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A box model for the Atlantic meridional overturning circulation: wind driven, buoyancy controlled or both?

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Recent numerical experiments point to the importance of freshwater forcing, i. e. buoyancy forcing, and transport in determining the stability and sensitivty of the AMOC. This is in apparent contrast with the prevailing view of an AMOC driven by wind–induced upwelling in the Southern Ocean. To discuss the issue, a box model is developed, building on [1]. Similarly to other studies, we find that the wind stress over the Southern Ocean is a necessary condition for an interhemispheric overturning circulation. A dependency of the downwelling flux in the north on the North–South density difference is needed to reproduce the results from GCMs. The role of the freshwater transport at the southern border of the Atlantic in determining AMOC stability is also clarified.

1. Box model definition

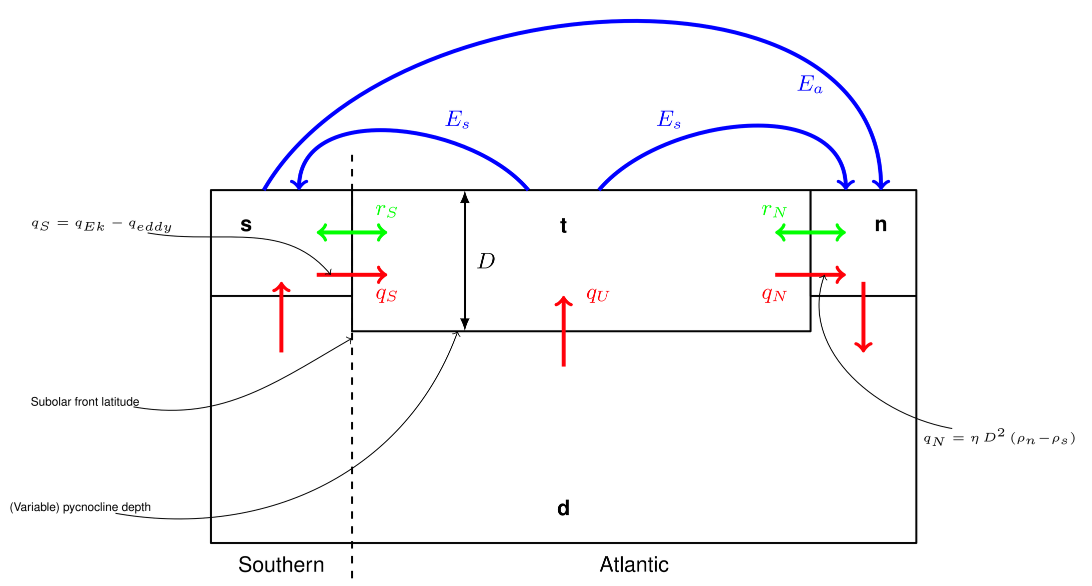

Figure A *Box model structure with net volume fluxes, gyre (diffusive) exchanges and atmospheric freshwater fluxes.*

The model includes:

- dynamic pycnocline model;
- dynamic salinity and prescribed temperatures;
- atmospheric freshwater transport (as a virtual salt flux);
- gyre exchanges: r_S and r_N.

Given the definitions $M_{ov} = -\frac{1}{S_0} q_S (S_s - S_n)$ and $M_{az} = -\frac{1}{S_0} r_S (S_s - S_t)$, the freshwater budget for the Atlantic basin reads:

$$\boxed{E_s - E_a = M_{ov} + M_{az}} \qquad (1)$$

2. Scaling for downwelling flux

Classical "Stommel" scalings for the downwelling with $q_N \propto (\rho_n - \rho_s)$ [2] fail to represent the correct sensitivity to wind–stress:

