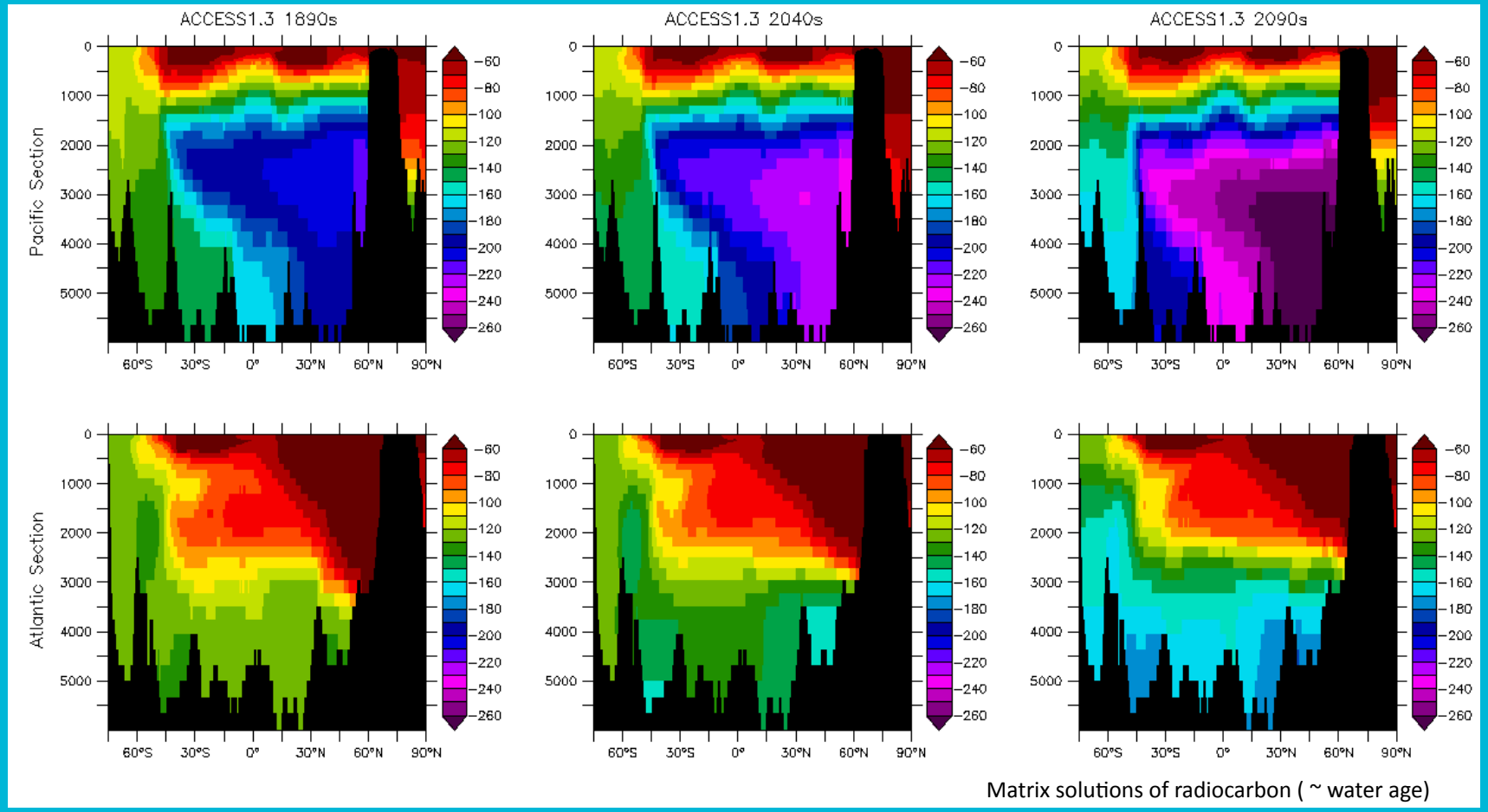

Matrix solutions of radiocarbon (~ water age)

Using transport matrices to probe circulation in ocean models – and miscellaneous topics

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Matt Chamberlain – COSIMA, May 2018

