Stratospheric Influence on Tropical Cyclone Intensification

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Background

Tropical cyclones (TC) are rapid rotating storms which pose as one of the most significant natural threats [1]. Rising SSTs associated to climate change will further increase TC intensities [2], therefore it is crucial to understand their intensification process, and dynamics to enhance forecasts and minimize their impacts.

According to literature, in intense cyclones stratospheric air may intrude in the eye, forming a high-level warm core at the tropopause [3] which lowers the hydrostatic pressure at the surface thus instensifing the TC [3][4].

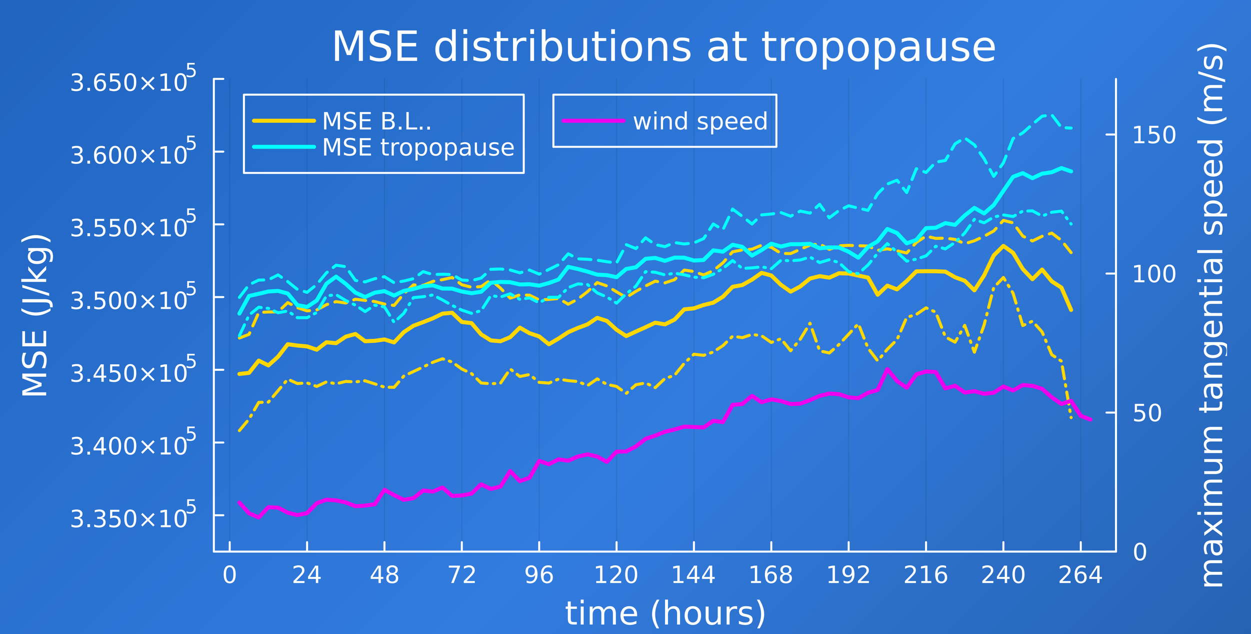

Fig. 1: 90°(dashed), 50°(solid) and 10°(dash-dotted) percentiles of MSE distribution in the cyclone's core along with cyclone intensity (purple line)

In this study, we analyse the outcomes of the non-hydrostatic model NICAM run under realistic settings according to the DYAMOND protocol [5].

Moist static energy (MSE) was used as metric for heating imbalance between the boundary layer (BL) and the tropopause, as this quantity is approximately conserved in moist adiabatic processes.

Fig. 1 shows how the MSE increase at the tropopause can't be explained solely due to its increase at the boundary layer, such that other sources of energy have to be accounted for.

