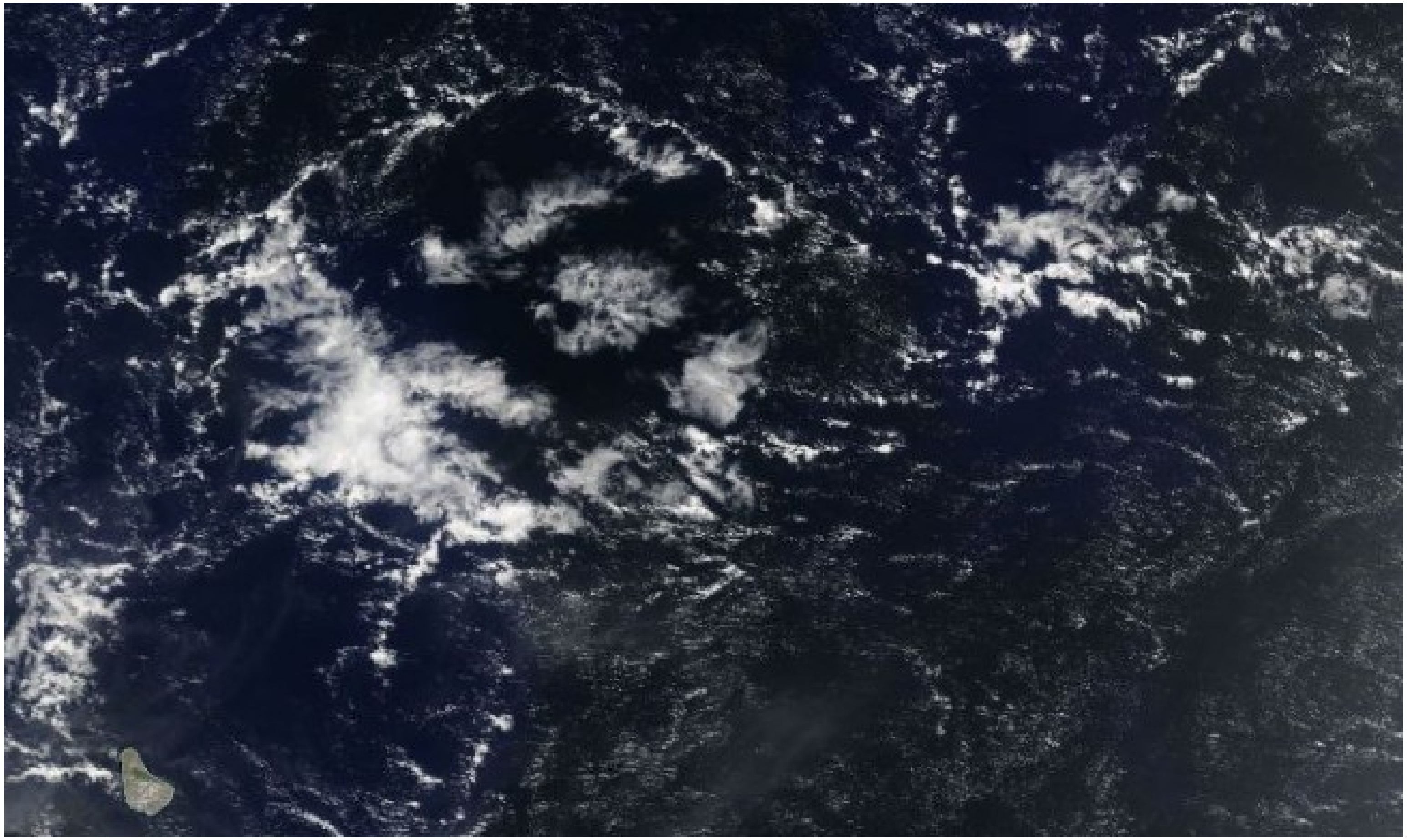
Cold pools created by shallow cumuli – from observations to parameterizations



Source: Worldview, 27/05/2019 – East of Barbados

Ludovic Touzé-Peiffer

with contributions from Grandpeix J.Y., Rochetin N., Vogel R.

