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Comment on acp-2021-1038

Anonymous Referee #2

Referee comment on "A global view on stratospheric ice clouds: assessment of processes related to their occurrence based on satellite observations" by Ling Zou et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-1038-RC1, 2022

General comments:

(1) There is a lot of really interesting material here, but it seems somewhat unfocused and in places a little confusing. The manuscript is way too long for the average reader, I suggest tightening it up quite a bit and or consider writing two papers.

(2) SIC in the stratosphere might suggest moistening (as the authors state), but interest in that process is mostly associated with convection penetrating the tropical tropopause. In this paper, the extra-tropical and tropical SIC are sort of lumped together.

For example, SIC moistening in the stratospheric extra-tropics is unimportant since air is moving downward there and will soon exit the stratosphere. Whereas SIC in the tropics is very important since air is moving upward and SIC could be changing the water vapor budget. I guess my point is to wade through 34 pages of material here, the motivation could be clearer.

(3) I think the correlation with gravity waves is really part of the correlation with tropopause temperatures and isn't a separate effect. In Fig. 5 you see that the correlation maps (5a) and (5b) are nearly identical. As noted below, the cold temperatures are due to a number of things and gravity waves will be one of them, I am not sure how you separate them in a correlation sense, but I am pretty sure they overlap.

(4) The SIC correlation with aerosols is interesting, but aerosols are associated with fires as well as volcanoes. The CALIPSO measurements are a direct measure, I don't see how SO2 adds anything to this analysis. You should also mention more clearly why you are correlating with aerosols. Basically, aerosols provide CN and thus clouds form at lower RH so cloud formation should be approximately correlated with aerosols if the environment is at saturation. Volcanic eruptions and fires contain a lot of water so there might be other things going on. I would argue that this whole analysis might be a separate and interesting paper. BTW, OMPS-LP also produces an excellent aerosol data set that is independent of CALIPSO.

(5) One question I was left with is: Do SIC occurrences well above the tropopause differ from those that are near the tropopause. Your statistics in Figure 1 suggest occurrences up to about 1 km above, but are the outliers very different? Those clouds have more of a potential of moistening the stratosphere.

Please focus Abstract on salient points, it is way too long.

Specific comments

Ln 38 *net* radiative heating? You need to be careful here. High thick cirrus will produce surface heating by blocking IR cooling to space. Do you mean *in situ* cooling?

Ln 43 Paragraph starting line 43, I presume you are not including Polar Stratospheric Clouds in this discussion. What does 'high altitude' mean? Above the tropopause?

Ln 59 Sentence starting with 'With … ' makes no sense to me.

Ln 67 Awkward English. 'Nucleation of ice crystals occurs in the presence of cold temperatures.'

Overall comment on ln 34-119. On one hand this is a very thorough review of the literature, but its goal is occasionally illusive. Here is what I got from 80 lines of text:

Ice clouds form in cold temperatures

Cold temperatures are due to dynamics.

Ice clouds are also injected by convection

Aerosols impact cloud formation

I suggest that the reader might benefit from a reorganization of this material along these points.

Ln 148 Spline interpolation can produce a new minimum temperature which is colder than the adjacent model levels, and the actual location of the minimum between the two model levels is unknown. Given the reliance of this study on the exact location of the tropopause, it seems appropriate to have more extended discussion which occurs later in the paper. Perhaps you could move that here. More explicit discussion of the uncertainty in the tropopause height might me appropriate.

Ln 157 CALIPSO averages their backscatter data over many profiles – this averaging is the effective along track resolution of the data. You should mention this.

Ln 164 I don’t see why you are including daytime aerosols. The S/N during the day drops significantly. If ice cloud detection is affected, aerosols will be worse since their backscatter cross section is smaller.

Ln 169 You should mention earlier that this study is not including PSCs.

Ln 180-190 I am surprised that you are using AIRS for deep convection. MODIS has the same channels (and others) and is more frequently cited for identifying cold cloud tops in the 8 and 10.6 μ channels. Furthermore, MODIS or VIIRS has higher spatial resolution.