Miscellaneous topics/other activities…

- Decadal Forecast Project
  - Modifying ocean parameterisations to reduce model bias and improve dynamics of simulated climate modes (friction, neutral physics, Richardson no., ice albedo).
  - Implement other GDFL atmospheric models (e.g., 'AM2.5')
- Bluelink
  - Assimilating ocean data into ocean-ice OFAM.
- ESM/Ocean-BGC
  - ongoing…

Transport Matrices - Overview

Advection and mixing are diagnosed from ocean models and used to build transport matrices for further analysis:

- Can rapidly find steady-state solutions for various tracer fields in the deep ocean.
- Demonstrate the matrix solutions give good representation of the “forward” model.
- Use matrix solutions to:
  - probe the output and diagnose the circulation of simulated ocean, and,
  - explore various climate scenarios, showing here the shutdown of Antarctic Bottom Water formation in climate projections.

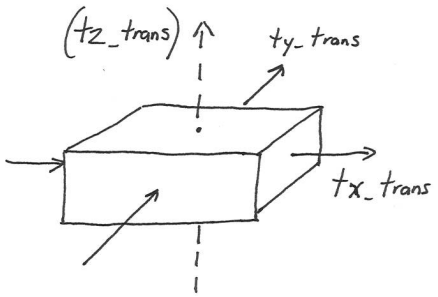
The transport matrix

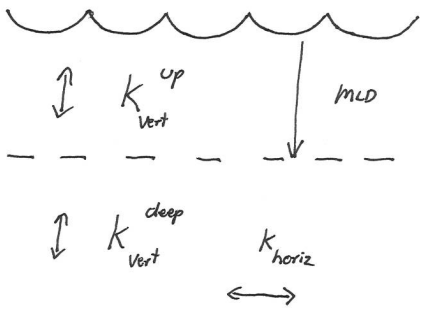
- Reduce the 3-D tracer field to a vector, *x* (size ~2.6e6 for ACCESS 1-deg. ocean).
- Transport matrix (**A**) built from generic ocean model output:
  - advection from decadal averages of transport fields (***T***), and,
  - mixing terms, vertical (deep and upper ocean) and horizontal; upper ocean defined by mixed layer depth or diagnosed from tracer fields

$$\frac{\partial}{\partial t}x_i = \sum_j \frac{\max(0,T_{ij})}{vol_{ij}}x_j + \sum_j \frac{\min(0,T_{ij})}{vol_{ij}}x_i + \sum_j \frac{k_{ij}A_{ij}}{vol_{ij}d_{ij}}\left(x_j - x_i\right)$$

Include forcing term *b*…

d*x*/dt = **A***x* + *b*.

