Institute of Science and Technology Austria

Influence of the Wind Stress Curl on the Eddy Saturation Behavior of the ACC in a Barotropic Perspective

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I. Introduction

- The strength of zonal transport of the Antarctic Circumpolar Current (ACC) is almost independent of the variations in westerly winds over the Southern Ocean; this phenomenon is called **eddy saturation**.
- The eddy saturation has been studied in both barotropic and baroclinic contexts in the presence of topography, yet many aspects of its dynamics remain elusive. ([1, 2, 3, 4, 5, 6, 7, 8, 9])
- We focus on barotropic eddy saturation, which occurs in a narrow band of wind stresses where topographic-barotropic instability takes place.
- We investigate whether the amplitude of the wind stress curl relative to that of a constant background wind stress can also modulate barotropic eddy saturation by modifying the global vorticity budget of a doubly periodic quasigeostrophic flow.

Background figure is taken from Vallis, 2017. [10]

II. Barotropic QG Model

- Solved using DEDALUS [11].
- Monoscale topography, $L = 775$ km, $H = 4$ km, $h_{rms} = 200$ m [7]

$$\eta = \sqrt{2}\eta_{\rm rms}\cos(14x/L).$$

- Doubly periodic 2D domain, $2\pi L \times 2\pi L$, and 512×512 grid.
- The vorticity equation with the added wind curl term is given as:

$$\partial_t \nabla^2\psi + J\left(\psi - Uy, \nabla^2\psi + \eta + \beta y\right) = -D\nabla^2\psi' - \partial\tau_y. \qquad (1)$$

The wind curl enters the vorticity equation through the stream function.

$$\psi = \psi' + V_{sv}x \qquad (2)$$

where V_{sv} is defined as:

$$V_{sverdrup} = -\frac{-\partial\tau_y}{\beta} \qquad (3)$$

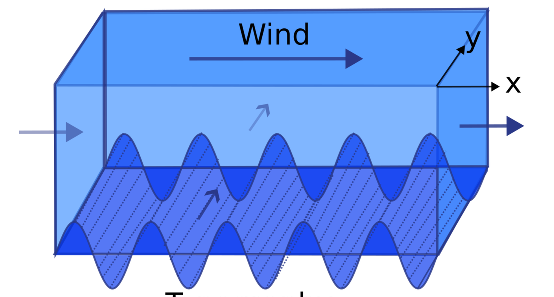
We solve for the potential vorticity and the mean zonal velocity equations:

$$\partial_t\nabla^2\psi' + J\left(\psi' - Uy, \nabla^2\psi' + \eta + \beta y\right) + V_{SV}\left(\nabla^2\psi'_y + \beta + \eta_y\right) = \underbrace{-D\nabla^2\psi}_{\text{ekman drag + hyperviscosity}} - \underbrace{\partial\tau_y}_{\text{wind curl}} \qquad (4)$$

$$\partial_t U = \underbrace{F}_{\text{wind forcing}} - \underbrace{\mu U}_{\text{bottom drag}} - \underbrace{\langle\psi\partial_x\eta\rangle}_{\text{form stress}} \qquad (5)$$

- The eddy kinetic energy is decomposed into the total eddy kinetic energy (EKE) and standing eddy kinetic energy (sEKE).

$$\text{EKE} = \frac{1}{2}\overline{\langle|\nabla\psi|^2\rangle}$$
$$\text{sEKE} = \frac{1}{2}\left\langle|\nabla\bar{\psi}|^2\right\rangle \qquad (6)$$



III. Eddy Saturation with Uniform Wind

We validate our method against Constantinou (2018) [7] for a uniform wind profile where $\partial_y\tau = 0$ and F are varying.

