CRM and LES approaches for simulating tropical deep convection: successes and challenges

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with contributions from
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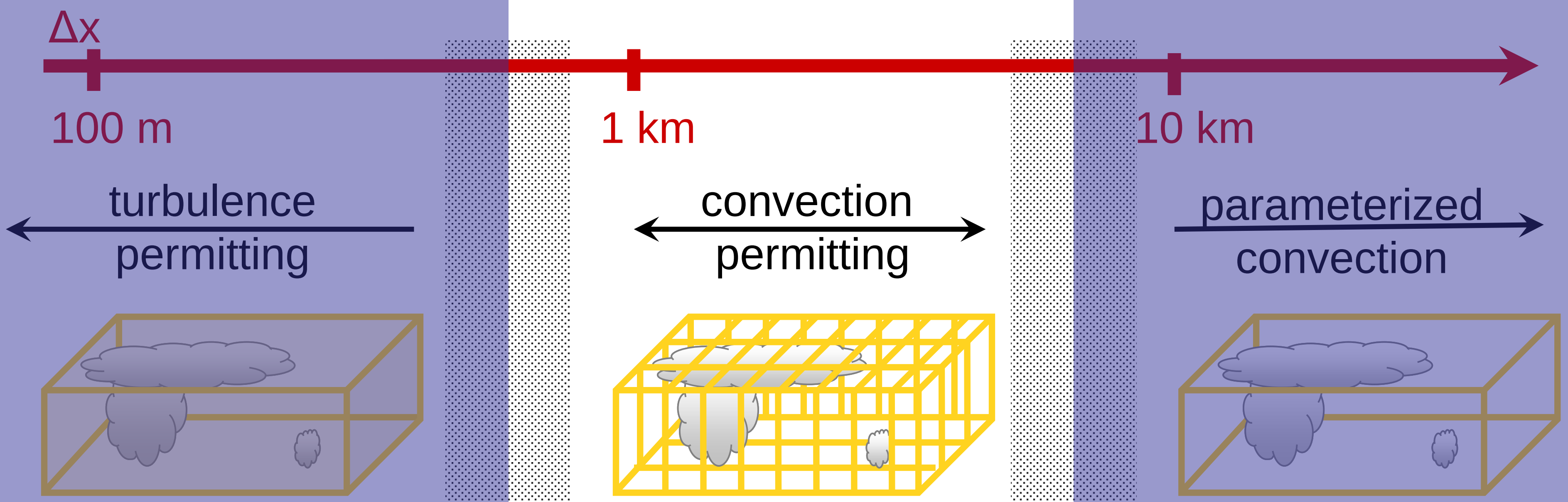
Representation of deep convection



Δx

100 m

1 km

10 km

turbulence permitting

convection permitting

parameterized convection

CRM
cloud-resolving
model

RCM/GCM
climate model

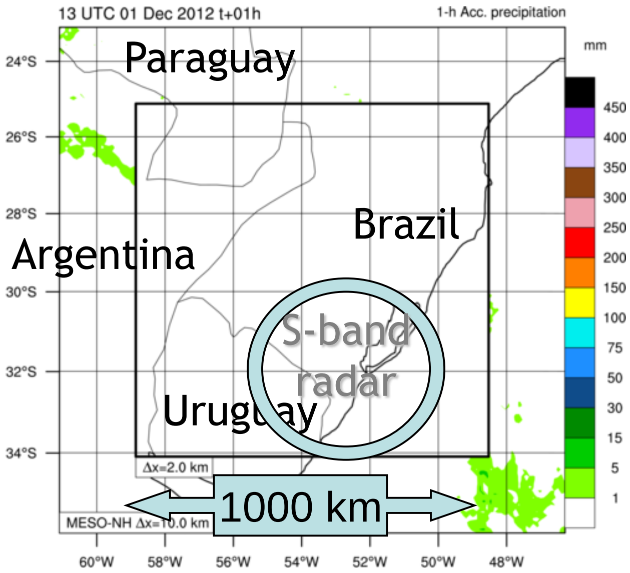
- large uncertainties

LES
large-eddy
simulation

- Uncertainties on turbulence, microphysics and radiation

- Uncertainties on microphysics and radiation

Assessment of cloud forecasts



36-h daily forecasts with Méso-NH w/ Δx = 2 km for the CHUVASUL field campaign (Nov.-Dec. 2012)

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

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*

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

Machado and Chaboureau, Mon. Wea. Rev. 2015

Tracking of cloud systems

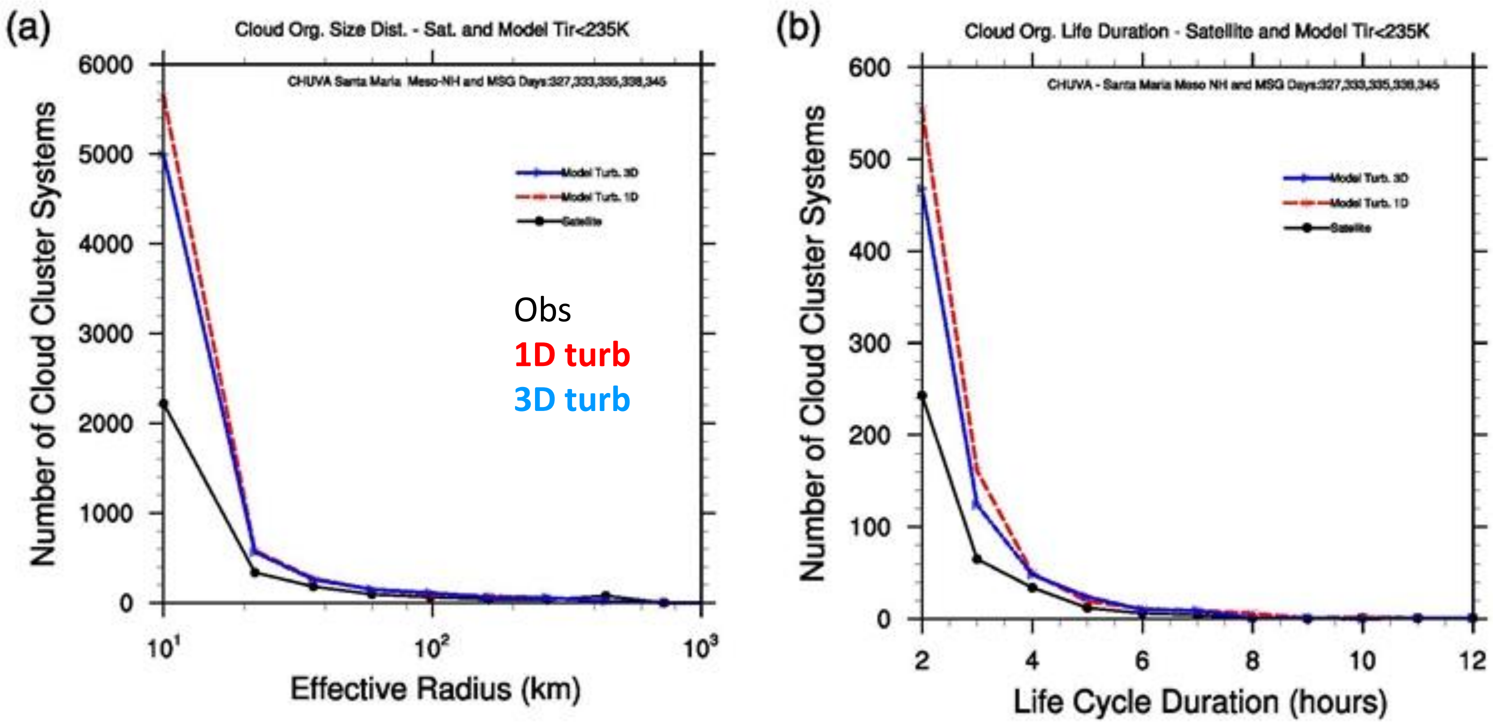


FIG. 7. Organization of clouds (Tir < 235 K) observed by MSG and simulated by Méso-NH with 1D and 3D turbulence for the 5 golden days simulations. (a) Size distribution and (b) life cycle duration.

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

Sensitivity to the mixing length

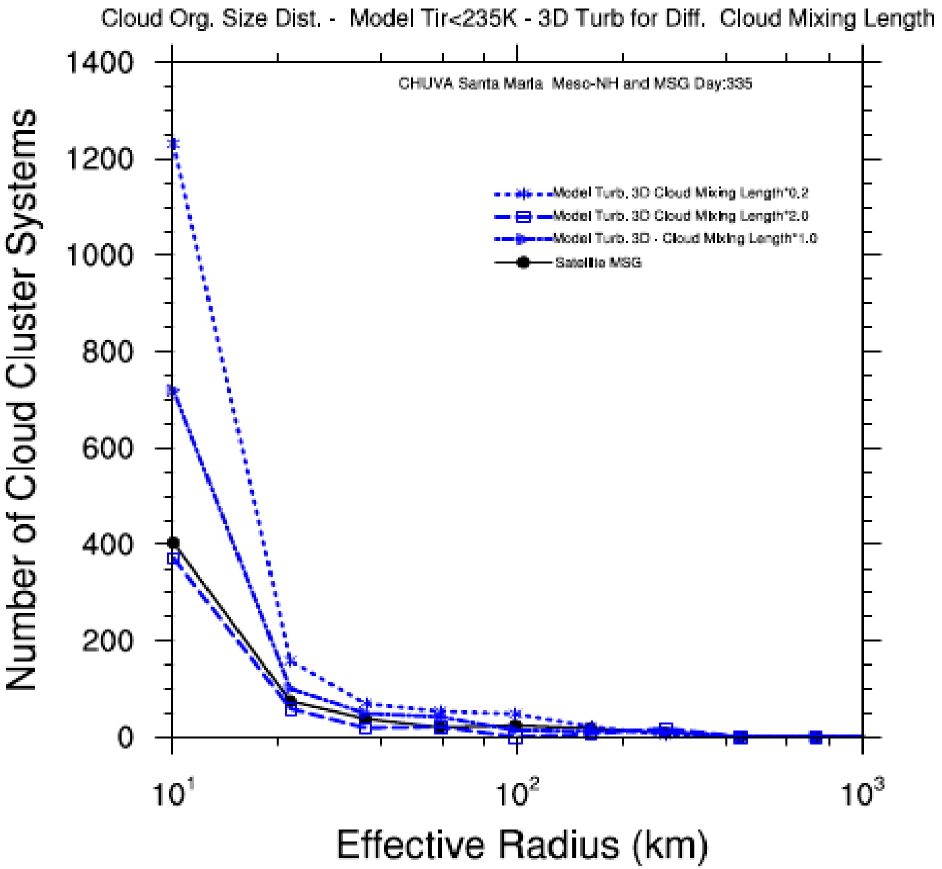


FIG. 11. Organization of clouds (Tir < 235K) observed by MSG and simulated by Méso-NH with 3D turbulence for cloud mixing length multiplied by 0.5, 1.0, and 2.0, for simulation of Julian day 335.

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

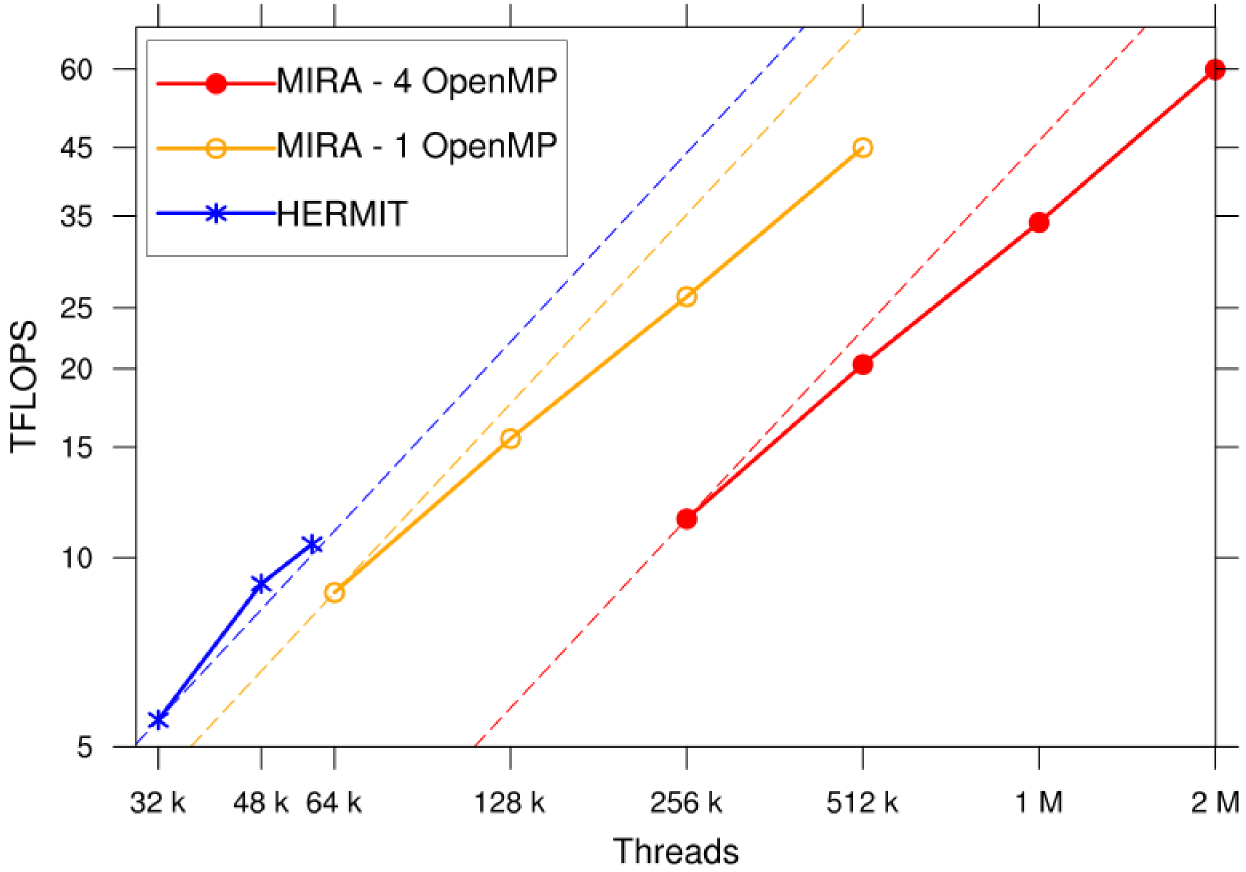
Mixing length 2 times smaller: much more small systems