Ln 205 Gravity waves at 4μ are detected in the 30-45 km region (see Hoffmann and Alexander (2010), Fig. 3). These waves, propagating vertically, will have much lower amplitude at their tropopause source. For example, assume the wave is detected with a 0.5 K BT temperature (e.g. Hoffmann and Alexander Fig. 1) and using their the center of the weighting function, this wave is at ~40km, then the amplitude of the wave at 18 km will be about 0.05K by energy conservation. There is also a spatial correction, as the wave move from the source it will decrease in amplitude. For example, let's say the wave is detected 1000km from the convective system and the convective system has a radius of 100km. Then the source wave will have an amplitude 3 times larger than the detected wave. The author needs to discuss these possible or indicate why they are unimportant corrections.

Ln 213 The difference between 7.1μ and 7.3μ bands as a method of estimating SO_2 assumes you can neglect water vapor which will be important where the tropopause is below 8 km. Volcanic SO_2 is more easily detected in the UV bands – OMI on Aura is making those measurements coincident with CALIPSO and AIRS and might be a better choice. I am still unsure why we should even use SO_2 data since the aerosols come from CALIPSO and SO_2 will not be evident in aerosols due to fires.

Ln 227 'over the tropical continents.'

Ln 228 Awkward wording… 'The weakest signal..'

Ln 250 SIC associated with double tropopause are clearly an 'edge of the tropics' phenomenon – not surprising since that is where double tropopauses occur. I am not sure why these are important. They aren't contributing to dehydration of the stratosphere and double tropopauses are often associated with cloudy systems so I am not sure of their impact on the radiation budget…

Ln 275 Kim et al. emphasized the cooling rate, not just the low temperature was associated with cirrus. Obviously, you need to have a saturated environment for clouds to form, cooling the air creates saturation and ice crystals form. But once they form, they fall out so if the air is just cold and not cooling you don't see as many clouds. I think you should clarify this point.

Ln 290, Ln 304-6 What is the explanation for positive correlations? SIC's show up where temperatures are warmer. Ln 306 appear to be guesses. You might consider that the positive correlations are associated with cooling air not cold air as suggested by Kim (see above).

Ln 335 Convection will push the tropopause upward. So what you are doing here is finding the deep convection using AIRS and then interpolating the ERA5 tropopause height onto the point, and if the cloud observations are above the ERA5 tropopause it is a SIC. How do you know you have correctly located the tropopause? In fact, you don't know if the cloud is above or below the tropopause and thus whether it is truly a SIC. You need a coincident temperature profile (perhaps GPS) to prove this. At least give the reader some idea of the uncertainty in these estimates for the tropopause in these cases.

BTW, radar measurements over the US coincident with soundings show that convection drives the tropopause upward, collapses and leaves behind a residual cloud. You should quote some of these references to justify your assertions.

Ln 349-356 This discussion doesn't add anything to the paper.

Ln 364 'measurements are not significantly observed in tropics' ???

Ln 358-384 Since SICs at high latitudes are correlated with cold temperature anomalies and cold temperature anomalies are correlated with gravity waves, I am not sure I understand how these terms are independent in Fig 5. In fact, the correlation pattern in Fig. 5 are almost identical. I suggest that you present a map of correlations between temperature anomalies and gravity waves… This might give us more insight as to the causes. More specifically, cold temperature anomalies can be generated by mesoscale events as well as gravity waves. It is of interest to separate the two which I think might be lumped together in your analysis.

Ln 385 I am not sure why you are even using the AIRS SO2 since CALIPSO measurement of

aerosols is more of a direct measure of the influence of aerosols on cloud formation.

Furthermore, aerosols are also due to fires (see the anomaly at end of the period shown in Fig. 10 which is the Australian fires.) – see major comments.

Ln 427 Spearman

Ln 460 Table not Tab.

Ln 467 where did ‘Atmospheric Turbulence’ estimation come from?

Ln 481, 485 Fig. 6a

Ln 475 to 485. This is a very interesting discussion but still does not incorporate the point that deep convection can push up the tropopause so that SIC observations that are apparently above the tropopause are actually in the troposphere. Unless a GNSS RO measurement is made exactly at the right spot, the ERA5 reanalysis will place the tropopause at the wrong altitude.

Ln 494 It seems to me that the event frequency will over emphasize the SIC occurrence above convection. If you’re trying to connect these observations with stratospheric hydration (which is why I am interested in this) then occurrence frequency is the appropriate measure. If you are interested in the morphology of these events, then event frequency is appropriate. It might help to discuss some of these issues at the beginning of this section to motivate the reader.

Ln 511 OMPS-LP makes aerosol limb measurements and is active for most of the period you studied.