Intensity oscillations in tropical cyclones: surface vs mid and upper tropospheric processes

Andrea Polesello[1,2], Giousef Alexandros Charinti[1], Agostino Niyonkuru Meroni[2], Caroline Jane Muller[1], Claudia Pasquero[2]

1) [1]Institute of Science and Technology Austria, Klosteneuburg, Austria
2) [2]Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy

EGU general assembly 2025

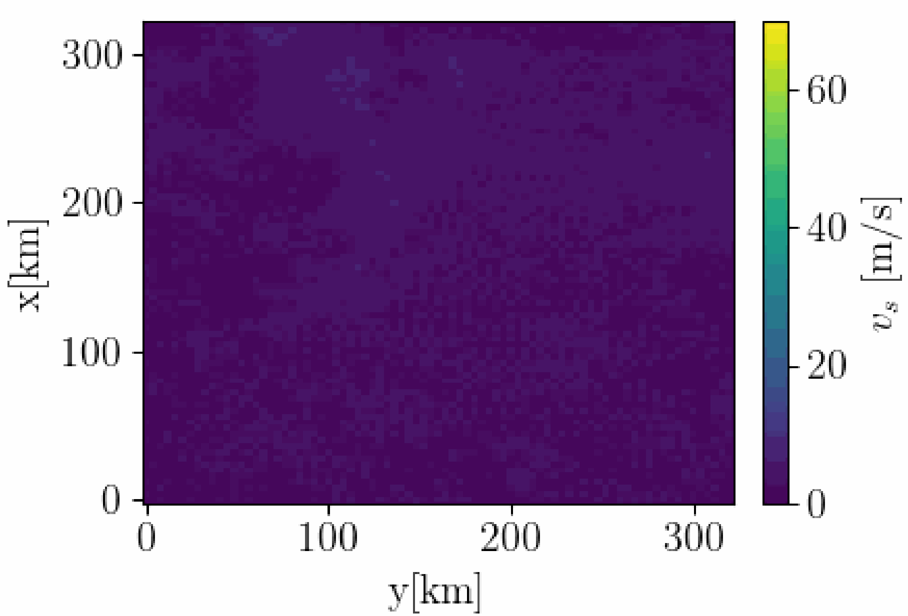
Tropical meteorology and tropical cyclones session, 28-04-2025

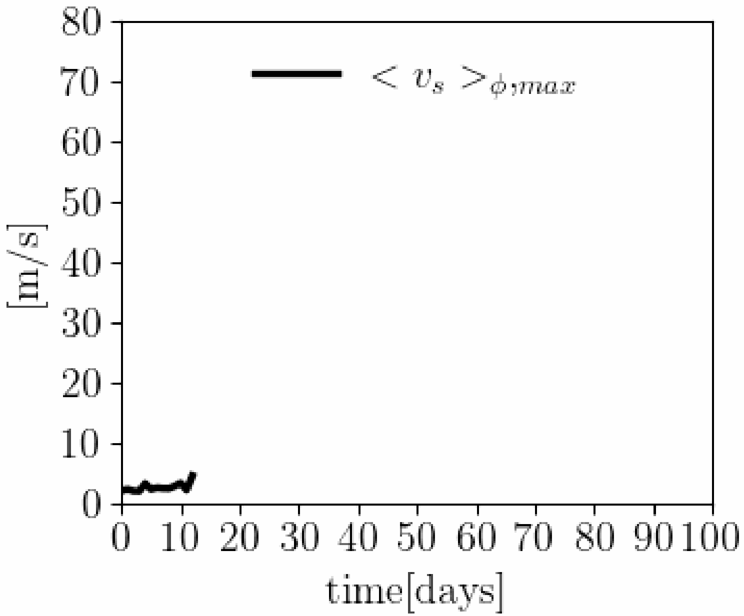
Tropical cyclone intensity: an overview

- Emanuel's (1986) potential intensity: $v_{PI}^2 \propto \frac{(T_{surf} - T_0)}{T_0}$
- Rotating radiative-convective equilibrium simulations (Wing et al. 2016, Muller & Romps 2018) showed non-monotonic/oscillating intensity evolution.

Tropical cyclone intensity: an overview

- Emanuel's (1986) potential intensity: $$v_{PI}^2 \propto \frac{(T_{surf} - T_0)}{T_0}$$
- Rotating radiative-convective equilibrium simulations (Wing et al. 2016, Muller & Romps 2018) showed non-monotonic/oscillating intensity evolution.





