INTENSIFICATION MECHANISMS OF TROPICAL CYCLONES

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1. WISHE theory of tropical cyclone intensification

- The main source of energy of a tropical cyclone are sea-air fluxes of energy (latent and sensible), that are proportional to surface wind speed
- Positive feedback between increasing wind and fluxes is fundamental for tropical cyclone intensification
- Balance of energy fluxes and energy dissipation in the boundary layer leads to the establishment of a steady state at the so called **Potential Intensity** (PI) [1][2]

$$V_{PI}^2 \approx \frac{C_k}{C_D}\frac{T_s - T_0}{T_0}(k_0^* - k)$$

$$\Downarrow$$

- PI depends on troposphere boundary conditions only (T_0 tropopause temperature, T_s surface temperature, $(k_0^* - k)$ thermodynamical (thermal+chemical) disequilibrium between the ocean and surface air)
- Simple treatment of convection (atmosphere assumed neutral to moist convection), with CAPE dynamics considered not fundamental for tropical cyclone intensification. [3]

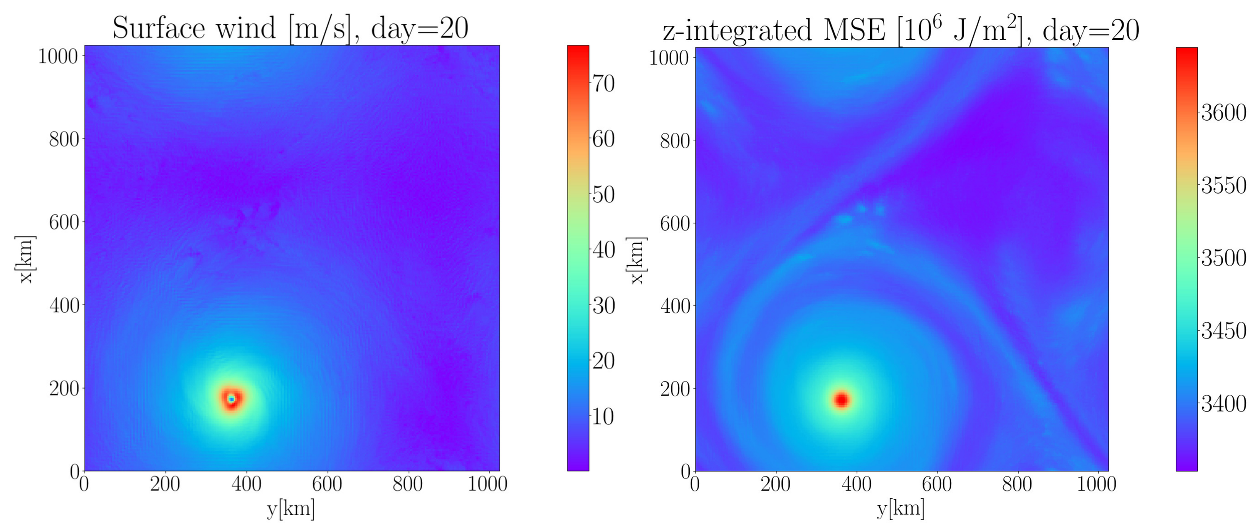
2. Merging WISHE and convection

- The main goal of the research was the characterization of convective dynamics inside a tropical cyclone, especially its mutual dependence on the atmospheric properties along the air column, through the analysis of CAPE accumulation and consumption: indeed any possible impact of this complex dynamics over evolution of a tropical cyclone would not be considered in a purely WISHE-based framework.
- In addition, we also wanted to test the hypothesis that WISHE feedback is fundamental for tropical cyclone intensification, or whether radiative feedbacks alone could lead to the development of a mature storm
- In summary, we wanted to include convection in the WISHE framework, to understand the relative importance of each of all along their positive and negative feedbacks on the intensity evolution of a tropical cyclone.