Cold pools in observations

Barbados Cloud Observatory (BCO)

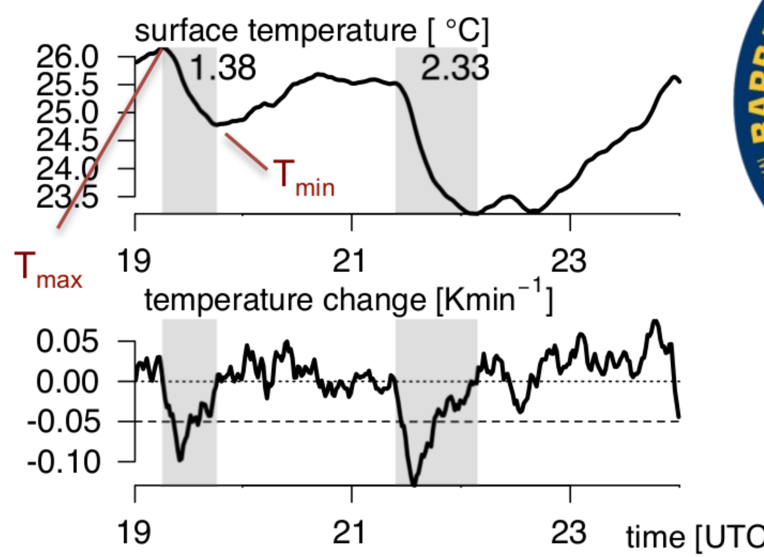
- samples undisturbed trade-wind conditions – clouds at Barbados are representative of clouds in the trade wind regions *(Medeiros and Nuijens, 2016)*
- Up to 8 years of ground-based remote sensing & *in situ* data

(S. Schnitt)

Cold pools detection algorithm

1) smooth 1-min surface temperature data with 11-min centered linear filter
2) T fil (t)-T fil (t-1) < -0.05 K
3) Identify T max and T min in front
4) retain cold pools with ΔT < -0.5 K

   + more conditions for separating nearby cold pools, defining end of cold-pool wake etc.

