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/

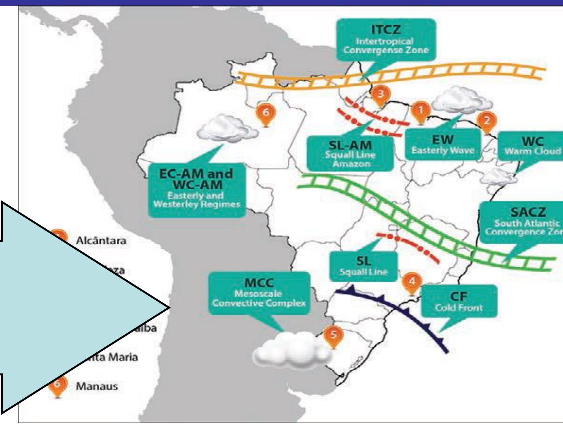
with contributions from Luiz A. T. Machado (CPTEC, Brazil),
Thibaut Dauhut and Irene Reinares Martínez (LA, Toulouse, France)

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)



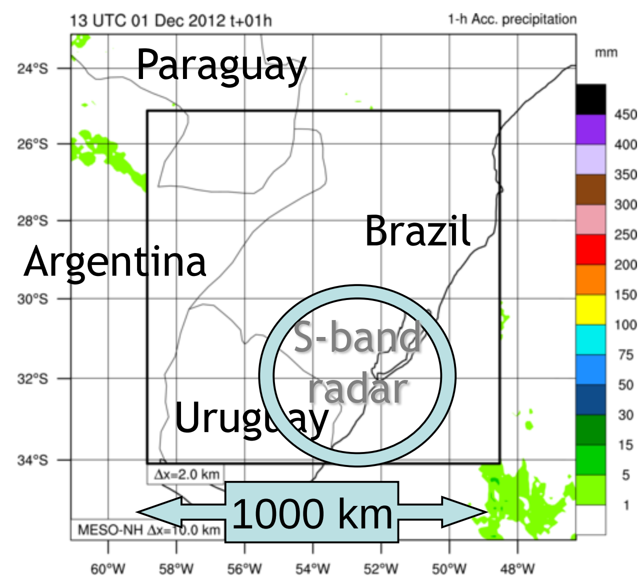
CHUVA SUL from 15 November to 15 December 2012 focused on mesoscale convective systems

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

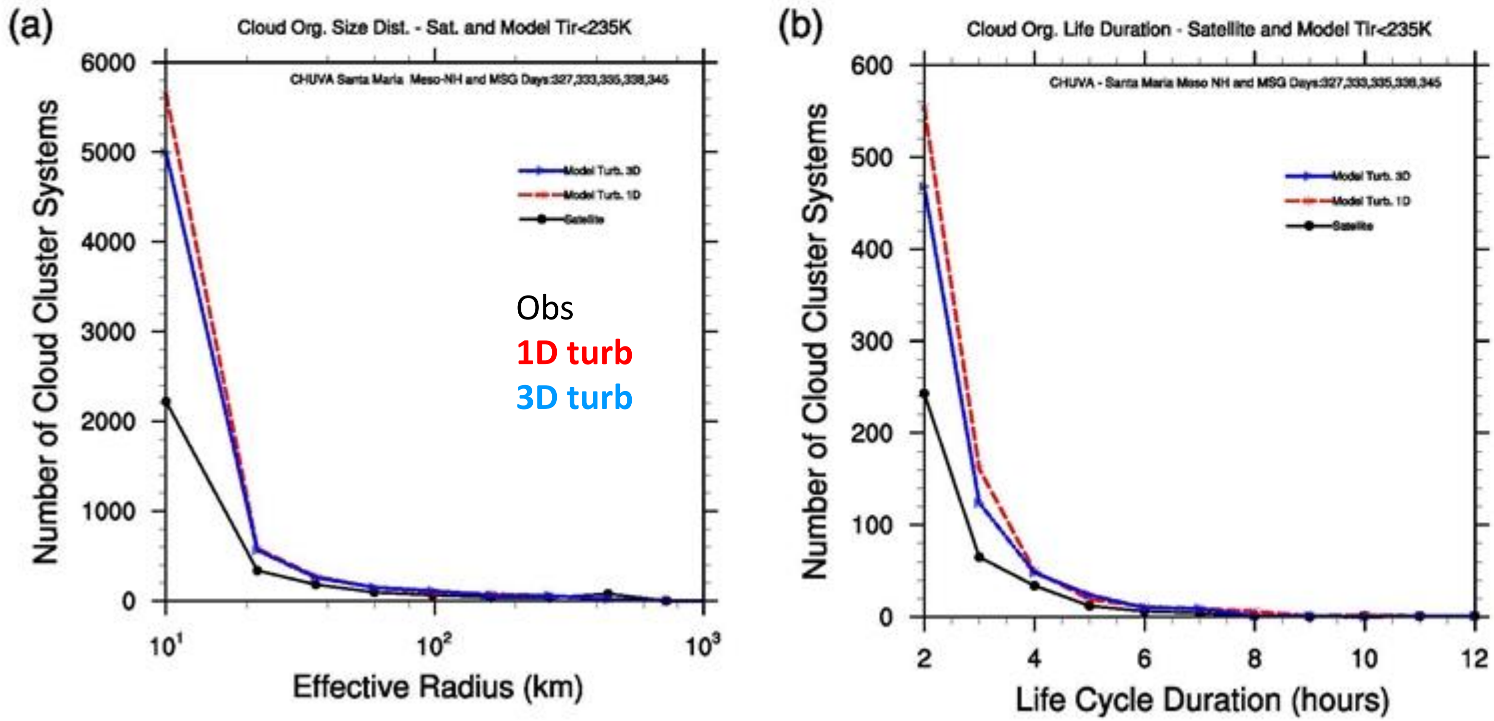


FIG. 7. Organization of clouds (Tir < 235 K) observed by MSG and simulated by Méso-NH with 1D and 3D turbulence for the 5 golden days simulations. (a) Size distribution and (b) life cycle duration.