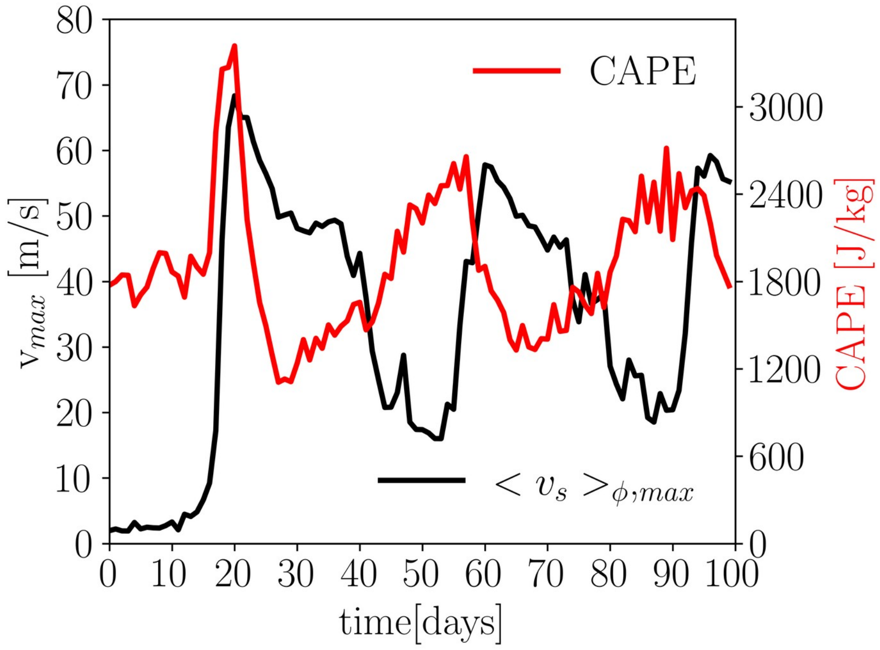
Research questions and simulation setup

- Which are the most relevant processes in shaping the oscillating intensity evolution of tropical cyclones in RCE?
- Are upper-level processes more important than low-level dynamics?
- What's the role of the interactive radiation feedback?

- System for Atmospheric Modelling (SAM,cloud resolving)
- 1024 x 1024 x 27 km doubly-periodic domain
- SST=300 K uniform and not interactive
- $\Delta x = \Delta y = 4$ km
- RCE with $f = 10^{-4}$ s
- CTRL run with interactive radiation

CAPE-wind oscillations

- Clear intensity oscillations during CTRL run
- Undiluted, pseudo-adiabatic CAPE (computed between two angular momentum surfaces) oscillates out of phase with the wind



