# POTENTIAL INTENSITY OF TROPICAL CYCLONES IN HIGH RESOLUTION SIMULATIONS

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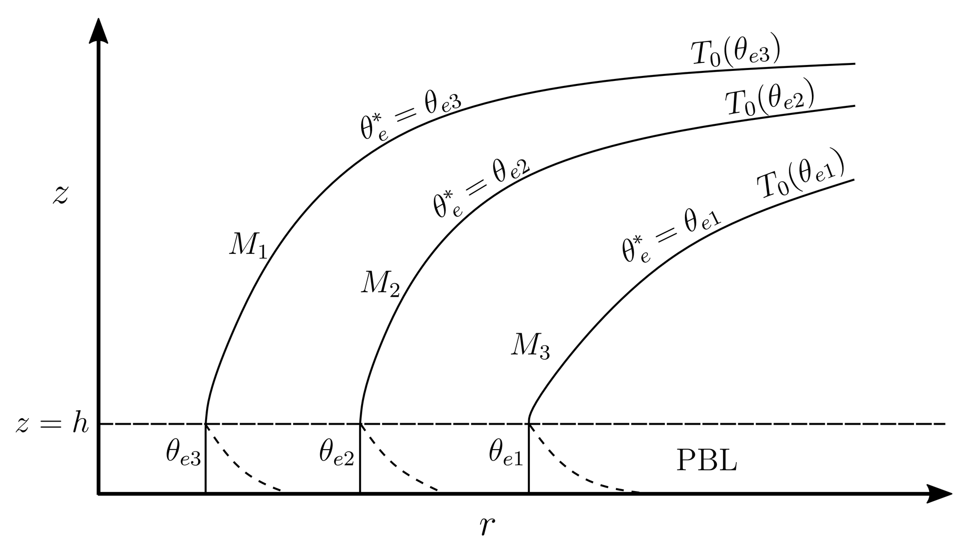
## 1. How are tropical cyclones intensified?

- High sea surface temperatures (close to 27 °C) contribute significantly to intensification
- Wind shear and dry air inhibit intensification
- The main sources of energy of a tropical cyclone are sea-air fluxes of energy (latent and sensible), that are proportional to surface wind speed. These fluxes drive intensification and this positive feedback is defined as Wind Induced Surface Heat Fluxes (WISHE) [1].
- In this study we investigate the intensification and re-intensification of tropical cyclones in idealized simulations (radiative-convective equilibrium)
- Furthermore, we attempt to derive the potential intensity of the simulated cyclones by looking at isolated processes in their intensification and re-intensification cycles

## 2. Basic equations

Below are the equations for the potential intensity $V_p$, defined according to [1] (neglecting thermal dissipation), the enthalpy $k$ and the frozen moist static energy $h$:




$$V_p^2 = \frac{c_k}{c_d}\frac{T_s - T_0}{T_s}(k_s^* - k_1) = \frac{c_k}{c_d}\frac{T_s - T_0}{T_s}\frac{S+E}{\rho_1 v_1 c_k}, \quad (1)$$

$$k = c_p T + L_v q_v, \quad (2)$$

$$h = c_p T + gz + L_v q_v - L_f q_i. \quad (3)$$

Figure 1. Assumptions of the Emanuel1986 [1] and later models. Surfaces of constant angular momentum $M$ and equivalent potential temperature at saturation $\theta_e^*$ coincide in the eyewall above the planetary boundary layer (PBL) as a result of the assumption that the troposphere is neutral to moist convection.

- $T_s$, $T_0$ ... sea surface and outflow temperature
- $c_k$, $c_d$ ... heat and drag coefficient
- $k_s^*$, $k_1$ ... sea surface and near surface air enthalpy
- $S$, $E$ ... sensible and latent heat flux
- $\rho_1$, $v_1$ ... near surface air density and velocity
- $q_v$, $q_i$ ... water vapor and ice mixing ratio
- $c_p$ ... dry air heat capacity and latent heat of vaporization
- $L_v$, $L_f$ ... latent heat of vaporization and sublimation
- $M$ ... angular momentum
- $\theta_e$ ... equivalent potential temperature
- $r$ ... radial distance from the storm center

## 3. Experimental setup

The simulations are performed using the high-resolution, cloud-resolving model System for Atmosphere Modeling (SAM) [2], which allows to explicitly solve the convective motion and characterize its feedbacks on the cyclone intensity.

