Flux correction and AMOC stability: Results from a dynamical box model

Anand Gnanadesikan, Richard Kelson and Michaela Sten
Johns Hopkins University

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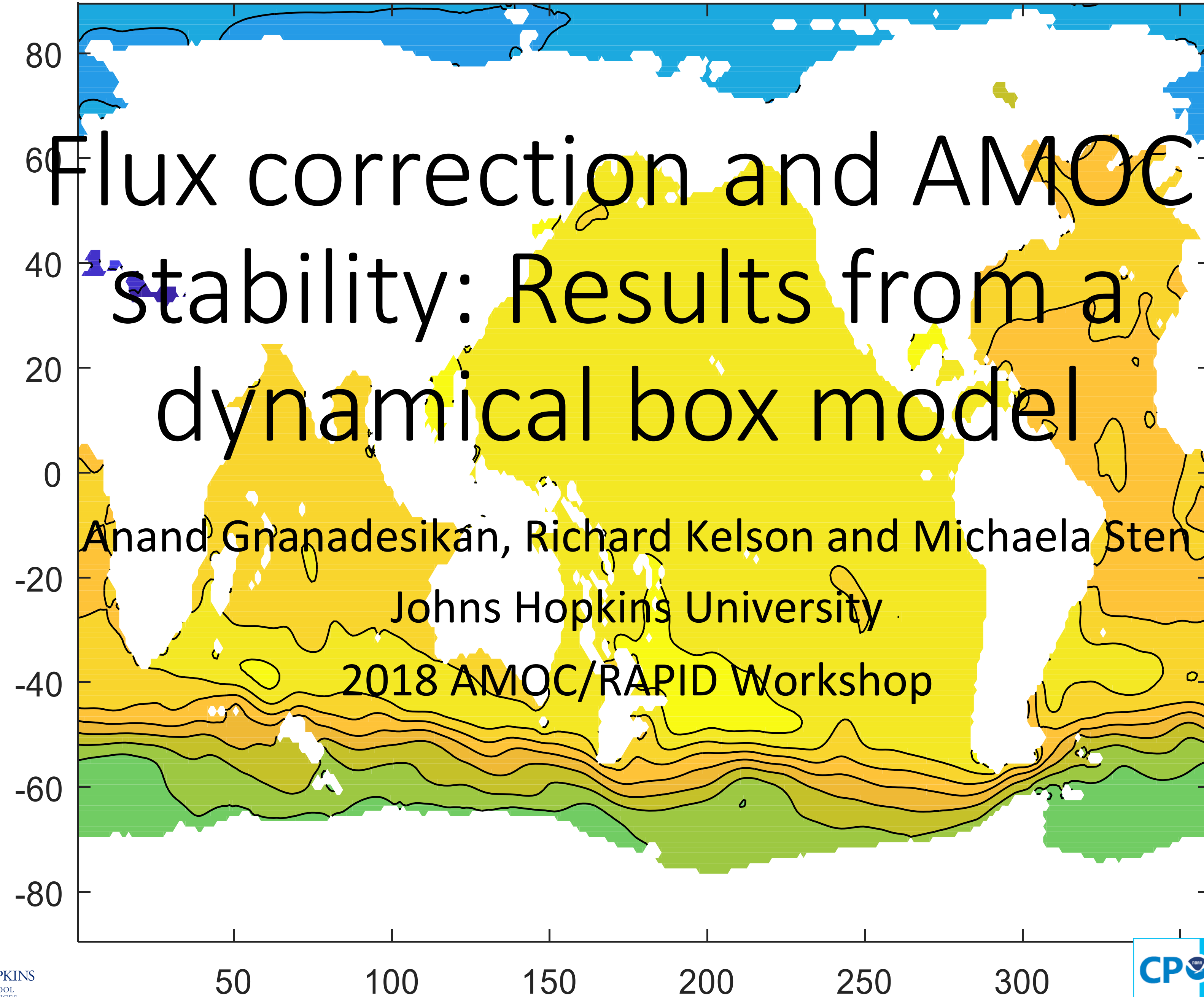

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Motivation

The Atlantic

The Atlantic Ocean and an Actual Debate in Climate Science

Scientists have recently begun to re-examine a scary question: Will a crucial ocean current shut down?

CLIMATOLOGY

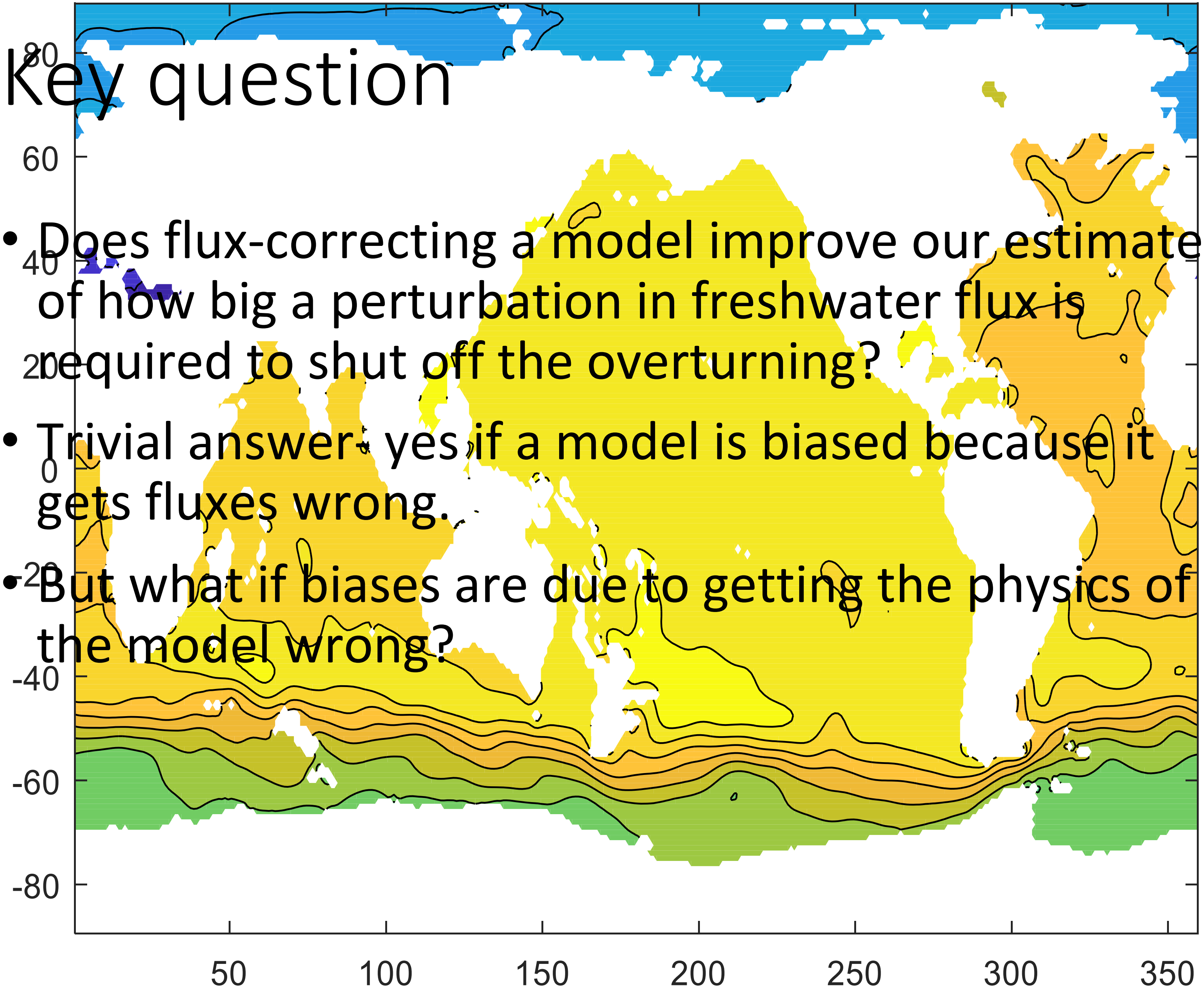
Overlooked possibility of a collapsed Atlantic Meridional Overturning Circulation in warming climate

