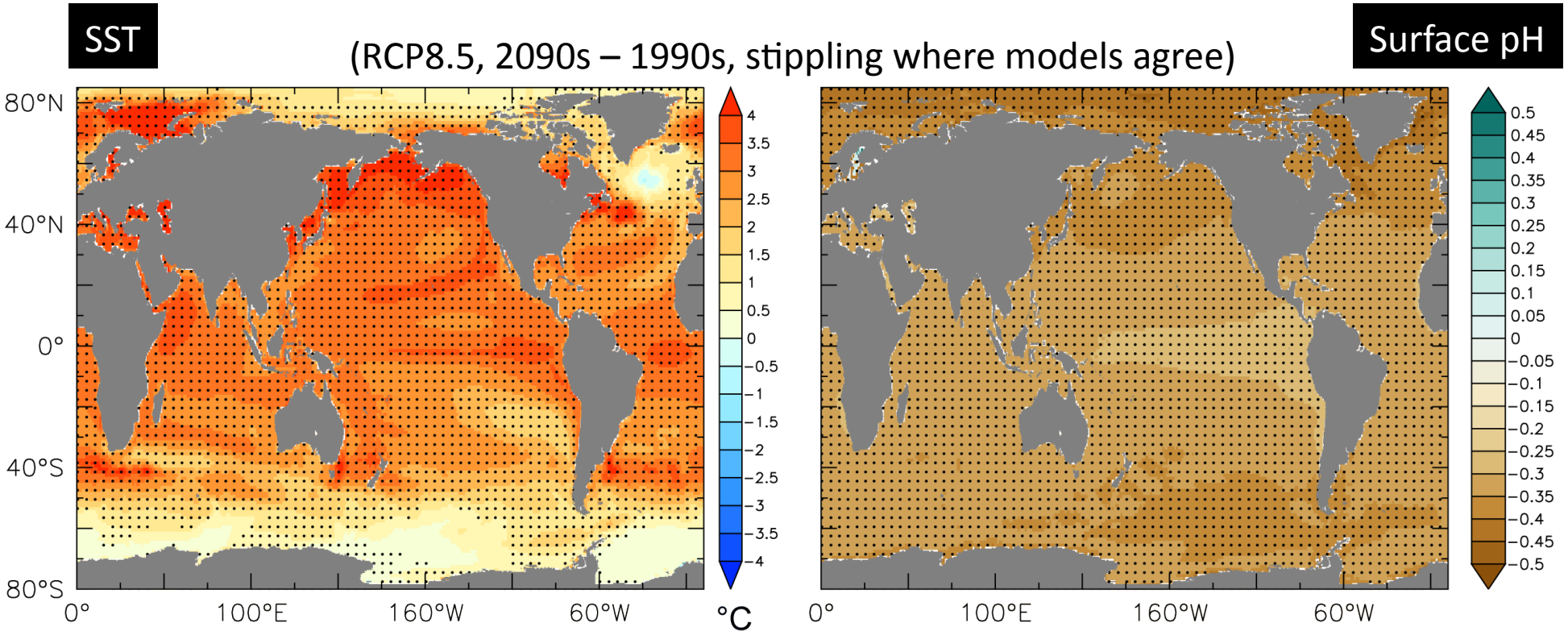
Global mean

- SST
- Surface pH
- Oxygen Content
- Integrated NPP



Warmer (+0.7 to 2.7°C), more acidic (-0.07 to -0.33),
less oxygenated (-1.8 to -3.5%) and less productive (-2 to -8.6%) ocean

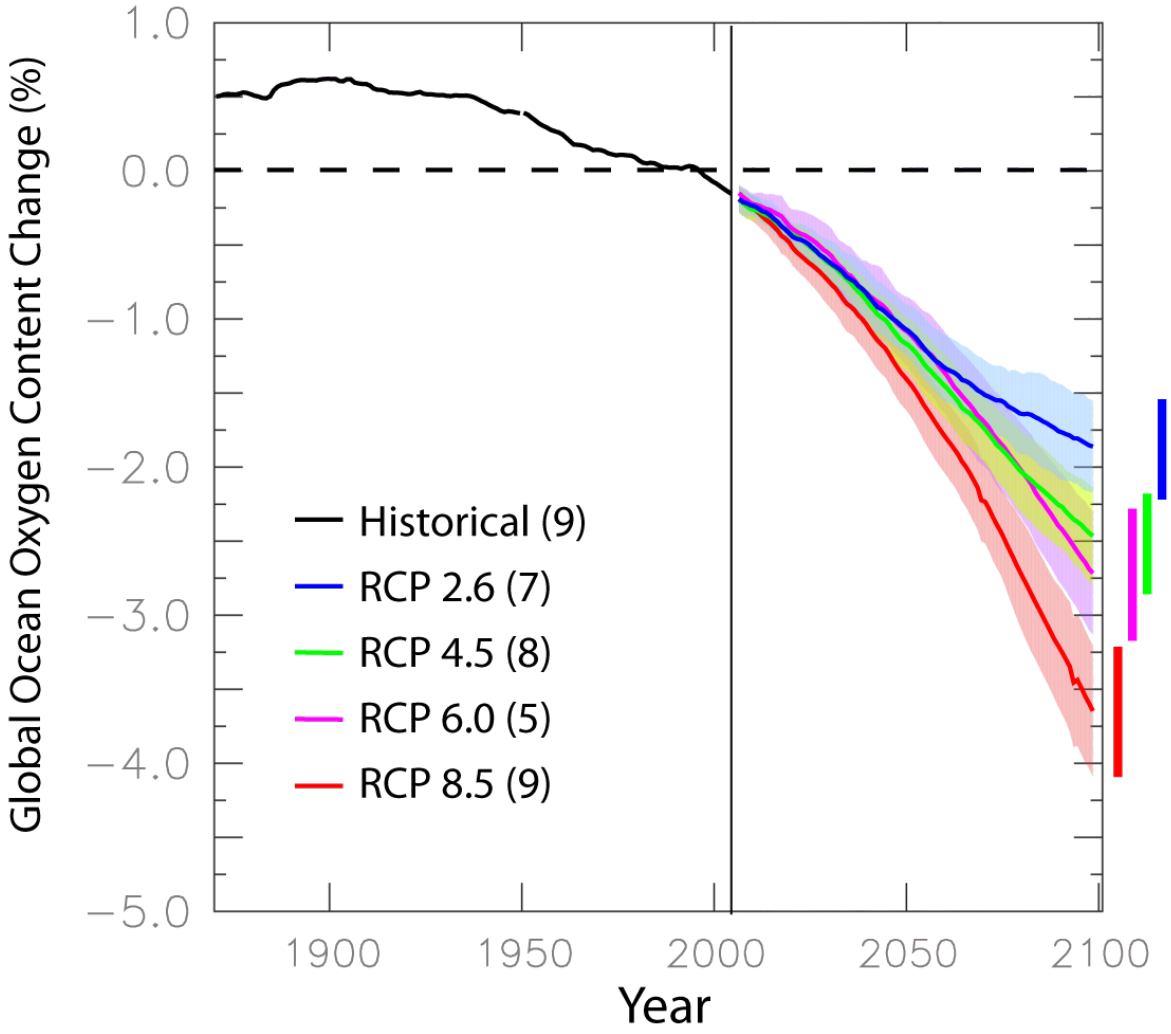
Multiple Stressors: changes in temperature and pH at the surface



- Projected pH very homogeneous vs. projected SST very variable spatially

Multiple Stressors: changes in dissolved O_2

- Global-mean O_2 decrease simulated by all models

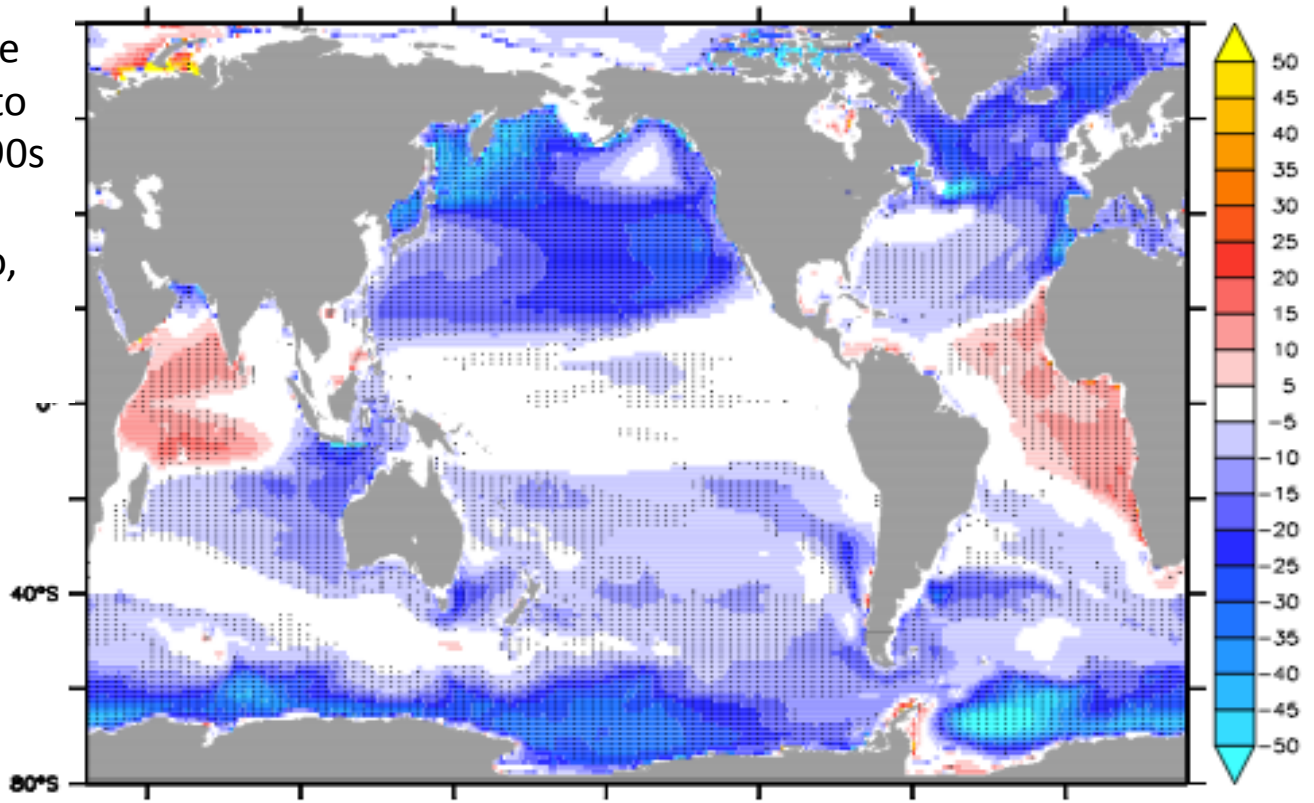


- Mechanisms: warming-driven solubility changes , ventilation changes.

Multiple Stressors: changes in sub-surface O_2

- Global-mean O_2 decrease simulated by all models
- Large regional contrasts:
  - → consistent decrease at high/mid latitudes
  - → increase in the tropical indian and atlantic oceans
  - → major uncertainty in the tropical pacific / for suboxic waters.

