The Modified Quasi Geostrophic (MQG) Model

The model was written by Orli Lachmy, as part of her PhD thesis. Details of it can be found in Lachmy and Harnik (2014). The dynamical balance and variability of the different regimes are further described in Lachmy and Harnik (2016, 2020).

A 2-level spherical QG model written as separate but coupled equations for the zonal mean and perturbation (deviations form zonal mean), with added ageostrophic advection terms to the zonal mean equation. The model thus resolves the three main components of the global circulation - the overturning circulation cells (Hadley, Ferrel, Polar), the zonal jet streams, and baroclinically unstable midlatitude Rossby waves. We use a version of modified spherical QG equations which allow for both cyclonic and anti-cyclonic wave breaking and which conserve energy and enstrophy.

We run the model to equilibrium state varying different parameters. We find that eddy amplitudes are a key parameter which controls the type of jet stream. Following is an example where we vary the strength of damping on the waves. As we strengthen eddy damping, and shift from stronger to weaker eddies, the model transitions between three main dynamical regimes:

Eddy driven jet – A midlatitude jet in a wide Ferrel cell, jet meanders, a range of wave modes, with zonal wave numbers 1-4.

The variability in this regime is nonlinear, with the leading variability involving the jet splitting and merging. Each phase of the leading EOF is conducive to growth of different wave modes, which upon modifying the mean flow they decay, with other modes growing more efficiently.

Merged jet – A stronger jet in a narrower Ferrel cell, very low zonal wind variability, a dominant zonal wave number 5 mode. Mixed eddy & thermal driving.

The variability in this regime is closer to a wave-mean flow dynamics in the sense that a single zonal wavenumber dominates and when it grows and saturates, it does not shift the jet latitude. The dominant mode is not the most unstable linear wave, rather it is the mode which allows this wave-mean flow dynamics to exist.

Subtropical jet – A jet at the Hadley cell edge, some jet pulsation, zonal wave number modes 2-5, with low wave numbers in high latitudes and the medium scale wave number 5 weakly growing on the subtropical jet. This regime is closest to a linear model in which the waves grow on the jet but do not grow enough to affect it.

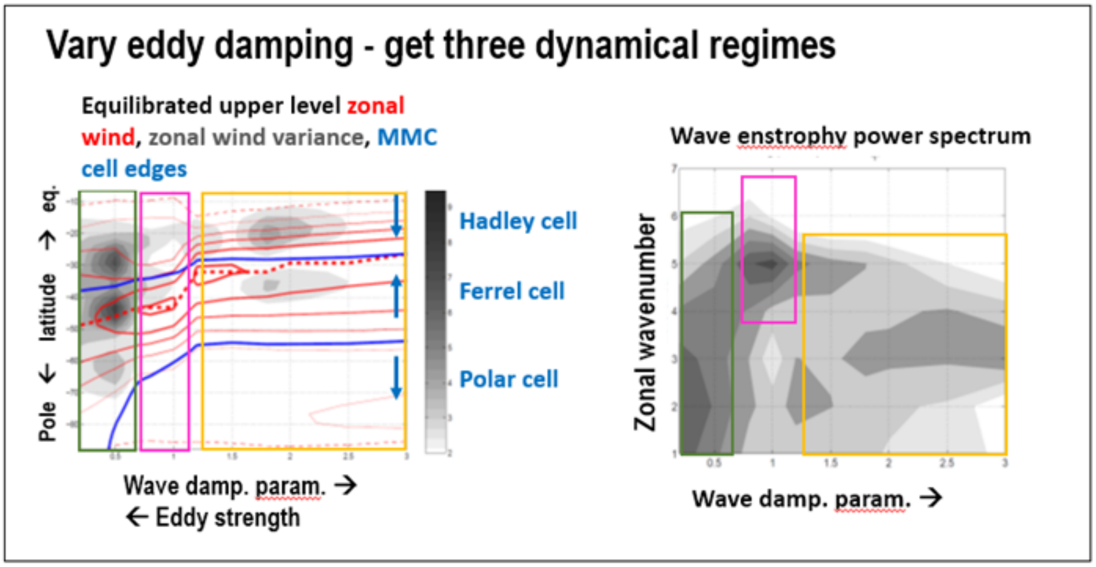

Figure: Upper level equilibrated fields, as a function of the wave damping parameter, with low damping/strong eddies on the left. Shown are: Left- the variation with latitude of zonal mean wind (red contours, dashed line marks the jet axis), zonal wind variance (gray shading) and the lines of zero meridional wind (blue, edges of Hadley and Ferrel cells). Right- the wave enstrophy power spectrum as a function of zonal wavelength.

The structure of upper level PV gradients differs considerably for the subtropical jet compared to the other jet regimes, while the lower level PV gradients hardly change between the different runs:

In the Eddy driven jet and Merged jet regimes the upper level PV gradients are in mid latitudes, above a region where the surface meridional PV gradients are negative. This allows efficient baroclinic eddy growth.

In the Subtropical jet regime, the upper level PV gradients shift with the jet to the subtropics, equatorwards of the region of negative surface meridional PV gradients. This makes baroclinic growth of eddies inefficient. In fact, the fastest growing modes are weakly unstable high latitude modes, which are far enough from the subtropical jet to not affect it.

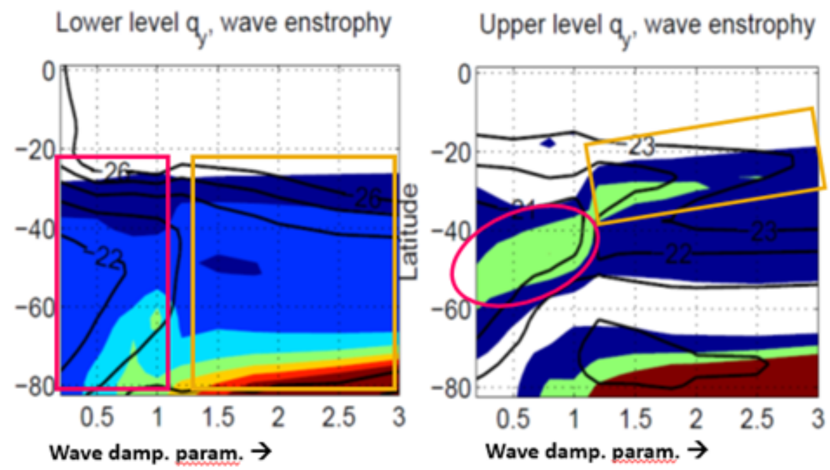

Figure: Left: The magnitude of equilibrated lower level meridional PV gradients (colors) and wave enstrophy (contours) as a function of latitude and the wave damping parameter. Only regions where the PV gradients are of negative are shaded. Right- as in the left plot but for the upper level, with regions of positive PV gradients above a certain positive threshold are shaded.