Successes and challenges in the simulation of tropical deep convection at high resolution

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Representation of deep convection

\[ \Delta x \]

100 m

- turbulence permitting

1 km

- convection permitting

10 km

- parameterized convection

- UNCERTAINTIES ON TURBULENCE, MICROPHYSICS AND RADIATION

- UNCERTAINTIES ON MICROPHYSICS AND RADIATION
Very deep convection in a Giga-LES

Hector the Convctor

- 2560 x 2048 x 256, 1.34 billion gridpoints
  \( \Delta x = 100 \text{ m and } \Delta z = 40 - 100 \text{ m} \)
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data

How does the very deep convection hydrate the stratosphere?

Video on https://youtu.be/xjPumywGaAU

Dauhut et al., Atmos. Sci. Lett. 2015
Comparison with SCOUT-O3 observations

The Giga-LES reproduces correctly the details of Hector as its overshoots into the stratosphere.
Sensitivity to horizontal resolution

The vertical velocity for the most rapid updrafts generally decreases with reduced resolution.

The magnitude of the moistening tends to converge with $\Delta x \geq 200$ m.

<table>
<thead>
<tr>
<th>$\Delta x$ (m)</th>
<th>$\Delta H_2O$ (%)</th>
<th>$\Delta H_2O$ (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600</td>
<td>+12</td>
<td>+2222</td>
</tr>
<tr>
<td>800</td>
<td>+13</td>
<td>+2252</td>
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<tr>
<td>400</td>
<td>+27</td>
<td>+4525</td>
</tr>
<tr>
<td>200</td>
<td>+18</td>
<td>+3263</td>
</tr>
<tr>
<td>100</td>
<td>+16</td>
<td>+2776</td>
</tr>
</tbody>
</table>

Dauhut et al., Atmos. Sci. Lett. 2015
A grid spacing of $\Delta x = 200$ m or 100 m is required for a reliable estimate of the hydration of the stratosphere.
Overturning in Hector

Two key circulations

Overshoot overturning
Tropospheric overturning

Dauhut et al., J. Atmos. Sci., 2017
The very deep convective phase is characterized by a maximal intensity of the two overturnings and large latent heat release due to ice formation.
Identification of the tallest updrafts

Step 1: detection of updrafts on every gridpoint where $w>10$ m/s

Step 2: identification of updrafts as object

Step 3: Statistics of updrafts

Dauhut et al., J. Atmos. Sci., 2016
The tallest updrafts, why bother?

In TTL, the two tallest updrafts contribute to >90% of the transport by all the updrafts.

The isentropic analysis corroborates the Eulerian computation with $w>10$ m/s, except in lower tropo and around the tropopause (#) where weak motions matter for the irreversible flux.
Formation of the tallest updrafts

12:15 Deep Convection

Convergence intensified by cold pools

13:15 Very Deep Convection

14:15 Convective Cluster

Dauhut et al., J. Atmos. Sci., 2016
Properties of the tallest updrafts

The tallest updrafts that overshoot the stratosphere are larger, stronger, more buoyant, carrying more water, having more MSE, a larger lapse rate, less diluted than those occurred one hour earlier and after.

Dauhut et al., J. Atmos. Sci., 2016
How do overshoots hydrate the stratosphere?

700 overshoots identified, 46 overshoots last more than 10 min. They are diverse in shapes and impacts above the tropopause.

Non-hydrating overshoots

Hydrating overshoots

Cloud contour at 17 km (10^{-5} kg/kg)
Hydrating and non-hydrating overshoots

The 46 overshoots that last > 10 min

19 overshoots are larger than 5 km

The hydrating overshoots reach higher altitudes...

...and exhibit large absolute values of buoyancy.
The mechanisms inside the hydrating overshoot A

The **top-entrainment** of stratospheric air is crucial to warm the overshoot and to produce the hydration by ice sublimation.

Dauhut et al., J. Atmos. Sci., submitted
Representation of deep convection

- **LES** (large-eddy simulation)
  - Turbulence permitting
  - Uncertainties on microphysics and radiation

- **CRM** (cloud-resolving model)
  - Convection permitting
  - Uncertainties on turbulence, microphysics and radiation

- **RCM/GCM** (climate model)
  - Parameterized convection
  - Large uncertainties

- Δx

- 100 m
- 1 km
- 10 km
Convective hydration during StratoClim

What is the fate of the water injected by overshoots?

Simulation starting at 00 UTC 6 August 2017 from ECMWF analysis and run for 3 days, Δx=2.5 km, 2000 x 1440 x 144, 400 million gdpts

From 06:20 to 06:48 UTC on 8 August 2017

Tropopause

Observation: solid line
Simulation: cross marks
StratoClim data courtesy of S. Khaykin and M. Krämer

Lee et al., Atmos. Chem. Phys., in preparation
Injection of water by overshoots

Lee et al., Atmos. Chem. Phys., in preparation
Advection of the hydration patch

Water vapor

Ice content

Tropo. tracer

Lee et al., Atmos. Chem. Phys., in preparation
Convective vs. turbulent mixing

Lee et al., Atmos. Chem. Phys., in preparation
What controls the distribution and variability of precipitation?
What is the radiative impact of dust on the atmosphere?

Three simulations starting at 00 UTC 9 June 2006 from ECMWF analysis and run for 6 days

- **HiRes/DUST** $\Delta x = 2.5$ km, 3072 x 1536 x 72, 1/3 billion gdpts, with dust radiative effects
- **LowRes** $\Delta x = 20$ km with KFB convective parameterization and dust scheme
- **NODUST** $\Delta x = 2.5$ km, w/o dust radiative effect

Reinares Martínez and Chaboureau, Mon. Wea. Rev., 2018a,b
Distribution of precipitation

- Deep convective clouds: BT<230K
- MCSs = large DCCs (Deff> 120km)
- Long-lived MCSs: duration>6h
- Cirrus anvil clouds 230K<BT<260K

- Long-lived MCSs produce 55% of precipitation, thus a large part of the diurnal cycle. This is well captured by the CRM simulations

OBS: MSG 10.8 µm brightness temperature and TRMM 3B42 rain product
Characteristics of long-lived MCSs

OBS: most organized long-lived MCSs in SWA

HiRes/DUST agreement with OBS except in SWA (too small, short-lived and slow, small northward meridional component)

LowRes drawbacks more pronounced

DUST long-lived MCSs less numerous than NODUST in SWA

The CRM simulations lack the degree of organization of the long-lived MCSs over SWA. The CRM with dust does a better job due to the stabilization of the lower atmosphere (large CAPE), which inhibits the triggering of convection (large CIN).
Conclusions

✓ CRM approach was successful in representing cloud and precipitation distribution – MCSs, diurnal cycle, etc.
✓ A higher skill was obtained with dust radiative effects over north Africa, but cloud organization is lacking: errors in initial conditions, drawback in parameterization of microphysics, of turbulence?
✓ Convergence in dynamics, hydration is almost reached with LES

Future plans
✓ Case studies of deep convection using an aerosol-aware microphysical scheme – avoiding the saturation adjustment and looking for aerosol-cloud interactions: Application to the AEROCLLO-sA/ORACLES/CLARIFY field campaign (Aug. 2017)
✓ Investigation of convective overshoots over longer periods