Review of “How heating tracers drive self-lofting long-lived stratospheric anticyclones: simple dynamical models,” by Kasturi S. Shah and Peter H. Haynes.

General Comments

This article examines the dynamical response to heating induced by solar absorption of wildfire smoke or volcanic aerosols in the stratosphere. The motivation is to understand various observed aspects of newly discovered tracer-driven anticyclones. Using a simple axisymmetric model, the authors are able to reproduce many of the salient features of these phenomena. In particular, they provide an explanation for the observation of a single-signed potential vorticity anomaly and vertical temperature dipole. Another 2-D model is used to explore the initial stages of formation. The paper is well written and provides useful new insight into these newly-discovered phenomena.

Specific Comments

Line 38: You often say “smoke or aerosol”. Isn’t smoke considered an aerosol?

For the cooling term (Eq. 3), is the T relative to the background temperature so that if T=Tb, then you wouldn’t get cooling?

Line 263: What do you mean by “weakly stable configuration”.

Line 281: Is the heating actually in units of K/day? This seems like an extremely small heating rate. If the heating was K/s, that would translate to ~4 K/day, which is on par with the observed heating. I saw later in the discussion that you use the units of K/s (line 669), so I assume that is true throughout the paper. Please check units in text and figures.

Figure 2b: It is difficult to see the symbols for tracer maximum and QGPV minimum. Maybe in both 2a and 2b you could place these at ~600 km on the x-axis so they are easily seen?

Figure 2c:

- The grey line is very difficult to see.
- The initial anticyclone extends all the way up to 40 km, albeit small. Is this expected?
- The QGPV minimum appears to have a slight oscillation with period of a few days. Is this just a numerical artifact?
- In the limit of W small, but integrated a long time, do the two PV anomalies rise together, or do they separate as seen here?
- Might help to label the color bar with units.

Figure 3:

- Is the radial location of the minimum temperature always at r=0?
- Is this the absolute temperature minus the background temperature?
- Again, hard to see the grey line.
- May want to label the units either near the color bar or in the caption.
- Text refers to Figure 3a on line 305, but there is no 3a in the actual figure. May want to label all the panels in this figure and other figures to help the reader.

- On the right column, the labels say “Steadily translating solution v numerical solution”. But this is q, not v, right?
- For the right column, are the units consistent with the labeled values on the contours?

Line 333-4: I’m confused how the estimate for the PV anomaly is f. Why doesn’t this depend on the heating rate, since in the limit of zero heating wouldn’t there be no PV anomaly. I see you discuss this further in the last section, but it still doesn’t make intuitive sense.

Line 384: The diffusivities are constant, yet horizontal diffusivity in the stratosphere has been shown to vary, e.g., having minima associated with significant barriers to horizontal mixing associated with vortices (e.g., Haynes and Shuckburgh, 2000). Can the authors comment on whether you would expect similar diffusivity structures in these newly discovered tracer-driven vortices? Is there a way you could simulate this effect in your model by having diffusivity depend on model variables, such as PV gradient?

Figure 4:

- May want to include labels for (a), (b), …, (f) on the figure
- Are the units for heating correct, about 10^-5 K/day or should they be K/s?
- Hard to see tracer maximum and QGPV minimum symbols.
- The tracer distributions have what appears to be a very narrow maximum and then a broader elevated region, which is different from the observations. In the top and bottom cases there are actually two distinct maxima. Do you have any comment on this structure?
- It appears the temperature minimum is co-located with the QGPV minimum. Is that correct? If so, this is also different from observations.

It might be useful to plot a schematic diagram, similar to Figure 1b, for this simulation. This would help the reader to compare more directly with observations.

Is there a significant radial wind in these simulations? It would be nice to see the complete u, v, w structure.

The vortex stripping experiments are used to help remove tracer that occurs well below the maximum. How much of a role does vertical diffusion play in this remnant low-level tracer? What happens if you run the model with very small or very large vertical diffusion?

Figure 5:

- May want to include labels for (a), (b), (c), (d) on the figure
- On line 442 I think you have the panels reverse: (a) should be without, (b) should be with
- Does the temperature dipole structure have better agreement to observations in this case than in the previous? Is there cooling above and warming below the QGPV minimum? Again, a schematic like Figure 1b would be nice.

Figure 6:

- Again, may want labels on the individual figure panels.
- Again, it would be interesting to see the structures in the wind fields for this case.

- Again, the temperature dipole does not agree with Figure 1b. The minimum peaks at the same location as the PV minimum. Any idea why this is the case?

The discussion of the instability in the x-z plane was very interesting. I wonder if it would be beneficial (not for this paper, but for future work) to also perform the 2-D analysis in the x-y plane (e.g., shallow water system) where a heating tracer is initially placed in an irrotational flow. The heating could increase the layer thickness and cause rotation via geostrophic balance, which would help to contain the tracer against horizontal shearing flow. This wouldn't model the lofting effect but could help to understand some of the self-organizing flow.

Line 673: There were at least three vortices from the 2019/2020 Australian wildfires. I think you mean the largest vortex, since the others ascended at a slower rate and didn't go as high or last as long.

Lines 687-689: Might be useful to quote your typical azimuthal velocity and temperatures produced in your simulations and compare them to observations.

Lines 720-722: Some discussion of vortex resistance to shear was also presented in Allen et al. (2020), https://doi.org/10.1175/JAS-D-20-0131.1 which was a follow-up to Kablick et al. (2020) and provided more detailed analysis of dynamical properties of the main anticyclone associated with the Australian New Year event, in addition to examining one of the 2017 Pacific Northwest Event plumes.

Technical Corrections

Line 3: should be "carbon monoxide"

Line 30: should be "carbon monoxide"

Line 31: Should be "have shown" to match the subject "fields"

Line 148: "a r a" sounds funny. Maybe remove first "a"

Figure 1 caption: "and volcanic eruptions" can be removed before the first set of references

Line 330: remove "is" from "ascent is tends"