Determining the Eddy Feedback Strength of the Baroclinic Annular Mode and Atmospheric Blocking In An Idealized Quasi-Geostrophic Model

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1. Introduction

Understanding the dynamical contributions to atmospheric blocking from large-scale atmospheric circulation has important implications for disaster preparation and mitigation in the midlatitudes. Yet, predicting blocking events using short-to-medium-range weather forecast systems is difficult due to the persistence of blocks beyond synoptic time scales. Despite this, a theory connecting blocking events with large-scale modes of variability in the midlatitudes has not been established. One potential candidate is the recently discovered Baroclinic Annular Mode (BAM), which describes a 20-30 day regularly pulsing storm pattern in the Southern Hemisphere. A recent study suggests that the positive phase of BAM enhances blocking occurrence, implying that BAM and blocking may share similar dynamics.

Inspired by this, we hypothesize that BAM modulates atmospheric blocking, and synoptic eddy feedback sustains BAM, which would be conducive to block formation. Eddy feedback processes describe how small perturbations to the atmospheric mean flow interact with each other to influence large-scale dynamical patterns. Various eddy feedback processes influence the strength of the BAM, yet quantifying these processes remains a challenge. To address this, we adopt a linear response function (LRF) approach that has been recently proposed as a framework to evaluate the eddy feedback strength to a climate state and determine the most excitable dynamical mode. As a test of the LRF methodology, we first apply it to a two-layer quasi-geostrophic model and attempt to calculate the eddy feedback associated with the annular mode, a pattern of variability which describes the variations in position and intensity of the midlatitude jet stream.

2. Methodology

The LRF **L** approximates the mean-state response of a system to imposed forcings, defined as

$$\mathbf{Lx} = -\mathbf{f}$$

where **x** is a state vector defining the system and **f** is the imposed forcing.

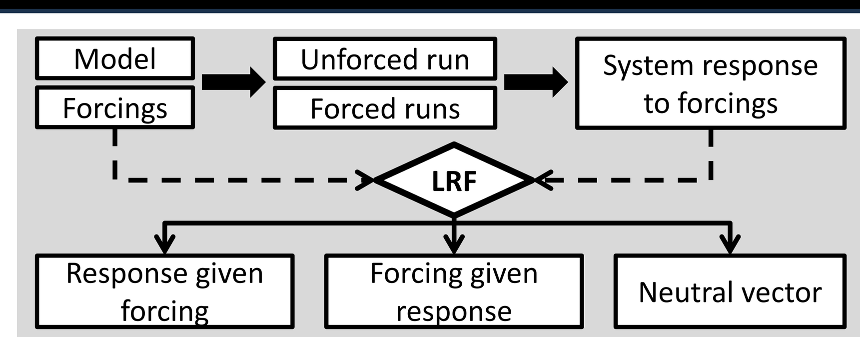

Figure 2. Schematic of LRF procedure.

We systematically apply weak localized forcings and find the mean response, collecting both in matrices. Then we calculate the LRF using the equation

$$L = -FR^{-1}$$

The LRF can be used to determine the system's response to an arbitrary forcing, the forcing needed to achieve an arbitrary response, and the system's most excitable mode (called the neutral vector). For each model, we use the LRF to find a forcing that yields the annular mode pattern. We will calculate the eddy feedback strength by projecting the anomalous eddy momentum flux onto the anomalous zonal wind.

We adopt a quasi-geostrophic (QG) model which contains essential dynamical and physical processes for BAM and blocking while ignoring those of secondary importance. We will calculate a LRF for the model in two climatological basic states–corresponding to the positive and negative phases of BAM–by repeatedly running each model, applying a different weak localized forcing each time, and systematically analyzing the outputs compared to unforced runs using matrix computations. Using the LRF, we will show the response of synoptic eddies and blocking events to an imposed BAM state.

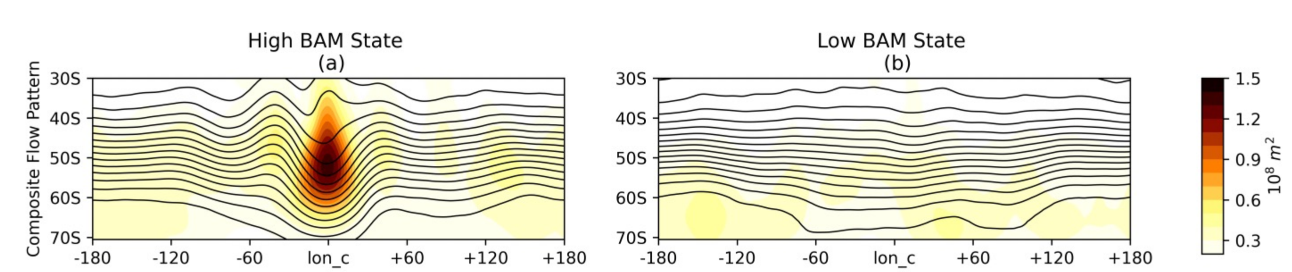

Figure 3. High and low climatological basic states for BAM, courtesy of Zhaoyu Liu.

