Object-based approaches for exploring high-resolution simulations

Jean-Pierre CHABOUREAU
Laboratoire d’Aérologie, University of Toulouse, CNRS, UPS, France
http://mesonh.aero.obs-mip.fr/chaboureau/

with contributions from Luiz A. T. Machado (CPTEC, Brazil),
Thibaut Dauhut and Irene Reinares Martínez (LA, Toulouse, France)
Motivation

- **Cloud-scale processes are important for weather and climate**
  - They can lead to extreme events, e.g. flash floods, gusts, ...
  - They account for the global mean
- **High-resolution simulations can resolve cloud-scale processes**
  - Added-value on means and variability, e.g. diurnal cycle, ...
  - Realistic representation of scale-interaction across a large range with various objects contributing to the global mean
- **Statistical studies can be made using an object-based approach.** Examples for:
  - Assessment of cloud forecasts over Brazil using cloud tracking and its sensitivity to the turbulence parameterization
  - Tracking of deep convective clouds over West Africa
  - Properties of the tallest updrafts of Hector the convector
Assessment of cloud forecasts

CHUVA (‘rain’ in Portuguese): 6 field campaigns between 2010 and 2014 (Machado et al. BAMS 2014)

CHUVA SUL from 15 November to 15 December 2012 focused on mesoscale convective systems

36-h daily forecasts with Méso-NH w/ Δx = 2 km

Assessment of forecasts using cloud tracking

Tracking of cloud systems:
MSG observation, threshold Tir<235K and tracking with ForTraCC* algorithm

Tracking of rain cells: S-band radar, CAPPI altitudes 2-15 km, threshold reflectivity>20 dBZ, ForTraCC*

2 sets of Méso-NH forecasts that differ in the turbulence parameterization:
• 1D turbulence
  vertical flux only (horizontal flux neglected); BL89 mixing length
• 3D turbulence
  flux both in the vertical and the horizontal; Deardorff mix. length

*ForTraCC: Forecast and Tracking the evolution of Cloud Clusters (Vila et al. Wea. Forecasting 2008)
Tracking of cloud systems

Size distribution
Too many small systems forecasted, 20% reduction with 3D turbulence

Life cycle duration
Too many short lifetime systems, reduction with 3D turbulence

The tracking technique reveals a major drawback in the forecasts

Fig. 7. Organization of clouds (Tir < 235 K) observed by MSG and simulated by Meso-NH with 1D and 3D turbulence for the 5 golden days simulations. (a) Size distribution and (b) life cycle duration.
Tracking of rain cells

3D turbulence: reduction of small rain cells

... but a too large reduction of reflectivities between 20-32 dBZ without decreasing the reflectivities between 32-46 dBZ

and still too many cells with tops in [8-12 km]

Fig. 9. Organization of rain cells (reflectivity larger than 20 dBZ) observed by the S-band radar and simulated by Meso-NH with 1D and 3D turbulence for Julian days 333 and 335 simulations.

Fig. 10. Reflectivity from S-band radar and Meso-NH simulations with 1D and 3D turbulence for Julian days 333 and 335 simulations. (a) Histogram of reflectivity at 2-km altitude and (b) normalized histogram of echo cloud-top height using the 0-dBZ threshold.
Sensitivity to the mixing length

**3D turbulence:** Deardorff mixing length *inside clouds* scaled by a factor of 2

**Mixing length 2 times smaller:** much more small systems

**Mixing length 2 times larger:** much less small systems in agreement w/ observations

The tracking technique can help for tuning the turbulence parameterization

---

**Fig. 11.** Organization of clouds (Tir < 235K) observed by MSG and simulated by Méso-NH with 3D turbulence for cloud mixing length multiplied by 0.5, 1.0, and 2.0, for simulation of Julian day 335.
Deep convective clouds over W. Africa

- What controls the distribution of precipitation over West Africa?
- Can CRMs simulate precipitation in a realistic manner?

Two simulations of 6 days, starting at 00 UTC 9 June 2006:

- **HiRes** $\Delta x=2.5$ km, 3072 x 1536 x 72, 1/3 billion gdpts, 7 TB
- **LowRes** $\Delta x=20$ km with KFB convective parameterization
- Standard Méso-NH parameterizations: ICE3 bulk microphysics, 1D turbulence, RRTM radiation, dust by DEAD + ORILAM only radiative effects, outputs every 3 h

**Assessment of simulations** with
- MSG observation, BT at 10.8 µm
- TRMM 3B42 rain product

**Identification of cloud types**
- Deep convective clouds BT<230K
- Cirrus anvil clouds 230K<BT<260K
- Low-level clouds BT>260 K

**Tracking of DCCs**
Overlap method a la ForTraCC

**Properties of DCCs**
Rain, clouds, dynamics, etc.
Assessment of precipitation and DCCs

**Added-value of HiRes**
- Higher rain rate
- Diurnal cycle ~OK

Maximum occurrence of DCCs coincident with highest precipitation

HiRes agrees well with TRMM. Less scattered precipitation for LowRes
Precipitation and DCC clusters

- In the observations, DCCs contribute to ~70% of precipitation.
- HiRes agrees with observations. LowRes underestimates the contribution of DCCs to precipitation.
- TRMM has larger DCC clusters and a larger dispersion in the distribution than HiRes and LowRes.

PhD work of Irene Reinares Martínez
Deep Convective Cloud Tracking

Trajectory of long-lived, medium-to-large DCCs (duration > 6h; Deff> 120 km)

- Simulated DCCs are more numerous and have a shorter life than observed
- DCCs propagate south-westward in the observation; more westward in the simulations

- Analysis of the properties of DCCs currently under investigation
Analysis of updrafts in a Giga-LES

Hector the Convective

- 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

Video on https://youtu.be/xjPumywGaAU

Dauhut et al., Atmos. Sci. Lett. 2015
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, accepted pending minor revisions
The tallest updrafts, why bother?

The two tallest updrafts account for more than 90% of the total mass flux into the Tropopause Tropical Layer

Dauhut et al., J. Atmos. Sci., 2016, accepted pending minor revisions
Formation of the tallest updrafts

12:15 Deep Convection

13:15 Very Deep Convection

14:15 Convective Cluster

Convergence intensified by cold pools

Dauhut et al., J. Atmos. Sci., 2016, accepted pending minor revisions
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, accepted pending minor revisions
Conclusions

The object-based approach applied in different contexts allows us

- To highlight the importance of a particular process
  - The role of the tallest updrafts in the convective transport

- To reveal salient properties of objects
  - The too large number of small cloud systems
  - The too large number of DCCs propagating in a wrong direction
  - The very low dilution of the tallest updrafts

- To serve as a guide for developing parameterization
  - The number of cloud systems changes drastically with the turbulence parameterization and the mixing length

- Issue on big data: it needs a large volume of storage

The 17th AMS conference on mesoscale processes, 24-28 July 2017, San Diego, CA welcomes papers on scale interactions and at the weather/climate interface