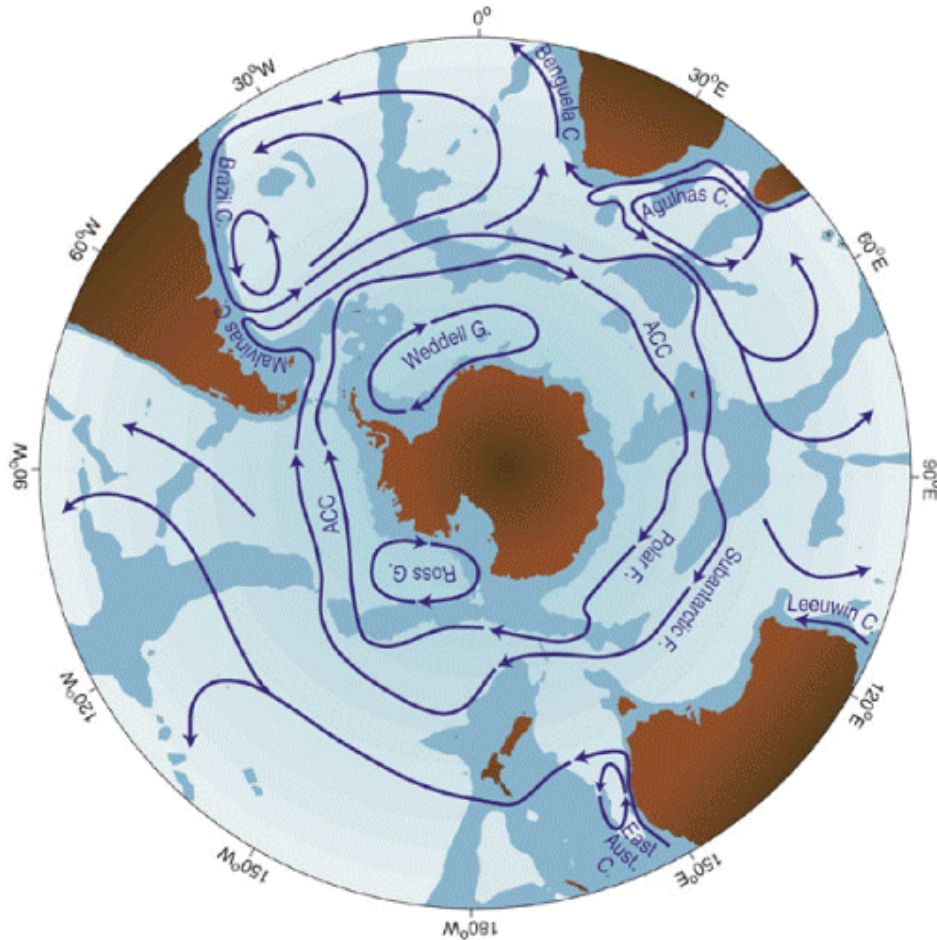


The response of Southern Ocean
Carbon Dioxide Fluxes to
Increased Wind Stress:
A Modeling Study

Nikki Lovenduski & Taka Ito
Department of Atmospheric Science
Colorado State University

Motivation



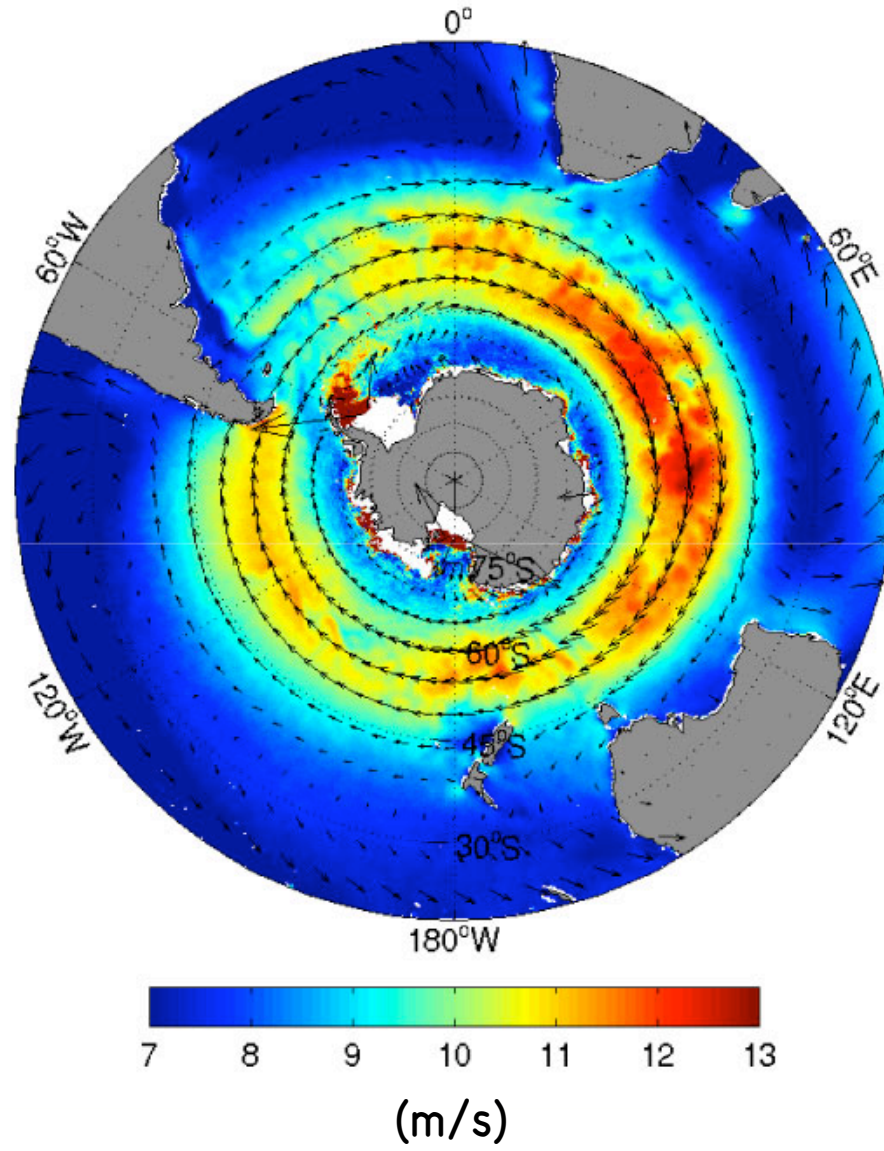
Southern Ocean

- zonally unbounded
- a place of ocean renewal
- stores ~40% of oceanic anthropogenic CO₂
- has been experiencing large changes in the past few decades

Rintoul et al. 2001

Part I. Mean State

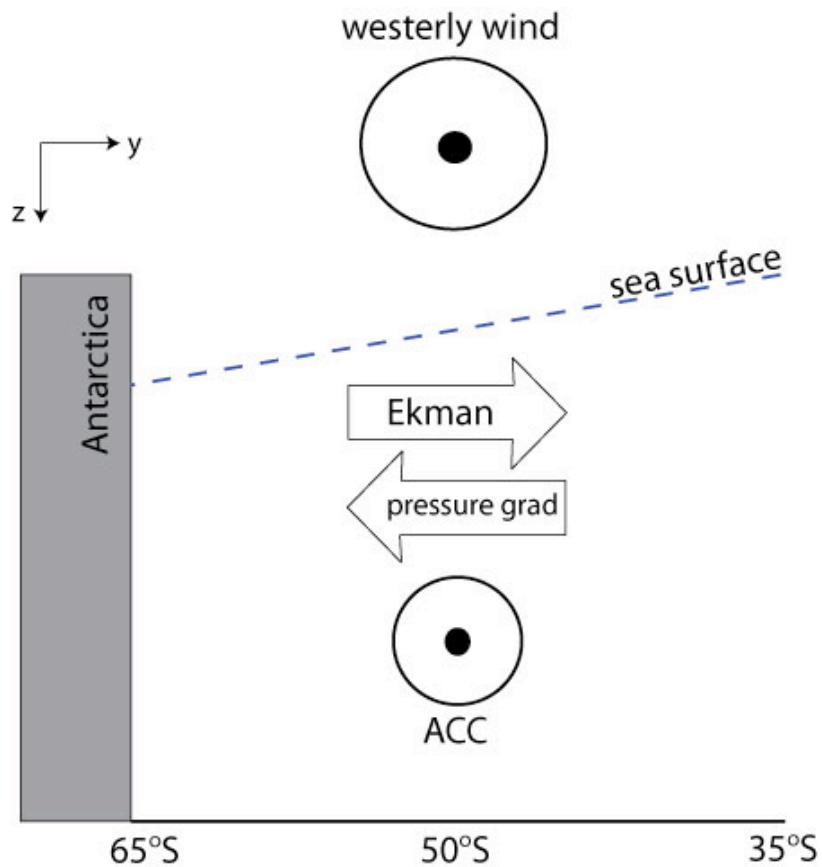
The Southern Ocean is Windy !



