Review #1

Major comments

1. The lower CALIOP lidar returns (SR) denotes the lower number of aerosol particles (=cleaner air) and/or the smaller aerosol particles. The authors should show the lower SR does not denote the smaller aerosol particles. This is because, if deep convections dehydrate LS, size of water-soluble aerosol particles in LS would be smaller and SR would be lower by the convections. This scenario is inconsistent with the paper. The authors should explain the definition of "clean" and the relation between "clean" and SR.

However, convection over land hydrates the Lower Stratosphere and not the opposite (Khaykin et al.,2009, Corti et al.,2088).Thus if particles were water-soluble, convection would result in a Scattering Ratio increase and not the opposite.

A definition of "clean air" is given p6.l21-22. We discuss the possible effect of the microphysics on the aerosol size paragraph 6.1.1 p13.

"It has been shown by Hamill and Steel (1981) that sulfate particles can growth significantly in the presence of water vapor at low temperature and thus result in SR-1 enhancements. The amplitude of the effect depends on the initial concentration of the particles and the amount of nitric acid (HNO_3) available. Assuming an initial concentration of sulfate of 10 particles/cm^3 and using water vapor, temperature and HNO_3 observations from MLS/Aura, the Mie SR-1 increase was shown to not exceed 10% in the worst case, mainly because of the very low HNO_3 concentration near the tropical tropopause. The change in retrieved aerosols profiles is not significant '.

»

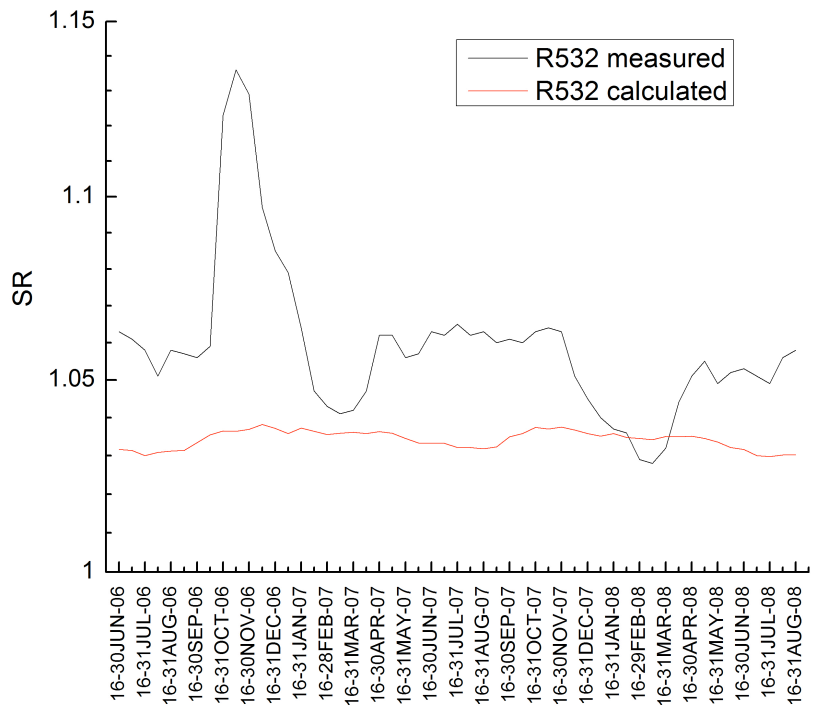

Fig a. Evolution of the mean SR (16-18 km) in the tropics (20N-20S) from CALIPSO (black) and calculated (red) using an initial concentration of 10part/cm^3 and water vapor, temperature and nitric acid from MLS/Aura.

Fig a shows that the minimum of aerosol during wintertime in the TTL cannot be explained by microphysical processes associated with evaporation of H2O/HNO3 on sulfate aerosols.
We have produced fig a to support our discussion but decided not to include it in the manuscript.

2. The authors should show the mechanism that deep convections cleanse aerosol particles in LS because the authors do not show deep convections cleanse them directly. For example, the theoretical simple estimation of the cleansing time is needed to validate their discussion.

Independent in situ measurements from backscatter sondes and optical particles counters demonstrate that the low aerosol loading of the lower stratosphere (fig.3) is geophysical. However, after accounting for all the possible mechanisms, we found that deep convection is the most coherent process to explain the rapid vertical propagation of the clean air feature.

Minor comments

1. The authors should explain all figures in detail in the text; e.g., I cannot find when and

which figure the authors describe at P168, L24, and P170 L11.

Changed L5p6 by : " …The remaining feature seen at 480-520 K (21 km) in March-April 2009 after the laser changeover (Fig.1, Fig .2)…"
Changed L25p7 by : « ….20S-10N during the Northern Hemisphere Winter at 14-20 km (Fig.1, Fig.2). »

2. P170−171: The authors should explain the method to retrieve the mean zonal cloud top. I believe the cloud top of deep convections should be averaged. The authors should also explain whether there is a relation between the cloud top height and cleans- ing. I think there isn't because the cloud top heights in Fig. 4 are almost the same. If so, the occurrence frequency of deep convections is more important for cleansing and it supports the paper.

