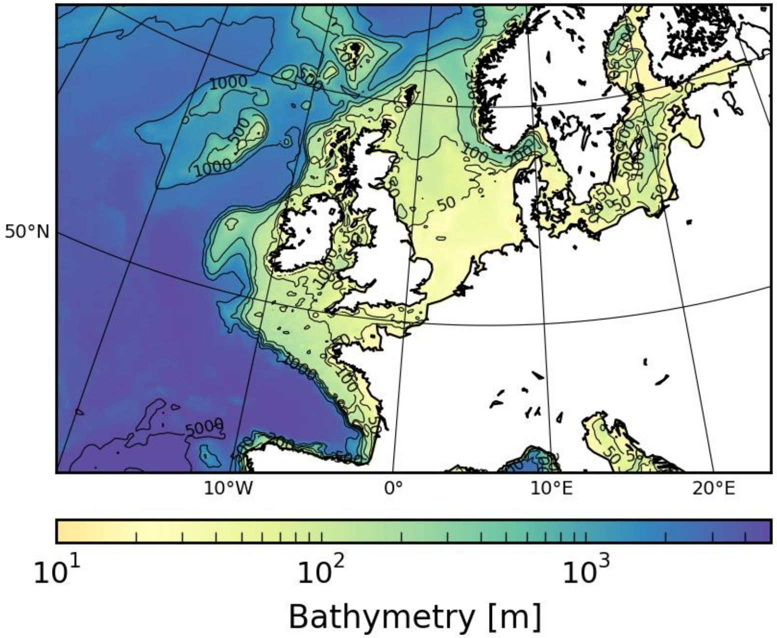
The future regime of Atlantic nutrient supply to the Northwest European Shelf

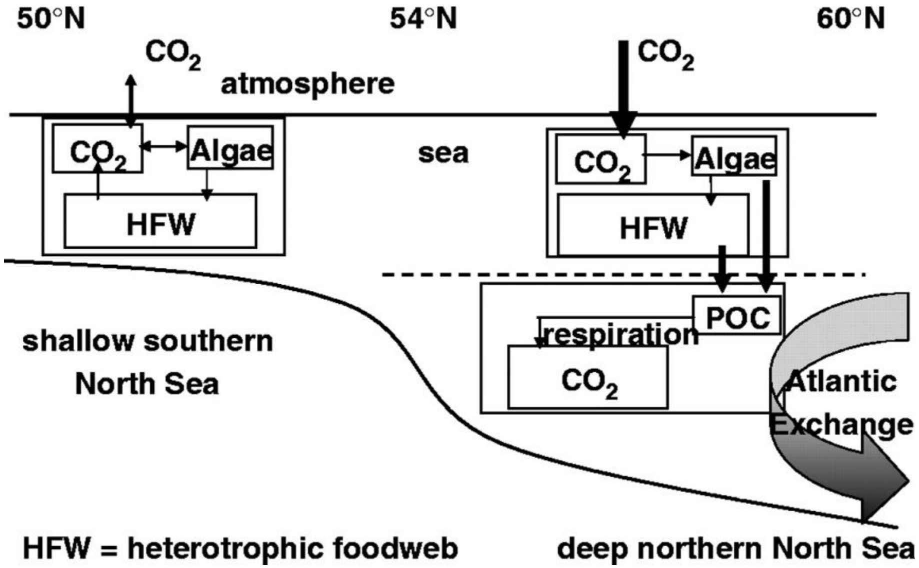
Moritz Mathis,
Alberto Elizalde,
Uwe Mikolajewicz

Max-Planck-Institute for Meteorology
Hamburg

RACE!

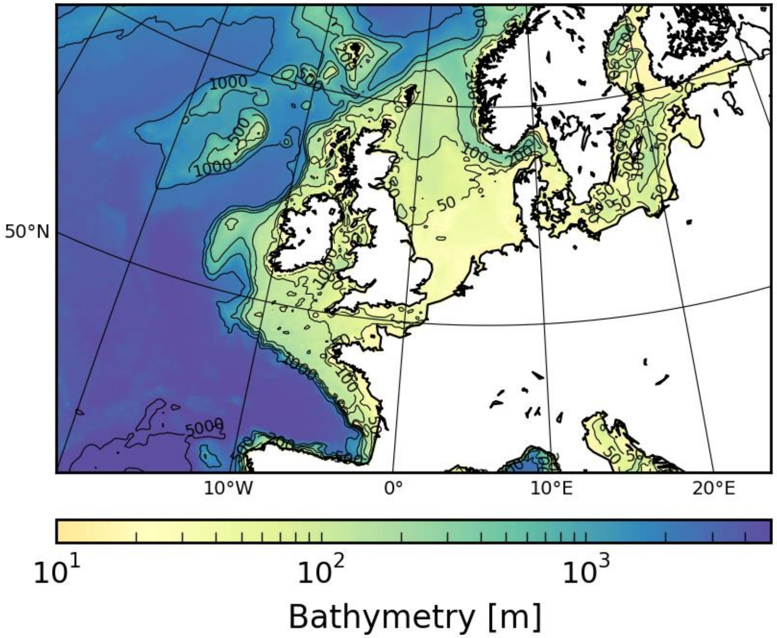
The shelf carbon pump

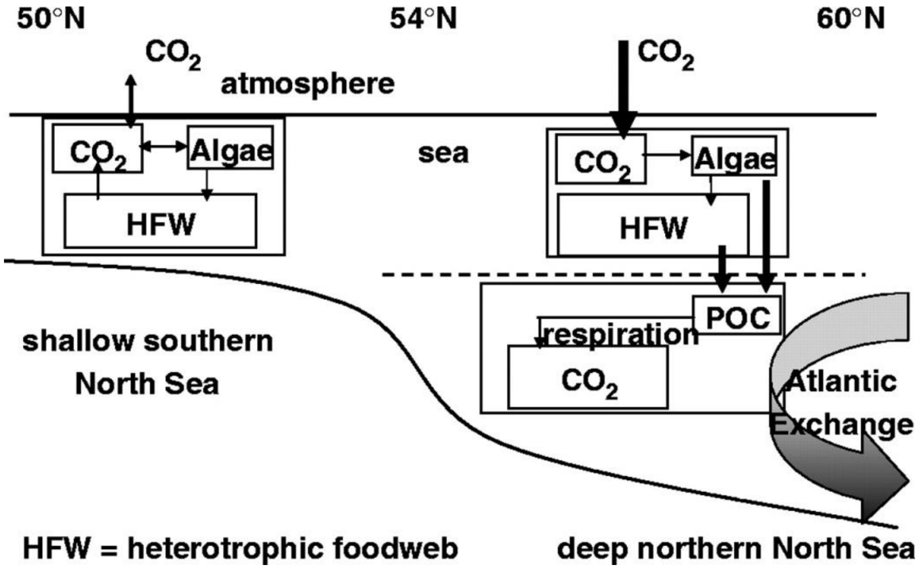




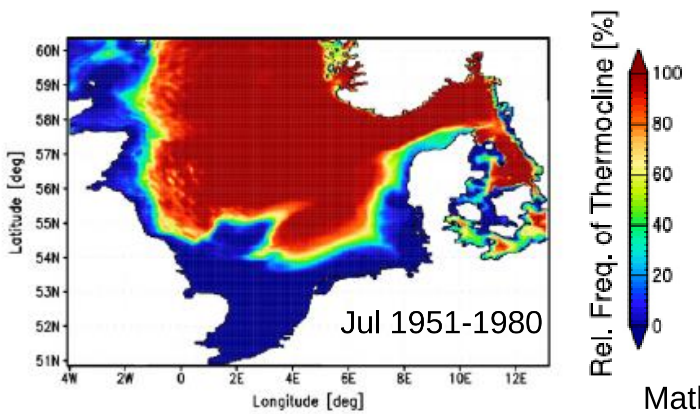
Thomas et al. (2004)

The shelf carbon pump



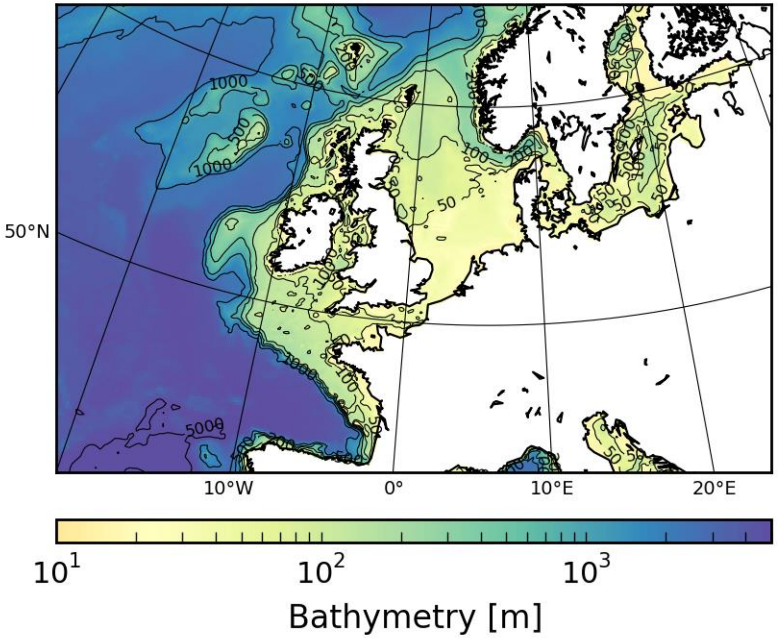


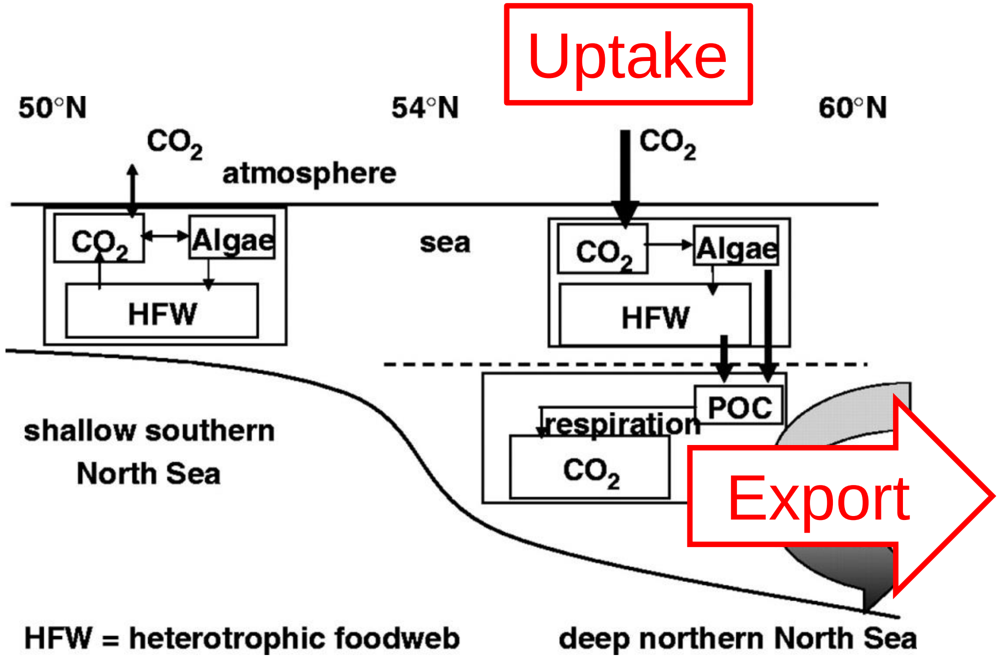
Thomas et al. (2004)



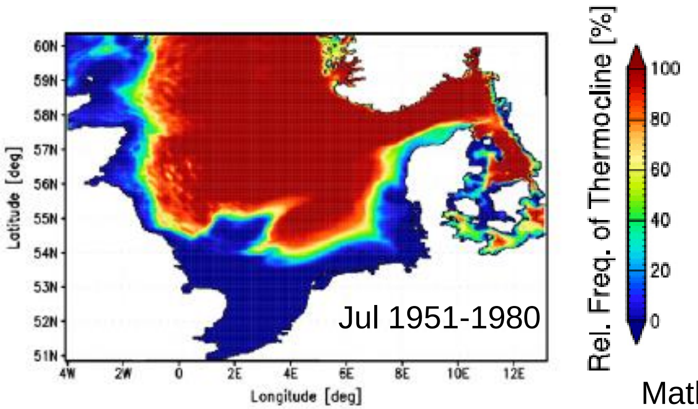
Mathis et al. (2013)

The shelf carbon pump



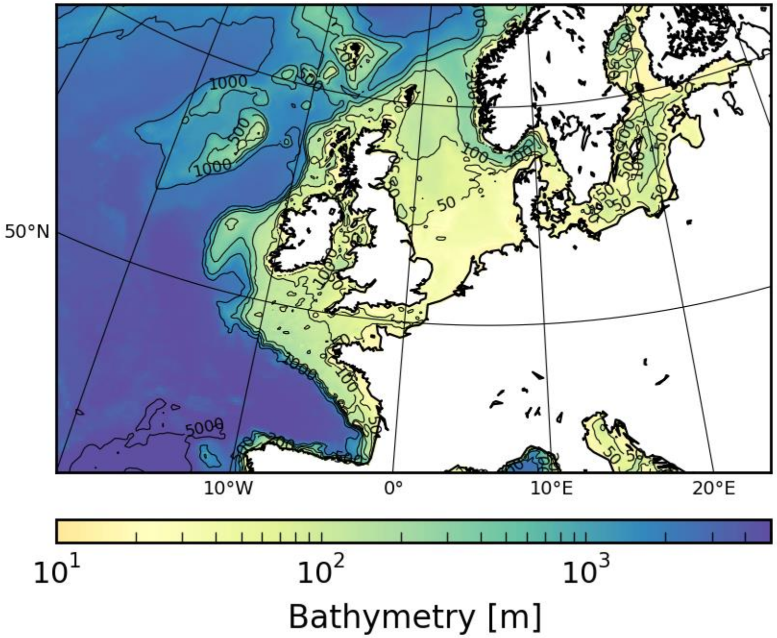


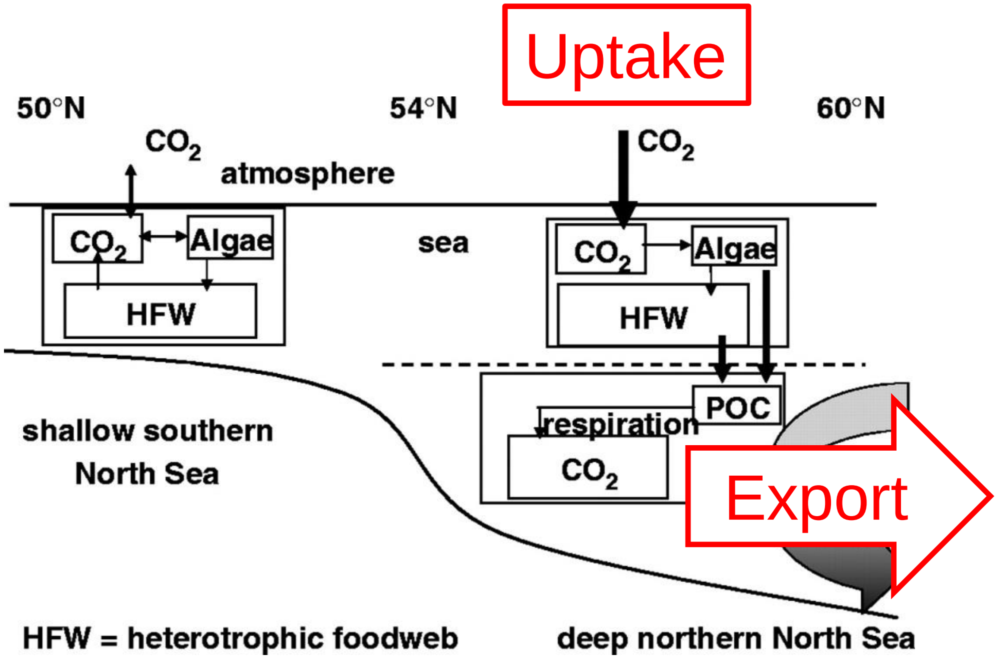
Thomas et al. (2004)



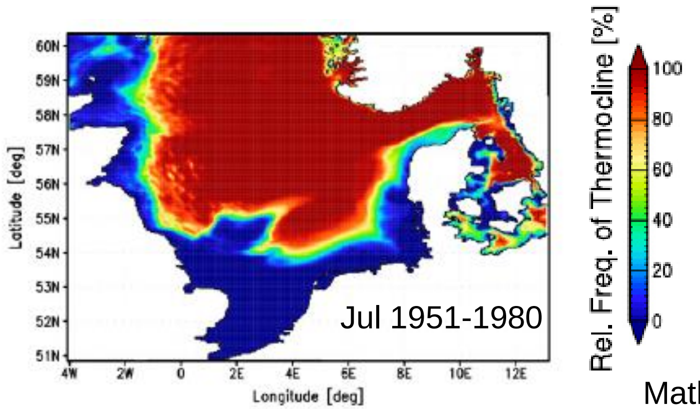
Mathis et al. (2013)

The shelf carbon pump





Thomas et al. (2004)



Mathis et al. (2013)

- North Sea is a sink for CO_2

Atlantic nutrient supply

- Shelf carbon pump
- Primary production requires
    - Light
    - Nutrients
    - Temperate water
- Nutrient import from the Atlantic
    - 80% nitrogen
    - 90% phosphorus
    - 84% silicate

Thomas et al. (2009)