Absolute Change in O_2 from 200 to 600m, from 1990s to 2090s (RCP85 scenario, model-mean, mmol/m3)

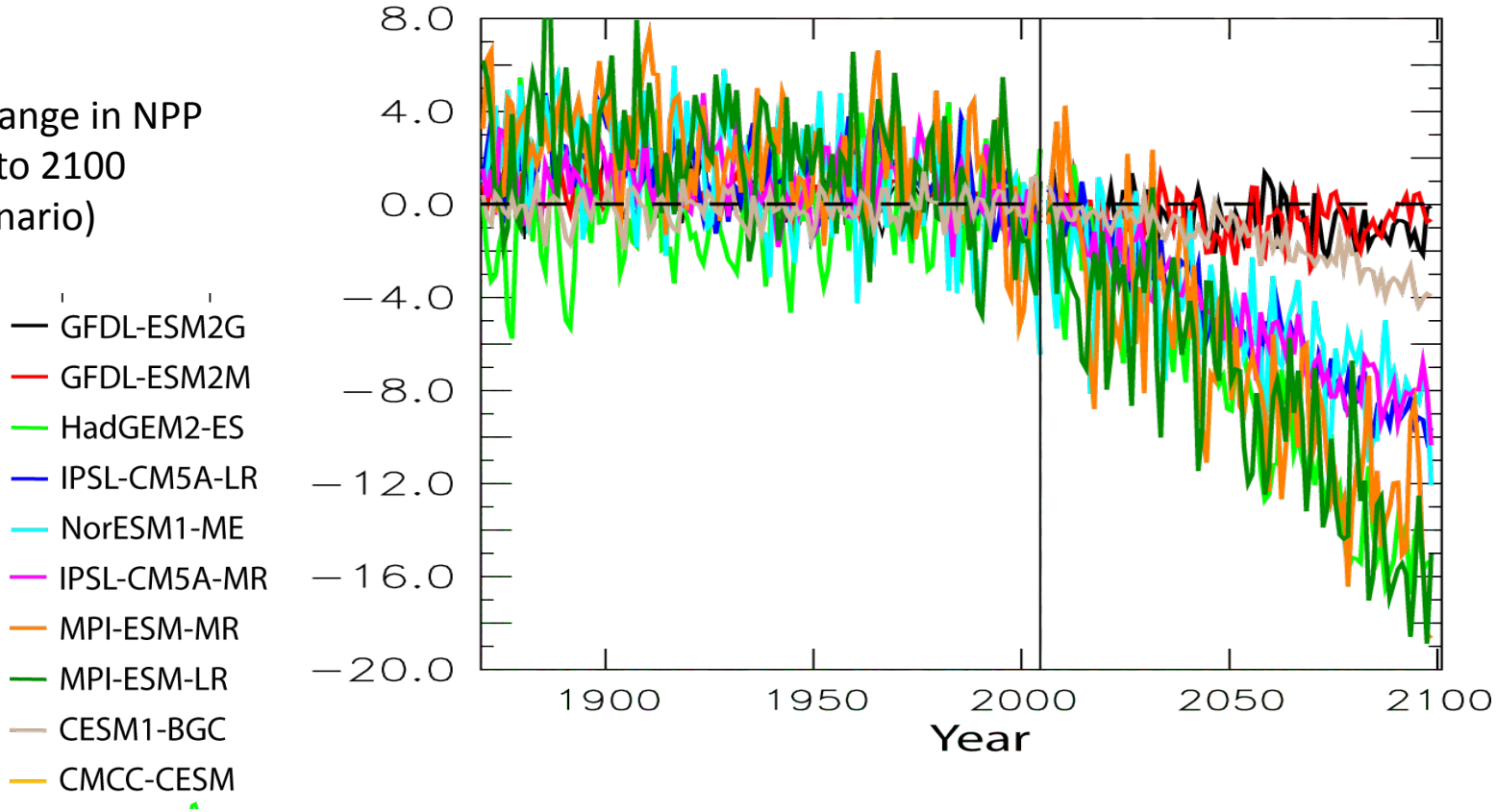


Stippled regions: when >80% of the models agree on the sign of change

Multiple Stressors: changes in NPP

- Global-mean decrease simulated by most models, ranging from -2 to -18 % for RCP8.5

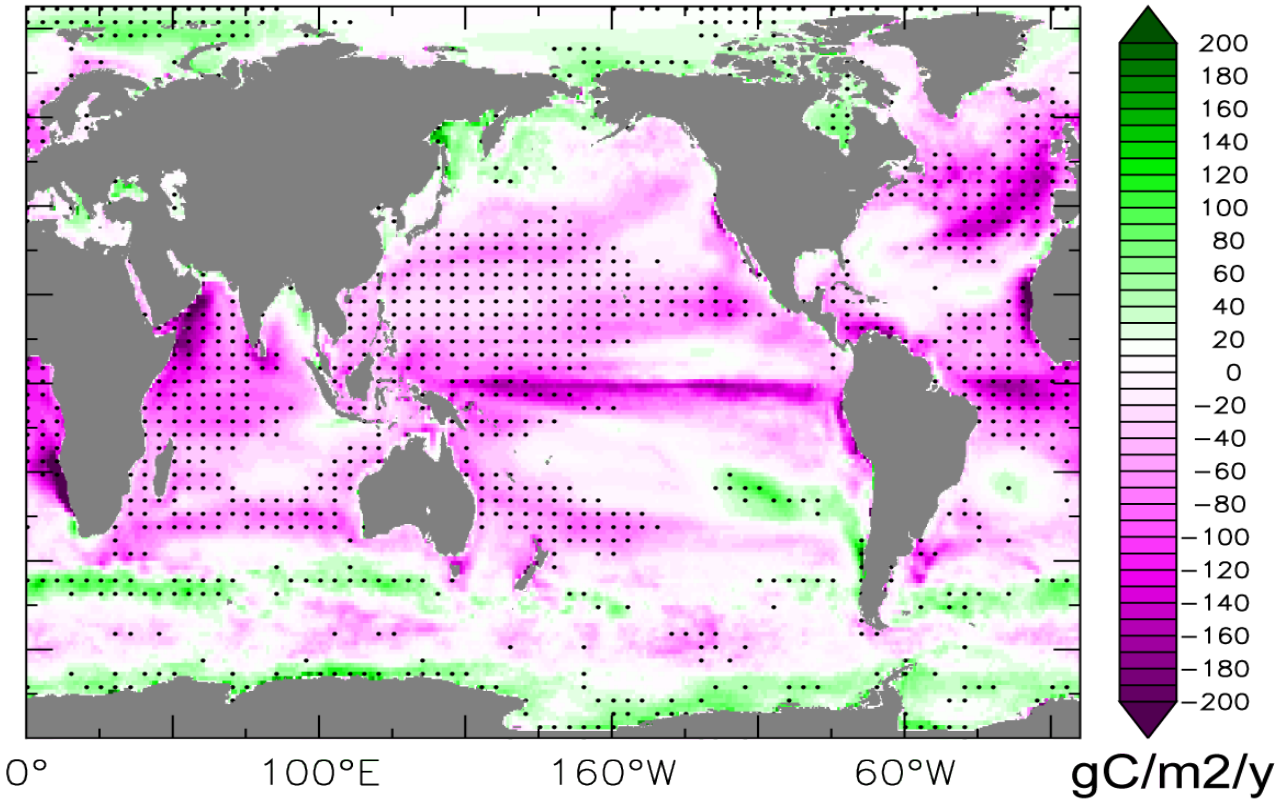
Relative Change in NPP
from 1870 to 2100
(RCP85 scenario)



Multiple Stressors: changes in NPP

- Global-mean decrease simulated by models
- Large regional contrasts: -50% in N. Atl, -20% in the tropics, increase in the SO

Change in NPP from 1990s to 2090s (RCP85 scenario, model-mean)

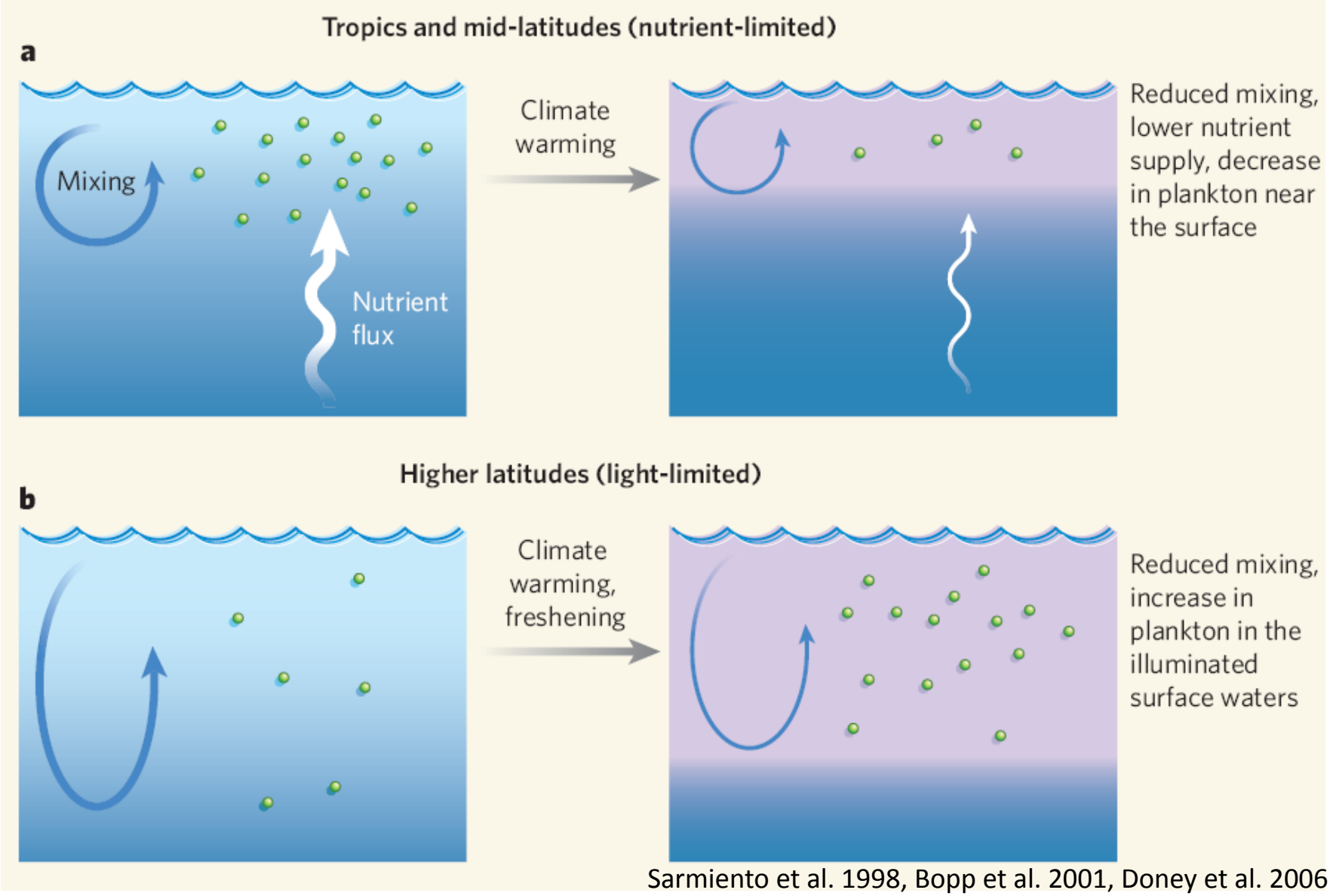


Stippled regions: when >80% of the models agree on the sign of change

- Mechanisms: increased ocean stratification → reduced nutrient supply / light limitation

Multiple Stressors: changes in NPP

- Mechanisms: increased ocean stratification → reduced nutrient supply / light limitation