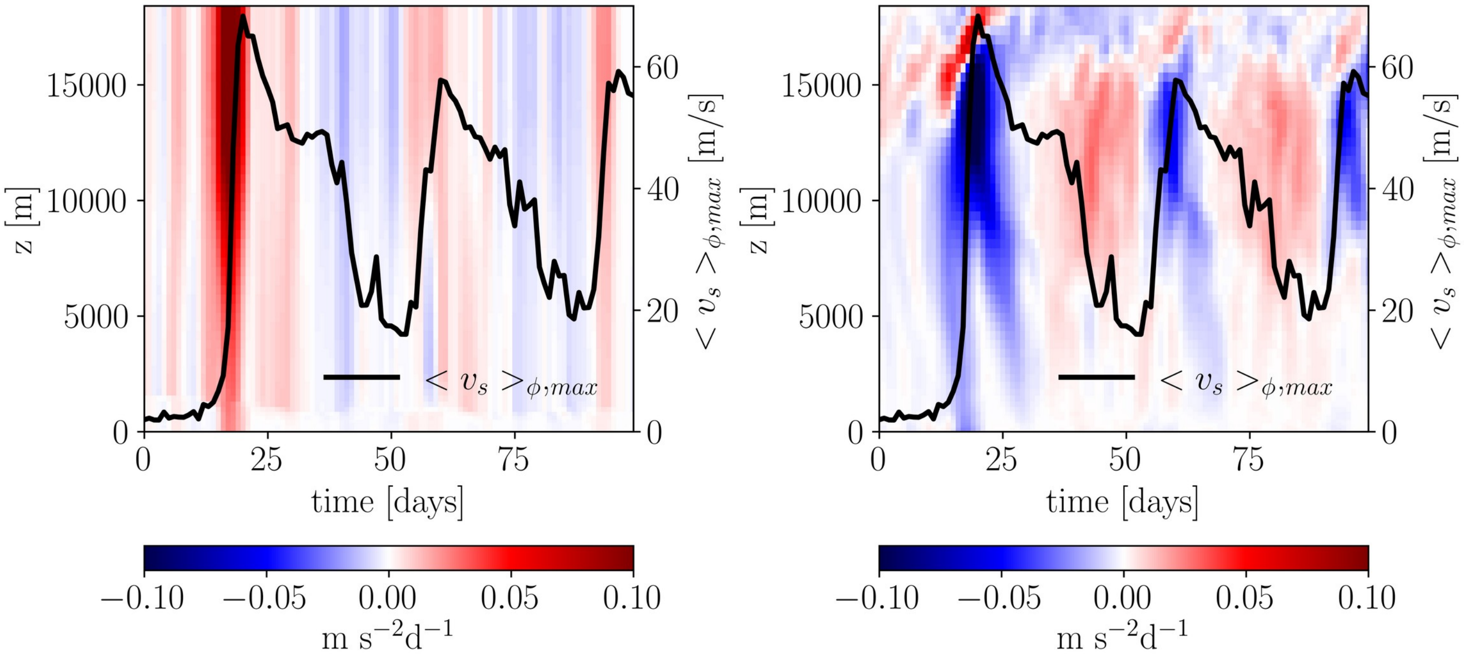
Parcel vs environment

- Buoyancy variations in CTRL decomposed into parcel and environmental contributions

$$\Delta b = g\Delta \left(\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right) = g\frac{\Delta T_{v,parcel}}{T_{v,env}} - g\Delta T_{v,env}\frac{T_{v,parcel}}{T_{v,env}^2} \equiv \Delta b_{parcel} + \Delta b_{env}$$

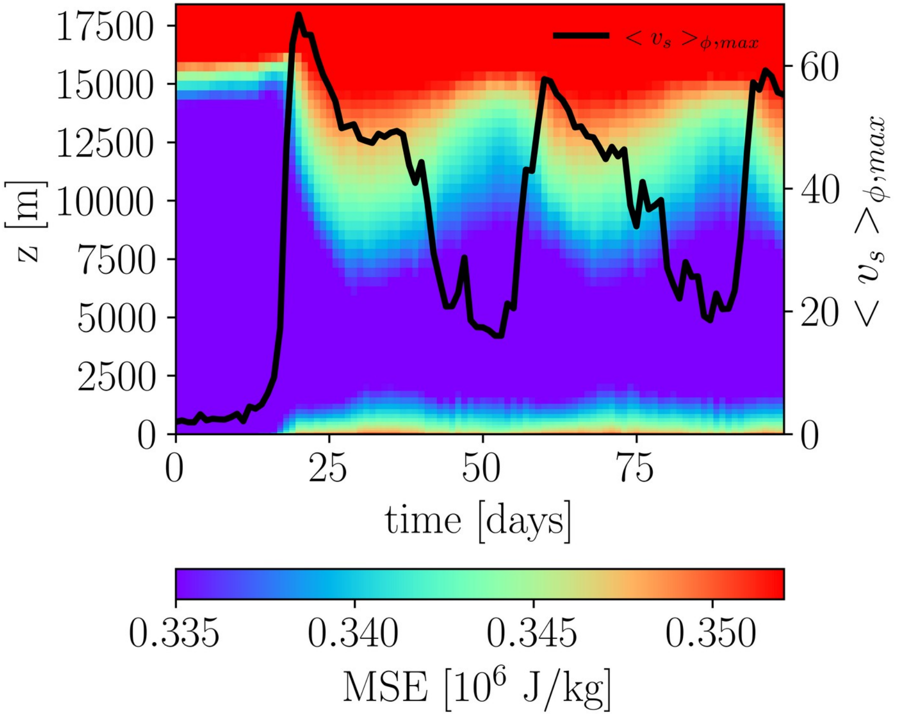
Parcel vs environment

$$\Delta b_{parcel} = g \frac{\Delta T_{v,parcel}}{T_{v,env}} \qquad \Delta b_{env} = -g \Delta T_{v,env} \frac{T_{v,parcel}}{T_{v,env}^2}$$