Wei Liu,[1*†] Shang-Ping Xie,[1] Zhengyu Liu,[2] Jiang Zhu[2]

Changes in the Atlantic Meridional Overturning Circulation (AMOC) are moderate in most climate model projections under increasing greenhouse gas forcing. This intermodel consensus may be an artifact of common model biases that favor a stable AMOC. Observationally based freshwater budget analyses suggest that the AMOC is in an unstable regime susceptible for large changes in response to perturbations. By correcting the model biases, we show that the AMOC collapses 300 years after the atmospheric CO_2 concentration is abruptly doubled from the 1990 level. Compared to an uncorrected model, the AMOC collapse brings about large, markedly different climate responses: a prominent cooling over the northern North Atlantic and neighboring areas, sea ice increases over the Greenland-Iceland-Norwegian seas and to the south of Greenland, and a significant southward rain-belt migration over the tropical Atlantic. Our results highlight the need to develop dynamical metrics to constrain models and the importance of reducing model biases in long-term climate projection.

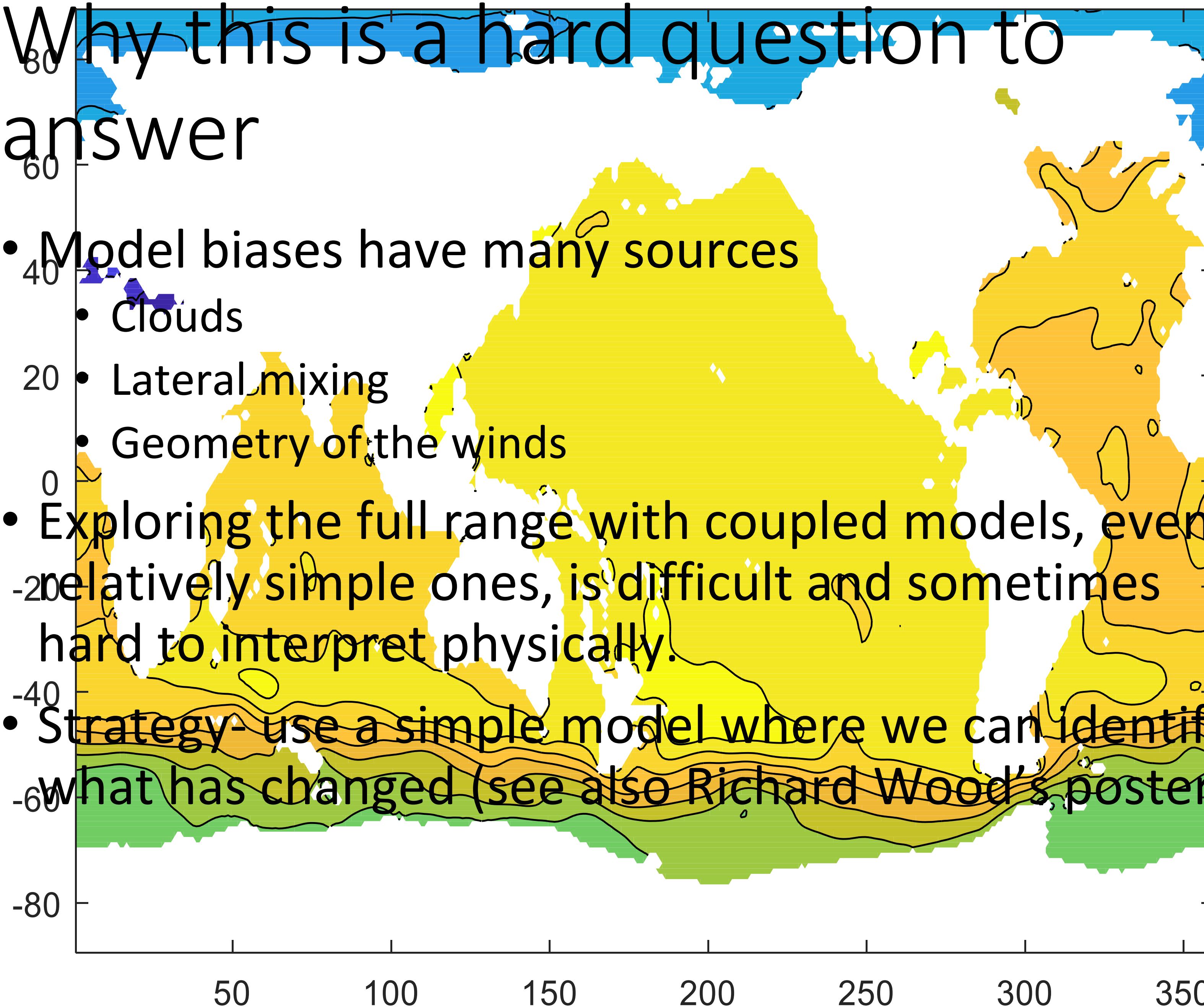
Key question

- Does flux-correcting a model improve our estimate of how big a perturbation in freshwater flux is required to shut off the overturning?
- Trivial answer- yes if a model is biased because it gets fluxes wrong.
- But what if biases are due to getting the physics of the model wrong?

