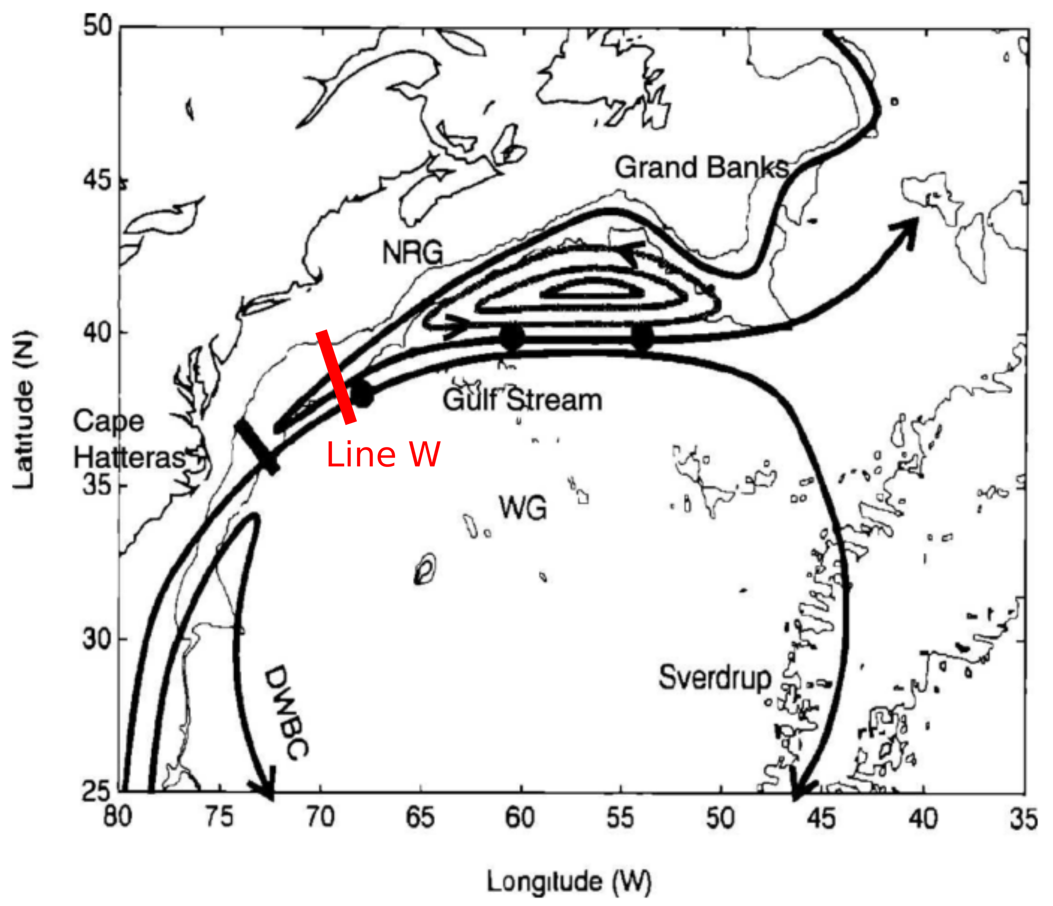
Interaction between the Gulf Stream Northern Recirculation Gyre and the Deep Western Boundary Current – A Model Study

Isabela Le Bras[1,2] (ilebras@whoi.edu) Steven Jayne[2] and John Toole[2]
[1] MIT-WHOI Joint Program [2] Woods Hole Oceanographic Institution

