Observational evidence for aerosols increasing upper tropospheric humidity

Reply to Anonymous Referee #2

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Atmospheric Chemistry and Physics Discussions 14.10.2016

Comments by Referee #2:

This is an interesting paper that studied the relationships between aerosol loading and upper tropospheric humidity using satellite remote sensing data. The paper is very well written and easy to follow. The authors have comprehensively explored many elements of uncertainty, however I still have some questions on the analysis. I suggest the publication of the manuscript after addressing some comments as follows.

Authors' response:

We thank the Anonymous Referee #2 for his/her comments. The reviewer raises some questions in the specific comments. Please find our response below.

Specific comments:
1. During the summer season, there might be diurnal variation of precipitations. Since the UHR change could result from the convective transport of marine boundary layer air to the upper troposphere and AODs are measured 11 hours ahead of URH, differences in diurnal variability between precipitation (UHR) and AODs are likely to contribute to the seen relationships. Suggest test it.

We agree that there might be a diurnal cycle in convection in the area. In our analysis we have used AOD data obtained at 10:30 a.m., UTH data at 9:30 p.m. and precipitation data from 8:30 a.m. to 8:30 a.m. local solar time. As the time of the observation is always the same (once per day), diurnal cycle cannot affect our results.

2. The binning approach is not totally convincing for excluding the meteorological/ synoptic effects on AOD. In addition, the value ranges of those bins are not clear. I would think more logically one should compare the 10-m wind speed and surface humidity between high AOD and low AOD scenarios and test the statistical significance of 10-m wind speed differences and surface humidity differences between the high and low AOD scenarios. Not only that AODs are influenced by humidity but also it has significant contributions from large size natural sea salt aerosols (their emission rates are wind speed dependent).

We agree that AOD depends on both low level wind speed and surface humidity. However, the effect of AOD on UTH is seen in every class of 10-m wind speed and 2-m relative humidity – except the bin with the largest surface relative humidity. Therefore, although AOD depends on those meteorological variables, AOD's effect on UTH cannot be due to, e.g., wind speed increasing AOD and UTH separately. If wind speed would affect AOD and UTH separately, and thereby cause a positive relation between AOD and UTH, then binning by wind speed would remove, or at least diminish remarkably, such a relation.

Referee #2 asked about the values of meteorological parameters of bins in Figure 10. We have now added a mean value of each meteorological parameter in the bins to Figure 10.

3. Is it possible to only use clear sky AOD (with cirrus fraction = 0 or < 0.1), given that cirrus clouds lead to biases in AOD values? Does the results change when using only clear sky AODs?

Using only clear-sky AOD would be problematic considering the nature of the phenomenon. As the effect of aerosols on UTH is expected to occur via sublimation of anvil cirrus clouds, it is expected that some cirrus clouds remain in the same 1 deg x 1 deg grid box. So the occurrence of cirrus clouds also reflects the occurrence of deep convection in the area and therefore we would not recommend studying only cases with cirrus fraction below 0.1.

However, the results for cirrus fraction smaller than 0.1 can be seen in Figure R1. UTH in general is lower, as expected, when cirrus fraction is low. Also error estimates are larger. However, with large UTH values, the effect can still be clearly seen in the data (Figure R1 b).

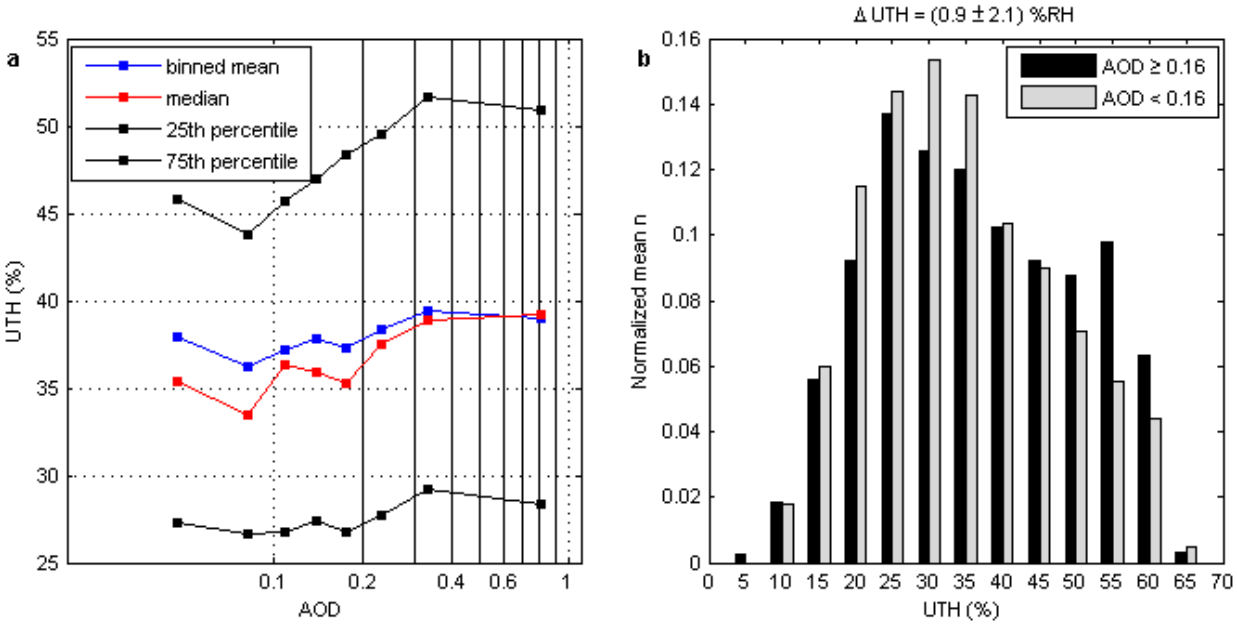

Figure R1. Same as Figure 6 in the manuscript, but only for values with cirrus fraction below 0.1. Number of data points was 4636.

Minor comments:
Page 7, Lines 10 and 15: I disagree that bulk microphysics cannot capture important aerosol effects, and only spectral bin microphysics can capture the effect. Through improved coupling between aerosols and microphysics in conjunction with maybe some improvement in the bulk microphysics (including ice nucleation scheme), there is no reason that more detailed bulk microphysics cannot simulate those effects.

We have modified the last paragraph of Section 4 in the revised manuscript as follows:

"Namely, as noted by Khain et al. (2015), the only feasible option in current general circulation models is to use bulk microphysics parameterization schemes. However, bulk microphysics schemes have trouble in producing aerosols' effect on cloud cover and cloud top height. As a result, the effect of aerosols on UTH is not correctly included in the current projections of climate change produced by general circulation models."