

Review of “Sources and variability of surface ozone over the Tibetan Plateau revealed by in situ observations and EMAC model simulations” by Yihan Zou et al.

Zou et al. study the causes for the temporal variability of surface ozone over the Tibetan Plateau by combining in situ observations at two sites with the results from a global atmospheric chemistry climate model. The focus is on the time period between 2010 and 2012 for which observations are continuously available at both sites. The model output comes with source-tagged O<sub>3</sub> tracers to allow for a quantification of contributions to the modeled O<sub>3</sub> at the two sites. The major results of this study according to the authors are the capability of the model to capture the observed O<sub>3</sub> variability. The O<sub>3</sub> variability is mainly attributed to long range transport from tropospheric and stratospheric source regions. The stratosphere is particularly important to explain a spring maximum and this source is related to the location of the subtropical jetstream. During summer tropospheric source regions at mid-to-high latitudes serve as sources for the O<sub>3</sub> variability. During the transition time period, i.e., pre-monsoon, O<sub>3</sub> abundance is strongly linked to O<sub>3</sub> sources in South and Southeast Asia.

The authors address an interesting question about which source regions and transport processes contribute most to explain ozone levels at a remote site with negligible local precursor emissions. Such analysis sheds new light in local air pollution. The combination of model and in situ data is a very good choice (i) to show the model capability to add information to a complex question on transport processes in a complex environment and (ii) to put the observations into a broader perspective. The source tagging method is a very good approach to identify potential contributions of various source regions. Consequently, the study addresses a question which is well placed into the scope of ACP. However, I think the authors do not fully use the capabilities of the model for their analysis. More so, I think several explanations lack the necessary depths to comprehensibly address the topic and the discussions are often too descriptive. I will lay out my major concerns in more detail below and recommend major revision at this stage before the manuscript is ready for publication.

## Major comments

### 1. Data analysis time period

The authors focus their analysis on a three year time frame, from 2010-2012. I guess this is based on the availability of the observational data. I think it is always good that -with model data at hand- the authors compare the model with the observational data. But I wonder why the authors limit themselves to this time period. I ask because transport processes which affect inter-annual variability of pollution may depend on large scale patterns such as ENSO or the phase of the QBO. I think it would be at least good to address this topic in the discussion to give an outlook on whether and if how much such variability on longer time scales could affect the results. This also includes a brief discussion on whether the chosen time period of this study can be regarded as a good representative in terms of average conditions.

### 2. Seasonal patterns of surface ozone from the stratospheric sources

First of all, the entire discussion is only centered around the position of the jet as cause for the seasonal differences. However, an important fact which is not mentioned at all is the background ozone in the lower stratosphere. This depends a lot on the stratospheric circulation and particularly on the downwelling in the stratosphere. Said differently, you could have a constant transport from the lower stratosphere into the

troposphere, but would get different contributions from the stratosphere to the surface O<sub>3</sub> due to a varying background O<sub>3</sub> in the lower stratosphere.

So, an important quantity to look at here would be the ozone at the level of the tropopause or even in the lower stratosphere, both in absolute numbers and the NTST-O<sub>3</sub> fraction.

Then the discussion on Rossby waves and downward transport. This discussion is in the current form also too brief. It is simply argued that the position of the jet is the proxy for the surface NTST-O<sub>3</sub>. As mentioned in the text, the wave breaking is the crucial factor and this topic is not addressed in much detail. So instead of the position of the jet, a seasonal distribution showing the location of wave breaking (position, frequency) would be more informative. Or a map of the occurrence of tropopause folding events. From the literature, it is well known that the tropopause folds occur over the Tibetan Plateau but how EMAC represents this is not clear at this point. So, the processes relevant for the stratospheric contribution could be discussed in more detail.

