Complexity and the Earth System

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With

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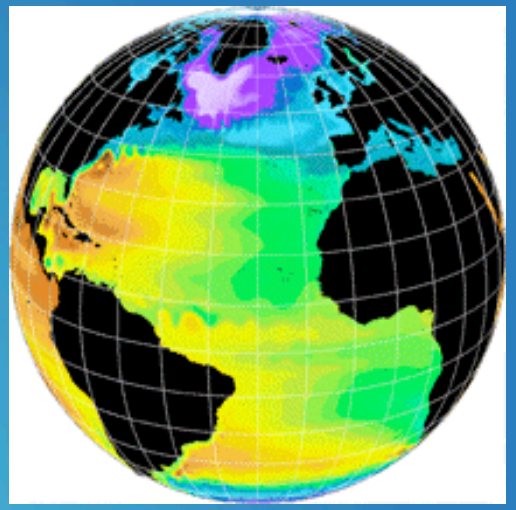
Earth from Space: the Blue Planet

Complexity in the Earth System:

structural & scientific

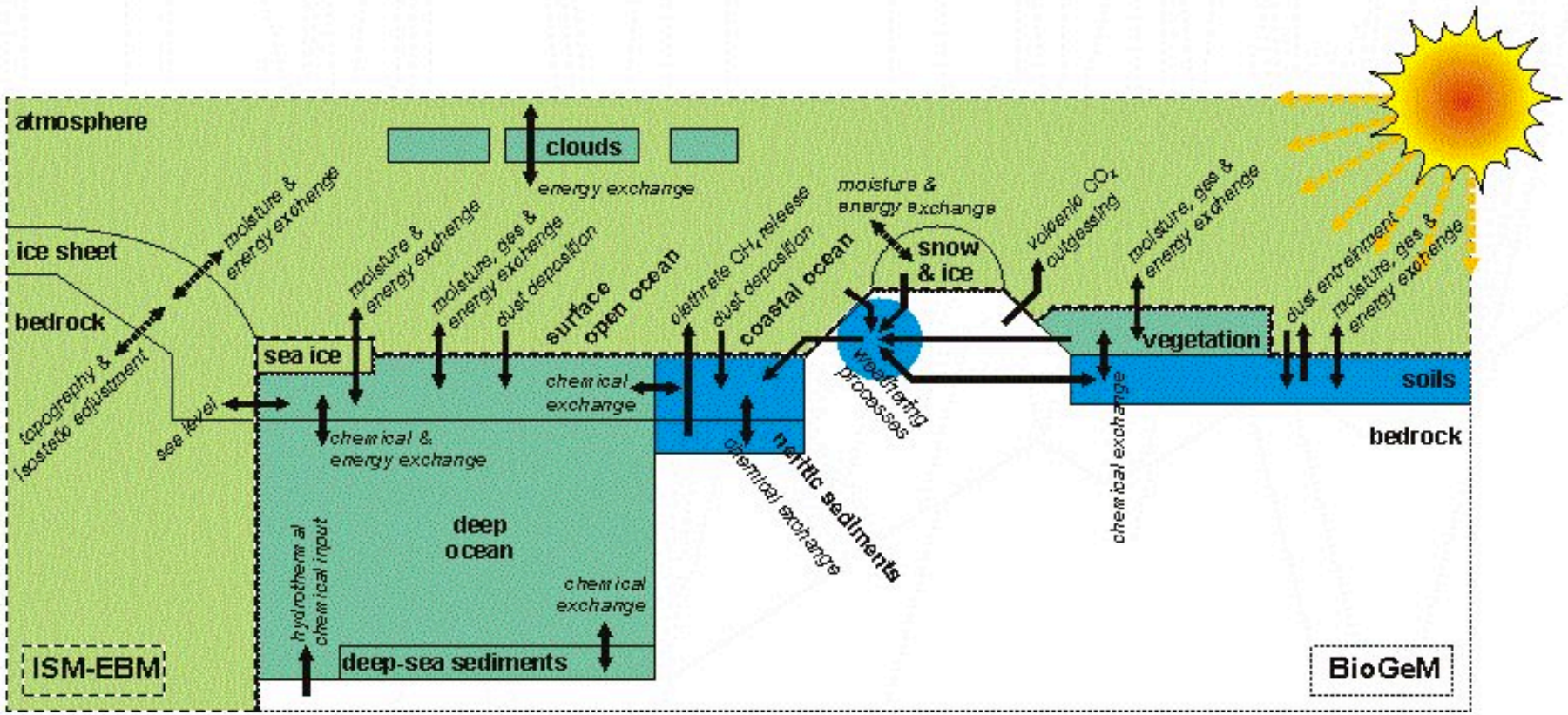


The Earth System comprises

- ***the solid Earth and the land surface***
- ***the hydrosphere (oceans, rivers & lakes)***
- ***the atmosphere***
- ***the cryosphere (sea-ice, glaciers and the ice caps)***
- ***the biosphere – both terrestrial and marine.***

- ***Interdisciplinary (we need many "ologies")***
  - ***Physics, Chemistry, Biology, Geology, Meteorology, Oceanography, Glaciology, Ecology…***

The Earth System (according to GENIE)



KEY

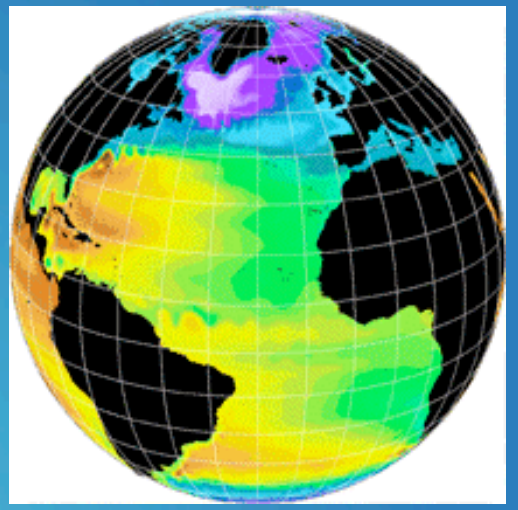
Model component pre-exists - little further work required

Model component pre-exists in part - development required

Model component does not exist - develop from scratch

Slide courtesy of A. Ridgwell (Genie)

Complexity in the Earth System



Many variables (in 4 dimensions)

e.g. Temperature, Salinity, Velocity
Phosphate, Nitrate, Silicate, Carbon (various)

Spatially heterogeneous
(so we need to resolve this to some extent)

Time dependent (from hours to aeons)

Highly non-linear; especially in physics
=> turbulence & eddies
and in biology (too many species !!)…

Cascades:
(1) of predation…

Jonathan Swift (ca 1700); on ***predation***

- So, naturalists observe, a flea
- has smaller fleas that on him prey;
- And these have smaller still to bite ’em;
- And so proceed, *ad infinitum*.

Cascades:
(2) of turbulence

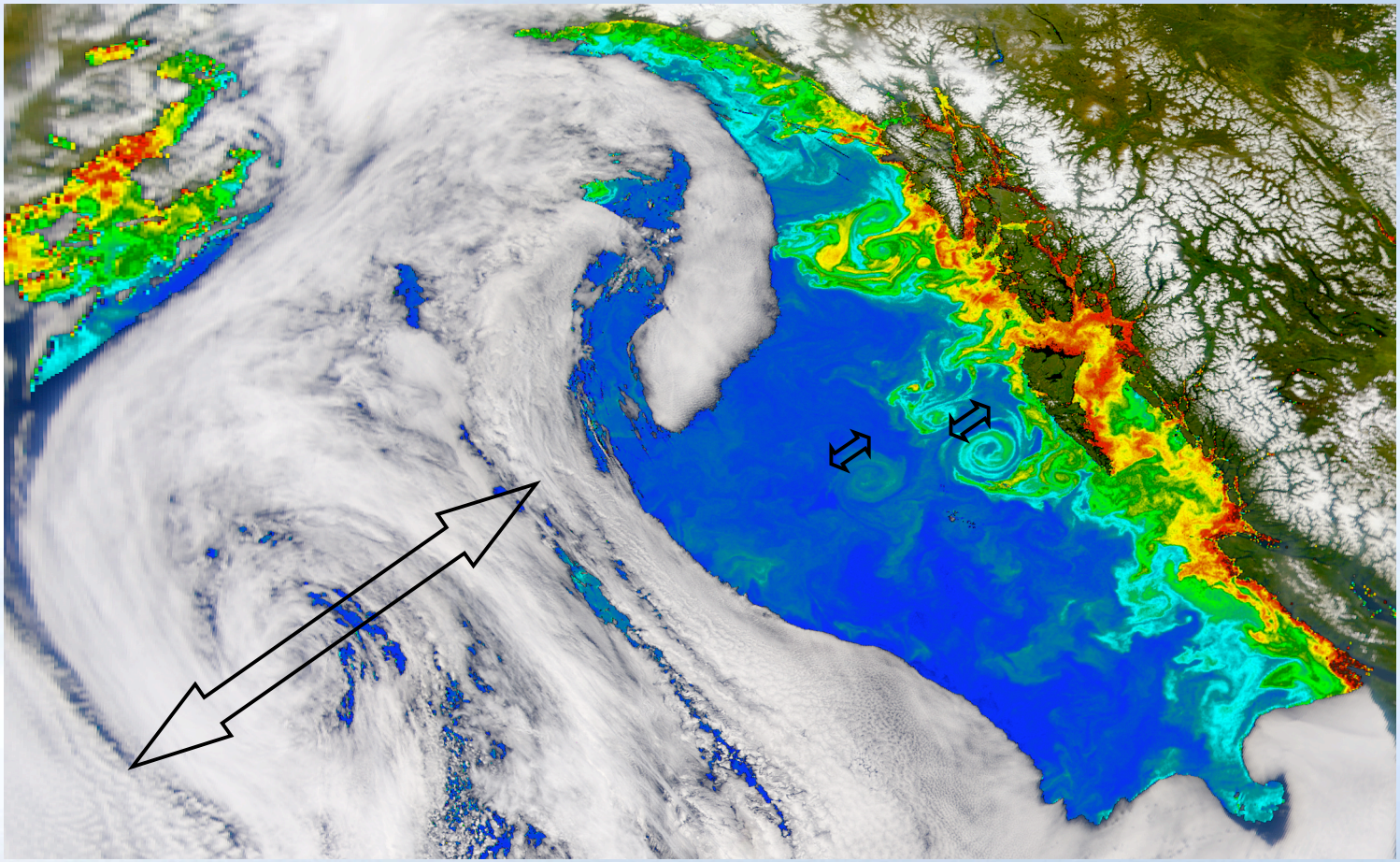
L.F.Richardson (ca 1930) on ***turbulence***…

- “Big eddies have little eddies,
- and little eddies have smaller eddies,
- that feed on their vorticity,
- and so on to viscosity.”