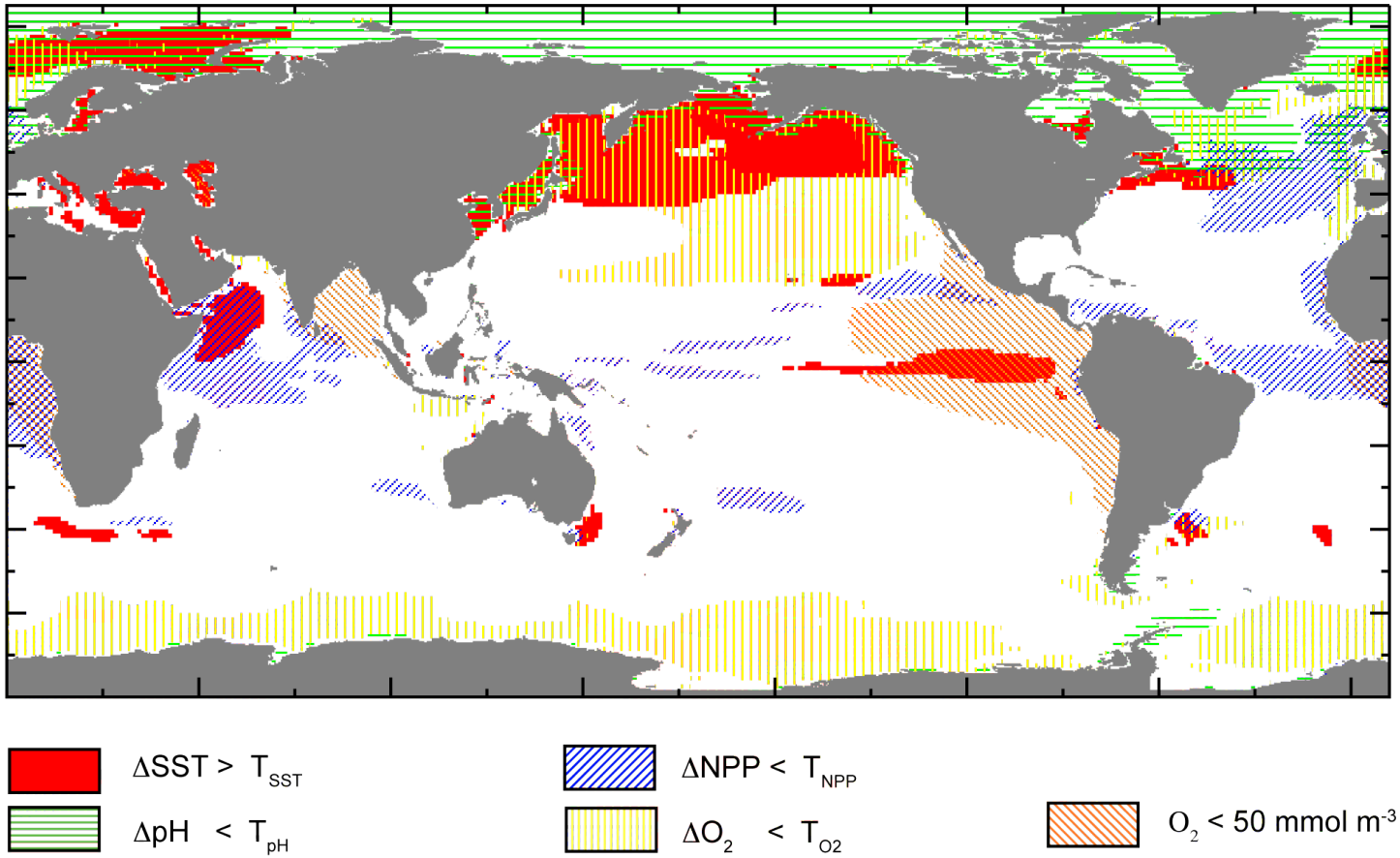
Sarmiento et al. 1998, Bopp et al. 2001, Doney et al. 2006

Multiple Stressors: summary

- Climate-change driven modifications of O_2 and Net Primary Productivity are much more uncertain and show very different spatial patterns than T & pH

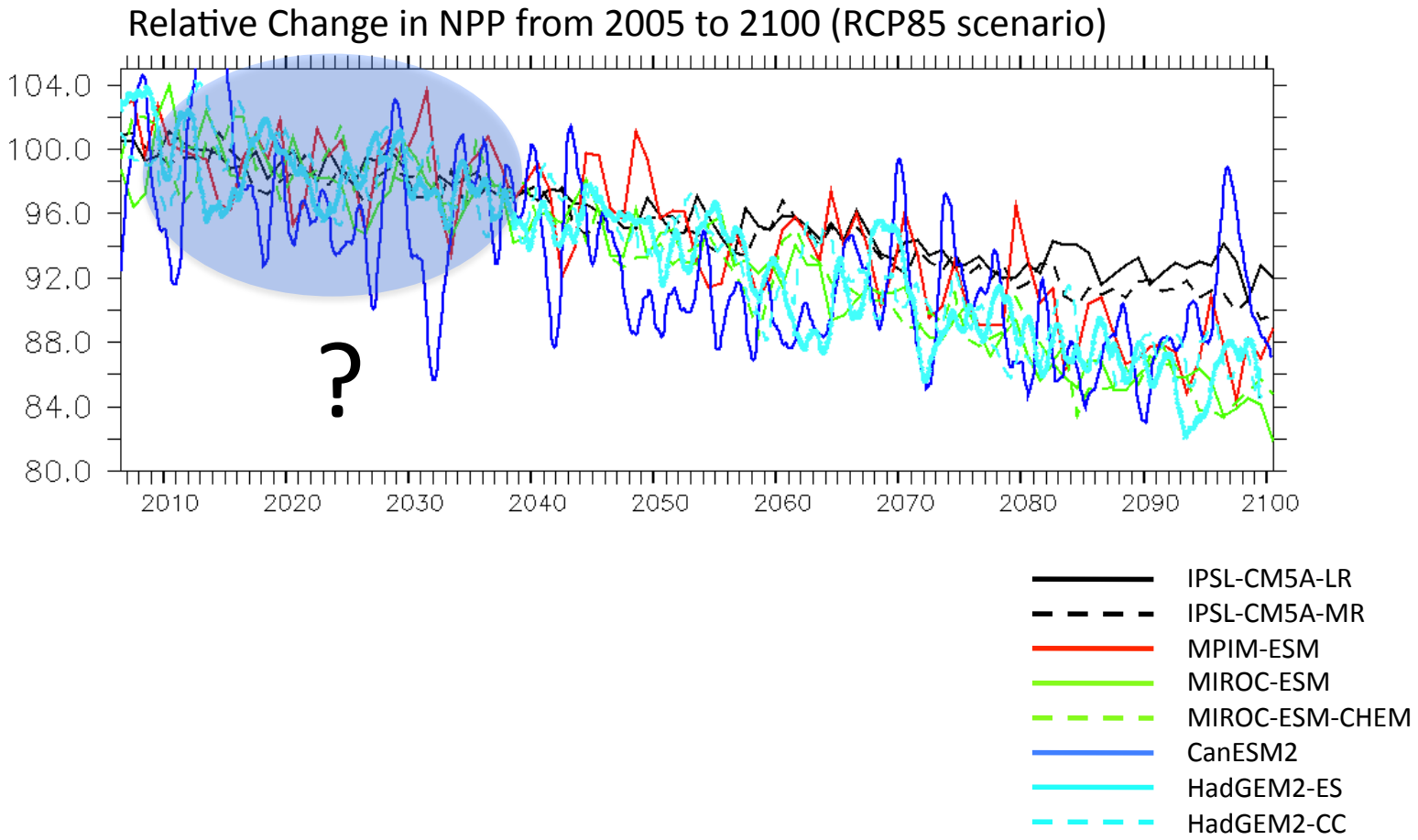
- Regions impacted by largest / robust changes in SST, surface pH, sub-surface O_2 and NPP.

RCP8.5 - 2090s, changed from 1990s



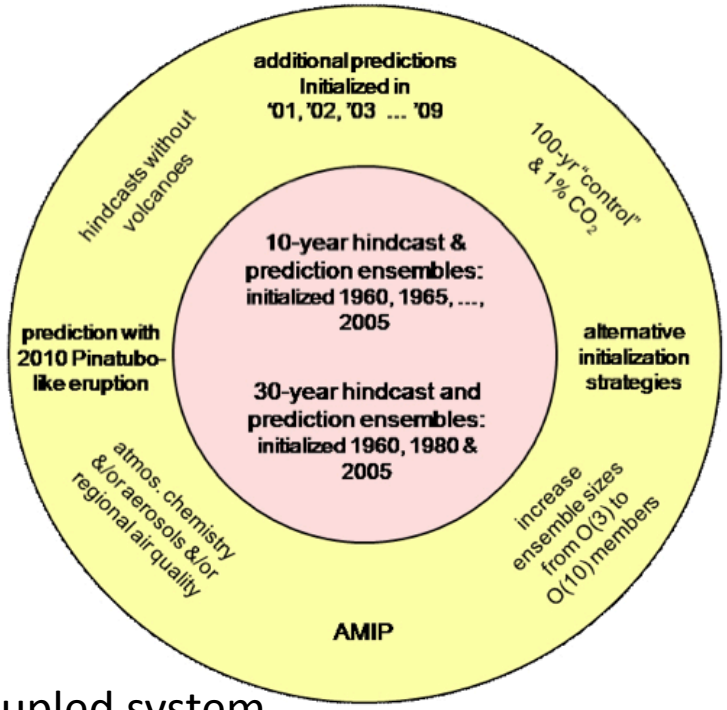
Decadal Predictability

No use of of climate simulations for the next decades or so (2010-2030) as internal variability tends to dominate on these time-scales



Decadal Predictability : Method

… but near-term CMIP5 decadal predictions

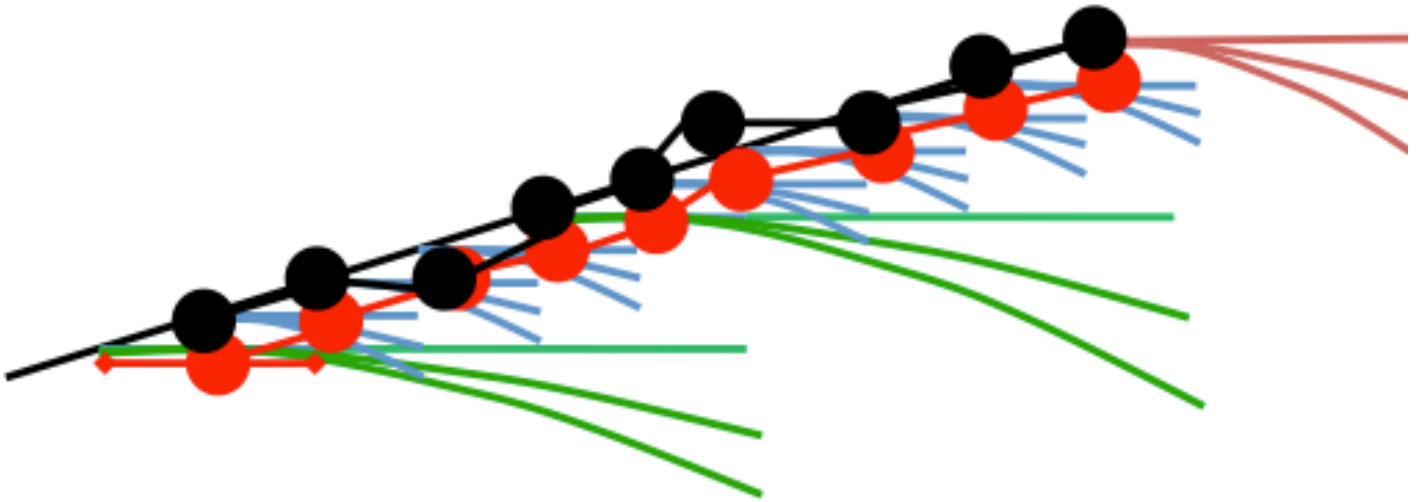


→ IPSL-CM5 includes a marine biogeochemical component (PISCES, Aumont and Bopp, 2006)

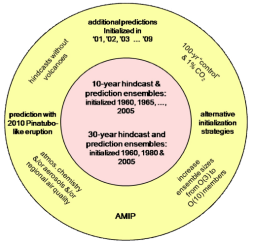
→ Hincast and prediction ensembles

→ Only SST anomalies are used to nudge / initialize the coupled system

→ Hindcasts/Prediction ensembles (3 x members) every year from 1997 to 2011.

