St. Andrews
22 July 2013

ROAM @ Liverpool

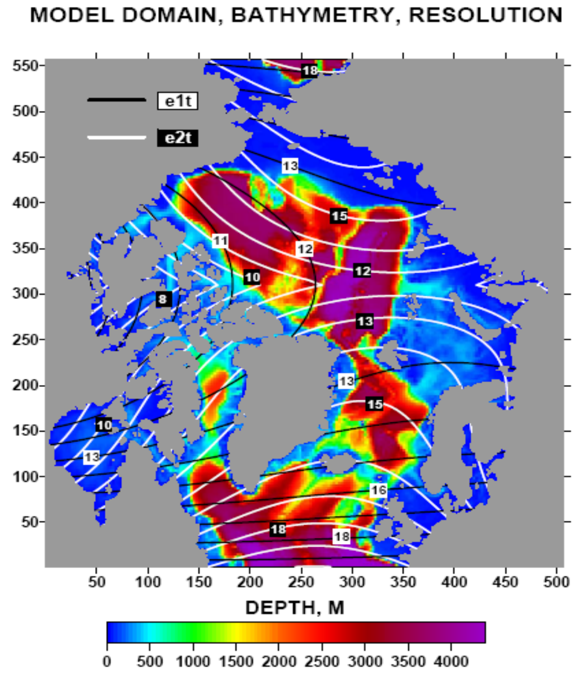
NEMO-Shelf Arctic Ocean modelling

Maria Luneva, Jason Holt, Sarah Wakelin

NEMO-shelf Arctic Ocean model

- About 50% of the Arctic is shelf-sea (<500m depth)
- These regions dominate biogeochemical cycling, but:
  - are typically poorly-resolved
  - omit important processes

  For example:
  - ocean-shelf carbon transport
  - tides

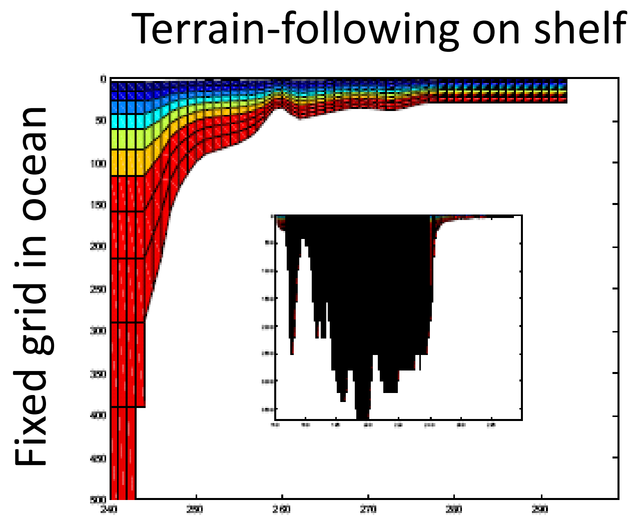


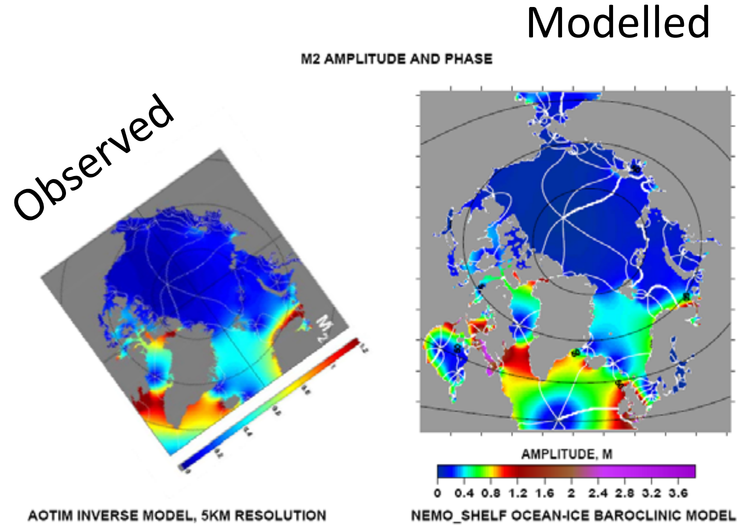
NEMO-shelf Arctic Ocean model

To address this we draw on the NEMO-shelf model

- as used operationally by Met Office

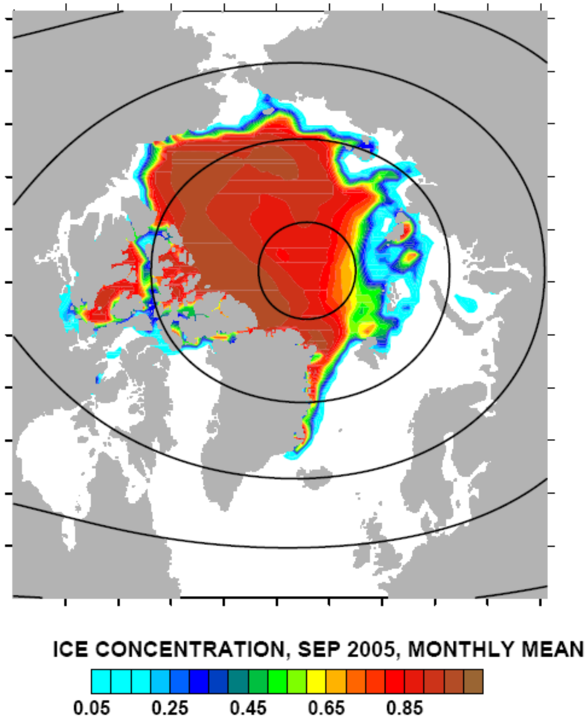
- Start with cut-out of global 1/4^{o} model
- Adding tides, hybrid terrain following coordinates and advanced mixing schemes
- Coupling to MEDUSA underway
- Next step ...
  - Move to 1/12^{o} pan-Arctic model



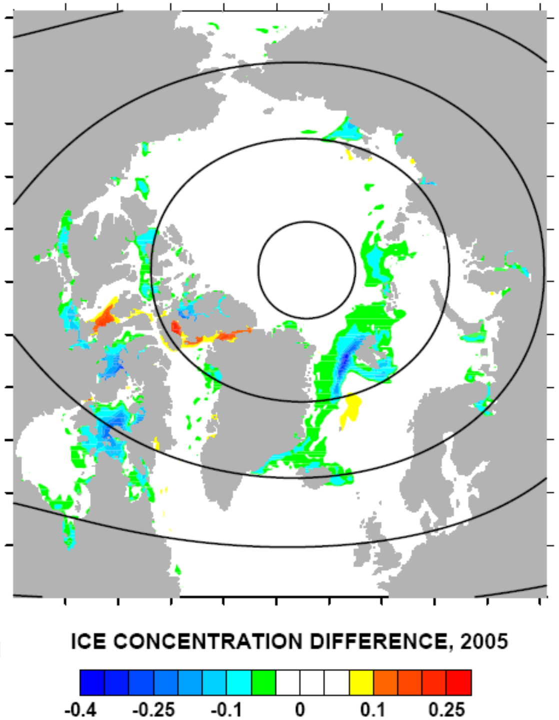


Effect of tides on ice cover and SW

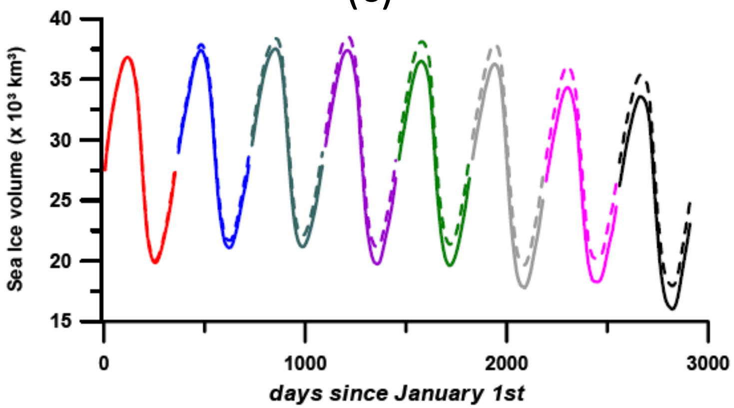
(a)



(b)



(c)



Runs with tide/no tides: 2000-2007
initial conditions: ORCA-25 NOCS
surface forcing DFS5.1

Up to 2007 the reduction in total ice volume due to the effects of tide reaches $5x10^3$ km^3, about 20% of total mean ice volume.

The effects of tide is not homogeneous. In some regions (Figure b) the action of tides increases the ice concentration and volume. The reduction in ice leads to increases in SW radiation (+ve feedback)

(a) Ice concentration with simulation with tides.

(b) Difference in ice concentration between simulations with tides and no tides

(c) Evolution of total ice volume with time. Solid line - with tides included, dashed line - not.

