Response to the comments by Referee #4

We greatly appreciate the reviewer for his/her thorough review and constructive comments. We have revised our manuscript as much as possible following his/her comments. Our response to each comment is described as follows:

Response to major comments:

Title: Since this study is on the Antarctic it should be reflected in the title.

The title has been revised as follows:
"Simultaneous occurrence of polar stratospheric clouds and upper-tropospheric clouds caused by blocking anticyclones in the Southern Hemisphere"

p20008, l7-8: Tropospheric clouds are not located around the tropopause and slightly above rather than in the troposphere. Tropospheric clouds form and stay in the troposphere though they can penetrate the tropopause. This so-called overshooting convection occurs rather in tropical and midlatutdinal cyclones than in polar cyclones. PSC presence/formation has been associated to deep tropospheric cloud systems, thus clouds that extend over several kilometers altitude in the troposphere.

To examine the effect of tropospheric cyclones on the PSC/UC frequency, we have newly performed an analysis similar to Fig. 6a but for the cyclonic PV anomalies (Fig. 6b). It is shown that the PSC/UC frequencies in the altitude range of 8-24 km are significantly low near the cyclone. We have newly added several sentences regarding Fig. 6b to the 3rd paragraph of Section 3.2.

P2008, l10: Do you mean here that the blocking highs lift the tropopause up to 15 km or that there bulging effect is visible up to 15 km?

The vertical extent of anticyclonic PV anomaly is estimated to 15 km (Fig. 8d). The vertical e-folding scale of temperature anomaly associated with PV anomaly is estimated as Rossby height, which is 5 km in the present case. Thus the vertical extent of temperature anomaly extends to 20 km (15 km + 5 km). This point has already been discussed in Section 3.2.

P2008, l13: There have never any PSC been observed outside the polar vortex. PSC form within the Antarctic and Arctic vortices. In both hemispheres, outside the vortex the temperatures are too high for PSC formation.

The analyzed region is confined to the region inside the polar vortex in Section 3.3. The 7th sentence of Abstract has been removed. The Table 2 and Fig. 9 together with their explanations have also been revised (the 2nd sentence of the 2nd paragraph of Section 3.3, and the 2nd sentence of the 3rd paragraph of Section 3.3, respectively).

P20009, l9-11: From the Teitelbaum et al. (2001) study it becomes not clear if they looked at cyclones or anticyclones. Thus, the text referring to this study should be changed and it should be written as in the Teitelbaum conclusion that they find a connection between PSCs and miniholes to synoptic-scale dynamics or synoptic scale tropospheric cyclogenes. Further, cyclones or anticyclones do not appear near or around the tropopause, they extend over the entire troposphere.

First, Teitelbaum et al. (2001) mentioned in the abstract that 'we show that when both PSCs and localized ozone minima appear, they are associated with anticyclonic potential anomalies near the tropopause'. They also showed several cases of PSCs observed by POAM II above tropospheric anticyclonic PV anomalies, which are associated with the elevation of the tropopause (their Fig. 2).

Second, according to the theory of baroclinic instability, the growth of synoptic cyclone and anticyclone are understood as interaction of PV anomalies at the ground and tropopause (Holton, 2004; Vallis, 2006), as mentioned in the 5th paragraph of Section 3.2. It is quite common in tropospheric cyclone/anticyclone studies to analyze the PV distribution near the tropopause height (e.g., Hoskins et al., 1985; Davis and Emanuel, 1991; Nakamura and Wallace, 1993).

P2009, l22: Studies as the McDonald et al. (2009) study performed for the Arctic should be discussed here as well.

We have added description of the study by Dörnbrack and Leutbecher (2001) in the 2nd sentence of the 3rd paragraph of Section 1.

P20010, l25 ff: Also Arctic studies on this topic as e.g. the study by Achtert et al. (2012) should be discussed here.

We have added description of the study by Achtert et al. (2012) in the 3rd sentence of the 4th paragraph of Section 1.

P20010, l28: There is no need for inventing an abbreviation for blocking highs. Blocking highs should be refereed to as blocking highs and not as BHs.

We have removed the acronym "BH" and changed "BH" to "blocking high" in the manuscript.

P20011, l14: Tropospheric clouds are definitely in the troposphere. Otherwise these would be stratospheric clouds.

