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

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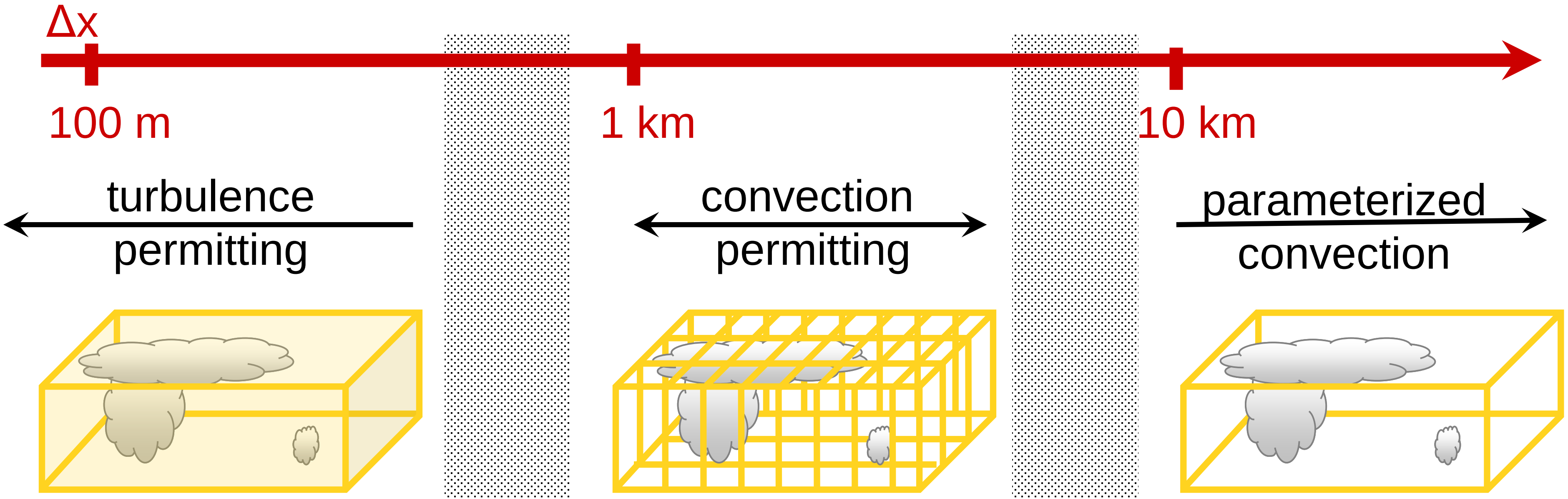
Representation of deep convection



Δx

100 m

1 km

10 km

turbulence permitting

convection permitting

parameterized convection

LES

large-eddy simulation

- Uncertainties on microphysics and radiation

CRM

cloud-resolving model

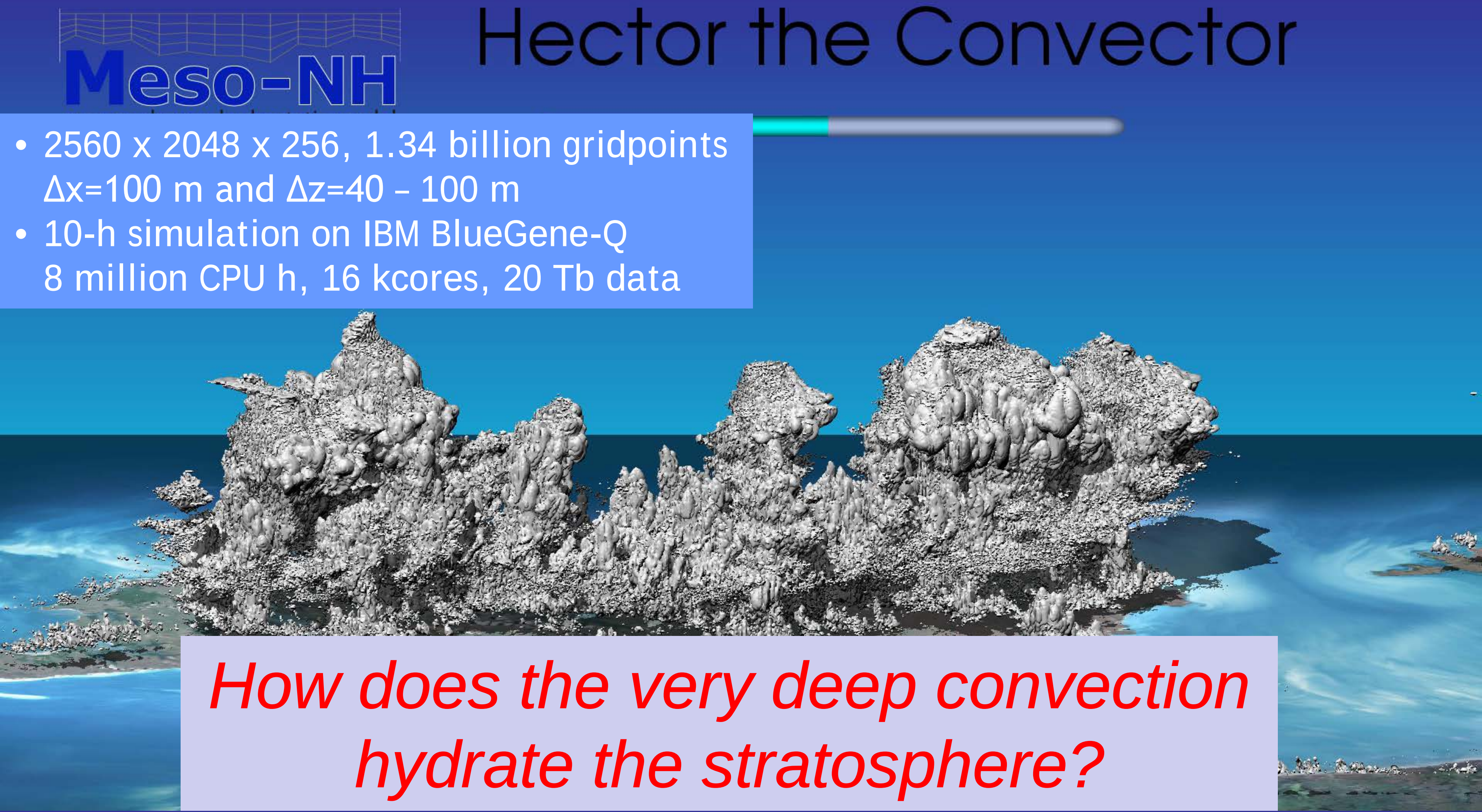
- Uncertainties on turbulence, microphysics and radiation

RCM/GCM

climate model

- large uncertainties

Very deep convection in a Giga-LES



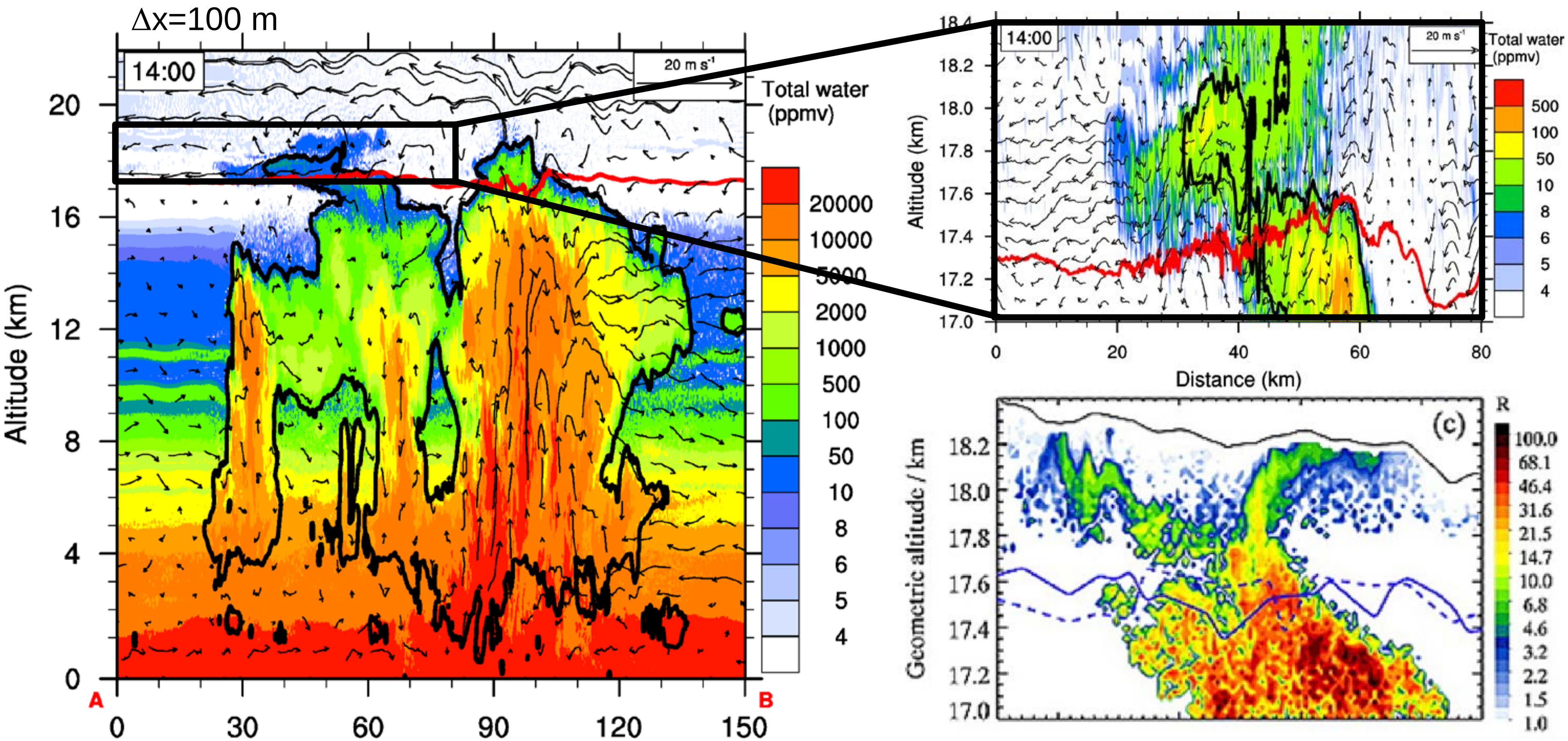
- 2560 x 2048 x 256, 1.34 billion gridpoints
  Δx=100 m and Δz=40 – 100 m
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data

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

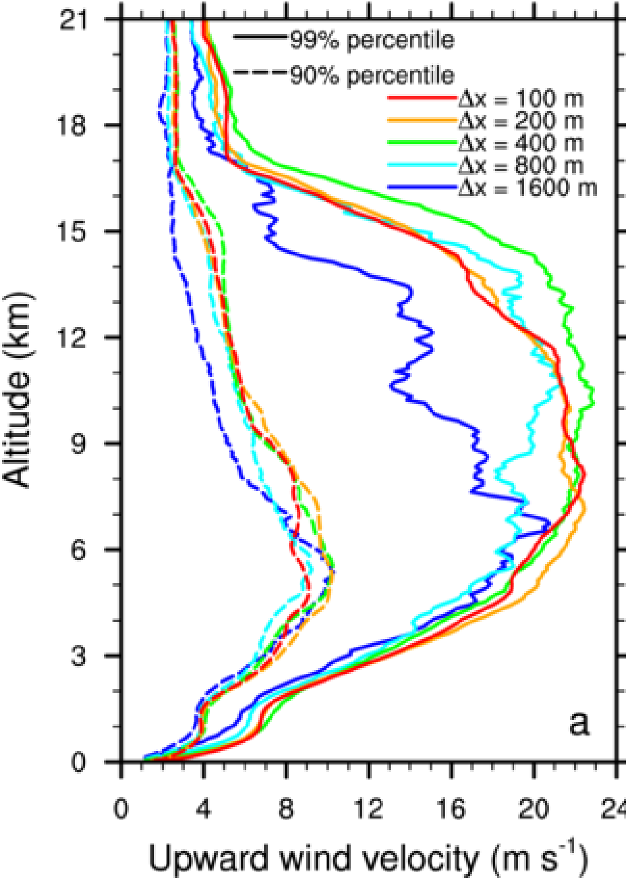


Observed

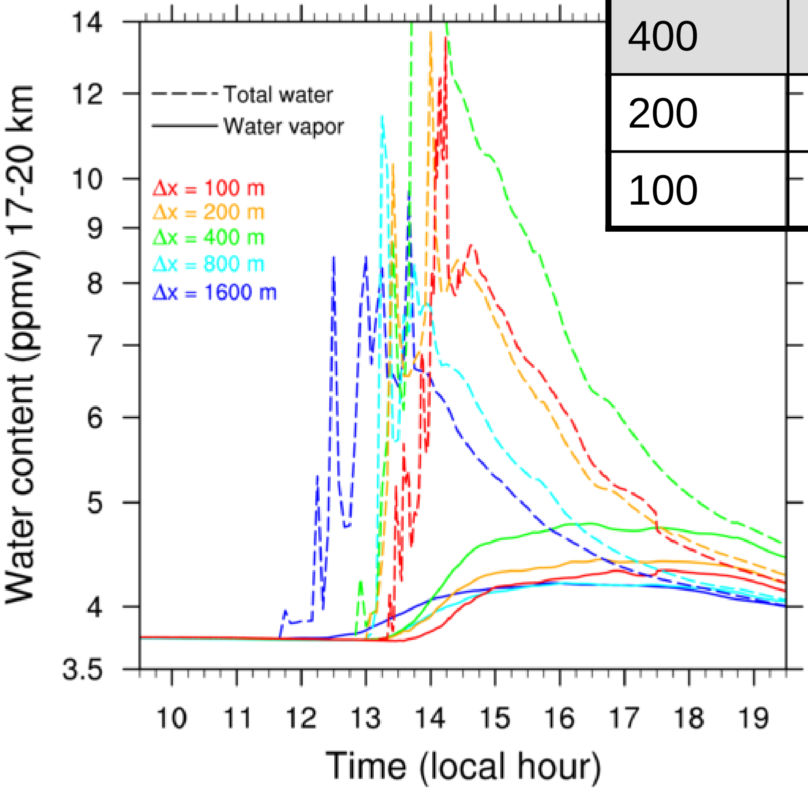
The Giga-LES reproduces correctly the details of Hector as its overshoots into the stratosphere

