Dear Reviewer:
Thank you for your 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”. Those comments are very helpful for improving the quality of our manuscript. We have studied the comments carefully and made revisions accordingly. The responses to the comments are provided below.

Major Concern:

1. “During the ENVISAT operation time, SCIAMACHY and SABER had different flight geometry, making it quite difficult to collocate the data measured by two devices in both time and space, i.e., find a sufficient number of pairs of SCIAMACHY and SABER measurements corresponding to close values of time, latitude and longitude simultaneously. Therefore, the authors, first, average the initial measured data near local time 22 hours over a month and only then start the retrieval procedures. Note all mentioned algebraic equations are nonlinear. Evidently, there is a question about the correctness of the approach, but the paper does not provide an analysis of possible errors caused by such collocation of data measured by two independent instruments.”
Response: Thank you for this insightful comment. We agree with the reviewer that averaging the initial measured data prior to retrieval can introduce biases due to nonlinear dependence of the retrieval algorithm on input data. In our retrieval procedure, to minimize the impact of outliers and measurement noise, we employed monthly zonal medians, rather than arithmetic means. Nevertheless, the use of medians may still introduce nonlinearity-related biases, which need to be carefully evaluated.

Since SCIAMACHY and SABER have different sampling geometries, a direct collocation to quantify this bias is challenging. However, SABER provides a unique opportunity to assess this nonlinearity error, as it offers synchronous measurements of OH radiance (2um), temperature, total density, and ozone. Although the SABER 2.0um channel differs from the SCIAMACHY (9-6) transition, both emissions are dominated by the $H+O_3$ reaction, and the functional dependence of the heating rates on temperature and reactant concentrations is mathematically analogous. Therefore, we employ SABER data to evaluate the bias caused by the pre-retrieval aggregation approach. The collisional parameters employed in the retrieval are taken from Mlynczak et al. (2013).

As our objective is to quantify the error specifically introduced by the pre-retrieval aggregation approach, we focus on the relative differences between the two methods, both using data within a 22:00 LT (± 1 h) window: (1) Median of individual retrievals, where heating rates profiles are first retrieved from each individual SABER profile and then the monthly zonal median is taken within 5° latitude bins; (2) Retrieval from median profiles (our method), where the input spectral data are first aggregated as monthly zonal medians within 5° latitude bins and then used for retrieval.

This evaluation is conducted using one full year of SABER observations from 2005.

Figure 1 illustrates the mean absolute relative difference (ARD) between the two methods for different seasons and latitude bands. The black, blue, and red lines represent the ARD for the heating rates of reaction (R1) H + O_3, reaction (R5) O + O + M, and the total heating rate (R1-R7), respectively. Columns correspond to winter, spring, summer, and autumn, while rows represent latitude bands centered at 60°N, 30°N, 0°, 30°S, and 60°S, each spanning ±10°.

For reaction (R1) H + O_3 (black line), the bias introduced by our method is remarkably small, with relative differences generally remaining below 3%. For reaction (R5) O + O + M (blue line), the bias is mostly within 10%, but can occasionally reach ~15% above 95 km. The total chemical heating rates for R1-R7 (red line) show a bias generally within ~10% in the main heating region of 85-96km. The larger discrepancies (10-20%) observed at 80 km are primarily attributed to the significantly smaller heating rates at this altitude, where minor absolute deviations translate into comparatively large relative errors.

