The ranking of the effect of proxies on the space and time variability of stratospheric ozone profiles

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Abstract

The paper is focusing on the relative importance of proxy time series for explaining variations in the vertical ozone profiles. Studied proxies include:

(1) dynamical proxies (Quasi Biennial Oscillation (QBO), El Niño Southern Oscillation (ENSO), Arctic Oscillation (AO), Antarctic Oscillation (AAO) and Tropopause Pressure)

(2) extraterrestrial proxies (11-year solar cycle) and

(3) stratospheric composition proxies (aerosol optical depth at 525 nm and equivalent effective stratospheric chlorine; EESC).

Results are presented for ozone profiles from 5 well maintained Lidar stations located in the northern mid-latitudes, northern subtropics and southern mid-latitudes and collocated SBUV measurements. We present the short and long term ozone variability attributed to each proxy and its ranking at 7 vertical ozone layers over Hohenpeißenberg (47.8° N, 11.0° E), Haute Provence (43.9° N, 5.7° E), Table Mountain (34.4° N, 117.7° W), Mauna Loa (19.5° N, 155.6° W) and Lauder (45.0° S, 169.7° E).

In order to investigate both qualitatively and quantitatively the attribution of ozone variations to the different proxies, we have used a multi-linear regression method (WMO, 2014; Zerefos et al., 2017).

Contribution of proxies to ozone variability

Figure 1 shows the amplitude [(max–min)/2] of ozone variability attributed to each proxy for the 7 vertical layers and for Hohenpeißenberg, Mauna Loa and Lauder. The amplitude of QBO related variations below 10 hPa, down to 40 hPa, is on the order of 2% of the mean. The smallest QBO amplitudes are found in the uppermost layers 13 and 14 (0.5% of the mean or less). The footprint of the solar cycle is clearly seen in the middle and upper stratosphere with amplitudes around 2% of the mean. The amplitude of AO (AAO in the Southern hemisphere) in the zonal mean is about 1% of the mean. At individual levels or stations it can be as high as 4% of the mean. The contribution of ENSO (MEI) is typically less than 1% of the mean at Hohenpeißenberg and Lauder, but up to 4% for the Mauna Loa SBUV data. The effect of tropopause height variations is most evident in the lower stratospheric layer 8, where it reaches 4% for the SBUV data at Lauder and Hohenpeißenberg, but only 2% for the lidar data. The lidars have better altitude resolution than SBUV in the mid and lower stratosphere, and do not include a substantial contribution from levels below 40 hPa / 26 km. In the upper levels, tropopause height related ozone variations generally decrease. Transient effects from large AOD of volcanic origin (El Chichon, Pinatubo) can contribute substantially to the ozone variability, from 4 to 6% of the mean, but for shorter time periods (2 to 3 years) after the volcano. Finally, the EESC proxies representing halogen chemistry carry the largest and most significant ozone variations, up to 5% of the mean in the upper stratosphere.

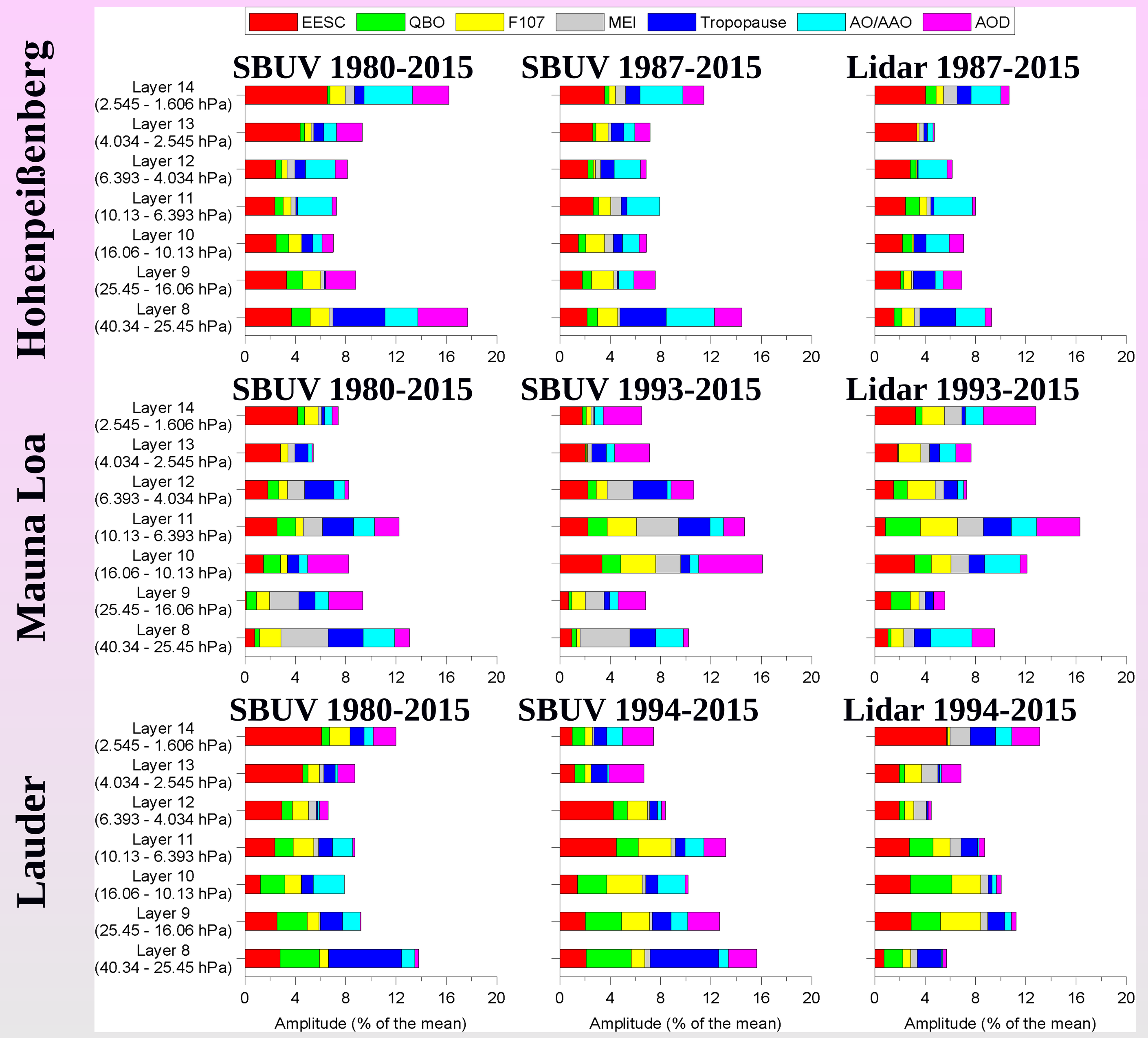

Figure 1. Amplitudes [i.e. (max-min)/2] of ozone variations attributed to EESC and its orthogonal function, QBO, F10.7, MEI, Tropopause, AO (or AAO at Lauder) and AOD (525 nm) for each stratospheric layer. All values are expressed in % of the long-term mean at each layer. Stations shown are: Hohenpeißenberg, Mauna Loa and Lauder. Left panel: SBUV overpass data for 1980-2015. Middle panel: SBUV overpass data for common period with lidar. Right panel: lidar monthly means.

The temporal evolution of ozone variations attributed to natural proxies and to EESC terms is presented in Figure 2. The figure shows time series of ozone anomalies and regression results from 1980 to 2015 SBUV monthly mean overpasses, averaged over Hohenpeißenberg, Haute Provence and Table Mountain, at layer 8 (40.34-25.45 hPa) and layer 13 (4.034-2.545 hPa). The major long-term variations come from the two orthogonal EESC terms, the solar cycle and AOD. The major contribution from AOD is highly limited to the periods of El Chichon and Pinatubo.

Another look at the long-term ozone variations is given in Figure 3. The upper time series shows the observed SBUV overpass anomalies, the middle series the variations after removing all natural proxies except the orthogonal EESC terms, and the lower series shows the remaining ozone residuals after removing all natural proxies and orthogonal EESC terms. One can clearly see that removing the natural proxies has little effect on the slowly moving long-term ozone trends. Most of the long-term variability is congruent with the EESC proxies, especially in the upper stratospheric layer 13. After removing the variability attributed to all proxies (natural and orthogonal EESC terms), it was found that both in the upper and lower stratosphere the overall trends (1980-2015) were insignificant at the 99% confidence level.

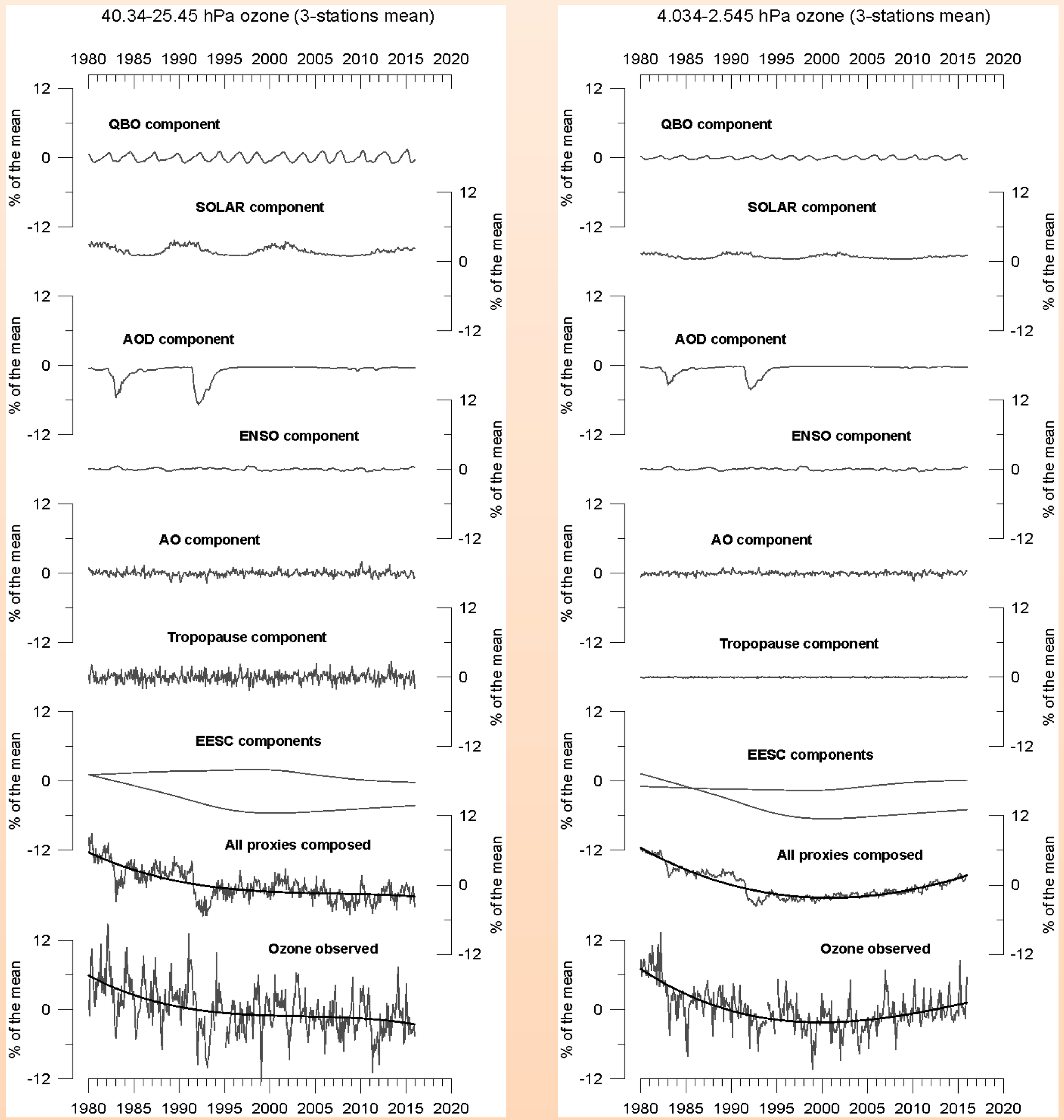

Figure 2. (a) Ozone variations attributed to the different proxies (QBO, Solar, AOD, ENSO, AO, Tropopause, EESC and its orthogonal function) at layer 8 (40.34-25.45 hPa, centered at about 24 km height) for SBUV overpasses averaged over Hohenpeißenberg, Haute Provence and Table Mountain. (b) Same as in (a) but for layer 13 (4.034-2.545 hPa) centered at about 40 km height. The lower most curves give the observed deseasonalized SBUV time series. Thick solid curves are 3rd degree polynomial fits to the data.

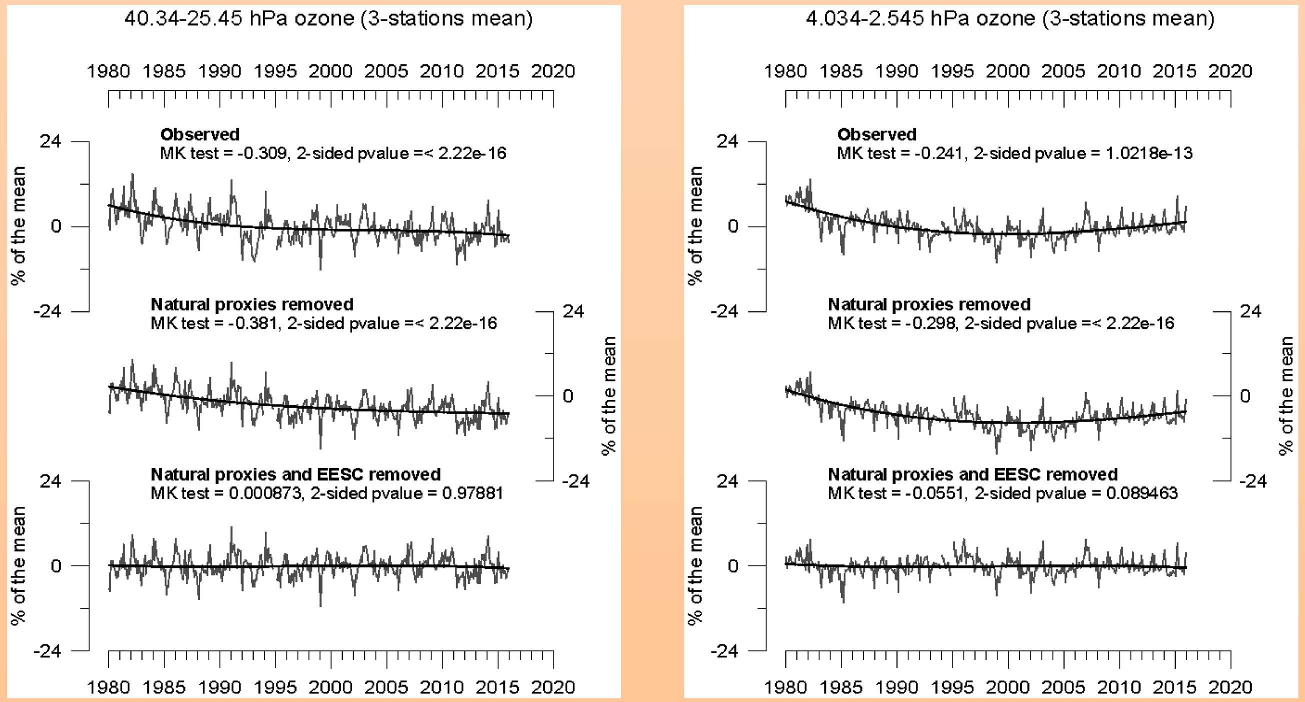

Figure 3. (a) Ozone anomalies from SBUV overpasses averaged over Hohenpeißenberg, Haute Provence and Table Mountain for layer 8 (40.34-25.45 hPa). (b) Same as in (a) but for the layer 13 (4.034-2.545 hPa). Top: Original deseasonalized time series. Middle: Time series with natural proxies removed, but EESC related variations remaining. Bottom: Time series with natural proxies and orthogonal EESC related variations removed. MK test refers to the Mann-Kendall trend test.

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