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

Sensitivity to horizontal resolution



Δx (m)	ΔH_2O (%)	ΔH_2O (t)
1600	+12	+2222
800	+13	+2252
400	+27	+4525
200	+18	+3263
100	+16	+2776

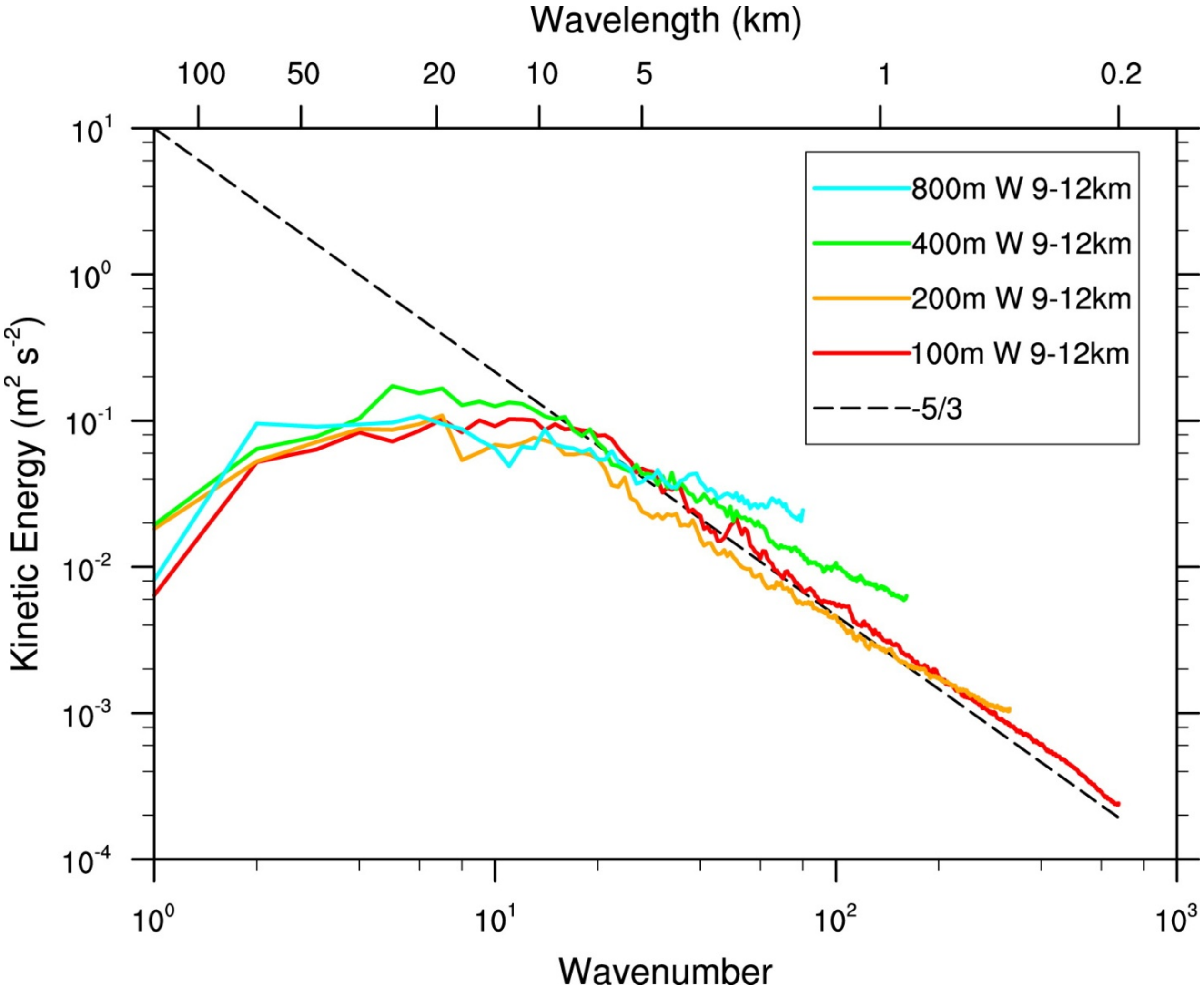


The vertical velocity for the most rapid updrafts generally decreases with reduced resolution