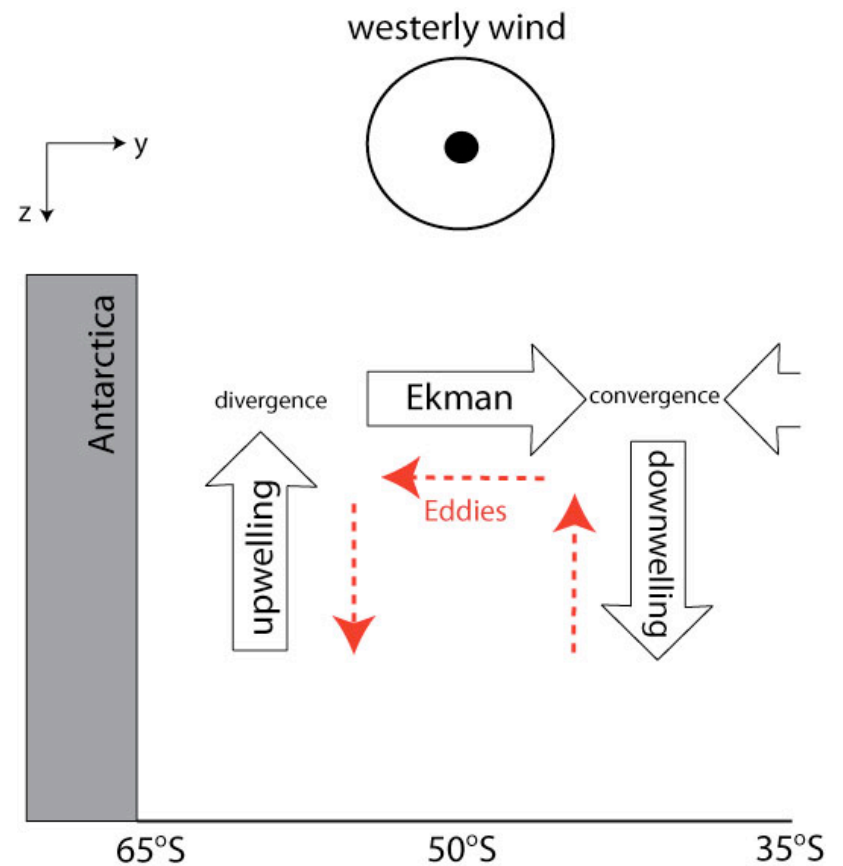
QuikSCAT

Southern Ocean Circulation: A simple view

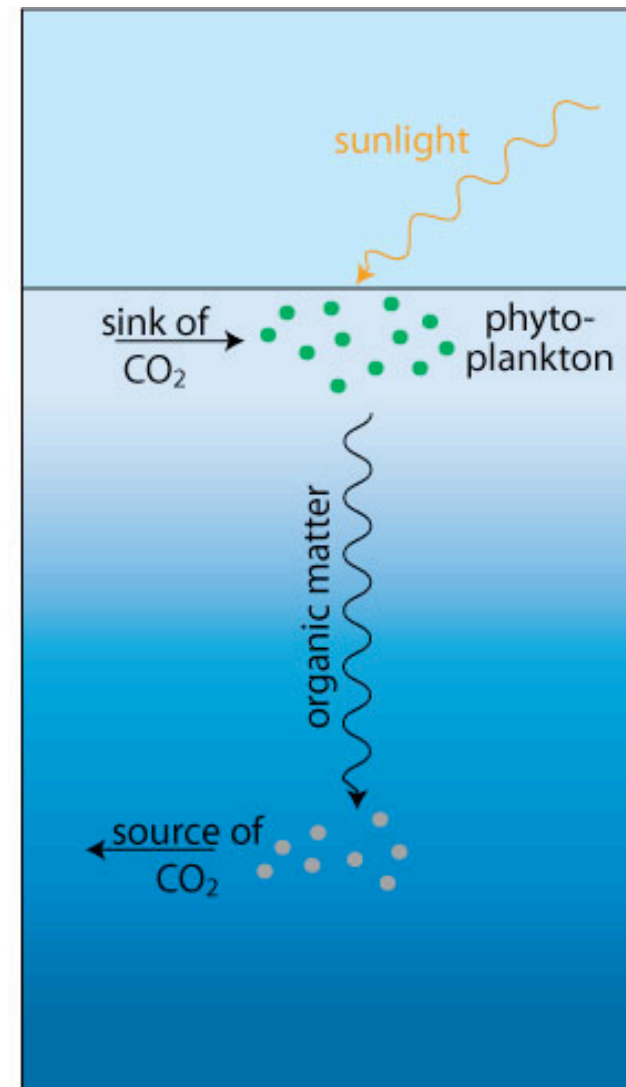
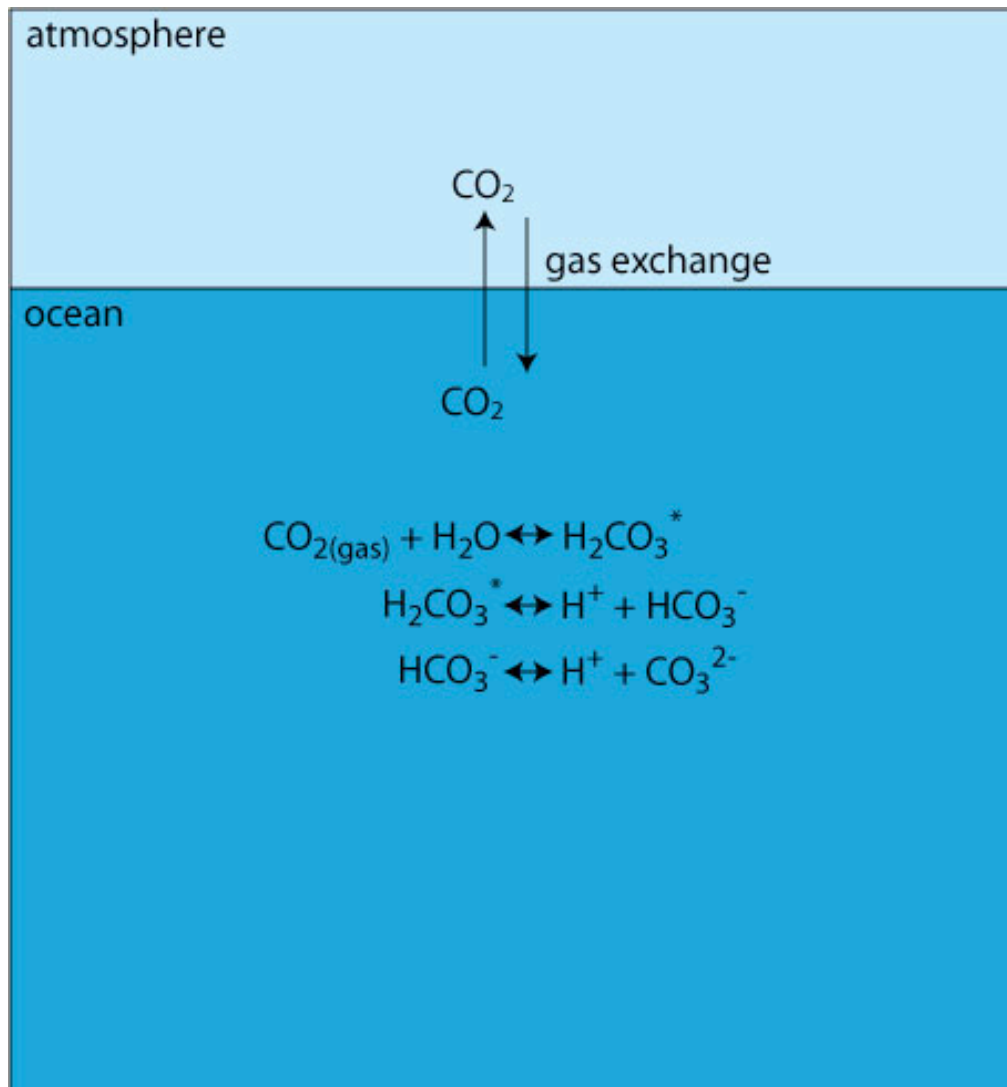
Geostrophic