3. The experimental setup

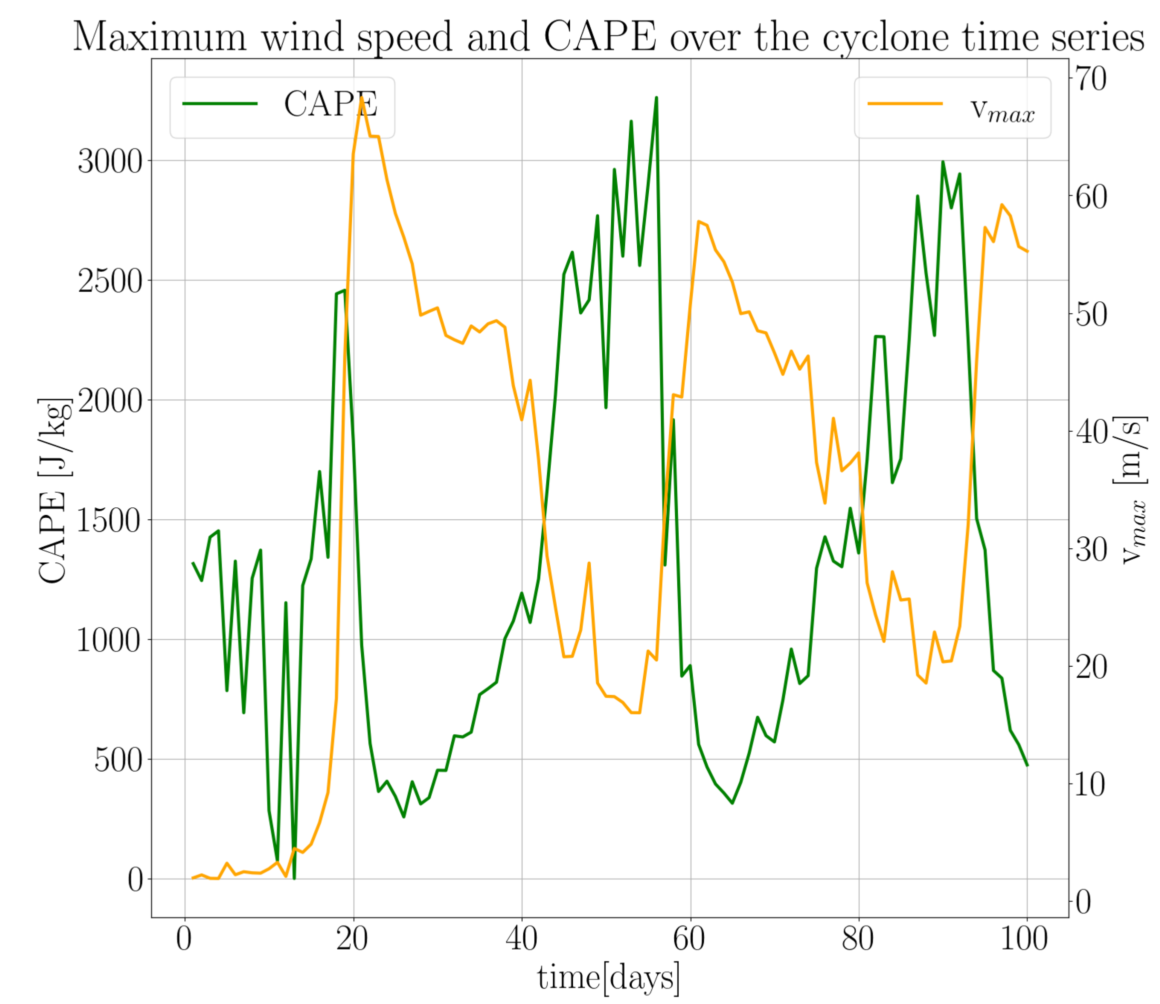
To investigate the subject, we performed simulations using the high-resolution, cloud-resolving model System for Atmosphere Modelling (SAM, [4]), that allows to explicitly solve the convective motion and to characterize its feedbacks on the cyclone intensity.

- 256 $\times$256 km$^2\times$27 km domain over a ocean at fixed and uniform SST=300K, 100 days of run, horizontal resolution of 4 km
- f=10^{-4} s^{-1} to have small cyclones (following [5])
- Control (CTRL) run and noWISHE (WISHE effect deactivated by homogenizing the wind speed entering the calculation of surface fluxes)



