INFLUENCE OF THE 2015-2016 ENSO EVENT ON LENGTH-OF-DAY VARIATIONS

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ABSTRACT. Since the 1980's it is very well known that the El Niño Southern Oscillation (ENSO) event involves a large atmospheric excitation that induces changes of the Earth rotation rate at inter annual scales. In return, ENSO is the trigger of atmospheric teleconnections affecting the global atmospheric circulation. In this work we analyze the regional behavior of the anomalies in the motion terms of the axial component of the Atmospheric Angular Momentum (AAM) taking into account the teleconnections between the ENSO 2015-16 event and other expected regional phenomena. In this way we attempt to confirm previous results that classify this ENSO episode as mixed behavior (i.e. EP and CP type of El Nio).

1. INTRODUCTION.

The austral summer 2015-2016 was unusual and particularly active for the Pacific ocean and the tropical Pacific atmosphere. An El Niño event took place and it has been recorded as one of the most intense (Lambert et al., 2017). Moreover, almost simultaneously, there was an anomaly in the stratospheric Quasi Biennial Oscillation (QBO) (Newman et al. 2016).

ENSO is defined as the most conspicuous interannual variability of the Earths climate system (Yeh et al., 2018). During the canonical El Niño (EN) conditions the easterly trade winds are weakened and the westerly winds increases and as a result the surface of the tropical Pacific ocean gets warmer than usual. Consequently, this effect is linked with the raise in the wind terms (also called motion terms) of the AAM causing that the rotation of the Earth becomes slower and the length-of-day (LOD) increases (Chao, 1989, Dickey et al, 2007). On the opposite, during La Niña (LN) the easterly winds blow stronger than normal in the tropical Pacific resulting in a lower than normal Sea Surface Temperature (SST) over the area (Yeh et al., 2018). This event is then related with an acceleration in the speed of the Earth's rotation, i. e. a shortening of LOD (de Viron and Dickey, 2014).

Since 2005 several studies (see Ren and Jin, 2011 for a brief) addressed the existence of two types of EN that can be classified according to the resultant interaction with the tropical Pacific ocean: the Eastern Pacific (EP) and the Central Pacific (CP) type.

During an EP type El Niño the atmospheric pressure gradient is caused by the high pressure system present over the eastern Pacific Ocean and a low pressure system over Indonesia. This causes that the tropical Pacific ocean interacts with the atmospheric Walker circulation. The EP events were the first characterized and therefore named "canonical El Niño".

In a Central Pacific type event the Pacific Ocean interacts with the Hadley circulation. As a result the air rising near the Equator, flows poleward at a height of 10-15 kilometers and descends about 30° latitude, returning then equatorwards near the surface. This CP type of EN event is also named a El Niño Modoki or Dateline El Niño.

On the other hand, the QBO is an 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).

Since the 80s (see Gross, 2007 and references therein) it is very well known that ENSO excites noticeable interannual variations on LOD and these are caused by changes in the AM of the zonal winds. Besides that, Dickey et al. (1994) studied the ENSO 1982-83 and analyzed a stratospheric AAM time series obtained by integrating (100-50 mbar) data from numerical weather models. The authors asseverate that the wind terms of the stratospheric AAM account for about 20 % of the LOD variance relative to the atmosphere below 100 mbar. More recently Zhou et al. (2008) not only confirmed that the wind terms dominate the intraseasonal variation of the Earth rotation but also confirmed that the stratospheric wind contribution is just about 20 % of the tropospheric AAM wind term.

Recently some authors had linked the stratospheric QBO with ENSO although these links are neither direct nor linear. In 2017, Barton and McCormack linked the abnormal QBO 2015-16 with the ENSO phenomenon 2015-2016, that turned out to be one of the strongest events registered. One year before Newman et al. (2016) reported the anomalous feature in the QBO during the Northern Hemisphere winter of 2015-2016. The expected downward propagation of the westerly phase of the stratospheric winds was modified and there was an anomalous upward displacement from 30 hPa to 15 hPa. This happened in QBO for the first time since 1980.