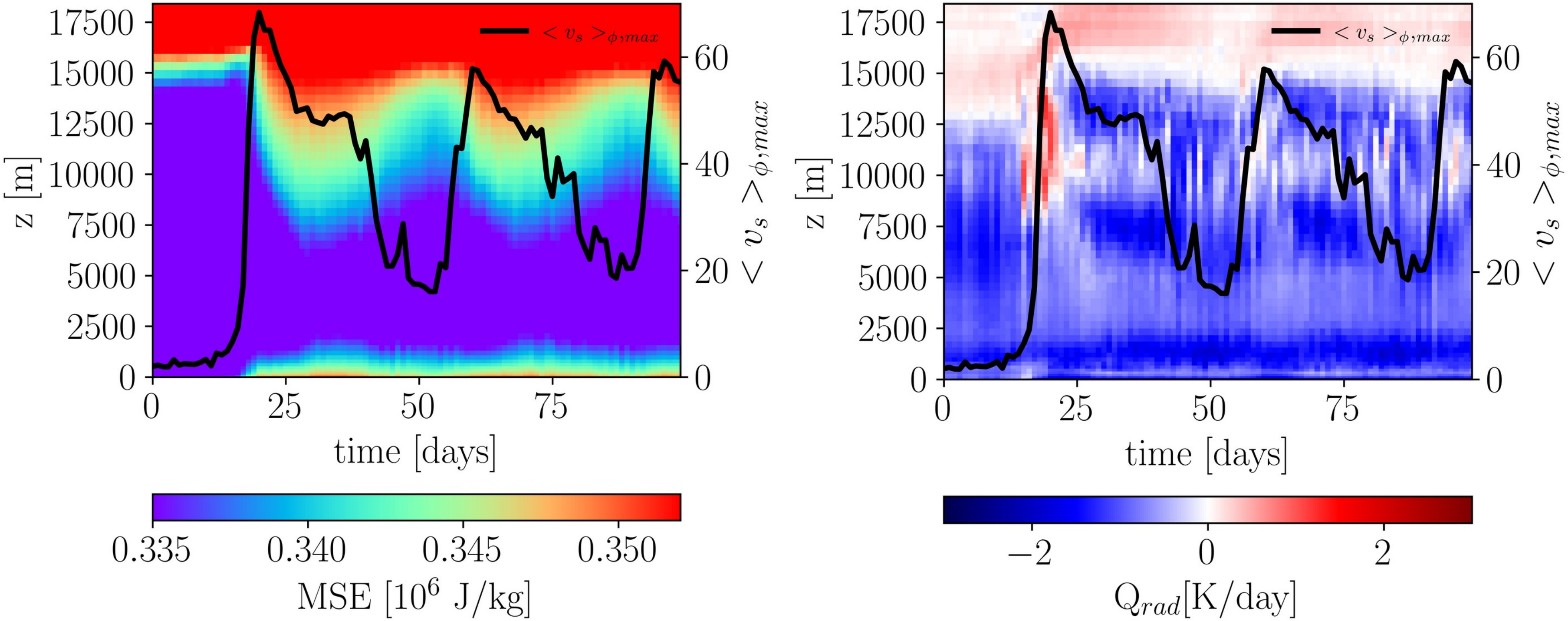
- Buoyancy variations mostly due to environment
- Upper level warming and cooling phases

Diabatic upper level warming

- $MSE_{upper} > MSE_{BL}$ → not only convective heating
-
- 

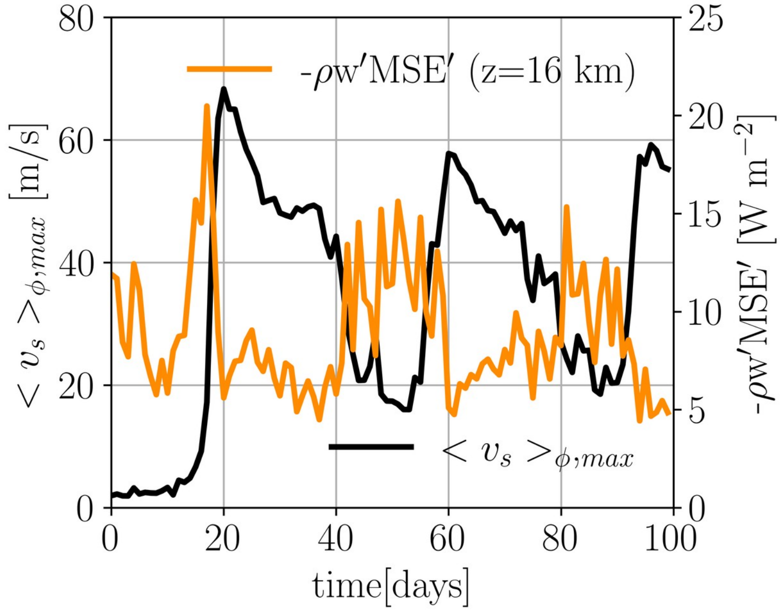
Diabatic upper level warming

- $MSE_{upper} > MSE_{BL}$ → not only convective heating
- No clear signal of strong radiative heating
-



Stratospheric MSE transport

- Net MSE downward transport from the stratosphere during the intensification phases
- Convection overshoots into the stratosphere, leading to mixing with high-MSE stratospheric air



Upper level cooling

- Upper level cooling destabilizes the troposphere before re-intensification
- What if radiation was not interactive?

