Responses to Referee 1.

Thank you for your review of our manuscript. Your questions and comments really helped us clarify our goals and added valuable content to the study. Below are our responses to each of your questions/suggestions.

Major Comments

1. Based on the results from the back trajectory model simulations, only 1.9% and 0.5% of the total trajectory accounts for convectively influenced particles at 150 and 100 hPa, respectively. Over 99% of particles over the Tibetan Plateau, which is convectively influenced, is based on those small numbers. My first question would be what explains the origin of the rest of the particles up to about 98.1 (and 99.5) %, that are not influenced by convection? It seems to me that convection has very little impact on the ULAC. I am also curious to know if allowing back trajectory simulations up to 24 hours, instead of 6 hours, will change the results significantly and if the results are meaningful.

The relatively small percentage of convective parcels is consistent with previous satellite estimates of tropical convection. For example, Gettelman et al. (2002) found that ~0.5% of tropical convection reaches the cold point tropopause. This is somewhat analogous to our 100 hPa trajectories. Liu and Zipser (2005) showed that ~1.3% of tropical convection made it to 14 km. This result is analogous with our 150 hPa trajectories. These similarities indicate that our numbers are reasonable and also that our 6 h cutoff is consistent with our goal of isolating deep convection. This does not say, however, that the rest of the ULAC parcels were not influenced by convection at some point. In fact, Bergman et al. (2013) recently published a study similar to ours, but using global models. They released 30-day back trajectories from the ULAC and found that 78% of them reached the PBL during the 30 days. However, they note that the largest uncertainty was "small-scale convective cells that are typically not well represented in low-resolution data sets" and that such convection likely "are important for the transport of air from the PBL to the 100 mbar anticyclone on time scales of 30 d and less." Thus, our study compliments theirs by examining the role of smaller-scale deep convection. So, we believe sticking with the 6 h trajectories is necessary to examine deep convection and to filter out large-scale processes that are well represented in global models.

The editor also pointed this out to us, and we have tried to state this caveat throughout the manuscript. In particular, in the Summary and Conclusions section, we have a few sentences to reiterate it: Pg. 24830, lines 23-29. We also have added an extended discussion of the above stated topics on lines 319-335 of the updated manuscript.

Thank you for pointing this out. We clearly did not do a good enough job in this section to put our results into context. Hopefully the added text will clarify any confusion.

2. One of the main points of this paper is that only the high resolution WRF run with less than 4-km horizontal grid can be used resolving convection over this

region. It would be helpful to show the coarser resolution (36 or 12 km grids) model runs failing to simulate any key features shown in the high-resolution model runs for comparison.

This is a great suggestion. However, a very recent study by colleagues Klich and Fuelberg (2013; available in ACPD) already presented an extensive breakdown of the role of horizontal grid spacing on vertical transport. They compared results from 45 km, 15 km, and 5 km grids both qualitatively and quantitatively. Their results highlighted the importance of the 5 km grid in simulating deep convection embedded within the warm conveyor belt of an extratropical cyclone that the other domains could not resolve. This motivated us to use a 4 km grid over the entire SE Asia region.

A limitation of the current study was the amount of computer resources available to us. Because the 4 km domain spanned SE Asia, the WRF output files were extremely large. So, to save space, we only saved output from the innermost domain. Previous studies (e.g., Done et al. 2004; Weisman et al. 2008; Kain et al. 2008) have done such analyses and have shown that 4 km grid spacing is the "coarsest" necessary to provide useful information about convective storms. Based on these studies and that of Klich and Fuelberg (2013), we do not believe an additional comparison would be "new" science. We have added sentences to the text (lines 166-169) that state our reasoning for this.

3. It needs to be clearly mentioned in the paper that the transport of pollutants might not be as efficient as transport of water vapor into the stratosphere though the ULAC as there is less pollutant sources over the TP than the surrounding regions. For instance, even though > 90% of convectively influenced particles originate from the TP, their contribution to the chemical composition within the ULAC can be less.

