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Comment on acp-2021-90

Anonymous Referee #1

Referee comment on "Empirical evidence for deep convection being a major source of stratospheric ice clouds over North America" by Ling Zou et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-90-RC1, 2021

This is an interesting paper examining the frequency and distribution of clouds in the lowermost stratosphere over North America from many years of satellite-based lidar observations. It is generally demonstrated that stratospheric clouds are found commonly over the central Great Plains of the United states during the warm season and over the northwestern portion of North America and Atlantic Ocean during the cool season. It is further argued by comparing with satellite-based classification of deep convection that most of the stratospheric clouds are closely located (or juxtaposed) with convection. Much of the remaining clouds identified are linked with gravity waves (which are in large initiated by deep convection). These linkages are made somewhat loosely, as is common in a lot of prior work, but the association is logical and mostly appropriate. Some attempts to deal with spatial offsets between ongoing deep convection and stratospheric clouds are carried out and shown to have a minor, but important, effect on the results. Examining the frequency of stratospheric clouds is important and justified well in the paper, but some efforts to strengthen the evaluation and messaging throughout are recommended below.

General Comments:

1. On the characterization of stratospheric clouds as "cirrus": based on my evaluation of the paper, I expect a great deal of the stratospheric clouds identified are indeed overshooting cumulonimbus clouds rather than distinct (or mostly separate) cirrus clouds. To avoid confusion or misenterpretation of the focus of this work, I would recommend that the authors refer to clouds examined here as stratospheric clouds (or stratospheric ice clouds).

2. One theme of the paper that I think needs a bit of work is the messaging throughout on the potential sources / formation mechanisms for the stratopheric clouds examined. Deep convection is discussed as only delivering water vapor to the stratosphere (e.g., see lines 74-86; 195-196; 328-330 as examples), when in fact many of the studies the authors cite

demonstrate that the primary pathway for delivering water to the stratosphere is via ice. Thus, much of the clouds examined (especially those linked to deep convection) are very likely residual cloud material from previous injection. The stratosphere is often far too dry otherwise to enable in situ cirrus formation, for which some requested additions to the paper below may help sort out.

3. There is some analysis given to demonstrate sensitivity of linkages between convection and stratospheric clouds to the thresholds used for deep convection classification, which is helpful. For broader context of the occurrence of stratospheric clouds and their potential impact, I would recommend the authors add a figure to show the tropopause-relative altitude distribution of stratospheric clouds identified (by season). It would also be helpful to know what these distributions looked like for populations linked with deep convection and gravity waves. Because the background stratospheric water vapor concentration is 3-6 ppmv (with higher concentrations sometimes found within 1 km of the tropopause), I would expect the gravity wave process to be largely confined to the lowest kilometer of the stratosphere. This would also help to provide confidence in some of your linkages and their seasonality and allow you to assess potential sensitivity of your results to the tropopause-relative altitude threshold used.

4. The potential significance of poleward transport of water from the TTL to aid in stratospheric cloud formation is a bit overstated in my opinion. While there has been some evidence that this can occur, much of the broader analyses conducted (especially those looking at double-tropopause versus single-tropopause regions; e.g., see Schwartz et al 2015 - http://doi.org/10.1002/2014JD021964) have demonstrated that such transport is typically far drier than the extratropical lower stratosphere. Thus, I expect such a stratospheric cloud source to be exceedingly rare. I recommend the authors expand the discussion to point out this limitation.

5. Much of the remaining uncertainty in the association of stratospheric clouds with convection comes from the lack of an exploration of time offsets between convection occurrence and stratospheric cloud detection. This is explained somewhat generally as "atmospheric transport" in the paper, but I believe it should be given more attention/discussion. I suspect much of the residual could be linked to convection with more trajectory analysis and consideration of time offsets between storm occurrence and stratospheric cloud detection. The lifetimes of clouds in the stratosphere following convective injection (as summarized in the paper) and the downstream offsets of distributions shown certainly support the argument that much of those clouds that do not directly coincide with convection are linked closely in time with prior tropopause-reaching/overshooting convection. I am not necessarily suggesting the authors conduct such trajectory analyses, but they could do so for the instances where they don't have a clear linkage between stratospheric clouds and deep convection/gravity waves as they already demonstrated this conceptually in Figure 9 and it would be a nice addition to the paper. Improving the discussion throughout to emphasize a potential timing offset would help clarify some of the sources of uncertainty mentioned and contrast well with the spatial offsets which are given a fair amount of attention.

6. The summary of past ground-based (and some satellite-based) analyses of overshooting convection over North America is good, but there are several recent GPM

studies of overshooting that should be listed here and would help round out the discussion: Liu & Liu (2016) - http://doi.org/10.1002/2015JD024430, and Liu et al. 2020 - https://doi.org/10.1029/2019JD032003.

Specific Comments / Technical Corrections:

Lines 37-38: "two-third" should be "two-thirds", and "actually was" should be "is"

Lines 59-60: What is meant by "kind of controversial" here? It doesn't follow the argumentation leading this, so please be more explicit.

Line 62: "direct injection of air" and ice!

Line 67: "central" should be "central Great Plains"

Line 82: "up to 1-6 km" should be "up to 6 km". When specifying a maximum possible altitude, specifying ranges should be avoided.

Line 83: "convective system" should be "convective systems"

Line 90: "lead" should be "leads"

Line 133: "cirrus clouds top" should be "cirrus cloud top"

Line 177: "μ" should be "μm"

Lines 238-240: I would recommend also pointing out duration!

Figure 4: caption says "purple lines", but these appear blue to me.

Figure 5: why is the green line in the top panel a different color here?

Line 319: "up to 1-4 km" should be "up to 4 km", though note earlier it was stated that this could be up to 6 km (see line 82 comment above).

Line 322: "are averagely about". What exactly do you mean here? Please clarify.