Response to Reviewer 1 comments
Manuscript Number: EGUsphere-2024-1144
Manuscript title: Spatial and temporal variation in long-term temperature and water vapor in the mesopause Region, by Chaman Gul et al.,

30th July 2024

Dear anonymous reviewer,

Thanks for the comments, suggestions, and recommendations for the EGUspher-2024-1144 manuscript. Comments are constructive and we quite improved the manuscript after addressing all the comments. We have thoroughly considered and carefully addressed all issues mentioned in the comments and have properly outlined every single change made in response to reviewer comments as suggested. We have made the required corrections in the revised manuscript (visible in tracked change mode) and prepared a list of point-by-point responses as given below starting from page #2 of this document. We have attached two copies of the revised manuscript, one with track change mode having all edits/corrections and the other is a fair copy of the manuscript where we have accepted all the mentioned edits/corrections. The reviewer's comments are in **black** text, the author's responses are in **blue** text, the modified/corrected text from the revised manuscript is in bold **brown** text, and references are in green text. Modified line numbers are in **yellow highlighted** text.

Response to reviewer 1 (R1) comments (Cs):

Reviewer #1: Review of "Spatial and temporal variation in long-term temperature and water vapor in the mesopause Region" by Gul et al.

General comments by reviewer 1:

(R1-C1) This article investigates long-term change in temperature and water vapor using observations from the NASA SABER satellite instrument. The quality of writing, overall organization, and implementation of the English language are substandard, which detracts from the task of reviewing the scientific merit of the work.

Response to (R1-C1):

Thank you very much for your precious time and multiple constructive comments. We have modified/revised the manuscript (including the language improvements), made the required corrections in the revised manuscript (visible in tracked change mode), and prepared a list of point-by-point responses as given below.

(R1-C2) Regarding the scientific quality of the work, I believe there are major flaws that lead me to recommend rejecting this paper. It seems that poorly written papers are increasingly common, and I feel that the community is in danger of either lowering our standards or exhausting the review process. Regarding the scientific quality of the paper, I have some important concerns which are the basis for my recommendation to reject this paper. Foremost is that there is no description of how the Authors determined trends from the observations. There are numerous resources that describe the derivation of trends from geophysical observations, and the Authors need to consider these methods and include the references. An important factor here is that the observed parameter is being modulated by another forcing mechanism, perhaps one that is periodic in nature, and that this dependence contaminates the derived trend. Of relevance here is that temperature and H2O in the mesosphere respond to the 11-yr solar cycle (see references in this paper), with less H2O and higher T near solar maximum. Looking at Figure 3, there is a clear 11-yr. solar cycle dependence in T and H2O (solar maxima were roughly 2002 and 2013). This is extremely important because the SABER time series begins near solar maximum and ends near solar minimum, giving the appearance of a massive cooling trend (and rising H2O). If the Authors derived their trends from simple linear regression to the time series, then the results are likely not representative of the actual trends due to rising greenhouse gasses. The trends should be derived using multiple linear regression with the inclusion of at least two terms, 1) the solar cycle (e.g., using Lyman – alpha) and 2) time (i.e., the trend). The trend derived in this manner will be less affected by haphazard alignment between the observations and the solar cycle, as is clearly evident here. Many authors would choose to also include terms such as the QBO, AO, and ENSO. Again, there are accepted ways to do this and the Authors must adopt these approaches and describe what they did in the paper.

Response to (R1-C2):

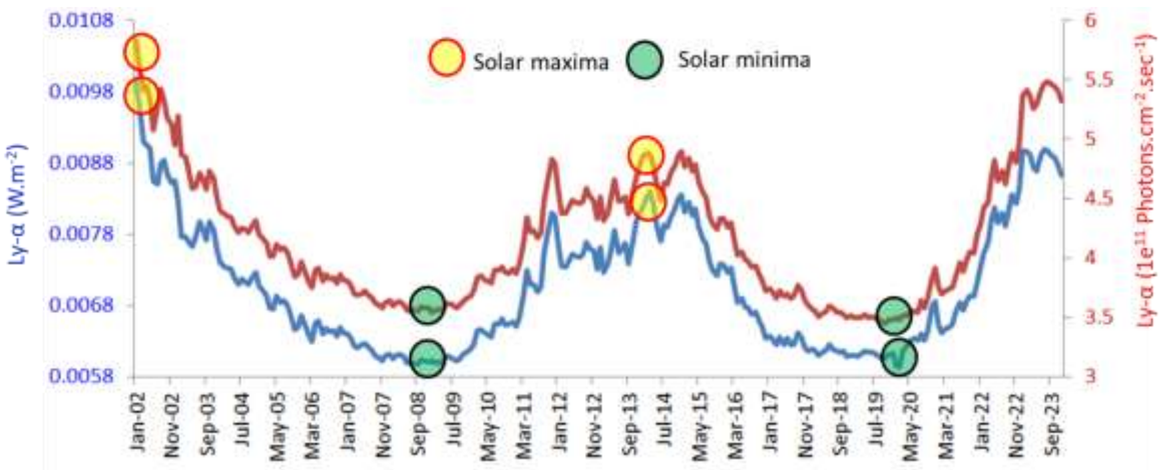
To investigate the long-term trend from the observations and solar response of the mesopause temperature, we used multiple linear regression analysis. We derived trends using multiple linear regression with the inclusion of two terms, 1) the solar cycle (e.g., using Lyman – alpha) and 2) time (i.e., the trend). We have updated the text accordingly (section 2.3.1 of the revised manuscript) and the same is given below

"2.3.1. Multiple linear regression analysis

To investigate the long-term trends (temperature and WV) and the solar response of the mesopause temperature, a three-component harmonic fit is applied to remove the seasonality from the monthly data series. Then a multiple linear regression model is performed to solar activity, linear trend, and residual temperatures versus constant. Applying the regression analysis to latitude-averaged temperature and WV provides a more statistically significant value of their trends. Lyman-α flux is a proxy for solar activity, so the monthly mean of Lyman-α solar flux is used in multiple linear regression equation (1) as a measure of solar variability. Multiple linear regression analysis technique has been used by multiple authors in the past (e.g., Chandra et al., 1997; Hervig et al., 2015, 2016; Yue et al., 2019). To analyze the temperature and WV trends using multiple linear regression with the inclusion of the solar cycle and time we applied the following multiple regression analysis for trend estimation.

$$\mathbf{Temperature} = C_o + C_1(\mathrm{Lyman.}\,\alpha) + C_2(\mathrm{time}) + \mathrm{error} \qquad (1)$$

Where C_0 is constant (intercept), C_1 and C_2 are regression coefficients characterizing the linear long-term trend (temperature and WV per year) and solar activity term. We calculate temperature and WV trends using multiple linear regression involving monthly temperature and WV (SABER) data over time. Before applying the multiple regression model we calculate solar radiation according to monthly data sets. For example, Monthly means of the Lyman-α index are computed for each month, yielding 176 points for both global and equator."



A subpart of Figure 1: Lyman- α index during January 2002-December 2023.

(R1-C3) The paper suffers from a high degree of ambiguity in the presentation of their results, but also in the quotation of results from previous work. For example, look at the paragraph starting on line 470. The quoted trends are widely varying, yet there is no mention of the relevant latitude, altitude, or season for these results, and it is bewildering to try and make sense of it. This is just one example of the inadequate writing in this paper, and I feel that publishing these results in the present form would do more harm than good.

Response to (R1-C3):

In the revised text we have provided detailed information as suggested. We have included the relevant latitude, altitude, or season for these results in the mentioned paragraph and other places in the manuscript. We have modified the paragraph as suggested (lines 613-617 of the revised manuscript) and the same is given below

A cooling trend in temperature was also reported by other authors in the past (Zhao et al., 2020 (avg: −0.75 K/decade, latitude: 83°S to 83°N, altitude: 80-100 km); Dalin et al., 2020 (-2.4 K/decade, latitude: 57°N, altitude: 80-100 km, season: winter and summer); Yuan et al., 2019 (~-2.4 K/decade, latitude: ~42°N, altitude: 92 and 97 km, season: winter and summer); French et al., 2020 (-1.2 K/decade, latitude: 68S, altitude: 87 km, season: winter)). Mlynczak et al. (2022) (latitude: 55°N to 55°S, altitude: mesosphere and lower thermosphere, season: annual) found significant cooling and contraction during 2002-2019 due to a weaker solar cycle.