St. Andrews
22 July 2013

ROAM @ Southampton

(Modelled) Arctic and global impacts of ocean acidification

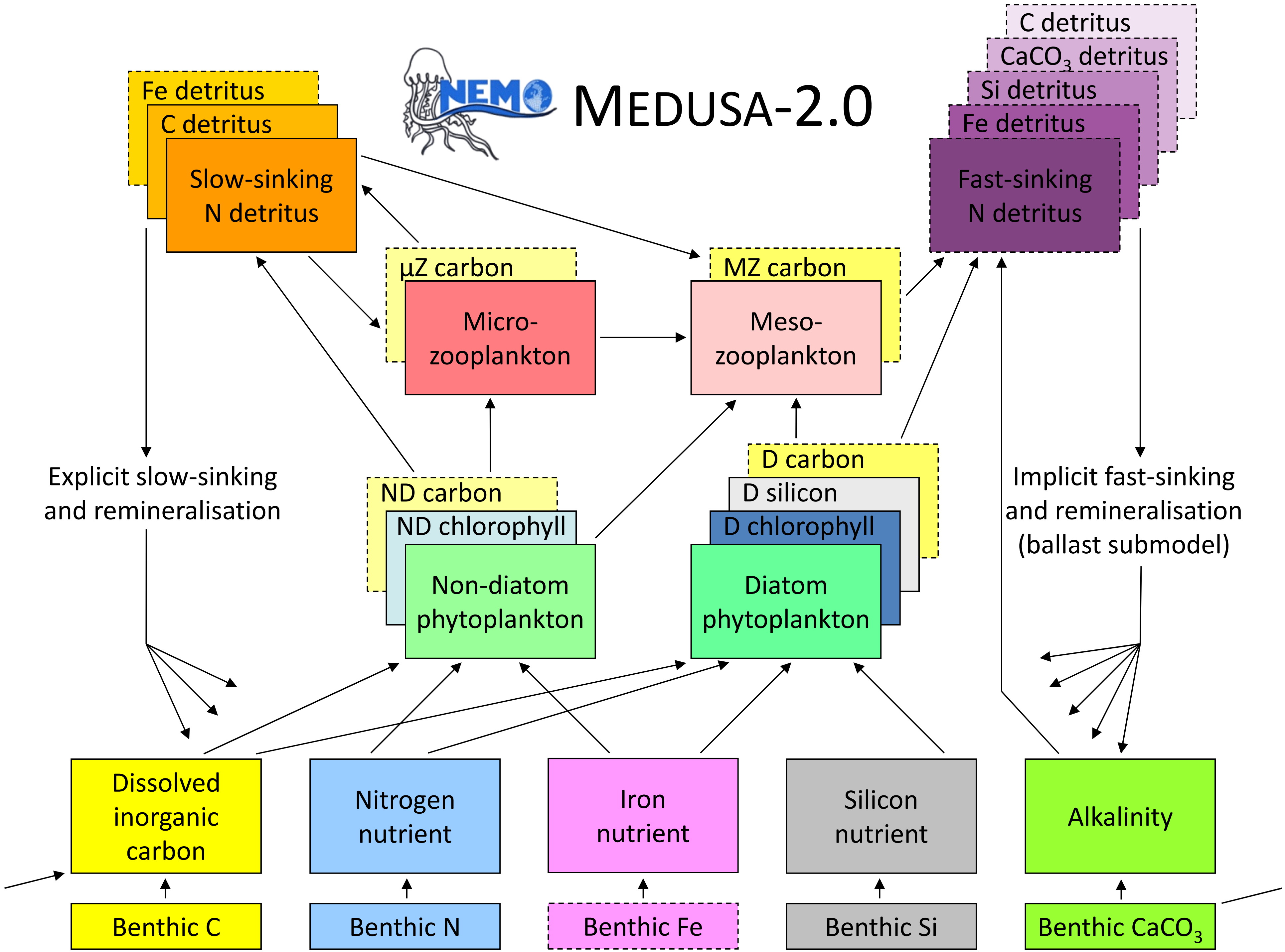
Andrew Yool, Katya Popova, Tom Anderson
and the NOC, Southampton NEMO team
(+ Dan Bernie, UKMO)

Activities

- Completion of trial runs of MEDUSA-2
- Simulations complete of MEDUSA-2 for RCPs 2.6 and 8.5 at 1-degree
- Sensitivity runs on Arctic acidification
- Sensitivity runs on parameterisation of calcification
- Manuscripts submitted on above
- (Ongoing) preparation of corresponding ¼-degree run, to be initialised at 1980

Simulations

- NEMO GCM, 1-degree resolution
- MEDUSA-2 biogeochemistry (N, Si, Fe, C, O_2)
- Surface heat, freshwater and momentum forcing provided by UKMO CMIP5 output
- Initialised at 1860, run out to 2005 under historical CO_2, then run out to 2100 under RCP2.6 (low, unlikely) and **RCP8.5** (high, likely) scenarios
- Analysis at global and regional (Arctic) scales
- Sensitivity analyses on:
  - Calcification feedback
  - Climate Change vs. Ocean Acidification


MEDUSA-2.0
Fe detritus
C detritus
Slow-sinking N detritus
C detritus
CaCO3 detritus
Si detritus
Fe detritus
Fast-sinking N detritus
μZ carbon
Micro-zooplankton
MZ carbon
Meso-zooplankton
Explicit slow-sinking and remineralisation
ND carbon
ND chlorophyll
Non-diatom phytoplankton
D carbon
D silicon
D chlorophyll
Diatom phytoplankton
Implicit fast-sinking and remineralisation (ballast submodel)
Dissolved inorganic carbon
Nitrogen nutrient
Iron nutrient
Silicon nutrient
Alkalinity
Benthic C
Benthic N
Benthic Fe
Benthic Si
Benthic CaCO3