The method to derive the cloud top is now explained L1P5 and L8-9P8 :

"…. Finally, clouds below 20 km have been filtered on the same grid by removing all pixels for which the mean volume depolarization ratio (δ) is greater than 5% using Eq (2)… »

« ….The zonal cloud top is determined using the mean zonal depolarization ratio (δ), derived from the statistics of cloudy/aerosols pixels separation as described in section 2…. »

In fact, fig.4 shows that the mean cloud top is reaching the highest levels during winter time supporting the conclusion of this study.

3. Overshooting is not defined as an area of rainfall and a radar reflectivity factor like the paragraph from P171, L15. Those are an empirical threshold of TRMM-PR. The authors should use "a deep convection" instead of "overshoot" in the text or they should add a comment of the exact definition of overshooting in the text. Or the authors should estimate overshooting by use of CALIOP/CloudSat and ECMWF/AIRS data.

Overshooting features are defined in this study by air masses crossing the 380 K potential temperature level often considered as the altitude of the tropopause in the tropics.

P172, L11: The authors should estimate a size of aerosol particles by use of a color ratio or the other methods. The data of an optical particle counter does not represent a size distribution of the global aerosol particles.

Unfortunately, the relatively high noise level of the 1064 nm channel combined with problems of calibration do not allow to use those measurements for estimating an accurate color ratio that would give us relevant indication about the size of aerosols

in the UT/LS.

5. P172, L7 (Figure 6): "<0.1" and up to "0.6" are not clear in the figure. The authors should enlarge the figure and draw it with a different color bar.

Figure 6 has been changed.

6. P174, L19: How do the authors estimate the values?

The method to determine the mass flux between the troposphere and the stratosphere is described in appendix 1.

7. I believe the section 4.3 is not necessary. Some of them should be included in the introduction.

This part discusses the possible others mechanisms that could explain the cleansing of the UTLS. We think it is important to keep it.

8. The authors should summarize eruptions in a table, such as the eruption date, the name of mountain, latitude and longitude, and the country. The eruption dates arrowed in Fig. 1 are also helpful to understand.

A table (table 1) listing the plume detected by CALIPSO is now included.

9. Figure 1: The authors should write the retrieval method of the potential temperature. Why did the two volcanic plumes become one in 2006?

The potential temperature is computed using a "classical" formula THETA=TEMP(K)*(PO(=10^3)/PRESSURE(Pa))^(R/Cp). **Since it is a common variable used by the atmospheric community, we do not want to include the formula in the manuscript.**

10. Figure 2: I believe the dotted line is not necessary because there is no description about it in the text.

This is done L26-29P6 :

« ….The vertical propagation of the clean air during the NH winter 2007-2008 is compared in Fig. 1 and Fig. 2 to the theoretical ascent of the lowest bulb of clean air from 380 K to 500K using Yang et al (2008) estimations. The observed propagation is much more rapid than the one deduced from the radiative ascent model….'

11. Figure 4: What is the color? Figures are too small. It should be ">5%", not "=5%."

Corrected

Figure 4 is now bigger with a color scale.

12. Figure 5 (upper): There are two peaks of Nb but there is one peak of SR in 2007. The authors should write the reason briefly.

Figure 5 has been modified to combine AOD from MODIS/Aqua and convective information from TRMM mesoscale convective systems.

13. Figure 8: The authors should describe the rectangle in the figure in detail.

The following sentence was added L11-14P12 :

«…a mass conservation flux is applied to the rectangle on the top of the anvil to estimate the amount of clean tropospheric air required at a level z to cleanse up the lower stratosphere.. »

14. The authors MUST check all references. FOR EXAMPLE, years of many refer- ences are incorrect, Schoeberl et al (2008) is not listed in the Reference, and Bourassa et al (2010) isn't in the text.

Corrected

Review #2

Major questions in addition to those from reviewer 1:

1. I understand authors use TRMM instead of CloudSat to describe the deep convection to include the important deep convection over land, which A-Train misses due to the diurnal cycle. However, TRMM PR only observe very large ice particles in the convective cores, it tends to emphasize more on the land convection with stronger updraft. The convection over ocean can also reach very high altitudes but with lower radar echo and they happen very frequent also. What are the impacts of those weak systems in your AI calculation? What would be the difference by using CloudSat cloud occurrence at 15 km to calculate AI? Can you predict the same trend as shown in Figure 7?

A new figure 7 is produced with an AI calculated with TRMM and Cloudsat
The following paragraph is added :

"

The relationship between AI and CALIPSO SR is reasonable, indicating that air masses transported by deep convection from the relatively clean surfaces of the southern tropics (Congo, Amazonia and Indonesian Islands) may be indeed responsible for the cleansing the TTL during the NH winter. The contrast between the convective cleansing observed in the South and the reinforcement of aerosols in the TTL in the North is consistent with the increased AI during the NH summer by convective lofting of natural and anthropogenic aerosols during the Asian and African monsoon seasons (Fig. 7).

