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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Variability of the total ozone trend over Europe for the period1950–2004 derived from reconstructed data" *by* J. W. Krzyścin and J. L. Borkowski

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Anonymous Referee #1

The referee wrote: 'The definition of trend in this paper is a bit unusual for the ozone and UV analysis field. Customarily, (see Ziemke et al., JGR) a synthetic time series is constructed with linear and higher order terms. The higher order terms remove the larger cyclic changes in the data leaving the linear coefficient, which is the long-term linear trend. Your definition seems to represent significant deviations from the mean over short time subsets of the entire series. The other proposed definition, using the endpoints of a smoothed time series does not seem realistic for the satellite era of measurements since 1979. Previously published ozone analysis shows a smoothed variation of ozone clearly reaching a minimum after the Mt. Pinatubo eruption, and then shows recovery. The recovery continues because of the atmospheric reduction of chlorine producing compounds. This is not well reflected in the present paper, which arbitrarily ends the O3 time series in 2004 instead of continuing to the end of 2007. There is no reference to satellite era ozone trends, which would differ from the results presented here. This must be fixed before publication. For latitudes up to 60 degrees, the variations smoothing kernel do not appear to be significant relative to a straight line fit for estimating trends (see your figure 4).'

Our response: First of all we should be aware there is no precise definition of trend. It is usually spoken of as a nonrandom (deterministic) smooth function representing long-term movement or systematic variations in a series. Priestley (1981) refers to a trend as 'a tendency to increase (or decrease) steadily over time . . [or to] fluctuate in a periodic manner,' .Kendall (1973) says 'the essential idea of trend is that it shall be smooth . . .'. Our definition of trend follows these ideas, so we do not agree that it is 'a bit unusual';. We extract from time series a smooth component and the level of smoothness is objectively calculated by the wavelet analysis that takes into account the length of the time series and variability in shorter-time scales. Finally we use the kernel smoother with 8-year bandwidth, which is very close to the selected wavelet component, but it can be applied to time series with no equidistance time points. Fitting a long-term linear trend as Ziemke et al. proposed is too far going assumption in case of an appearance of first signs of the ozone recovery. Why select the linear term as a trend? May be a third order polynomial would be better? But what about the fourth order polynomial? It would be even better? Where is the desired smoothness level? Our method gives the answer! Our method is also able to provide many characteristics of the trend component. We can calculate what is the deviation from the mean level in selected year (for example at the end of the time series). We can find the curve's minimum (somewhere after Mt. Pinatuba eruption). Subsequent recovery is clearly seen on Figure 4. We are especially interested in the ozone deviation at the end of time series but the rate of the recovery can be easily calculated (the recovery problem

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is beyond our analysis). We estimate the ozone change (in %) in selected time intervals (Fig.8 and 9) as a difference between ending and starting point. The rate of ozone change (%/10-year) is the difference divided by the time interval between both time points (see Fig.6). Thus, we provide a clear picture of the ozone changes in recent decades. The ozone strong decline in 1985-1994 and a kind of the trend overturning in the period 1995-2004 are shown in Fig.9. So the known basic features of very recent ozone changes over Europe are reproduced. Why we stop our calculation in 2004. Our statistical model has been trained on the satellite NIWA data base for the period 1979-2004. After training the daily ozone data are reconstructed back to 1 January 1950. It means that our model exactly reproduces the satellite data. The correspondence between the modeled and satellite data is very high. For the model verification with the ground-based and satellite data see our recent paper; Krzyscin, Statistical reconstruction of daily total ozone over Europe 1950 to 2004, J.Geophys.Res., 113, D07112, doi:10.1029/2007JD00888, 2008. The extension of the ozone data base to 2007 is possible but it is better to rely on the satellite measurements. The satellite period 1979-2004 is used for the model training and it appears that the length of the period is enough long to tune a good model. The basic idea of the paper is to delineate ozone long-term variability before the satellite era. To summarize the examined ozone data base reproduces the satellite ozone (1979-2004) and provides the satellite equivalent of the ozone data in the pre-satellite era. We do not discuss in the paper how our model is compared with, for example, with a linear trend model. Sometimes the linear approximation can be as good as the flexible curve (see problem discussed by reviewer for latitudes up to 60 degrees). If the long-term change in total ozone is almost linear our model will select a curve close to a straight line (see almost linear change in ozone in the period 1985-1994 from the wavelet analysis shown in Fig.3)

The reviewer wrote:

'The paper must include the identity of various ground-based data sets used in this analysis. A table giving location, instrument type, and duration of the data would be a

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good idea. Also, some indication of the accuracy and precision of the reference data sets should be supplied to allow the reader to judge the quality of the reconstructed ozone field. This would also allow the estimation of the smallest change that is statistically significant. Currently, the article is using purely synthetic estimates of error from just statistical analysis. Since you are proposing this as an extension of real data, the errors must be properly propagated through the model. Because of the availability of satellite data from 1979 to the present, the current analysis should end at 1978 and then join to the satellite data. Additionally, the reconstruction analysis should be performed for the satellite era, 1979 to present, and then compared to the satellite data. The reconstruction should use the same number of stations for the satellite era as for the pre-satellite era. Such a comparative analysis would lend some confidence to the reconstruction for the entire 1950 to 2004 period.'