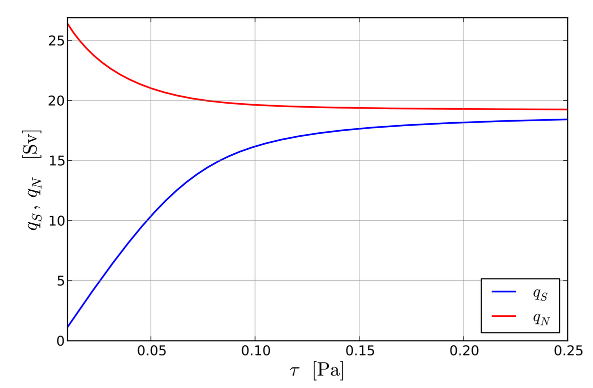

Figure B *Sensitivity of q_S and q_N to wind stress at the steady state, for a purely buoyancy driven AMOC. The sensitivity of q_N is wrong.*

This is solved by introducing a dependency on D^2. The dependency on $(\rho_n - \rho_s)$ is needed to reproduce the GCM sensitivity to freshwater anomalies, thus we assume:

$$\boxed{q_N = \eta\,(\rho_n - \rho_s)\,D^2,} \qquad (2)$$

as suggested by [3], recovering the correct sensitivity:

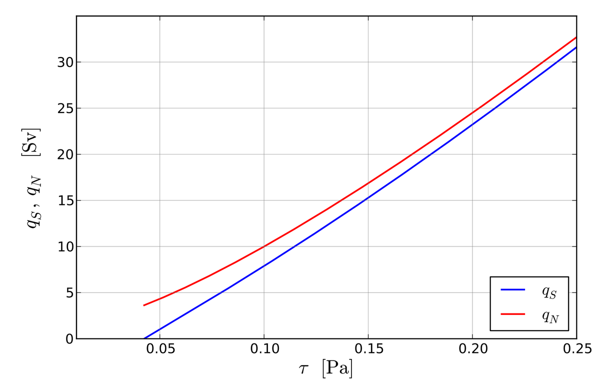

Figure C *Sensitivity of q_S and q_N to τ, with q_N given by (2).*

3. Bifurcation diagrams

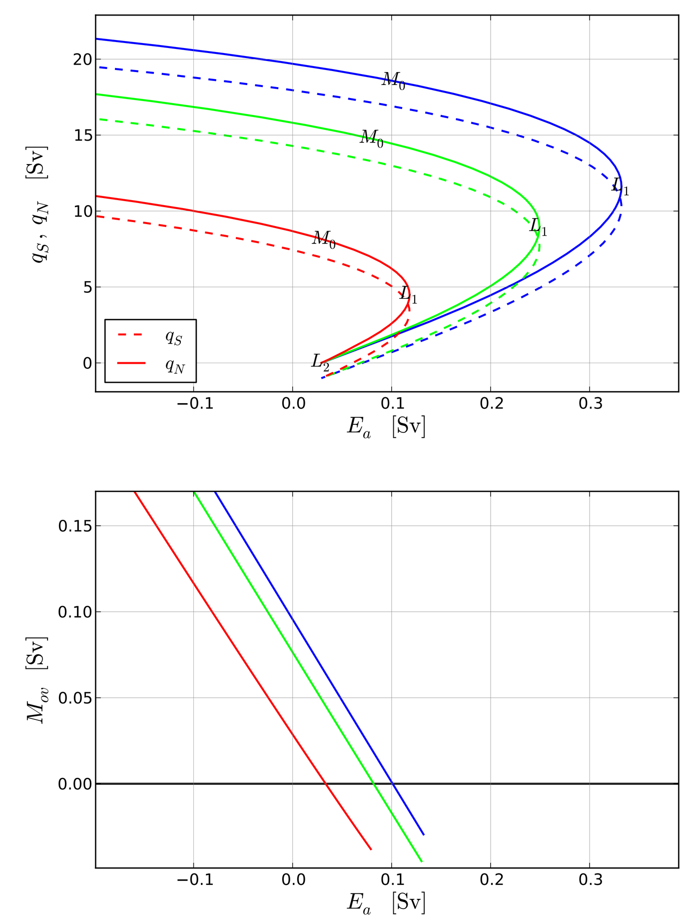

Figure D *Bifurcation diagrams for the overturning circulation strength (top) as a function of the asymmetric water vapour transport E_a. In the lower panel, M_{ov} is shown (plot stops before the limit point for clarity). In both panels, increasing values of the hydraulic constant η in (2) are used going from red to blue. L_1 and L_2 are limit points, marked only on q_N for clarity. The point where M_{ov} changes sign is marked by M_0 in the top panel.*

4. $\mathrm{M_{ov}}$ and AMOC stability

Is M_{ov} an indicator of AMOC stability?

