The manuscript investigates chemical and thermal variability in the mesosphere, with a particular focus on the role of upwelling in the polar summer. The study is based on satellite data (MLS, SABER, SOHIE). A major finding of the manuscript is a causal chain involving upwelling, transport of water vapour and resulting odd hydrogen, effects of odd hydrogen on odd oxygen, and the role of odd oxygen on heating the upper mesosphere. In polar summer condition, the additional effect of Polar Mesospheric Clouds on water vapour is considered (cold trap, dehydration above the cloud).

Relationships between relevant quantities are investigated using correlation analysis and time-lag analysis applied to the satellite data. The temperature around 80 km altitude is used as a proxy for the strength of the mesospheric upwelling, which makes sense considering the adiabatic cooling connected to the upwelling.

Model simulations would be beneficial for this study, as they could help to distinguish between the role of various processes. However, I understand that model simulations are beyond the scope of the current manuscript. Rather, the major achievement of this manuscript is tracing the suggested mechanism in the satellite data.

The manuscript is well written. The figures are very well designed and instructive.

I recommend the manuscript for publication after some major revisions and text corrections.

General comments:

The manuscript is instructive and nicely illustrates the suggested relationships. However, I disagree with the authors in calling this a “novel mechanism”. Rather the individual processes and relationships described in the manuscript are well known and already part of atmospheric numerical model. This also includes the effect of the mesospheric cold trap for models that include PMC microphysics or that are coupled to PMC microphysics. As stated above, the manuscript is valuable in clearly describing the connections between upwelling, odd hydrogen abundance, odd oxygen abundance, and heating. But do not call it a novel mechanism.

The manuscript correctly describes that upwelling affects odd oxygen through (1) lower temperatures that affect the reaction $O + O_2 + M$, and (2) generation of PMC, resulting in dehydration and reduced HO_x/O_x chemistry. However, there is another major effect of upwelling/downwelling on odd oxygen concentrations in the upper mesosphere: controlling the transport from the large atomic oxygen reservoir in the lower thermosphere. The authors address this process late in the manuscript (Section 4.3, Lines 294-300). Based on the time lag analysis, the authors rule out a major effect of this transport on the observed variability of odd oxygen in the upper mesosphere. Nonetheless, the variability of odd oxygen sources is a very important topic for this manuscript. Therefore, I suggest to describe sources of odd oxygen and their variability already in Section 1.2 (“Ozone chemistry and variability”). Currently, this section only focuses on sinks of odd oxygen.

The authors state that there is a fundamental difference between the "freeze-drying effect" by PMCs as described in earlier literature and the "cold trap" effect by PMCs described in the current manuscript. I do not agree. Both are based on the same physical principle: water vapour freezes to PMC particles while the PMC particles sediment, the particles then sublimate and release the water vapour. What varies from case to case is the altitude difference (and thus the time difference) between the freezing and the sublimation. The authors may want to argue that altitude difference may be smaller than suggested by other studies. However, they should not claim that this a fundamentally different process ("cold trap" rather than "freeze drying").

Earlier studies of the PMC cold trap generally found a local or a regional effect: The cold trap affects the distribution of water vapour in the polar mesosphere region. The current manuscript suggests that the PMC cold trap affects water vapour all the way to lower latitudes and to the winter hemisphere. I do not find this convincing, and I do not think that the PMC cold trap is needed to explain enhanced water vapour ("hydration") at these latitudes. Rather, a much more direct explanation of the connection between T80s (upwelling) and the global hydration in Figure 4a and Figure 10a is the continuity equation: When there is more upwelling near the summer pole, mass conservation will lead to horizontal transport of water vapour towards lower latitudes and the winter hemisphere.

Hence, some statements must be revised. Two examples: Line 137, "cold-trap effect induced winter hemisphere hydration" should be replaced with "winter hemisphere hydration that is induced by summer pole upwelling in combination with meridional transport". Line 309-310, "we demonstrate that the cold-trap effect effectively explains global-scale interannual H_2O variability" should be replaced by "we demonstrate that updraft in combination with meridional transport effectively explains global-scale interannual H_2O variability"

Section 1 provides a good review of the processes connected to water, PMC, odd oxygen and the thermal balance in the mesosphere. Much of Section 2.2 is then a repetition of Section 1. I recommend to shorten Section 2.2.

Text corrections:

Line 9: Remove "the" from "Using the MLS..."

Line 10: The manuscript refers to temperatures and concentration at specific altitudes, not in altitude ranges. Therefore, clarify by replacing "above 90 km" with "near 90 km".

Line 13: Change to "toward the winter hemisphere".

Line 14-15: Change "... due to ozone chemical equilibrium assumption, and..." to "... due to chemical equilibrium, and..."

Line 15: Change "chemical heating of O/O3 reduces the T90 in winter hemisphere..." to "chemical heating by O/O3 reactions reduces T90 in the winter hemisphere..."

Line 33: Clarify by replacing "... H_2O maxima in December" by "... H_2O maxima in the summer hemisphere"

Line 39: Change to "suggesting an incomplete understanding"

Line 32: Solar UV is expected to affect H2O, which in turn is experctyed to affct PMC. Therefore, clarify by changing to "influences H2O, and thus PMCs, (Rehmberg et al..."

Line 54: Clarify by changing to "...these advances in understanding, ..."

Line 66: Change to "with a rate exceeding..."

Line 69: Change to "exhibiting an unexpected warming"

Line 73: Change to "affects mesospheric winds"

Line 91-92: Clarify by changing to "...orbits, focusing on zonal..."

Line 102: Change "instruments" to "instrument".

Line 107: Change to "after which SOFIE measurements shifted..."

Line 110: Change to "upwelling on interannual timescales".

Line 119: Change to "towards the winter hemisphere".

Line 123: Change to "while it inhibits..."

Line 130: Change to "T90s in the summer..."

Line 132: Change to "enables a quantitative..."

Line 139: Change to "to the ozone..."

Line 162: Change to "that O_3 at 90 km is..."

Line 163: Change to "during which PMCs are weak..."

Line 206: Change to "... %/K) have been derived from..."

Line 226: Change tp "similar to Figs. 6-7..."

Line 245: Change to "... sensitivities have been derived from..."

Line 280: Change to "shows that these processes..."

Line 295-296: Change to "above the mesopause height. and gravity waves..."

Line 296: Change "tends" to "tend".

Line 296: Change to "at altitudes above the mesopause"

Line 301: Change to "or the temperature profile"

Line 302: Change to "supporting a shrinking effect"

Line 308: Change to "climate of the upper mesosphere"

Line 312: Change “depletion of H” to “depletion by H”