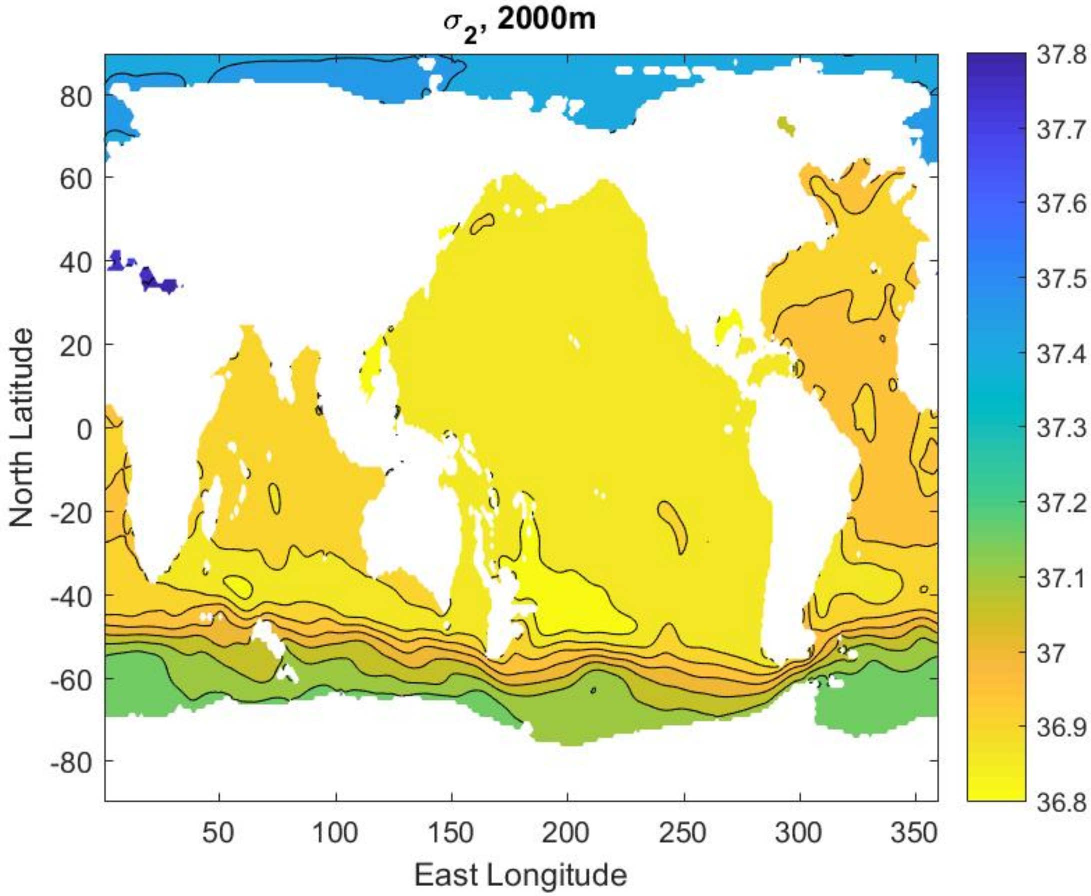


Why this is a hard question to answer

- Model biases have many sources
  - Clouds
  - Lateral mixing
  - Geometry of the winds
- Exploring the full range with coupled models, even relatively simple ones, is difficult and sometimes hard to interpret physically.
- Strategy- use a simple model where we can identify what has changed (see also Richard Wood's poster)



Key idea in the background



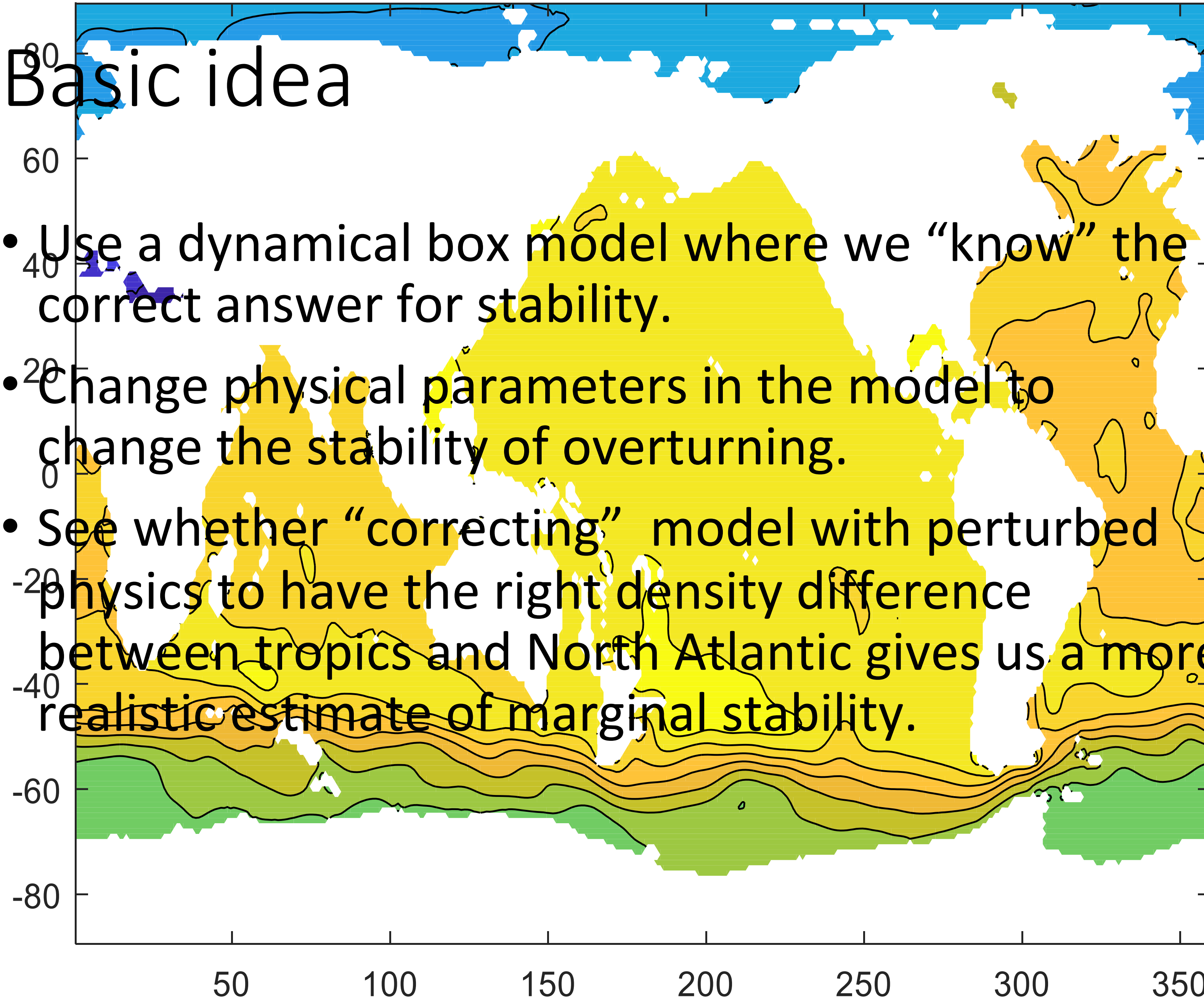
Density of waters in North Atlantic….

… is lower than density of waters upwelling in the Southern Ocean.