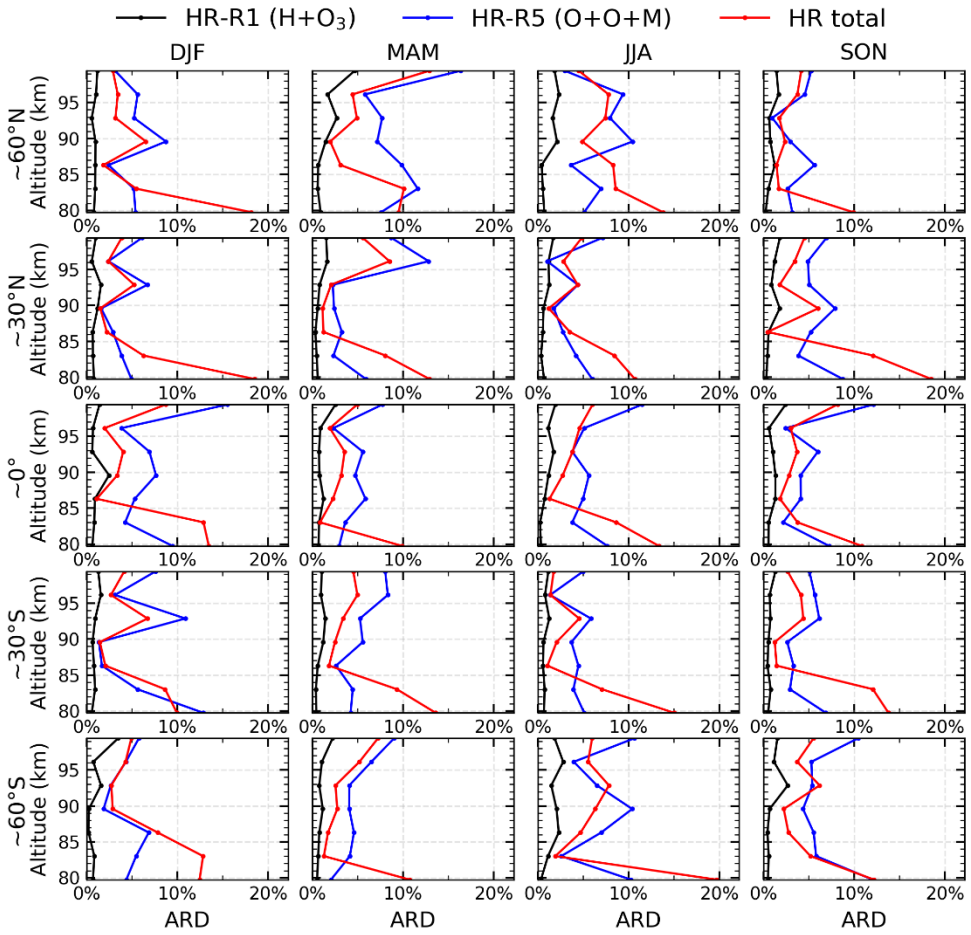

Figure 1. Mean absolute relative difference between the two methods across different seasons and latitude bands for the heating rates of reaction (R1) H + O_3 (black), reaction (R5) O + O + M (blue), and the total chemical heating rate (R1–R7; red).

Furthermore, to provide a statistical quantification for the uncertainty analysis in our

manuscript, we calculated the annual mean of the absolute relative difference for all monthly zonal profiles in 2005, as shown in Figure 2. It shows that for the H + O_3 reaction, the bias introduced by our retrieval strategy remains below 3%. For the O + O + M reaction, the bias is generally within 10%. The bias for the total chemical heating rate is within 5-15%.

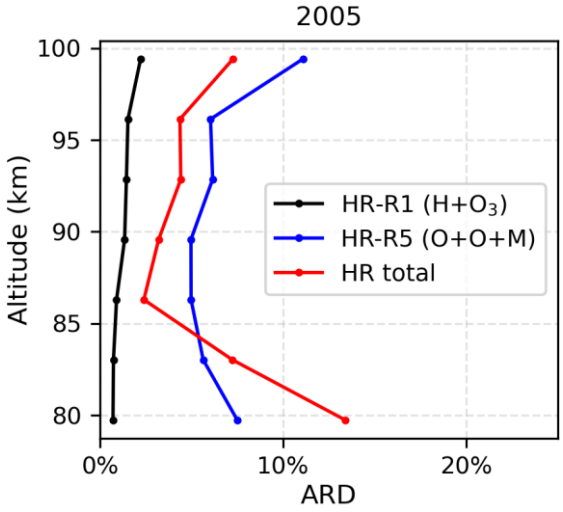

Figure 2. Annual mean absolute relative difference between the two methods for all monthly zonal profiles in 2005 for the H + O_3 heating rate (R1), the O + O + M heating rate (R5), and the total chemical heating rate (R1–R7).

Comparing these uncertainty values with the uncertainties induced by other retrieval parameters presented in Section 3.1 (e.g., temperature and quenching rates), we find that the error introduced by the pre-retrieval median approach is smaller than those associated with other dominant sources of uncertainty (30%-60%). Therefore, the systematic bias caused by the non-linearity of the aggregation process is relatively minor and does not significantly affect the main conclusions of this study.

Revisions in the manuscript:

The discussion of the nonlinearity-induced uncertainty has been incorporated into Section 3.1 (Uncertainty analysis) and Appendix A (Lines 380-409). The error bars in Figure 1 of the revised manuscript have been updated accordingly.

Lines 191-193: “In addition, the use of monthly zonal median data prior to retrieval can introduce biases due to the nonlinear dependence of the retrieval algorithm on its inputs. This nonlinearity-induced uncertainty is evaluated using synchronous SABER observations, as detailed in Appendix A.”
Line 205: “The nonlinearity-induced uncertainty is estimated to be below 3%”
Line 212: “The nonlinearity-induced uncertainty is approximately 10%”
Line 220: “The nonlinearity-induced uncertainty is in the range of 5-15%.”
Lines 380-409: See Appendix A of the revised manuscript for details.