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

The tracking technique can help for tuning the turbulence parameterization

Adaptation of Meso-NH to large grids

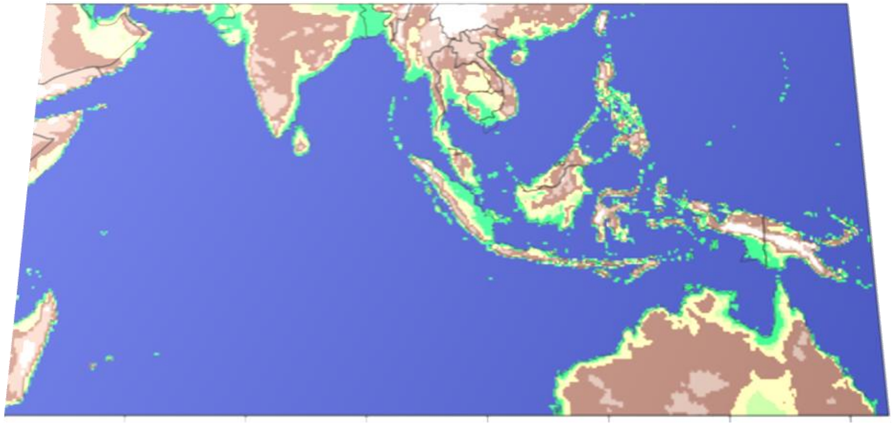
- Changes in I/O and pressure solver lead to run Meso-NH with million grid points and with 1-10 kcores for research use
- 60 sustained TFLOPS was achieved using 2 billion threads for a grid of 4096 × 4096 × 1024 points (17 billion grid points)



Lac et ai., in preparation for GMD

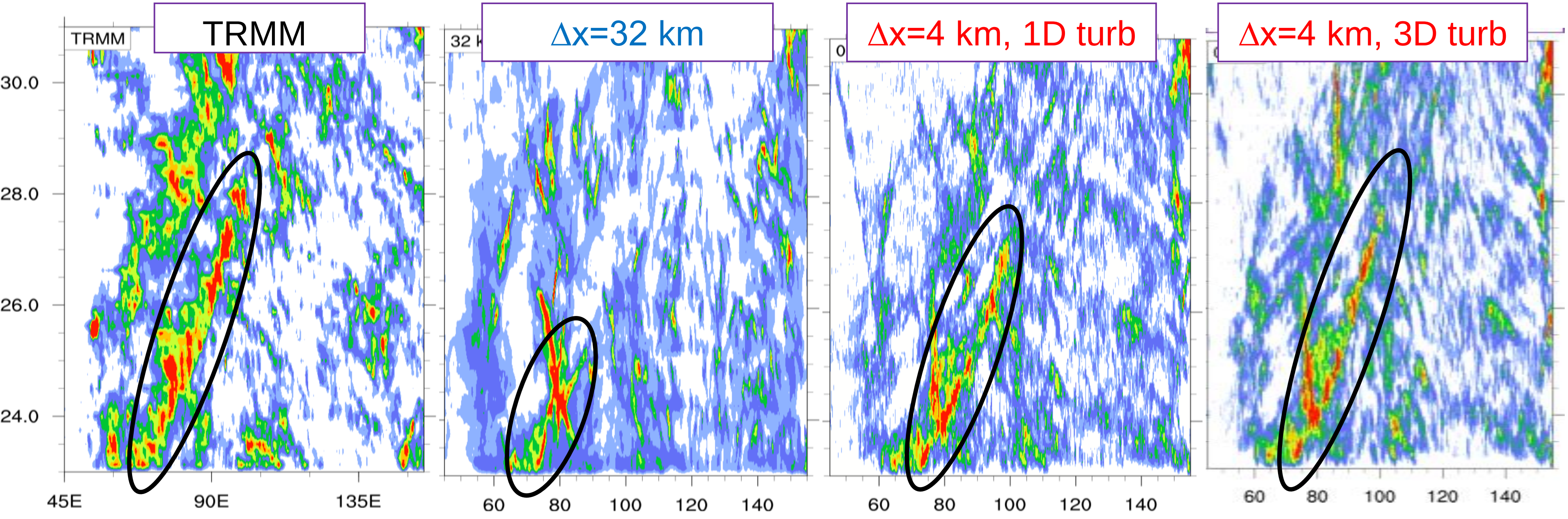
Simulations of MJO episodes

- What is the role of convection in the propagation of MJO signal?



23-30 Nov. 2011, 6-14 April 2009, 9-28 Feb. 2013

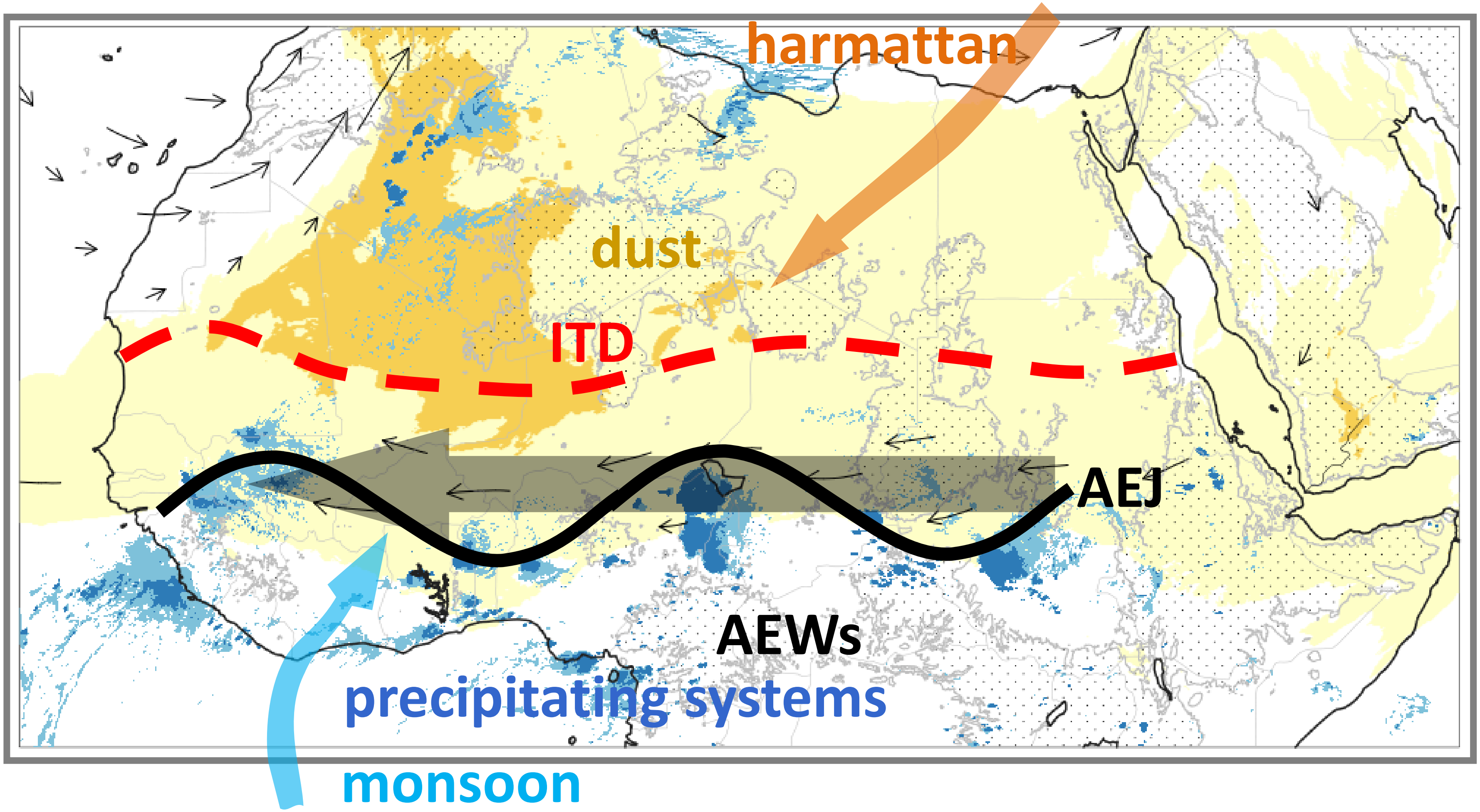
- **HiRes** Δx=2.5 km, 2400 x 1800 x 72, 1/2 billion gridpoints
- **LowRes** Δx=32 km with KFB convective parameterization



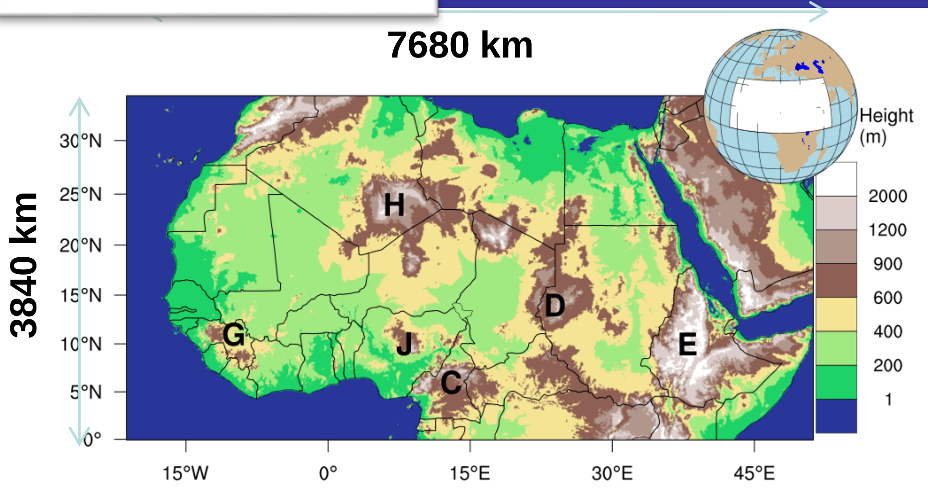
MCSs over northern Africa

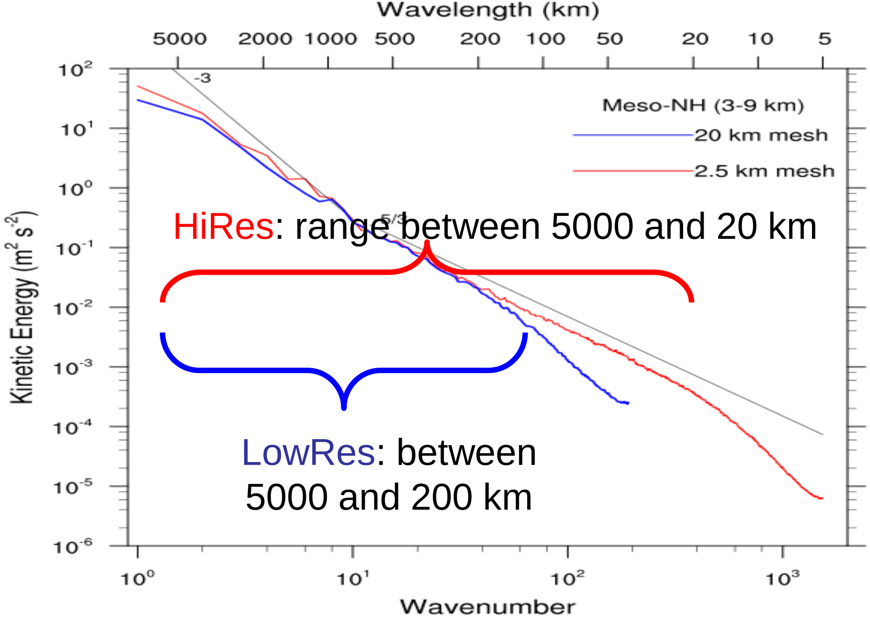
- What controls the distribution and variability of precipitation?
- What is the radiative impact of dust on the atmosphere?

An AMMA case study: 9-14 June 2006 (Flamant et al., 2009)



Cloud-Resolving Modeling





HiRes: range between 5000 and 20 km

LowRes: between 5000 and 200 km

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

- **HiRes** Δx=2.5 km, 3072 x 1536 x 72, 1/3 billion gdpts, 7 TB , with dust scheme
- **LowRes** Δx=20 km with KFB convective parameterization and dust scheme
- **HiNod** Δx=2.5 km, no radiative effect of dust

Standard parameterizations: SURFEX, ICE3 bulk microphysics, 1D turbulence, RRTM radiation, dust by DEAD + ORILAM

Assessment of simulations with MSG BT observation and TRMM 3B42 rain product

Identification of cloud types

- Deep convective clouds (DCCs): BT<230K
- Cirrus anvil clouds 230K<BT<260K

Tracking of large DCCs (Deff> 120 km) **= MCSs** using an overlap method

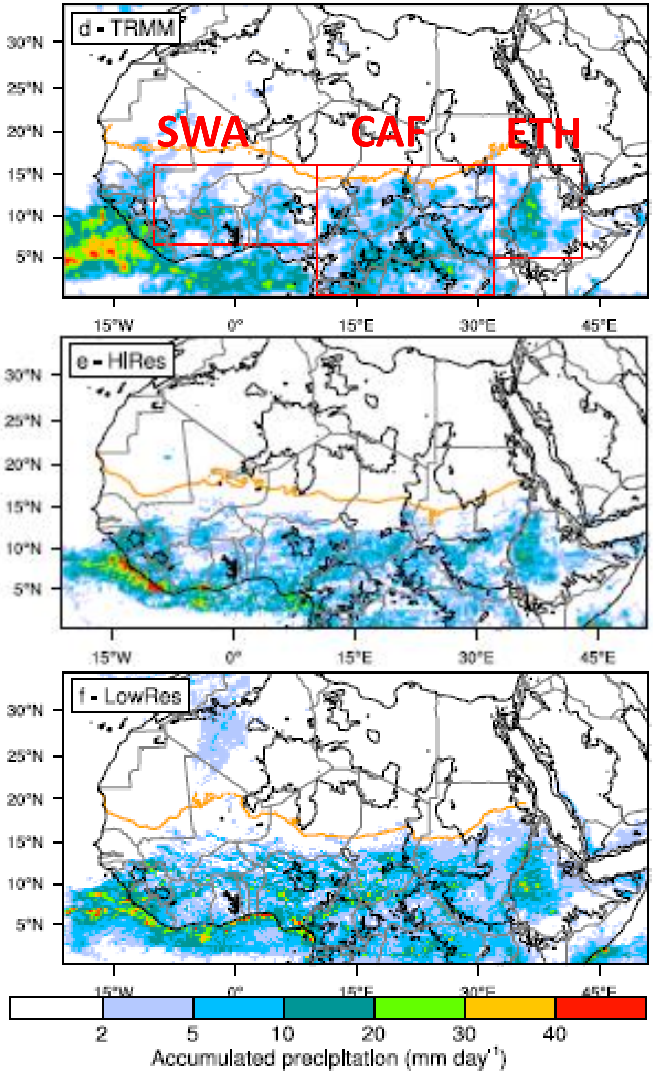
Properties of long-lived MCSs

Rain, clouds, dynamics, etc.

