National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Physical processes mediating climate impacts in regional sea ecosystems

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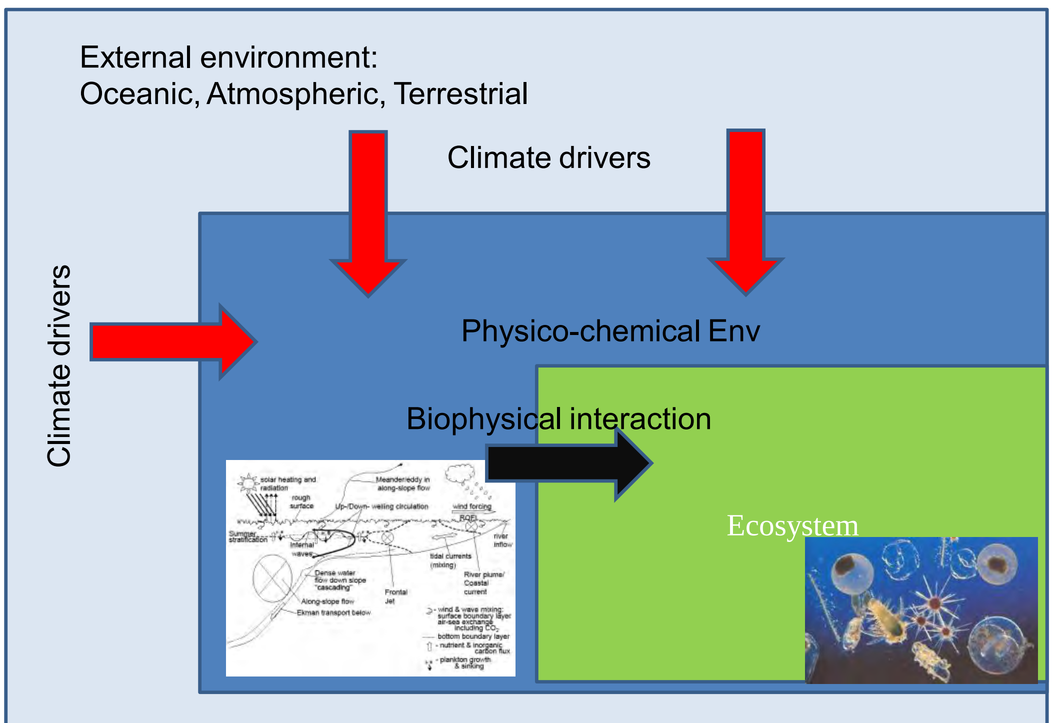
The Big questions....

How can we make future climate projections of regional sea ecosystems that are reliable enough to inform decisions or opinions?

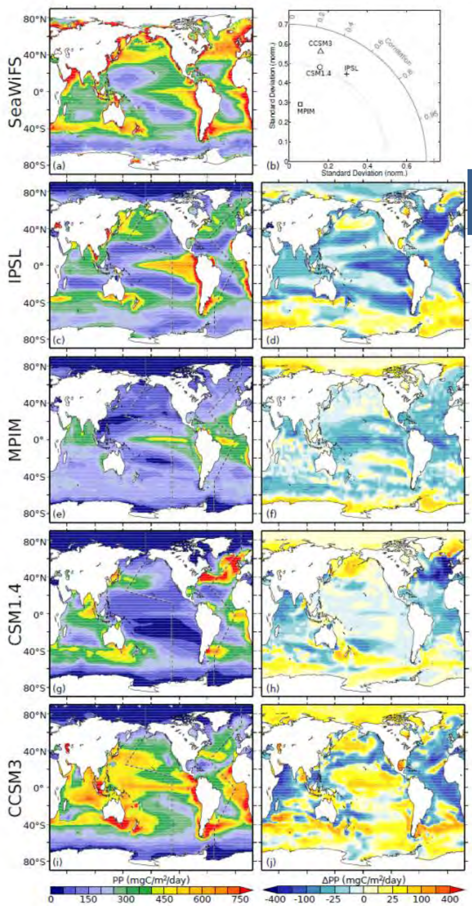
How do we begin to understand the uncertainty in the projections?



Downscaling global change

Projected changes

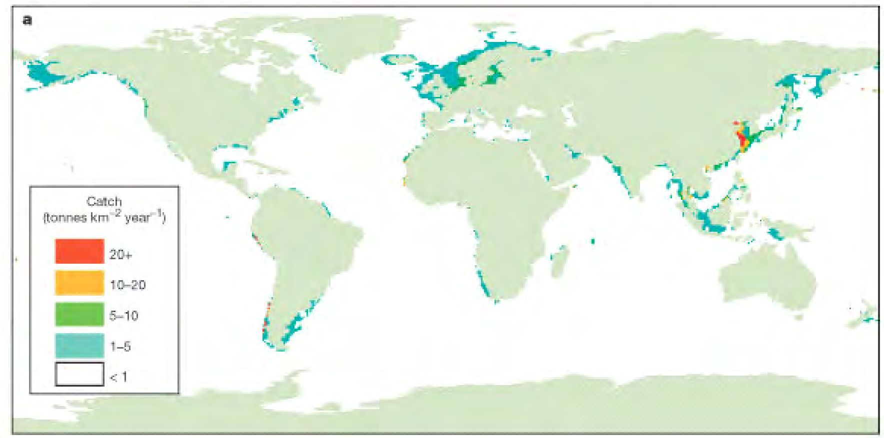
netPP   Δ netPP



Streinacher et al 2010

?

Global Fish Catch



Watson and Pauly, 2001

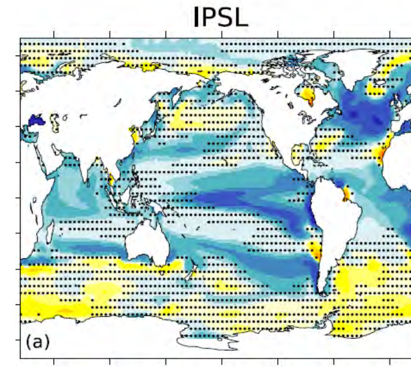
Focus PP as the engine of the ecosystem
Multi model ensemble (AR4):
Decrease in mid- low- latitude basins
- Increased stratification, slowed circulation

Increase (variable) in high latitudes
- Relaxation of light limitation

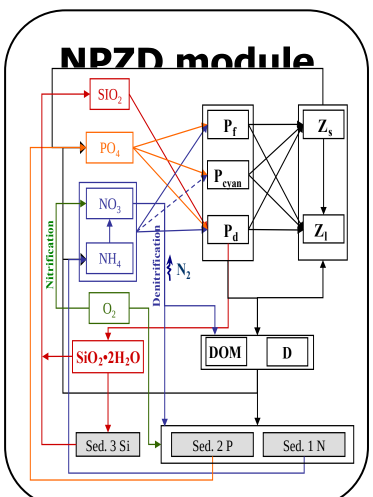
Big mismatch in scales

MEECE: Models and downscaling approaches

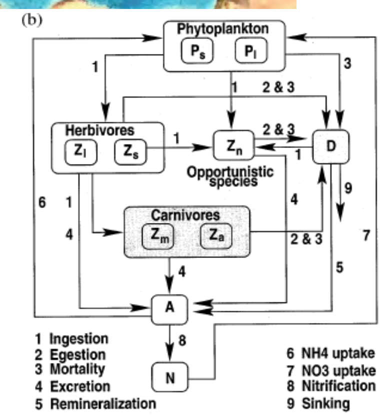
- Three models in five (out of ten) regions



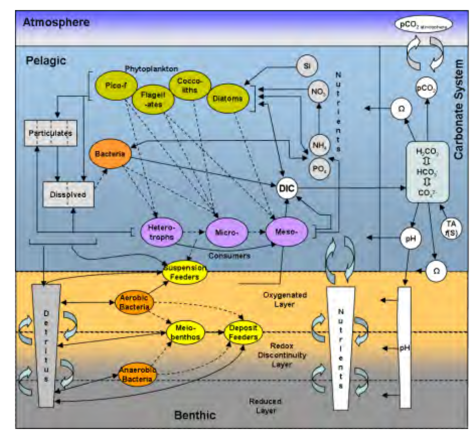
IPSLCM4 + other AR4/5 models
A1B Timeslice experiments:
2080-2099 v's 1981-2000