Small

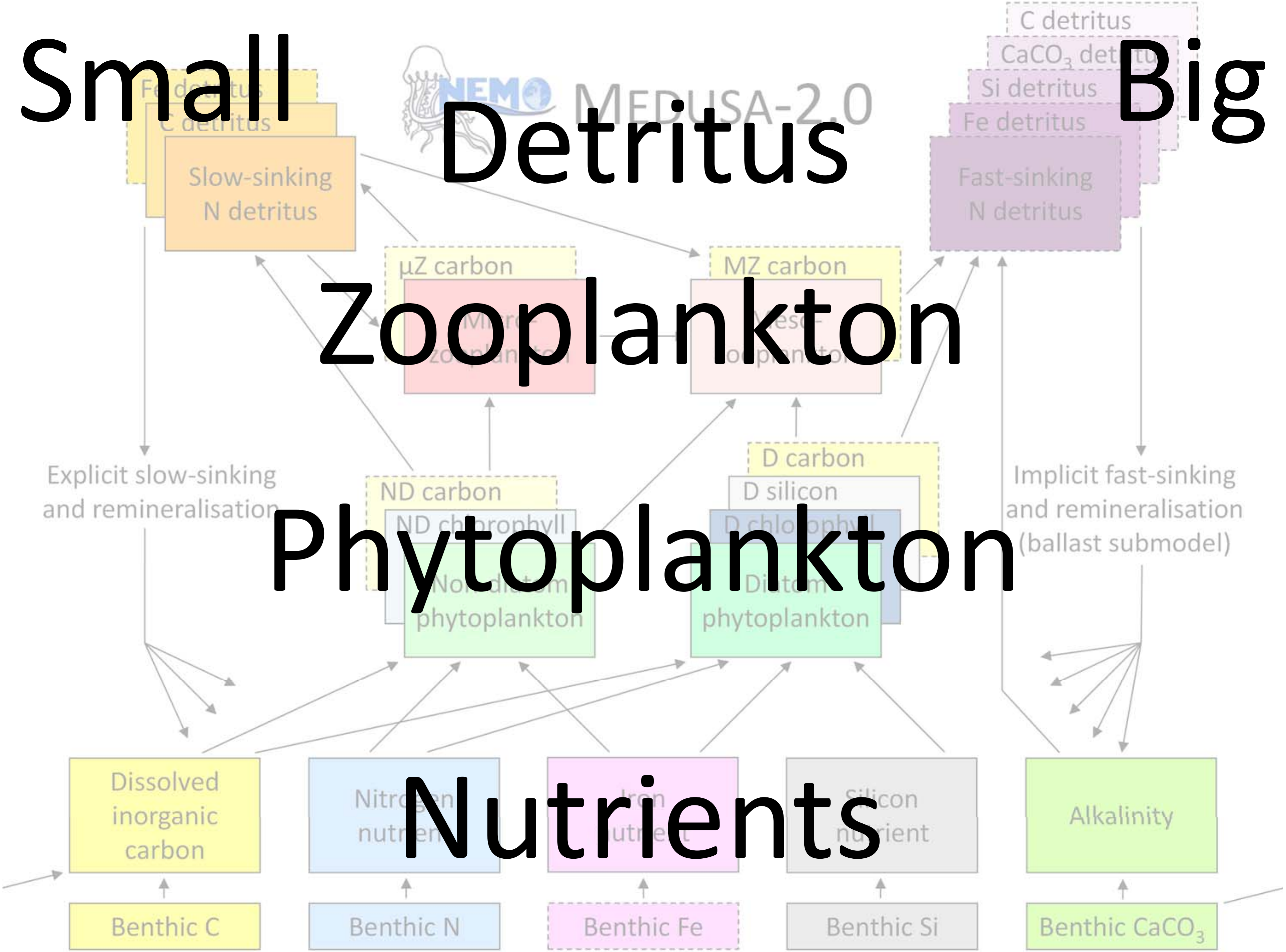
Big

Detritus

Zooplankton

Phytoplankton

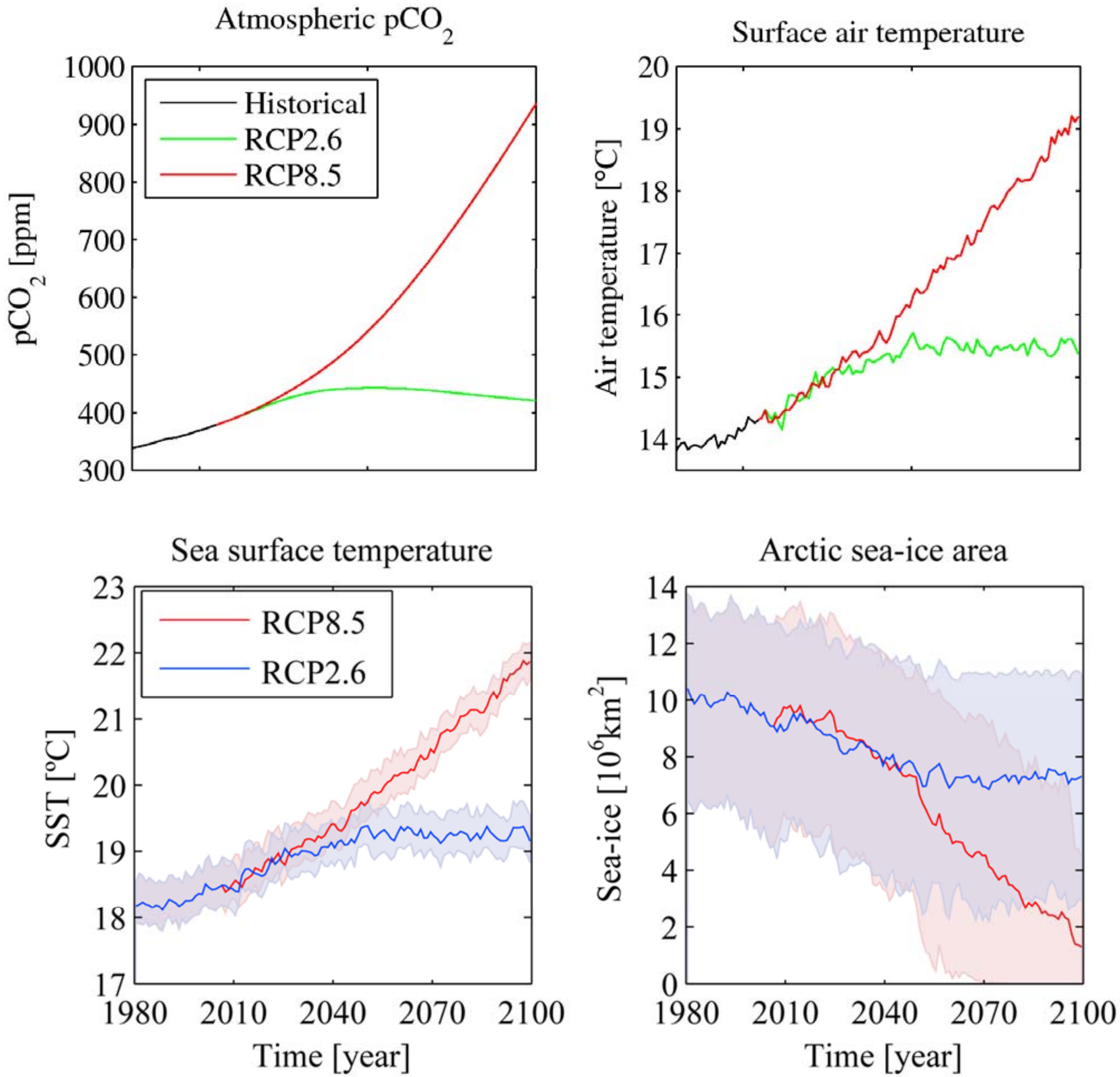
Nutrients



RCPs 2.6 and 8.5

Forced

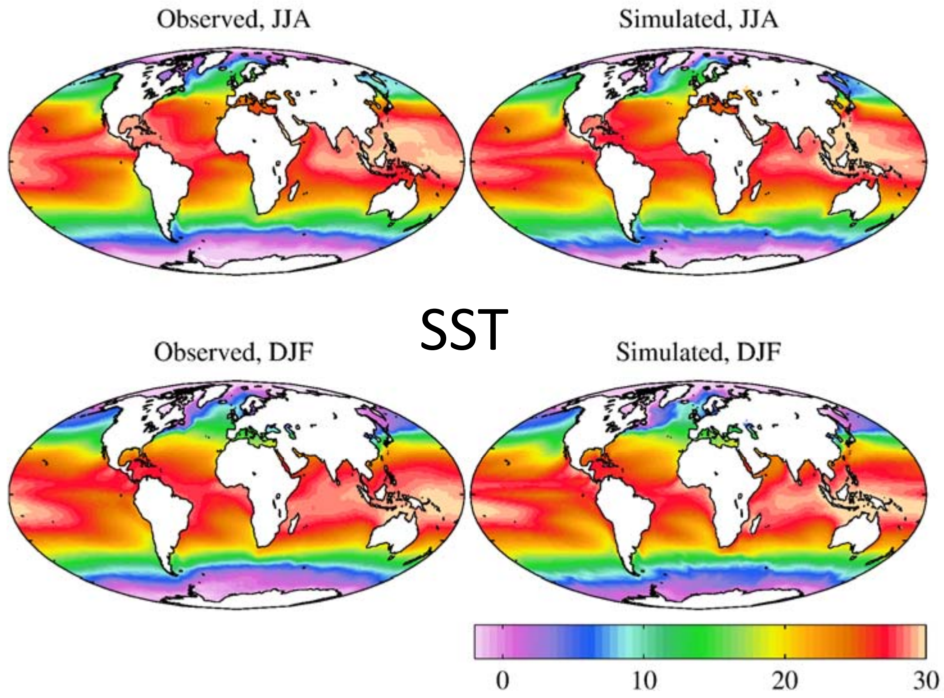
Dynamic



Forced

Dynamic

Global scale

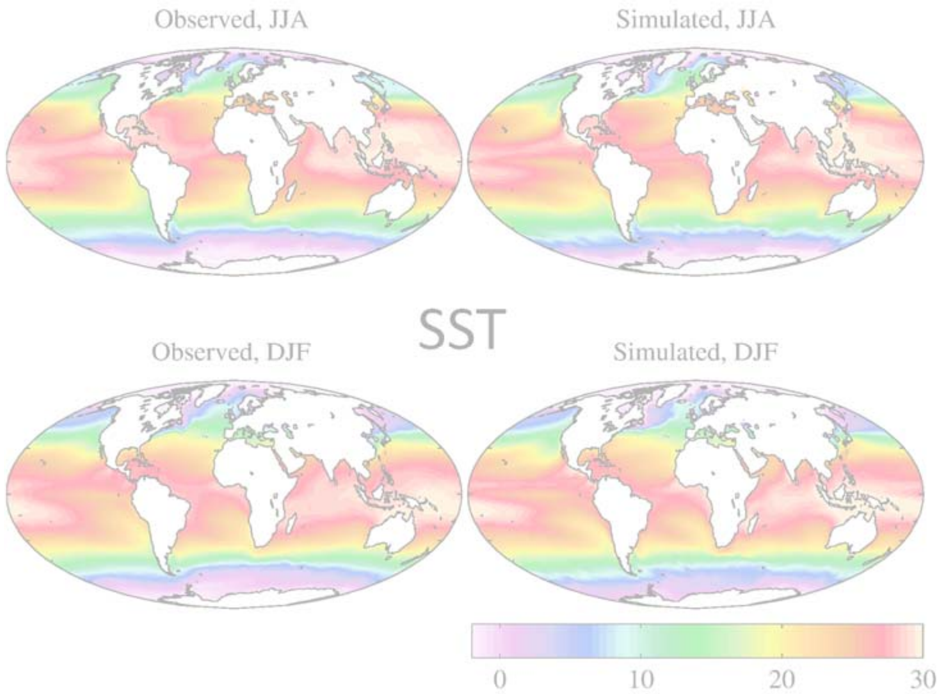


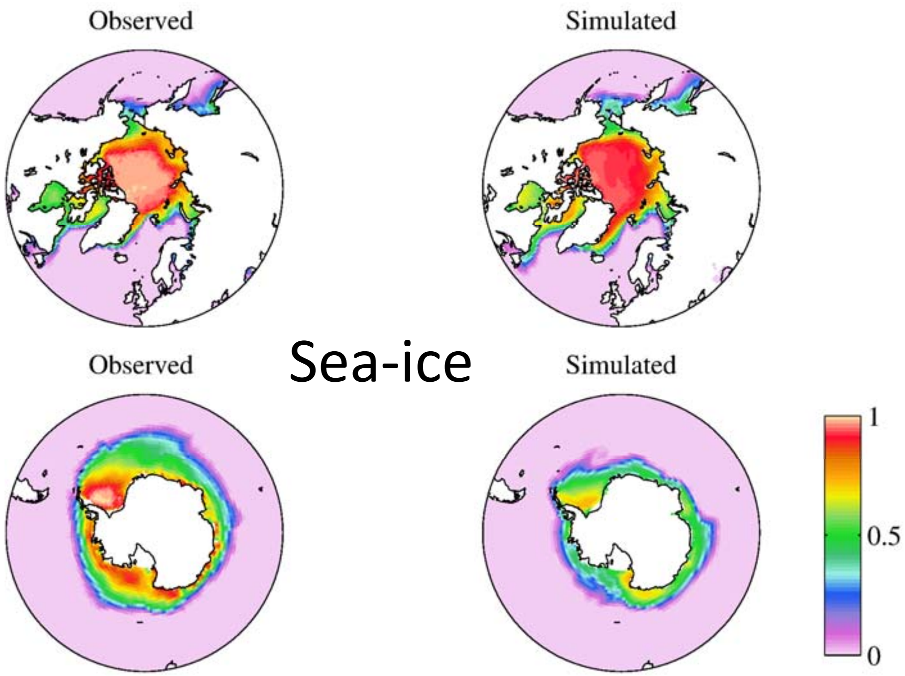
Model validation

- Circulation too “healthy”