(fractals and self-similarity are quite old ideas)

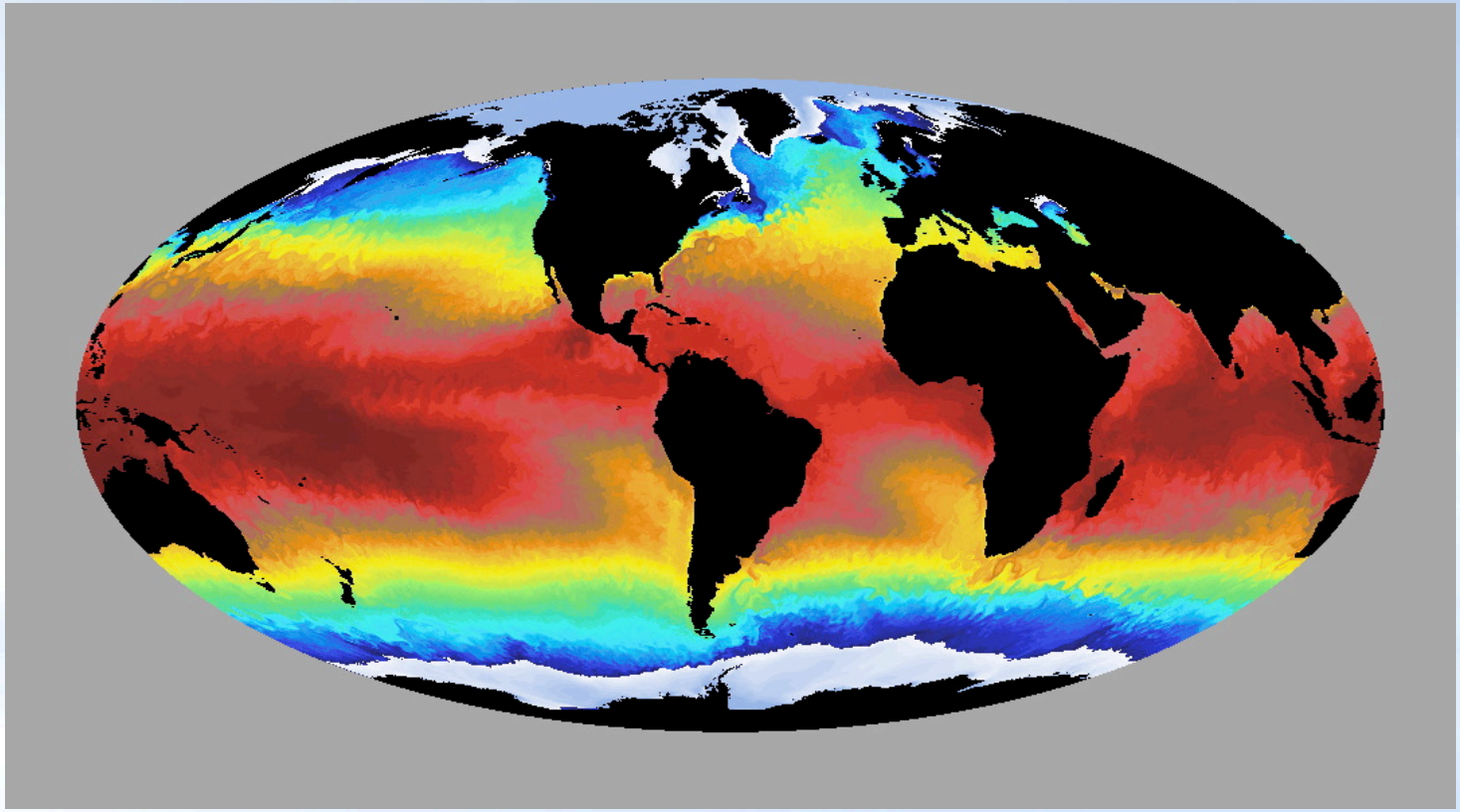
Mesoscale Eddies in Ocean & Atmosphere

Satellite image of ocean colour (& visible - clouds): NE Pacific



- Ocean eddies are smaller than atmospheric eddies, by an order of magnitude
  - yet “eddy” fluxes also play a key role in ocean circulation
  - with impacts on Climate and Biogeochemical Cycles

Eddy-resolving models of the World Ocean
e.g., OCCAM (superseded by the NEMO project)

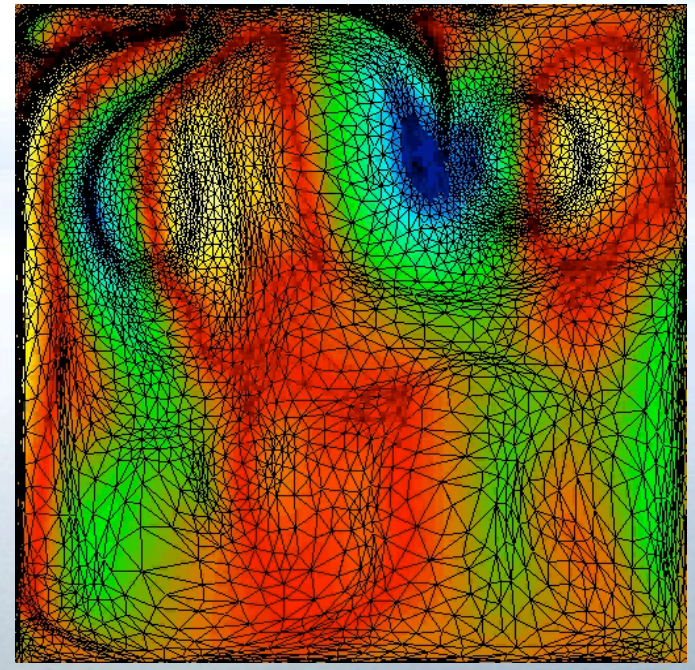


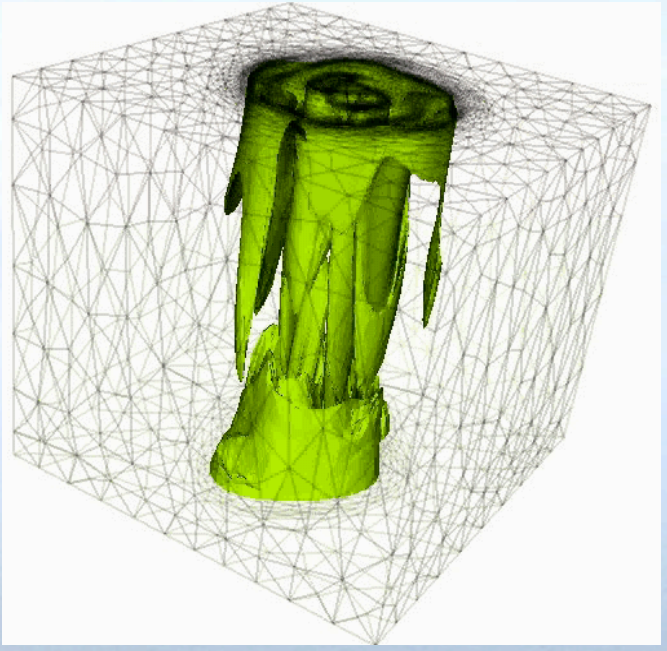
- four 3-D datasets (salinity, temperature, current): 4 x 1/12° x 1/12° x 66 levels
- ~60% ocean (full-depth equivalent - 71% ocean, average depth 4000 m)
- so 4 x 0.6 x 4320 x 1735 x 66 = 1,187,239,680 individual data values
- every 5 days for 1985-2006 = 1606 datasets, so ~1.9 x 10^{12} data in total!

Future Developments?

