Response to reviewer 2 (RC2)

The study by Ladstaedter et al. shows Global Navigation satellite based temperature analysis of the tropopause altitude and temperature. The analysis covers 2002-2024 and provides a global view on the tropopause using the lapse rate tropopause LRT according to WMO. The authors further apply multiple linear regression with regressors for QBO and ENSO to derive trends of the LRT-height, and the LRT temperature. Seasonally and regionally resolved trends are presented. The authors also check for trend robustness with regard to the end date of data set.

They find a significant positive temperature increase at the LRT in the tropics and southern subtropics over time with, but no significant rise in LRT altitude. Instead the northern extratropics show an increase in LRT-height, and partly weak positive trend.

Despite providing no analysis for the trend differences the paper provides extremely interesting data to the community. It is very well written, Figures are clear and the topic is well within the scope of ACP.

I recommend the paper for publication with just very few minor remarks to be considered and which are given below.

Thanks to the reviewer for your recommendation to publish the manuscript. We provide responses to your comments below.

Data:

1) Given the change of available profiles from COSMIC in the year 2007: How does this affect the trend estimates and statistics?

It is correct that the transition from the early CHAMP period which had fewer occultation events (2002 to mid-2006), to the later COSMIC/METOP period (mid-2006 to 2024) requires careful consideration of its impact on climatological time series. A widely used approach here is to use a reference field, such as the ERA5 reanalysis to estimate the bias due to incomplete sampling. However, for the following reasons, in this study we decided to use the data directly, without sampling bias correction: Firstly, RO has a considerably better vertical resolution than ERA5, particularly around the tropopause. Therefore, we expect ERA5 to miss details about the lapse rate structure and conclude that it is not a valid reference for this application. Secondly, as the timeseries now extends to 2024, the fraction of the timeseries with less dense sampling compared to the later period has become small (4.5 yrs compared to 18.5 yrs), and the trend uncertainty due to sparse sampling has decreased accordingly. Finally, we nevertheless redid our analysis with sampling bias correction based on ERA5 fields, and the overall trend structure did not change (Fig. R1). The sampling bias correction reduces some noise in the regionally resolved patterns, but does not change our conclusions.