Model validation

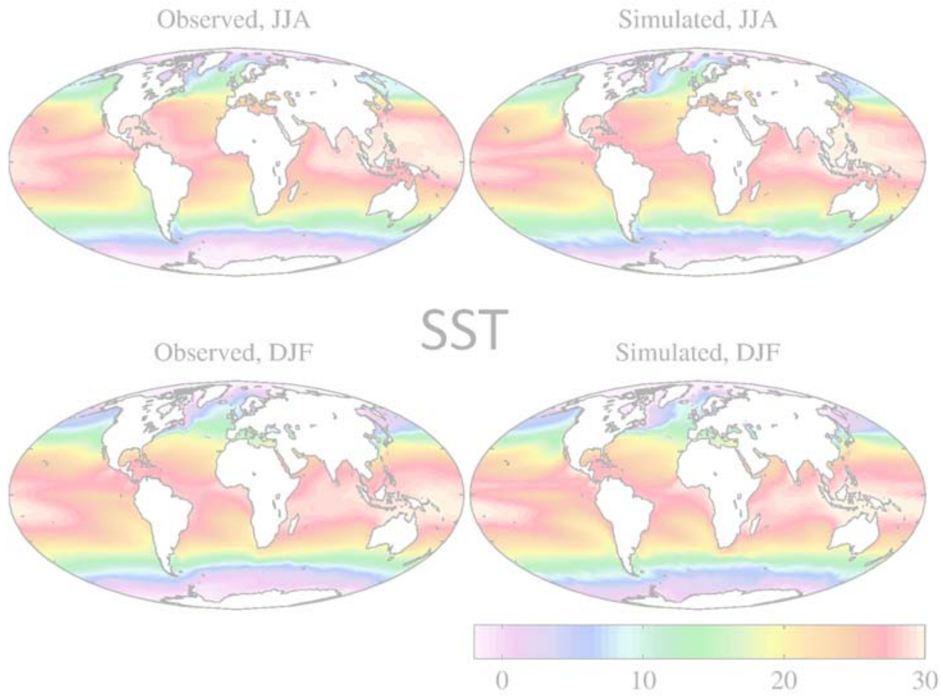
- Circulation too “healthy”
- Arctic sea-ice good; Antarctic sea-ice generally too low

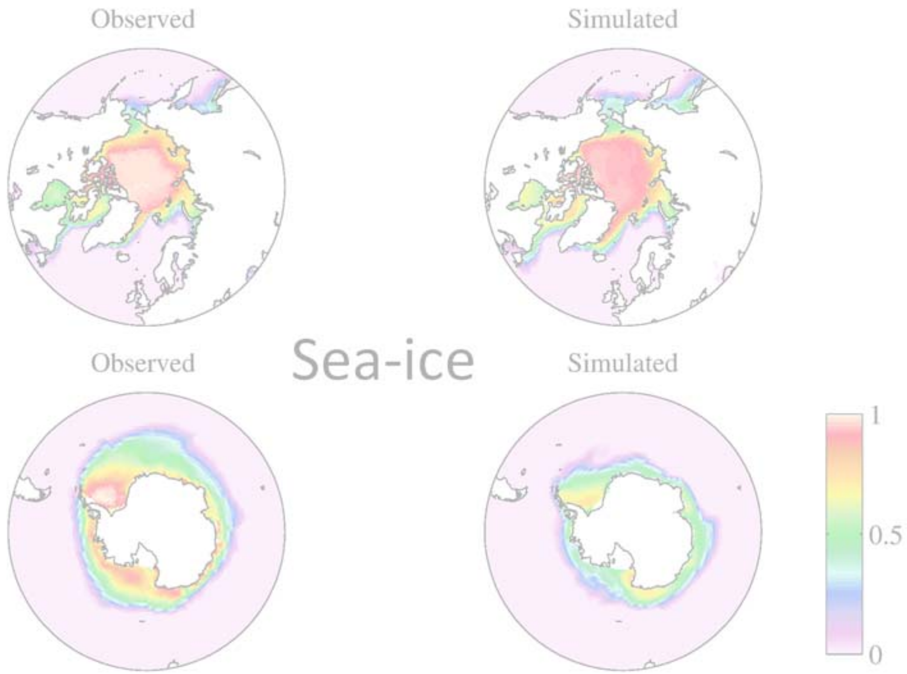


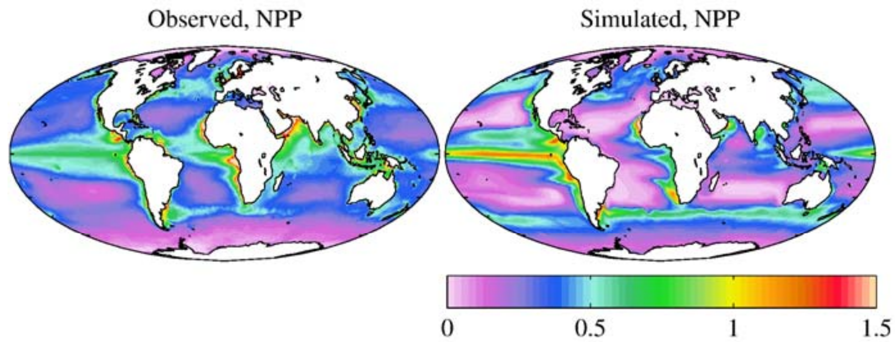


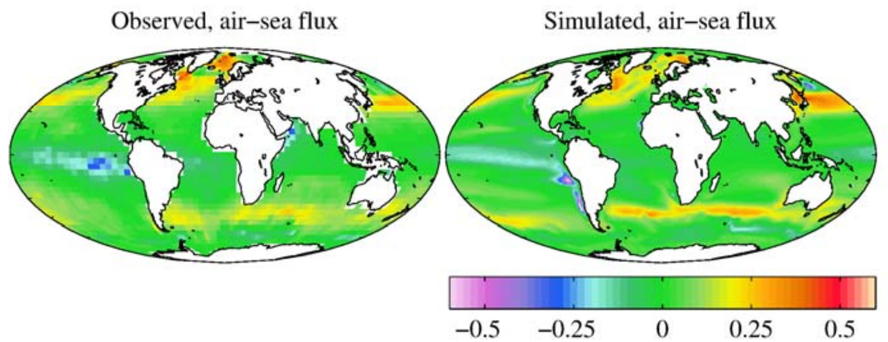
Model validation

- Circulation too "healthy"
- Arctic sea-ice good; Antarctic sea-ice generally too low
- NPP on the low side with usual distribution problems
- CO_2 flux good, emphasising limited role of MEDUSA