The magnitude of the moistening tends to converge with Δx>=200 m

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

Spectrum of vertical velocity

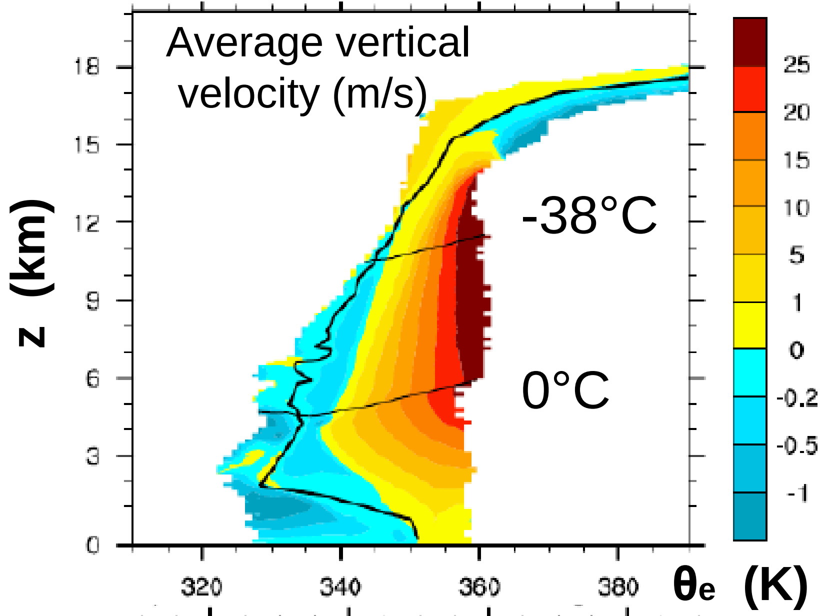


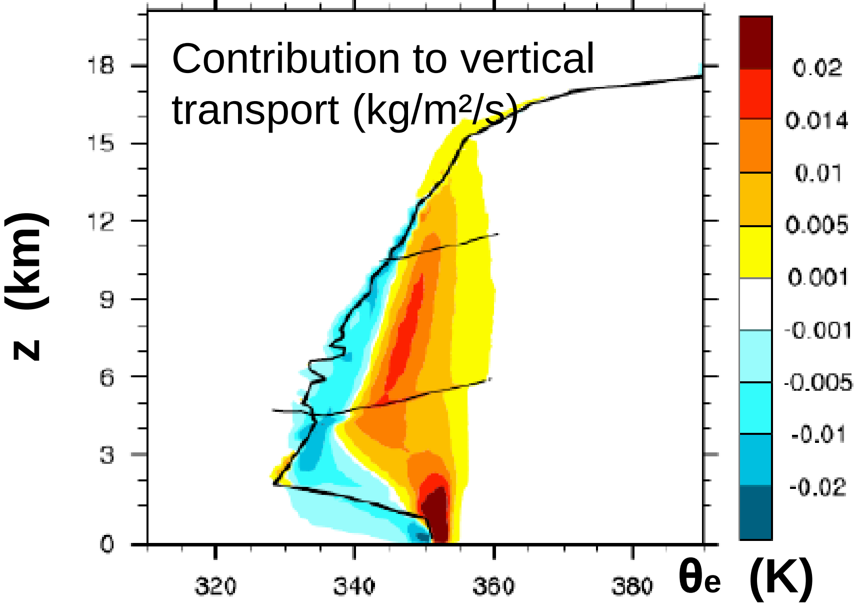
13:00

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

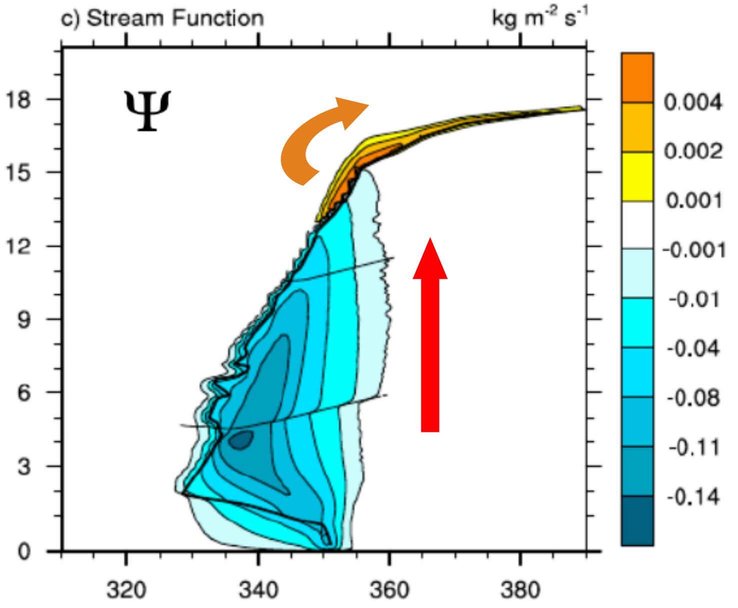
Overturning in Hector





Very deep convection
13:31 – 13:45

Two key circulations



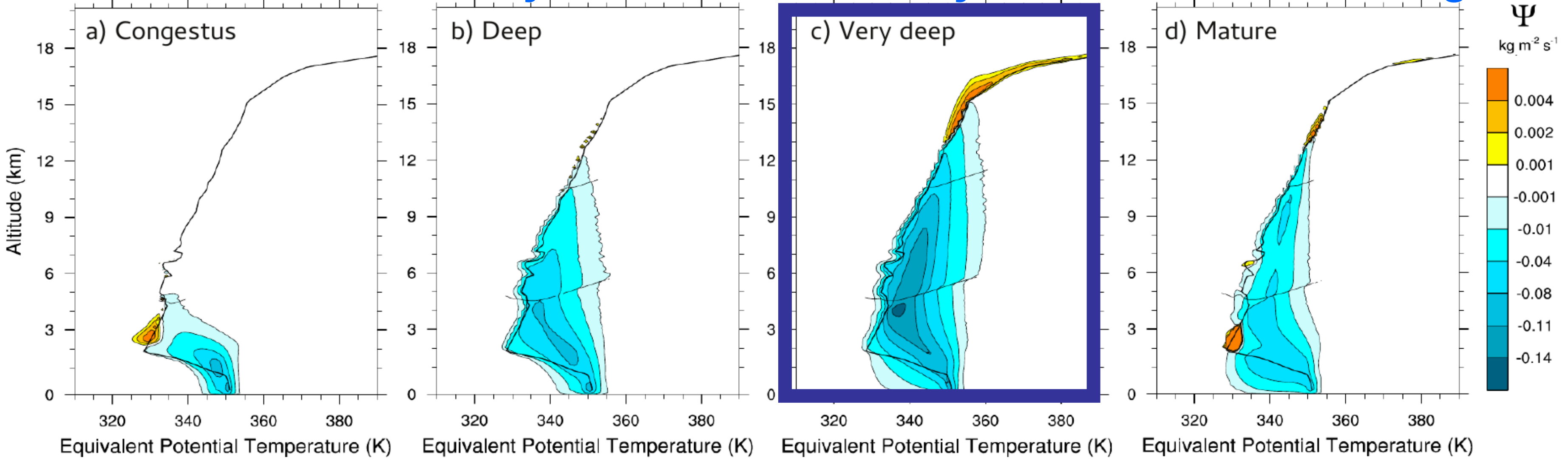
Overshoot overturning

Tropospheric overturning

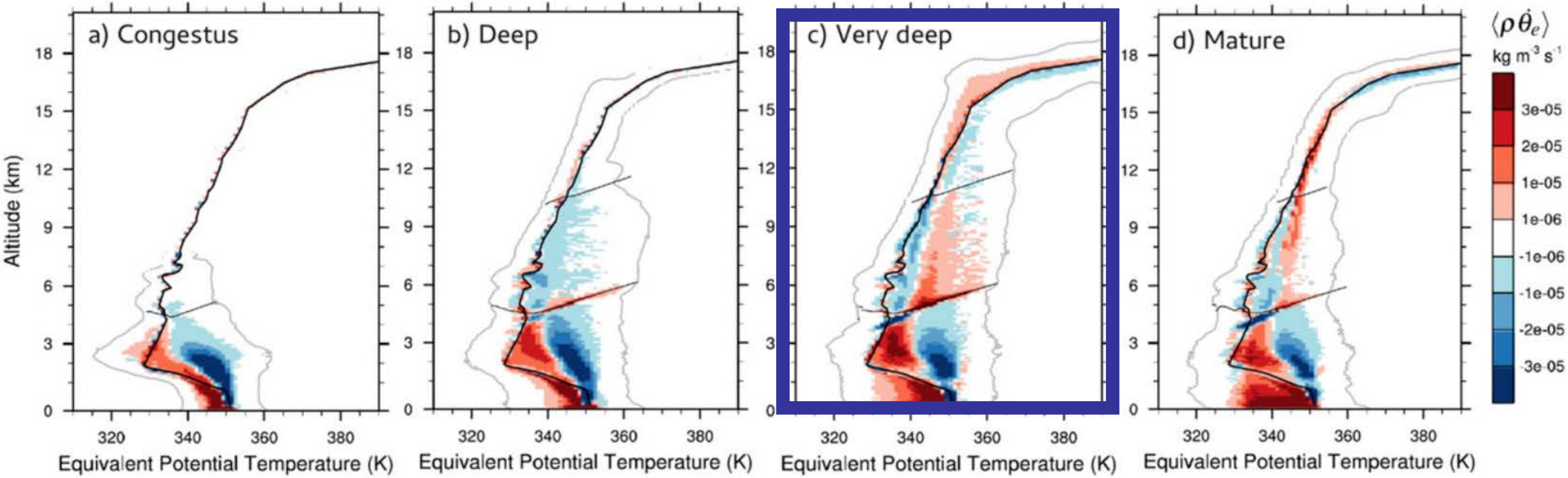
Dauhut et al., J. Atmos. Sci., 2017

The very deep convective phase is

… characterized by a maximal intensity of the two overturnings



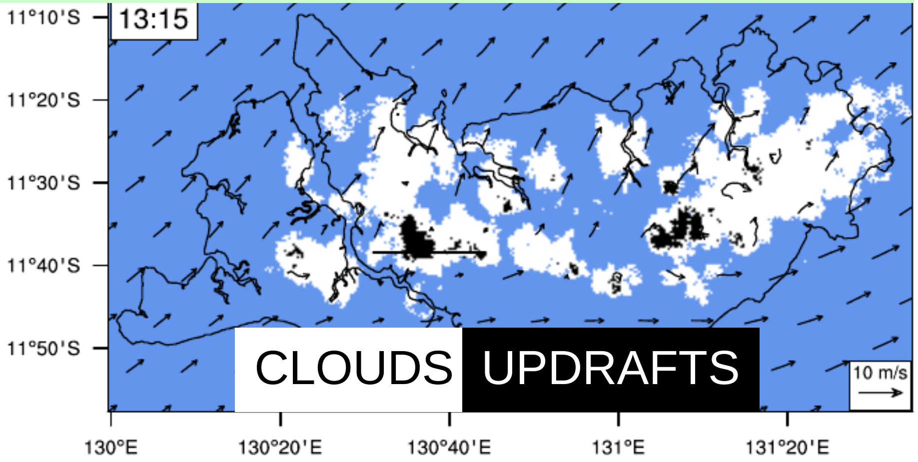
and large latent heat release due to ice formation



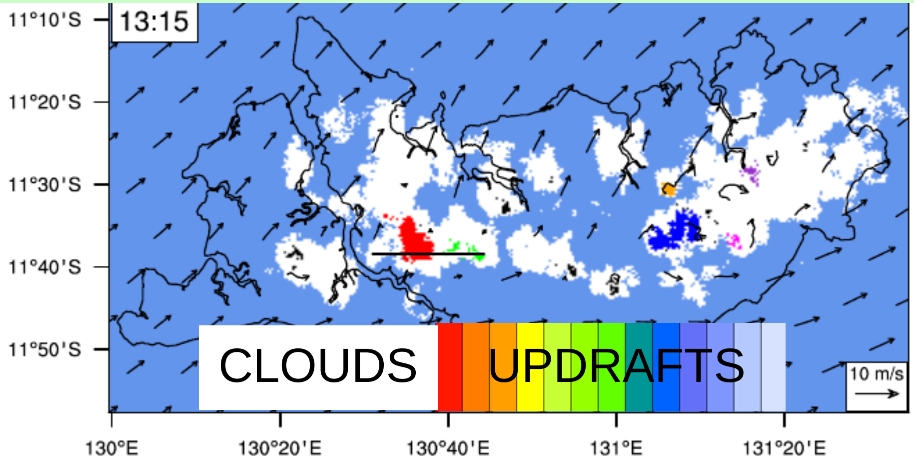
Dauhut et al., J. Atmos. Sci., 2017

Identification of the tallest updrafts

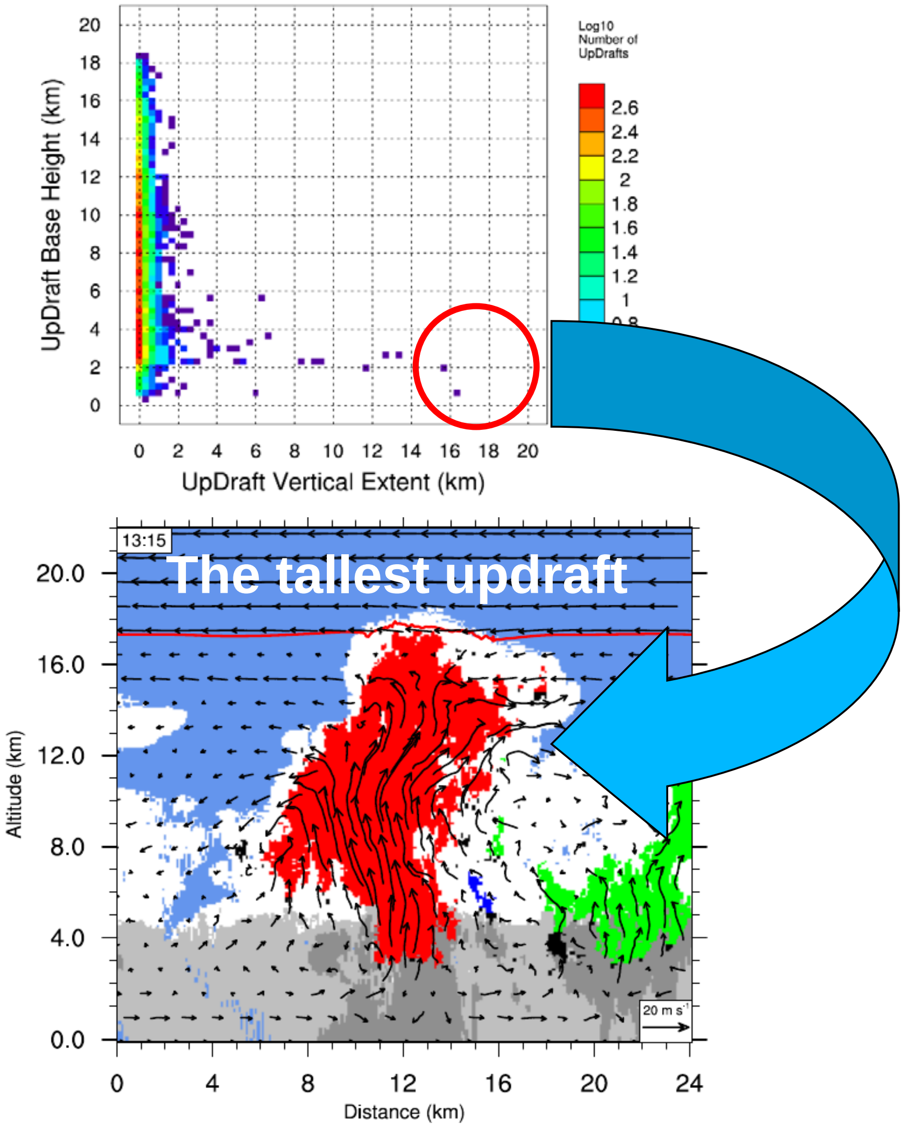
Step 1: detection of updrafts on every gridpoint where w>10 m/s