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

Machado and Chaboureau, Mon. Wea. Rev. 2015

Tracking of rain cells

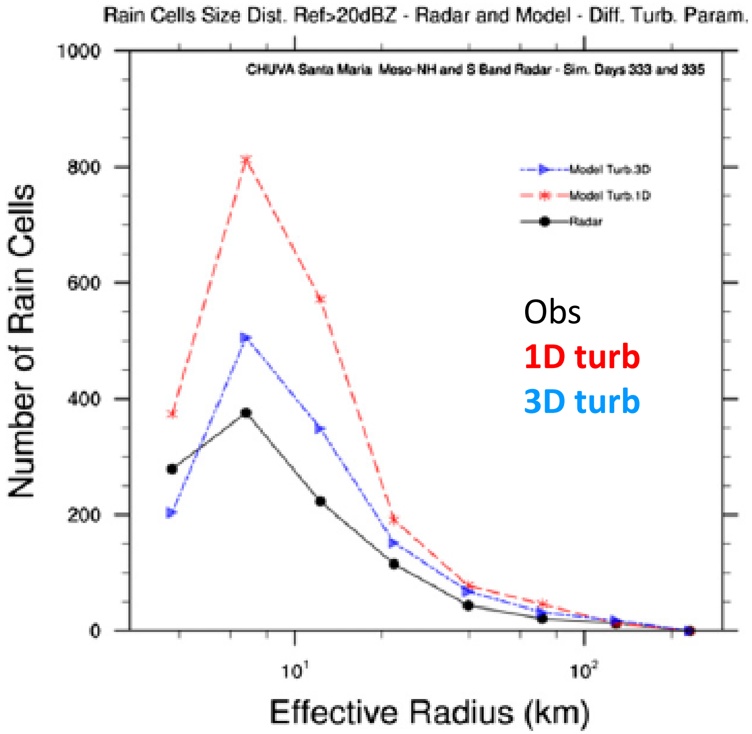


FIG. 9. Organization of rain cells (reflectivity larger than 20 dBZ) observed by the S-band radar and simulated by Méso-NH with 1D and 3D turbulence for Julian days 333 and 335 simulations.

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]

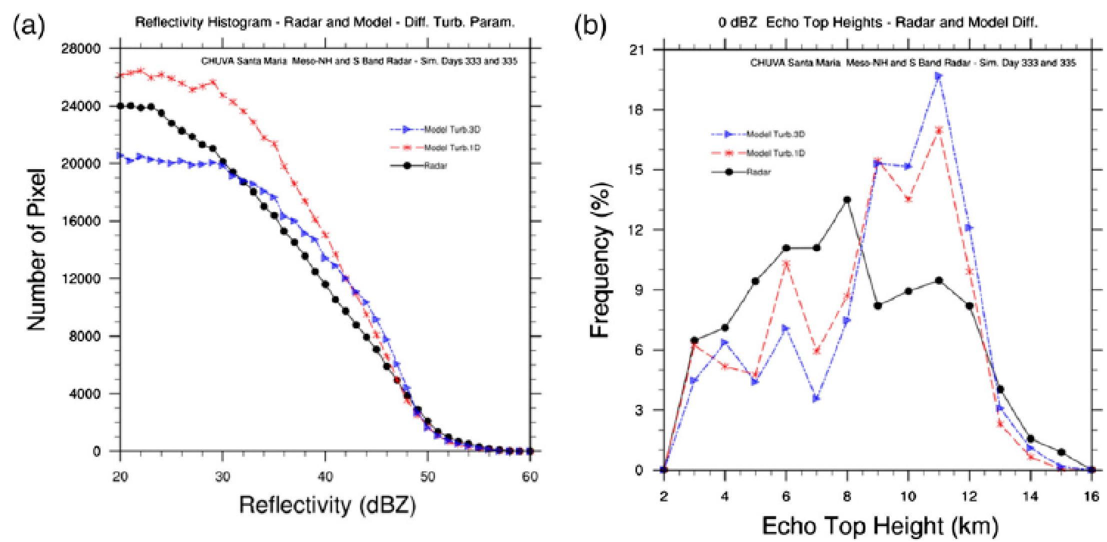


FIG. 10. Reflectivity from S-band radar and Méso-NH simulations with 1D and 3D turbulence for Julian days 333 and 335 simulations. (a) Histogram of reflectivity at 2-km altitude and (b) normalized histogram of echo cloud-top height using the 0-dBZ threshold.

Sensitivity to the mixing length

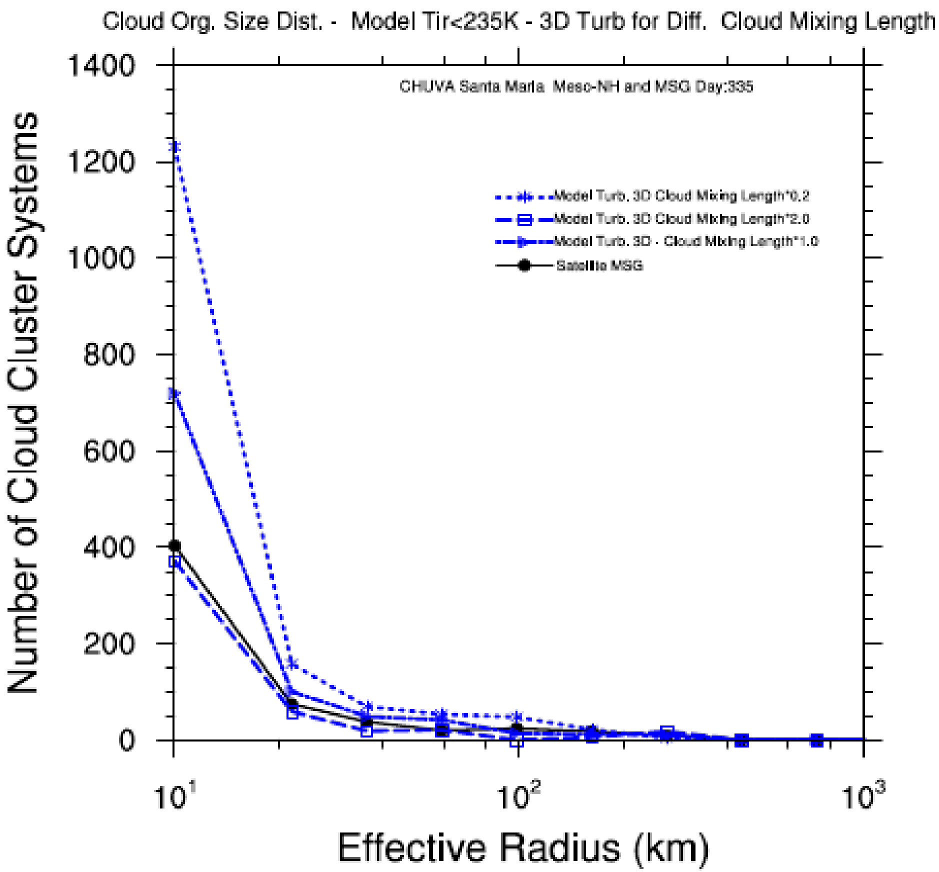


FIG. 11. Organization of clouds (Tir < 235K) observed by MSG and simulated by Méso-NH with 3D turbulence for cloud mixing length multiplied by 0.5, 1.0, and 2.0, for simulation of Julian day 335.