However, the rapid cleansing of the TTL up to 19-20 km during the SH convective season shows significantly higher vertical propagation than of the aerosol enhancement in the NH convective season that is limited to 16-17 km. This might be related to the influence of the aerosols on convection intensity. Rosenfeld et al. (2008) suggested that the vigorous convection as inferred from the Convective Available Potential Energy is maximum with AOD close to 0.25. This value is remarkably close to the lowest AI values reach (that represent also a mean AOD) in the Southern tropics during the NH winter when the cleansing is more intense, reaching as high as 19-20 km… »

2. It is known that the deep convection reaches the maximum over the West Pacific in DJF. How would that relate to your cleansing? At least the convection over water has low aerosol sources. Could this high vs. low aerosol in the upper troposphere be just due to the seasonal cycles of convection over land vs. over ocean, just like the starting of CO tape recorder explained by Liu et al. 2008 (GRL)?

The Western Pacific is often referred to be the entrance door for troposphere air masses to reach the stratosphere also called "the stratospheric fountain" (Newell, 1981). In fact, model trajectory (Fuegistaler et al., 2005) indicates that a very large fraction of air parcels entering the stratosphere crossed the tropopause over this region. Very low water vapor measurements from HALOE/MLS (Read et al., 2007) confirm that air would be dehydrated during its ascent through extremely cold temperature at the tropopause level over the Western Pacific and could explain the dryness of the stratosphere. Besides, Cloud top temperature derived from Infrared black body emission shows also coldest feature above this region.
However, Liu and Zipser (2005) have shown that brightness temperature is not a good proxy of deep convection. In fact cloud top derived from this method can also be large-scale thick cirrus not directly related to convection but experimenting very cold temperature since located at the tropopause. Morever, cirrus clouds cover is shown to be maximum above the Western pacific without always evident connection with convection (Sassen et al., 2008). With the TRMM radar, Liu and Zipser (2005) have reveal that the deepest and strongest convective events occur over land and not over maritime region. Even if the convection ocean has low aerosol source, it is not going to affect the TTL aerosol budget since not penetrating the TTL. Very recent aerosol composition measurements have revealed that marine aerosols don't reach levels above 12-14 km during oceanic convective events over the Western Pacific whereas air masses rich with organic materials often penetrate the TTL over Amazonia (Fryod et al., 2009,2010, ACP).

3. Please be clear on how you calculate AI. Did you use the daily mean AOD for each TRMM OPT cases or the monthly mean? Calculating AI using monthly mean of AOD and the individual cases of convection could be misleading if there is a large daily variation of AOD.

This is a very good point that motivated us to er-think the method of calculation of the Aerosol Index. Due to the important daily variability in AOD, we have change the method of extraction of AOD by using MODIS/aqua instead of CALIPSO.

This is described P9-10

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As previously shown, the cleansing of the lower stratosphere is correlated with the southern tropics convective season, but if not anticorrelated with the northern

hemisphere season. We evaluate the convective transport of low versus high aerosol loading of tropospheric air masses in the TTL by studying the geographical position of MCSs as seen by the TRMM radar relative to the amount of aerosols in the troposphere. Since deep convection is known to show a pronounced diurnal cycle of peak intensity in late afternoon (Liu and Zipser, 2005), we have used the Aerosol Optical Depth (AOD) from MODIS on the TERRA satellite platform at 10h30 am local time. Figure 6 represents bimonthly maps from October 2007 to September 2008 of MCS locations reaching at least 14 km tagged with the nearest value of MODIS AOD in space and time. Since more than one day of observations is required to obtain a complete spatial coverage, two day mean AOD maps have been constructed with a spatial resolution of 3° lon x 3° lat from the MODIS level 3 daily joint aerosol/water vapor and cloud product. As shown by Liu and Zipser (2005), the maps indicate that deep convection is dominant over land during the local summer convective season. The statistics of tagged-AOD MCSs is given in Table 2 for the different maps of Fig. 6. In Oct-Nov, the maximum of potential aerosols lofting occurs over East Amazonia next to the arid N-E Brazil, where a maximum CO in the lower stratosphere was also reported by Schoeberl et al. (2006). In Dec-Jan 08, the convective activity is greatest above the continents of the southern hemisphere, in South America, South Africa, Indonesia and northern Australia. MCS occurred in relative clean environment (AOD<0.4) 73% of the time except in Central Africa where convection coincides with the beginning of biomass burning season as shown by the number of fires associated with CO emission (http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MODAL2_M_AER_OD&d2=MOD14A1_M_FIRE). During this period, the Harmattan wind from the north-east advects Saharan dust towards MCSs in Western Africa. Later in the winter season (Feb-Mar 08), the ITCZ and land convection have moved northward but still remain in clean tropospheric conditions with 76 % of MCS with AOD<0.4. In early spring, in Apr-May, the aerosol loading associated with convection increases (MCS of AOD>0.4) by 10 % compared to previous periods. This polluted convection occurs primarily in Western and Central African regions of biomass burning and Saharan dust, but also in South East Asia when the monsoon onset is

