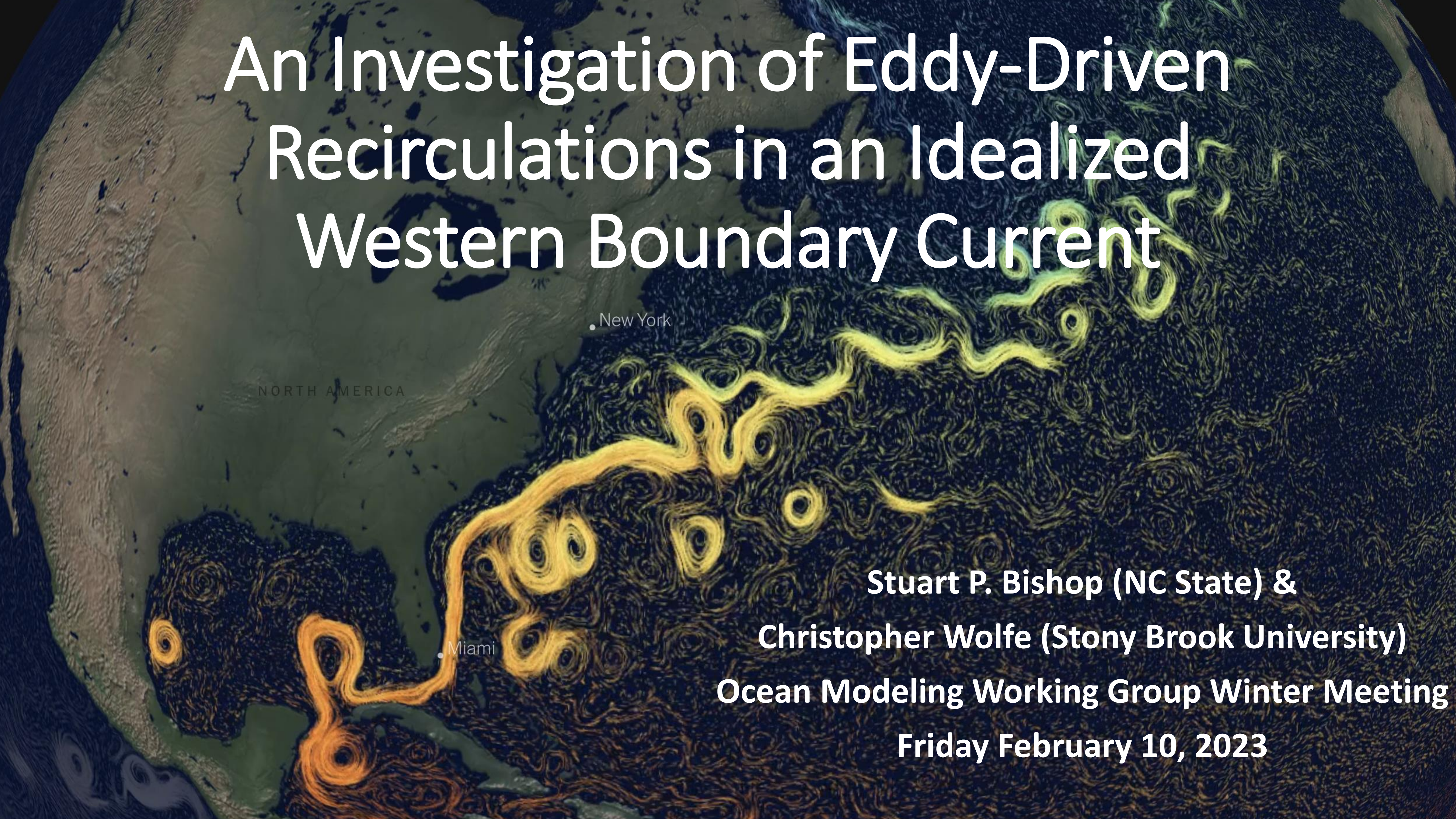
An Investigation of Eddy-Driven Recirculations in an Idealized Western Boundary Current



Stuart P. Bishop (NC State) &

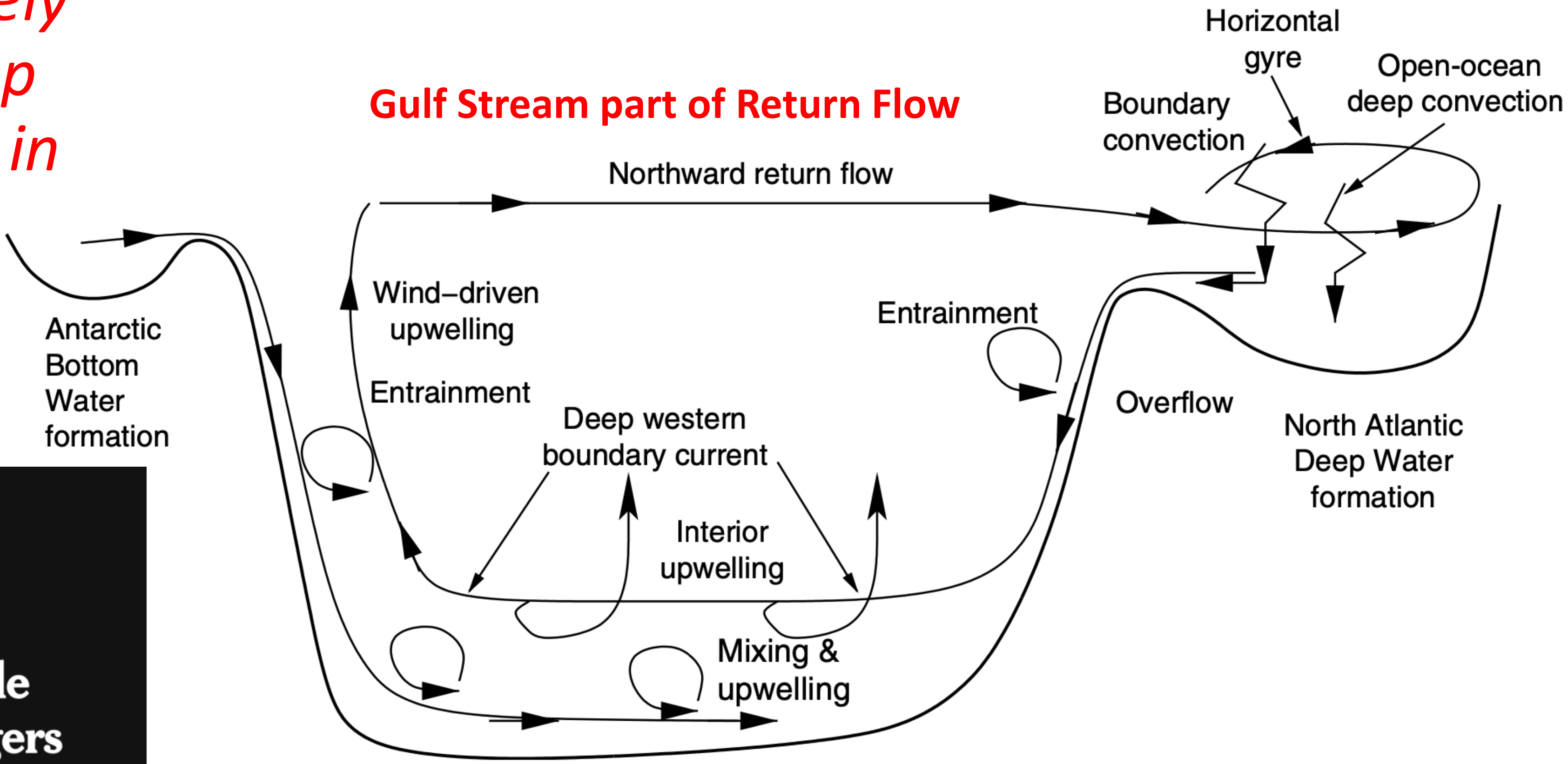
Christopher Wolfe (Stony Brook University)

Ocean Modeling Working Group Winter Meeting

Friday February 10, 2023

Atlantic Meridional Overturning Circulation (AMOC) Schematic

- *The Gulf Stream is widely accepted to slow if deep water formation slows in the polar regions.*



Latitude

Huang Ocean Circulation Text.