We have newly performed an analysis of the PSC/UC frequencies based on tropopause-relative altitudes (z_{TP}) (Fig. 5). The tropopause definition (h_b) proposed by Wilcox et al. (2012) has been used in the revised manuscript. We have found that the PSC/UC frequencies in z_{TP} = 6-13 km (i.e., PSCs) have positive correlation with those in

z_{TP} = 0-2 km. This point has been discussed in the 6th paragraph of Section 3.

P20011, l15: What actually is done here? It sounds like your algorithm is not able to differentiate between tropospheric and stratospheric clouds. How can you then derive the simultaneous occurrence of tropospheric and stratospheric clouds if you even don't know what has been measured?

We have significantly revised Fig. 3 and 4. In the left panels of Fig. 3, the correlation coefficients of PSC/UC frequency at two different altitudes in the time period of June through September of 2007-2011 are shown. In the left panels of Fig. 4, the correlation coefficients of PSC/UC frequency in each month are shown. The vertical resolution of the correlation coefficient has been changed to 1 km. We have also revised the explanations of Fig. 3 and 4 in the 2nd-6th paragraphs of Section 3.1 and the figure captions.

P20012, l1: If the tropopause is located at 7-8 km, the altitudes of 9-11 km are in the lower stratosphere. Thus, how can you then refer to this altitude region as UT/LS?

As already mentioned, blended tropopause by Wilcox et al (2012) is used in the revised manuscript. The average and standard deviation of tropopause height (h_b) are 8.5 km and 1.4 km, respectively, in June through September in the latitude range of 55°S-82°S. Thus the altitude range of 9-11 km is regarded as the UT/LS region, which is a transition layer between troposphere and stratosphere (Gettelman et al., 2011). We have added an explanation about the definition of the tropopause height in the 6-7th paragraphs of Section 2.

P20012, l2: In 9-11 km one can expect solely stratospheric clouds. To get tropospheric clouds one has to consider the altitude regions below.

The altitude ranges in Figs. 3, 4, and 6 (Figs, 2, 3, and 4 in the original manuscript) have been extended from 9-30 km to 3-30 km using the CALIPSO lidar Level 2 Vertical Feature Mask (VFM) data. The PSC/UC frequency in the altitude range of 3-9 km is calculated using the VFM data. We have found that the PSC/UC frequencies below 7 km have little correlation with those in 15-25 km (Figs 3 and 4). We have also added an explanation of the CALIPSO lidar Level 2 VFM data to the 4th paragraph of Section 2.

P20012, l4-5: In figure 1 CALIPSO level 1 and level 2 data are compared, but why does this figure show that the algorithm works also for the lower stratosphere? What is the difference between the level 1 and level 2 data? If CALIPSO level 2 data allows a characterization into "clear air", "cloud" and "stratospheric" why isn't this data been used? It would at least allow to differentiate between stratospheric and tropospheric clouds which the applied algorithm obviously cannot.

First, the difference between the cloud detections using the Level 1 data and Level 2 data primarily comes from the difference of the physical quantities used in each cloud detection process. The cloud and aerosol detection algorithm in the Level 2 data are based on total attenuated backscatter coefficients (or scattering ratios) (Vaugan and Powell, 2005). On the other hand, the algorithm using the Level 1 data is based on not only the scattering ratios but also depolarization ratios to enhance the detectability for the optically-thin stratospheric clouds. Pitts et al. (2009) found that inclusion of depolarization ratios results in increase in PSC areal coverage by 15% compared to the algorithm only using scattering ratios. We have added this explanation as the 4th-5th sentences of the 1st paragraph of Section 2.

Second, classification of feature types in the Level 2 VFM data in the polar winter has the following problem. The classification of 'stratospheric' flags depends on the thermal tropopause heights from GEOS5 meteorological data. However, the thermal tropopause definition frequently gives inappropriate estimates for the polar night region as the static stability is quite low in the lower stratosphere there (CALIPSO Quality Statement Summary (eosweb.larc.nasa.gov/PRODOCS/calipso)). The numbers of "cloud" and "stratospheric" flags are examined for 60°S-82°S in the altitude range of 8-20 km (Table 1). It is shown that the number of clouds in the stratosphere should significantly decrease if "cloud" flags in $z > h_b + 2$ km were treated as tropospheric clouds. We have also added this explanation as the 8-9th paragraphs on Section 2.