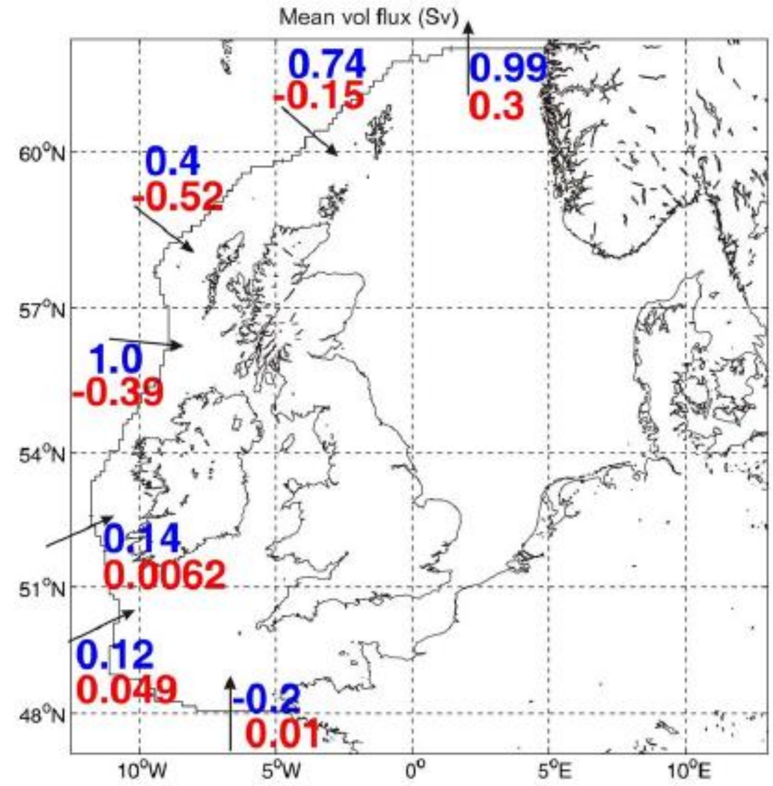
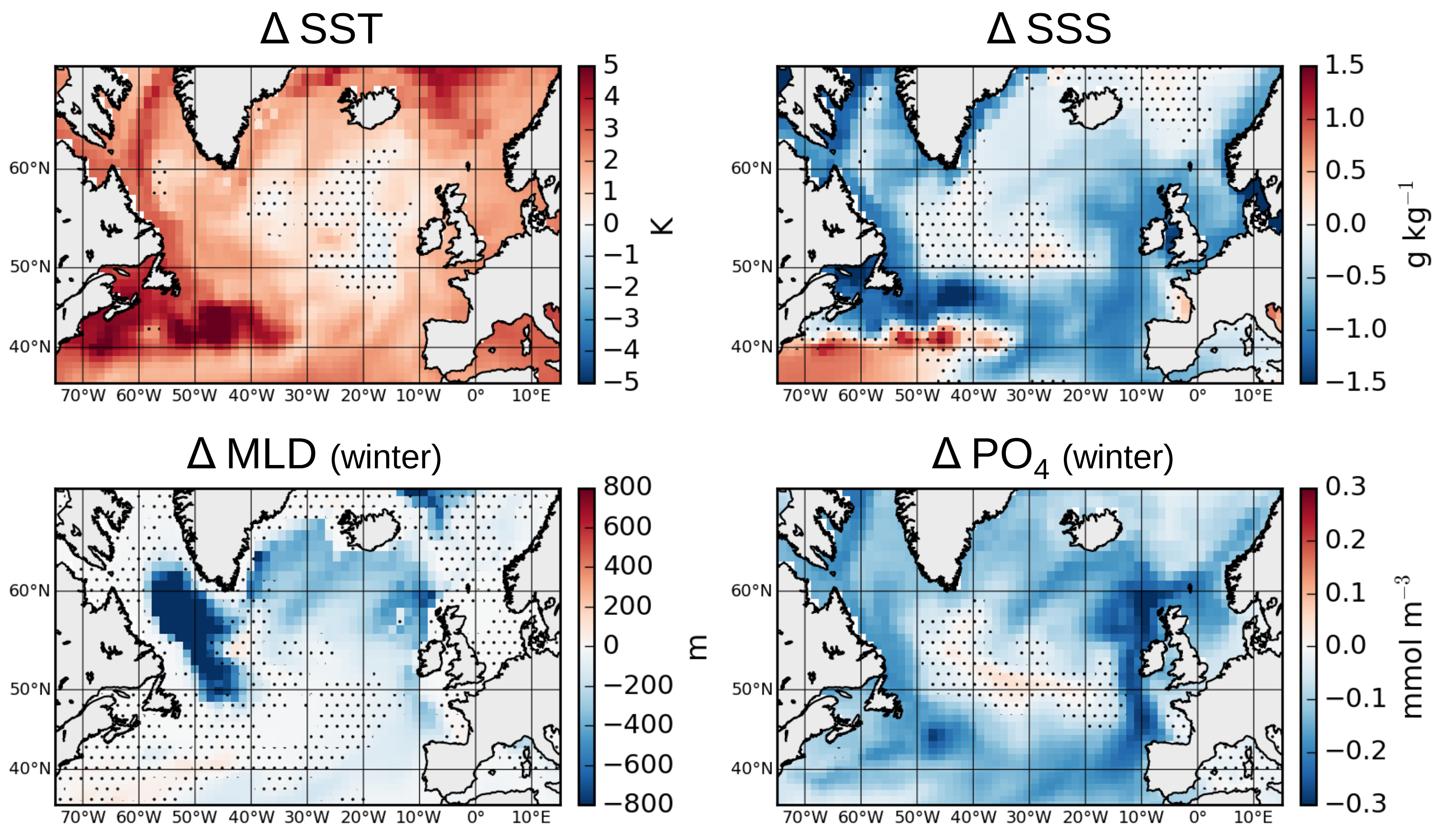


Fig. 3. Fluxes (Sv) above 150 m (blue) and below 150 m depth (red). All fluxes are across the 200 m contour shown; positive is onto the shelf except next to Norway (positive to north).

Huthnance et al. (2009)

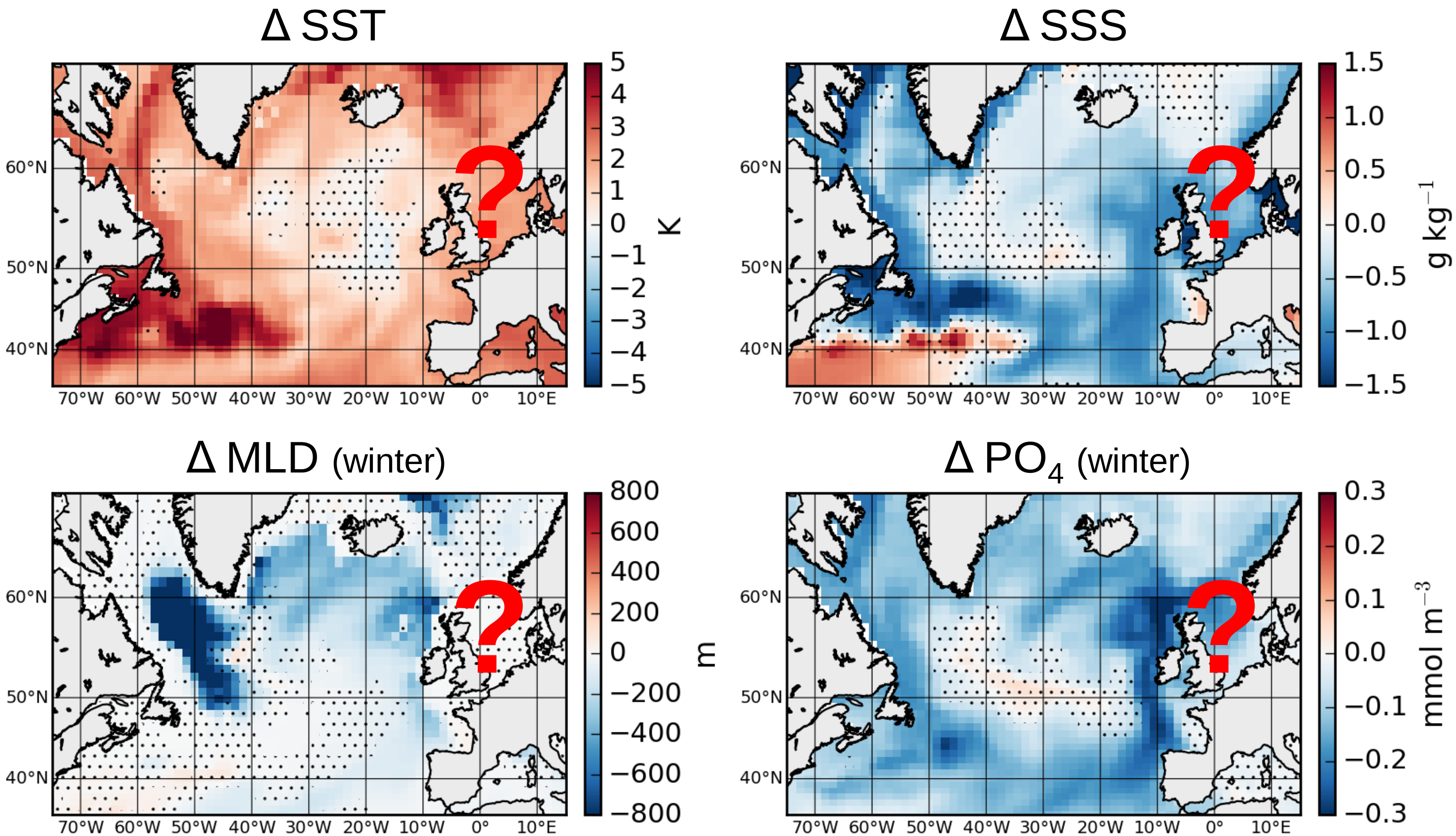
Subpolar North Atlantic in a warming climate

MPI-ESM-LR (RCP8.5)



Subpolar North Atlantic in a warming climate

MPI-ESM-LR (RCP8.5)

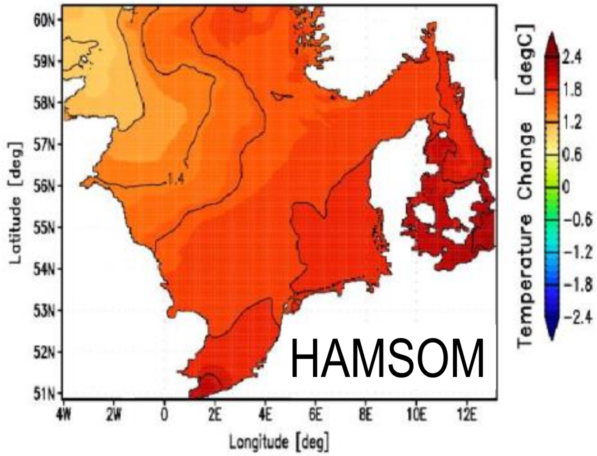


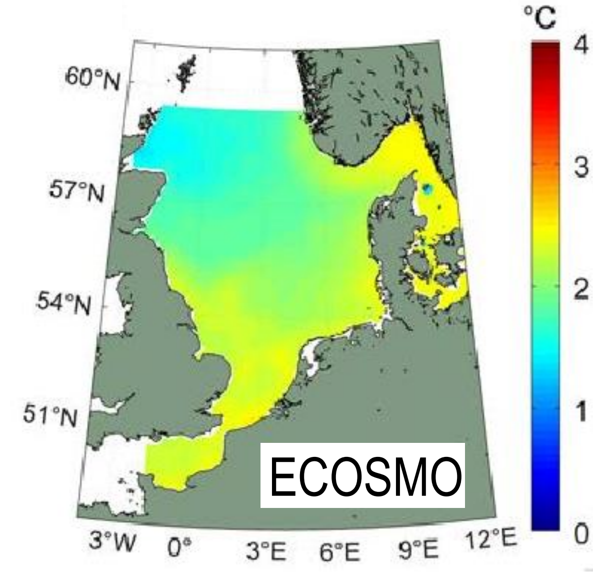
- How do changes in the North Atlantic affect climate and primary production on the shelf?

Downscaling SST change (A1B scenario)

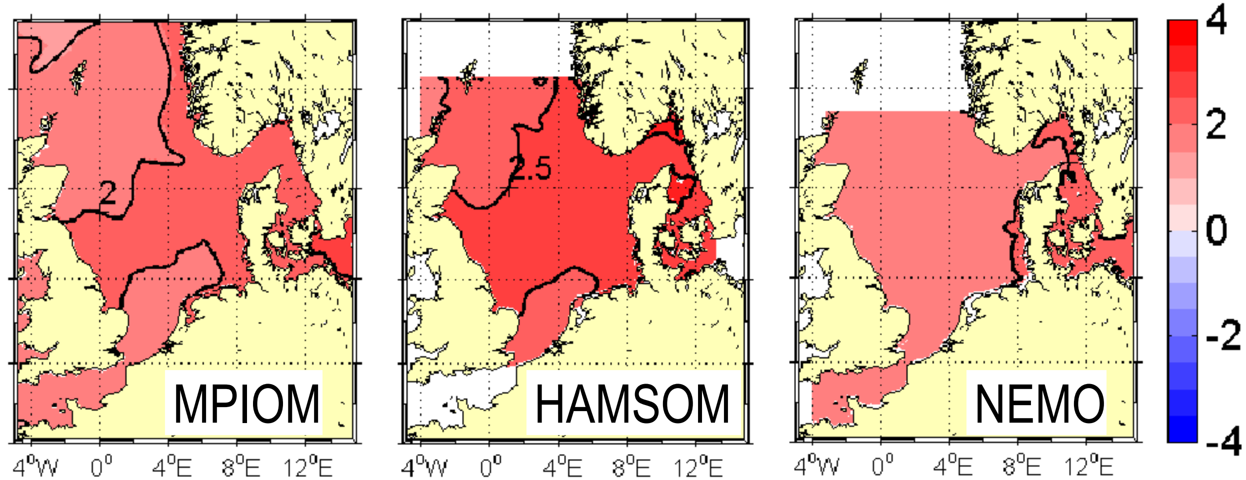
All forced with ECHAM5/MPIOM

Uncoupled
(Mathis & Pohlmann, 2014;
Wakelin et al., 2010)





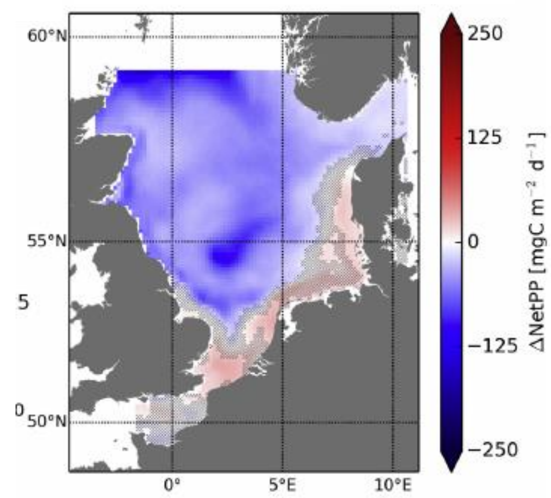
Coupled
(Bülow et al., 2014)

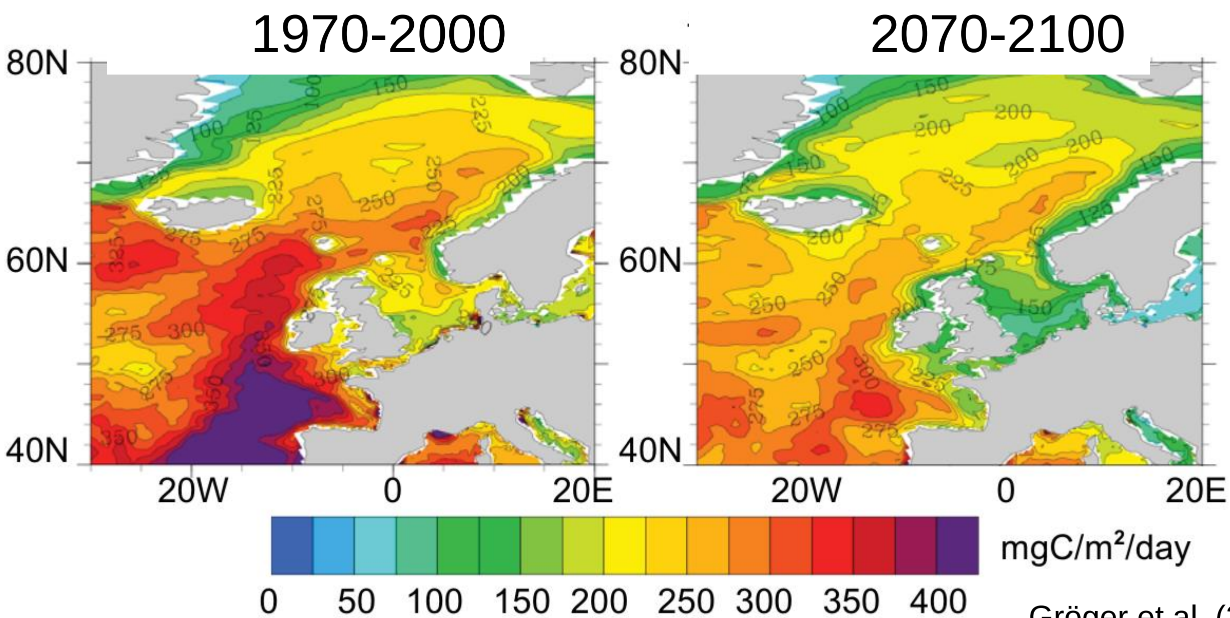


Change in primary production

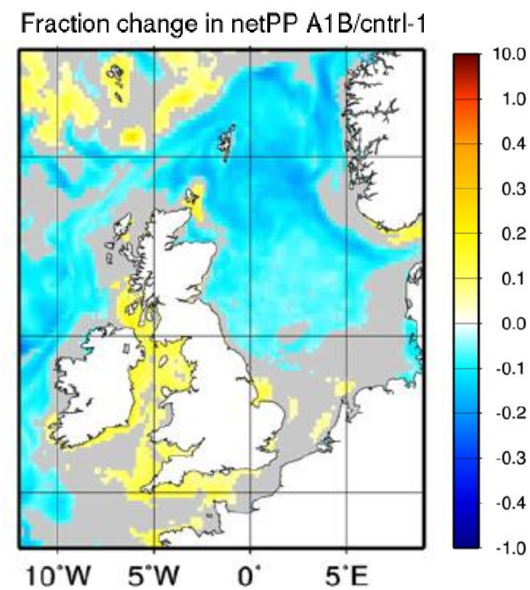
- Uncoupled ocean downscaling
- Limited domain size (except Gröger)
- No sediment resuspension
- A1B scenario
- Only 1 realization
- No control run

Holt et al. (2016)





Gröger et al. (2013)



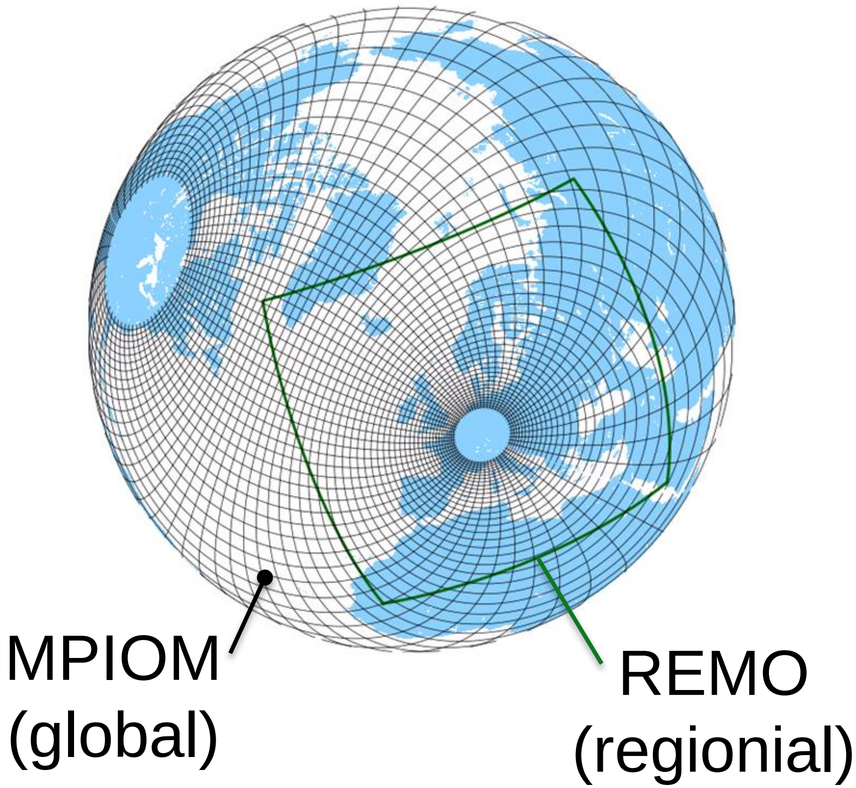
Wakelin et al. (2015)

Structure of this presentation:

- Changes until 2100
- Changes until 2150
- Why use a large ocean domain

Regionally coupled ocean-atmosphere model

- Global ocean model with nondiametrical poles (North Sea 5-12 km) with tides
- Regional ocean-atmosphere coupling over EURO-CORDEX domain (25 km)
- Closed hydrological cycle global HD model
- Ocean biogeochemistry model HAMOCC incl. sediment resuspension