The New York Times

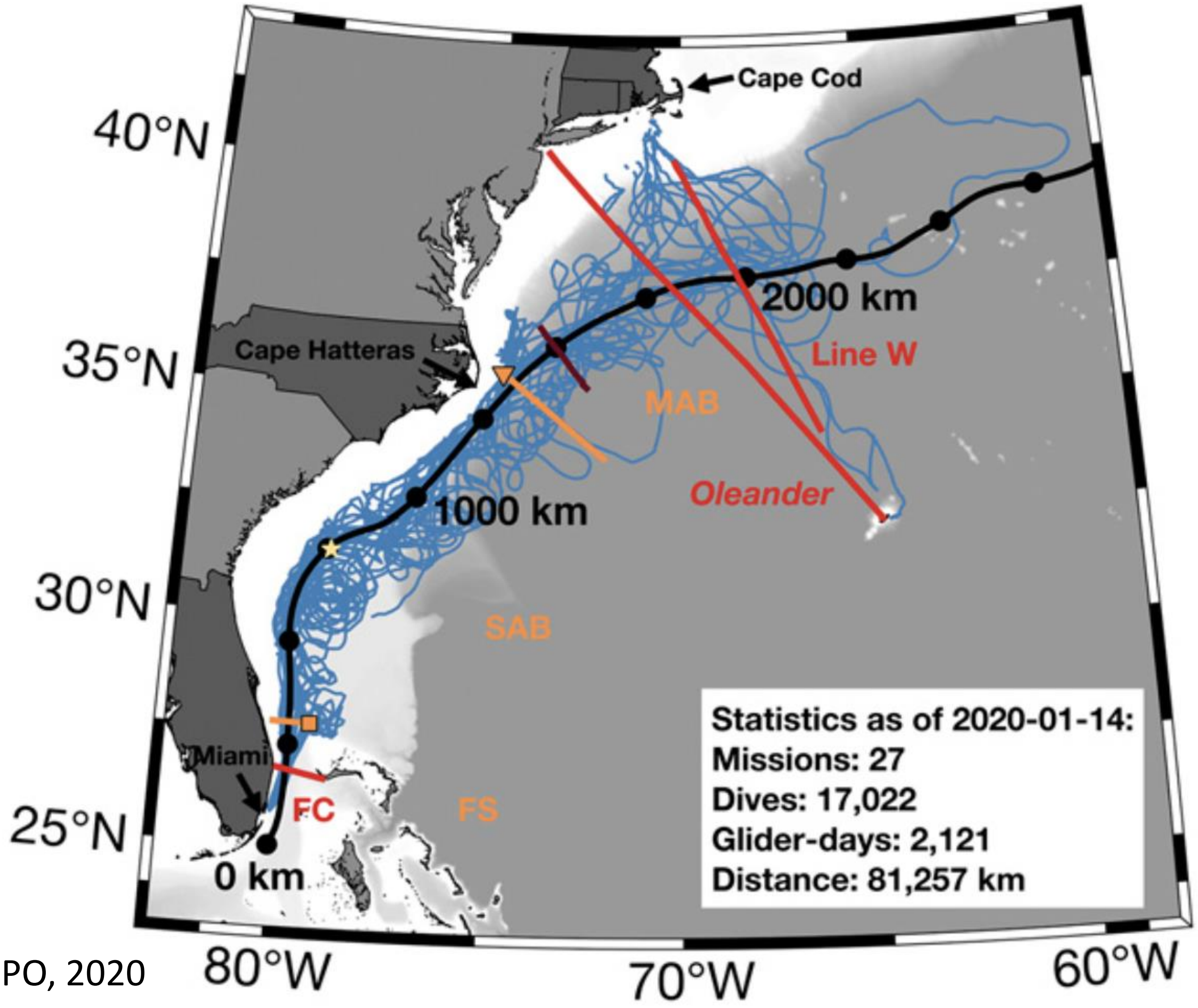
In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers

The warming atmosphere is causing an arm of the powerful Gulf Stream to weaken, some scientists fear.

By MOISES VELASQUEZ-MANOFF and JEREMY WHITE

Gulf Stream Along-Stream Transport

- Gulf Stream Transport increases from 32 Sv (Florida Straits) to 150 Sv (60°W).
- After separation at Cape Hatteras eddy-driven recirculation gyres (RGs) add 20-40 Sv.



Heiderich and Todd JPO, 2020

No Observed Trend in Gulf Stream Transport (Yet!)

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2013GL058636

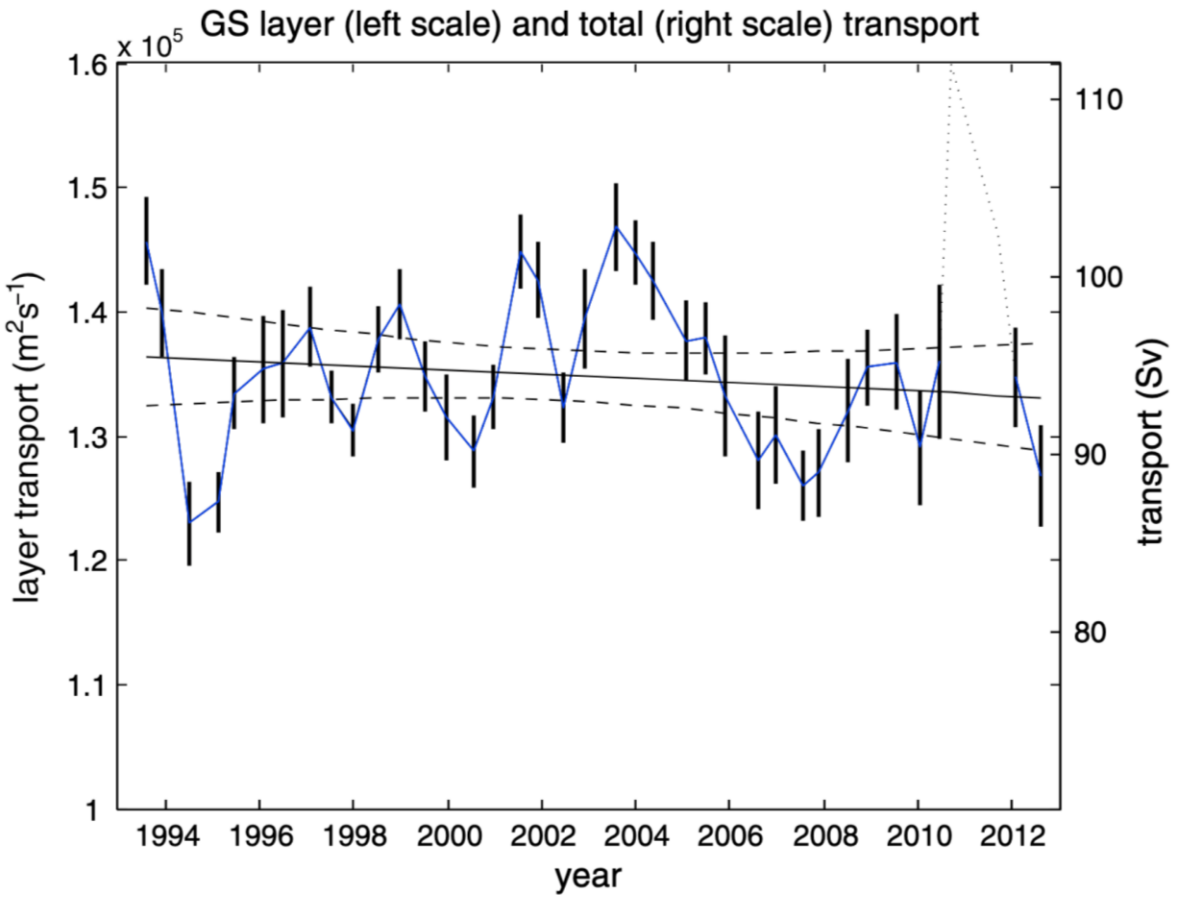
Key Points:
- Vessel-mounted ADCPs measure currents and transport accurately
- Gulf Stream shows no weakening unlike recent assertions in literature
- Clear need for more comprehensive measurements of ocean currents

On the long-term stability of Gulf Stream transport based on 20 years of direct measurements

