INTENSIFICATION OF TROPICAL CYCLONES

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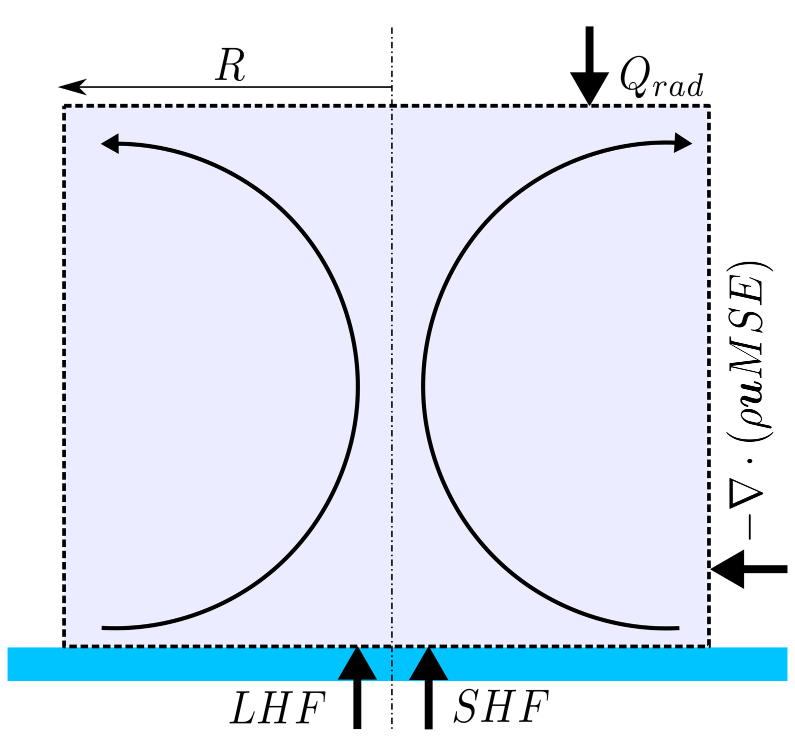
1. How are tropical cyclones intensified?

- 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].
- Here we investigate intensification and re-intensification of tropical cyclones in idealized simulations (radiative-convective equilibrium).

2. Basic equations

We consider a domain centered around the cyclone which extends up to a radius R over which we compute the energy budget of the cyclone. In this analysis, R corresponds to the radius of 34 kn (17.5 m s^{-1}) winds, also used by [2].



$MSE = c_pT + L_vq_v - L_iq_i$ Moist static energy
$LHF = c_pL_v\|\boldsymbol{u}_{air}\|(q_s(SST) - q_{air}))$ Latent heat flux
$SHF = \rho c_p\|\boldsymbol{u}_{air}\|(SST - T_{air})$ Sensible heat flux
Q_{rad} Radiative heating rate

T_{air} ... air temperature
SST ... sea surface temperature
$\boldsymbol{u}_{air}$ ... wind velocity at surface
q_v, q_i ... vapor/ice mixing ratio
q_s ... vapor mixing ratio at saturation
p ... specific heat capacity at constant pressure
ρ ... density
L_v, L_i ... latent heat of vaporization/fusion

Schematic of the terms entering the energy budget in the cyclone

The energy budget of the cyclone follows [3] and given by

$$\frac{DE}{Dt} = \frac{d(\rho MSE)}{dt} + \nabla \cdot (\rho \boldsymbol{u} MSE) - SHF - LHF - Q_{rad} = 0.$$

