# FINAL REPORT PROGRAM LEFE

| Program LEFE/IMAGO | LIMA-TROPIC : Interactions aérosols naturels – microphysique dans les systèmes convectifs tropicaux | Years 2017-2019 |
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**Context:** Forecasting the track, intensity, structure and associated hazards of tropical cyclones remains an ongoing challenge. One key issue lays on numerical models limitation in terms of physical parameterizations. In particular, we must pay careful attention to cloud microphysics representation due to its fundamental role in latent heat distribution and precipitation.

**Objectives:** The objective of LIMA-TROPIC was to investigate how cloud microphysics representation in a mesoscale model can impact the evolution of tropical cyclones. Two main questions were addressed: what is the role of sea salt aerosols in tropical cyclone development? Through which processes ice crystals impact the tropical cyclone structure and intensity?

**Main results**: In order to fully represent the aerosol-microphysics-dynamics interactions in tropical cyclones, an original coupling between the ORILAM aerosol scheme and the two-moment microphysics scheme LIMA has been developed in the cloud-resolving model Meso-NH. A sea salt aerosol emission parameterization has been introduced in Meso-NH/SurfEx: these aerosols are emitted by strong winds and waves. Their implementation in the aerosol scheme enables their transport by advection, sedimentation and turbulence, and their dry or wet deposition. These aerosols can serve as cloud condensation nuclei (CCN) thanks to the ORILAM-LIMA coupling (Hoarau et al., 2018a). A first evaluation of this coupling is performed through the simulation of tropical cyclone Dumile (2013) in the South-West Indian Ocean (SWIO). Using a one-moment microphysics scheme produces a more intense and symmetric system tracking too far to the west. In the aerosol-microphysics coupled simulation, sea salt aerosols, the main source of CCN, are preferentially produced in regions with high winds and waves, which reinforce convective asymmetries compared to the simulation with the one-moment scheme. Using a two-moment microphysics scheme without explicit sea salt emission led to a dramatic weakening of Dumile after 24 h of simulation due to the consumption and scavenging of all interstitial CCN in the inner core (Figure 1). The importance of explicitly considering sea salt aerosol emissions associated with high winds and waves in tropical cyclones is a critical point for simulating long-lasting systems that need to generate their own CCN.

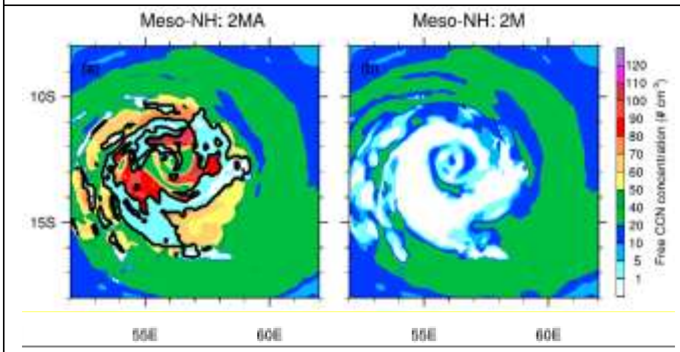


Figure 1: Number concentration (cm$^{-3}$) of interstitial (colors) and activated (black isolines at 50 cm$^{-3}$) CCN associated with sea salt particles. The horizontal cross sections are taken at 2,000-m altitude on 1 January at 12 UTC for the simulations of tropical cyclone Dumile with aerosol-microphysics coupling (2MA, right) and with microphysics only (2M, left). After only 12 hours of simulation, the number concentration of interstitial CCN in 2M is almost zero in the inner core of the system: all interstitial CCN initially present in the domain being activated or scavenged. In the absence of sea salt emission in 2M, there is no longer a CCN source for cloud droplets to form in the inner core except those transported from the cyclone environment. From Hoarau et al. (2018a).

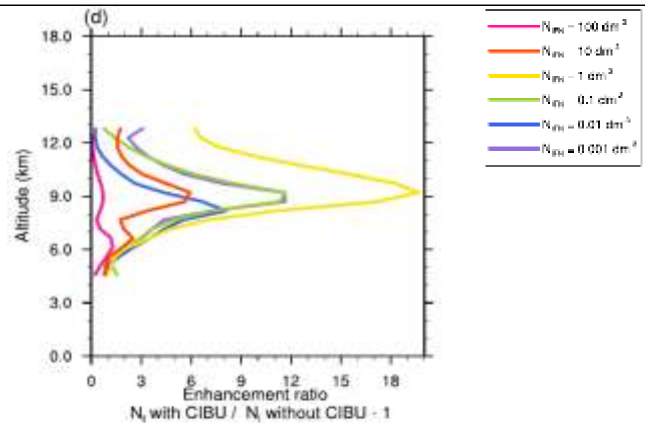


Figure 2: CIBU enhancement factor of ice crystal number concentration ($N_i$) plotted as a function of the initial ice freezing nuclei (IFN) concentrations ($N_{IFN}$ ; dm$^{-3}$). The enhancement ratio due to CIBU is low (< 1) for high IFN concentrations (~100 dm$^{-3}$) but can reach a factor of 20 at 9,000 m height in the case of moderate $N_{IFN}$ (~1 dm$^{-3}$). Increasing $N_{IFN}$ too much leads to smaller pristine crystals that need a longer time to grow before being included in the snow aggregates category. On the other hand, a low $N_{IFN}$ initiates fewer snow aggregates and thus fewer graupel particles, so the whole CIBU efficiency is also reduced. From Hoarau et al. (2018b).