ECOSMO: Barents, Baltic, North Sea



POM-BIMS_ECO:
Black Sea



POLCOMS-ERSEM:
Atlantic Margin

http://www.meeceatlas.eu/Menu/

The common forcing: IPSL CM4

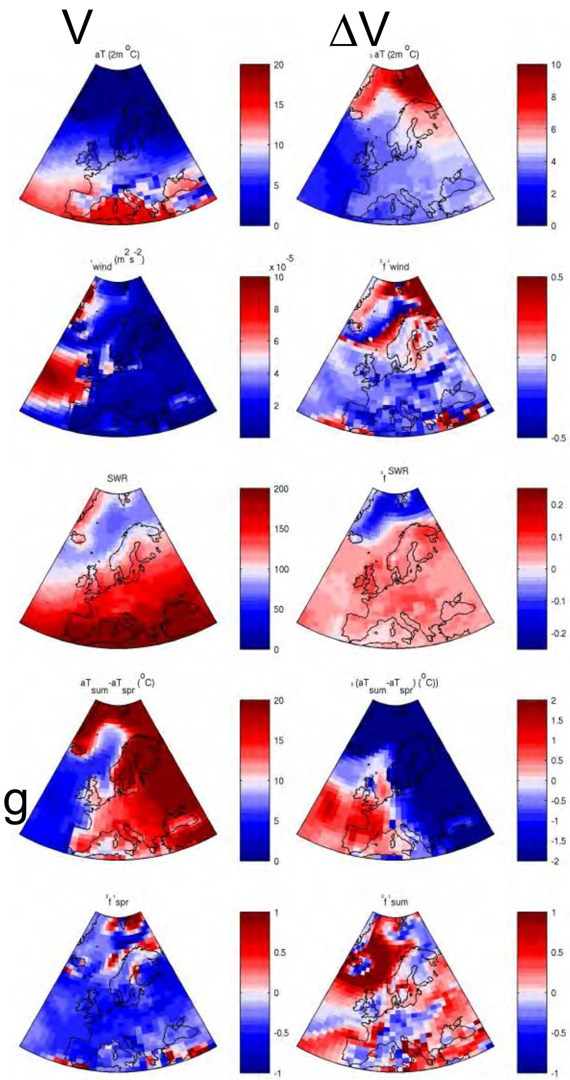
Air temp

Wind Stress

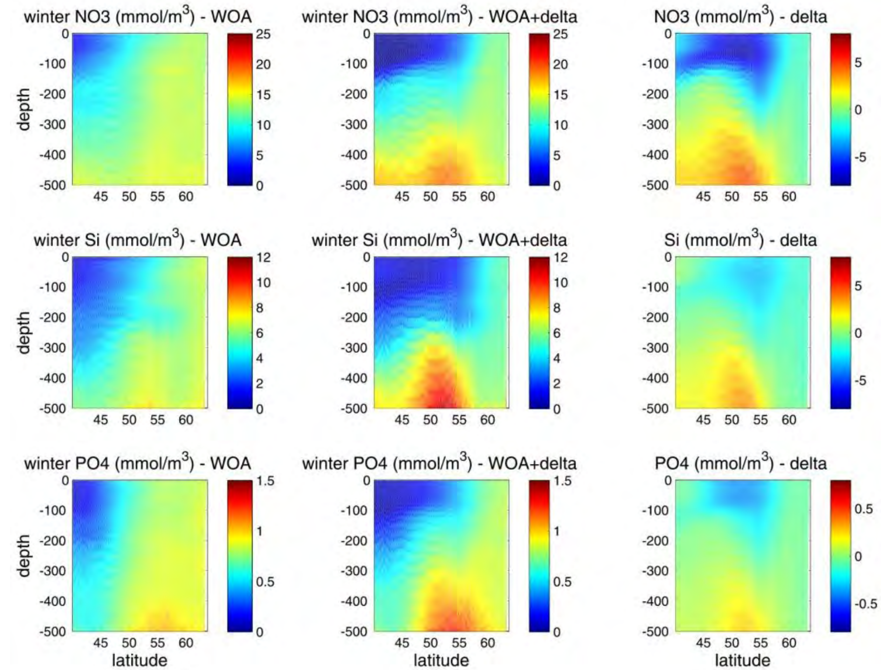
SWR

Air temp
Summer - Spring

Wind Stress
Spring



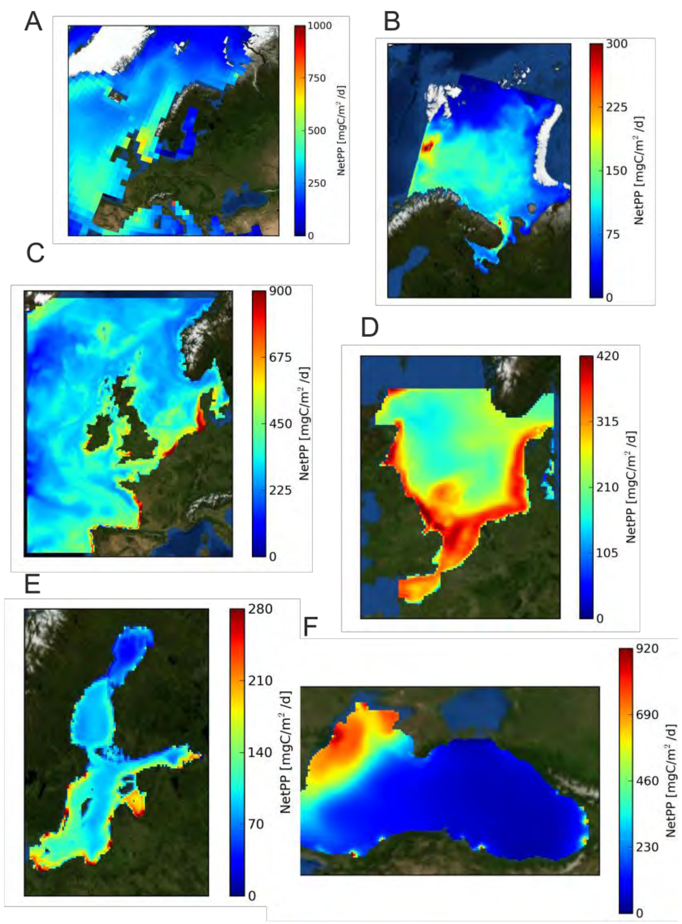
Oceanic nutrient boundary conditions



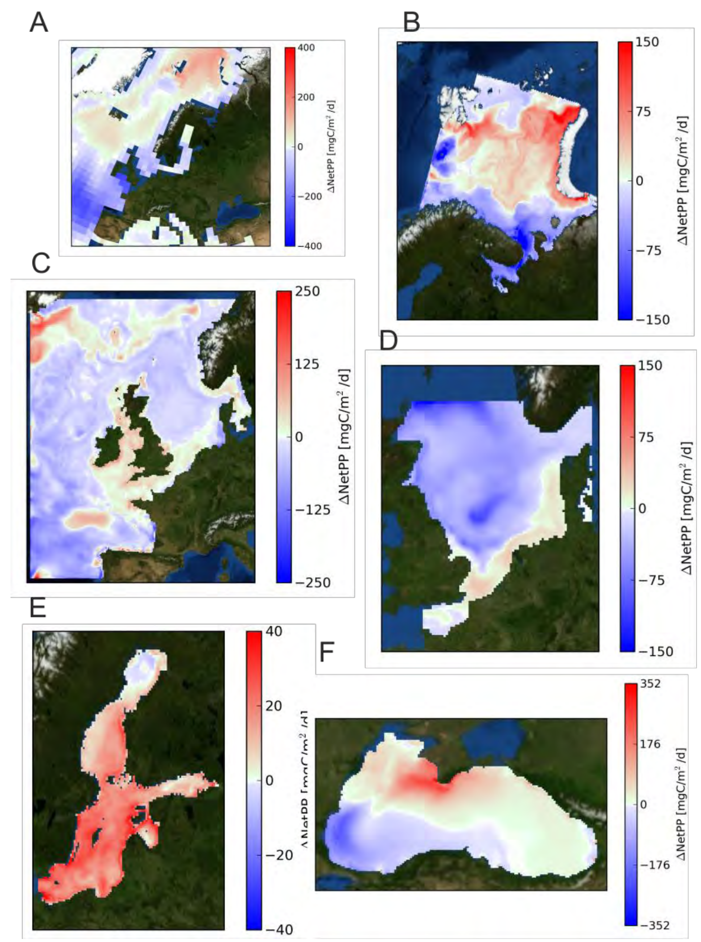
A single ‘sensitivity’ experiment
No assessment of likelihood at this stage

Change in netPP: Five regions and Global

netPP



A1B - CNTRL



- Heterogeneous change, positive and negative regions – not seen in global model
- Suggests added value from downscaling

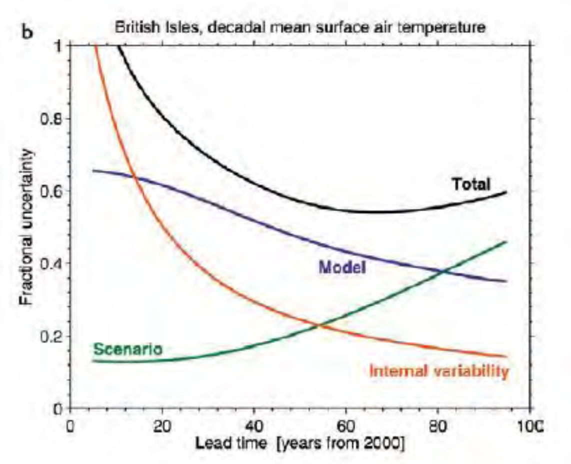
How to address uncertainty for a multiply coupled system?

