

K. P. Aathira^{1,2*}, M. Pramitha², B.L. Madhavan³, and M. Venkat Ratnam³

¹School of Physics, Indian Institute of Science Education and Research, Thiruvananthapuram, India.

²School of Earth, Environmental and Sustainability Sciences, Indian Institute of Science Education and Research, Thiruvananthapuram, India.

³National Atmospheric Research Laboratory, Gadanki, India.

pramitha@iisertvm.ac.in

Abstract

The key Tropopause inversion layer (TIL) parameters, the width and strength, and the radiative effects of water vapor and ozone on TIL formation over the tropical station, Gadanki are investigated. A heating rate analysis reveals that, the stronger and narrower TIL in summer is a result of radiative heating driven by ozone in the lower stratosphere and cooling by water vapor in the upper troposphere, leading to an enhanced temperature inversion. Further, the latitudinal variation in TIL forcing due to water vapour is proposed. The adiabatic processes majorly forces the tropical TIL and radiative cooling forces the polar TIL. This hypothesis requires further testing with global datasets and models, incorporating other established TIL forcing mechanisms.

Introduction

- ❖ TIL is a deviation from the typical decrease in temperature throughout the troposphere.
- ❖ The TIL is a very stable layer in the upper troposphere lower stratosphere (UTLS) region, and inhibits vertical motions, regulating the exchanges between stratosphere and troposphere.
- ❖ Thus, the mechanisms that strengthens the TIL becomes important in controlling STE.

- ❖ There is a pronounced seasonality for all parameters except for TIL strength.
- ❖ The summer UTLS experience a temperature inversion due to radiative heating of ozone and radiative cooling due to water vapor.
- ❖ The summer TIL is forced due to the temperature inversion due to ozone and water vapor, while the initial formation of TIL might be due to other mechanisms like Brewer Dobson circulation.

Latitudinal variation in TIL forcing mechanisms

- ❖ Kunkel et al. (2016) showed that a combination of different adiabatic and diabatic processes likely drives the formation of the TIL.
- ❖ In TIL studies, relative humidity with respect to ice (RH_i) is used as a moisture proxy since temperatures near the tropopause are low, making ice the stable phase.
- ❖ Köhler et al. (2024) reported that sharper or stronger TILs occur on the one hand for higher RH_i values, which points to the adiabatic contribution and on the other hand also for sharper gradients of RH_i at the top of the moist layer, indicating diabatic processes.