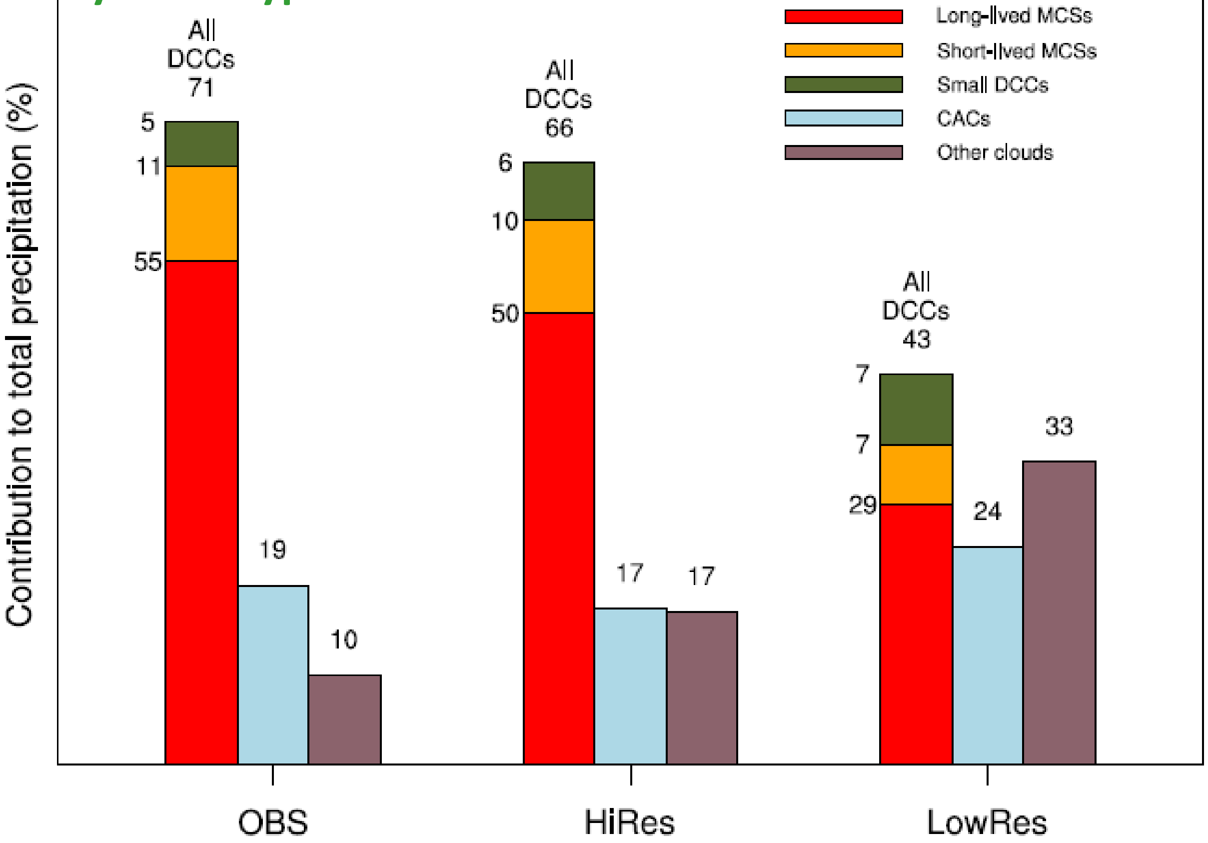
PhD work of Irene Reinares Martínez

Distribution of precipitation

Spatially



By cloud type



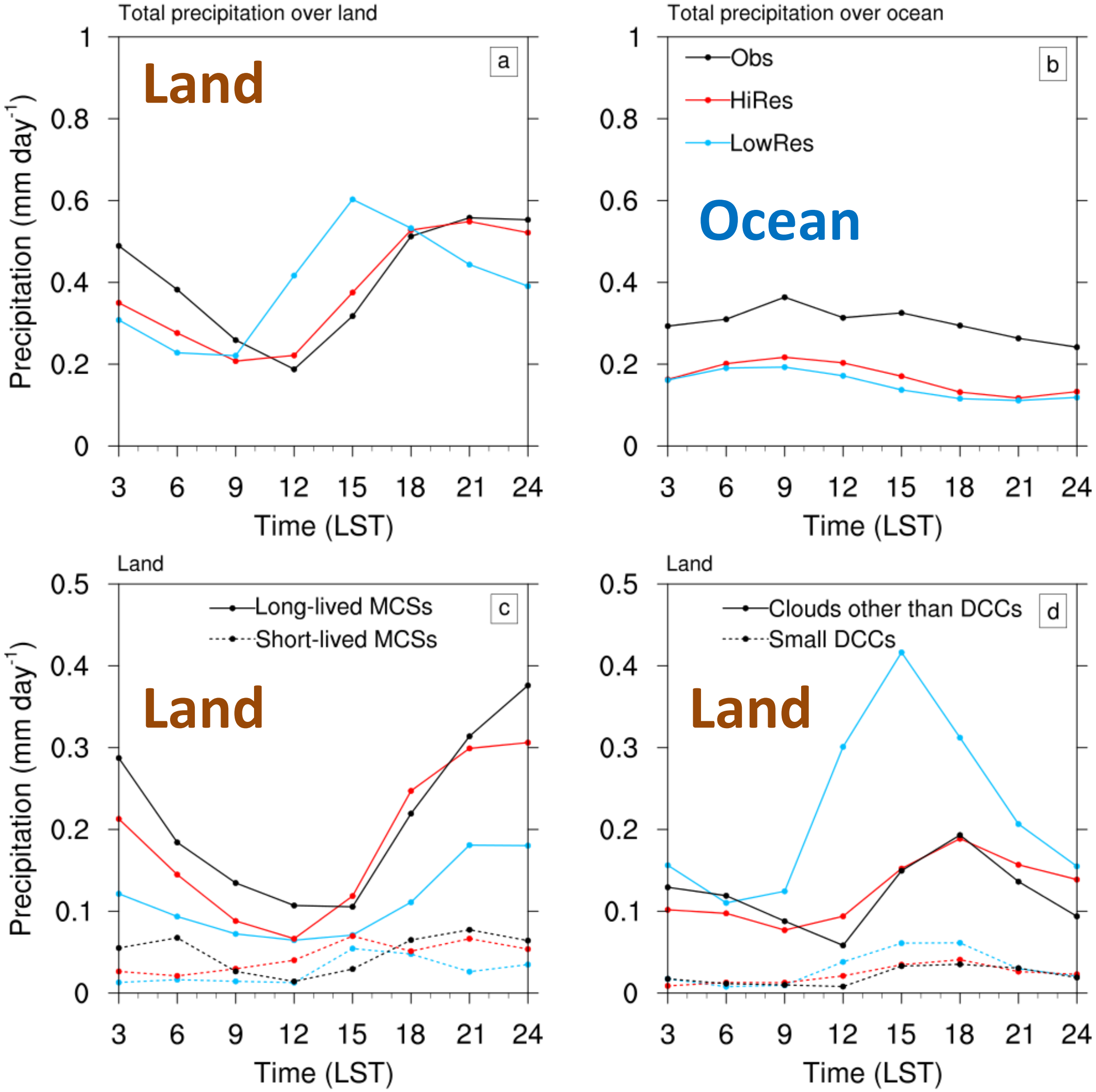
Most of precipitation south of 15°N

LowRes: low values more frequent

Long-lived MCSs (>6h) account for 55% of precipitation

Good agreement between **OBS** and **HiRes**

Diurnal cycle of precipitation

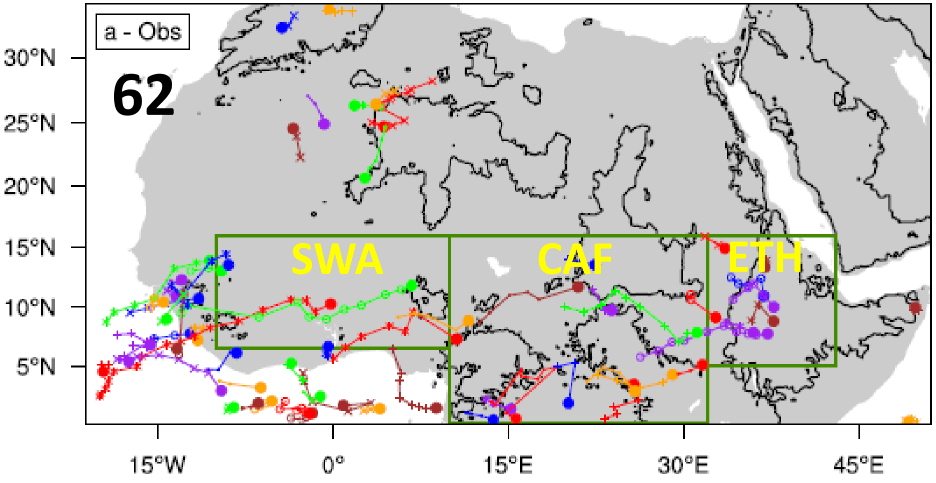


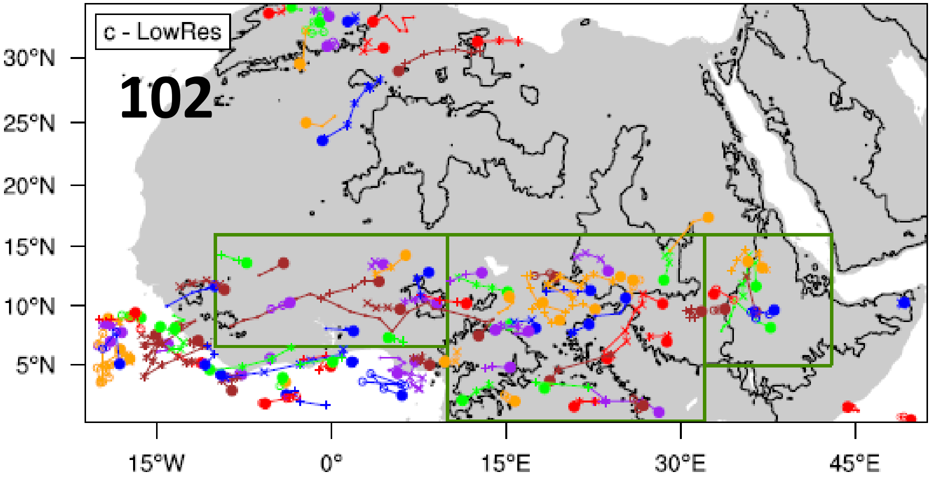
OBS: maximum of precipitation at 21 LST 1st contributor: long-lived MCSs

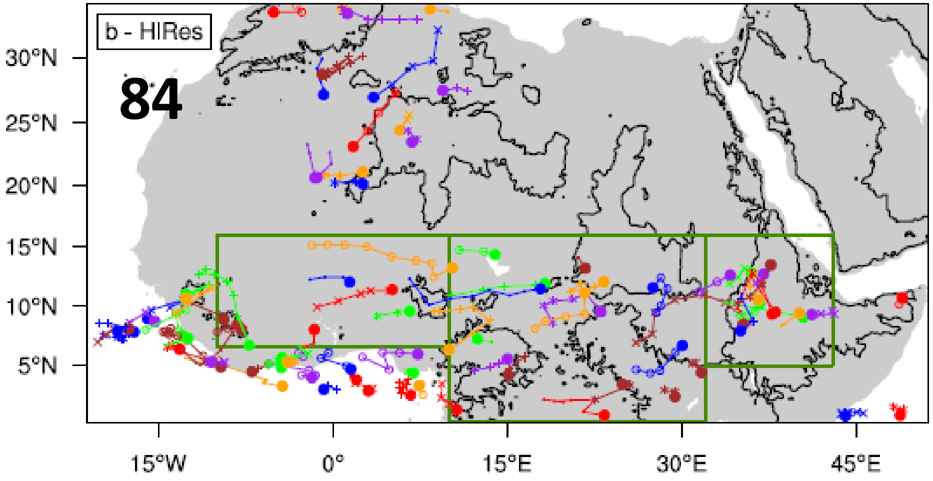
HiRes good agreement in amplitude and phase. Lack of nocturnal precipitation (mostly from long-lived MCSs)

LowRes peak too early (15 LST)