Step 2: identification of updrafts as object



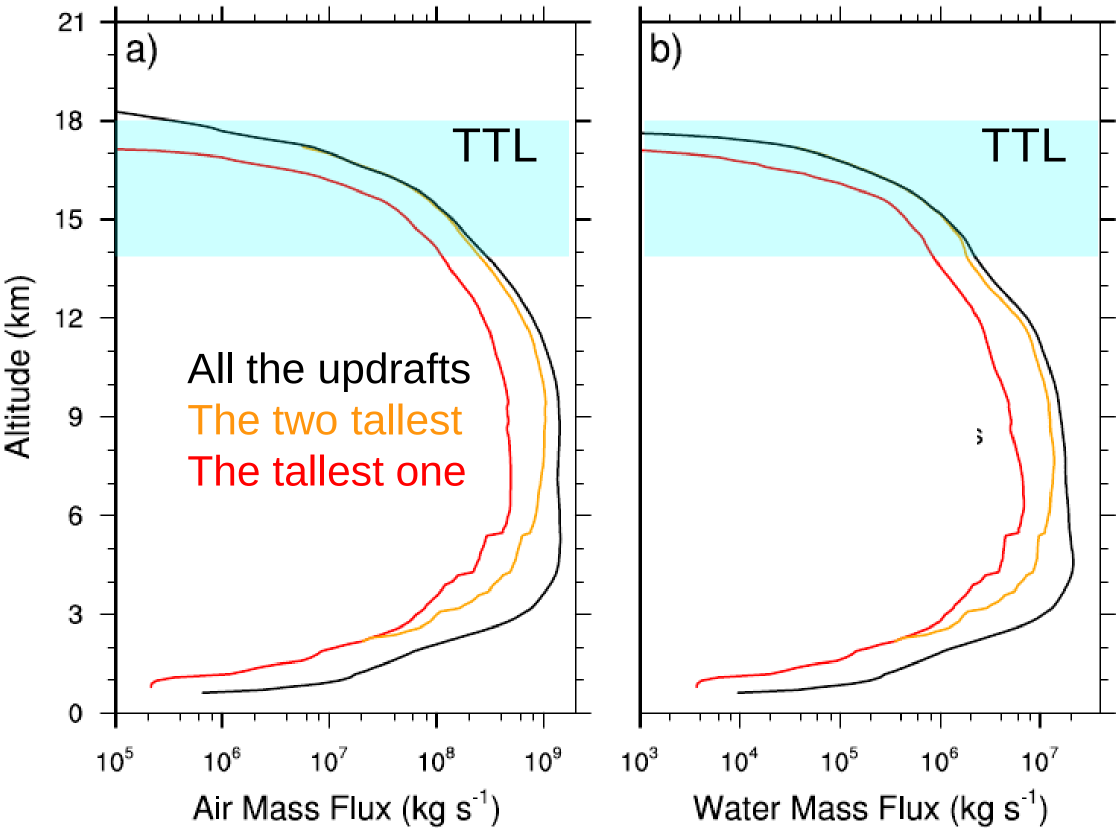
Step 3: Statistics of updrafts

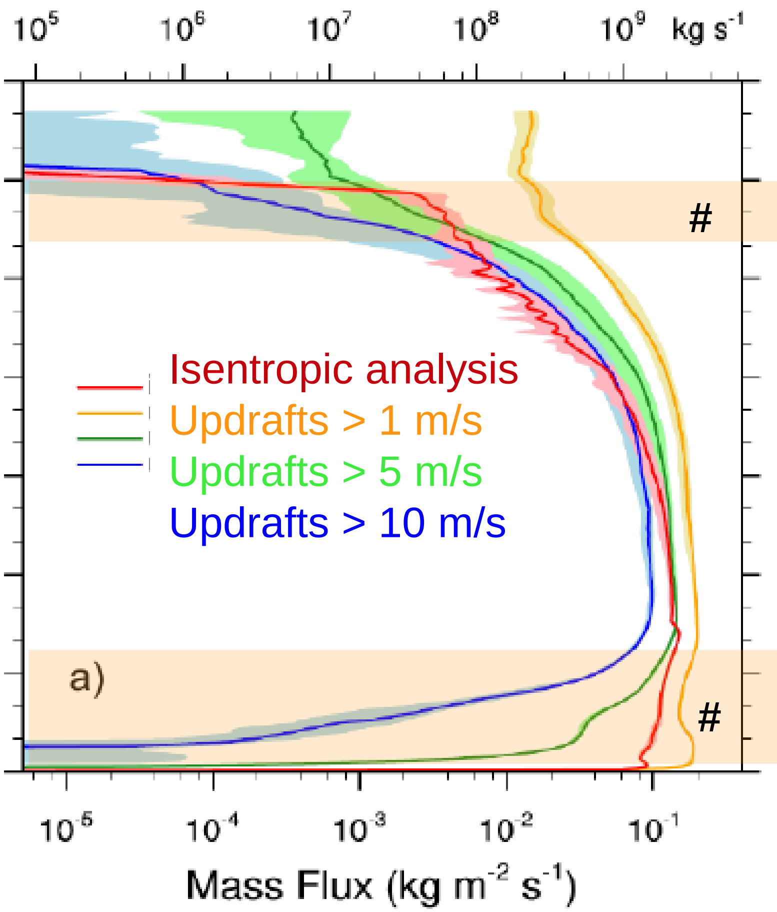


Dauhut et al., J. Atmos. Sci., 2016

The tallest updrafts, why bother?

Very deep convection phase





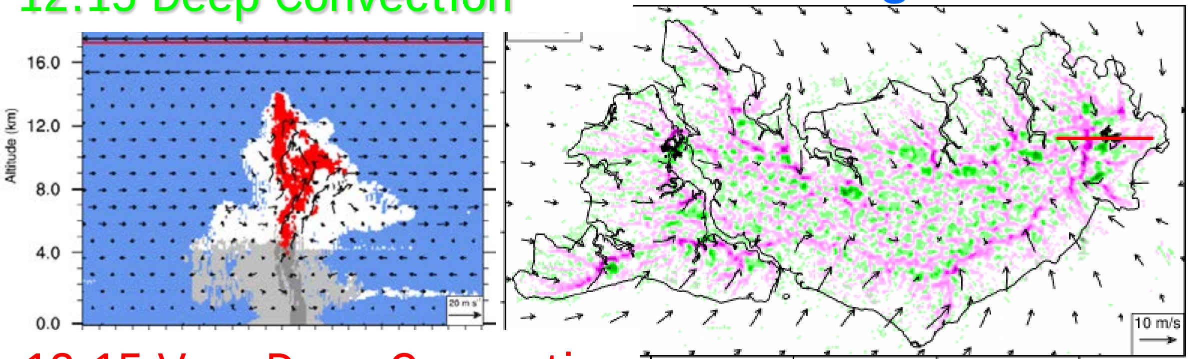
In TTL, the two tallest updrafts contribute to >90% of the transport by all the updrafts.

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.

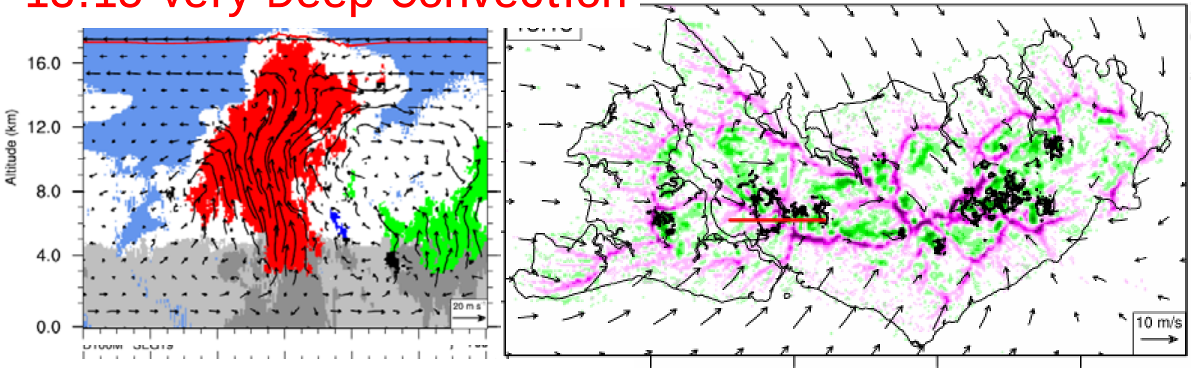
Dauhut et al., J. Atmos. Sci., 2016, 2017