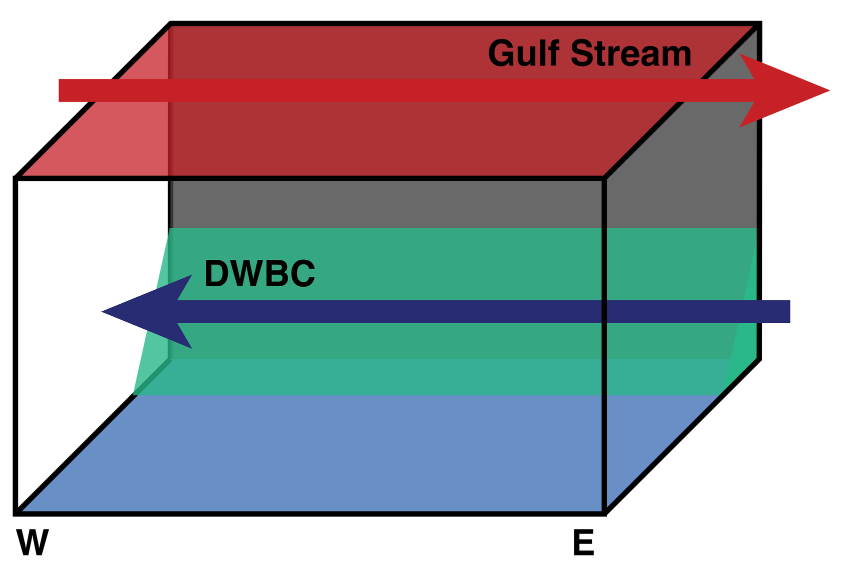
Introduction

The Northern Recirculation Gyre (NRG) coexists with the Deep Western Boundary Current (DWBC) at depth. Given increasing evidence of DWBC water stirring into the interior (e.g. Bower et al. 2009), we model the interaction between the NRG and the DWBC to gain a mechanistic understanding of processes which could shape the structure of the AMOC.



Left: Schematic of the barotropic circulation in the western North Atlantic adapted from Hogg (1992), Zhang and Vallis (2007).

We use an idealized two-layer Quasi-Geostrophic model.



Potential Vorticity (PV):

$$q_n = \nabla^2\psi_n + \beta y \mp \frac{1}{S_n}(\psi_1 - \psi_2) + \eta_B$$

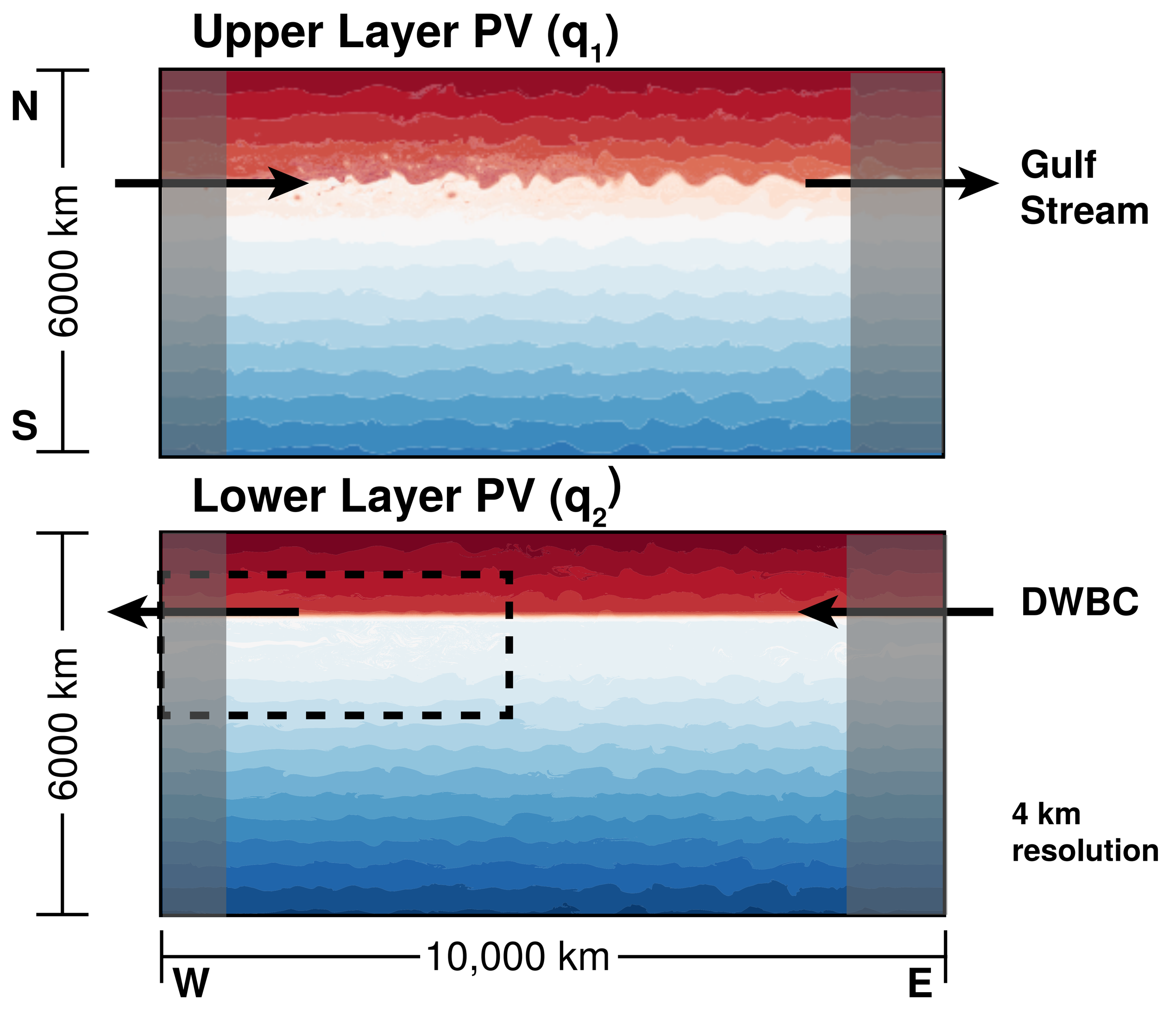
Conservation equation:

$$\frac{\partial q_n}{\partial t} + u_n \cdot \nabla q_n = A\nabla^4\psi_n - \nabla R \cdot \nabla \psi_n$$

Balance between time-mean (5 years after 20 year spinup) and "eddy" (deviations from time-mean) terms:

$$\nabla \cdot \overline{u_n}\,\overline{q_n} + \nabla \cdot \overline{u_n' q_n'} = 0$$

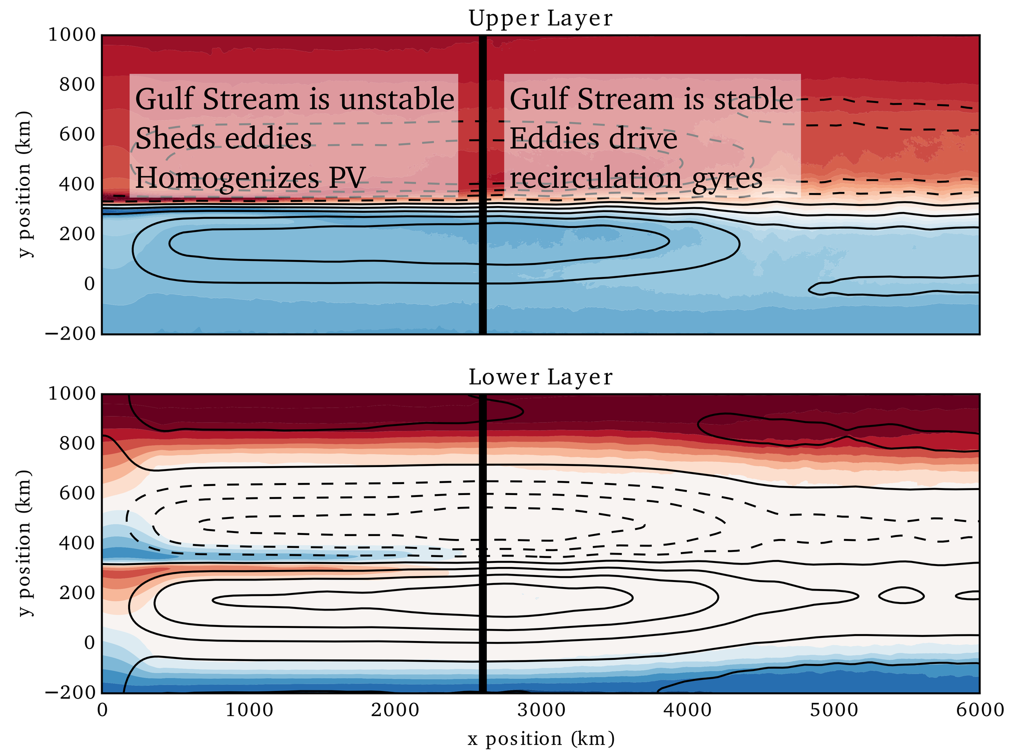
- An unstable Gulf Stream flows eastward in the upper layer.
- Barotropic recirculation gyres emerge in the time mean.
- A DWBC flows westward in the lower layer to the north of the Gulf Stream on a topographic slope.
- Inflow and outflow imposed as boundary conditions.
- High friction sponge regions in the east and west isolate the interior from the boundaries.
- We focus on a subdomain of the model.