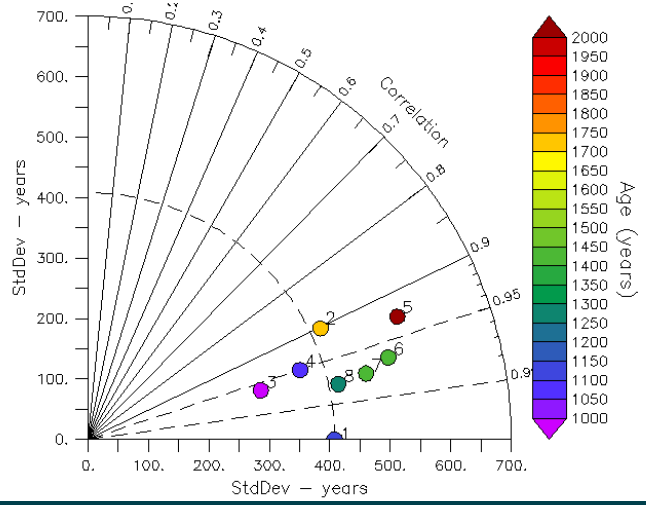




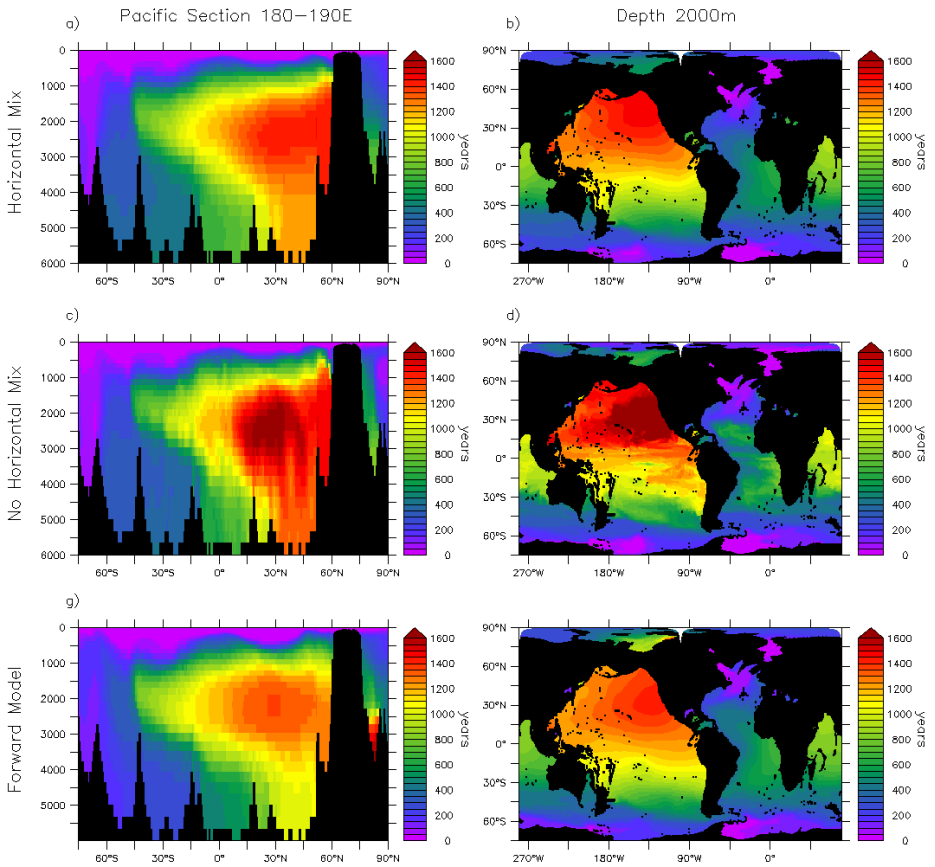
- Steady state solutions can be found by 1000+ year integration of forward model (several months of computer time!?),
  or by 'just' solving for steady state… "*x* = **A**$^{-1}$*b*."

- Matrix solutions can be compared to the forward model – ACCESS-ocean with CORE
  - 1) Age tracer:
    boundary condition => set tracer to zero at surface,
    source term => tracer ages at constant rate in ocean interior.

    Solution compared to age tracer from forward model, initialised with a best guess and integrated to steady state (brute force).