Our response.

We agree with the reviewer. The same ideas were in our mind before this trend analysis. All these problems have been exactly discussed in our recent article published in JGR, 'Statistical reconstruction of daily total ozone over Europe 1950 to 2004', 113, D07112, doi:10.1029/2007JD008881.

The reviewer wrote:

'This paper should show the long UV and ozone time series obtained in the Moscow area. Of particular interest is the large change seen before the satellite era that is present in the Moscow data (see Chubarova).'

Our response The comparison with the total ozone time series for the Moscow area is not possible as this region is outside the area with the reconstructed ozone. The boundaries of the region was decided during the management committee meetings of the COST-726 in 2006. At that time there was no interest to reconstruct the ozone data for that region. It is worth mentioning that comparison of the measured total ozone in Moscow with the reconstructed ozone is not straightforward as the ozone

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measurements were done with the filter instrument M83 and M124 . Quality of such instrument is much lower than the Dobson spectrometer. The Dobson ozone data for the European stations (Arosa, Belsk, Lerwick, Oxford, Uppsala, and Longyearbyen were examined in our recent JGR paper explaining the model. An examination of the ozone behavior near the east boundary of the area (Fig.8 and 9) suggests that there was not large fluctuation of the total ozone here in the 1960s and 1970s, so large change in the surface UV over Moscow area was not forced by the total ozone change. The same conclusion could be inferred from Fig.7.7 of Scientific Assessment of Ozone Depletion (2006), where results of Chubarova's analysis were shown.

The reviewer wrote.

'This paper should not be published until the additional analysis is performed to improve the credibility of the data reconstruction. A paper based on statistical inference without validation, is not suitable, particularly when the data are available. Some explanations need to be supplied as to why simple linear trends are not sufficient. The ozone recovery is a good reason, but then the analysis should be extended to 2007. See your Figure 4.'

Our response.

The validation of the model has been the main objective of our recent paper published in JGR (Krzyscin, 2008). The justification of not using the linear trend is shown in Fig.3a, where the straight line (the kernel smoother with bandwidth of 55-year is shown) underestimates the ozone values at the beginning of the time series and overestimates at the end. It is possible that after the removing the 'natural' fluctuations from the ozone series (due to changes in the atmospheric dynamics) the straight line will describe much better the shape of the residual ozone. However, it should be kept in the mind that we would like to have the long-term pattern of ozone for a UV reconstruction and our trend comprises both anthropogenic and 'natural' effects. The idea is to extract a smooth component from the whole ozone data as UV radiation is sensitive to overall total ozone change comprising both 'natural' or 'anthropogenic' signal. We agree that an extension to 2007 will be desirable. However, our main focus is the early total ozone data (for 1950s and 1960s) as at that time the total ozone was measured only by few ground-based stations. Now we have many satellite sources of the ozone data. Our statistical model was trained on the satellite data, so it reproduces exactly the measured data but for analyses of recent changes of the ozone field it will be better to rely on the original (satellite) data.

The reviewer wrote:

'The paper is reasonably well written, but needs some editorial help to clarify the English sentence structure. Most of the figures are clear, but the contour plots need to be improved to make the results more readable. As it is now, the contours are not easily readable.'

Our response. The grid has been removed from the contour plots making figures more readable.

Questions and short comments

'Does the NIWA O3 database contain the trends from the satellite era?'

NIWA O3 database starts in October 1978 with the results of TOMS onboard the Nimbus 7 satellite. The statistical model has been training on the subset of NIWA data, i.e., the database used is since January, 1, 1979 and only for Europe. The data base comprises the satellite-based ozone measurements from 4 Total Ozone Mapping Spectrophotometer (TOMS) instruments, 3 different retrievals from Global Ozone Monitoring Experiment (GOME), and data from 4 Solar Backscatter Ultraviolet (SBUV) instruments. The data were homogenized by a comparison with the ground-based Dobson spectrophotometer stations. (for details see our recent paper in JGR).