- 1024 $\times$1024 km$^2$$\times$27 km domain over a ocean at fixed and uniform sea surface temperature $T_s$, horizontal resolution of 4 km
- Coriolis parameter $f = 10^{-4}$ s$^{-1}$ such that the cyclone's size is smaller than the domain size, following Muller and Romps [3]
- Fixed coefficients for the surface fluxes $c_k = c_d$ =1.5$\times$10$^{-3}$, following Cronin and Chavas [4]
- Sensitivity simulations varying $T_s$, (297 K, 300 K and 303 K)

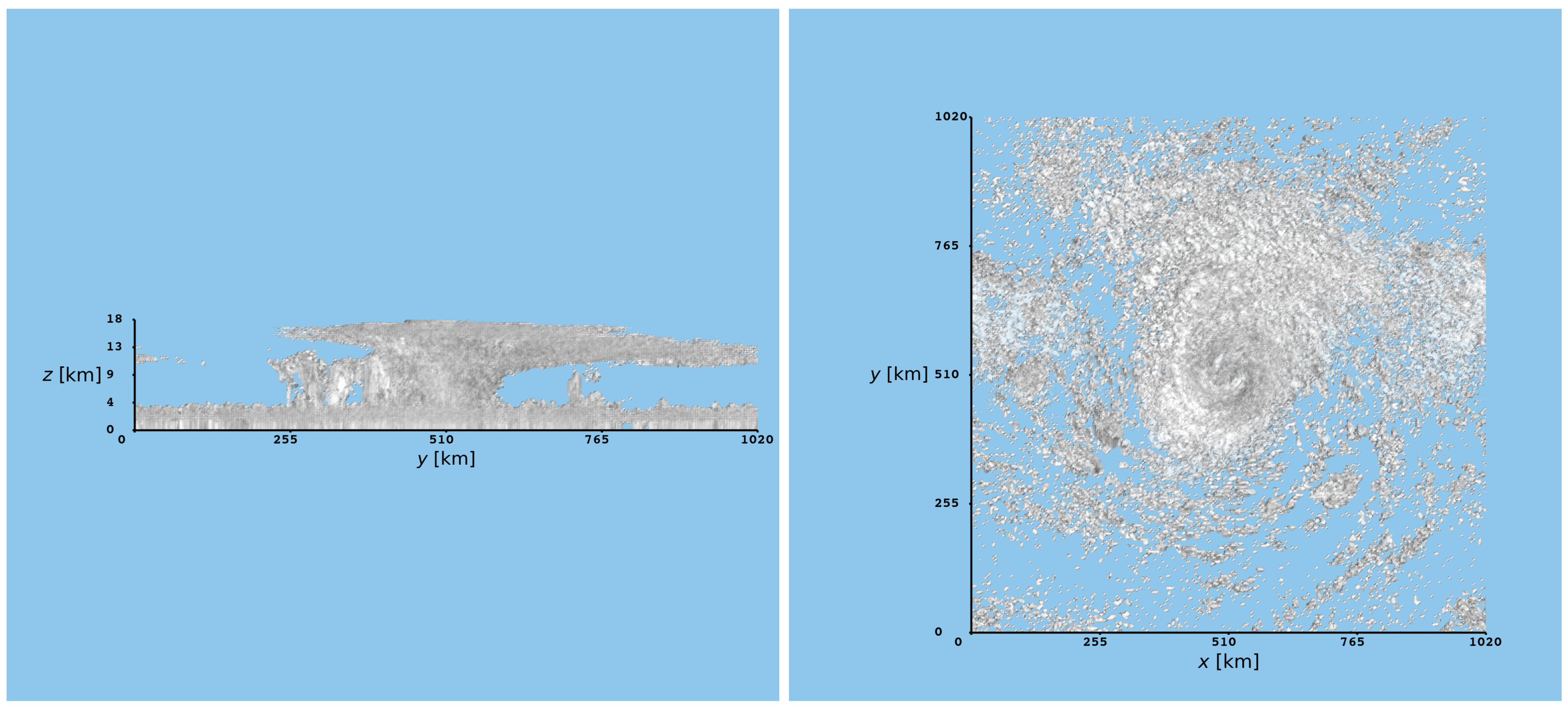



Figure 2. Snapshots of the mature cyclone in its highest intensity showing the cloud water mixing ratio. Range between $10^{-7}$ and $10^{-3}$ kg/kg.

## 4. Potential intensity evolution

In a similar simulation setup, Polesello et al. [5] showed that upper tropospheric warming is responsible for