Formation of the tallest updrafts

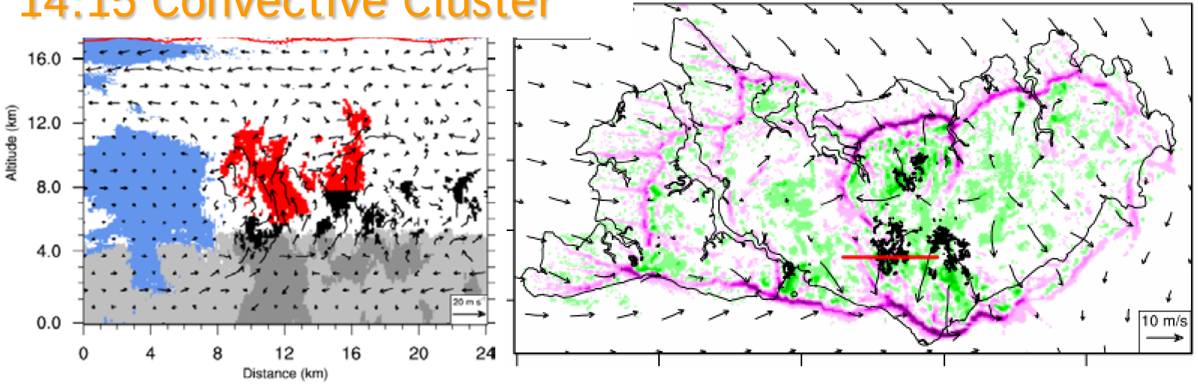
12:15 Deep Convection



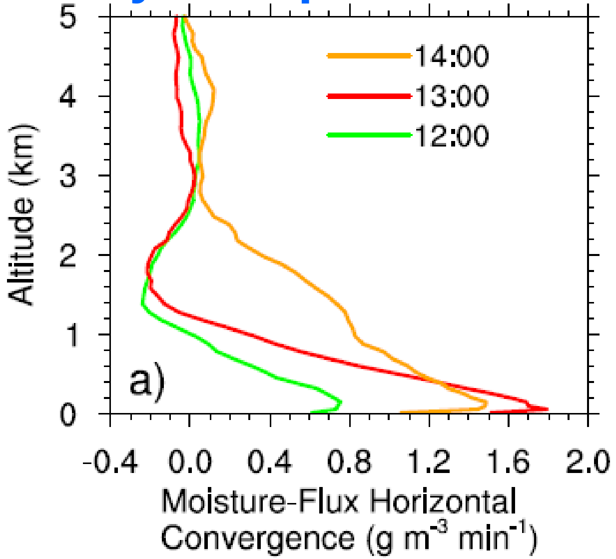
13:15 Very Deep Convection

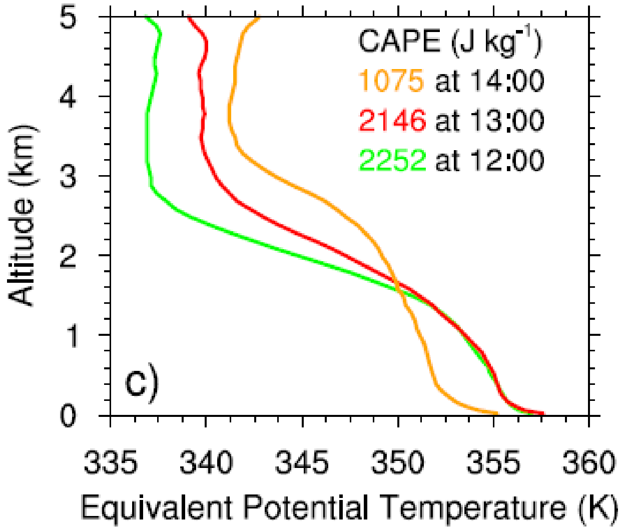


14:15 Convective Cluster



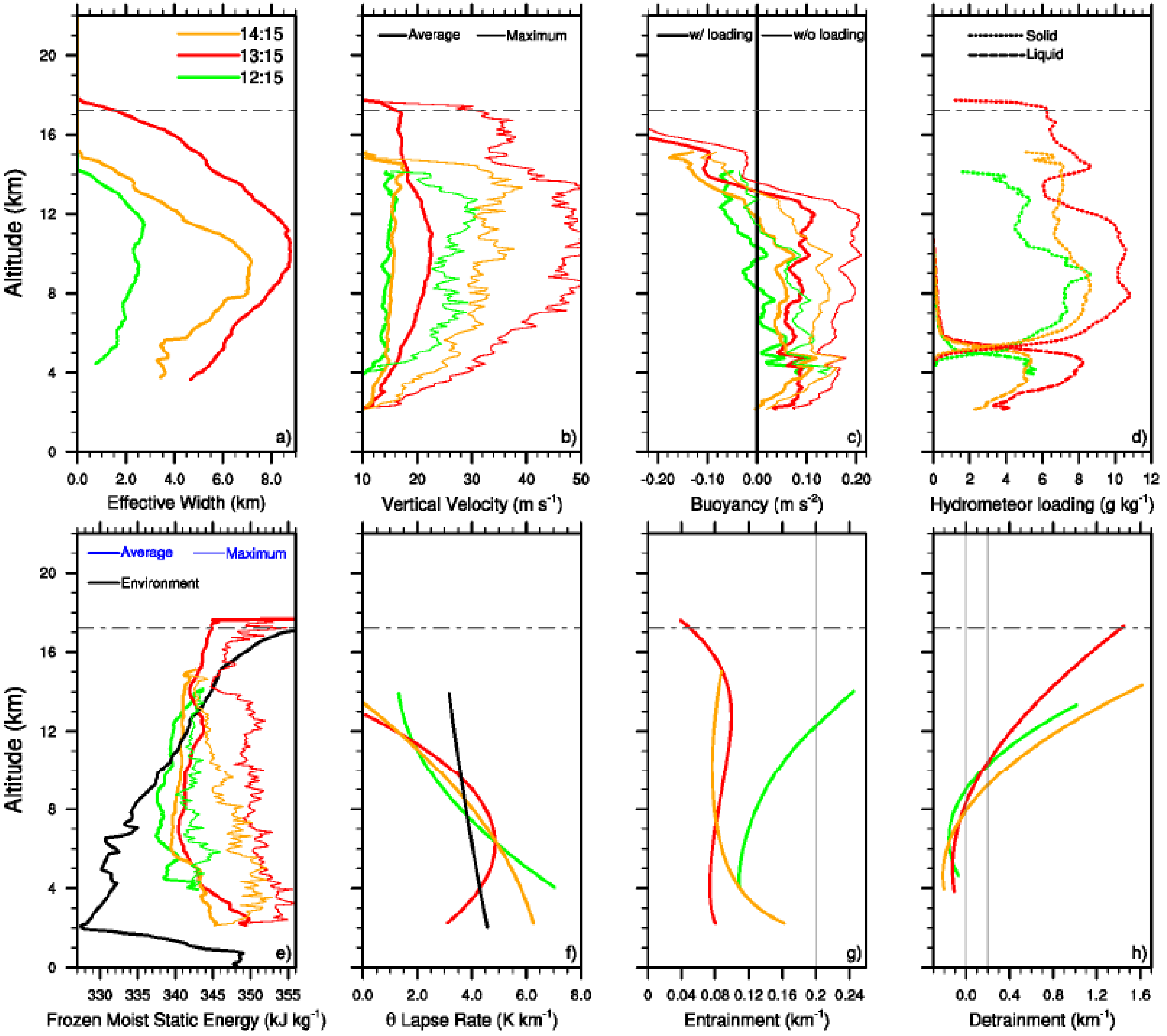
Convergence intensified by cold pools





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

Properties of the tallest updrafts



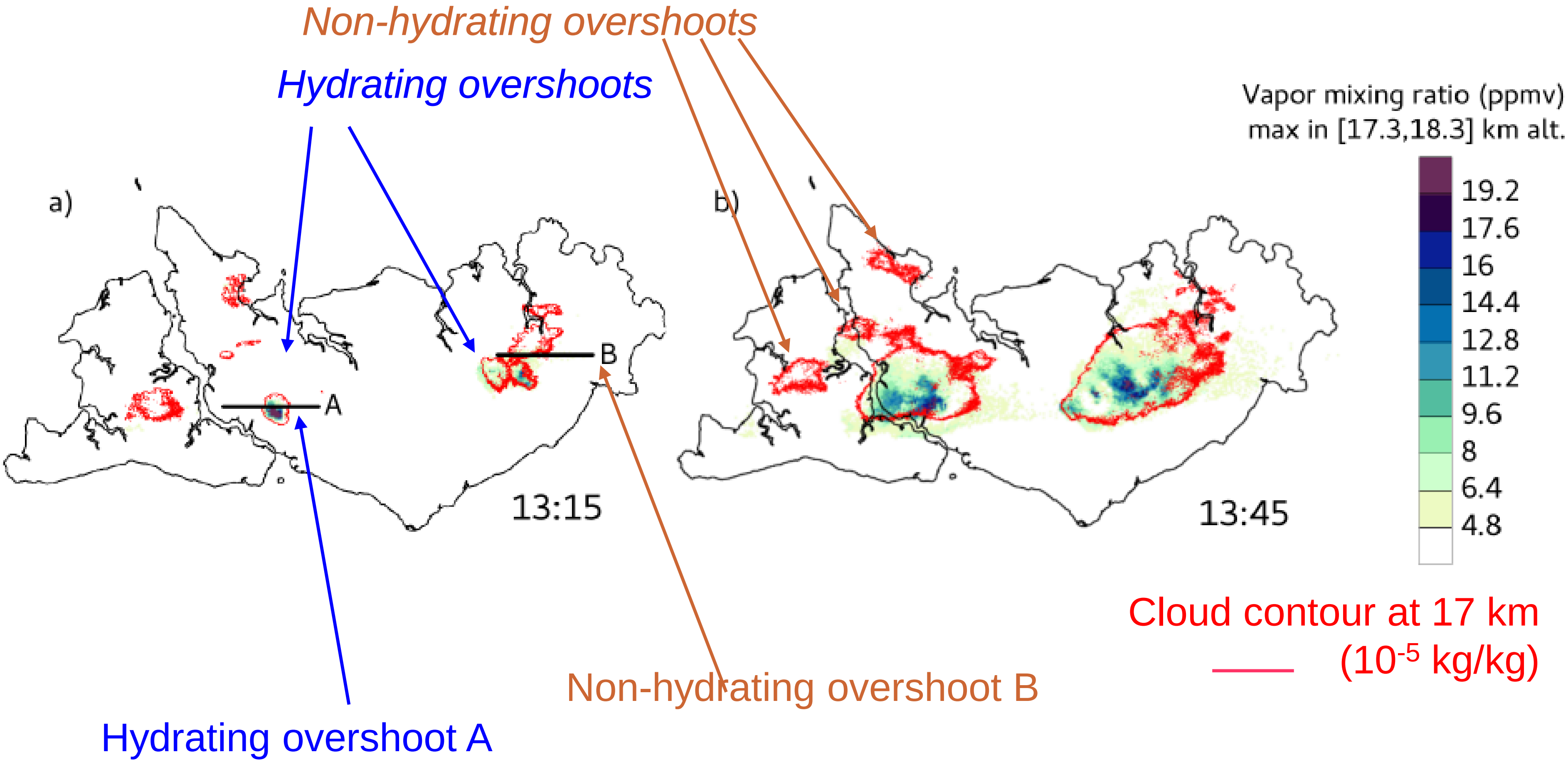
The tallest updrafts that overshoot the stratosphere are
larger,
stronger,
more buoyant,
carrying more water ,
having more MSE,
a larger lapse rate,
less diluted
than those occurred one hour earlier and after.

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

How do overshoots hydrate the stratosphere?

700 overshoots identified, 46 overshoots last more than 10 min

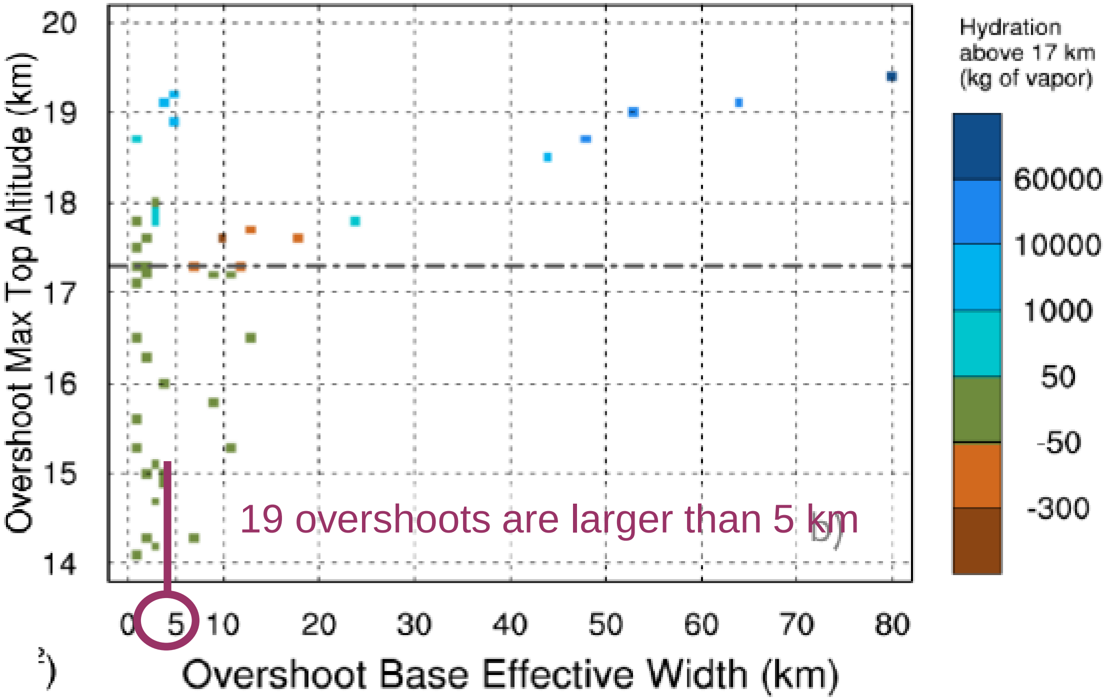
They are diverse in shapes and impacts above the tropopause



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

Hydrating and non-hydrating overshoots

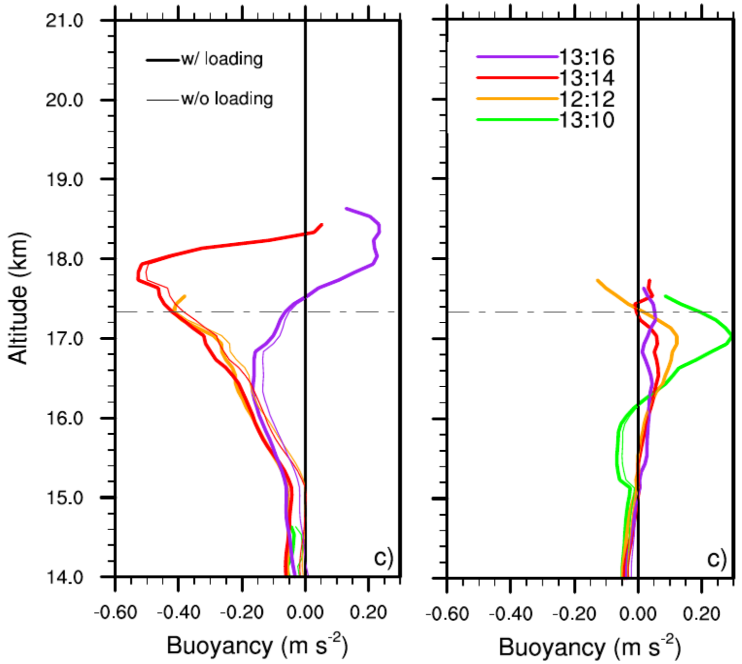
The 46 overshoots that last > 10 min



19 overshoots are larger than 5 km

Hydrating overshoot A

Non-hydrating overshoot B

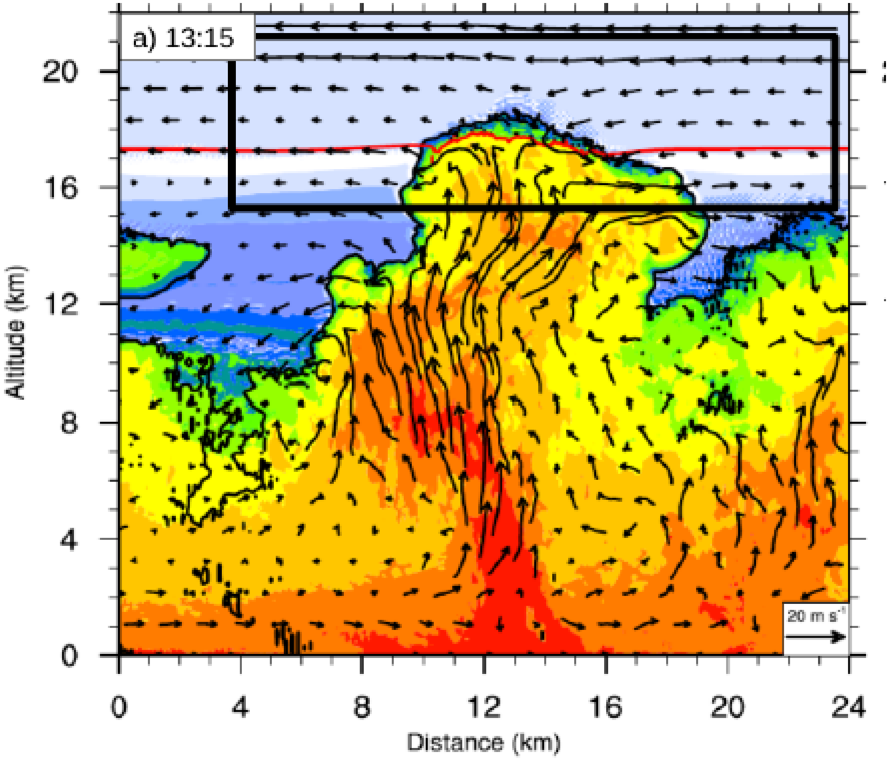


The hydrating overshoots reach higher altitudes...