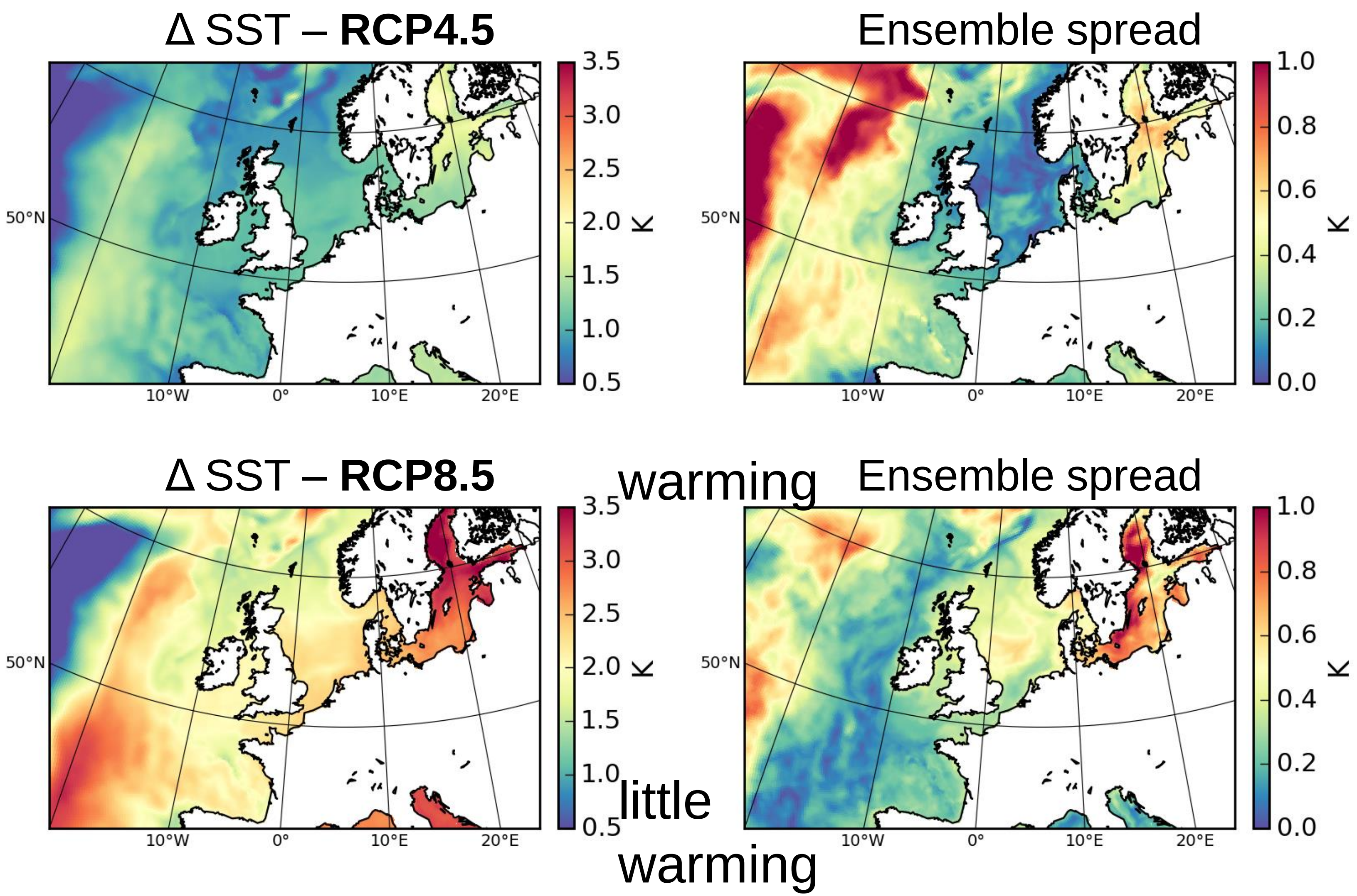
Mikolajewicz et al. (2005)
Elizalde Arellano (2011)
Sein et al. (2015)

Downscaling of CMIP5 simulations

Forcing:

- MPIESM-LR simulations
- historical,rcp4.5 and rcp8.5 with 3 ensemble members
- Common spinup 1850 to 1920
- From 1920 onward with respective historical simulation for ensemble members
- piControl

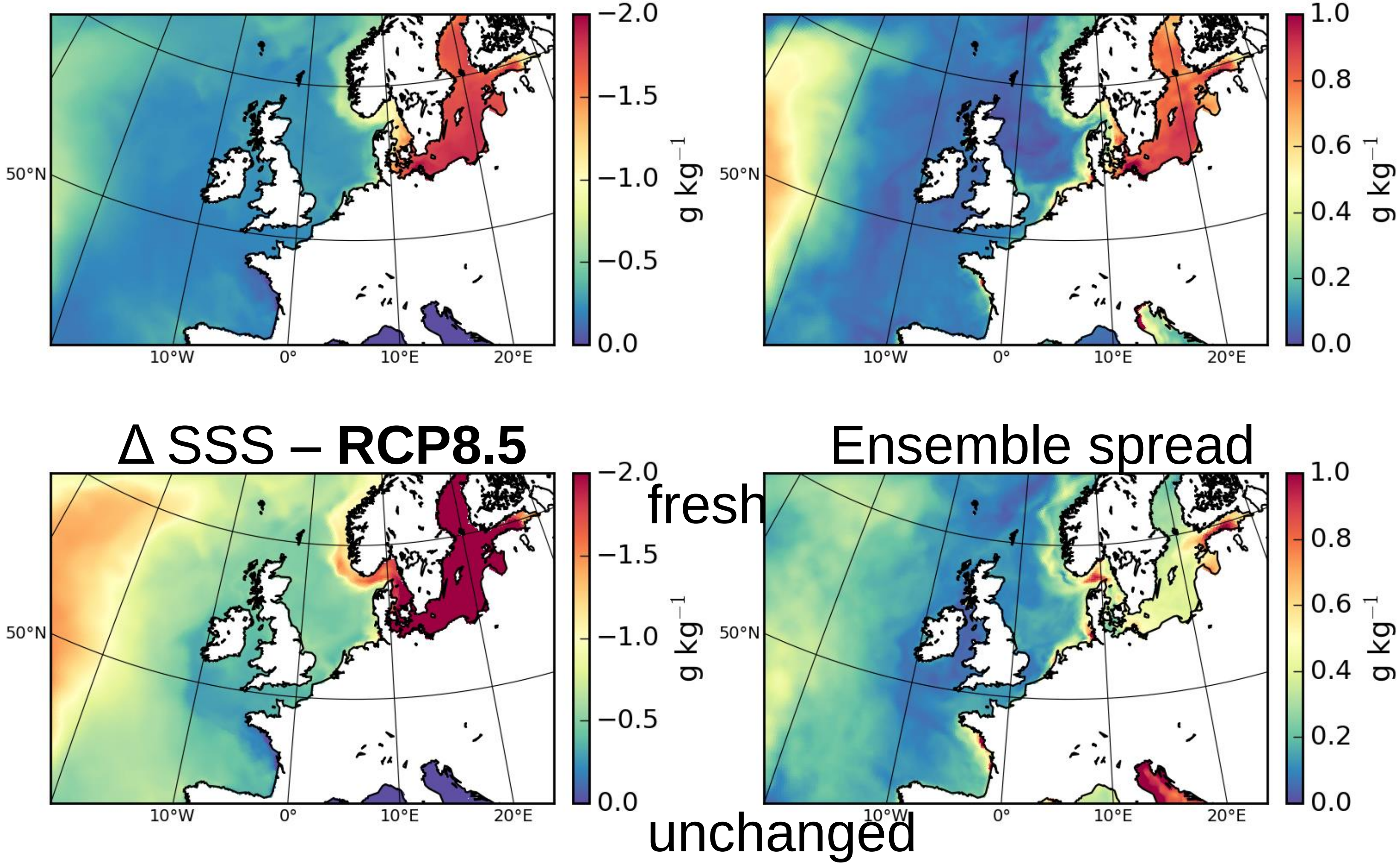
Change in temperature (2071-2100 minus 1971-2000)



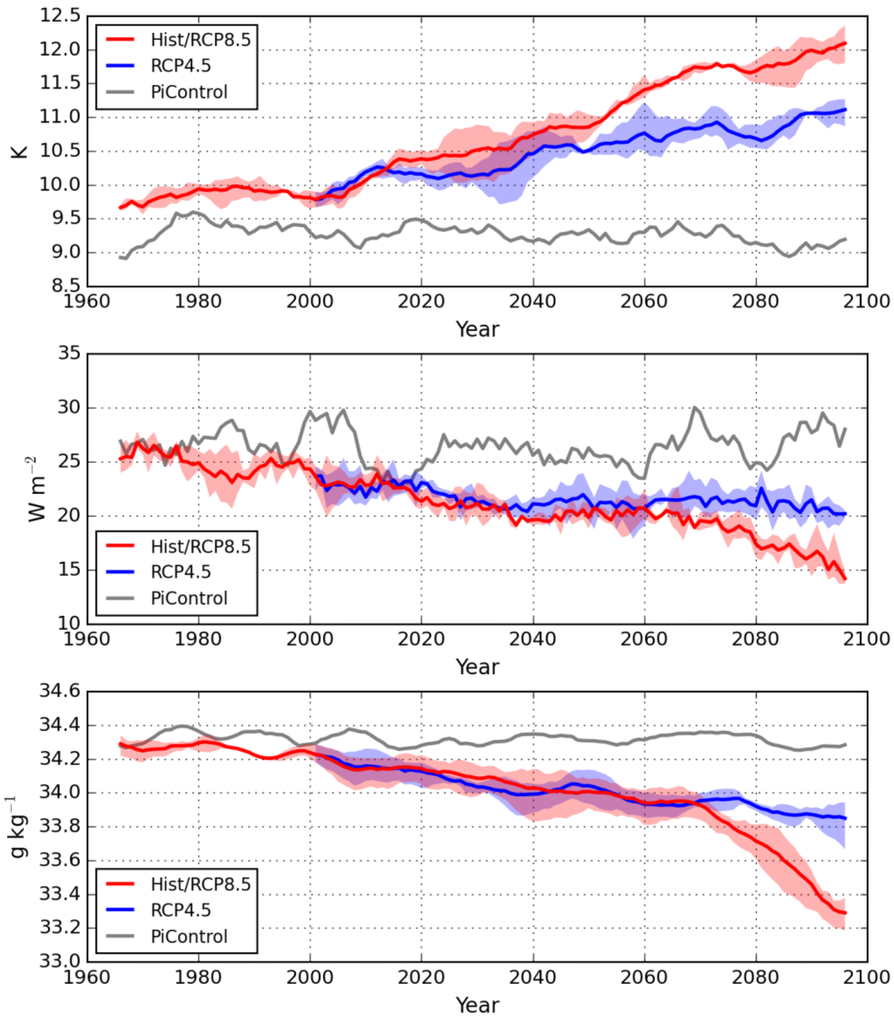
Change in salinity (2071-2100 minus 1971-2000)

Δ SSS – **RCP4.5** | Ensemble spread

Δ SSS – **RCP8.5** | Ensemble spread



Change in northern North Sea SST and SSS

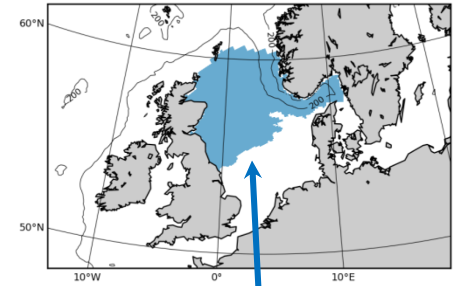


1960 2000 2100

Sea Surface Temperature

Ocean heat release to atmosphere

Sea Surface Salinity



Depth >50m

piControl

rcp4.5

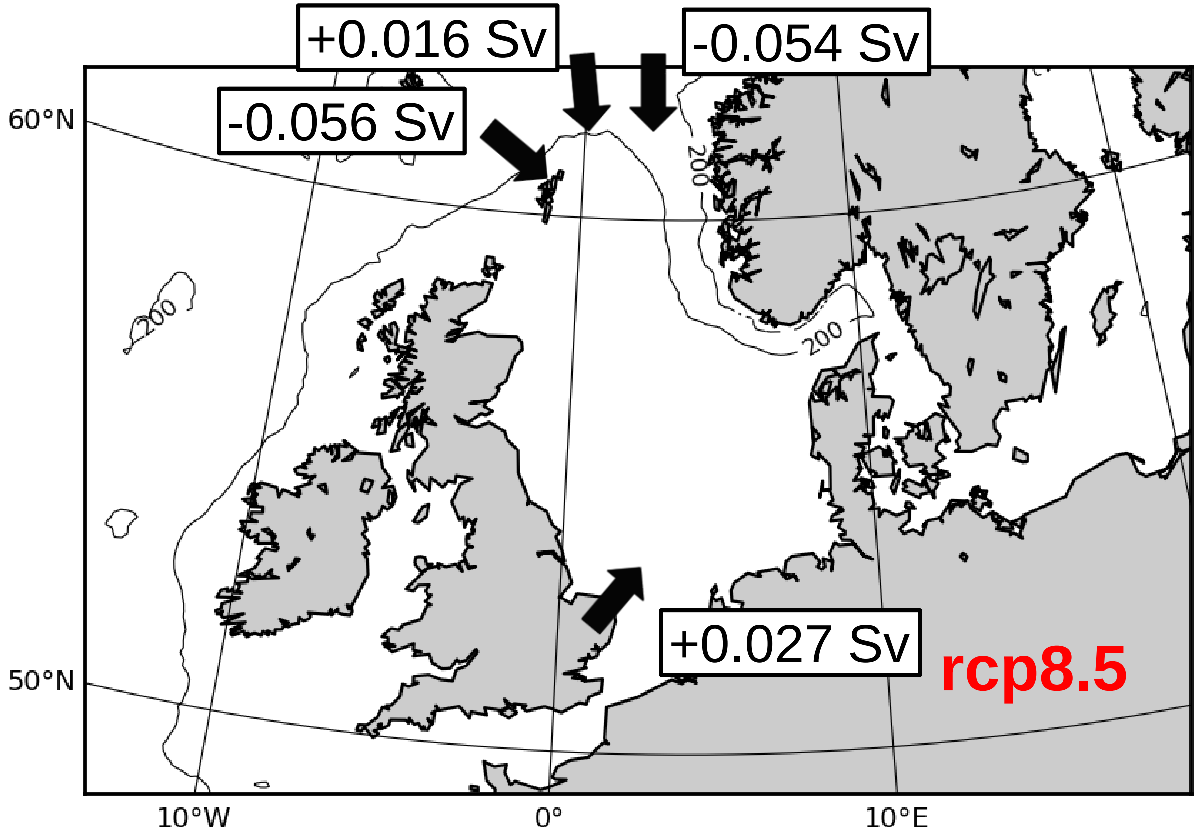
rcp8.5

Change in Atlantic inflow to North Sea (winter)

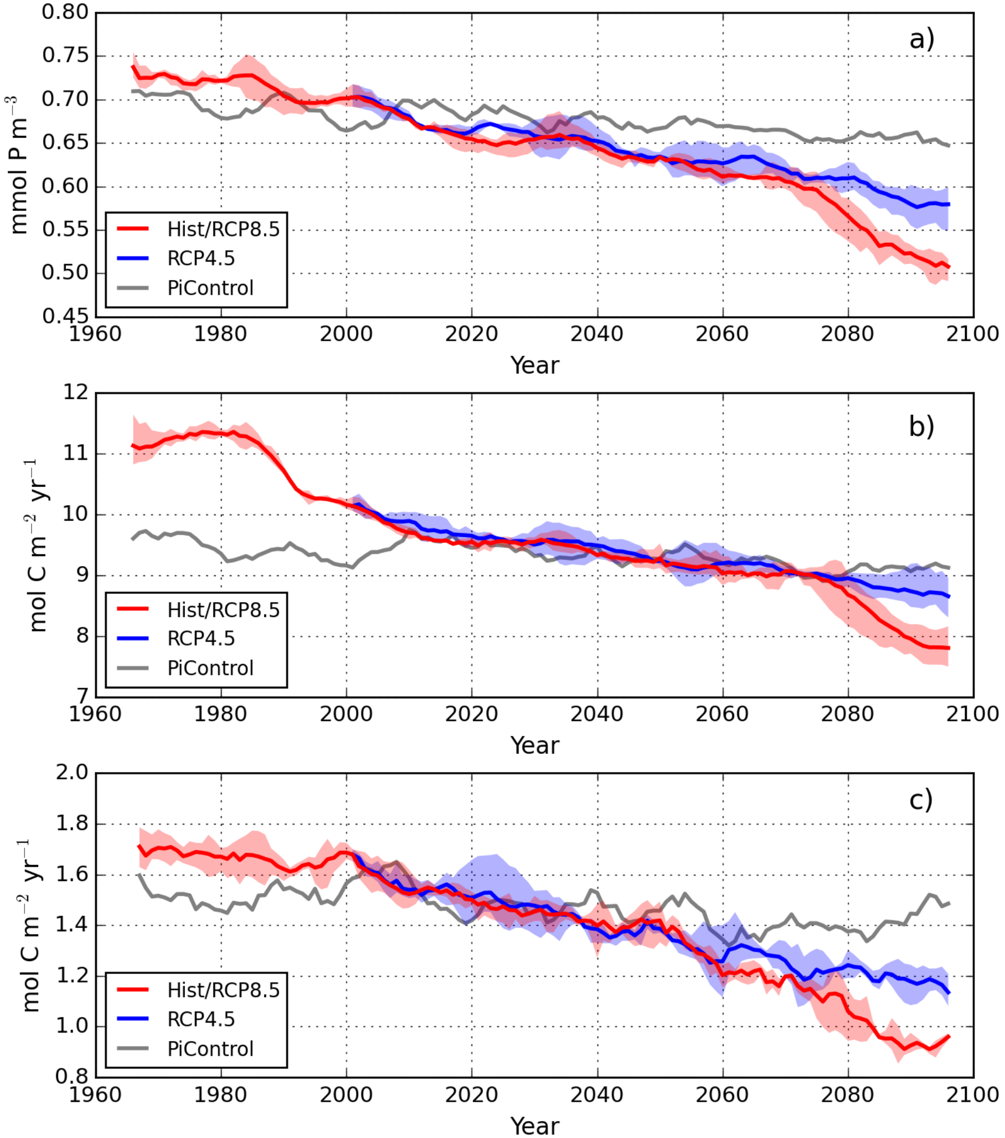
Linear trend/100yr

Net **rcp4.5** -0.020 Sv (statistically not significant)

Net **rcp8.5** -0.067 Sv



Time series northern North Sea



PO_4 of winter Atlantic inflow

Annual **primary production**

- RCP4.5 -20%
- RCP8.5 -25%
- (2071-2100) - (1971-2000)

Annual **CO_2 uptake**

piControl
rcp4.5
rcp8.5

Conclusion I (until 2100)

Main Results:

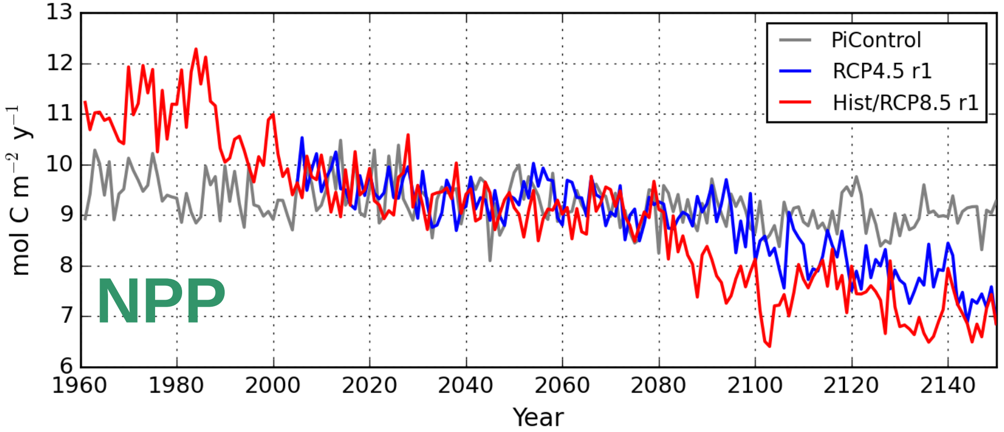
- Warming
- Freshening and enhanced runoff into Baltic.
- Reduced productivity due to reduced nutrient concentration in inflowing Atlantic water.
- Strong signals and enhanced variability after 2080.