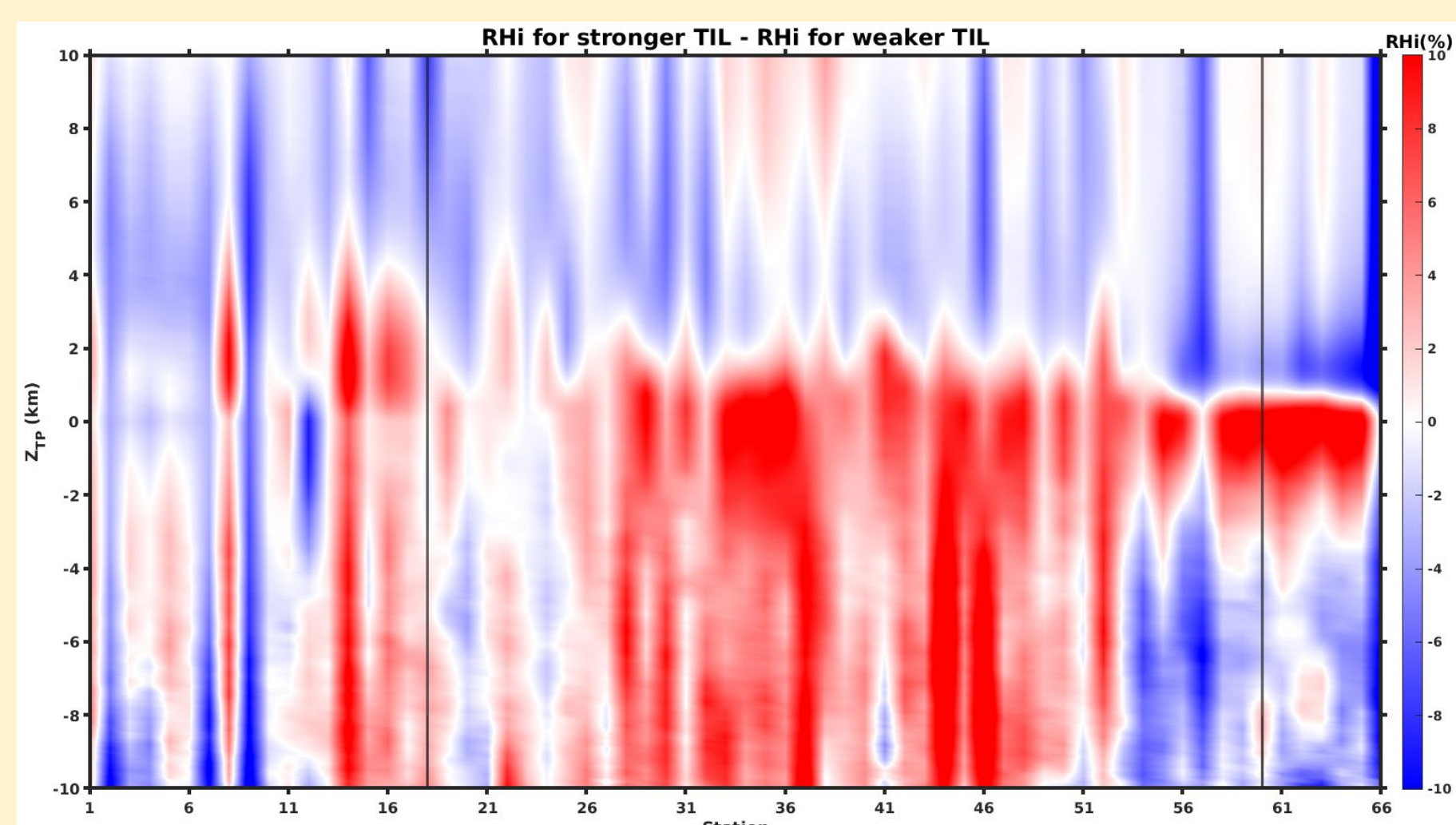


Fig.5. RH_i for stronger and weaker TIL

- ❖ The RH_i gradient is sharper for stronger TIL in poles and the tropospheric RH_i is enhanced for stronger TIL in tropics.

Radiosonde for TIL studies

- ❖ Radiosonde data from 2006 to 2024 is obtained from **NARL, Gadanki** (13.5° N, 79.2° E).
- ❖ Heating rate is calculated using SBDART.
- ❖ **US high resolution radiosonde 6-second data** have been downloaded from <https://www.sparc-climate.org>
- ❖ The station network consists of 96 observing sites with data for upto 15 years (1998-2012) from which 66 stations in the Northern Hemisphere with more than 85% data points have been selected.
- ❖ Tropopause is identified using the WMO lapse rate tropopause definition, lowest level with LR less than 2 K/km is identified as tropopause if the condition is satisfied for the next 2 km.