Upper level cooling

- Upper level cooling destabilizes the troposphere before re-intensification
- What if radiation was not interactive?

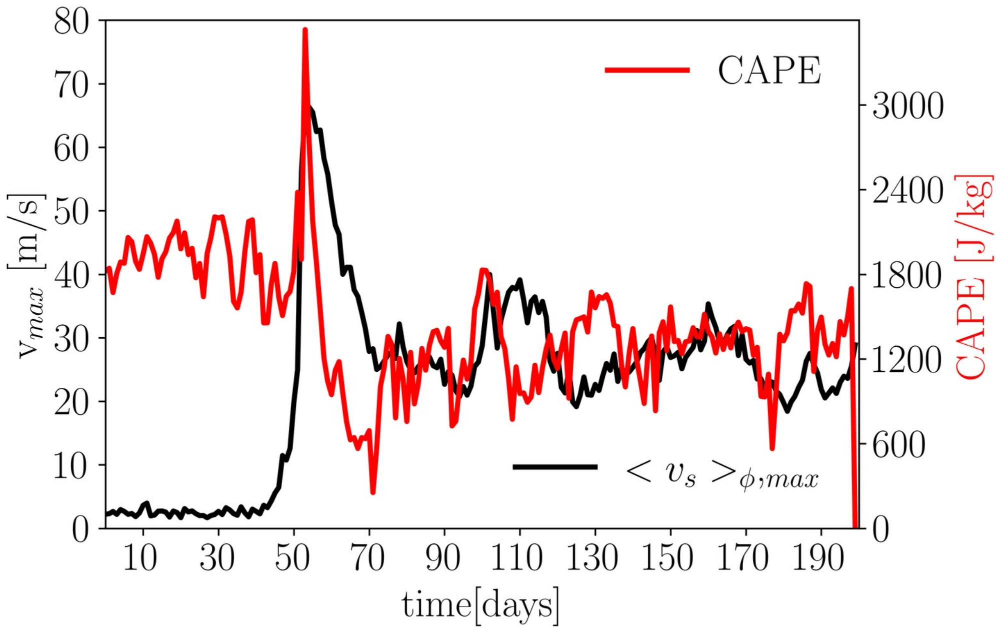
FIXRAD simulation with imposed Q_{rad} = Q_{rad} (z), from non-rotating RCE simulation

Upper level cooling

- Upper level cooling destabilizes the troposphere before re-intensification

- What if radiation was not interactive?

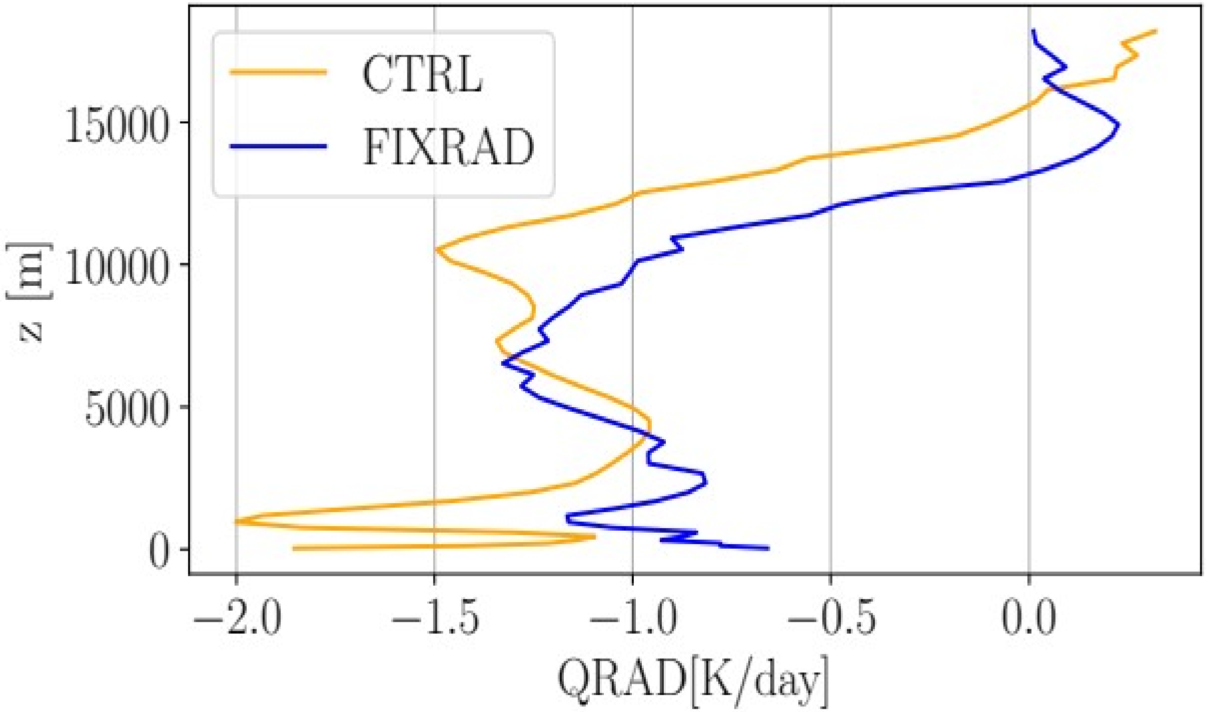
FIXRAD simulation with imposed $Q_{rad} = Q_{rad}(z)$, from non-rotating RCE simulation