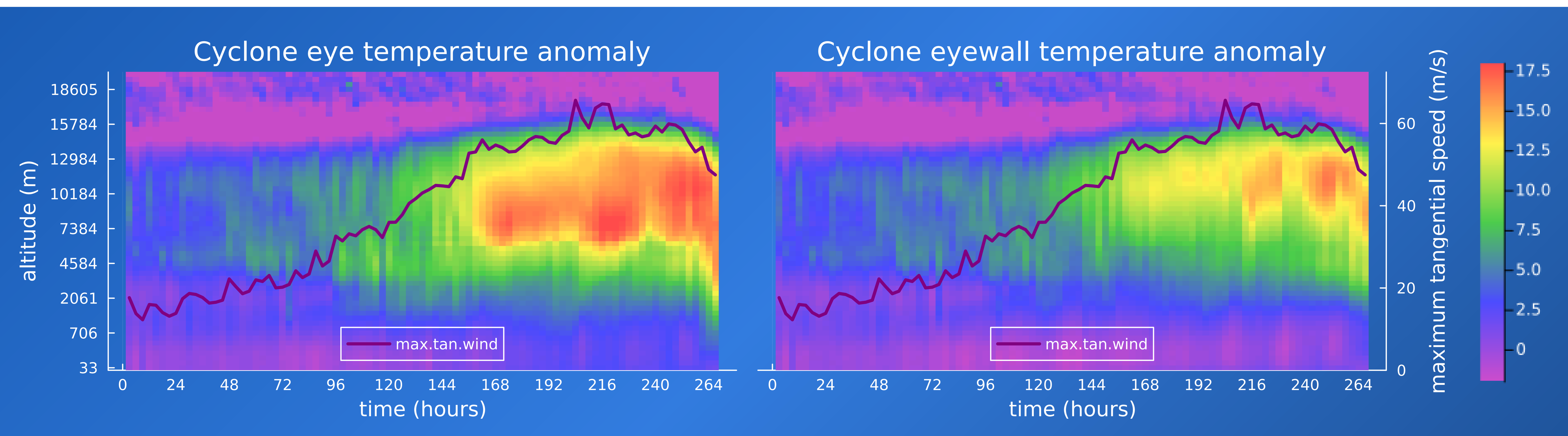

Fig. 2: Temperature anomalies relative to the same region occupied by the cyclone 3 days prior to its passage

Core heating

Temperature anomalies were calculated both in eye and eyewall. These show how the first have a prevailing role in heating due to subsiding air in this region. However, the increase of MSE beyond BL values can be justified only by the descent of air from a higher and warmer region, such as the stratosphere, since the role of diabatic heating was ruled out in [6].

Hydrostatic pressure

High-level warming contribution was estimated by comparing the hydrostatic pressure from the model output with the one calculated assuming moist adiabatic ascent of a BL air parcel (T parcel). The latter shows the maximum intensity a cyclone would reach if it were driven solely by moist convection.

The output hydrostatic sea-level pressure (SLP) is initially higher than the one calculated from T parcel. This is possibly due to the radiative cooling caused by the cyclone's injection of water around the tropopause (Fig. 3b).

After a brief transient in which the two temperature profiles equalize leading to the similar SLP (Fig.3a, t=144), the output displays warming beyond the moist adiabat at the tropopause (Fig.3c). This leads to a decrease of the core pressure of about 20 hPa with respect to the idealized case.