T. Rossby[1], C. N. Flagg[2], K. Donohue[1], A. Sanchez-Franks[2], and J. Lillibridge[3]

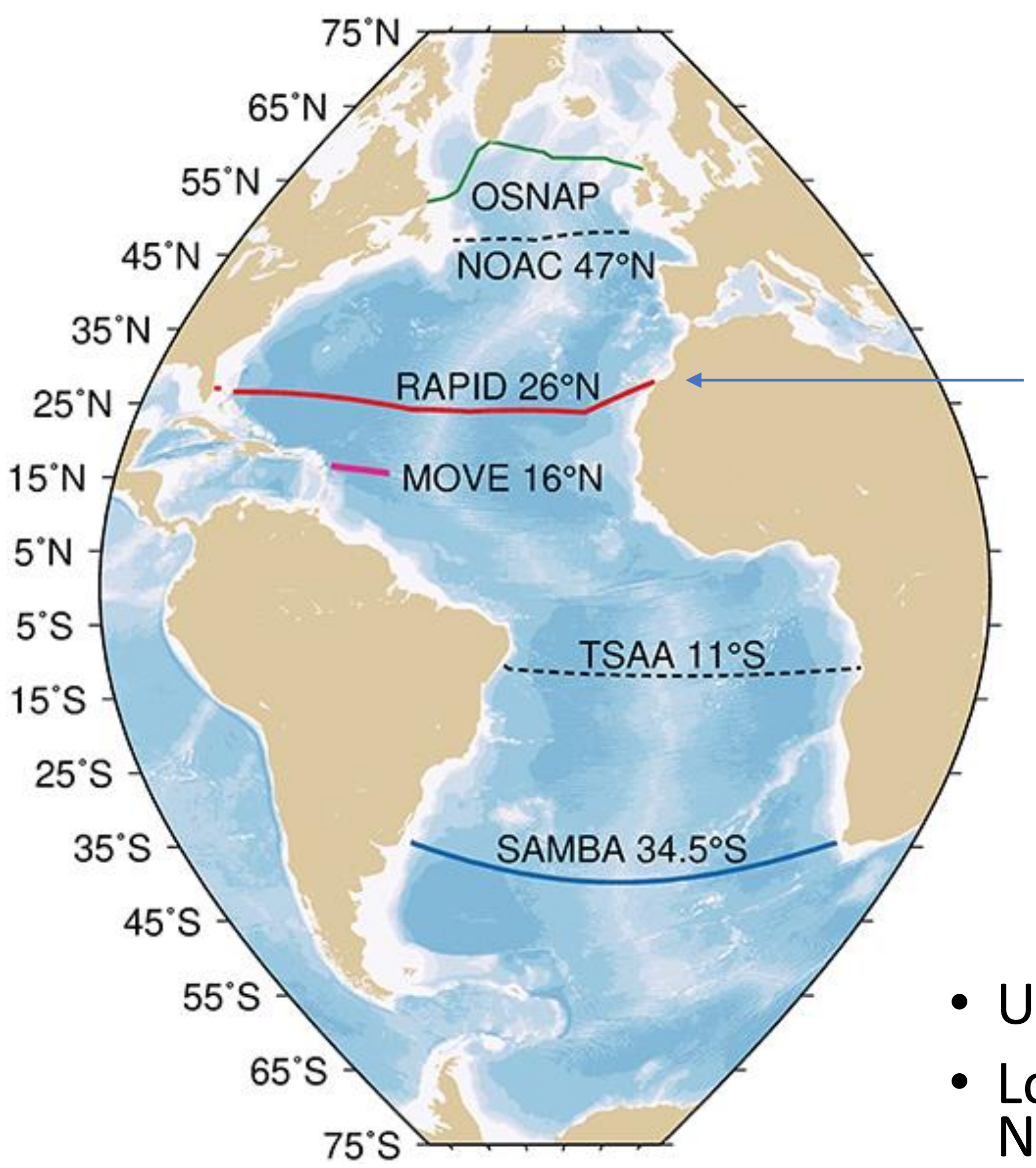
[1]Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island, USA, [2]School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, New York, USA, [3]NOAA Laboratory for Satellite Altimetry, College Park, Maryland, USA

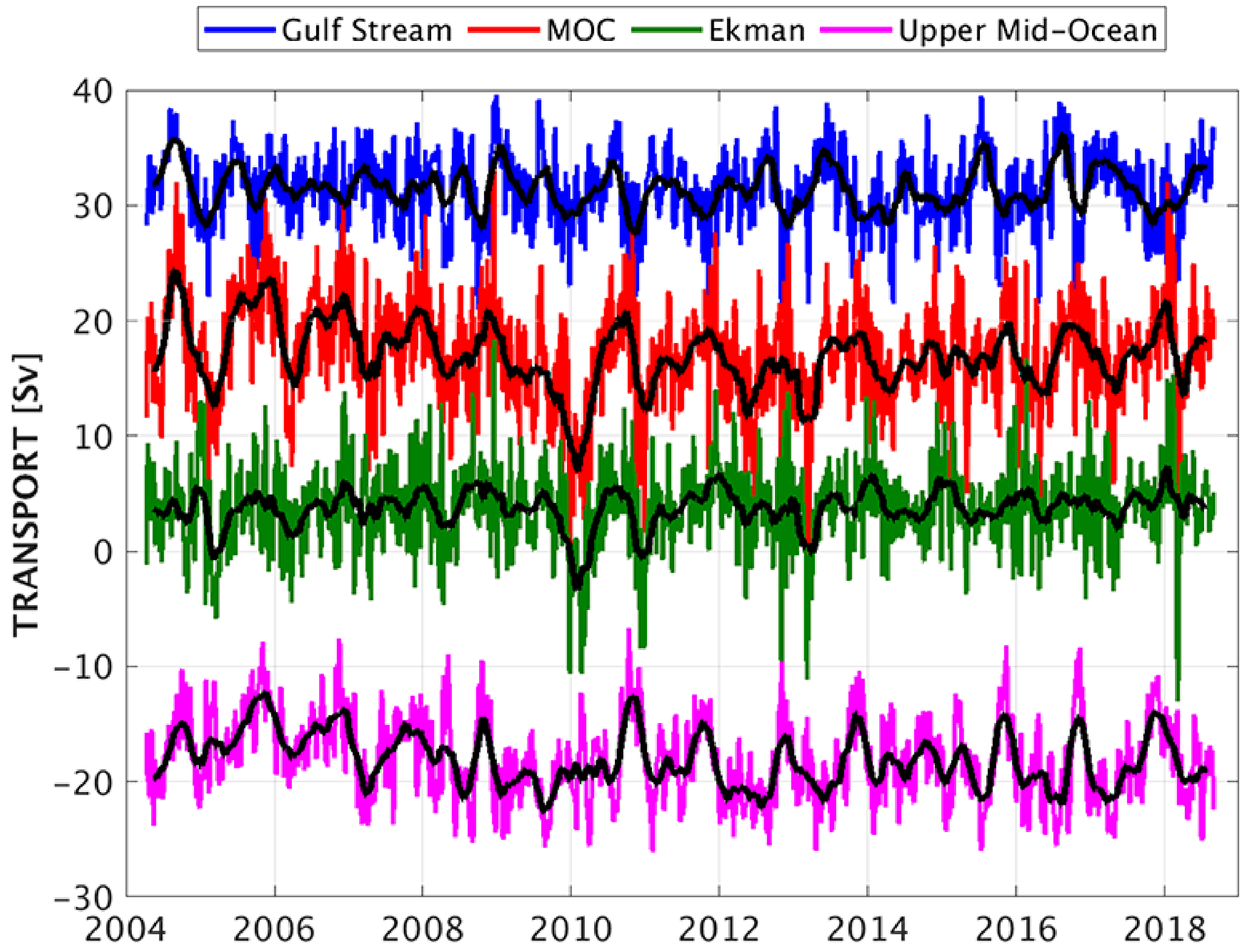
Tom Rossby



- The Oleander ADCP derived Gulf Stream transport does not show a statistically significant trend over the 20-year record.

Efforts to Measure AMOC: RAPID & OSNAP

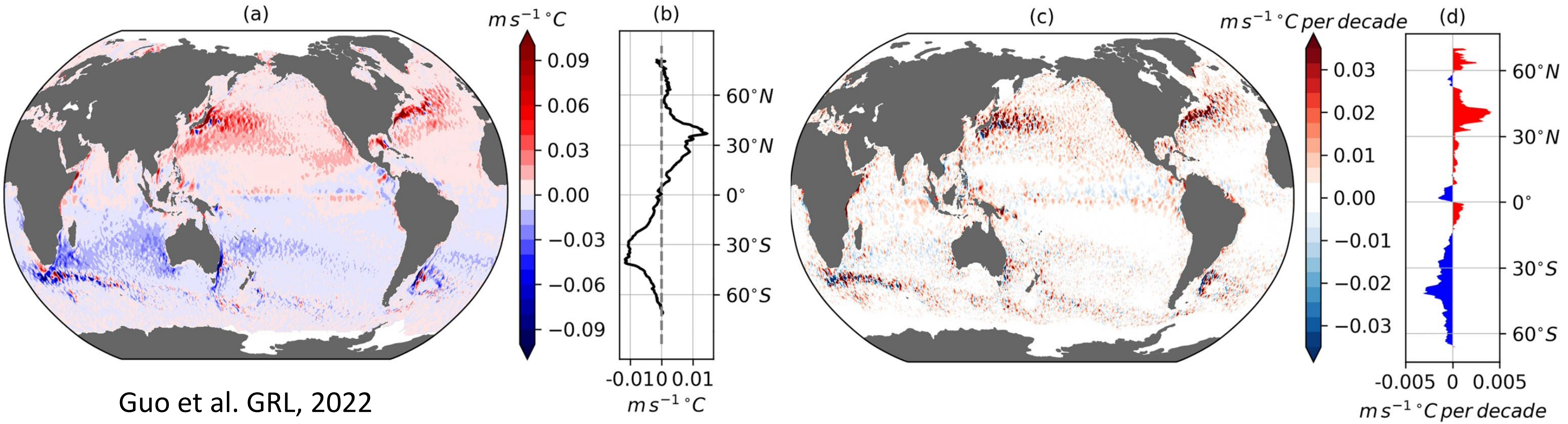




- Upper limb of AMOC mean is stable with no trend.
- Lots of interannual variability (notably 2010, negative NAO event).