Information related to altitude, latitude, and season are also updated in the revised Table 1. Please have a look at the response to your comment (R1-C11, following pages) where we have provided the revised Table 1.

(R1-C4) While this paper should be rejected, I believe that the subject matter is of interest and that it could represent a useful contribution after major revisions. To this end I offer some high-level suggestions below, but refrained from commenting on the ubiquitous flaws in writing, organization, and English, as this would consum too much time. I hope that the Authors will find some expert help to improve the writing and use of English. Please note that properly revising this paper will require much more consideration than offered in my comments below.

Response to (R1-C4):

Thank you for allowing us to improve the writing and use of English. The paper has been carefully reviewed by the co-authors. Multiple edits/improvements related to writing, organization, and English are visible in the revised track-changed version of the manuscript. A few examples of these updates are given below.

1. We revised all figures and tables.
2. We added additional required sections, for example, section 2.3 Solar cycle response, and section 2.3.1 Multiple linear regression analysis.
3. We removed less relevant (or having a repetition of information) sections, for example, section 3.1.3 (relationship between temperature and WV). We already showed an inverse relation between temperature and WV in multiple locations.
4. We rewrite whole sections, for example first section of the introduction part.
5. We revised the captions of all figures as suggested
6. We have made corrections in almost every line of the revised manuscript.

Specific comments by reviewer 1:

(R1-C5) 1) The writing, organization, and use of English are substandard. To demonstrate this point, examine the first four sentences of the introduction:

> "Mesopause is one of the complex and intricate domain regions of Earth's atmosphere. It is the thermal transition area that plays an important role in the vertical coupling of the Earth's atmosphere. In the global mean temperature, mesopause is the coldest layer of the atmosphere (Zhao et al., 2020; Ortland et al., 1998). Polar summer mesopause is considered the coldest place on Earth (Ortland et al., 1998)."

The first sentence is confusing and serves no purpose. The second sentence is vague, and technically incorrect because much of the atmosphere is involved in some aspect of vertical coupling. The third and fourth sentences are awkwardly stated and somewhat redundant.

Response to (R1-C5):

We tried our best to improve writing, organization, and the use of language to present a better quality of work. We have revised/updated the whole paragraph (lines 47-69 of the revised manuscript) and the same is given below.

In the global mean temperature, mesopause is the coldest layer of the atmosphere (Zhao et al., 2020; Ortland et al., 1998), and exhibits a robust variation in temperature (Offermann et al., 2010; Dyrland et al., 2010; She et al., 2000; French et al., 2020b; Dalin et al., 2020; Grygalashvyly et al., 2014). Temperature is changing from ~160 to ~185 K, relatively cooler over the equatorial region and warmer toward both poles (Xu et al., 2007). The temperature at the summer pole ranges between 120 to 140 K and at the winter pole ranges between 180 to 210 K (Brasseur and Solomon, 2005). The amplitude of seasonal variations in the mesopause temperature increases with increasing latitude. The temperature and mean location of menopause are established by radiative and dynamical processes (e.g., Leovy, 1964; Holton, 1983) and also display large variability due to tides, gravity, and planetary waves. Short-term variability in temperature is primarily due to small-scale gravity waves and tides (Dalin et al., 2017; Zhao et al., 2020). Gravity and planetary waves (Dalin et al., 2017), and atmospheric tides (Smith, 2004) bring periodic variations in temperature. The temperature response to solar activity is ~+2 times greater in winter than in summer (Dalin et al., 2020). Winter mesopause temperature trends (−6 to −2 K/decade) are generally stronger than summer ones (−2 to +0.5 K/decade) (Offermann et al., 2010). This indicates that summer polar mesopause receives significantly more solar radiation than winter mesopause, but the temperature is lowest at summer polar mesopause observed anywhere on Earth. The height of the mesopause varies significantly with latitude and season (Xu et al., 2007; Wang et al., 2022). The mesopause height is approximately 90 and 100 km in summer and winter respectively (Brasseur and Solomon, 2005). At mid and high latitudes the mesopause is located near 85 km during the summer season (Smith, 2004). The mesopause is at a higher altitude at the equator for all seasons (Xu et al., 2007).

In the revised manuscript, the introduction section has four paragraphs. The first paragraph is about mesopause temperature and altitude. The second paragraph is about water vapor in the mesopause/atmosphere and its connection with temperature. The last paragraph has information about current work. Besides above mentioned paragraph, we made similar changes in other multiple places of the manuscript.

(R1-C6) One more example from lines 99-100:

"Spatially the region was divided into four parts (North Pole, Equator, and South Pole). Two two-degree latitude areas were selected for all longitude ranges (Figure 1)."

The first sentence states that the region (the globe?) was divided into 4 parts then mentions only 3, while the second sentence goes on to discuss only 2 latitude bands.

Response to (R1-C6):

We have revised the whole section, and clearly explained the study area (lines 110-124 of the revised manuscript), and the same is given below

"2.1. Study area

Spatial and temporal variations in long-term temperature and WV are analyzed in the mesopause region (80-100 km altitude). Spatially the region is divided into three latitude bins (Equator, Northern, and Southern Hemispheres). Taking temperature and WV data in 0° ± 1°, 80°N ± 1°, and 80°S ± 1° latitude bins represent the equator, northern hemisphere (NH), and southern hemisphere (SH) respectively. All latitudes, and longitudes of the mesopause covered by the SABER instrument during a year are represented by global mesopause. Twenty-two years (2002-2023) of monthly data from the SABER instrument on board the NASA Thermosphere, Inonosphere, Mesosphere, Energetic, and Dynamics (TIMED) satellite are analyzed during eight selected months of each year excluding the four transitional months (February, May, August, and November). The selected months for temporal analysis of temperature and WV are four equinoxes (March, April, September, and October), and four solstices (January, December, June, and July) months………"

(R1-C7) Figure captions: A figure caption must describe every aspect of the image, including details of the results (such as latitude, time, and height), and the origin of the results (such as "SABER observations" or "model results", or "trends derived from linear regression", etc…). It is not acceptable to do this only in the text, and then force the reader to go back and forth to understand a figure. An acceptable caption would be something like this (using Fig 4 as an example): **Figure 4**. Temperature and water vapor at 80 km altitude from SABER observations near the equator (0° ± 1° latitude). a) Time series of yearly mean T and H2O, based on months as indicated in Figure 4b. Trends are also shown, which were determined using multiple linear regression to the results. b) T and H2O time series for individual months as indicated. c) T and H2O versus month for individual years as indicated.

Response to (R1-C7):

We have revised all Figure's captions as suggested. A comparison table of previously used captions and revised captions along with page numbers in the revised text is given below