- Free up the 3-D mesh to evolve in space and time
- High resolution only when & where you need it …
- Preliminary results of Imperial College Ocean Model (ICOM)

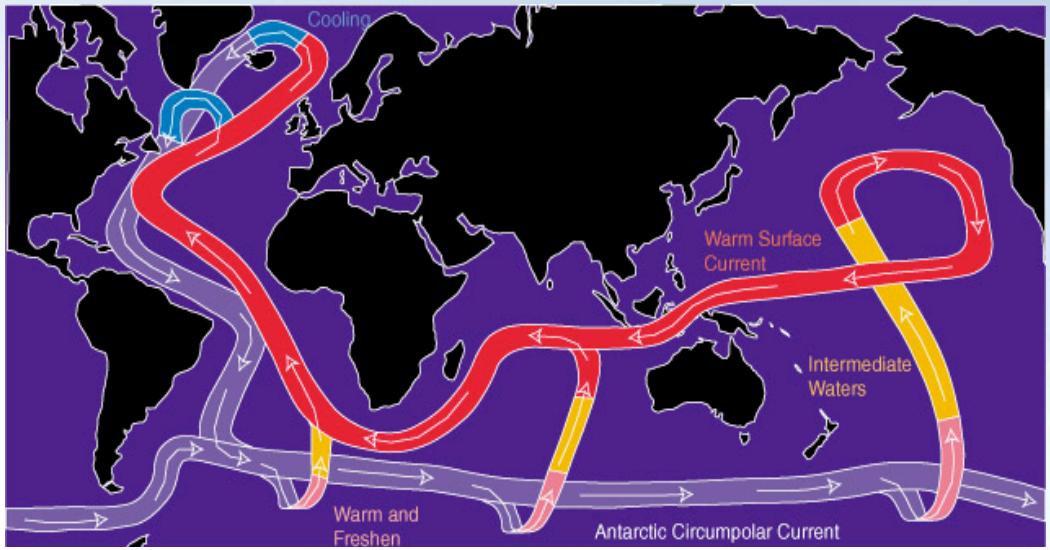
Horizontal mesh in idealized basin



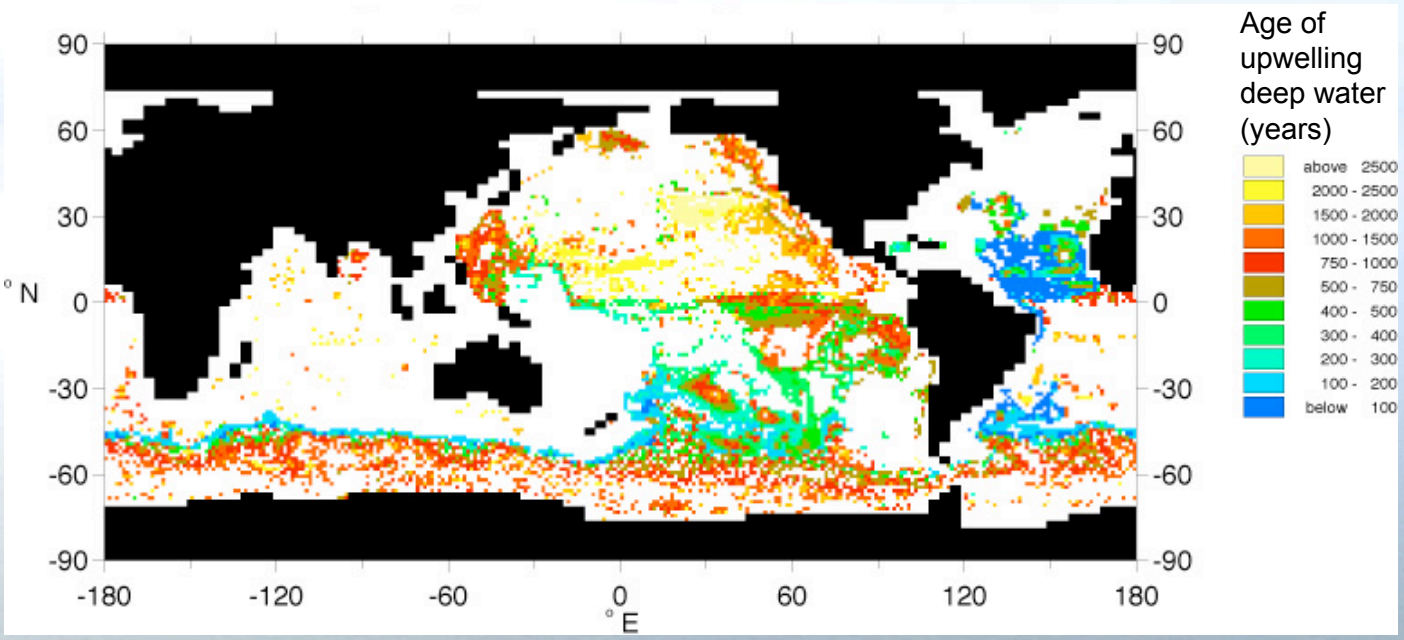


3-D visualization of convective event

Long-timescale climate processes



Observations and theory suggest a global “Conveyor Belt”, maintaining stable climate over the last ~10,000 years



Based on offline trajectory analysis, it is clear that the model Conveyor timescales exceed 1000 years

- So we need computationally cheaper models …

GENIE: a new Earth System Model of Intermediate Complexity: Bob Marsh et al (2001- now)

~2000

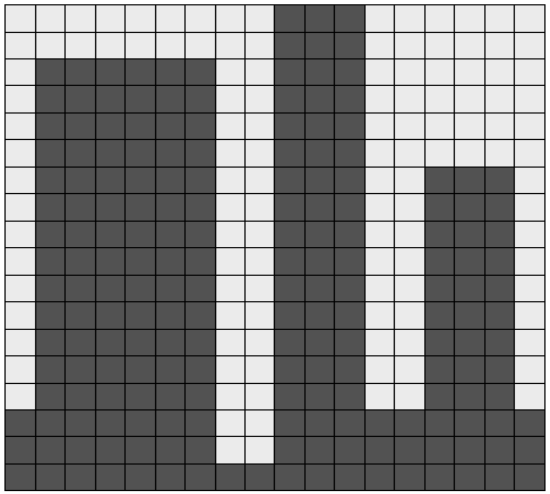
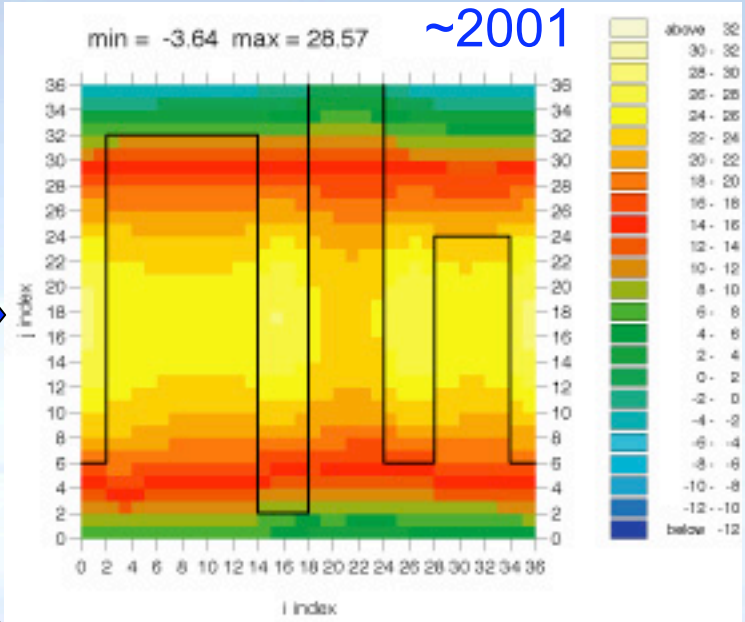
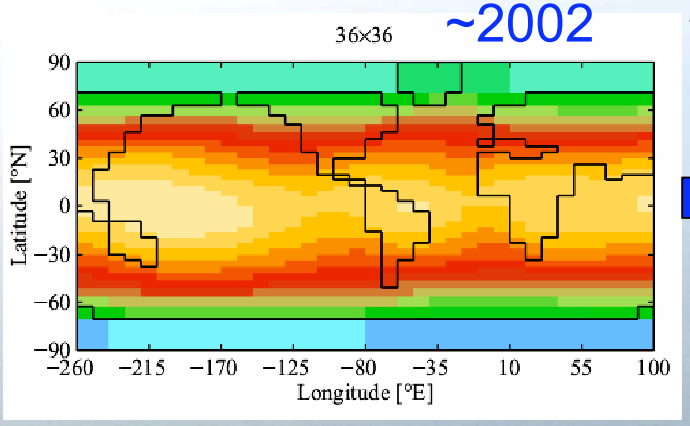


Figure 1: Diagram of the model domain, ocean cells are shaded dark grey. See text for explanation.