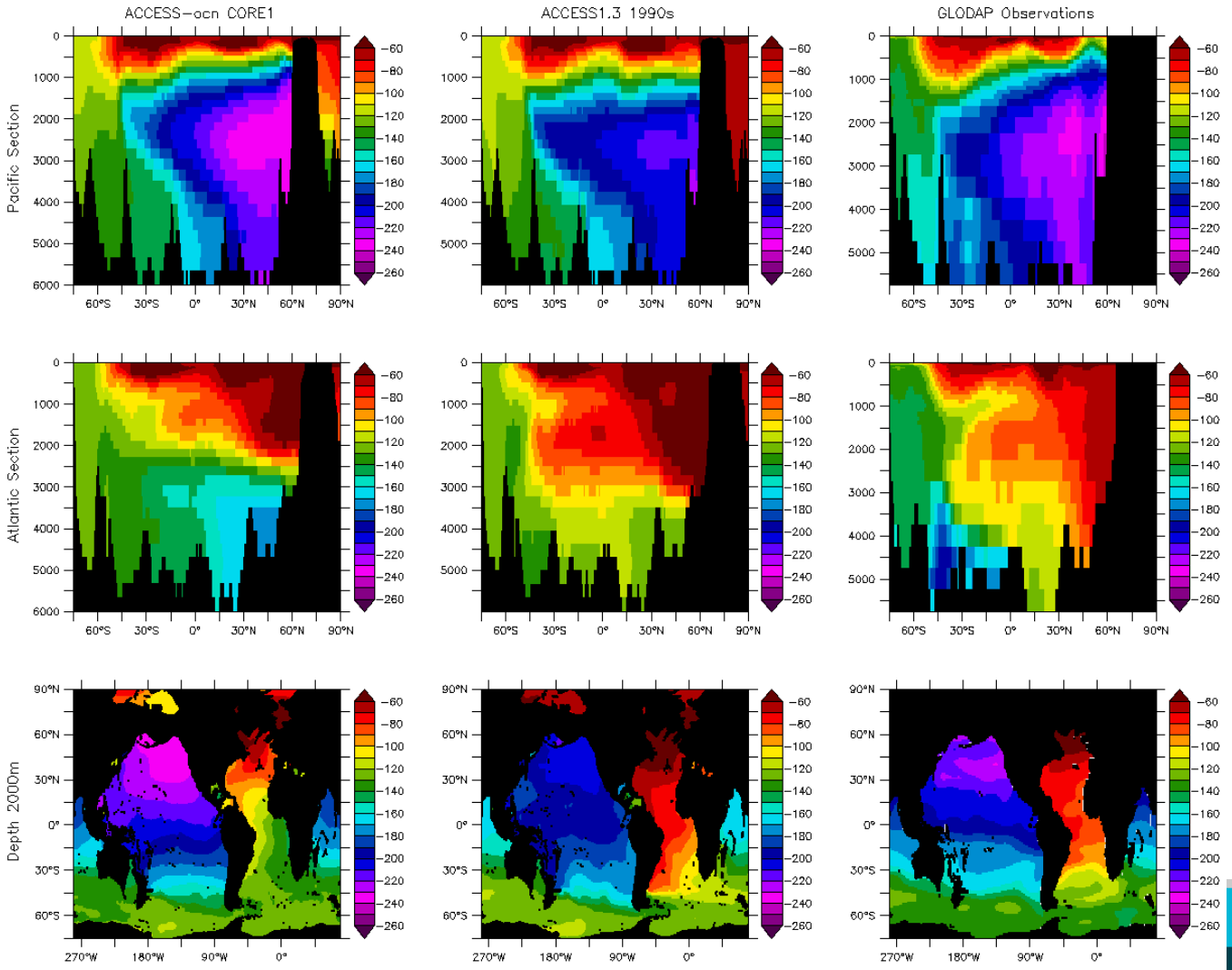
Taylor Diagram comparing age solutions from various matrices.



Water age from matrix solutions and forward ocean model.

Matrix solutions to probe ocean circulation

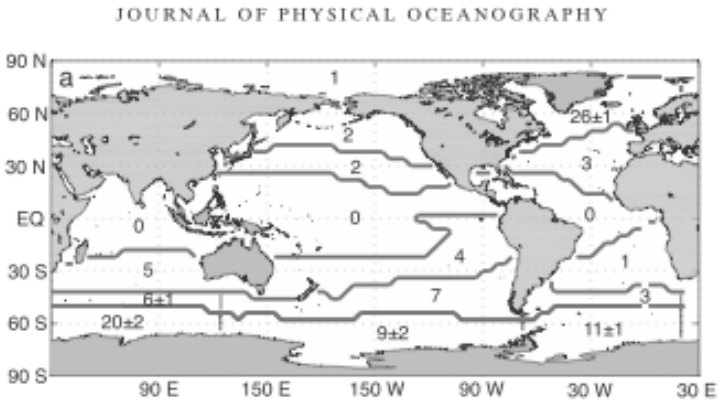
- Compare solutions of matrices from different ocean/climate model experiments to observations to characterise models.



Radiocarbon tracer fields (Δ-carbon units) for the ACCESS-core experiment, ACCESS1.3-historical experiment, compared with GLODAP observations.

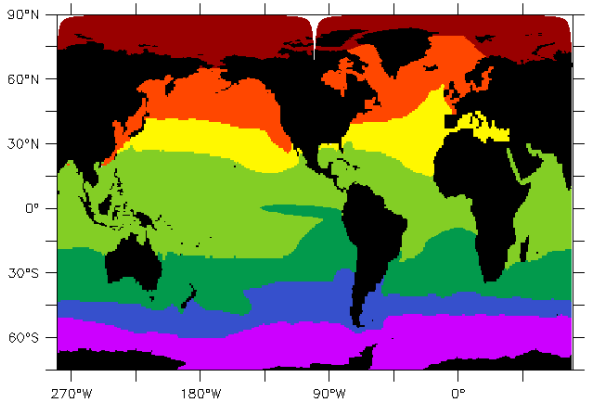
Compare models to observed water masses

- DeVries and Primeau 2011 use a “data-constrained ocean circulation model” to estimate fraction of ocean volume last ventilated from various surface regions.
- To map a particular water mass:
  Source term => zero, and,
  Surface boundary condition =>1 for region of interest and 0 everywhere else.