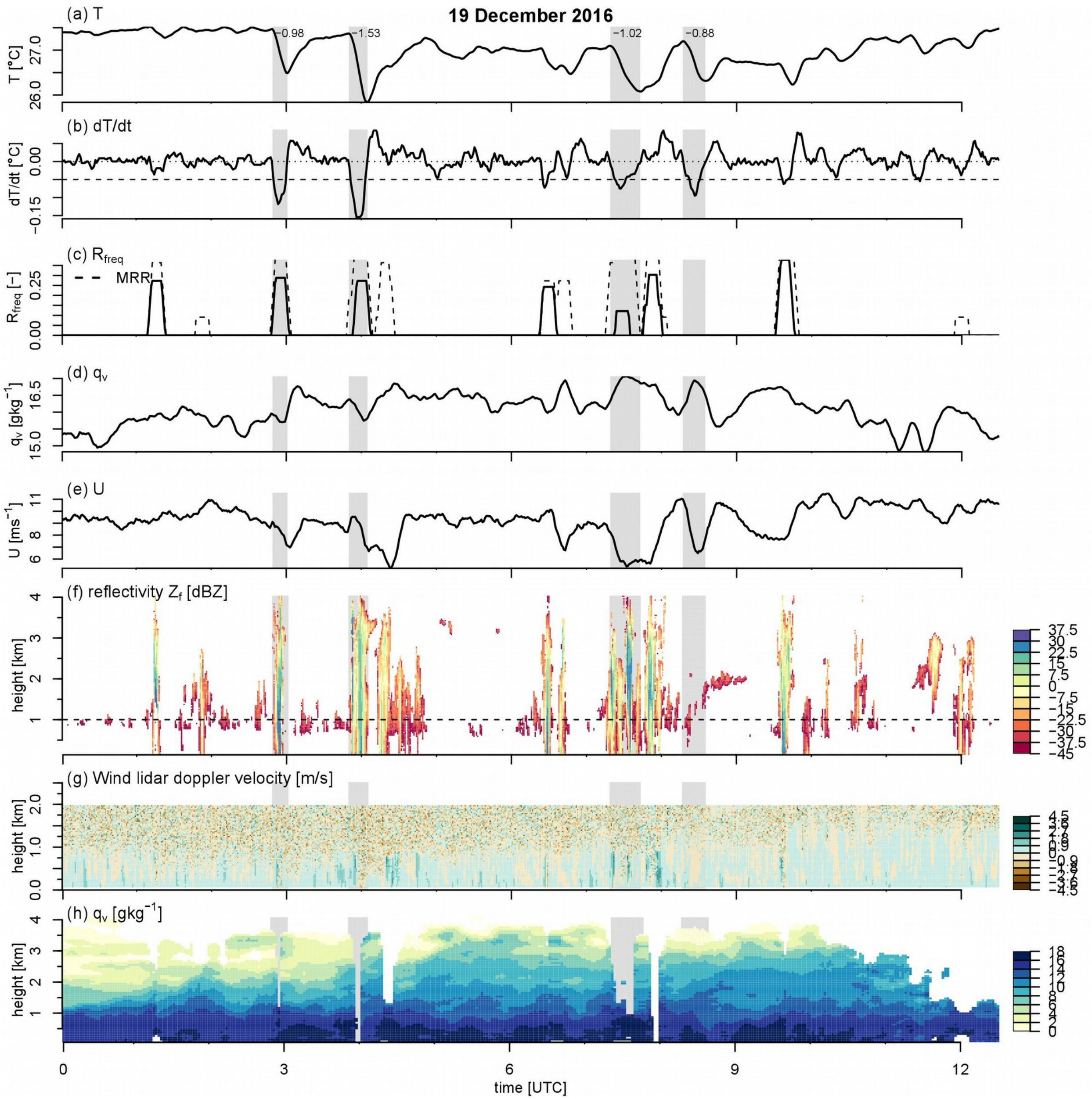


Courtesy R. Vogel

Cold pools in observations

Example case 19/12/2016

MODIS Aqua, 19.12.16, 17.20 UTC