Intensity and CAPE oscillations are damped!

Weaker cooling

Radiative cooling: CTRL vs FIXRAD



- Q_{rad} (domain mean) during weak phase of the CTRL cyclone (days 40-55) much much stronger than in FIXRAD

- Sharp difference at z >10 km

Conclusions

- Intensity oscillations of tropical cyclones in cloud-resolving, rotating RCE simulations were linked to an upper level warming-cooling cycle
- Warming (including mixing with the stratosphere) stabilizes the atmosphere and leads to intensity decay
- Interactive radiation feedback fundamental to generate strong radiative cooling that destabilizes the troposphere again, before a new intensification

Thank you for your attention and...

...check out our paper and ...

- https://doi.org/10.1029/2024MS004613

JAMES | Journal of Advances in Modeling Earth Systems®

Research Article | Open Access

Intensity Oscillations of Tropical Cyclones: Surface Versus Mid and Upper Tropospheric Processes

Andrea Polesello, Giousef Alexandros Charinti, Agostino Niyonkuru Meroni, Caroline Jane Muller, Claudia Pasquero

First published: 21 April 2025 | https://doi.org/10.1029/2024MS004613

SECTIONS PDF TOOLS SHARE

Abstract

Some of the classical models of tropical cyclone intensification predict tropical cyclones to intensify up to a steady intensity, which depends on surface fluxes only, without any relevant role played by convective motions in the troposphere, typically assumed to have a moist adiabatic lapse rate. Simulations performed using the non-hydrostatic, high-resolution model System for Atmosphere Modeling in idealized settings (rotating radiative-convective equilibrium on a doubly periodic domain) show early intensification consistent with these theoretical expectations, but different intensity evolution, with the cyclone undergoing an oscillation in wind speed. This oscillation can be linked to feedbacks between the cyclone intensity and air buoyancy: convective heating, radiative heating, and mixing with warm low stratospheric air warm the mid and upper troposphere of the cyclone stabilizing the air column and thus reducing its intensity. After the intensity decay phase, mid and upper tropospheric cooling, mostly through cold advection from the surroundings, cooled by radiation, rebuilds Convective Available Potential Energy, that peaks just before a new intensification phase. These idealized simulations thus highlight the potentially important interactions between a tropical cyclone, its environment and radiation.

...Alex's poster (tomorrow!)

Poster | Tuesday, 29 Apr, 08:30–10:15 (CEST), Display time Tuesday, 29 Apr, 08:30–12:30 Hall X5, X5.38

Upper level processes in simple models for tropical cyclones in high resolution simulations

Giousef Alexandros Charinti[1], Andrea Polesello[1], Caroline Muller[1], Andrea Davin[2], and Claudia Pasquero[2]
[1]Institute of Science and Technology Austria, Klosterneuburg, Austria
[2]University of Milan-Bicocca, Milan, Italy

Estimating the intensity of tropical cyclones has been a critical research topic in the field. Theoretical models such as the potential intensity (PI), first introduced by Emanuel 1986 [1], provide an upper bound for the intensity a tropical cyclone can achieve based on pre-storm conditions. However, PI and other similar models are based on idealized settings that may not always match real-world conditions, such as assuming a neutral atmosphere to moist convection. Using simulations from the high resolution cloud resolving model SAM [3] in rotating radiative-convective equilibrium settings, we assess the validity of the idealizations of the PI theory. We find that upper level processes are responsible for the intensity oscillations of the tropical cyclone in the simulations, as confirmed by a recent study [5]. We further show that when accounting for the upper level processes, it is possible to modify PI such that it approximately follows the observed intensity evolution.