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

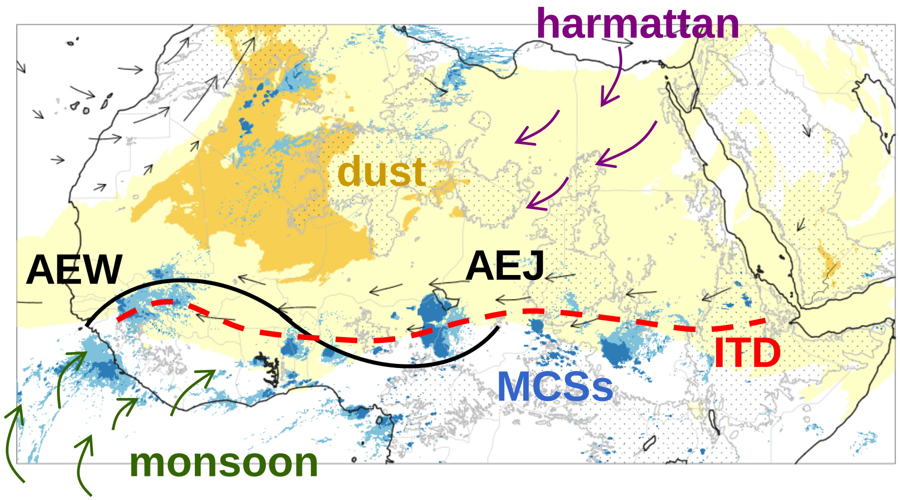
Mixing length 2 times smaller: much more small systems

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

The tracking technique can help for tuning the turbulence parameterization

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** Δx=2.5 km, 3072 x 1536 x 72, 1/3 billion gdpts, 7 TB
- **LowRes** Δx=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

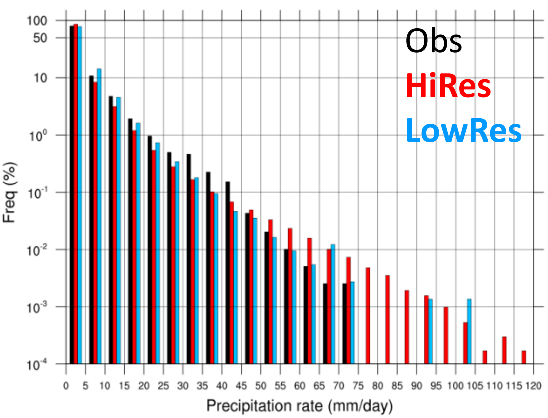
Properties of DCCs

Rain, clouds, dynamics, etc.