P20012, l11: How can you get the PSC type if you even don't know if a PSC or a UC was measured?

Because tropospheric clouds and aerosols may contaminate estimates of PSC composition, the PSC composition below 15 km (~400 K) was not examined in the present study. We have revised the last sentence of the 10th-11th paragraphs of Section 2.

P20012, l18-19: "Thus, the PSC composition below 15 km (400 K) is not examined in the present study". Why? With excluding this altitudes a large amount of PSCs is neglected. As can be seen in Pitts et al. and other studies, PSCs extend in the Antarctic frequently down to 10 km. When the algorithm for characterization works in in higher altitudes why shouldn't it be able to do it in lower altitudes. To my knowledge the Pitts et al. algorithm can characterize any PSC independent at which altitude it was measured.

As mentioned above (*P20012, l11*), because tropospheric clouds and aerosols may contaminate estimates of PSC composition, the PSC composition below 15 km (~400 K) was not examined in the present study.

P20012, l20-25: What was the reason that Gettelmann et al (2011) came to the conclusion that the PV definition for the tropopause may not be appropriate and why do you nevertheless apply this tropopause definition. Wouldn't especially for your study a tropopause definition as accurate as possible be unambiguous?

As mentioned in the response to '*P20012, l1*', we have altered the tropopause definition to that by Wilcox et al. (2012) (i.e., blended tropopause). The discussion about the difference among the thermal, dynamical, and blended tropopause heights has been added to the 6th-7th paragraph in Section 2.

P20013, l25: If the typical tropopause height is generally at 7-8 km which is lower than the UC altitudes than you are definitely not considering tropospheric clouds. These are obviously stratospheric clouds. What is done here is a correlation between polar stratospheric clouds in two different altitude regions. Tropospheric clouds are in this study not considered at all.

As mentioned in the response to the comment '*P20012, l2*', the altitude ranges in Figs. 3, 4, and 6 have been extended from 9-30 km to 3-30 km. Thus the present analyses include both PSCs and UCs.

We have calculated the correlation coefficients between PSC/UC frequency at one altitude and that at another altitude.

P20014, l1: Before the clouds at 15-25 km were referred to as PSCs, now they are PSCs/UCs which it is said they will be referred to as PSCs and the one between 9-11km as UCs. Thus a strict differentiation between PSCs and UCs (though at these altitudes only PSCs are found). Nevertheless, in the following text the expression PSC/UC is consequently used so that one hardly can follow which altitude region is considered.

We have revised the sentences in the 2nd-7th paragraphs of Section 3.1 so that 'PSC/UC' is not referred to as PSCs or UCs before results of the analyses based on tropopause-relative altitude are shown.

P20014, l10-13: Rephrase the sentence and be more precise. The seasonal variation in PSC altitude is simply due to the fact that they descend to lower altitudes during the coarse of the winter.

According to previous studies (Poole and Pitts 1994; Adriani et al. 2004; Pitts et al., 2007), the altitudes where PSCs are dominant lower gradually following the lowest temperature descent and irreversible loss of HNO_3 and H_2O due to the PSC sedimentation. We have revised the last sentence of the 4th paragraph of Section 2, and added Poole and Pitts (1994) and Adriani et al. (2004) as references.

P20014, l14-24: I don't see a correlation at all. Can one seriously call a correlation coefficient of 0.1 or 0.2 a correlation? Doesn't it show the opposite that there is no correlation at all?

We have revised Figs. 3 and 4, as mentioned in the response to the comment '*P20011, l15*'. We have found higher correlation coefficients (> 0.3) between PSC/UC frequencies at 15-25 km and those at 9-11 km.

P20014, Figure 2 and 3: These figures make no sense. What is correlated here? Why is the correlation symmetric? If there would be a connection between clouds in two different altitude regions a unsymmetric correlation should be found, showing a maximum at high altitudes in the e.g. x-range and according a maximum at low altitudes on the y-range. In this figure the correlation coefficient is highest for exactly the same altitudes in the x- and y-range.

As mentioned in the response to the comment '*P20013, l25*', the correlation coefficients between PSC/UC frequencies at two different altitudes are shown in Figs. 3 and 4, not correlation coefficients between PSC frequency and UC frequency.

P20015, l6: It is not clear if these clouds are UCs or PSCs. Further, I don't see any correlation at all.

