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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Tropospheric Ozone Variability during the East Asian Summer Monsoon as Observed by Satellite (IASI), Aircraft (MOZAIC) and Ground Stations" *by* S. Safieddine et al.

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We would like to thank Reviewer 3 for her/his comments. Below is a point-by-point response for the comments and suggestions raised in the review. The review is copied here in full (in italic), and then we dissect it and give our answers.

This is very well known that weather disturbances relieve polluted air masses from meso- to synoptic-scales. This study investigates such a process during the East Asian Summer Monsoon as observed by satellite (IASI), Aircraft (MOZAIC) and ground stations measurements of ozone. The present study is a well-conducted qualitative study ; however it doesn't report anything new. The subject has come up a number of times, one of the very first examples using the same datasets over the same region was by Barret et al. (2011).

We agree that a lot of previous studies over China and India linked weather disturbances to a decrease in pollutants concentrations, but to our knowledge our study is the first that provides a six-year regional distribution of tropospheric ozone columns over the whole region during the monsoon period from IASI, in particular over the whole Chinese region and correlate it to meteorological parameters.

The reviewer is referring to Barret et al. (2011) study "The detection of post-monsoon tropospheric ozone variability over south Asia using IASI data". Brice Barret is a co-author on this paper, and we benefited from his expertise for this study. Barret et al. discussed two events of anomalous drop in O3 and linked it to the crossing of large tropical storms over central India during November 2008. Here we highlight the main differences that can be identified between the two studies:

Different study period and altitude levels:
Barret et al. study is focused on post-monsoon period, in particular November-December 2008. After the validation section, the study shifts to discuss the elevated O3 concentrations in the mid-troposphere during Nov-Dec 2008. Our study on the other hand takes place during the monsoon season (May-September), and discusses the decrease in O3 concentrations in the lower troposphere.

Different processes involved in ozone production/loss:
Barret et al. suggests that the enhancement in tropospheric ozone in the post-monsoon season is linked to uplift of boundary layer air-masses transported from the polluted Indo-Gangetic plain and the photochemically processes favoring ozone production during transport, as well as subsidence of upper tropospheric air masses over northern India. Our results suggest a direct anti-correlation between tropospheric ozone and

cloud cover/relative humidity, processes not discussed in Barret et al., and that uplift of pollutants, and/or transport from the upper troposphere into the tropospheric ozone column studied, is not the driver of the decrease in tropospheric ozone (in the new version of the manuscript we added the analysis of vertical winds with a potential vorticity/relative humidity analysis).

China, the main region in our study is not studied in Barret et al.:
Barret et al., is focused on South Asia, and in particular on India, whereas our study focuses on all South and South-East Asia, including all of China. The only other study that analyzed the whole Chinese region during the summer monsoon season from satellite measurements was performed by Worden et al. (2009) and it was done using TES, and looking at mid-tropospheric O3 (we show the [0-6] km). Safieddine et al. (2013) and Dufour et al. (2010) also analyzed the seasonal variation of tropospheric ozone over different Chinese cities and linked the decrease seen in summer to the monsoon, but no detailed and/or spatial analysis were presented.

Therefore, we agree with Reviewer 3 that the relationship between the weather processes during the monsoon and different pollutants is rather well understood, but we hope that we showed in the above comparison with literature review and in particular the one in Barret et al. that our study brings new information. The manuscript was updated to take these comments into account, and improved following suggestions provided by the two reviewers.

To further the subject and delivering added value to end users, the present study should explain satisfactorily which one of the transport process or the lack of photochemical activity in overcast and cool conditions is the main process governing the change of the low tropospheric ozone column. The study may use other IASI species such as for example carbon monoxide and for which co-authors are principal investigators and experts at ULB and UPMC.

The study has been improved according to the Reviewer's suggestion. We added both CO maps and vertical winds. In this manner, we could check if the decrease or persistence of ozone is due to photochemical activity being hindered by cloud cover, or stimulated by the presence of anthropogenic precursors (CO). Vertical winds are used to check for uplift of pollutants. The following text was added and Figure 2 was updated with CO and vertical velocity fields. Section 3.1 is therefore updated as follows (changes are in bold):

"In order to look at the O3 response to change in meteorology during the monsoon, we show in Fig. 2 the monsoon period [May-August] of 2011 taken as an example year of a typical monsoon. Carbon monoxide (CO) total columns from IASI are also shown. **CO is often used as an anthropogenic pollution and biomass-burning tracer (e.g. Edwards et al., 2004; McMillan et al., 2010). Note that the seasonal variation of CO is such that it is lower in summer, because of the destruction of CO by the OH radical in the presence of sunlight.** We consider different meteorological parameters in order to highlight the relationship between change in meteorology and the [0-6] km O3 column. These are: i) the total cloud cover that gives an insight on the photochemical activity in the troposphere; ii) relative humidity, since increasing water vapor increases O3 loss as the production rate of the reaction H2O + O(1D)→ 2OH increases (where O(1D) is the product of the photo-dissociation of O3 in the presence of ultraviolet light), and iii) **horizontal and vertical wind fields. Horizontal wind speed and direction are used to assess monsoon strength and possible transport. Vertical velocity is used to investigate possible ascending motion of air masses from the boundary layer towards the free troposphere.** [. . .] In June, in particular, the monsoon becomes stronger as the wind force and the cloud cover (and therefore lower photochemical activity) increase over the regions < 20°N. A decrease in tropospheric O3 and **total CO columns is recorded over India, and over all the countries around the Bay of Bengal and South East China. In Southern India, negative (ascending winds, over the Arabian Sea) and positive (descending winds, over land) vertical velocities are present from the surface up to 700 hPa (we show here an example**

