Dear Reviewer:

We thank you for your thoughtful and constructive comments on our manuscript entitled "A new data set of nighttime chemical heating rates in the upper mesosphere and lower thermosphere derived from SCIAMACHY OH (9-6) emissions and SABER profiles". All comments have been carefully considered, and the manuscript has been revised accordingly. Our responses to the individual comments are provided below.

General comment:

A general comment would be to add a few more sentences on the magnitude of the other relevant heating terms (diabatic solar heating, impact of breaking GW, adiabatic heating) and perhaps also radiative cooling terms. This will allow the reader to better appreciate the importance of the chemical heating in the mesopause region.

Response: Thank you for this helpful comment. We have revised the Introduction to include a comparative overview of the major energy budget terms in the mesopause region. Recognizing that these terms vary with altitude, we focus on representative peak magnitudes within the 80-100 km altitude range to provide context. Specifically, we include estimates of radiative cooling, solar heating, chemical heating, and dynamical effects. This comparison highlights the important role of chemical heating in the region's energy budget.

The revised text is provided below (Lines 25-39):

"To better appreciate the importance of chemical heating in the mesopause region, we consider representative peak magnitudes of the major energy budget terms in the 80-100 km altitude range. Radiative cooling in this region is dominated by CO_2 15 µm emission, with magnitudes typically ~15 K/day (States et al., 2000; Mlynczak et al., 2022, 2024). This cooling is balanced by various heating terms. The diurnally averaged solar heating due to ultraviolet absorption by O_2 and O_3 typically amounts to ~10 K/day, while chemical heating rates are estimated to reach magnitudes of ~10-15 K/day (Mlynczak and Solomon, 1993; Mlynczak, 2000). Regarding dynamical effects, processes such as gravity wave breaking and adiabatic motions can produce large local heating or cooling rates, reaching several tens of K/day in localized layers or during transient events (e.g., Lübken, 1997; Gardner and Yang, 1998; Vincent, 2015; Grygalashvyly et al., 2024). However, on a global and annual mean basis, the total energy input from solar radiation and chemical reactions is generally considered sufficient to account for the radiative cooling by CO_2 (Mlynczak et al., 2013, 2018), while the net contribution of dynamical effects is estimated to be relatively small.

Given the significant contribution of chemical heating to the energy budget, accurate quantification of its rates is crucial. Furthermore, such quantification provides important insights into mesospheric inversion layers (Ramesh et al., 2017) and enables energetic constraints on the concentrations of key reactive species, such as atomic oxygen (Mlynczak et al., 2013)."

Specific comments:

Line 9: “accounting for roughly one-third to one-half of the total heating above ~86 km.”
The total chemical heating or the total overall heating (including GW and solar?). I think you only mean the chemical heating here.
Response: Thank you for this comment. We agree that the original wording was ambiguous and have revised the text accordingly.

Revised text (Line 9): “accounting for roughly one-third to one-half of the total chemical heating above ~86 km.”

Line 21: “The stored chemical energy is subsequently released as heat through various exothermic reactions”
A certain part of it is also emitted as radiation (airglow), right?
Response: Thanks for pointing this out. We agree that a fraction of the stored chemical energy is emitted as radiation. The text has been revised accordingly to clarify this point.

Revised text (Line 22): “The stored chemical energy is subsequently released primarily as heat, and partly as airglow radiation, through various exothermic reactions”

Line 72: “covering latitudes typically from 30S to 50N and 0 to 80N”
This is a bit unclear? When are the different ranges covered?
Response: We thank the reviewer for pointing this out. First, we apologize for a typo in the original text regarding the latitude range. The text "30°S to 50°N" was incorrect; it was intended to be 50°S to 30°N. To improve clarity and reflect the full seasonal coverage, we have revised the sentence to state that the coverage varies seasonally between 50°S and 80°N.

The latitudinal region covered by SCIAMACHY limb observations varies seasonally, as shown in Figure 1. This variation is driven by the seasonality of solar illumination geometry. Furthermore, these measurements do not cover the entire latitude range on the night side of the Earth, because blocks of limb measurements are interrupted by calibration measurements (Bovensmann et al., 1999). Specifically, the coverage of 0° to 80°N corresponds to the Northern Hemisphere winter, while the coverage of 50°S to 30°N corresponds to the Northern Hemisphere summer.