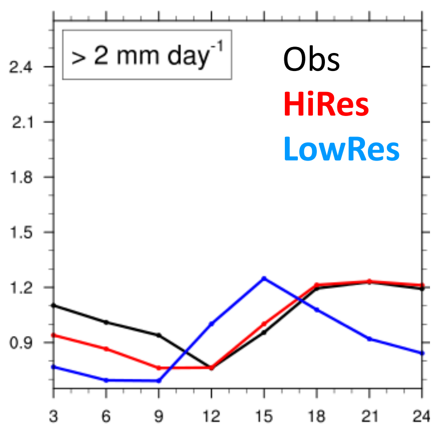
Assessment of precipitation and DCCs

Added-value of HiRes

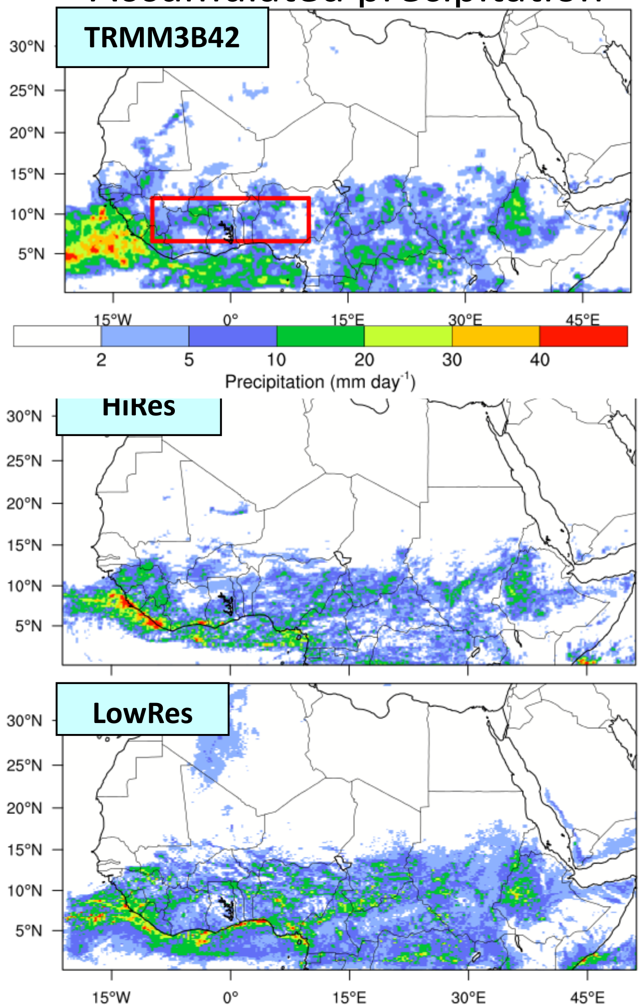
- Higher rain rate



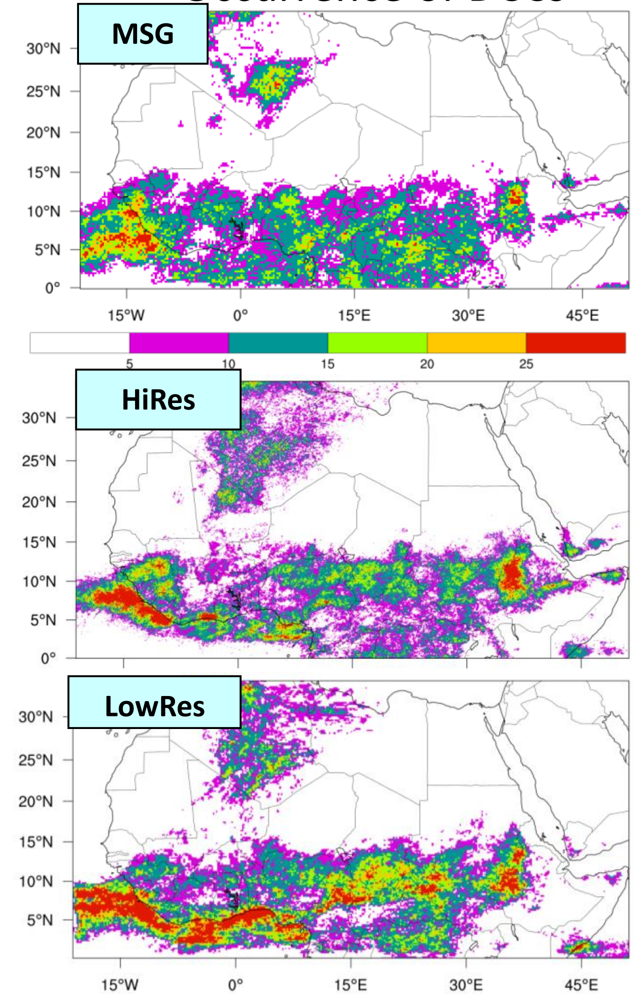
- Diurnal cycle ~OK



Accumulated precipitation



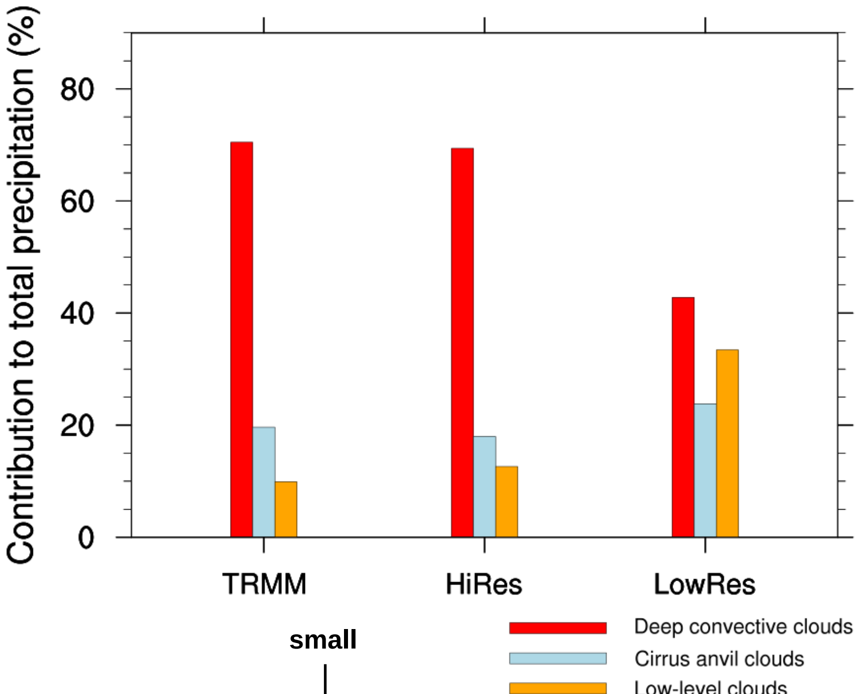
Occurrence of DCCs



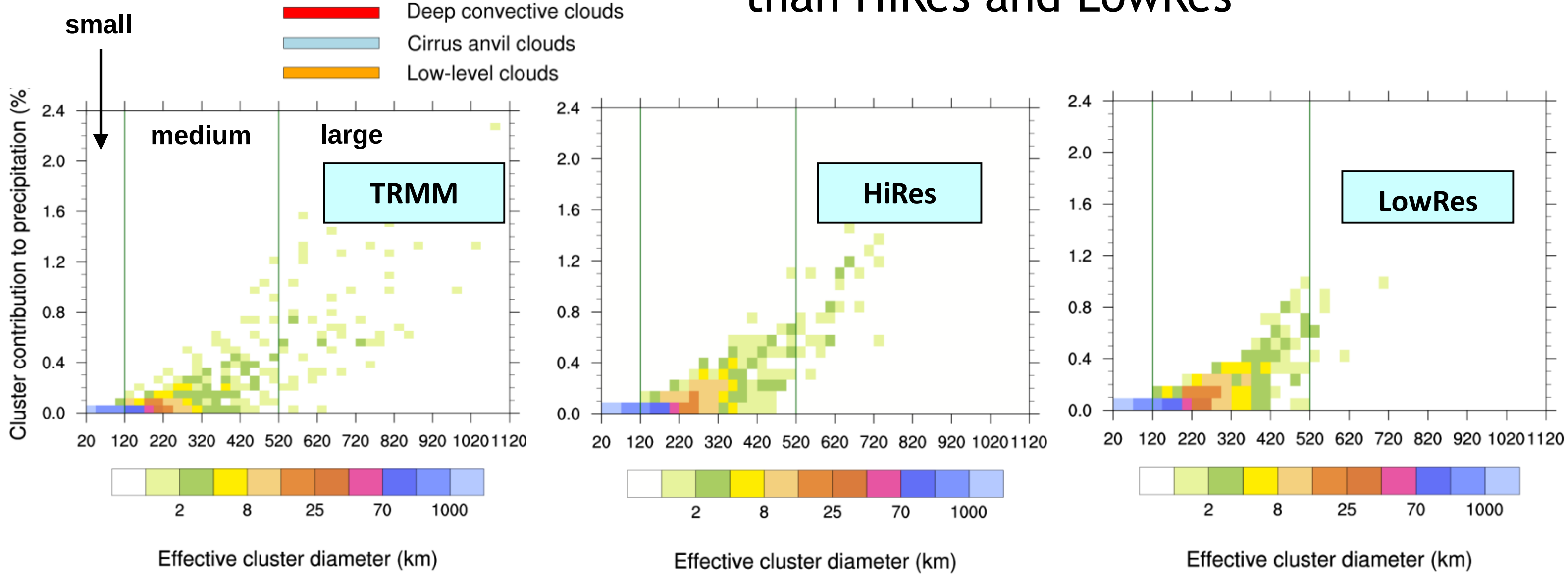
→ **Maximum occurrence of DCCs coincident with highest precipitation**

→ **HiRes agrees well with TRMM. Less scattered precipitation for LowRes**

Precipitation and DCC clusters

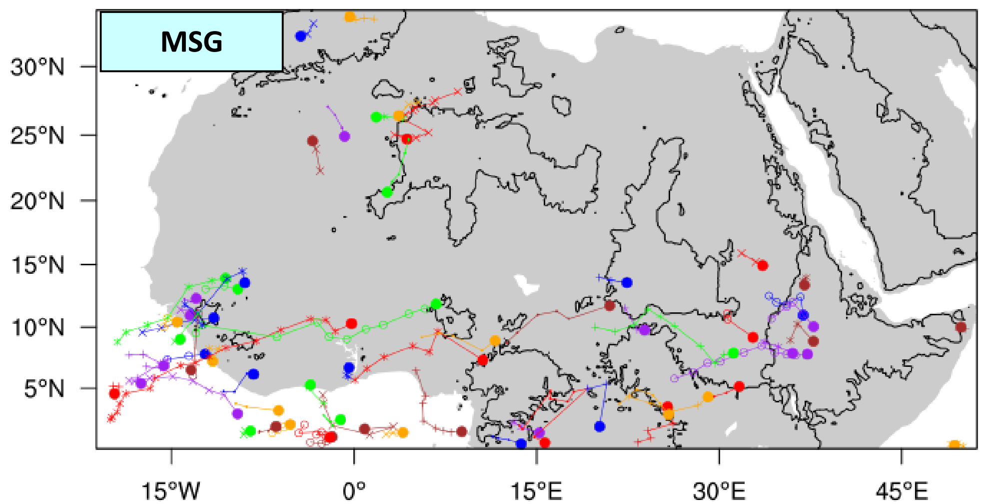


- In the observations, DCCs contribute to ~70% of precipitation
- HiRes agrees with observations. LowRes underestimates the contribution of DCCs to precipitation
- TRMM has larger DCC clusters and a larger dispersion in the distribution than HiRes and LowRes