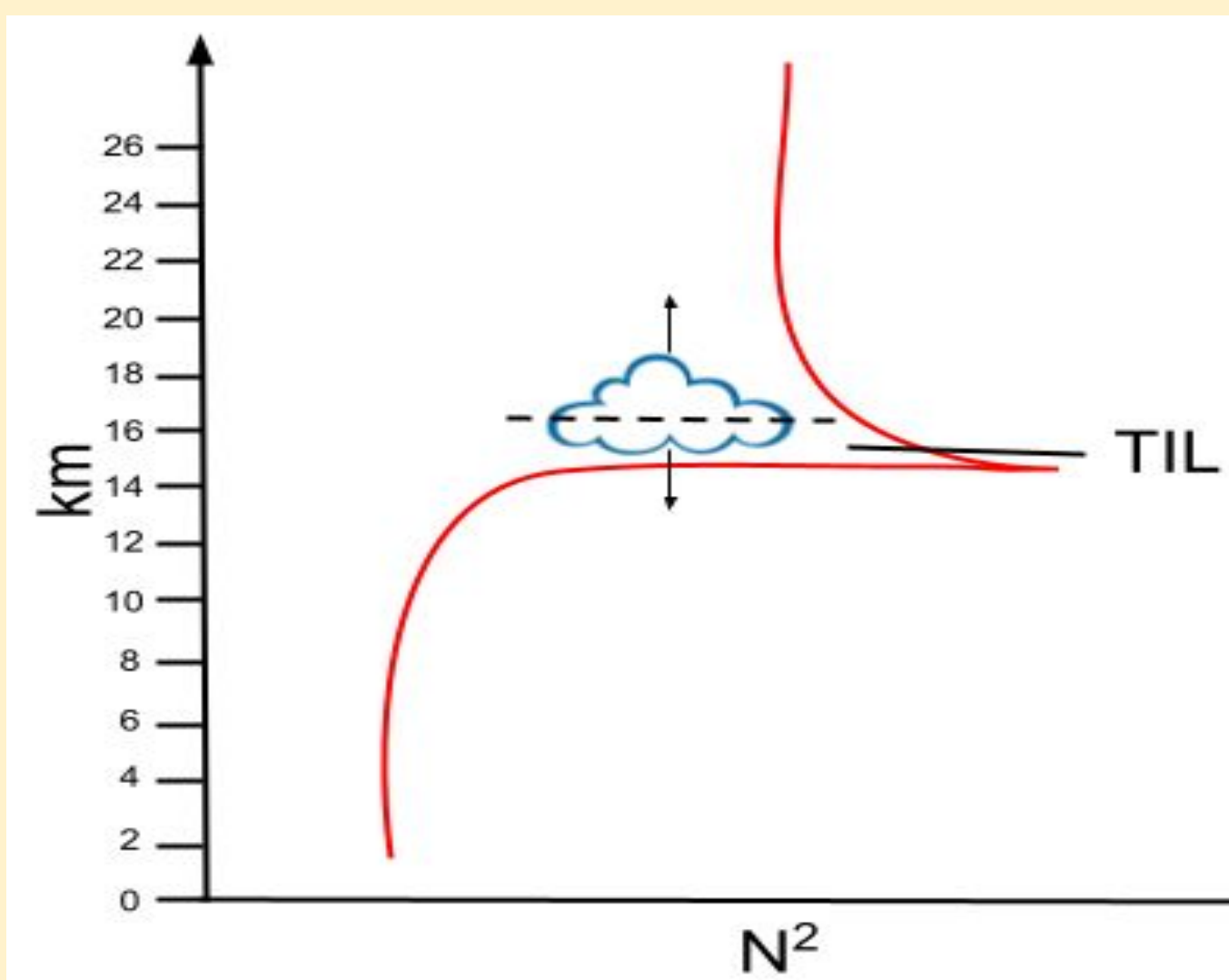


Fig.1. Schematic representation of TIL

TIL over Gadanki

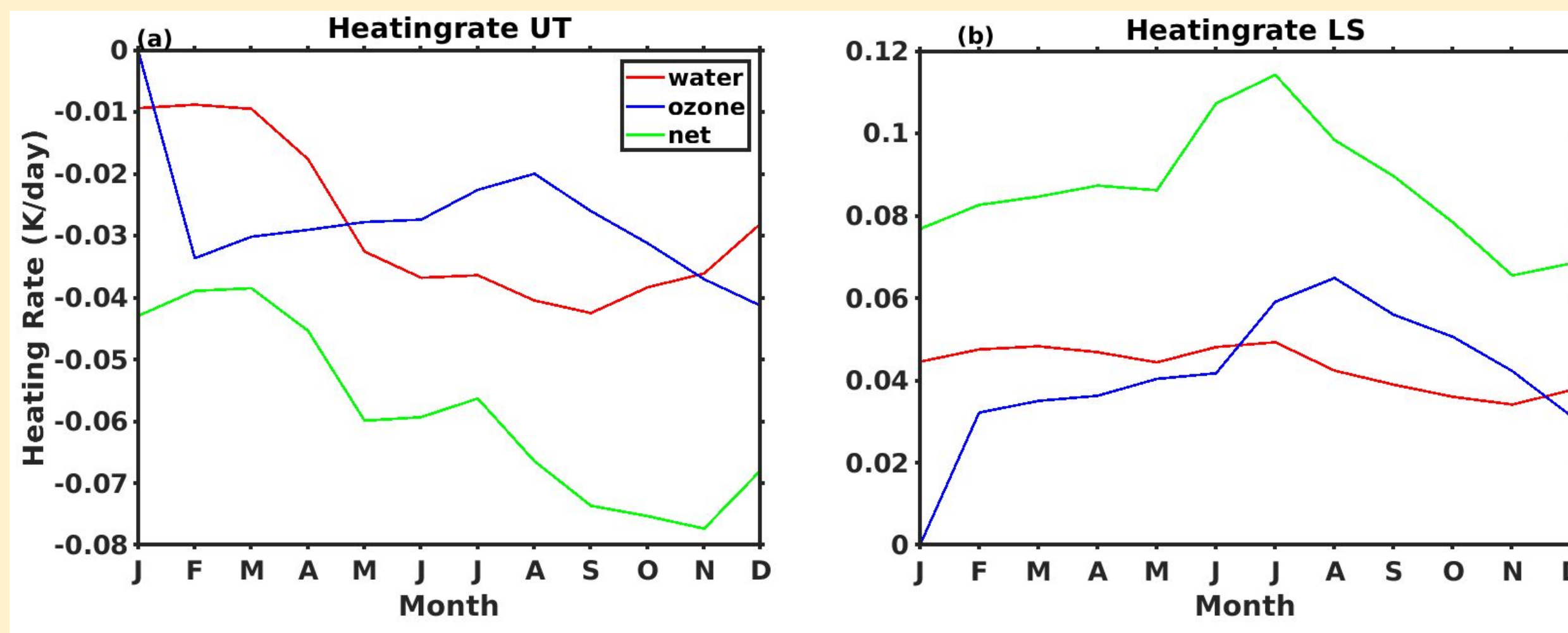


Fig.3. Seasonal variation in the heating rate in upper troposphere (UT) and lower stratosphere (LS) (Aathira et al., 2025)

Summary

- ❖ In summer, the TIL is narrower in both categories, but the weaker category does not show a strengthening with increased temperature inversion; but responds to the seasonal cycle of BDC.
- ❖ The stronger and narrower TIL in summer is a result of radiative heating due to ozone in LS and cooling due to water vapor in UT, leading to an enhanced temperature inversion, and modulating the UTLS.
- ❖ When analysing the role water vapor plays, we propose that the adiabatic processes in the tropics majorly forces the TIL there and radiative cooling in the poles forces the TIL, while mid-latitudes are a combination of both.