### 3. Tropospheric sources

The discussion around Fig. 6 and generally in Sect. 5.2.1 highlights seasonal differences of surface O<sub>3</sub> in relation to the seasonal mean 500 hPa wind. I have some issues in seeing the direct connection between the mid-tropospheric wind and surface ozone. I assume the 500 hPa wind represents some sort of "surface" wind over the Tibetan Plateau. However, this is not the case in most other source regions. So, the connection between surface precursor emissions at pressures usually much higher than 500 hPa and the wind at 500 hPa is missing. So how much of these emissions are lifted to the respective altitudes. I can imagine that the authors use the 500 hPa wind as sort of "steering" wind (which is true to some extent for the horizontal transport), but I am missing the vertical component in that discussion.

A second point here is chemistry. Although the focus of the paper is on transport, ozone is difficult to interpret without the consideration of chemical effects. At least to the degree to provide some background information on precursor species and their distributions, e.g., through observations of or modeled CO, CH<sub>4</sub>, NMVOCs. This would help to understand and interpret the O<sub>3</sub> distribution over the Tibetan Plateau.

### 4. Tagged and total O<sub>3</sub>

The discussions in the analysis sections 4 and 5 mainly focus on the tagged O<sub>3</sub>. Although this is more a technical comment I put this under major because it affects large parts of the manuscripts and several figures. A lot of the discussions are made based on the tagged O<sub>3</sub> and in particular the figures show only this tagged O<sub>3</sub>. I would like to have a reference on how much the tagged O<sub>3</sub> is compared to the total O<sub>3</sub> in these figures (essentially Figures 4 and following). So, the discussion and interpretation would generally benefit from absolute references to total modeled O<sub>3</sub> or relative contributions (tagged/total). I am aware that this is presented in Figure 3 and in some places discussed in the text, but I think the readers would value if this is put in more context in the other figures as well.

### 5. Presentation of the events

Sect. 5.1.2 and Sect. 5.2.3 focus on the presentation of so called events, that is time periods of enhanced O<sub>3</sub> and its variability at the two observational sites. I like the general idea of including these discussions because they provide more insight on the process level. However, I would like to have more information on these events and why

they have been picked. Are these common events? How frequent do such events occur? Do the ones shown differ significantly from other, similar events? And also I would like to have more visual context here: a time series at the observational sites for the respective event as well as comparison with the model, at least to see how good the model performs here? In total, the events are a little bit too descriptive with too little background information and the analysis could go further in terms of temporal evolution and model performance analysis. For the troposphere, I also would like to have some more information on precursor emissions and chemical evolution during the transport.

#### Minor comments and technical recommendations (in order of appearance)

- General remark: The manuscript is quite heavy on acronyms. This disturbed my flow of reading at several points and I wonder whether the authors may introduce a table which summarizes the commonly used acronyms.
- P6, L5: Why has RCP8.5 been chosen? Does this affect the O<sub>3</sub> concentrations substantially?
- P6, L9: Which reanalysis? ERA5?
- P6, L12: What is the temporal sampling of the model data at the two sites? 6 minutes? This is important for the interdaily variability comparison discussion.
- P6, L20: Why are 14 source regions defined (all with an individual acronym) and then only 3 used? Maybe for the sake of clarify, just say that there are originally 14 which have been lumped into three source regions for the analysis.
- P6, L 30 ff: Why do you start your discussion with the interdaily variability? Maybe start with a more general description of the observations. So, it is more difficult to put the variability into context to the absolute values.
- P 7, L 3-5: A correlation coefficient (why coefficient is used here?) of 0.72 leads to a coefficient of determination of smaller about 0.5 which is in my opinion not very large and I would even argue that the model should be able to simulate the O<sub>3</sub> at the sites with this "precision" to make any valid comparisons.
- P8, L1-3: Do you have an explanation why the model has a bias to the observations? Or more precisely, what are the major causes of the deviations which you report? Is it an interpolation artifact or does this point to a more general issue?
- P12, L10: "of the" → "of the"
- Figures 7, 9, 10: PBL wind: Is this a model based PBL? How deep is the PBL here and well does the model represent the PBL over this complex terrain?
- P24, L13: remove "that" at the beginning of the line
- P25, L14: What is meant with "multi-scale" ?
- P25, L14-15: What is the difference between westerly circulation and subtropical westerly jet?