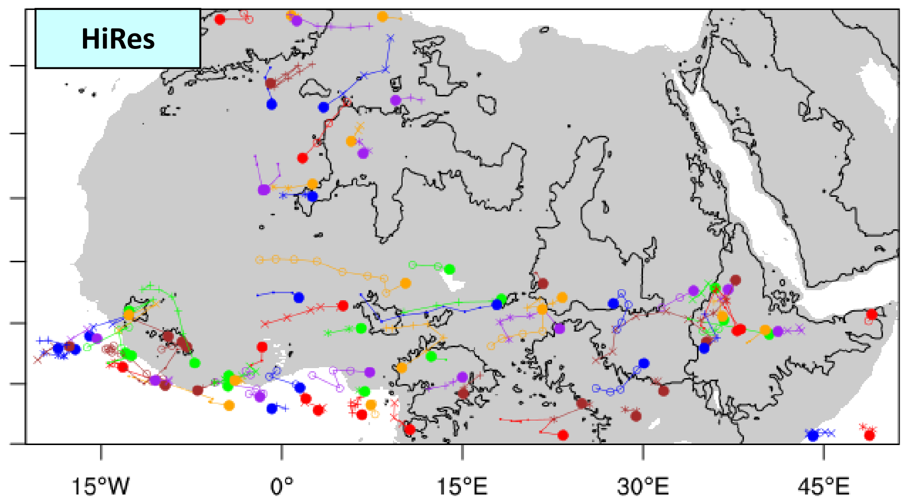


Deep Convective Cloud Tracking

OBS, longest trajectory = 48 h, nb trajectories = 62



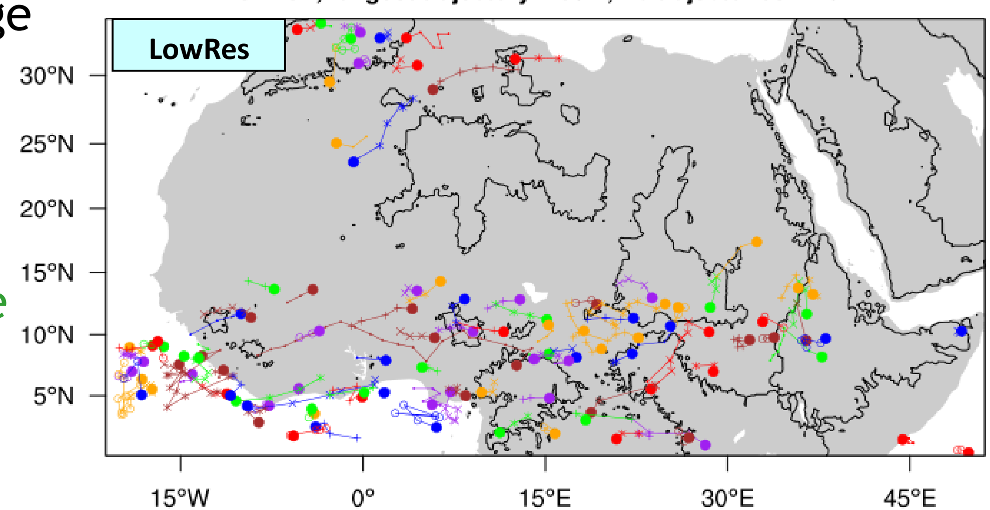
SHDST, longest trajectory = 39 h, nb trajectories = 84



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

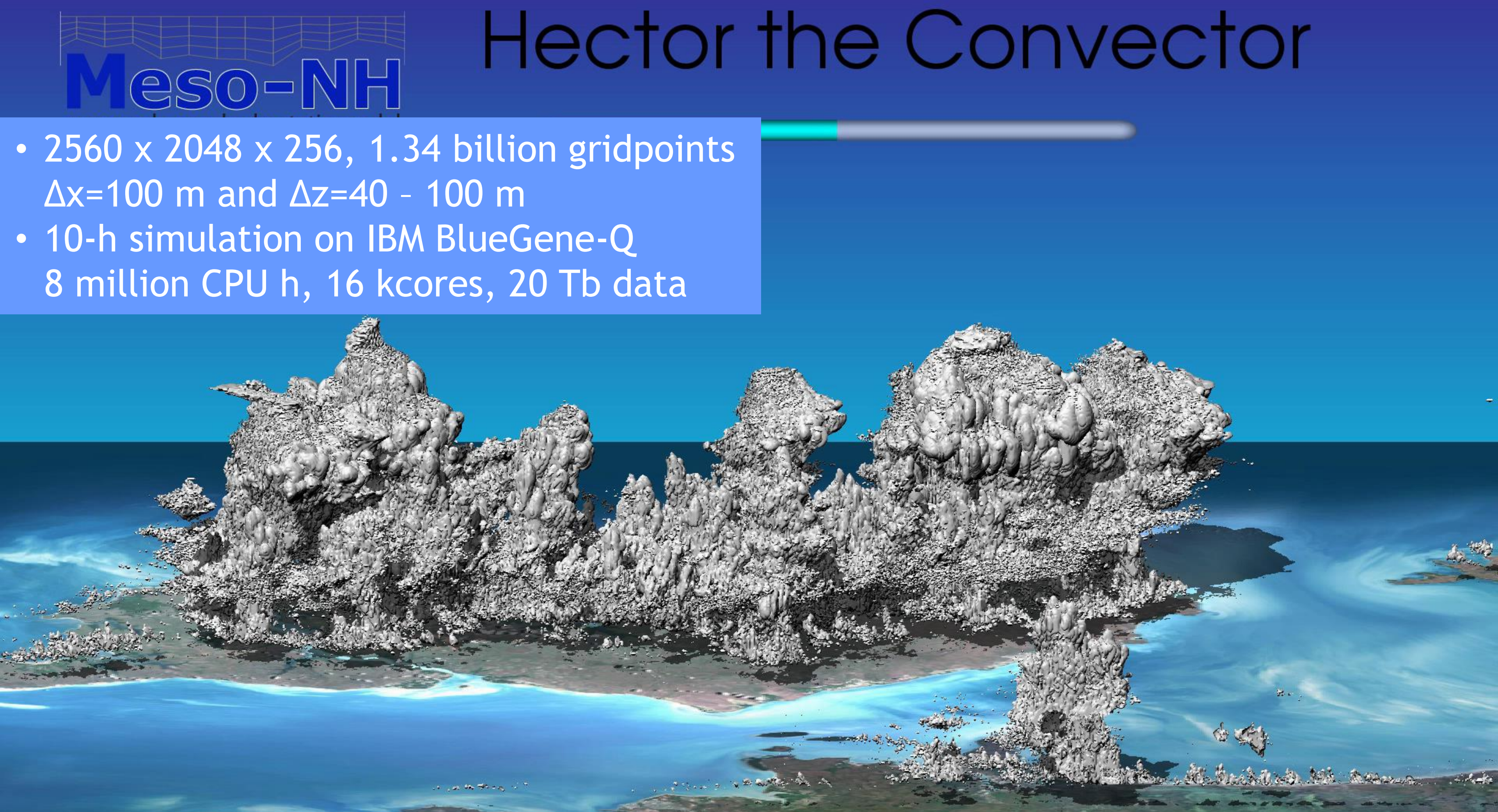
SLDST, longest trajectory = 60 h, nb trajectories = 104