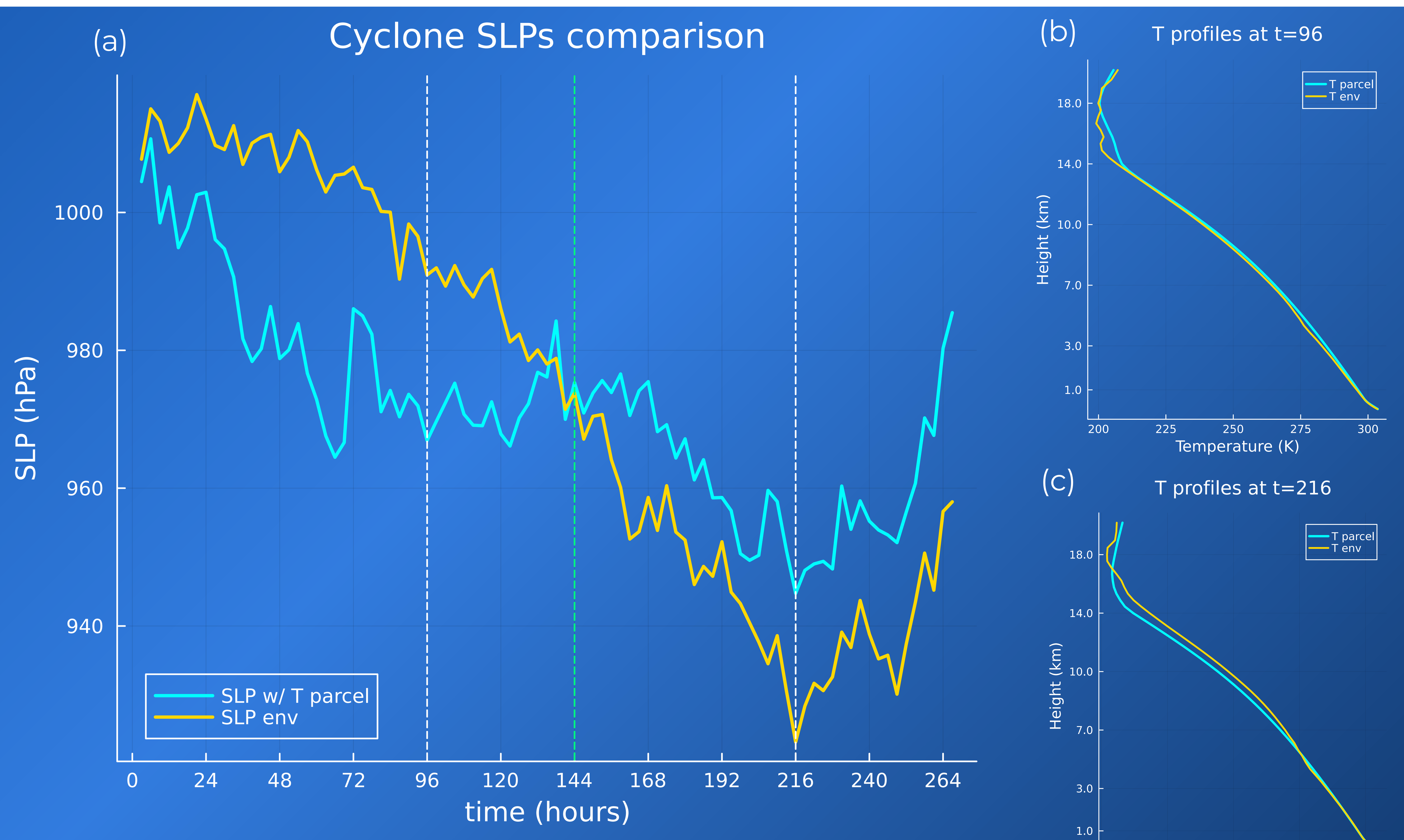

Fig. 3: SLP minima time series (a) and the temperature vertical profiles during b) and at the end of intensification (c)

Intensification rate

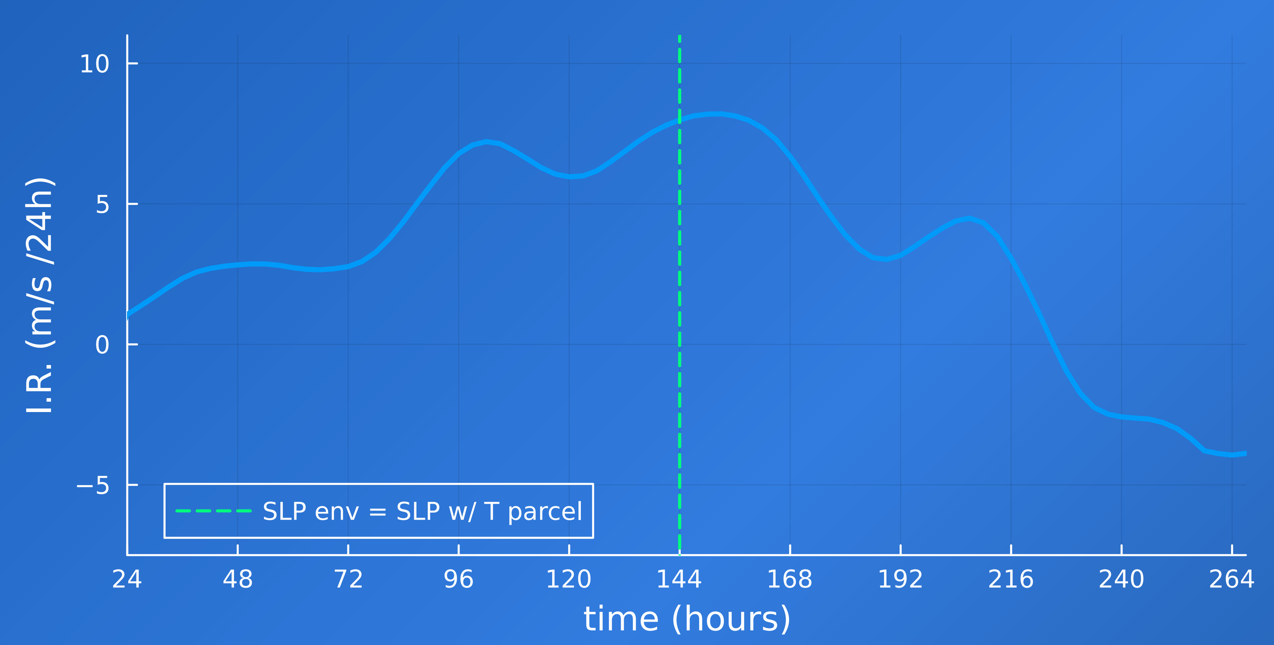

Fig. 5: Intensification rate (solid blue line) temporal series

The intensification rate (IR) [3] shows that after the hydrostatic pressure becomes lower than the one corresponding to T parcel profiles, the warm core stabilizing effects on the air column kicks in, reducing IR up to dissipation

Conclusions

Our findings indicate a pronounced high-level warming in the eye of the cyclone and an increase in MSE during intensification, which eventually exceeds the boundary layer value. This evidences the contribution of stratospheric air intruding from the top of the storm to the intensification of the cyclone. The stratospheric air warms the upper troposphere beyond the moist adiabat profiles, leading to two main effects:

- It reduces the hydrostatic pressure beyond what could have been achieved if only convection were involved in the intensification, thereby increasing the overall cyclone strength
- It stabilizes the air column, inhibiting convection. This stabilization is dominant and it is evidenced by a decrease in the cyclone's intensification rate that starts when the temperature profiles equalise

References

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