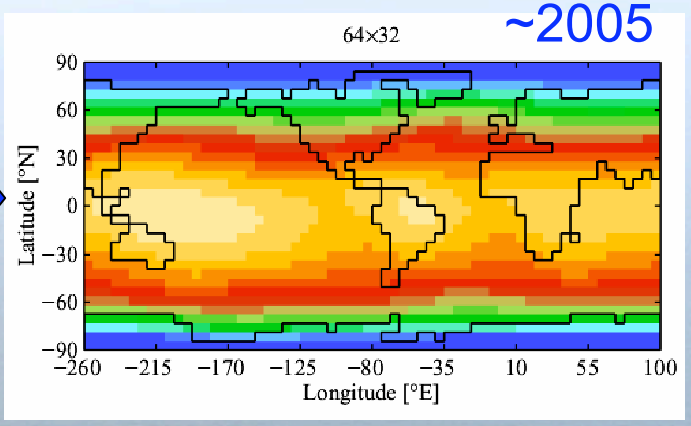
~2001



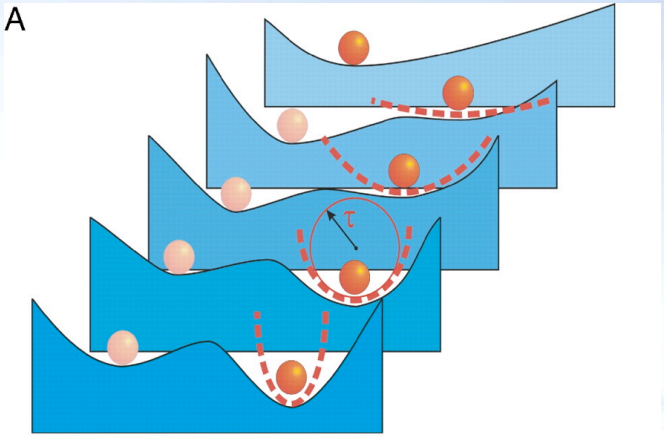
~2002

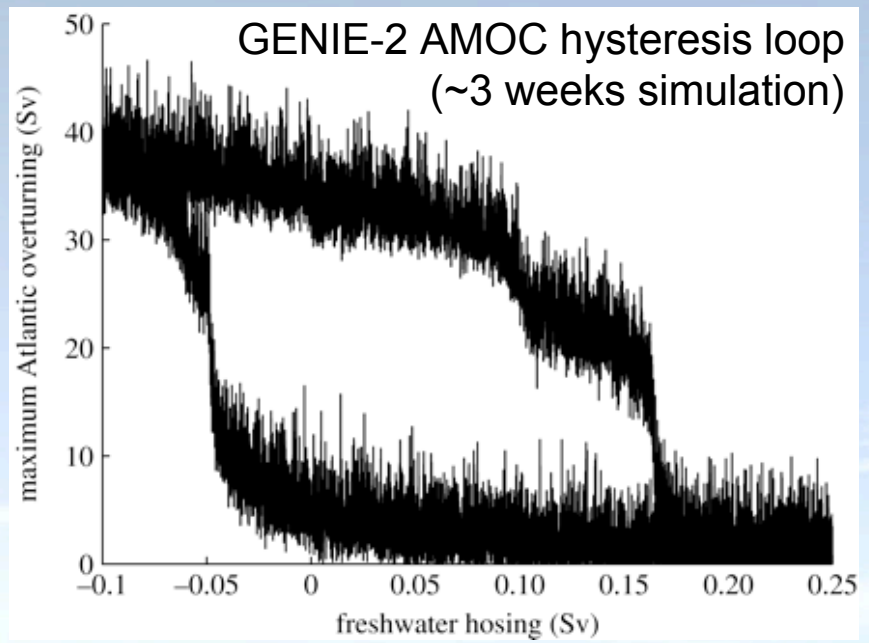


~2005

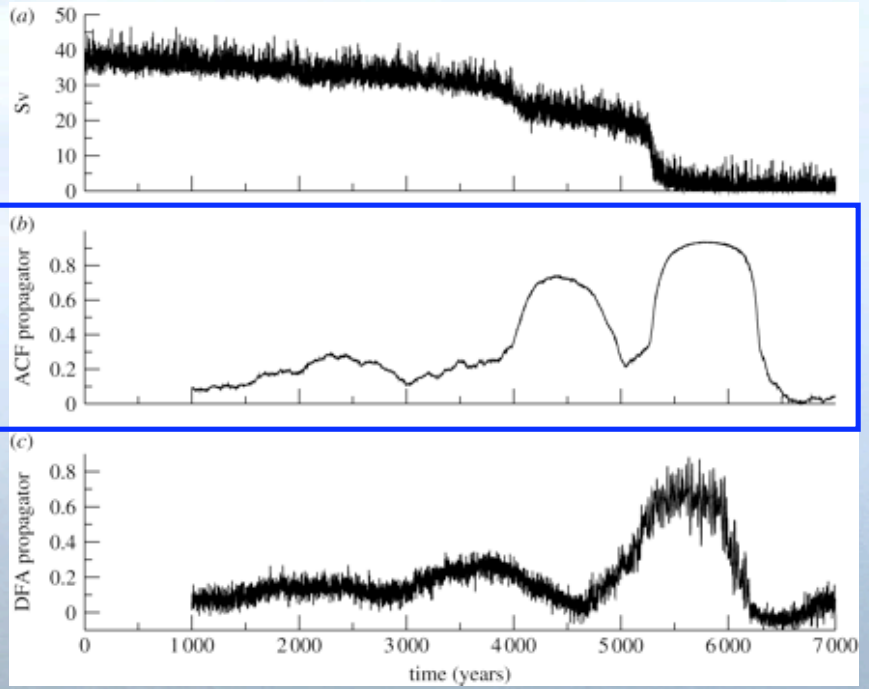


Predicting the approach to an AMOC bifurcation point (collapse) with an EMIC





The 'ACF propagator' is a measure of slowing decay rate of perturbations in the data and hence the flatness of the potential well. A critical value of '1' corresponds to infinitely slow decay and bifurcation—a flat potential