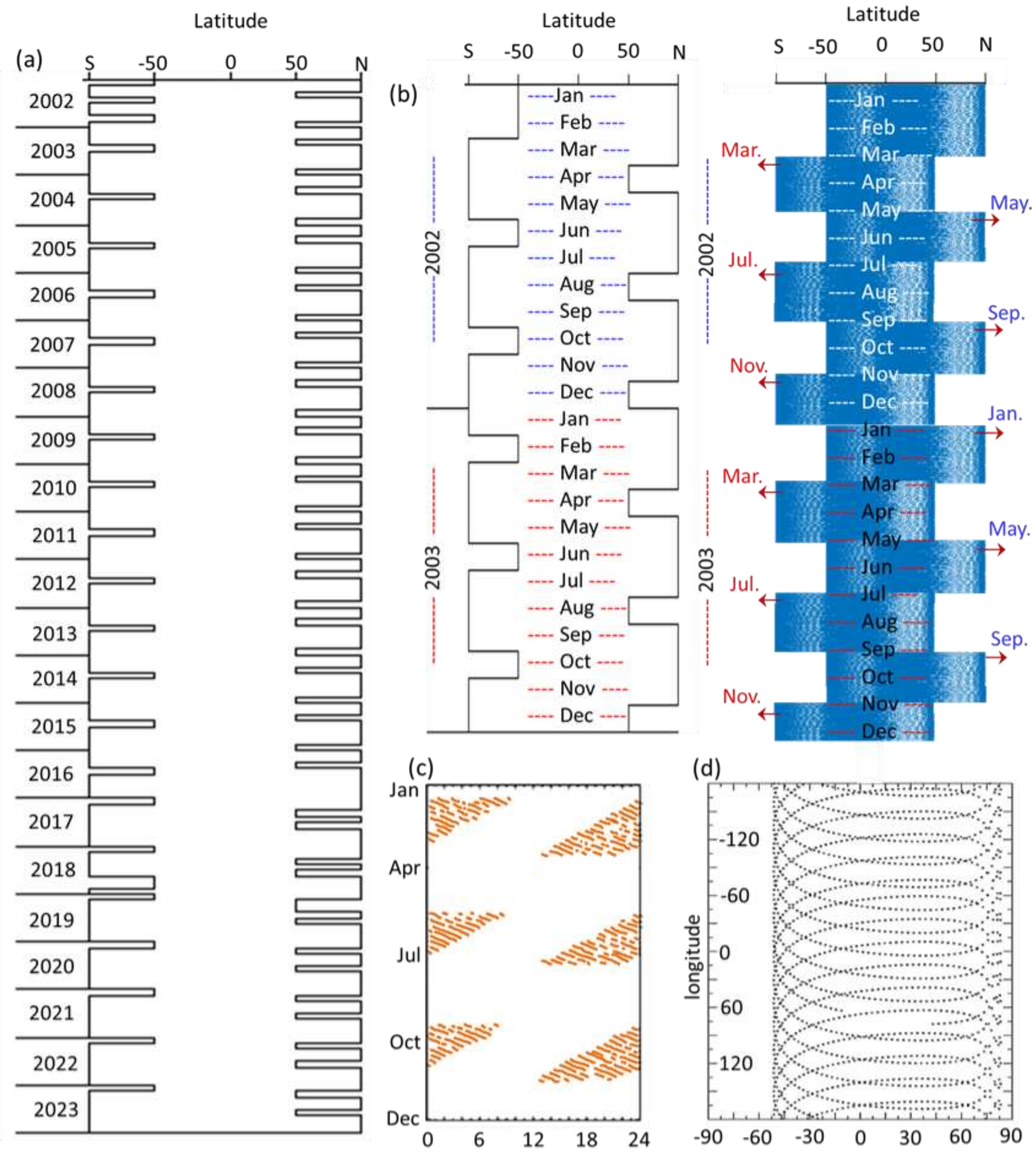
Fig. #	Previous caption	Revised caption used in the revised manuscript	Page #
1	Study area (a) spatial range of selected regions, (b) temporal range from selected years from 2002 to 2023.	SABER instrument latitude coverage versus time for observation and Lyman-α solar index. a) Monthly data coverage in selected months versus latitude ranges from January 2002 to December 2023, excluding transitional months. b) Comparison of SABER latitude coverage and monthly data versus time during years (2002-2003). c) Typical temporal coverage of TIMED-SABER instrument measurements. d) Latitude versus longitude tangent point locations for one day of observations in its north viewing phase (83°N to 52°S) – a north viewing yaw mode. e) Lyman- α index during January 2002-December 2023.	7
2	Variation of temperature and water vapor in the mesopause region during 2002- 2023 for the whole mesopause region.	Temperature and water vapor gradient between 80-100 km altitudes from SABER observations at the three selected latitude bins during 200-2023. a) Equator (0° ± 1°). b) Northern hemisphere (80°N ± 1°). (c) Southern hemisphere (80°S ± 1°), in the indicated months, by averaging all January, June, and September values from 2002 to 2023.	11
3	Relationship between temperature and water vapor content a. yearly averaged temperature and water vapor in selected, b. temperature, c. water vapor for two selected years.	Temperature and water vapor at 80-100 km altitude from SABER observations on the global scale. a) Time series of yearly mean temperature and WV, based on selected months as indicated in Figure 3c. b) Differences of the SABER annual temperature and fit curve (residuals). c) Temperature and WV time series for individual months of 2002 and 2018. d) Differences in the SABER annual temperature and fit curve during 2002.	16
4	Temporal variation of temperature and water vapors over the equator	Temperature and water vapor at 80-100 km altitude from SABER observations near the equator (0° ± 1° latitude). a) Time series of yearly mean temperature and WV, based on months as indicated in Figure 4c. b) Differences of the SABER annual temperature and fit curve (residuals). c) Temperature and WV time series for individual months as indicated. d) Temperature and WV versus month for individual years as indicated.	19
5	is the Same as Figure 4 but represents the North Pole	Temperature and water vapor at 80-100 km altitude from SABER observations near the NH	21

		(80° ± 1° latitude). a) Time series of yearly mean temperature and WV, based on months as indicated in Figure 5c. b) Differences of the SABER annual temperature and fit curve (residuals). c) Temperature and WV time series for individual months as indicated. d) Temperature and WV versus month for individual years as indicated.	
6	Same as Figure 4 but represents the South Pole region	Temperature and water vapor at 80-100 km altitude from SABER observations near the SH (80°S ± 1° latitude). a) Time series of yearly mean temperature and WV, based on months as indicated in Figure 6c. b) Differences of the SABER annual temperature and fit curve (residuals). c) Temperature and WV time series for individual months as indicated. d) Temperature and WV versus month for individual years as indicated.	24
7	Difference in north-south temperature (a,c) and water vapor content (b,d) at two equinoxes (March and September) and two solstices (January and July)	Difference in NH-SH temperatures and NH-SH, WV at 80-100 km altitude during selected months of equinoxes (March and September) and solstices (January and July). a, c) Water vapor content difference. b, d) Temperature difference.	26
8	Intra-annual temperature and water vapor variations. The left column is for Temperature and the right column is for water vapor in selected months a. July, b. January, c. March, and d. September	Inter-annual variations in monthly mean temperature and water vapor from SABER observations over selected bins of latitudes during 2002-2023. The left column is for temperature temporal variation and the right column is for water vapor temporal variation in selected months. a) 22 years monthly mean for July. b) 22 years monthly mean for January. c) 22 years monthly mean for March, and d) 22 years monthly mean for September.	27
9	Temperature and water vapor trends for selected locations and months during the study period.	Temperature and water vapor trends during selected four months as indicated. a) Temperature and WV trends over NH (80°N ± 1°). b) Temperature and WV trends over SH (80°S ± 1°). c) Temperature and WV trends over the equator (0° ± 1°). d) Temperature and WV trends on the global scale.	29
10	Three-dimensional variation of temperature and water vapor in selected months a,c) January 2002 and b,d) July 2015 for the North Pole region.	Two-dimensional (latitude, and altitude) variation in temperature (K), and WV (ppmv) at three latitudes as indicated, and three altitudes (80 km, 90 km, and 100 km) during January 2003.	34
11	This is a new added figure in the revised manuscript.	Two-dimensional (latitude, and altitude) variation in temperature (K), and WV (ppmv) at three latitudes as indicated, and three altitudes (80 km, 90 km, and 100 km) during June 2023.	35

(R1-C8) Figure 1: This illustration is not needed, as most readers already understand these concepts. What would be much more useful is a plot of the SABER latitude coverage vs. time, as this is somewhat complicated. I show an example below of how this could be done. Note also that the SABER latitude vs. month is slowly changing over the years, and one must be very careful when constructing a 20+ yr. time series. For example, coverage of high northern latitudes included July in early years, but not during the recent several years. As a result, the Author's choice of June and July for high latitudes introduces a systematic bias in the time series, in that July is no longer represented in recent years. Illustrating these aspects of the data would be much more useful and relevant.

Response to (R1-C8):

We have replaced Figure 1 with a new Figure as suggested (page 7 of the revised manuscript) and the same figure is given below.



Revised Figure 1. SABER instrument latitude coverage versus time for observation. a) Monthly data coverage in selected months versus latitude ranges from January 2002 to December 2023, excluding transitional months. b) Comparison of SABER latitude coverage and monthly data versus time during years (2002-2003). c) Typical temporal coverage of TIMED-SABER instrument measurements. d) Latitude versus longitude tangent point locations for one day of observations in its north viewing phase (83°N to 52°S) – a north viewing yaw mode.