Scenario ➡ Global ESM ➡ Regional Physics ➡ Regional Ecosystem

- Each model has
  - internal variability,
  - structural uncertainty
  - parameter uncertainty
- a 9D space: to big to build a PDF from ensembles

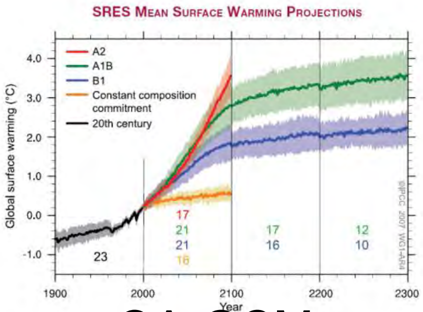
Instead

- Need a deeper understanding of systems response and drivers
- Here confidence in the sign of change would be a good start
- Guide ensemble design



Hawkins and Sutton BMS, 2009

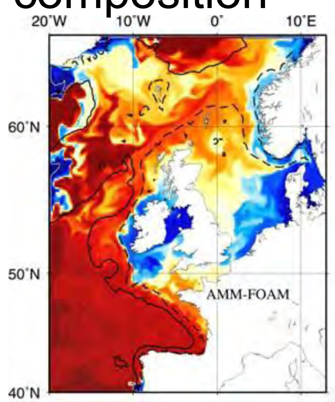
Physics process controlling phytoplankton growth



OA-GCMs

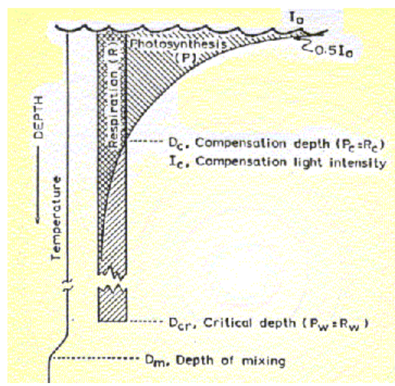
Three key general mechanisms

Biogeochemical composition



Winter mixing
Seasonal upwelling
Ocean-shelf exchange

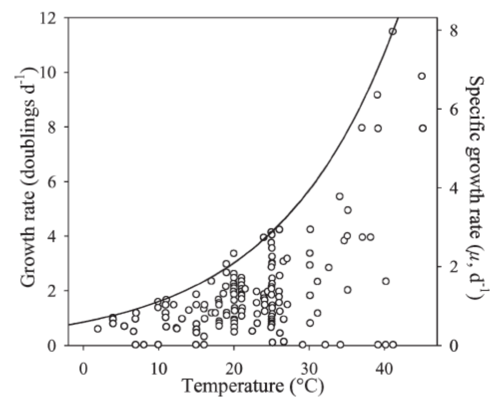
Phytoplankton blooms/Meso-scale processes



Sverdrup (1953)

Turbulence-stratification-light Interplay

Physiological response

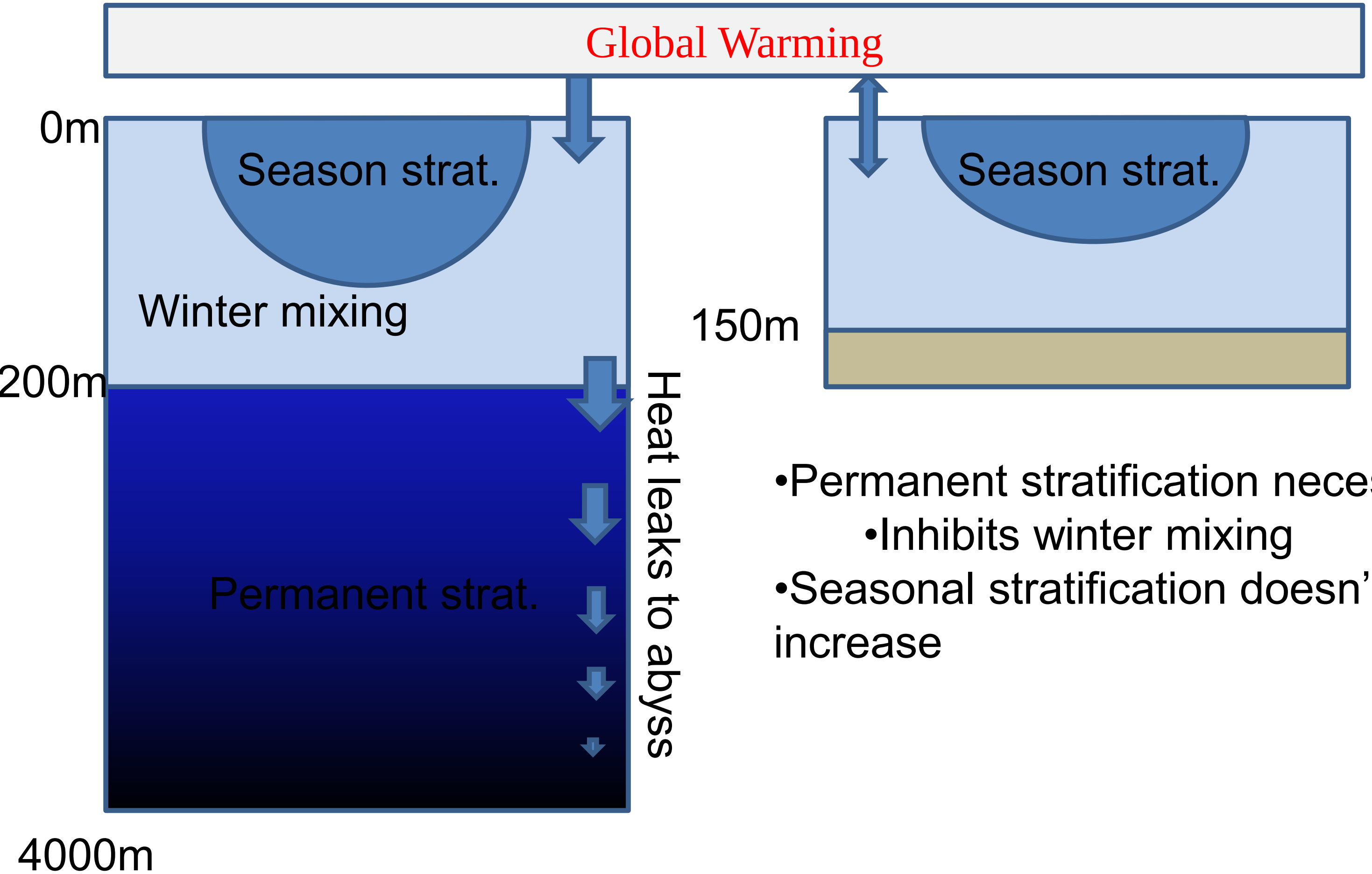


Eppley (1972)

Growth rate response to temperature: autotrophic and heterotrophic

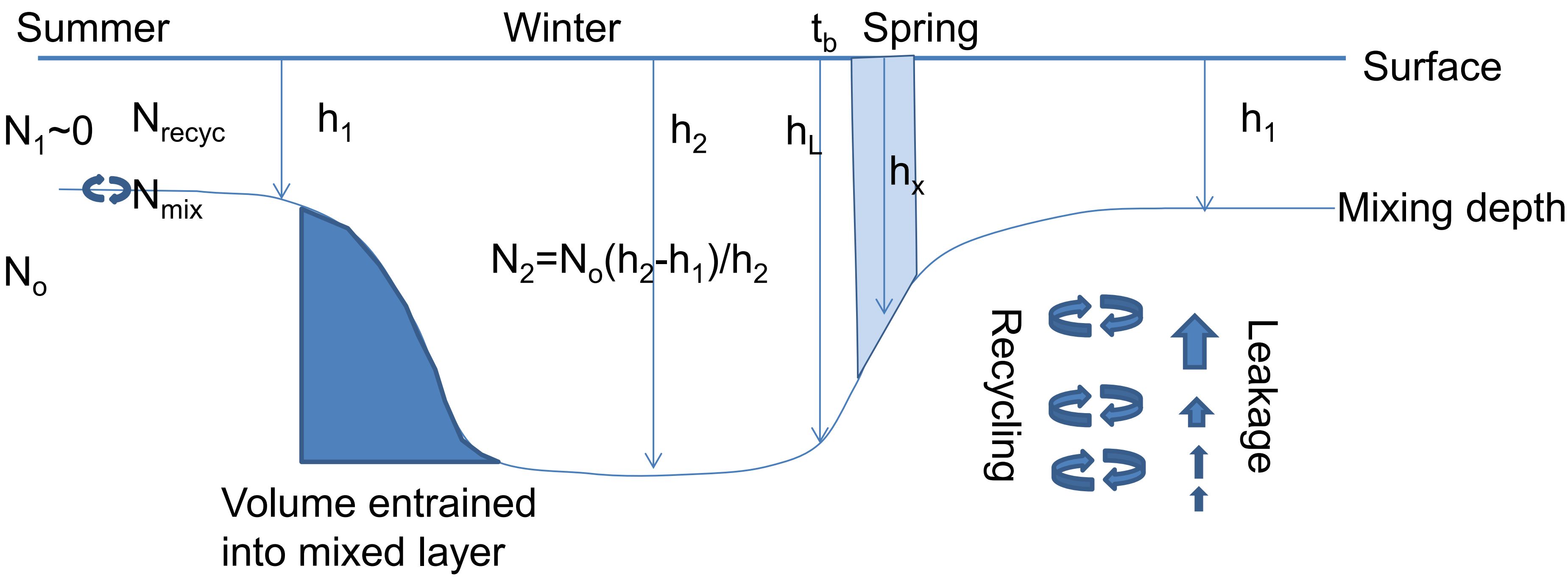
A key difference between open ocean and shelf seas