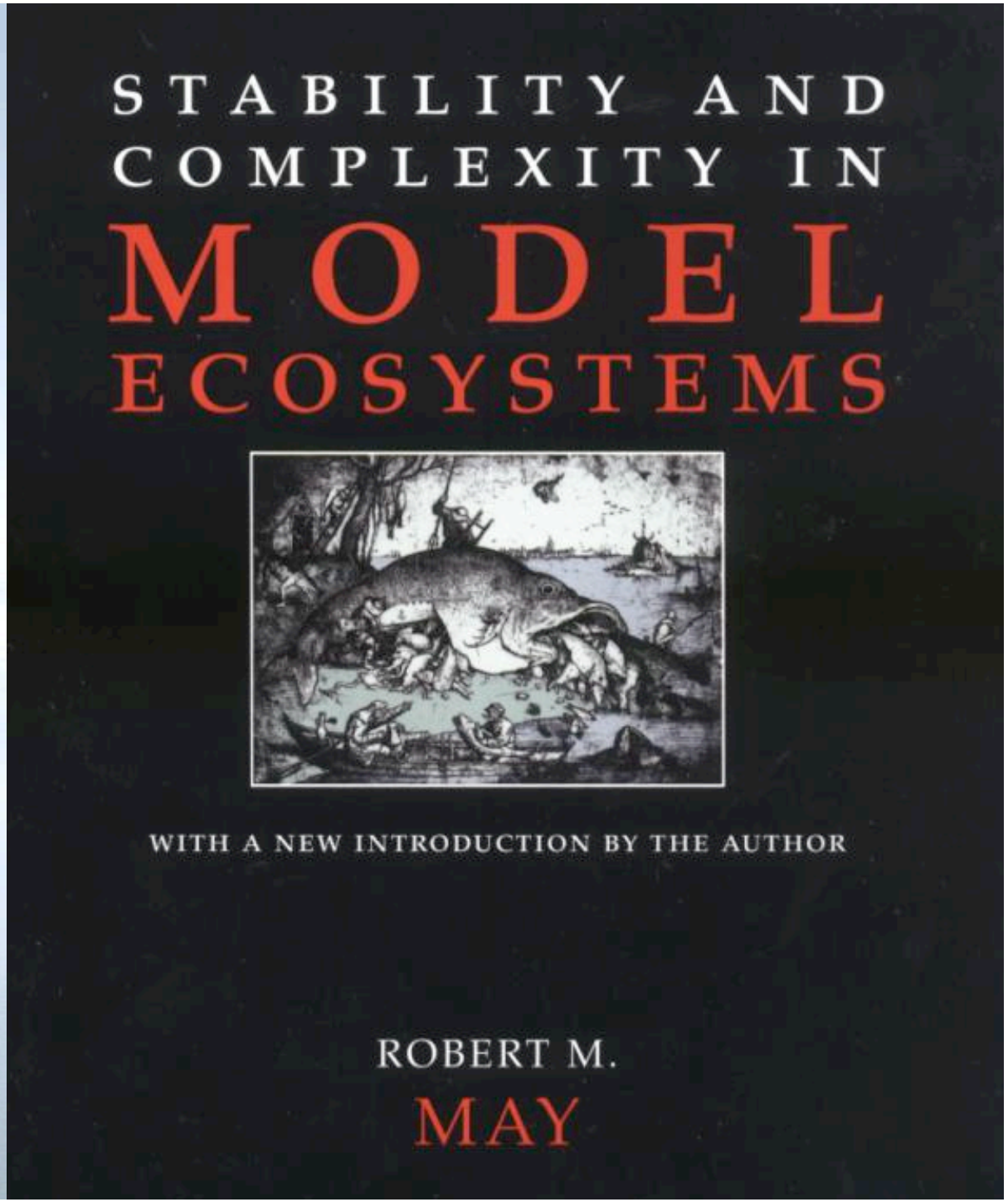


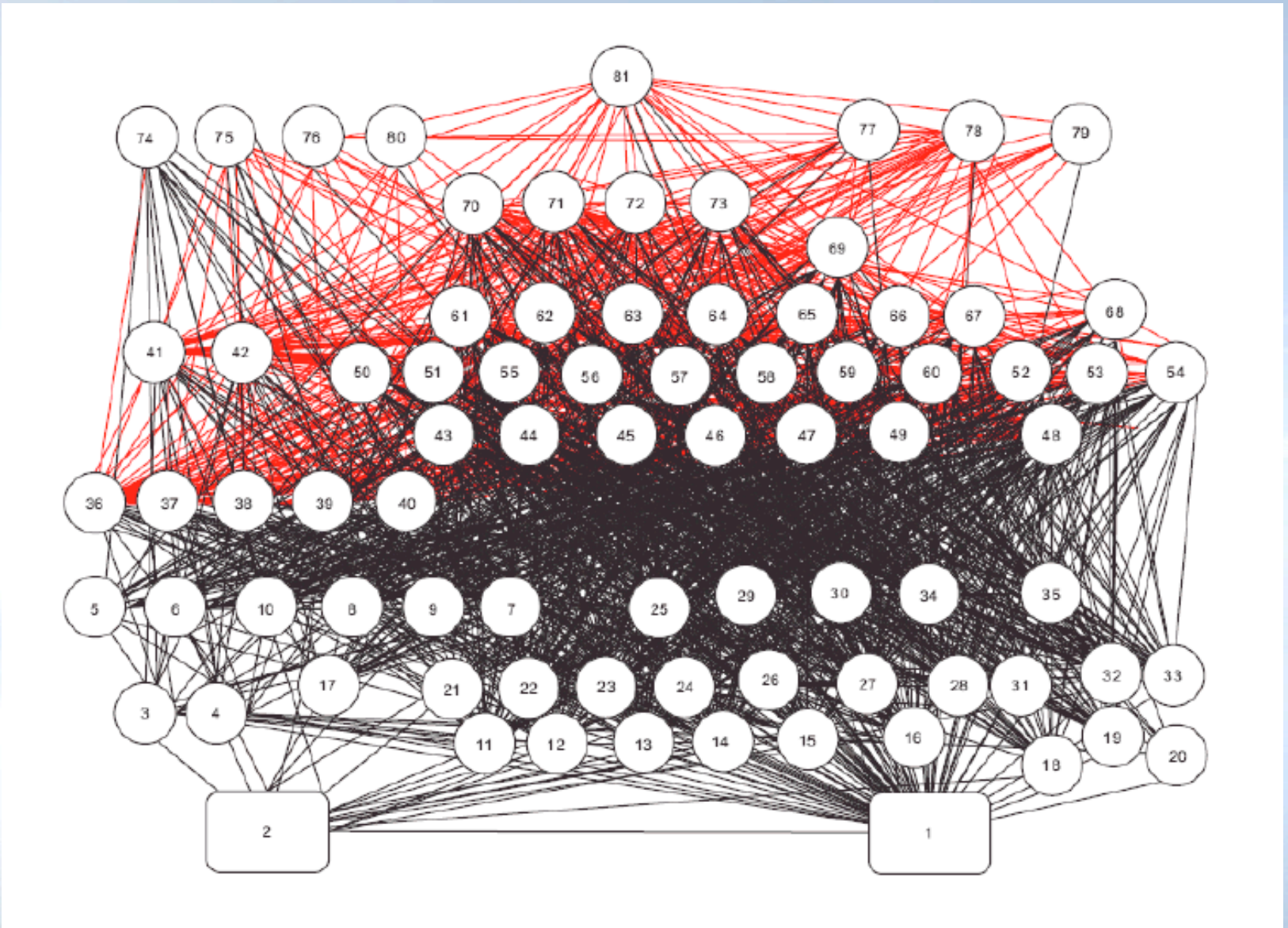
Lenton, et al. (2009). Using GENIE to study a tipping point in the climate system. Phil. Trans. R. Soc. A, 367, 871-884. Doi:10.1098/rsta.2008.0171

Bob May

Second Edition

1961(!)





North Atlantic food web (for fish only) from Link (2000)

NB: Box 2 = all phytoplankton !!! (and Box 81 = humans)

How many species (or functional groups) is enough ?

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HORIZONS

Plankton functional type modelling: running before we can walk?

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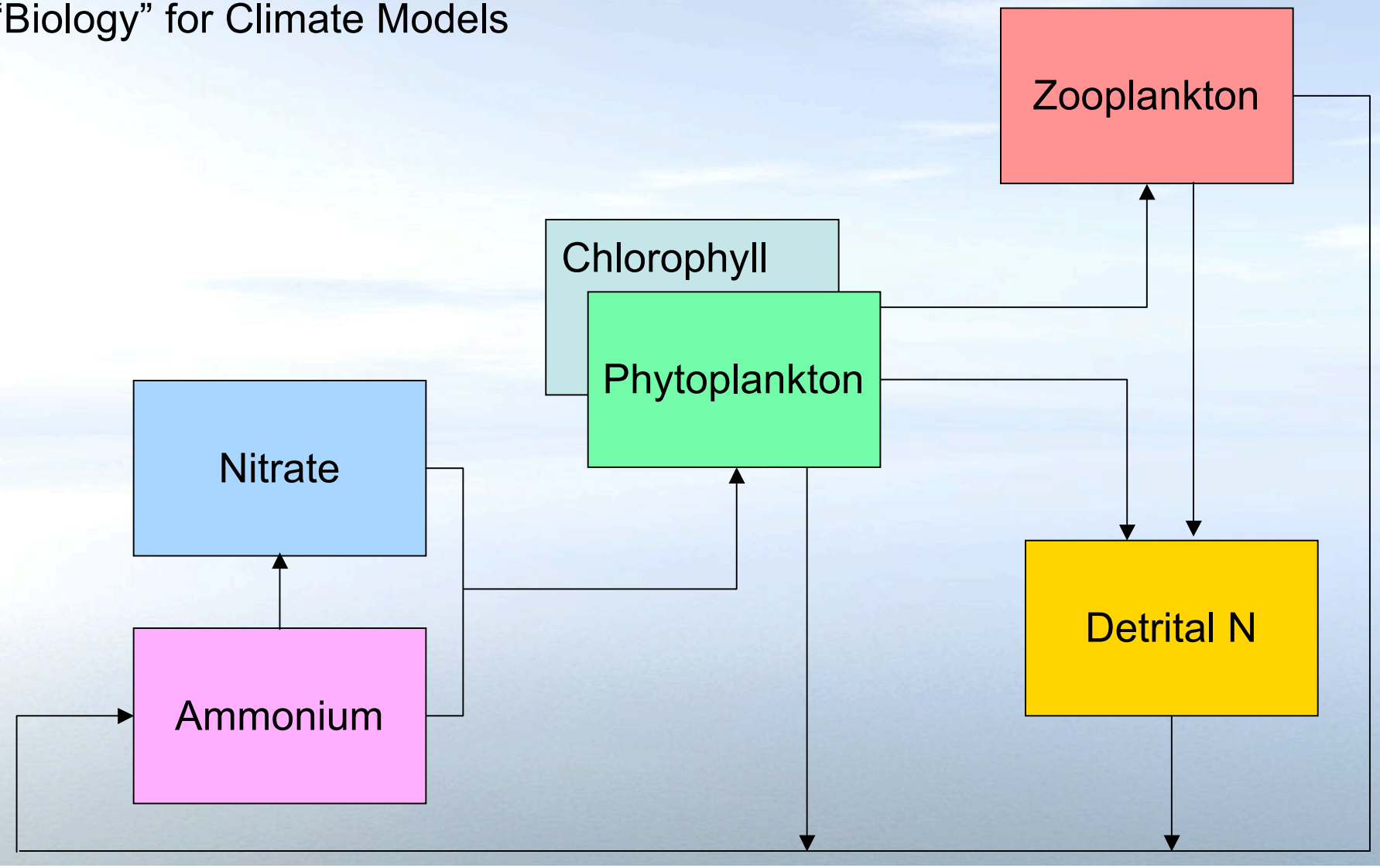
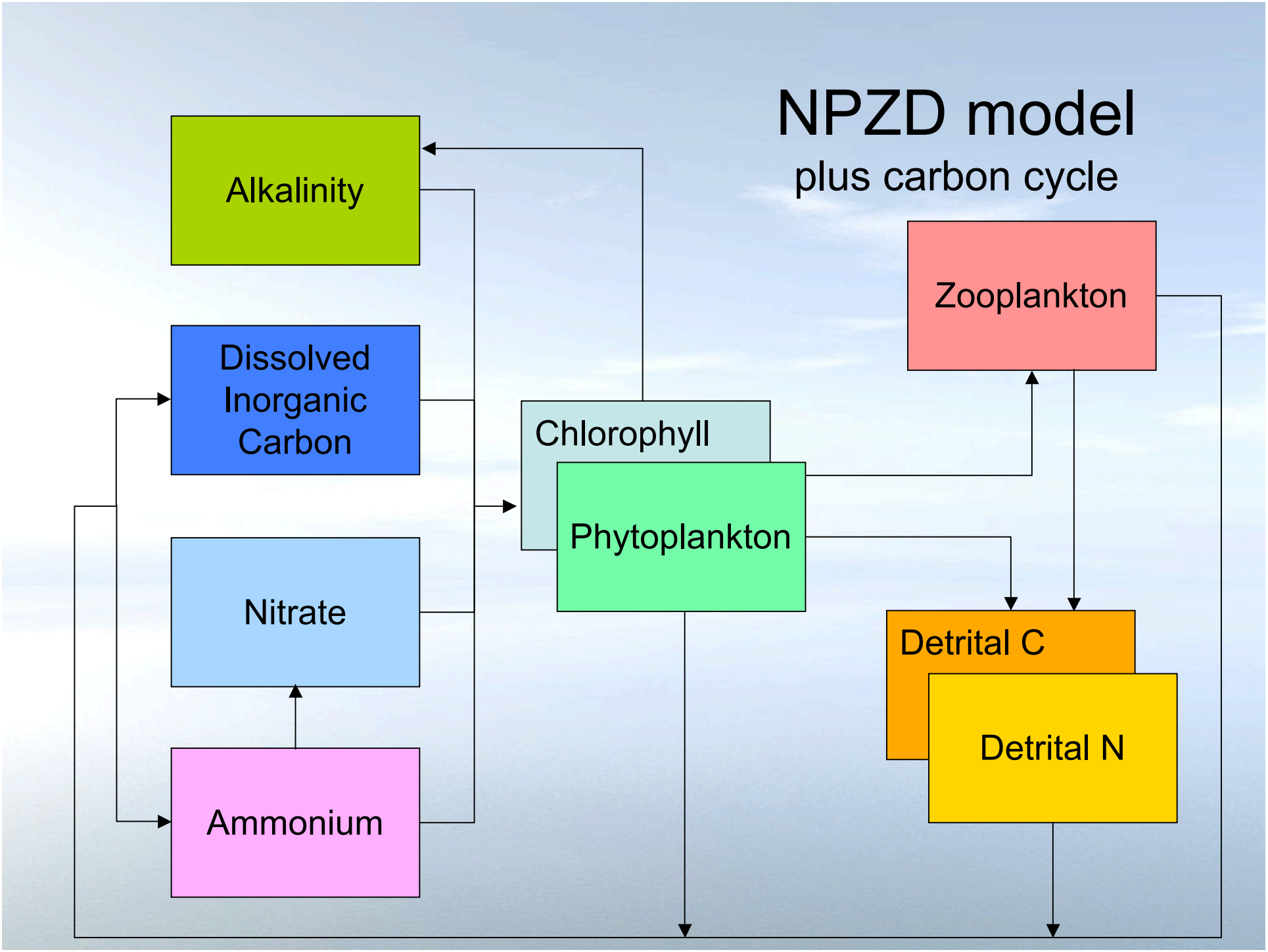
NPZD model