We have illustrated the mentioned aspects in the methodology section (lines 126-164 of the revised manuscript) and the same is given below

"2.2. TIMED-SABER instrument

The TIMED-SABER satellite views 90° to the right of the velocity vector of the TIMED spacecraft, and completes a full 24-hour local time coverage in 60-63 days (Russell III

et al., 1999; Mlynczak et al., 2003; Figure 1). The SABER instrument scans the atmosphere from the troposphere up to the lower thermosphere and obtains vertical profiles kinetic temperature and volume mixing ratio of WV (Russell et al., 1999). The instrument performs near-global measurements and provides an excellent quality of the measured infrared limb radiances (Esplin et al., 2023). Technical description of the SABER instrument and further relevant information are discussed by Mlynczak, (1997) and Russell III et al. (1999). TIMED satellite rotates 180° about its yaw axis and provides latitude coverage continuously in the range of 53°S to 83°N and then switching to 83°S to 53°N every ~60 days (Russell III et al., 1999). Due to the asymmetrical latitudinal coverage of the SABER instrument, there are some missing measurement months at high latitudes (52°N-83°N or 52°S-83°S). Multiple studies (e.g; Forbes et al., 2021; Liu et al., 2017; Das, 2021) are limited to the latitude band ~50°S to ~50°N, mainly due to the TIMED ~60 days yaw cycle. In the present study, we have included high-latitude regions from both hemispheres along with some missing data. For example, coverage of high northern latitudes included July in the early years, but not during the recent several years (2017-2023)………" Please have a look at this section in the revised manuscript for full details.

(R1-C9) Latitudes used in the study: Given the excellent coverage provided by SABER, is there a reason to examine such narrow latitude bands (±1°), and only three latitudes (80°S, 0°, 80°N)? Regarding the ±1° latitude bands, I would generally expect a reduction in random variability for averaging over a wider latitude range (e.g., ±5°). The global mean (latitudes from 80°S - 80°N) is referred to as the "whole mesopause", which is ambiguous. Just call it the global mean. Furthermore, creating a global mean temperature can be misleading, since this approach combines different seasons in both hemispheres, and for SABER will include biases introduced by the changing latitude coverage with month (and year). For this reason, the best "global" representation of SABER data would be 52°S – 52°N, as has been done by previous authors.

Response to (R1- C9):

A relatively wider latitude range is multime used in the past. For example, a 10° latitudinal band from 83°S to 83°N is recently used by Zhao et al. (2020). Wang et al. (2022) investigate the seasonal variability of the residual circulations and the mesopause temperature at different latitudes by selecting four 20° latitudinal bands centered at 10°S and 10°N for low latitudes, and 50°S and 50°N for mid-to-high latitudes. Grygalashvyly et al. (2014) subdivided the latitudes into 18 bins from 81.25°S to 81.25°N with step 10°, and searched for the absolute minimum, absolute maximum, averaged over the given period (Ave), and the standard deviations (SD) for those bins. Therefore selection of such narrow latitude bands (±1°) is one of the differences among other similar studies.

The selected three latitudes (80°S, 0°, 80°N) represent extreme distinct geographic locations. This is the first study to compare temperature and water vapor variability for 22 years of the SABER instrument. We processed hundreds of monthly data sets for all three selected latitude bins (for temperature and WV). The majority of the past studies focused on one variable (temperature or water vapor) for a limited time or over a specific location. The inclusion of mid-latitude region may be the focus of my future work.

We have replaced the word "whole mesopause" with global mean in the revised text. We updated this information in the text, and figure captions. Here is an example (lines 115-116 of the revised manuscript)

"All latitudes, and longitudes of the mesopause covered by the SABER instrument during a year are represented by global mesopause."

We agree that creating a global mean temperature can be misleading since this approach combines different seasons in both hemispheres and SABER will include biases introduced by the changing latitude coverage with month (and year). And we are aware that the best "global" representation of SABER data would be 52°S – 52°N, as has been done by previous authors (e.g; Forbes et al., 2021; Liu et al., 2017; Mlynczak et al., 2022; Das et al., 2021). We have included an additional section of uncertainty (section 6) in this manuscript and provide relevant uncertainties of this work in that section. The relevant point of section 6 (lines 741-745 of the revised manuscript) is given below

Creating a global mean temperature can be slightly misleading since this approach combines different seasons in both hemispheres (NH and SH), and for SABER it includes biases introduced by the changing latitude coverage with month (and year). For this reason, the best "global" representation of SABER data is 52°S – 52°N, as has been done by previous authors.

Reference

- Das, U., 2021. Spatial variability in long-term temperature trends in the middle atmosphere from SABER/TIMED observations. Adv. Sp. Res. 68, 2890–2903. https://doi.org/https://doi.org/10.1016/j.asr.2021.05.014
- Forbes, J.M., Zhang, X., Randall, C.E., France, J., Harvey, V.L., Carstens, J., Bailey, S.M., 2021. Troposphere-mesosphere coupling by convectively forced gravity waves during Southern Hemisphere monsoon season as viewed by AIM/CIPS. J. Geophys. Res. Sp. Phys. 126, e2021JA029734. https://doi.org/https://doi.org/10.1029/2021JA029734
- Liu, X., Yue, J., Xu, J., Garcia, R.R., Russell III, J.M., Mlynczak, M., Wu, D.L., Nakamura, T.,

2017. Variations of global gravity waves derived from 14 years of SABER temperature observations. J. Geophys. Res. Atmos. 122, 6231–6249. https://doi.org/https://doi.org/10.1002/2017JD026604

- Mlynczak, M.G., Hunt, L.A., Garcia, R.R., Harvey, V.L., Marshall, B.T., Yue, J., Mertens, C.J., Russell III, J.M., 2022. Cooling and contraction of the mesosphere and lower thermosphere from 2002 to 2021. J. Geophys. Res. Atmos. 127, e2022JD036767. https://doi.org/https://doi.org/10.1029/2022JD036767
- Zhao, X. R., Sheng, Z., Shi, H. Q., Weng, L. B., and Liao, Q. X.: Long-term trends and solar responses of the mesopause temperatures observed by SABER during the 2002–2019 period, J. Geophys. Res. Atmos., 125, e2020JD032418, 2020.

(R1-C10) 5) Altitudes used in the study: It is not clear what altitudes were used for the T and H2O shown in the paper. I think it might be an average for 80-100 km (based on the legend in Fig 1), but it is not really stated clearly anywhere. This is an important point because the SABER errors increase rapidly with height. Furthermore, you should probably not mix measurements below and above the mesopause in a single average. In any case the paper should describe, and justify, the altitudes examined. Additionally, the Authors should consider looking at all altitudes.

Response to (R1-C10):
A constant altitude range of 80-100 km is used throughout the work. We have mentioned this information in multiple places in the revised manuscript and the same is given below

(lines 102-104 of the revised manuscript):

"Discussion related to an analysis of 22 years of monthly temperature and WV profiles in the mesopause region (80-100 km altitude) are investigated."

(lines 111-112 of the revised manuscript):

"Spatial and temporal variations in long-term temperature and WV are analyzed in the mesopause region (80-100 km altitude)."

(lines 250-252 of the revised manuscript):

"These references focused on specific altitudes, and latitude ranges of the mesopause however, our mentioned results in this section focused on 80-100 km constant altitude of the mesopause."

(lines 753-756 of the revised manuscript):

"Our global mean temperature and WV content may mix measurements below and above the actual dynamic mesopause in a single average, because our measurements are based on a constant altitude range (80-100 km), throughout the study period."

We have included text related to altitudes and uncertainty in the revised manuscript (lines 753-756 of the revised manuscript) and the same is given below.

"Our global mean temperature and WV content may mix measurements below and above the actual dynamic mesopause in a single average, because our measurements are based on a constant altitude range (80-100 km), throughout the study period."