3. Results

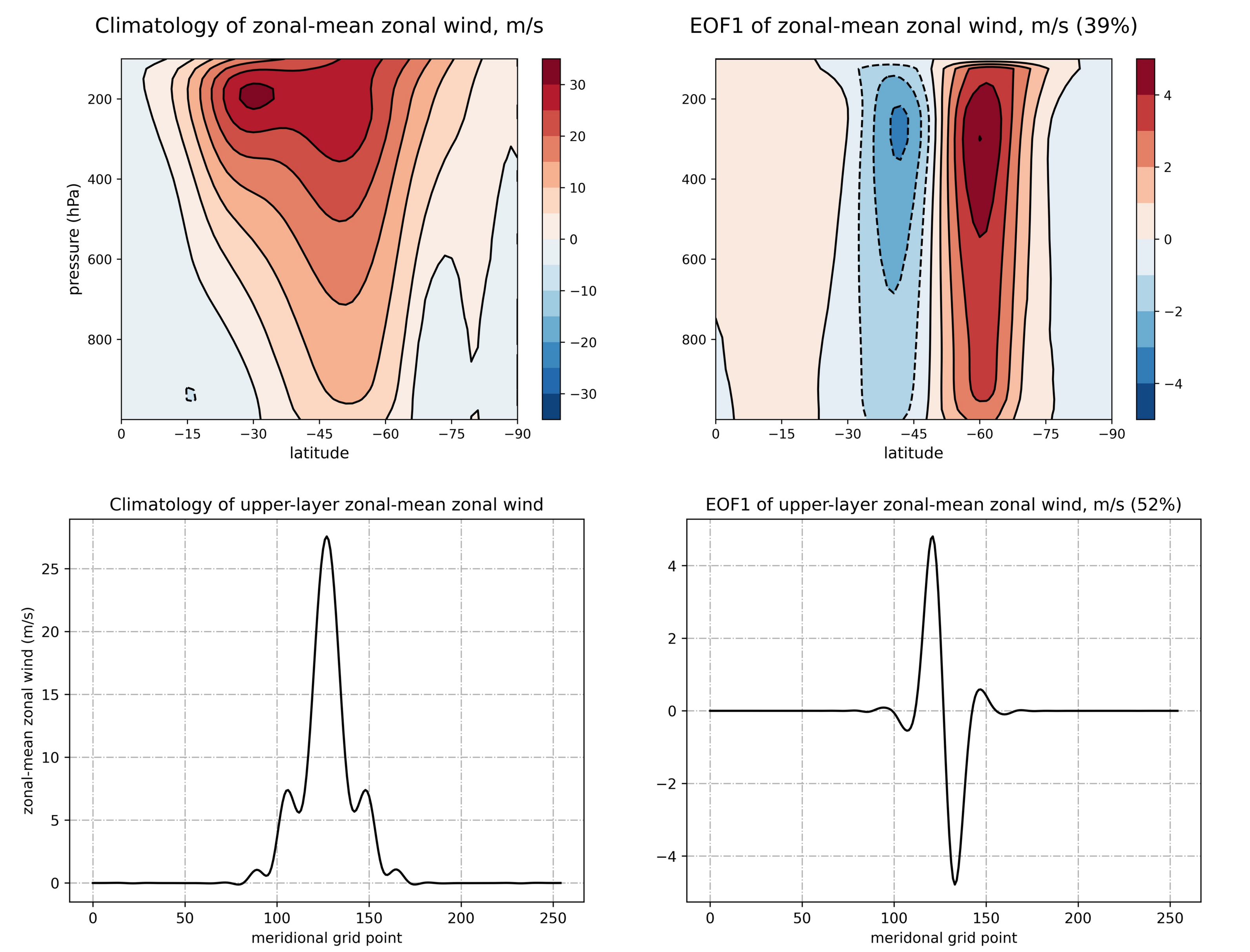

Figure 1. Climatology of zonal-mean zonal wind (left) and the annular mode (right) in ERA Interim reanalysis (top) and the upper-layer of the two-layer QG model (bottom).