at 850 hPa) suggesting exchanges of air masses vertically. Since CO chemistry does not depend on cloud cover, the decrease in CO between May and June suggests that transport might be the main driver of decrease in pollutants. During July and August, the monsoon reaches its maximal strength. Due to high cloud cover and strong horizontal winds, the tropospheric O3 columns show a large decrease. **For latitudes < 30°N, the drop in O3 is more notable, particularly over the Indo-Gangetic Plain where the decline in O3 is driven by decreasing photochemistry since CO values over this region do not follow the same trend.** Looking at specific regions, tropospheric [0-6] km O3 columns in Korea show a decrease in particular in July for O3 **(and not for CO)**, which coincides with the high cloud cover and relative humidity. On the other hand, and over North West of India and part of Pakistan, the low cloud cover and weak winds lead to the buildup of the high summer O3 over this region. **Enhanced IASI CO columns over this same region suggest build-up of pollutants**, and with little to no transport, the persistence of the [0-6] km O3 values. Looking at the winds plots over the different months, one can notice how the monsoon is stronger at the lower latitudes of the domain. Therefore the areas of Beijing, Tianjin and the North China Plain (black squares in Fig. 2) are in general less affected by the monsoon and they show much weaker O3 decrease. **High CO total columns, used as pollution tracer, indicate the anthropogenic origin of the observed ozone enhancements.** In fact, the persistence of O3 during the monsoon season in Beijing was previously documented using aircraft data from the MOZAIC program which suggested a summertime O3 maximum attributed to strong photochemical production (Ding et al., 2008). The other interesting region in China that shows little or no change is the area between the Chongqing and Sichuan provinces (and designated with a black circle in Fig. 2). This region does not exhibit any monsoon characteristics with low cloud cover and weak winds. This region is also between two mountains, making the persistence of O3 and CO during summer favorable. **The vertical velocity plots show that the monsoonal convection responsible of uplift of pollutants from the boundary layer to the free and upper troposphere, is more prominent for latitudes < 30°N,**

except for Southern India, in accordance with previous studies (e.g. Randel et al., 2010; Fadnavis et al., 2013, 2015)."

Finally, the declined correlation between IASI and MOZAIC ozone datasets obtained in the present study compared to the correlation obtained in Barret et al. (2011) may be worth to be discussed.

This is indeed an interesting point to investigate in the study. As Reviewer 4 also had comments for this part, we looked at the 6 years of MOZAIC/IAGOS dataset over this period and updated the discussion. Figure 3 (below) is updated and figure 4 (also below) is now replaced by the validation of IASI by the MOZAIC/IAGOS profiles over the monsoon for the period [2008-2013]. The discussion is therefore updated and we discuss the difference in correlations to the one reported in Barret et al. (2011) in detail.

The new discussion of Figure 4 is now as follows (changes are in bold):

"Figure 4 shows the correlation of [0–6] km O3 column retrieved from spatio-temporal coincidence of 363 IASI and MOZAIC/IAGOS smoothed profiles during **May–August of [2008-2013] (except for 2010 where no aircraft profiles were available), and over the airports located in the study domain (see Fig. 3 for the location). Over the five years, a good agreement between the two datasets is found with correlation of 0.73 and absolute relative bias of 12%±9%. Analysis of each year data leads to correlations ranging between 0.7 and 0.8 and bias ranging between 11 and 19%**. Our results suggest a good ability of IASI to reproduce O3 variability in the troposphere over this region. Discrepancies arise from the spatial resolution of the IASI footprint resulting in an observation averaged over tens of kilometers around the airport and therefore may include other surface O3 contributions. Moreover, the aircraft observation takes place at different times during the day whereas IASI observation is at around 9:30 a.m. and 9:30 p.m. local time. With its limited sampling time during the day and its lower sensitivity towards the surface, IASI observation is not able to capture the diurnal variation of O3 like an aircraft profile.**Our results show a declined correlation**

between IASI and aircraft products as compared to Barret et al. (2011) where they reported a correlation coefficient of 0.87 (12% ± 6%). This could be due to the different retrieval algorithm used: SOFRID (Barret et al., 2011) vs FORLI (Hurtmans et al., 2012). A discussion of the differences between the two algorithms can be found in Dufour et al. (2012). Another source of difference may arise from the different season and time period studied (Barret et al. (2011) uses a 6-month profiles over the period July–December 2008). Over the monsoon period, and in particular in May and June, the diurnal variability of tropospheric ozone is much more pronounced and highly dependent on the local meteorology. Therefore discrepancies between IASI and the aircraft profile will carry larger discrepancies given the ± 10h coincidence criteria we used. Moreover, our study takes only the column from [0-6] km O3 column from IASI whereas the lower tropospheric column used by Barret et al. 2011 is based on the column from the surface up to 250 hPa (10 km) and IASI is known to have a better sensitivity in the upper middle troposphere (Boynard et al., 2009; Safieddine et al., 2013).”