Additionally revised figures 2, 10, and 11 show spatial and temporal variability of temperature and WV at different altitude ranges of the mesopause region. Figure 2 (page 11 of the revised manuscript) is given below as an example

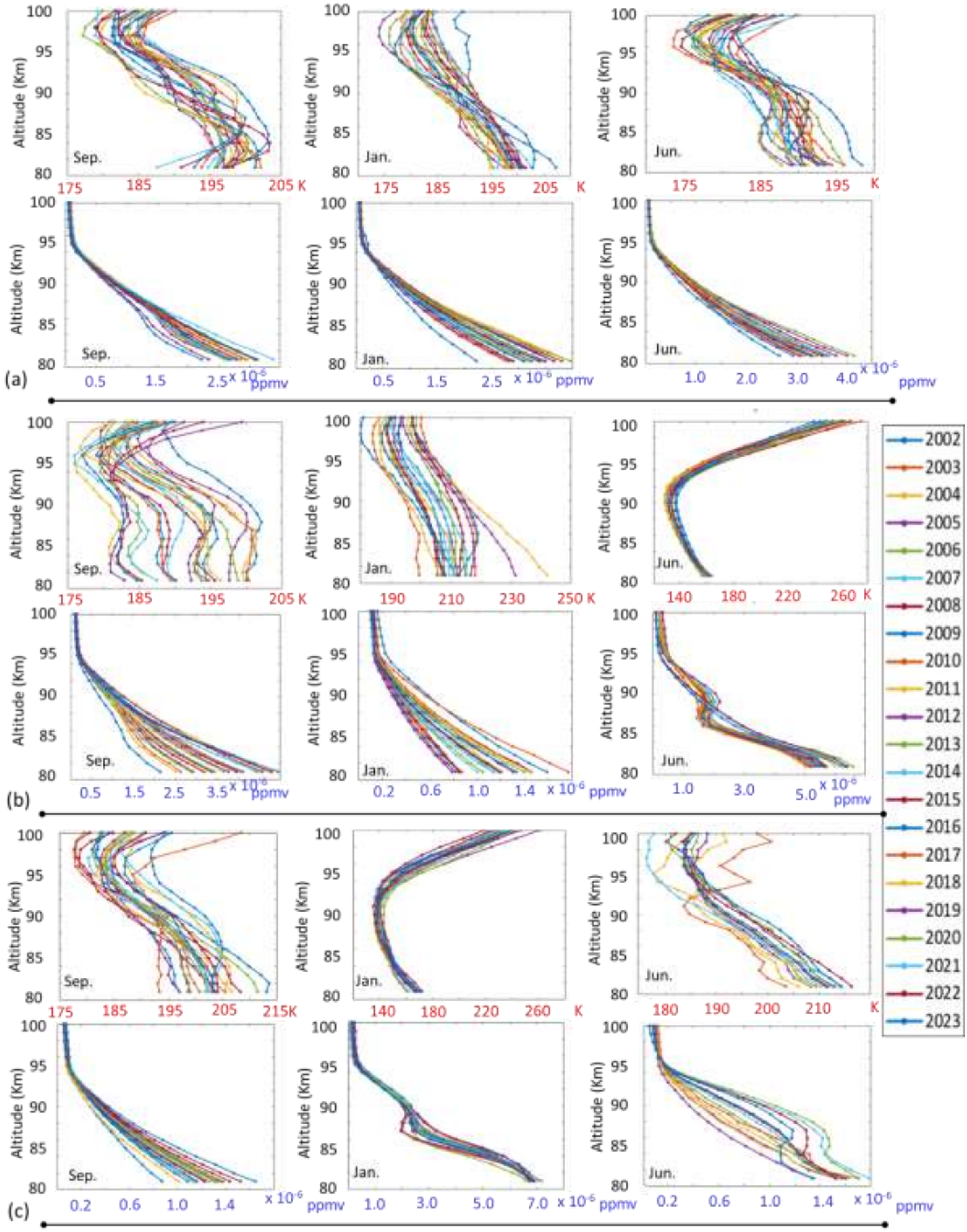


Figure 2. Temperature and water vapor gradient between 80-100 km altitudes from SABER observations at the three selected latitude bins during 200-2023. a) Equator (0° ± 1º). b) Northern hemisphere (80°N ± 1º). (c) Southern hemisphere (80°S ± 1º), in the indicated months, by averaging all January, June, and September values from 2002 to 2023.

(R1-C11) 5)Table 1: There appears to be a wealth of useful information here, but the results are poorly described and somewhat confusing. For example, the list appears to contain both absolute values of T and H2O, in addition to trends in these quantities. The trends are also listed alternately as per year or per decade, and this needs to be rectified. Results are also given for a wide range of altitudes, which is problematic given the strong altitude dependence in T and H2O in the mesopause region. In addition, numerous investigations have shown that trends in the upper mesosphere vary strongly with height (references listed in this paper), and can even change sign at roughly NLC altitudes (depending on latitude and season). Given these complexities, the presentation of results in Table 1 needs to be substantially revised, including a consideration of the altitude dependence. Perhaps these results would lend themselves to being plotted vs. height instead. Finally, Table 1 neglects the H2O trends derived from SABER and MLS observations by Yue et al. (2022, GRL; reference given in this paper), which are particularly relevant to the present study.

Response to (R1-C11):
We have updated Table 1 as suggested by the three reviewers (page number 14-16 of the revised manuscript) and the same is given below. Table 1 has more relevant details than the previous version of Tabl 1.

Table 1. Temperature and water vapor content comparisons with past studies in mesopause

Trend K/decade	Avg. Temp	Altitude (km)	Location/Season/Data source	References
Temperature				
Min:	184.54 K	80-100	Global/summer (Jun. and Jul.)/ SABER	This study
0	188.20 K		Global/winter (Jan. and Dec.)/ SABER	
	162.64 K		80°N ± 1° / summer (Jun. and Jul.)/SABER	
	201.14 K		80°N ± 1° / winter (Jan. and Dec.)/SABER	
Max:	193.21 K		80°S ± 1° / summer (Jun. and Jul.)/SABER	
-1.21	161.14 K		80°S ± 1° / winter (Jan. and Dec.)/SABER	
	185.81 K		0° ± 1° / summer (Jun. and Jul.)/SABER	
	188.95 K		0° ± 1° / winter (Jan. and Dec.)/SABER	
Min: 0	130-190K	80-100	83°N to 83°S- all latitudes/ SABER	Zhao et al., 2020
	188±2 K		83°N/Northern hemisphere / SABER	
Max:	135±2 K		83°S/Southern hemisphere / SABER	
-1.4	158±2 K		0°/Equator / SABER	
	139 K	90	80°S/January/ SABER	Wang et al., 2022
	180 K	86	40°S/January/ SABER	
	129 K	90	80°N/July/ SABER	
	161 K	83	55°N/July/ SABER	
	160 K	~100	30°N/ around equinoxes (March)/ SABER	Xu et al., 2007
	185 K	~80	30°N/ around equinoxes (March)/ SABER	
	124 K	~100	80°N /solstice period (June)/ SABER	
	135 K	~80	80°N /solstice period (June)/ SABER	
	133 K	~100	80°N /solstice period (December)/ SABER	
	143 K	~80	80°N /solstice period (December)/ SABER	
	~126 K	80-100	Summer polar region/ SABER	
	~190 K	80-100	Winter polar region/ SABER	
	156-162 K	84	45–50°N/ summer night time (Aura/MLS)	Dalin et al., 2023
	152-157 K	84	50–55°N/ summer night time (Aura/MLS)	
	147-151 K	84	55–60°N/ summer night time (Aura/MLS)	
	151-159 K	89	45–50°N/ summer night time (Aura/MLS)	
	147-153 K	89	50–55°N/ summer night time (Aura/MLS)	
	141-146 K	89	55–60°N/ summer night time (Aura/MLS)	