In view of the above, we recently investigated the influence of the QBO anomaly detected during the El Niño event 2015-2016 on the observed Earth rotation rate and the associated AAM (Fernandez and Bhm, 2019). The results indicated that, even taking into account this anomaly, the stratospheric contribution remains not powerful enough to justify the LOD anomalies but the tropospheric contribution of the combined ENSO effect does, as expected.

On the other hand, De Viron and Dickey (2014) studied the different types of ENSO (EP and CP) 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) asseverated 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.

In this study we seek to regionally characterize the contributions of the anomalies in the atmospheric angular momentum and its relationship with the teleconnections triggered by the ENSO 2015-16 event, taking into account that these connections are different depending on whether it is an EP or a CP event.

2. DATA AND METHOD.

In order to characterize the ENSO 2015-16 event we used the indexes ONI, N3 and N4. They are provided by the Earth System Research Laboratory of the NOAA Climate Prediction Center (`https://www.cpc.ncep.noaa.gov/data/indices/`).

Table 1: The Oceanic Niño Index (ONI) provided by the Climate Prediction Center (CPC), National Weather Service, USA. Values are computed as a 3-month running mean of SST anomalies in the Niño 3.4 region.

Year	**DJF**	**JFM**	**FMA**	**MAM**	**AMJ**	**MJJ**	**JJA**	**JAS**	**ASO**	**SON**	**OND**	**NDJ**
2015	0.6	0.6	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.5	2.6
2016	2.5	2.2	1.7	1.0	0.5	0.0	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6

The Oceanic Niño Index (ONI) is used to identify and distinguish El Niño (warm) and La Niña (cool) events in the tropical Pacific. It is the running 3-month mean Sea Surface Temperature anomaly for the Niño 3.4 region (5°N5°S, 170°-120°W) (Kousky and Higgins, 2007). In general, El Niño is characterized by a positive ONI greater than or equal to +0.5°C while La Niña events have a negative ONI less than or equal to -0.5°C.

El Niño 3 (N3) and El Niño 4 (N4) indexes correspond to the values of the SST at the Nio 3 (5°N-5°S, 150°-90°W) and Nio 4 (5°N-5°S, 160°E-150°W) areas respectively. By using N3 and N4, one could built NCP and NEP (Ren and Jin, 2011) from which we can discern if it is an EP or CP El Niño event.

$$\begin{aligned} NEP &= N3 - \alpha N4 \\ NCP &= N4 - \alpha N3 \end{aligned} \tag{1}$$

where

$$\alpha = \begin{cases} 2/5 & \\ 0 & \text{if } N3.N4 < 0 \end{cases}$$

In this study we used the Atmospheric Angular Momentum approach, it means that if 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, LOD).

The AAM employed for this study was computed by using data 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).

The axial components of the AAM can be written as:

$$AAM_z^{motion} = \int_0^{P^{surf}} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_0^{2\pi} \frac{r(\theta,\lambda)^3}{g}\, u(P,\theta,\lambda)\, cos^2(\theta)\, d\lambda\, d\theta\, dP \tag{2}$$

$$AAM_z^{mass} = \int_0^{P^{surf}} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_0^{2\pi} \frac{r(\theta,\lambda)^4}{g} cos^3(\theta)\, d\lambda\, d\theta\, dP \tag{3}$$

Let's call $Z(i,j,t)$ to the elements of AAM $_z^{motion}$ after performing the vertical integration from surface till ∞. Then,

$$\overline{Z(i,j)}^A = \sum_{t_A} \frac{Z(i,j)}{N_A} \tag{4}$$

where A = EN (El Niño), LN (La Niña) or N (Neutral); t_A and N_A refer to time and number of values, respectively. Moreover, g is the mean gravity acceleration, θ and λ refers to latitude and longitude; P is the atmospheric pressure and u are the zonal wind velocities.

Thus, the elements of the mean AAM $_z^{motion}$ anomalies are

$$\begin{aligned} \Delta Z^{EN}(i,j) &= \overline{Z}^{EN}(i,j) - \overline{Z}^{N}(i,j) \\ \Delta Z^{LN}(i,j) &= \overline{Z}^{LN}(i,j) - \overline{Z}^{N}(i,j) \end{aligned} \tag{5}$$

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`).

