Reply to review comments

We express our gratitude for the time and effort dedicated to the reviewing of our manuscript. We considered all comments and provided our detailed point-by-point responses below.

Anonymous Referee #2

General Comments

This carefully written manuscript advances our global/seasonal estimates of the occurrence frequency of cirrus clouds that, for CALIPSO satellite measurements, reside 0.5 km or higher above the tropopause; that is, stratospheric cirrus clouds. Polar stratospheric clouds or PSCs, primarily occurring over Antarctica, have been filtered out of this data set, and are not considered. This study builds on other studies by using for the first time the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS; onboard ESA's Envisat) limb measurements to detect stratospheric cirrus clouds 0.75 km above the tropopause (identified using ERA-interim global reanalysis). Due to the larger sample volume of the MIPAS atmospheric limb measurements, MIPAS can detect cirrus clouds down to optical depths of 2 x 10-5 compared to a detection threshold for CALIPSO of 1 x 10-3, resulting in 2 to 3 times more stratospheric cirrus cloud occurrence frequencies outside the tropics relative to CALIPSO.

I have only six fairly minor comments listed below. The paper is very well written and organized and makes a significant contribution to our knowledge of stratospheric cirrus clouds. The scientific methods and assumptions are valid and clearly outlined, and the results appear traceable.

Answer: Thank you very much for your encouraging comments!

Comment ∗ 1

Line 23: Not all cirrus clouds are optically thin; suggest removing "optically thin".

Answer: Thanks, done.
"Cirrus clouds are ice clouds that form at cold temperatures in the middle and upper troposphere."

Comment ∗ 2

Lines 31-37: Cirrus cloud occurrence frequencies vary considerably partly due to satellite instrument sensitivity (as mentioned here), but this may also depend on how cirrus clouds are defined (e.g. in terms of a temperature or altitude threshold, or in terms of pressure and optical depth as with ISCCP, etc.). Please indicate the cirrus definition when citing estimates of occurrence frequency for cirrus clouds.

Answer: Exactly, we have added cirrus clouds definitions according to different references.
The sentence was revised to:
"Depending on the satellite instruments sensitivities and cirrus cloud definition, the derived occurrence frequencies significantly differ, e. g. in global average 34.9 % cirrus clouds above 500 hPa were observed by the High Resolution Infrared Radiometer Sounder (HIRS) between June 1989 to May 1993 (Wylie et al., 1994), 16.7 % cirrus clouds, with cloud top temperature below -40° C and a visible optical depth below $\tau \approx 3.0$, were derived from a joint analysis of the space-borne cloud radar (CloudSat) and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) for the period from June 2006 to June 2007 (Sassen et al., 2008), and 13.5 % cirrus clouds with cloud top pressure below 440 mb and an optical thickness below 3.6 were reported in the International Satellite Cloud Climatology Project (ISCCP) D2 data, that was acquired between 1984 and 2004 by nadir viewing satellite instruments (Eleftheratos et al., 2007)."

Comment ∗ 3

Lines 123-133: How is ACI calculated? Is it simply the largest of the two values [i.e. ACI=max(CI, AI)]?

Answer: Yes. The ACI is the maximum value of the cloud index (CI) and the aerosol index (AI). For clarity we added the formula ACI=max(CI, AI) to the manuscript.

Comment ∗ 4

Lines 192-194: The JJA band of enhanced (4-8%) stratospheric cirrus downwind of the southern tip of South America is a "hotspot" for mountain-induced stratospheric gravity wave formation as described by Jiang et al. (2002, JGR) and Hoffmann et al. (2016, ACP), although the maximum in gravity waves in Jiang et al. is during SON (rather than JJA as shown in Hoffmann et al.). This suggests that the observed stratospheric cirrus enhancement in Fig. 3c resulted from mountain-induced gravity waves. The occurrence frequency for relatively thick ($0.3 < \tau < 3.0$) cirrus clouds downwind of the Southern Andes was found to be greatest during JJA in Mitchell et al. (2016, ACPD; see Mitchell et al. 2018, ACP, for additional details), corroborating the results of this study somewhat.

Answer: Thanks for those detailed information. We have added some discussion about the effects of deep convection and gravity waves on occurrences of stratospheric cirrus clouds at middle and high latitudes.

"Although the occurrence frequencies at middle latitudes are lower compared to the tropics, we see higher occurrence frequencies during the winter months. The stratospheric cirrus clouds at middle and high latitudes are located at and downwind of gravity wave hotspots (Hoffmann et al., 2013). In DJF, stratospheric cirrus clouds over North America, the northern hemisphere Atlantic, and Eurasia are correlated with orographically and convectively induced gravity wave hotspots, whereas the stratospheric cirrus clouds over the Northern Pacific are solely correlated with deep convection (Hoffmann et al., 2013). In JJA, stratospheric cirrus clouds occur in the oceanic downwind region of the southern tip of South America, which is a strong hotspot of orographic gravity waves (Jiang et al., 2002; Hoffmann et al., 2013). "

Comment ∗ 5

Lines 388-390: Please indicate that this sensitivity refers to cloud optical depth.

Answer: Done.

"The overall higher detection frequencies we attributed to MIPAS larger sampling volume at the tangent point and the higher detection sensitivity reaching down to cloud optical depths τ of 10^{-5} compared to 10^{-3} for CALIPSO."

Comment ∗ 6

Line 410: Suspect typo: "1% at nighttime" =>"1% during daytime"?

Answer: Thanks, done.

"At middle latitudes the occurrence frequencies also differ by a factor of 2 with 2 % at nighttime and 1 % at daytime ."