Overview of the Revisions

Laura Pan on behalf of all co-authors

We thank all three reviewers for the constructive comments and many helpful suggestions. Due to the significant amount of revision (i.e., most of the figures are changed), we would like to provide this Overview of Revisions in addition to the point-by-point responses. The changes summarized in this overview will be referred to in the point-by-point response to each reviewer.

The major criticisms from the three reviewers can be summarized as the following four aspects: 1) IASI CO retrieval upper tropospheric (UT) sensitivity is not adequately demonstrated, 2) The CO and O_3 data are not examined using data from the same year and are not combined as a complementary analysis, 3) Potential complementary information from the nadir and limb data was posed as a key question but not clearly answered, and 4) the objective of examining representations of the sub-seasonal scale variability in the limb and the nadir data is not sufficiently met. In the following, we outline how each of the four aspects are addressed in the revision.

- 1) IASI CO retrieval UT sensitivity
 - a) To verify and demonstrate the IASI retrieval UT sensitivity, we have introduced two new figures, Figs. 7r and 9r (here we us "r" to label the revised version). These two figures are included at the end of this overview.
 - b) Fig. 7r shows IASI CO at 150 and 500 hPa levels for a selected day. The consistency of the CO distribution with the flow pattern at the UT level and the distinct differences between the upper and middle troposphere distributions are effective indications of the independent UT information in the IASI CO retrieval.
 - c) Fig. 9r shows four selected cross-sections and the a priori profile for the retrieval. The cross-sections are selected with correspondence maps in Figs. 7r and 8r (not included). Here again the dynamical consistency of the locations of the UT enhancement, the independent variabilities of the UT and the lower to middle troposphere are all good indications of effective UT information content. In addition, the comparison between the vertical structure of the cross-section and the a priori profile is also a powerful demonstration of the UT retrieval information content.
 - d) We revised the averaging kernel plot (Fig. 1r-b) to show the averaging kernels for individual IASI retrieval layers and also MLS UT level averaging kernels for comparison.
- 2) O_3 and CO data from the same year
 - a) In this revision, we re-worked our analysis to use IASI 2008 CO data, which was not available to us at the time of the previous analysis.
 - b) Note, however, the CO and O₃ are analyzed independently in this work. These two tracers serve to examine two different aspects of the ASM dynamics:
 - The CO analysis is the main focus of this work, because the UT (150 hPa) CO variability is associated with both the convective uplifting of the boundary layer air and the horizontal transport driven by the anticyclone dynamics.

- For the O₃ analysis we focus on the 100 hPa level where the depression of ozone mixing ratio is primarily a result of the tropopause structure in this region and reflecting the troposphere (stratosphere) dominated air mass inside (outside) the anticyclone at this level. We choose to examine the 100 hPa O₃ to examine how MLS and OMI O₃ data seeing this structure.
- As a tracer at UT, O₃ is a more complicated as also pointed out by the reviewer 1. O₃ can be positively correlated with CO if the air is convective uplifted from a heavily polluted boundary layer. This type of CO-O₃ relationship analysis should be pursued by a dedicated study.
- 3) Nadir viewing sensors' contributions and how the two types of sensor complement each other
 - a) We have changed the approach to IASI CO analysis from using 12-16 km layer average to data near the 150 hPa level. This allowed a much better coincidence between the CO field and the dynamical field. With some additional technical improvements, we now see a consistent picture of sub-seasonal east-west variability of the UT CO from both MLS and IASI.
 - b) Although consistent, the IASI data show a stronger enhancement over the western Pacific mode of the anticyclone and a weaker enhancement over the Tibetan Plateau region compared to the MLS data. The former is likely due to the factor that the enhancement over the western pacific is potentially a layer with contribution from ~200 hPa. See Fig. 4r for seasonal average comparisons that supports this "tilted" structure. The latter is likely contributed by the reduced signal-to-noise ratio due to the reduced atmospheric column in the region of high surface elevation. The monsoon season's frequent cloudy conditions also cause wide range of missing data in this region. See Fig. 1r for cloud contribution to missing data in IASI.
 - c) The nadir data (both IASI and OMI) provide much more details in horizontal structure and variability due to the denser daily coverage. The quantitative evaluation of these structure should be targeted in future validation studies.
 - d) Furthermore, the vertical cross-section from IASI demonstrated the capability of identifying the source region in vertical transport. The 3D CO distribution also show that the CO UT enhancements in the Iranian mode (and the western Pacific mode) are not vertically transported from the local boundary layer, which supports model interpretations of eddy shedding. This is the first observational confirmation of the model study on the topic (Pan et al., 2016).
- 4) Satellite data representation of sub-seasonal scale variability in the ASM UT composition
 - a) We have focused more on the sub-seasonal UT CO variability seen by both the MLS and IASI data. We show that both datasets provide good representation of synoptic scale variability, but careful interpolations and gap fillings are required. An excellent correlation between the MLS CO and the Geopotential Height anomalies is demonstrated in a Hovmöller diagram (Fig 6r)
 - b) Most interestingly, both datasets show a regular enhancement over the western Pacific near Japan, associated with a local anticyclone system, known as the Bonin High. A good example is given by Fig 7r.