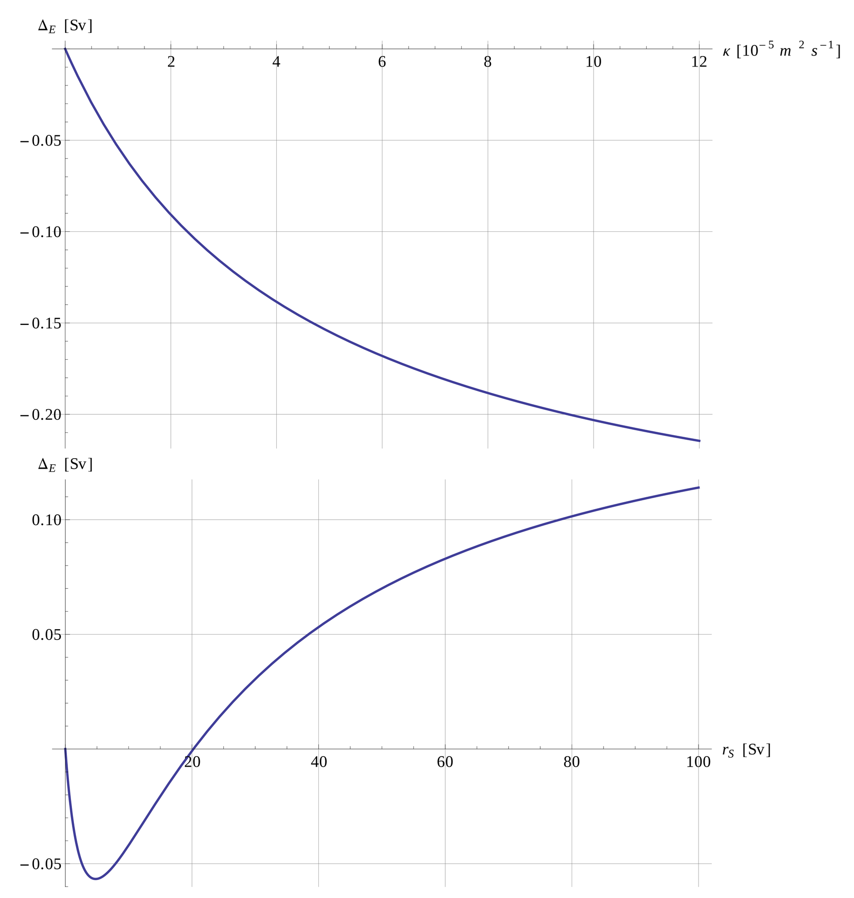

Figure E *Difference between E_a at L_2 and M_0 as a function of κ and r_S, measuring the goodness of M_{ov} as stability indicator. If M_{ov} is a perfect indicator, the difference is zero.*

M_{ov} is an ideal indicator of AMOC stability if no other feedbacks (vertical diffusion and southern subpolar gyre) outcompete salt–advection feedback.

5. Conclusions

- **a purely buoyancy driven AMOC can not account for the observed sensitivity to wind stress**
- **changes in the freshwater transport by the southern subpolar gyre affect AMOC stability (changing North–South density difference)**
- **freshwater transport by the AMOC ($\mathrm{M_{ov}}$) is a perfect stability indicator if salt–advection feedback is the dominant response to a perturbation of the AMOC.**

Bibliography

[1] H. L. Johnson et al. Reconciling theories of mechanically driven. . . Clim. Dyn. 2007, **29**:821–836
[2] C. Rooth, Hydrology and ocean circulation Progr. Oceanogr. 1982, **11**:131–149
[3] A. Levermann and J. Fürst, Atlantic pycnocline theory scrutinized. . . Geophys. Res. Lett. 2010, **37**:L14602

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