A multi-wave model for the Quasi-Biennial Oscillation: Plumb’s model extended

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In the Earth’s stratosphere, equatorial zonal winds reverse from easterlies to westerlies with a period of roughly 28 months. This phenomenon, known as Quasi-Biennial Oscillation (QBO), is driven by internal gravity waves (IGWs) propagating in the stratosphere and interacting with the ambient large-scale flow. Those waves are generated by the turbulent motions of the troposphere.

In 1977, an idealised model describing the generation of a reversing large-scale flow by two counter-propagating monochromatic internal gravity waves was developed by Plumb [1]. In 1978, the famous Plumb & McEwan’s experiment [2] validated this model using oscillating membranes to force a standing wave pattern at the boundary of a linearly stratified salty-water layer in a cylindrical shell container.

Recently, the effects of the wave dissipation and wave energy were studied by Renaud et al. [3] using the Plumb model in order to explain the QBO disruption observed in 2016. It was found that as the Reynolds number increases, bifurcations from periodic to non-periodic regimes are seen for the large-scale flow oscillations.

Here, we present the results obtained from an extended version of the Plumb’s model, taking into account the stochastic generation of IGWs in Nature. Our new model includes a wide spectrum of waves as forcing for the large-scale flow. A gaussian distribution of energy is used in order to compare monochromatic forcing results (characterised by a gaussian energy spectrum with a small standard deviation) with multi-wave forcing results (large standard deviation). Unexpectedly, we find that in a large parameter domain, gathering the energy of the forcing into one frequency results in non-periodic oscillations for the QBO while spreading the same amount of energy among many frequencies results in periodic oscillations. We also investigate more realistic distribution of energy for the forcing including classical convective spectra, with or without rotation. We find that different forcings result in very similar reversals. This result is quite relevant for Global Circulation Models (GCMs) where internal gravity waves are parameterised in order to drive a realistic QBO. However, our study suggests that driving a QBO with realistic characteristics (amplitude, period) does not involve that the input forcing (i.e. the wave spectrum characteristics) is realistic as well.

References:
