Supplemental material to
Extreme events in total ozone over Arosa: Part 1
Application of extreme value theory
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1. Discussion of the drawbacks of threshold estimation based on detrended datasets or various sub-periods

1.1 Trend components derived for the Arosa total ozone time series by STL decomposition with various time windows for trend extraction

As stated in section 2.4 the Arosa total ozone time series was not detrended before the threshold selection process. In the following section of the supplementary material the reasons are outlined in detail.

Detrending of a time series leads conditionally to a subjective a priori decision on the type of trend applied. Figure S1 shows various trend components for the Arosa total ozone time series after applying the Seasonal Decomposition based on LOESS (STL) (e.g. Cleveland et al., 1990) with different time windows (see caption of Fig. S1) for the trend estimator. From Fig. S1a-f it is obvious how strong a trend estimator is influenced by the time window chosen. Large time windows, as chosen in Figs. S1a-c, lead to almost linear trend estimates while shorter time windows, as chosen in Figs. S1d-f, lead to a highly variable structure of the trend component with time. Detrending of the Arosa total ozone time series with the trend components shown in Fig. S1 would lead to a highly diverse remainder, depending on the time window chosen for the trend component. Therefore, we decided to use two clearly different regimes for threshold estimation, namely an anthropogenically and volcanically unperturbed (1927-59) and an anthropogenically and volcanically perturbed time period (1960-2008) instead of a threshold estimation based on a detrended time series, which would lead to subjective results as outlined above.

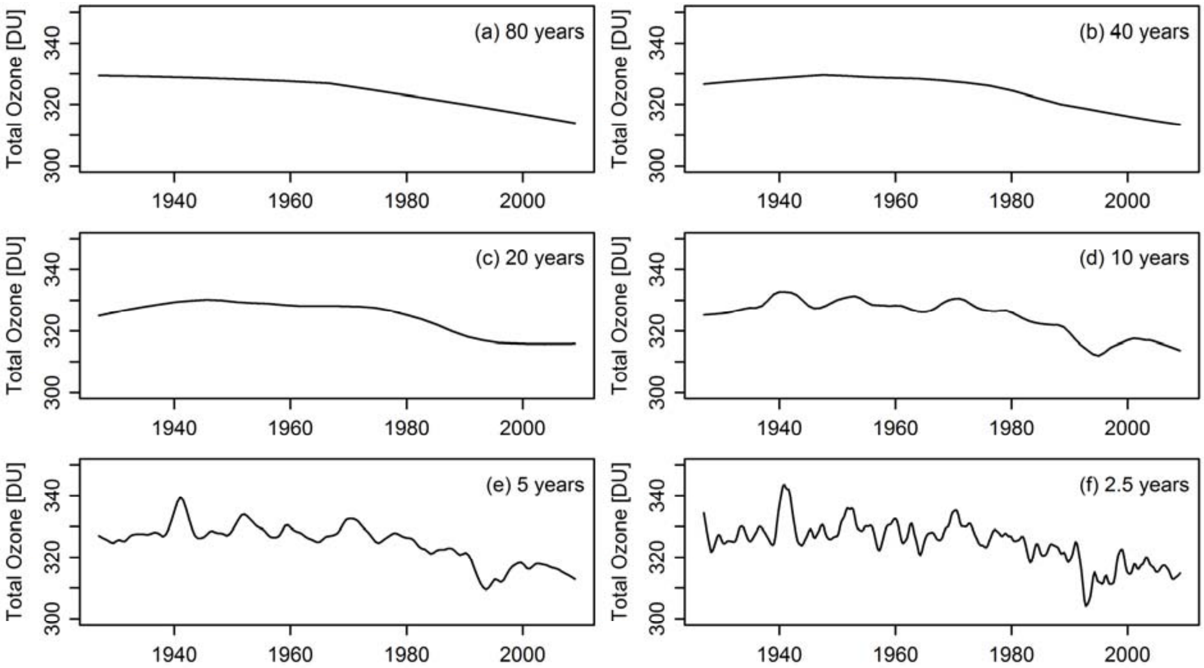

Fig. S1: Trend component of the Arosa total ozone time series (1927-2008) based on the Seasonal Trend decomposition procedure based on LOESS (STL) with time window (span in lags of the LOESS window for trend extraction) of (a) 80 years, (b) 40 years, (c) 20 years, (d) 10 years, (e) 5 years, and (f) 2.5 years.

