Abrupt climate change in a minimal model of the thermohaline circulation (THC)

André Paul

March 17, 2011

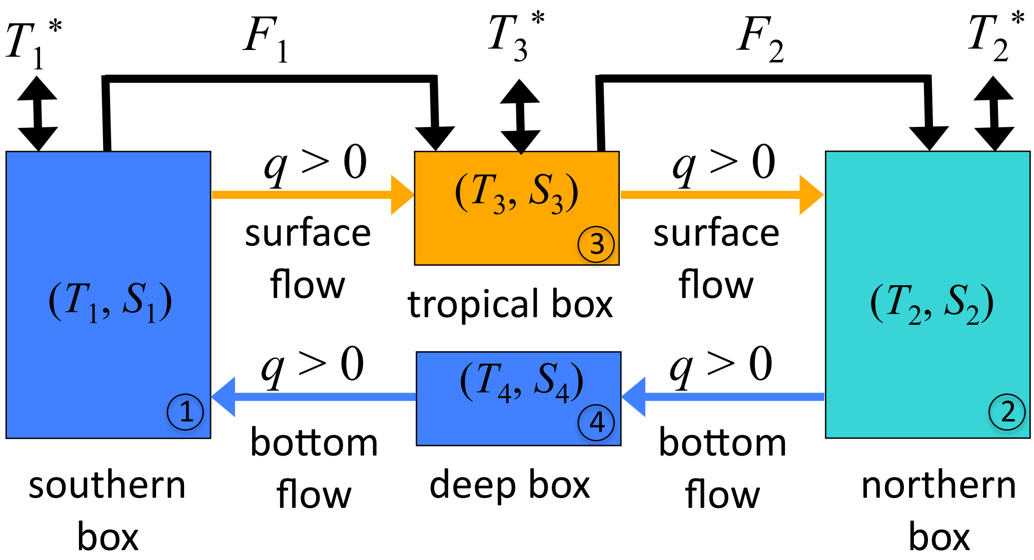

Figure 1: Sketch of the four-box model of the Atlantic thermohaline circulation. The temperatures T_1, T_2 and T_3 of boxes 1, 2 and 3 are restored to the relaxation temperatures T_1^*, T_2^* and T_3^*. The salinities S_1, S_2 and S_3 in these boxes are determined by the meridional freshwater fluxes F_1 and F_2 and the meridional flow of strength q. The flow parameter q in units of Sv (1 Sv = 1 Sverdrup = 1×10^6 m^3 s^{-1}) is proportional to the density difference between boxes 2 and 1.

1 Modes of the THC

Refer to Figure 1:

1. What are the two fundamentally different modes of the thermohaline circulation in the four-box model? Sketch the associated flow patterns.

2. Under which conditions will the thermohaline circulation be in one or the other of these modes?

2 THC thresholds and hysteresis in the four-box model

2.1 Remarks on the MATLAB implementation of the four-box model

The local working directory `thc_4box_02` contains:

- the forcing files `forcing_meltwater.prn` and `forcing_hysteresis.prn` and,
- after model execution, a history file `results.prn`.

The key parameters of the model can be conveniently modified by editing the file `thc_2box.in` (see Table 1)

Symbol	MATLAB name	Description	Default value	Unit
t_0	`xstart`	time to start	0	a
t_{end}	`xend`	time to stop	2000	a
Δt	`delx`	time step	5	a
Δt_{dump}	`dumpFreq`	interval for writing model output to results file	100	a
A_{h}	`a_th`	horizontal diffusion coefficient	0	$\mathrm{m^2\ s^{-1}}$
F_1	`wflx1`	freshwater flux from southern to tropical box	0.014	Sv
F_2	`wflx2`	freshwater flux from tropical to northern box	0.065	Sv
	`resf`	file for results	'results.prn'	
	`endf`	file for final values	'endval.prn'	
	`incf`	file to use for inital conditions	'p'	
	`frcf`	file for freshwater forcing	'forcing_meltwater.prn'	

Table 1: Parameters of four-box model

2.2 Control experiment/experiments without meltwater perturbation

- Ensure that the parameters `xend`, `wflx1` and `wflx2` are set to 2,000 years, 0.014 Sv and 0.065 Sv, respectively.
- Inspect the freshwater forcing data in the file `forcing_meltwater.prn`. Make sure that `frcf` is set to `forcing_meltwater.prn`. For the time being, set the maximum freshwater flux perturbation in columns 2 and 3 at year 750 to 0.0 Sv.
- 'Run' the model (type `thc_4box` in the MATLAB command window and press enter), observe the time evolution and final value of the overturning strength, vary the freshwater flux from the tropical to the northern box `wflx2` (suggested range: 0.25 to -0.25 Sv) and observe the time evolution and final value of the overturning strength. How does the final overturning strength depend on these settings?
- Repeat the last series of experiments, but reset `wflx2` to 0.065 Sv and vary the freshwater flux from the southern to the tropical box `wflx1` (suggested range: 0.25 to -0.25 Sv) and observe the time evolution and final value of the overturning strength. How does the final overturning strength depend on these settings? Compare.

- Finally set `incf` to `'endval.prn'` (which means 'initialize each new run from final values of previous run'). Again, run the model and vary the freshwater flux `wflx1` (from 0.25 to -0.25 Sv and back), observe the time evolution and final value of the overturning strength. How does the final overturning strength correspond to the freshwater flux? Compare.

2.3 Meltwater perturbation experiments

- Reset `wflx1` to 0.014 Sv and `wflx2` to 0.065 Sv. Reset `incf` to `'P'` (which means 'initialize each new run from built-in initial values').
- Now vary the maximum freshwater flux perturbation in the file `forcing_meltwater.prn` at year 750 between 0.01 and 0.4 Sv. Note that any entry in the second column affects `wflx1` and any entry in the third column affects `wflx2`. Thus first perturb `wflx1`, then `wflx3`. Observe the time evolution and final value of the overturning strength. Compare the two cases.
- Reset the maximum freshwater flux perturbation at year 750 to 0.2 Sv for `wflx1` and 0 Sv for `wflx2`. Vary the 'horizontal diffusion coefficient' `a_th` (suggested range: 0 to 3000 m s^{-2}). How is the final state of the model affected?

2.4 Hysteresis experiments

- Inspect the freshwater forcing data in the file `forcing_hysteresis.prn`. Make sure that `frcf` is set to `forcing_hysteresis.prn`. Set the parameters `xend` to 20,000 years. Set the maximum value of the perturbation to `wflx1` (second column) at year 5000 to 0.25 Sv and set the minimum value at year 15000 to -0.25 Sv. Run the model. Repeat this experiment for `wflx2` (third column).
- Now run the model for different values of `a_th`. How does the shape (height and width) of the hysteresis curve vary?