Revisiting the Quasi-Biennial Oscillation (QBO)

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Introduction

The Quasi-Biennial Oscillation (QBO) is revisited using ERA5 reanalysis dataset. The covering 40-year period (1979 to 2018) includes 18 QBO cycles. The zonal-mean acceleration due to the stratospheric waves is calculated within the framework of the transformed Eulerian-mean (TEM) equation:
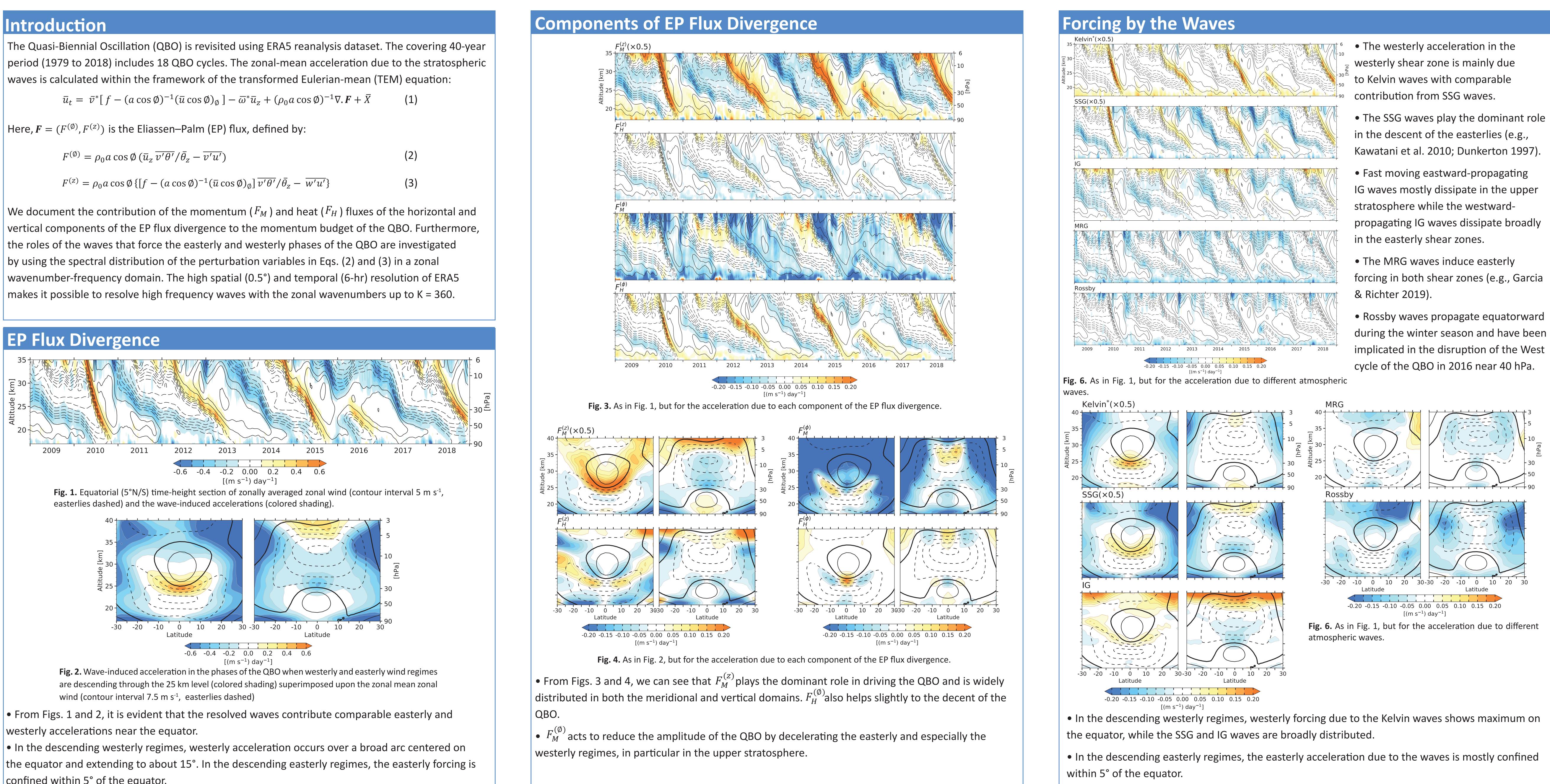
$$\bar{u}_t = \bar{v}^*[f - (a\cos\emptyset)^{-1}(\bar{u}\cos\emptyset)_\emptyset] - \bar{\omega}^*\bar{u}_z + (\rho_0 a\cos\emptyset)^{-1}\nabla\cdot\mathbf{F} + \bar{X} \quad (1)$$

Here, $\mathbf{F} = (F^{(\emptyset)}, F^{(z)})$ is the Eliassen–Palm (EP) flux, defined by:

$$F^{(\emptyset)} = \rho_0 a\cos\emptyset\,(\bar{u}_z\,\overline{v'\theta'}/\bar{\theta}_z - \overline{v'u'}) \quad (2)$$

$$F^{(z)} = \rho_0 a\cos\emptyset\,\{[f - (a\cos\emptyset)^{-1}(\bar{u}\cos\emptyset)_\emptyset]\,\overline{v'\theta'}/\bar{\theta}_z - \overline{w'u'}\} \quad (3)$$