Long-lived MCSs (>6h) tracks



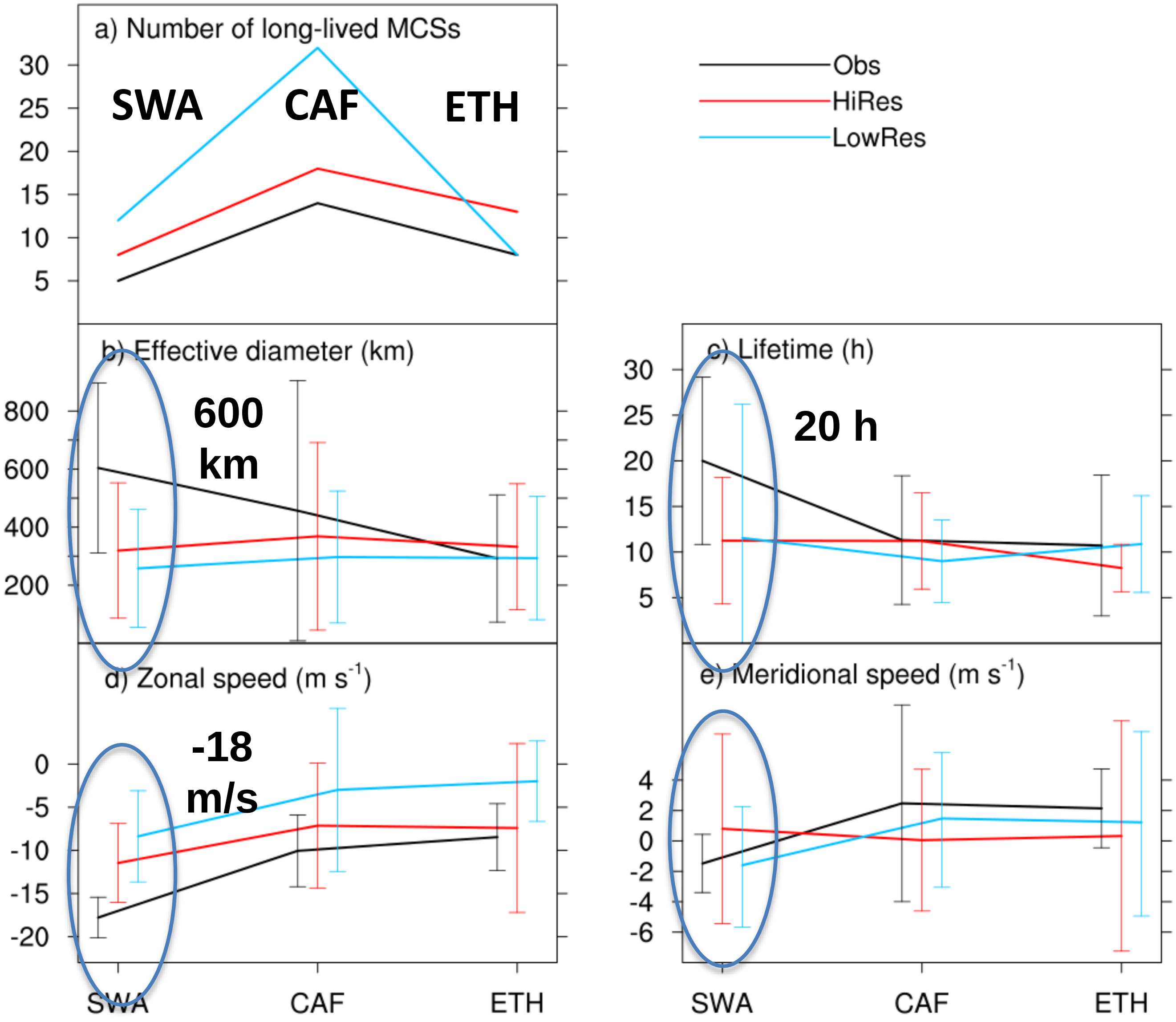




Propagation overall to the west

The number of trajectories differs
OBS: 62, **HiRes:** 84, **LowRes:** 102

Characteristics of long-lived MCSs

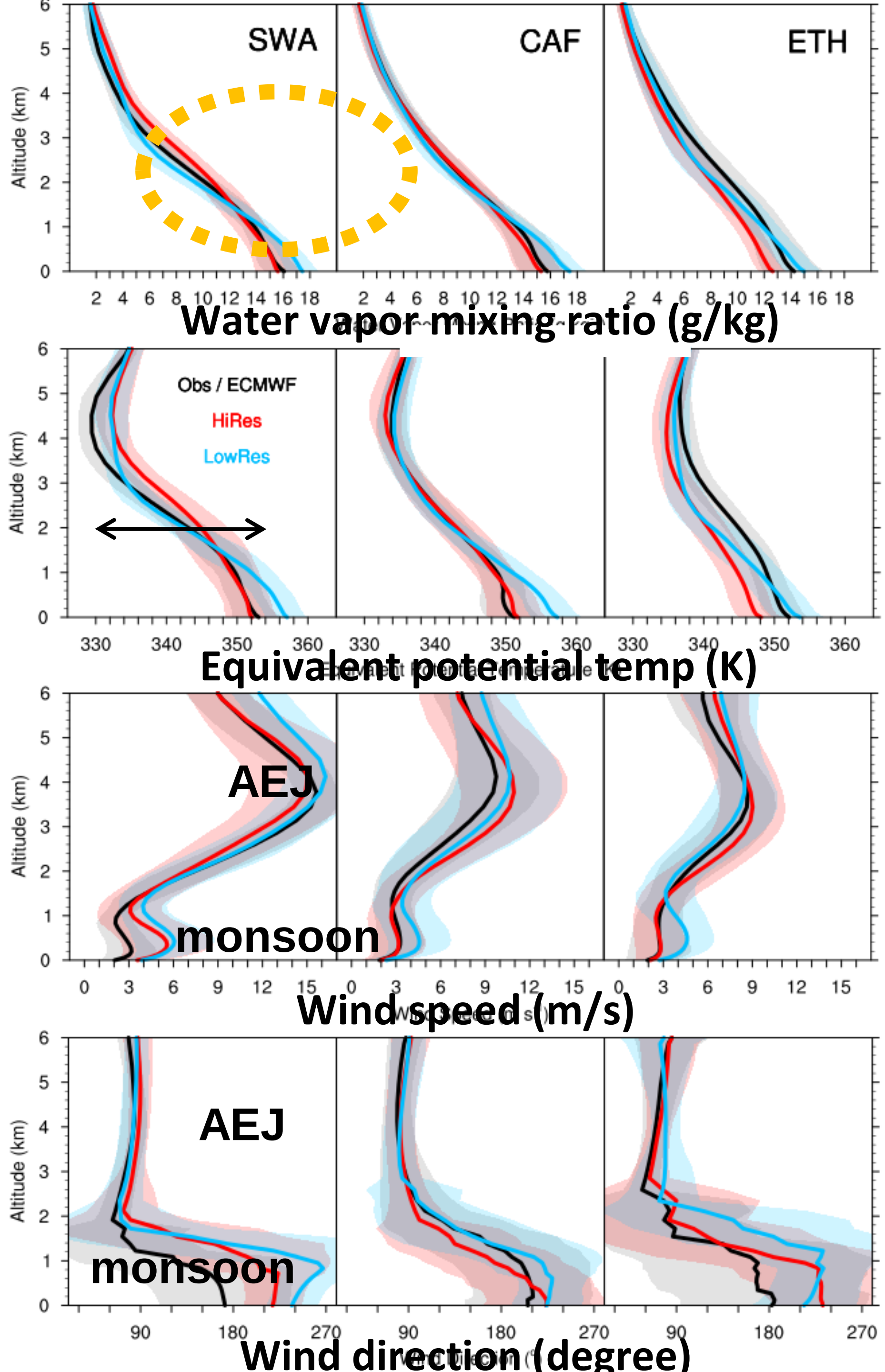


OBS: most organized long-lived MCSs in SWA

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

LowRes drawbacks more pronounced

6 h prior to the MCSs



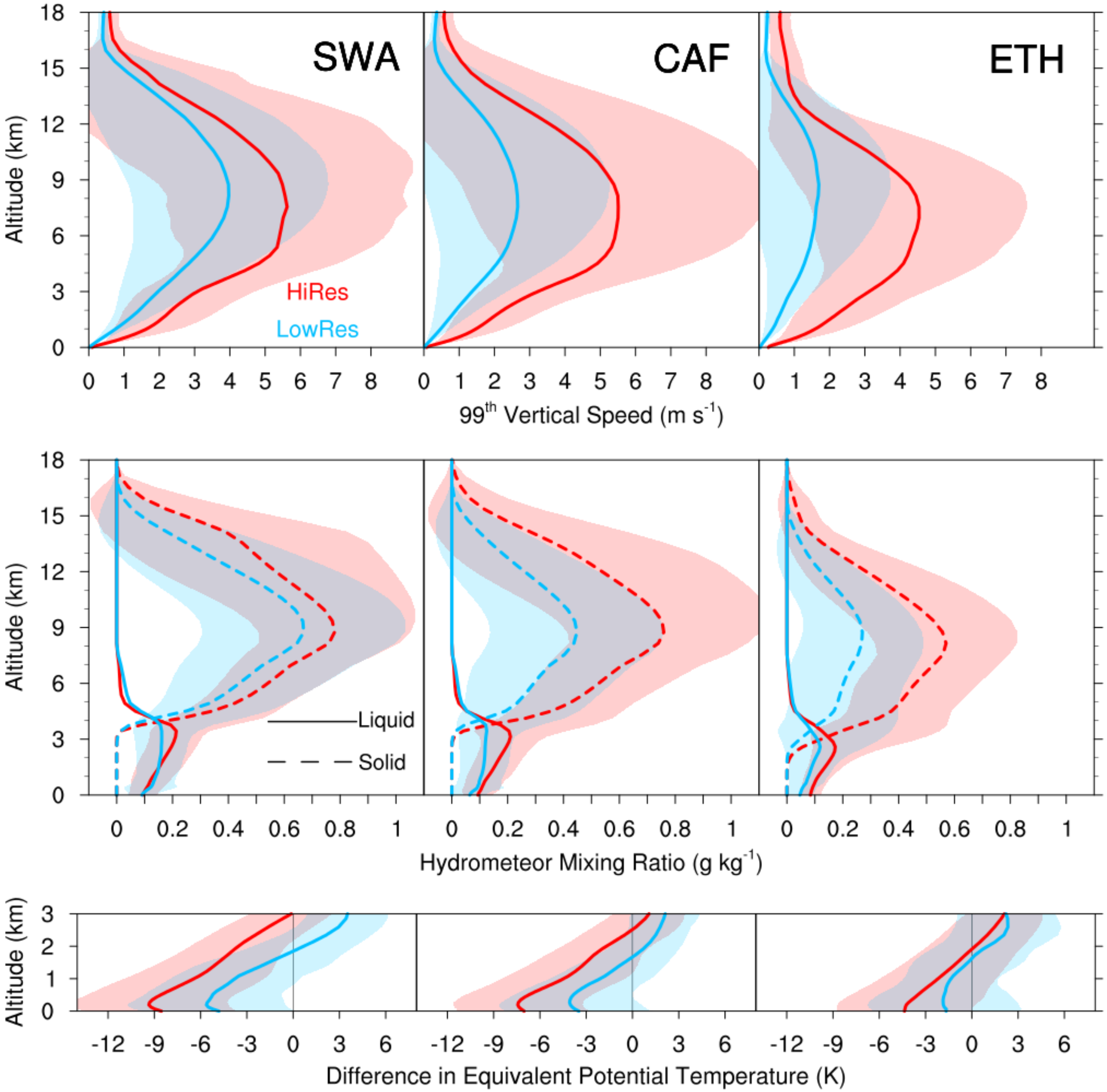
WVMR largest over SWA

OBS: largest conditional instability over SWA. **HiRes** agrees with **OBS**

HiRes wet bias at 2-3 km altitude

OBS: largest wind shear over SWA

Profiles inside MCSs

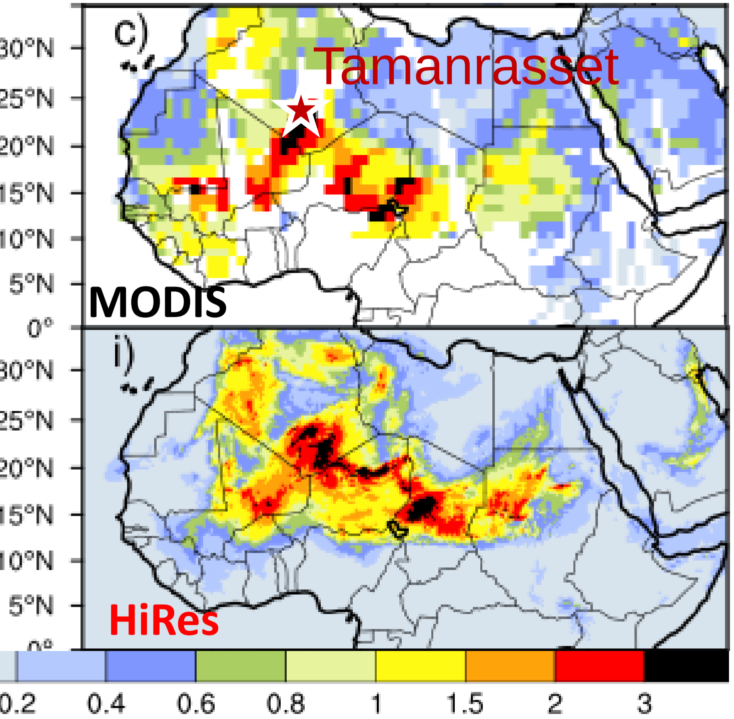


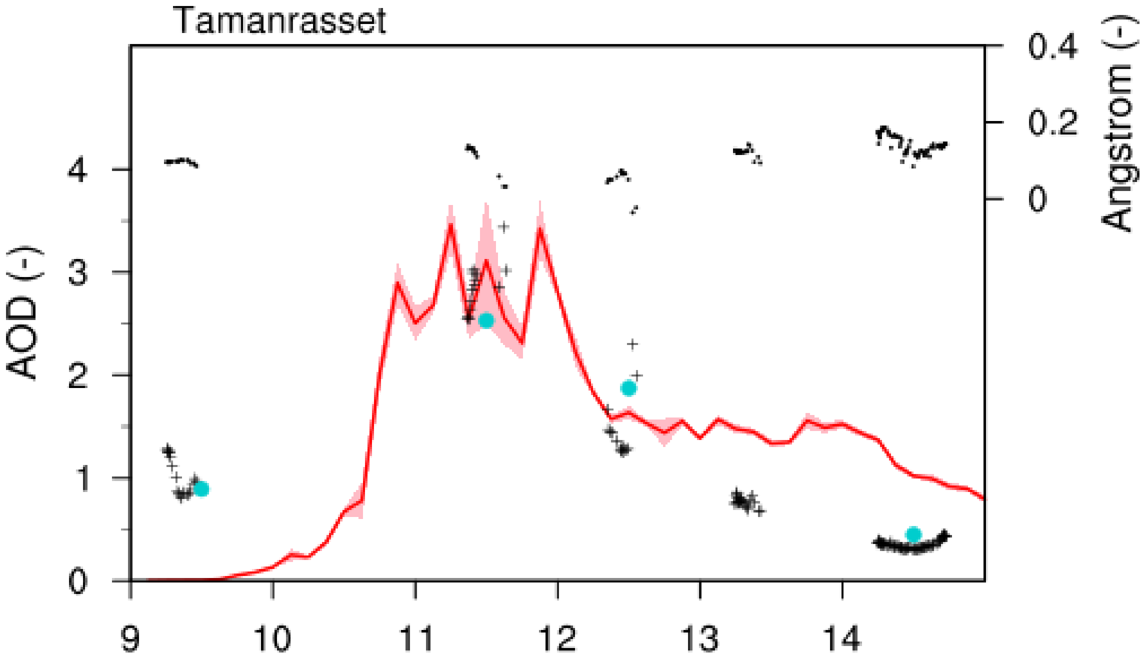
Most intense convection over SWA and CAF: strongest updrafts and cold pools, and largest hydrometeors loading

HiRes: convective updrafts better resolved leading to more intense convection than for **LowRes**