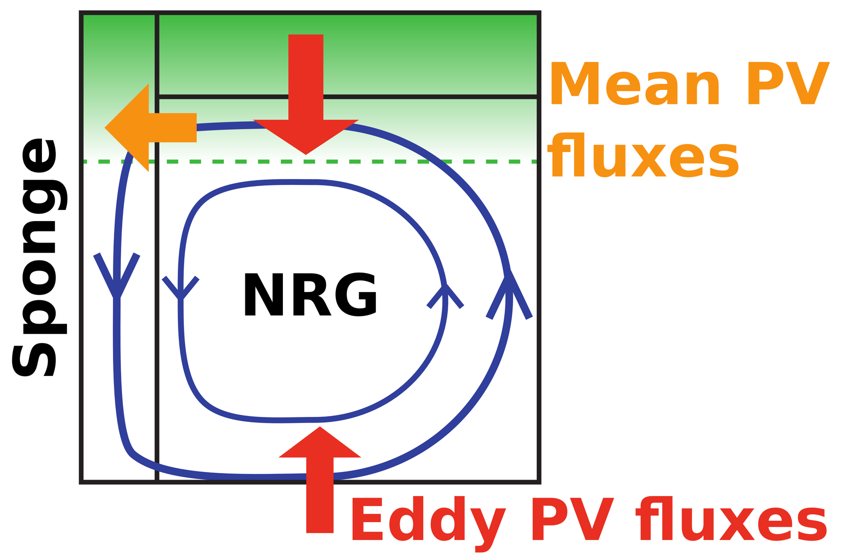


(Jayne et al 1996, Jayne and Hogg 1999, Waterman and Jayne 2011)

Recirculation Gyre Dynamics

As the unstable jet enters the domain, it is stabilized by a down-gradient eddy PV flux, which homogenizes PV. Downstream, where the jet has been stabilized, an eddy enstrophy convergence allows up-gradient eddy PV fluxes, which drive the recirculation gyres through nonlinear eddy rectification.

