Reviewer #3

General Comments

This manuscript presents a thorough evaluation of the global occurrence of stratospheric ice clouds (SICs) and their relationships with tropopause temperature, recent deep convection, gravity waves, and stratospheric aerosols. Potential relationships with modes of climate variability (QBO and ENSO) were also examined, but did not reveal strong association. The identification of SICs is based on the CALIPSO lidar observations, which are arguably the best available resource for global analysis, complemented by additional high-quality, satellite-based identification of the remaining parameters related to SICs. It was demonstrated well throughout that tropopause temperature and convection/gravity waves are strong controls for the occurrence of SICs, as expected. The analysis presented is thorough and the methods used are appropriate. It will be a meaningful contribution to the literature. I have one general comment related to an important element of the discussion that I believe is missing, but otherwise only a collection of suggested minor edits.

Answer: Thank you very much for reviewing our manuscript and for your comments and suggestions.

General Comments

an important limitation resulting from the use of CALIPSO data is bias introduced by the lack of sampling the diurnal cycle (critical for evaluating deep convection and, one would assume, much of the related SICs). I do not know how large the bias would be and am not aware of studies that allow one to quantify/estimate it well since it will be dependent not only on the frequency of sources, but also on the timescale of sublimation (which implies microphysics may be important, etc.). However, I do expect it is significant (especially over land masses). For example, overshooting convection in North America has a pronounced diurnal cycle with a frequency maximum that falls almost entirely between the CALIPSO sample times (e.g., see 10.1175/JAMC-D-15-0190.1, 10.1002/2017JD027718, 10.1029/2021JD034808). Other regions with frequent land-based overshooting storms have similar diurnal cycles. This suggests that much of the SICs that occur may not even be sampled, especially over land. Thus, the discussion throughout the manuscript requires an acknowledgement of this bias and how interpretations of the results might change.

Answer: Thank you for this helpful comment. We have added the discussion of the possible impact of the diurnal cycle of deep convection on the SIC detections from CALIPSO in Sect. 4.2.

'The sampling time of CALIOP may have an impact on the results presented here. While the diurnal cycle of high altitude reaching convection is well known (Hendon and Woodberry, 1993; Tian et al., 2006; Hohenegger and Stevens, 2013), little is known about the lifetime and diurnal cycle of SICs (Dauhut et al., 2020). At midlatitudes, over the central United States, the largest average fraction of overshoots was observed during the late afternoon to early evening local time (Cooney et al., 2018; Solomon et al., 2016), whereas CALIOP samples this area during the local minimum. In the tropics, the maximum precipitation from large mesoscale convective systems occurred in the local afternoon over land (Nesbitt and Zipser, 2003), but CALIPSO passes by the tropics after midnight (around 01:30 LT). Stratospheric clouds in the tropics have two peaks at 19:00–20:00 LT and the 00:00–01:00 LT from Cloud-Aerosol Transport System (CATS) lidar measurements. The expansion of convective clouds, the spread of winds, and the propagation of convective-generated gravity waves can all play a role in the high percentages of stratospheric clouds observed later (Dauhut et al., 2020). Since only measurements at 01:30 LT were used in this study, it is important to keep in mind the possible limitations associated with the diurnal cycles of deep convection and SICs.'

Specific Comments:

Line 17 - "and western" should be "and the western"

Fixed.

Line 37 – “hydrate stratosphere” should be “hydrate the stratosphere”

Fixed.

Line 40 – “, intensity” should be “, and the intensity”

Fixed.

Line 49 – “Six encounters…” the opening of this sentence is poorly phrased. Please revise.

We have revised the paragraph.

Line 72 – “ice clouds” should be “ice cloud”

Done.

Line 78 – “are” should be “is”

Fixed

Section 2.1 – I recommend defining the first and second lapse-rate tropopauses as LRT1 and LRT2, respectively. LRT is commonly used in the literature and helps to clearly communicate the definition used throughout. I would also recommend not bothering to define a cold-point tropopause acronym, since it is only used here.

Thank you. We have revised them throughout the entire manuscript.

Line 262 – recommend revising “motion of the Sun” to “location of peak insolation”. The sun isn’t moving…

We have revised this sentence.

Figure 2 – is this analysis relative to all observations or DT events only? Please add note to clarify.

We have revised in the manuscript. ’Occurrence frequencies of SICs associated with double tropopauses with respect to all profiles (a-d) and the fraction of SICs associated with double tropopauses to total SICs (e-h).’

Line 400 – “we” should be “were”

Fixed.

Figure 12 and related analysis – the overlap of several regions seems undesirable. It would be good to test sensitivity to having them be defined more exclusively.

Thank you. We have restructured the manuscript, and the regional analyses are removed from the manuscript.

Line 427 – “Spear-man” should be “Spearman”

Revised.

Line 448 – “Two” should be “The two” Line 480 – “in average” should be “on average” Line 486 – “, lowering” should be “, and lowering”

Revised.

Line 527 – “In the MIPAS” should be “In MIPAS”

Fixed.

Line 588 – “tropauses” should be “tropopauses”

Fixed

Line 599 – “its” should be “their”

Fixed.

References

Cooney, J. W., Bowman, K. P., Homeyer, C. R., and Fenske, T. M.: Ten Year Analysis of Tropopause-Overshooting Convection Using GridRad Data, Journal of Geophysical Research: Atmospheres, 123, 329–343, https://doi.org/10.1002/2017JD027718, 2018.

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Hendon, H. H. and Woodberry, K.: The diurnal cycle of tropical convection, Journal of Geophysical Research: Atmospheres, 98, 16 623–16 637, https://doi.org/10.1029/93JD00525, 1993.

Hohenegger, C. and Stevens, B.: Controls on and impacts of the diurnal cycle of deep convective precipitation, Journal of Advances in Modeling Earth Systems, 5, 801–815, https://doi.org/10.1002/2012MS000216, 2013.

Nesbitt, S. W. and Zipser, E. J.: The Diurnal Cycle of Rainfall and Convective Intensity according to Three Years of TRMM Measurements, Journal of Climate, 16, 1456 – 1475, https://doi.org/10.1175/1520-0442(2003)016⟨1456:TDCORA⟩2.0.CO;2, 2003.

Solomon, D. L., Bowman, K. P., and Homeyer, C. R.: Tropopause-Penetrating Convection from Three-Dimensional Gridded NEXRAD Data, Journal of Applied Meteorology and Climatology, 55, 465 – 478, https://doi.org/10.1175/JAMC-D-15-0190.1, 2016.

Tian, B., Waliser, D. E., and Fetzer, E. J.: Modulation of the diurnal cycle of tropical deep convective clouds by the MJO, Geophysical Research Letters, 33, L20 704, https://doi.org/10.1029/2006GL027752, 2006.