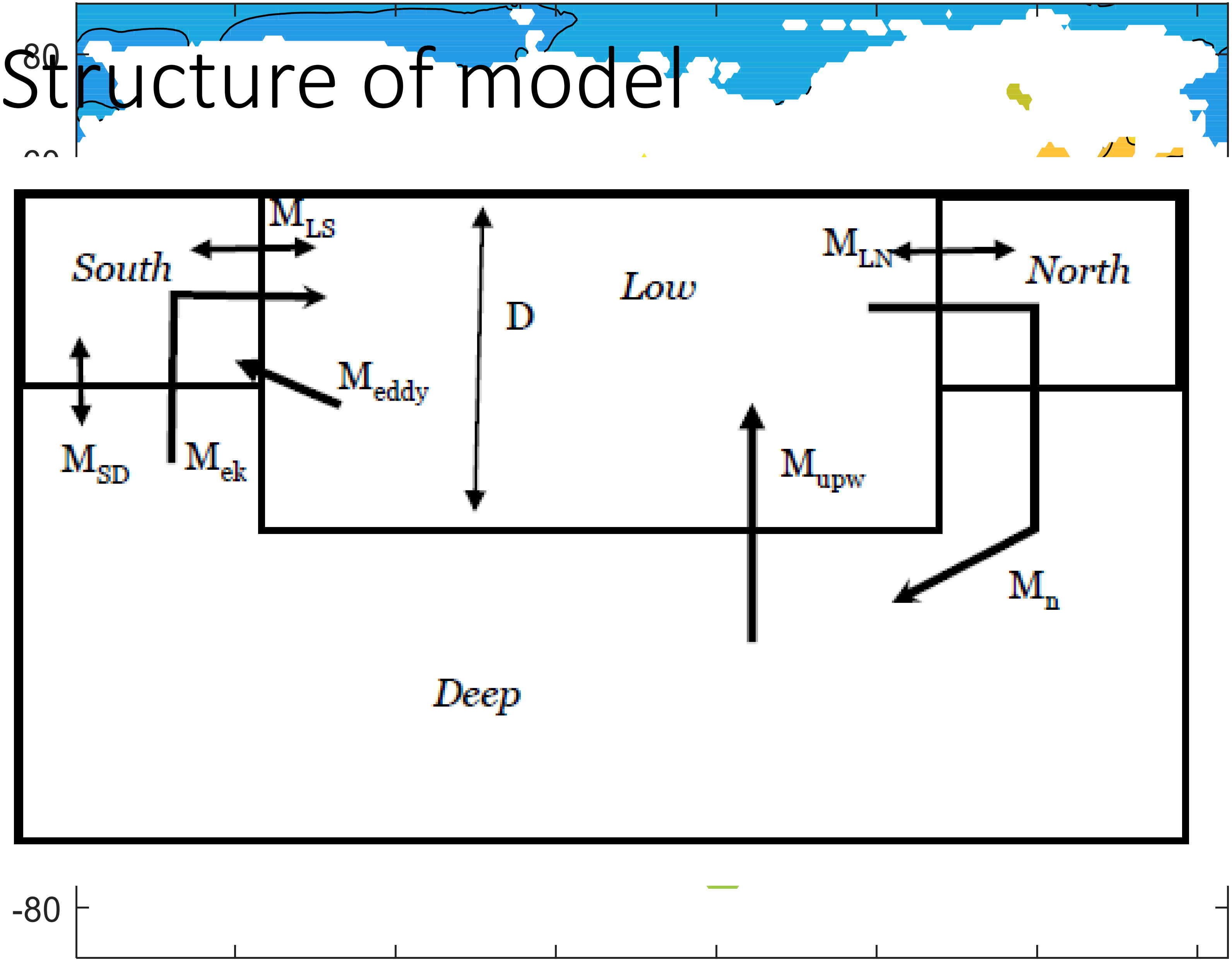
This implies a mechanically driven overturning, even down to the depth of the AMOC. (Gnanadesikan et al. J. Clim., 2005)

Basic idea

- Use a dynamical box model where we “know” the correct answer for stability.
- Change physical parameters in the model to change the stability of overturning.
- See whether “correcting” model with perturbed physics to have the right density difference between tropics and North Atlantic gives us a more realistic estimate of marginal stability.

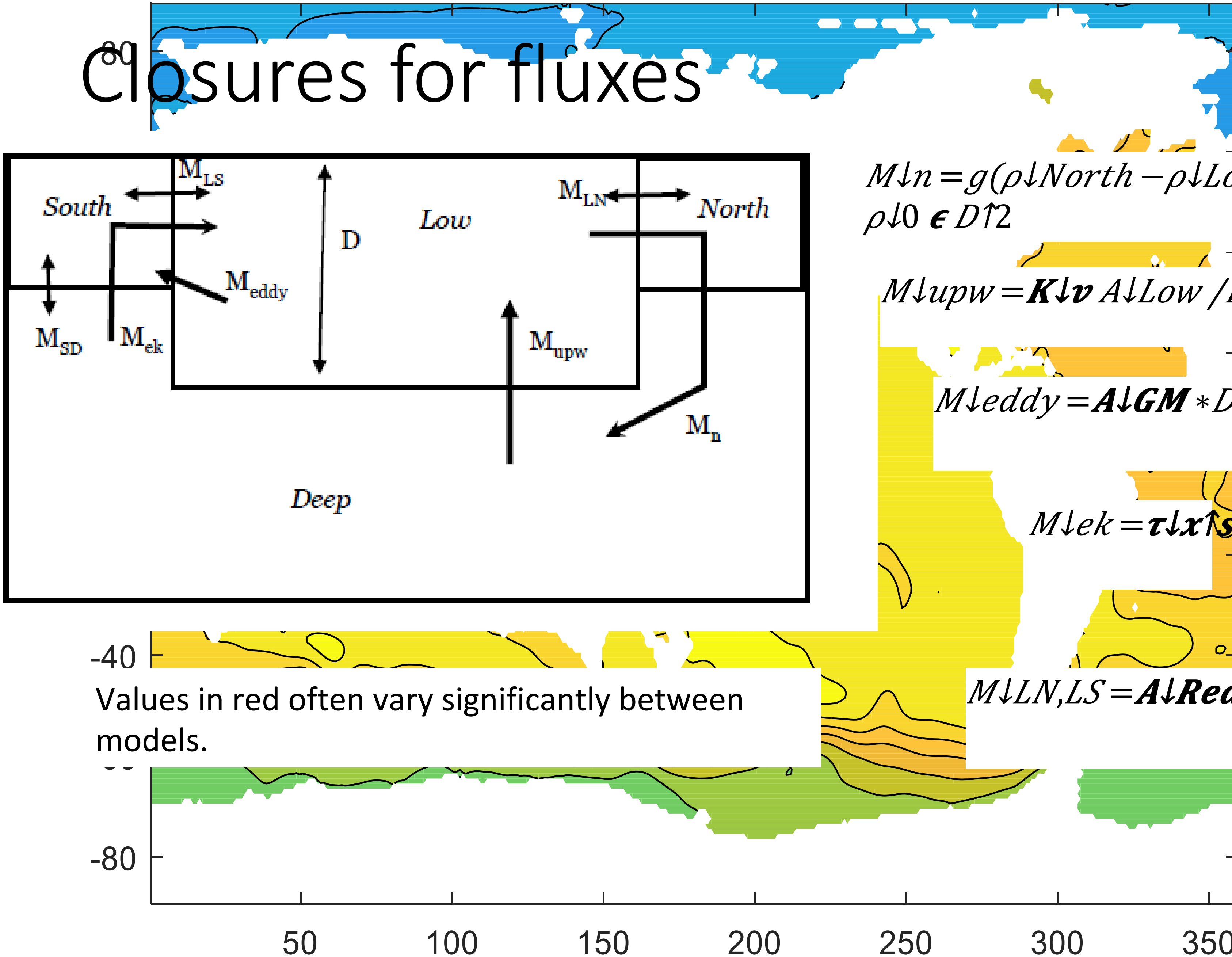


Structure of model



Gnanadesikan, 1999 as modified by Johnson, Marshall and Sproson, 2007

Closures for fluxes



$M_n = g(\rho_{North} - \rho_{Low})/\rho_0 \, \boldsymbol{\epsilon} \, D^2$

$M_{upw} = \boldsymbol{K_v} \, A_{Low} / D$

$M_{eddy} = \boldsymbol{A_{GM}} * D * L_x^s /$

$M_{ek} = \boldsymbol{\tau_x^s} \, L_x^s / \rho$

$M_{LN,LS} = \boldsymbol{A_{Redi}} \, L_x^{s,n}$

Values in red often vary significantly between models.