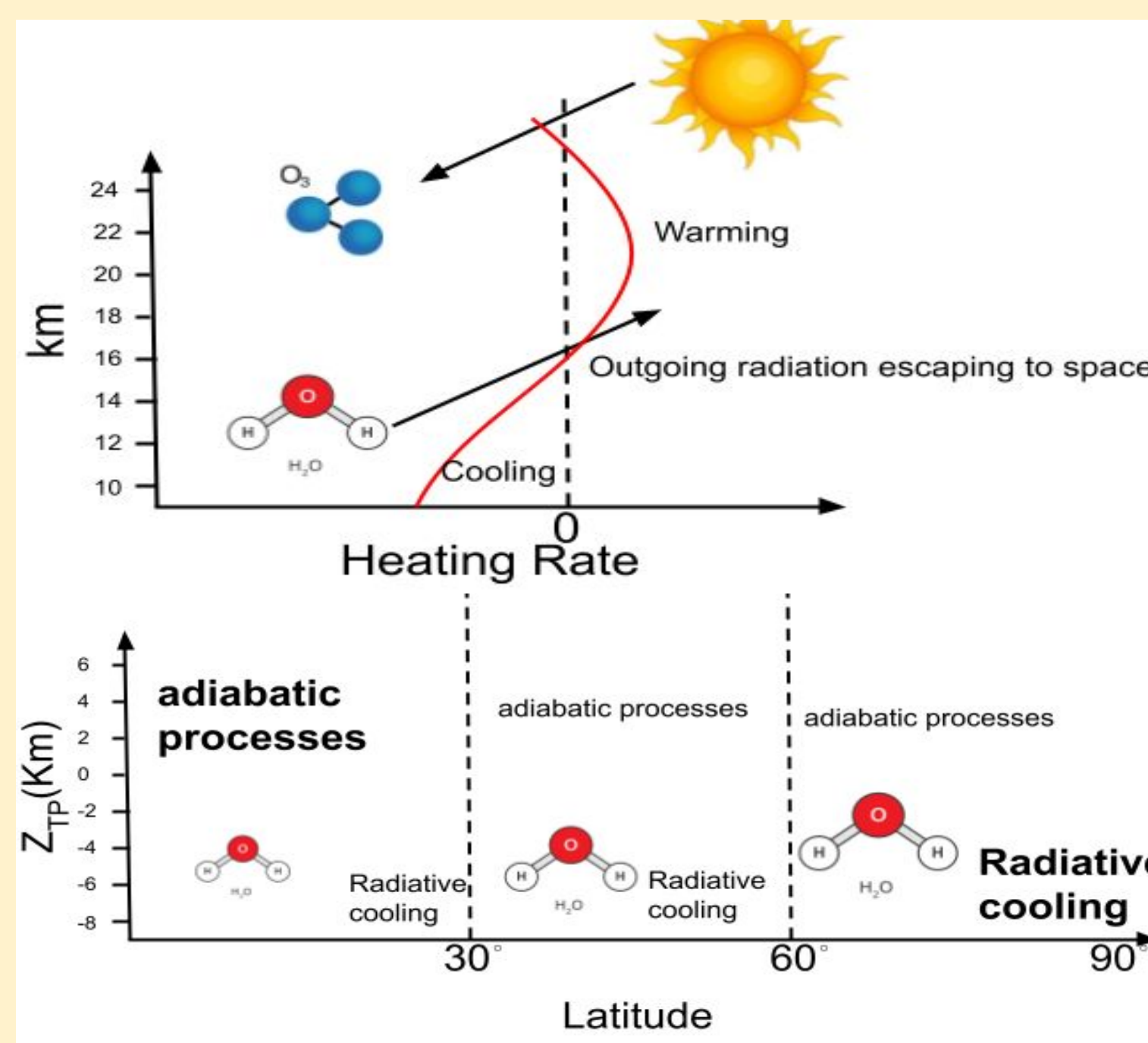


Fig.6. Schematic representation of TIL forcing mechanisms.

Calculating TIL

Proposed by Köhler et al, 2024.

- ❖ The TIL strength **sTIL**, is the maximum of the static stability $N^2_{\max}$ within 3 km above tropopause level and the altitude level of $N^2_{\max}$ is the TIL height **TILz**.
- ❖ Two additional heights are defined through two minimum values of N^2 : $UT-N^2_{\min}$ is the height of the minimum of N^2 in the upper troposphere, and $LS-N^2_{\min}$ is the height of the minimum of N^2 within 5 km above TIL height.
- ❖ The TIL depth **dTIL** is half of the height difference between the $UT-N^2_{\min}$ and $LS-N^2_{\min}$.

