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Influence of the abnormal QBO feature during 2015-2016 on the Earth rotation rate

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Introduction

Since the 90's it is very well known that the coupled phenomenon the El Niño-Southern-Oscillation (ENSO) involves a large inter-annual variation on Earth's rotation rate. Moreover, ENSO was also linked to the stratospheric event known as the Quasi-Biennial Oscillation (QBO) and several authors during the last 30 years claim for the influence of QBO effects on the Earth rotation rate superposed to ENSO.

Recently, an anomalous feature in the QBO occurred during the Northern Hemisphere winter of 2015-2016 (Newman et al., 2016). According to the authors, this abnormal feature is for the first time observed since 1980. Afterwards, Barton & McCormack (2017) linked this QBO feature with the last ENSO phenomenon 2015-2016, that turned out to be one of the strongest ENSO events registered.

The purpose of this work is to investigate the influence of the stratospheric QBO anomaly detected during the very strong El Niño event 2015-2016 on the observed Earth rotation rate and the associated AAM.

Comparison of LOD with atmospheric excitation: Results

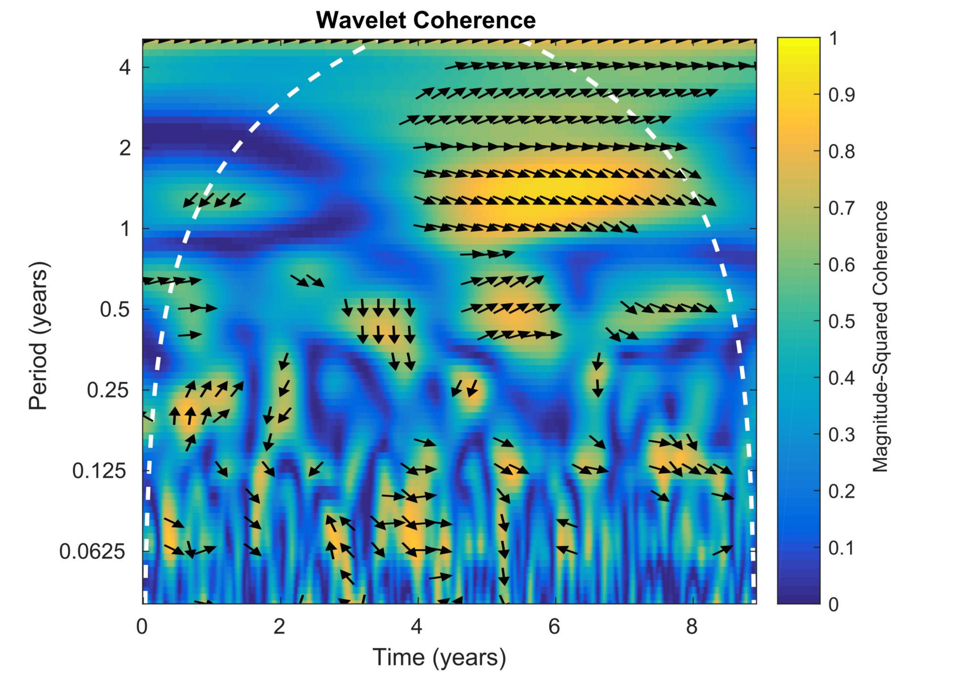


Figure 1 Wavelet coherence between SQBO (AAM computed between 100hPa and 1hPa.) and LOD. X-axis: time in years since 2010. Arrows refer to the phase lag.