Frajika-Williams et al. 2019

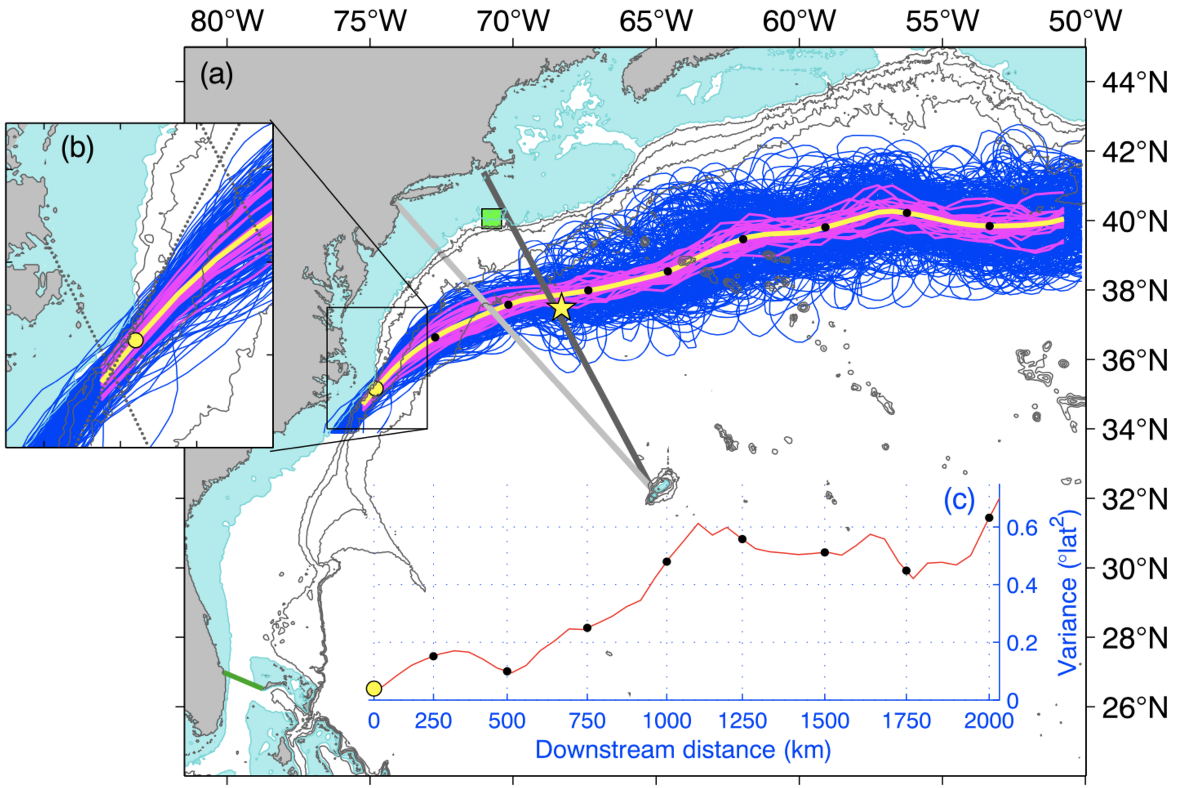
Changes in the eddy field

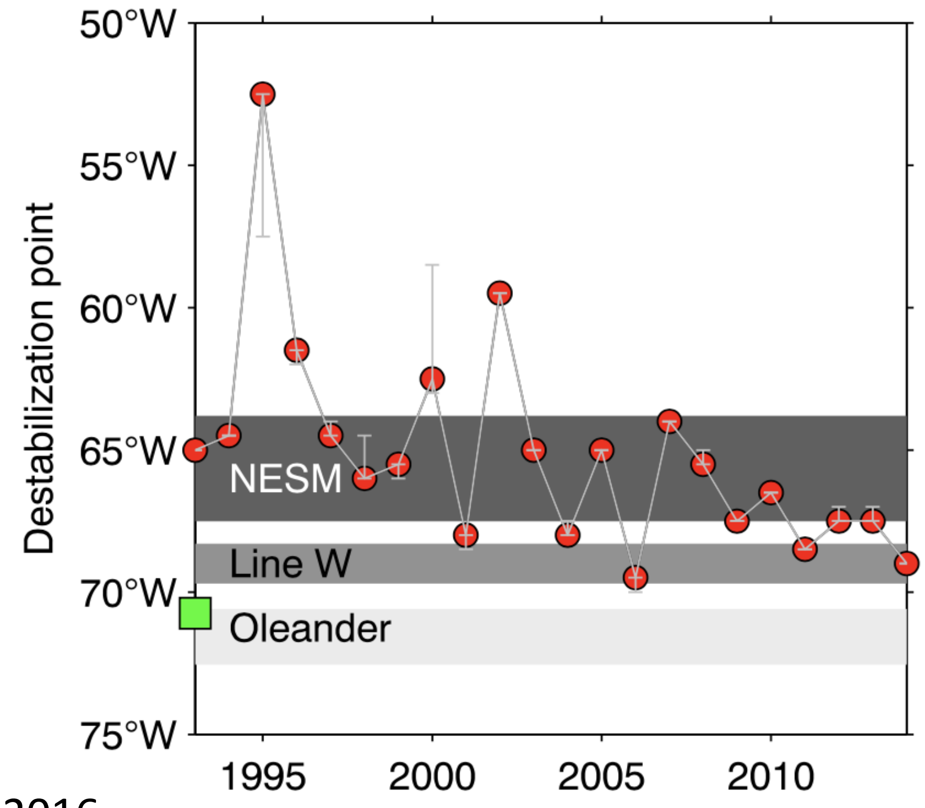


Guo et al. GRL, 2022

- Surface meridional eddy heat fluxes have an increasing trend poleward in both hemispheres in the midlatitudes.
- Two recent *Nature Climate Change* papers suggest WBCs will shift poleward with expansion of the Hadley cells and this leads to more eddies. (Beech et al. 2022, Li et al. 2022)
- Beech et al. 2022 strangely finds no increase in eddy activity in the North Atlantic, but virtually everywhere else.