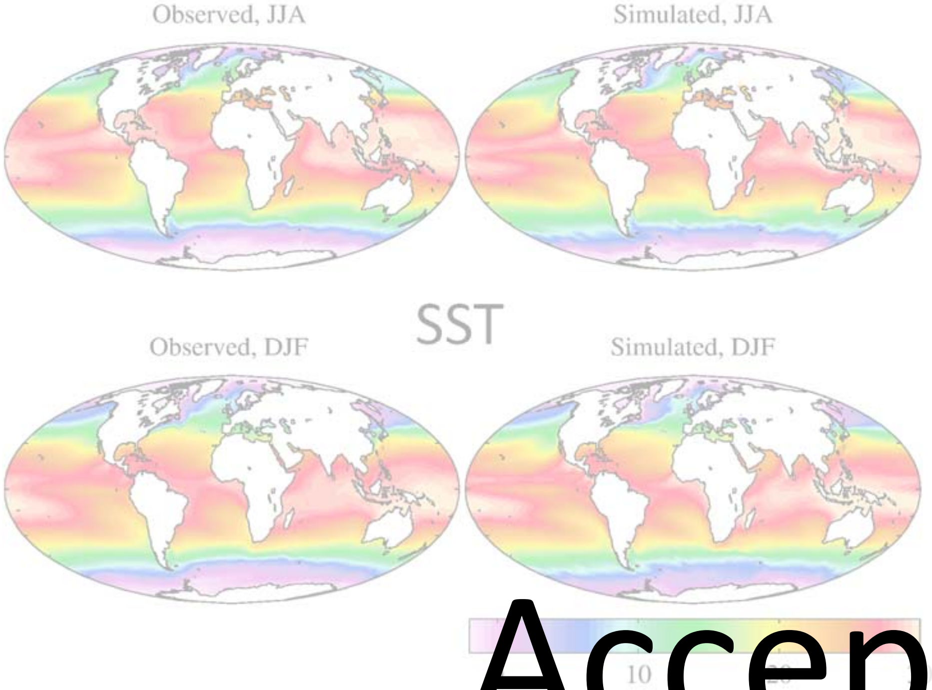


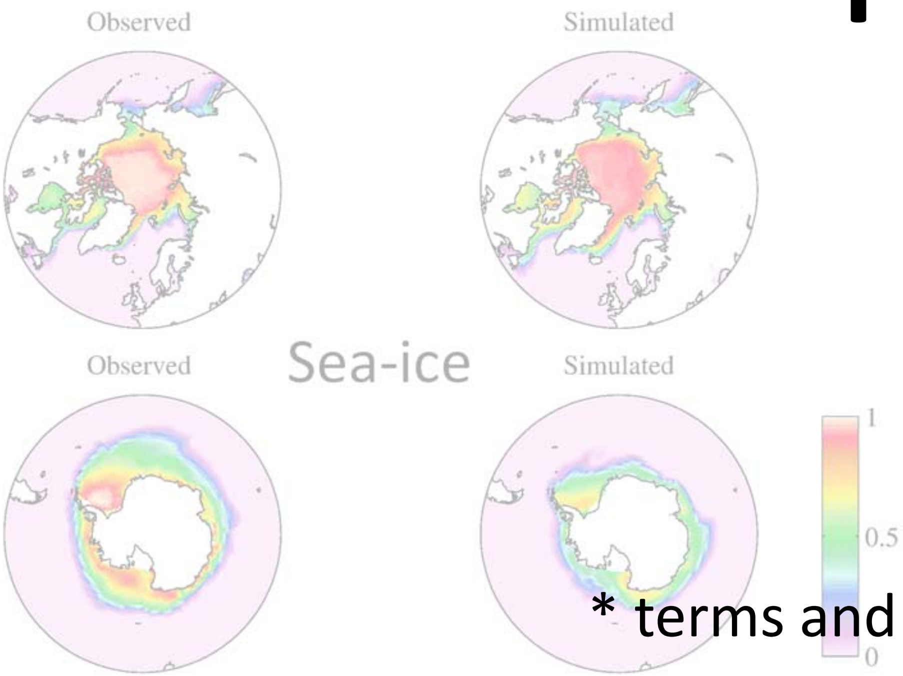


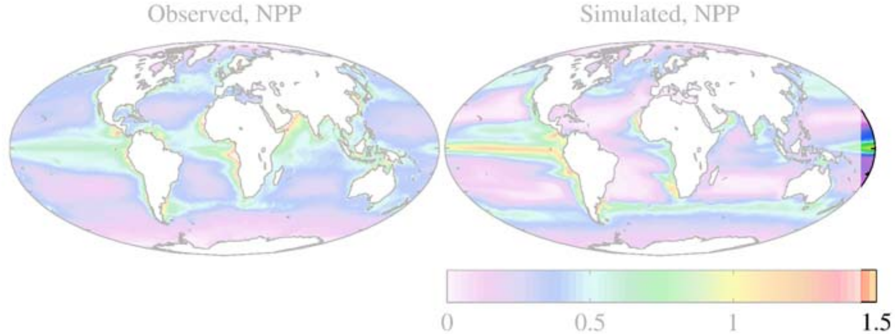
Model validation

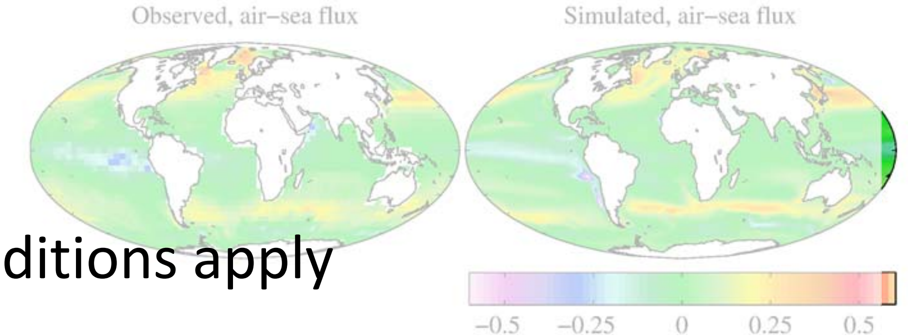
- Circulation too "healthy"
- Arctic sea-ice good; Antarctic sea-ice generally too low
- NPP on the low side with usual distribution problems
- CO_2 flux good, emphasising limited role of MEDUSA