Examples of cross-model variability

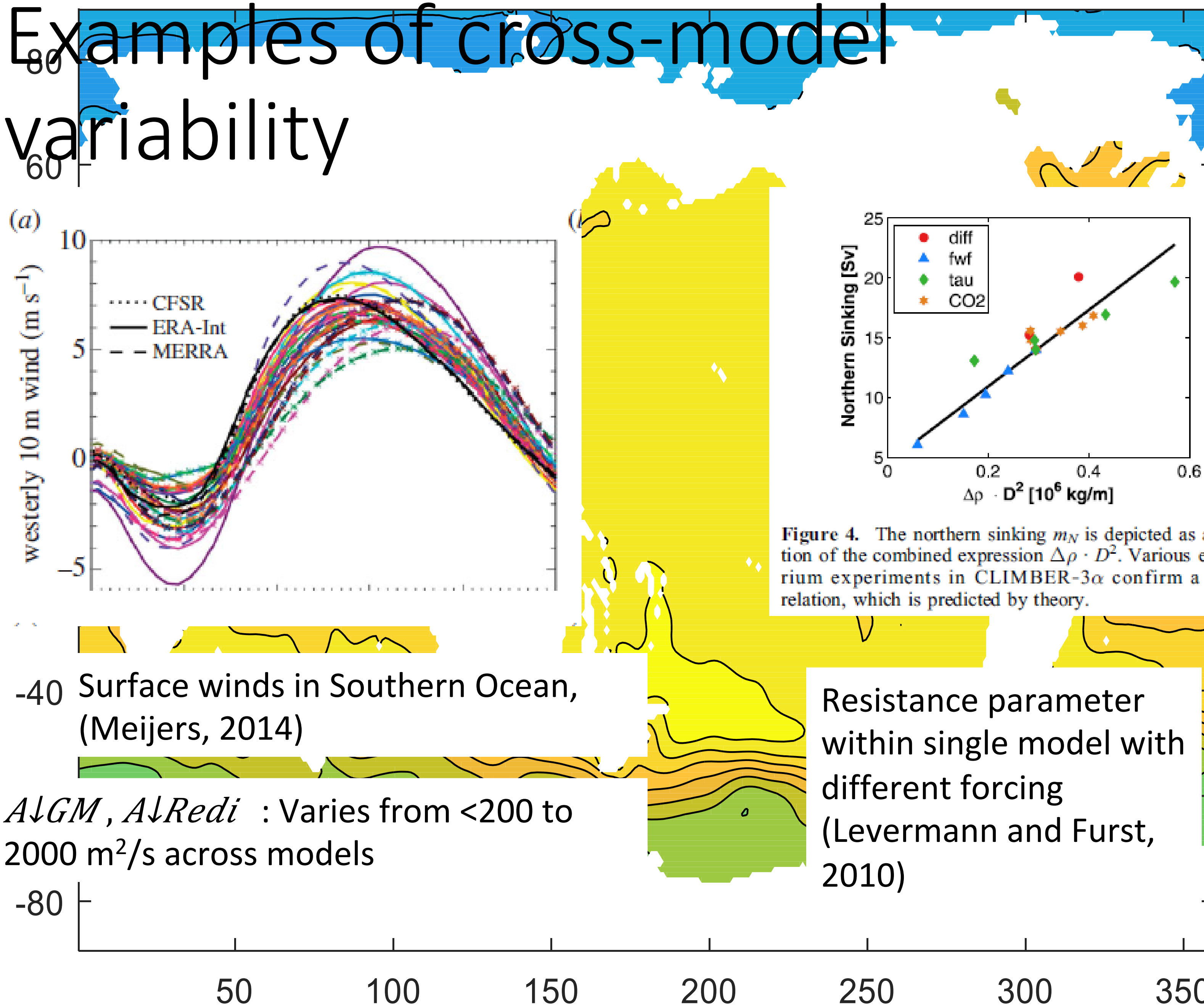


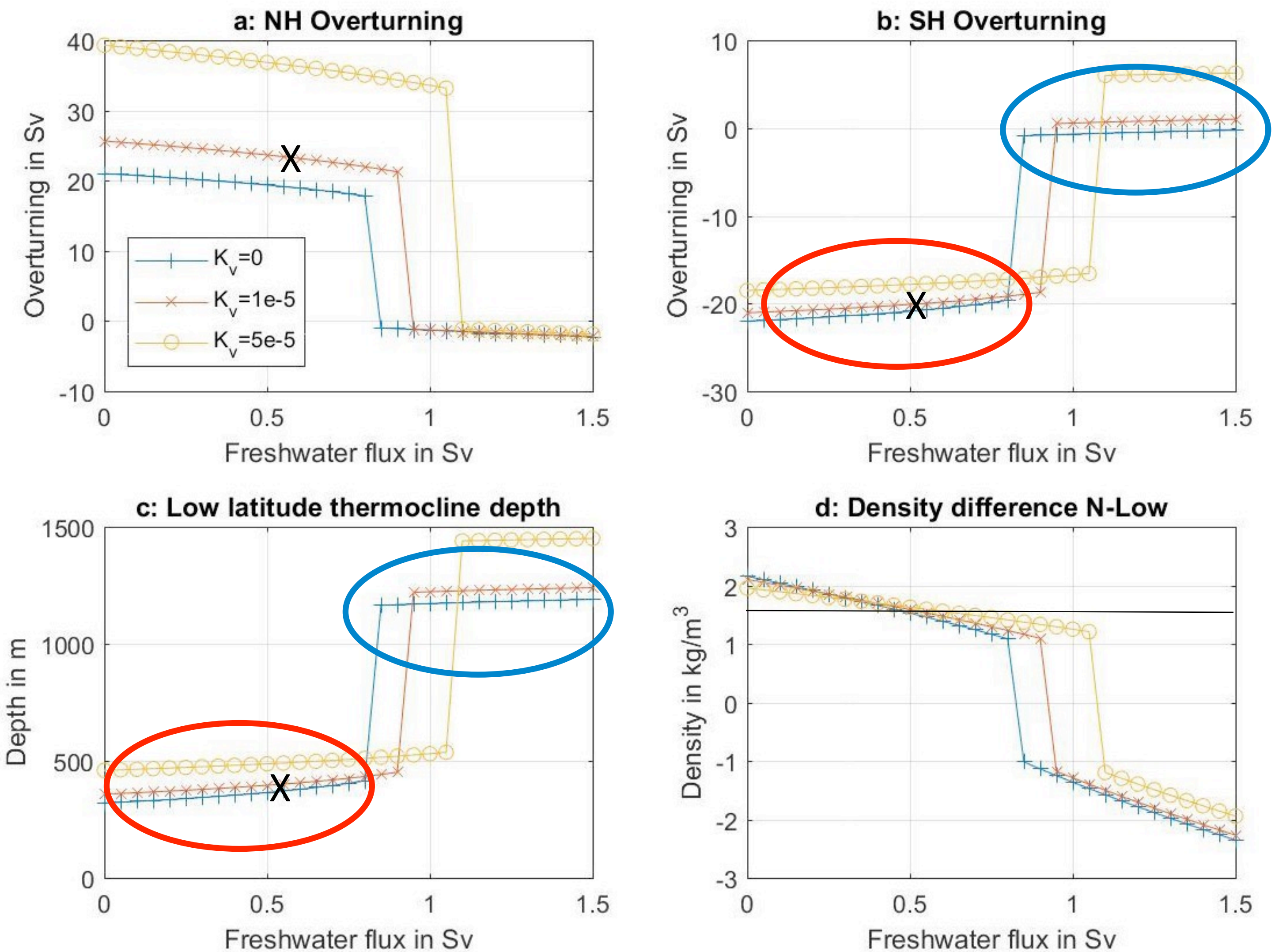
Figure 4. The northern sinking m_N is depicted as a function of the combined expression $\Delta\rho \cdot D^2$. Various equilibrium experiments in CLIMBER-3α confirm a linear relation, which is predicted by theory.