- Shelf seas are in (dynamic) thermal equilibriums,
- Deep ocean/regional seas are not



•Permanent stratification necessarily increases
    •Inhibits winter mixing
•Seasonal stratification doesn't necessarily increase

Nutrient Resupply: Deep-Ocean or -Sea



Available N for spring bloom

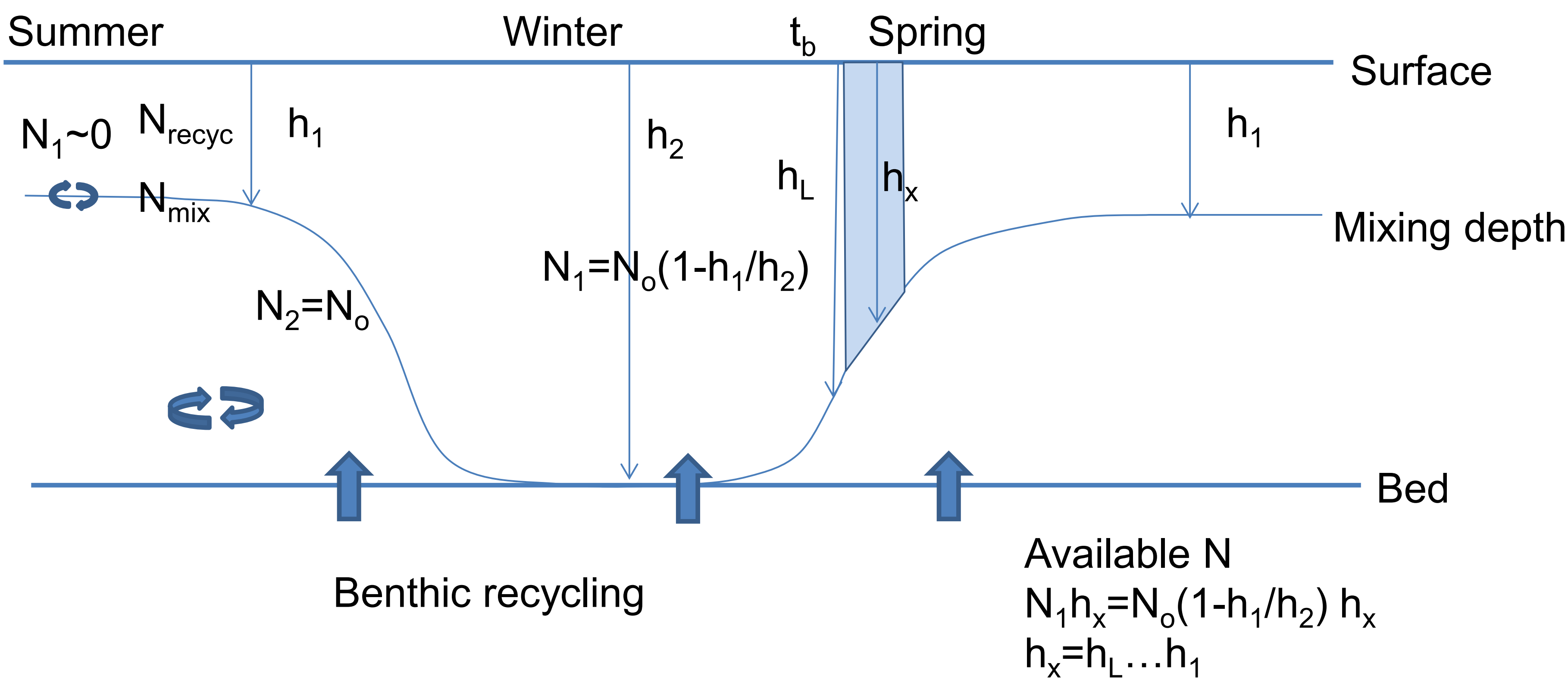
$N_2 h_x = N_o(1-h_1/h_2)\ h_x$ i.e. decreases with decreasing h_2

$h_x = h_L \ldots h_1$

How much N is available before onset of strong strat. ?

Depends on heating, mixing and growth rates

Nutrient Resupply: Shallow-Sea



h_2 is here fixed, so this big driver is absent

Variations in t_b, h_x, N_{mix} all still present

Nutrient Resupply: Regional seas

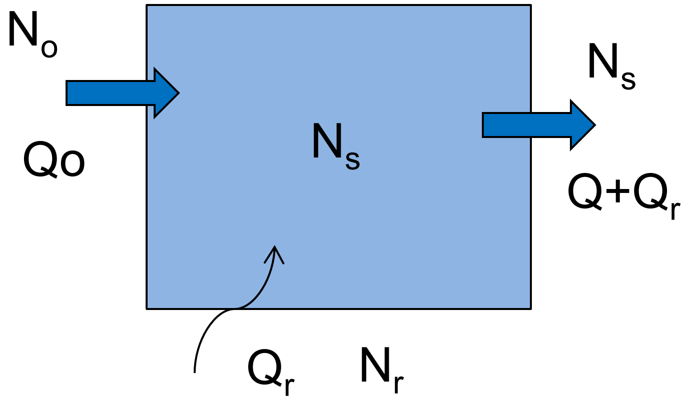
Regional seas are more sensitive to changes in total budget (c.f. big reservoir in open ocean)

Changes in external N will change internal, relative to other inputs

Care needed with this approach: seas are rarely horizontally 'well-mixed'

Budget in region
LOICZ type approach:

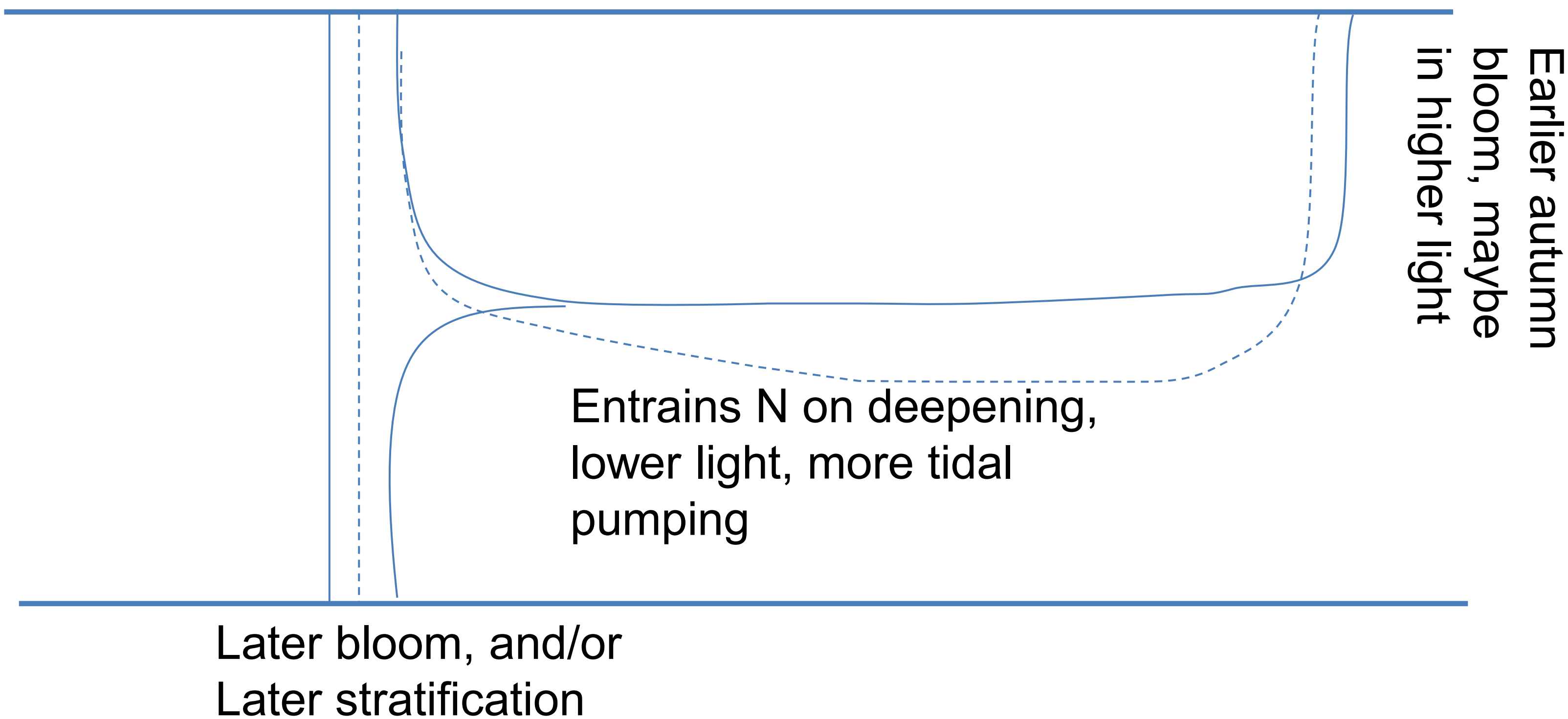
$$N_s = \frac{Q_o N_o + Q_r N_r + F_a}{Q_o + Q_r}$$