reaching the Bay of Bengal and Thailand. The highest level of aerosol associated with convection occurs during the NH summer (Jun-Jul 08 and Aug-Sep 08), where 25% of MCSs are associated with AOD>0.4 and 65% of MCS tagged with extreme AOD values (>0.6) are located over Southeast Asia (NE China and NW India). As shown by Dey et al. (2010), polluted aerosols with dust dominate the population of particles especially in northeast India and along the Indo-Ganges basin. Deep convection occurring over those regions could transport aerosols upwards, confirming the possible convective origin of an elevated layer observed during the Asian monsoon reported by Vernier et al., (2011a) "

The method to compute the AI is described L4P10 :

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$$AI(t) = \frac{1}{N} \sum_{n=1,.N} MCS(n,t) \times AOD(n,t) \quad \textbf{(3)}$$

where n is the index of each MCS (N the total) occurring in the time and space resolution as described below. The AI has been computed from TRMM and CloudSat MCSs extracted for the later one from the University of Utah database (http://trmm.chpc.utah.edu) by selecting convective events reaching 14 km of at least 500 km horizontal extension. «

Minor comments:

1. P 3, line 27, Zipser et al. (2006), also it is not on the reference list. 2. P 4, line 10, Ekman et al 2006 missing from the reference list. 3. P 4, line 13, Fryod et al. 2009 missing from the reference list.

Corrected

4. P 9, line 27-28, I am not sure what may indicate from these. You cannot claim that the cleansing is due to the OPT in SH, but pollution is due to the OPT in NH. Since TRMM OPTs are mainly from over land, it is hard to imagine Argentina OPTs would clean the air and but OPTs during Asian monsoon would pollute the air with aerosols.

Even if some places in the southern hemisphere (ex Oct-Nov Argentina) are conductive to convective systems development associated with relative high values of AOD, the overall picture given by this analysis shows that deep convection in the

southern hemisphere tends to occur in cleaner environment than in the north. Given the high population density and the extreme level of pollution associated with the Asian monsoon, the Southeast Asia could be potentially the main source of aerosols for the TTL. Summer aerosol maps at the tropopause level show a very distinct and unique aerosol feature associated with the Asian monsoon during the NH summer (Vernier et al., 2011a).

5. P 10, line 22, Liu et al. 2008 is missing from the reference list. 6. P 10, line 24, I see cleansing in 18-20 km has about one-three month lag from below in Fig 1. Could this just be part of BD circulation? Why do we need another explanation?

The exact reference is Liu et al.2007

7. Fig 7, why do not show all periods as Fig.5? Just emphasize on the period without the influence of volcanic aerosol in the discussion.

We now show the entire period but focus our discussion on the non-volcanic period 2006-2008.

Review #3

Major points

1. Convective overshooting
a) In order to underpin the fast vertical motion, I would draw on Fig. 1 an incurved vertical line starting at least on JAN-FEB 2008 (eventually on FEB 2007 and 2009) that will follow the propagation of the clean air from ~14 to ~20 km. Over this line, I would draw a line symbolizing the slow ascent by radiative heating, as on Fig. 2. This will help again stressing that the propagation of clean air from CALIOP in much more rapid that slow ascent.

We have followed your suggestion and modified fig.1 accordingly.

b) On Fig. 3 (left), the minimum in CALIOP SR around 19 km does NOT coincide with any minimum of aerosol mixing ratio from balloon-borne OPC (minimum from 14 to 19 km). It is fine for BKS measurements (same units) showing a minimum around 19 km. Is this related to the fact that you compare two different quantities, CALIOP SRs and OPC mixing ratios?

We have converted balloon-borne OPC size distributions into Scattering Ratios using Mie theory. See New fig.3

c) Fig. 4 : the 6 boxes absolutely needs to be enlarged and eventually the colours will need to be modified. It is impossible to detect the fine structures of less clean air around 16 km in the NH in APR-JUL, unless zooming a PDF file on a screen. Also, the Colour Chart is missing.

Fig.4 had been changed.

d) I really cannot understand Fig. 5, although I spent several days on it. If I consider CALIOP/TRMM measurements in the SH (lower panel), the convective overshooting period is in phase with the propagation of a minimum CALIOP SR, starting in Novem- ber. As on Fig. 1, you could eventually draw the vertical displacement of the miminum of SRs compared to the slow ascent calculations. This is obvious. Now I consider the same Figure, but for measurements in the NH (upper panel). Although the TRMM overshoots are 6-month out-of-phase compared to be SH, the CALIOP SR time evolu- tions at different altitudes in the NH are completely consistent with the one in the SH. I understand you can have horizontal transport and the propagation of (clean or pol- luted) air from one hemisphere to the other, but I am puzzled by the fact that 1) there is no phase shift if the SR evolution between the two hemispheres, and above all, 2) SR evolution is the same considering either SH or NH tropics. This is the main weakness of the paper, namely explaining why SRs in the SH and NH tropics behave consistently despite the fact that AODs and overshoots strongly differ.