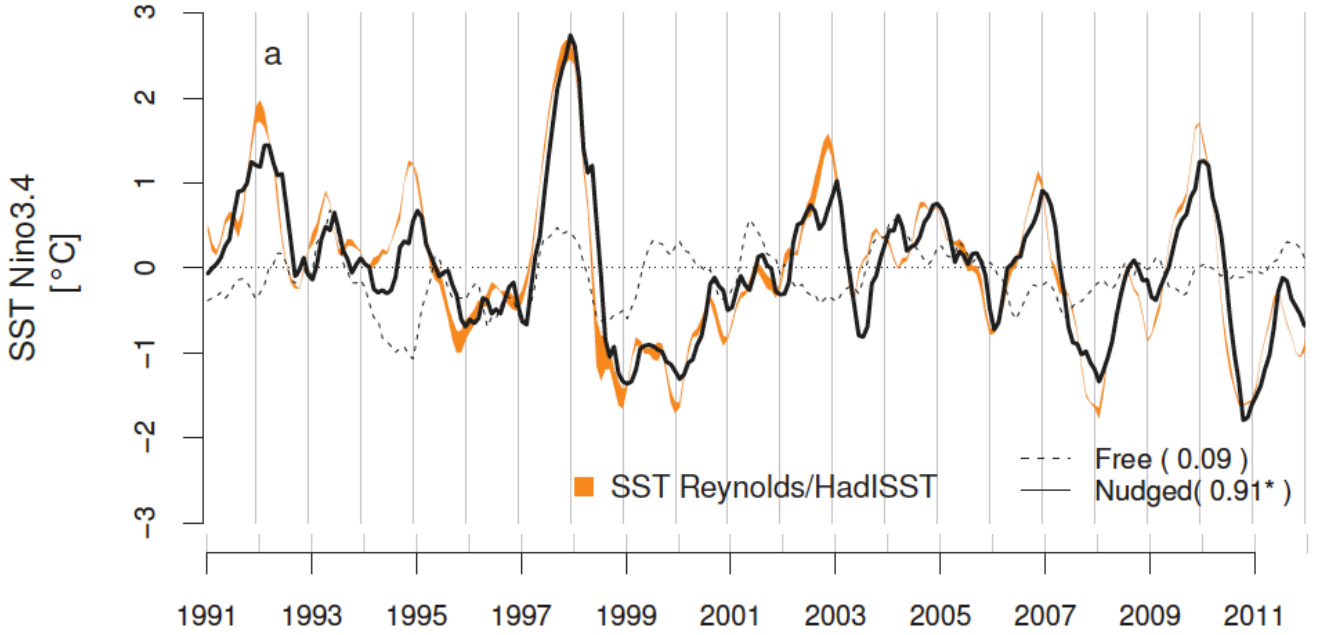


Decadal Predictability

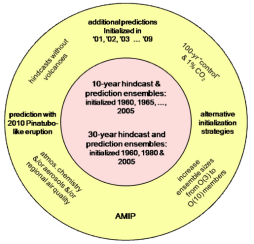


Nudged vs free simulation over 1991-2011

SST Nino3.4

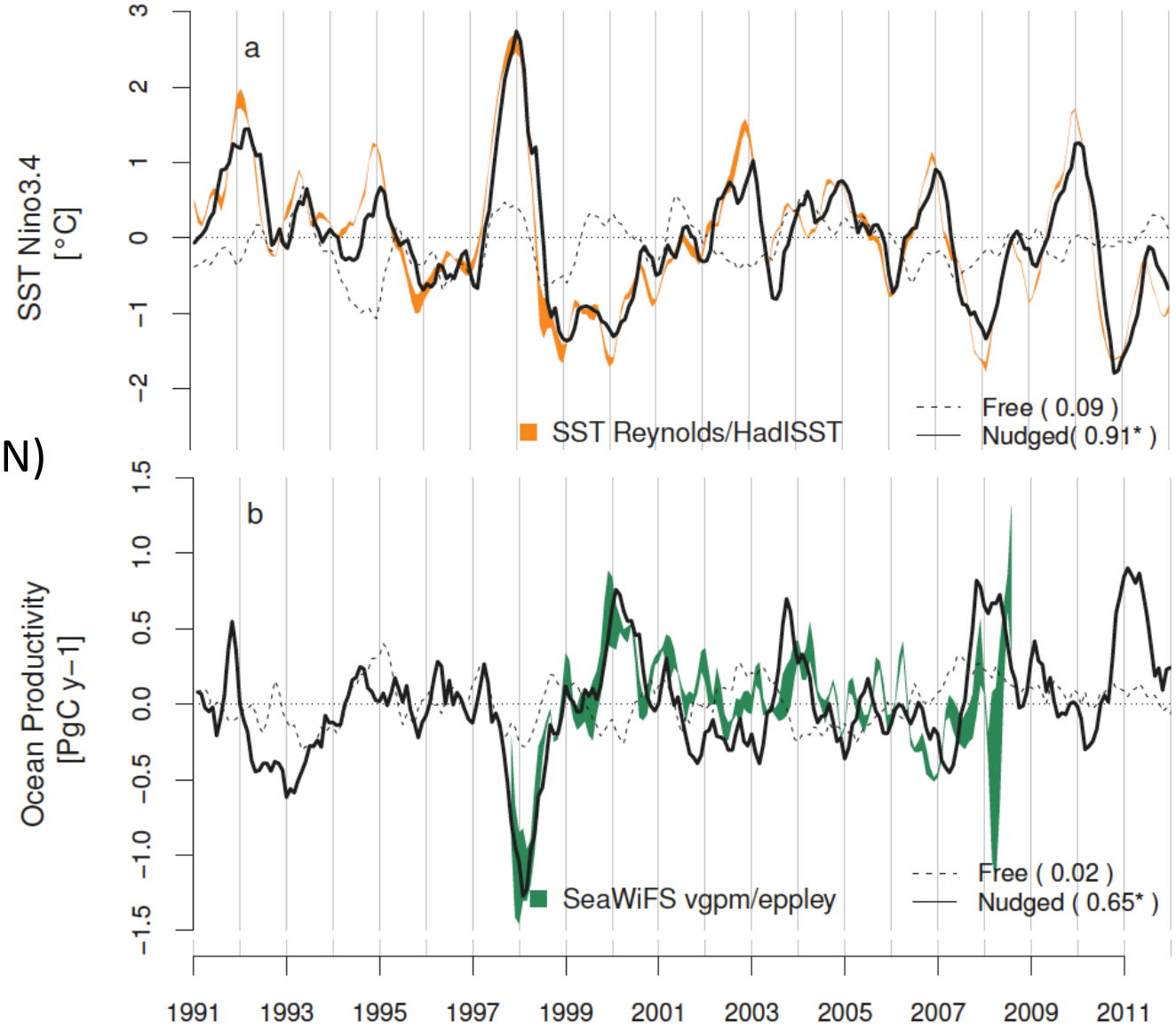


Decadal Predictability: Nudging



- Nudged vs free simulation over 1991-2011

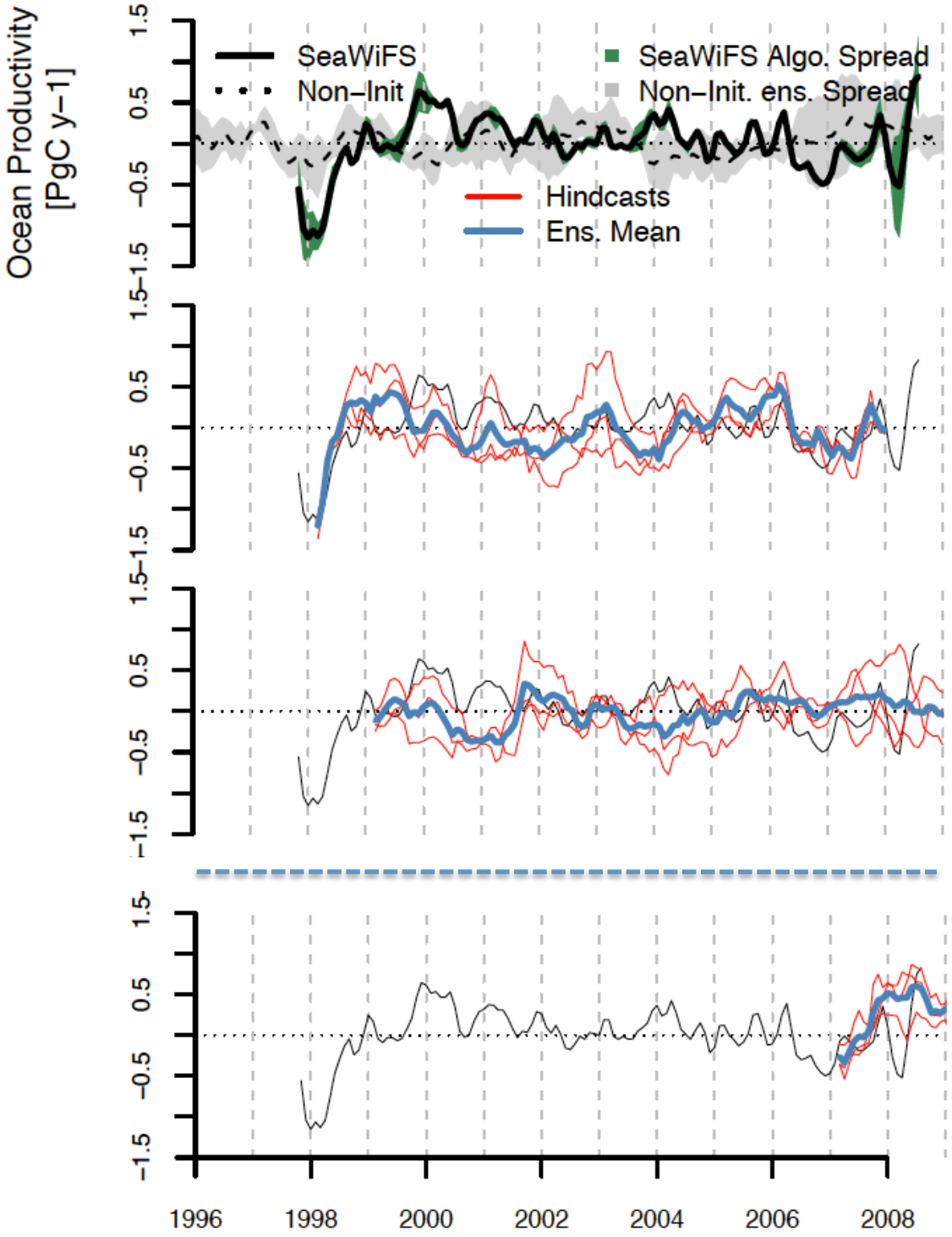
- Pacific NPP (30°S-30°N) also well correlated / in phase with observations



Séférian et al., in rev

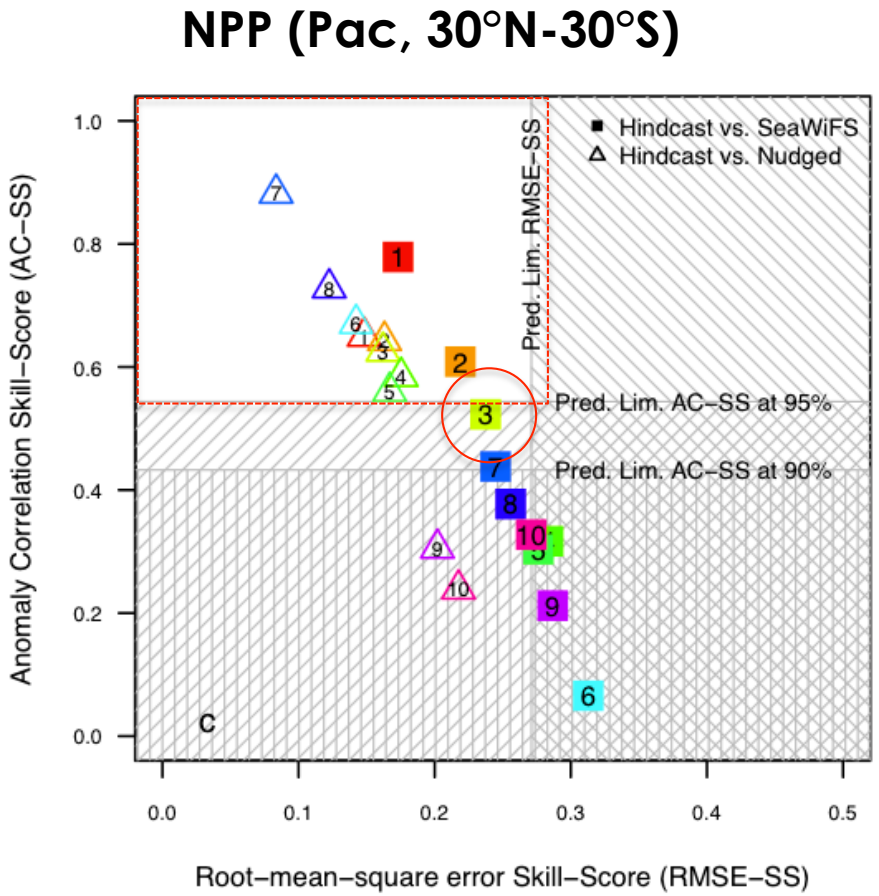
Decadal Predictability

Hindcasts / Predictions



Decadal Predictability: Skill scores

Skill score for 1 to 10 years of predictions (all the hindcasts)