Surface winds in Southern Ocean, (Meijers, 2014)

A_{GM}, A_{Redi} : Varies from <200 to 2000 m^2/s across models

Resistance parameter within single model with different forcing (Levermann and Furst, 2010)

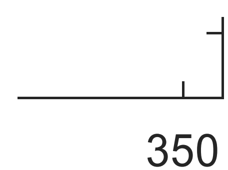
What happens as we increase NH freshwater flux?



Two basic states

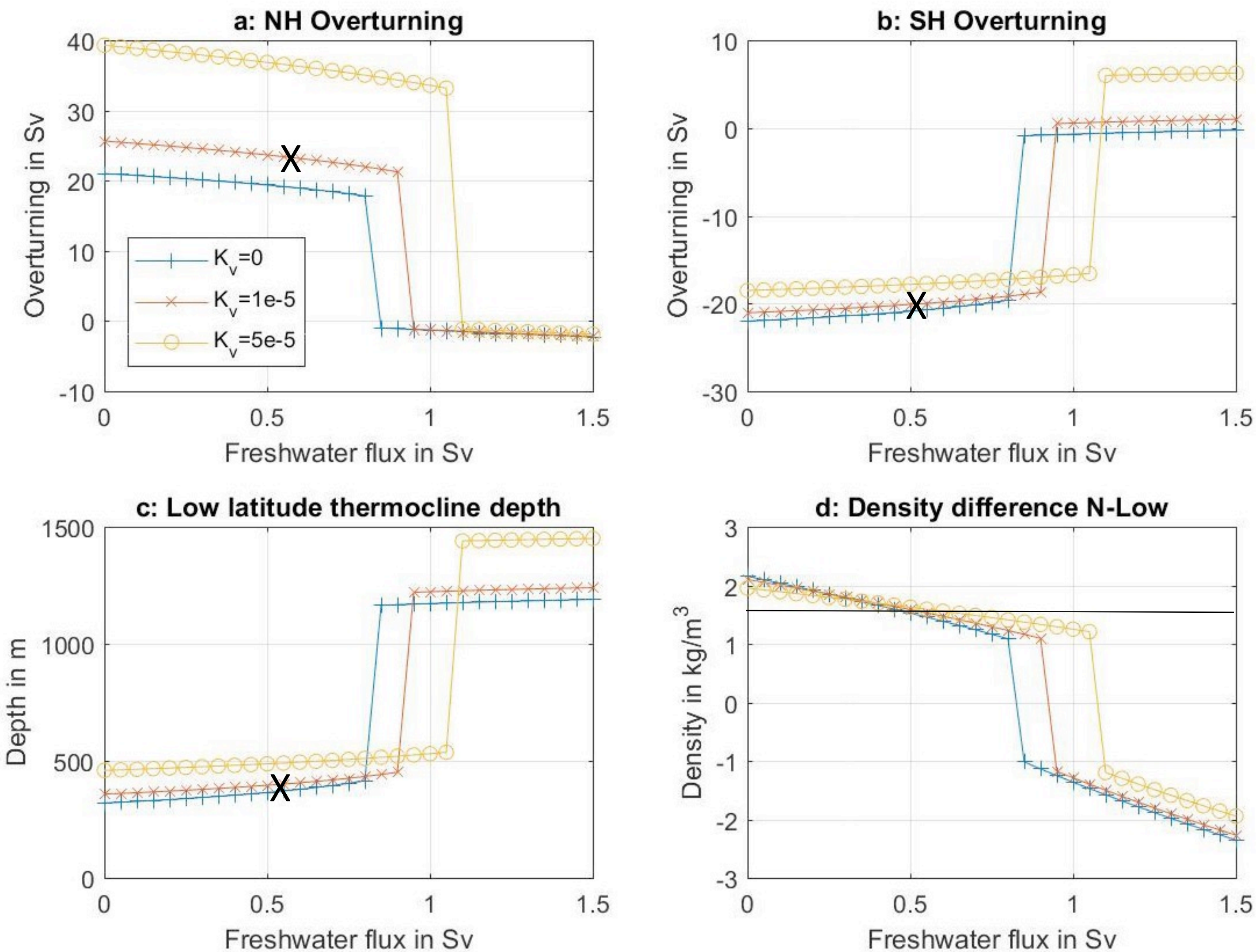
Shallow thermocline, SH eddies return small fraction of Ekman flux.

Deep thermocline eddies return Ekman+ LL upwelling flux.



What can we say about stability?

