Response to reviewer 3

Laura Pan on behalf of all co-authors

We thank the reviewer for many suggestions. Please see the overall response to reviewers, summarized in the Overview of Revisions.

Point-by-point responses

General comment:

The main objective of the paper is to demonstrate the ability of nadir viewing sensors to document the sub-seasonal variability of CO (IASI) and O3 (OMI) in the UTLS dur- ing the Asian Summer Monsoon (ASM) and their relationship with the dynamics of the Asian Monsoon Anticyclone (AMA). Since more than a decade this subject has been widely studied and documented with various satellite sensors and models. The goal of the present paper is not to bring new insight about the dynamical processes that control CO and O3 in the UTLS during the ASM. It mostly aims at demonstrating the capability of IASI to document UTLS CO. As detailed below, this demonstration is not fully convincing. Finally, the complementarity of CO and O3 data to document the AMA dynamics is not put forward because data of different years are used for both sensors. Three questions are proposed in the introduction (P2L33-34 P3L1-3) but no clear, positive and thorough answers are given in the paper as discussed in this review. For these reasons, I think this paper is not publishable in ACP and that major revisions and improvements are needed before the paper is re-submitted. As the paper focuses on satellite data capability in the UTLS, the authors should strengthen their demonstration and validation of IASI UTLS CO and the paper would rather be submitted to AMT than to ACP. Once or if IASI is proven to be able to document UTLS CO on a sub-seasonal scale in the AMA, they should take advantage of the complementarity of CO and O3 data from nadir sensors and of the long records to bring new insights in the ASM and AMA science.

These general concerns are addressed in the Overview of Revisions.

Detailed comments:

IASI UTLS COÂă : The largest part of the paper is dedicated to demonstrate that IASI is able to document the day to day variability of CO in the UTLS during the ASM over Asia.

-1/ The first part of the demonstration is based on literature. According to George et al. (2009) the IASI retrievals contain 0.8 to 2.4 independent element of information depending probably on the location. More details about the theoretical independent layers (when DFS > 1.5) and a focus on the region of interest (AMA) should be provided. Are there about 2 elements of information consistently above the AMA region or just about one ? The paper of De Wachter et al. (2012) is cited as a validation of IASI UTLS CO. Nevertheless, this paper compares IASI and MOZAIC columns for the 470- 250 hPa range which is not the UTLS. George et al. (2009) compares MOPITT and IASI CO tropospheric columns but not specifically UTLS columns. Barret et al. (2016) comparisons of IASI and model distributions concerns another IASI retrieval product.

These references are not cited to demonstrate IASI's capability for ASM study but to provide the context and to acknowledge the prior studies using IASI CO data. Our goal is to demonstrate the information by the dynamical consistency, which complements the theoretical study of information content, i.e. DOFS. See Point 1) in the Overview.

-2/ The second part is based on the retrieval characterization with the averaging kernels presented for the AMA region in Figure 1b. The 0-12 km kernel shows the largest sensitivity (HWHM) with values exceeding 0.7 between 2 and 13 km. IASI is therefore clearly sensitive in the mid-upper troposphere. The 12-16 km kernel displays a very low sensitivity over the whole troposphere and UTLS with a weak maximum with low values (below 0.25!) above 10 km. Furthermore, the values of the 12-16 km AvK are much lower than the values of the 0-12 km over the UTLS altitude range. This means that (i) the sensitivity to the UTLS is very low (ii) the two kernels are not independent with clear resolved maxima (iii) more information about the 12-16 km is contained in the 0-12 km retrieved column than in the 12-16 km column. From this characterization it is therefore not clearly proven that IASI is able to provide independent information about UTLS CO. The AvK is averaged over a large region with very different surfaces : desert, high mountains, low lands, oceans... As the AvKs depend on surface proper- ties, there is probably no homogeneity in the vertical sensitivity over the whole region and more details should be provided rather than refering to the general "averaging kernels discussion" from George et al. (2009).

This section, as part of data description, is also provided to set the background for the analyses. In the revision, we have provided the averaging kernels for the study domain. The goal of this work, however, is not a more detailed theoretical analysis of the information content, but rather to demonstrate the effect of the information content by looking at the performance of the data, i.e., a "process-based retrieval evaluation". This approach was not well demonstrated in the previous submission, but we are meeting the objective in this revision. See figs. 7r and 9r in the Overview of Revisions.

