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Interactive Comment

Interactive comment on "Exposure-plant response of ambient ozone over the tropical Indian region" *by* S. Roy et al.

S. Roy et al.

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Comment related to the calculation of AOT40.

The European CLs to protect vegetation against the adverse effects of O3 are expressed as an Accumulated exposure Over a Threshold of 40 ppb (AOT40). This index is calculated as the sum of differences between the hourly O3 concentrations $>$40 and 40 ppb, for each daylight hour with global radiation $>$=50 Wm-2 during the growing season which is three months for Europe (Keller et al 2006, Grünhage et al 1999) while in the present study the authors have calculated AOT40 during the daylight hours between 7 a.m. and 7 p.m. Authors have not considered the global radiations ($>$=50 Wm-2) while calculating the AOT40. 50 Wm-2 can be observed one hour after sunrise and one hour before sunset, eventually reducing the length of daylight hours by approximately two hours. Considering the geographical immenseness of India (65

E-95 E) the local time difference of 2 Hours from east to west can majorly influence any sort of calculations engrossing day light timings. Authors have not considered this difference and simply calculated between 7 a.m. and 7 p.m. (especially over Gangetic plane, the sun sets around 6 PM in winter with global solar radiation reaching below 50 Wm-2 around 5PM) The duration of the daylight time is different for different seasons, especially over the northern India. The daylight duration (global radiations 50 Wm-2) could vary between 8 hours in winter to 12 Hours in summer. Calculation of AOT40 considering the above said facts may result in different picture of AOT40 over India, mainly reduced AOT40 values during winter growing seasons.

Answer : The global radiation over different parts of Indian geographical region varies depending on the location, month and season of the year. It is difficult to demarcate the different areas of the Indian region based on the distribution of global radiation during the different time periods of the year. The sunrise and sunset timings vary even in a much shorter distance and accounting data as per exact timing and keeping the time duration equal (from statistical consideration) is very complicated issue. In view of this we have considered uniform timings for calculations and the observational data which we have used to assess the modeled AOT40 data at our chosen site Pune has been collected for the 7am-7pm time window without considering the global radiation factor. Moreover in order to simulate the AOT40 values over India taking the global radiation into account we need to calculate the value of global radiation for every daylight hour of each day, for each month of the year at each grid point which is not feasible. So considering the above mentioned aspects we have calculated AOT40 during the daylight hours between 7 a.m. and 7 p.m which corresponds to the maximum time slice of daylight hours including one or two additional hours at the edges close to sunset and sunrise. Since the hourly concentration of ozone in general does not rise immediately close to sunrise and is mostly in the waning phase close to sunset, this addition of one or two hours near the sunrise and sunset time may not significantly effect the AOT40 values over the Indian domain although our projection may be slightly on the higher side. Keeping the above things in mind we can say that the local time difference of 2

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Hours from east to west which has not been considered by us, may not have a major influence on the overall picture of AOT40 over India. In winter the hourly ozone values can be higher during the basic minimum time slice of 8.30AM to 4.30 PM as compared to other months, and can have a higher resultant cumulative effect in the AOT40 calculation. Hence it is difficult to say with surety that there would be reduced AOT40 values during winter period, if we had not considered the additional one or two hours close to sunrise and sunset time. However, we have added the above discussion in the manuscript and also clearly mentioned how the above issue can introduce an uncertainty in our result. In our expert opinion, we feel than uncertainty due to choice of timing interval in the results of AOT40 should not exceed more than +/-5%. The missing data part visible in the time series has cropped up due to a problem related with plotting the daily time series data and oversight as mentioned in the answers to other referees. We are sorry for this confusion. We have re-plotted all the daily time series figures from 2a-c with the required data placed in the missing gap accordingly. Daily or monthly AOT40 has no definition or meaning. Appropriate discussion of AOT40 during growing season is missing. Since AOT40 is an accumulative index, missing data can affect the AOT40 calculations, as lot of missing data can be seen in the ozone time series. Authors have not properly judged upshot about the calculation of AOT40 for the period of missing days/hours.