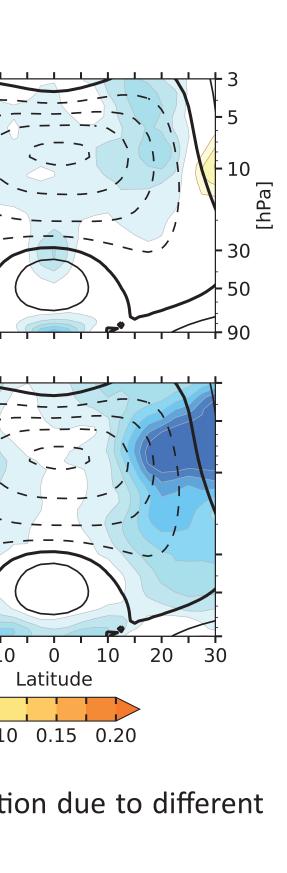We document the contribution of the momentum (F_M) and heat (F_H) fluxes of the horizontal and vertical components of the EP flux divergence to the momentum budget of the QBO. Furthermore, the roles of the waves that force the easterly and westerly phases of the QBO are investigated by using the spectral distribution of the perturbation variables in Eqs. (2) and (3) in a zonal wavenumber-frequency domain. The high spatial (0.5°) and temporal (6-hr) resolution of ERA5 makes it possible to resolve high frequency waves with the zonal wavenumbers up to K = 360.

EP Flux Divergence

Fig. 1. Equatorial (5°N/S) time-height section of zonally averaged zonal wind (contour interval 5 m s⁻¹, easterlies dashed) and the wave-induced accelerations (colored shading).

Fig. 2. Wave-induced acceleration in the phases of the QBO when westerly and easterly wind regimes are descending through the 25 km level (colored shading) superimposed upon the zonal mean zonal wind (contour interval 7.5 m s⁻¹, easterlies dashed)

• From Figs. 1 and 2, it is evident that the resolved waves contribute comparable easterly and westerly accelerations near the equator.
• In the descending westerly regimes, westerly acceleration occurs over a broad arc centered on the equator and extending to about 15°. In the descending easterly regimes, the easterly forcing is confined within 5° of the equator.

Components of EP Flux Divergence

Fig. 3. As in Fig. 1, but for the acceleration due to each component of the EP flux divergence.

Fig. 4. As in Fig. 2, but for the acceleration due to each component of the EP flux divergence.

• From Figs. 3 and 4, we can see that $F_M^{(z)}$ plays the dominant role in driving the QBO and is widely distributed in both the meridional and vertical domains. $F_H^{(\emptyset)}$ also helps slightly to the decent of the QBO.

• $F_M^{(\emptyset)}$ acts to reduce the amplitude of the QBO by decelerating the easterly and especially the westerly regimes, in particular in the upper stratosphere.

Forcing by the Waves

Fig. 6. As in Fig. 1, but for the acceleration due to different atmospheric waves.

• The westerly acceleration in the westerly shear zone is mainly due to Kelvin waves with comparable contribution from SSG waves.

• The SSG waves play the dominant role in the descent of the easterlies (e.g., Kawatani et al. 2010; Dunkerton 1997).

• Fast moving eastward-propagating IG waves mostly dissipate in the upper stratosphere while the westward-propagating IG waves dissipate broadly in the easterly shear zones.

• The MRG waves induce easterly forcing in both shear zones (e.g., Garcia & Richter 2019).

• Rossby waves propagate equatorward during the winter season and have been implicated in the disruption of the West cycle of the QBO in 2016 near 40 hPa.

Fig. 6. As in Fig. 1, but for the acceleration due to different atmospheric waves.

• In the descending westerly regimes, westerly forcing due to the Kelvin waves shows maximum on the equator, while the SSG and IG waves are broadly distributed.

• In the descending easterly regimes, the easterly acceleration due to the waves is mostly confined within 5° of the equator.

Take-Home Messages

• Among the four components of the EP flux, $F_M^{(z)}$ plays the dominant role in the accelerations that attend the descent of both easterly and westerly regimes of the QBO.

• The acceleration due to the resolved waves is proportional in the easterly and westerly shear zones. About half of the westerly acceleration is due to the Kelvin waves. Small-scale gravity (SSG) waves with wavelengths less than 2000 km produce comparable forcing in the shear zones and are responsible for the descent of easterly regimes.

• Laterally propagating planetary-scale Rossby waves from the winter stratosphere enter the tropics and induce easterly accelerations in the flanks of the easterlies, where they meet their critical lines.

Acknowledgment

References

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Table 1. The spectral distribution of the waves.

wave	wavenumber	frequency (cycle day⁻¹)
Kelvin⁺	1 ≤ K ≤ 20	ω < 0.4
small-scale gravity (SSG)	|K| > 20	-
inertio-gravity (IG)	|K| ≤ 20	ω ≥ 0.4
mixed Rossby-gravity (MRG)	-20 ≤ K ≤ 0	0.1 < ω < 0.4
Rossby	-20 ≤ K ≤ 0	ω ≤ 0.1