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The role of ocean and atmosphere feedbacks in maintaining bi-stability of the thermohaline circulation

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We have used the Grid ENabled Integrated Earth system modelling (GENIE) framework to undertake a systematic search for bi-stability of the thermohaline circulation (THC) with a 3-D dynamical atmosphere model (IGCM) coupled to a 3-D frictional geostrophic ocean model (GOLDSTEIN) and slab sea-ice. Three different ocean grids are used: (i) 36x36x8 longitude-sine(latitude), (ii) 72x72x16 longitude-sine(latitude), (iii) 64x32x8 longitude-latitude. In all cases, the IGCM is run at T21 resolution with 7 vertical levels and surface grid (iii). We contrast this with earlier work using an energy-moisture balance atmosphere model (EMBM) and ocean resolution (i).

For each model version, we constructed an ensemble of runs in which we vary atmospheric freshwater transport from the Atlantic to Pacific. The resulting ensembles are run toward equilibrium and then restarts are used to search parameter space for regions of THC bi-stability. A total of 407,000 model years were simulated in 3 months by using UK Grid computing resources, including 6 nodes of the National Grid Service, and additional clusters in Norwich, Southampton and Bristol.

We find bi-stability of the THC despite significant, quasi-periodic variability in its strength driven by variability in the dynamical atmosphere. The position and width of the hysteresis loop depends on the choice of surface grid (longitude-latitude or equal area), but is less sensitive to changes in ocean resolution. For the same ocean resolution, the region of bi-stability is broader with the IGCM than with the EMBM.

Feedbacks involving both ocean and atmospheric dynamics are found to promote THC bi-stability. THC switch-off leads to increased export of salt at the Southern boundary

of the Atlantic that tends to maintain the off state. THC switch-off can also generate net freshwater input to the Atlantic from the atmosphere that tends to maintain the off state. The ocean feedback is present in all resolutions, across most of the bi-stable region, whereas the atmosphere feedback is strongest in resolution (iii) and around the transition where the THC off state is disappearing. Here the ocean response reverses, promoting THC switch-on by reducing Atlantic salt export, but the atmosphere counteracts this by increasing net freshwater input. This appears to maintain some bi-stability even when the THC does switch on - weaker and stronger THC on states can be distinguished under the same boundary conditions and different initialisations of the model.