Holt et al 2012 *Biogeosciences*

Wind Effects: Mixing

Possible mixing effects of changing wind stress:
Idealised phytoplankton profile: dashed line is with increased wind

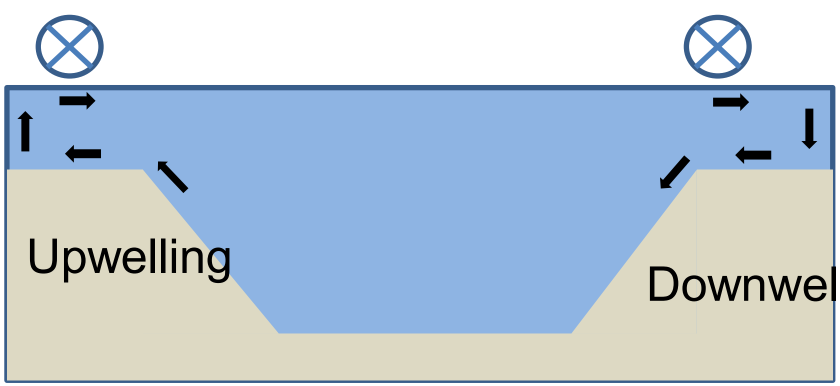


Very difficult to guess what overall effect would be: very dependent on details of mixing conditions

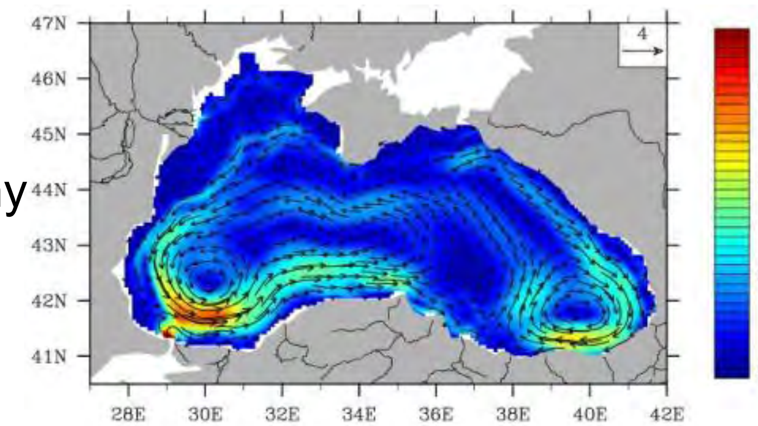
Wind effects: Circulation

Very regionally specific
Enclosed basin susceptible to large changes
•Taylor-Proudman theorem: follow topography in direction of Coastal Trapped Waves (same for thermal wind circulation, if stratification decreases shorewards)
•Not case for Black Sea

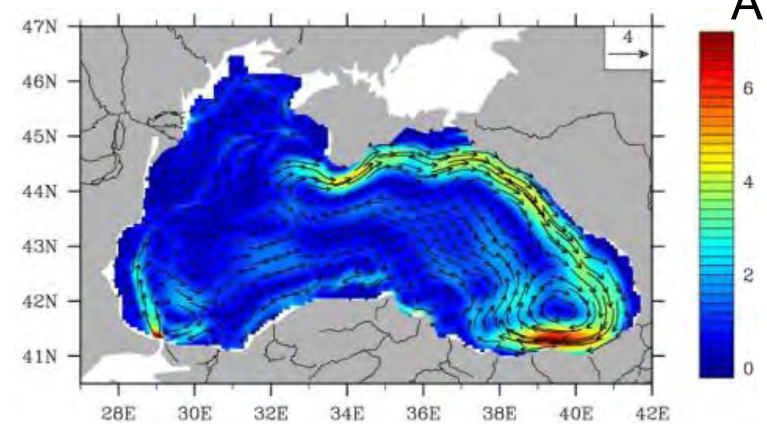
Up/downwelling according to Ekman theory
•Directly dependent on changes in wind stress



CNTRL



A1B



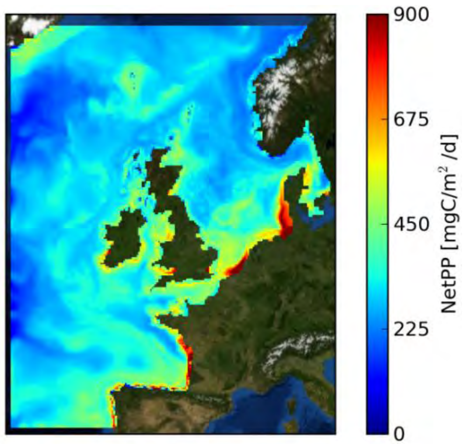
Attributed to changes in wind stress curl