-2.5	~177.6 K	97	41°N - 42°N / non summer months /Na lidar	Yuan 2019
-2.3	~177.6 K	92	41°N- 42°N /non winter months / Na lidar	
-3.8	~177.6 K	97	41°N - 42°N / winter /Na lidar	
-1.75	~177.6 K	92	41°N- 42°N /summer / Na lidar	
-2.3	160-230 K	87	51°N/ all seasons/SABER instrument	Offermann et al., 2010
Up	158-238 K	87	51°N/ all seasons/OH	
To	160-232 K	87	48°N/ all seasons/SABER instrument	
-6.0	145-235 K	87	48°N/ all seasons/ OH	
-6.8		~100	41°N (Lidar + SABER + Model)	She et al., 2009
-1.5	~184K	~91	41°N/January (Lidar + SABER + Model)	
- 0.64	~200 K	~85	41°N/January Na lidar	
-0.64	160-245 K	85-86	41°N/all seaons/Na lidar	She et al., 2015
-2.8	160-235 K	91-93	42°N/all seasons/Na lidar	
-0.23		87	69°S/winter /Hydroxyl airglow	French et al., 2005
-0.5		80-95	±52° latitude (WACCM-Model)	Garcia et al., 2019
-2.4	160-173 K	80-100	~57°N / summer mesopause (ground based)	Dalin et al., 2020
-0.4	202-218 K	80-100	~57°N/winter (ground based)	
-0.89	194-202 K	87	51° N/annual mean	Kalicinsky et al., 2016
	185-201 K	87	48◦ N/annual mean	
-4.0	135 K	90	78ºN/summer MLS on the Aura satellite.	Hall et al., 2012
	~200 K	90	78ºN/winter / radar observation	
-1.2	146-154 K	83	55–61°N/ annual /LIMA and MIMAS model	Lübken et al., 2018
-2.9	160-230 K	98.5	41°N/all season/ Na lidar	She and Krueger, 2004
-2.1	198-228 K	80-100	63°N/ January/ SABER	Ammosov et al., 2014
	196-215 K	80-100	63°N/ February/ SABER	
-2		80-100	middle & subpolar latitudes /summer/ model	Grygalashvyly et al., 2014
-0.5			middle & subpolar latitudes/ winter/ model	
-2.2		80-100	Middle latitudes/Airglow measurement	Perminov et al., 2014
-0.24	140-170 K	80 - 84	64–74°N/ all season/SOFIE	Hervig et al., 2015
-0.5	145-166 K	80-84	77°N /Satellite instrument and Model	Hervig et al., 2016
-1.2	140-220 K	87	68°S/ winter/ OH nightglow	French et al., 2020a
-0.3	~196 K	87	23-26°S /March-April/SABER & airglow	Noll et al., 2017
	145-235 K	~87	74°N /spectrometric observations of the OH	Medvedeva and Ratovsky, 2023
Water vapor mixing ratio				
	~1.30 ppmv	80-100	Global/summer/ SABER	This study
	~1.20 ppmv		Global/winter/ SABER	
	~1.90 ppmv		80°N ± 1º /summer/SABER	
	~0.49 ppmv		80°N ± 1º /winter/SABER	
	~0.67 ppmv		80°S ± 1º / summer/SABER	
	~2.30 ppmv		80°S ± 1º /winter/SABER	
	~1.20 ppmv		0° ± 1º /summer/SABER	
	~1.10 ppmv		0° ± 1º /winter/SABER	
	4.2-5.1 ppmv	84	45–50°N/ summer night time (Aura/MLS)	Dalin et al., 2023
	4.5-5.4 ppmv	84	50–55°N/ summer night time (Aura/MLS)	
	4.7-5.6 ppmv	84	55–60°N/ summer night time (Aura/MLS)	
	3.1-3.6 ppmv	89	45–50°N/ summer night time (Aura/MLS)	
	3.3-3.9 ppmv	89	50–55°N/ summer night time (Aura/MLS)	
	3.3-3.9 ppmv	89	55–60°N/ summer night time (Aura/MLS)	
	1-8 ppmv	80 - 84	64–74°N/ all season/SOFIE	Hervig et al., 2015
	5.4-5.8 ppmv	80-84	77°N /Satellite instrument and Model	Hervig et al., 2016
	0-7.0 ppmv	80-100	66°-79°N/SOFIE on AIM & ALOMAR lidar	Hervig et al., 2009a
	1-2 ppmv	95	66°-79°N/satellite measurement	
	1 ppmv	90	78°N/ summer/1-D model	Murray and Jensen, 2010
	3 ppm	86	67.9°N- Polar region/Summer/Model	Gumbel et al., 2003
	2.3 ppmv	85	Mid-latitude /Jul./Ground-based microwave	Bevilacqua et al., 1983
	1.6 ppmv	85	Mid-latitude /Sep./Ground-based microwave	
	1.0 ppmv	85	Mid-latitude /Jan./Ground-based microwave	
	1.2 ppmv	85	Mid-latitude /Apr./Ground-based microwave	
	0.1 ppmv	85	Mid-latitude /Dec./Ground-based microwave	
	1.1 ppmv	85	Mid-latitude /Apr./Ground-based microwave	

0-7.0 ppmv	80-100	66°-79°N/SOFIE on AIM & ALOMAR lidar	Hervig et al., 2009a
1-2 ppmv	95	66°-79°N/satellite measurement	
1.5-4.5 ppmv	80	69ºN/Ground-based microwave	Seele and Hartogh, 1999
2-2.5 ppmv	85	Polar summer/Jun., Jul., Aug.,/ground-based	
0.2 ppmv	84	67ºN/3-D model /	Von Zahn & Berger, 2003
3 ppmv	80-83	50ºN-80ºN/3-D model /	
~2.0 ppmv	80-83	50ºN-80ºN/3-D model /	
~1.5 ppm	90	72.5ºN /Jul., Aug./3D-Model and HALOE	Körner & Sonnemann, 2001
~3.5 ppm	85	72.5ºN /Jul., Aug./3D-Model and HALOE	
~5.1 ppm	80	72.5ºN /Jul., Aug./3D-Model and HALOE	
1.0 ppmv	~83	65°–70°N /winter / HALOE measurement	Hervig et al., 2003
8.0 ppmv	~83	65°–70°N /summer / HALOE measurement	
0.45 - 4.81 ppmv	80-94	78°N/ summer/Model,	Lubken et al., 2004
~4.5 ppmv	80	78°N/ summer/Model,	
3.4 ppmv	85	78°N/ summer/Model,	
1.98 ppmv	90	78°N/ summer/Model,	
2-4 ppmv	82	55°N–55°S/SABER	Yue et al., 2019
~3.5 ppmv	80	19.5°N/ Sep./Spectrometer mouna	Nedoluha et al., 2022

(R1-C12a) 6) Figure 7: These results are not described very well. What altitude is this for? Are you comparing Northern March to Southern March and Northern Sep. to Southern Sep.? If so then the differences are not meaningful as they are for two different seasons (e.g., spring vs. fall). Also, the diagram of Earth's orbital positions is not needed.

Response to (R1-C12a):
We used a constant altitude (80-100 km) throughout the study period as explained in the above response (R1-C10). We also include altitude-related information in the caption of Figure 7 (line numbers: 534-536).

Figure 7. Difference in NH-SH temperatures and NH-SH, WV at 80-100 km altitude during selected months of equinoxes (March and September) and solstices (January and July). a, c) Water vapor content difference. b, d) Temperature difference.

In Figure 7 we showed the annual difference in temperature between NH and SH during March. Similarly the annual difference in temperature between NH and SH during September. We have revised Figure 7 as suggested. We improved the text and described the information in clear statements as compared to the previous version of the manuscript (page 26 of the revised manuscript) and the same is given below.