Percent fraction of global water volume from various surface regions.

	ACCESS-core	ACCESS1.3-1990	DeVries and Primeau 2011
Arctic	0.3	1.1+/- 0.1	1
Subarctic	12.1	23.6 +/- 0.8	28 +/- 1
Nthsubtrop	8.0	12.4 +- 0.3	5
Tropics	3.6	7.0 +/- 0.6	0
Sthsubtrop	14.9	13.8 +/- 0.2	10
Subantartic	12.6	9.5 +/- 0.3	16 +/- 1
Antarctic	48.5	32.6 +/- 0.6	40 +/- 3



Water mass regions defined for matrix solutions

Percents of global ocean volume from regions shown to right.

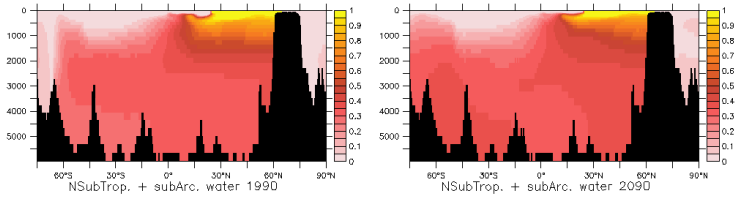
Compare different ocean/climate experiments

- Probe matrix solution for changes with climate. Build transport matrices based on 10-year averages of output.

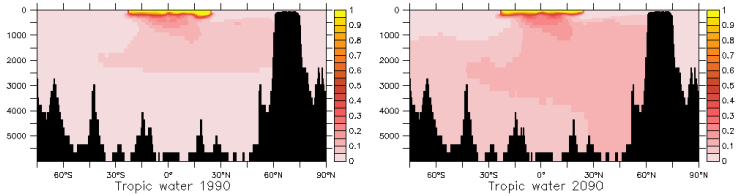
	ACCESS1.3-1890	ACCESS1.3-1990	ACCESS1.3-2040	ACCESS1.3-2090
Arctic	1.0	1.1	3.0	3.5
Subarctic	21.1	23.6	19.3	20.3
Nthsubtrop	11.0	12.4	13.9	15.7
Tropics	7.2	7.0	9.0	11.3
Sthsubtrop	14.7	13.8	19.7	25.6
Subantartic	9.8	9.5	11.3	19.9
Antarctic	35.2	32.6	23.8	3.7

Percents of water volume, from climate experiments.

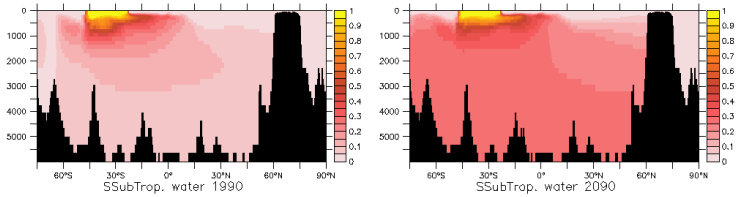
Nthsubtrop. + subArctic



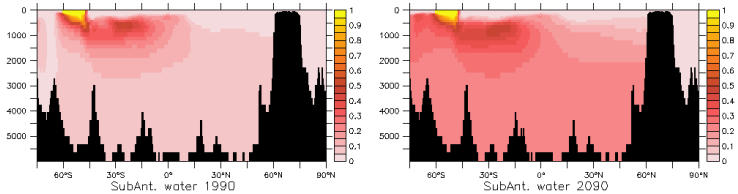
Tropics



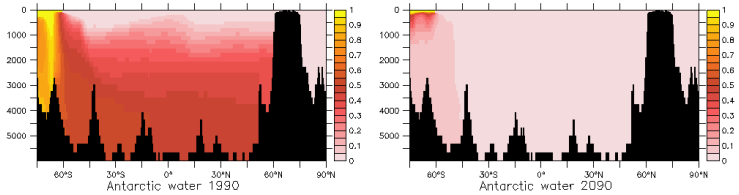
Sthsubtrop.



