1. Explain the term "Thermohaline" circulation. How is it captured in the Stommel model?

\*\*Thermo=heat and haline=saline=salt. It is the circulation driven by differentials in salt and heat content of the water. Temperature corresponds to the heat content and salinity to the salt content of the water. Since heating water up makes it *less* dense and saltier water is more dense, they act against each other in driving water along the density gradient. In the TH state, T-S > 0 and the thermal effect dominates, so we say it is thermally driven (this corresponds to a warmer world, but that is not directly why it is called the THermal state.) In the SA state, T-S < 0 and te haline effect dominates, so we say it is salinity driven.

1. Does the *fluid* flow in the same direction for each of the steady states (fixed points) of the Stommel model? What is the difference, in physical terms, between the TH and SA states?

\*\*A key here is that there is a difference between the cartoon of the Stommel model, with its overflow pipe at the surface and capillary tube at depth, and the actual mathematical model In the model itself, there is no distinction between upper and lower flow as the two boxes are fully mixed. There is just flow between the two boxes back and forth, which we think of as northerly upper flow and southerly lower flow—but that is not really in the model. Note also that there is no net flow of water measured in volume as the boxes stay the same size with the same capacity. The net flow occurs at the level of density. So there may be net flow in a northerly direction of less dense water and southerly of denser water (TH), with the reverse in the SA state. I think I have this right, but it is always possible I have got it backwards, so it is worth thinking it through for yourself.

1. How would you go about determining whether we currently live under conditions that correspond to a "bistable" situation for the Stommel model? What would this imply?

\*\*This would be a fun exercise. Look at Stommel’s original paper, and others that expand upon it, to see how to set the parameters.

1. How does the bistability in the Stommel model help us understand rapid warming and/or cooling? Does it explain the asymmetry in the time scales of warming and cooling seen in the historical record?

\*\*As discussed by some of the groups reporting last Tuesday, the jump up from the SA state to the TH state (where the SA state ceases to exist) can be invoked as an explanation of the rapid cooling. But the fact that the reverse jump (TH -> SA) would also be rapid indicates the weakness in the Stommel model explanation.

1. To what extent does the MOC bistability seen in the Stommel model manifest itself in the more complex models up the hierarchy?

\*\*This is a really important question and one that can be the basis of a project. Dijkstra devotes considerable space to a discussion of this issue. He, with collaborators, has shown that it can appear in EMICs under various situations. BUT, the more complex Earth system models as used in the IPCC have not shown a breakdown of the MOC. It is interesting to speculate as to why this is the case.

1. Dijkstra cites internal, oscillatory modes of variability in the MOC in section 10.4. Discuss the different modes he refers to, and the models he uses to capture the underlying processes.

\*\*These are the Howard-Malkus models and the deep flushing models. Look at Dikstra’s book for a discussion. The latter is one of the proposed projects.

1. Can it be shown that the TH state is attracting for all parameter values for which it exists? And similarly for the SA state? What about the "middle" state. is it always unstable?

\*\*I believe so, good math exercise! But perhaps annoyingly algebraic…