LOD data (2010-2019) was evenly spaced, taking one sample every 7 days. Then, the time 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). Finally, a 5.9-year periodic function was estimated from a longer LOD time series (1962-2019) and removed. The resultant LOD time series is named as LOD ENSO.

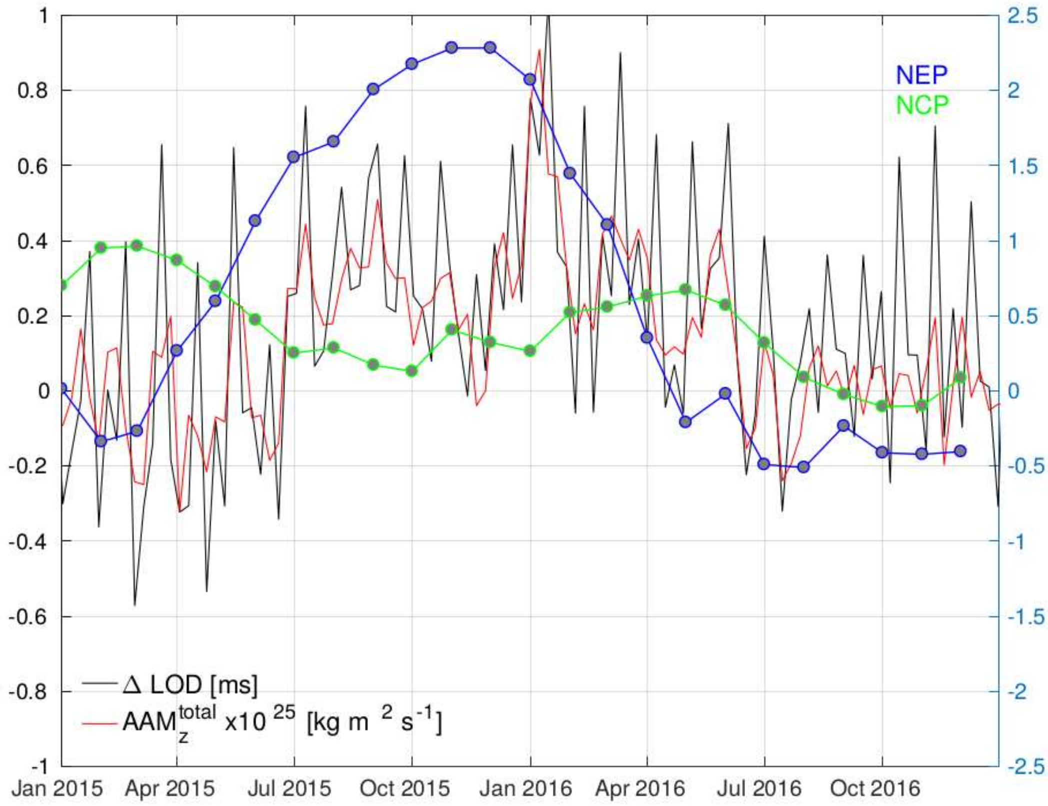

Figure 1: LOD ENSO along with AAMz, the NEP and NCP anomalies.

3. RESULTS

Figure 1 shows the detrended length-of-day time series (LOD ENSO) along with AAMz, and the EP and CP anomalies as defined by Ren and Jin (2011) for the period 2015-2016. Notice that a value of NEP is almost 5 times larger than NCP during austral summer (maximum of ENSO 2015-16). We can also see that NEP is the biggest and NCP values are less than 0.5 during the austral summer 15-16. Notice that, from Ren and Jin (2011), during a CP event NEP < 0.5. These results emphasize the behavior of an El Niño canonical event.

Figure 2 shows the AAM $_z^{motion}$ anomalies computed from Eq. (5) for the period t_{EN} = Jan 1, 2015- May 1, 2016 (top) along with the AAM $_z^{motion}$ anomalies for the period t_{LN} = Aug 2, 2016-Dec 31, 2016 (bottom). The correspondent periods for El Niño and La Niña were considered in agreement to the values of ONI (see Table 1). May 2, 2016- Aug 1, 2016 is the neutral period.