Yes, the aerosol variation in the southern or northern tropics depicts an annual cycle. However, the minimum during the NH winter tends to be located in the south (fig.4) at around 15S-5N and the maximum during the NH summer is further north at around 10N-30N (fig.4). We realized that separating each hemisphere to study the influence of the convection on the TTL aerosol loading is not a good solution since deep convection is not equatorial symmetric. For that reason, we have modified fig.5 by plotting the mean SR evolution between 14-17km in function of time and latitude on which we have superimposed TRMM and CALIPSO derived Inter Tropical Convective Zone in red and white. Besides, the horizontal transport at those levels is discussed with the mean merdionnal wind fields from ECMWF at 100hPa.

The following paragraph is added:

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To shed light on the relationship between cleansing episodes and deep convection, Figure 5 shows the latitudinal evolution of the SR between 14-17 km together with the location of the Inter Tropical Convergence Zone (ITCZ) at 14 km as inferred from the TRMM Mesoscale Convective Systems (MCS) position (red) and the CALIPSO cloud cover (white). White arrows show the mean meridional wind every 16 days derived from ECMWF at 100 hPa. The TRMM MCSs are selected by considering contiguous precipitating areas greater than 2000 km^2 of radar signal larger than 20 dBz reaching at least 14 km, with a minimum of 2 flashes as observed by the Lightning Imaging Sensor (LIS) also on TRMM. The flash discrimination is chosen to select only MCSs with strong updrafts inducing hail formation and lightning. All MCSs are extracted with those four conditions from the TRMM database (http://trmm.chpc.utah.edu/) from June 2006 to February 2009 and sorted into 16-day bins comparable to CALIPSO. The limits of the ITCZ (red line) from these observations are derived using the 10th and 90th percentile of latitudinal position of MCSs. The CALIPSO cloud area is derived from the depolarization channel as described above (Fig. 4). As above, the bounds of clouds are defined by the 10th and 90th percentile latitudinal location of cloudy pixels. The term “cloudy pixels” represents all types of clouds observed by CALIPSO including storms, anvils

and cirrus. During the NH winter, the clouds extend to higher latitude than the ITCZ defined by the MCSs location due to the persistent thick cirrus cloud layer up to 10°N in the West Pacific where the tropopause is the highest and coldest (Sassen et al., 2009). In contrast, the ITCZ area extends to higher latitudes than the clouds at 14-17 km in the summer of both hemispheres and particularly in the North. This is likely due to the less frequent clouds during CALIPSO overpasses at 1h:40 am and pm over land convective regions (monsoon in the north) whereas cloud cover exhibits a large diurnal cycle with a strong maximum around 16-17 h local (Liu and Zipser, 2007).

Aside from volcanic plumes during the NH winter 2006 (Tavurvur, 0-20S) and the NH summers of 2008 and 2009 (Kasatochi, Sarychev, 20-50N), the aerosols in the TTL show an annual cycle. The maximum cleansing of the 14-17 km layer is located in the middle of the ITCZ area in the southern hemisphere (5S -25S) during the northern winter but extends further north and south than the limits of the ITCZ area. As shown by the meridional wind arrows, this altitude level corresponds to the upper branch of the trade wind Hadley cell which is associated with the advection of airmasses from the ITCZ to the subtropics where there is no more convection. In contrast, it is the opposite in the northern hemisphere summer, where a maximum aerosols load is observed between 20-40°N in the northern part of the ITCZ area. The impact of convection on the TTL aerosols load thus may depends on the amount of aerosols available at the surface

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e) Now, we examine whether air lifted in the convective overshoots is poor or enriched in aerosols. Again, Fig. 6 is quite small and would require an enlargement. Anyway, on my screen zooming the PDF file, we can notice that associated with the overshoots, and particularly over the African continent, is a minimum in aerosol optical depths. Is this an issue to be raised regarding the sampling of the CALIPSO vs. TRMM measure- ments, namely a lack of CALIPSO data or actually a minimum in AOD?

Fig 6 was modified to combine AOD from MODIS/Aqua and TRMM. To avoid the sampling effect of CALIPSO AOD, available with a complete coverage after a period of 16 days only , we have chosen to use bi-daily maps of AOD derived from MODIS/Aqua.

See changes in section 4 :

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4. Modulation of the aerosol loading in the TTL by deep convection.