1.2 Threshold estimation on various time windows

One might argue that threshold estimation should be based on various shorter time periods, because a lot of inter-annual to decadal variability is visible in the Arosa total ozone time series (see Fig. 1 in the main paper). We decided not to use different sub periods, first for statistical reasons as a sufficient amount of data is necessary for the threshold selection process, and second because this would lead to a subjective a priori decision on the properties of the time series (similar to detrending of the time series, described in Sect. 1.1 of the supplement).

However, for discussion of the stability of threshold estimates, thresholds for low and high total ozone have also been estimated for three 20-year periods (1930-49, 1970-89 and 1980-99) and an extended “unperturbed” period (1927-69). The results for the threshold estimates for these 4 time periods and the thresholds applied (based on estimation on the time periods 1927-59 and 1960-2008) are shown in Fig. S2. From Fig. S2 it is clear that differences among the thresholds are quite small and so threshold selection is not highly sensitive to the time period chosen.

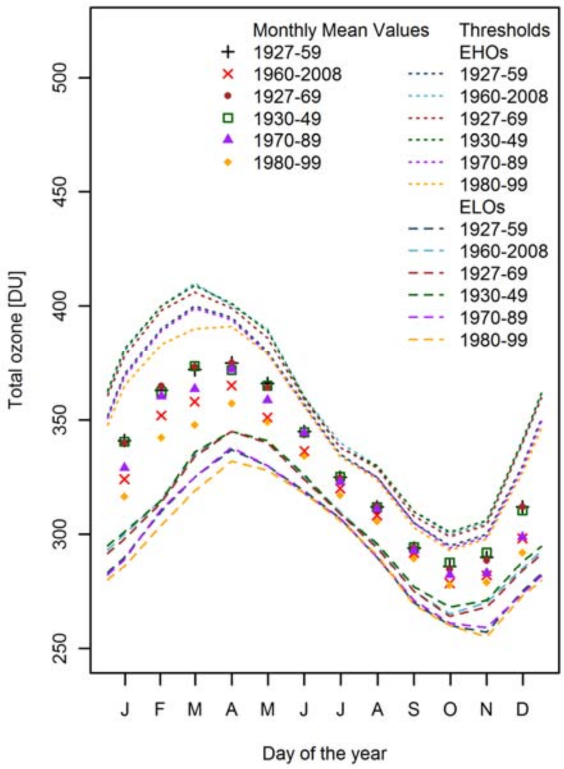

Fig. S2: Thresholds for extreme high (EHOs) and low (ELOs) total ozone and monthly means of total ozone over Arosa for the time periods 1927-59, 1960-2008, 1927-69, 1930-49, 1970-89 and 1980-99. Note: Thresholds estimated on the time periods 1927-59 and 1960-2008 (see also Fig. 8 in the main paper) are used for determination of ELOs and EHOs in Rieder et al. (2010a,b).

However, threshold estimates for February and March, based on the time period 1980-99, differ slightly from those for other time windows. This is expected as this 20-year time period is strongly influenced by the volcanic eruption of Mt. Pinatubo. A similar deviation does not occur for thresholds estimated for the time period 1970-89 (influenced by the eruption of El Chichón), indicating the major influence of the Mt. Pinatubo eruption on column ozone, visible also in annual mean values. However, the effect of this deviation in threshold estimates is small as it affects them only in late winter and early spring.

