THE NATURAL FACTORS AFFECTING OZONE: A CORRELATION ANALYSIS IN LONG-TERM SERIES

Arianna Religi[1], Bianca Mezzina[2], Oindrila Nath[3] and Carol Ordoñez-Aquino[4]

[1]University of Geneva, Geneva, Switzerland,
[2]University of Barcelona/Barcelona,
[3]National Atmospheric Research Laboratory, ISRO, India,
[4] Service of Meteorology and Hydrology in Perú, Lima, Perú

1. Introduction

Ozone is a greenhouse gas which has a large impact in various ways on people, both directly and indirectly. Availability of long-term datasets from space-borne and ground-based measurements has made the study of ozone variability popular among atmospheric science community. There are several natural as well as anthropogenic factors that affect the ozone trend. In this current study we have attempted to investigate the response of ozone to several natural factors, i.e. El Niño Southern Oscillation (ENSO), the 11-year Solar Cycle, the Quasi-biennial Oscillation (QBO), and volcanic aerosols for available total ozone column data. The 11-year solar cycle produces changes in stratospheric ozone. An increase in solar ultraviolet radiation during the maximum phase of the solar cycle increases ozone by 2.4-3%, compared to the annual mean value. ENSO is a natural oscillation in the tropical Pacific Ocean and atmosphere, involving variations in sea surface temperature, sea-level pressure, atmospheric circulation, and much more. With an irregular cycle of about 2-7 years, it represents the most important mode of interannual climate variability, with impacts extending to remote regions of the world. The QBO is a dominant feature of the equatorial lower stratosphere, consisting of an extremely regular oscillation from westerly to easterly winds, with a period of about 28 months; these changes in circulation regimes are due to the downward propagation of bands of alternate zonal winds from the top of the lower stratosphere to the tropopause. The QBO can affect global stratospheric circulation and it has been shown to modify the stratospheric poleward transport of ozone, influencing its interannual variability both in the tropics and in the mid-latitudes; in fact, about 2-3% of the total interannual variability of ozone appears to be related to the QBO (Staehlin, 2001; SPARC CCMVal Report, 2010). Two major volcanic eruptions were El Chichón (Mexico, March 1982), when solar radiation reaching terrestrial surface was reduced by 3-4% and Mount Pinatubo (Philippines, June 1991), whose explosion generated gases and particles that reached heights between 30-35 km, altering the natural chemical processes of the atmosphere.

2. Datasets

Total ozone column (TOC) data used in this study contain ground-based annual mean total ozone anomalies from 1964-2014 for tropical regions (20°S-20°N) and a near-global average (60°S-60°N). The data were obtained from the Network for the Detection of Atmospheric Composition Change (NDACC) Brewer-Dobson Spectrometer sites (WMO, 2014). Anomalies were computed from monthly zonal mean total ozone data by subtracting the annual cycle from the period 1998–2008 because this period was considered quite stable (it is long enough to cover one solar cycle, ozone level was fairly constant, and no major volcanic eruption occurred). ENSO, QBO, solar cycle, and volcanic eruption proxies are taken from available datasets online [solar cycle: F 10.7 flux (ftp://ftp.geolab.nrcan.gc.ca/data/solar_flux/monthly_averages/maver.txt), ENSO: Niño3.4 index from NOAA, QBO: Free University of Berlin and Volcanic eruption: percentage transmission (WMO report, 2014)].

3. Results and Discussion

Figure 1 shows TOC anomalies which clearly decline from the early 1980s to the mid-1990s, and thereafter there is a slow recovery phase. Since 2000, observed TOC fluctuates around an overall constant level. Figure 2 clearly shows the recent periods of solar maximum and minimum whereas Figure 3, Figure 4, and Figure 5 depict the aerosol proxy, Niño 3.4 index, and zonal wind at 30 hPa, respectively.