In additional to these key changes, we have explored a number of different technics to improve the methods of interpolations and filling data gaps. The improved analysis leads to a much stronger set of conclusions in this paper. Below we included the figures specifically referenced in this overview.



Figure 1r (a). Retrieval geolocations for IASI CO (gray crosses) and the MLS CO (red dots) on August 1, 2008 for the study domain. Both day and night observations are included. (b) IASI averaging kernels for 19 retrieval layers from surface to 19 km, labelled by the layer-center altitudes, and the standard MLS averaging kernels for the UTLS products (215, 147, and 100

hPa, in dark green, black and purple lines, respectively). The IASI curves are the averages of all profiles from the study domain (0 - 180 E, 10S-60N) on August 1st 2008.



Fig. 4r. JJA 2008 seasonal average CO mixing ratio for (a) MLS at 147 hPa, (b) MLS 147 and 215 hPa average, and c) IASI 150 hPa. Superimposed white contours are the 14.3 km and 14.2 km GPH (from GFS analysis) at 150 hPa. Note that the color scales for IASI and MLS CO are different. Both MLS and IASI are $3^{\circ} \times 2^{\circ}$ longitude-latitude binned averages.



Figure 6r. Hovmöller diagrams of the 150 hPa Geopotential Height (GPH) and 147 hPa MLS CO anomaly for JJA 2008. The Anomalies are calculated with respect to daily means over the latitude band 10–40 degree N and longitude range 0 - 220 degree east, in 5 degree longitude bins. The dashed line in each panel indicates the location of the mean (zero anomaly) of the opposite field. The Pearson's correlation of the two fields for the 3 months is 0.84.



Fig. 7r. IASI CO at (a) 500 hPa, (b) 150 hPa levels and (c) MLS CO 147 hPa product for a selected day (26 July 2008). Dynamical fields of Geopotential Height (GPH, white contours) and horizontal winds (black arrows) are superimposed. Elevated terrains are indicated by gray shadings. The location of the Tibetan plateau (using 3 km elevation) is also shown in the maps.



Figure 9r. Selected latitude-height cross-sections of the IASI CO retrieval. The retrieval a priori profile is shown at the left of each panel (labeled "A"). The days and the location of the cross sections are selected to highlight the different vertical structures of the three modes of the anticyclone: a) 90°E on July 16 (Tibetan mode), b) 135°E on July 18 (Western Pacific mode), c) 50°E on July 22 (Iranian mode), and d) 135°E on July 27 (Western Pacific mode). The corresponding maps are given in Figs. 7r and 8r.