Acceptable!*

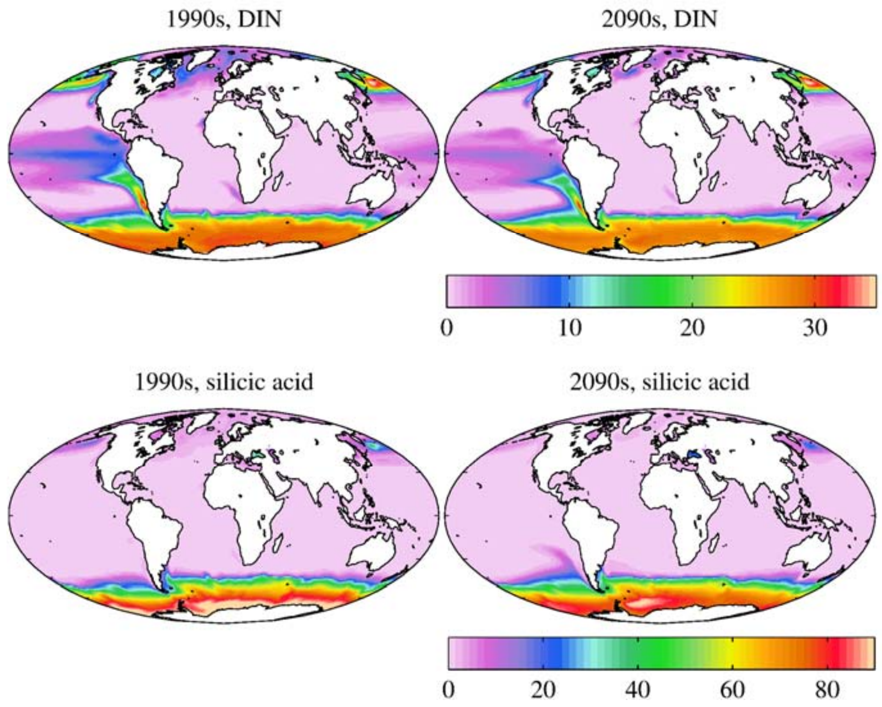






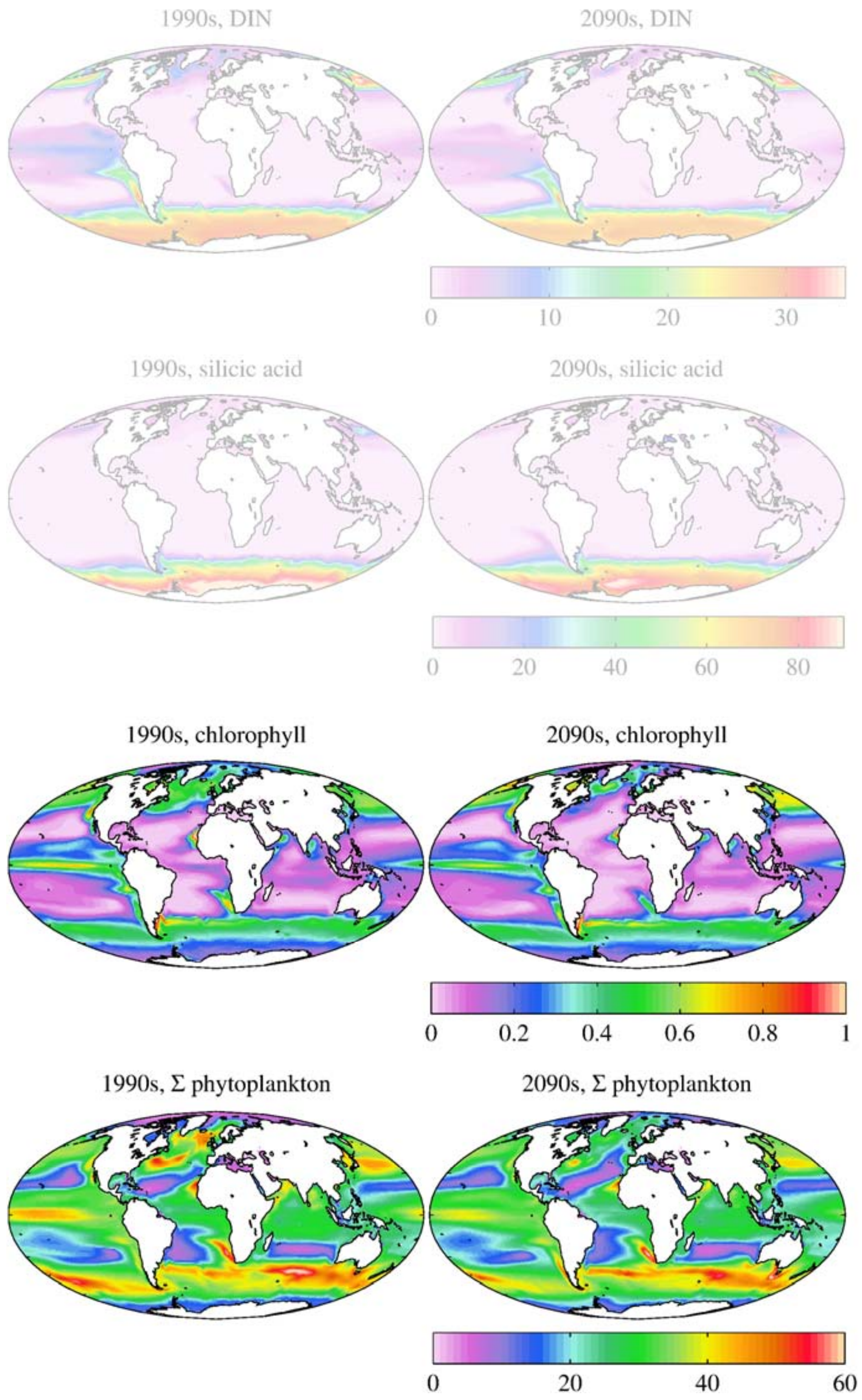


* terms and conditions apply



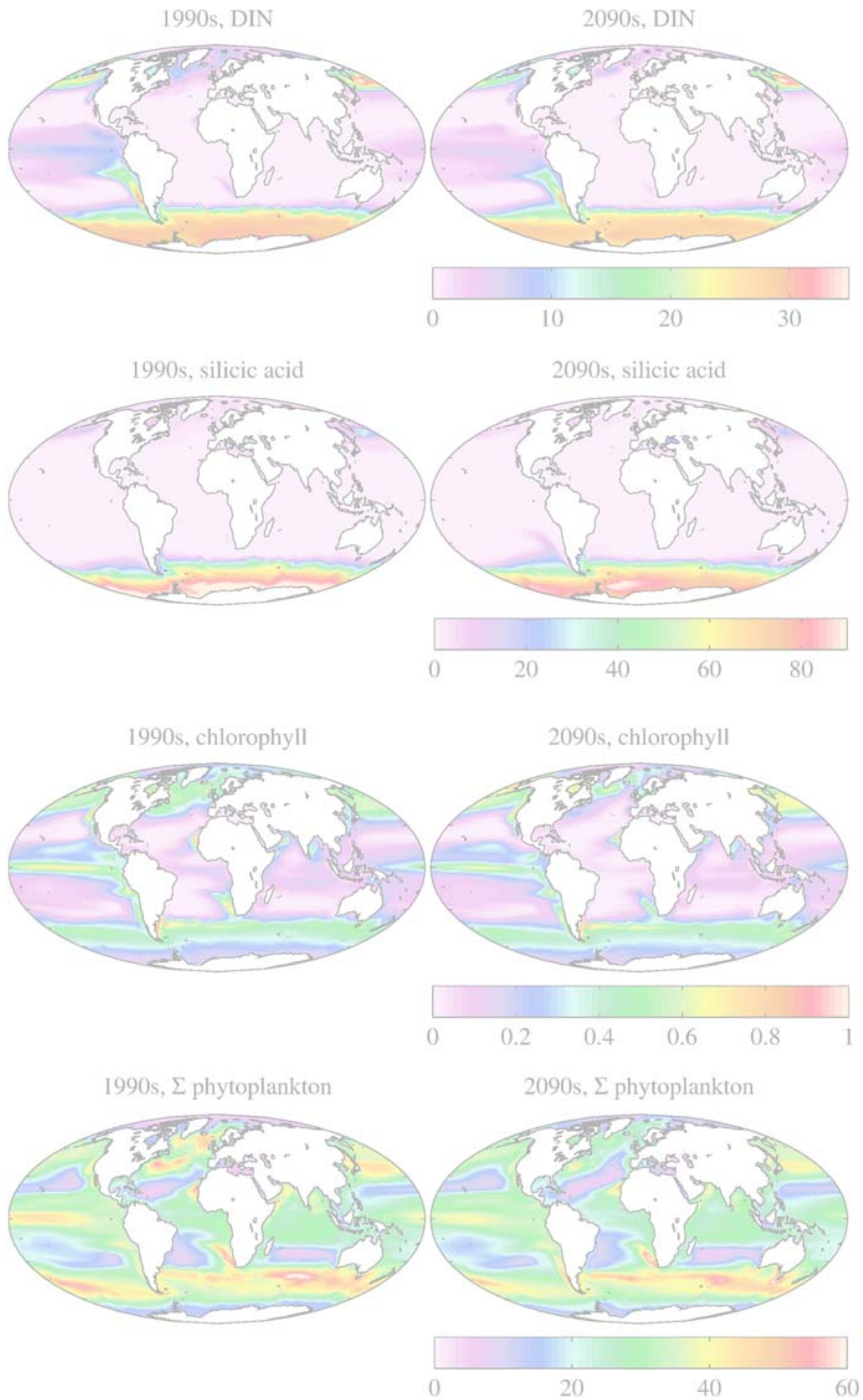
1990s vs. 2090s

- Decline in N and Si nutrients due to stratification, but rise in Fe as it is unused



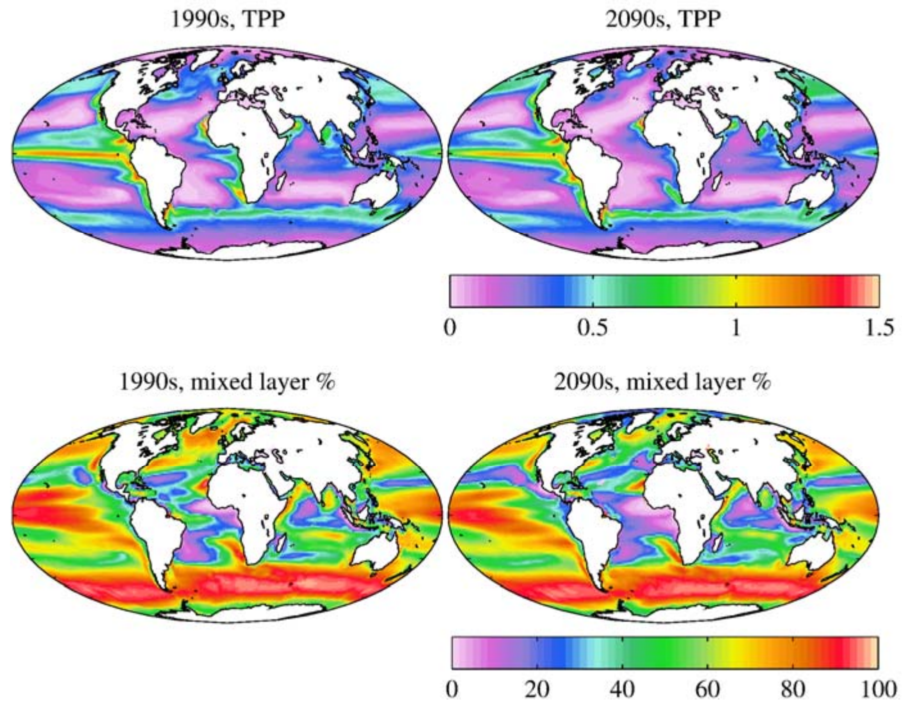
1990s vs. 2090s

- Decline in N and Si nutrients due to stratification, but rise in Fe as it is unused
- Concomitant general decline in ocean productivity



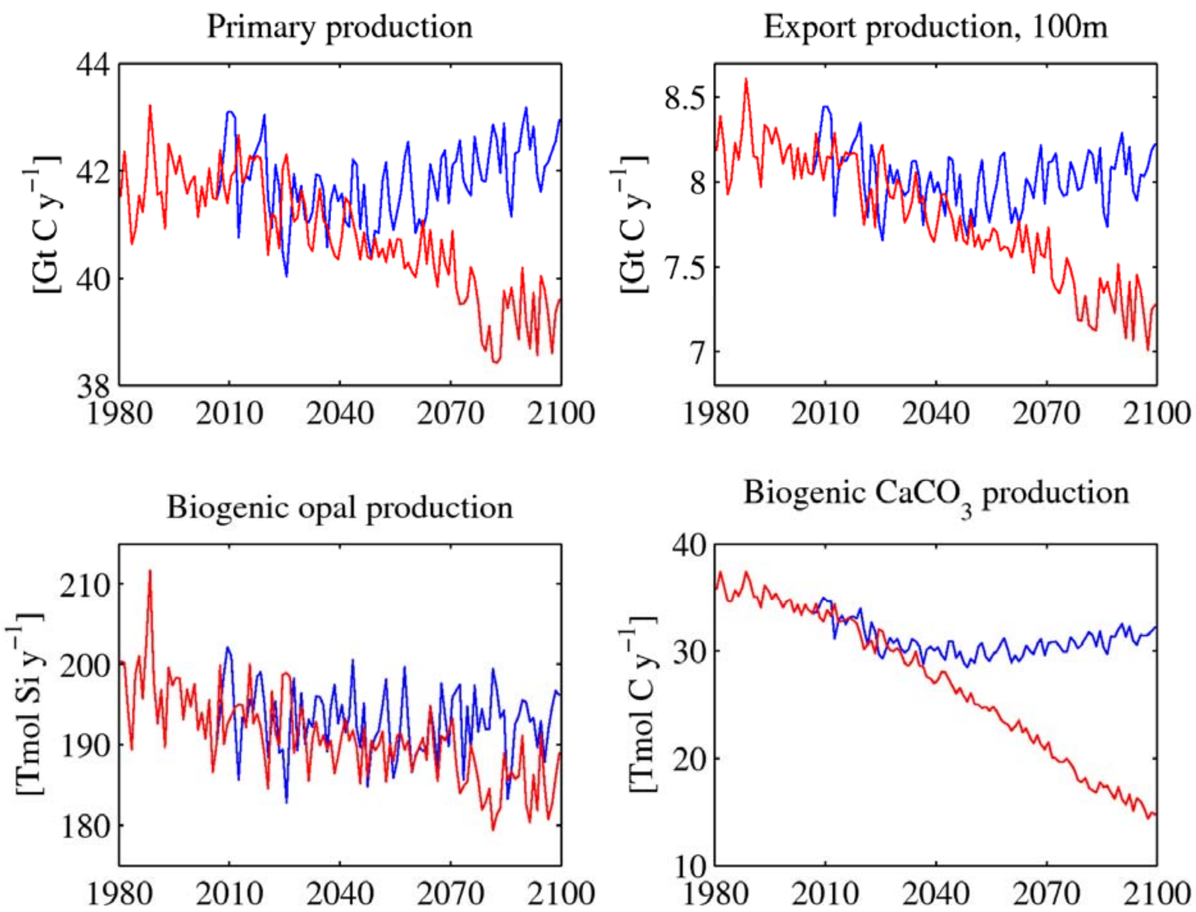
1990s vs. 2090s

- Decline in N and Si nutrients due to stratification, but rise in Fe as it is unused
- Concomitant general decline in ocean productivity; especially North Atlantic, down by > 20%
- Arctic productivity up by 60%



RCP2.6 vs. RCP8.5

Red = RCP8.5; Blue = RCP2.6



- Direction of changes similar between runs
- Differences obviously in magnitude
- Biogeochemical changes relatively minor under RCP2.6
- RCP2.6 simulation shows some recovery (e.g. Arctic sea-ice) by year 2100
- Significant change is not inevitable