The results are basically consistent with results obtained with a similar model applied to the CMIP4 scenario A1B

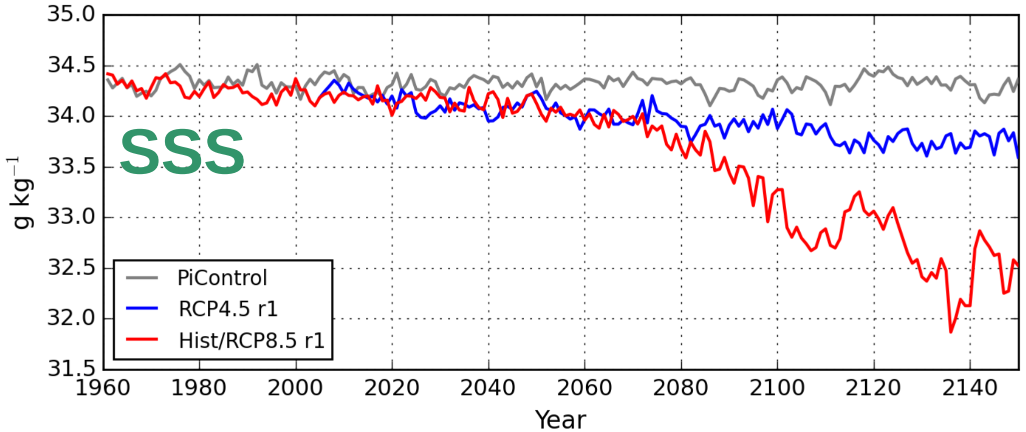
What happens after 2080?

Continuation of simulations until 2150, but only one ensemble member as forcing availabe
=> no ensemble possible

Time series NPP
and SSS in the northern North Sea until 2150



Annual
primary production
northern North Sea

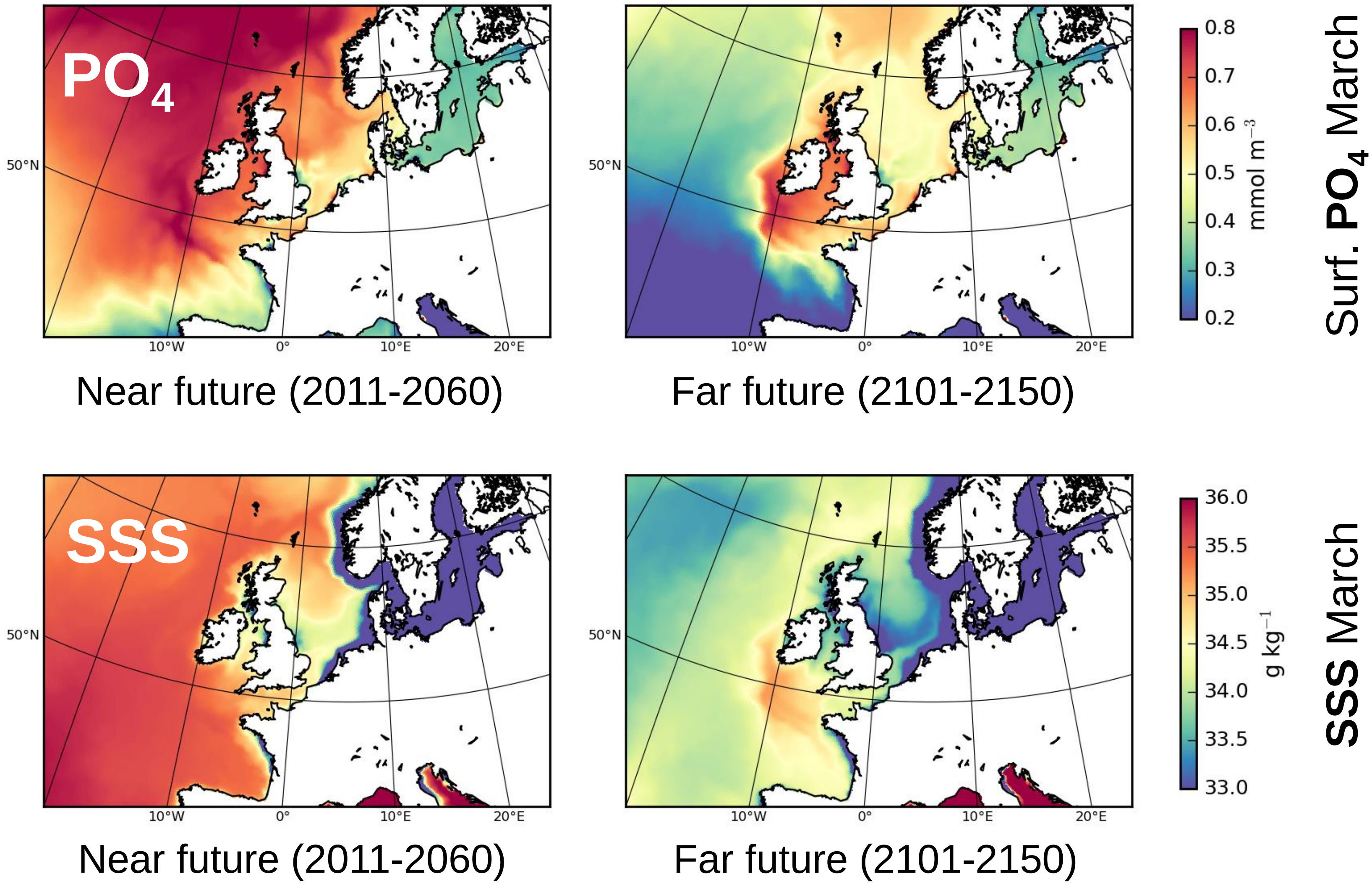


Annual
SSS
northern North Sea

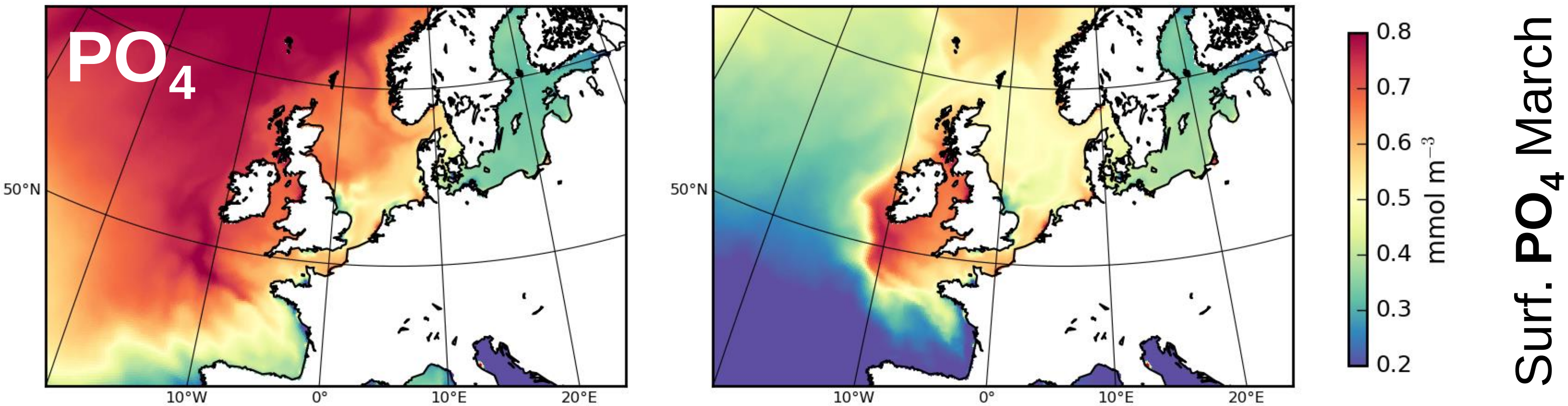
2000 2050 2100 2150

piControl
rcp4.5
rcp8.5

Ocean-shelf nutrient and salinity front

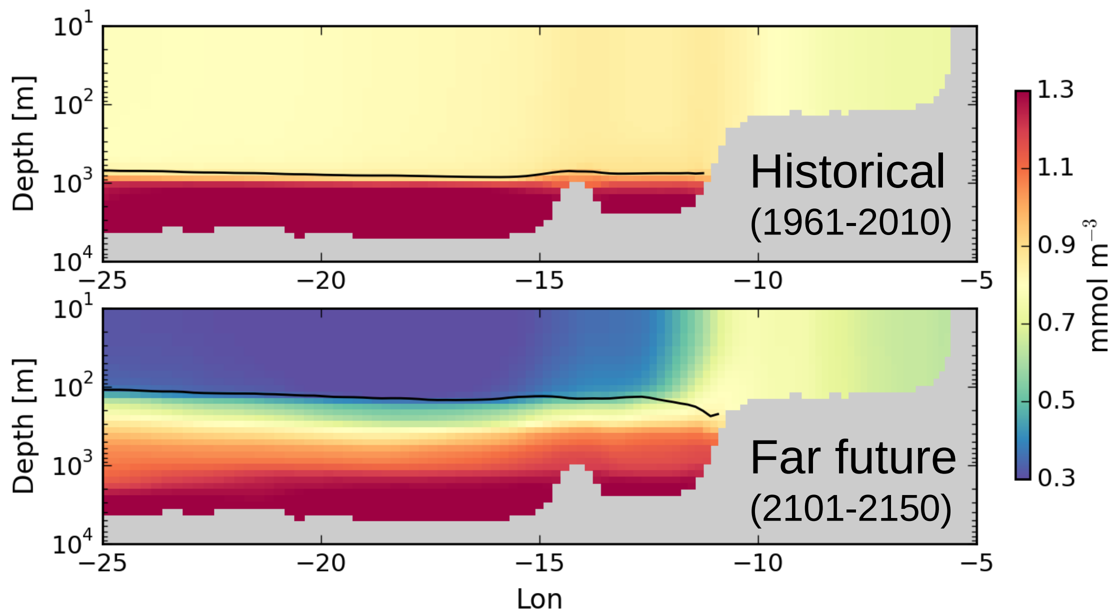


Ocean-shelf nutrient front



Near future (2011-2060)   Far future (2101-2150)

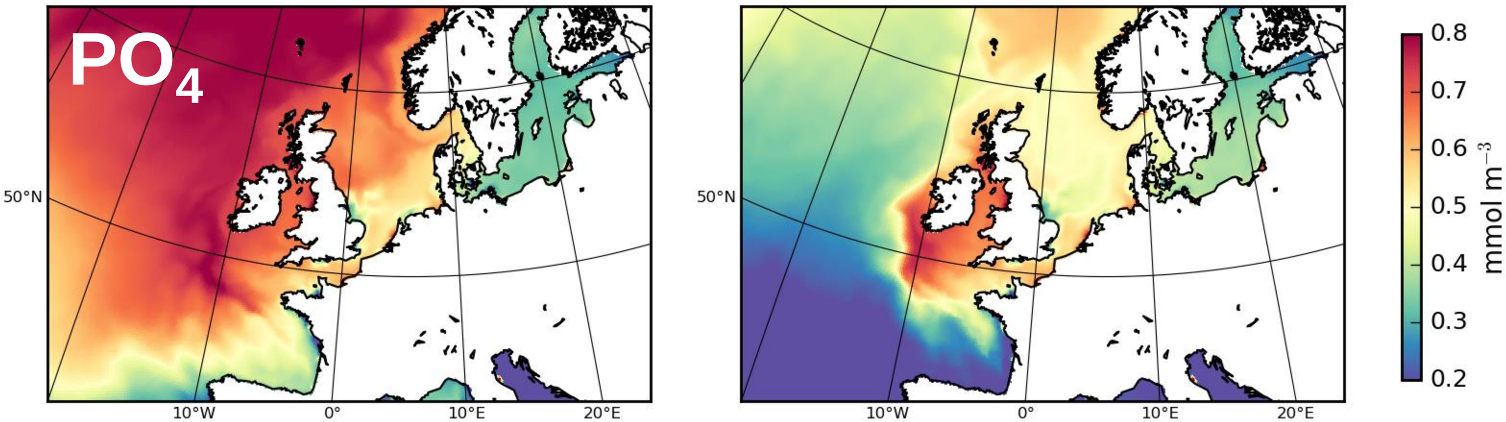
Section along 50°N



PO_4
March
50°N

Black line: **MLD**

Ocean-shelf nutrient front

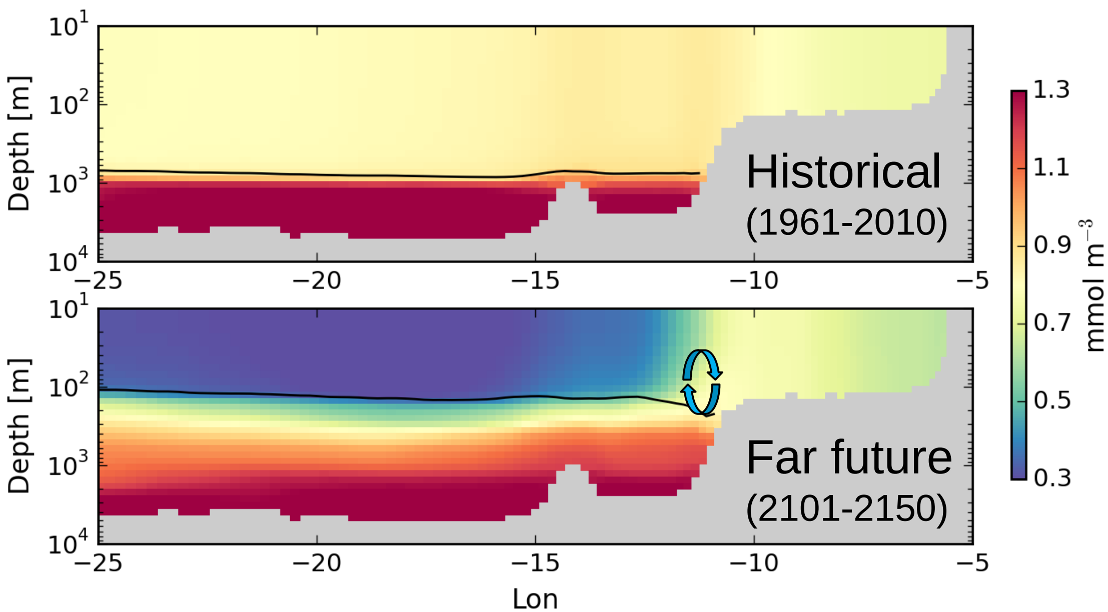


Near future (2011-2060)

Far future (2101-2150)

Surf. PO_4 March

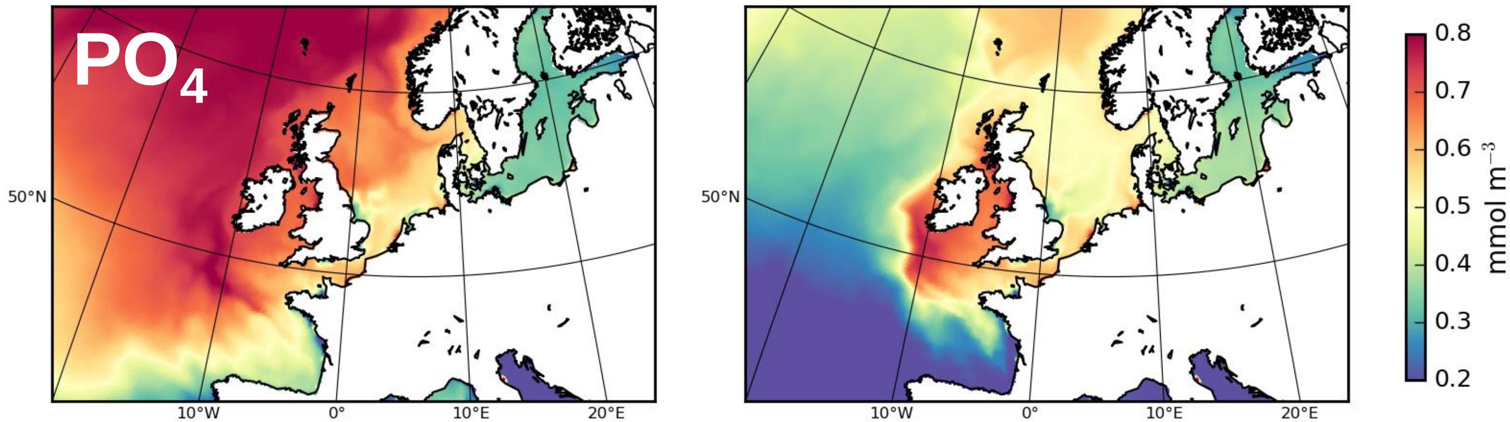
Section along 50°N



PO_4
March
50°N

Black line: **MLD**

Ocean-shelf nutrient front

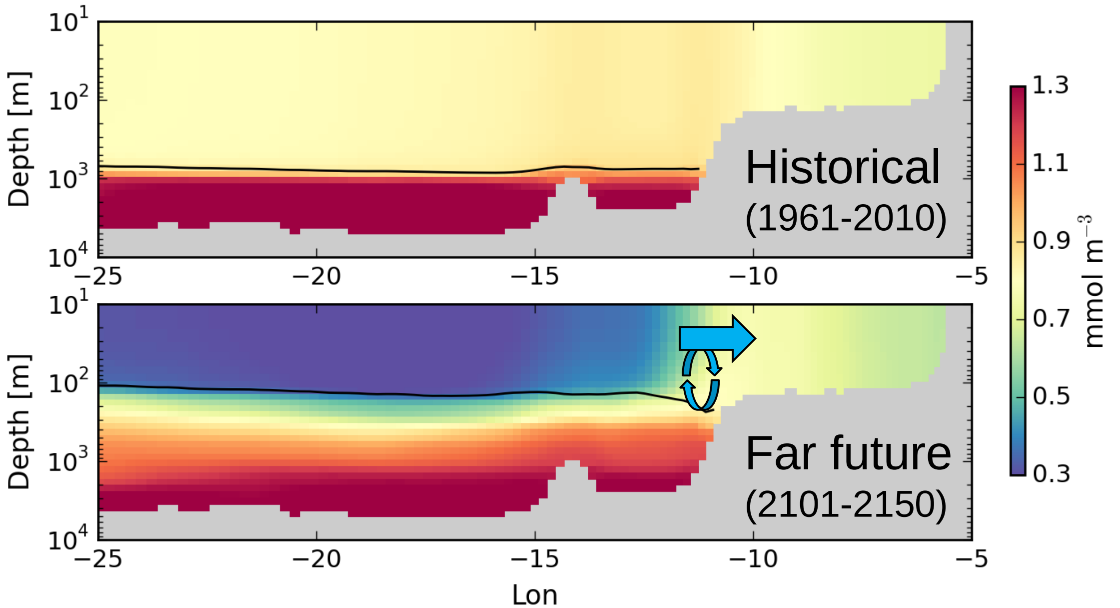


Near future (2011-2060)

Far future (2101-2150)