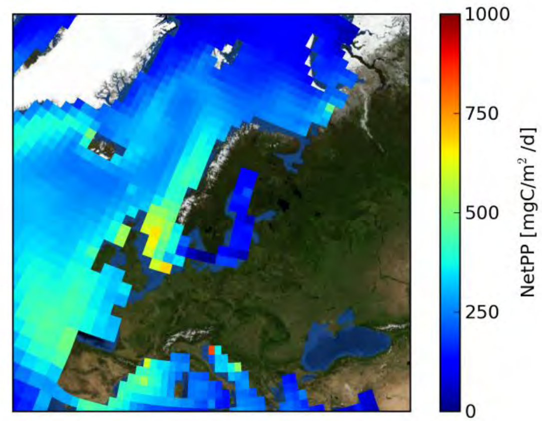
Illustrations from NW European shelf

Regional Model

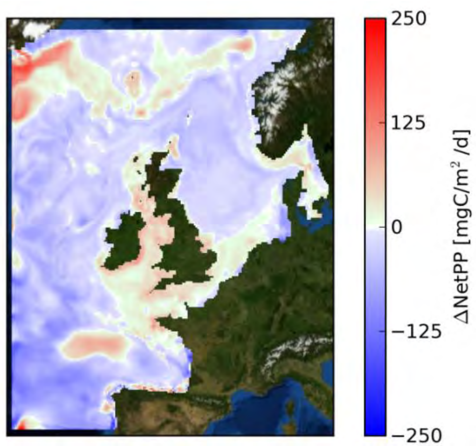
Global

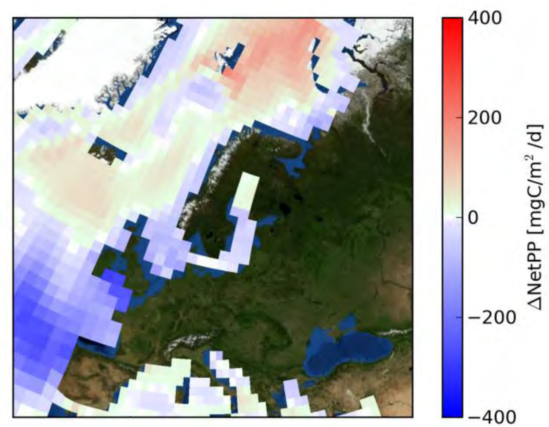
netPP





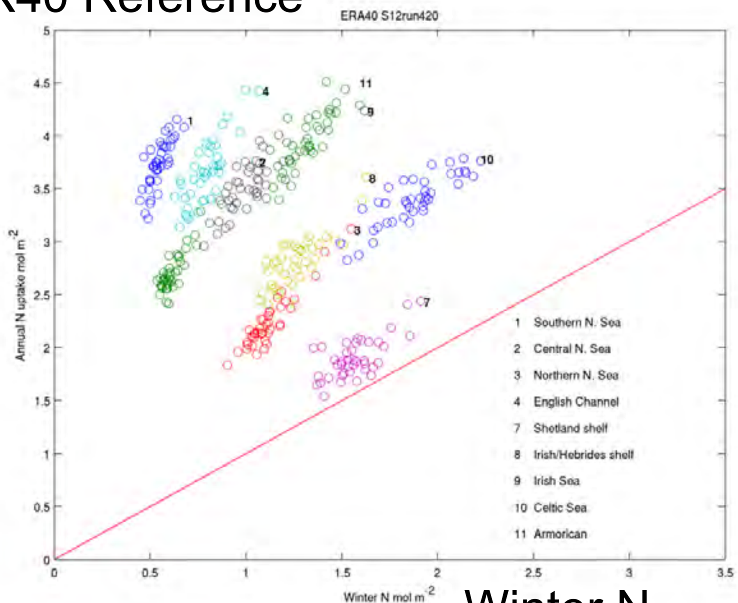
ΔnetPP

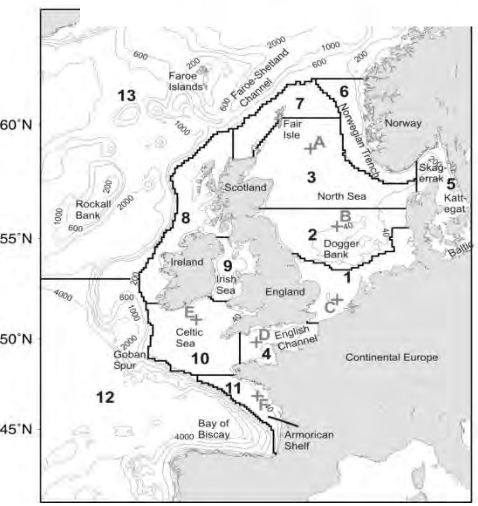




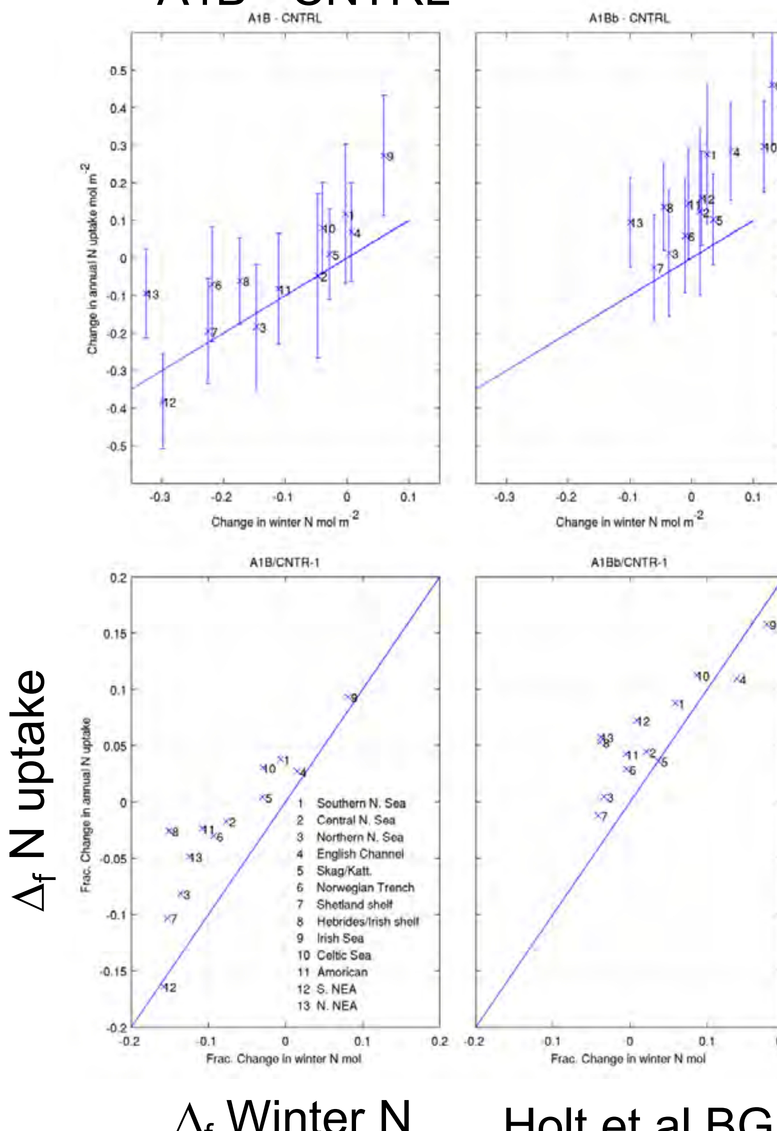
Phytoplankton growth (1): Ocean-shelf Exchange
Regional winter N v's N uptake following year

ER40 Reference





A1B - CNTRL

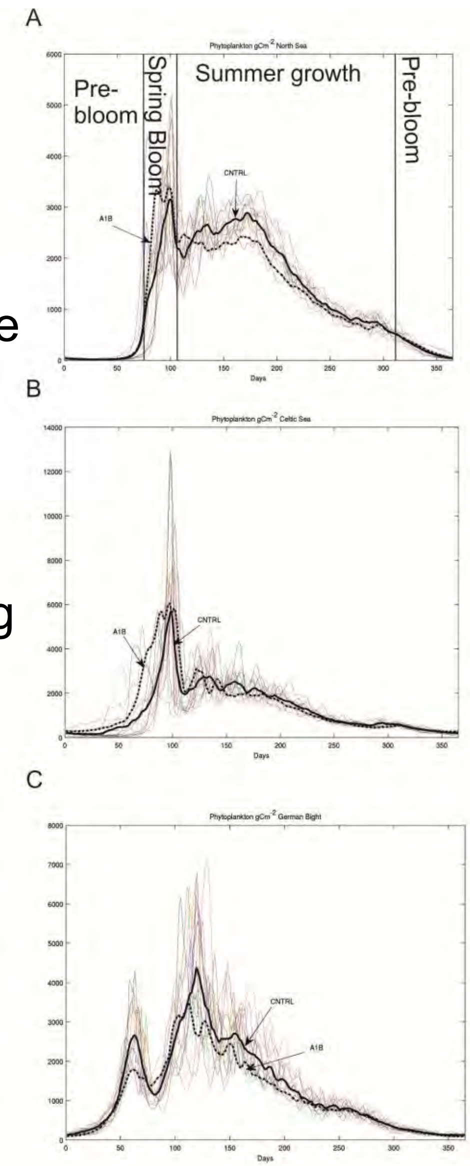


Holt et al BGS 2012

Phytoplankton growth(2): Mixing-light response

Phytoplankton require nutrients and light
- Nutrient re-supply controlled by
  - Horizontal and vertical cross-gradient transport
  - Often diffusive on sub-seasonal timescale
- Light controlled by
  - season/latitude
  - atmospheric and in-water composition
- In Early bloom:
  - Phytoplankton respond to reduced mixing but full depth nutrient flux still active. Huisman et al *L&O* (1999) 'critical turbulence'

A simple heuristic approach:
Average properties over three stages, defined by thresholds:
- netPP>0.2*netPPmax
- N<0.2*Nwint
- Netpp<0.2*netPPmax