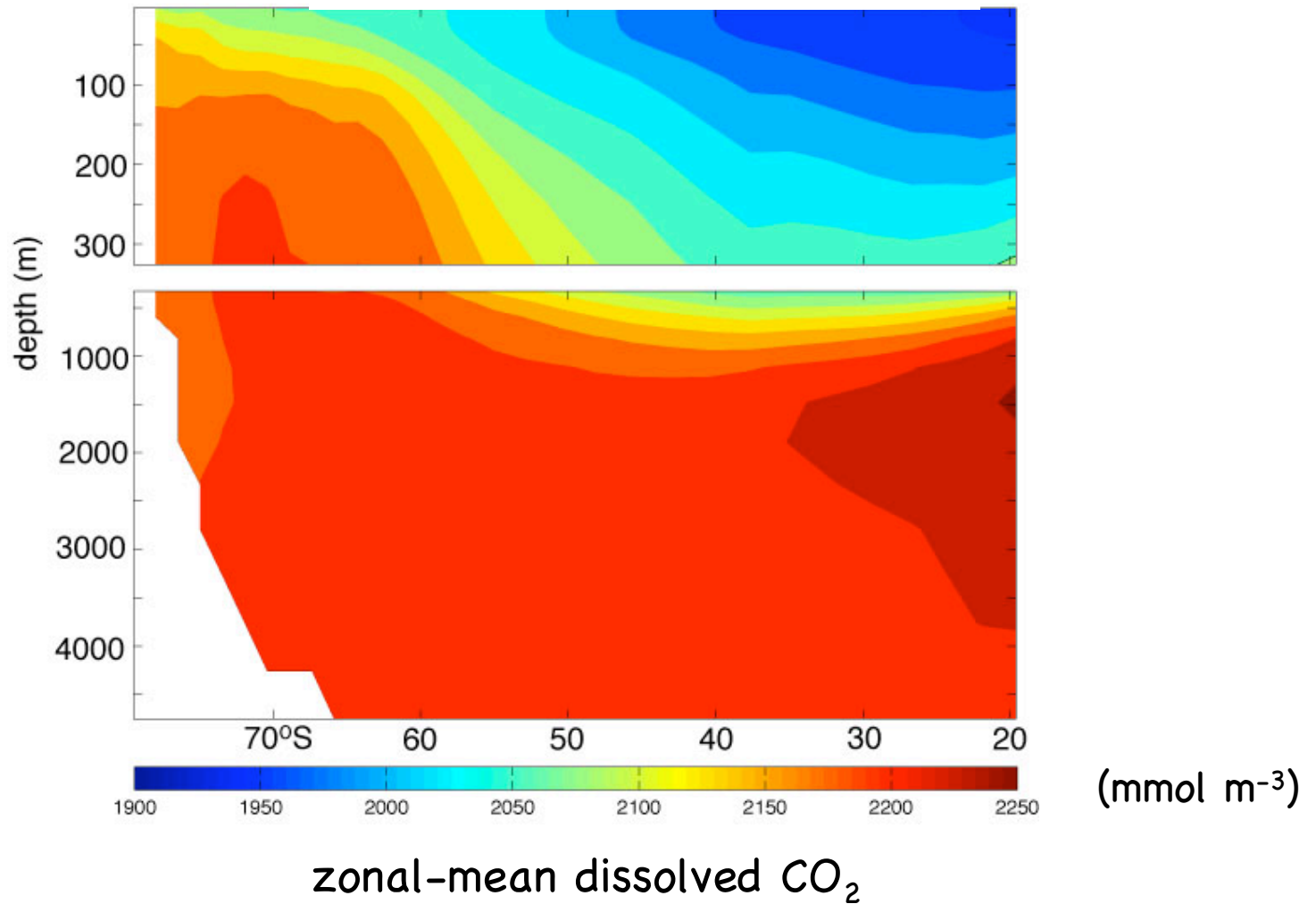
Ageostrophic



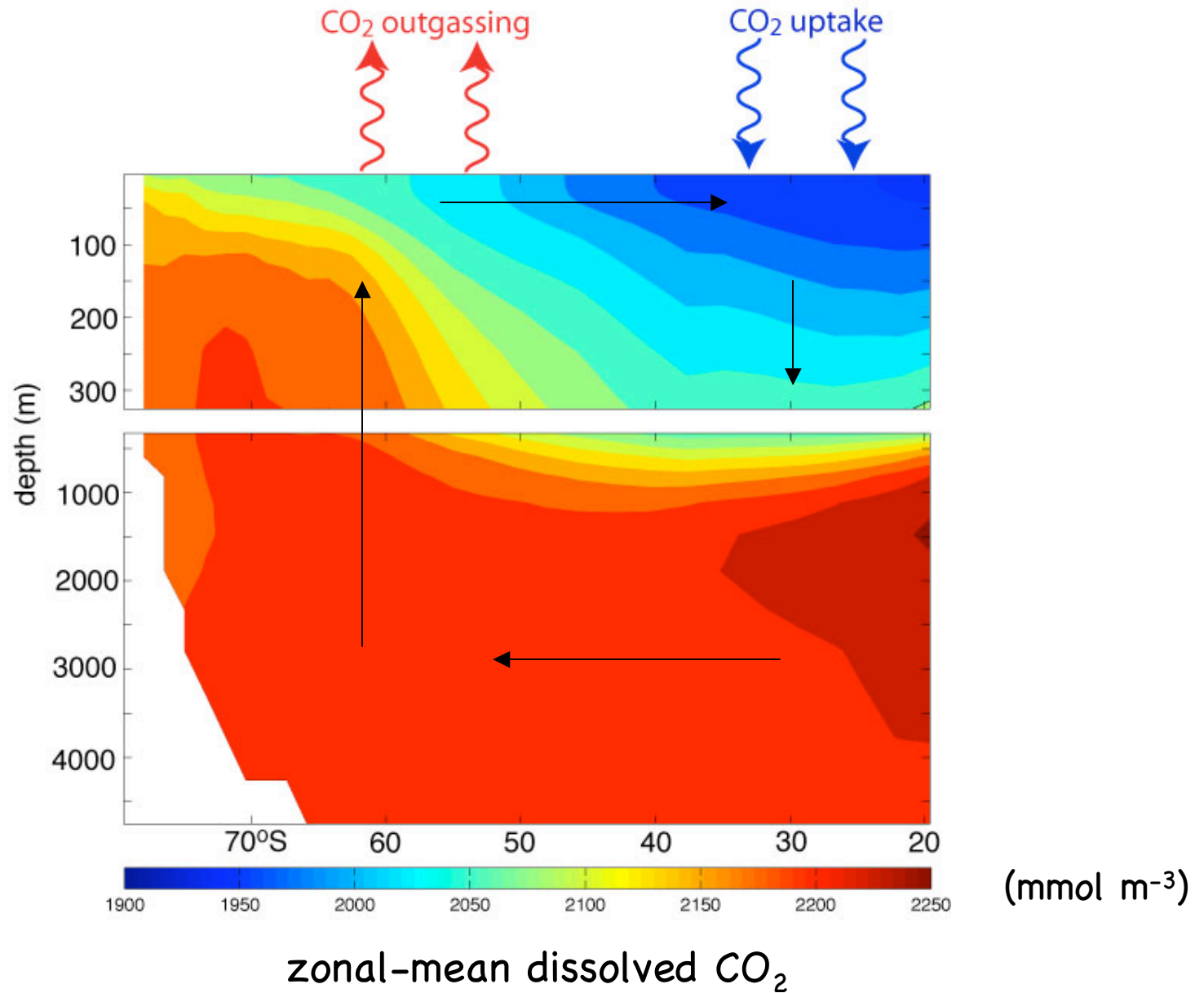
Air-sea CO₂ exchange



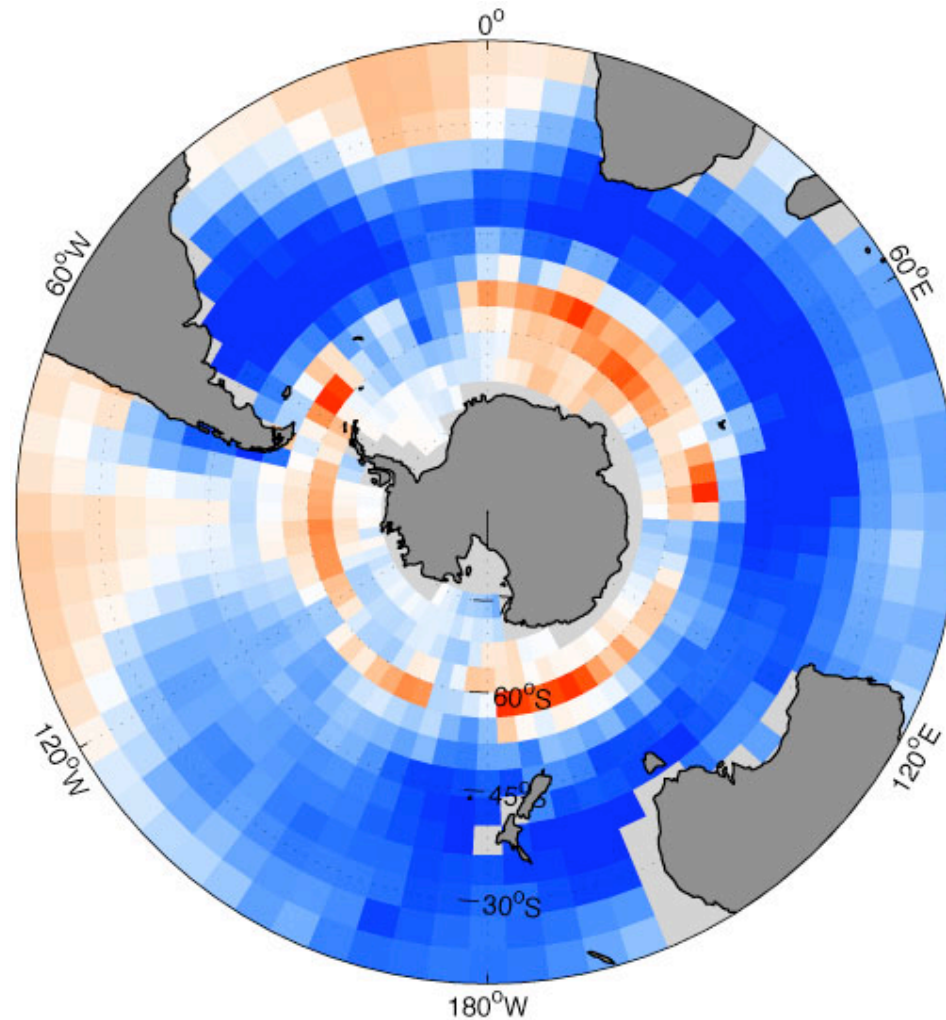
Southern Ocean Circulation & CO₂



Southern Ocean Circulation & CO₂



Southern Ocean air-sea CO₂ exchange



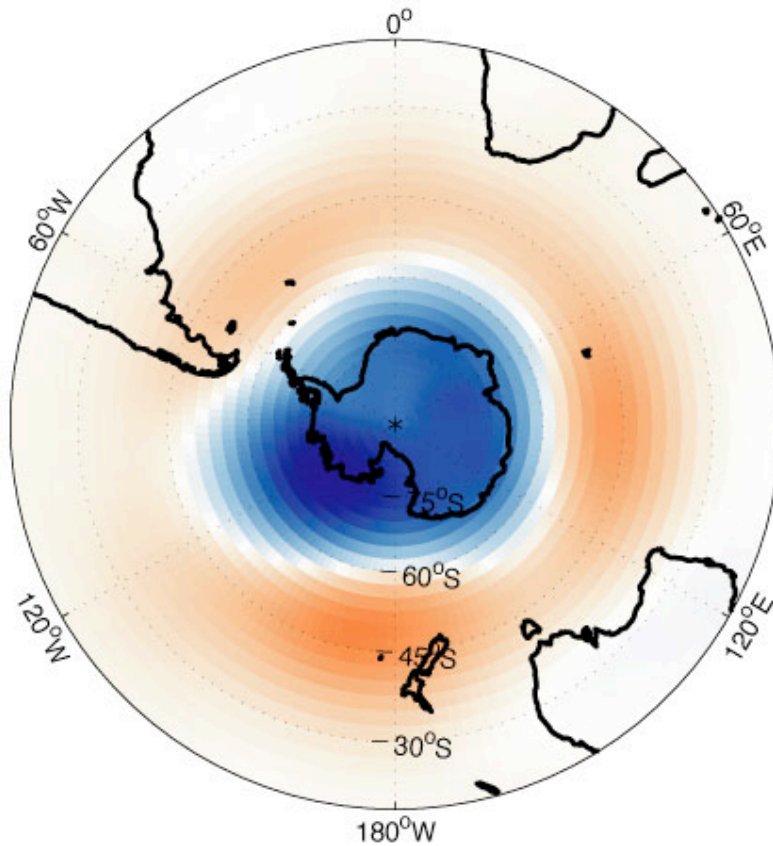
[mol m⁻² yr⁻¹]

Takahashi et al. (2009)

Part II. Variability & Long-term Changes

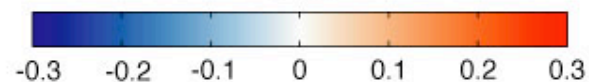
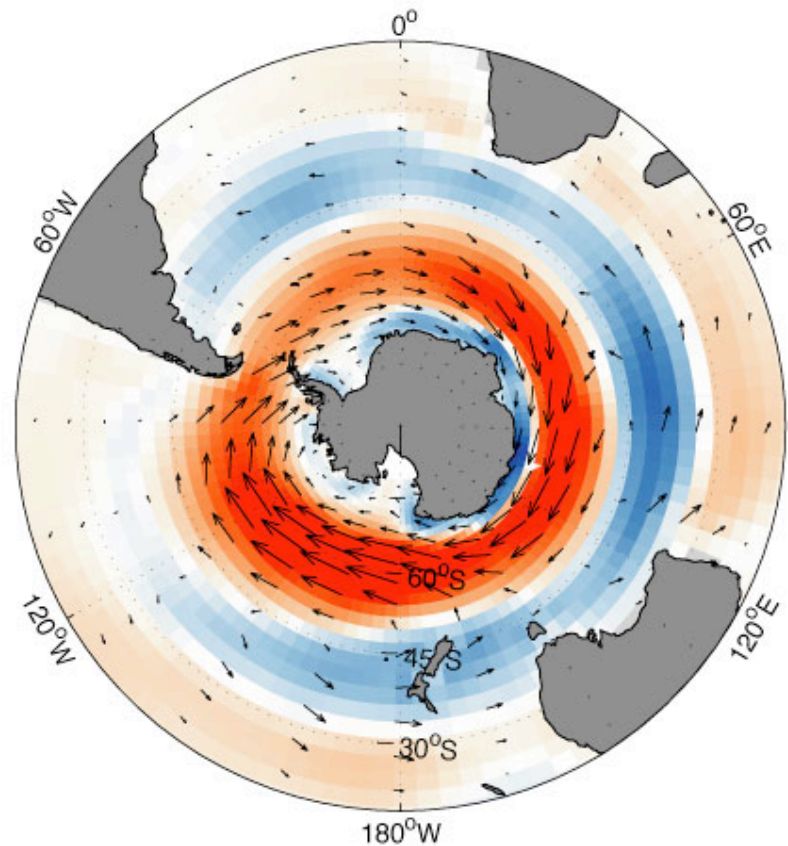
The Southern Annular Mode (SAM)

Regression of geopotential height anomalies onto the SAM



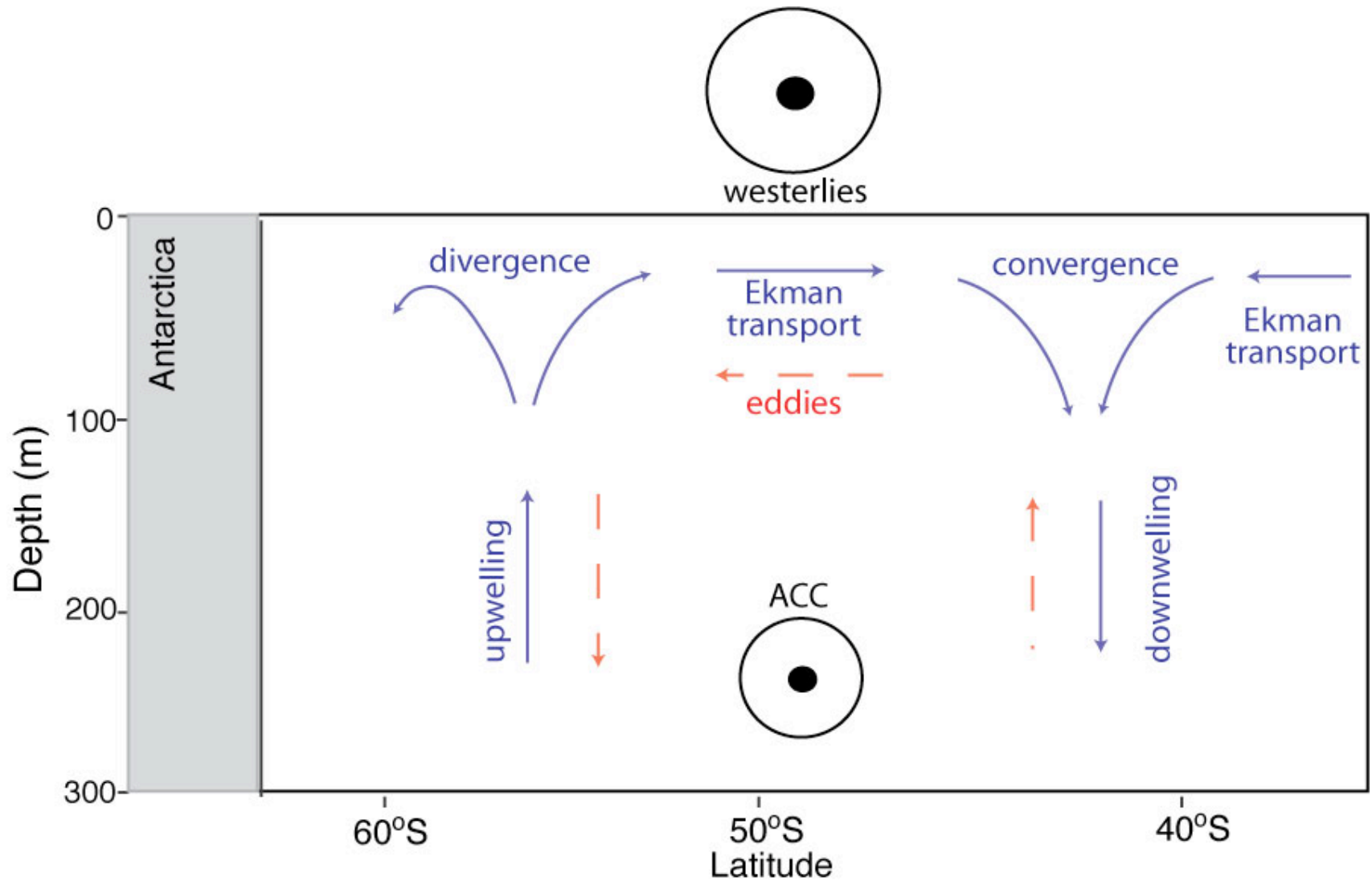
(m)