Assessment of dust

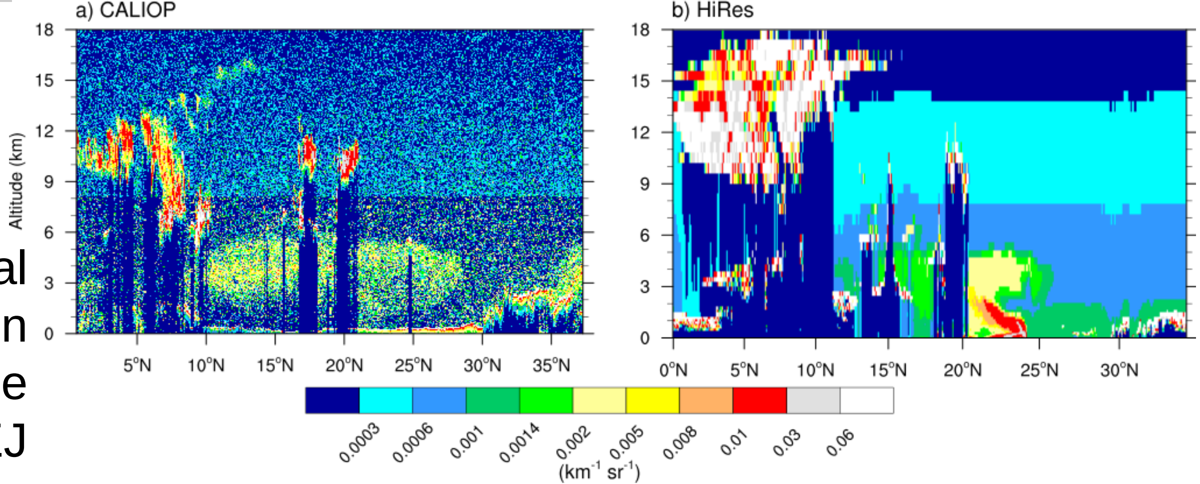
11 June 2006 around 1200 UTC





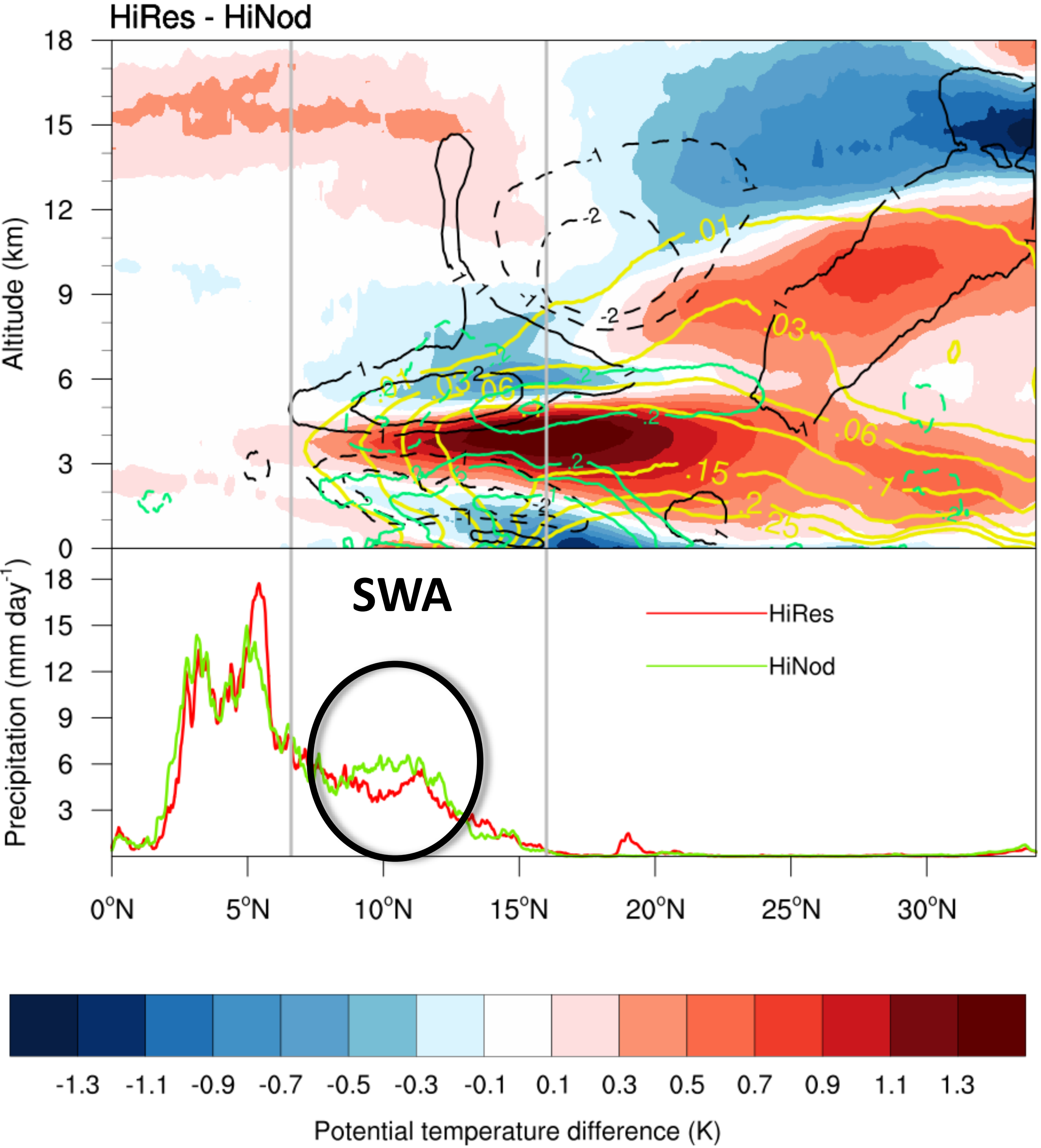
AOD larger in SWA than in other sub-regions

14 June 2006 around 0000 UTC



Vertical stratification captured: plume within AEJ

Impact on SWA

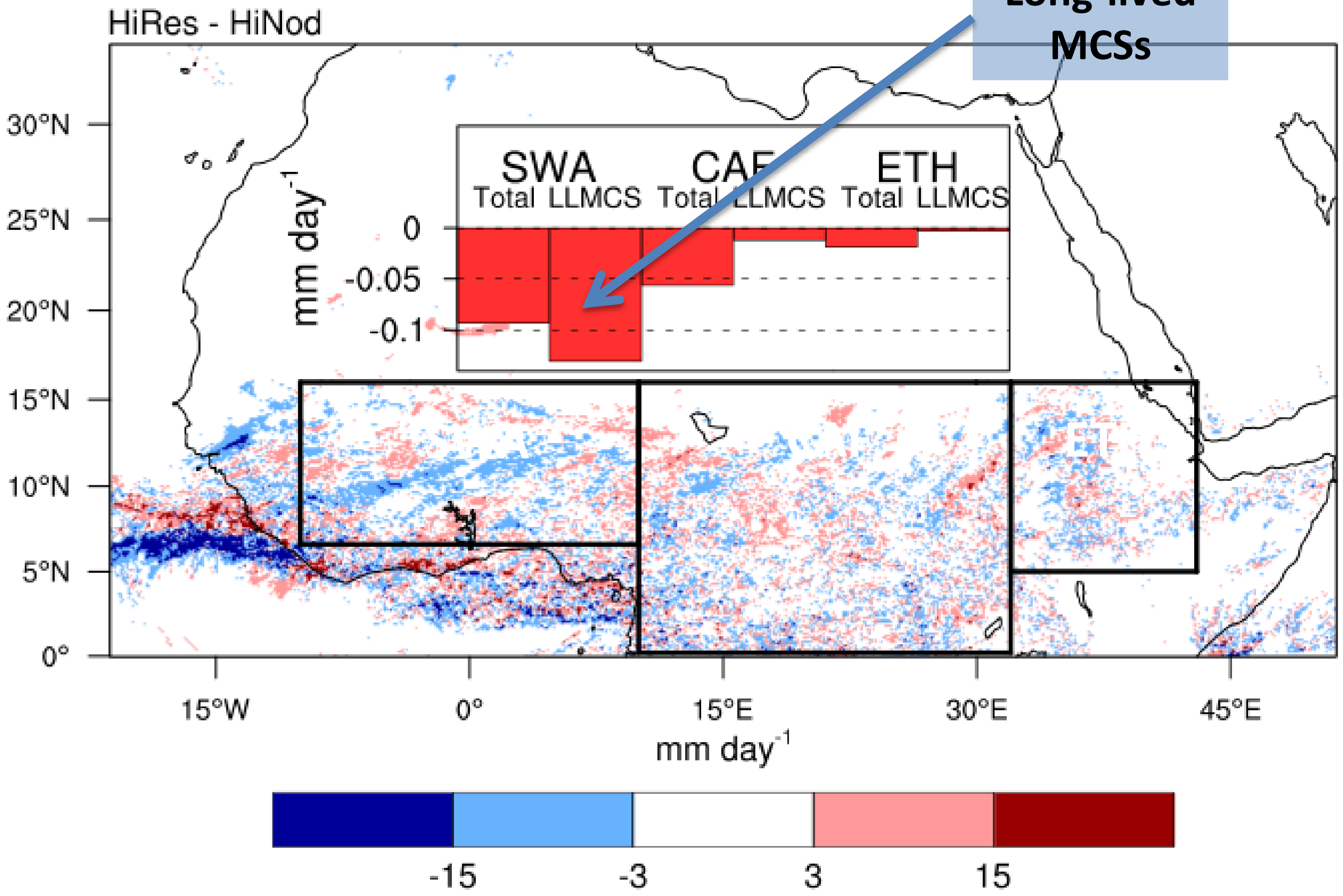


HiRes: warming at 3 to 5-km altitude (1.3 K) and cooling in the near-surface (0.3 to 0.9 K) with respecto to **HiNod**

HiRes: Increase of conditional stability

HiRes: moistening below 2-km altitude (1 g/kg) and <u>precipitation decrease</u> with respect to **HiNod**

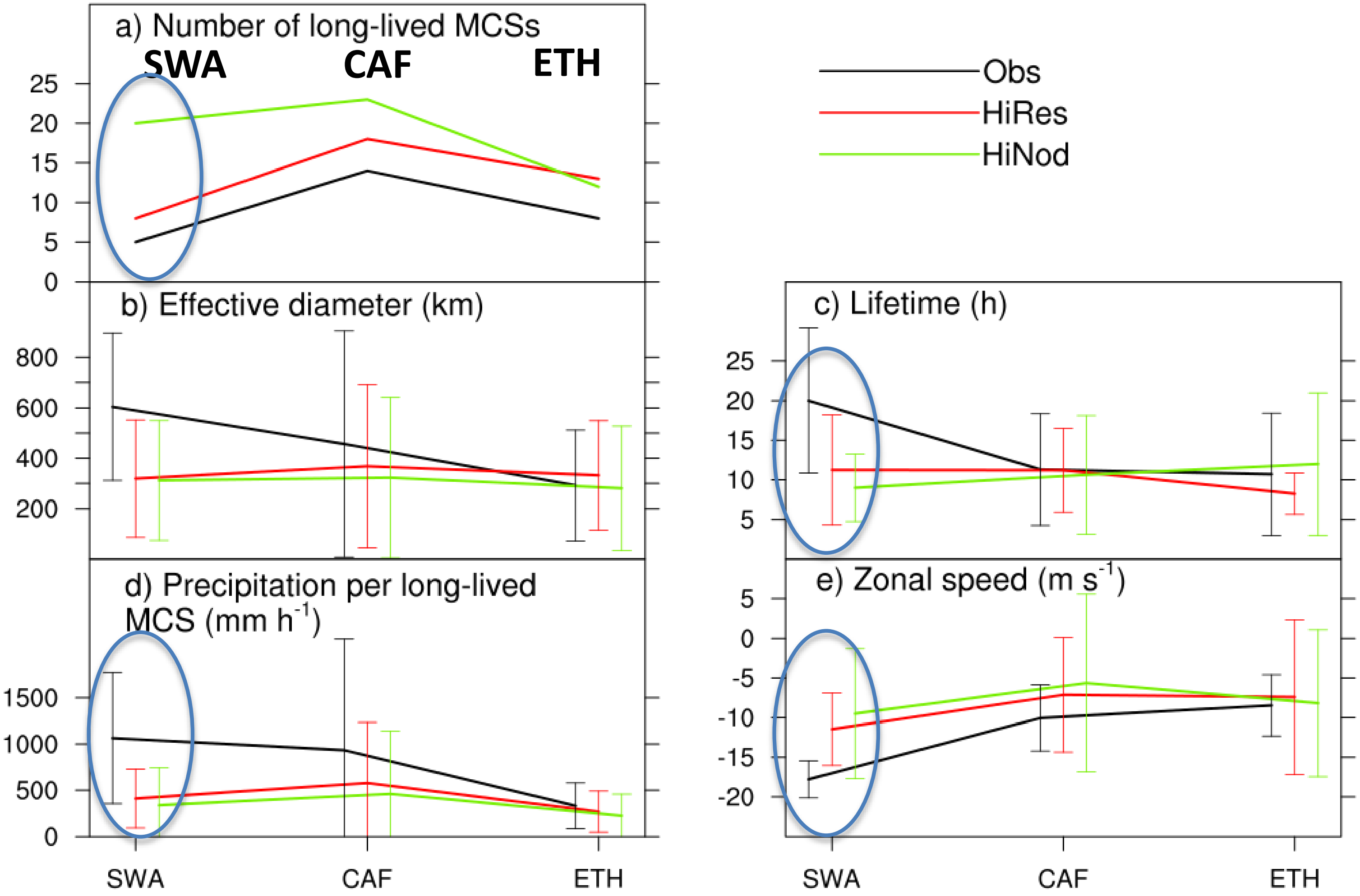
Impact of dust on precipitation



Long-lived MCSs

HiRes: rainfall drop in SWA mainly due to long-lived MCSs

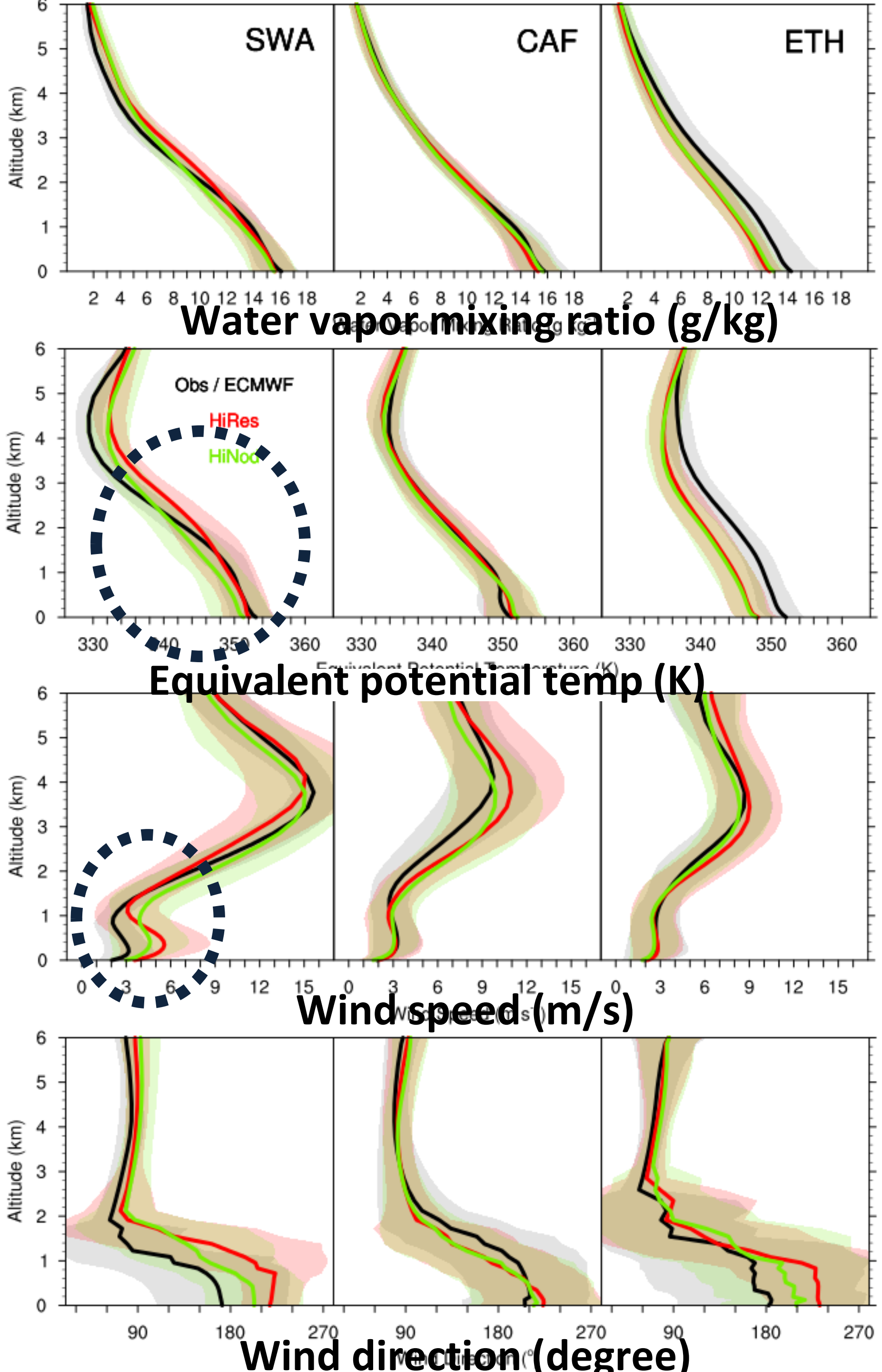
Impact of dust on long-lived MCSs



HiRes long-lived MCSs less numerous than **HiNod** in SWA

But long-lived MCSs longer-lived and more precipitating than in **HiNod**

6 h prior to the MCSs



Water vapor mixing ratio (g/kg)