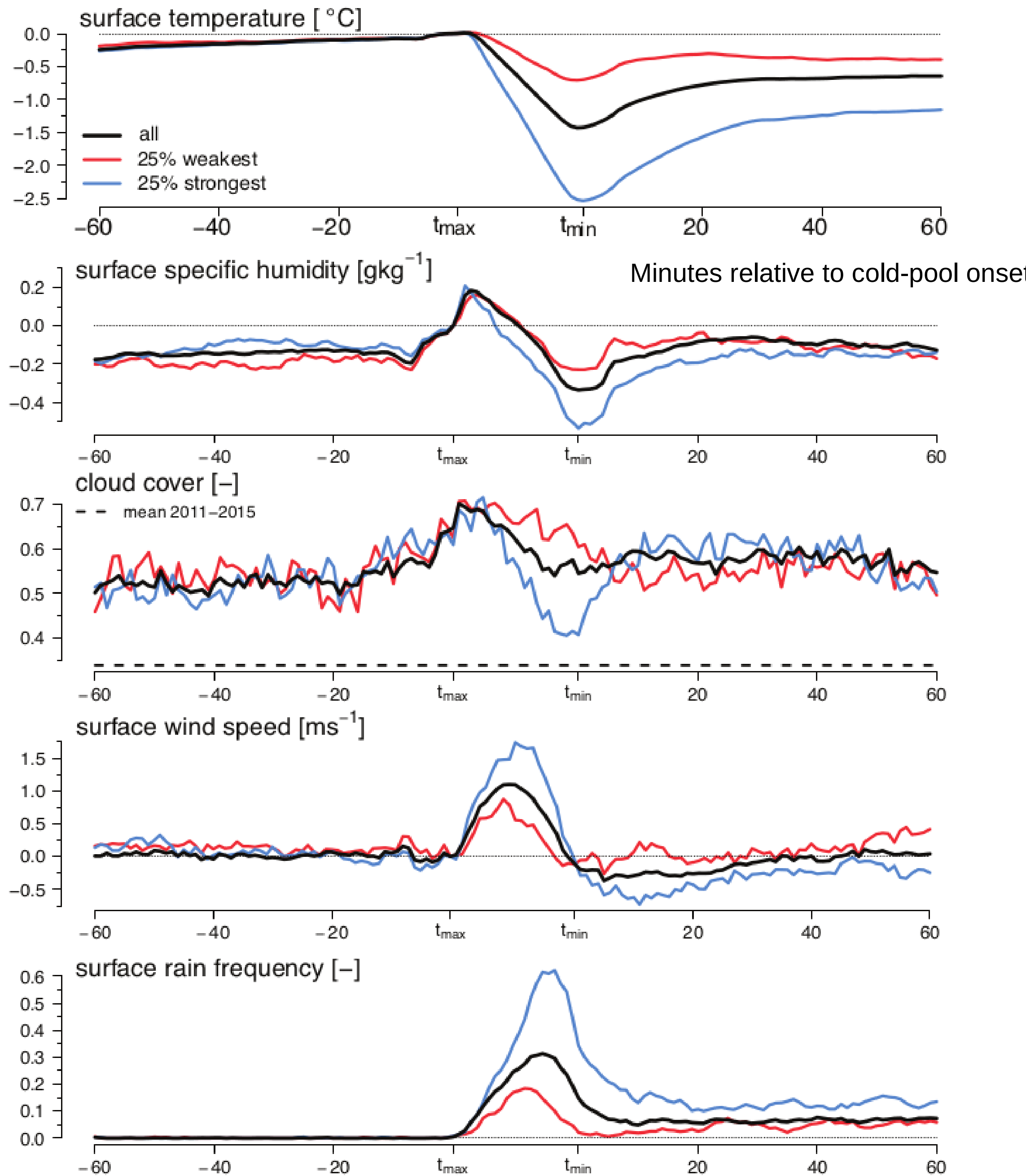


Courtesy R. Vogel

Cold pools in observations

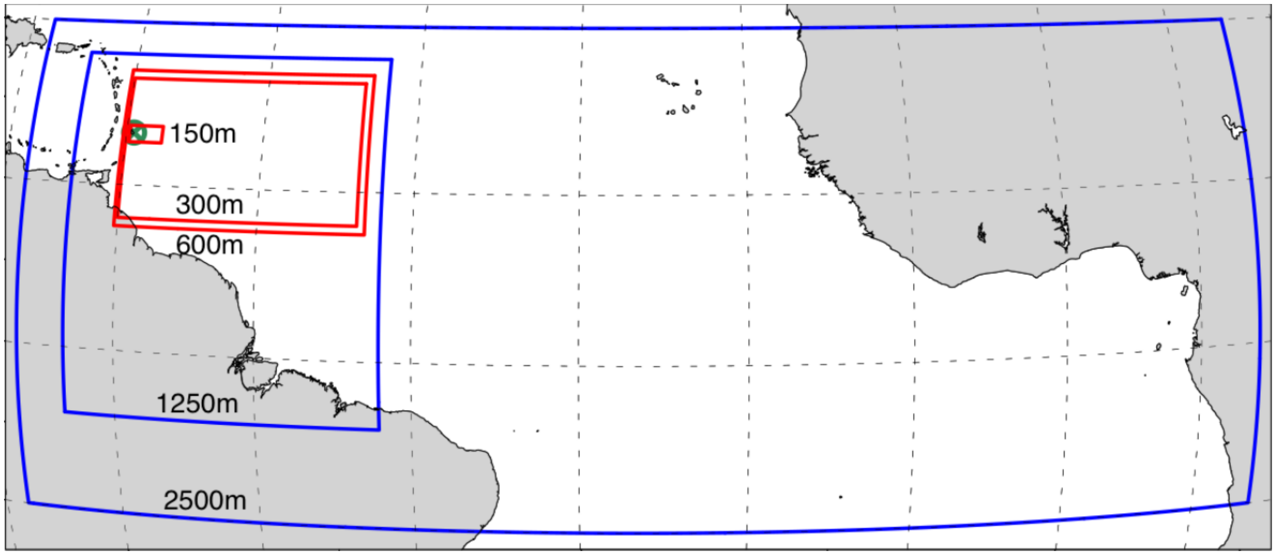
Composite case (~ 1000 cold pools analyzed)