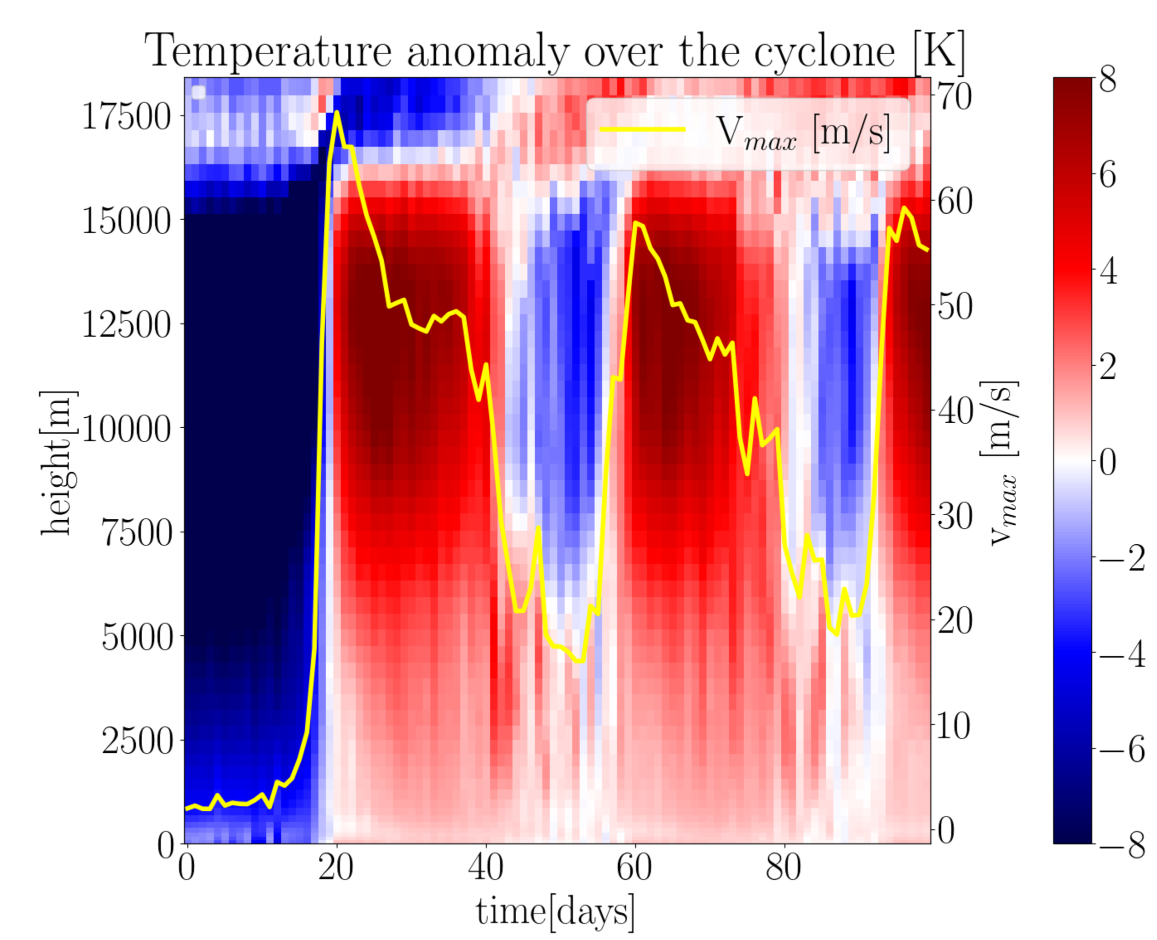
4. Control run: the oscillating intensity

Looking at the results of the CTRL run, both the maximum surface wind speed and CAPE show oscillating times series, with a phase difference between each other: quick intensification phases correspond to CAPE consumption ones, and decay phases to CAPE buildup, with peak intensity lower than the Potential Intensity predicted by WISHE theory for our boundary conditions. High initial CAPE triggers convection, that exports air aloft, reducing sea level pressure and driving thus the surface intensification.