Equivalent potential temp (K)

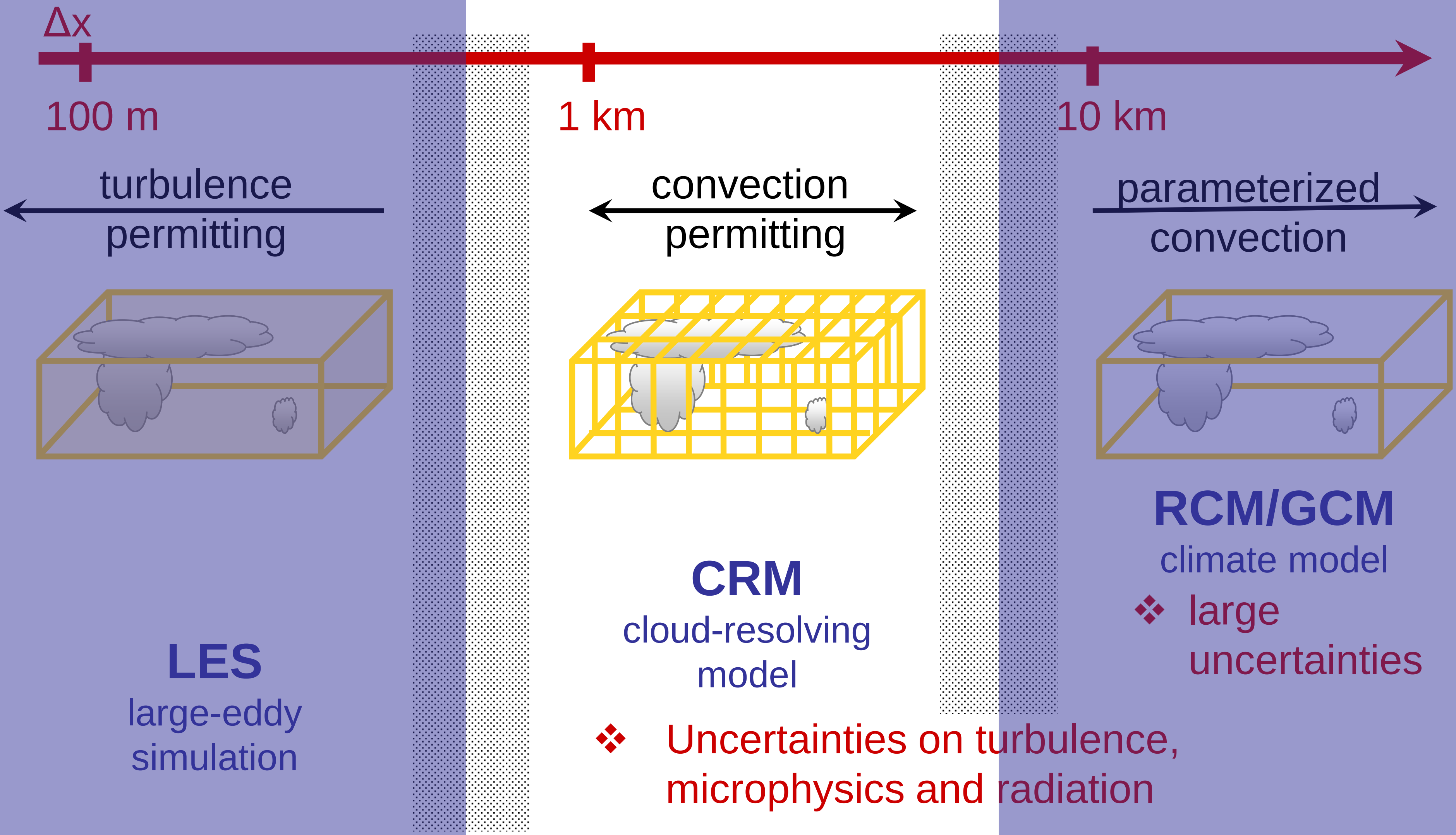
Wind speed (m/s)

Wind direction (degree)

More CAPE because less triggering of long-lived MCSs

Wind-shear is increased with dust

Representation of deep convection



Δx

100 m

1 km

10 km

turbulence
permitting

convection
permitting

parameterized
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LES
large-eddy
simulation

CRM
cloud-resolving
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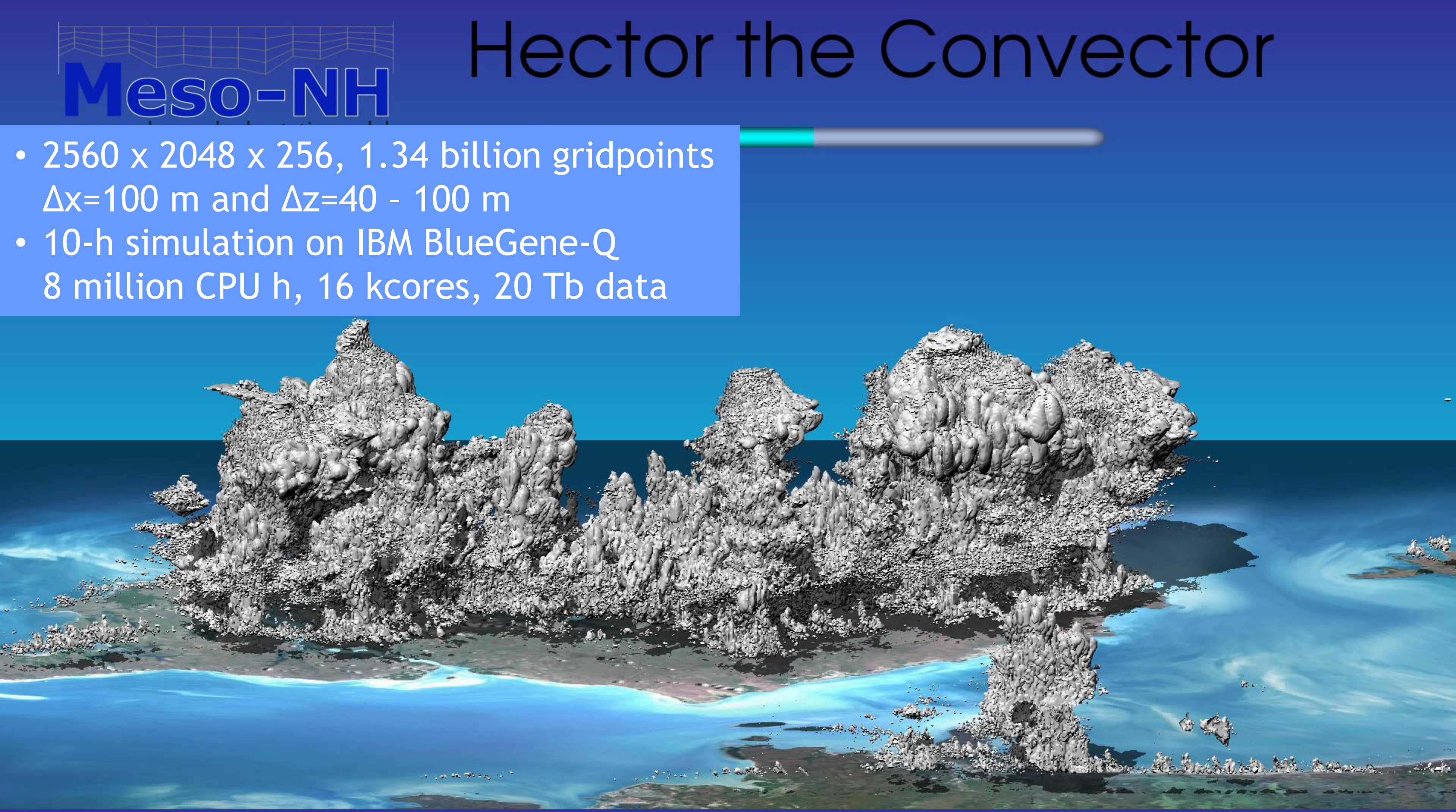
RCM/GCM
climate model

- large uncertainties

- Uncertainties on turbulence, microphysics and radiation

- Uncertainties on microphysics and radiation

Analysis of updrafts in a Giga-LES

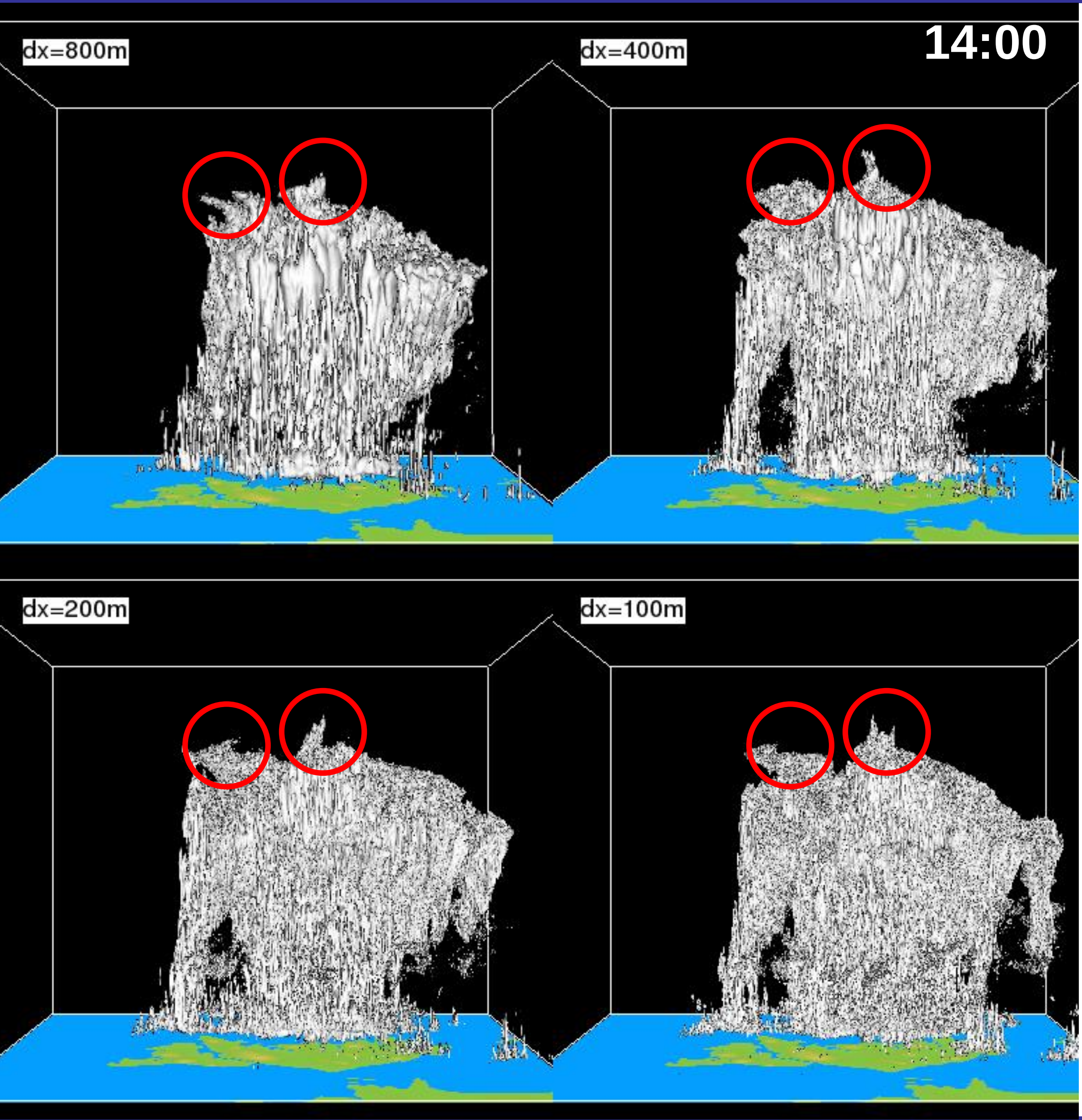


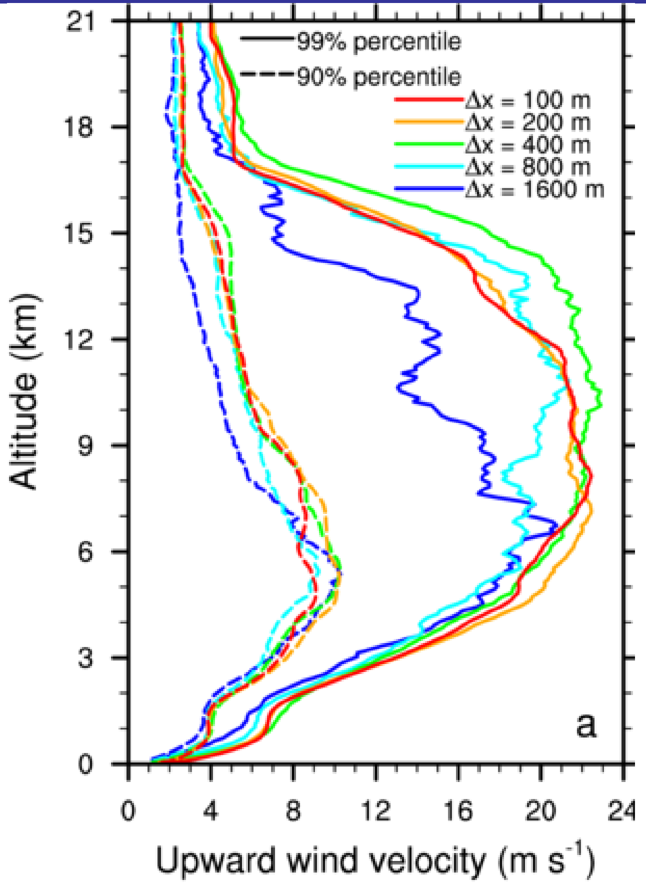
- 2560 x 2048 x 256, 1.34 billion gridpoints
  Δx=100 m and Δz=40 – 100 m
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data