Destabilization Point in Gulf Stream Shifting

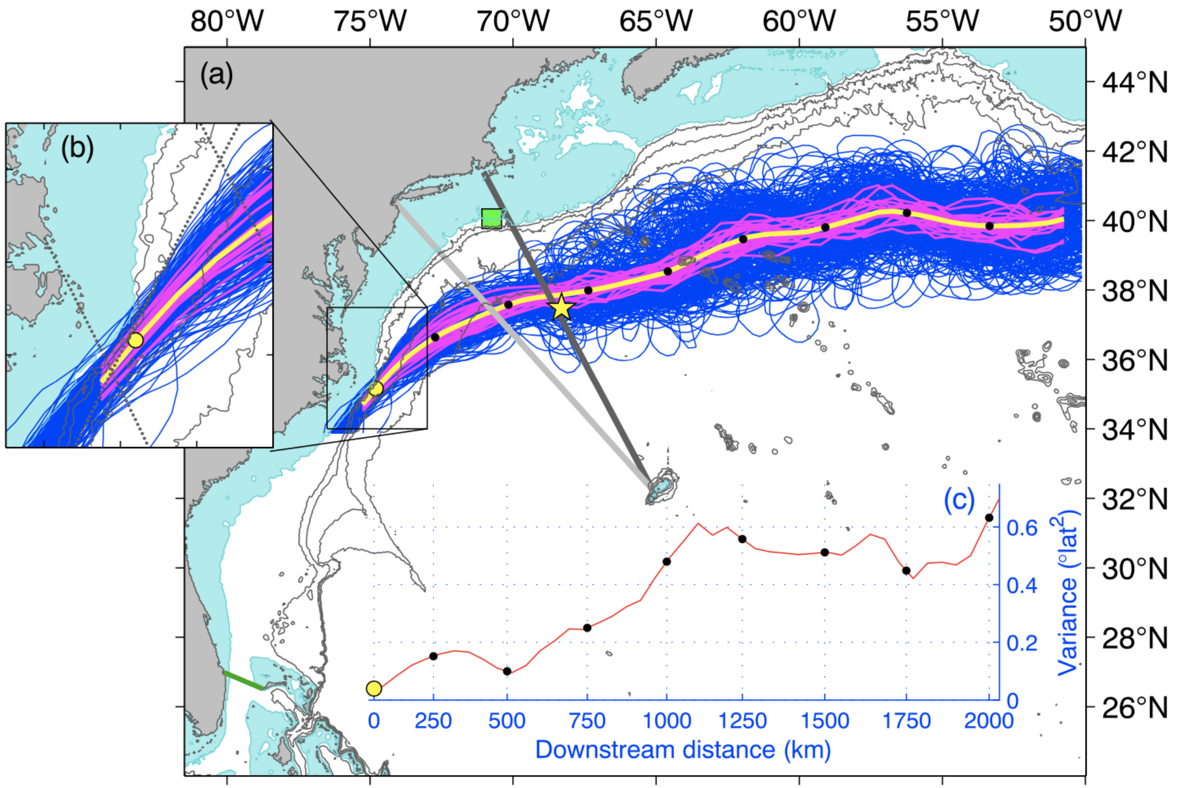




Andres GRL, 2016

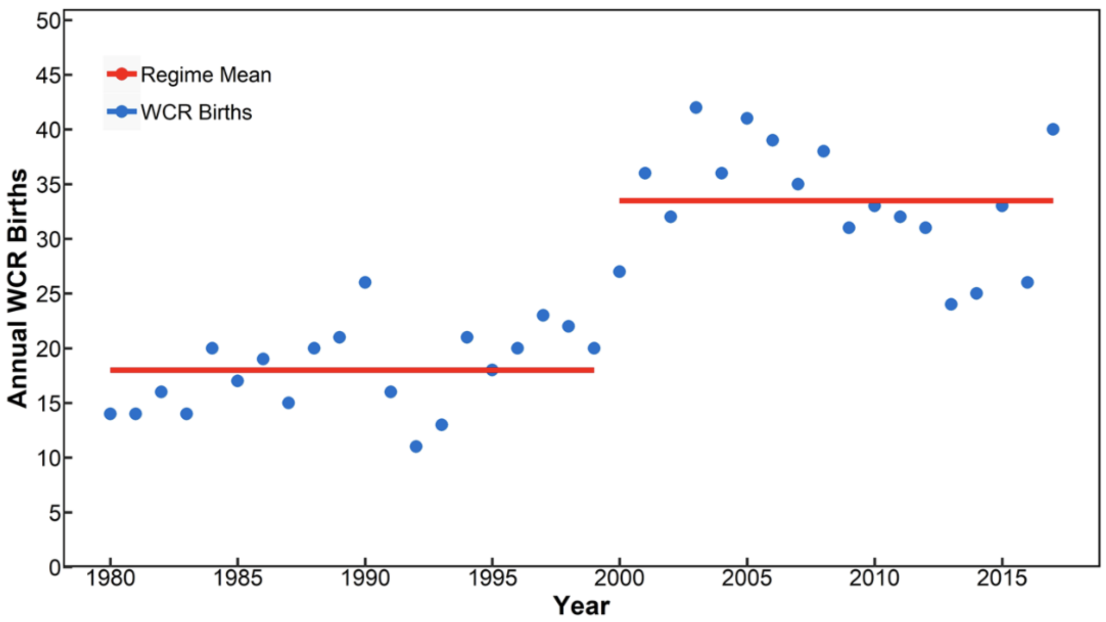
- The point downstream of Cape Hatteras where the variance of the 25 cm SSH contour exceeds $0.5(^{o})^{2}$ has been migrating west.

Destabilization Point in Gulf Stream Shifting



Andres GRL, 2016

Number of Warm Core Rings

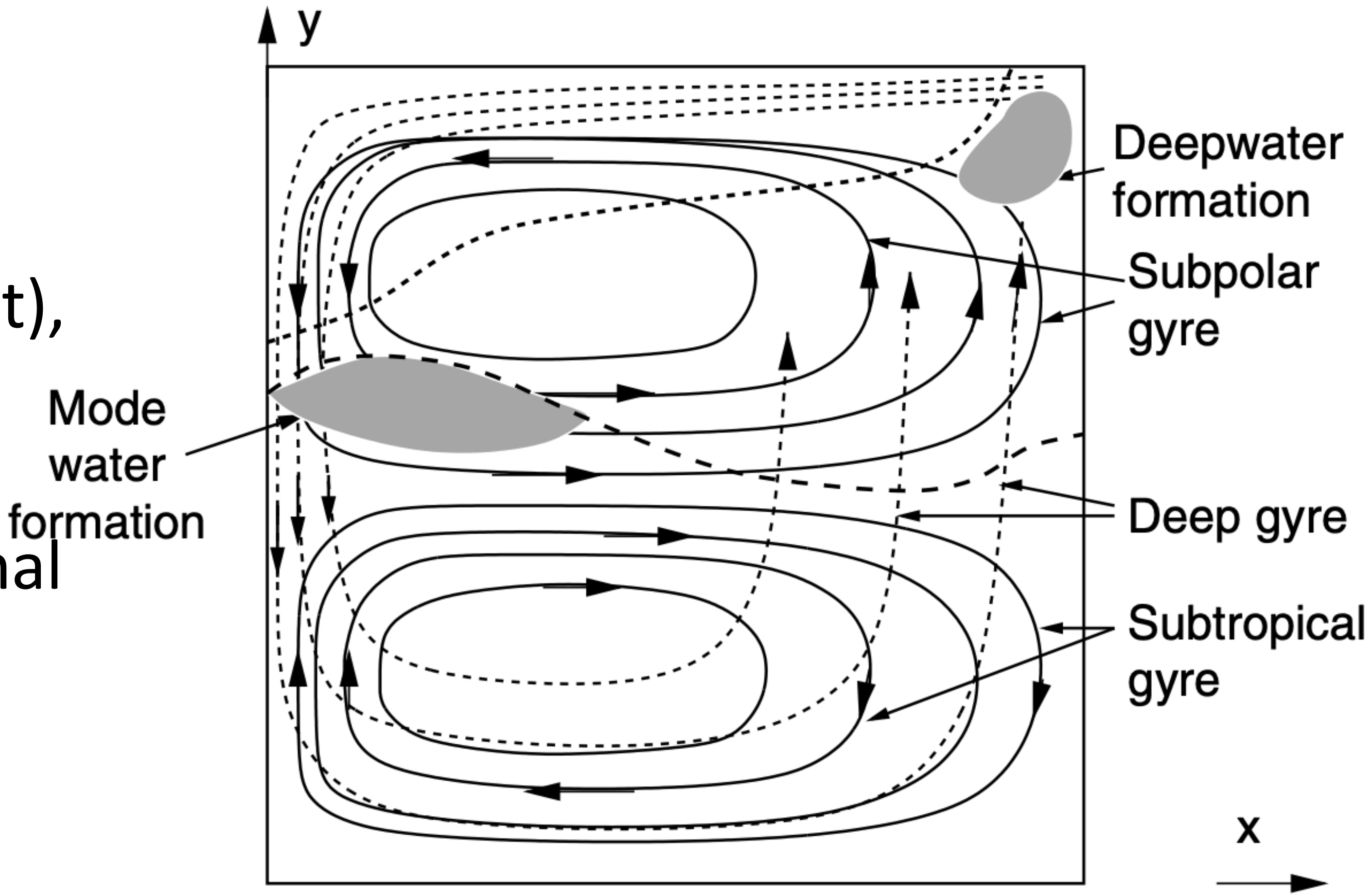


Gangopadhyay et al. 2019

- The point downstream of Cape Hatteras where the variance of the 25 cm SSH contour exceeds $0.5(^{o})^2$ has been migrating west.
- Warm Core Rings (WCRs) numbers have also been increasing in recent years.
- High-resolution climate models struggle with Gulf Stream separation → idealized approach

Sensitivity to Thermal Boundary Condition: Huang 1989

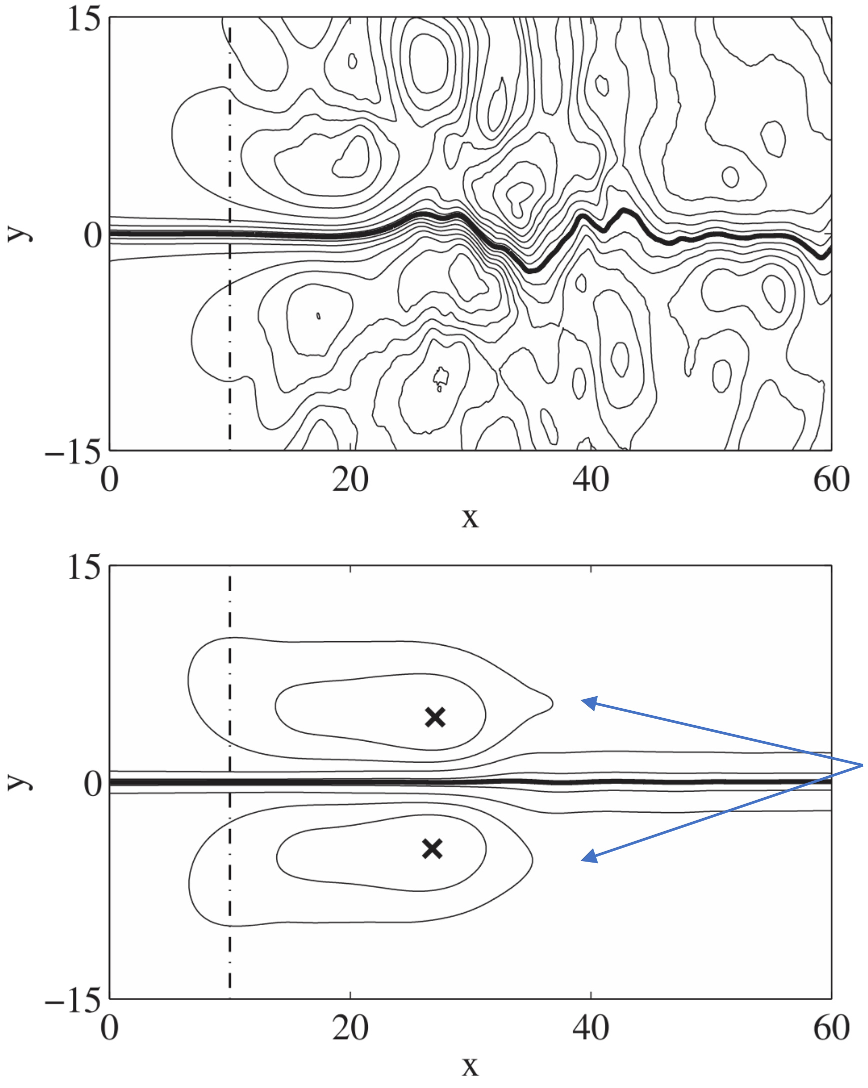
- In a coarse resolution (look up resolution) with both wind and thermal forcing.
- Consists of a mixed layer (constant), 3 moving layers, and a stagnant abyssal layer.
- Demonstrates sensitivity to thermal boundary conditions:
  - **Long** restoring time scale → **Pacific**
  - **Short** restoring time scale, strong deep water formation → **Atlantic**