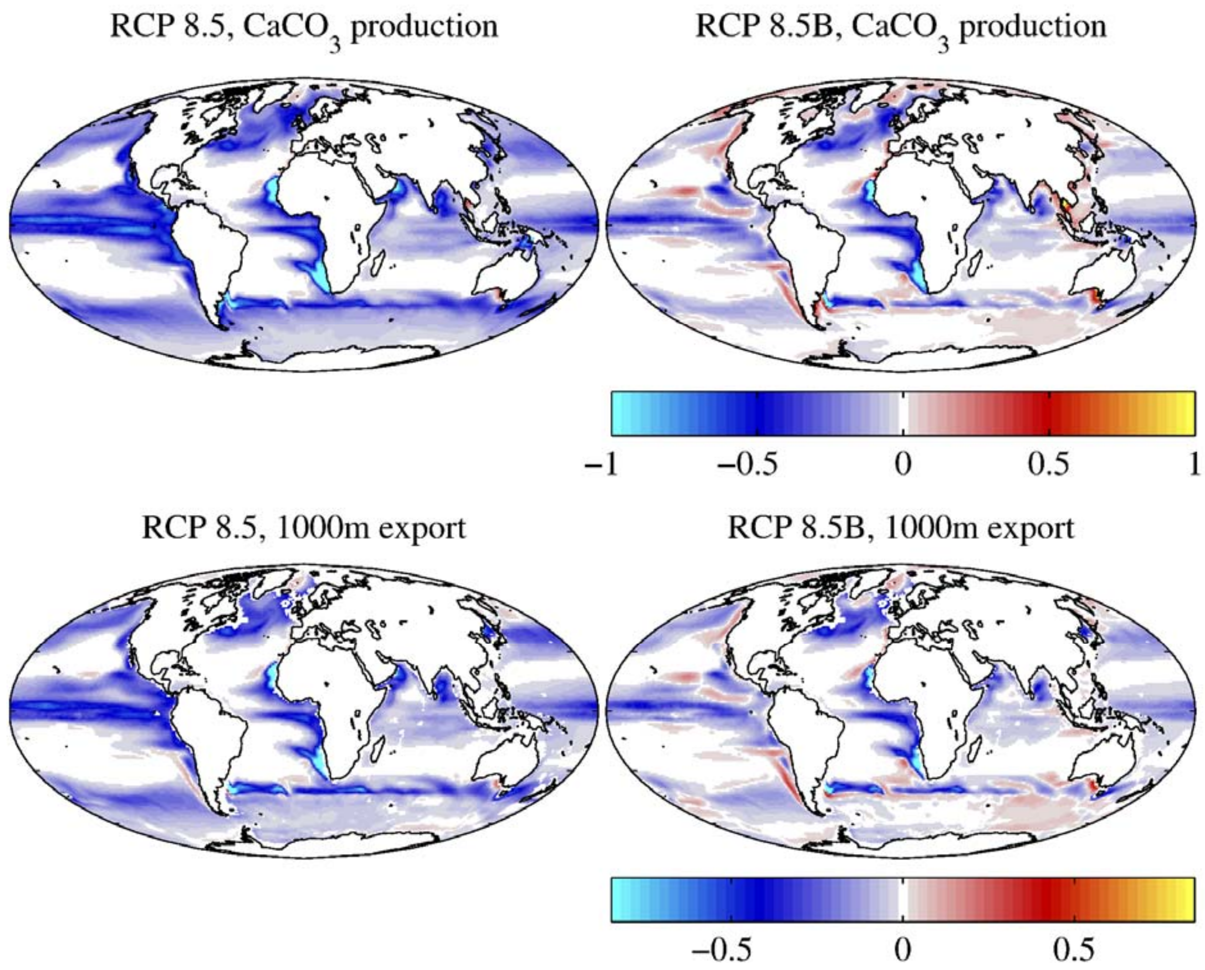
What about acidification impacts?

- MEDUSA-2.0 includes a version of Ridgwell *et al.* (2007)'s dynamic $CaCO_3$ submodel:

$$\text{rain ratio} = (\Omega_{calcite} - 1)^{\eta} \cdot r_0$$

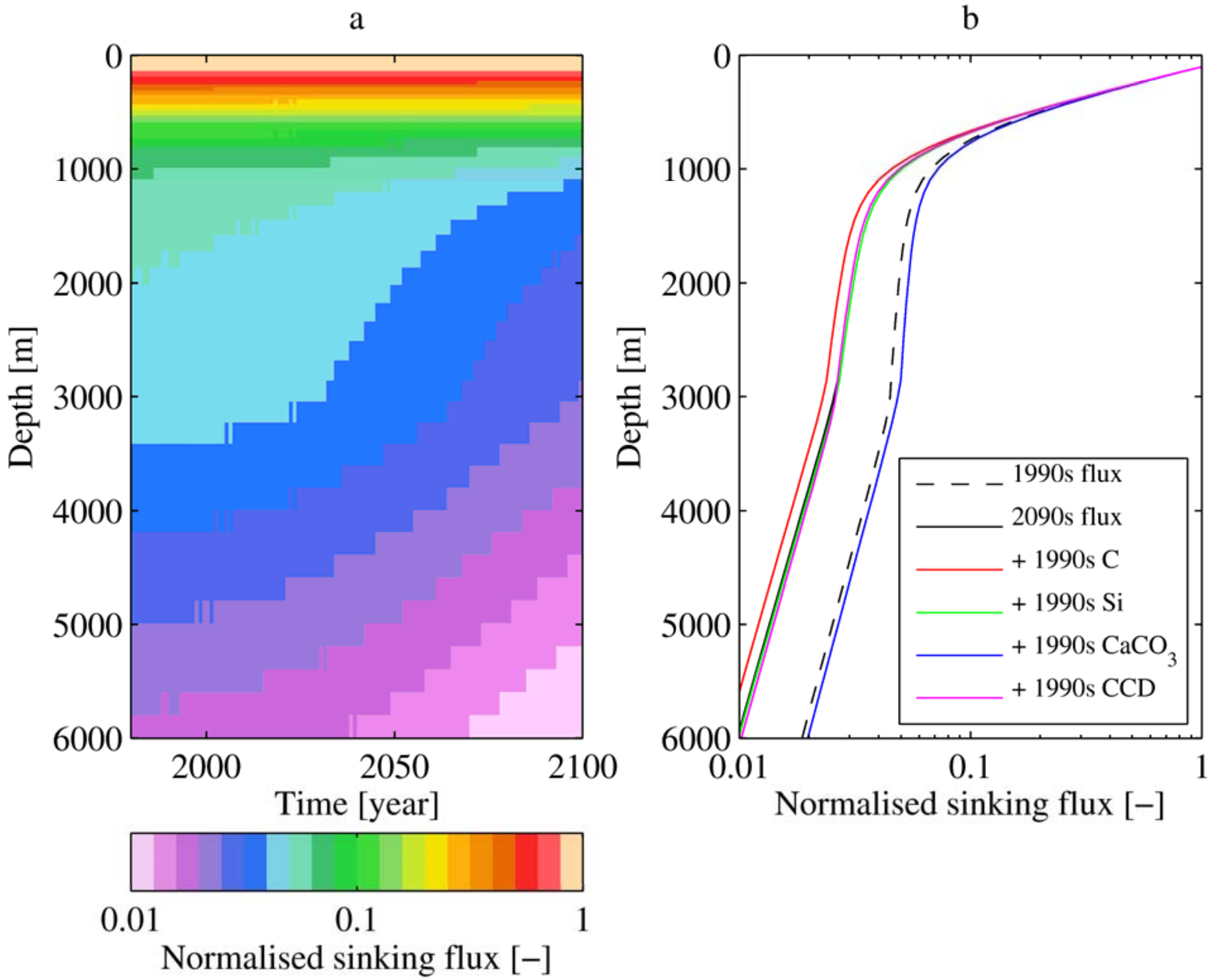
- Where a default rain ratio, r_0, is modified by local (or surface) calcite saturation, $\Omega_{calcite}$
- As sensitivity analysis, average 1990s rain ratio "locked-in" for 21st century regardless of OA
- $CaCO_3$ production still linked to production of detritus and dissolution still $\Omega_{calcite}$-dependent

Calcification sensitivity



- Minor changes to BGC tracers
- BGC fluxes generally similar but with some exceptions
- Calcification: -56% → -17%
- Export, 1000m: -41% → -18%
- Deep sea communities may be impacted disproportionally by OA-driven change