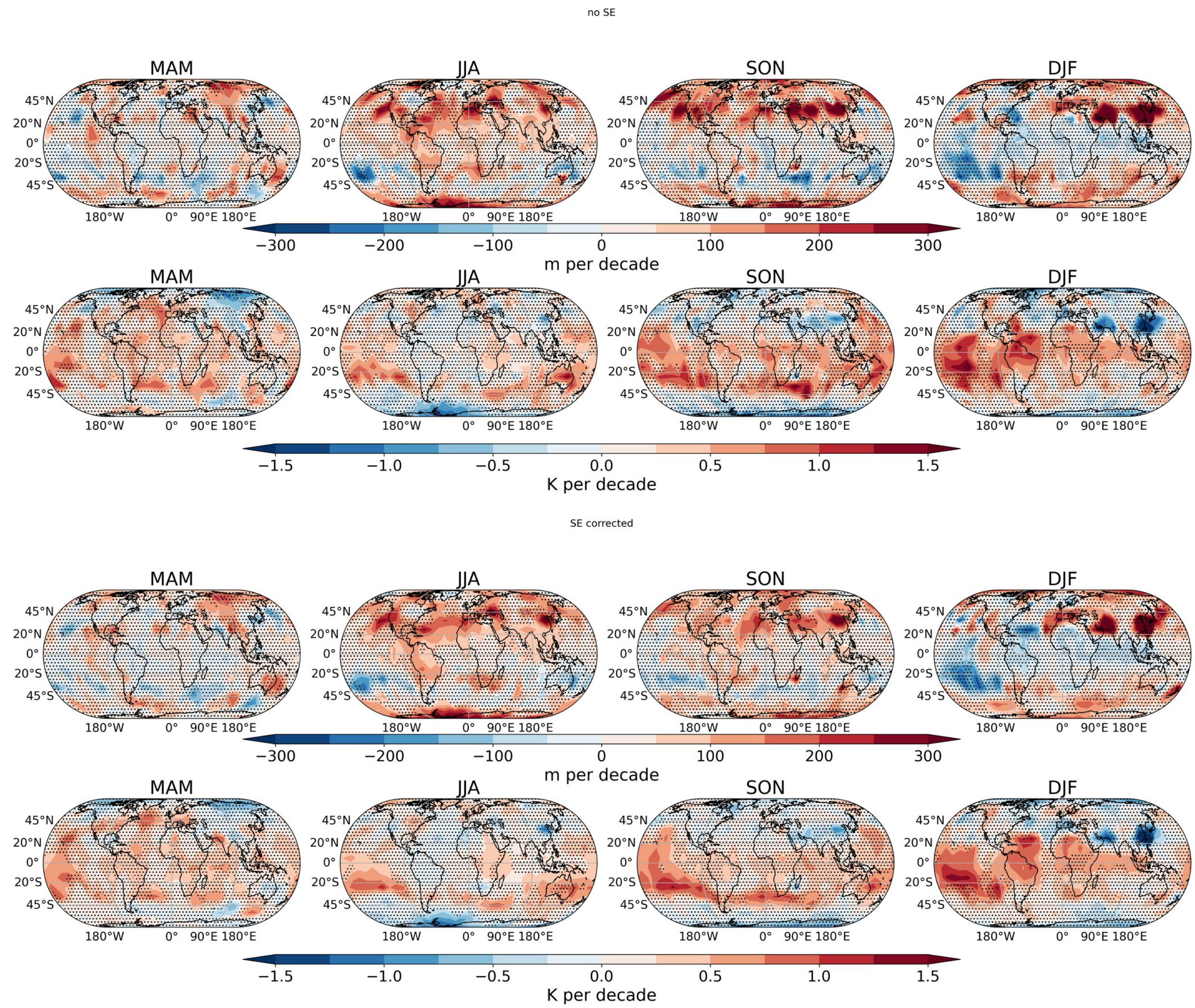

Fig. R1: Observed seasonal trends in lapse rate height (top rows) and temperature (bottom rows). The top panel shows the trends without sampling bias correction, the bottom panel with sampling bias correction using ERA5 reference fields.

In accordance with our aim of being as close as possible to the original measurements, we therefore chose not to apply sampling bias correction here. We have added the following paragraph to line 94-100 of the manuscript to explicitly discuss this topic:

We note that the number of measurements involved in the RO time series varies due to the transition from the early single-mission RO period (2002 to mid-2006) with less measurements to the later period (mid-2006 to 2024) when more RO missions contributed (Gleisner et al., 2020). In many applications, it is favorable to apply a correction for the resulting sampling bias caused by incomplete atmospheric sampling using a background field such as the ERA5 reanalysis (Foelsche et al., 2008; Scherllin-Pirscher et al., 2011). In our case, applying such a correction does not alter the overall trend values and patterns (not shown). Therefore, we have chosen not to correct for these sampling inhomogeneities here, since the decreased vertical resolution of such a background field could tamper with the pure observational information contained in the RO profiles.

2) Though the GNSSS data are a valuable and well established data set for deriving tropopause altitudes, the authors should provide in this manuscript a short paragraph on temperature uncertainties since they derive temperature trends here, despite given in other literature sources.

We added the following in the data section (line 71-74) to discuss the RO uncertainties in some more detail, and to cite some more references:

The systematic uncertainty in the UTLS is estimated to be below 0.1 K, with the lowest values around the tropopause (Scherllin-Pirscher et al., 2011b, 2021; Schwarz et al., 2017). Random uncertainty can already be neglected for small aggregation sizes, and the structural uncertainty due to processing choices is less than 0.1 K in that region (Steiner et al., 2020b).

Methods:

Regarding potential multiple tropopauses: How are these treated?

Does the analysis take the upper, or the lower one, or exclude such multiple cases particularly in the subtropics?

We only consider the first (lowest) tropopause found by the lapse rate algorithm. Analyzing the more complex vertical structure of the subtropics, which often manifests as multiple tropopauses, is beyond the scope of this work. However, this has been analyzed using RO, e.g. by Wilhelmsen et al. 2020 (doi: 10.1029/2020GL089027). To clarify in the manuscript that we use only the first tropopause, we have added the following to line 87-89:

According to the WMO lapse rate definition, a second tropopause might occur above the first, which is a phenomenon common in the extratropics (e.g., Randel et al., 2007). In this study, however, only the lowest (first) tropopause is considered when multiple tropopauses are found in the temperature profile.