- ➢ Analysis of the properties of DCCs currently under investigation

Analysis of updrafts in a Giga-LES

- 2560 x 2048 x 256, 1.34 billion gridpoints
  Δx=100 m and Δz=40 – 100 m
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data

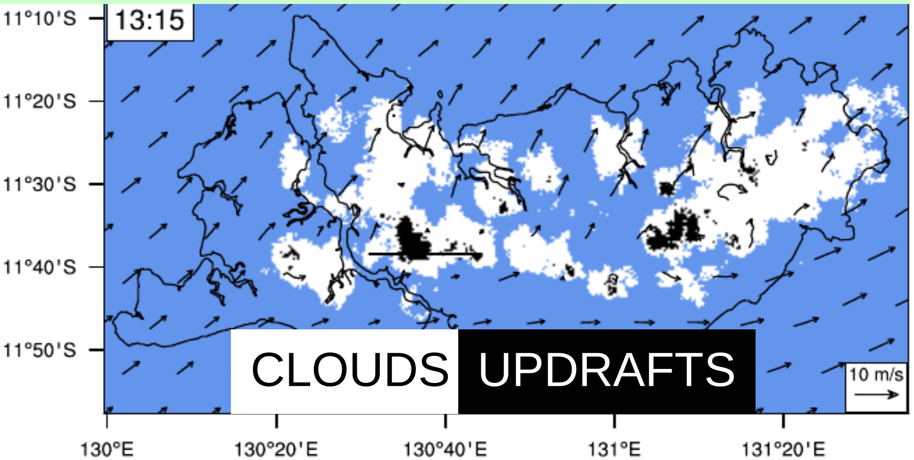


Video on https://youtu.be/xjPumywGaAU

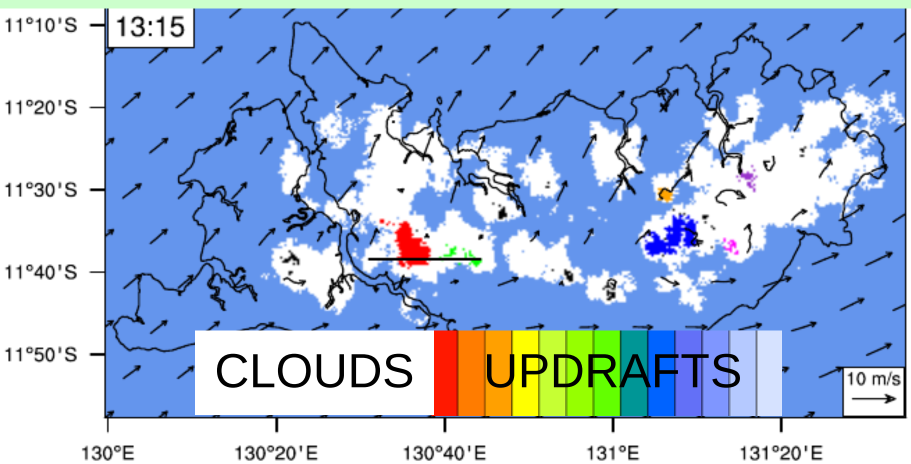
Dauhut et al., Atmos. Sci. Lett. 2015

Identification of the tallest updrafts

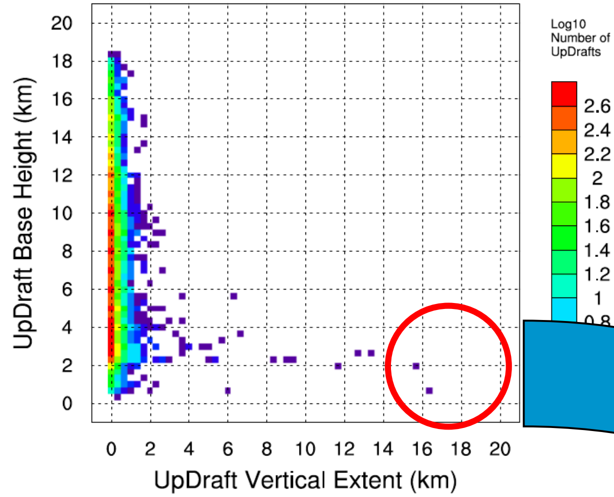
Step 1: detection of updrafts on every gridpoint where w>10 m/s