When computing the correlation with the ozone time series negative, non-negligible values are obtained, with almost double the amplitude for the tropical ozone time series compared to the near-global average (-0.33 vs. -0.12; see Table1). The negative sign of the correlation agrees with the idea that a positive (warm) ENSO is associated with increased ascending motions in the tropical stratosphere and an enhanced Brewer-Dobson circulation; thus, more ozone is transported from tropical regions towards higher latitudes, where the increased descent leads to ozone accumulation in the lower polar stratosphere (Cagnazzo et al., 2010). However, other processes linked to ENSO may also influence the tropical column ozone, such as variations in the tropical tropopause height and other local effects. The smaller correlation value obtained when considering the 60°S-60°N belt is probably due to the two opposite responses in the tropics and mid-/high latitudes, both concurring in the resulting value. In the case of the QBO a large, positive correlation (0.52; see Table1) is obtained for the tropical band, comparable with the solar cycle: this is in agreement with several studies indicating that the QBO is the dominant factor in ozone variability at the equator (Baldwin et al., 2001). For the other near-global average the value is opposite in sign and rather small (-0.14), an interesting feature that may be related to a more complex response in the extra-tropics both temporally and spatially (Baldwin et al., 2001). As expected, a positive correlation between solar cycle and ozone in both the latitude ranges indicates the production of more ozone when there is higher solar insolation. Two large volcanic eruptions in the last century (El Chichón in 1982 and Mt Pinatubo in 1991) temporarily decreased solar transmission (Figure 3). Volcanic particles increase ozone depletion for a few years before they are removed from the stratosphere by gravitational settling and large-scale atmospheric transport. Therefore, volcanic eruption cannot be the only cause of the continuous long-term decrease in global ozone.

4. References

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Table 1

	Solar Cycle	QBO	ENSO	Volcano
TCO (20°S-20°N)	0.48	0.52	-0.33	0.24

Table 2

	Solar Cycle	QBO	ENSO	Volcano
TCO (60°S-60°N)	0.60	-0.14	-0.12	-0.04

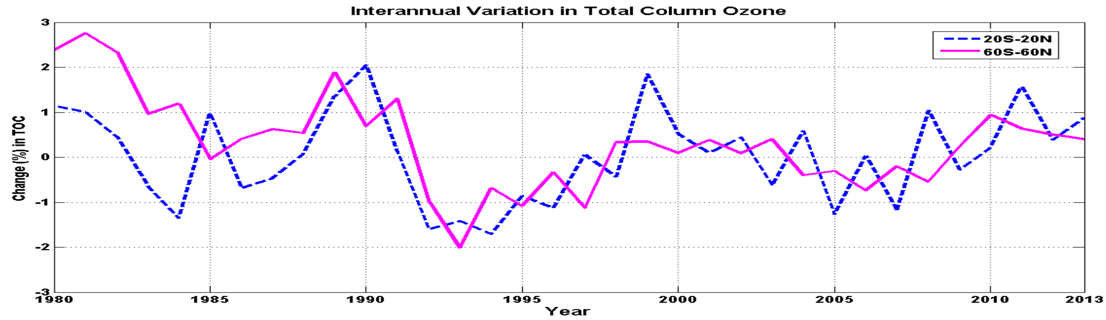

Figure 1. Total Column Ozone anomalies for the period 1980-2013 (mena of the period 1988-1998 is removed to create the anomalies).

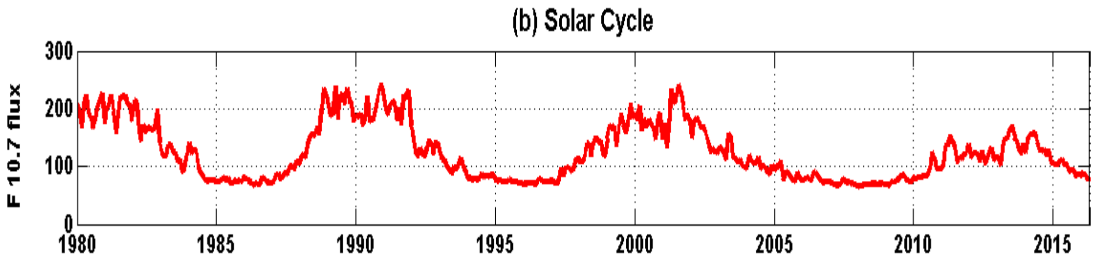

Figure 2. F10.7 solar flux.