- 3/ The third and largest part of the demonstration is based on comparisons/validation with MLS UTLS CO. - The MLS daily data are interpolated to provide a global distribution. This methodology is questionable with so sparse data (space of about 15° longitude or 1600 km between observations in the tropics!). This can be seen on Figure 4 with plumes of high CO over the Bay of Bengal or the north western Pacific that are not related to real observations. A better methodology should be to average over 5 to 7 days as is normally done with MLS data and to compare with IASI aver- ages or to use data assimilation. - Concerning the averaged seasonal distributions, there is a relative agreement between IASI and MLS CO. Nevertheless looking in more details, there are large discrepancies which are not so clear because of the large do- main displayed. The inside of the AMA is characterized by homogeneous high CO with MLS while lower CO appears to the north (north of 30°) and to the east of the AMA with IASI. Furthermore, the latitudinal gradient of CO between the tropical UT (high CO) and extratropical LS (lower CO) detected by MLS is not detected by IASI. It is especially clear for the southern tropical Indian Ocean and Pacific around 30S. These discrepan- cies are probably due to the fact that IASI detects the highest UTLS enhancements of CO that coincide with the deepest convection in the monsoon region from the Arabian sea to south-east Asia. It seems that IASI also detects UTLS enhancements over the African monsoon because of strong convective uplift of BB plumes. It could be inter esting to show the whole African monsoon region to confirm this ability and strengthen the demonstration as it is the aim of the paper. The border of the AMA is shown with a very thick white line that partly hide the CO distribution. - - - An important proof of the ability of IASI to detect high CO in the UTLS independently from the lower-mid tropo- sphere would be to show the tropospheric columns. In the eastern and central part of the AMA (ASM region) high tropospheric CO due to large emissions should be present contrarily to the western and northern part. The latitude-pressure section displayed in Fig. 7 rather shows that the information is mixed over the whole troposphere and UTLS (see comment below). - The correlation plot between IASI and MLS CO also shows some consistency between the two datasets but the correlation coefficient is rather low (r2 = 0.52 « 1). As mentioned, this low r2 and the reduced slope indicates a rather low sensitivity of IASI to UTLS CO. Whether it is due to the use of a single a priori profile is not obvious and has not been demonstrated. Without specific sensitivity tests using other a priori profiles, the statement p6l14-15 should be removed or modified. - Finally, daily MLS and IASI CO distributions corresponding to different dynamical situations of the AMA are compared. It is mentioned that with IASI "the spatial distributions show many finer scale structures" than with MLS. Given the low UTLS sensitivity and possible mixing of UTLS and tropospheric information as discussed above, it is difficult to know whether these finer scale structures are really in the UTLS. FurthermoreÂă: (i)- we see no holes in the IASI daily distributions in the ASM region impacted by very large and deep clouds. This means that the IASI observations have been interpolated and that part of the finer scale structures could be interpolation artifacts such as those discussed for MLS. It would be much better to see raw IASI data without interpolation.

Otherwise, averages over a few days would be much better than absolutely trying to show daily distributions with spurious features. (ii)- many of those finer scale structures are not detected by MLS such a CO bubbles in the south eastern Indian Ocean on 18 and 20 August, or over the north western Pacific on 20 and 24 August... over equa- torial Africa, some high CO spots are detected by IASI and not by MLS on 18, 20, 24 August. They may correspond to BB plumes in the middle troposphere but this has to be discussed thorough-fully. (iii)- the westward elongation of the AMA highlighted by the GPH field (west of 30˚E) is very clear and consistent with MLS but not detected by IASI on 24 and 26 of August. This is again a probable evidence that IASI is not sensitive enough to detect UTLS CO enhancements that correspond to low integrated amounts outside of the convective and polluted regions.

We agree with the reviewer that the issue of interpolation to fill the orbital gaps and missing data in single-day maps was not carefully discussed in the previous submission. In the revision, we have dedicated a figure and a paragraph of specific discussions on the topic. We have tried various multi-day running mean etc. Eventually we found that a careful interpolation of data from each day can be an effective use of the data for analyzing the day-to-day dynamical consistency.