the de-intensification of the cyclone. In the present simulations, we confirm this finding with Fig. 3 which shows that the domain horizontal mean moist static energy is particularly increasing above 10 km after the cyclogenesis at day 20 for the simulation with $T_s$=300 K. A similar result is observed in all other simulations as well. In our study, the outflow temperature is taken at the equilibrium level EL which is computed assuming an idealized parcel ascent, following the thermodynamic equations of SAM.

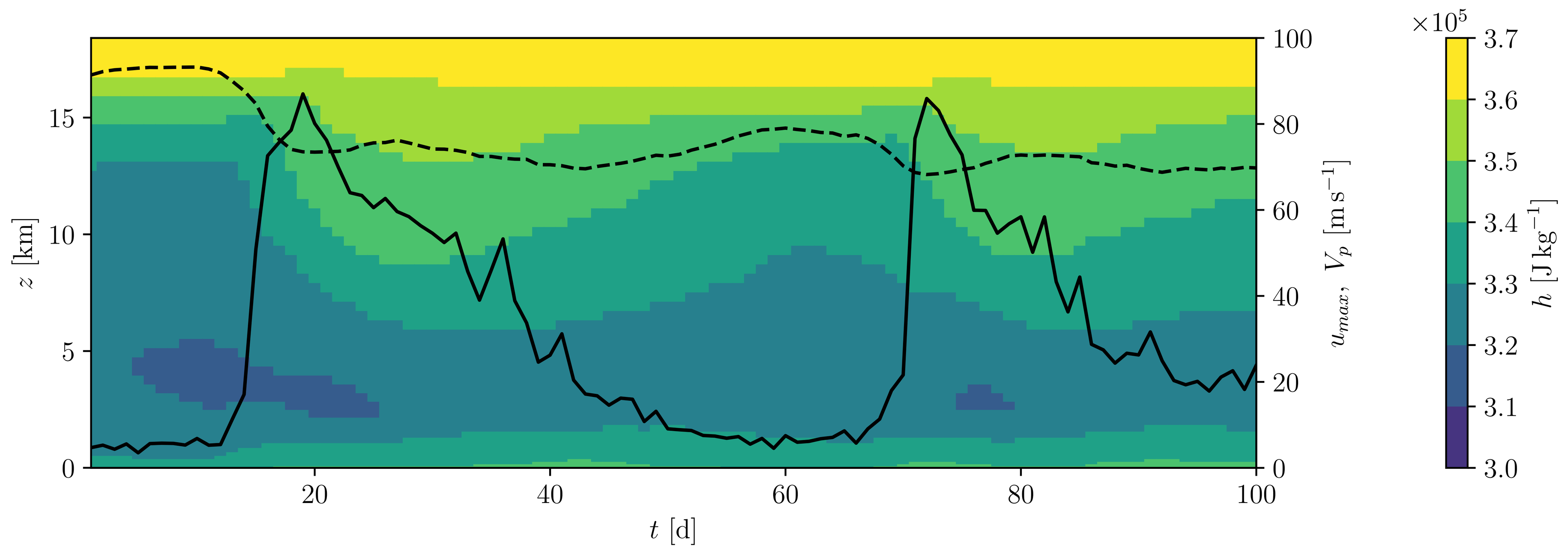



Figure 3. Hovmöller plot of the horizontal mean moist static energy $h$ together with the maximum velocity of the cyclone $u_{max}$ (full) and the potential intensity $V_p$ defined with a domain averaged outflow temperature at 18km (dashed).