Surf. **PO_4** March

Section along 50°N



PO_4
March
50°N

Black line: **MLD**

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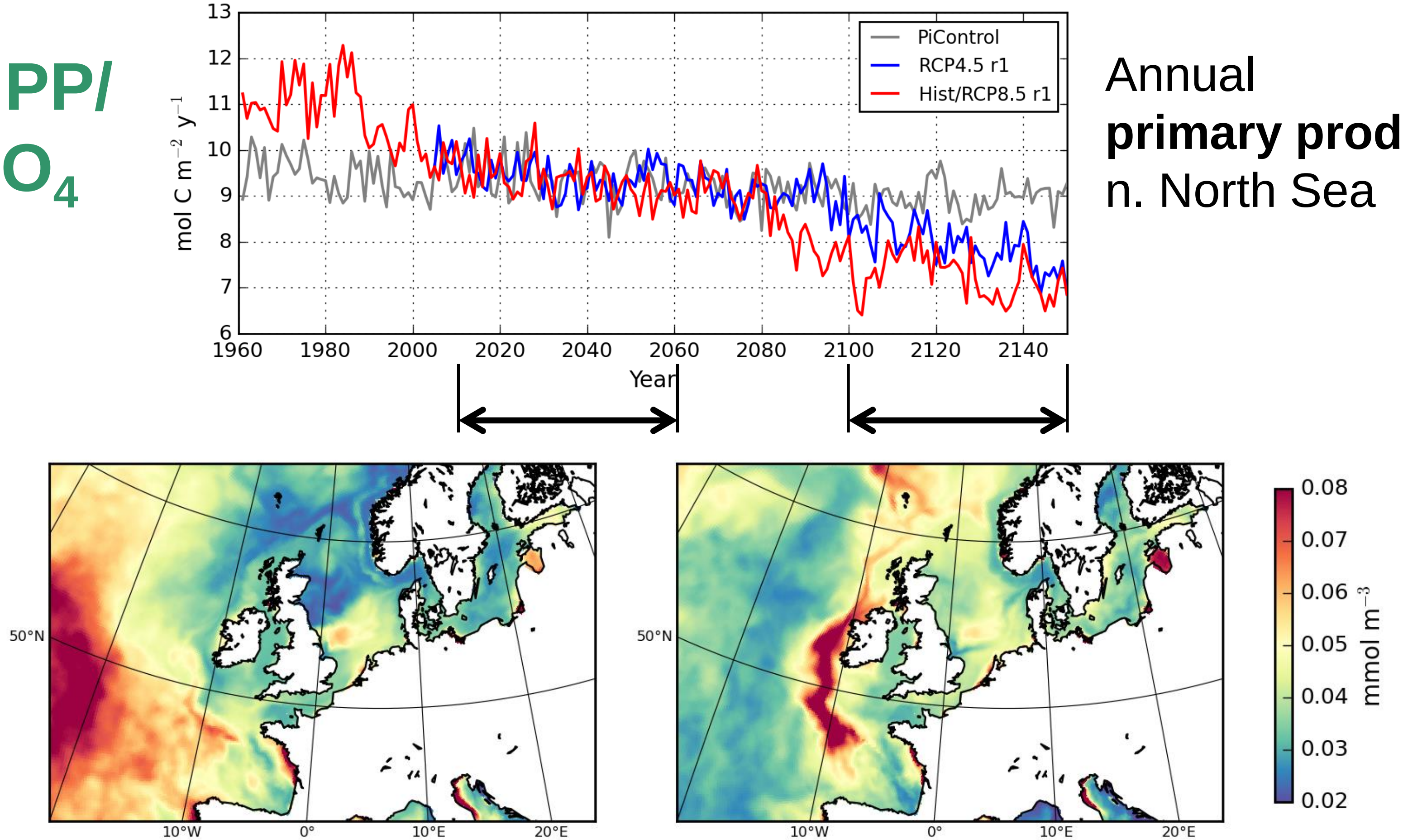
Enhanced variability at the shelf break

NPP/ PO_4



Annual **primary production** n. North Sea

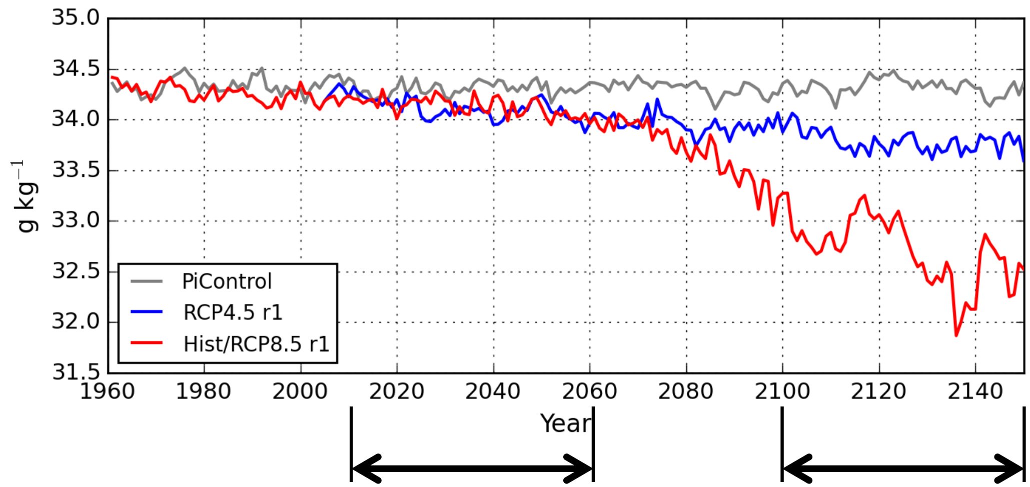
Near future (2011-2060)

Far future (2101-2150)

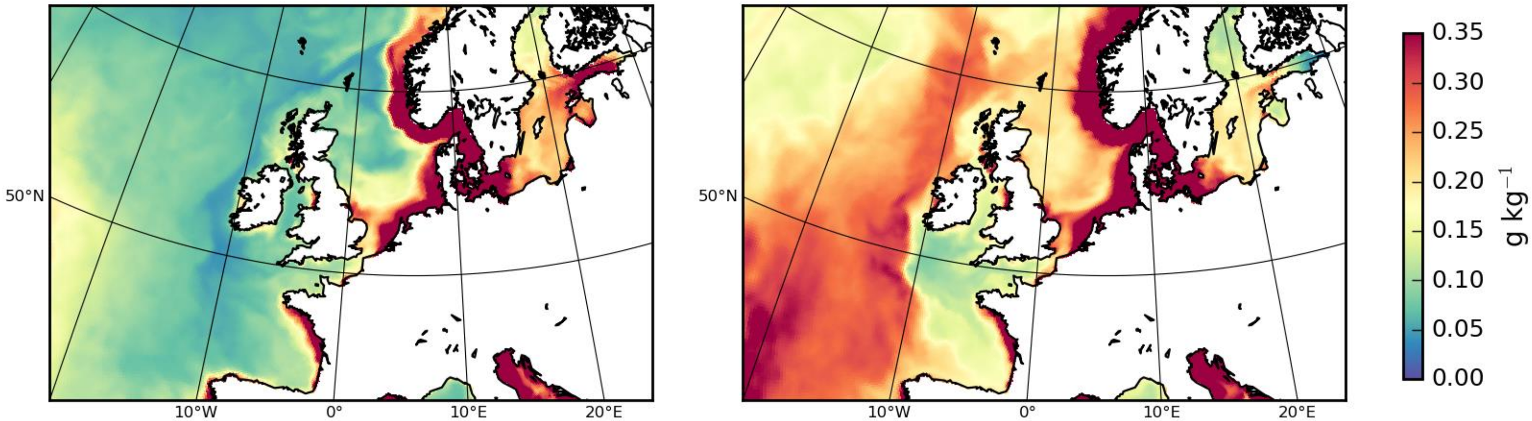
stdv. of surf. **PO_4** winter

Enhanced variability at the shelf break

SSS



Annual
SSS
n. North Sea



St. dev. of **SSS** winter

Near future (2011-2060)

Far future (2101-2150)

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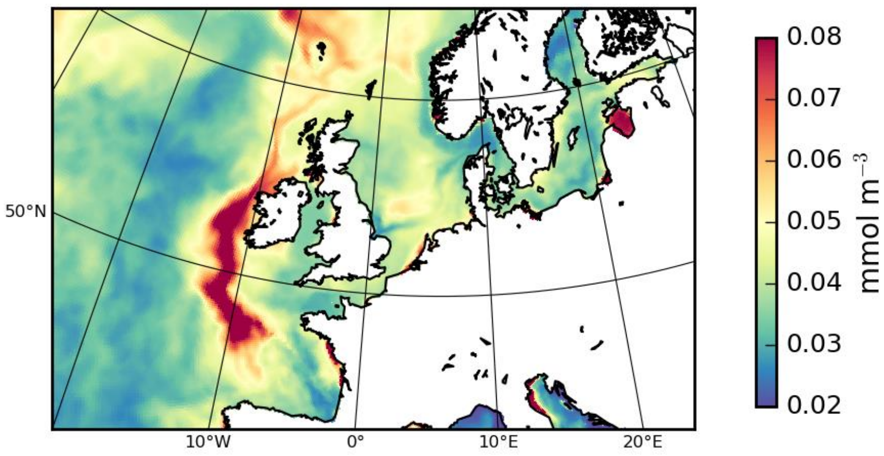
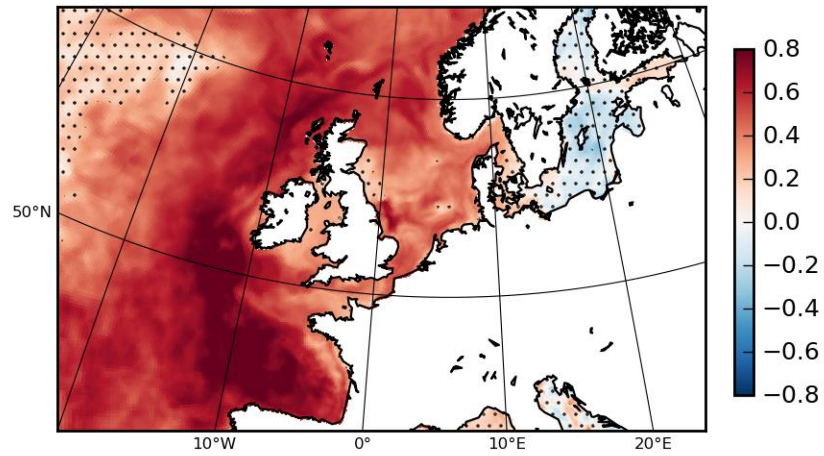
Enhanced variability at the shelf break

St. dev. surf. $\mathbf{PO_4}$ winter



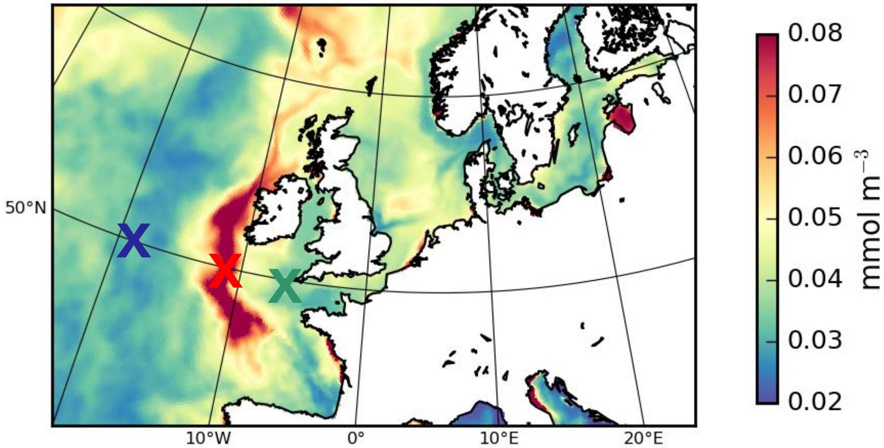
Far future (2101-2150)

Spatial correlation

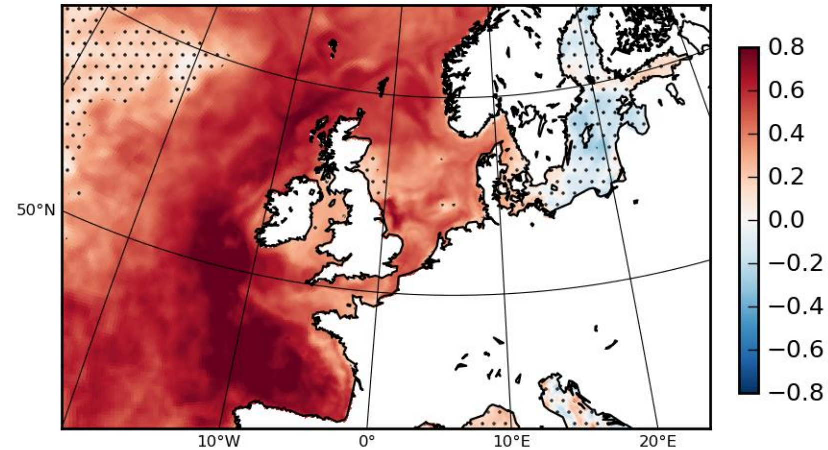


Enhanced variability at the shelf break

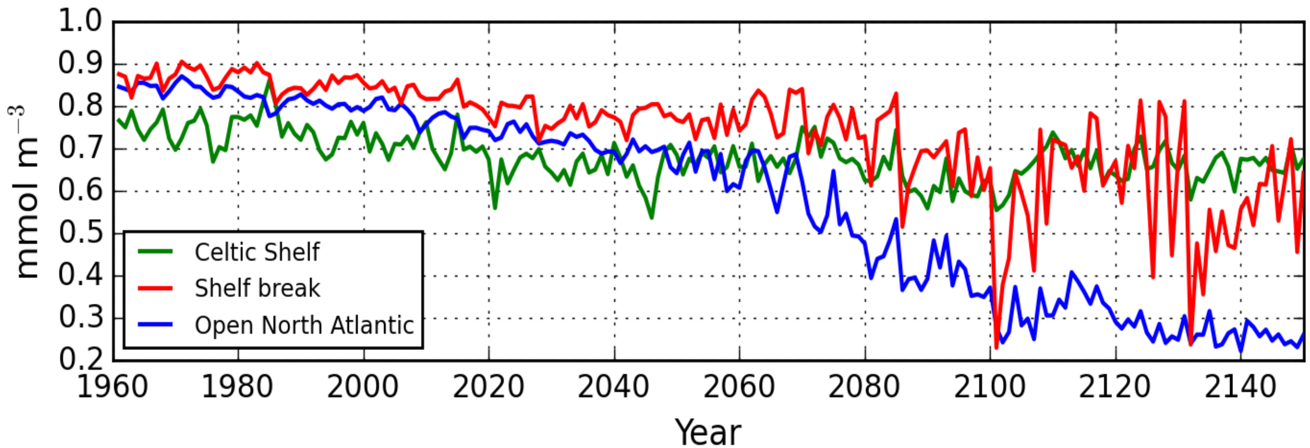
St. dev. surf. **PO_4** winter



Spatial correlation



Far future (2101-2150)

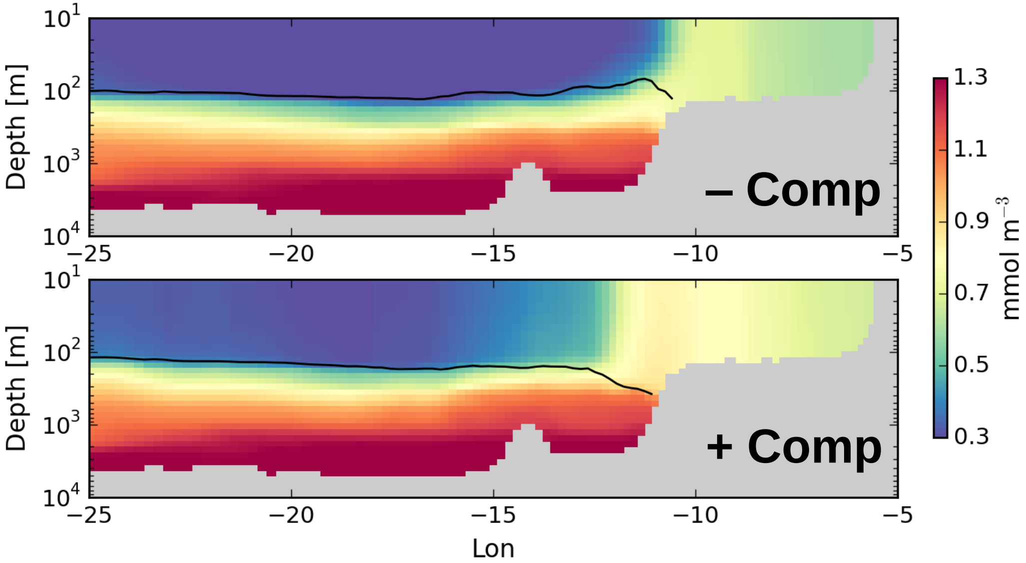


Surf. **PO_4**
March
50°N

Strong variability after 2080

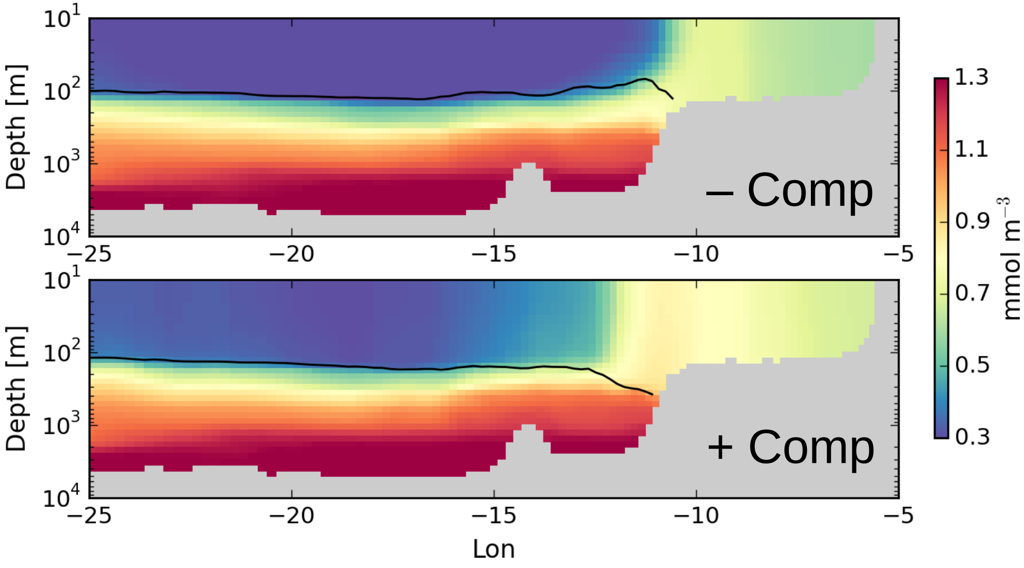
Approach:
Composite analysis 2100 to 2150
NPP+/- 1 stdv