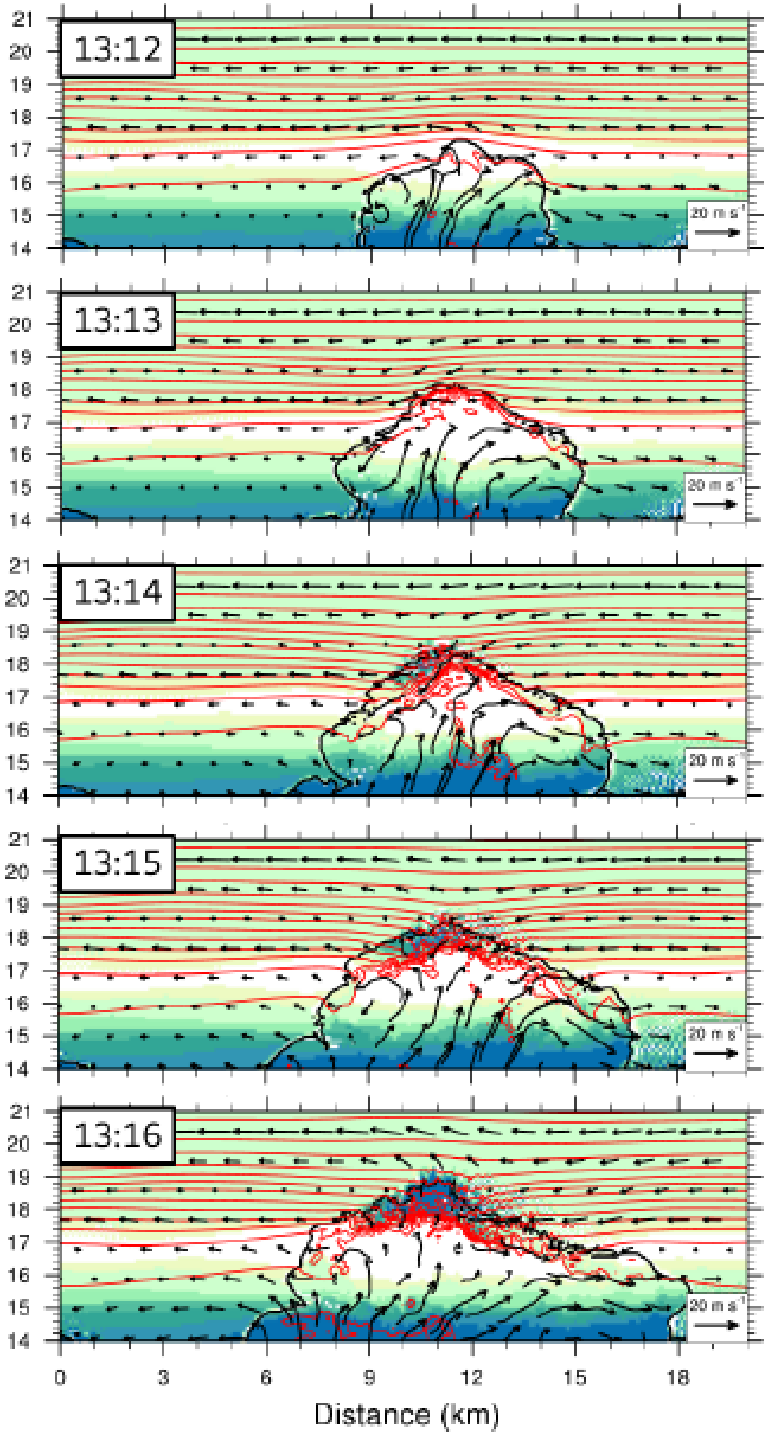
…and exhibit large absolute values of buoyancy.

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

The mechanisms inside the hydrating overshoot A

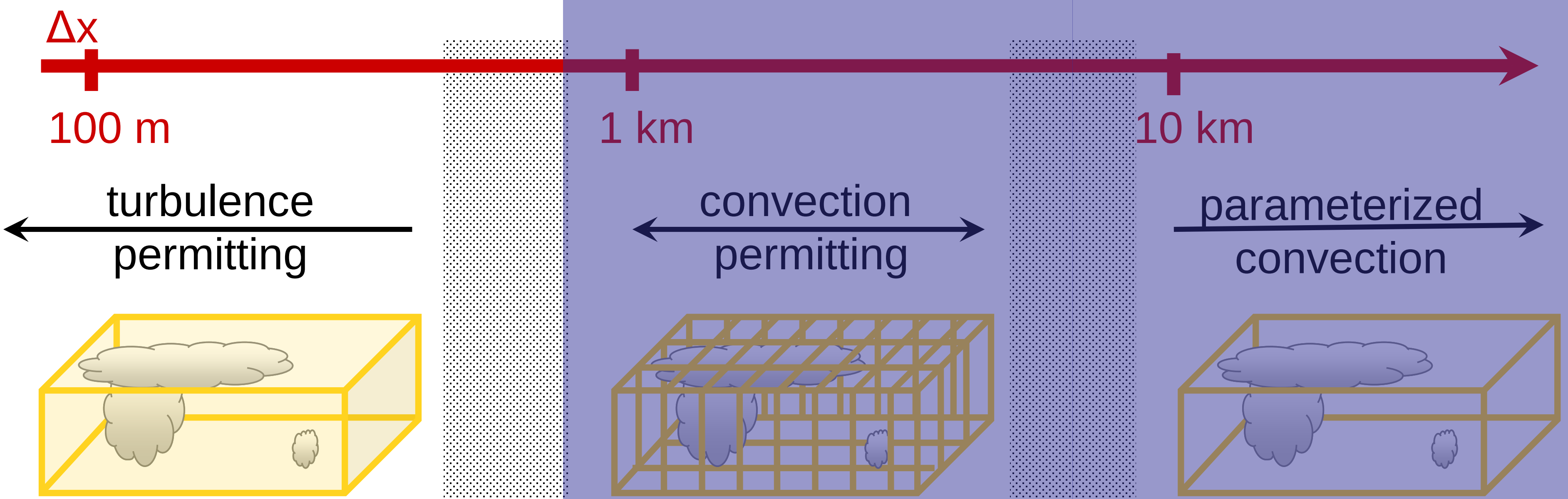


The **top-entrainment** of stratospheric air is crucial to warm the overshoot and to produce the hydration by ice sublimation.



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

Representation of deep convection



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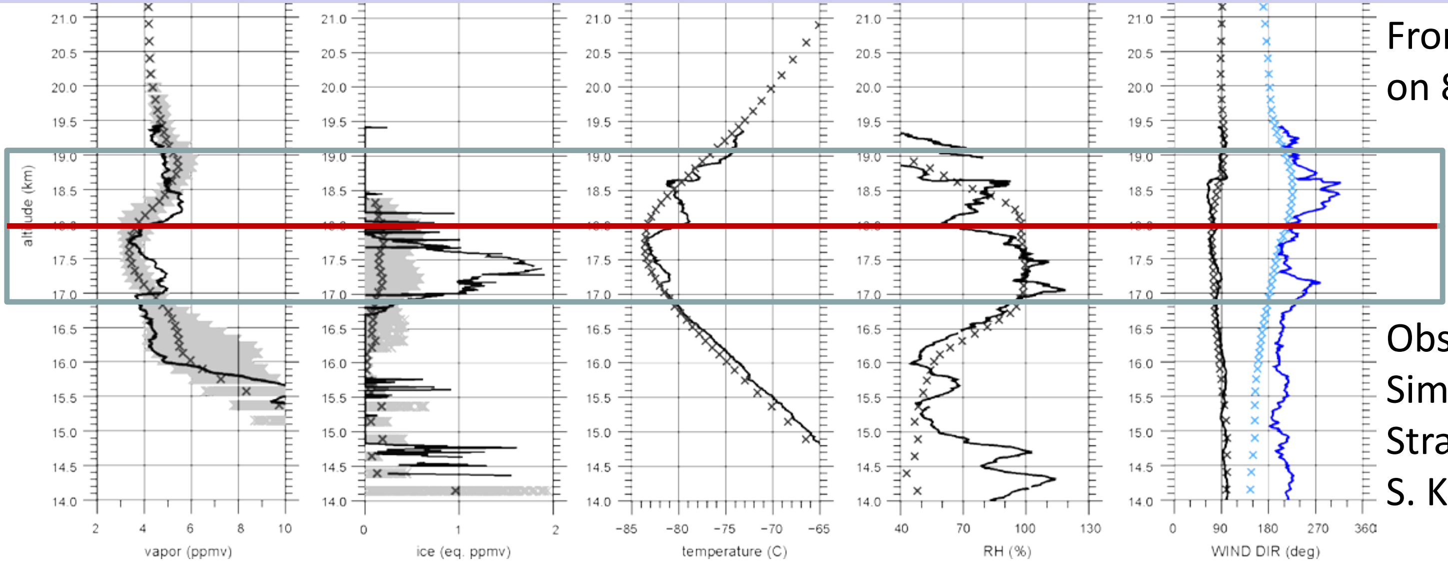
Convective hydration during StratoClim

What is the fate of the water injected by overshoots?