Ballasting breakdown



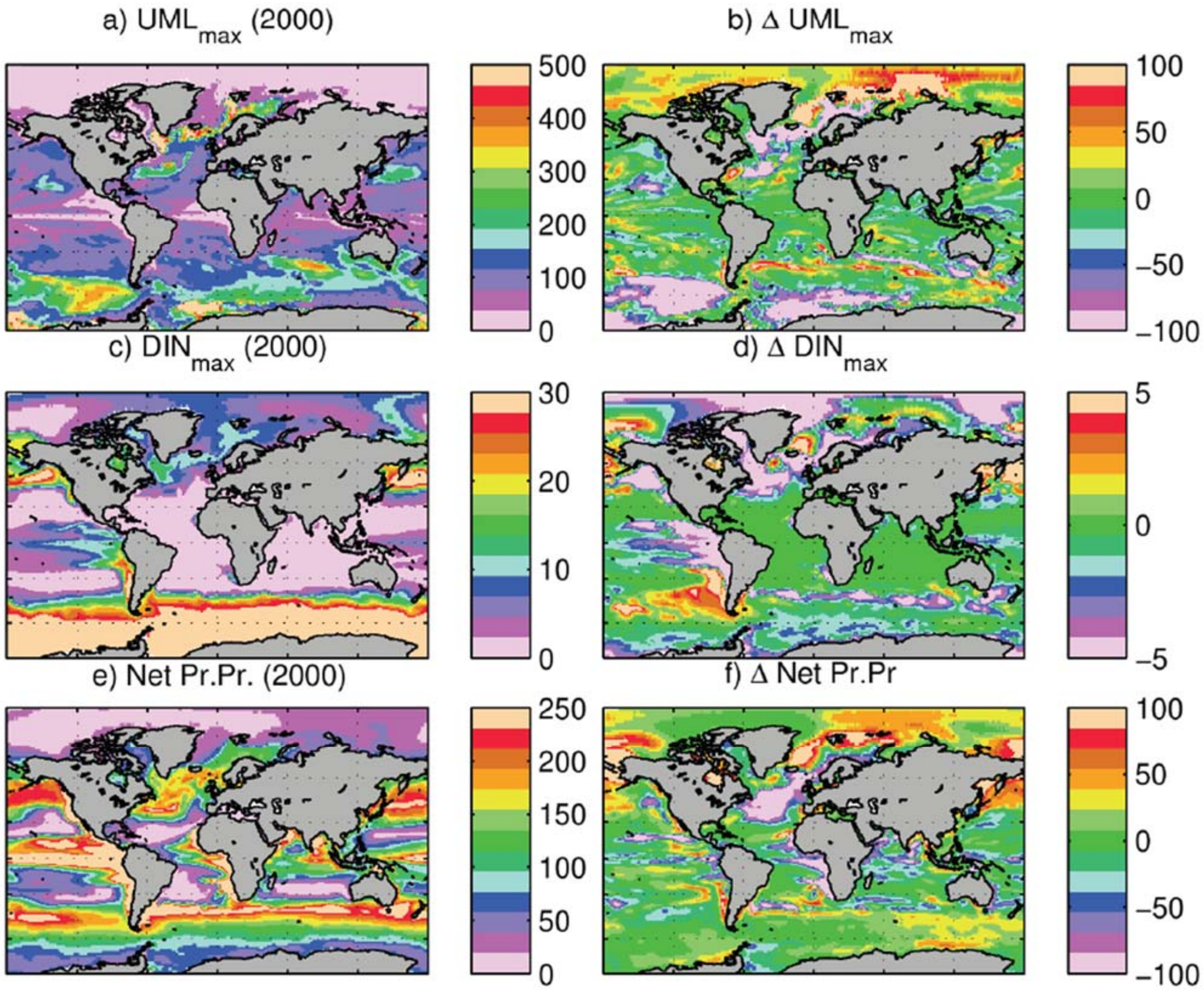
- As noted, significant shoaling of remin. during 21st century
- More factors than $CaCO_3$ in play for fast-sinking detritus
- C_{org}, opal, $CaCO_3$ and CCD depth
- Factors separated via 1990s substitution
- $CaCO_3$ production is dominant

Global conclusions

- All regions of the World Ocean (except the Arctic) experience **falling productivity** due to **decreased nutrient availability**; productivity generally shifts downwards and to non-diatoms
- Near-surface export production declines **broadly in line** with primary production; however, because of OA-driven changes to calcification, the export flux decreases **above and beyond** the production decline, increasingly so with depth, with **potential consequences for seafloor communities**
- This key result relies on MEDUSA–2.0's use of OA-sensitive calcification and the ballast hypothesis; this suggests improving understanding of such poorly constrained processes is critical for accurate future forecasts

Arctic scale

Change in the Arctic



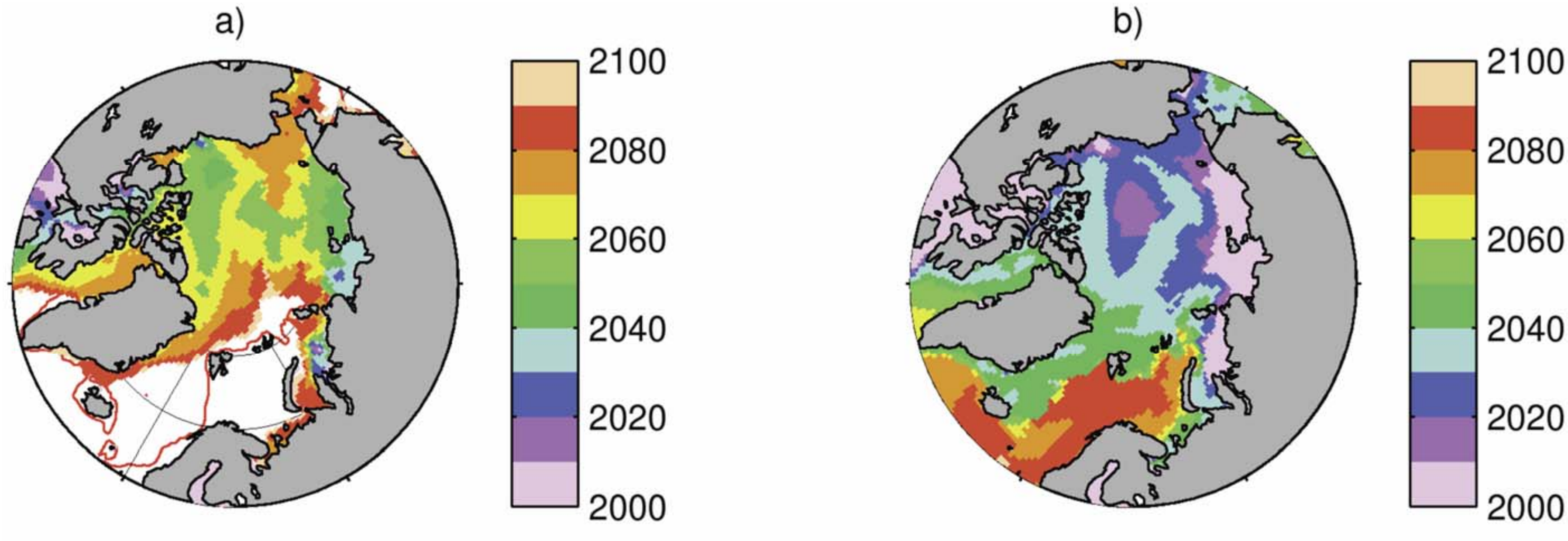
Under RCP8.5, the Arctic is forecast here to have some of the largest changes in the World Ocean:

- Mixed layers are deeper across the region
- Low surface nutrients are further lowered
- But production is still increased under a longer ice-free summer season with higher vertical mixing

Undersaturation dates

Calcite, surface

Aragonite, surface



- The decade in which calcite and aragonite become undersaturated
- Calcite remains supersaturated beyond 2100 in the N. Atlantic
- Aragonite becomes undersaturated throughout region before 2100
- Broad-scale similarity between date-maps, but differences too
- Differences relate to timing of ice-loss and details of circulation

Arctic conclusions

- Results find that Arctic is the first basin to exhibit widespread undersaturation with respect to aragonite and, later, calcite
- Climate change feedbacks critical in driving spatio-temporal heterogeneity of declines in Ω and pH_{SWS} in the Arctic
- Onset of surface undersaturation shows great variability (up to a century) as a result of differences in retreat of sea-ice, changes in freshwater input and changes in stratification (with implications for use of lower resolution models – like ours!)
- In line with previous studies, the strongest driving force – and the largest uncertainty in prediction– is the rate of decline of sea-ice; model intercomparisons of OA need to assess this in relation to model projections of sea-ice retreat

Manuscripts

1. Yool, A., Popova, E. E., and Anderson, T. R.: MEDUSA-2.0: an intermediate complexity biogeochemical model of the marine carbon cycle for climate change and ocean acidification studies, *Geosci. Model Dev. Discuss.*, 6, 1259-1365, doi:10.5194/gmdd-6-1259-2013, 2013.
2. Popova, E. E., Yool, A., Coward, A. C., and Anderson, T. R.: Regional variability of acidification in the Arctic: a sea of contrasts, *Biogeosciences Discuss.*, 10, 2937-2965, doi:10.5194/bgd-10-2937-2013, 2013.
3. Yool, A., Popova, E. E., Coward, A. C., Bernie, D., and Anderson, T. R.: Climate change and ocean acidification impacts on lower trophic levels and the export of organic carbon to the deep ocean, *Biogeosciences Discuss.*, 10, 3455-3522, doi:10.5194/bgd-10-3455-2013, 2013.

Manuscripts

1. Yool, A., Popova, E. E., and Anderson, T. R.: MEDUSA-2.0: an intermediate complexity biogeochemical model of the marine carbon cycle for climate change and ocean acidification studies, *Geosci. Model Dev. Discuss.*, 6, 1259-1365, doi:10.5194/gmdd-6-1259-2013, 2013.
2. Popova, E. E., Yool, A., Coward, A. C., and Anderson, T. R.: Regional variability of acidification in the Arctic: a sea of contrasts, *Biogeosciences Discuss.*, 10, 2937-2965, doi:10.5194/bgd-10-2937-2013, 2013.
3. Yool, A., Popova, E. E., Coward, A. C., Bernie, D., and Anderson, T. R.: Climate change and ocean acidification impacts on lower trophic levels and the export of organic carbon to the deep ocean, *Biogeosciences Discuss.*, 10, 3455-3522, doi:10.5194/bgd-10-3455-2013, 2013.

Ongoing

- As yet unresolved difficulties encountered setting MEDUSA-2 up on HECTOR
- Upon completion of this – and finalisation and publication of current manuscripts! – will initialise ¼-degree simulation (1980-2050)
- Analysis to focus on detail of Atlantic collapse and patterns of Arctic under-saturation
- <u>Very interested</u> to hear of interesting OA feedbacks for sensitivity analyses

Available output (1-degree)

- Historical (1860-2005), future (2005-2099)
  - RCP2.6, RCP8.5
- Calcification sensitivity runs (2001-2099)
  - RCP2.6, RCP8.5
- RCP8.5 CC / OA sensitivity runs (1860-2099)
  - *Default:* *+CC* *+OA*
  - Control: –CC –OA
  - Climate: +CC – OA
  - Acid: –CC +OA
- Mixing, sea-ice sensitivity runs (2001-2099)

Send me an e-mail: `axy@noc.ac.uk`