Stronger temperature drops are related to stronger humidity drops, stronger wind speed increases, higher rain frequencies and a slight decrease of the cloud cover at the end of the cold pool front.



Courtesy R. Vogel

High resolution simulations



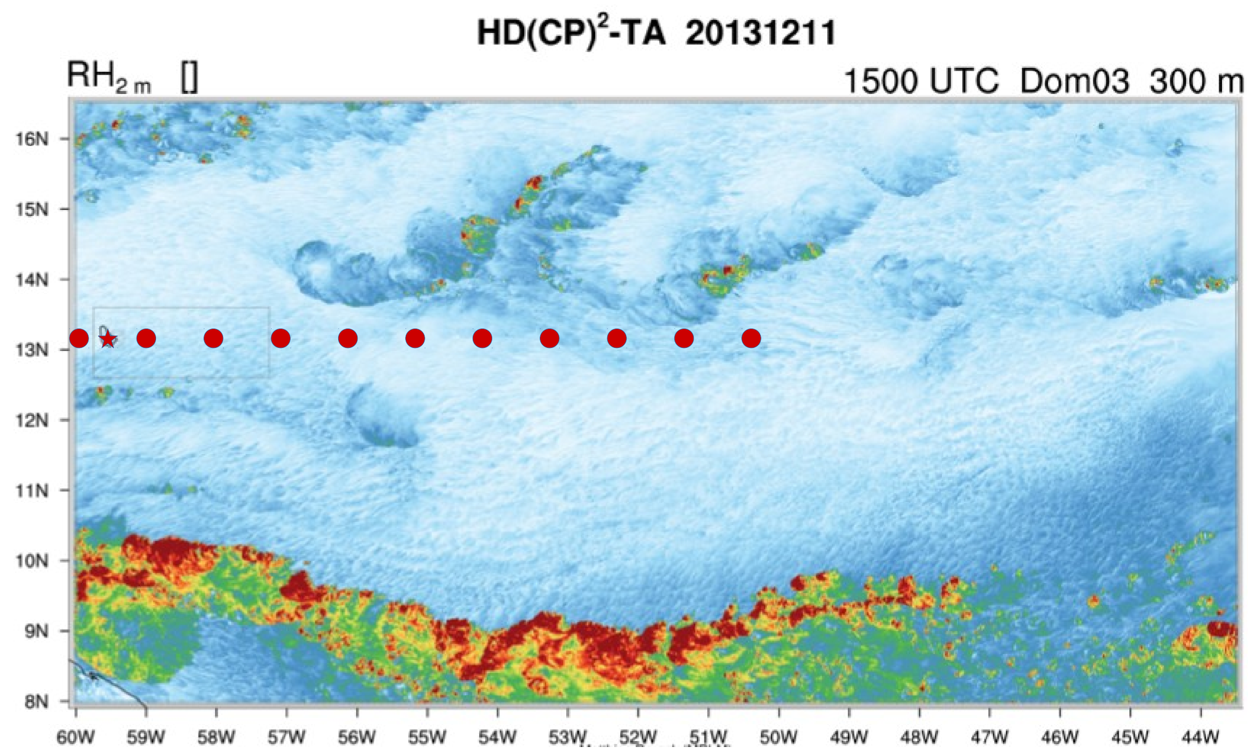
ICON Large Eddy Simulations

- 300m resolution, 150 vertical levels
- Initialization and lateral boundary conditions from 1.25km-resolution runs
- Model output every 15 minutes and first 4 hours are spinup
- No cloud parameterization; different schemes for turbulence and microphysics