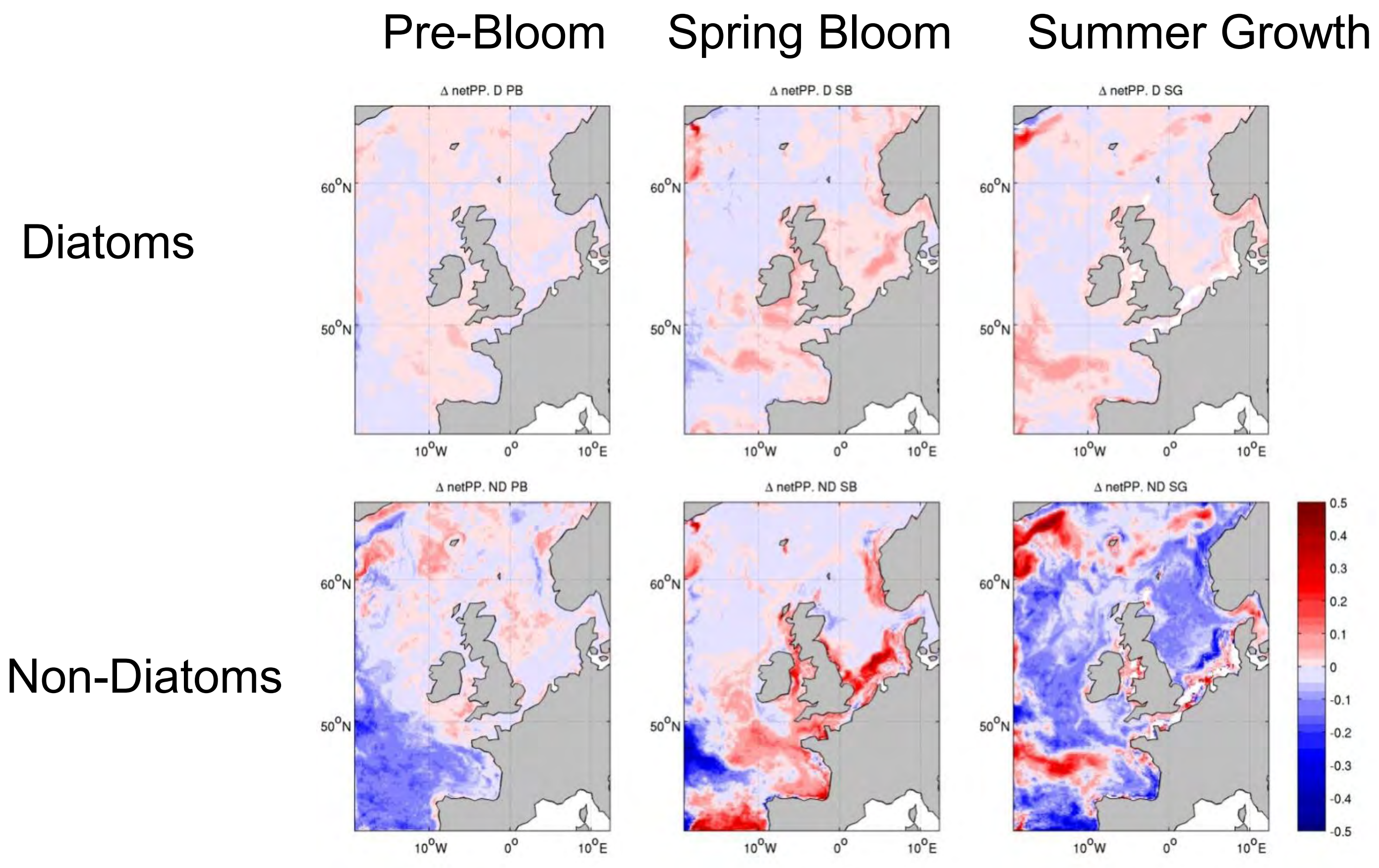


North Sea

Celtic Sea

German Bight

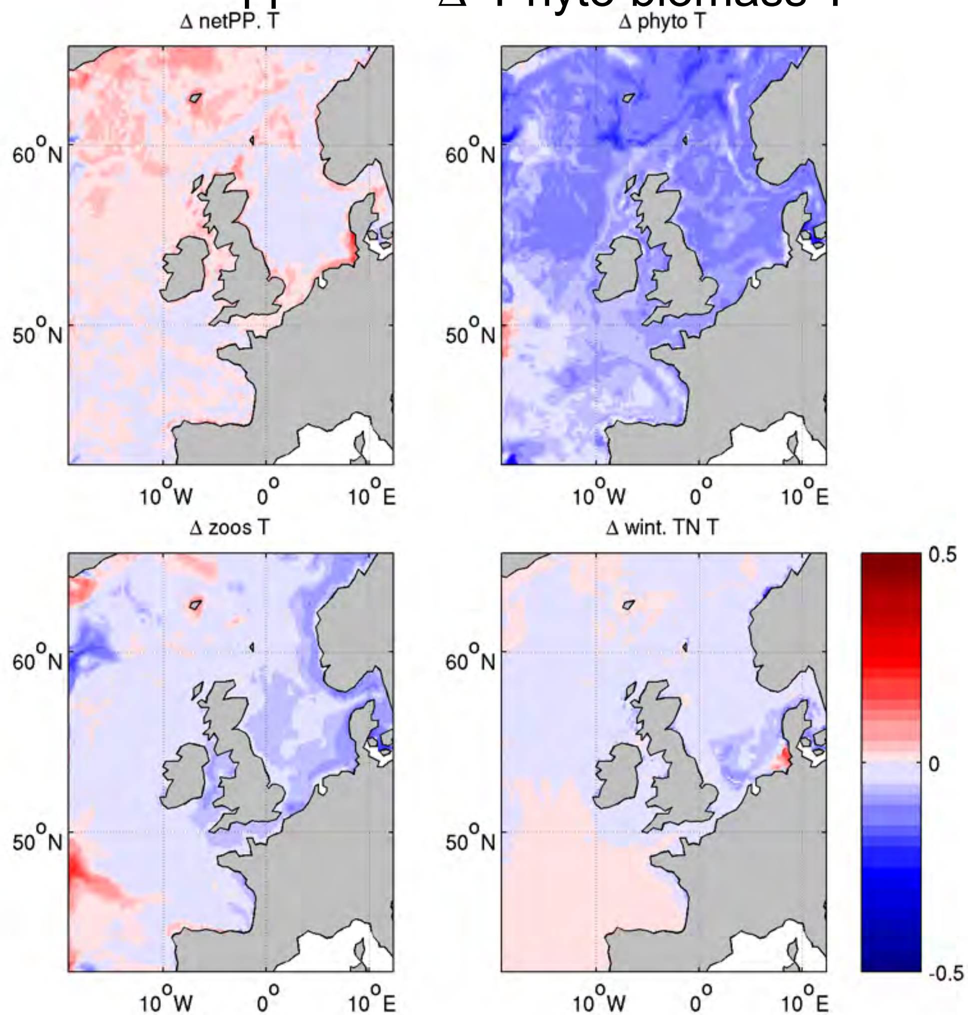
Phytoplankton growth(2): Mixing-light response



- Earlier/longer spring bloom means more efficient silicate usage
- Increased stratification impacts mid-water production in summer
- Different to what suggested in ocean ocean: shift to smaller groups

Phytoplankton growth (3): Temperature effects

Δ netpp T   Δ Phyto biomass T



Δ Zoo biomass T   Δ Wint TN T

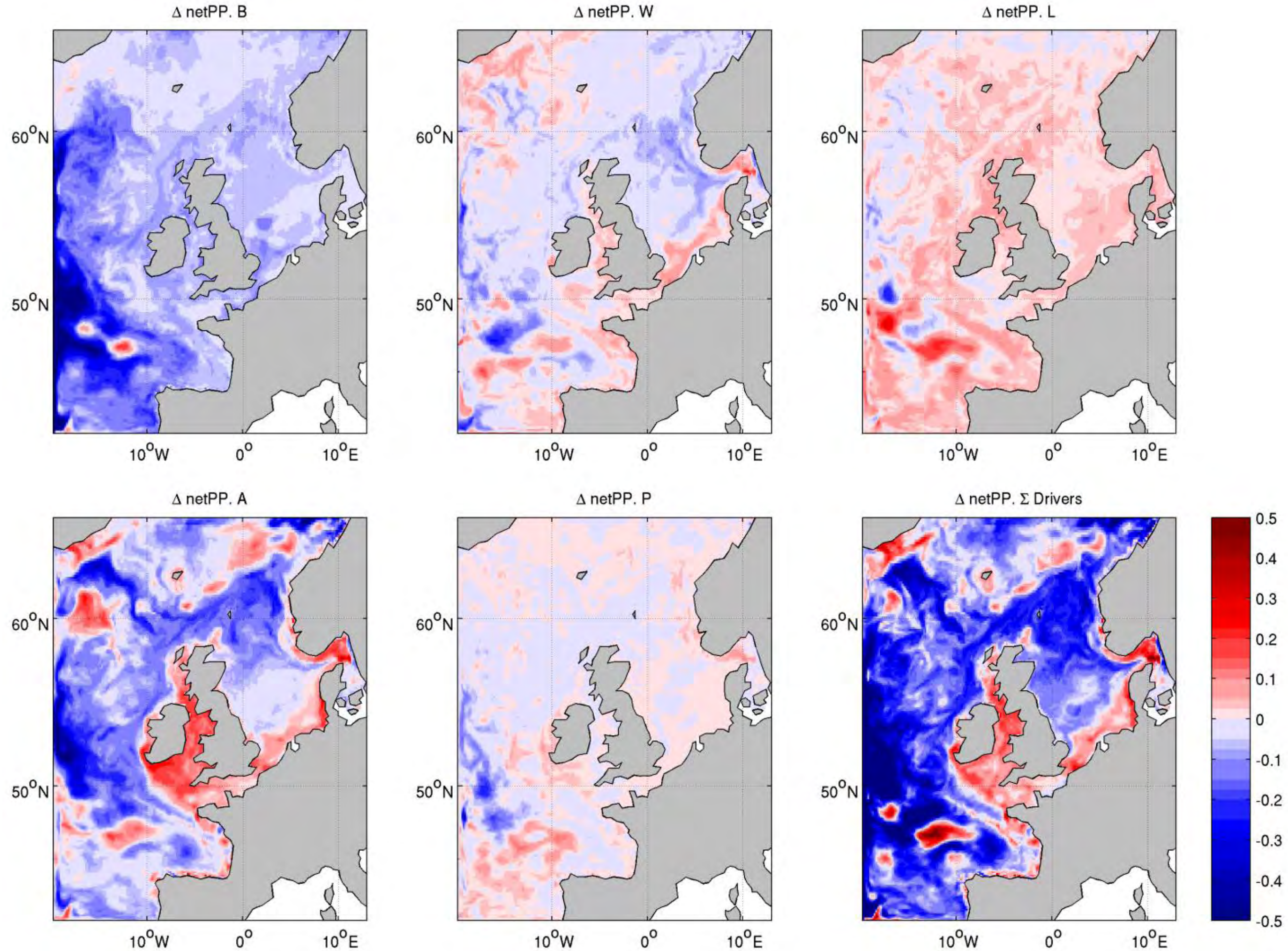
- Experiments with T dependence removed
- Temperature dependence is much more apparent on plankton biomass than netPP
- Heterotrophs and autotrophs have same q10 parameterisation