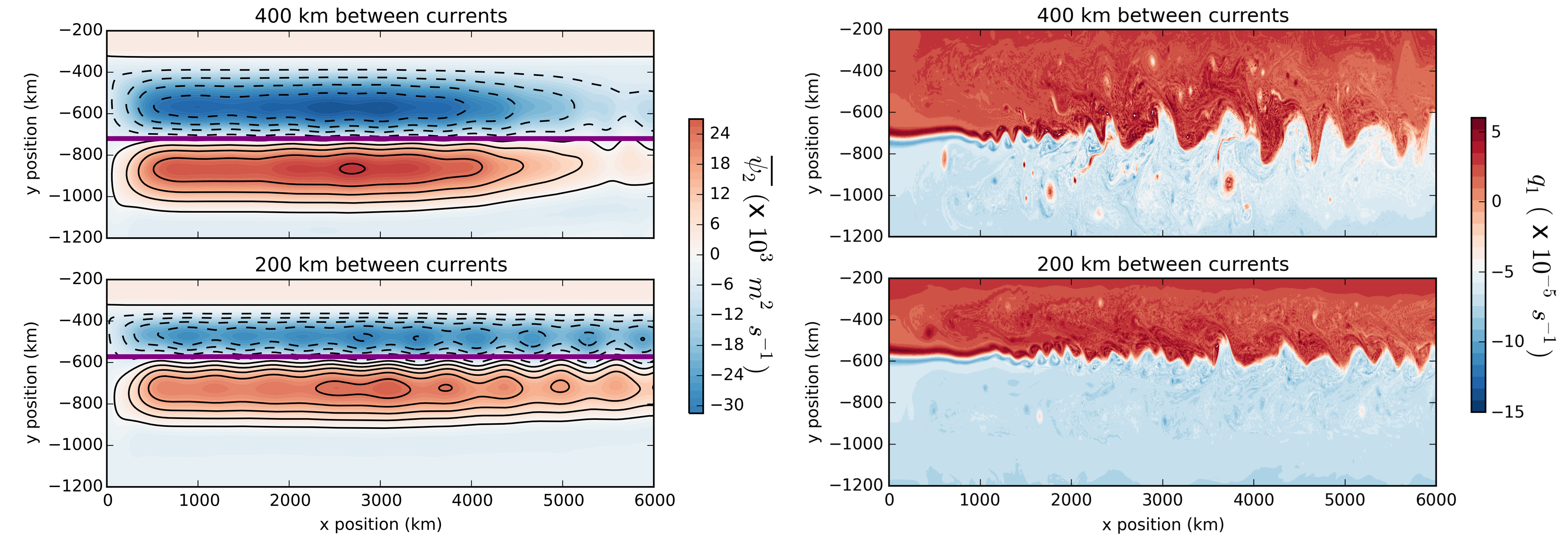




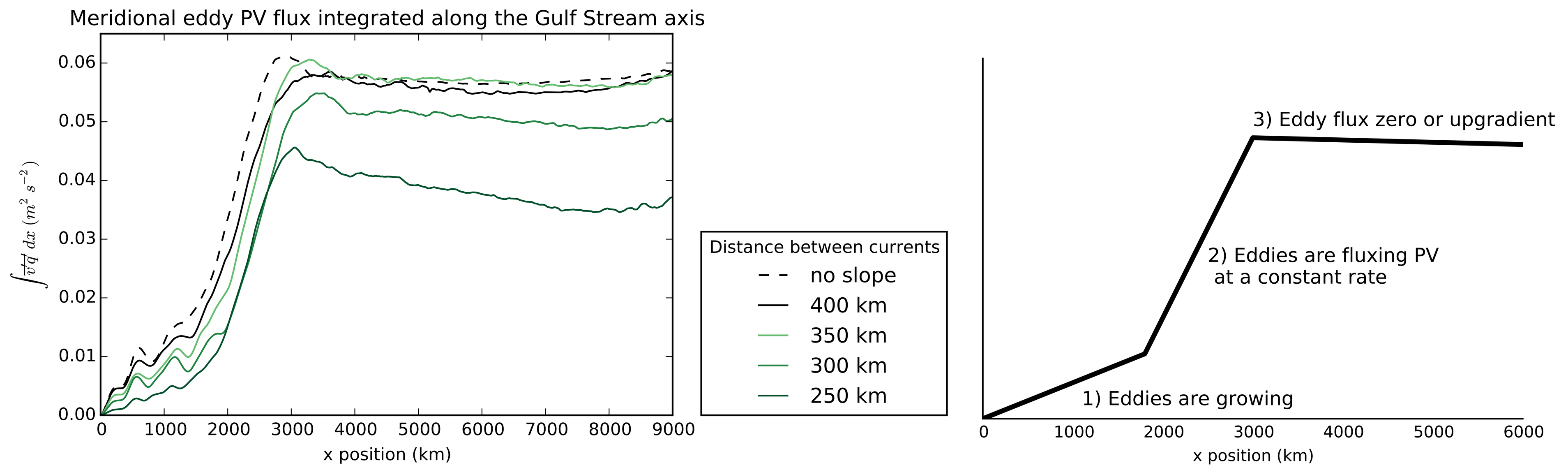
Left: Time mean streamfunction (ψ) in black and time mean PV in red/blue. PV is homogenized within recirculation gyres. *Right:* Schematic depicting time mean balance between eddy and mean PV fluxes for the NRG.