As previously shown, the cleansing of the lower stratosphere is correlated with the southern tropics convective season, but if not anticorrelated with the northern hemisphere season. We evaluate the convective transport of low versus high aerosol loading of tropospheric air masses in the TTL by studying the geographical position of MCSs as seen by the TRMM radar relative to the amount of aerosols in the troposphere. Since deep convection is known to show a pronounced diurnal cycle of peak intensity in late afternoon (Liu and Zipser, 2005), we have used the Aerosol Optical Depth (AOD) from MODIS on the TERRA satellite platform at 10h30 am local time. Figure 6 represents bimonthly maps from October 2007 to September 2008 of MCS locations reaching at least 14 km tagged with the nearest value of MODIS AOD in space and time. Since more than one day of observations is required to obtain a complete spatial coverage, two day mean AOD maps have been constructed with a spatial resolution of 3° lon x 3° lat from the MODIS level 3 daily joint aerosol/water vapor and cloud product. As shown by Liu and Zipser (2005), the maps indicate that deep convection is dominant over land during the local summer convective season. The statistics of tagged-AOD MCSs is given in Table 2 for the different maps of Fig. 6. In Oct-Nov, the maximum of potential aerosols lofting occurs over East Amazonia next to the arid N-E Brazil, where a maximum CO in the lower stratosphere was also reported by Schoeberl et al. (2006). In Dec-Jan 08, the convective activity is greatest above the continents of the southern hemisphere, in South America, South Africa, Indonesia and northern Australia. MCS occurred in relative clean environment (AOD<0.4) 73% of the time except in Central Africa where convection coincides with the beginning of biomass burning season as shown by the number of fires associated with CO emission (http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MODAL2_M_AER_OD&d2=MOD14A1_M_FIRE). During this period, the Harmattan wind from the north-east advects Saharan dust towards MCSs in Western Africa. Later in the winter season (Feb-Mar 08), the ITCZ and land convection have moved northward

but still remain in clean tropospheric conditions with 76 % of MCS with AOD<0.4. In early spring, in Apr-May, the aerosol loading associated with convection increases (MCS of AOD>0.4) by 10 % compared to previous periods. This polluted convection occurs primarily in Western and Central African regions of biomass burning and Saharan dust, but also in South East Asia when the monsoon onset is reaching the Bay of Bengal and Thailand. The highest level of aerosol associated with convection occurs during the NH summer (Jun-Jul 08 and Aug-Sep 08), where 25% of MCSs are associated with AOD>0.4 and 65% of MCS tagged with extreme AOD values (>0.6) are located over Southeast Asia (NE China and NW India). As shown by Dey et al. (2010), polluted aerosols with dust dominate the population of particles especially in northeast India and along the Indo-Ganges basin. Deep convection occurring over those regions could transport aerosols upwards, confirming the possible convective origin of an elevated layer observed during the Asian monsoon reported by Vernier et al., (2011a)

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f) I understand there is slightly more AODs in the NH compared to the SH in the vicinity of the convective overshootings. Then, an Aerosol Index is calculated. This is indeed a good idea. Unfortunately, Fig. 7 shows the time evolution of the AI considering the whole tropical band, 20◦S-20◦N. You absolutely need to consider the two bands (NH and SH tropics) and eventually the global tropics since at this stage, I do not really know why SRs behave similarly in the NH and the SH. Furthermore, on this Fig., CALIPSO SRs and AIs seem not to be sampled in the same interval: 15 days for SR, and 30 days for AI. This should be stated or calculated using the same time sampling. Finally, I cannot understand the sentence "The minimum observed, delayed by 2 months. . .", and more generally, all the paragraph starting Page 173 Line 22.

We decided not to separate each hemisphere to compare the SR evolution and the AI since the horizontal transport effect is not taken into account in this study. For this reason, we average the CALIPSO SR (fig.7) inside the ITCZ as inferred from CALIPSO cloudy pixels (white areas fig. 5).

AI and SR are now compared base upon this new method as described P11 :

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To better quantify the impact of convection on the TTL aerosol load, we have created an Aerosol Index (AI, Eq. 3) that is the average of the tagged MCS-AOD occurring within a 16 days period and a zonal latitude band of 4 degrees. It is given by

$$AI(t) = \frac{1}{N}\sum_{n=1,.N} MCS(n,t) \times AOD(n,t), \quad (3)$$

where n is the index of each MCS (N the total) occurring in the time and space resolution as described below. The AI has been computed from TRMM and CloudSat MCSs extracted for the later one from the University of Utah database (http://trmm.chpc.utah.edu) by selecting convective events reaching 14 km of at least 500 km horizontal extension. Figure 7 shows a comparison between this index and the mean CALIOP SR between 14 and 17 km. To emphasize the effect of deep convection on the TTL aerosols, we have calculated the mean CALIOP SR within the ITCZ from the 10th and 90th percentile CALIPSO cloudy pixels (latitude band within the white line in Fig. 5). Since volcanic plumes from Tavurvur and Sarychev contaminate the years of 2006 and 2009, respectively (Fig. 1, 2 and 5), we focus on the 2007-2008 period. The annual cycle of TTL aerosols from CALIPSO is well matched by the AI deep convection-AOD model without significant phase lag using TRMM as well as CloudSat. However, the strong summer time CALIPSO SR peak is not seen on the AI that rather shows a slight maximum expending from April to November.

