Stochastic parameterization of moist convection estimated from LES data

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We report on the development of a methodology for stochastic parameterization of moist convection in General Circulation Models (GCMs), using the data-driven approach proposed by [1]. We use data from convection-resolving Large-eddy simulation (LES) to estimate stochastic processes that represent convection. These stochastic processes take the form of Markov chains that are conditioned on the resolved scale state of the atmosphere. They mimic, in a computationally inexpensive manner, the convective behavior observed in the LES. Therefore, our model can be seen as an emulator of LES. We explore cases of shallow and deep convection.

1. Large-eddy simulation (LES)

To estimate a stochastic process representing convection in a model column with a given resolution, we use data of a model that is able to resolve moist convection: LES. In particular we use Dutch Atmospheric LES (DALES), a non-hydrostatic atmospheric high-resolution model. The horizontal and vertical grid-point distance is on the order of tens of meters, while the horizontal size of the domain with doubly periodic boundaries is on the order of tens of kilometers and the vertical size is on the order of a few kilometers for shallow convection and around 25 kilometers for deep convection. The time step is on the order of seconds and we save data every minute. Fig. 1 displays a snapshot of LES.

2. The grey zone

As a motivation for usage of stochastic models, we calculate the resolved and unresolved parts of the vertical heat flux for various length scales using LES data. In the grey zone these parts are of the same order. The standard deviation of the unresolved flux is large in the grey zone and only becomes small for length scales 3 > 10 km (Fig. 2).

3. Markov chains

We use data-driven Markov chains, introduced by [1], to mimic convection observed in LES data. First, we discretize LES fields by assigning each column to one of a finite number of convective states. Then we estimate transition probability matrices from the discretized LES data. The time step is 1 minute in every case we consider. We make the stochastic convection response sensitive to the resolved-scale state by using conditional Markov chains (CMCs). We also introduce spatial coupling to neighboring sites in which case the Markov chains become equivalent to stochastic cellular automata (SCA). A schematic overview is given in Fig. 3.

4. Shallow convection

In [2] we use conditional Markov chains, conditioned on heat and moisture profiles, to mimic shallow cumulus convection simulated by LES based on the steady case BIOMEX. To discretize the LES data we cluster the pairs of vertical flux profiles into 10 clusters (Fig. 4) and we cluster pairs of heat and moisture profiles into 10 clusters. Each minute the Markov chain jumps randomly between the flux profiles. In a single-column model setup the CMCs are able to mimic the convection of the LES (Fig. 5).

5. Deep convection

In [3] we mimic the development of deep convection during one day (TRMM-LBA). Inspired by [4], we classify LES columns into 5 convective states distinguished by cloud top and rain water path:
- clear sky
- shallow cumulus (SN)
- congestus (CC)
- deep convection (DE) and stratiform (ST).

If cloud top is zero, then a column is classified as clear sky. Fig. 6 shows the classification into the four cloud types. Fig. 7 shows a snapshot at the final time of the LES (left) and cloud fractions and their standard deviation over subdomains of 4.8^2 km^2 (right).

Conclusions

LES-data-driven conditional Markov chains are able to mimic convection in a computationally inexpensive way and therefore are promising for future usage in convection parameterizations in weather and climate models. They can generate the correct variability in the convective part of the subgrid response.

References


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