Feedbacks on Gulf Stream Instability

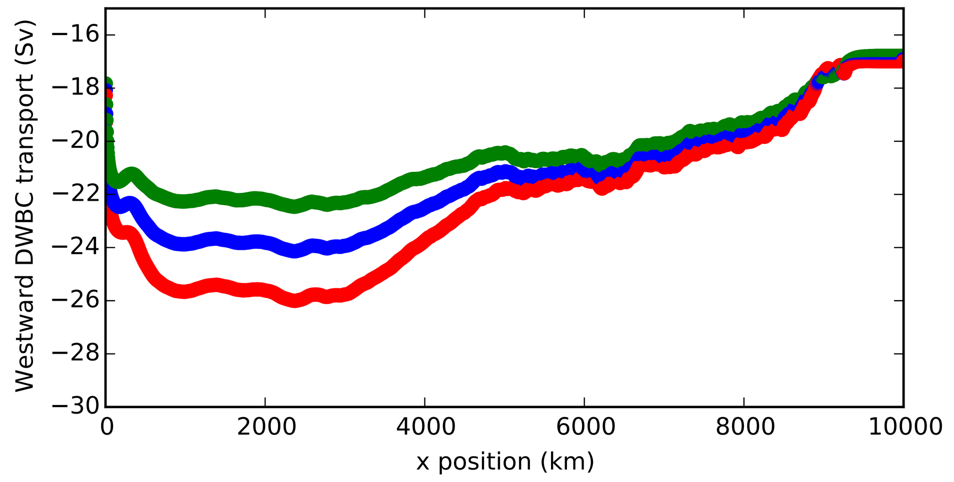
When the Gulf Stream is further north, the recirculation gyre is elongated zonally and its transport decreases (*left, below*). The character of its instability field also appears to undergo a change (*right, below*).



Below: By examining the zonal evolution of meridional eddy PV fluxes at the Gulf Stream axis, we can link this change to a decrease in the eddy growth rate caused by meridional proximity to the continental slope.