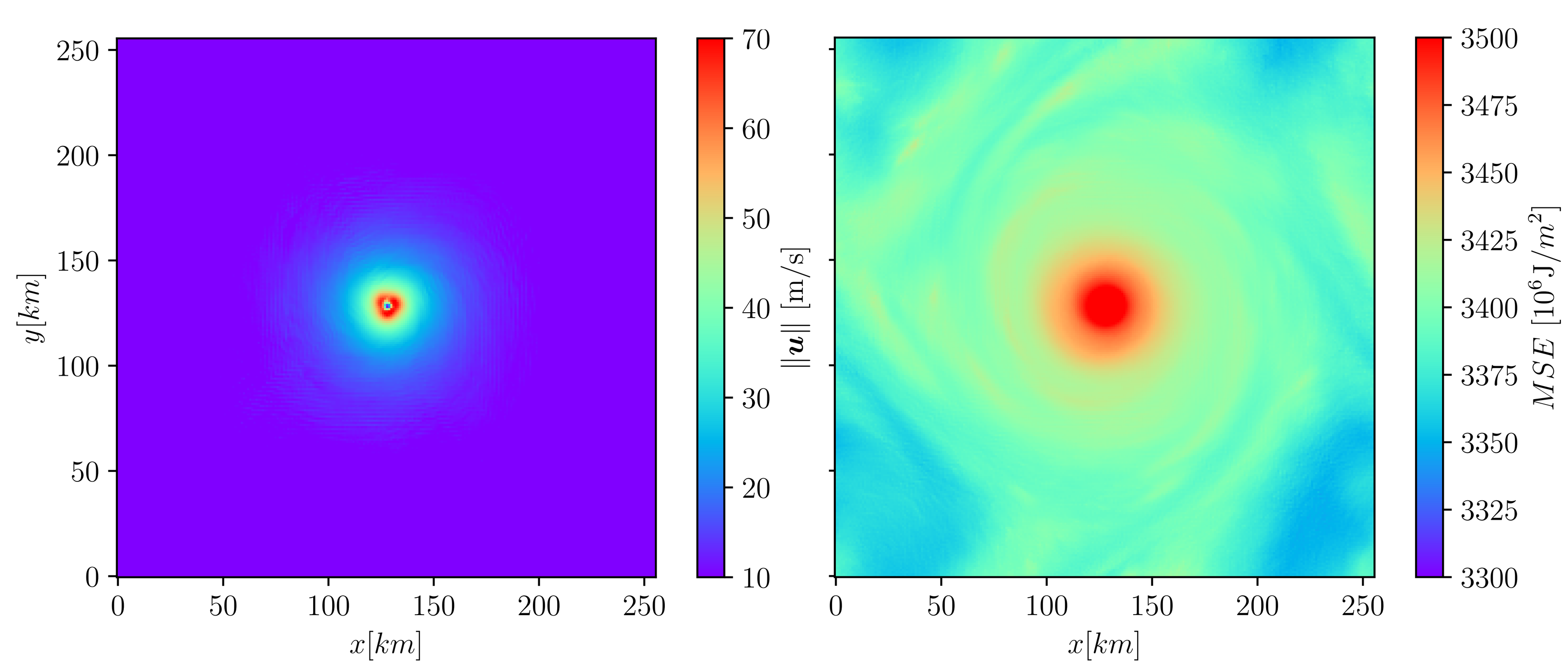
Within the same domain, we also computed the Convective Available Potential Energy (CAPE), which is an important diagnostic of atmospheric stability and can be defined as

$$CAPE = \int_{LFC}^{EL} \frac{T_{v,parcel} - T_{v,env}}{T_{v,env}}\, dz.$$

3. Experimental setup

The simulations are performed using the high-resolution, cloud-resolving model System for Atmosphere Modeling (SAM), [4], which allows to explicitly solve the convective motion and characterize its feedbacks on the cyclone intensity.

- 256 ×256 km^2×27 km domain over a ocean at fixed and uniform SST=300K, horizontal resolution of 4 km
- f=10^{-4} s^{-1} such that the cyclone's size is smaller than the domain size (following [5])
- Control (CTRL), homogenized radiation in space but variable in time (HOMORAD) and fixed radiation without time variations (FIXRAD) runs
- The time frame of the analysis is set between the start of cyclogenesis and the next 80 days, in order to compare the different runs.
- The center of the cyclone, R and the start of cyclogenesis are determined in an initial pre-processing of the simulation results.