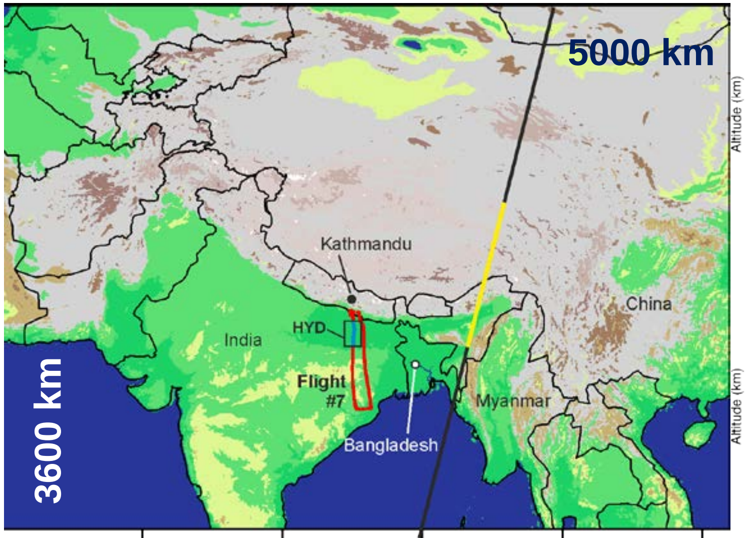


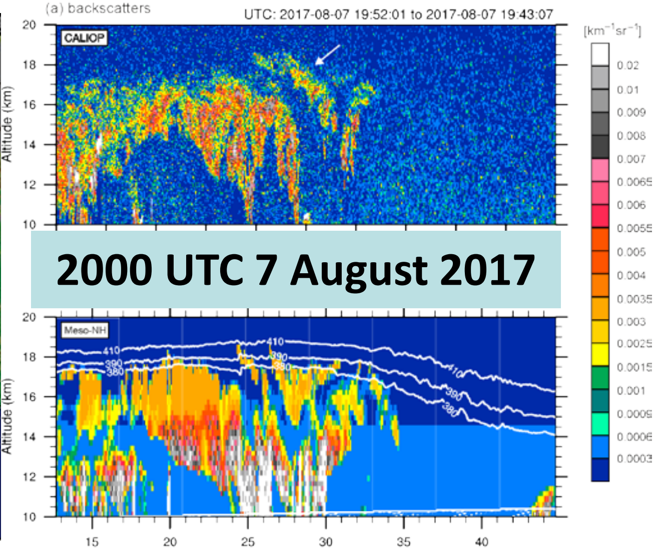
Tropopause

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

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

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

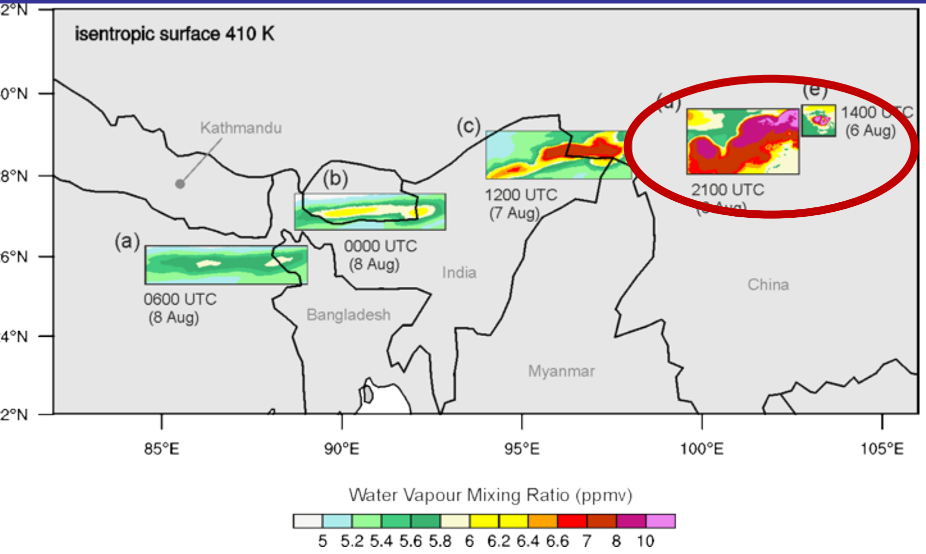


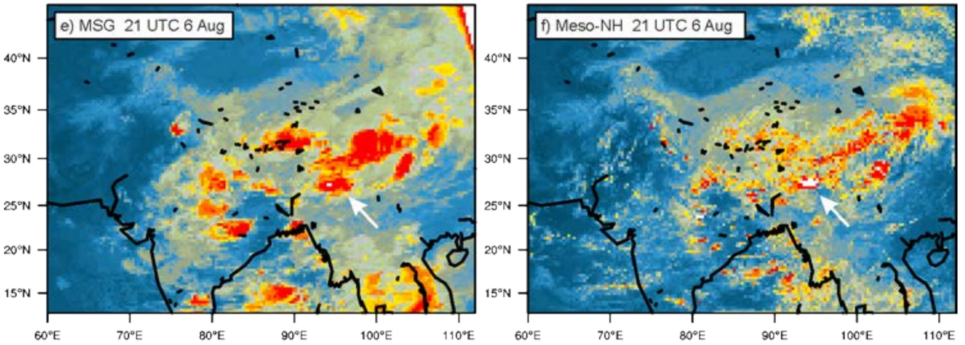


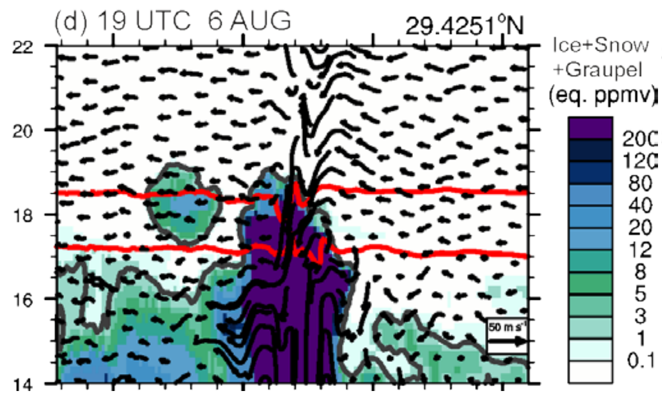
2000 UTC 7 August 2017

Lee et al., Atmos. Chem. Phys., in preparation

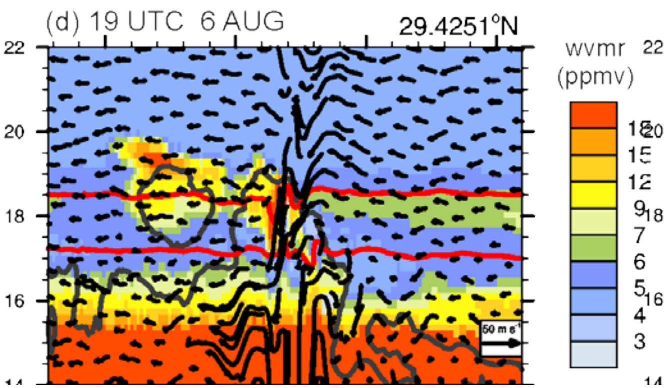
Injection of water by overshoots



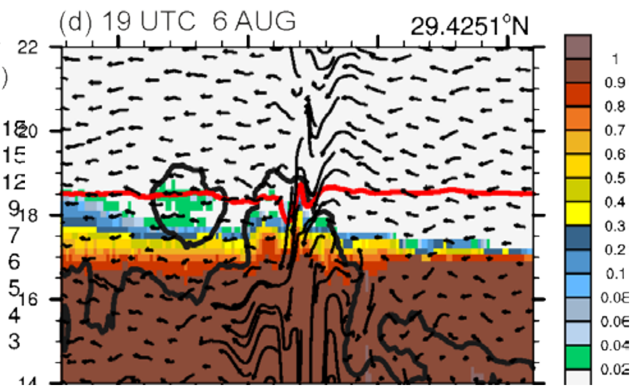




Ice content



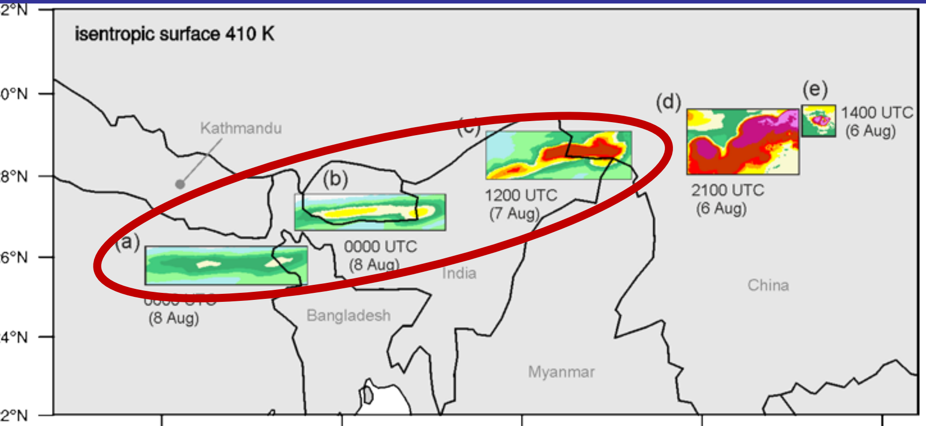
Water vapor

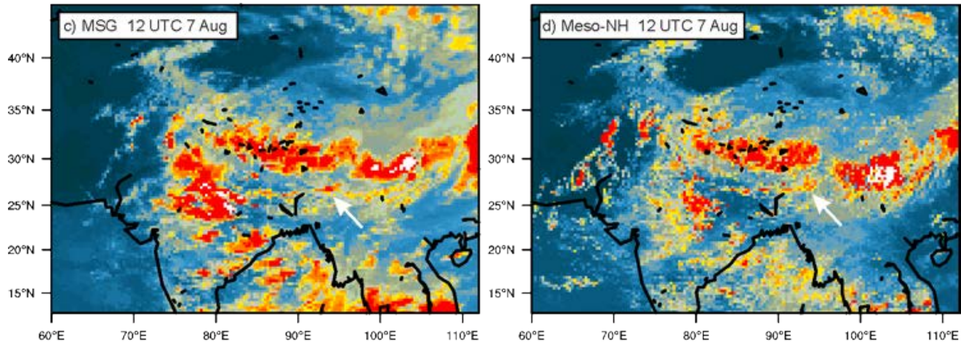


Tropospheric tracer

Lee et al., Atmos. Chem. Phys., in preparation

Advection of the hydration patch

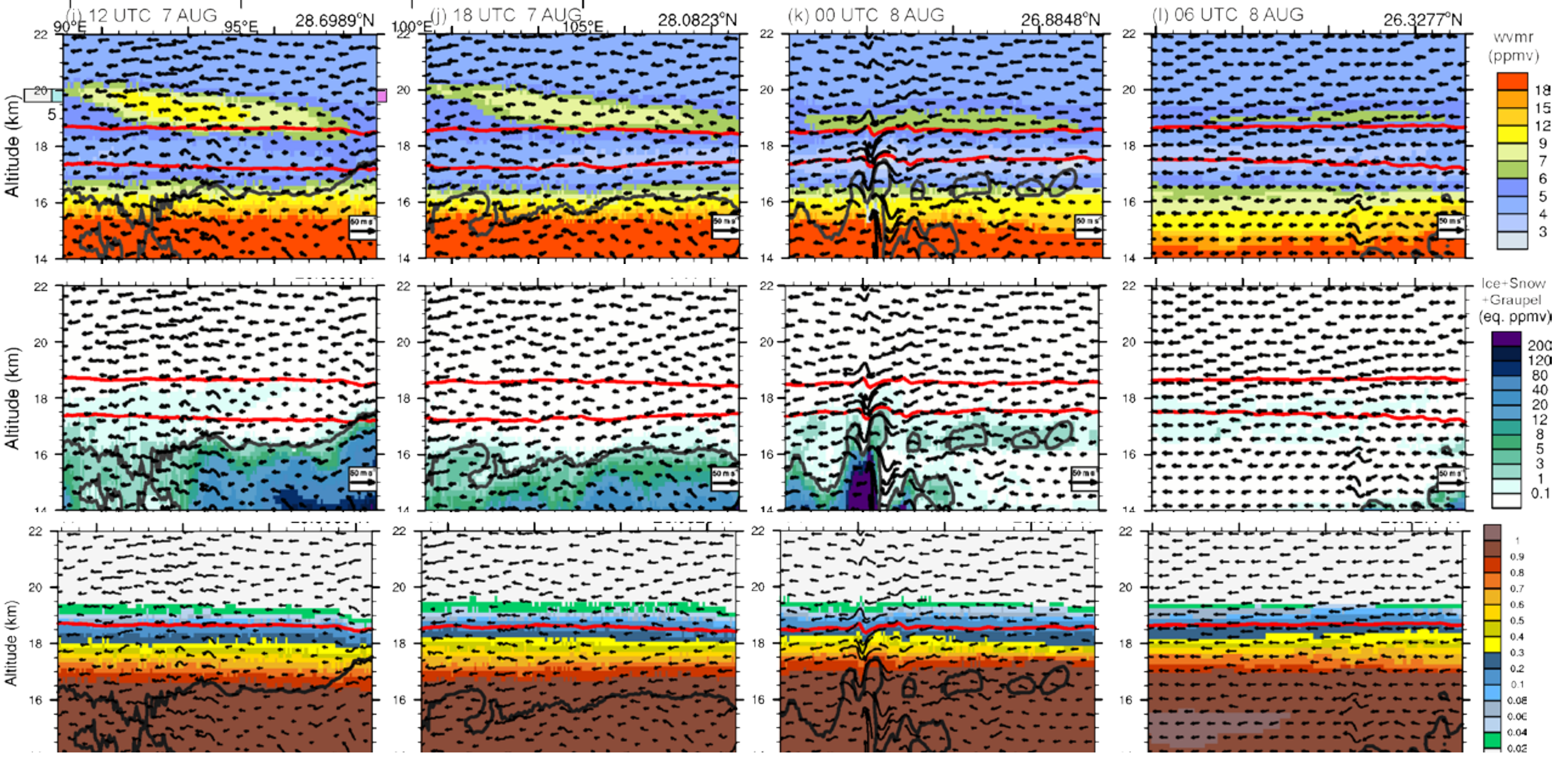




Water vapor

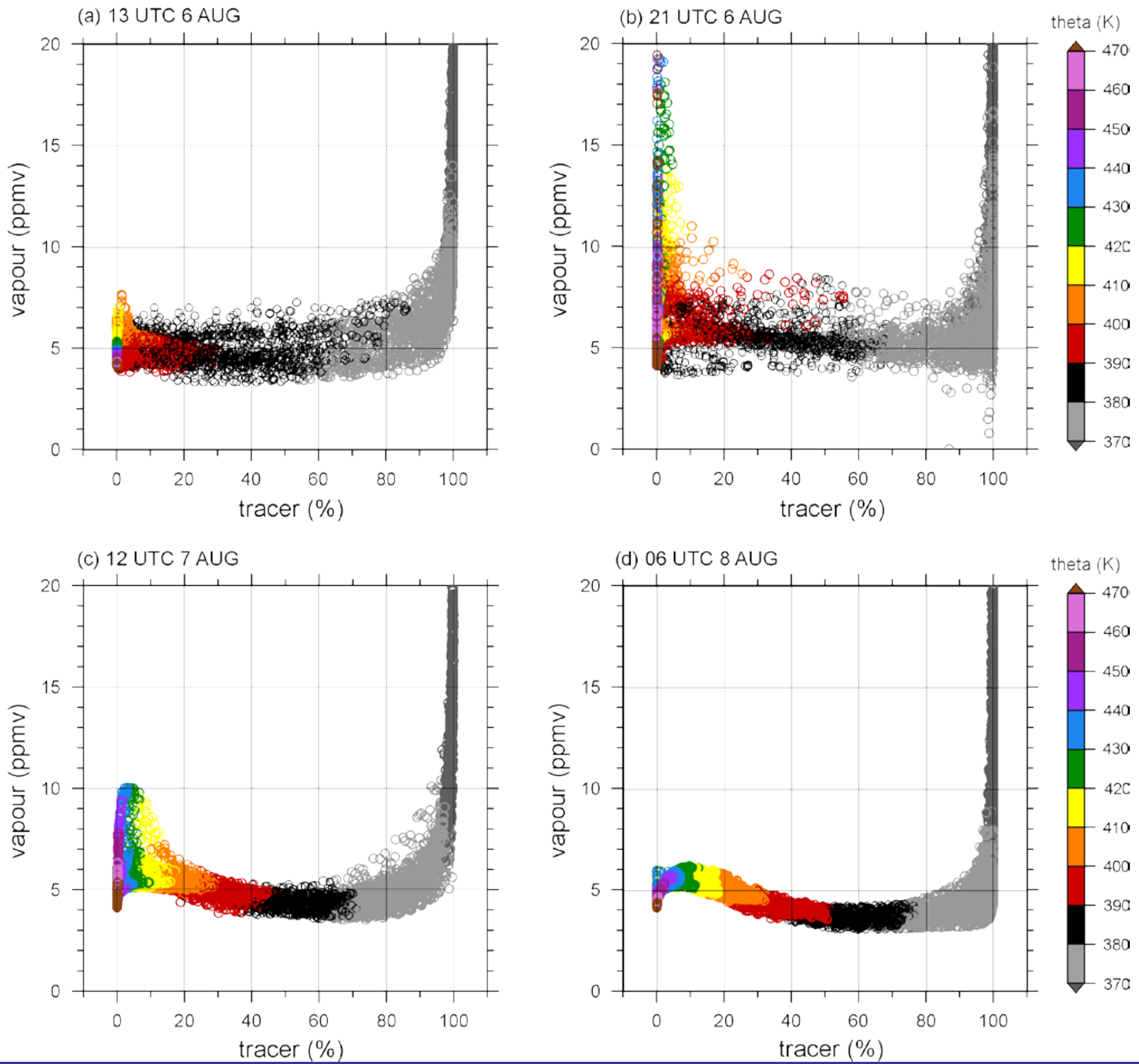
Ice content

Tropo . tracer



Lee et al., Atmos. Chem. Phys., in preparation

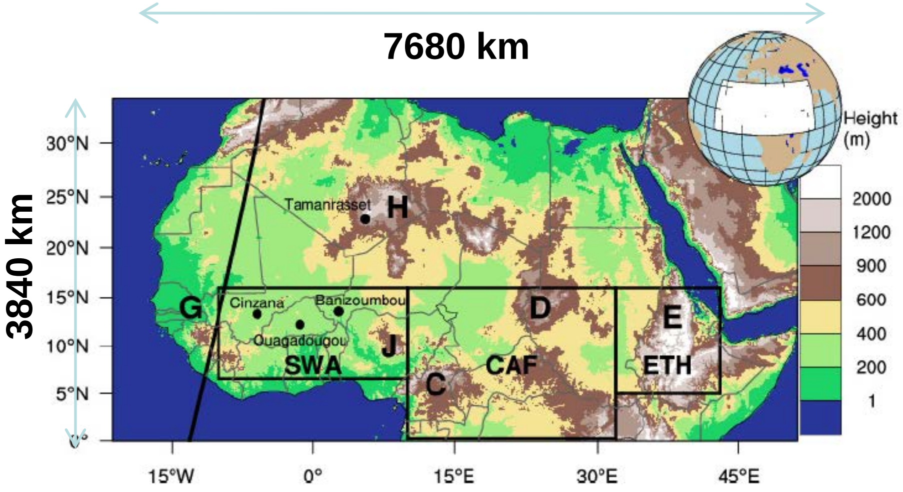
Convective vs. turbulent mixing



Lee et al., Atmos. Chem. Phys., in preparation

MCSs over north Africa

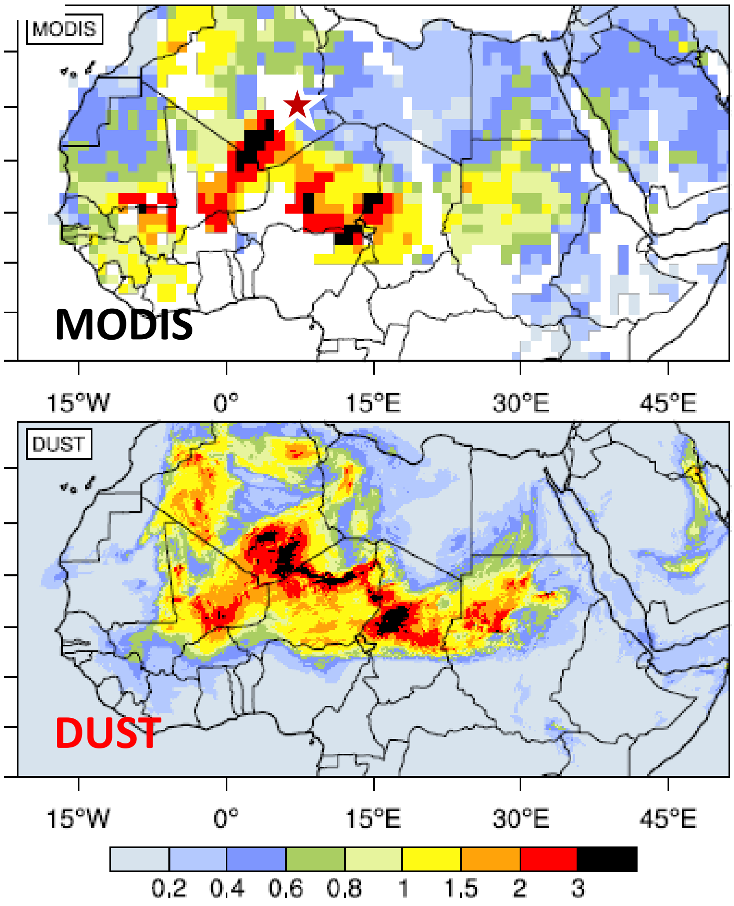
- ➢*What controls the distribution and variability of precipitation?*