(with ammonium and chlorophyll)

Andrew Yool & colleagues (NOC)

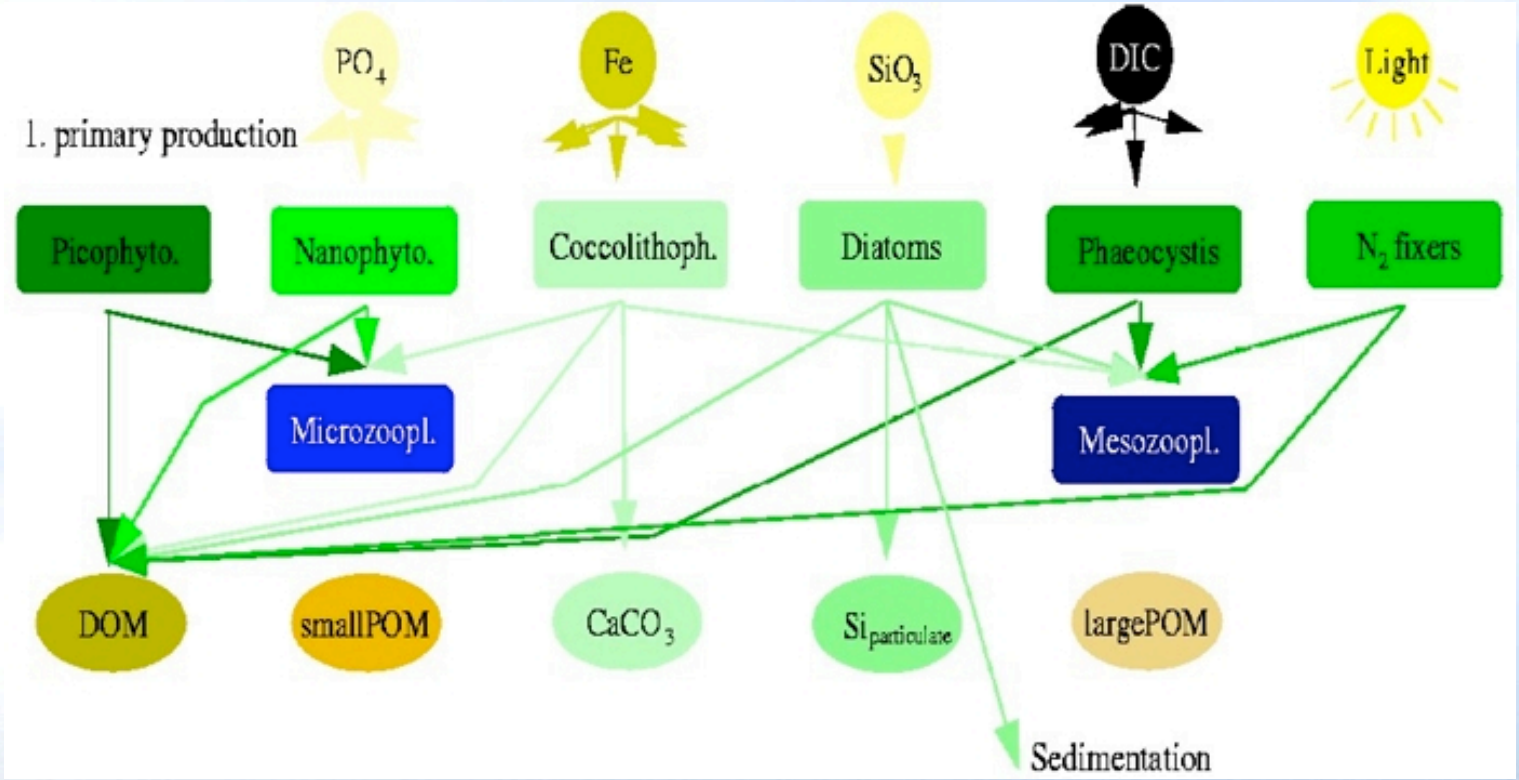
"Biology" for Climate Models




NPZD model
plus carbon cycle
Alkalinity
Dissolved Inorganic Carbon
Nitrate
Ammonium
Chlorophyll
Phytoplankton
Zooplankton
Detrital C
Detrital N

Dynamic “Green Ocean” model

(Corinne le Quere & colleagues, UEA)

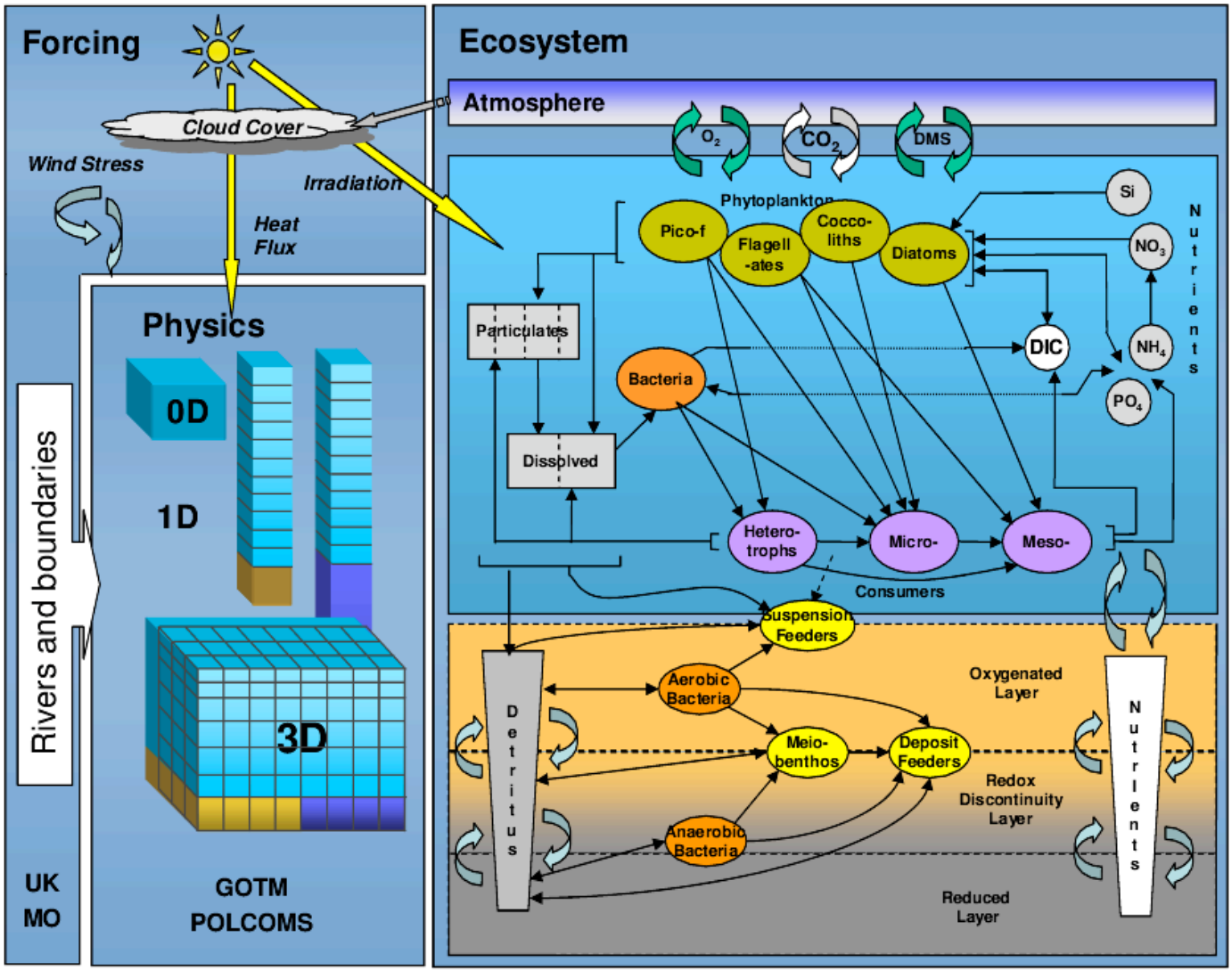


3 nutrients

6 phytop.