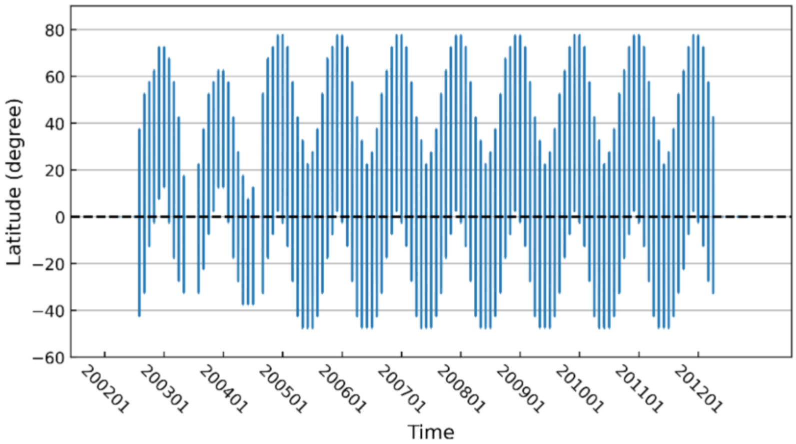

Figure 1. Latitude coverage of SCIAMACHY limb nighttime observations. (Sui et al., 2024)

Revised text (Lines 87-88): “The latitudinal region covered by SCIAMACHY limb observations varies seasonally between 50°S and 80°N, depending on the solar illumination geometry and calibration measurements performed on the night side of the satellite orbit (Bovensmann et al., 1999; Sui et al., 2024).”

Line 84: “the data from both instruments were processed into monthly zonal medians” How is the "median profile" determined exactly? By taking the median at every altitude? Please explain.

Response: Thank you for this comment. The median profile was determined by calculating the median of all valid measurements within each monthly latitude bin at each altitude level independently.

Revised text (Line 101): “the data from both instruments were processed into monthly zonal medians calculated independently at each altitude level”

Same paragraph: Due to the drifting TIMED orbit, there will only be SABER measurements on a few days per month within a 2 hour local time bin? How does this affect the analysis? It would be good to mention how many days of SABER measurements per month are used for the analysis.

Response: Thank you for this insightful comment. Due to the drifting TIMED orbit, SABER does not provide continuous daily sampling at a fixed local time. As a result, measurements within the 22:00 LT (± 1 h) window are available only on a limited number of days per month.

We performed a statistical analysis of the SABER sampling frequency for one example year (2005). Globally, each month contains 18-31 days with coverage within the 22:00 LT (± 1 h) window. When considering the 22:00 (± 1 h) window and 5° latitude bins, each latitude bin contains on average about 9 sampling days per month. Approximately 75% of the bins are sampled on more than 5 days, and about 40% are sampled on more than 10 days.

The primary impact of this limited sampling is the potential aliasing of short-term variability into the monthly statistics, leading to increased statistical uncertainty at individual latitude bins. However, it is unlikely to introduce a systematic bias. The sampling pattern is determined by orbital geometry rather than by atmospheric conditions, and monthly zonal medians are used instead of means, which reduces sensitivity to transient outliers.

Furthermore, the analysis focuses on monthly representative heating rate profiles and their seasonal and latitudinal variations, rather than resolving day-to-day variability at individual latitude bins. The resulting fields exhibit coherent and smooth large-scale patterns, consistent with known tidal and seasonal structures (see Figs. 2–8).

In summary, while the limited number of sampling days may slightly increase random uncertainty at some latitude bins, it does not affect the main conclusions regarding the seasonal and latitudinal structures discussed in this study.