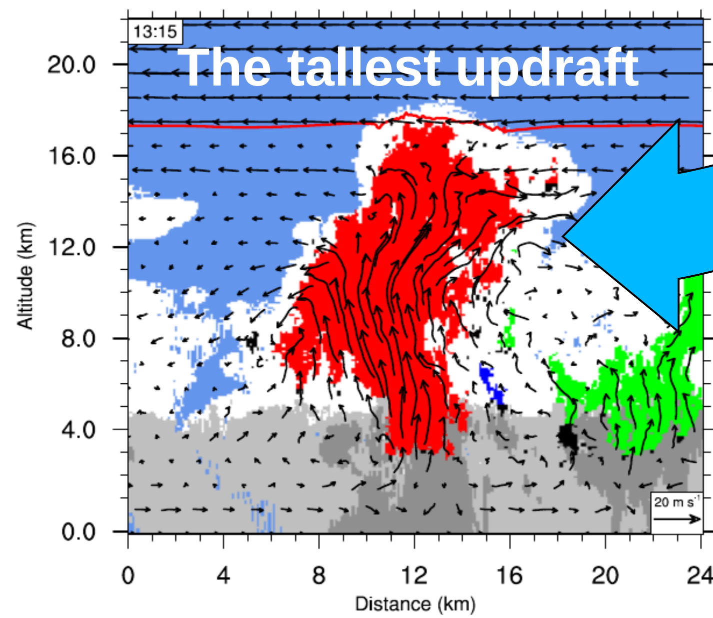


Step 2: identification of updrafts as object

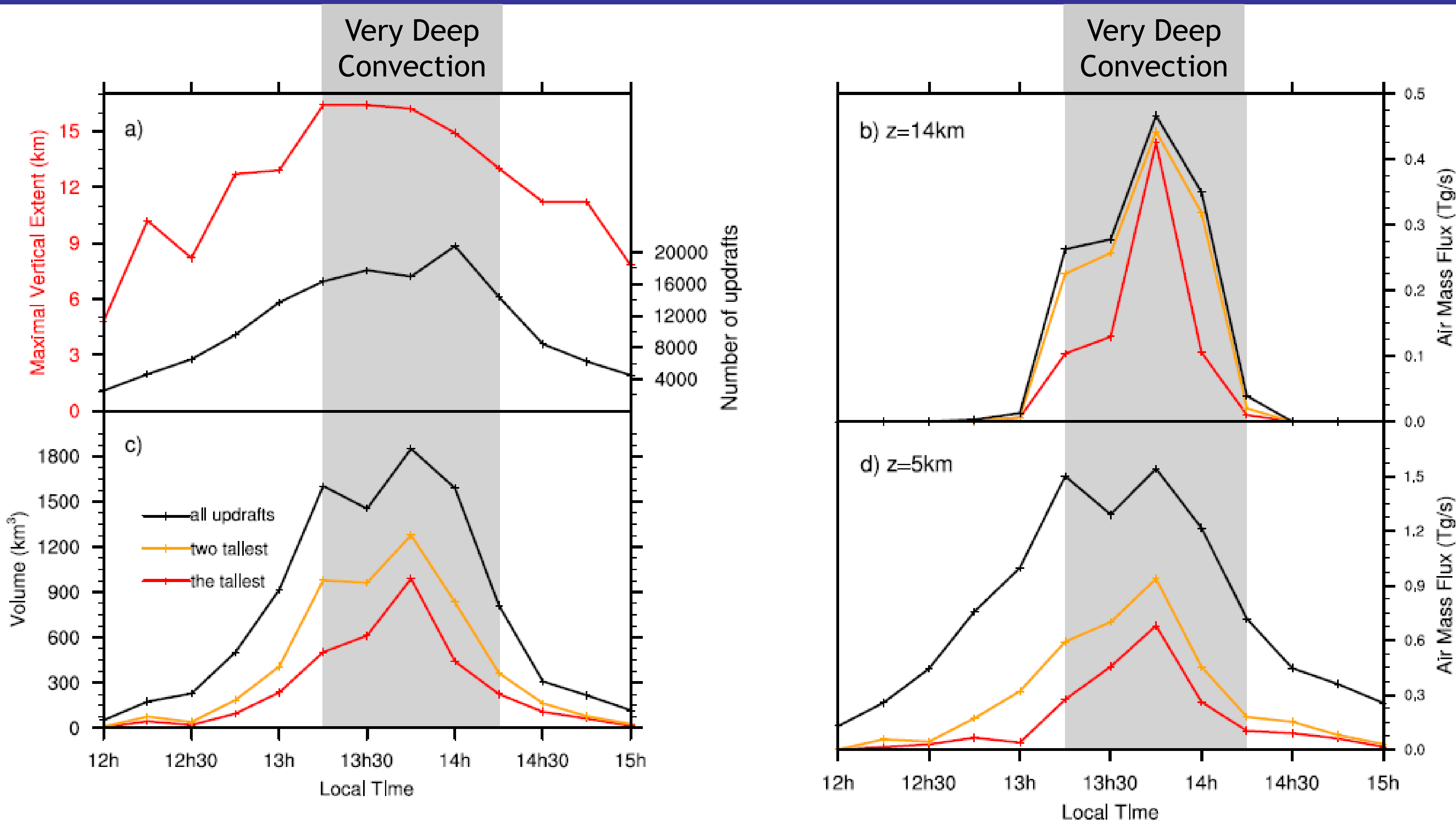


Step 3: Statistics of updrafts





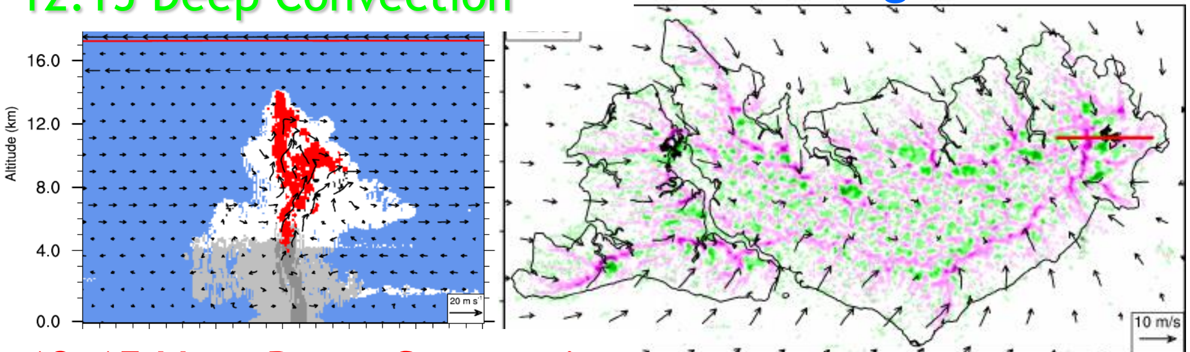
The tallest updrafts, why bother?



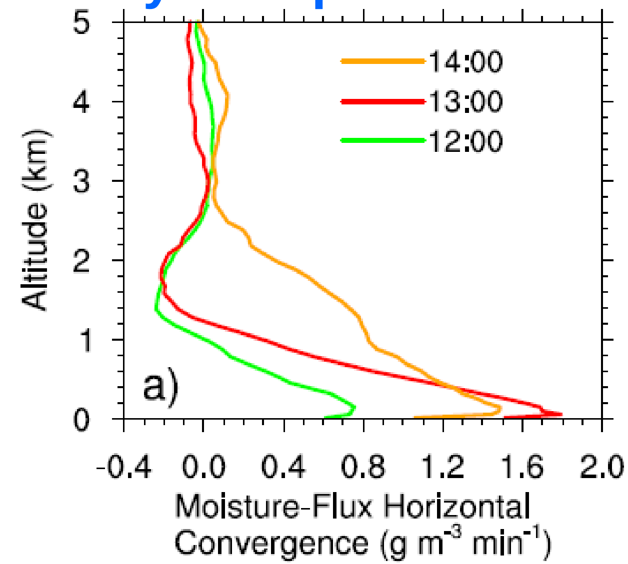
The two tallest updrafts account for more than 90% of the total mass flux into the Tropopause Tropical Layer