2 zoop.

5 detritus



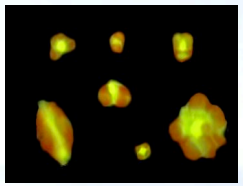
Plymouth Marine Laboratory

ERSEM model schematic

PLANKTOM 5.0: implemented in two GCMs

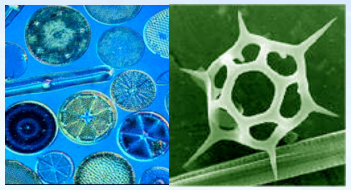
(Tom Anderson & colleagues, NOC)

PO_4 Fe SiO_3 DIC light



nanophytos

calcifiers



diatoms

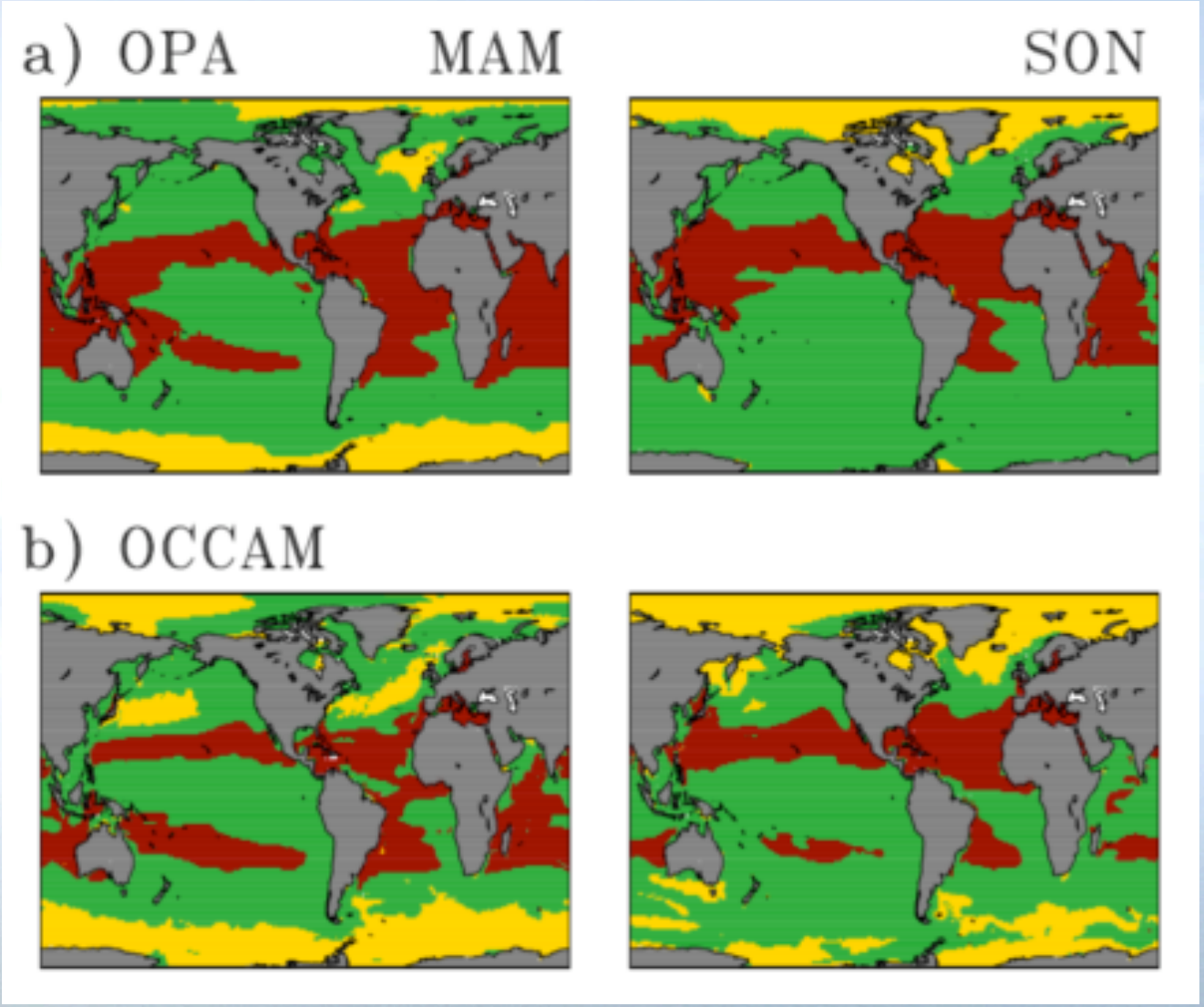
Microzoo-plankton

Mesozoo-plankton

DOM small POM $CaCO_3$ $Si_{particulate}$ large POM

Phytoplankton functional types in two GCMs

Yellow: diatoms, green: mixed phyto, brown: coccolithophores



Bablu Sinha and Tom Anderson

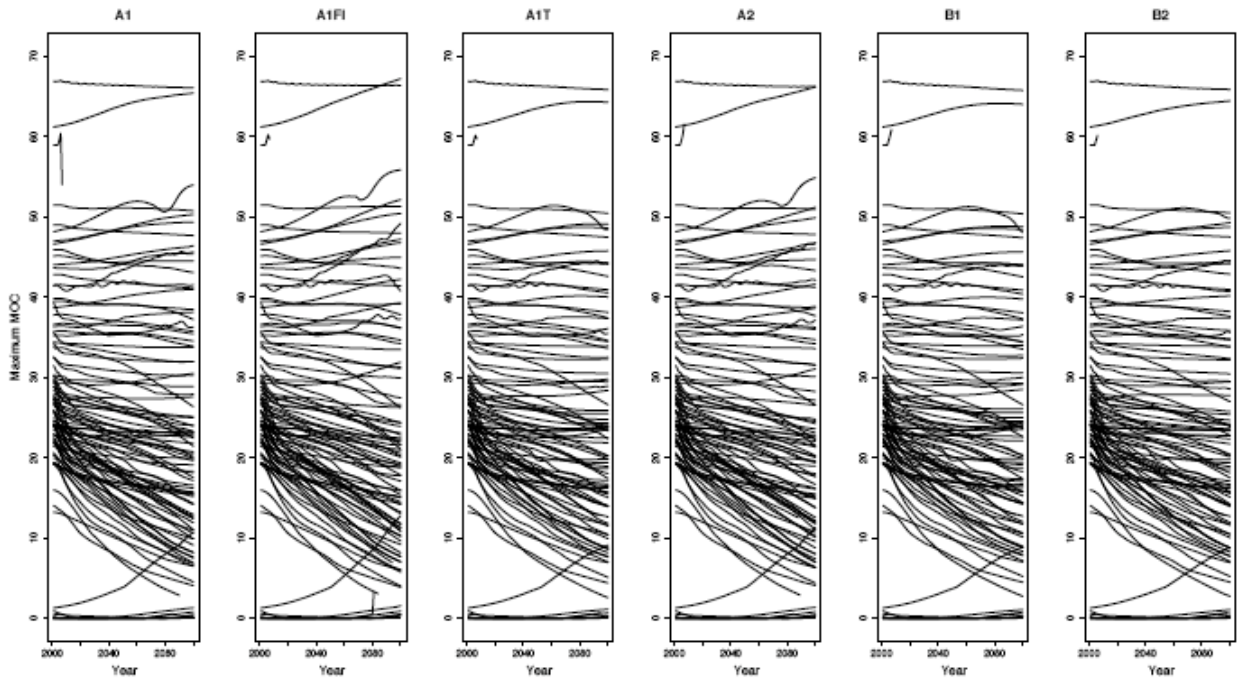
Complex Models are too slow

- Especially for Monte Carlo work
- To get pdf's & assess uncertainty (etc)
- We need too many realisations…
- But we can (sometimes) use Emulators