The relationship between AI and CALIPSO SR is reasonable, indicating that air masses transported by deep convection from the relatively clean surfaces of the southern tropics (Congo, Amazonia and Indonesian Islands) may be indeed responsible for the cleansing the TTL during the NH winter. The contrast between the convective cleansing observed in the South and the reinforcement of aerosols in the TTL in the North is consistent with the increased AI during the NH summer by

convective lofting of natural and anthropogenic aerosols during the Asian and African monsoon seasons (Fig. 7).

However, the rapid cleansing of the TTL up to 19-20 km during the SH convective season shows significantly higher vertical propagation than of the aerosol enhancement in the NH convective season that is limited to 16-17 km. This might be related to the influence of the aerosols on convection intensity. Rosenfeld et al. (2008) suggested that the vigorous convection as inferred from the Convective Available Potential Energy is maximum with AOD close to 0.25. This value is remarkably close to the lowest AI values reach (that represent also a mean AOD) in the Southern tropics during the NH winter when the cleansing is more intense, reaching as high as 19-20 km.

ther shows a maximum expending from April to November.

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2. Aerosol mixing ratio

I am not a specialist in aerosols, but all the discussions related to the impact of over-shooting at the global scale (Section 4.2) depends on 1) the fact that you suppose (SR-1) to be proportional to an aerosol mixing ratio, and 2) a conceptual model de- scribing the mass flux conservation in terms transport processes. First of all, you have to clearly specify why the proportionality assumption is valid in this particular context. What kind of approximations you perform? Note for instance the differences in SRs and mixing ratios in Fig. 3. Secondly, the conceptual model refers to a sort of long-lived species since only transport processes are taken into account. In my opinion, aerosols cannot be considered as long-lived species, since several processes can alter its evo- lution (wash out, sedimentation, nucleation, etc.). My understanding of the calculation performed is that, by only considering transport terms, you get rid of other loss terms, that can eventually be negligible, I can admit this point but we do not know. This needs to be developed or discussed. At that stage, I would consider these calculations as an

C501

upper limit of the troposphere-to-stratosphere mass flux, explaining why the figures are so big (up to 20 times) compared to values from radiative calculations.

To discuss the limitations of the method, we added the following paragraph L27-31 P 12, P13-L1-5

“

There are, however, some limitations in the validity of the method used in the above calculations. The conversion of the Scattering Ratio into an aerosol-mixing ratio required a constant phase function in time and altitude meaning that aerosol

composition and size distribution remained the same. However, even if, as measured by Froyd et al. (2009) over Costa Rica, the aerosols above the tropopause are for 75% made of sulphate-organic particles, 20% of them were of carbonaceous material. Since organics particles are known to be more absorbing than scattering, this would imply that the phase function used in the conversion would not be conservative below the tropopause. In addition the calculation applies only if aerosols are long lifetime tracers, insensitive to changes by microphysical processes. But since sulfate-organic particles are dominants in the convective SH region and microphysical processes have little impact on these as discussed below (section 6), the above limitations are expected to have little impact on the conclusions.

"

Minor points:

P. 169, L. 1: write "do not" instead of "don't"

Corrected

P. 172, L. 18: you should remove the first "WV"

Corrected

P. 172, L. 26: should be "anticorrelated"

I don't think so. We speak here about the clean air(low aerosol loading) that is correlated with the convection in the southern hemisphere.

P. 174, L. 11: "beta-aero" and "beta-mol" are not defined

Corrected by (SR-1) (SR-1=β_{part}/β_{mol})

And β_{part}, β_{mol} are defined P5L9-12 :

"….Where β_{part} and β_{mol} represent the molecular and particulate backscatter… »

P. 175, L. 18: the reference "Pommereau et al., 2010" is not present is the Reference List.

It is indeed Pommereau et al., 2011, now in the reference list.

P. 185, Caption of Fig. 1, remove one “after”.

Corrected

P. 186. Fig. 2, as proposed in Fig. 1, I would draw one line (maximum of 3) showing the evolution of the clean air bubbles along the vertical in FEB 2007, 2008, and 2009.

Done

P. 189, Fig. 5, again I would draw a vertical line showing the vertical displacement of the clean air parcels in the SH and NH tropics. Eventually, show the radiative heating calculations.

Fig.5 has been modified

P. 191, to be split into 2 or 3 Figs.: NH, SH and global tropics. P. 192, Fig. 8: y label is missing, I guess “height”, together with the x label and values.

Fig.7 and Fig.8 have been corrected.