Anomaly correlation Skill Score

$$AC-SS=\frac{1}{N}\frac{\sum(p-\overline{p})(o-\overline{o})}{\sum(p-\overline{p})^2\sum(o-\overline{o})^2}$$

Root Mean Square Error Skill Score

$$RMSE-SS=\frac{1}{N}\sum\left[(p-\overline{p})-(o-\overline{o})\right]^2$$

Potential Predictability (hindcats vs nudged)

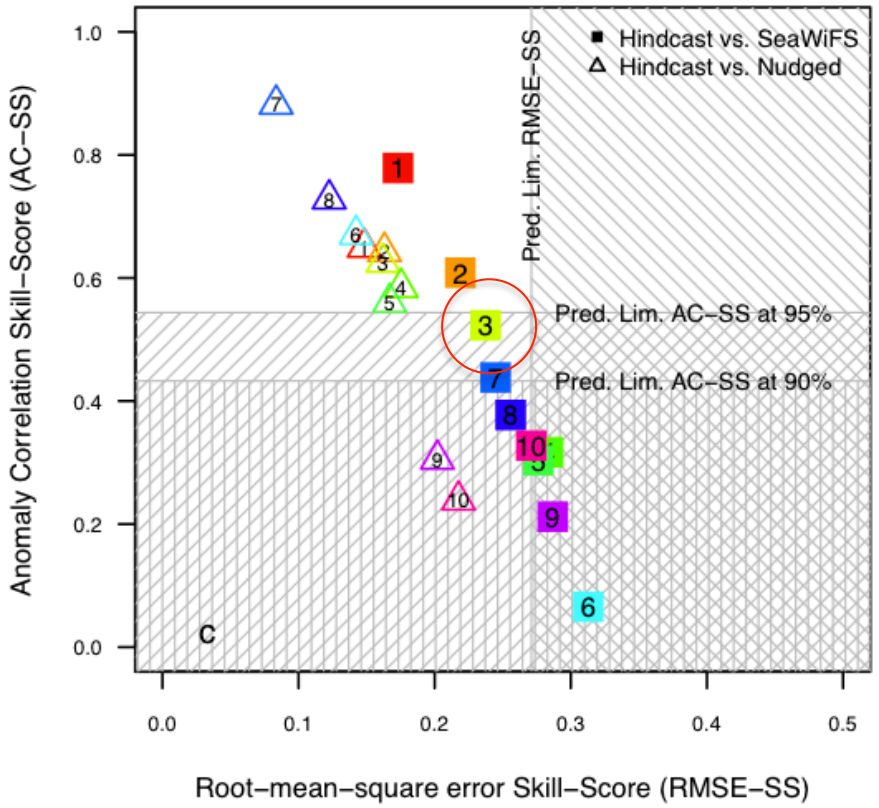
Predictability (hindcats vs obs)

Séférian et al., submitted

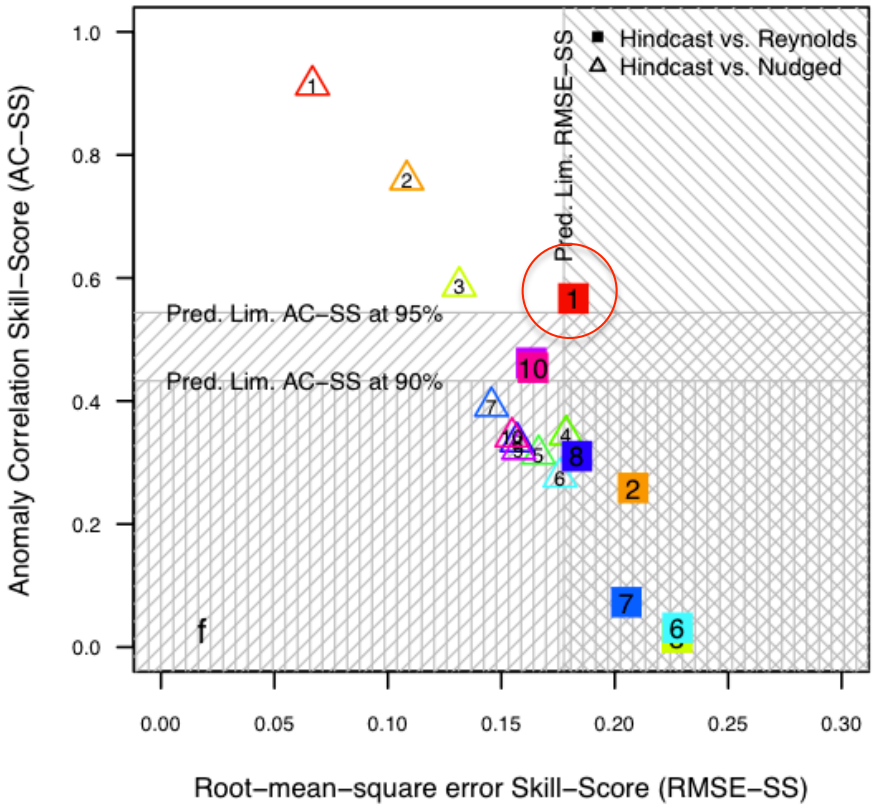
Decadal Predictability : Skill scores

Skill score for 1 to 10 years of predictions (all the hindcasts)

NPP (Pac, 30°N-30°S)



SST

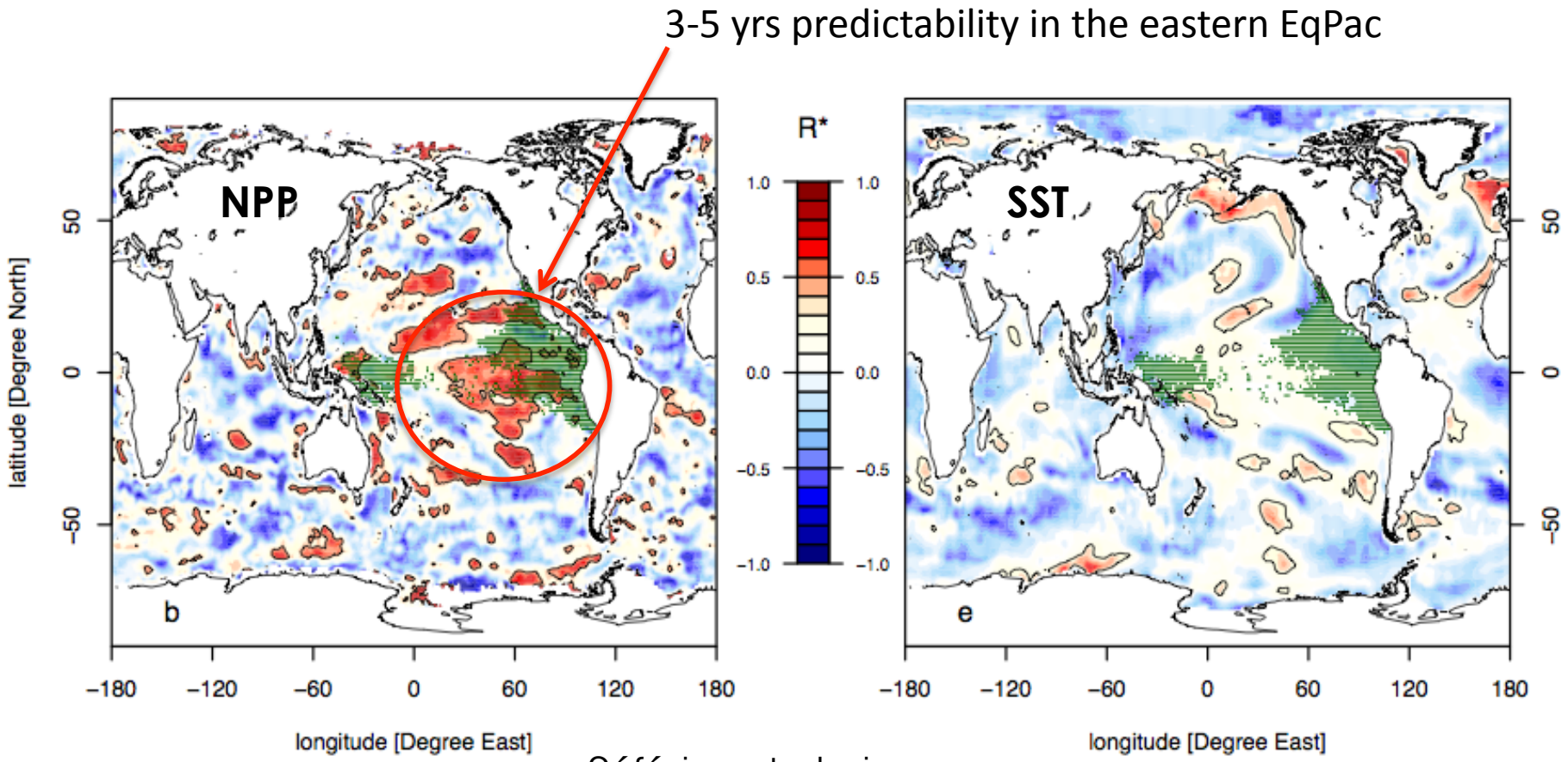


Less than 1-yr for SST, but up to 3-yrs for NPP….

Séférian et al., submitted

Decadal Predictability : Regional Skill scores

Correlation skill score for 3 to 5 years of predictions (all the hindcasts)