Fig. 6r in the Overview of Revisions provides the Hovmoller diagram for the JJA 2008, where MLS 147 hPa CO and GPH showed excellent correlation.

The answer to point 2 and 3 found in the paper is given P8L19-21, starting with "we speculate...". This is probably the answer of the discrepancies but (i) if true it proves that IASI is not really able to detect CO in the UTLS independently from the mid troposphere and therefore that the product is not so valid to characterize the AMA com- position and dynamics at the sub-seasonal scale (ii) as this is somehow the central point of the paper, the demonstration should be more thorough and based on comparisons between 0-12 km and 12-16 km distributions (as mentioned above) and a latitude pressure sections at a location west of 90E and/or a longitude-pressure section at the center of the AMA to show wether the east-west lower tropospheric and UTLS gradients are different.

This is addressed in the revision. See Overview point 1).

The vertical structure of IASI CO over the ASM region is finally displayed on Figure7. As discussed in the paper, the uplift of CO within the monsoon region up to 100 hPa is "clear" around 20°N. Nevertheless this latitude-pressure section needs some explanations aboutÂă : (i) the CO concentrations is homogeneously high over the whole troposphere and UTLS in the convective region. This could be explained by the color scale which saturates at 100 ppbv (in that case the authors should change this color scale to show the detailed vertical structure) or by the fact that the information provided by IASI is not sufficient to separate the lower tropospheric pollution from the convective outflow which seem to be mixed together. Indeed, convection detrains preferentially at high altitude (above 200 hPa) and convective enhancement should not be connected to lower tropospheric enhanced CO. (ii) We also see large CO vmr north of the Himalaya range from the surface to 200 hPa. This region (Tibetan plateau) is not impacted by important emissions nor by deep convection. How can such elevated CO reaching such high altitudes be explainedÂă ? (iii) The same is true between 10S and 10N below 300 hPa. Which emissions and transport processes are responsible for these high CO concentrations over the Indian Ocean up to 300 hPa ?

We have provided 4 vertical cross sections and their corresponding maps in revised figures. See Figs 7r and 9r in the Overview.

The Hovmoller diagram of Fig. 8 corroborates the low sensitivity of IASI to UTLS CO enhancements in the western part of the AMA and the detection of features of high CO on the eastern part that are not detected by MLS and not consistent with GPH anomalies. This is rather problematic to state that IASI is able to detect CO in the UTLS.

We have revised this figure. In the revised analysis, the two sensors' dynamical consistency are demonstrated separately. We also make a point that the dynamical consistency is much better demonstrated using carefully interpolated data, instead of coarsely binned and smoothed data. One of the new Hovmoller diagram is included in the Overview.

OMI UTLS O3: As already mentioned, the choice of 2008 for OMI and 2012 for IASI raises the usefulness of presenting/using both datasets. The explanation of that choice is not fully convincing. IASI 2008 data are available and it is not clear that the results for a single monsoon season may be impacted by jumps induced by changing L2 data (when does this change occurs?). It is mentioned that "O3 and CO data are examined separately" which is a real weakness of the paper because (i) if the aim was to characterize the relationship between UTLS composition and AMA dynamics, the complementarity of both gases as pollution and stratospheric tracers would have been a strength (ii) the OMI part is much shorter than the IASI and comes to the conclusion that OMI O3 documents correctly the UTLS which has been shown elsewhere. There- fore, the OMI O3 part could be removed from the paper which should concentrate in proving the IASI CO UTLS capability. A future paper could focus on the dynamics- composition relationship using the O3/CO complementarity.

See Point 2) in the Overview of Revisions. It is true that the OMI part is shorter, but the data demonstrated nicely the ozone at 100 hPa is strongly correlated with the ASM tropopause structure.

IASI is also providing information about the O3 vertical distribution and should logically ave been used preferentially for obvious coincidence criterion with IASI CO. Why is IASI O3 not used or even mentioned in the paper?

At the time when this work was performed there was still a bias issue with the IASI product (eg see discussion in Boynard et al. 2016), and hence we used the OMI data that we had available. The bias is now corrected in the current version of the IASI dataset and we will look into using the IASI ozone in future work.