Answer: Although the threshold level as directed by the UNECE and WHO is 3000 ppb h accumulated over a 3 months growing season, a pertinent point to be noted is that the same is exceeded in several parts of the Indian region even in a single month. So we have chosen to calculate and analyze the AOT40 values on shorter time scales like a month or even smaller like a day. From the daily AOT40 time series we have further identified the Plant Exceedance Days (PED) at the receptor site Pune, where PED is defined as those days when the daily AOT40 value exceeds the critical limit (Beig et al, 2008). However as per the suggestion of the referees we have incorporated the 3-monthly AOT40 plots over the Indian region and its associated discussion in the paper. As far as comment related to missing data is concerned, it is redundant in view of the

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answer to previous comment as there are no missing data. Appropriate discussion of AOT40 during growing season is missing. In India, and especially in northern India, there are two distinct seasons, kharif (June to October), and rabi (October to March) as mentioned by authors. However the crop seasons are different for different part of India. Answer: We have added brief descriptions related to the two major crop growing periods over India in the paper.

Page 4148, line 5 AOT40 values are higher than the critical level in some parts of western India during the month October, which is a "Kharif" crop growing season in India. The month of October is harvesting month of Kharif crop, thus this statement has no meaning.

Answer: Following the referees comment we have reframed the above mentioned sentence in page no. 4148 and line no. 5 from “As can be seen from Fig. 3, the AOT40 values are higher than the critical level in some parts of western India during the month October, which is a “Kharif” crop growing season in India” to the following- “As can be seen from Fig.3, the AOT40 values are higher than the critical level in some parts of western India during the month of October”.

Page 4147 line 10 Daily AOT40 values were found to be almost zero during most of the time in the monsoon (June to September). Jul-Sep is growing season for Karif crops; mainly rice in Northern India, Low values of AOT 40 indicates no threat to crop production. Authors should indicate this in the paper. Answer: The above mentioned sentence refers to the comparison of modeled daily AOT40 values with the observed data for the year 2003 at the chosen site Pune which is in south west India. So following the reviewer’s comment we have added the sentence “Since July-September is mostly growing season for Kharif crops in India like mainly rice in Northern India, low values of AOT40 during this period indicates no threat to crop production” in the paper after line no.10 in page no.4147.

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Page 4146, line number 6 Figure 1 shows the comparison between monthly AOT40 values calculated from the model and from the point observation at Pune for the year 2003. It is found that observed monthly AOT40 values lying reasonably in the same range as the modeled values at Pune indicating that our model is capable of reproducing the monthly AOT40 values. Looking at figure 1, 2a-c, it can be seen that the model simulation underestimates the ozone concentrations. It is advisable to show some more statistics like correlation, MAE or RMSE in order to have the clear picture of simulated results.

Answer: What we wanted to state that the model is capable of reproducing the monthly AOT40 values obtained by observations at Pune reasonable well, in general. However, if we look at it in finer detail then we find that there is an underestimation in the modeled values especially during the winter/spring months of highest ozone concentration (December to March). However, on some occasions, model also overestimate the values. So essentially there is no clear cut bias in terms of overestimation or underestimation when we compare our modeled results with the observational data. The reason for this discrepancy is given in the answers to the comments of referee-3 which we are restating again below: The model has underestimated the ozone values during the winter/spring months of higher concentration. The observational site is situated in the northwestern side of the Pune city (18.54 N, 73.81E). Major industries are located in the northeastern and eastern side of the site around 20-25 km away. During the winter time since the predominant wind pattern is northeasterly so the pollutants emitted from these industries can enhance the level of ozone precursors and hence the ozone at the receptor site. Since the regional model has the coarser resolution (0.5o x 0.5o), the effect of above mentioned local emission sources in the locality of the receptor site (which is on a subgrid scale) can not be captured by the model. This may have resulted in the underestimation of the modeled ozone levels during the winter period. In figure 1a, we find that the observed daily AOT40 values comes out to be zero for most parts of the monsoon months from June to September and the modeled daily AOT40 values replicates the same phenomena. However in figures 2b and 2c we see that

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the model overestimates the ozone values during the monsoon months from June to September. Although the model is able to capture the overall variability in the precipitation pattern over India (larger than 0.5o x 0.5o scale) to a reasonable extent it was unable to capture any sudden, localized excess rainfall event (much smaller than the model resolution) which has happened during the monsoon months of the year 2003 as per the rainfall records (IMD-report, 2003). This will obviously result in reduction of observed ozone but there will not be any manifestation of the same on the modeled results due to coarser resolution.

So in conclusion we wish to mention that some small differences are unavoidable due to the above reasons but, in general, model is able to capture distinct seasonal pattern very well as discussed in detail elsewhere (Roy et al 2008).