Regression of Wind Stress anomalies onto the SAM

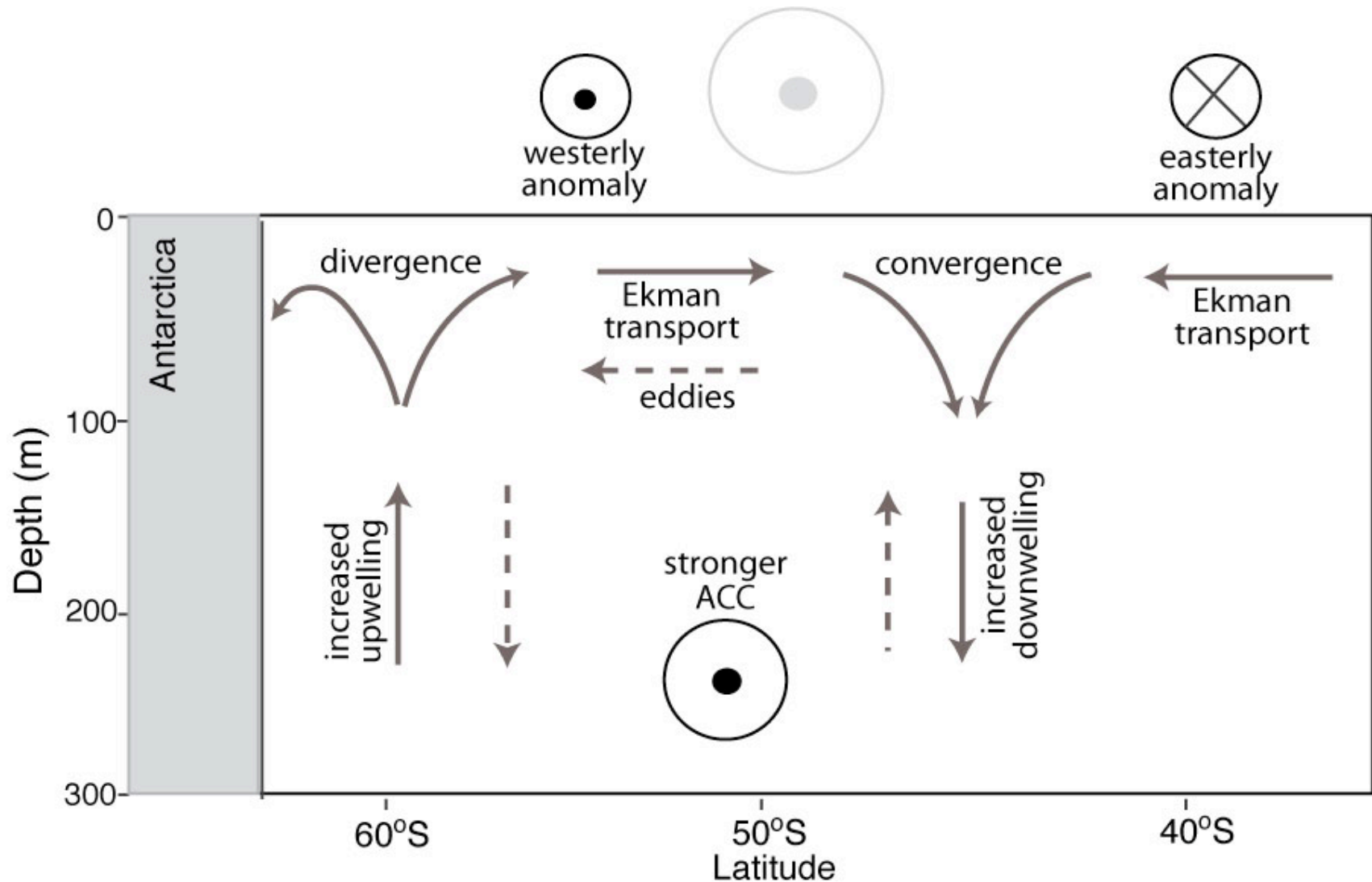


(dyne cm⁻²)

Mean Southern Ocean circulation



Oceanic response to a positive SAM



adapted from Hall & Visbeck (2002)

How has Southern Ocean Air-Sea CO₂ flux changed in the last 50 years?

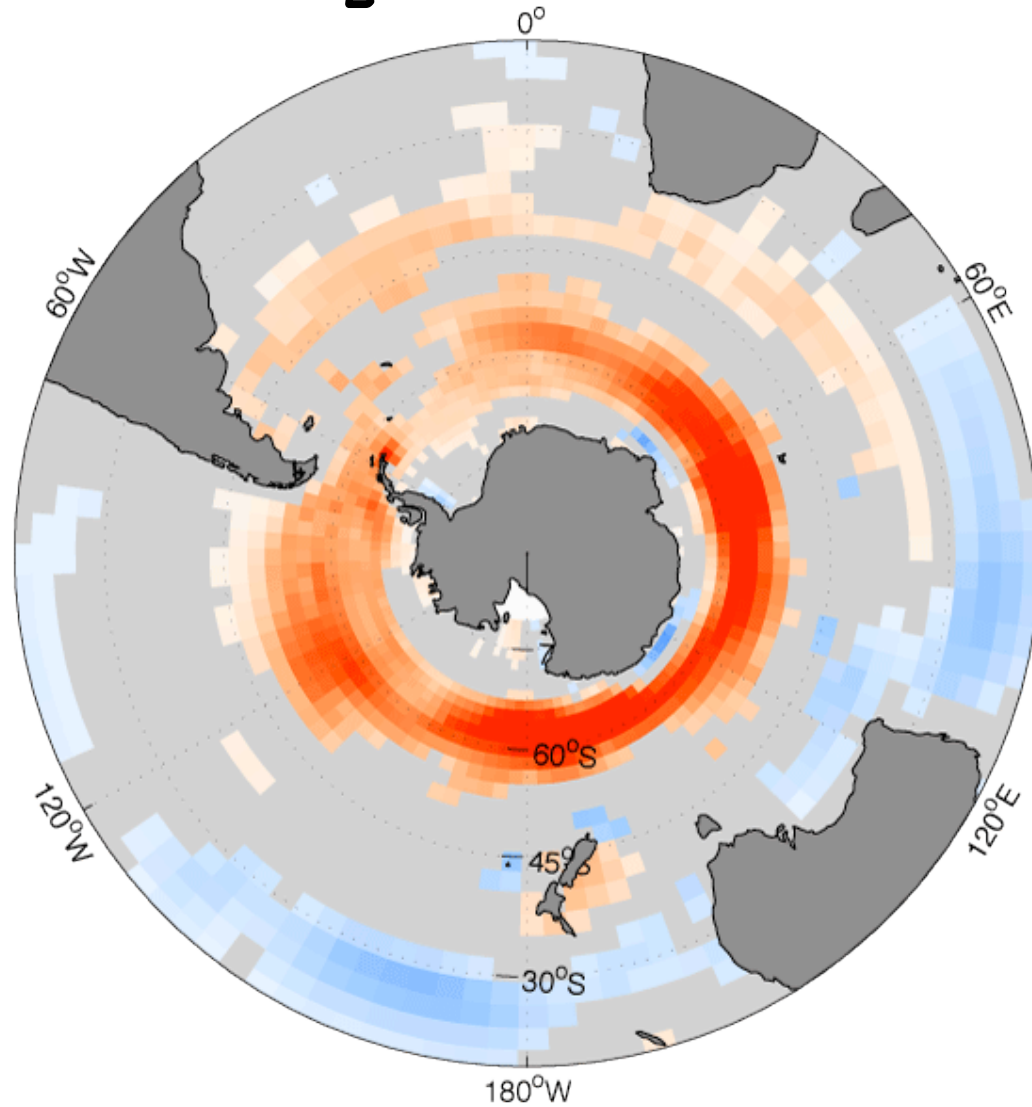
Part II (A): Using a “Realistic”
Ocean General Circulation Model

Ocean General Circulation Model

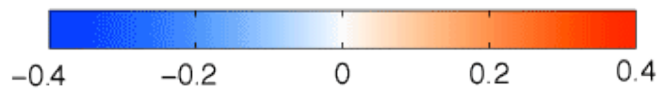


- Atmospheric “forcing” (wind stress, air temperature, precipitation, etc.) given as boundary conditions
- Embed a complex biogeochemical-ecological model into the physical framework

Air-sea CO₂ Flux and the SAM

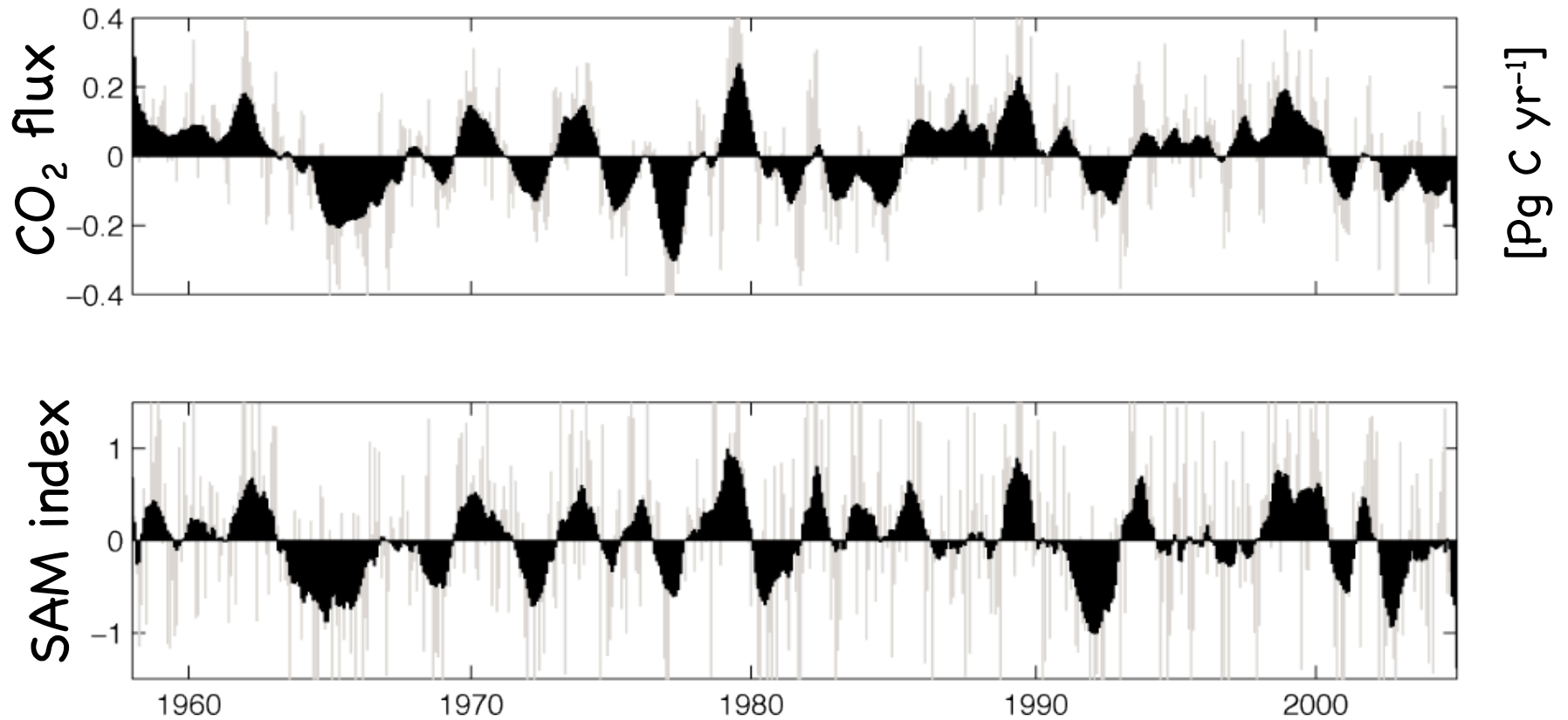


Lovenduski et al. (2007)