Enhanced variability at the shelf break

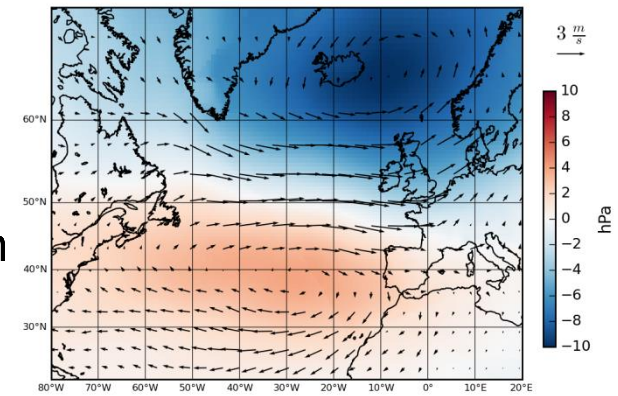


PO_4
March
50°N

Enhanced variability at the shelf break

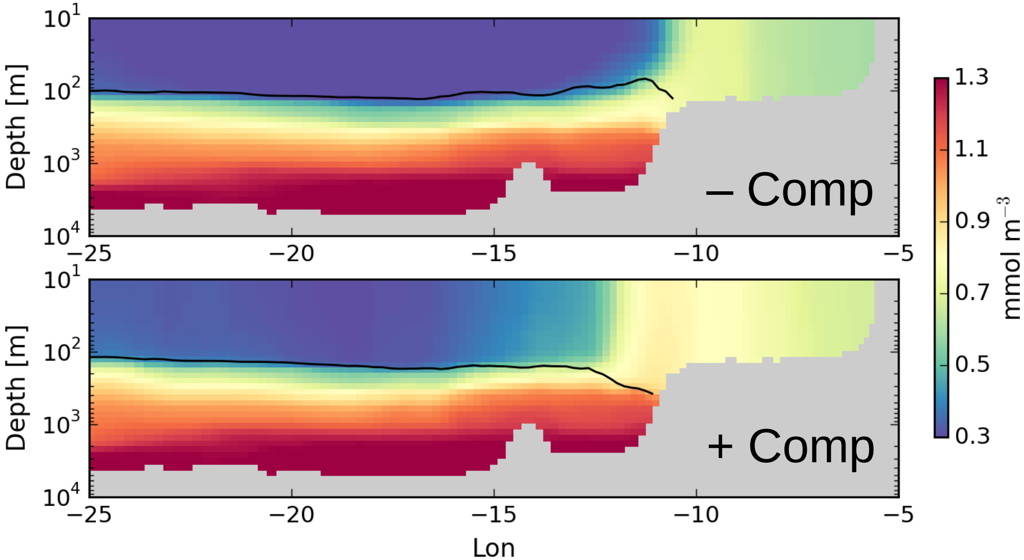


PO_4
March
50°N

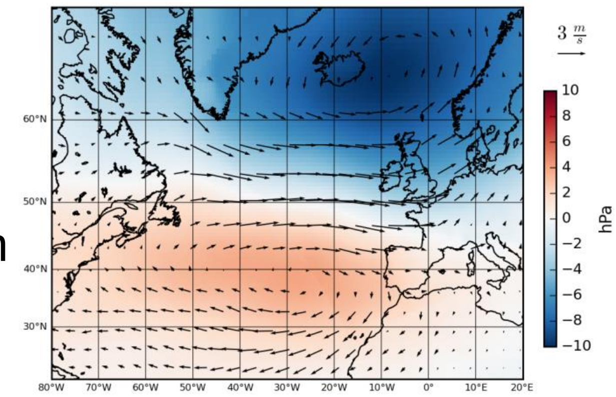


Pos-Neg Composite
winter **SLP**

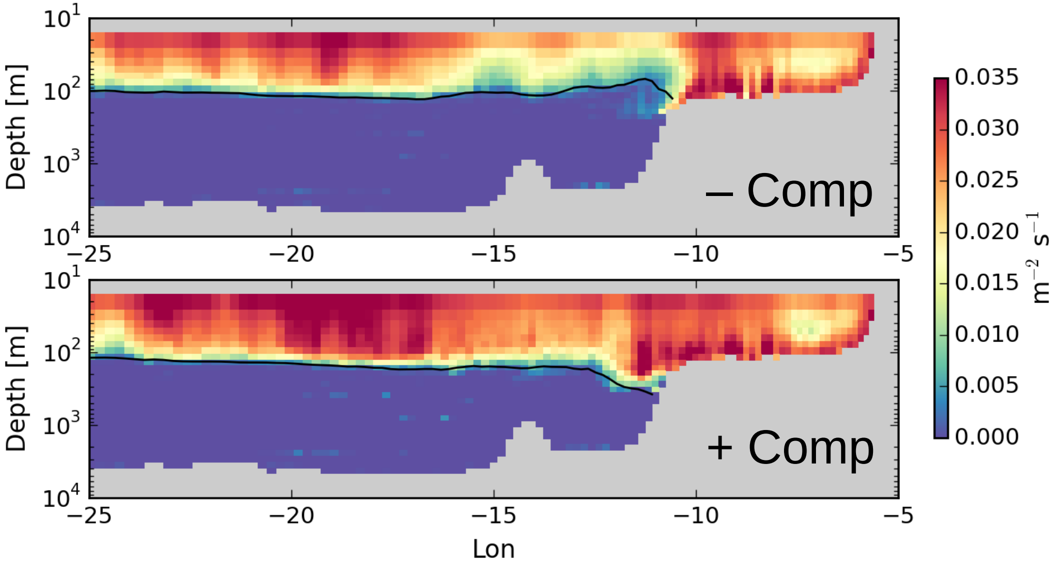
Enhanced variability at the shelf break



PO$_4$
March
50°N



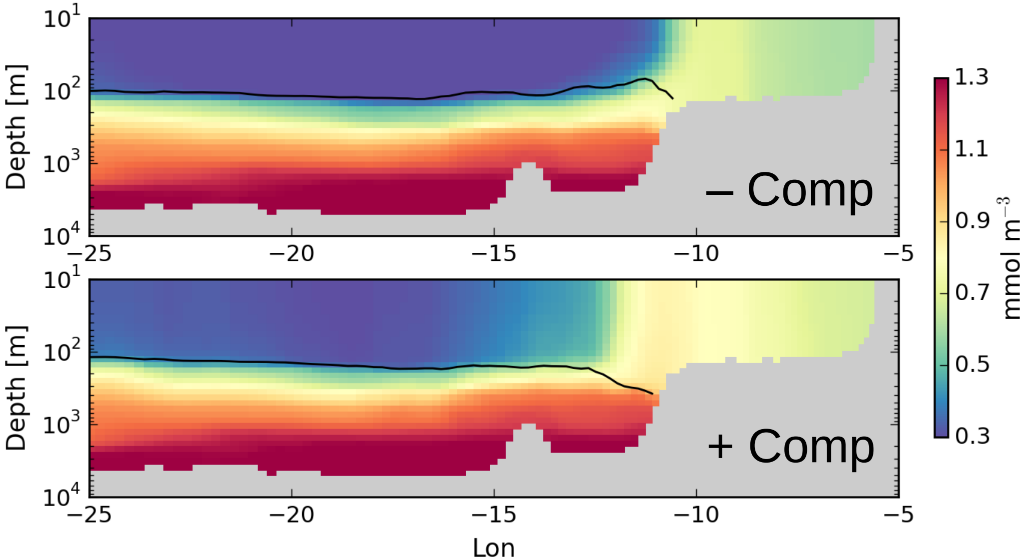
Pos-Neg Composite
winter **SLP**



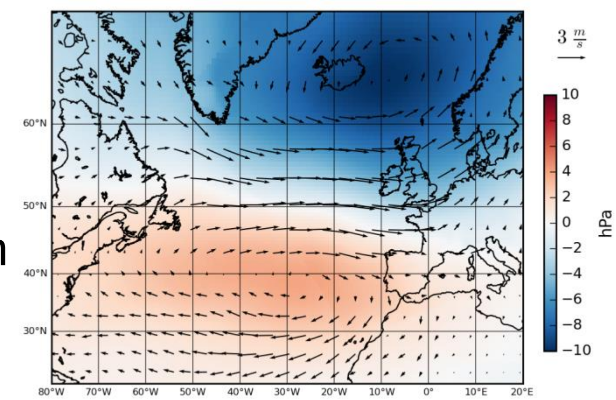
Diapycnal mixing coefficient
March
50°N

Black line: **MLD**

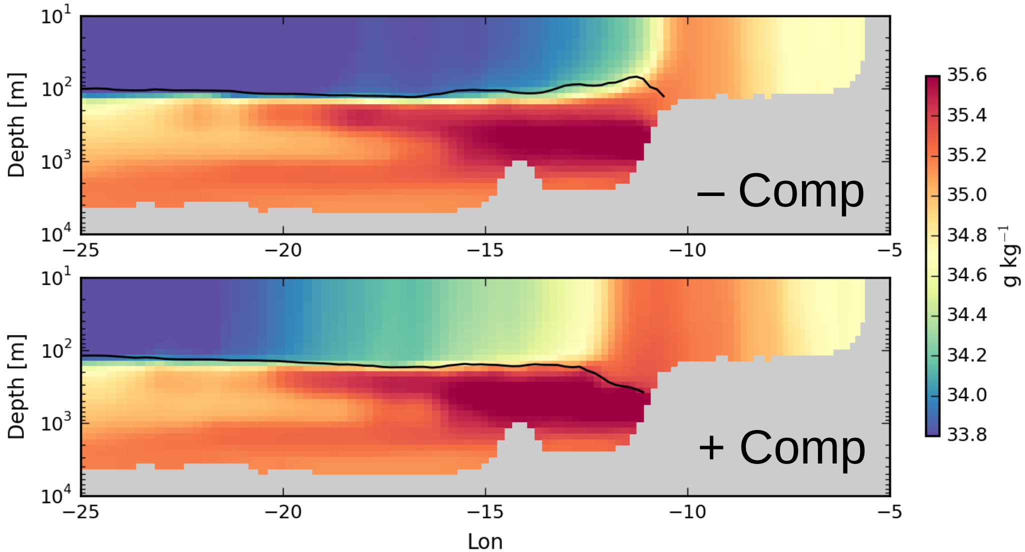
Enhanced variability at the shelf break



PO_4
March
50°N



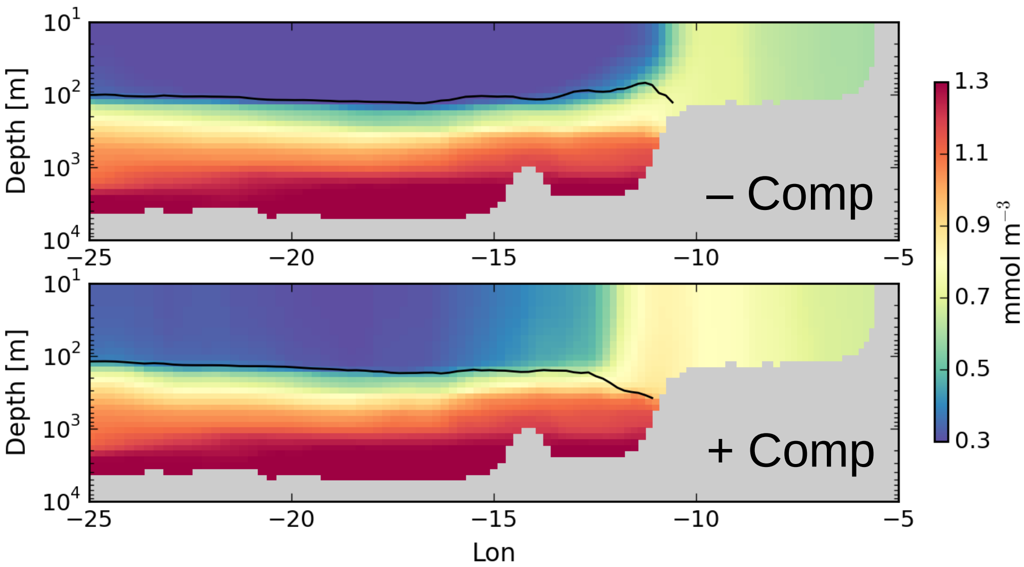
Pos-Neg Composite
winter **SLP**



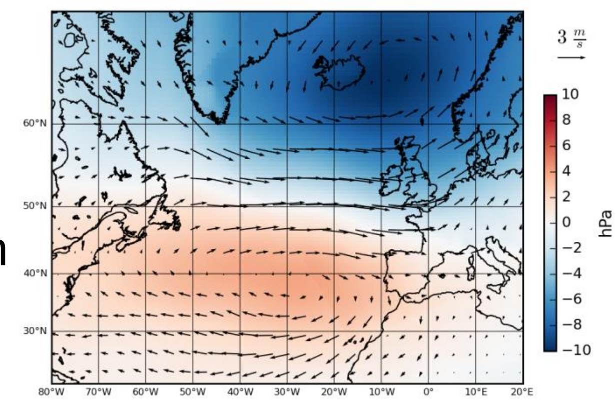
Salinity
March
50°N

Black line: MLD

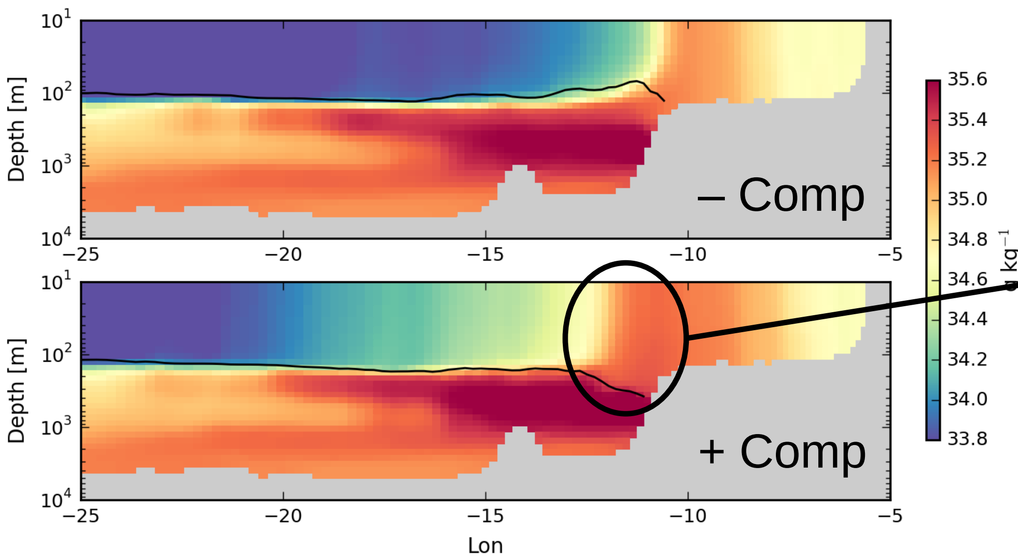
Enhanced variability at the shelf break (2101-2150)



PO_4
March
50°N



Pos-Neg Composite
winter **SLP**



Salinity
March
50°N

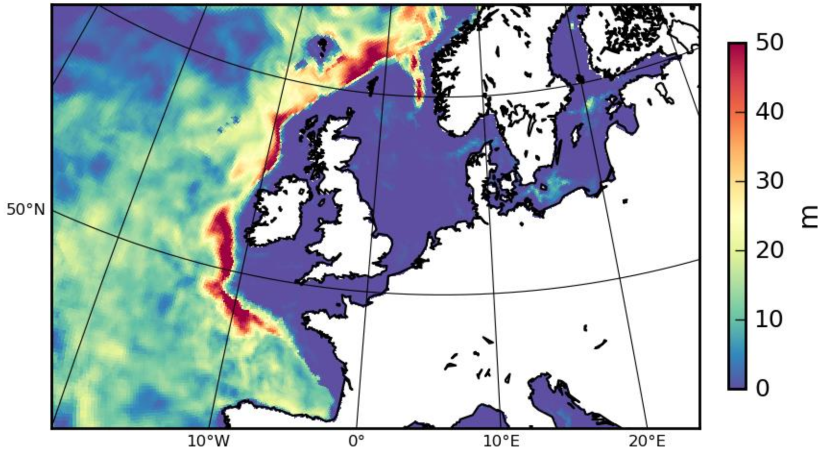
Density
+0.7 kg m^{-3}

Surf. heat flux
+50 W m^{-2}

Black line: MLD

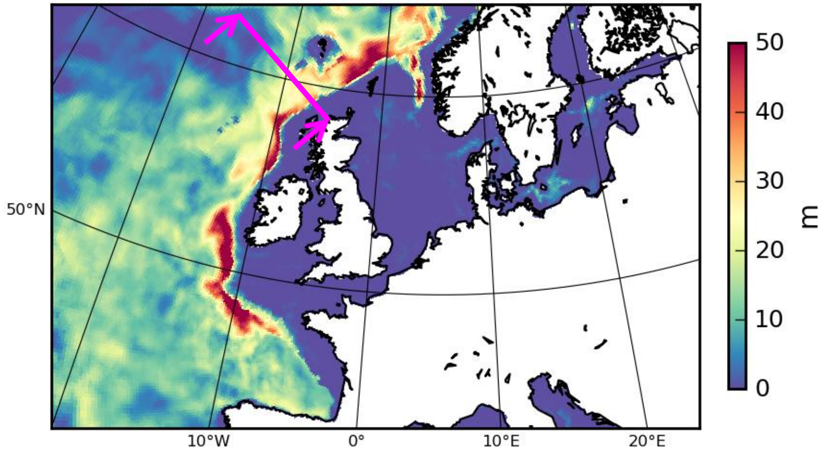
Enhanced variability at the shelf break (2101-2150)

Pos-Neg Comp. **MLD** March

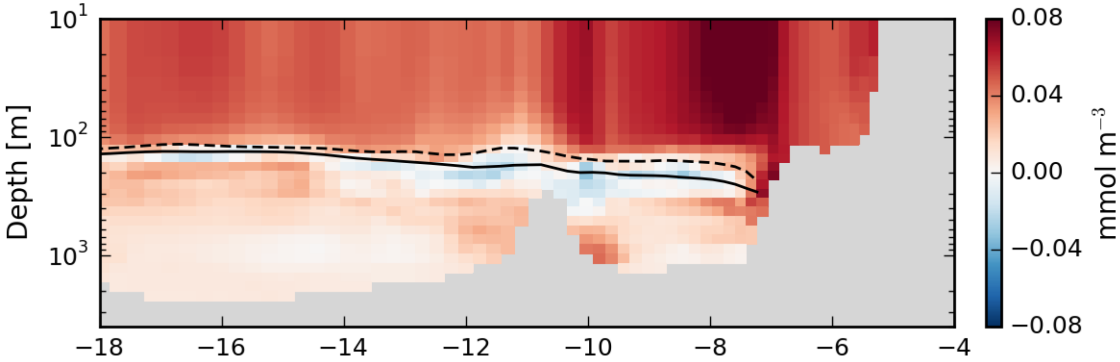


Enhanced variability at the shelf break (2101-2150)

Pos-Neg Comp. **MLD** March

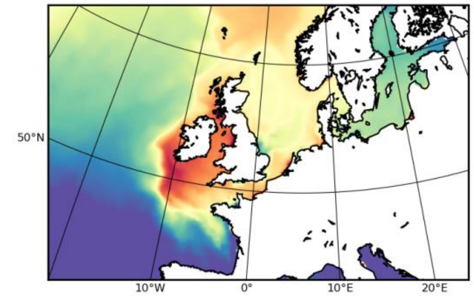


Pos-Neg Comp. **PO_4** March, 58°N



Future regime of Atlantic nutrient supply (RCP8.5)

- Ocean-shelf nutrient front
  - Low concentrations in the Atlantic
  - Higher concentrations on the NWES



Future regime of Atlantic nutrient supply (RCP8.5)

- Ocean-shelf nutrient front
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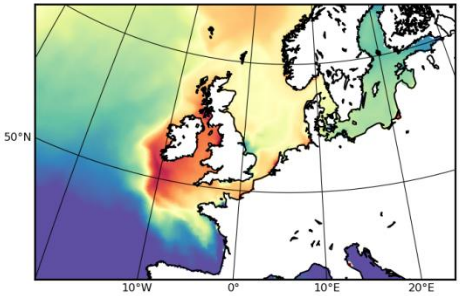
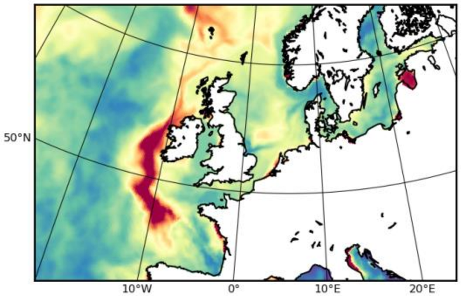
    - Higher concentrations on the NWES
- High variability along the continental margin
    - Interannual and multidecadal variations due to NAO and SPG





Future regime of Atlantic nutrient supply (RCP8.5)