Revised Figure 7:

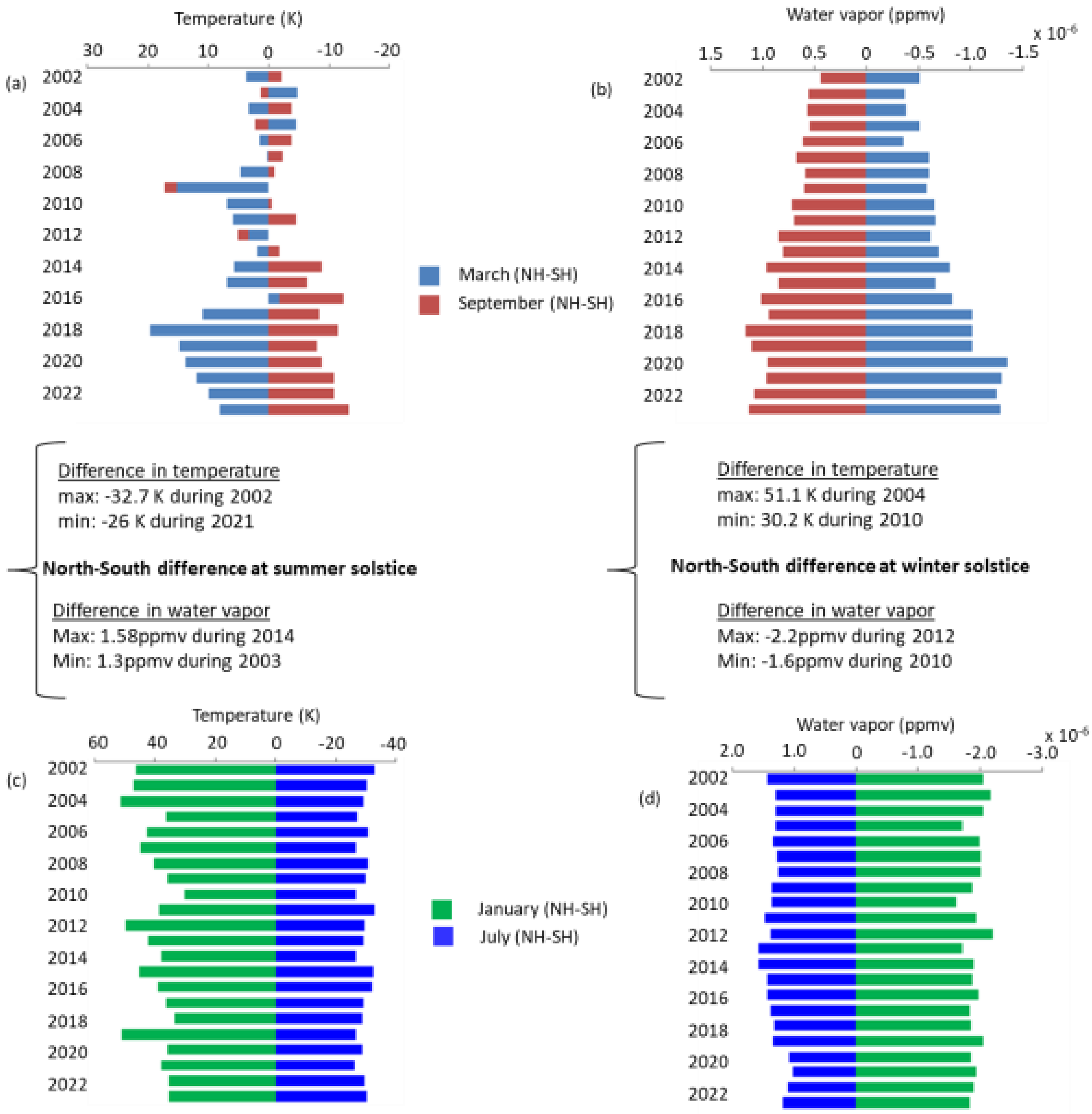


Figure 7. Difference in NH-SH temperatures and NH-SH, WV at 80-100 km altitude during selected months of equinoxes (March and September) and solstices (January and July). a, c) Water vapor content difference. b, d) Temperature difference.

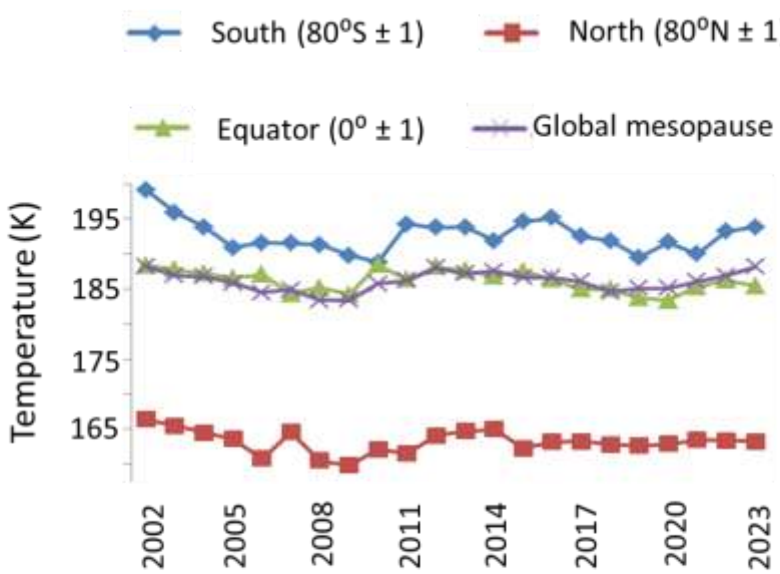
(R1-C12b) 6) Figure 7: Finally, a better illustration of these results would be a line plot of difference vs. year.

Response to (R1-C12a):
A line plot of differences vs. year is already provided in the next Figure (Figure 8)

(R1-C13) 7) Figure 8: Why are you comparing the temperature and H2O, for summer and winter, in different hemispheres? If your aim is to illustrate the seasonality then do it in the same hemisphere. If you are concerned with differences between hemispheres, then compare the same seasons in the north and south (e.g., for summer use June in the north vs. December in the south). Later in the text (line 421-423) you quote large seasonal differences of 156, 210, and 186K. Nowhere in the results are such differences evident, and this should be checked.

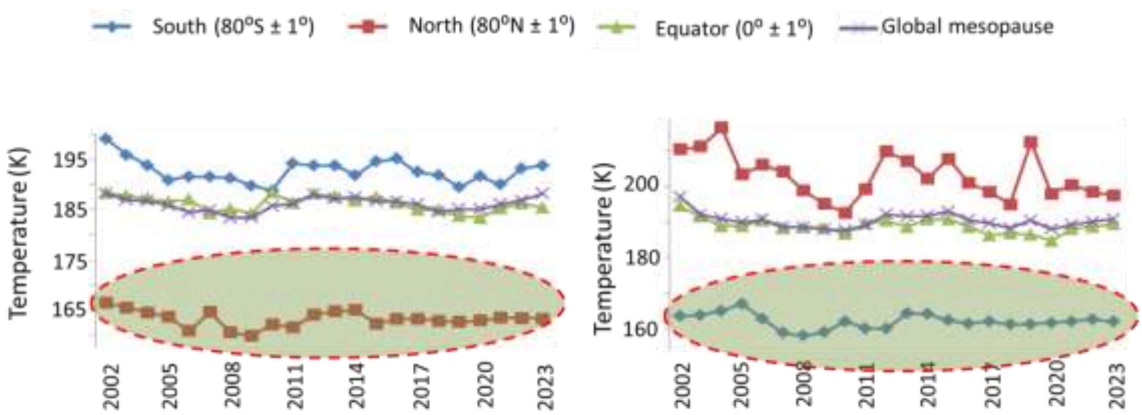
Response to (R1-C13):

In Figure 8, we are presenting inter-annual variations in monthly mean temperature and water vapor from SABER observations over selected bins of latitudes during 2002-2023. For example, Figure 8a shows 22 years of July mean temperature for each individual year. Figure 8a also compares July's mean temperature in different Hemispheres as shown below.