As mentioned in the response to the comment '*P20011, l14*', we have newly performed the analyses of the PSC/UC frequencies based on tropopause-relative altitudes (z_{TP}) (Fig. 5). We have found that PSC/UC frequencies in z_{TP} = 6-13 km (i.e., PSCs) have positive correlation with those in z_{TP} = 0-2 km. This point has been discussed in the 6th paragraph of Section 3.

P20015, l19-20: Since I do not understand the figure and further do not see a correlation and thus one cannot follow your conclusion.

We have revised the manuscript including figures as much as we can. We hope that the reviewer can understand the revised figures.

P20015, 23-24: As mentioned before tropospheric clouds are located in the troposphere. There is overshooting convection, but this is more common in the tropics and midlatitudes than in the polar regions. As I understood this analyses the authors haven't checked for every day and measurement where the tropopause location was. Maybe they should do that and then maybe they will find that the tropopause was located higher than 7-8 km and thus they could get clouds in the troposphere. However, the tropopause won't nevertheless be higher than 10 km and thus they still wouldn't get any tropospheric clouds.

As mentioned in the response to the comment '*P20011, l14*', we have newly performed the analyses of the PSC/UC frequencies based on tropopause-relative altitudes (Fig. 5). We have found that the PSC/UC frequencies in z_{TP} = 6-13 km (i.e., PSCs) have significantly positive correlation with those in z_{TP} = 0-2 km. On the other hand, it has also been shown that PSC/UC frequencies below the tropopause have little correlation with those in z_{TP} = 6-13 km above the tropopause. This point has been discussed in the 6th paragraph of Section 3.

P20015, General comment: I would suggest that the authors difference the clouds in the troposphere into cloud types (cirrus, deep tropospheric clouds etc) as it was done in Achtert et al. (2012).

From the analyses based on the tropopause-relative altitudes (Fig. 5), it is shown that PSC/UC frequencies in $z_{TP} < 0$ have little correlation with those in $z_{TP} >$ 6-13 km above the tropopause. Thus, we have not discussed further the depth of the tropospheric clouds.

P20016, l1: I still have difficulties to follow what kind of clouds are exactly in this PSC/UC group. If there is a gap, than it seems that there is a clear separation between tropospheric clouds and stratospheric clouds and that these *are thus not occuring in one single layer. This is also something I would expect. At least it is like that in the Arctic. There is a gap of a few km between tropospheric clouds and stratospheric clouds since only in higher altitudes temperatures become low enough for PSC formation.*

As mentioned in the response to the comment '*P20012, l2*', the altitude ranges of Fig. 3, 4 and 6 have been extended from 9-30 km to 3-30 km. Thus 'PSC/UC' frequency includes that of both PSCs and UCs.
In Fig. 7a, the cloud-free altitude range (i.e., cloud gap) is seen around z ~ 14 km. We have also confirmed that the cloud gaps similar to that shown in Fig. 7a are frequently observed in the Antarctic, in particular, in June and July.

P20017, l19: Do you results imply that Wang et al. (2008) are wrong or do you results show that additional to cyclones also anticyclones can induce PSC formation?

We have examined the meteorological situation for two cases of simultaneous occurrence of PSCs and UCs shown by Wang et al. (2008) for 25 July, 2006 and Adhikari et al. (2010) for 25 June, 2006. We have newly added a figure showing the polar-stereo projection maps of geopotential heights at 300 hPa for the two cases. In both cases, tropospheric anticyclones are seen in the region where PSCs and UCs are observed. We have newly added the discussion section (Section 4) before the concluding remarks section.

P20017, l24: "stratosphere mixing process". Please rephrase. It is not clear what you mean.

We have revised the 2nd sentence of the last paragraph of Section 3.2 as follows:
"A plausible candidate to supply of H_2O rich air from the troposphere to the cold stratosphere is the mixing processes."

P20017, l20-30: The cooling process which leads in connection with the anticylones to a cooling of the stratosphere is not properly explained. Further, more H2O would mean more PSC formation. Thus, the injection of H2O rich air cannot be the explanation for the cloud gap.