## 5. Potential intensity and outflow temperature

In order to isolate the effect of temporal changes of the outflow temperature on the potential intensity, we fix the enthalpy disequilibrium terms in (1) at the initial time step such that

$$V_{p,T_0}^2 = \frac{c_k}{c_d}(k_s^* - k_1)|_{t=0}\frac{T_s - T_0}{T_s} \quad (4)$$

Fig. 4 shows consistent results across all simulations, where $V_{p,T_0}$ closely follows the maximum observed velocity after peak intensification and subsequent decay phases. However, when the upper level warming subsides, $V_{p,T_0}$ returns to pre-cyclone values.

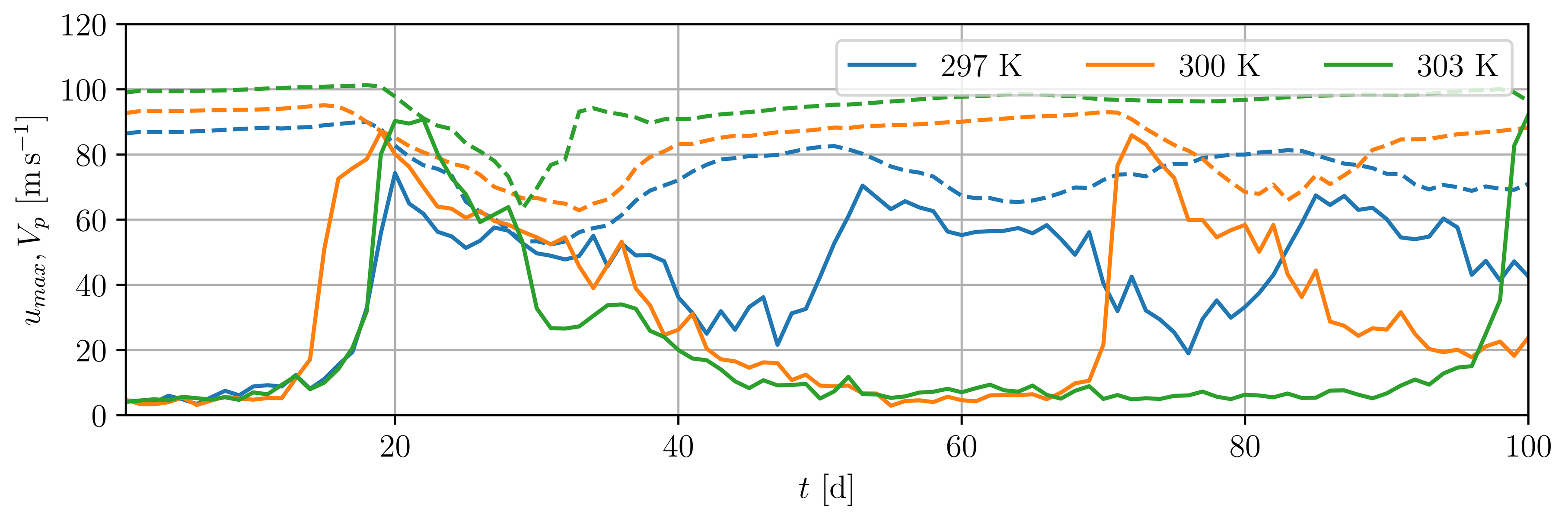



Figure 4. Evolution of the potential intensity considering only temporal fluctuations in the outflow temperature $V_{p,T_0}$ (dashed) and maximum observed velocity $u_{max}$ (solid) for each simulation following (4).