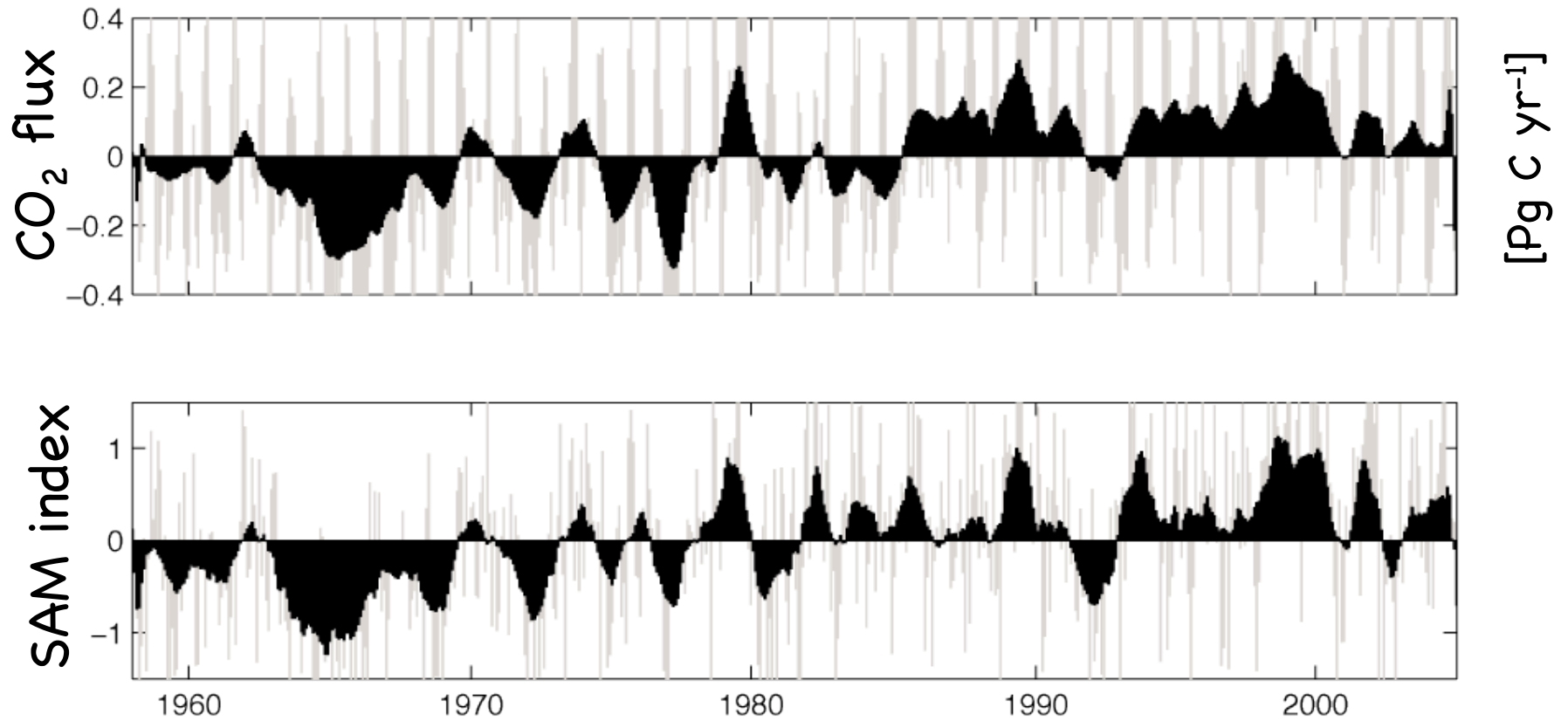


[mol m⁻² yr⁻¹]

CO₂ & SAM Variability

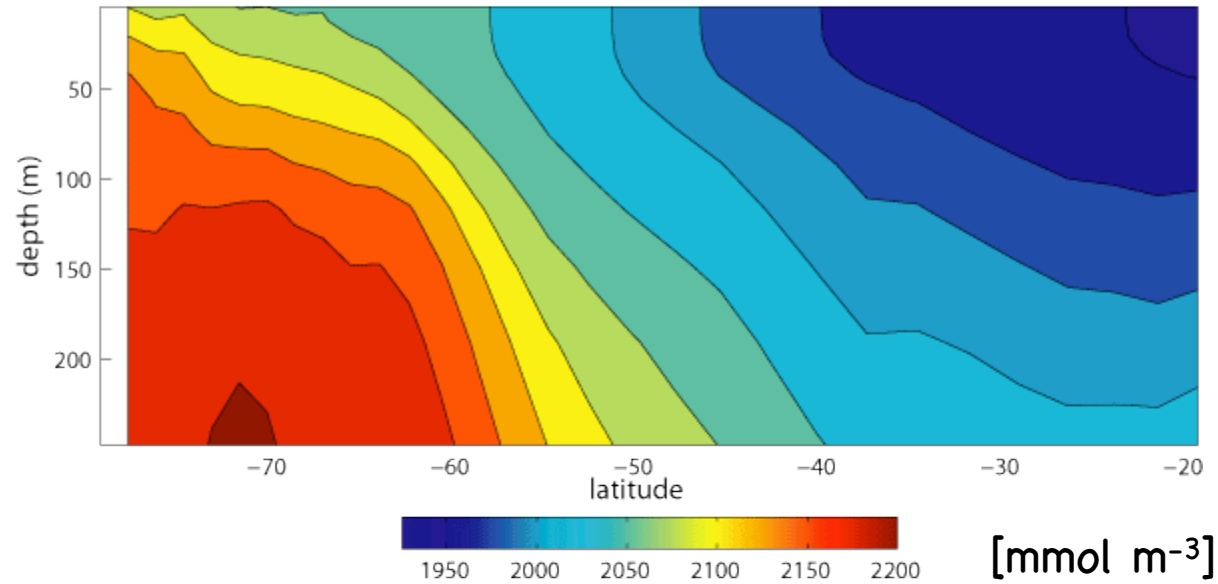


CO₂ & SAM Trends

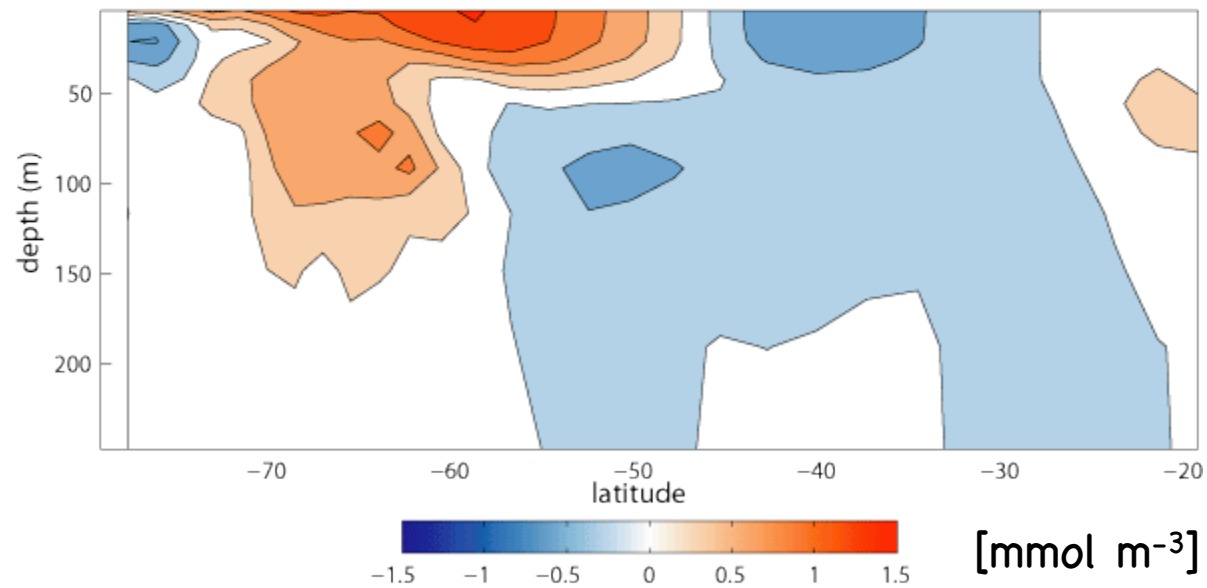


Dissolved CO₂

mean



regression
with SAM

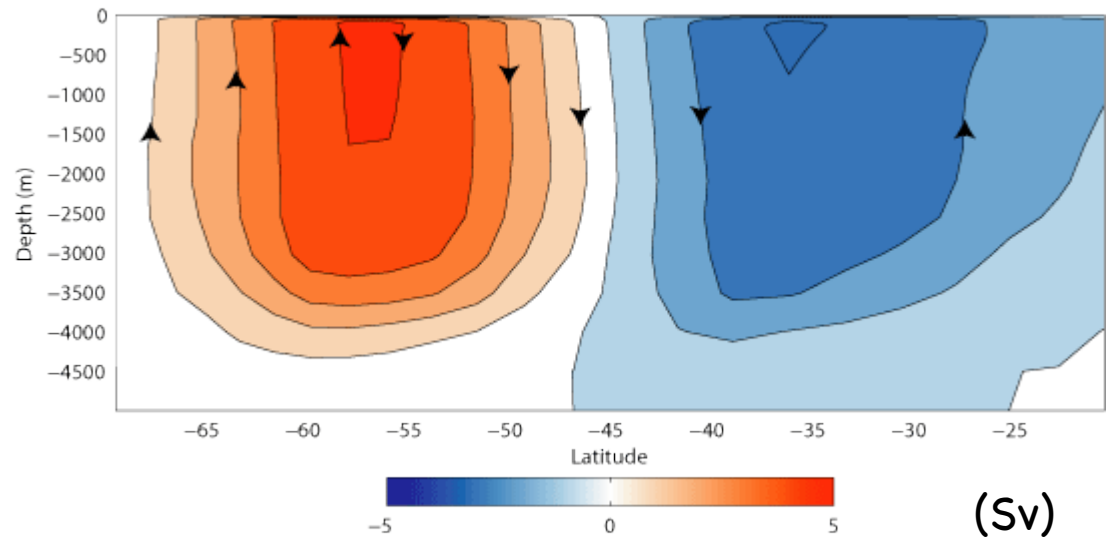


CO₂ and circulation changes

- Positive SAM associated with elevated concentrations of surface CO₂
- Surface CO₂ changes are primarily controlled by circulation changes