In the original manuscript, we used two altitudes of 13 km and 14 km as the altitude where cloud gaps are located. This is our simple mistake. We are very sorry about it. We have considered that 14 km is more appropriate denoting the cloud gap.
This sentence is not intended to explain the cooling process due to the tropospheric anticyclones. The main point of this sentence is the vertical extent of H_2O intrusion from the troposphere is 13 km at the highest (Pfister et al., 2003). This fact suggests that the potential for cloud formation in $z > 13$ km is smaller than that in $z < 13$km from the viewpoint of the mixing ratios of H_2O.
We have revised the last sentence of the last paragraph of Section 3.2.

General comment: I would recommend the authors to check some previously published studies of PSC measurements, especially from lidar which show that the PSCs tend to occur in two layers and also that there is usually a gap between PSCs and UCs. Thus, there is no real need to explain this gap by a dynamic process. Tropospheric clouds are found up to the tropopause and stratospheric clouds somewhere above depended on where it is getting cold.

We have read previous papers about PSCs using a ground-based lidar such as Carslaw et al. 1998; Carslaw et al. 1999; Shibata et al., 1999; Dörnbrack and Leutbecher, 2001; Adriani et al., 2004.

The negative temperature anomalies associated with anticyclonic PV anomaly near the tropopause decay exponentially with altitude, as mentioned in Section 3.2. Thus the vertical profile of the negative temperature anomalies cannot explain existence of the cloud gap when the mixing ratios of H_2O are assumed to be constant. The high mixing ratios of H_2O above the tropopause but below 13 km due to the intrusion of H_2O from the troposphere is a plausible candidate to explain the existence of clouds around and slightly above the tropopause heights (see also the response to '*P20017, l20-30*').

P20018, l15-18: You derive just 15% for a connection between blocking highs and PSC/UC occurrence, thus blocking highs seem to have a minor influence on PSC/UC formation. The connection between cyclones and simultaneous PSC and UC occurrence has been shown to be much higher, e.g. Wang et al. (2008) got 66% , Adhikari et al. (2010) got 70% and Achtert et al. (2012) got 72%. Thus, the connection between deep tropospheric clouds and PSC occurrence is much stronger than the connection to blocking highs.

First, 44% of simultaneous occurrence of PSCs and UCs are associated with blocking highs, not 15%.

The difference between the previous studies and our study may come from the algorithm of cloud detection. While the cloud detection in the previous studies is based on the attenuated scattering ratios only, the cloud detection process in our study is based on the scattering ratios and depolarization ratios, as mentioned in the response to the comment '*P20012, l4-5*'.

The relation between cyclones and PSC/UC frequencies are discussed in the 3rd paragraph of Section 3.2 and "Discussion" section, as mentioned in the responses to the comment '*p20008, l7-8*' and '*P20017, l19*'.

P20018, l20: I still don't understand why both CALIPSO data sets are used. What is the difference between Level 1 and Level 2 data? Why isn't just the on used which is more suitable for this study?

This point has already been discussed in the response to '*P20012, l.4-5*'.

P20019, l7: As long as the tropopause is at 7-8 km this two layers are in the stratosphere and thus stratospheric clouds and not tropospheric clouds. Unless you can't show that the tropopause was higher and that these clouds at 9-11 km were in the troposphere your conclusion on a connection cannot hold.

This point has already been discussed in the response to ‘*P20011, l14*’.

P20019, l20: This seems to be quite variable and only in some years high correlation coefficients are found. Thus, this does not provide a clear picture.

The interannual variation of the correlation coefficients is likely related to that of polar vortex in the stratosphere and of tropospheric blocking highs. However, this is beyond the scope of our study.

P20019, l23-24: Since PSC occur solely within the polar vortex this result is not astonishing. However, I cannot understand how can you get a correlation of PSCs and UCs outside the vortex if there are no PSCs outside the vortex? The analyses needs definitely to be revised. It seems that there is something wrong.

This point has already been discussed in the response to ‘*P2008, l13*’.

P20020, l5-9: I am sorry, but I still not convinced that you have shown a connection between blocking highs and simultaneous PSC and UC occurrence. Although 32% is much higher than 17% it is still not showing a clear relation, as e.g. the studies locking at the connection between deep tropospheric clouds.

We have newly added a table, which shows the probability of simultaneous occurrence of PSCs and UCs when blocking high is present or not (Table 3). It is shown that the probability of simultaneous occurrence of PSCs and UCs in the presence of blocking highs is three or more times as high as that in the absence of blocking highs. We have also added an explanation of Table 3 as the 8th-9th sentences of the 2nd paragraph of Section 3.3.