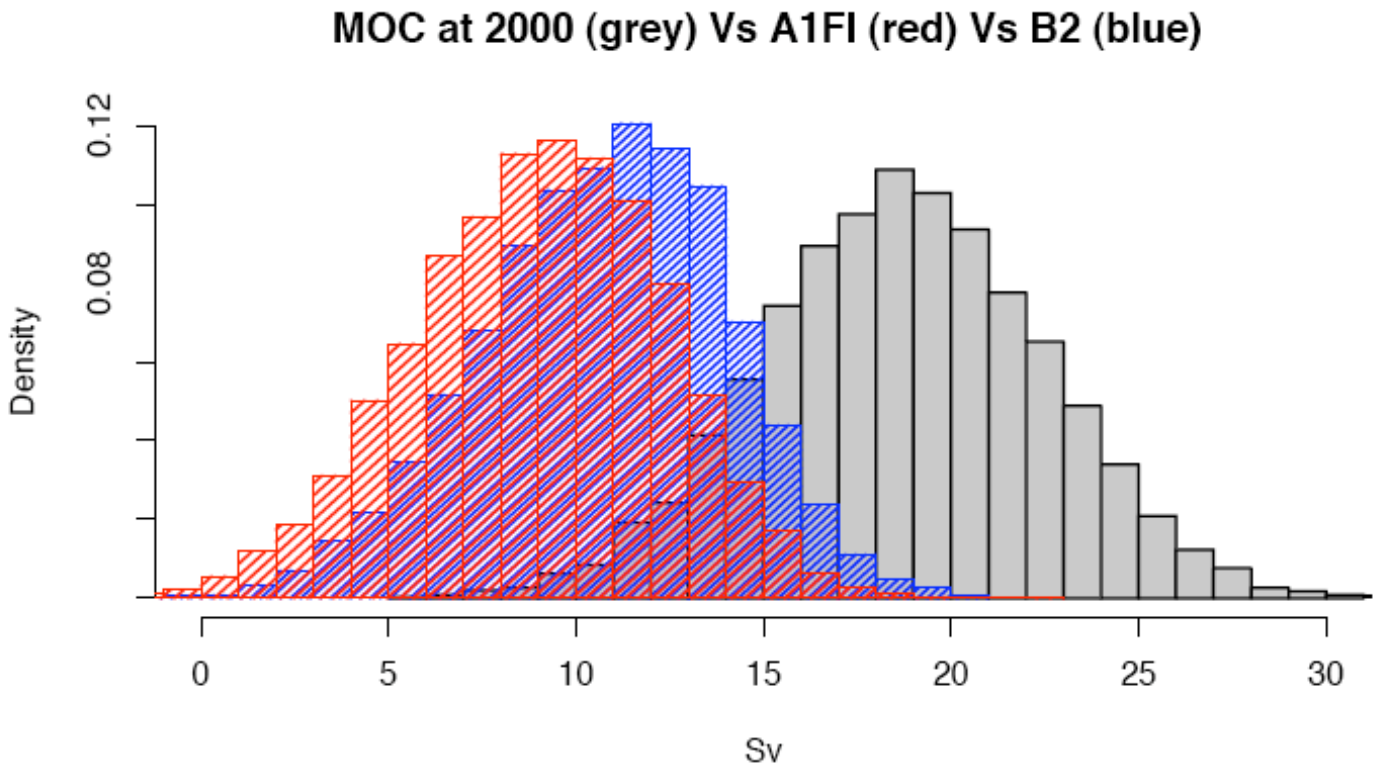
- Peter Challoner & colleagues

Projections of AMOC strength for various IPCC scenarios

GENIE projects the Future

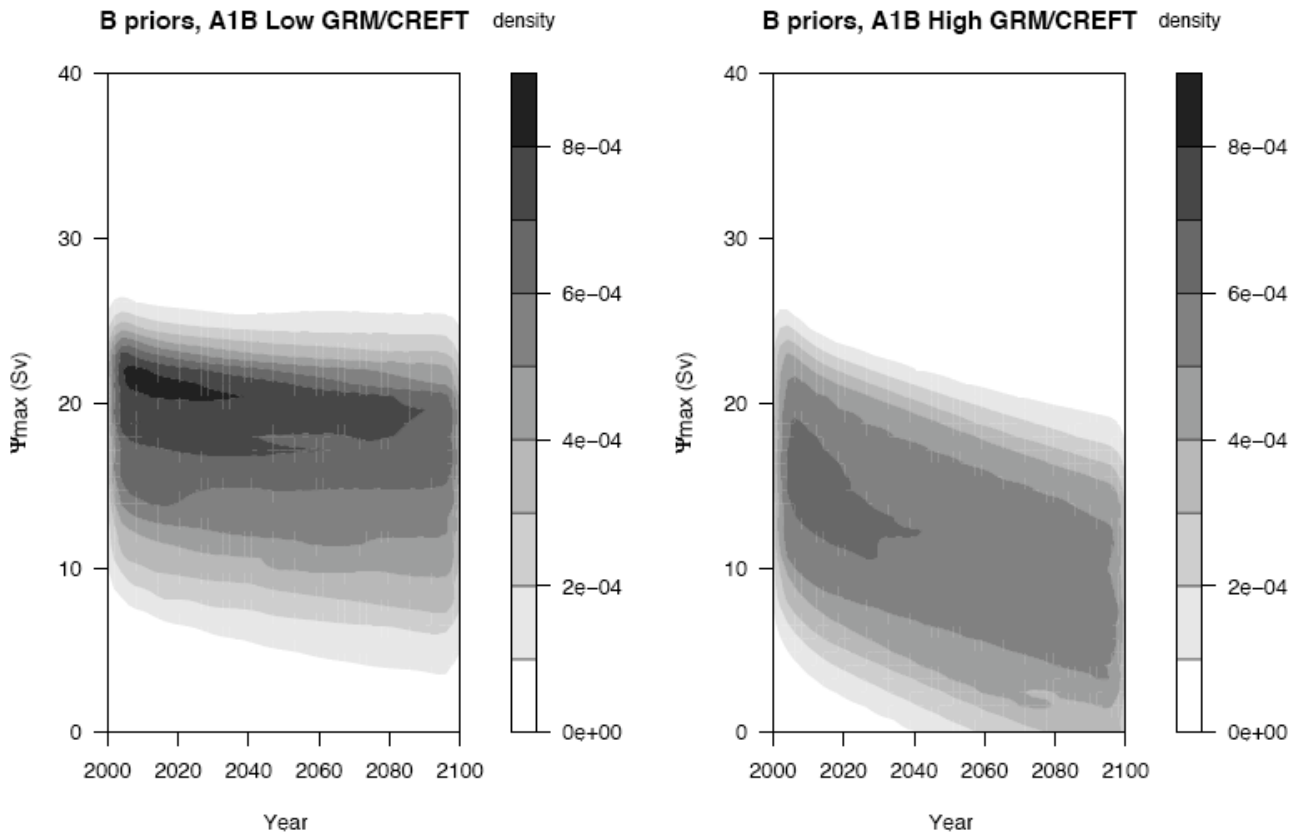


Probability of AMOC strength for various IPCC scenarios



Time trajectories of pdf's of AMOC strength to 2100

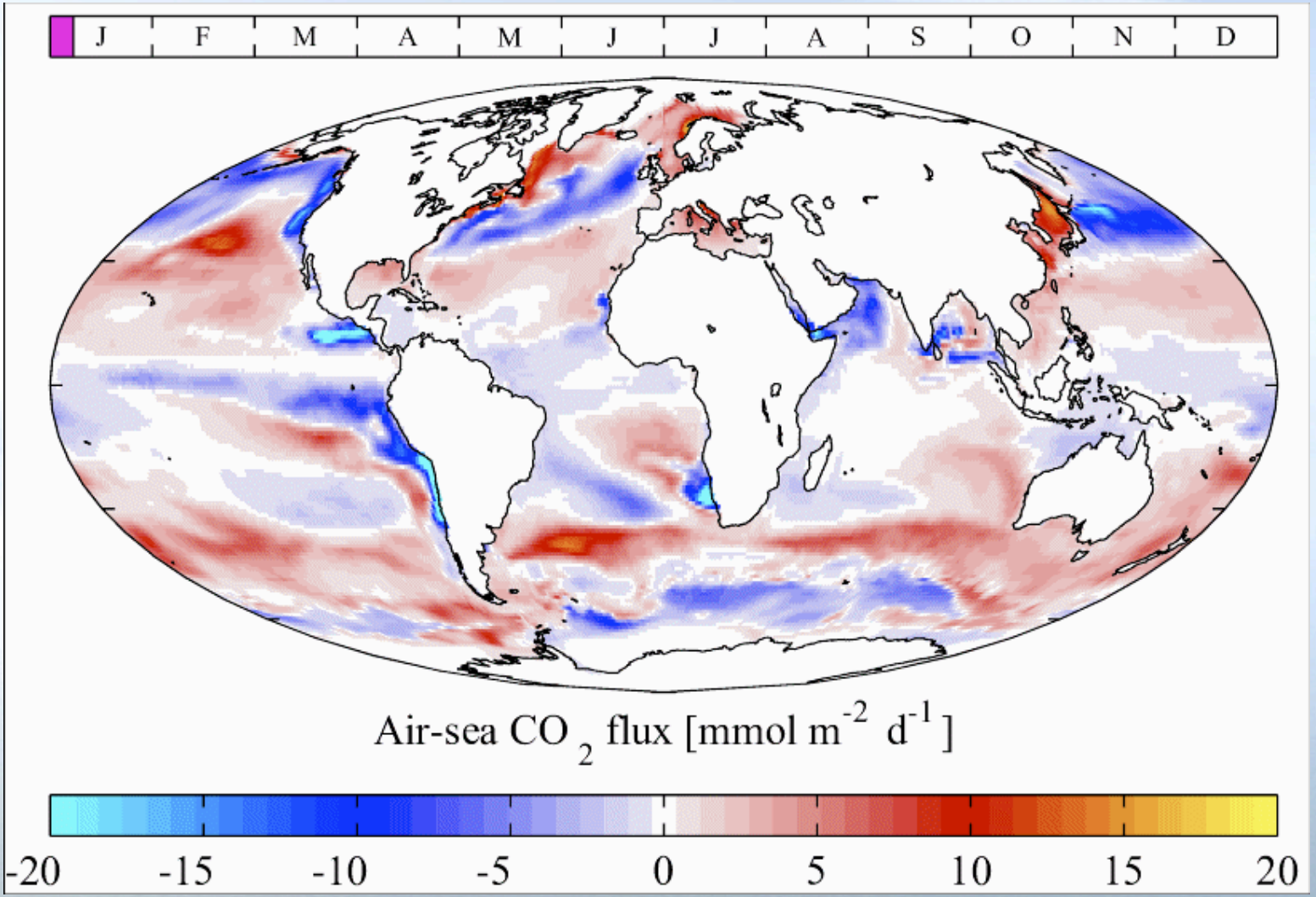
Our pdf max MOC through the 21st century



Flux of CO_2 into the Ocean

The seasonal cycle simulated by OCCAM

(with thanks to Andrew Yool)



"Man has lost the capacity to foresee and to forestall. He will end by destroying the Earth"

Albert Schweitzer, quoted by Rachel Carson, in her dedication of "Silent Spring", (1962)