From Figure 2 (top) the time averages of the axial AAM wind anomalies during El Niño shows intense activity in Indonesia, North and South Atlantic ocean at mid latitudes and at the North Pacific ocean including North Eurasia and partially North America. Most of these events are expected as ENSO teleconnections without distinguishing between EP or CP El Niño (Yeh et al., 2018). Focusing in the North Pacific this could be the result of the ENSO-like atmosphere-ocean interactions linked to SST anomalies. Although such SST variabilities have a decadal timescale (Pacific Decadal Oscillation, PDO; Interdecadal Pacific Oscillation, IPO), both effects (ENSO and

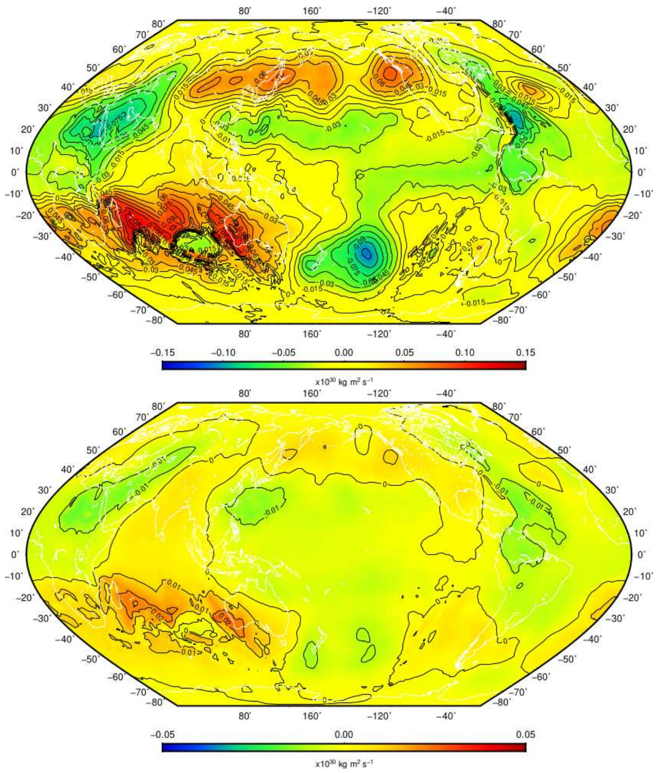

Figure 2: AAM $_z^{motion}$ anomalies during El Niño (top) and La Niña (bottom).

PDO/IPO) can be in phase or out of phase in association with the connection between atmospheric effects around the Pacific basin (Yeh et al., 2018). At last, the results in the Atlantic and Indian oceans also come from variabilities in the SST although they have another explanation. In figure 2 (bottom) we can see the axial AAM wind anomalies during La Niña. Notice that the scale is 1/3 smaller than the previous one. Here we can corroborate that there is not significant activity in AAM from the winds during La Niña.

The secondary effects of the teleconnections are in precipitation and temperature changes recorded in different parts of the planet. Because such effects are different depending on whether it is a EP or CP type of El Niño, we emphasize that our conclusions are preliminary and much work still needs to be done.

4. DISCUSSION

ENSO 2015-16 has been recorded as one of the three extreme events (Lambert et al., 2017), but the literature does not converge when classifying it as clearly defined as EP type (e.g. see Palmiero et al., 2017). Effectively, the recent work of Lambert et al., (2017) specifically studied the influence of the atmospheric torques on Earth rotation for the ENSO 15-16 concluding that it contradicts the expected behavior of the mountain torque for an intense EP type El Ninõ. ENSO has been shown to have a strong impact on different parts of the planet through atmospheric teleconnections. Such teleconnections are sensitive to the longitudes and different according to the type of EN (Yeh et al., 2018). According to the same authors, such connections involve changes in the regional pattern of surface temperature, precipitation and atmospheric circulation outside the tropical Pacific, more specifically, on the North Pacific, the Indian and the Atlantic Ocean.

Provided that we are analyzing the axial component of the motion terms of the AAM, we should carefully study and characterize the resultant effect of such teleconnections on the atmospheric winds (atmospheric circulation, tropical cyclone activity, etc.) for well-known EP and CP El Niño events.

Because these preliminary results are not conclusive some more work has to be done. Our next steps will include an analysis of the differences between the teleconnections for some other EP and CP events from global meteorological parameters, understanding their impact on the conservation of the Earth's total angular momentum.

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