2. “The authors compared new CHR data with SABER data and revealed essential systematic differences. At the same time, the article does not provide convincing

reasons to believe that the quality of the new CHR data is better than SABER CHR data, which exceeds significantly the new data in spatiotemporal resolution."

Response: Thank you for this comment. We fully agree and acknowledge that the SABER dataset possesses significantly superior spatiotemporal resolution compared to SCIAMACHY. However, the use of SCIAMACHY also has its own distinct advantages. Compared to SABER chemical heating retrievals based on the 2.0 um OH emission, our retrieval using SCIAMACHY OH (9-6) emissions rely on a simpler and more direct photochemical model. This approach depends on fewer dynamical and spectroscopic parameters and therefore minimizes the propagation of uncertainties associated with multi-step cascade modeling.

In addition, it is scientifically valuable to have more than one determination of the heating rate. This is especially the case since there are few observations and many potential sources of uncertainty. SCIAMACHY provides measurements independent of SABER, serving as an independent constraint. Even when using identical background atmospheres, systematic differences remain in the retrieval results, which is a crucial scientific finding, representing the systematic uncertainties arising from instrumental and retrieval parameters (Zhu et al., 2018, 2020; Wu et al., 2025). Therefore, the value of this new dataset is not to claim one dataset is definitively better, but to provide a new dataset for reference and discussion, helping the community better understand the uncertainties in the mesopause energy budget.

We have added statements on the research motivation in revised manuscript:

Lines 72-74: "Given the considerable uncertainties in deriving heating rates from airglow observations, independent determinations using different instruments and retrieval approaches are essential for characterizing systematic biases and building confidence in the results."

Lines 349-352: "The retrieval using OH (9-6) emissions relies on a relatively simple and direct photochemical model, which depends on fewer dynamical and spectroscopic parameters and therefore minimizes the propagation of uncertainties associated with multi-step cascade modeling."

Lines 365-368: "Even when using identical background atmospheres, systematic differences remain in the retrieval results, which is a crucial scientific finding, representing the systematic uncertainties arising from instrumental and retrieval parameters (Zhu and Kaufmann,2018; Wu et al., 2025)."

Lines 372-374: "Since there are few observations and many potential sources of uncertainty involved, having more than one independent determination of the heating rate is scientifically valuable. SCIAMACHY provides measurements independent of SABER and thus serves as an important observational constraint on UMLT chemical heating."

3. "In addition, there are no restrictions on obtaining CHR data at the altitudes of 80-85 km, where, according to Kulikov et al. (ACP, 2023, 2024), the equilibrium conditions of nighttime O3, OH, and HO2 may be disturbed."

Response: Thank you for this helpful comment. We agree that at the altitudes of 80-

85 km, dynamical transport can significantly perturb the nighttime chemical equilibrium of O_3, OH, and HO_2, as discussed by Kulikov et al. (2023, 2024). This limitation was not sufficiently discussed in our manuscript.

Our retrieval is based on SCIAMACHY OH (9-6) emission, which is directly proportional to the production rate of OH(v) via reaction (R1) H + O_3, as described in Eq. (1) of the manuscript. Although [O] in the loss term is derived assuming ozone equilibrium, at 80-85 km the quenching of OH(v) is dominated by collisions with N_2 and O_2, while quenching by O is 2-3 orders of magnitude smaller (Smith et al., 2010, Fig.1). As a result, the inferred reaction rate for (R1) H + O3 and its associated heating rate are relatively insensitive to deviations from the ozone equilibrium assumption at this altitude range. Consequently, the retrieved [H] is also only weakly affected by the ozone equilibrium assumption.

In contrast, the densities of O, OH, and HO_2 derived from chemical equilibrium relationships are more sensitive to the validity of the equilibrium assumption. This can introduce larger uncertainties in the heating rates for reactions (R3-R7) at 80-85 km. However, for (R5) O +O +M, our primary focus is on its dominant heating layer located above 85 km (Fig. 3 in our manuscript), and thus the main results for this reaction are largely unaffected.

For the total chemical heating at 80-85 km, uncertainties may be larger due to the partial contribution of reactions relying on equilibrium assumptions. Nevertheless, since reactions R1 and R2 together account for roughly half of the total chemical heating in this altitude range, the results still can provide a reasonable estimate of the magnitude of chemical heating.