[1] K. A. Emanuel, J. Atmos. Sci. 43, 6 (1986).
[2] K. A. Emanuel et al., Annu. Rev. Earth Planet Sci. 31, 1 (2003).
[3] M. F. Khairoutdinov, D. A. Randall, J. Atmos. Sci. 60, 4 (2003).
[4] C. J. Muller, D. M. Romps, PNAS 115, 12 (2018).
[5] A. Polesello, G. A. Charinti, A. N. Meroni, C. J. Muller, C. Pasquero (submitted, 2025).
[6] A. A. Wing, K. A. Emanuel, J. Adv. Model. Earth Syst. 6, 1 (2014).

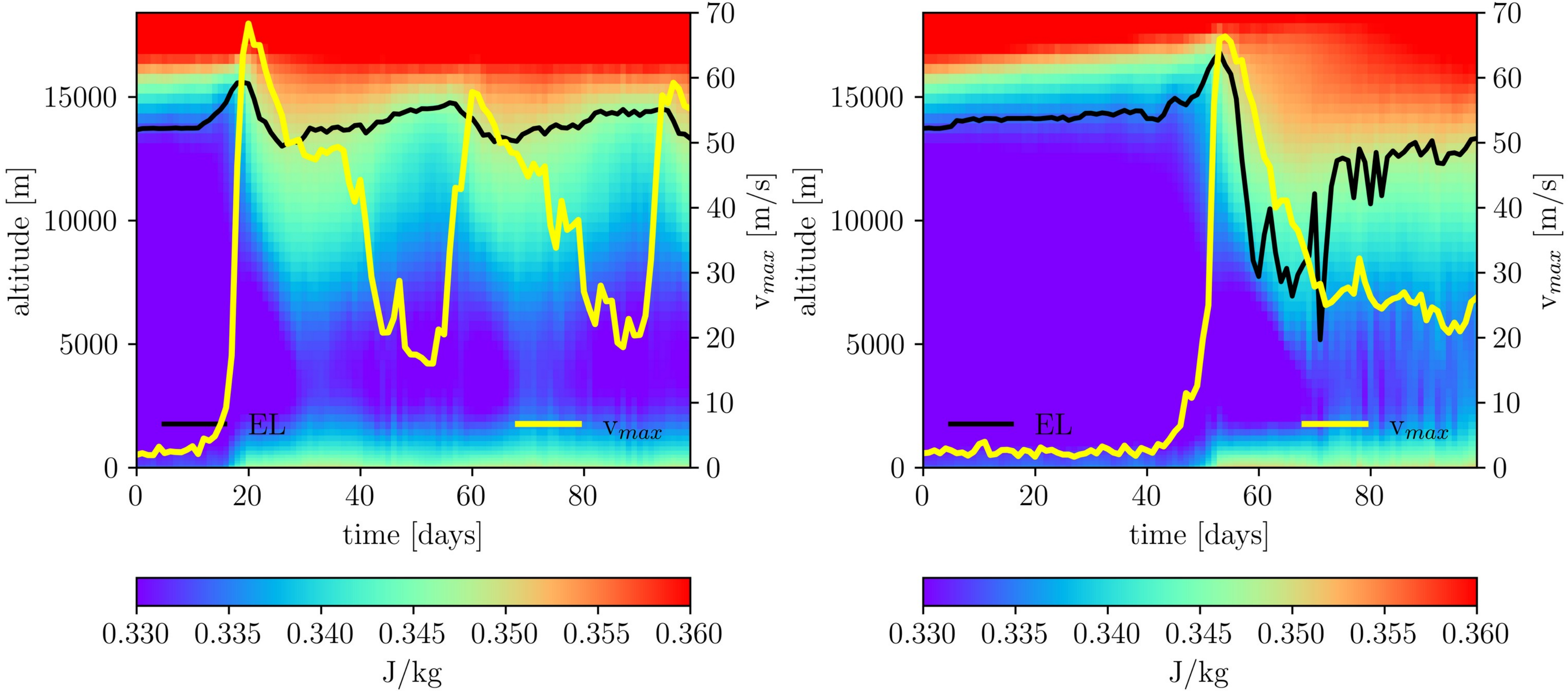
How to cite: Charinti, G. A., Polesello, A., Muller, C., Davin, A., and Pasquero, C.: Upper level processes in simple models for tropical cyclones in high resolution simulations, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-6646, https://doi.org/10.5194/egusphere-egu25-6646, 2025.