Meteograms

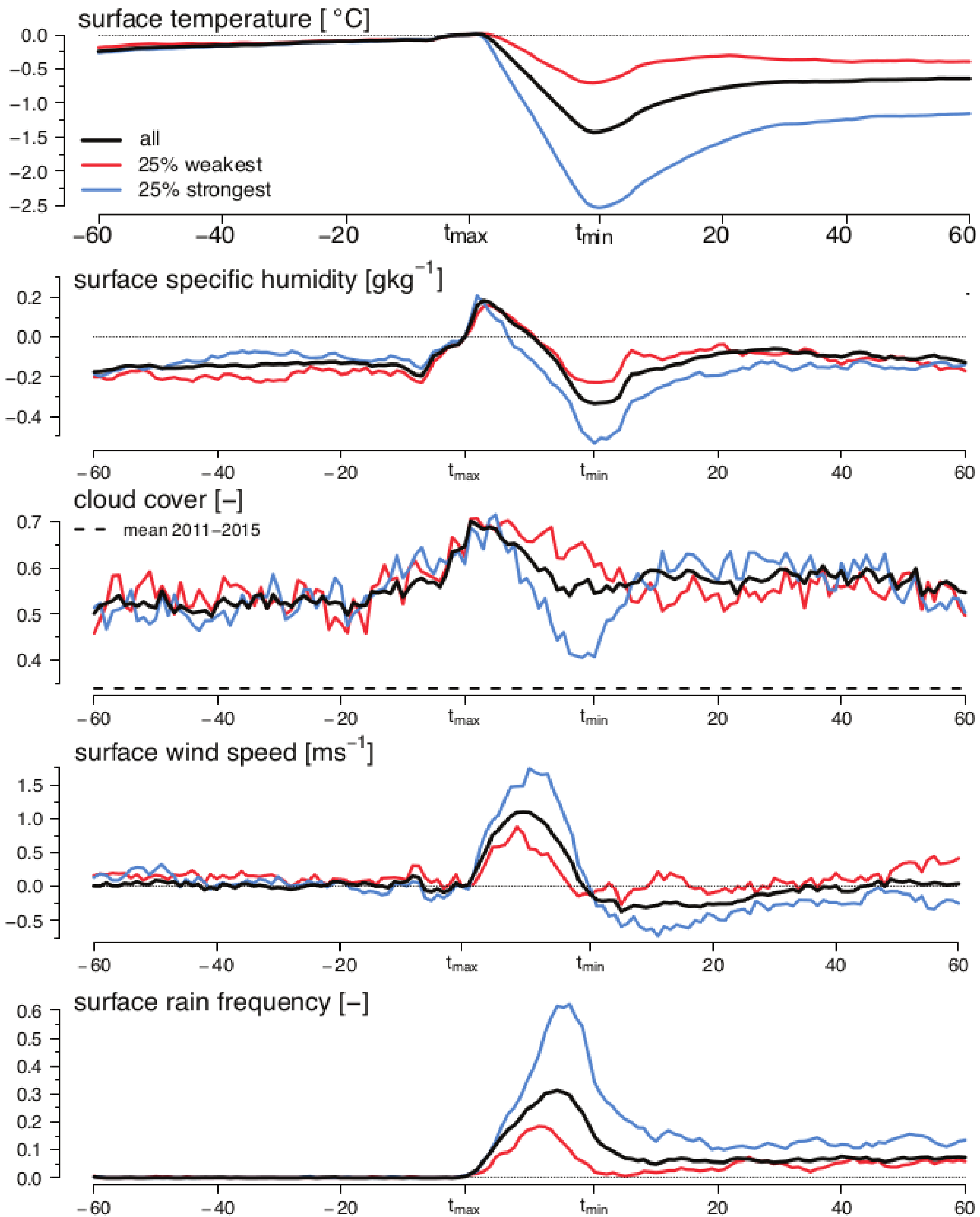
- Available for 300m, 600m and 1250m-resolution runs
- 12 points available (including BCO)
- Temporal resolution: 36 seconds
- 4 days in December 2013, 4 days in August 2016