P20021, l12: I am still convinced that you just have looked on PSCs in different altitude layers. The altitudes 9-11 km are much too high for tropospheric clouds. If there was a significant lifting of the tropopause during certain days you first have to proof this.

This point has already been discussed in the response to ‘*P20015, l23-24*’.

P20022, l4-6: A water vapour entrainment from the troposphere into the stratosphere cannot explain the cloud gap. If water vapour is enhanced due to cross tropopause mixing PSC formation would rather be enhanced when suppressed since water vapour is needed for their formation (especially for ice particles).

This point has already been discussed in the responses to comments ‘*P20017, l20-30*’ and ‘*General comment*’.

Table 1: How can you now state which clouds where exactly simultaneously observed when you cannot exactly differentiate between tropospheric and stratospheric clouds? Doesn’t this table exactly show that blocking highs

seem to have no influence at all. The numbers for simultaneous PSC and UC clouds are nearly the same for each year independent of the presence or absence of blocking highs.
Further, numbers are highest for occurrence of PSCs without any underlaying UCs and presence of blocking highs showing that the major mechanism is a different one like e.g. synoptic cooling.

First, from correlation coefficient maps shown in Figs. 3-9, clouds in the altitude ranges of 9-11 km and 15-25 km are referred to as UCs and PSCs in the present study, respectively.
Second, the blocking highs cover about 15% of the latitudinal area in 55°S-82°S on average, as mentioned in the 8th sentence of the 1st paragraph of Section 3.3. If the simultaneous occurrence of PSCs and UCs were independent of blocking highs, 15% of the simultaneous occurrence of PSCs and UCs would be accompanied with blocking highs. In fact, 44% of simultaneous occurrence of PSCs and UCs are accompanied with blocking highs (Table 2), which strongly indicates that the concurrent occurrence of PSCs and UCs is likely to be accompanied with blocking highs.
Second, as mentioned in the response to the comment ‘*P20020, l5-9*’, it has also been shown that the probability of simultaneous occurrence of PSCs and UCs in the presence of the blocking high is three or more times as high as that in the absence of the blocking highs. These facts suggest that blocking highs strongly affect simultaneous occurrence of PSCs and UCs.
Finally, we are not sure what the reviewer referred to as ‘synoptic cooling’. The word ‘synoptic’ only means the horizontal scale from several-hundred kilometers to several-thousand kilometers.

Figure 2: I would expect one axes to be the altitudes of PSCs and the other for UCs. Which axes is showing which altitudes and why is the distribution symmetric? One would expect and unsymmetric distribution if there is a connection between PSCs at 15-25 km and UCs below.

This point has already been discussed in the response to ‘*P20014, Figure 2 and 3*’.

Figure 4: At which longitude is the reference latitude? Is it the same for all cases or are the blocking highs found at different locations? Since only clouds above 9 km are considered and PSC occur down to these altitudes in the Antarctic it seems for me that these frequencies are solely PSCs without any UCs.

As mentioned in the 3rd sentence of the 1st paragraph of Section 3.2, a reference longitude is determined as the longitude where PV anomalies from the zonal mean are positive and maximized in the zonal direction at 72.5°S on a 300 K-isentropic surface for each day, and their values are larger than 1.5 PVU. The composite can include the same anticyclones on different dates.
As mentioned in the response to the comment ‘*P20012, l2*’, the altitude range of Fig. 6 has been extended from 9-30 km to 3-30 km. Thus the PSC/UC frequency shown in Fig. 6 includes both PSCs and UCs.

Figure 5d: Is the colour scheme really equivalent latitude? What is the purpose of the figure? What exactly is shown here.

To make why equivalent latitude is used (Fig. 8c) clearer, we have added a latitude-pressure section of modified PV (Lait, 1994) (Fig. 8a) and equivalent latitudes as a function of on modified PV on several isentropic surfaces (Fig. 8b). From Fig. 8b, one-to-one correspondence between the modified PV and equivalent latitudes is clear for each isentropic surface. Thus, equivalent latitude is regarded as a normalized potential vorticity (PV) in a specific isentropic surface. Because Ertel's and modified PV are materially conserved in the adiabatic and inviscid flow, the equivalent latitude indicates which latitude the air parcel originally comes from. We have also added an explanation of equivalent latitude and its relation with modified PV in the 7th-8th paragraphs of Section 3.2.

