Convective systems in climate models facing spaceborne observations and storm-resolving simulations

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Convection is a major source of high clouds in the climate system. Their radiative effects are crucial for the Earth's energy budget and their heating rates within the atmosphere significantly drive the large-scale circulation. However, the limited understanding of dynamical and microphysical processes in deep convective clouds poses a significant challenge to climate research.

Deep convective clouds develop precipitating and non precipitating anvils: as a result of mass conservation, the vertical mass flux convergence at the tropopause translates into a horizontal divergence of mass and cloud condensates. The spreading anvil is easily detected in satellite observations and its expansion rate informs on the strength of convective updrafts as well as compensating downdrafts. The tracking of convective systems in sequential geostationnary infra-red images, combined with measurements made by orbiting satellites (A-Train, TRMM, GPM-core, Megha-Tropiques) already provides unique observationnal constraints on physical processes involved in the anvil life cycle (e.g. Bouniol et al. 2016, 2021).

In general circulation models (GCM) such as those used for climate projections, clouds associated with deep convection are subgrid-scale and need to be represented via a set of equations named parameterizations. They involve parameters that can be highly uncertain, such as convective core size, the fall speed of ice crystals or the variance of the subgrid-scale moisture distribution. Therefore, a better documentation and understanding of the physical processes driving the formation, life cycle and dissipation of anvil clouds is key to improve their representation in GCM. It is all the more critical that the response of these clouds in the context of climate change is uncertain (Mauritsen and Stevens 2015, Bony et al. 2016).

By the end of the current decade, new concepts of spaceborne observations will available to quantify dynamical features within mesoscale systems. The C2OMODO concept that should join the AOS train orbit will be dedicated to the measurement of convective mass flux and convective core sizes. Even if still in discussion, it would nicely complement measurements made by other instruments on the same orbit, such as radars that will provide additional informations on the convection properties.

The aim of this PhD is to investigate how those coming observations can be used to evaluate and improve the representation of the life cycle of convective systems in climate models. To achieve this, a set of diagnostic tools that can be used to frame a number of future analyses based on the C2OMODO and more generally the AOS train observations will be developed. The goal is twofold: (i) build diagnostics that may directly be useful for evaluating and developing GCM parameterizations and (ii) propose level-2 data products based on such spaceborne observations that will help better constrain climate model parameterizations.

Since the launch of the C2OMODO tandem is scheduled for the end of the decade, these developments will be performed using global storm-resolving (non-hydrostatic) simulations performed in the framework of the DYAMOND project (Stevens et al. 2019). These simulations span over 40 days and provide at 2.5-km resolution all the dynamical and thermodynamical fields required to document convection and its organization. In particular, variables such as convective mass flux, cloudiness and radiative properties, which are expected from the AOS missions, can be estimated.

The PhD work will encompass three main different tasks:

- detect and track the mesoscale convective systems within some of the DYAMOND simulations (especially ARPEGE-NH), to build a composite view of their life cycle, especially in terms of dynamics, cloudiness and radiative properties. The sensitivity of this life cycle will be assessed with respect to the mesoscale system environment. These composites will be compared to those that have already been done using spaceborne measurements (Bouniol et al. 2016, 2021) and thereby provide the first quantitative analysis of convection properties at the scale of the tropics within such global storm-resolving simulations.

- quantify the impact of technical choices (e.g. orbit inclination, swath width) on the statistics of mesoscale convective system physical properties that will be available thanks to the C2OMODO facility.
- Investigate how the observed fields can be used to inform the development of convection parameterizations of climate models. This implies the development of a methodology to confront mesoscale convective events simulated by a climate model with observations. The results should in turn provide guidance to identify potential missing constraints in convection parameterizations and document the required accuracy of future spaceborne observations to provide them.

Skills

Good programmation skills including visualisation tools
Data processing
Knowledge in atmospheric physics

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