We have added a clarification in Lines 103-109:

"Due to the precessing orbit of the TIMED satellite, SABER measurements within the 22:00 LST window are available on a limited number of days per month. A statistical analysis for 2005 shows that each month includes 18-31 days with measurements in the 22:00 LST (±1 h) window. When aggregated into 5° latitude bins, each bin contains on average about 9 sampling days per month; approximately 75% of the bins are sampled on more than 5 days, and about 40% on more than 10 days. Despite this limited temporal sampling, the use of monthly zonal medians effectively reduces the influence of short-term atmospheric variability and outliers, providing representative climatological profiles."

Line 95: "Under optically thin conditions, the volume emission rate for a transition v→v' depends linearly on the upper-state population and the corresponding Einstein A-coefficients."
I'm not sure what the intention behind this statement is, but I think that the VER itself (at a specific point in the atmosphere) depends linearly on the upper-state population and the Einstein coefficients also for non optically thin conditions.
Response: Thank you for pointing this out. We agree that the VER depends linearly on the upper-state population and the Einstein coefficients, regardless of the optical depth.

Our original intention was to highlight that, under optically thin conditions, radiative transfer effects (such as self-absorption) along the line of sight can be neglected, allowing the observed radiance to be directly related to the local VER.

We have revised the text to clarify this point in Lines 119-122:

"Under optically thin conditions, radiative transfer effects along the line of sight can be neglected, allowing the observed radiance to be directly related to the local volume emission rate (VER). The VER for a transition v→v' depends linearly on the upper-state population and the corresponding Einstein A-coefficients."

Equation (1): the equation is perhaps wrong. What are your units of “volume emission rate”. Usually the units are photons / s / cm^3. If this is the case then the factor of E_96 is wrong. Please specify the units of VER and correct, if necessary.

Response: Thank you for pointing this out. The volume emission rate (VER) is defined as photons / s / cm^3. We have clarified the units in the manuscript in Line 127 and removed the factor E_96 from Equation (1).

Equations (3) and (4): How are these equations solved? (3) depends on [HO2] and (4) on [OH]?

Response: Thank you for this question. Equations (3) and (4) form a coupled set of algebraic equations for [OH] and [HO_2]. Under the assumption of local chemical equilibrium, they are solved simultaneously to obtain the two species.

We have clarified this in the manuscript in Line 154-156:

“Equations (3) and (4) form a coupled set of algebraic equations for [OH] and [HO_2], which are solved simultaneously under the assumption of chemical equilibrium.”

Line 132: “The stored energy is released back into heat through two main pathways:” Why “back”? The chemical energy was never in the thermal energy pool, right? And: part of the chemical energy is emitted as EM-radiation (airglow).

Response: Thank you for pointing this out. We agree that the use of "back" was inaccurate and a portion of this energy is radiated as airglow. We have revised the sentence to remove "back".

Revised text (Line 163): “The stored energy is released primarily as heat through two main pathways”

Line 178: “The total RSS uncertainty for Reaction (R5) is estimated to be 45-60%” Why only up to 60% if the temperature effect only already leads to uncertainties of up to 60%?

Response: Thank you for this comment. For most perturbation sources considered in the uncertainty analysis, positive and negative perturbations lead to comparable changes in the derived heating rates. However, the retrieval exhibits a pronounced asymmetric response to temperature perturbations. For example, at about 96 km, a positive temperature perturbation can induce a ~60% change in the R5 heating rate, whereas a negative perturbation induces a smaller response of ~30%. In our original manuscript, we used the average magnitude (~45%) as a representative uncertainty associated with temperature when estimating the RSS. While this approach captures the typical sensitivity, it does not explicitly reflect the upper bound of the uncertainty.

To address this, we have re-evaluated the total RSS by using the maximum temperature-induced perturbation for the temperature term when estimating the upper uncertainty bound. Consequently, the total RSS uncertainty range for Reaction

(R5) has been updated to 45-80% in the revised manuscript. The error bars in Figure 1 of the revised manuscript have been updated accordingly.

Revised text (Line 213): “The total RSS uncertainty for Reaction (R5) is estimated to be 45-80%”

Line 188: “for the seven chemical reactions and their total, calculated using Eq. (5)”
I suggest moving “calculated using Eq. (5)” behind “for the seven chemical reactions.”
Response: Thank you for this suggestion. We have revised the text accordingly to avoid ambiguity.