Page 4147 line 15

Although the model qualitatively reproduces a similar phenomena, a reasonable quantitative agreement was not obtained in this regard possibly due to the inability of the regional model with 0.5*0.5 degree resolution, to capture any sudden, localized excess rainfall event which has happened during the monsoon months of the year 2003 as per the rainfall records (IMD-report, 2003) which is discussed in detail by us elsewhere (Roy et al., 2008). REMO-CTM had been validated with precipitation data over India (Roy et al 2008). It has been mentioned in Roy et al., that "The model is able to capture the variability in the precipitation pattern over India to a reasonable extent which is an essential factor for simulating such key species in the atmosphere" but in the present study inability of the model to capture the precipitation is discussed. Please elucidate this contradictory statement.

Answer: In fact there is no contradiction. When we talked about model validation and reasonably good agreement in our earlier paper (Roy et al., 2008), we were talking about the comparison and the features which could be resolved in a model resolution beyond 0.5 x 0.5 degree. What we mentioned in the present paper (which is quoted by

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the referee) is some feature, within a small local region much smaller then the model resolution (0.5x0.5 degrees) and obviously model will not be able to resolve such small scale features as also discussed above. Hope it is clear now. We also tried to reframe some sentences in the revised version to make it clearer.

Figure 3, two color bars for three panels, one is missing?? Two color scales for the figures are confusing. Is it possible to show AOT40 for all months or at least for the growing season of kharif (July, Aug, Sep) and rabi (Dec, Jan, Feb)

Answer: We have replotted the monthly AOT40 graphs in Figure 3 with same color scale and color legend in order to avoid the confusion. As per the suggestion of the referees we have added the 3-monthly plots for the AOT40 over the Indian region for the months of November to January and February to March which mostly comprises the rabi crop season. Since AOT40 values during the growing season of Kharif crop from June to September is comparatively lower, so their adverse effect on crops and vegetation are not significant in this period. Considering the said aspect we have chosen to include the 3-monthly AOT40 plots only for the months corresponding to the Rabi crop season.

As far as I understood, Authors have simulated the Ozone concentration from REMOCTM and recalculated AOT40. Authors also mention "observed AOT40". Since AOT40 is calculated from simulated and observed concentrations. Please specify these facts in the paper.

Answer:We have extracted the daily, monthly and 3-monthly AOT40 values from the modeled hourly concentrations of ozone over the Indian region with the application of codes and scripts using the methodology and definition already mentioned in the paper. The monthly and daily observed AOT40 values at the receptor site Pune has been calculated from the hourly ozone values with the help of codes and programs following the same methodology and definition. We have specified this fact in the paper following the referee’s advice.

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AOT40 calculations have been reported by Mittal et al, 2007, considering more number of measurements over India which has been refereed by the authors. Ahammed et al 2005, Pulikesi et al 2006, Gupta et al 2007 and Debaje et al 2008 reports the lower concentrations as compared to discussed in this paper. Paper from Debaje et al gives more detailed information about ozone concentration in rural and suburban area in western Maharashtra which also included Pune. I hope there are more papers available on ozone measurement over India. Although the data available at different location referred in this paper is not for year 2003, but can be used for comparison purpose in the absence of data.

Answer: The AOT40 comparison with Mittal et al. (2007) has been included in this paper as per the remark of referee-2 although they are not for identical conditions. As far as measurement of ozone reported by Debaje et al. (2008) is concerned, we wish to mention that those measurements are made using the traditional K-I techniques which is very sensitive to several local factors (K-I solution purely, variation with temperature and humidity, etc.) and if not accounted properly may introduce significant error and in general known to underestimate the ozone level. Appropriate observations are made using the proven online optical analyzer and considered to me more robust and accurate. As far as comparison of ozone with Ahammed et al. (Anantapur) data is concerned, we compared our model results (Roy et al., 2008) and the comparison is found to be quite reasonable. In fact we validated our model by comparing results obtained by 4 observational Indian stations in our above paper as discussed above.

References: Ahammed et al 2005, Seasonal variation of the surface ozone and its precursor gases during 2001& 2003, measured at Anantapur (14.62_N), a semi-arid site in India Debaje et al, 2008, Surface ozone variability over western Maharashtra, India Gupta et al 2007, Variability in the vertical distribution of ozone over a subtropical site in India during a winter month Grünhagea et al 2009. The European critical levels for ozone: improving their usage Keller et al 1999 High-resolution modelling of AOT40 and stomatal ozone uptake in wheat and grassland: A comparison between 2000 and the

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hot summer of 2003 in Switzerland. Pulikesi et al 2006, Surface ozone measurements at urban coastal site Chennai, in India.

Answer: Most of these reference are either cited in our earlier paper (Roy et al., 2008) (which is cited in the present manuscript) or cited here.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 4141, 2009.

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