Review of "Stratospheric impact of the anomalous 2023 Canadian wildfires: the two vertical pathways of smoke" by Khaykin et al.

Reviewer Summary

This manuscript presents a comprehensive and well-structured analysis of the 2023 Canadian wildfires and their impact on the stratosphere, with a clear distinction between pyrocumulonimbus (PyroCb) and warm conveyor belt (WCB) transport pathways. The study addresses an important topic with high relevance to atmospheric chemistry and climate, particularly in the context of increasing wildfire activity under climate change. The main strength of the paper lies in its careful multi-source observational analysis and event-by-event classification. The primary weakness is the lack of discussion on why the period of peak fire activity did not yield significant stratospheric intrusions, which leaves a gap in the mechanistic understanding. I recommend **acceptance after minor revisions**, provided the authors address the points detailed below.

General Comments

The manuscript is well written, logically structured, and addresses an important topic that will likely gain further relevance under ongoing climate change and the projected increase in wildfire frequency and intensity. The analysis of the 2023 Canadian wildfires and their impact on the stratosphere is both thorough and insightful, particularly in distinguishing between PyroCb and WCB pathways. My recommendation is to accept the manuscript for publication in *Atmospheric Chemistry and Physics* after the authors address the following points, which aim to improve the clarity, completeness, and scientific context of the work.

1. **Reconsideration of the PyroCb dominance statement (lines 45–50)**
   In light of the results presented, showing that out of 142 detected PyroCb events, only three (event #1 and partially events #6 and #7; Table 1) were associated with measurable stratospheric impact, the authors may wish to revisit their statement that PyroCb activity is the *primary* source of combustion products entering the stratosphere. It could be valuable to discuss whether the current findings are consistent with this prevailing view or whether alternative pathways, such as WCB transport, might warrant greater emphasis.

2. **Potential human-induced biases in PyroCb detection (Section 2.2)**
   The manuscript notes the use of an “analyst-in-the-loop” approach for PyroCb identification (line 80) in the global database of 761 events (2013–

2023). The authors could elaborate on any potential human-induced biases in this process. In particular, could such biases have contributed to under-detection of PyroCb events during August–October 2023?

3. **Clarification of the SALD product's origin and validation (Section 2.6)**
   It is not entirely clear whether the Stratospheric Aerosol Layer Detection (SALD) product, which is derived from OMPS-LP observations, is a locally developed dataset specifically for this study, or an existing product previously used and validated. If the latter, references should be provided; if the former, additional methodological details and validation steps would strengthen the study's reproducibility and robustness.

4. **Missing explanation for lack of stratospheric intrusion during peak fire activity**
   While the manuscript clearly distinguishes between PyroCb- and WCB-driven events, it does not address why the period of most intense wildfire activity (June-July), when nearly all PyroCb events were recorded (Fig. 1B) and most of the fire energy was released (Fig. 1A), failed to produce significant stratospheric intrusions.

   Possible explanations might include:
   a. Reduced intensity or frequency of WCB activity during June–July.
   b. A lower tropopause height during September–October, favoring stratospheric intrusion.

   These hypotheses could be evaluated using available datasets, and other explanations may also be relevant. To aid such an analysis, it may be useful to:

   - Extend Fig. 4's time frame to include May–July.
   - Disaggregate Fig. 8A by month or split into May–July and August–October periods.

   Without addressing this question, the interpretation of the results remains incomplete, as highlighted by the summary on lines 664–668, which implicitly raises the question of *why* this pattern occurred.

5. **Comparison of CO observations with model output (Section 3.5)**
   The analysis in Section 3.5 could be further strengthened by comparing the measured CO concentrations with predictions from the MOCAGE model (if available). Such a comparison would help assess consistency between observations and simulations and provide additional context for interpreting the results.

6. **Inclusion of injected mass estimates for additional wildfire events (lines 650–658)**
   Since the authors have already compared their results to other wildfire events (e.g., in Australia), it would be informative to also include the estimated injected aerosol masses for these events, not only for the PNE event. This would provide a more complete comparative framework for evaluating the 2023 Canadian wildfire injections.

Specific (Technical) Comments

1. **Spectral range classification** (lines 103–104 vs. lines 113–114)
   In lines 103–104, the 300–380 nm range is described as encompassing both "UV and visible spectral regions," whereas in lines 113–114, the 340–380 nm range is referred to solely as "UV spectral bands." The authors should ensure consistent terminology and spectral classification throughout the manuscript.
2. **Reference formatting** (line 131)
   The reference to *Taha et al., 2021* appears with inconsistent font formatting. Please standardize to match the manuscript's reference style.
3. **Clarification of Fig. 2C reference** (Section 2.7, line 143)
   It is unclear why Fig. 2C is referenced here and what specific information it contributes to this section. Additionally, the relevance of the "16 km" value mentioned in this context should be explained.
4. **Integration of data sources** (end of Section 2)
   After introducing all data sources, it would be beneficial to add a brief methodological statement summarizing how these datasets are integrated in the analysis. This would help readers understand the workflow and interconnections between the various observational and model products used.
5. **Justification for WCB diabatic heating statement** (lines 498–499)
   The statement that "the low concentration of aerosols in the WCB plumes limits the degree of internal heating and thereby does not enable diabatic self-lofting in the stratosphere" requires either a quantitative calculation or supporting reference to substantiate the claim.
6. **Potential missing context before line 518**
   The paragraph beginning at line 518 appears to reference preceding material that is absent. Phrases such as "another CO enhancement..." and "1.5 hours later" clearly indicate continuity with earlier discussion.

The authors should verify whether relevant preceding text has been inadvertently omitted.