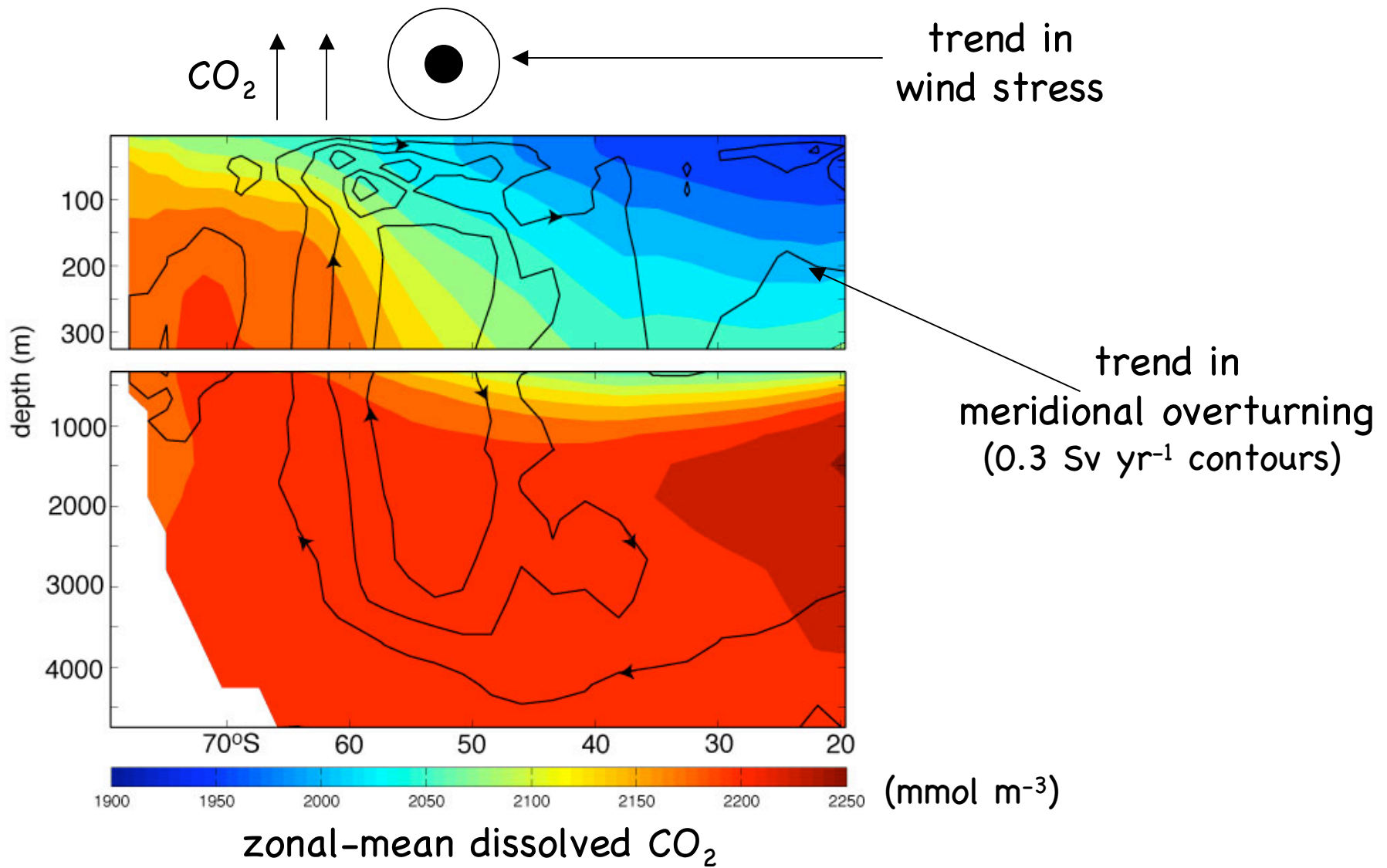


meridional overturning regression



Lovenduski et al. (2007)

Underlying causes of change

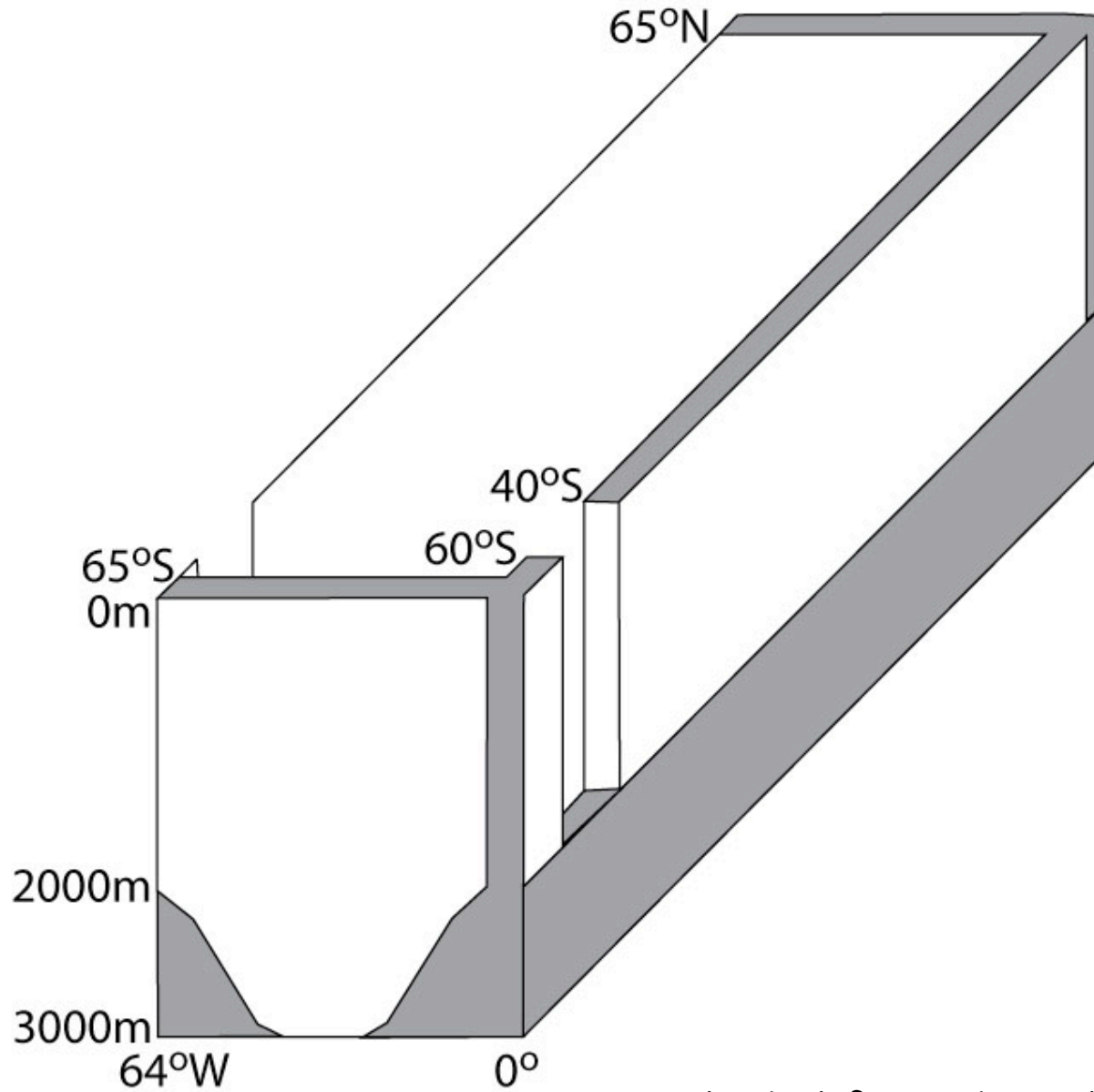


Lovenduski et al. (2008)

**What role do subgrid-scale
processes play?**

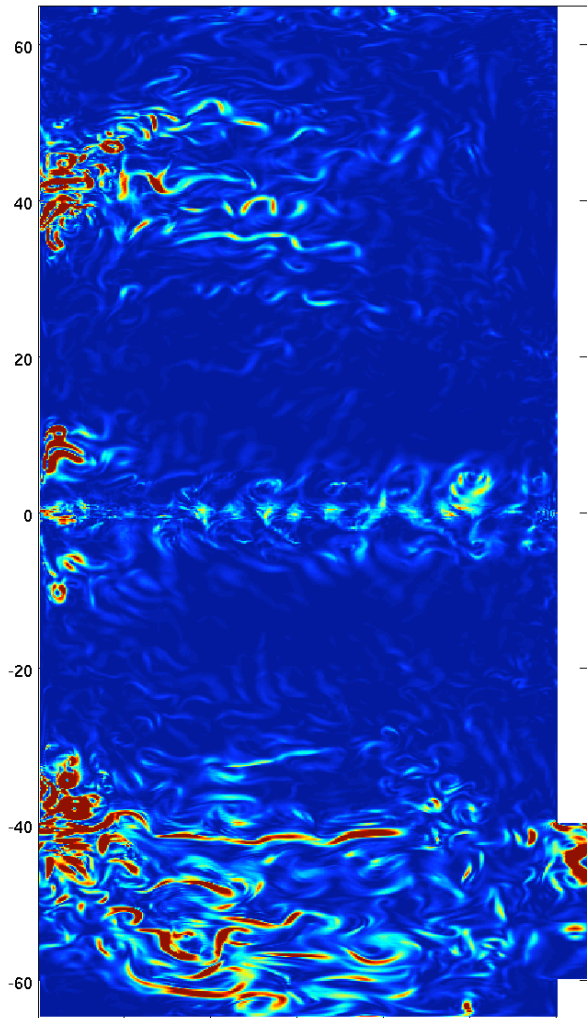
**Part II (B): Using an Idealized
Ocean General Circulation Model**

Sector model



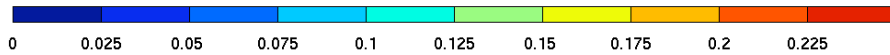
adapted from Ito and Follows (2005)

Eddies!