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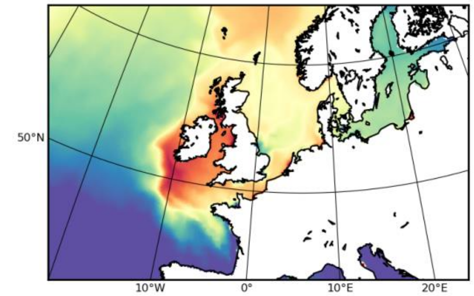
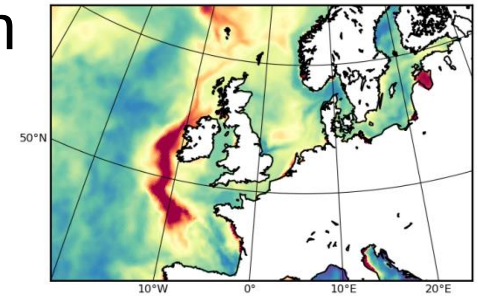
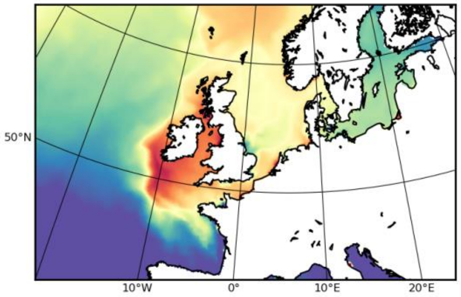
- Induced by shallow Atlantic winter MLD





Future regime of Atlantic nutrient supply (RCP8.5)



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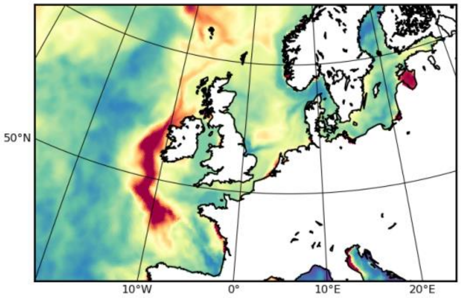

- High variability along the continental margin
  - Interannual and multidecadal variations due to NAO and SPG
- Induced by shallow Atlantic winter MLD
- Leads to enhanced variability in northern North Sea primary production

Future regime of Atlantic nutrient supply (RCP8.5)

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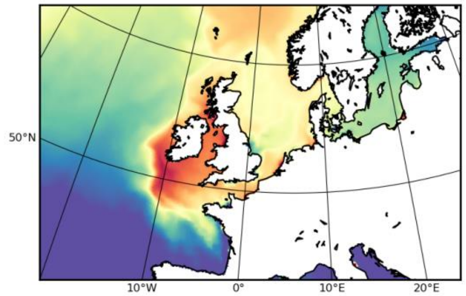

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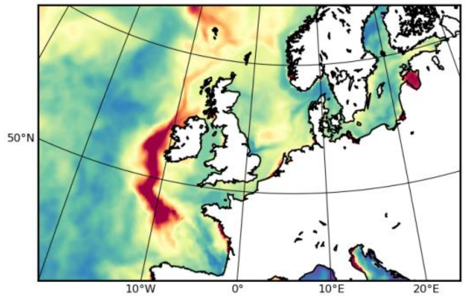
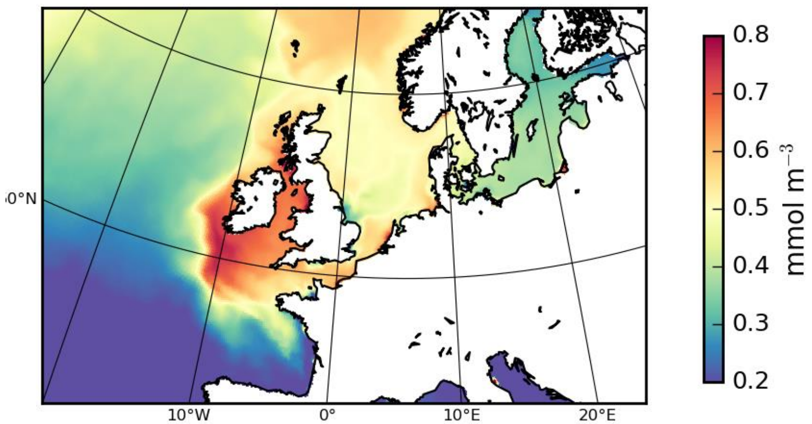


- Induced by shallow Atlantic winter MLD
- Leads to enhanced variability in northern North Sea primary production
- Destabilizes the ecosystem and hinders its adaptation to the future climate

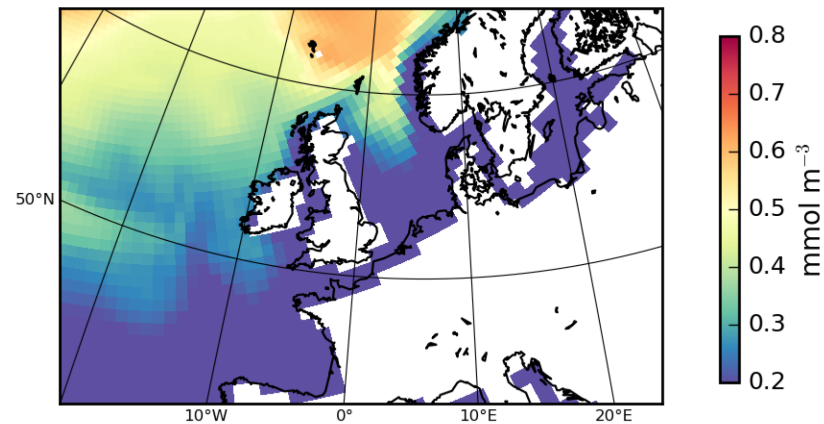
What is the benefit of using a global ocean model?

Surface **PO_4** March
Far future (2101-2150)

Downscaling with REMO/MPIOM



MPI-ESM-LR



Using a regional climate system model with a small ocean domain will lead to an overestimation of the reduction in NPP!

Changes in SST (RCP8.5 2071-2100 minus 1971-2000)

Global

Regional

Coupled

Uncoup.

Glob. Atm.
Glob. Oce.

Glob. Atm.
Reg. Oce.

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Glob. Oce.

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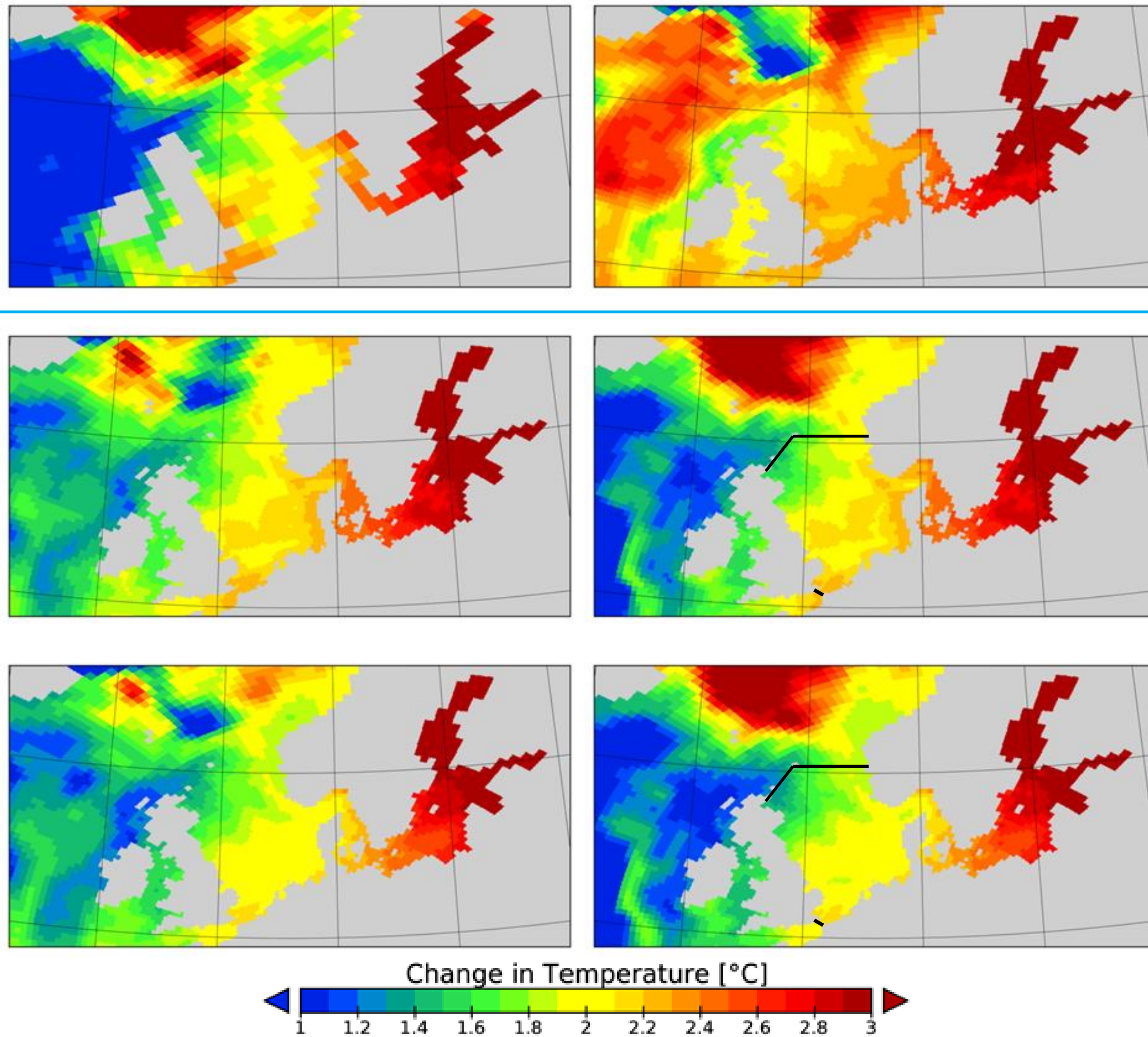


Changes in salinity (RCP8.5 2071-2100 minus 1971-2000)

Global

Regional

Coupled

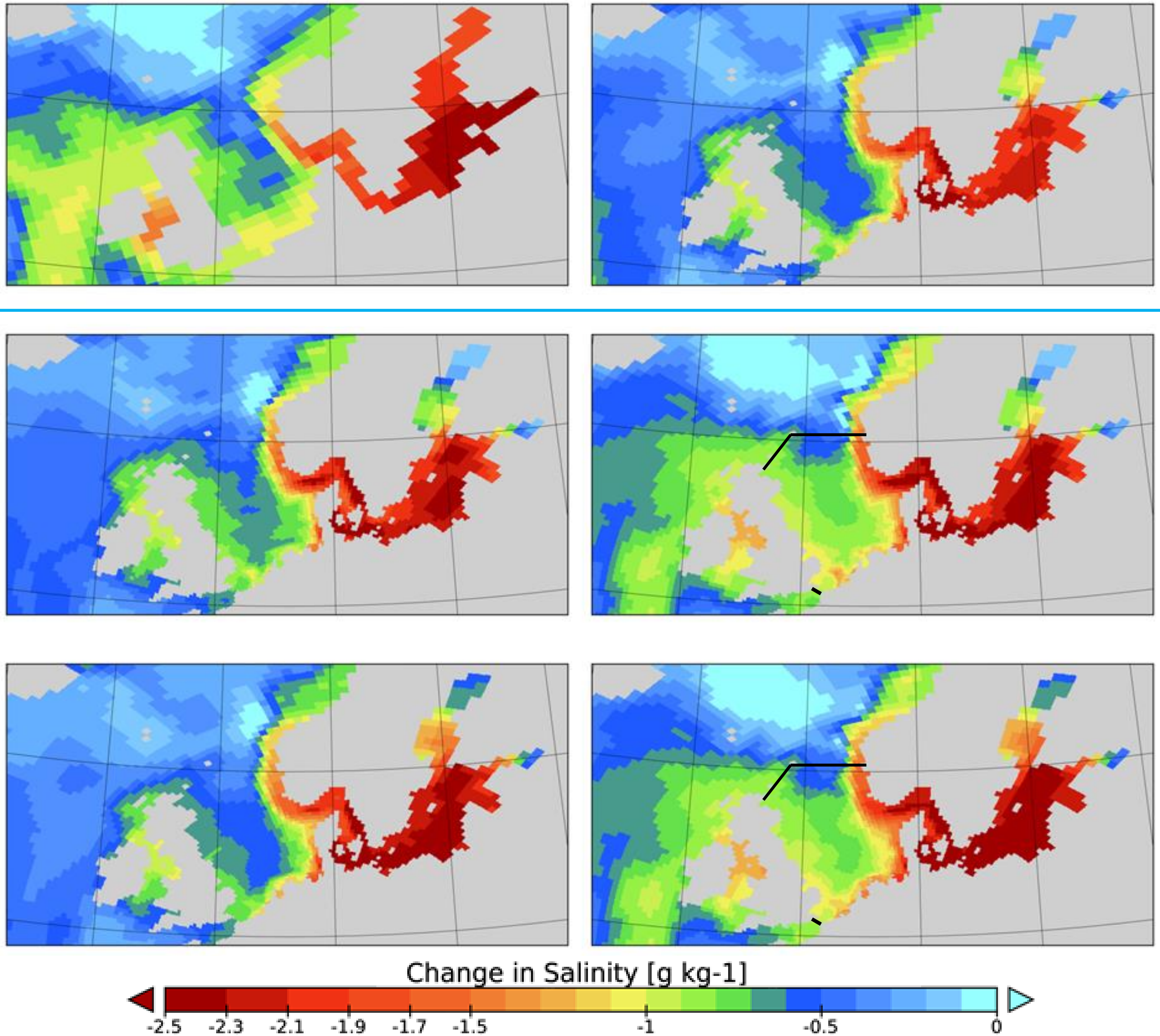
Uncoup.

Glob. Atm.
Glob. Oce.

Glob. Atm.
Reg. Oce.

Reg. Atm.
Glob. Oce.

Reg. Atm.
Reg. Oce.



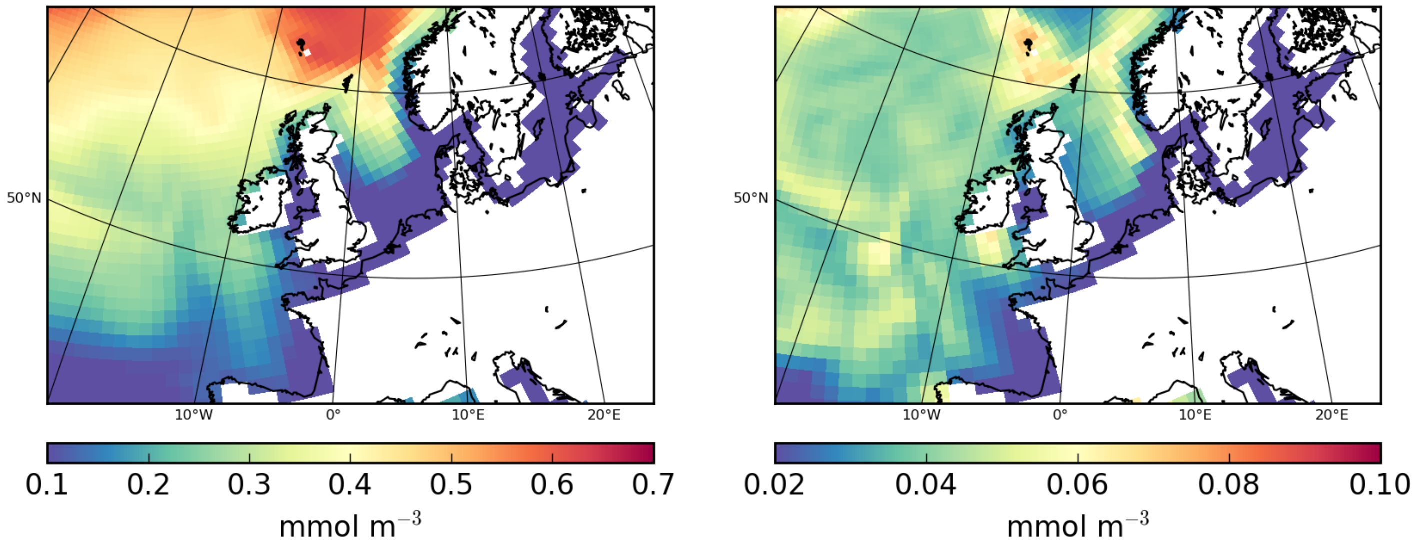
Mathis et al., Climate Dynamics in press

Conclusion III

The ocean domain needs to be sufficently large (and include the shelf edge), otherwise the downscaling simulations will be strongly affected by the insufficient simulation of processes at the shelf edge.
This is of particular importance for salinity and nutrients.
For temperature this is less important

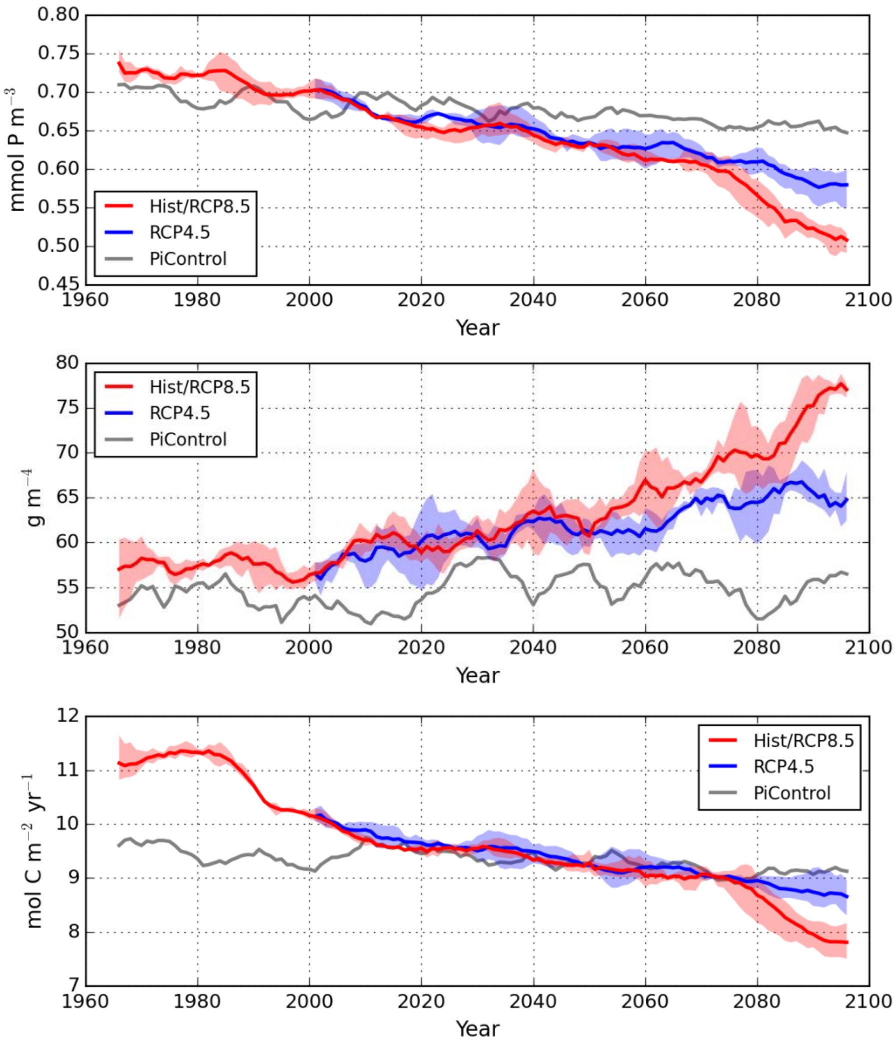
GCMs are not able to simulate such regime shifts

MPI-ESM-LR: Surf. **PO_4** March 2101-2150 (mean and std. dev.)