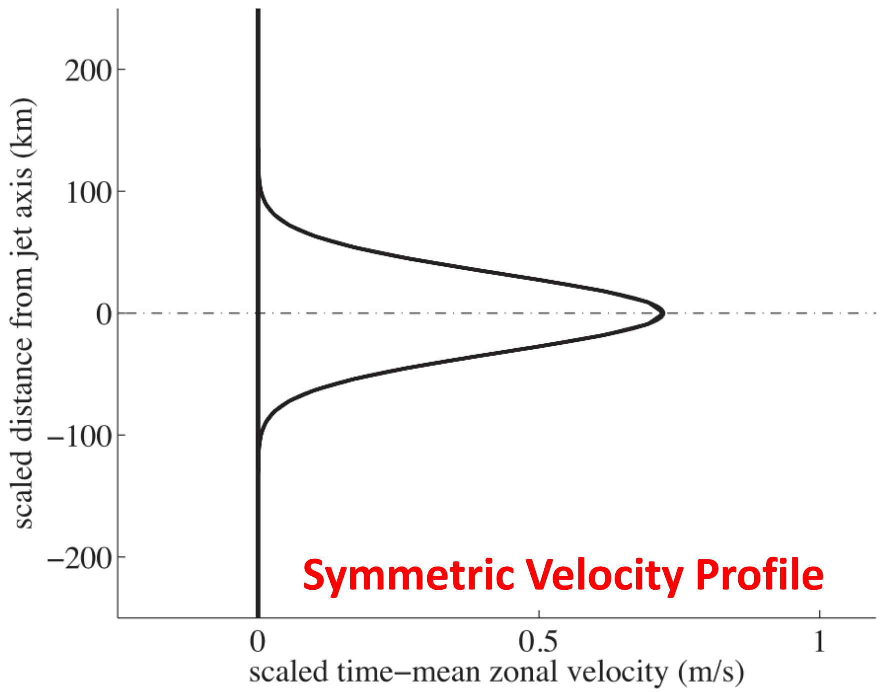


Huang Ocean Circulation Text. (Fig. 5.177)

Eddy-Driven Recirculation Gyres (RGs): Waterman and Jayne JPO, 2011

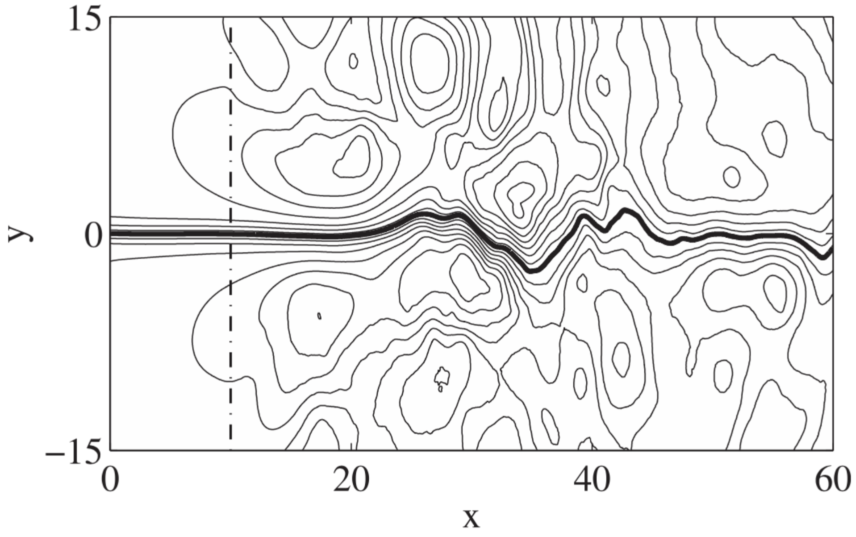
- QG (~4km) eddy-resolving.
- 1 & 2 layer configurations.
- Symmetric inflow conditions.
- Symmetric RGs develop on north and south.