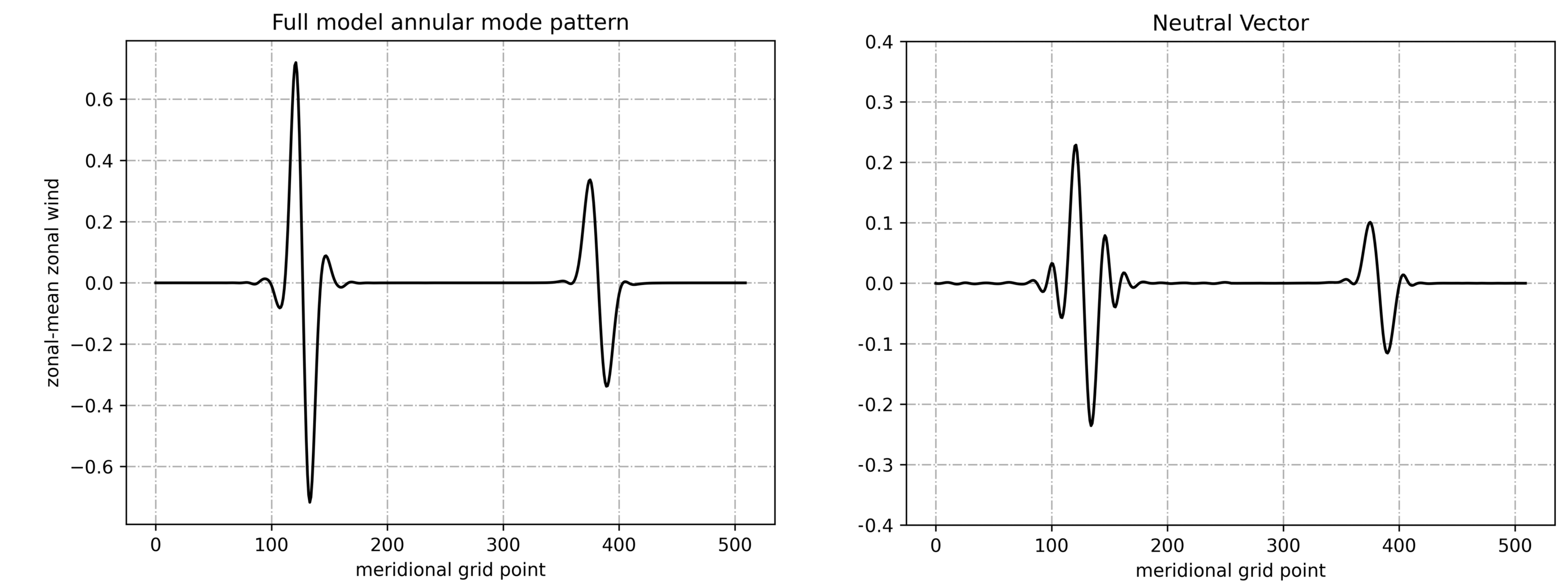

Figure 4. The annular mode pattern in the upper and lower layers of the model (left), and the neutral vector obtained from the model's LRF (right).

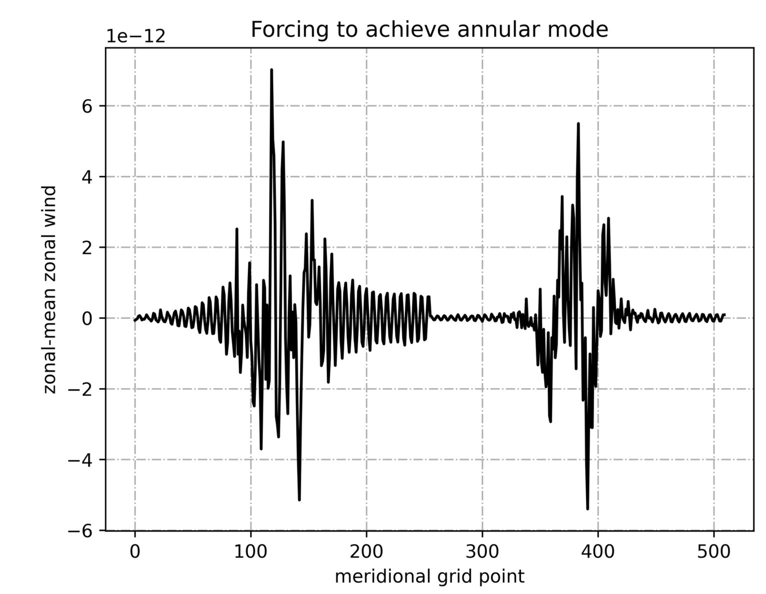

Figure 5. The forcing needed to achieve the annular mode pattern, obtained from the LRF.

4. Conclusions and Future Work

As of now, we can conclude that the we are able to successfully calculate the model's LRF. Furthermore, the LRF is able to successfully capture the annular mode as a true dynamical mode of the system, as the annular mode and neutral vector are a close match.

The next steps are to force the model using the pattern obtained from the LRF, then calculate the eddy feedback. Next, we will repeat this process two more times, with the high and low BAM state imposed. These results will help us to understand how eddies drive the BAM, which in turn influences atmospheric blocking.

If you have any questions, please contact me via email: calhoun9@purdue.edu.