The revised text in Line 234: “for the seven chemical reactions calculated using Eq. (5) and their total”

Line 203: “Further calculations show”
“Further calculations” are not something complicated but just adding the results for R1 to R4?
Same sentence: the total heating from the odd-hydrogen reactions does not decrease with altitude over the entire altitude range shown, right? And the total heating by the odd-oxygen reactions does not increase with altitude over the entire altitude range. Please limit the statement accordingly.
Response: Thank you for this helpful comment. We agree that the wording “Further calculations show” in the original manuscript was unclear and potentially misleading. In this context, “further calculations” refer to the relative contributions from the odd-hydrogen reactions (R1-R4) and the odd-oxygen reactions (R5-R7) to the total chemical heating. These relative contributions decrease and increase with altitude, respectively, over the entire altitude range shown (80-100 km).

The manuscript has been revised accordingly in Lines 252-255:

“We further evaluated the relative contributions of odd-hydrogen reactions (R1-R4) and odd-oxygen reactions (R5-R7) to the total chemical heating over the 80-100 km altitude range. The results show that the relative contribution from the odd-hydrogen reactions decreases with altitude, whereas that from the odd-oxygen reactions increases. The two contributions become comparable near 92 km.”

Figure 2, 3 etc.: I suggest mentioning in the Fig. caption that the results are for 22:00 LST, because some of the signatures are tidal (as is discussed below).
Response: Thank you for this suggestion. We have revised the figure captions (Figures 2, 3, etc.) to explicitly state that the results correspond to 22:00 LST.

Line 226: Space missing in “atitude.In”
Response: Thank you for pointing this out. The missing space has been corrected in Line 271.

Line 261: “which is driven by the semiannual cycle of the migrating diurnal tide.”
It would be good to provide a reference here.

Response: Thank you for this helpful suggestion. We have added appropriate references to support this statement (Zhang et al., 2006; Smith et al., 2013) in Line 306.

Line 293: “These discrepancies are expected, as they directly reflect the known systematic differences in atomic oxygen and hydrogen densities retrieved from SCIAMACHY and SABER, which have been analyzed in detail by Zhu and Kaufmann (2018) and Wu et al. (2025), respectively.”
Please elaborate this a bit more. How big are the differences in [O] and [H] and what are the effects on the heating rate estimates.

Response: Thank you for this helpful suggestion. We have expanded the discussion to quantify the differences in atomic hydrogen and atomic oxygen and to clarify how these differences affect the heating rate estimates. Because the same background atmospheric inputs (temperature, ozone, and total number density) are used in this comparison, the R1 heating rate scales linearly with [H], so the relative differences in the R1 heating rates follow the relative differences in [H]. In contrast, the R5 heating rate scales with $[O]^2$, meaning that relative differences in [O] are amplified in the heating-rate comparison (approximately twice the fractional [O] difference, to first order).

The quantitative differences in [H] and [O] and their effects on the heating rates are described in the revised manuscript Lines 338-346:

“Under the same background atmospheric inputs (temperature, ozone, and total number density), these discrepancies are expected, as they directly reflect the known systematic differences in atomic oxygen and hydrogen densities retrieved from SCIAMACHY and SABER (Zhu and Kaufmann, 2018; Wu et al., 2025). For Reaction (R1), the heating rate is linearly proportional to the atomic hydrogen density. Consistent with the heating rate differences, the SABER-retrieved [H] is approximately 35% higher than the SCIAMACHY values at 96 km, but 20-45% lower below 92 km. In contrast, the heating rate of Reaction (R5) depends on the square of the atomic oxygen density, which amplifies the impact of differences in [O]: SABER-retrieved [O] is higher than SCIAMACHY by 5-10% at 95-96km, whereas below 90 km, SABER [O] is lower than the SCIAMACHY values by about 25-45%, leading to much larger discrepancies (40-80%) in the resulting heating rates.”

Once again, thank you for taking the time to review our manuscript and for your helpful comments.

Sincerely,
Xiaolin Wu and Yajun Zhu for all authors

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