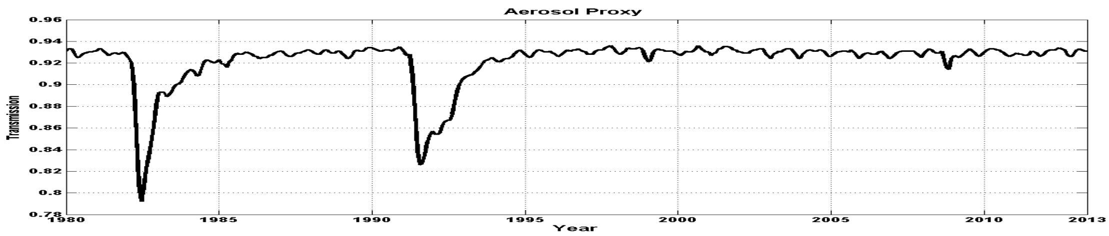

Figure 3. Volcanic Eruption proxy.

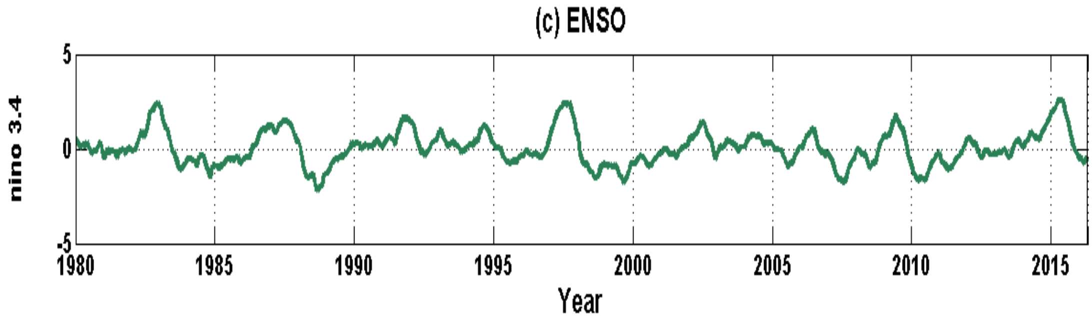

Figure 4. Nino 3.4 index.

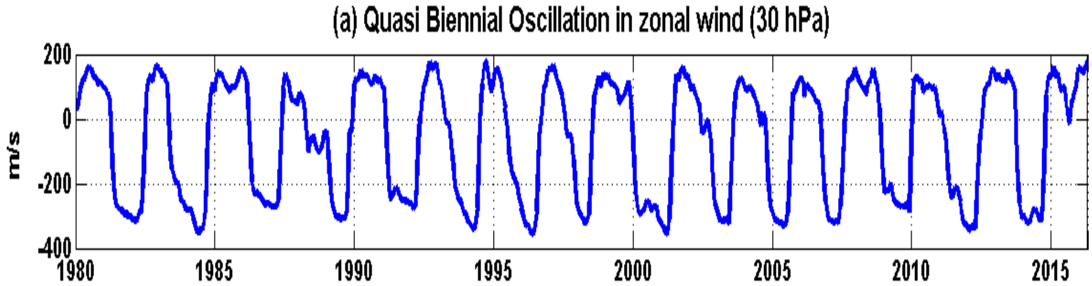

Figure 5. QBO index - zonal winds at 30 hPa.