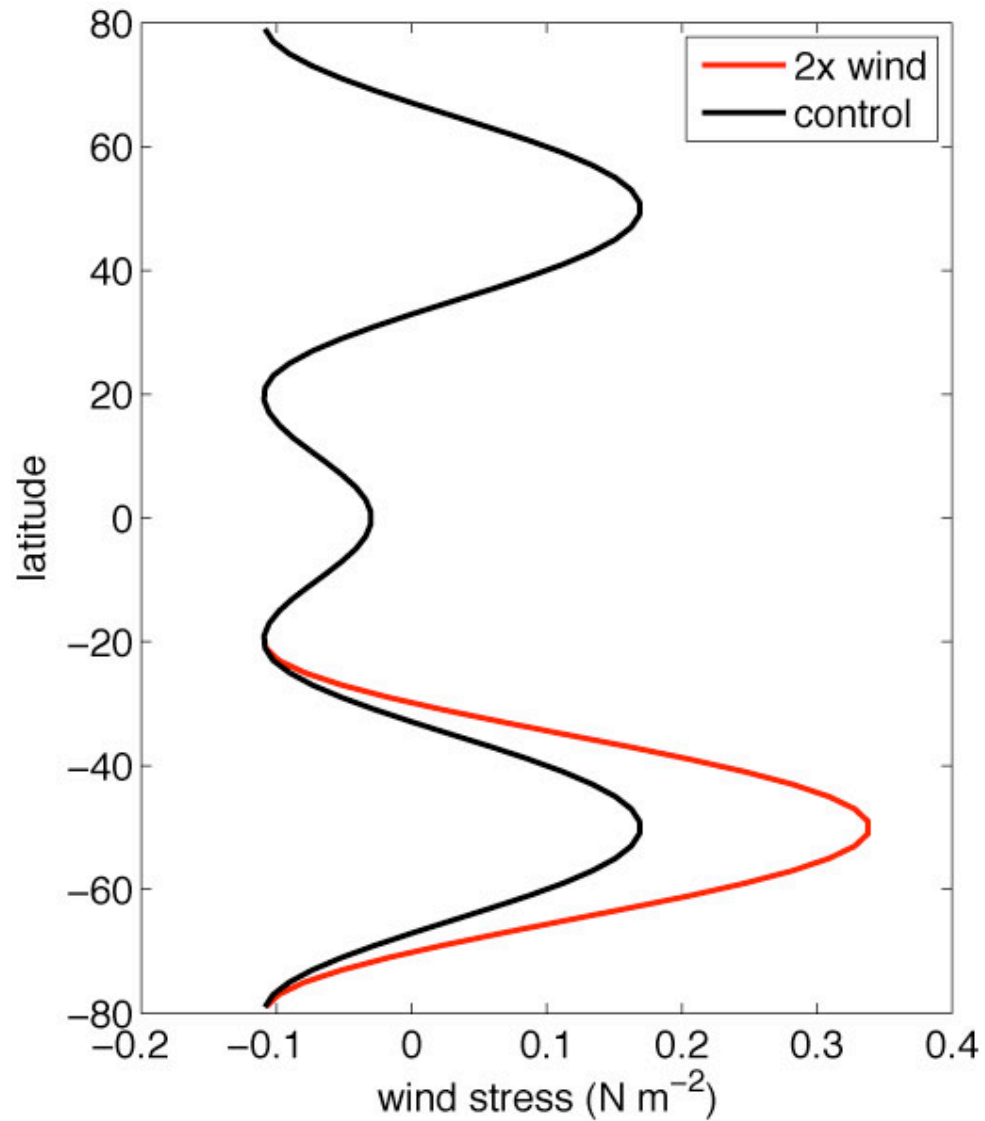


open channel in
Southern Hemisphere

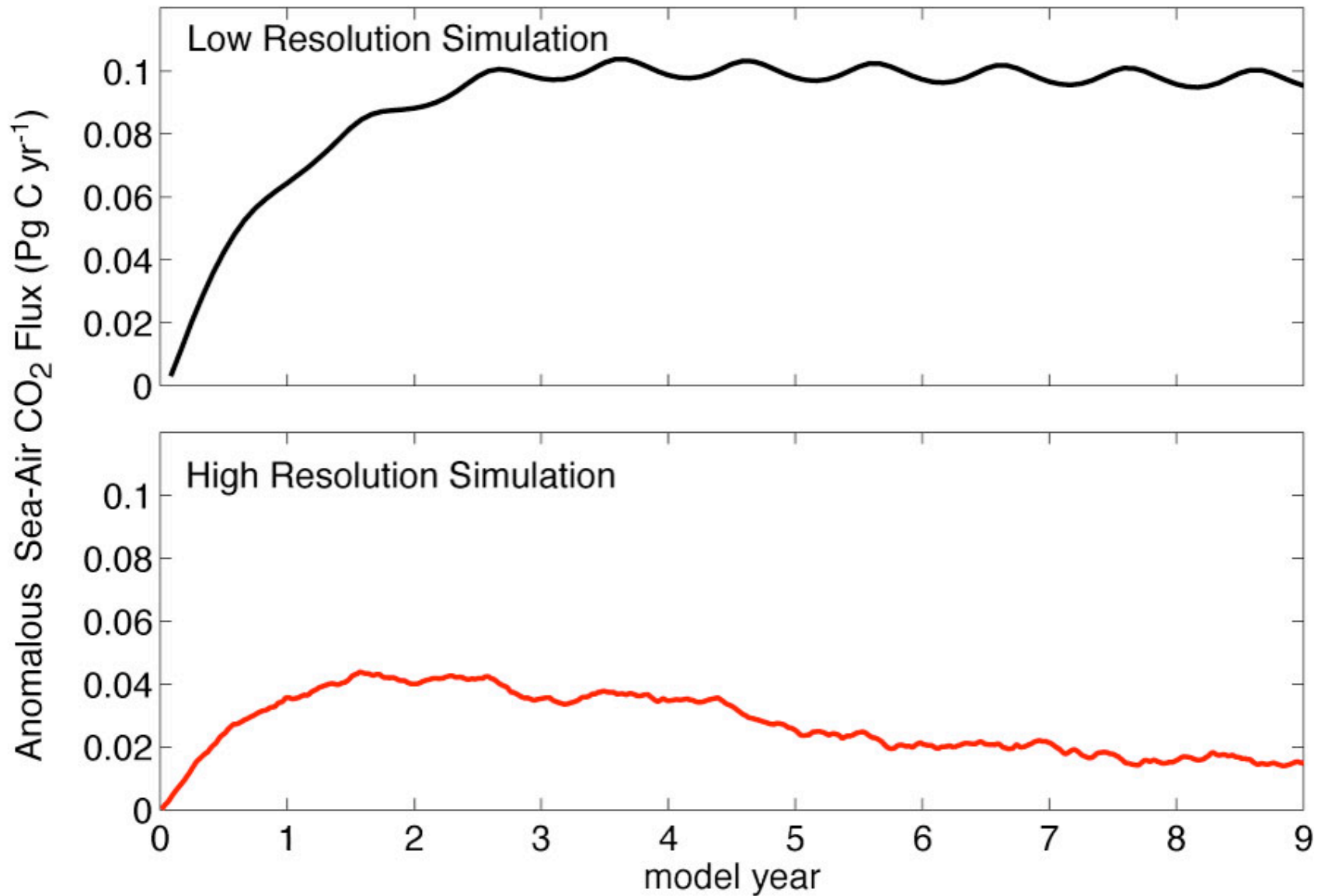
surface ocean EKE [m^2/s^2]