SubAnt.



Antarctic

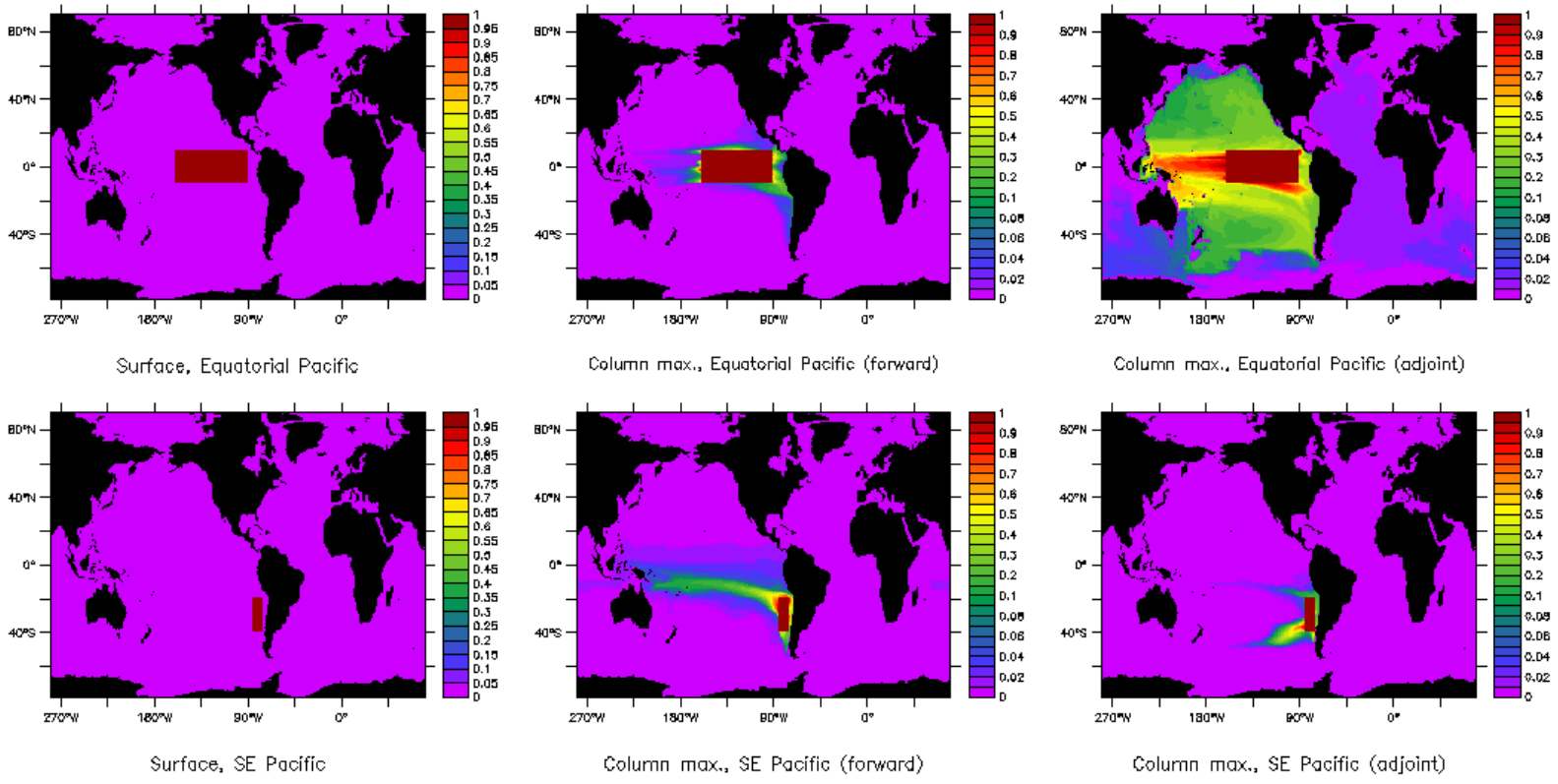


Pacific sections of different water masses show shutdown of Antarctic bottom water by 2090s(RCP8.5).

NB. Shown are steady-state matrix solutions whereas the ocean state in 2090s will be transient; solutions are characterising the circulation at this time.