'How was vorticity calculated before 1979? It sounds as if the model is based on balloon sondes for temperature.'

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'The vorticity and temperature are taken from NCEP/NCAR Reanalysis-1 data base. The meteorological variables are based on GCM simulations controlled by the radiosonde results (before the satellite era) and the satellite results...'. The source of the data is added to the revised manuscript (section 2, in paragraph 2)

'This paper should show the long-term Belsk and Moscow UV data time series. The reconstruction should be compared with the data.'

The main objective of the paper is the total ozone reconstruction over Europe. The model has been verified using the Dobson and satellite ozone measurements. The UV reconstruction for selected stations is quite different problem. The total ozone is one of many UV model input parameters. Even under clear-sky condition we need aerosols characteristics to simulate surface UV. In this ACP special issue there will be at least one paper focusing on the UV reconstruction within COST-726 activity with use of our reconstructed total ozone data base.

'Computing trends from start and end points would not apply to the era from 1979 to the present. Why would it apply to the entire period? Mt. Pinatubo effects destroyed this possibility for the 1979 - 2007 period.'

The trend model used here is based on fitting a smooth curve to the data without a priory setting the shape of the trend curve (as it is for standard straight line fit to the data). Having smooth curve we can calculate the ozone change between any two points. It is worth mentioning that the smooth curve is able to delineate known long-term behavior of the mid latitudinal total ozone, i.e., fast decline in the 1980s up to mid 1990s, a kind of stabilization or small increase afterwards.

'What is the mechanism for the winter month trend'

We explain in the revised manuscript. 'It seems that changes in the atmospheric chemistry are not responsible for the continuation of the decline tendency over the European 35N region in winter. The effective chlorine loading in the stratosphere is now decreas-

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ing, i.e., it acts in opposite direction causing at least no further decline of ozone. Thus, changes in the atmospheric dynamics are possible source of the ozone behavior in this region. More frequent transport of the ozone poor tropical air masses is possible source of the ozone trend there.' These statements appear in the revised manuscript. section 4 in paragraph 4.

'Ozone has increased since 2000 even in the winter based on satellite data (SBUV-2).'

The smoothed curve selected by the wavelet analysis is not very sensitive to small changes with time scale of few years. The ozone trend turnaround in the period 1995-2004 is also demonstrated in the reconstructed data (Fig.4) but the positive trend is not statistically significant.

'How do the trends compare with daily variability?'

The paper is about long-term changes. The daily variability have been discussed in our previous paper, Krzyscin, (2008).

'This analysis contradicts the ground-based data obtained by Bias from Thessaloniki. The data shows that the main cause of UVB increase is a reduction in pollution aerosols not from O3 changes.'

Our analysis deals with the long-term changes in total ozone, i.e., one of the UV forcing factors. It seem possible than other factors like changes in cloudiness and/or aerosols are more important UV forcing factors over special sites as Thessaloniki.

'The differences in Figures 1 and 2 do not seem significant given the errors in the underlying measurements.'

Fig.1 and Fig.2 illustrate that the ozone field over Europe has been changed since the 1950s. Here we present the ozone distribution for two months (March and June) without precise statistical judgment when the ozone depletion is stronger. In next sections we calculate the errors of the trend and mean ozone level estimates. 95% confidence ranges of the estimates are quite large when compared with the estimates, so we are

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not able to find if there are statistically significant differences in trends between the European regions. We discuss that in some regions the trends are larger or smaller.

’Referring to Figure 4: The linear fit to this data at 60N has a slope of -0.1 +/- 0.02 or +/- 0.04 at the 95% confidence level. The change is 6% over the entire period. This implies about an 8% increase in erythemal irradiance for 60N since 1950 and considerably more (15%) for short UVB wavelengths such as 305 nm. The deviations of your kernel smoother from the straight line fit are smaller than the 2-sigma error limit, and are not significant, except for the 1995 minimum. The scatter at high latitudes is too large for the kernel smoother to give believable results. It is not clear that these results are any better than a simple straight line fit.’

We do not claim that our method is better than other trend methods. Our method defines in objective way a level of smoothness that takes into account the length of the time series. It is possible that our method selects for some periods that a linear approximation is reasonable (see for example the period 1985-1995 in Fig. 3). The most important difference between our and linear concept is that our method is able to delineate the trend variations throughout the analysed period. Linear method gives only one value for the whole period. The linear concept fails if there is the trend turnaround in time series. The reviewer linear estimate at 60oN provides significant ozone decline. One can erroneously infer that this tendency will be continued in next years as adding new data cannot change so strong negative trend. Our method is more flexible at this point.

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