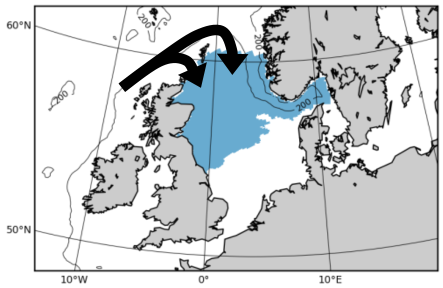


- No tides
- Weaker slope current
- Limited ageostrophic exchange at the shelf break
  -> grid resolution matters
- No sediment resuspension

Change in n. North Sea primary production



PO_4 of winter Atlantic inflow



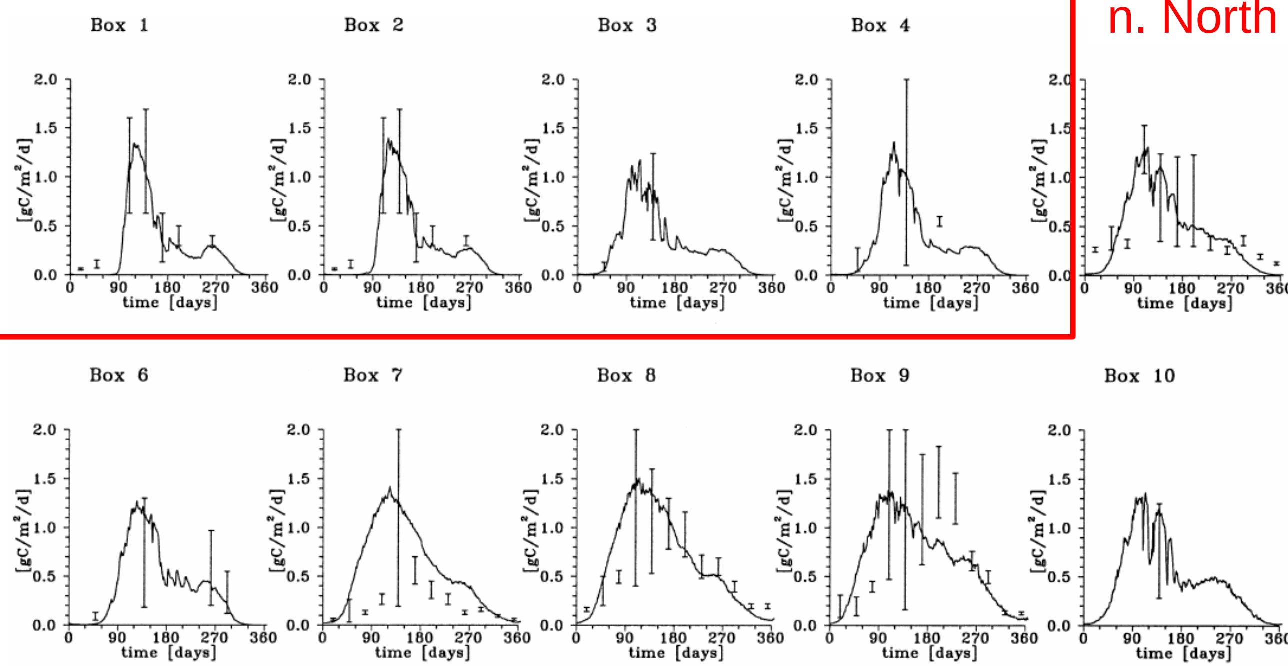
Summer **stratification**

Annual **primary production**

- RCP4.5 -20%
- RCP8.5 -25%

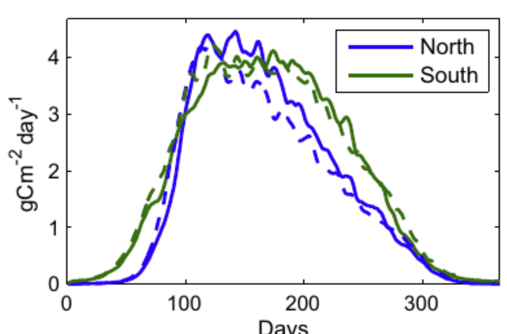
North Sea primary production

n. North Sea

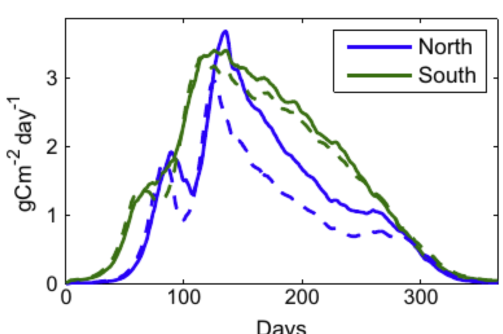


Moll (1998)

ERSEM North Sea

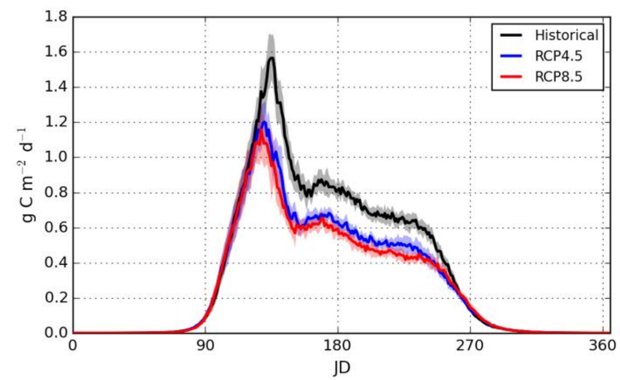


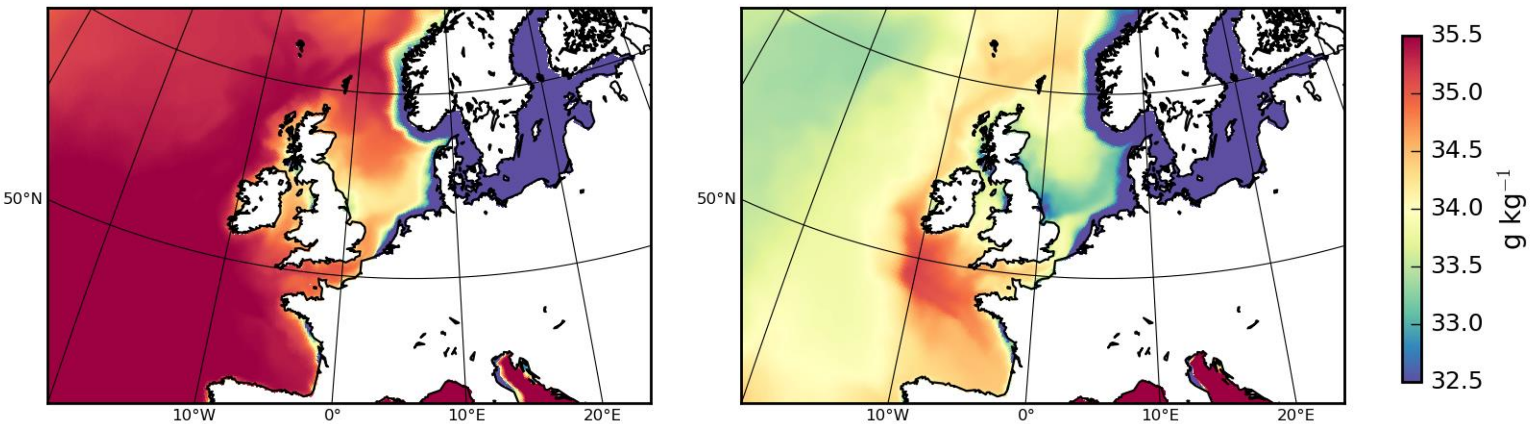
ECOSMO North Sea



Holt et al. (2016)

HAMOCC n. North Sea



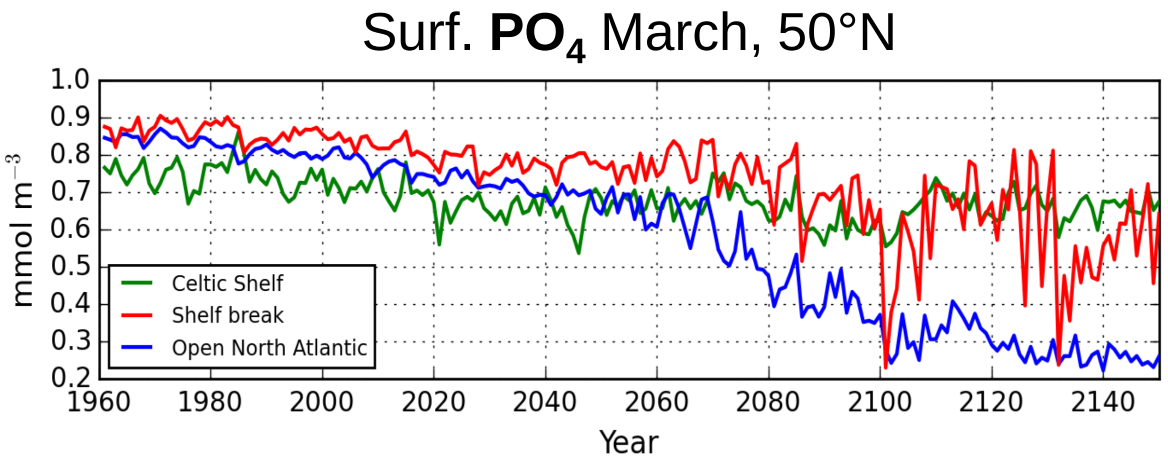


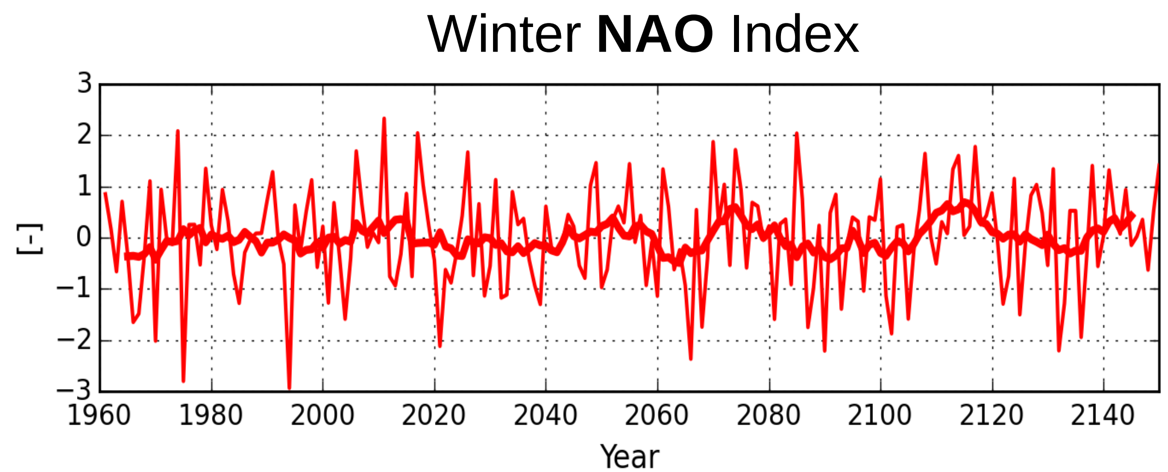
Near future (2011-2060)

Far future (2101-2150)

SSS winter

Interannual and multidecadal variations

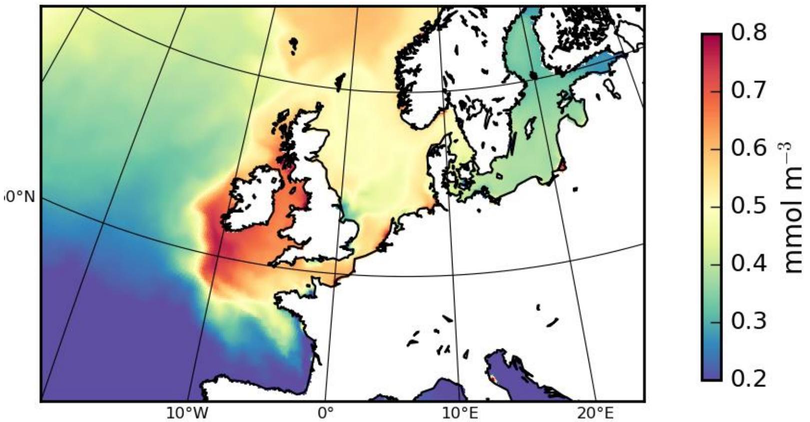


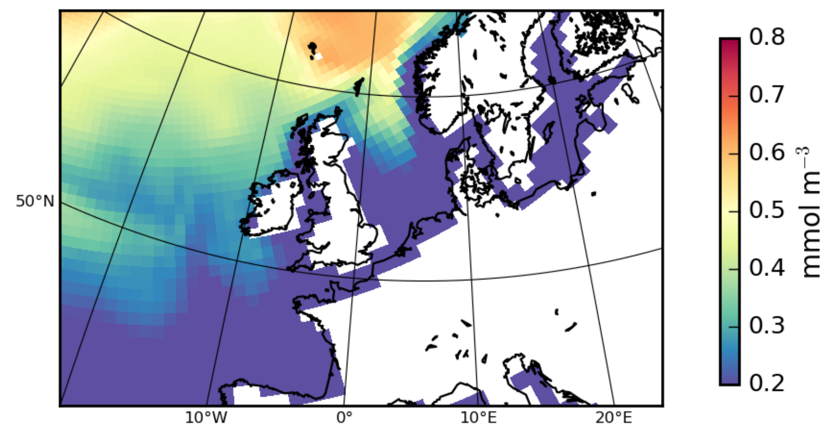


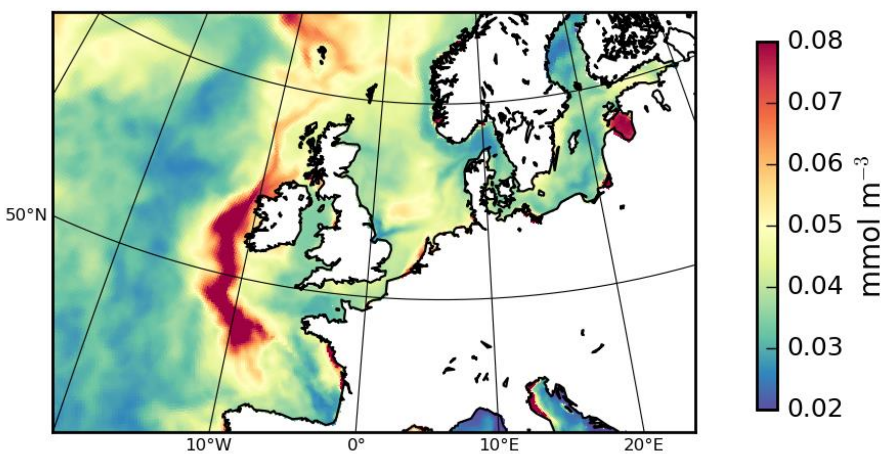
What is the benefit of using a global ocean model?

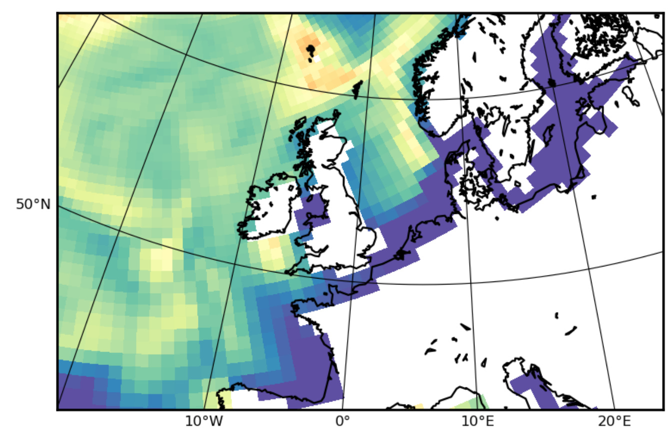
Surface **PO_4** March Far future (2101-2150)

Downscaling with REMO/MPIOM **MPI-ESM-LR**



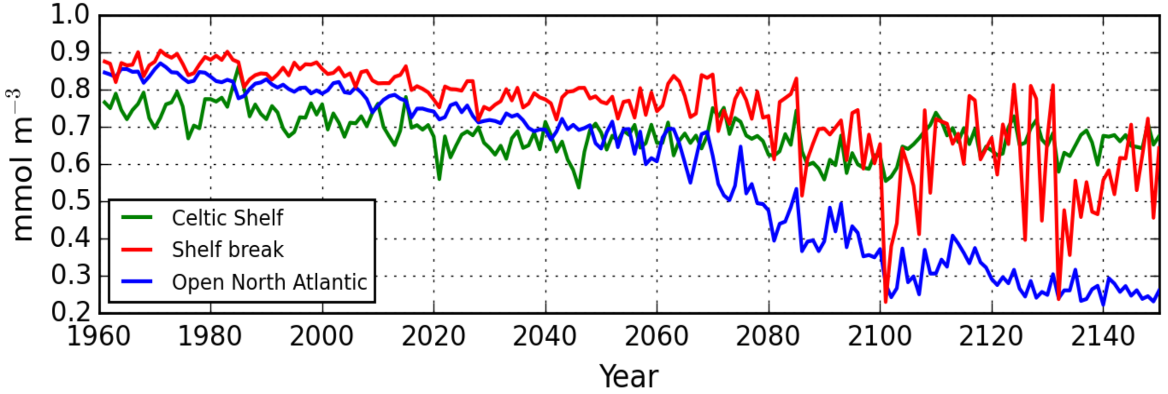




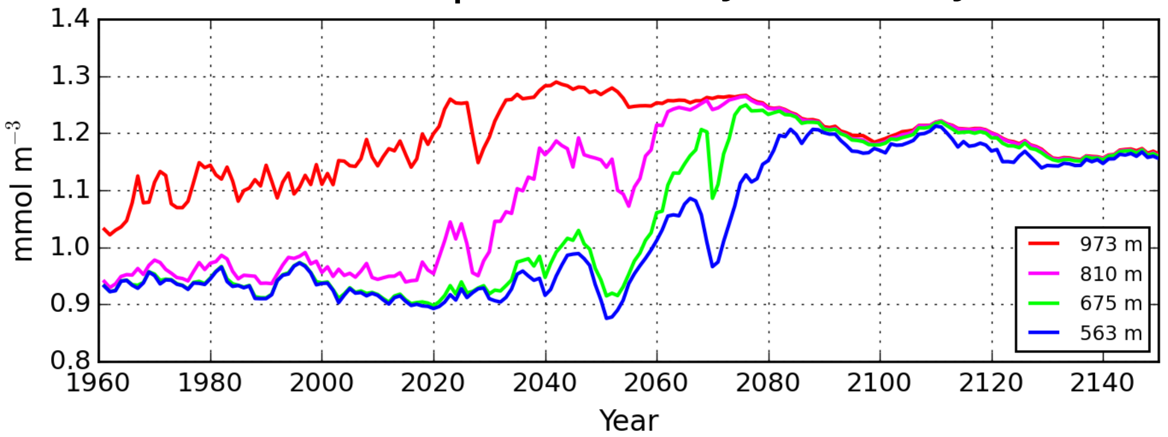


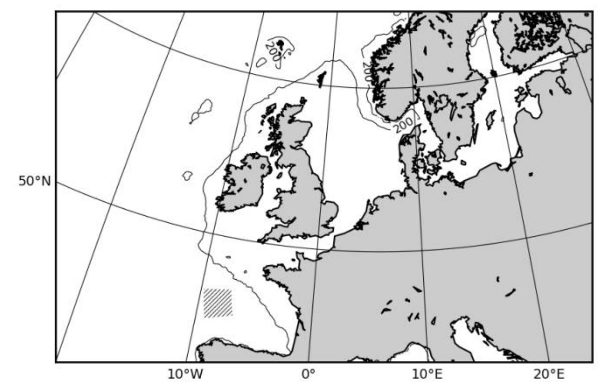
Enhanced multidecadal variability

Surf. **PO_4** March, 50°N



PO_4 March, Bay of Biscay





Enhanced variability of salinity