## 6. Potential intensity and enthalpy disequilibrium

Next, we consider changes in the potential intensity arising from the actual latent heat released into the system. For this purpose, we use the precipitation over the cyclone $P_{cycl}$ as a proxy and furthermore fix $T_0$ to the first time step. The area that the cyclone encloses is defined by the radius of 17 ms$^{-1}$ winds. This essentially modifies (1) to

$$V_{p,k}^2 = \frac{c_k}{c_d}\frac{T_s - T_0}{T_s}\bigg|_{t=0}(k_s^* - k_1)\frac{P_{cycl}}{S+E}. \quad (5)$$

Fig. 5 shows a very close match between $u_{max}$ and $V_{p,k}$ and also suggests that it is possible to infer the intensity of the cyclone without accounting for time variations of $T_0$.

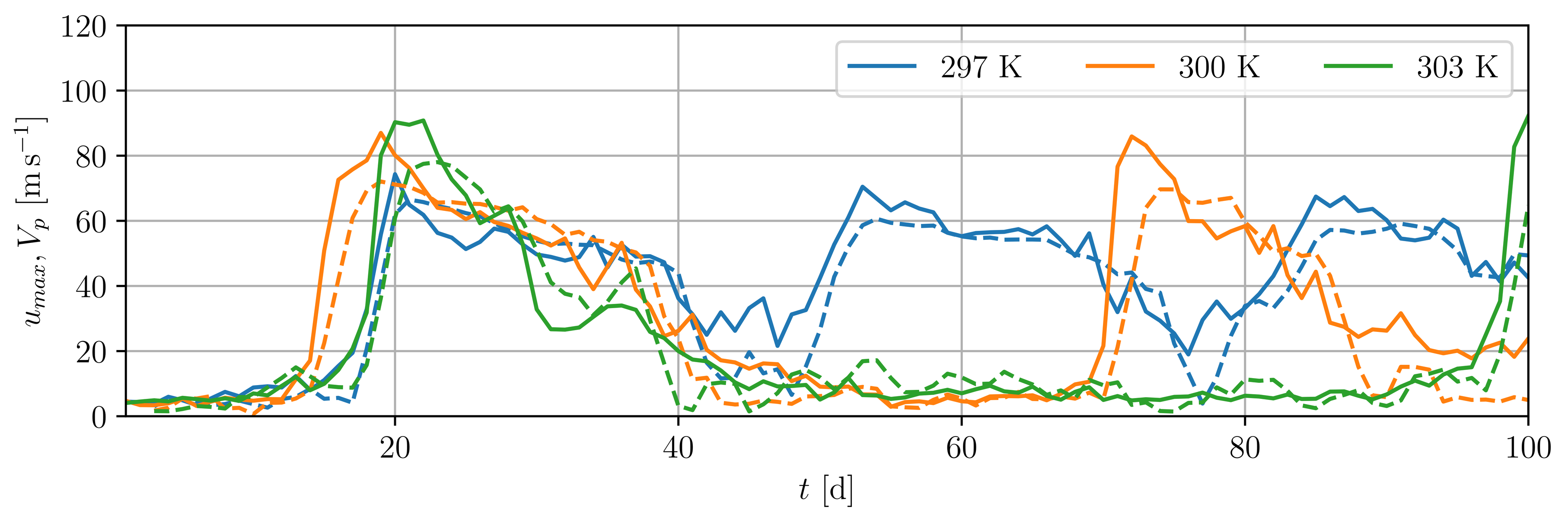



Figure 5. Same as Fig. 4, but with $V_{p,k}$ from (5).

## 7. Conclusion

- Upper level warming reduces the intensity of the cyclone in the peak and early decay phases and we can account for it in evolution of potential intensity
- By measuring the precipitation over the cyclone, we can derive a modified potential intensity of the cyclone which closely follows its maximum observed velocity even when temporal variations of the outflow temperature are neglected
- Future work: apply the same analysis in more realistic, larger domain simulations

## References

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