Wind Perturbation Experiment

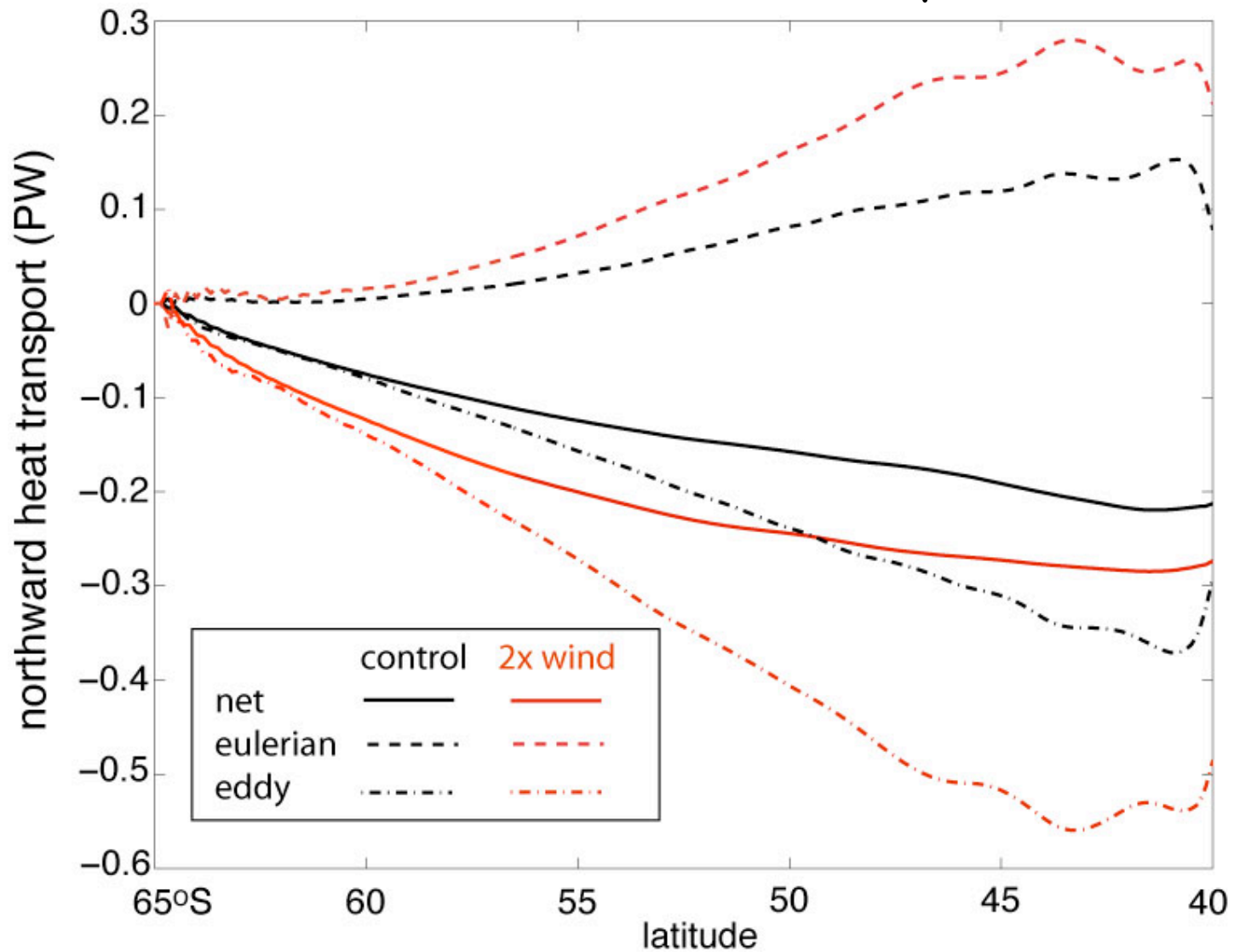


Southern Ocean Sea-Air CO₂ Flux Anomaly

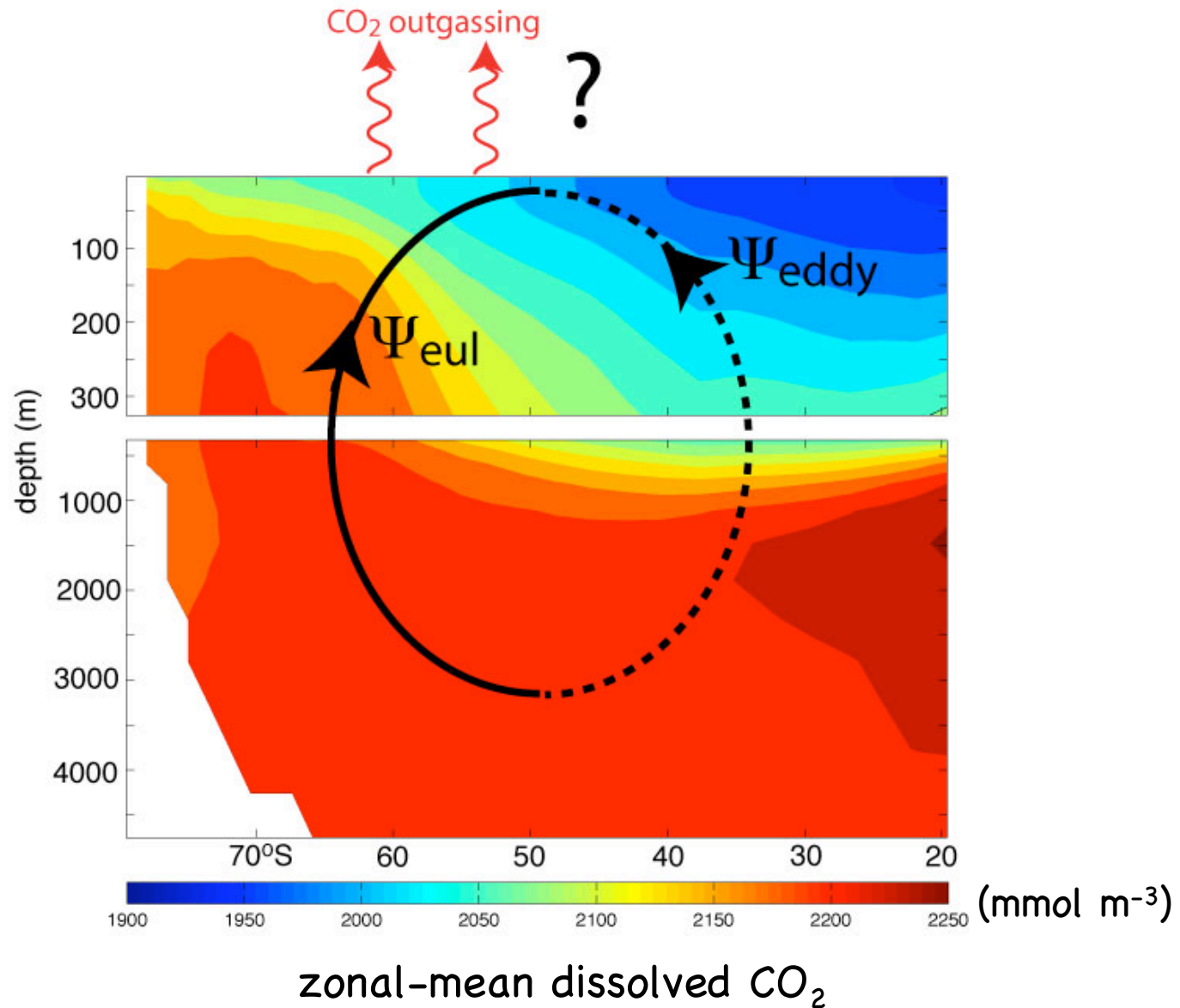


Circulation Changes

Mean Northward Heat Transport

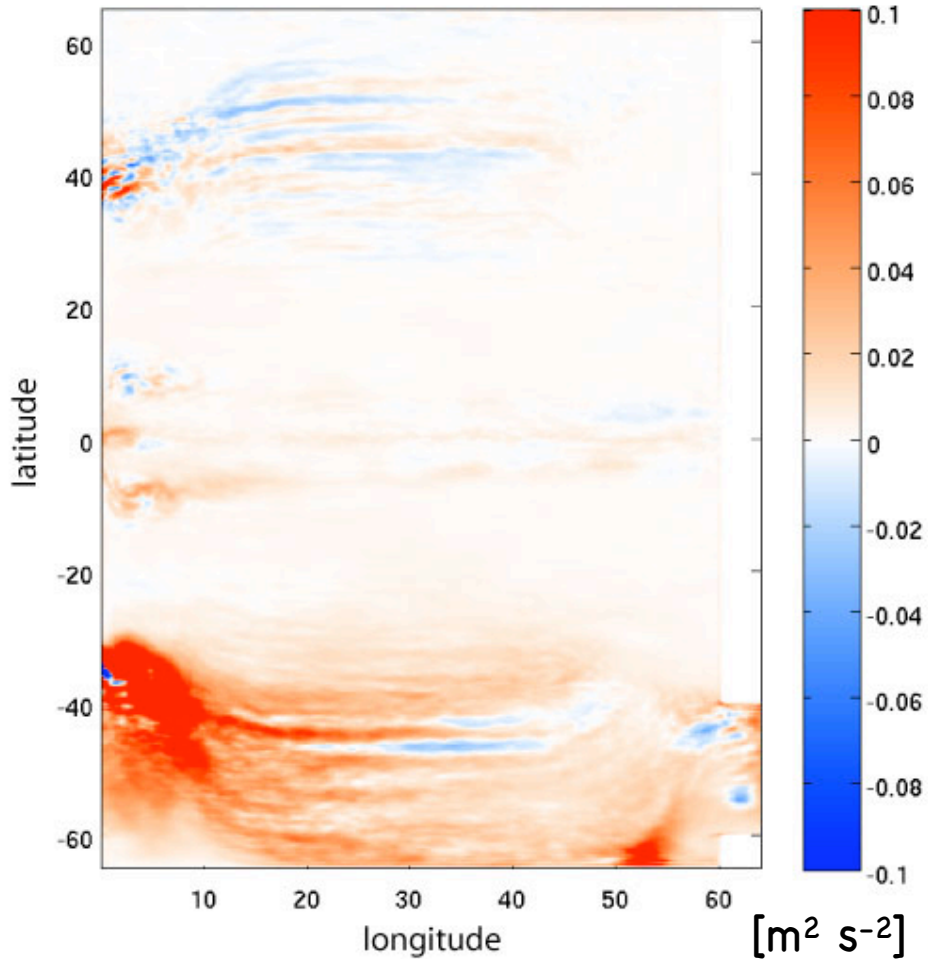


Implications for CO₂ Flux

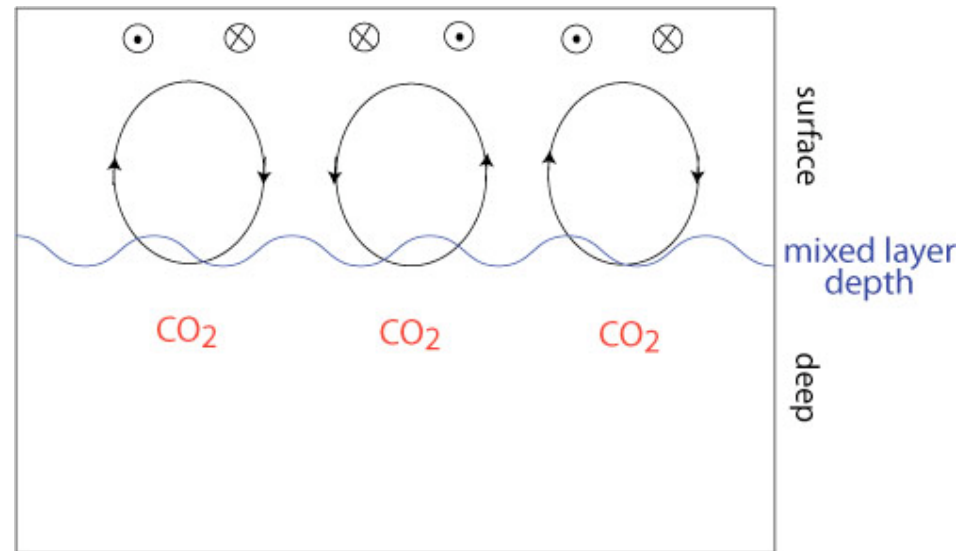


What causes the anomalous outgassing?

Eddy Kinetic Energy

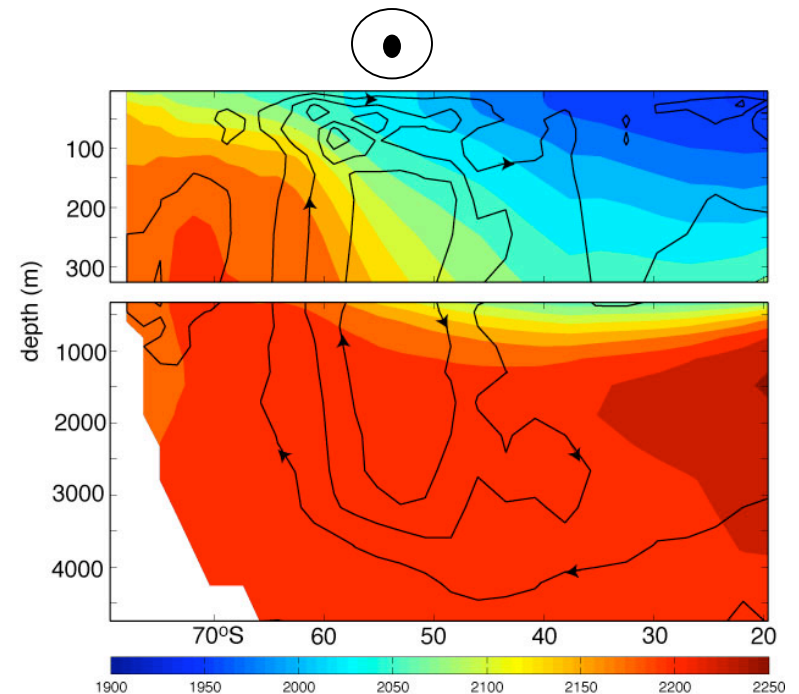


Surface Turbulence



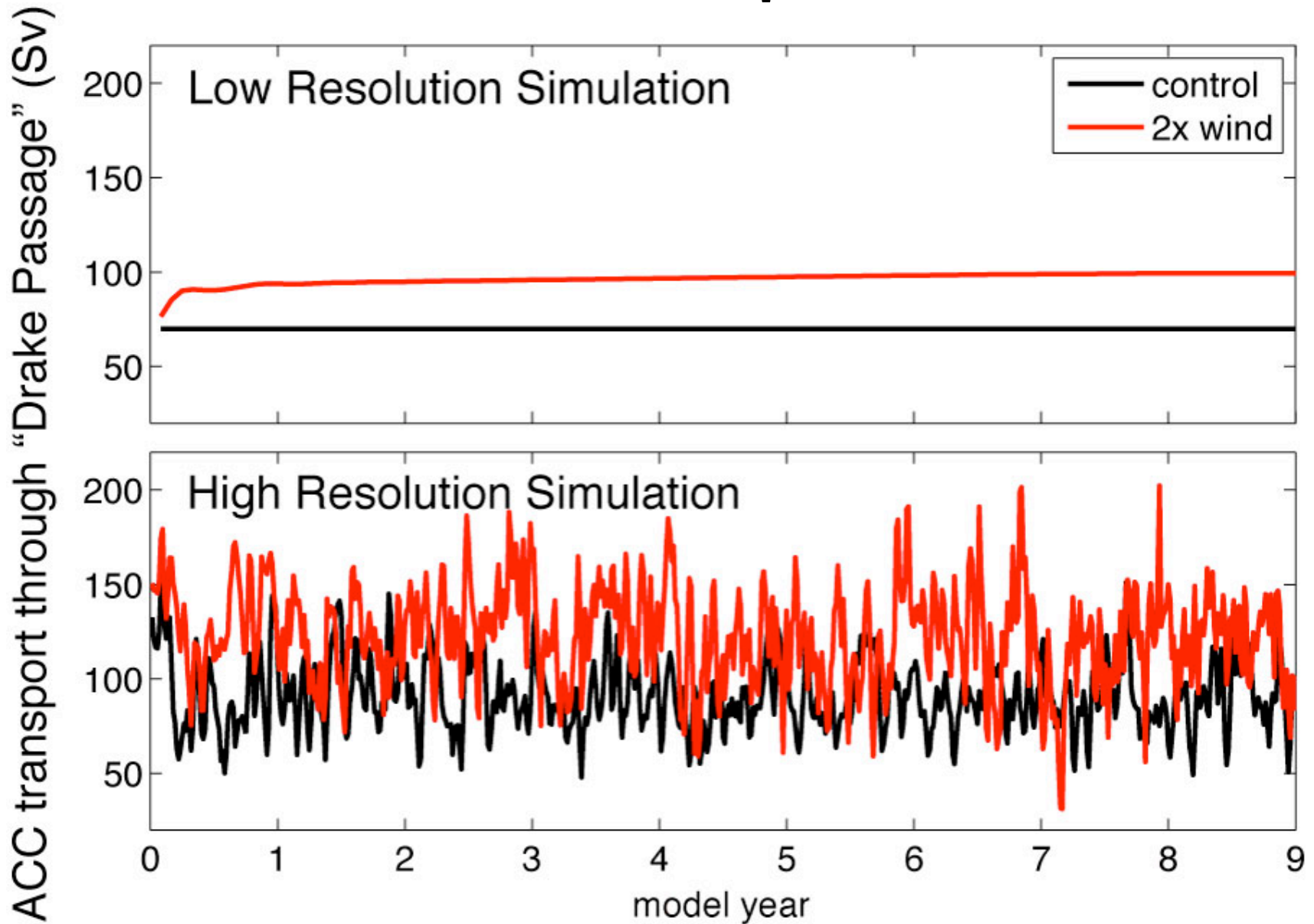
Conclusions

- Coarse resolution models suggest that the Southern Ocean has anomalously degassed CO_2 into the atmosphere over the past few decades as a result of stronger winds and overturning.
- An idealized, high-resolution model suggests that increased wind will also lead to anomalous degassing of CO_2 , but the mechanisms are not as clear.



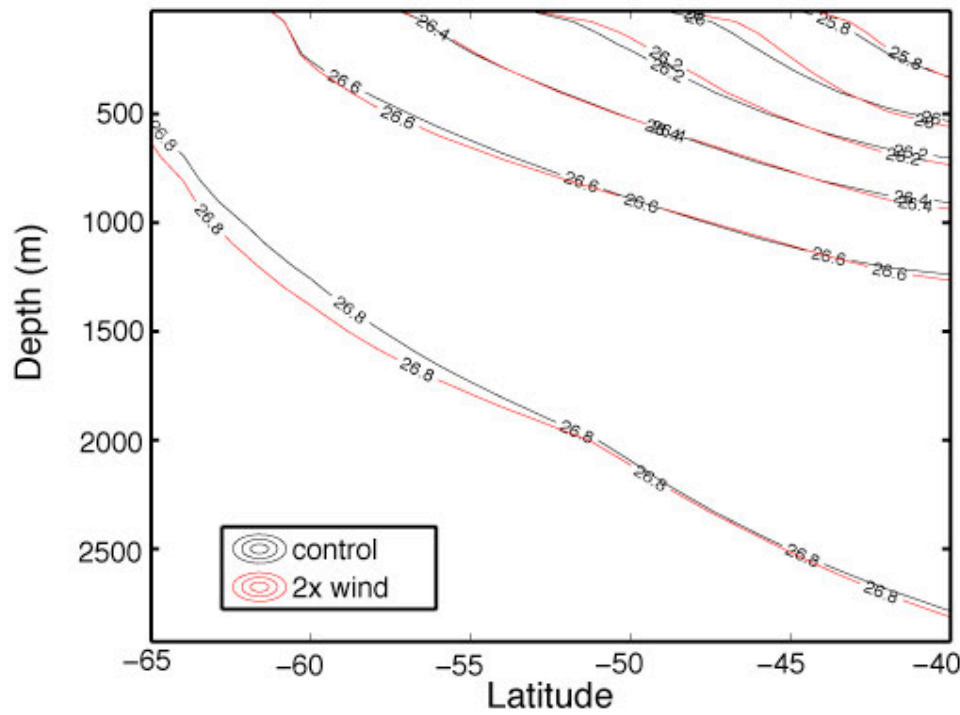
The End!

ACC Transport



Isopycnal Slumping

Low Resolution Simulation



High Resolution Simulation