Formation of the tallest updrafts

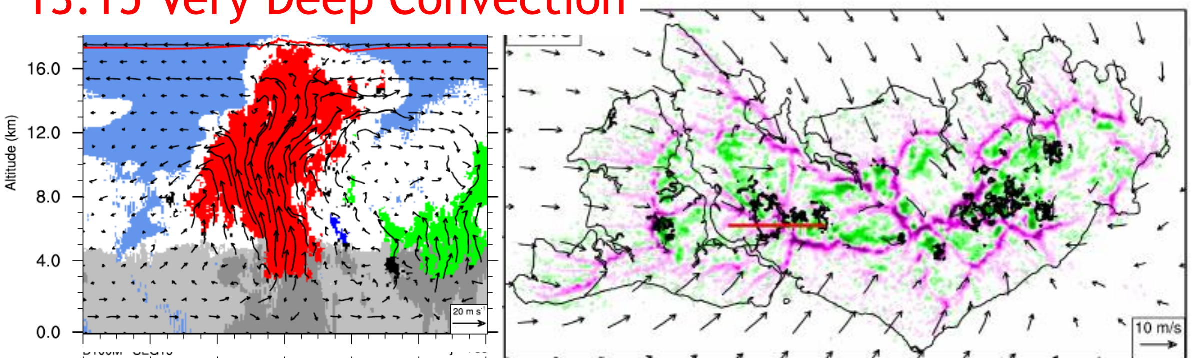
12:15 Deep Convection

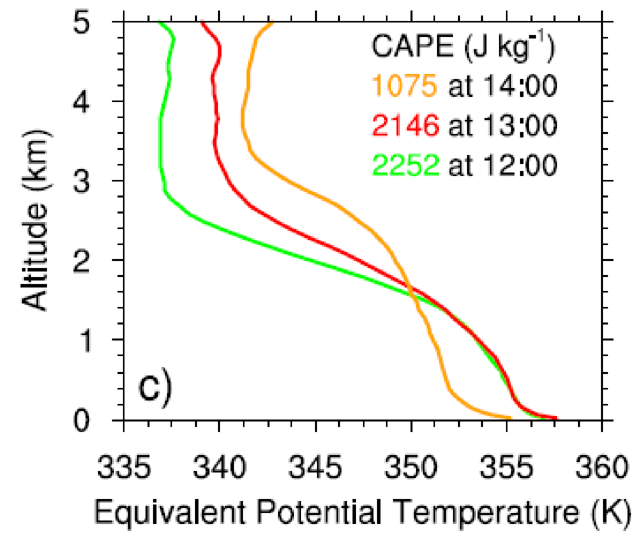


Convergence intensified by cold pools

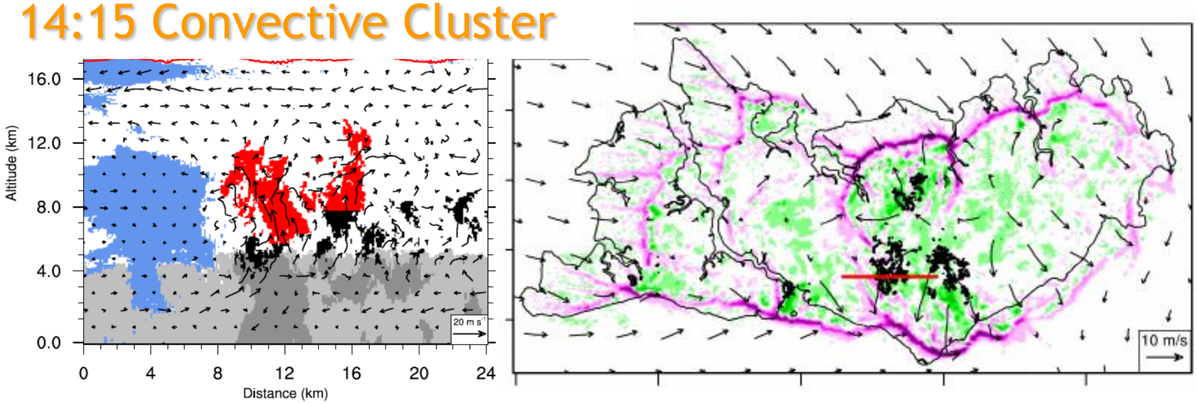


13:15 Very Deep Convection

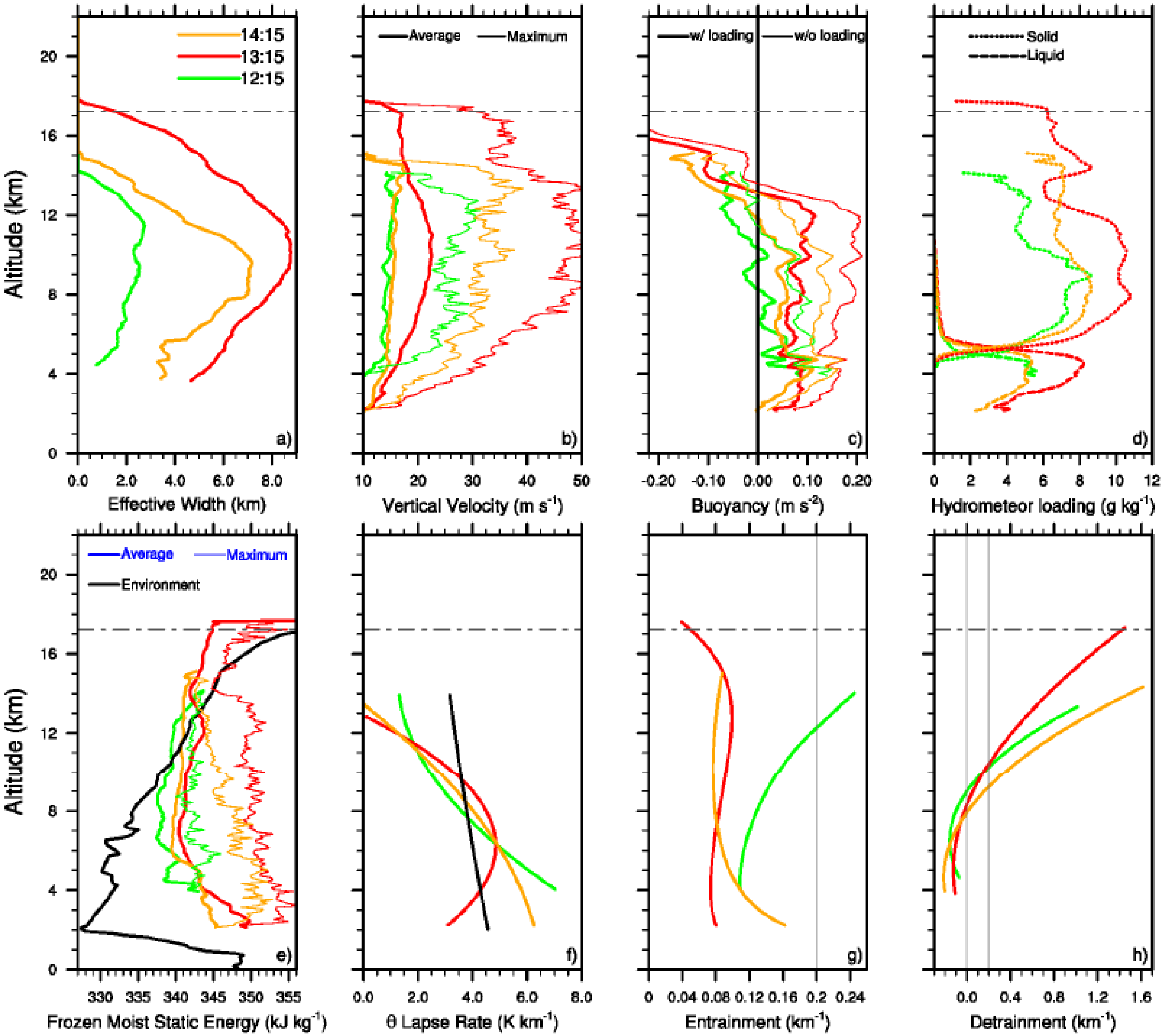




14:15 Convective Cluster



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