Review #4

General Comments
This paper presents temporal and spatial variabilities of aerosols measured by CALIOP lidar in the tropical Upper Troposphere and Lower Stratosphere from 2006 to 2009. The evolution of aerosols includes fast cleansing events between 14-20 km as well as volcanic eruptions and convective events over the Asian monsoon. The aerosol cleansing events are explored in depth in connection with tropical convection and flux calculations in the Tropical Tropopause Layer (TTL). It is noteworthy that the recalibrated aerosol products used in this study (as shown in Vernier et al., 2009) show the details of transport processes in the TTL, which has not been shown from other tracers. And the amount of mass flux from the troposphere to the lower stratosphere is significant based on this study. However, apart from all the numbers presented in this study, the large mass flux contribution by overshooting deep convection in the tropics is still puzzling to me. According to Liu and Zipser (2005), only 1% of deep convection reaches as high as 14 km and 0.1% penetrates 380 K isentropic surface. And the cleansing events reach up to 20 km well above the tropopause. The results in this study will be more convincing if the authors can include any evidence of convection reaches up to higher altitudes.

Specific Comments
1. The aerosol layers related to the monsoon convection (May-Nov?) are not clearly shown and hard to separate from the volcanic plumes in Fig. 2 (the last paragraph on page 168). It would be helpful to indicate volcanic eruptions and the monsoon events as separate symbols. Or if the monsoon convective events are annually repeated, the annual cycle can be extracted from the variability.

Numbers associated with table 1 indicate now aerosol feature associated with volcanic/fire plumes and also Monsoon ("M"). They are placed in fig.1 and fig.2. The Monsoon feature is the object of a separate paper (Vernier et al., 2011a).

2. In Fig. 2, CALIOP SR has the minimum at 400-440 K layer in early 2008. If this clean air is originated from the troposphere, the minimum should be located at lower levels? Also the maxima in the summers of 2008 and 2009 are located at the same layer (400-440K).

In fig.2, clean air at 400-440 K in early 2008 are connected with clean air at lower levels (360-400 K). The maxima in 2008 and 2009 at 400-440K are volcanic plumes from Kasatochi and Sarychev. They have been injected directly at this level after each eruption, so that their intensity is less pronounced at 360-400 K lower levels (360-400 K).

3. 1st sentence on Page 170 – The reason for 2 months' averaging is not clear to me. The authors used 16-day average in the previous figures and the effect of QBO in the zonal asymmetry should be small at this altitude.

The reason is mainly due to the noise. At low aerosol levels, we need to average more data to obtain a reasonable Signal to noise Ratio. We found that a two months averaging is a good trade off between lower noisy picture and good resolution. The effect of the QBO between 25-34 km (fig.5) is a consistent feature that was already by SAGE II in the past (Trepte et al., 1992).

We have decided too keep this paragraph the way it is.

4. It is shown in Liu & Zipser (2005) that tropical convection has prominent semiannual cycle with maximum intensities in spring of both hemispheres (Apr and Sep). It is hard to reconcile this with convective time series in Fig. 5.

Yes, tropical deep convection has a dominant semi-annual cycle between 20N-20S. However, if we take separately each hemisphere (0-20S and 0-35N), we observe an annual cycle with a phase lag of 6 months in each one of them. The semi-annual cycle observed in the all tropics is very likely due to the fact that the summer time convection associated with the Asian monsoon above 20N is in the average 20N-20S. By plotting (not shown) the total number of MCS reaching 14 km [40N-40S], the picture resulting depicts an annual cycle with a maximum during the NH summertime, modulated during spring and fall seasons by the convection over Central Africa and Amazonia.

5. In section 4.2, the unit of the flux is shown as kg/s instead of kg/m2/s (Yang et al., 2008). And Yang et al. (2008) have shown fluxes in layers not every1-km level as shown in Table 1. I am wondering about how the comparisons in Table 1 are made.

The flux from Yang et al.,2008 has been extracted at the middle of each km layer. The mass flux in this paper is given kg/m2/day. It is then converted in kg/s by multiplying by the surface of the tropics (20N-20S) and dividing by (3600*24 s) to get it in days.

Technical Comments

1. Page 170, line 16 – Mote et al. (2008) should be Mote et al. (1998). 2. Page 171, line 16 – times series should be time series

Corrected

3. Using different color scales in Fig. 4 and increasing the size of the figure might help to follow the events details.

We have increased the size of fig.4

4. The lines in Figure 5 would be more recognizable if the legend is put outside of the frame.

Fig.5 has been modified.

5. Page 172, line 18 – WV water vapor (WV) should be water vapor?

Corrected

6. Overlaying PDF of the TRMM OPFs on top of the white dots (or replace them) in Fig. 6 will help to quantify the convective activities.

Fig.6 is modified and a table to support the discussion is added

7. Page 173, line 17 – 14-17 km?

Yes, 14-17 km

8. Page 175, line 5 – Halogen Occultation Experiment

Corrected

9. Page 175, line 29 – Numerical Weather Prediction (NWP) models

Corrected

10. Page 176, line 10 – by radiative heating

Corrected