Driver – Response experiments

- B: Boundary nutrients
- W: Wind
- L: SWR
- A: Air temp
- P: Precip

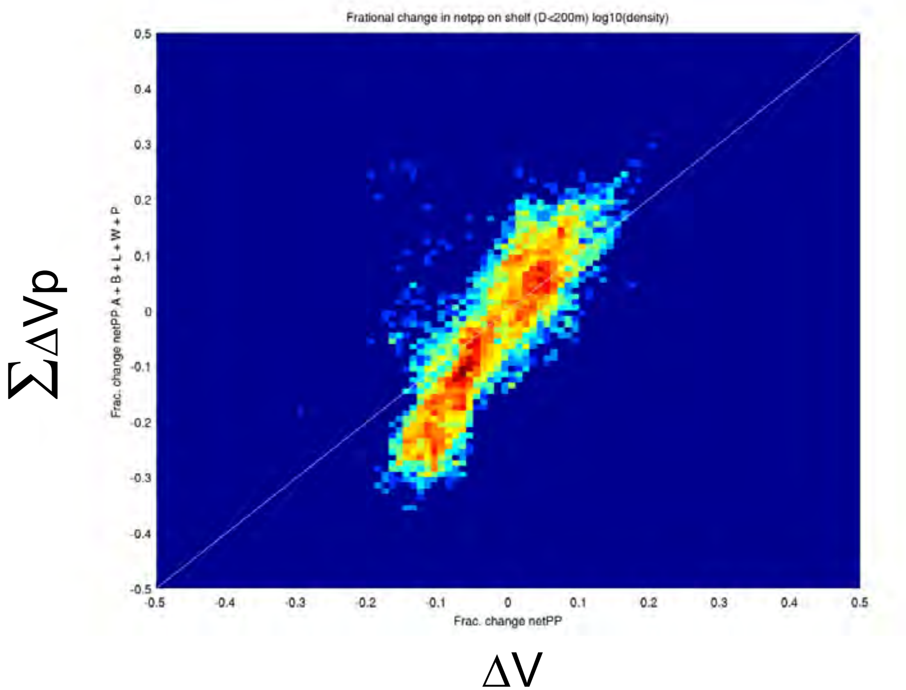
Random present day year is swapped in to future forcing

$\Delta V_p = \Delta V - \Delta V_{p'}$



How linear is the system?

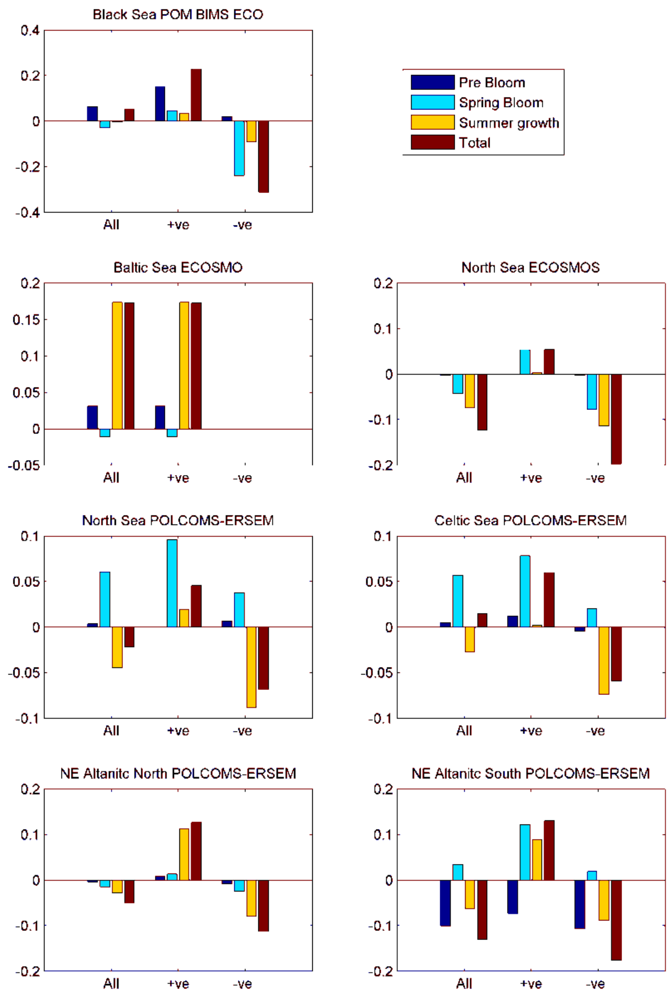
•System is close to linear but tendencies to a damping
•Combined effect less than sum of drivers
•Ecosystem feedback e.g. grazing?



- The system has multiple competing drivers acting in positive and negative sense
- General driver response wrt net PP:
  - Reduced ocean nutrients: –ve
  - Increased wind: +ve mixing, –ve growing season
  - Increased SWR: +ve
  - Increased air temp: -ve stratification +ve growth rates.

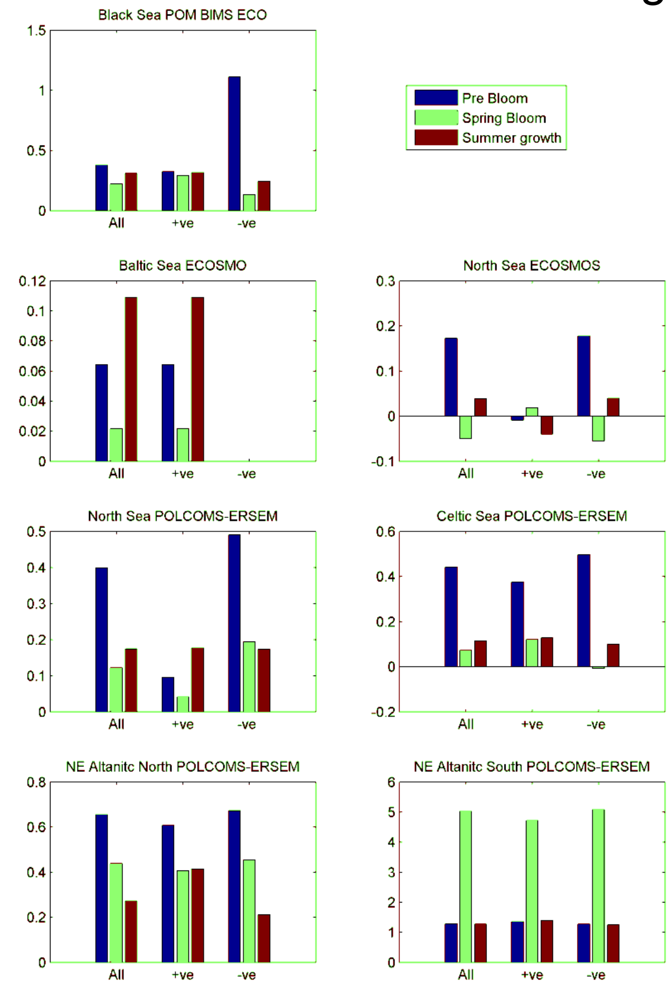
The MEECE Experiments: Common analysis

netPP Fractional change



Divided by +ve and –ve region, scaled by total

Stratification: Fractional Change



Potential Energy Anomaly (200m)

Qualitative summary of Driver - Responses

	Black Sea	Barents Sea	Baltic Sea	North Sea	NW Shelf
Drivers					
Air temp.	+ve	+ve	+ve	+ve	+ve
Wind	curl(w) -ve	+ve	+ve (Winter)	-ve (Summer)	-ve
Precip	+ve	+ve	+ve		+ve
SWR	+ve	+ve	+ve	+ve	+ve
Nut. BC				-ve	-ve
Response					
netPP	-ve East +ve west	+ve	+ve	-ve Open shelf +ve Coastal	-ve Open shelf (NS) +ve Coastal/Celtic Seas
Phyto Biomass	-ve East +ve west	+ve North -ve South	+ve	-ve Open shelf +ve Coastal	-ve Open Shelf/coast +ve Celtic Sea
Diatom Fraction	-ve East +ve west				+ve
Growing season timing		+ve	+ve	+ve	+ve

Driver-Response is not unique. Changes to mixing-light (+ice) appears to be important in many cases

Conclusions

- Climate change impacts in regional seas are highly nuanced, with multiple competing drivers and interactions
  - Highly dependent on regional conditions
  - Drivers of different sign can mitigate - locally or across gradients of response
  - Isolated seas vulnerable to single drivers
  - Enhance uncertainty: Often dependent on uncertain aspects of forcing
- Shallow seas are not susceptible to changes in permanent stratification
  - A major vector of change for open-ocean systems is absent
  - Instead vulnerable to changes in ocean-shelf exchange (again more nuanced)
- Deep basin, regional seas are subject to changes in permanent stratification
  - But here wind effects (circulation and mixing) dominate
- Provides a guide for forcing ensemble selection to aid understanding of uncertainty