This is a very important point and thank you for bringing it to our attention. The following statement has been added to the manuscript:

Lines 482-485: "*However, note that the dominant role of the TP and SS regions in moistening the ULAC does not imply that they transport more pollutants into the upper levels because pollution transport depends on their source distributions, which were not considered in the current study.*"

We also have added the following to the Summary and Conclusions section:
Lines 623-626: "*It should be noted that our results show only a physical and dynamical pathway for boundary layer air to enter the ULAC through the TP and SS regions. Quantifying the amount of pollution that each region transports would require detailed knowledge of source distributions and a coupled meteorological-chemical simulation with convective-permitting grid spacing.*"

<u>Specific Comments</u>

1. WRF has very fine vertical resolution of 380 m in the upper troposphere and lower stratosphere. Even though it is easier to understand results at 100 and 150 hPa, I am curious to know variabilities at the levels between those two levels. I believe in the earlier studies, numbers of vertical levels in the data or the model were very limited (e.g., Dunkerton, 1995)

There are ~5-7 model levels between 100 – 150 hPa in WRF at any given time step. However, because WRF uses a pressure-based vertical coordinate, this can change depending upon thermodynamic conditions. We chose these two levels based on previous studies, but also for our specific case. The 100 hPa level was very near the tropopause and the 150 hPa level was ~2 km below the tropopause. Thus, these two levels spanned the TTL. The typical height difference between 150 mb and 100 mb is only ~ 2.4 km. The approximate variability between these two levels can be inferred from the results showing a 1.4% decrease in convection reaching 100 hPa versus 150 hPa. This indicates that only the deepest convection reaches 100 hPa. Thus, from 150 to 100 hPa we would expect a decrease in the amount of convective trajectories reaching the ULAC. Previous observational studies (e.g., Gettelman et al., 2009; Wang and Sassen, 2008) have shown a similar drop off in convection reaching these two levels.

We have added a statement to this effect on lines 325-327: "*Also, the 1.4% decrease in the number of convective trajectories reaching the 100 hPa ULAC versus the 150 hPa ULAC is an indicator of the variability that exists between those two pressure levels*."

2. P24812, L6 – Remove Fueglistaler et al., 2009

This reference was misplaced. Thank you for catching it. The sentence now reads:

"*A common approach for diagnosing the pathways by which air travels to the UTLS is to perform back trajectory analyses on a global scale (e.g., Bonazzola and Haynes, 2004; Fueglistaler et al., 2004; James et al., 2008; Tzella and Legras, 2011; Bergman et al., 2012) to determine the sources of air comprising the tropical tropopause layer (TTL; Gettelman and Forster, 2002; Fueglistaler et al., 2009).*"

3. Fig. 1 – I would recommend showing water vapor from WRF simulations along with MLS

We considered doing this. However, the problem is that the MLS is a 4 month JJAS average and we only ran WRF for 10 days. We tried to plot MLS for the 10 days of the simulation, but the observations were too sparse to give a "nice" picture. For comparison, the 10-day average WRF water vapor mixing ratio could be plotted, but it might be confusing to readers because the plot would be over a much smaller domain than the global MLS figure. We believe it is most important to show the global MLS water vapor to really emphasize how much the ASM ULAC stands out.

4. Section 2.4 – I am wondering if precipitation data (for example, TRMM) can be used instead of lightning data as convective proxies. What are the advantages or disadvantages using lightning data versus precipitation?

This is a great question that we explored. The problem with precipitation data, such as TRMM, is that it captures shallow, warm-rain events along with deep convection. And, because we wanted to focus on deep convection, we felt that lightning was a better proxy in this region of sparse observations. It is for this same reason that we evaluated our WRF simulation against the FY-2D brightness temperatures instead of TRMM. TRMM also is polar-orbiting, thus limiting its temporal resolution.

We have added the following statement to the manuscript to reflect our choice:
Lines 232-233: "*Although precipitation data also can be used for locating deep convection, they also capture shallow, warm-rain events that are not the focus of the current study*."

5. Figs.3 & 4 – I think that the geopotential height fields at 100 or 150 hPa can be representative of the strength of ULAC because it is a response to the convective forcing at the surface. I am wondering how representative or relevant the geopotential height at 700 hPa (low pressure in the lower stratosphere) to the ULAC?

The 700 hPa figure was not meant to be relevant to the ULAC, just the general evaluation of the WRF simulation. Because a common feature of the ASM is a broad region of low pressure near the surface, this part of the evaluation was to show that WRF captured this aspect of the ASM. The idea was to show a level in the lower-to-mid troposphere and a level in the upper troposphere to show that WRF was doing an OK job at simulating the observed synoptic features before we used it for further analysis.

6. The back-trajectory model results shown in Fig. 6 are almost confined within the anticyclone. I would expect particles spread broadly outside of the anticyclone boundaries but with highest density exists inside or near the TP.

Because of the 6 h cutoff to the back trajectories, it is hard for a large spread to occur. We believe that with longer back trajectories over a much greater period (e.g., an entire monsoon season), more spread would exist. However, this probably would be more due to the oscillation of the ULAC, and less due to horizontal transport. As mentioned in the introduction, the ULAC creates a "trapping" mechanism. It should be noted that this trapping works both ways: if parcels cannot leave horizontally, it will be hard for them to enter horizontally also. Thus, convection will have to be located very near the ULAC for parcels to enter. Bergman et al. (2013) recently showed this same phenomenon, but using an ensemble of global models.