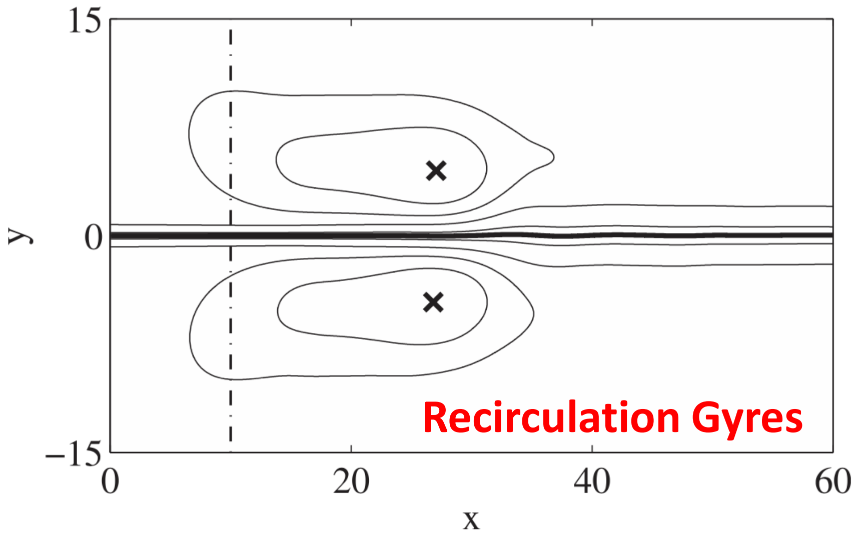


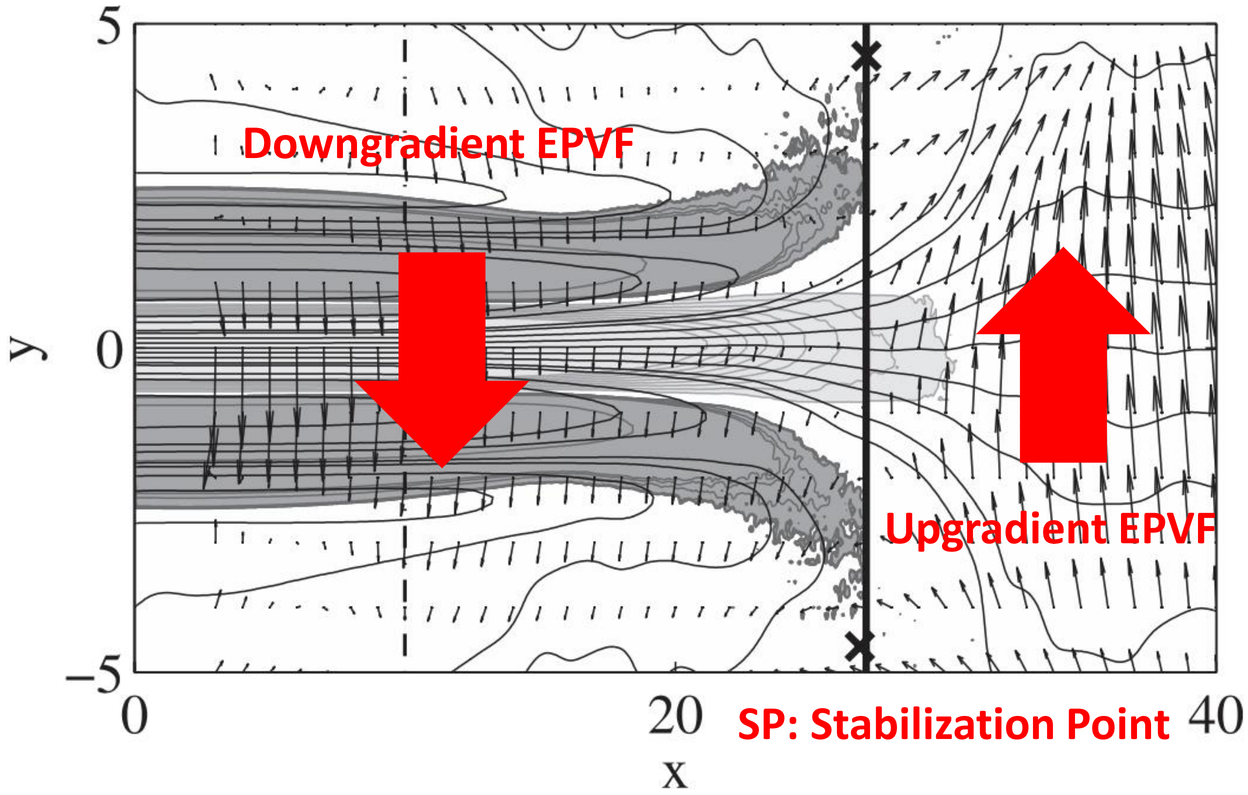


Eddy-Driven Recirculation Gyres (RGs): Waterman and Jayne JPO, 2011

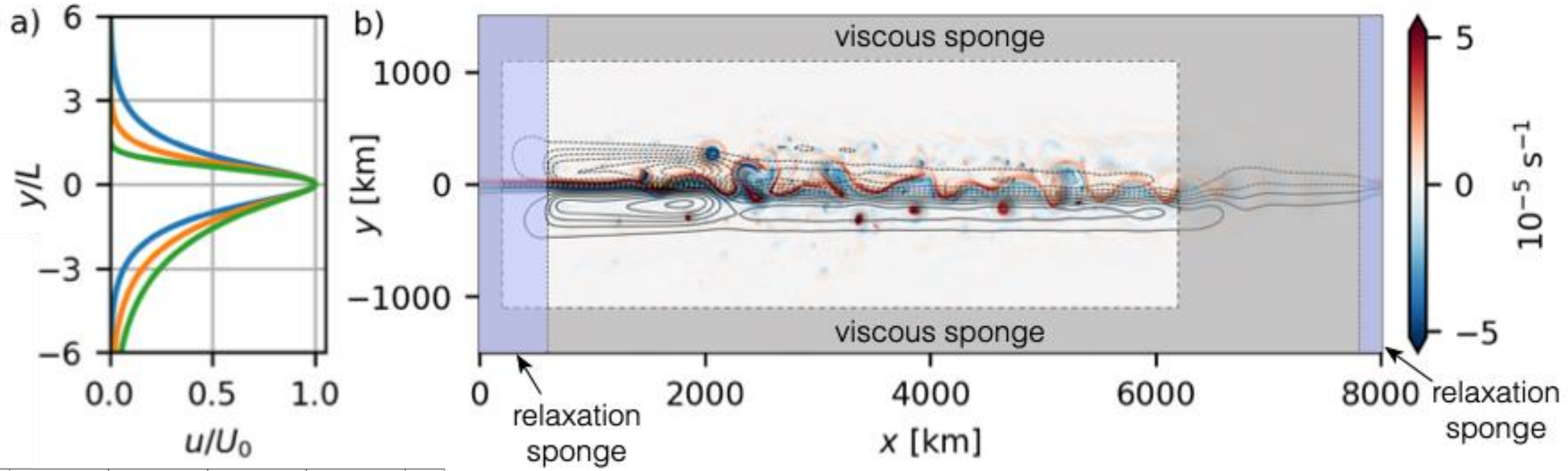
- Downgradient eddy PV flux upstream of SP
- Upgradient eddy PV flux downstream of SP
- Radiates waves that drive RGs centered at SP

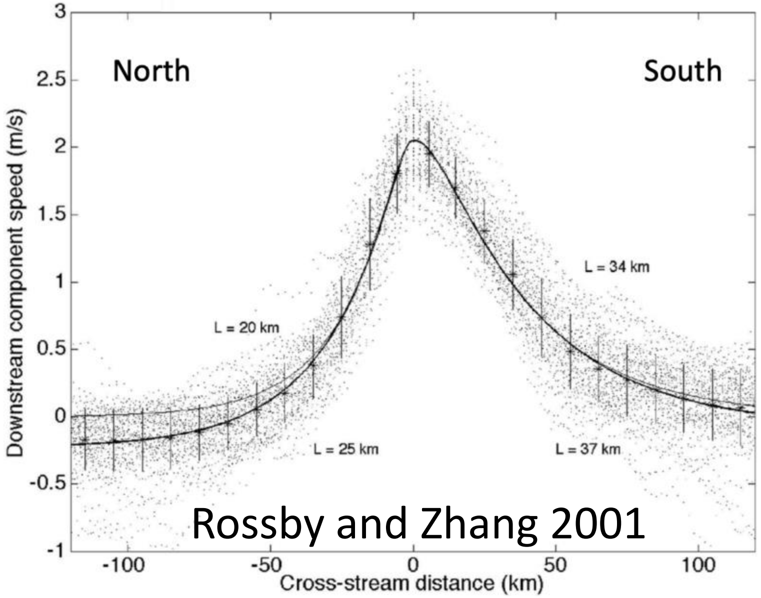






MOM6 Experiments

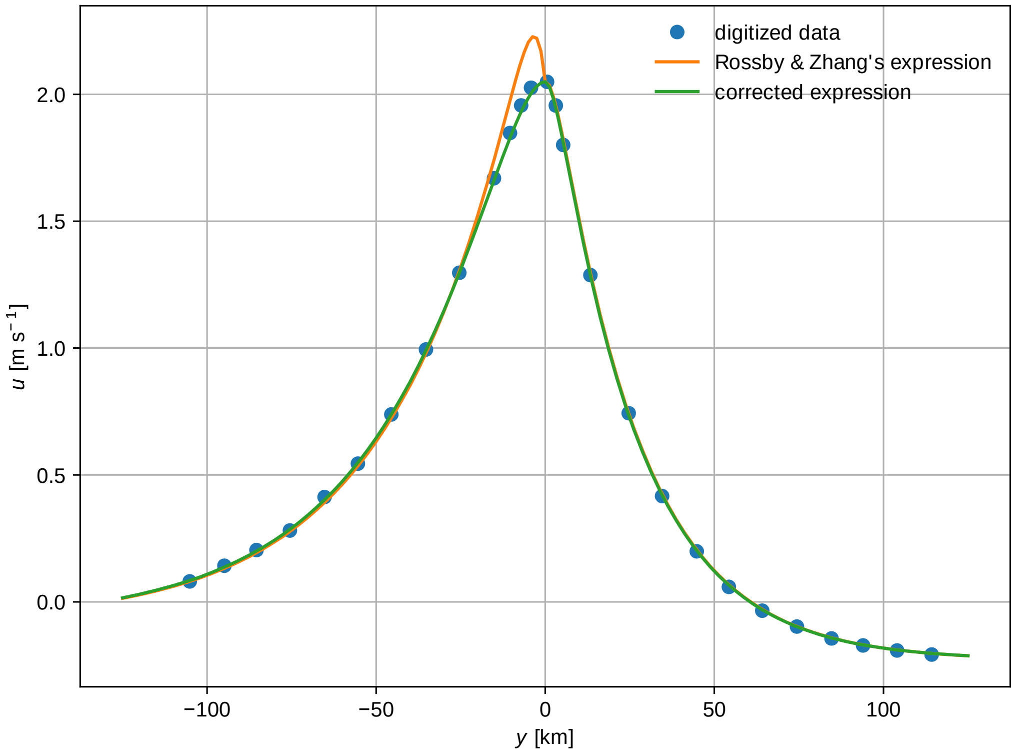




Rossby and Zhang 2001

- Jet configuration:
  - 2-layer, flat bottom, 5 km grid.
  - 5000 m depth, 8000 km x 3000 km on beta plane
- Advantages using Primitive Equations
  - No assumptions on Rossby number for QG.
  - Can include jet asymmetry (Deformation scale shortens).
  - Provide opportunity to study impacts on overall circulation.

2-Layer with Adjustable Jet Asymmetry



Rossby-Zhang 2001 (RZ2001)

$$u = \begin{cases} 2.75e^{y/37} - 0.62e^{y/3} - 0.08 & y < 0, \\ 2.61e^{-y/25} - 0.33e^{-y/3} - 0.23, & y > 0, \end{cases}$$

Upper Layer Jet Profile w/ Adjustable Asymmetry (delta > 0 <1)

$$u_1 = U_0 \begin{cases} e^{y/L(1+\delta)} & y \leq 0, \\ e^{-y/L(1-\delta)} & y > 0, \end{cases}$$