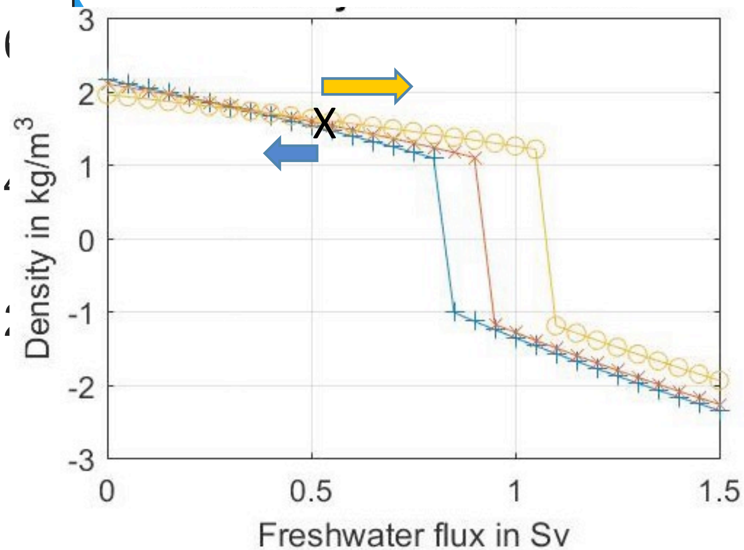
- If we get the freshwater flux correct

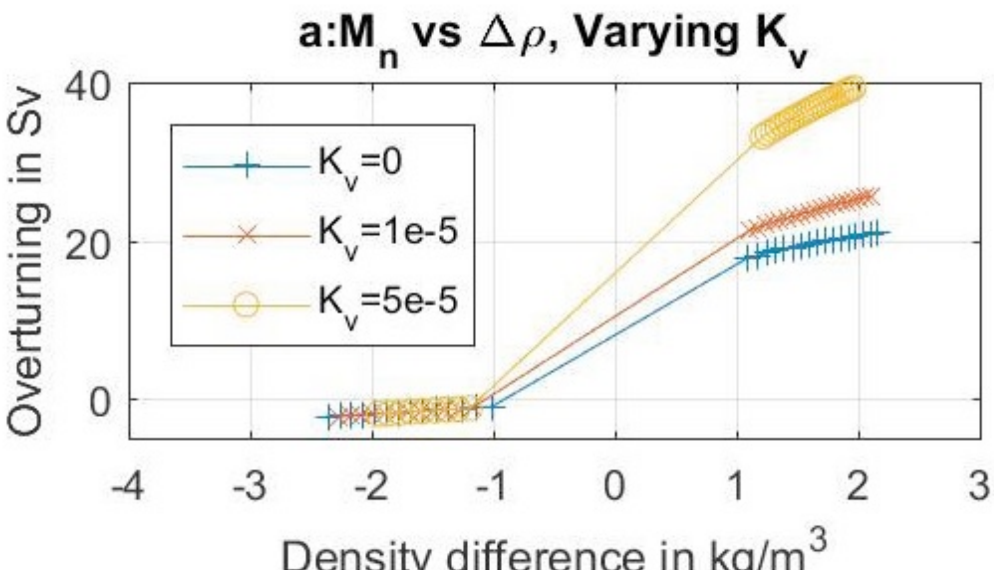


High mixing model too stable.. Will also have too large a density difference

Low mixing model too unstable. Will also have too small a density difference.

Density vs. overturning: Different K_v





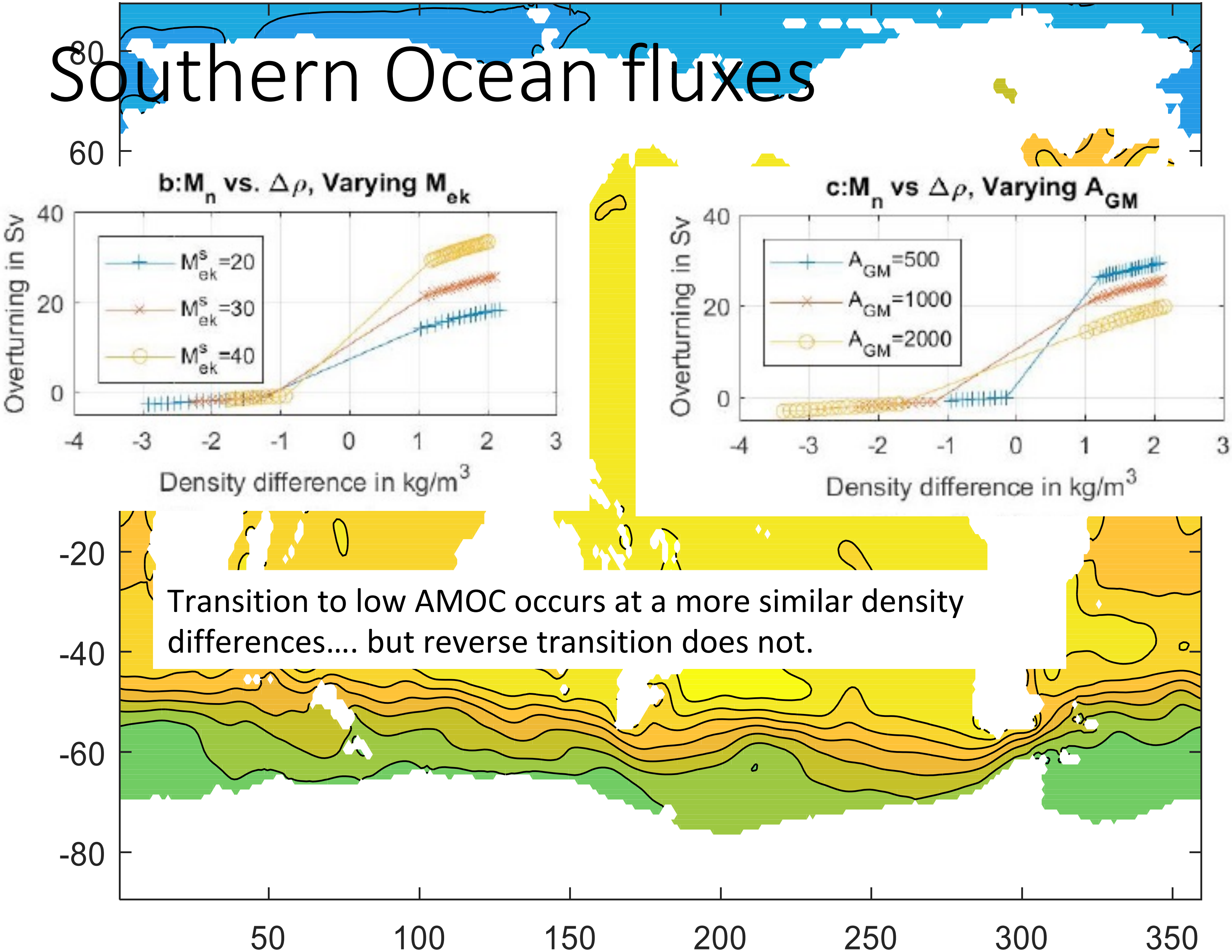
Flux correction moves the low mixing model away from the instability point, moves the high mixing model towards it

Even though there is no way to flux correct the perturbed models to get the right overturning…

Collapse occurs at *roughly* the same density difference.