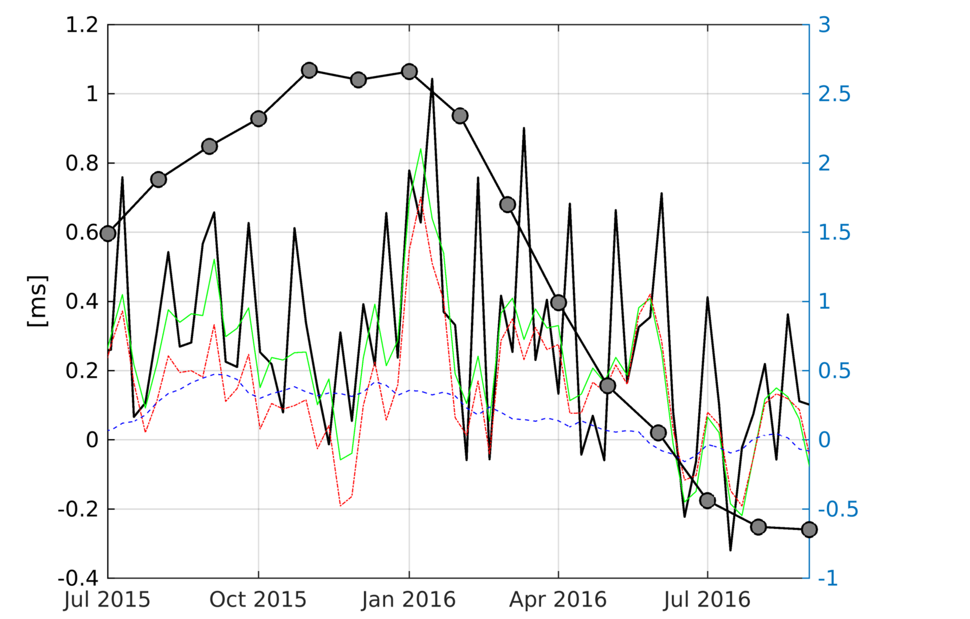


Figure 2 Time series of weekly LOD (Black, thick line), Total AAM (Green); AAM TQBO (red dashed dotted line) and AAM SQBO (blue dashed line) during the ENSO (2015-16) event. Monthly Niño 3.4 index (gray dots, right axis) is superimposed.

According to Abarca del Rio et al., (2000) there is a QBO signal in the troposphere (TQBO) linked to the Southern Oscillation. The authors asseverated that both QBO signals, SQBO and TQBO, are linked from waves vertically propagating in the atmosphere and they are unrelated but during ENSO when they are in phase.

From **Figure 1**, the wavelet coherence plot shows that the abnormal stratospheric feature is detected in 2015 and it is in phase with respect to ΔLOD. You can also see that this good coherence remains up to 2018.

From **Figure 2**, you can see a small time lag (10-20 days) between total AAM and LOD. This feature was already reported in earlier papers. Moreover, it is shown that SQBO is not intense enough. Thus, the atypical variability in zonal winds could not excite distinguishable LOD variations. On the other hand, TQBO explains a large part of the total AAM.

The QBO abnormal feature

The Quasi-Biennial Oscillation (QBO) is a stratospheric event in the tropical lower stratosphere (about 18–30 km in altitude) that controls the zonal mean wind variability and changes the downward descending easterly and westerly zonal winds with an approximate period of 28 months (Baldwin et al., 2001).