Response to minor comments:

p2008, l2: state already here that CALIPSO data is used.

We have revised the 1st sentence of Abstract as follows:
"This study statistically examines the simultaneous appearance of polar stratospheric clouds (PSCs) and upper tropospheric clouds (UCs) using the CALIPSO lidar observations for five austral winters of 2007-2011."

P20010, l4,5 and further in the text: "Höphner" should be "Höpfner".
P20011, l10-11: "range up to....." from which altitude? Write 40 km instead of 40.0 km.

We have revised the manuscript following the comments.

P20017: What is meant with "other regions"? Please be more precise.

We have revised the 1st sentence of the last paragraph of Section 3.3.

P20016, l8: "at" instead of "in".

The expression has been revised following the comment.

P20016, l11 and 27: Rephrase, don't start the sentences with "next".

We have removed 'next' from the first sentences of the 5th-6th paragraphs of Section 3.2.

P20018. l19: add "layer" after two.

The expression has been revised following the comment.

References:

Achtert, P., Karlsson Andersson, M., Khosrawi, F., and Gumbel, J.: On the linkage between tropospheric and polar stratospheric clouds in the Arctic as observed by space-borne lidar, Atmos. Chem. Phys., 12, 3791-3798, 2012.

Adhikari, L., Wang, Z., and Liu, D.: Microphysical properties of Antarctic polar stratospheric clouds and their dependence on tropospheric cloud systems, J. Geophys. Res., 115, D00H18, doi: 10.1029/2009JD012125, 2010.

Adriani, A., Massoli, P., Di Donfrancesco, G., Cairo, F., Moriconi, M. L., and Snels M.: Climatology of polar stratospheric clouds based on lidar observations from 1993 to 2001 over McMurdo Station, Antarctica, J. Geophys. Res., 109, D24211, doi: 10.1029/2004JD004800, 2004.

Dörnbrack, A., and Leutbecher, M.: Relevance of mountain waves for the formation of polar stratospheric clouds over Scandivania:A 20 year climatology, J. Geophys. Res., 106(D2), 1583–1593, 2001.

Davis, C. A., and Emanuel, K. A.: Potential vorticity diagnostics of cyclogenesis, Mon. Wea. Rev., 119, 1929-1953, 1991.

Holton, J. R.: An introduction to Dynamic Meteorology, 4th ed., Academic Press,, Burlington, USA, 535 pp, 2004.

Lait, L. R.: An alternative form for potential vorticity, J. Atmos. Sci., 51, 1754-1759, 1994.

Nakamura, H., and Wallace, J. M.: Synoptic behavior of baloclinic eddies during blocking onset, Mon. Wea, Rev., 121, 1892-1903, 1993.

Pfister, L., Selkirk, H. B., Jensen, E. J., Podolske, J., Sachse, G., Avery, M., Schoeberl, M. R., Mahoney, M. J., and Richard, E.: Processes controlling water vapor in the winter Arctic tropopause region, J. Geophys. Res., 108, 8314, doi: 10.1029/2001jd001067, 2002.

Pitts, M. C., Thomason, L. W., Poole, L. R., and Winker, D. M.: Characterization of polar stratospheric clouds with spaceborne lidar: CALIPSO and the 2006 Antarctic season, Atmos. Chem. Phys., 7, 5207-5228, doi: 10.5194/acp-7-5207-2007, 2007.

Poole, L. R. and Pitts, M. C.: Polar stratospheric cloud climatology based on stratospheric aerosol measurement II observations from 1978 to 1989, J. Geophys. Res., 99, 13,083-13,089, 1994.

Vallis, G. K., Atmospheric and Oceanic Fluid Dynamics: Fundamentals and Large-Scale Circulation, Cambridge University Press, Cambridge, UK, 745 pp, 2006.

Vaugan, M. A., and Powell, K. A.: CALIOP algorithm theoretical basis document. Part 2: Feature detection and layer properties algorithms, 2005

(http://www-calipso.larc.nasa.gov/resources/pdfs/PC-SCI-202_Part2_rev1x01.pdf).

Wilcox, L. J., Hoskins, B. J., and Shine, K. P.: A global blended tropopause based on ERA data. Part I: Climatology, Quart. J. Roy. Meteorol. Soc., 138, 561-575, doi: 10.1002/qj.951, 2012.