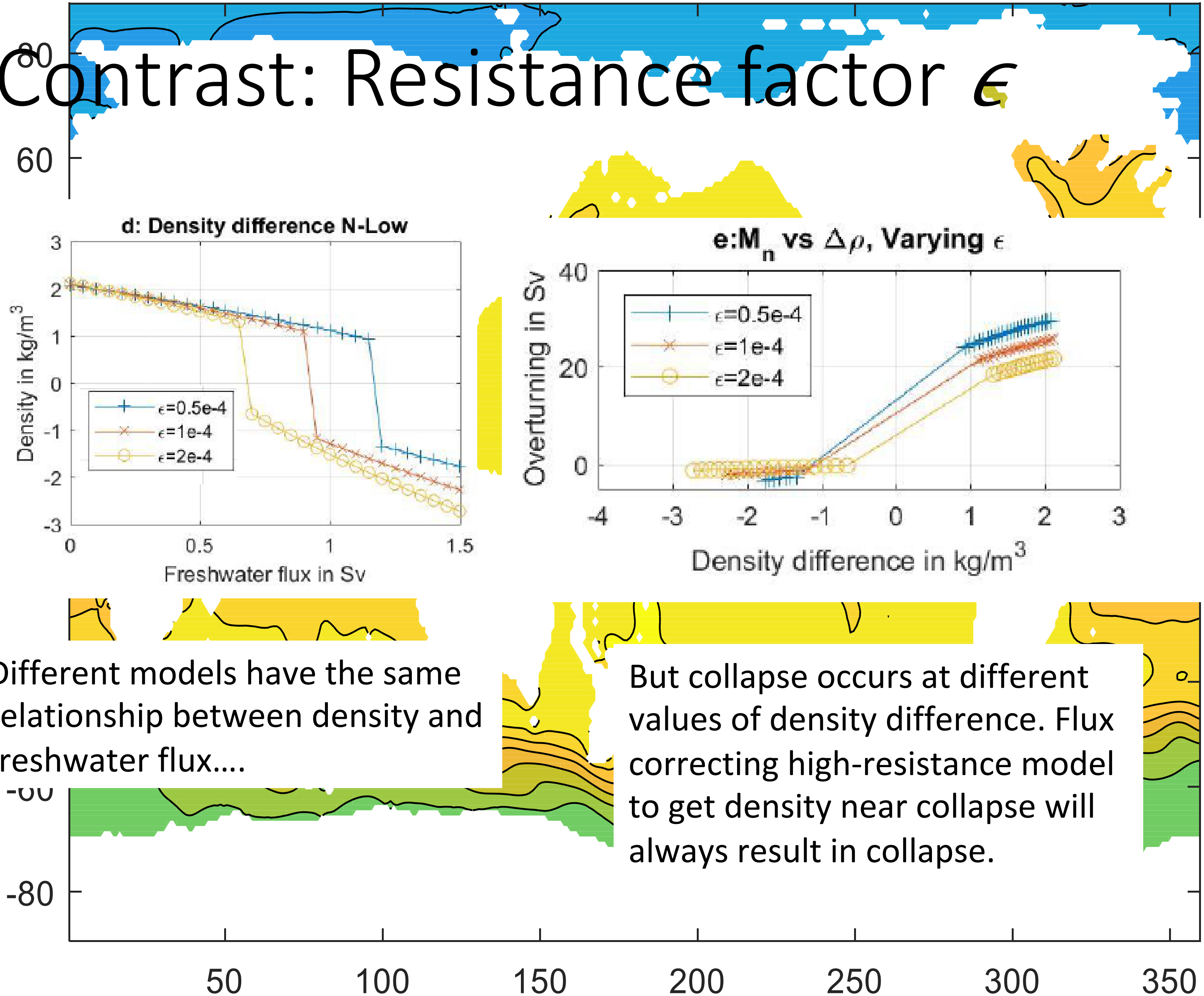
Flux correction gets about 80% of the answer.

Southern Ocean fluxes



Transition to low AMOC occurs at a more similar density differences…. but reverse transition does not.

Contrast: Resistance factor ϵ



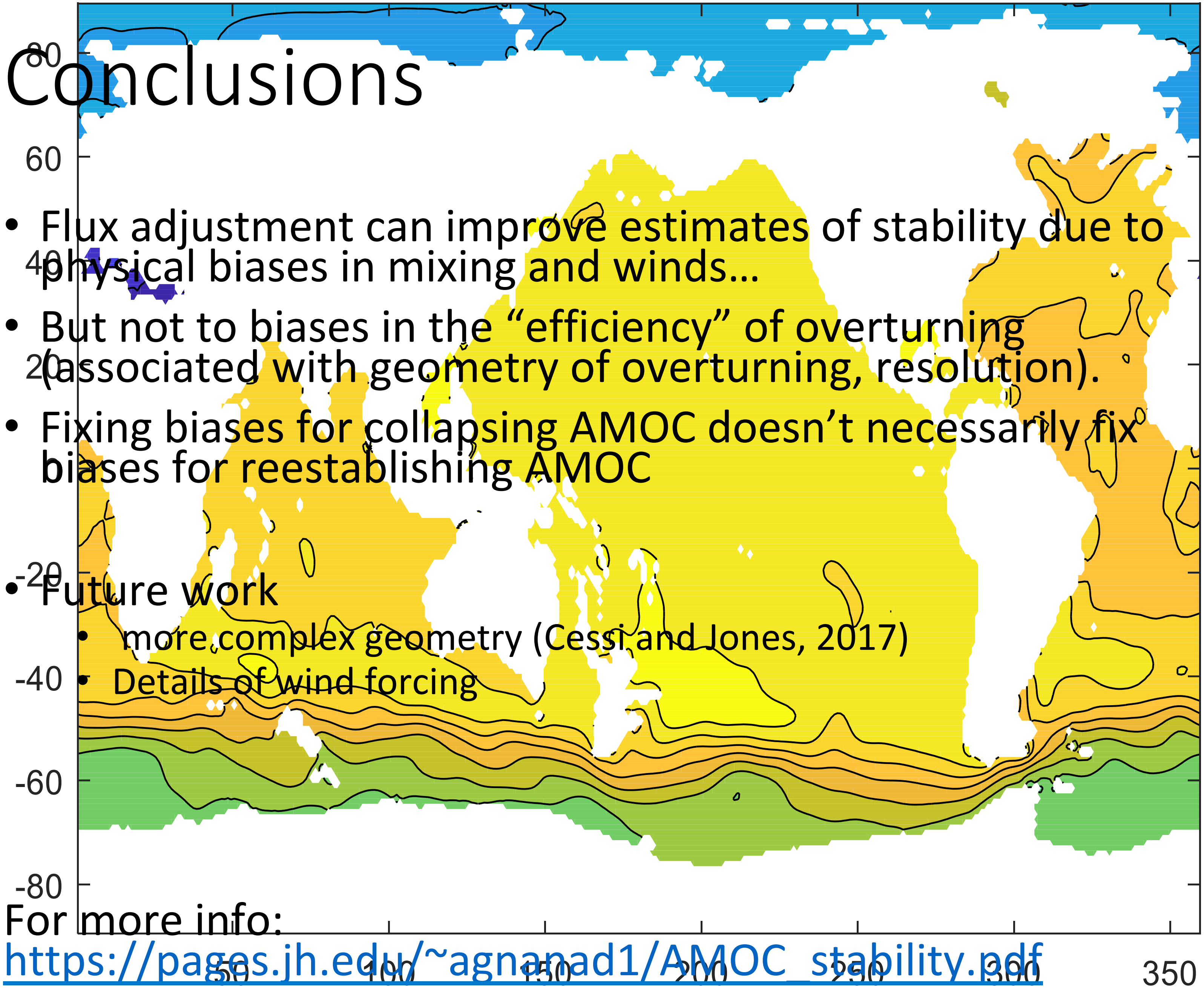
Different models have the same relationship between density and freshwater flux….

But collapse occurs at different values of density difference. Flux correcting high-resistance model to get density near collapse will always result in collapse.

Conclusions

- Flux adjustment can improve estimates of stability due to physical biases in mixing and winds…
- But not to biases in the “efficiency” of overturning (associated with geometry of overturning, resolution).
- Fixing biases for collapsing AMOC doesn’t necessarily fix biases for reestablishing AMOC

- Future work
  - more complex geometry (Cessi and Jones, 2017)
  - Details of wind forcing



For more info:
https://pages.jh.edu/~agnanad1/AMOC_stability.pdf