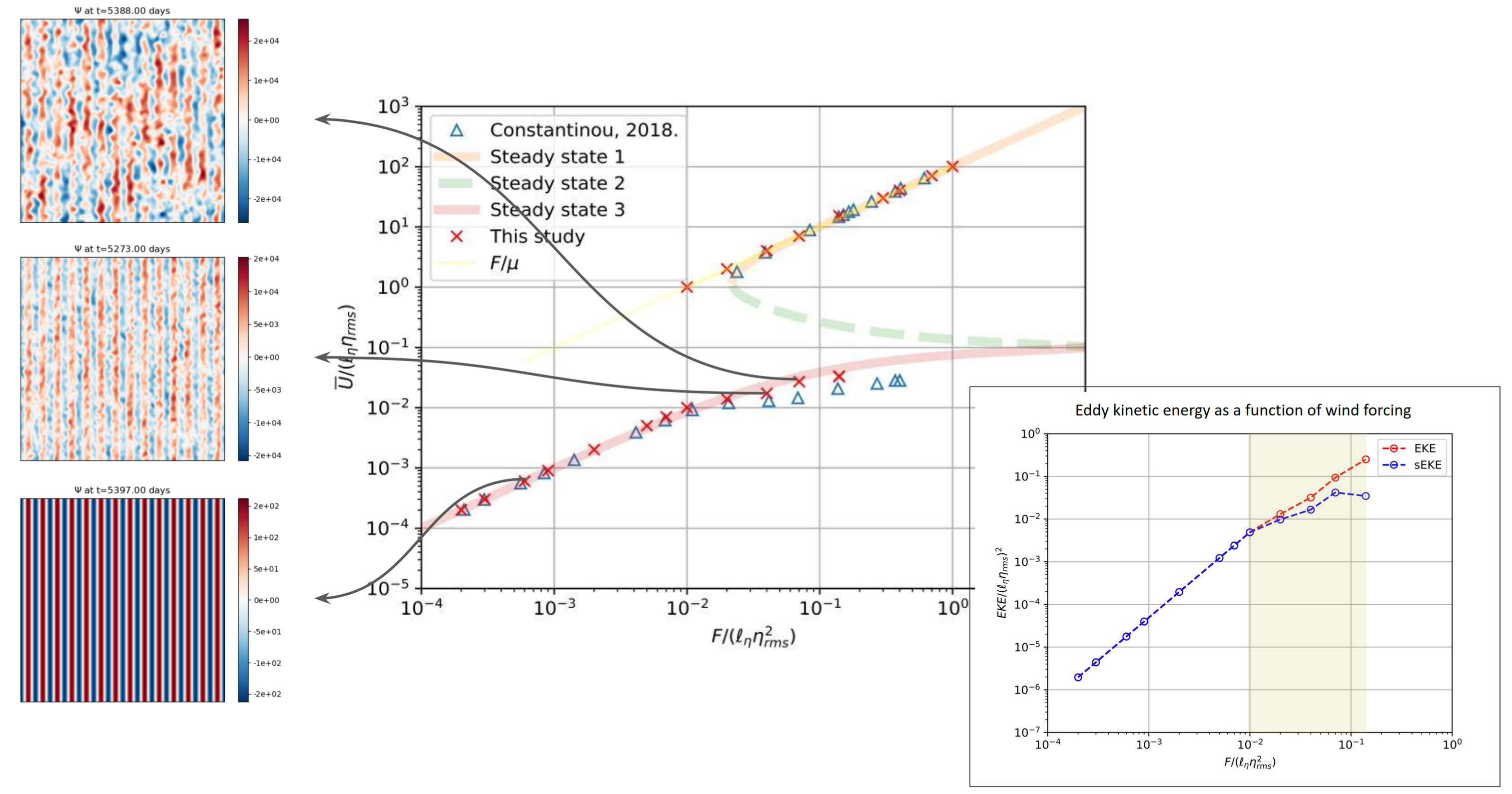


Figure 1. (Left) The time-mean large-scale domain averaged zonal nondimensional flow U as a function of nondimensional mean forcing. The highlighted lines show the analytical steady-state solutions of Eq (4) and Eq (5). Three eddy streamfunction snapshots are given for different values of F. [7] (Right corner) The nondimensional EKE and sEKE as a function of the nondimensional wind forcing.

- Lower branch region before the eddy saturation regime is dominated by the **form stress and wind forcing** terms and shows laminar characteristics.
- In the eddy saturation region, EKE increases, while the mean zonal transport and sEKE stay nearly constant.
- Higher branch region is dominated by **bottom drag and wind forcing** and also exhibits laminar characteristics.

IV. Sensitivity of the Volume Transport and Eddies to the Wind Curl with Zero Mean Wind Stress

We solve equations (4) and (5) where $F = 0$ and $\partial_y\tau = constant$ varies.