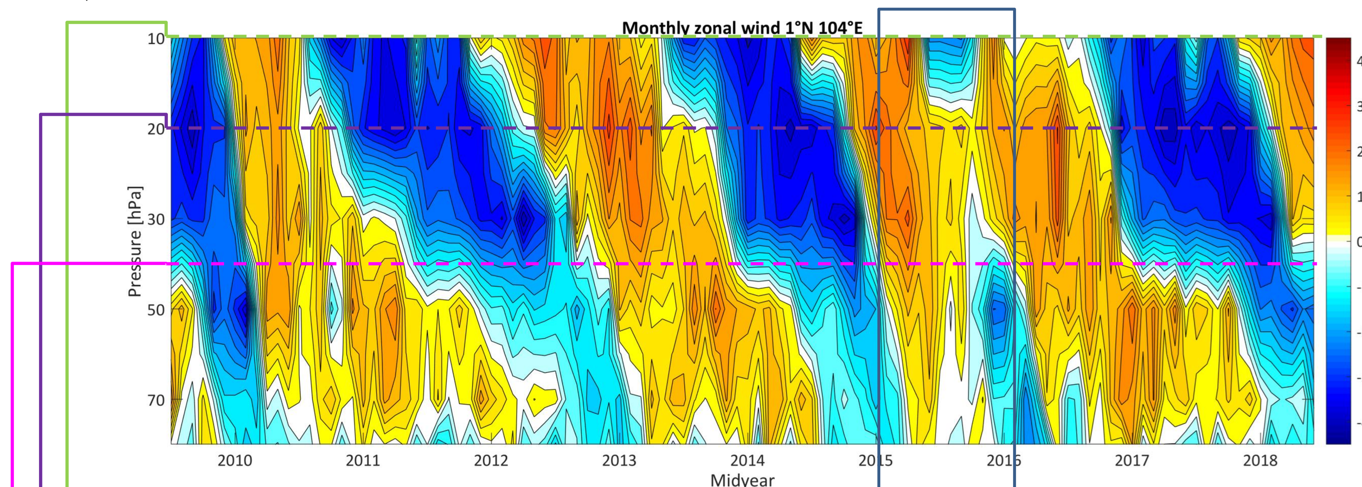


Figure 3 Time series of zonal mean wind velocities between 70 hPa. and 10 hPa. at Singapore (1° N, 104° E). Data source: ECMWF operational analysis.

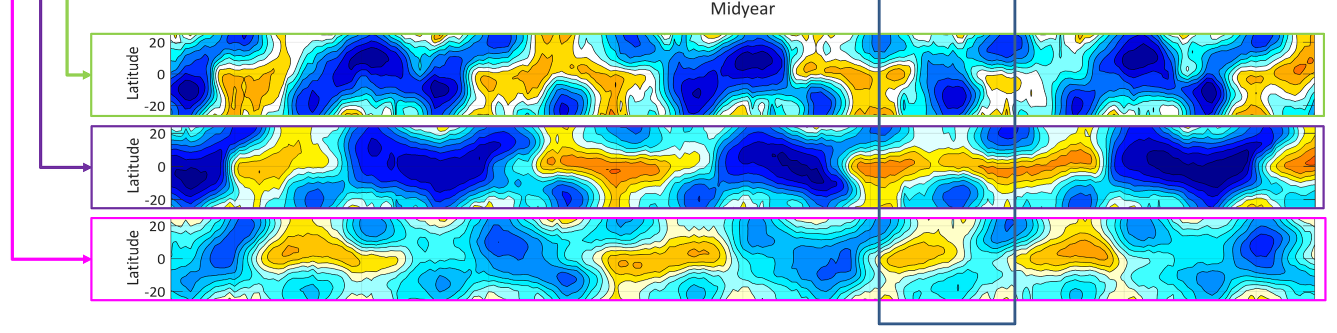


Figure 4 Mean zonal winds at 10, 20 and 40 hPa. Time axes and colorbar as of Figure 3.

During the transition from 2015 to 2016 the expected downward propagation of the westerly phase was modified and there was an anomalous upward displacement from~30 hPa to 15 hPa. These westerlies interrupt the easterly phase downward propagation that developed at 10 hPa at the end of 2015. The QBO disruption was deduced by Newman et al. (2016), mainly from radiosonde data.

Data and methods

We used the Atmospheric Angular Momentum (AAM) approach: considering that the angular momentum of the system Earth is conserved, we estimated the Earth rotation change. In this case: the change in the angular velocity of the Earth with respect to an inertial frame (the variation to the Length-Of-Day, ΔLOD).

Following Gross (2007), from the linearized Liouville equations, the changes in the LOD induced by the AAM variations are:

$$\Delta LOD\ (t) = \frac{0.997}{C_m\, \Omega}\left[h_z(t) + 0.75\, \Omega\, \Delta I_{zz}(t)\right]\mathrm{LOD}_0$$