Rossby Number

$$\varepsilon = \frac{U_0}{f_0 L},$$

Beta Number

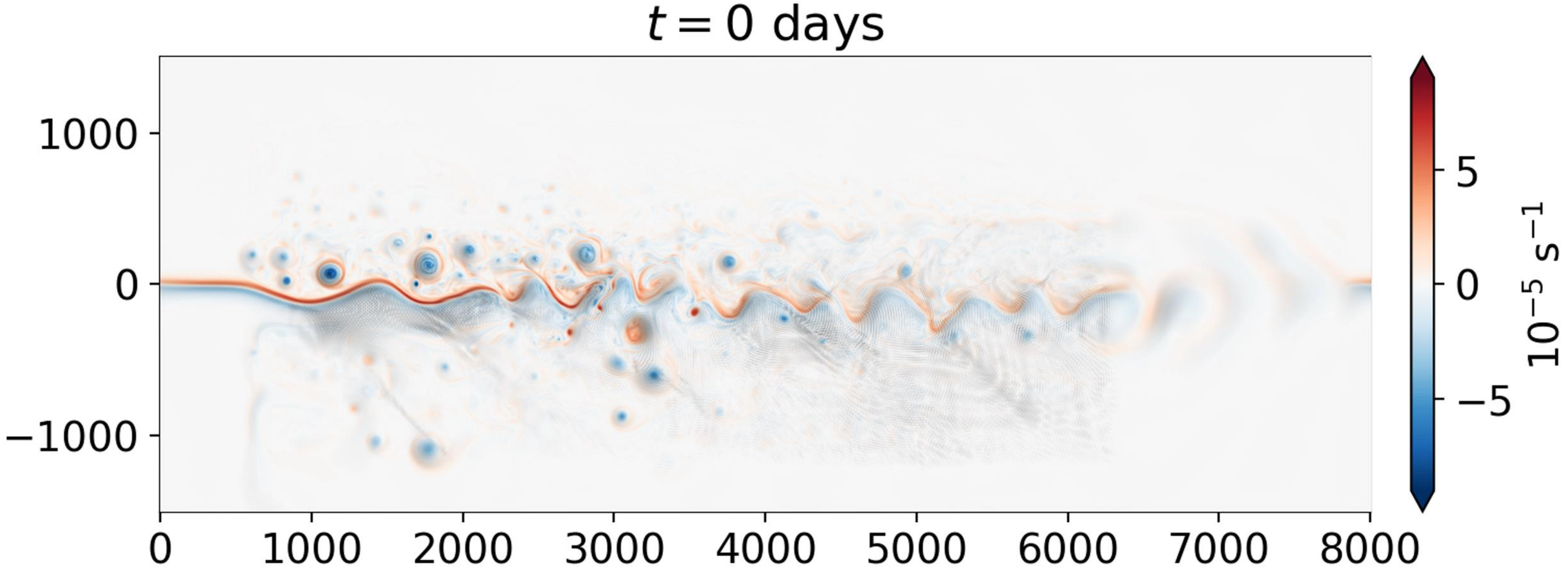
$$b = \frac{\beta L}{f_0},$$

Inverse Burger Number

$$F_{mn} = \frac{f_0^2 L^2}{g'_m H_n},$$

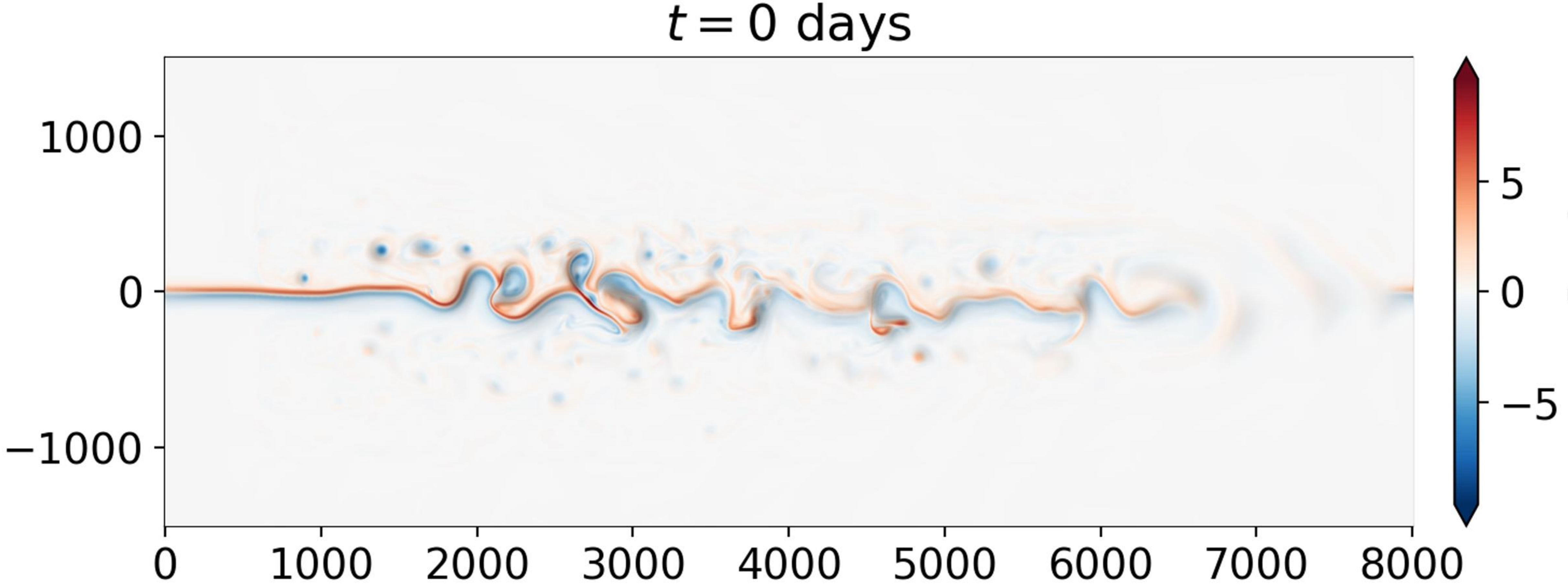
- Jet characteristics specified by Rossby, Beta, and Inverse Burger numbers.
- Using delta = 0.26, and Rossby Number 1.2.
- Gaussian convolution performed to smooth out velocity discontinuity (L/2 width).
- Stagnant lower layer.

5 km Jet with Smagorinsky



- Waves radiate away from the jet.
- The jet has a general southward drift.

5 km Jet with Velocity Relaxation (UV Sponge)

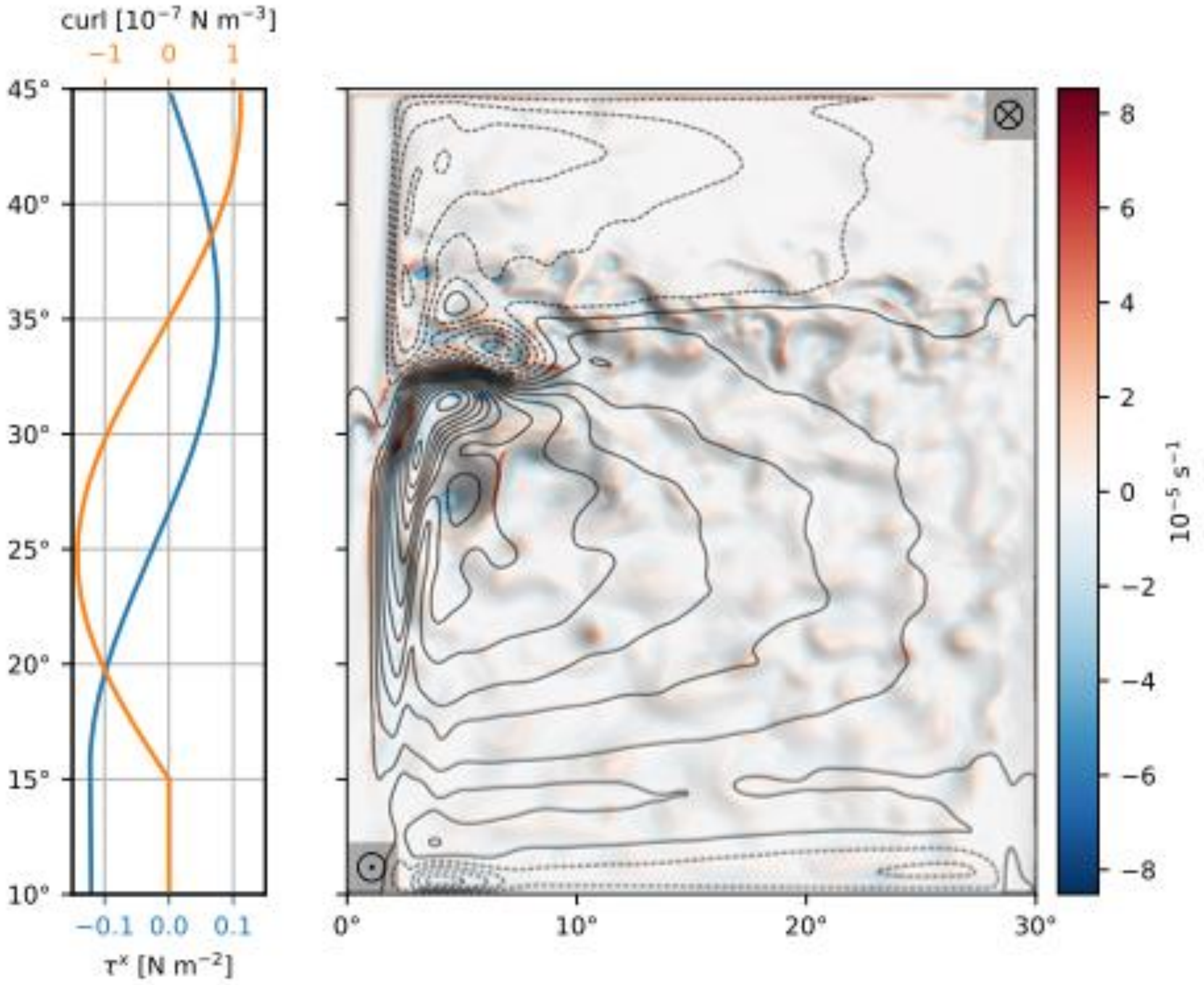


- A combination of velocity relaxation and viscosity is used to simulate "open" boundaries.
- Velocity relaxation has the **advantage** that it will give you exactly the velocity profile you want, but this can be a **disadvantage** if you don't know what the velocity should be. Viscosity has no effect on inform flow (for free slip boundaries), so can be used to gently push the velocity toward uniform flow.
- This removes radiating waves and southward drift of the jet.

Future work

- Implement a 3-layer jet configuration to allow for baroclinic instability.
- Run gyre experiments systematically modifying the wind and introduce an overturning circulation (*imposed through diapycnal mixing sponge layers at corners*)

Thanks: Gustavo Marques, Frank Bryan, & Gokhan Danabasoglu.



(left) zonal wind stress (blue) and wind stress curl (orange) and (right) mean barotropic streamfunction (contours) and instantaneous surface vorticity/SSH (colors/shading) for a 1/8° 3-layer double gyre simulation without overturning. The contour interval is 3 Sv. The regions of downwelling and upwelling for the cases including an overturning circulation are indicated by the symbols ⊗ and ⊙, respectively.