Revisions in the manuscript:

We have discussed the potential impact of this limitation on our retrieval results in Section 3.1 (Uncertainty analysis) in Lines 222-232:

“It should be noted that the retrieval relies on the assumption of chemical equilibrium for O_3, OH, and HO_2. This assumption may not hold in the 80-85 km altitude range, depending on season and latitude (Kulikov et al., 2018, 2023, 2024). However, the retrieved [H] and the heating rate of Reaction (R1) are only weakly affected. This is because the reaction rate $k_1[H][O_3]$ is determined by the observed OH (9-6) emission and the total OH (v = 9) loss rate. At 80-85 km, the total loss rate is dominated by radiative decay and quenching by O_2 and N_2, while the contribution from atomic oxygen quenching is two to three orders of magnitude smaller (Smith et al., 2010, Fig. 1). Thus, errors in [O] caused by the equilibrium breakdown do not significantly propagate to the R1 heating rates. In contrast, the densities of O, OH, and HO_2 derived from chemical equilibrium relationships are more sensitive to the validity of the equilibrium assumption, potentially introducing larger uncertainties in the heating rates for Reactions (R3-R7) at 80–85 km. Nevertheless, for Reaction (R5) O + O + M, our primary focus is on its dominant heating layer located above 85 km, and thus the main results for this reaction are largely unaffected.”

Specific comments:

1. Lines 110-115. The authors claim that the chemical production and loss of nighttime ozone are in equilibrium within the range 80–96 km and further apply this assumption to the chemical heating rate retrieval in this altitude range. This contradicts the results of Kulikov et al. (JGR 2018, ACP 2023) showing that the lower boundary of the ozone balance depends on the season and latitude and can be located at an altitude of several kilometers above 80 km. In particular, Kulikov et al. (ACP 2023) presented the spatiotemporal evolution of this boundary retrieved from the SABER/TIMED data in 2002–2021. Below, one can see the time evolution of monthly mean altitude of this boundary at different latitudes reprinted from Figure 11 of the paper.

Response: Thank you for this comment. We agree that our previous statement implying ozone chemical equilibrium across ~80-96 km was not sufficiently precise. As shown by Kulikov et al. (2023), the lower boundary of nighttime ozone chemical equilibrium depends on season and latitude and typically varies at approximately 80-85 km.

However, as discussed in our response to Major Concern 3, we conducted a detailed analysis on the impact of this equilibrium assumption. The results indicate that the dominant heating source, reaction (R1) $H + O_3$ is only weakly affected by this assumption at 80-85km. While for reaction (R5) O + O + M and the total chemical heating rates, deviations from ozone equilibrium may introduce additional uncertainty; however, the altitude region below 85 km does not correspond to the main heating region and therefore does not significantly affect our primary conclusions.

We have revised lines 138-143 to explicitly acknowledge that the lower boundary of ozone chemical equilibrium is variable and can rise above 80 km depending on season and latitude. We have also added a discussion in Section 3.1 (Uncertainty analysis), Lines 222-232, to clarify the impact of this limitation on our retrieval results.

Lines 138-143: “Recent studies indicate that the lower boundary of the nighttime ozone chemical equilibrium depends on season and latitude and can be located several kilometers above 80 km (Kulikov et al., 2018, 2023). The potential impact of deviations from chemical equilibrium is discussed in Sect. 3.1 and is found to be limited for the primary heating structures considered in this study. Therefore, we adopt 80 km as the nominal lower boundary for the retrieval. Under this equilibrium assumption, the following relation holds:”

2. Lines 122-127. The authors noted here: “These densities are inferred assuming chemical equilibrium, with the lower boundary altitude ranging from 73 to 85 km depending on season and latitude (Kulikov et al., 2024b).” Nevertheless, as one can see from text and Figures of this paper, the chemical heating rate is calculated in the altitude range of 80-96 km, regardless of season and latitude.

Response: Thanks for this comment. Because direct measurements of atomic oxygen

and hydrogen in the 80-100 km region are challenging, the assumption of ozone chemical equilibrium is commonly adopted in retrieval studies (e.g., Smith et al., 2010; Xu et al., 2012; Mlynczak et al., 2013, 2018). In addition, the chemical heating from the dominant exothermic reaction H + O_3 is only weakly sensitive to the ozone equilibrium assumption at 80-85 km, making it reasonable to start the retrieval at 80 km.

However, we acknowledge that the breakdown of ozone equilibrium at 80-85 km may significantly affect the inferred [O], [OH], and [HO_2] and the associated chemical heating rates.

We have added a discussion in Section 3.1 (Uncertainty analysis), Lines 222-232, as shown above in Major Concern 3, to clarify the impact of this limitation on our retrieval results.

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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