Video on https://youtu.be/xjPumywGaAU

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

Sensitivity to grid spacing

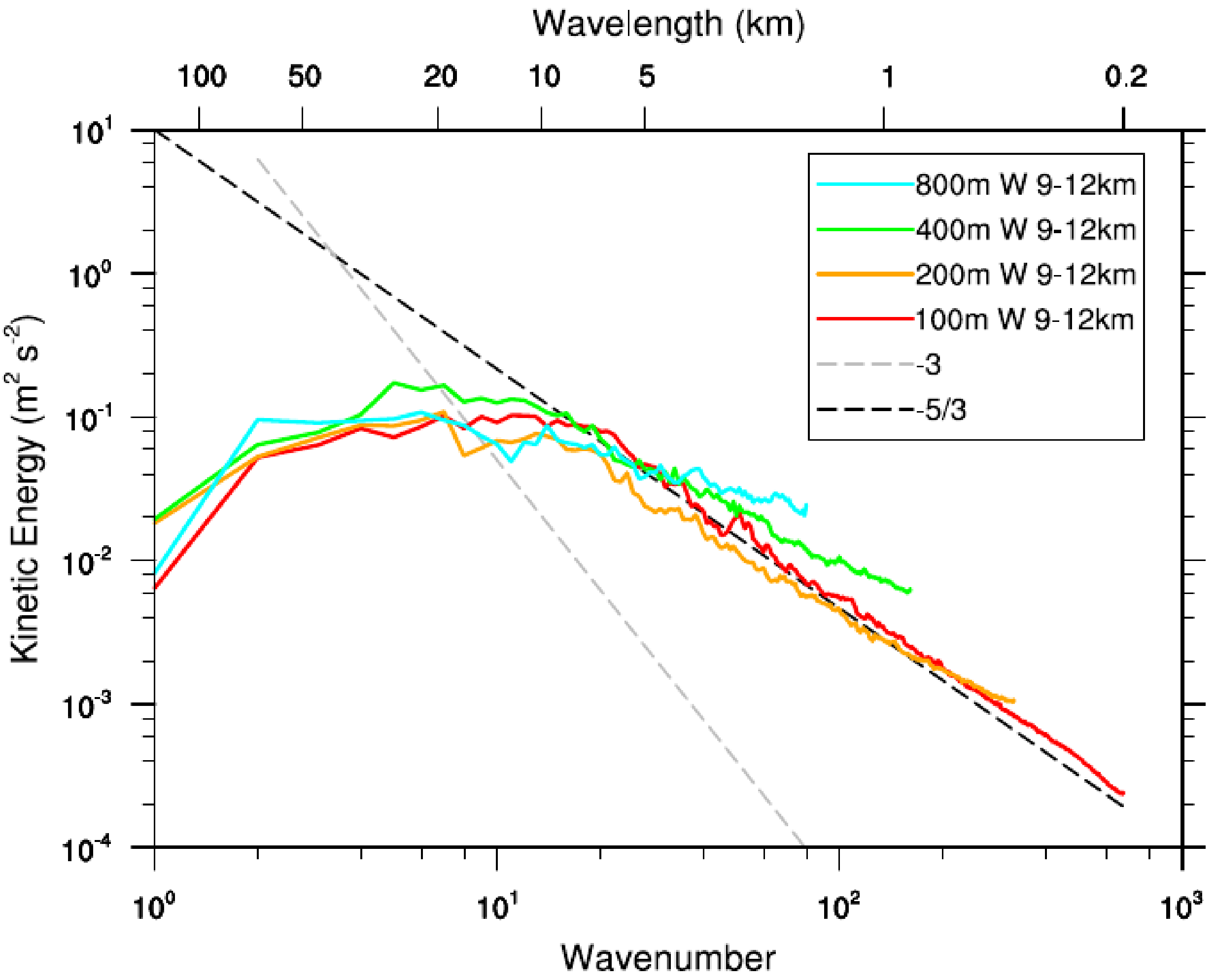




The vertical velocity for the most rapid updrafts generally decreases with reduced resolution

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

Spectrum of vertical velocity

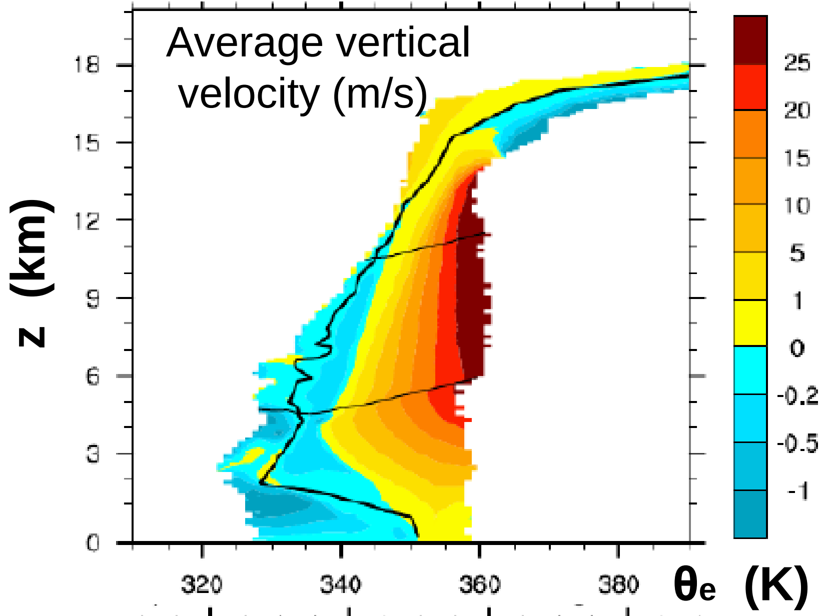


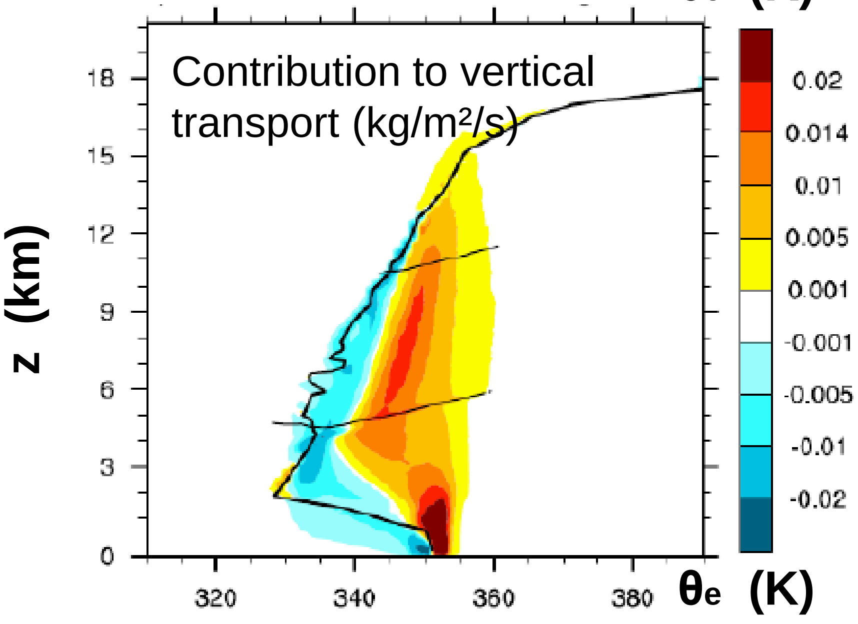
13:00

A grid spacing of Δx=200 m or 100 m is required for a reliable estimate of the hydration of the stratosphere

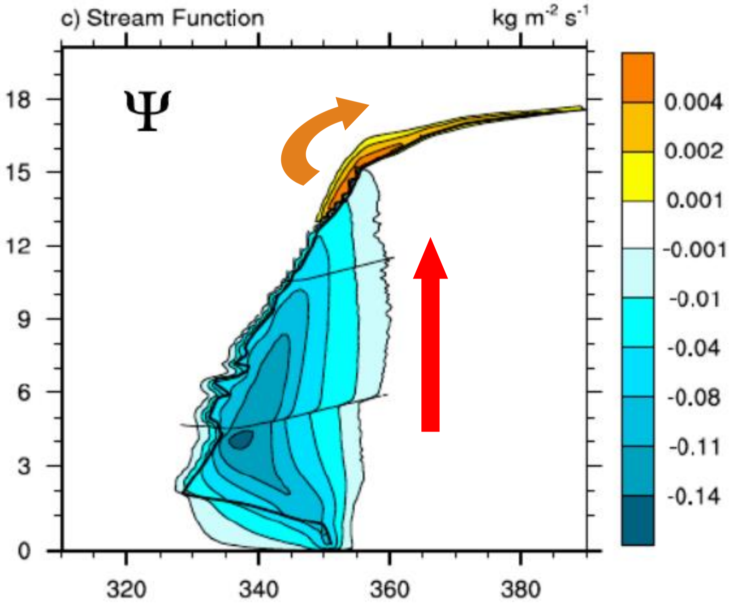
Dauhut et al., J. Atmos. Sci., 2016

Overturning in Hector


Average vertical velocity (m/s)


Contribution to vertical transport (kg/m²/s)

Two key circulations


c) Stream Function

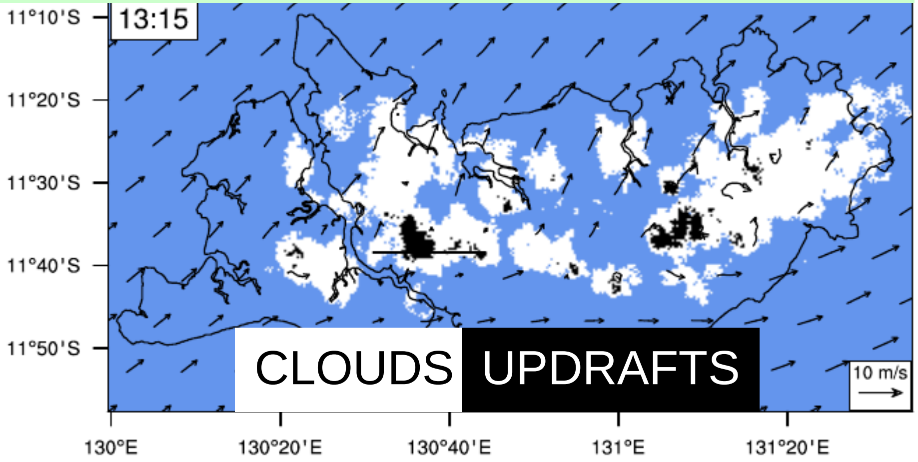
Overshoot overturning

Tropospheric overturning

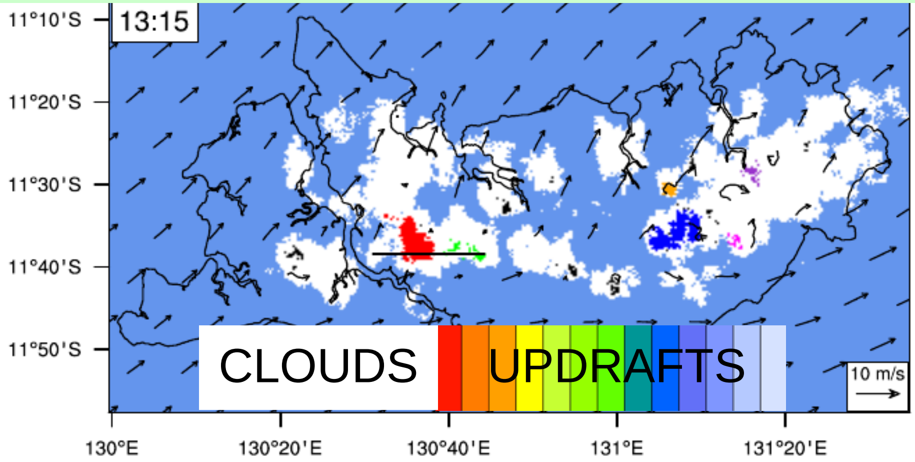
Dauhut et al., J. Atmos. Sci., 2017

Identification of the tallest updrafts

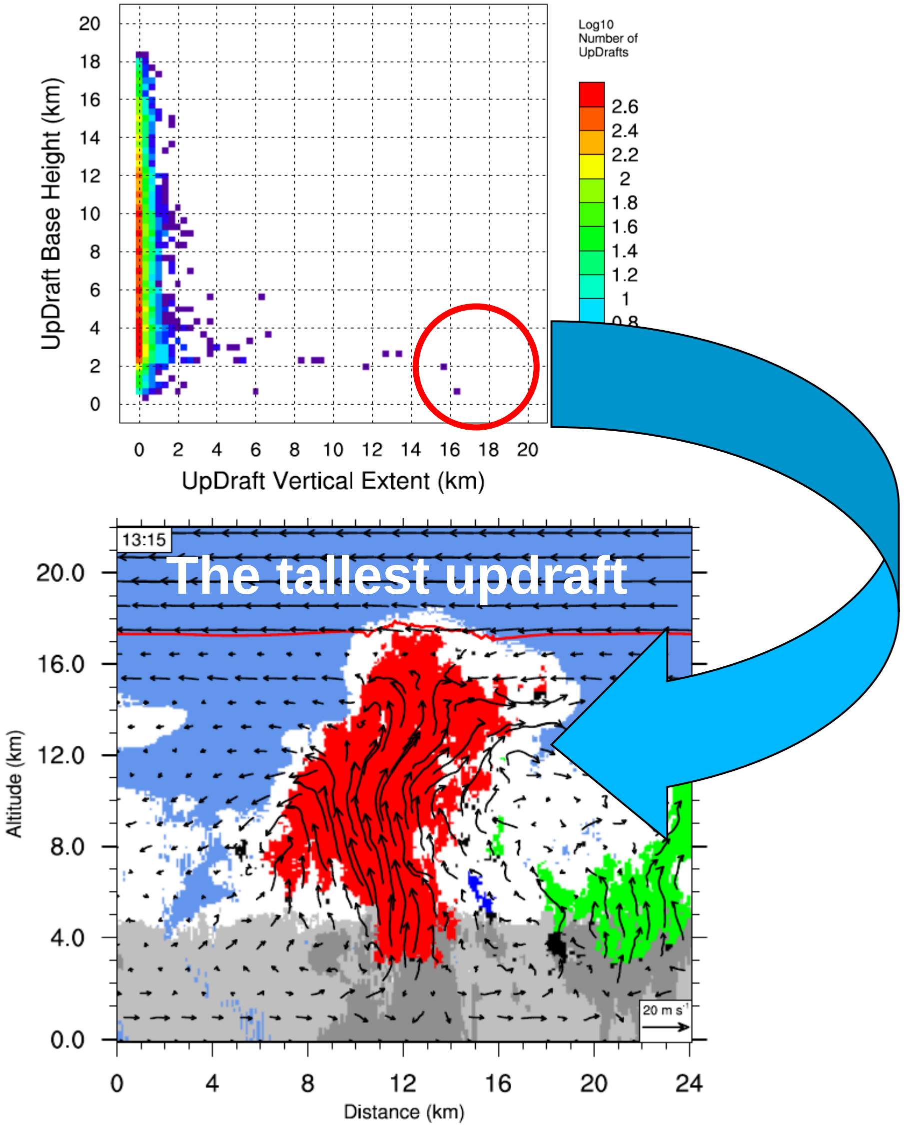
Step 1: detection of updrafts on every gridpoint where w>10 m/s