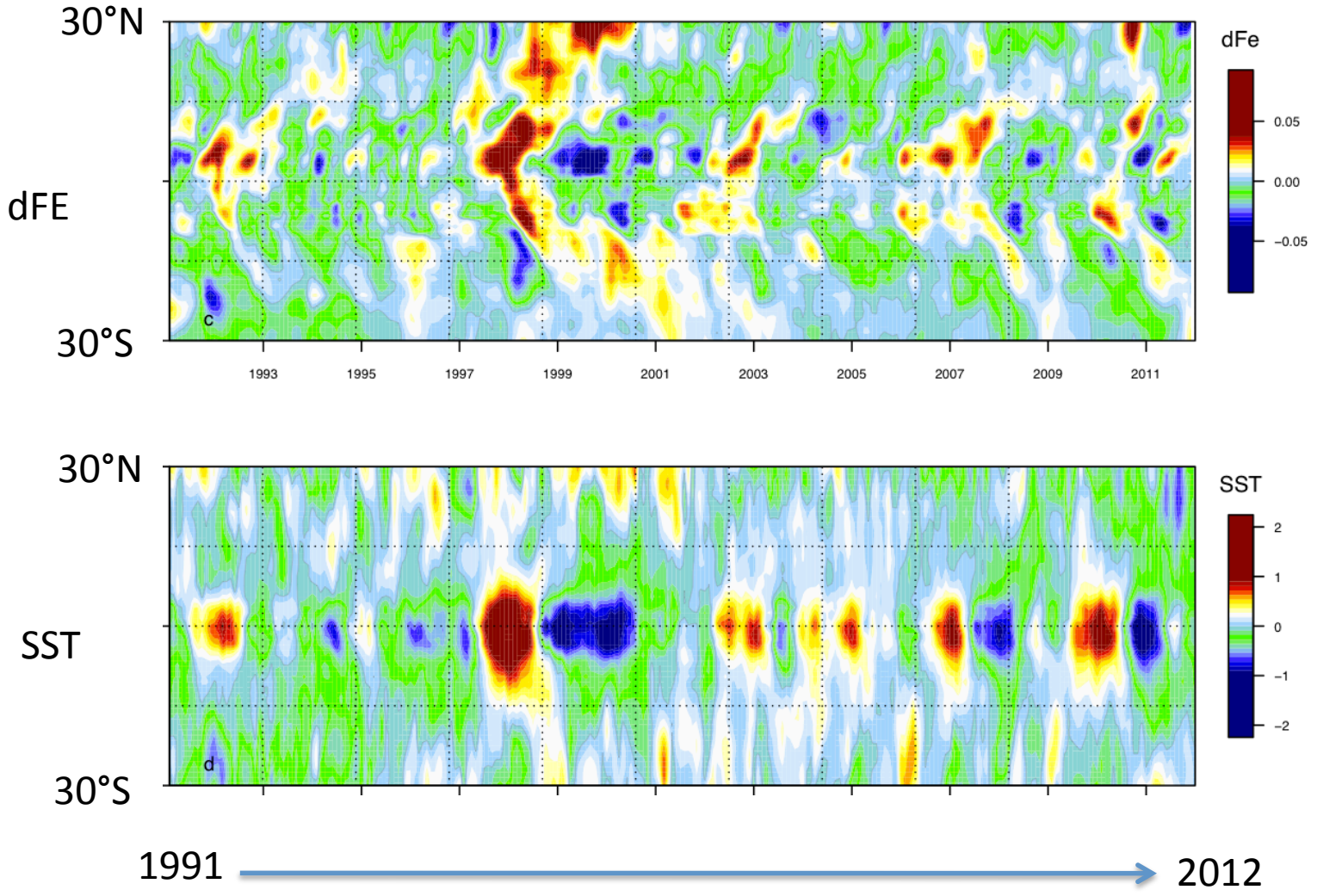
Séférian et al., in rev

Fishing areas

Decadal Predictability : Mechanisms

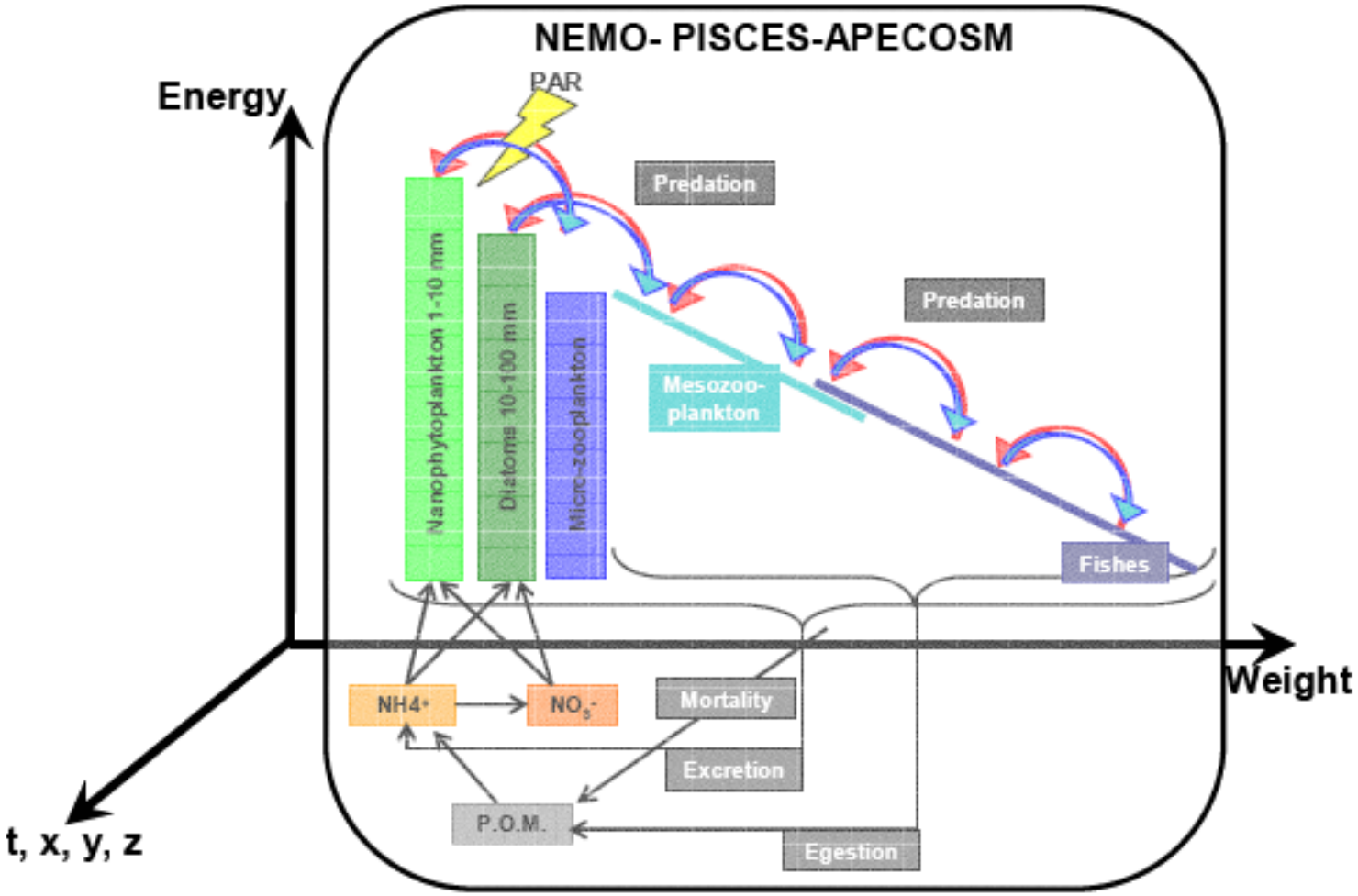
Transport of nutrient anomalies without any interactions with the atm.

Zonal anomalies of Fe and SST in the Eq Pac (30°S to 30°N), from 1991 to 2012



Towards coupled climate & end-to-end ecosystem modelling

Towards Online Coupling: PISCES-APECOSM



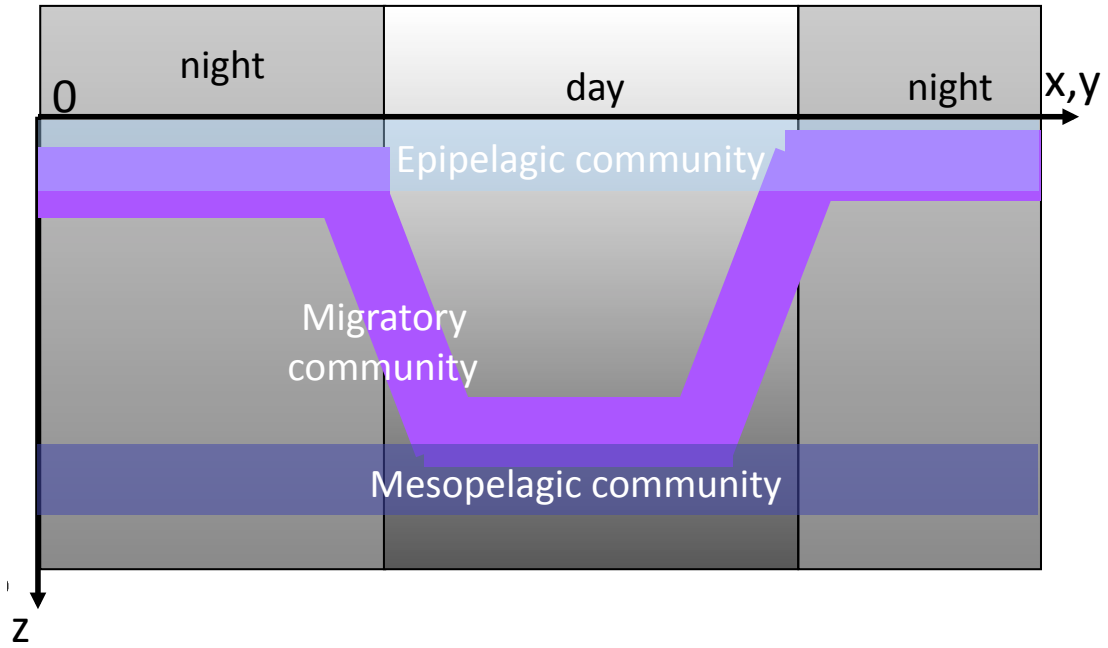
Aumont, Maury et al.

Towards coupled climate & end-to-end ecosystem modelling

Towards Online Coupling: PISCES-APECOSM

The ecosystem is divided into 3 Open Ocean Pelagic Communities (OOPC)

Depth distribution is constrained by light, oxygen, food and temperature



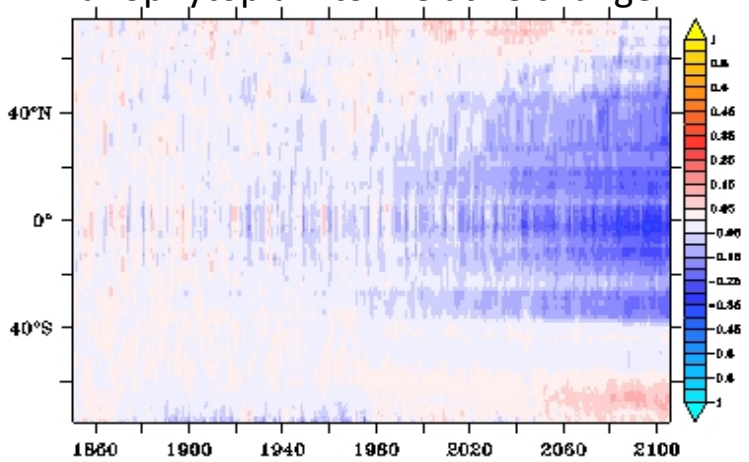
Each OOPC is divided into n size-classes

Maury et al. 2010

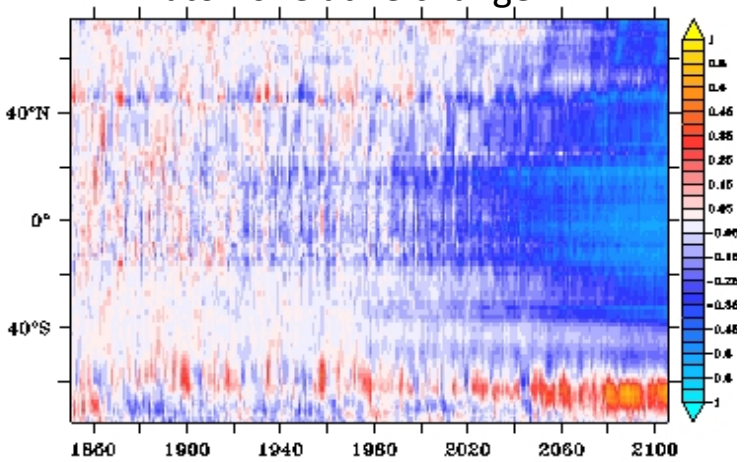
Towards coupled climate & end-to-end ecosystem modelling

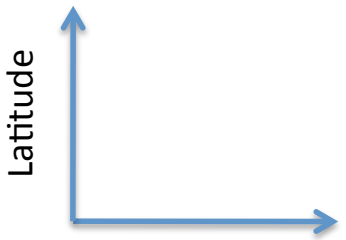
PISCES-APECOSM : : Preliminary RCP85 results