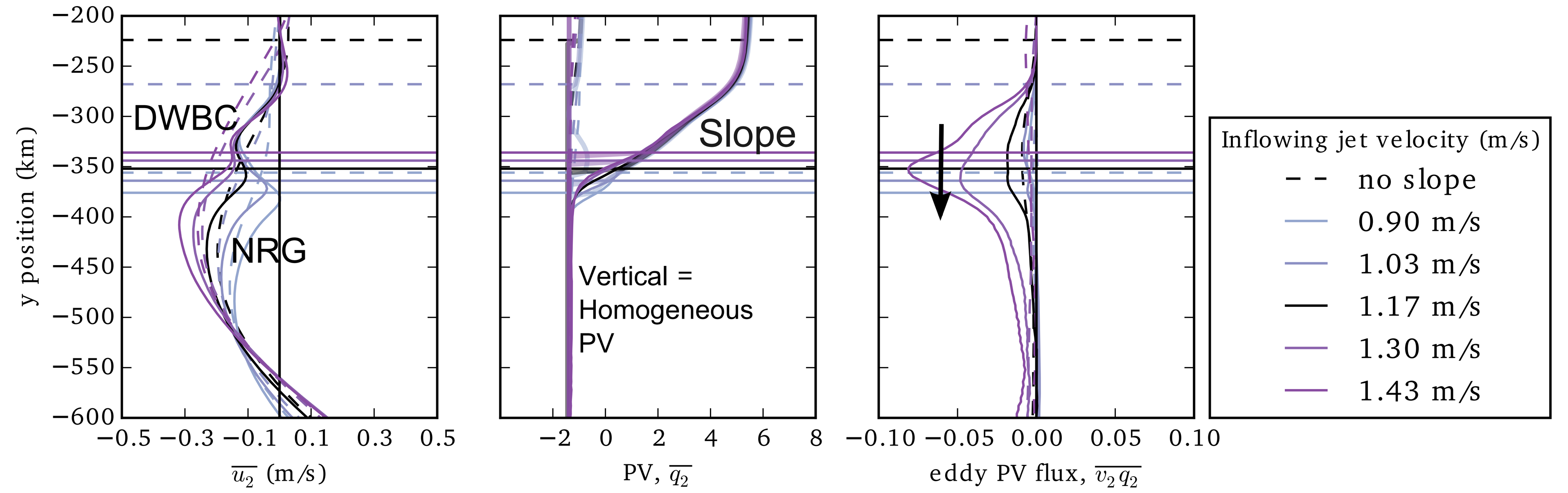


DWBC Stirring

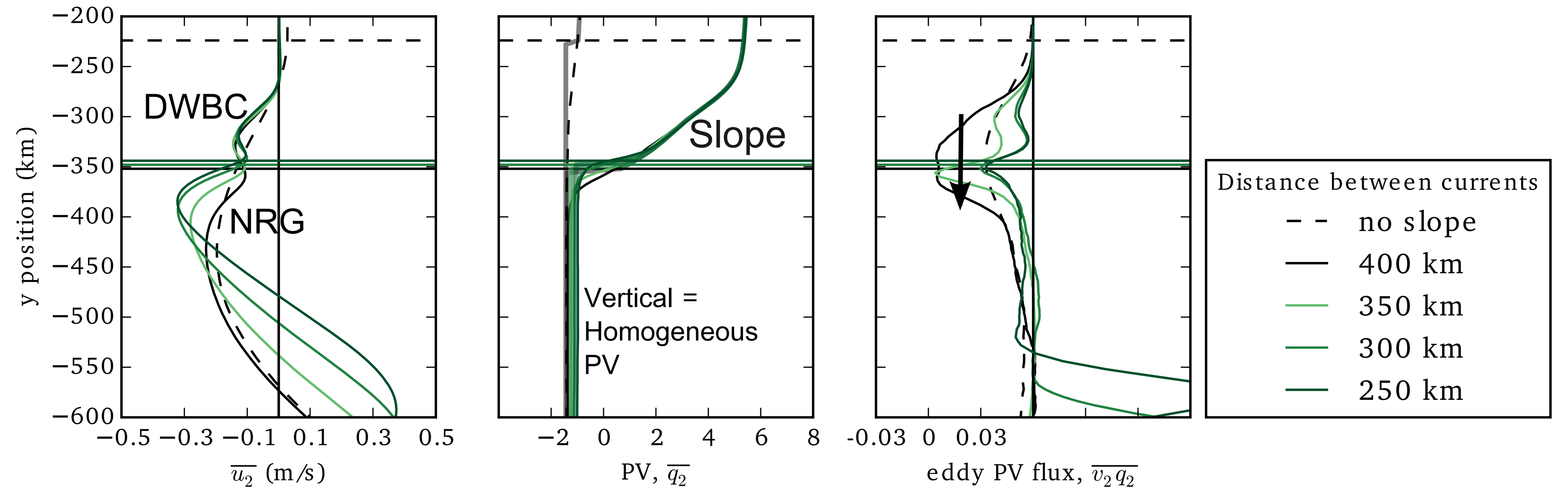


Left: DWBC transport integrated from the north to 3 different latitudes in the model base case. Inflowing and outflowing transport is 17 Sv. The DWBC entrains water as it flows westward, most notably as it encounters the NRG.

Below: A faster inflowing Gulf Stream leads to **1.** Faster NRG **2.** Penetration farther into slope by the NRG **3.** Larger eddy flux at the NRG/DWBC boundary



Below: Moving the Gulf Stream axis further north (closer to the slope) leads to **1.** Less NRG transport **2.** Penetration only slightly farther into slope by the NRG **3.** Smaller eddy flux at the NRG/DWBC boundary
→ Counterintuitive result, see "feedbacks" section



Conclusions

- The continental slope can restrict the size of the Gulf Stream's Northern Recirculation Gyre.
- The Northern Recirculation Gyre can merge with the DWBC at depth, and its adjustment is associated with eddy fluxes that stir the DWBC with the interior. The DWBC entrains water as it encounters the NRG.
- Proximity to the slope can damp instability growth in the Gulf Stream.
- These mechanisms may shape the circulation in the western North Atlantic, with potential feedbacks on the AMOC and climate system.

References: Bower et al. *Interior pathways...* Nature 2009, Hogg *On the transport...* DSR 1992, Zhang and Vallis *The role of...* JPO 2007, Jayne et al. *Recirculation gyres...* JPO 1996, Jayne and Hogg *On recirculation...* JPO 1999, Waterman and Jayne *Eddy-mean flow...* JPO 2011, Le Bras *Dynamics of North Atlantic Western Boundary Currents...* Ph.D. Thesis 2017

Acknowledgements: NSF grants OCE-1332667 and 1332834, Mike Spall, Glenn Flierl, Amy Bower and Harriet Alexander.