Step 2: identification of updrafts as object

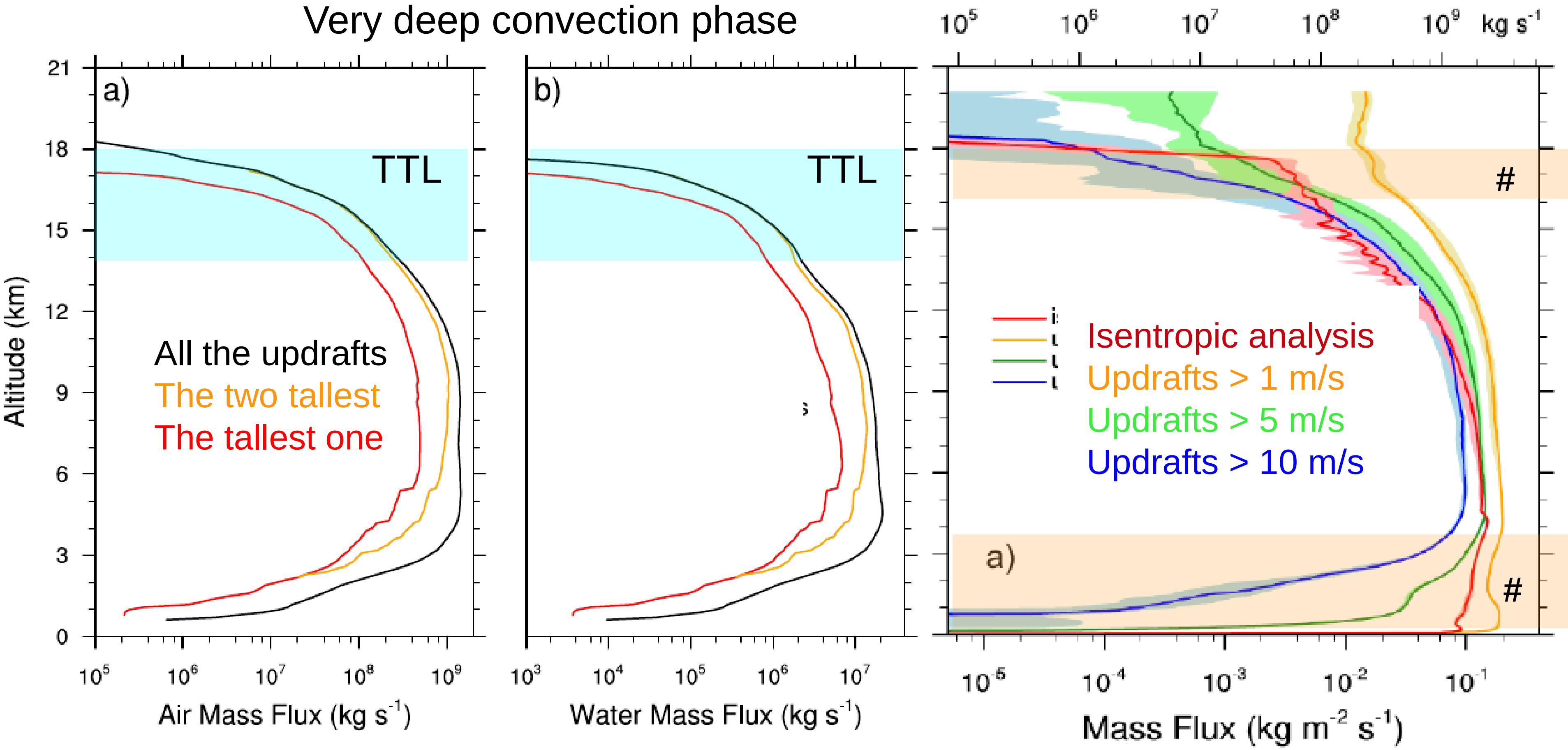


Step 3: Statistics of updrafts



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.

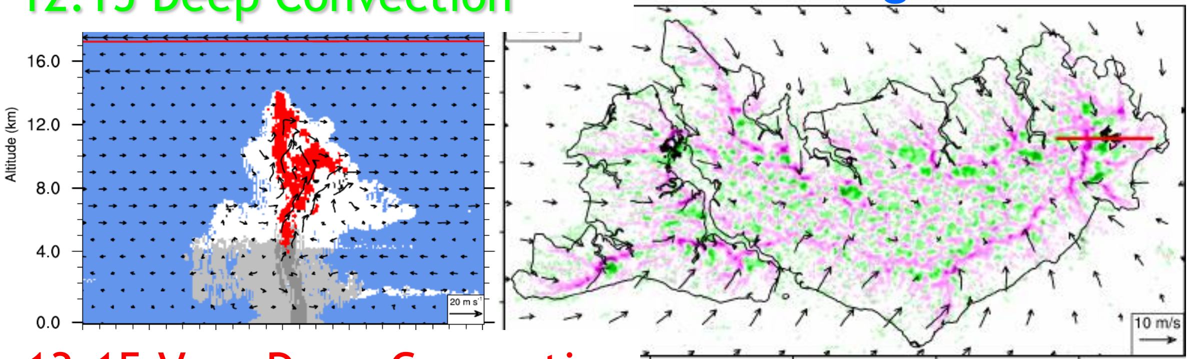
The isentropic analysis corroborates the Eulerian computation with w>10 m/s, except in lower tropo and around the tropopause (#) where weak motions matter for the irreversible flux.

Dauhut et al., J. Atmos. Sci., 2016, 2017

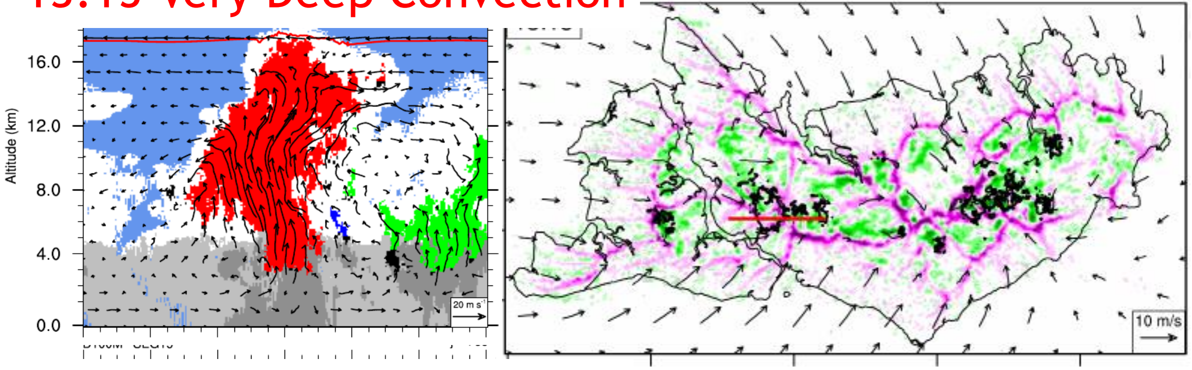
Formation of the tallest updrafts

Convergence intensified by cold pools

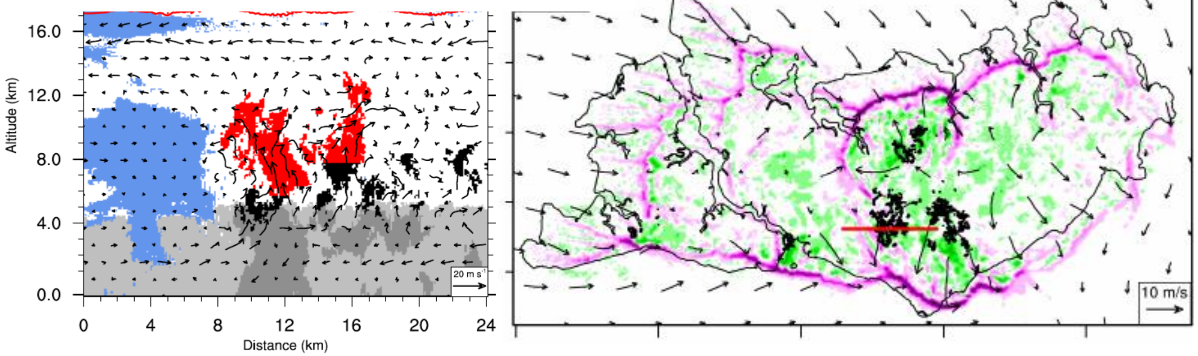
12:15 Deep Convection

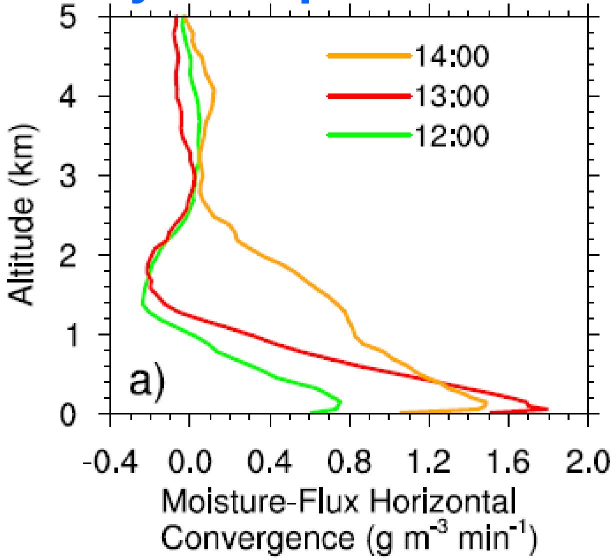


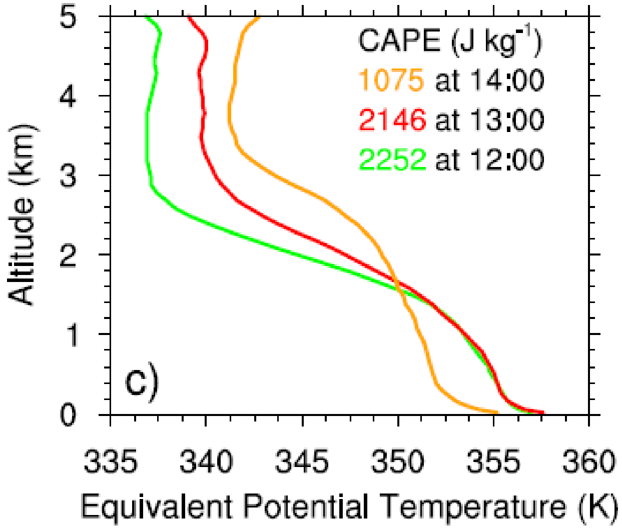
13:15 Very Deep Convection



14:15 Convective Cluster

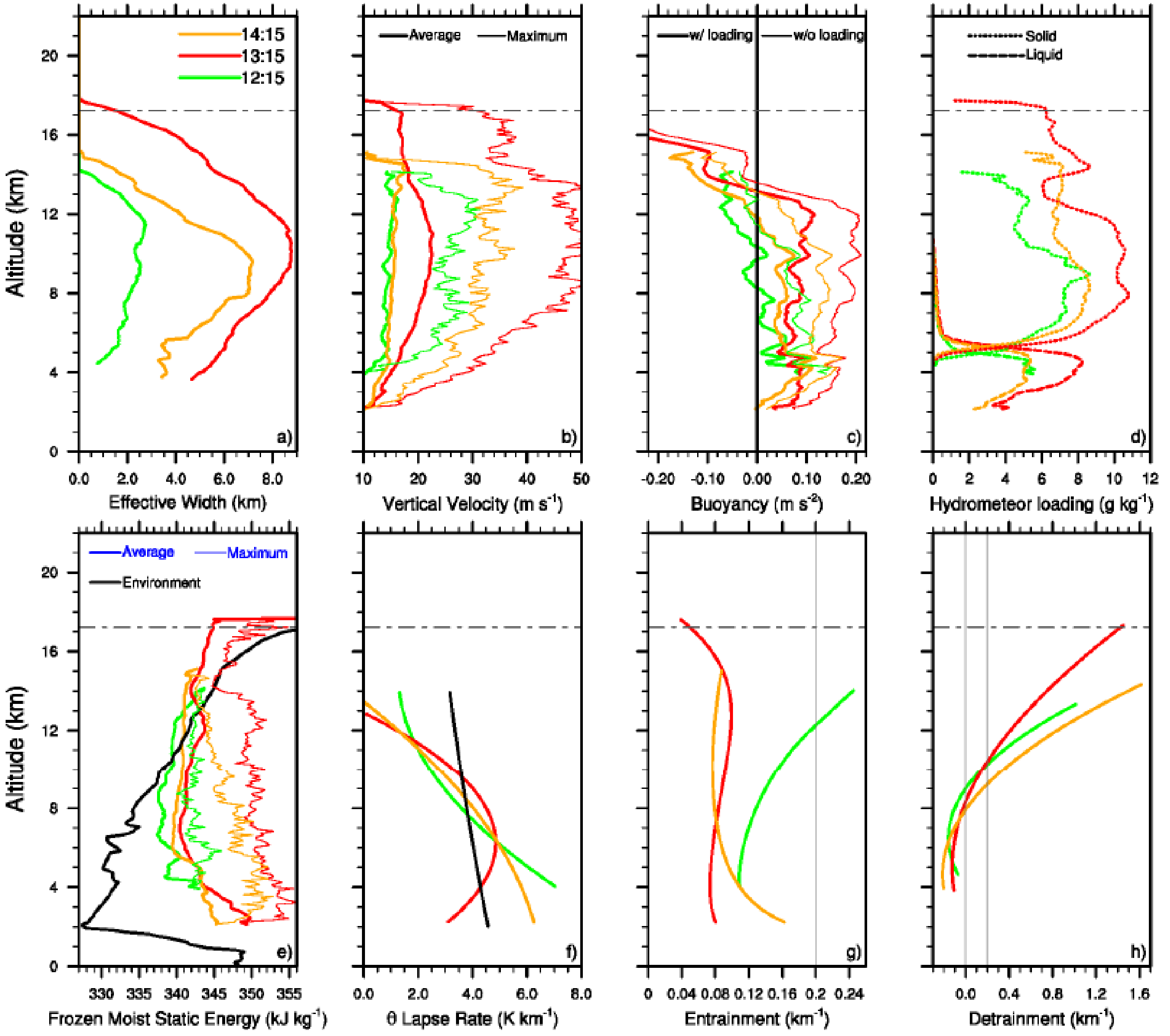






Dauhut et al., J. Atmos. Sci., 2016

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

Final remarks

- ✓ CRM approach was successful in representing cloud and precipitation distribution – MJO signal, diurnal cycle, etc.
- ✓ But it lacks some cloud organization, which is very sensitive to the turbulence parameterization
- ✓ Some convergence can be obtained with LES

❖ **Future plans**

- ✓ Case studies using more sophisticated physics: aerosol aware microphysical scheme (LIMA), coupling with ocean and wave
- ✓ Application to field campaigns: DACCIWA (SW Africa, July 2017), StratoClim (Nepal India, JA 2018), NAWDEX (N. Atlantic SO 2017)
- ✓ Adaptation of Meso-NH to GPU is under progress