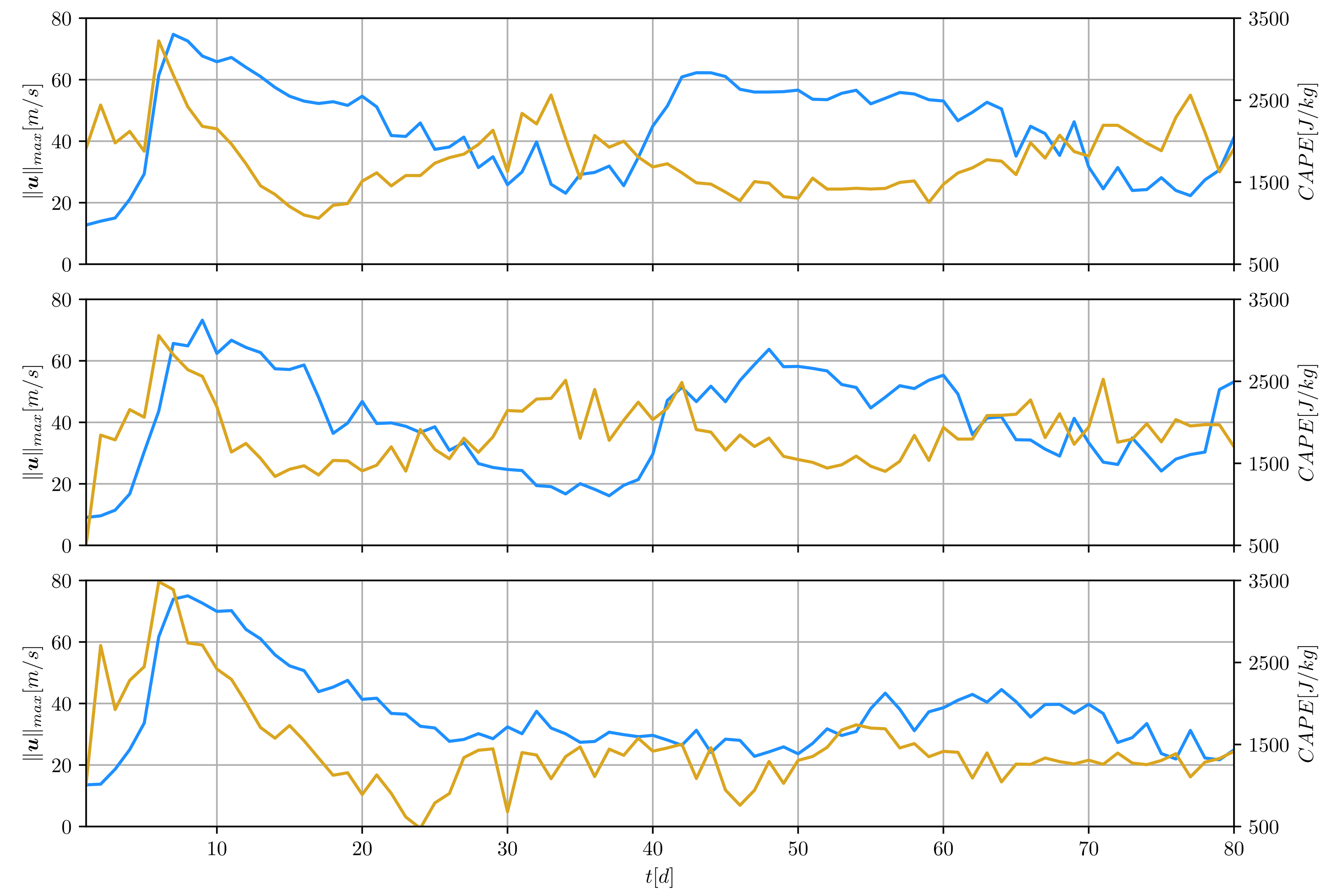


Snapshots of the mature cyclone in the CTRL run. The left panel shows surface wind speed highest in the eyewall region, and the right panel moist static energy highest in the eyewall and the eye.