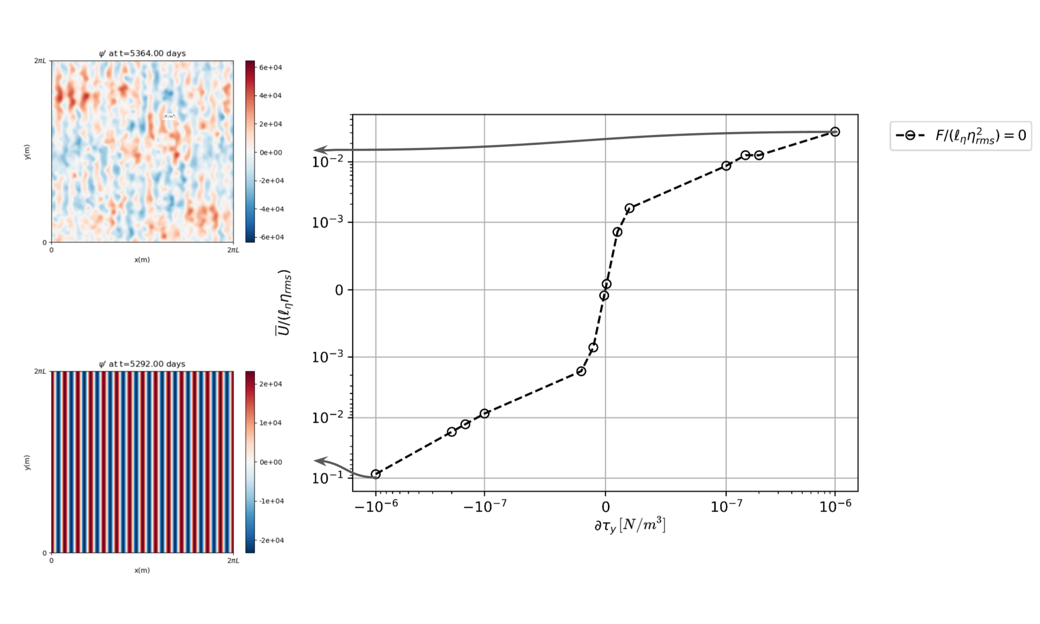


Figure 2. The mean zonal transport where $F = 0$, for varying wind stress curl values. On the left, two decomposed eddy streamfunction snapshots are given for negative and positive values of the largest wind stress curl magnitudes.

Take away: Asymmetrical nonzero mean zonal flow solutions exist for zero mean forcing.

V. Sensitivity of the Volume Transport and Eddies to the Wind Curl with Nonzero Wind Stress

We solve equations (4) and (5) with a constant wind curl where F and $\partial_y\tau = constant$ varies.

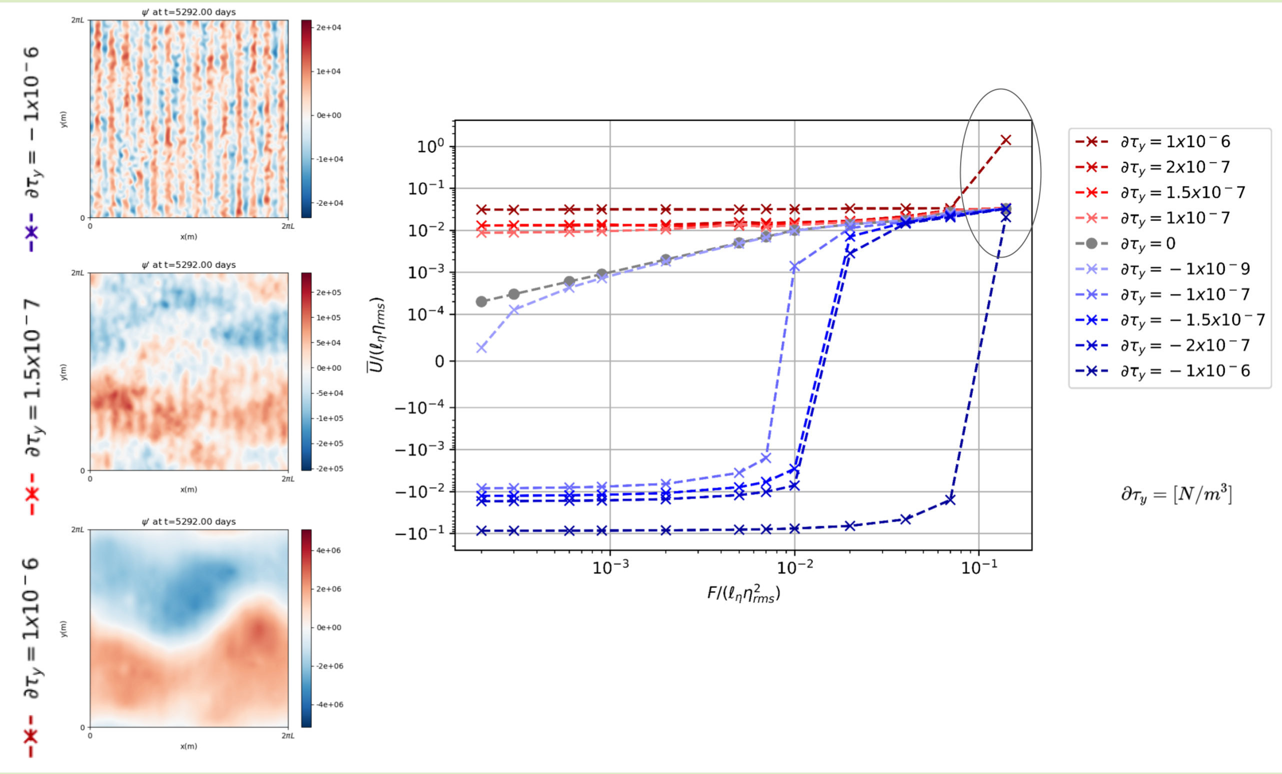


Figure 3. The mean zonal transport where F varies for varying wind stress curl values. On the left, three decomposed eddy streamfunction snapshots are given for various wind curl magnitudes, for nondimensional $F = 0.14$.

Take away:

- The lower branch is not observed for positive higher values of wind stress curl.
- Bifurcation to the upper branch realizes at lower forcing values with increasing wind stress curl values.
- An asymmetry in the system with varying eddy profiles.
- We report that the zonal transport and the eddy saturation regime are sensitive to the wind stress curl.

VI. Future Work

- Analytical solutions for different stable and unstable regimes exist depending on the (1) wind profile and (2) topography with a focus on eddy saturation regime.
- The source of the asymmetry in the system.
- Further experiments with various topography and wind profiles.

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