Nanophytoplankton relative change

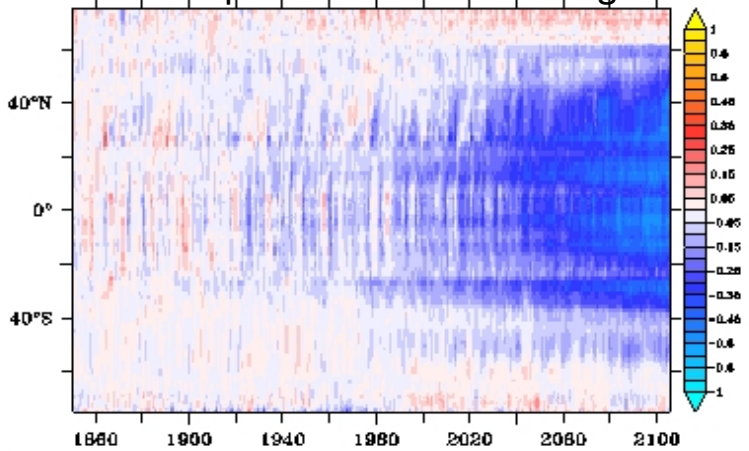


Diatoms relative change

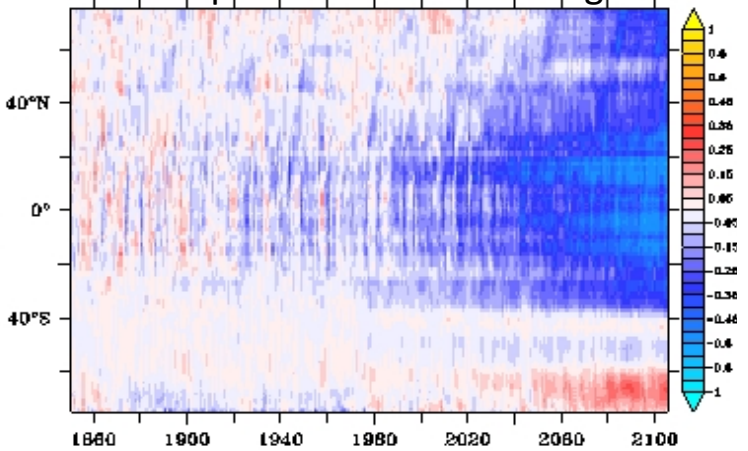




Microzooplankton relative change



Mesozooplankton relative change



LOWER TROPHIC

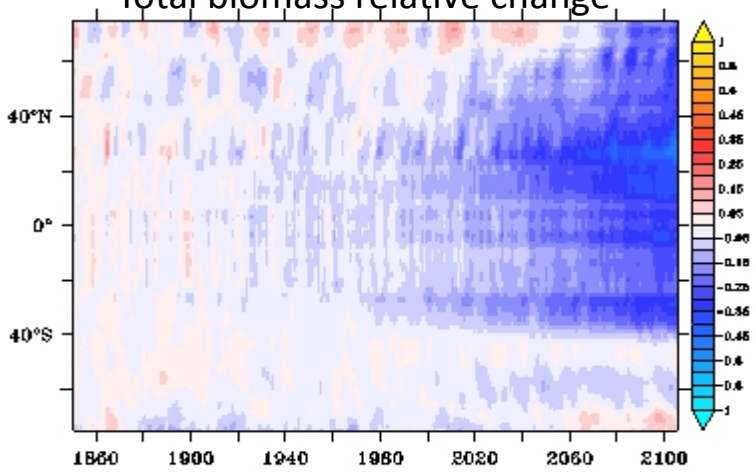
15% drop of total biomass in 2100 compared to preindustrial values

Large disparity among plankton functional types:
Phyto : -8%, Diatoms : -16%,
Microzoo : -20%, Mesozoo : -20%.

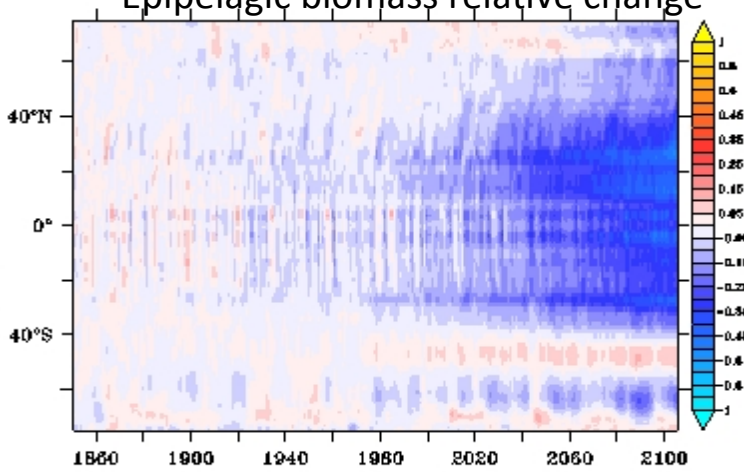
Towards coupled climate & end-to-end ecosystem modelling

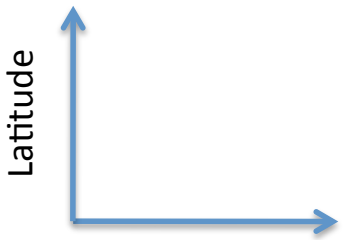
PISCES-APECOSM : : Preliminary RCP85 results (see talk by S. Dueri for more details)

Total biomass relative change

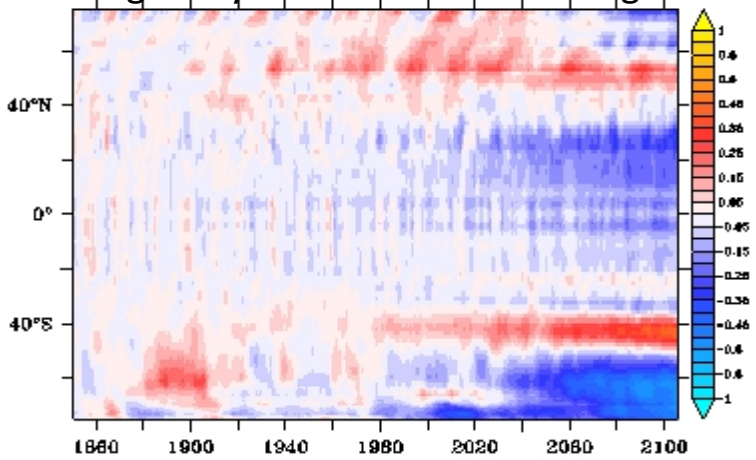


Epipelagic biomass relative change

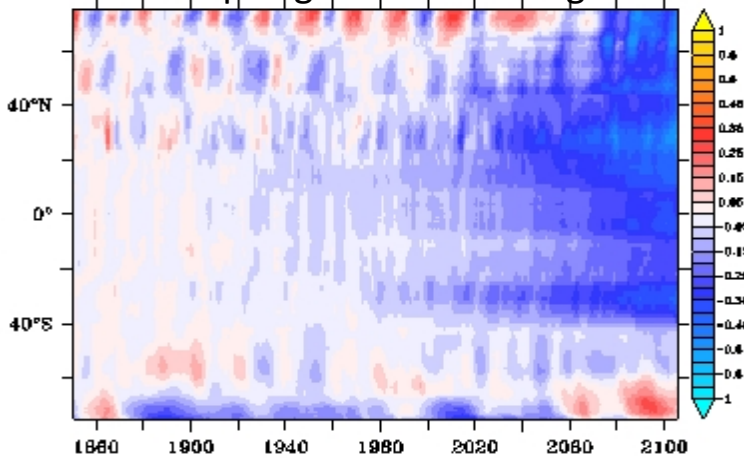




Migratory biomass relative change



Mesopelagic relative change



UPPER TROPHIC

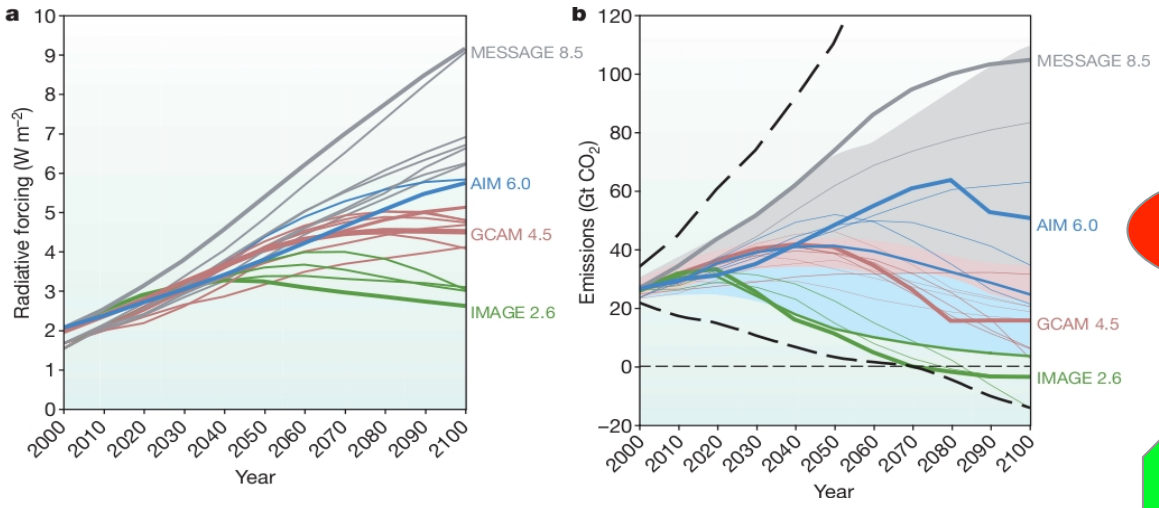
23% drop of total biomass in 2100 compared to preindustrial values

Large disparity among communities:
Epipelagic : -22%, Migratory : -8%,
Mesopelagic : -30%

Lefort et al. in prep

Towards coupled climate & end-to-end ecosystem modelling

Climatic scenarios:



IPSL model

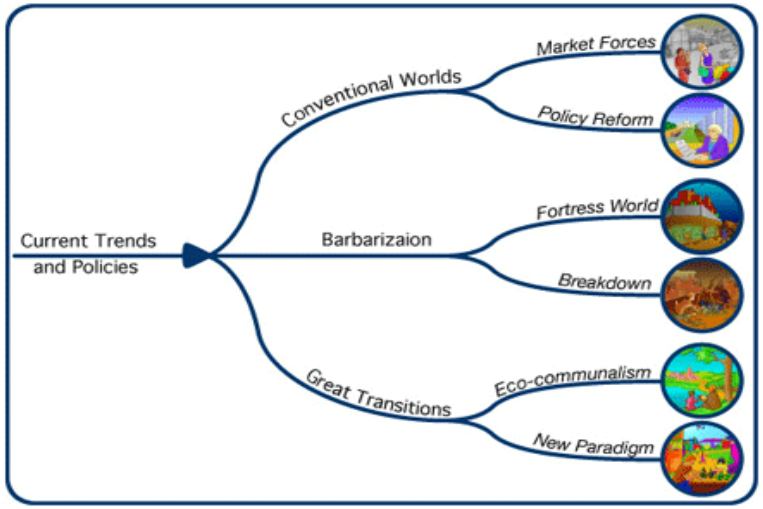
E2E model

1. Sensitivity

2. Retroactions

3.Fishing scenarios ?

Governance scenarios:



ANR-MACROES

Conclusions & Perspectives

- New IPCC-type Earth System Models offer the opportunity to look more systematically at the impact of CC on marine ecosystems

- **Stressors :** Early results show contrasting changes in pH/T/O_2/NPP
  and large uncertainties / model spread for NPP and for low O2 zones.

- **Decadal Predictions:** Promising results for the EqPac, but only one model so far…

- **End-to-end modeling:** Very different approaches that need to be compared (FishMIP)
  but fishing scenarios (?), regional / global (?)