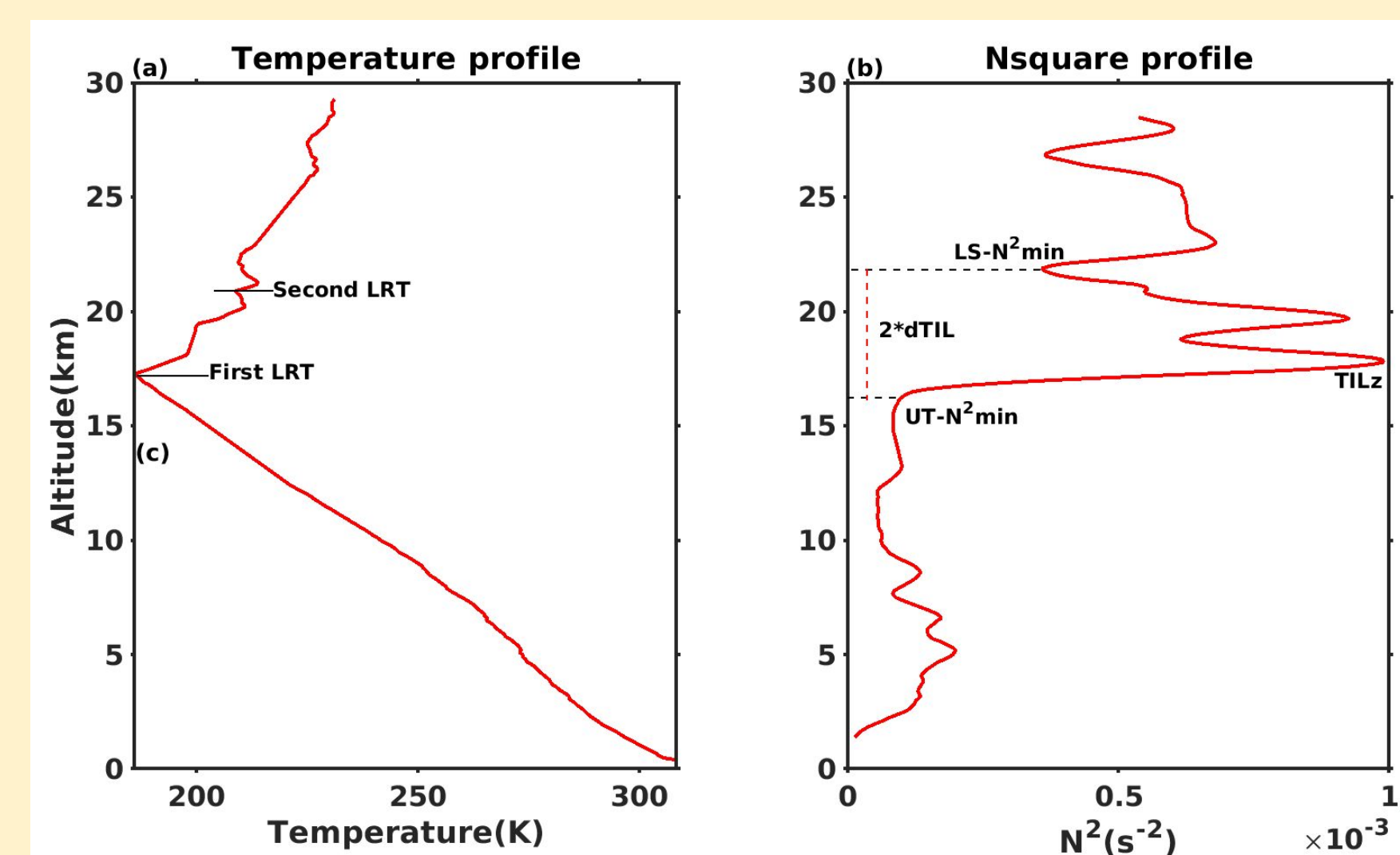


Fig.2. Schematic representation of TIL calculation

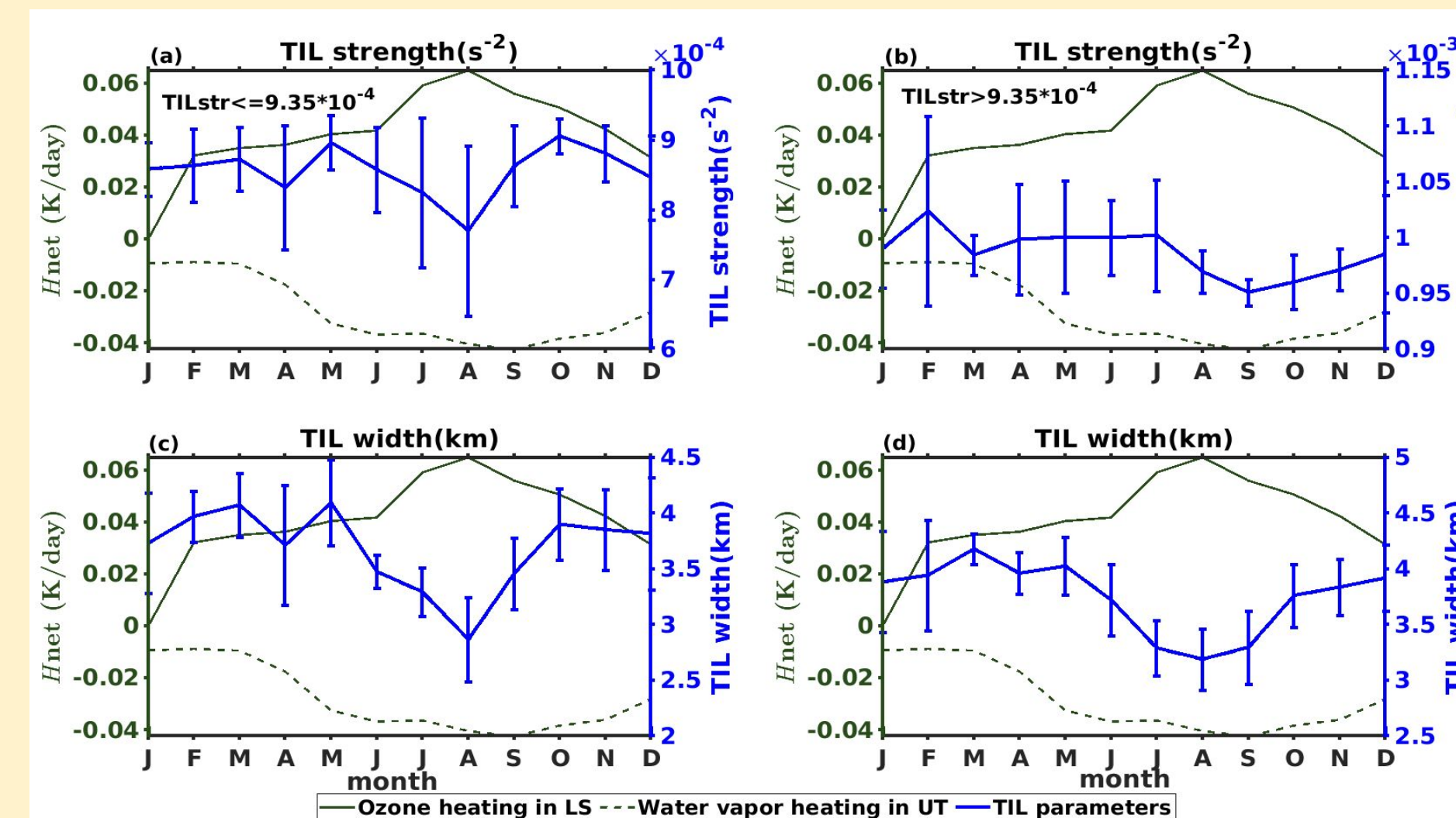


Fig.4. Seasonal variation in TIL with heating rates in UTLS (Aathira et al., 2025)

References

- Köhler, D., Reutter, P. and Spichtinger, P., 2024. Relative humidity over ice as a key variable for Northern Hemisphere midlatitude tropopause inversion layers. *Atmospheric Chemistry and Physics*, 24(17), pp.10055-10072.
- Kunkel, D., Hoor, P. and Wirth, V., 2016. The tropopause inversion layer in baroclinic life-cycle experiments: the role of diabatic processes. *Atmospheric Chemistry and Physics*, 16(2), pp.541-560.

Acknowledgement

The authors acknowledge the staff of the National Atmospheric Research Laboratory (NARL), Gadanki, for the radiosonde and ozonesonde data.

One of the authors, M. Pramitha, gratefully acknowledges the Department of Science and Technology (DST), Government of India for providing the fellowship during the course through the DST-INSPIRE faculty scheme for the financial support and research opportunity provided for her work.

The authors acknowledge the free availability of U.S. high vertical-resolution radiosonde data provided by SPARC (Stratosphere-troposphere Processes And their Role in Climate).

One of the authors, K P Aathira, acknowledges the funding and resources provided by IISER Thiruvananthapuram to complete this study.