We mention this in lines 340-342 of the revised text.

7. The histograms in Fig. 9 show very symmetrical distributions. It would be interesting to compare this with diurnal cycles of convection observed from satellite to see if they have the same diurnal cycles.

The references mentioned on pg. 24822 ln. 29 and pg. 24823 ln. 1 are observational studies that mention the diurnal nature of convection over the TP. For example, below is Fig. 5 from Yaodong et al. (2008).

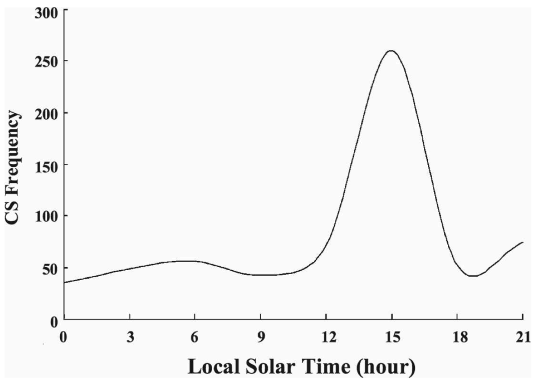


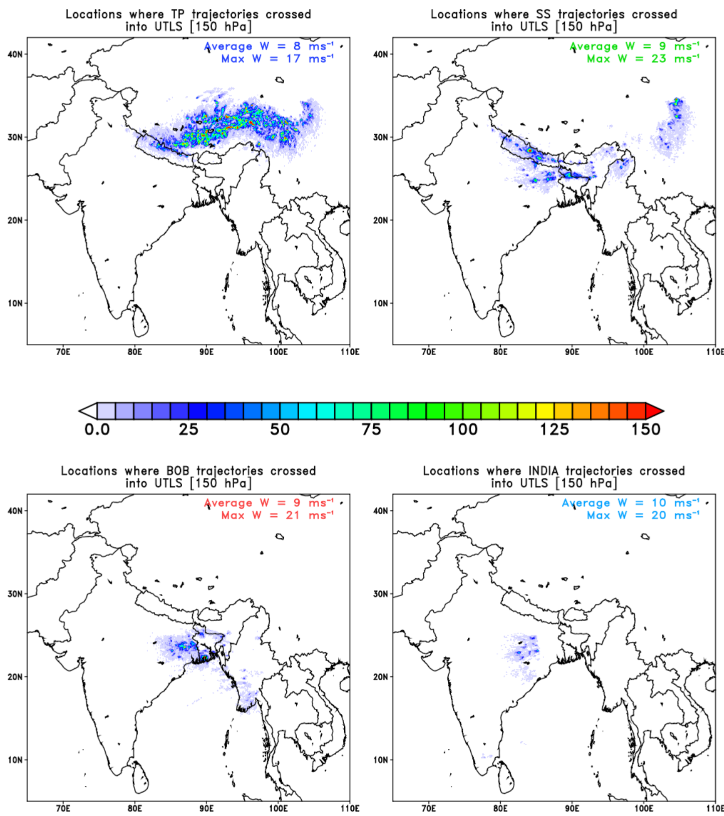
FIG. 5. Diurnal cycle of initiation of summer Tibetan CSs in 1998–2001.

Although they were looking at convective systems and not trajectories, these satellite-derived observations also show this same highly symmetrical distribution, which are consistent with our back trajectories.

Also, lightning is our surrogate for convection, and Fig. 10 shows its symmetries to be similar to the trajectories. We have not changed the text here.

8. Section 3.3 – I would like to know where the particles are located at 150 hPa if not inside the anticyclone as a result of the forward-trajectory run. Are they located near the anticyclone? How many particles end up their journey within the anticyclone?

Because this was only 1 day of the simulation, we did not want to present numbers stating the percentages that ended inside the ULAC vs. those outside the ULAC. The values likely would change greatly with increasing duration of the trajectories, or increasing the number of days simulated with 15 minute output. We were mainly using these just as a way to determine transport characteristics in each region, without restricting them to enter the ULAC. Below is an image of where the convective parcels crossed the 150 hPa surface:



The locations in which the convective parcels cross the 150 hPa surface, summed over the 16th of August, are very close to their source. This is not surprising because of the short (6 h) trajectory time.

9. I would recommend marking Xs on the lakes in Fig. 14 as it's done in Fig. 13.

Thanks, this is a great recommendation and has been added.

10. Titles and annotations of the figures can use larger fonts.

All of the figures have been remade with larger fonts.