Transport irréversible jusqu'en stratosphère
dans une LES de Hector the Convector

Thibaut Dauhut, Jean-Pierre Chaboureau, Patrick Mascart
Laboratoire d'Aérologie (Univ. Toulouse, CNRS, UPS)

Olivier Pauluis
(Institut Courant, Université de New York, New York et Abu Dhabi)

AMA 2017 – DEPHY2  2 février 2017
Very deep convection quickly transports PBL air directly into the stratosphere.

→ **How much?** About $10^{-4}$ kg/m²/s at the top of the systems (Gettelman et al. 2002, Küpper et al. 2004, Chaboureau et al. 2007, Dauhut et al. 2016)

Contribution to the cross tropopause water mass flux up to 18% (Dauhut et al. 2015)

→ estimates based on arbitrary thresholds
→ overestimation due to oscillatory motions?

→ **How?** By few very tall, large, strong, loaded updrafts (Dauhut et al. 2016) controlled by surface processes: breeze, cold pools, convergence lines weakly diluted

→ estimate of dilution
→ role of latent heat release?
Very deep convection quickly transports PBL air directly into the stratosphere

How much? About $10^{-4}$ kg/m²/s at the top of the systems

Contribution to the cross tropopause water mass flux up to 18% (Dauhut et al. 2015)

→ estimates based on arbitrary thresholds
→ overestimation due to oscillatory motions?

How? By few very tall, large, strong, loaded updrafts (Dauhut et al. 2016)
controlled by surface processes: breeze, cold pools, convergence lines
weakly diluted
→ estimate of dilution
→ role of latent heat release?
LES DE HECTOR AVEC

\[ \Delta x = 200 \text{ m} \quad \Delta z = 40 \text{ à } 100 \text{ m} \quad \Delta t = 0.2 \text{ s} \]

1/3 billion grid points, 3D output every minute!

Atmosphere initialised with 9:30 Darwin sounding
Open-boundary conditions

5h15 simulated \[ [9:30 – 14:45] \]
> 1 million CPU hours on BG-Q *Turing*
> 8,000 cores
> 40 To of data

3D turbulence, mixed phase microphysics,
interactive surface by SURFEX scheme (sea, land)

Similar development in 100 m simulation:
The first Giga-LES of very deep convection (Dauhut et al. 2016)
Hector the Convecter

Available at https://youtu.be/xjPumywGaAU
Cloud contour at 0.01 g/kg hydrometeore content
Compute all the irreversible transport

Consider all the air parcels (strong updrafts and slow transport) & Filter out reversible motions (waves..)

Isentropic Analysis

Mass Distribution inside Hector

Very deep convection
13:31 – 13:45

Visiting Olivier Pauluis, NYU

Equivalent Potential Temperature
How does the air circulate inside Hector?

Very deep convection
13:31 – 13:45

Mean vertical velocity (m/s)

Contribution to vertical transport (kg/m²/s)

Only the updrafts (> 10 m/s)
How does the air circulate inside Hector?

Very deep convection
13:31 – 13:45

Two key circulations:
- overshoot overturning
- troposphere overturning

Mean vertical velocity (m/s)

Contribution to vertical transport (kg/m²/s)

0°C

-38°C

0°C

Mean vertical velocity (m/s)

Contribution to vertical transport (kg/m²/s)
Congestus convection

Deep Convection

Very deep convection

Mature convection

\[ \theta_e (K) \]

\[ z (km) \]

\[ \Psi \] kg m\(^{-2}\) s\(^{-1}\)

-0.14
-0.04
-0.01
0.001
0.002
0.004

320 340 360 380

\[ \theta_e (K) \]
How much air is transported by very deep convection?

- across the tropopause $\sim 3.5 \times 10^{-3}$ kg/m$^2$/s
  larger than in previous studies $\sim 10^{-4}$ kg/m$^2$/s

- in the lower troposphere $\sim 10^{-1}$ kg/m$^2$/s
Is latent heat release important?

Latent heat release overrides the cooling due to mixing during the very deep convection phase.
Entrainment → 0.04 /km
Conclusions and perspectives

The vertical transport by Hector reaches $3.5 \times 10^{-3}$ kg/m²/s across the tropopause → about 30 x more than in previous studies of very deep systems

The contribution to the global mass flux may be higher!...
But, is the transport similar in the other very deep convective systems?

How to take this cross tropopause transport into account in GCMs?

At the scale of the system, the transport is organised in 2 main overturnings:
  troposphere overturning & overshoot overturning

Diabatic tendency changes at the transition from deep to very deep convection
  latent heat release due to ice formation > energy loss due to mixing

Minimum of entrainment during very deep convection phase
  → locally down to half the rate found for the tallest updrafts

How sensitive are these results to our representation of the microphysics?
Microphysical properties of Hector during its very deep phase

- B (buoyancy)
- S (snow mixing ratio)
- I (ice mixing ratio)
- G (grape mix ratio)
- C (cloud liquid water mixing ratio)
- R (rain water mixing ratio)
The air parcels for which the diabatic tendency changed from deep to very deep convection.
Diabatic tendencies with $h_m$ insensitive to latent heat release