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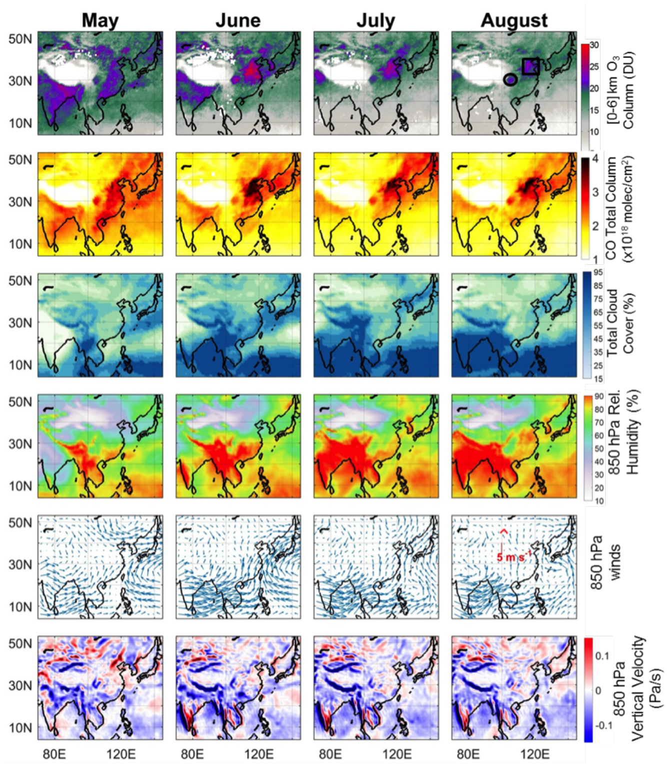

Fig. 1. Figure 2. Monthly averaged tropospheric [0-6] km O3 column from IASI, CO total columns from IASI, along with ECMWF total cloud cover, relative humidity, horizontal and vertical winds at 850 hPa

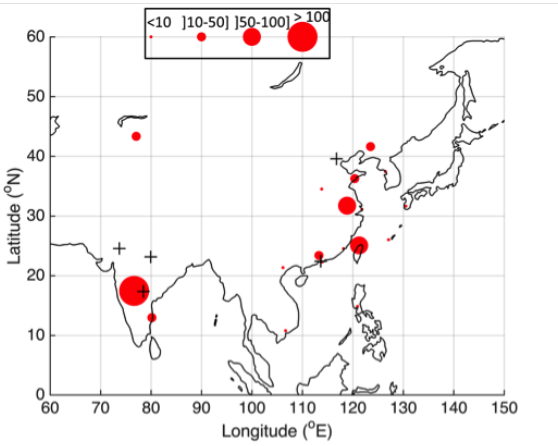

Fig. 2. Figure 3. In red and scaled to number of observations: location of the MOZAIC/IAGOS flight data at the different airports in our study domain. The "+" sign locations corresponds to the ground stations

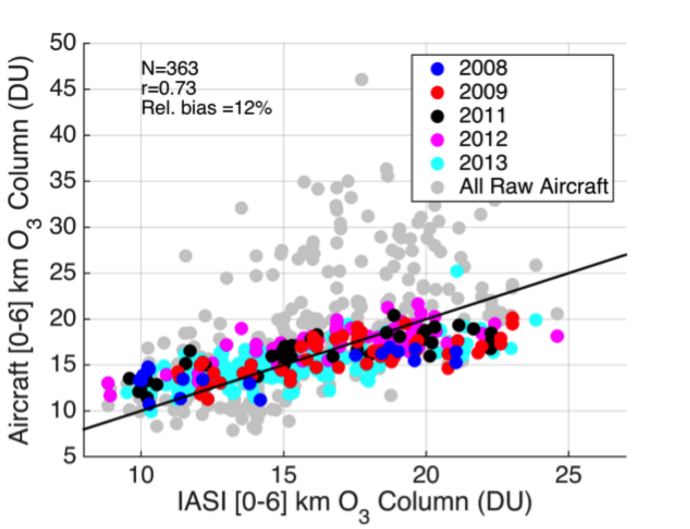

Fig. 3. Figure 4. The [0–6] km O3 columns retrieved from IASI correlation with 363 coincident MOZAIC/IAGOS profiles convolved with IASI averaging kernels for the period May–August of [2008-2013].