Further work

- Improve fidelity of the matrix.
  - enable calculation of deep BGC fields,
  - generate ‘spun up’ initial conditions.
- Application to new scenarios; e.g. track water from arbitrary regions of interest in various climates.



Summary/Review

- Demonstrate transport matrix solutions give reasonable representations of circulations from parent ocean models.

- Matrix solutions map water masses and diagnose model circulation; useful for deep ocean tracers (e.g. age tracer).

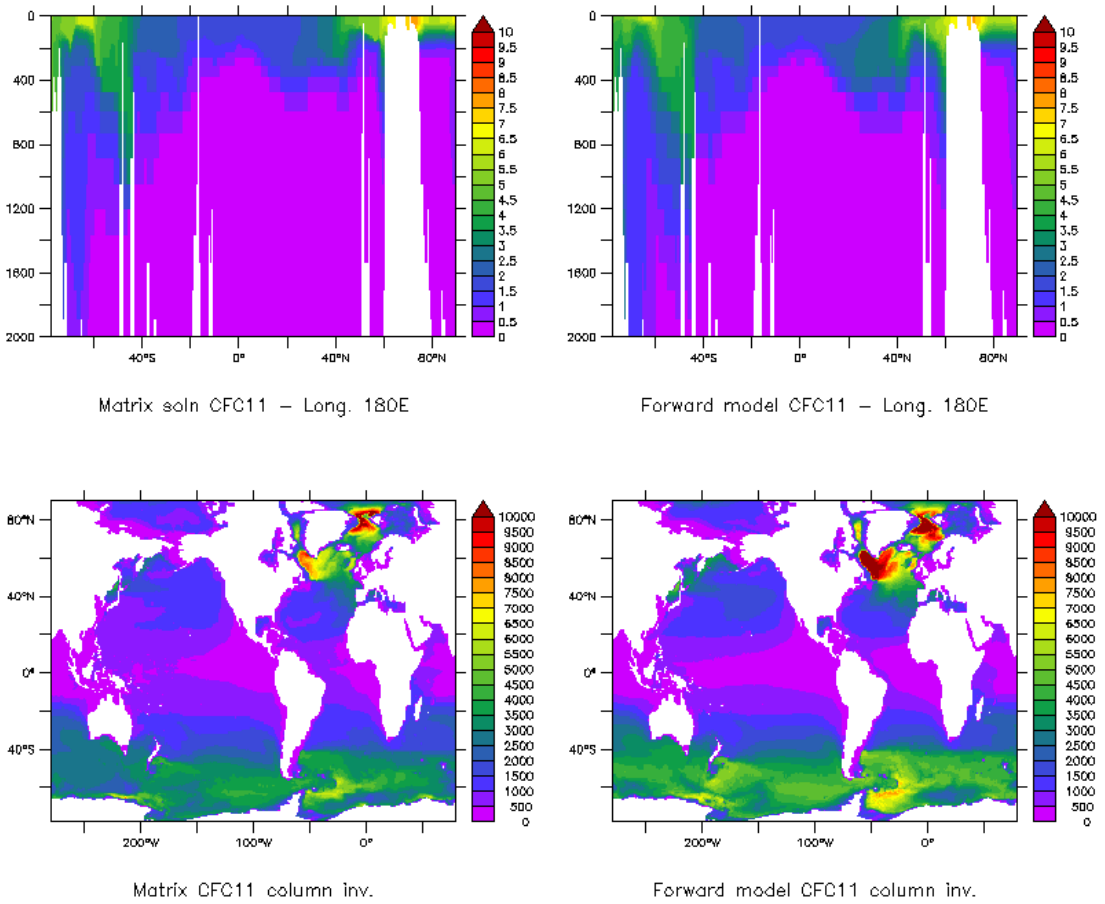
- Matrix solutions enable probing of changes in water masses in response to climate change; show a drop off in Antarctic Bottom Water formation under RCP8.5.

Thank you

Test matrix solution (cont.)

- 2) CFC tracer: built from series of solutions with different ‘decay’ terms to approximate atmospheric CFC history.

  Boundary condition => set to ‘observed’ field,
  Source term => series of decay constants to represent CFC time history (most significant terms ~20 years).



CFC-11 concentrations from matrix solution and forward ocean model.