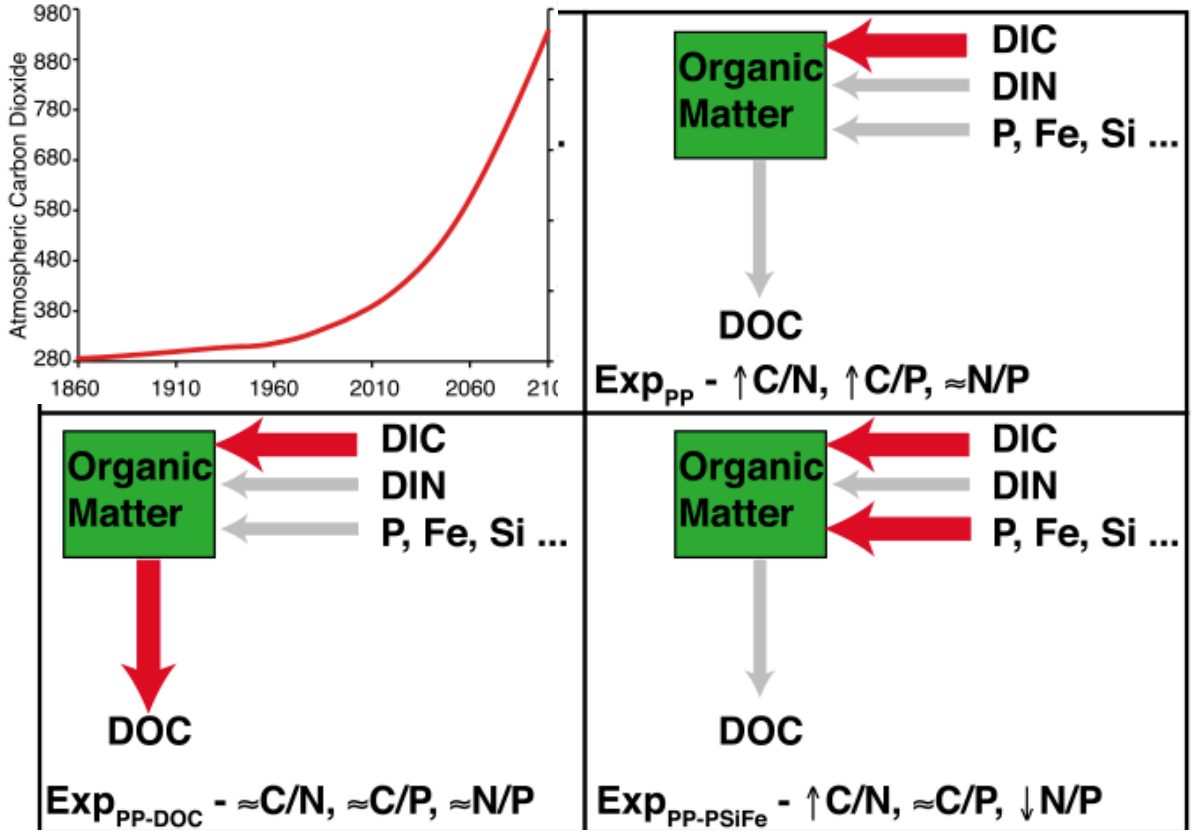
Focus on hypoxic and suboxic waters : Ocean Acidification?

- No effect of acidification on organic matter stoechiometry in these simulations…
- Changes in C/N ratios (Riebesell et al. 2007) tested by Oschlies et al. (2008)

→ Large increase (+40% !) in suboxia volume driven by an increase in C/N ratios.

- *Tagliabue et al. (2011) :*

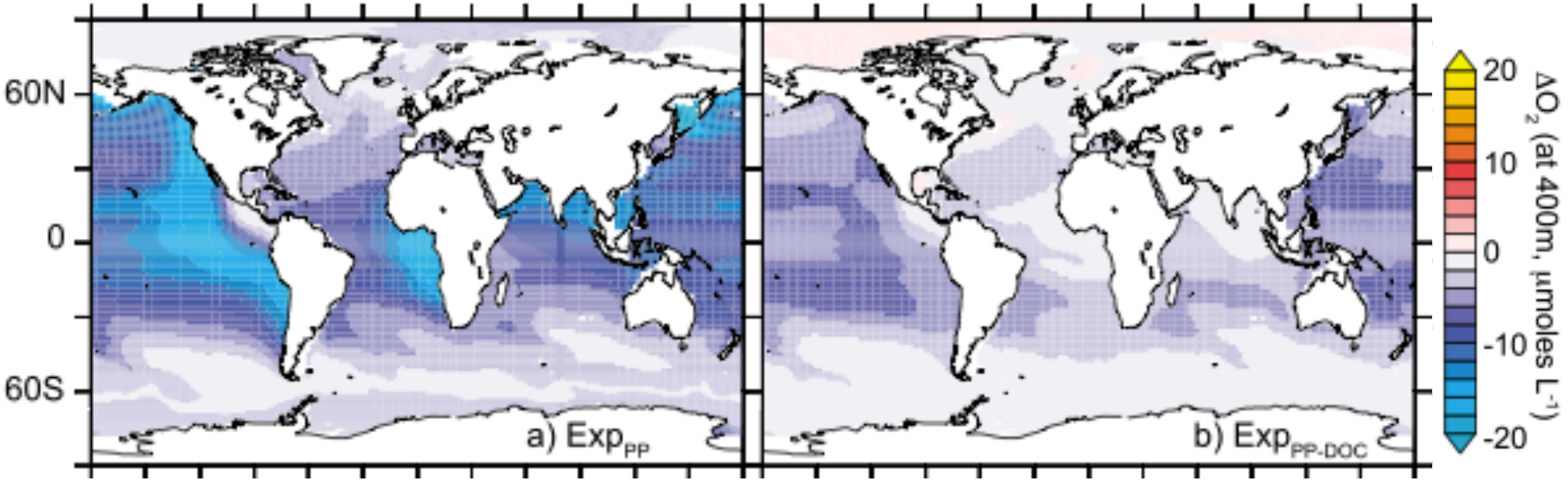
CNP version of PISCES model
No climate change
Only forcing : CO2 & acidification
3 different assumptions on phyto physiological response to OA



Focus on hypoxic and suboxic waters : Ocean Acidification?

Tagliabue et al. (2011) :

Changes in $[O_2]$ at 400m, in 2100 vs 1860.

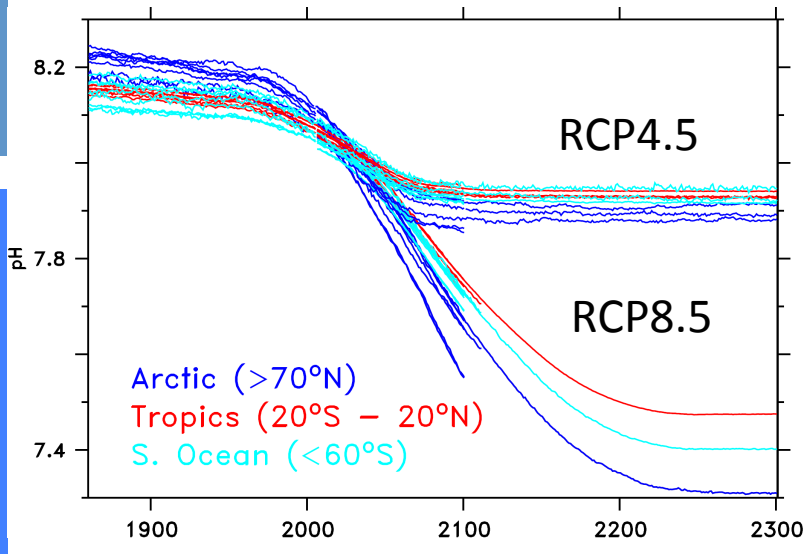


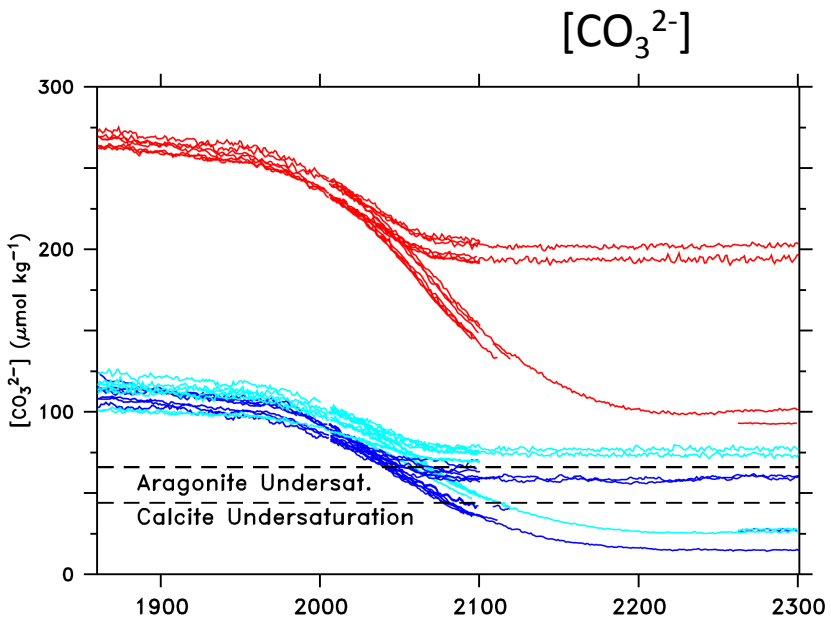
Excess carbon → POC

Excess carbon → DOC

Biogeochemical Drivers

- Changes in pH / Ocean Acidification



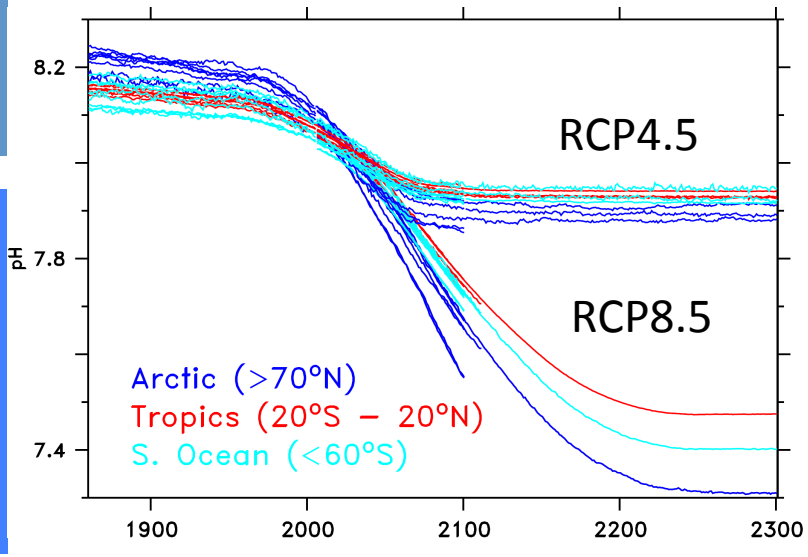


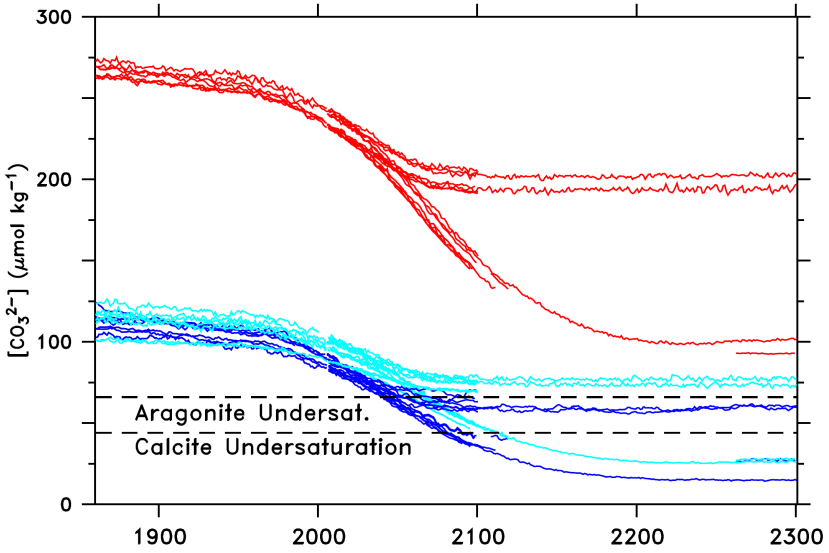
Aragonite / Calcite undersaturation
reached at the surface in polar oceans

→ Implications on calcification / trophic food webs?

Biogeochemical Drivers

- Changes in pH / Ocean Acidification





Increase in C/N ratios
of organic matter (Riebesell et al. 2008)

→ Implications on food “quality” ?