(Figure 8a - July)

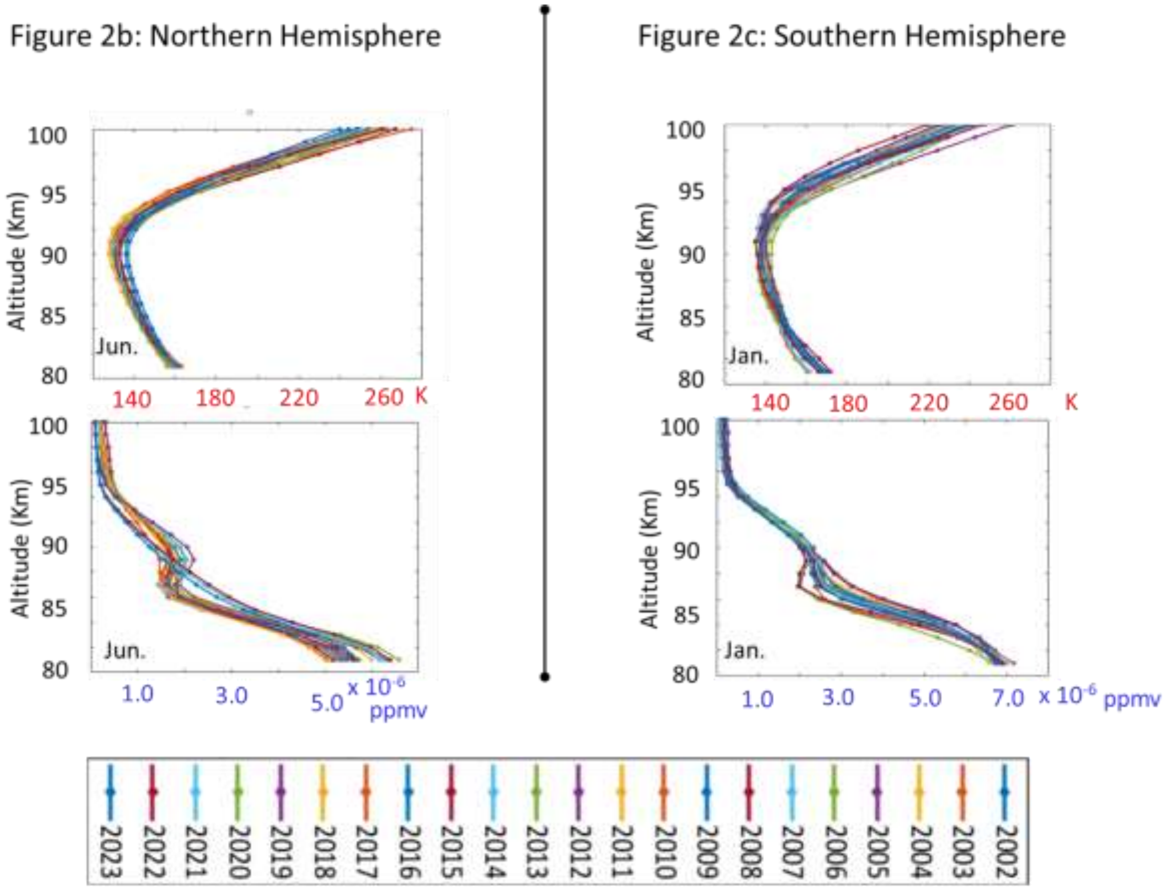
This is also a kind of compression during the same seasons in the north and south as you suggested [e.g., for summer use July in the north (Figure 8a, red line) vs. January in the south (Figure 8b, blue line)], as mentioned below



(Figure 8a - July) (Figure 8b - January)

Readers can compare similar hemispheric comparison in the revised Figure 2, and we have included relevant text in the revised manuscript (lines 566-567) as given below

“The vertical temperature and WV gradients during June at NH (Figure 2b) are quite similar to the vertical temperature and WV gradients during January at SH (Figure 2c).”



Later in the text (line 421-423)

The quoted line (previously 421-423) has been replaced by a new sentence (lines 649-650 of the revised manuscript) and the same is given below.

“SH is warmer than NH during July (~29 K) and September (~5 K) and colder than NH during January (~40.6 K) and March (~6.3 K).”

(R1-C14) 8)Throughout the article you refer to the “north pole” and “south pole”, yet your results are for 80°N and 80°S, which are not the poles. Please be specific and use the nomenclature 80°N and 80°S.

Response to (R1-C14):

Agree, we have used a specific nomenclature as suggested (lines 112-115 of the revised manuscript) as given below

“Spatially the region is divided into three latitude bins (Equator, Northern, and Southern Hemispheres). Taking temperature and WV data in 0° ± 1°, 80°N ± 1°, and

80°S ± 1° latitude bins represent the equator, northern hemisphere (NH), and southern hemisphere (SH) respectively."

And then we used this nomenclature throughout the text of the revised manuscript.

(R1-C15) 9)Figure 10: The results are very hard to interpret, please try another approach.

Response to (R1-C15):

Agree, we have removed longitude in the revised Figures. We introduced two figures instead of one figure which displays relatively better information related to spatial variability of temperature and WV(page number 34 of the revised manuscript) and the same is given below

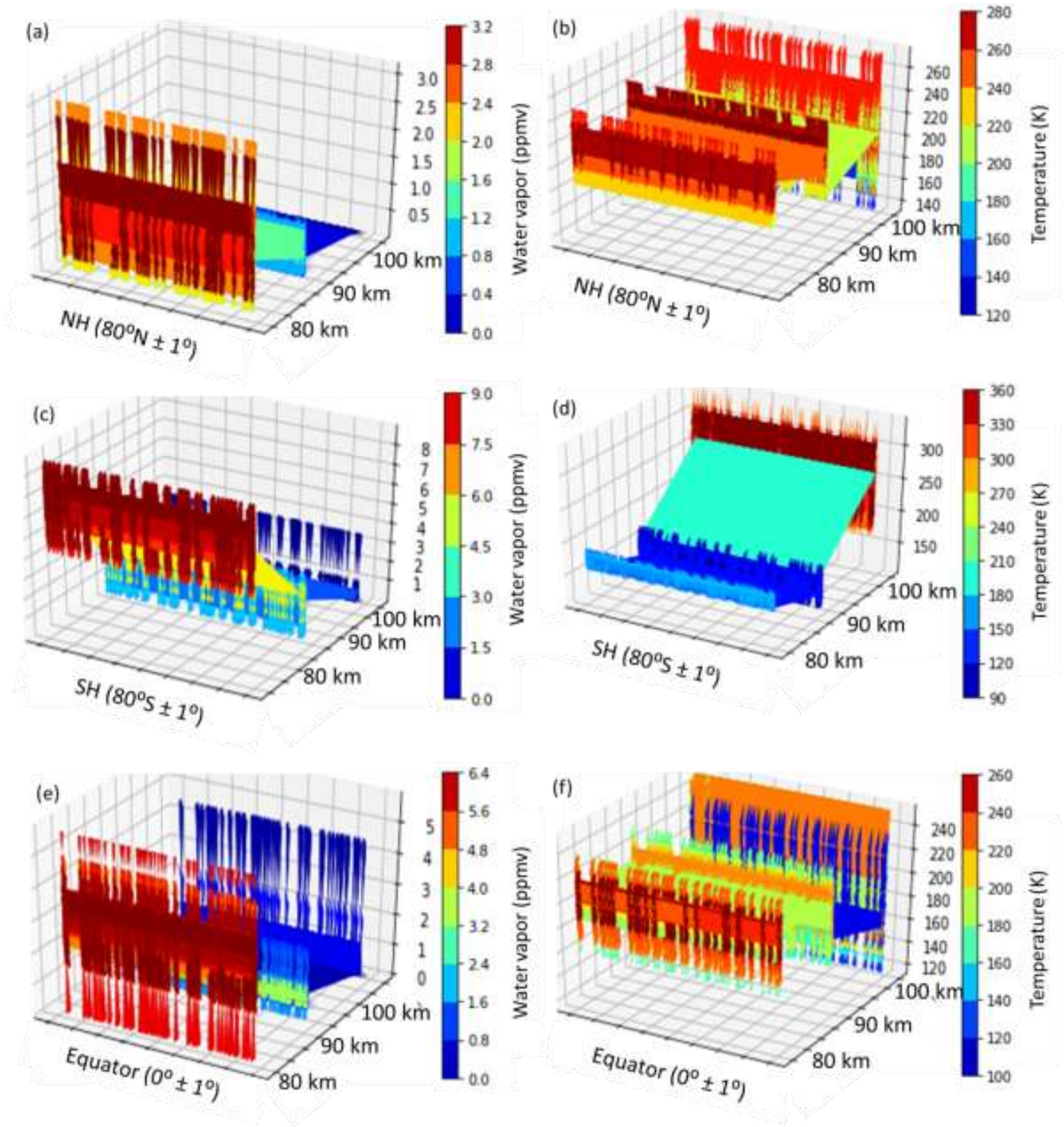


Figure 10. Two-dimensional (latitude, and altitude) variation in temperature (K), and WV (ppmv) at three latitudes as indicated, and three altitudes (80 km, 90 km, and 100 km) during January 2003.

Thanks to anonymous reviewer 1 for his/her constructive comments and suggestions.

------------------------ End of the response to reviewer 1 -------------------------