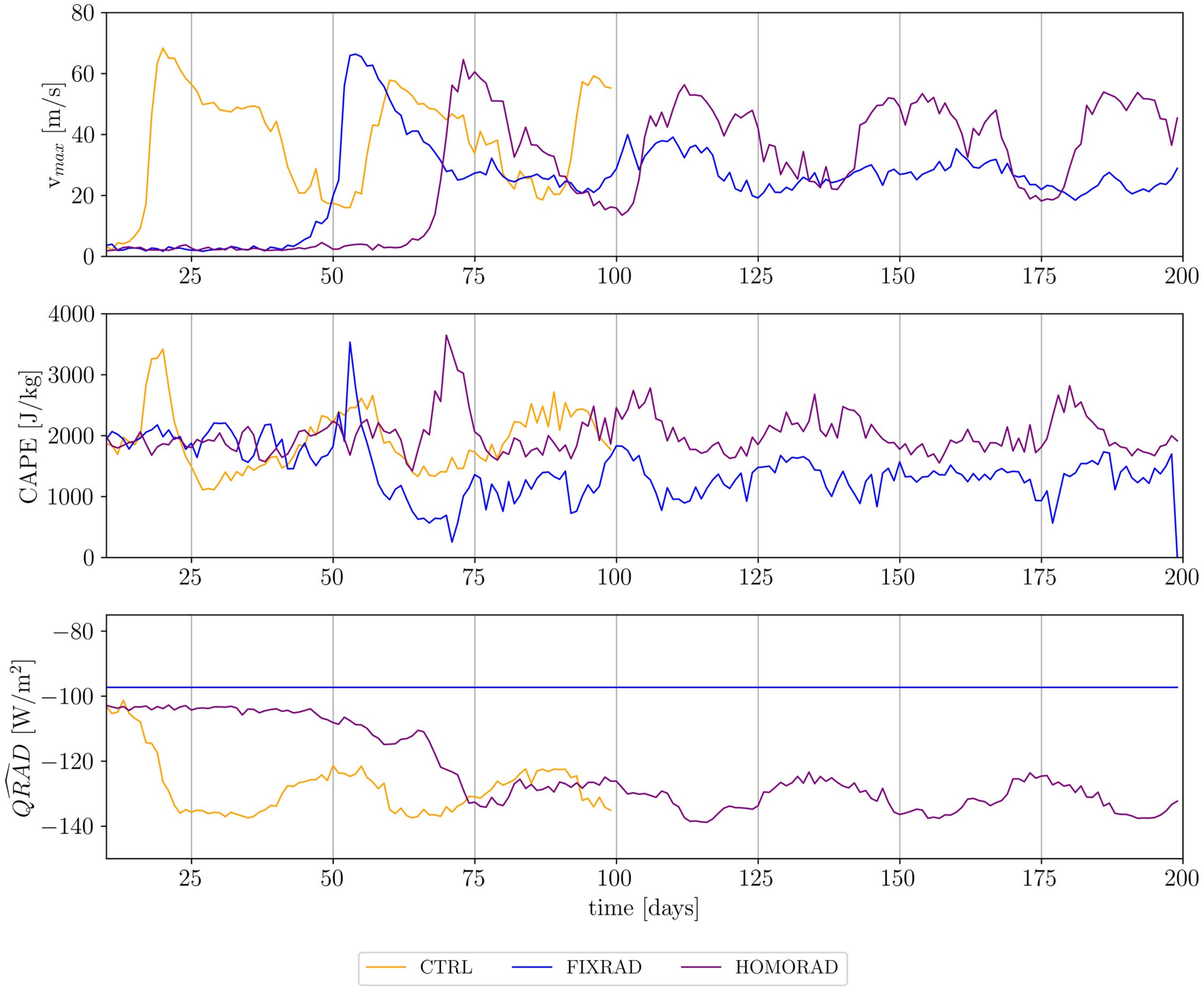
SUPPLEMENTARY SLIDES

REFERENCES

- Emanuel, K. A., 1986: An Air-Sea Interaction Theory for Tropical Cyclones. Part I: Steady-State Maintenance. J. Atmos. Sci., 43, 585–605, https://doi.org/10.1175/1520-0469(1986)043<0585:AASITF>2.0.CO;2.
- C.J. Muller, & D.M. Romps, Acceleration of tropical cyclogenesis by self-aggregation feedbacks, Proc. Natl. Acad. Sci. U.S.A. 115 (12) 2930-2935, https://doi.org/10.1073/pnas.1719967115 (2018).
- Wing, A. A., S. J. Camargo, and A. H. Sobel, 2016: Role of Radiative–Convective Feedbacks in Spontaneous Tropical Cyclogenesis in Idealized Numerical Simulations. J. Atmos. Sci., 73, 2633–2642, https://doi.org/10.1175/JAS-D-15-0380.1.

MSE CTRL vs FIXRAD





- HOMORAD: Q_{rad} interactive but horizontally homogenized
- Oscillations are there: Q_{rad} domain mean matters more than local Q_{rad} in the cyclone

Upper level cooling: CTRL vs FIXRAD