Cloud-radiation interactions are suspected to influence the track, the structure and the intensity of tropical cyclones. Then, specific developments on the ice phase in LIMA are in progress to enable a better description of the ice water content, the ice crystal effective radius and the ice crystal shape, which are used as input for the radiation scheme. Two main developments are considered. First, secondary ice formation mechanisms are thought to explain the discrepancy between low ice nucleating particles and high ice crystal number concentrations observed at warm subzero temperatures. The collisional ice breakup (CIBU) mechanism has been implemented in LIMA: when fragile snow aggregates collide with dense graupel, small fragments of ice are produced, increasing ice crystals number concentration. A first evaluation on idealized case studies has confirmed that CIBU has an essential role in compensating for ice freezing nuclei deficit (Figure 2). A reduction of the precipitating area and an invigoration of the convection with higher cloud tops are also found (Hoarau et al., 2018b). Secondly, additional variables to prognose the number concentration of ice crystals with different habits (plates, columns, irregular crystals and polycrystals) have been introduced in Meso-NH and LIMA. Different coefficients of the mass-diameter and fall speed-diameter relationships and of the capacitance are attributed to each ice crystal habit, and microphysical processes are computed accordingly. In each grid mesh, the ice crystal effective radius is computed from the prevailing ice crystal habit in terms of number concentration, and is passed to the radiation scheme. This enables a consistent treatment of the aerosol-microphysics-radiation interactions in clouds. The implementation of several ice crystal habits is being evaluated on the 15 May 2015 storm over Cayenne sampled during the HAIC field campaign. Considering several ice crystal habits enables to produce ice water content, effective radius and number concentration in good agreement with in-situ observations and DARDAR products (Barthe et al., in prep.a).

An ocean-wave-atmosphere simulation of tropical cyclone Idai (2019) including the aerosol-microphysics-radiation coupling developed was performed (Barthe et al., in prep.b). The added value of such a coupling is being evaluated through observations from the ReNovRisk campaign and satellite products.

In addition and to improve our understanding of the meteorology of this region, the variability of the vertical distribution of clouds over the SWIO has been investigated using the DARDAR mask product (Vérèmes et al., 2019). Following this study, the ice water content from the DARDAR product is used over a 10-year period (2007-2017) in the SWIO to investigate the microphysical properties of tropical storms in this region according to the region of the system (eye wall, precipitating band, cirrus clouds) and their intensity stage (Faustine Mascaut M2 internship ; Vérèmes et al., in prep.).

**Future of the project:** The ICARRE (Ice Crystals in deep convective Clouds: interactions with Aerosols, Radiation & Electricity; LA, CNRM, LaMP, LATMOS) project has been submitted to ANR AAPG 2021. Some developments initiated in LIMA-TROPIC are going on (secondary ice crystals formation, ice crystal habits, ice microphysics – radiation interactions).

**Publications, communications and PhD thesis :**

- 3 publications (3 additional publications are in progress), 8 communications, 1 PhD thesis

Hoarau, T., Couplage aérosols-microphysique pour la simulation des cyclones tropicaux : Cas du cyclone tropical Dumile (2013), Thèse de l'Université de La Réunion, https://hal.archives-ouvertes.fr/tel-01879641/, 2018.

Hoarau, T., C. Barthe, P. Tulet, M. Claeys, J.-P. Pinty, O. Bousquet, J. Delanoë, and B. Vié, Impact of the generation and activation of sea salt aerosols on the evolution of Tropical Cyclone Dumile. J. Geophys. Res. Atmos., 123, 8813-8831, https://doi.org/10.1029/2017JD028125, 2018a.

Hoarau, T., J.-P. Pinty, and C. Barthe, A representation of the collisional ice break-up process in the two-moment microphysics scheme LIMA v1.0 of Meso-NH. Geosci. Model, 11, 4269-4289, https://doi.org/10.5194/gmd-11-4269-2018, 2018b.

Vérèmes, H., C. Listowski, J. Delanoë, C. Barthe, P. Tulet, D. Roy, and F. Bonnardot, Spatial and seasonal variability of clouds over the South Indian Ocean based on DARDAR cloud classification product, Quart. J. Roy. Meteor. Soc., 145, 3561-3576, https://doi.org/10.1002/qj.3640, 2019.