- ➢*What is the radiative impact of dust on the atmosphere?*



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

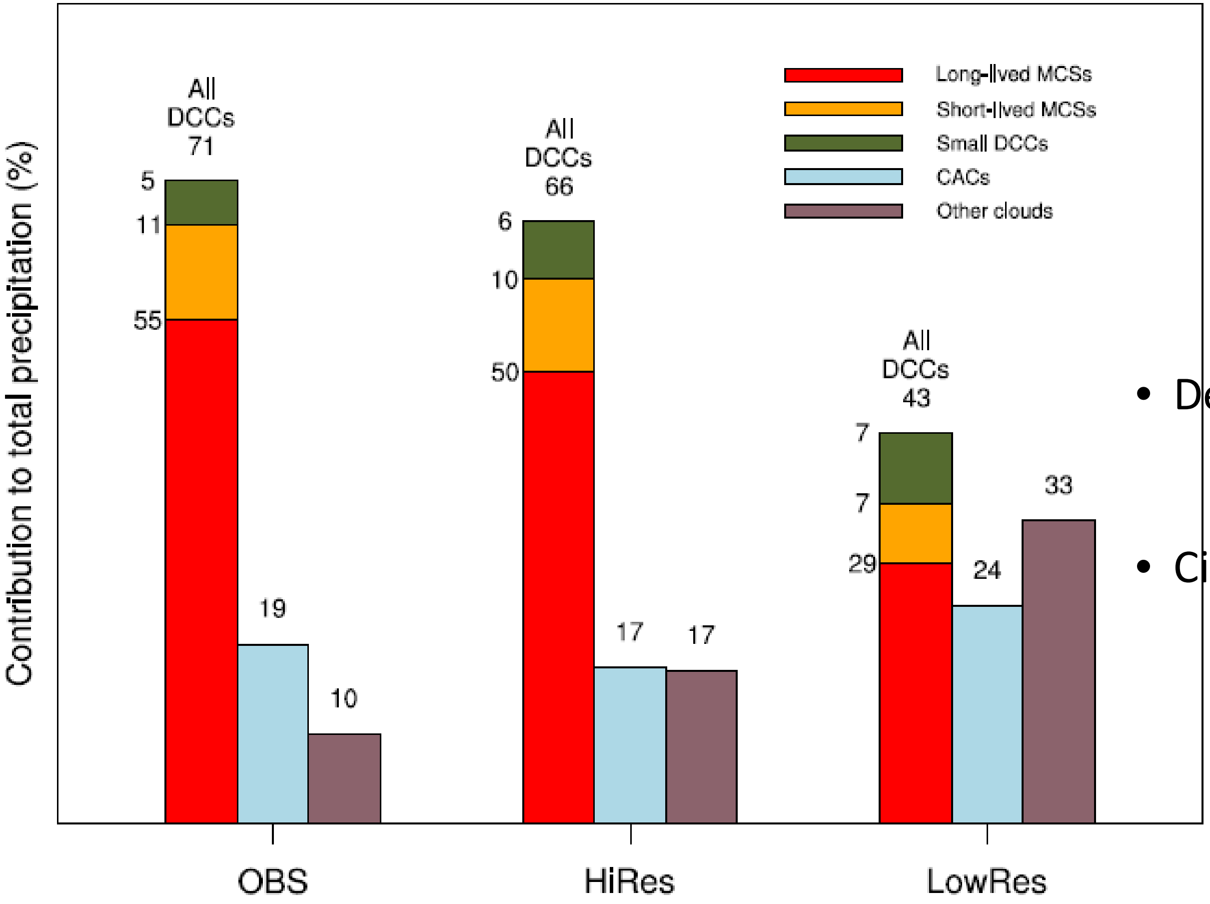
- **HiRes/DUST** Δx=2.5 km, 3072 x 1536 x 72, 1/3 billion gdpts, with dust radiative effects
- **LowRes** Δx=20 km with KFB convective parameterization and dust scheme
- **NODUST**Δx=2.5 km, w/o dust radiative effect

11 June 2006 around 1200 UTC



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

Distribution of precipitation



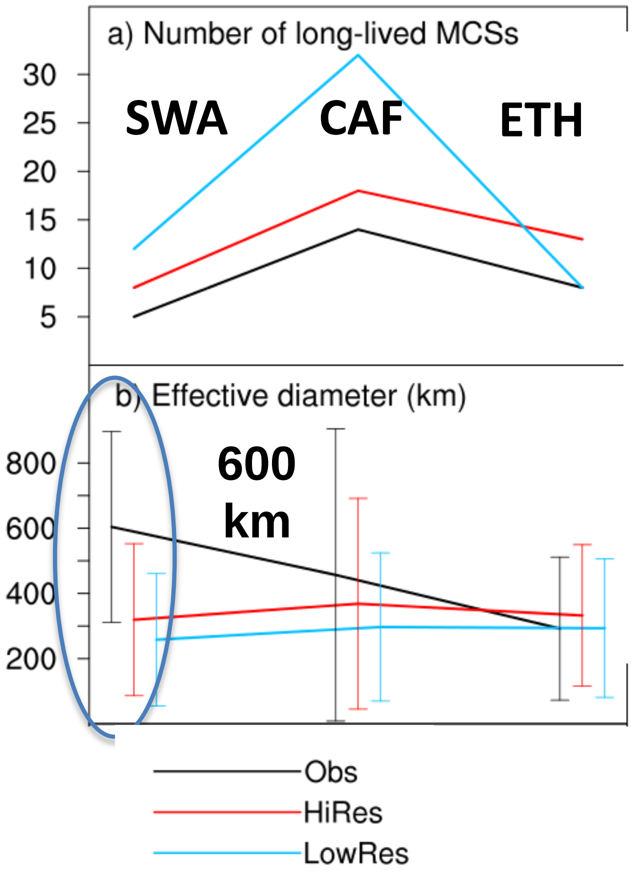
OBS: MSG 10.8 µm brightness temperature and TRMM 3B42 rain product

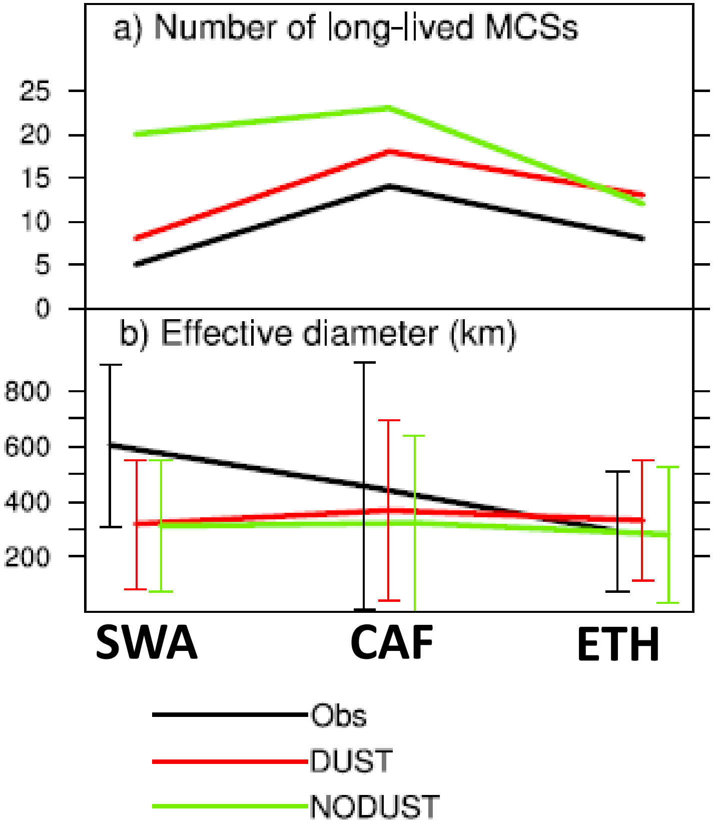
- Deep convective clouds: BT<230K
  - **MCSs** = large DCCs (Deff> 120km)
  - **Long-lived MCSs:** duration>6h
- Cirrus anvil clouds 230K<BT<260K

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

Reinares Martínez and Chaboureau, Mon. Wea. Rev., 2018a

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).**

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

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 AEROCLO-sA/ORACLES/CLARIFY field campaign (Aug. 2017)
- ✓ Investigation of convective overshoots over longer periods