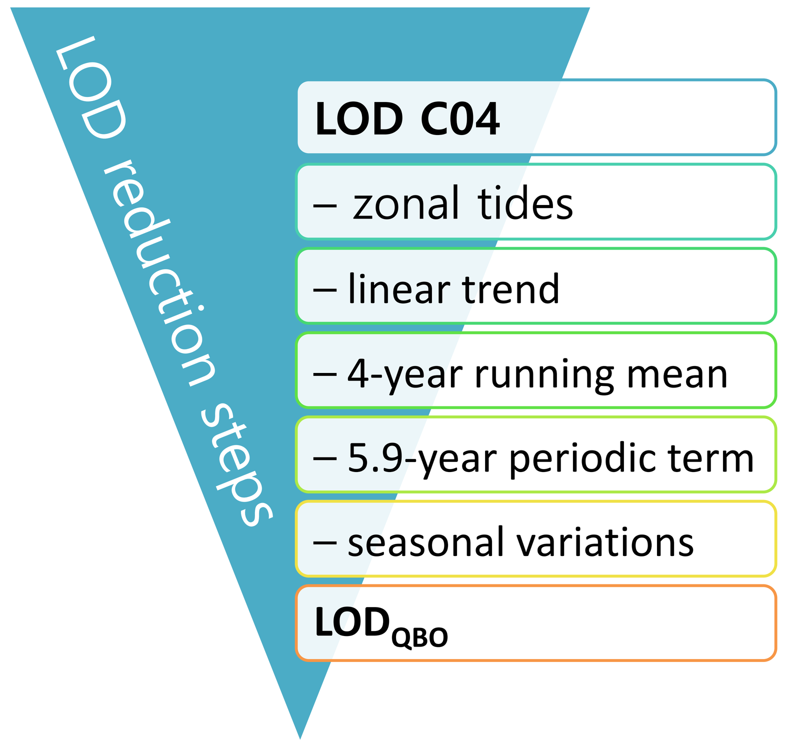
where

$C_m = 7.11236\ \times 10^{37}\ kg\ m^2$	$\Omega = 7.292115\ \times\ 10^{-5}\ rad/seg$
h_z : z-component motion term	ΔI_{zz}: z-component mass term
LOD_0 is the nominal length of the solar day (86400 seconds).	

LOD series were taken from the International Earth Rotation and Reference System Service (IERS) Earth Orientation Parameters (EOP) 14 C04 series. This multi-technique combined series is publicly available at the IERS Earth Orientation Center web site (https://datacenter.iers.org/eop.php).

The AAM employed for this study were determined from the operational analysis of the European Centre for Medium-Range Weather Forecasts (ECMWF). Mass and motion terms were calculated as volume integrals over pressure increments as described in Schindelegger et al. (2011).

Several AAM data series were computed from different pressure limits. Thus, the QBO contribution is divided into two: Tropospheric Quasi-Biennial Oscillation (TQBO) between 1000 hPa and 100 hPa and Stratospheric Quasi-Biennial Oscillation (SQBO) between 100hPa and 1hPa. The abnormal feature in zonal winds is expected to affect the SQBO.



To analyze and study the atmospheric effect of ENSO and QBO event 2015-16 on LOD, we considered the period 2010-2019. Data was evenly spaced, taking one sample every 7 days. The LOD series was processed to remove the effects of zonal tides, secular tidal breaking, post-glacial rebound and variations in the fluid core angular momentum (Lambert et al., 2017), as well as seasonal variations (annual and semi-annual). These reduction steps are summarized schematically in Figure 4. The 5.9-year periodic function was estimated from a longer LOD time series (1962-2019).

A wavelet coherence analysis was performed. The advantage of this technique is its simultaneous localization in time and in frequency domain.

If $C_x(a,b)$ and $C_y(a,b)$ are the continuous wavelet transform of the x and y signals at scales a and position b and * indicates the complex conjugate, then

$$WaveCoh_{xy}(x,y) = \frac{\left|C_x^*(a,b)\ C_y(a,b)\right|^2}{\left|C_x(a,b)\right|^2\left|C_y(a,b)\right|^2}$$

Discussion

De Viron and Dickey (2014) studied the different types of ENSO (EP, eastern Pacific and CP, central Pacific) and their influence on LOD variations. They conclude that the EP kind of ENSO is more than twice as large as CP and that explains the different impact of the ENSO events on Earth rotation. Lambert et al, (2017) also study this particular ENSO (2015-16). They ascertain that although the three extreme ENSO events (1982-83, 1997-98 and 2015-16) produced comparable answers in LOD excitations (near 1 ms.), the ENSO 2015-16 is a mix kind EP-CP. The unusual ENSO 2015-16 episode was also accompanied by another important stratospheric feature, such as the earliest Stratospheric Final Warming (SFW, reversal of the stratospheric circulation that marks the end of the winter season) in decades (Palmeiro et al, 2017).

Although this preliminary results indicate that the SQBO excitation is not powerful enough to justify the observed LOD anomalies, the TQBO does. Thus, the nature of the vertical propagation link between troposphere and stratosphere during ENSO events could be studied in more detail also taking into account the zonal behavior of this link.

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