4. Maximum surface wind velocity and CAPE

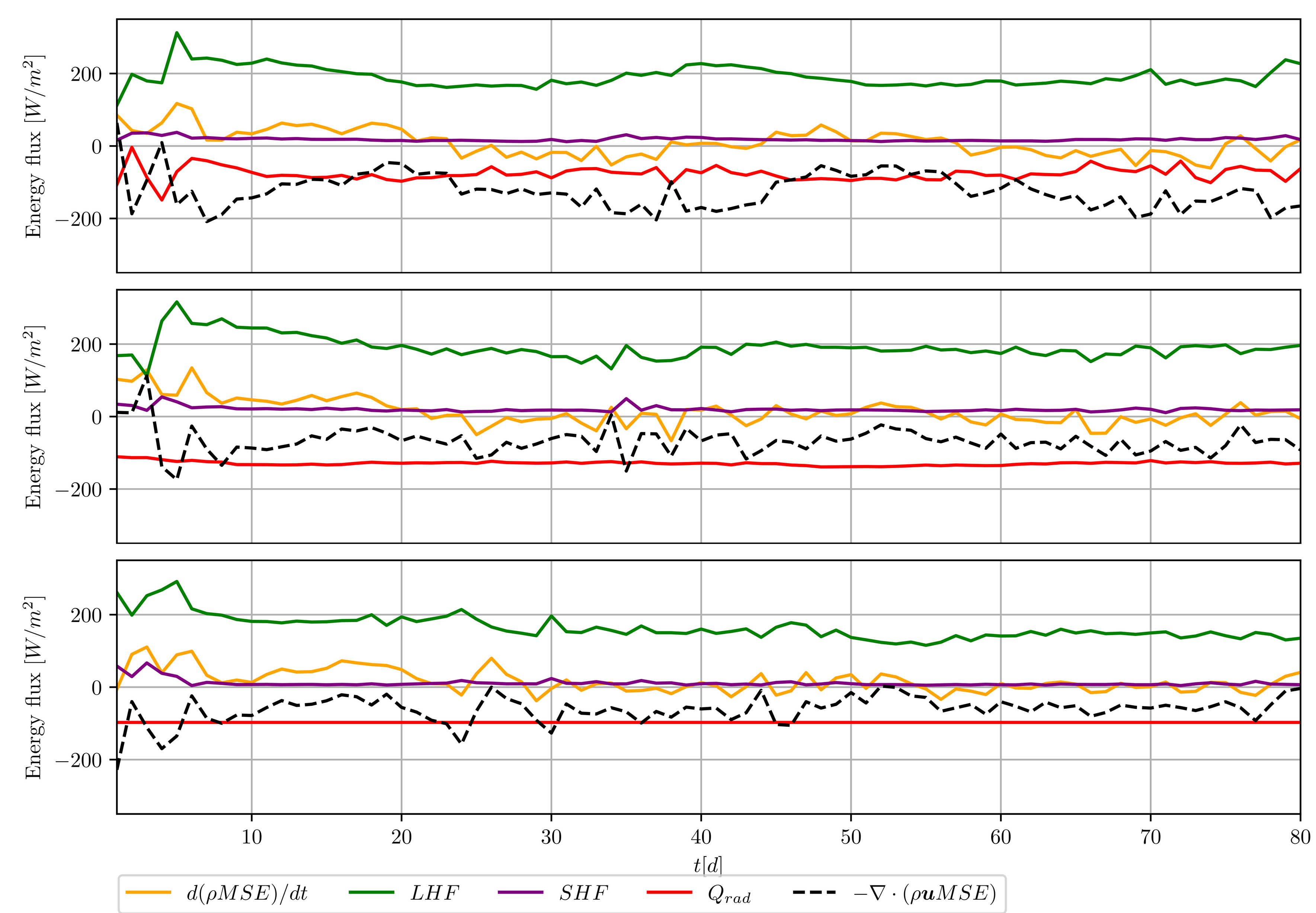
Cyclogenesis occurs the fastest in the CTRL run, followed by the HOMORAD and FIXRAD runs. In all runs, both the maximum surface wind velocity and CAPE show oscillations. An intensification phase corresponds to a decay phase in CAPE and vise versa. Peak phases of CAPE imply that the air becomes more buoyant, which reduces the sea level pressure and drives intensification. In the FIXRAD run, we observe no significant oscillations following cyclogenesis. These results show that the intensification phases of the cyclones are closely related to the oscillations in CAPE, and are sensitive to the time evolution of radiation. We now investigate further the physical origin of these oscillations in more detail, using an energy budget analysis.

Evolution of the maximum surface wind velocity (blue) and CAPE (yellow) in the simulations CTRL (top), HOMORAD (middle) and FIXRAD (bottom).



5. Energy budget of the cyclone

Domain mean energy budget terms in the CTRL (top), HOMORAD (middle) and FIXRAD (bottom) simulations as a function of time.



In this section, we investigate the leading terms in the intensification phases of the tropical cyclone by looking at the domain mean energy budget. During intensification phases, the energy of the cyclone is mainly lost due to the circulation, expressed by $-\nabla \cdot (\rho \boldsymbol{u} MSE)$. On the other hand, the cyclone gains energy mostly from the surface fluxes, LHF and SHF, due to the WISHE effect. Comparing HOMORAD and FIXRAD suggests that the reduced sink from the circulation in the HOMORAD is responsible for the intensification. The circulation impacts CAPE through its effect on the temperature profile, which we plan to further investigate.

6. Conclusion

- Coupling of CAPE with cyclone intensity: upper level warming (convective and radiative) reduces CAPE and inhibits intensification, then upper level cooling through entrainment increases CAPE and triggers a new intensification.
- WISHE feedback was confirmed to be a fundamental positive feedback that drives intensification.
- Without radiative feedbacks, the energy budget exhibits fewer oscillations.
- Future work: repeat simulations on larger domains to confirm that the results are not affected by the double periodicity of the domain.

References

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