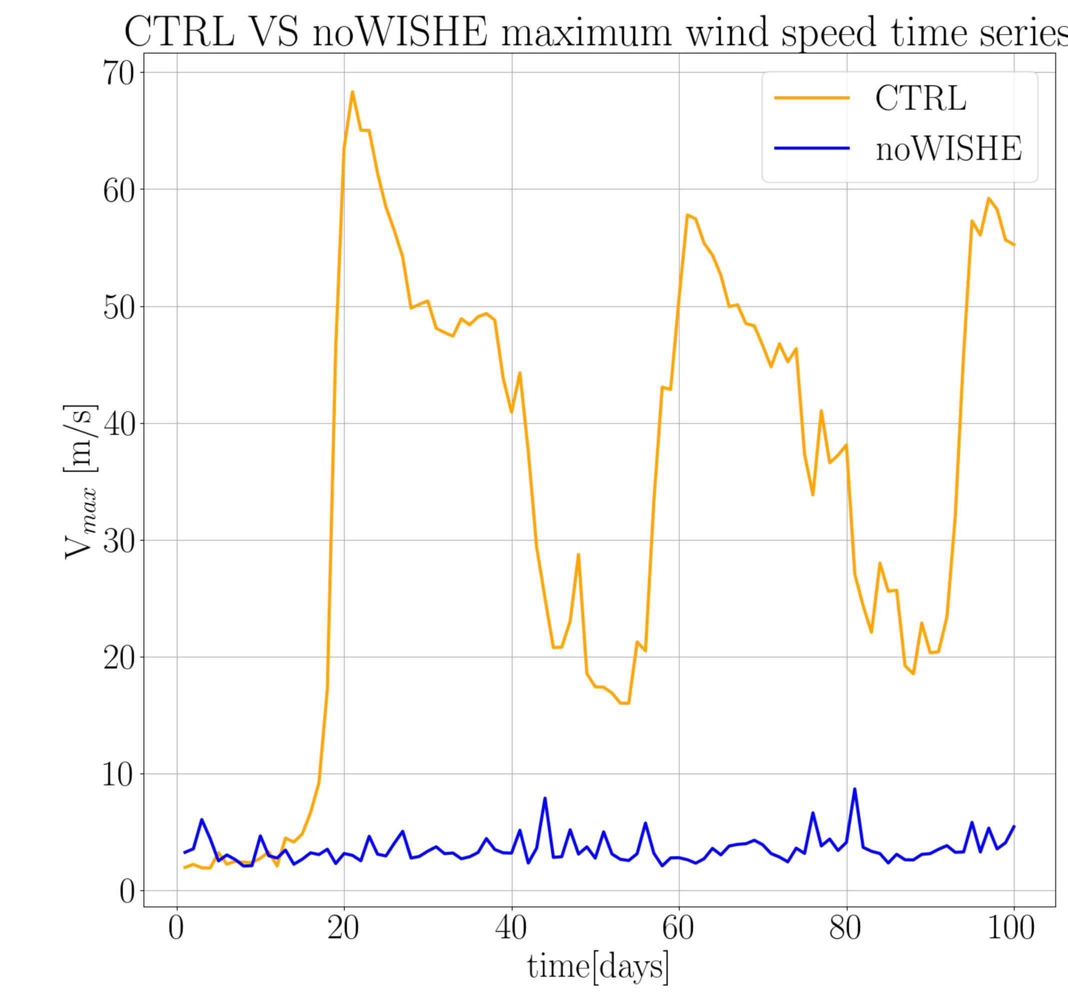
5. Upper level warming and cooling

The origin of CAPE oscillating evolution were traced back to a temperature oscillation occurring in the upper troposphere above the cyclone: the cyclone intensifies quickly, with WISHE increasing surface air buoyancy, but then convective trasnsport and radiation absorption by clouds increase the buoyancy of upper level air, stabilizing the atmosphere and reducing CAPE. When the cyclone reaches its minimum intensity, its upper troposphere cools down through entrainment from the surroundings: this leads to an increase in CAPE, that triggers then a new intensification.



6. noWISHE run

The noWISHE run showed no cyclogenesis at all, with maximum wind speed never even reaching the 17 ms^{-1} threshold of tropical storms, proving the crucial importance of WISHE feedback for TC intensification.



7. Conclusions and possible further work

- The intensity evolution of the simulated tropical cyclones differ significantly from the predictions of simple WISHE-based models.
- CAPE-intensity mutual interaction seems to be the origin: upper level warming (convective and radiative) reduces CAPE and leads to cyclone decay, then upper level cooling through entrainment increases it and triggers a new intensification
- WISHE feedback was confirmed to be fundamental for tropical cyclone intensification
- Further works may try to reproduce the same experiments on larger domains (to avoid to be mislead by effects given by the doubly periodicity of the domain) or to look at cloud resolving realistic simulations ([6]) to possibly identify the same intensity pattern.

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