To analyze the influence of this threshold deviation, Fig. S3 provides a comparison of the frequency of days with extreme low and high total ozone computed from the thresholds used in this study and those estimated on the 1980-99 time window. Figure S3a shows results for spring, while Fig. S3b shows results for winter in 1980-99. From Fig.S3a it is obvious that the overall pattern in ELOs and EHOs is not changed for spring season. The use of a different threshold does not affect the shape of the distribution and only slightly affects the total frequency, increasing the frequency of EHOs on average by 3% and decreasing the frequency of ELOs by 2%. For the winter season (Fig. S3b) a similar result is found. However, the pattern in the frequency of ELOs is different between 1985 and 1988. The difference in the threshold values applied leads during winter season on average to a slight increase in the frequency of EHOs (about 3%) and a slight decrease in the frequency of ELOs (about 5%). From both figures it is clear that fingerprint identification of dynamical and chemical phenomena, as described in Rieder et al. (2010a,b), is not affected by the application of a slightly different threshold.

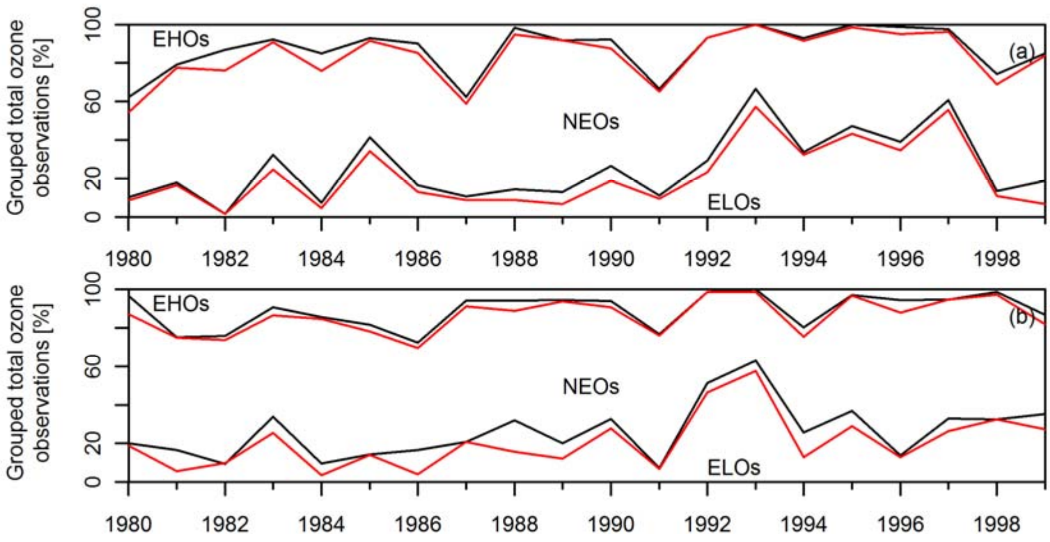

Figure S3: Evolution of fractions of extreme low (ELOs) and high (EHOs) total ozone and not extreme days (NEOs) for (a) spring (MAM) and (b) winter (DJF) in 1980-99 based on different thresholds applied. Solid black lines represent the result based on thresholds estimated on the time period 1960-2008 (used in the analysis of Rieder et al. (2010a,b)), solid red lines represent the results based on thresholds estimated on the time period 1980-99.

Based on the results presented above, we conclude that the main findings of the study are robust and do not depend on the time windows used for threshold determination. As consequence we prefer to use the longest (unperturbed and perturbed) time windows (1927-59 and 1960-2008), to compute thresholds for extreme low and high total ozone, for statistical reasons.

References:

Cleveland, R. B., Cleveland, W. S., McRae J. A., and Terpenning I.: STL: A Seasonal-Trend Decomposition Procedure Based on Loess, Journal of Official Statistics, 6, 71, 1990.

Rieder, H. E., Staehelin, J., Maeder, J. A., Peter, T., Ribatet, M., Davison, A. C., Stübi, R., Weihs, P., and Holawe, F.: Extreme events in total ozone over Arosa – Part 1: Application of extreme value theory, Atmospheric Chemistry and Physics Discussion, 2010.

Rieder, H. E., Staehelin, J., Maeder, J. A., Peter, T., Ribatet, M., Davison, A. C., Stübi, R., Weihs, P., and Holawe, F.: Extreme events in total ozone over Arosa – Part 2: Fingerprints of atmospheric dynamics and chemistry and effects on mean values and long-term changes, Atmospheric Chemistry and Physics Discussion, 2010.