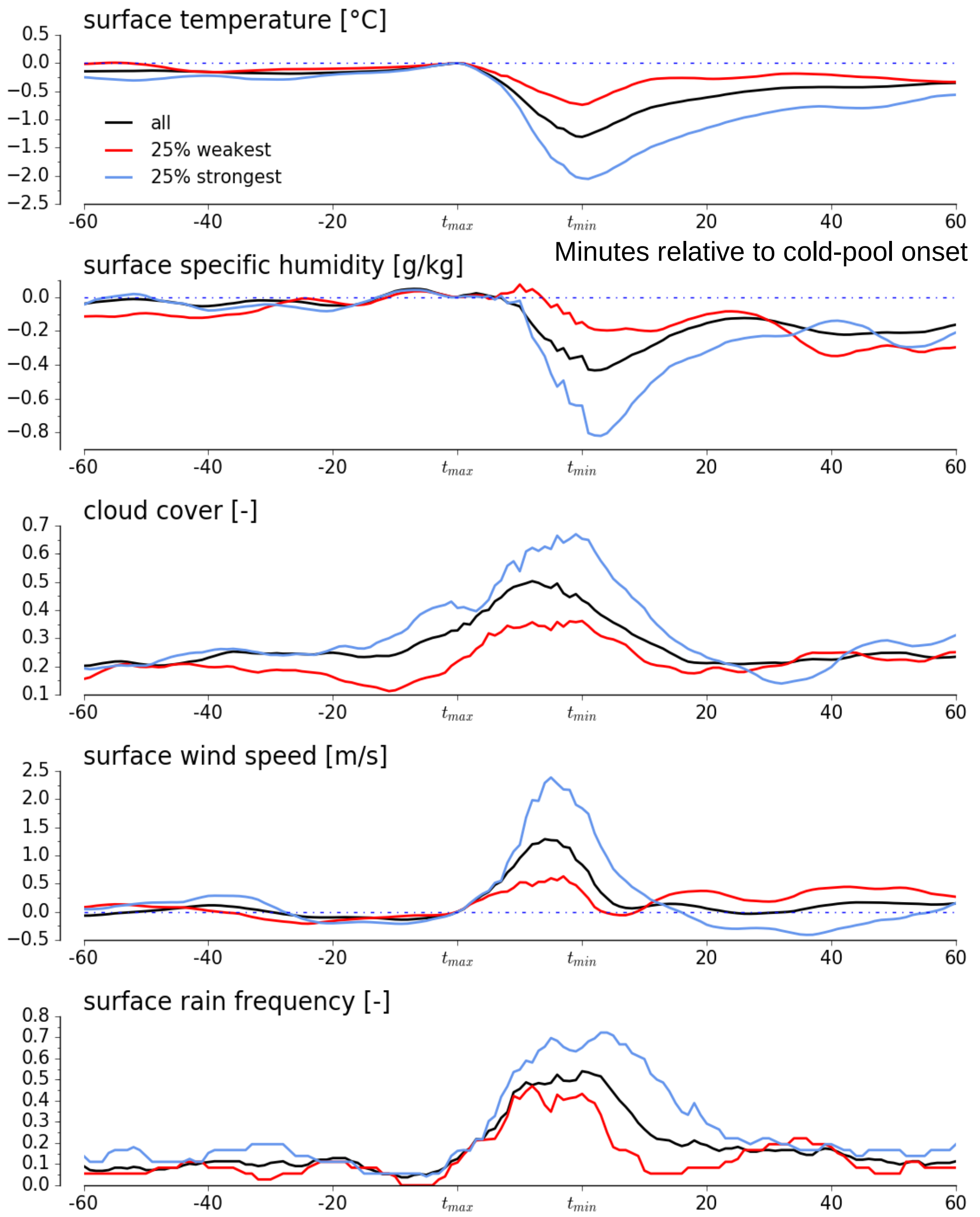
→ allow for direct comparison with BCO observations



Observations at BCO from 2010 to 2017 - ~ 1000 cold pools analyzed

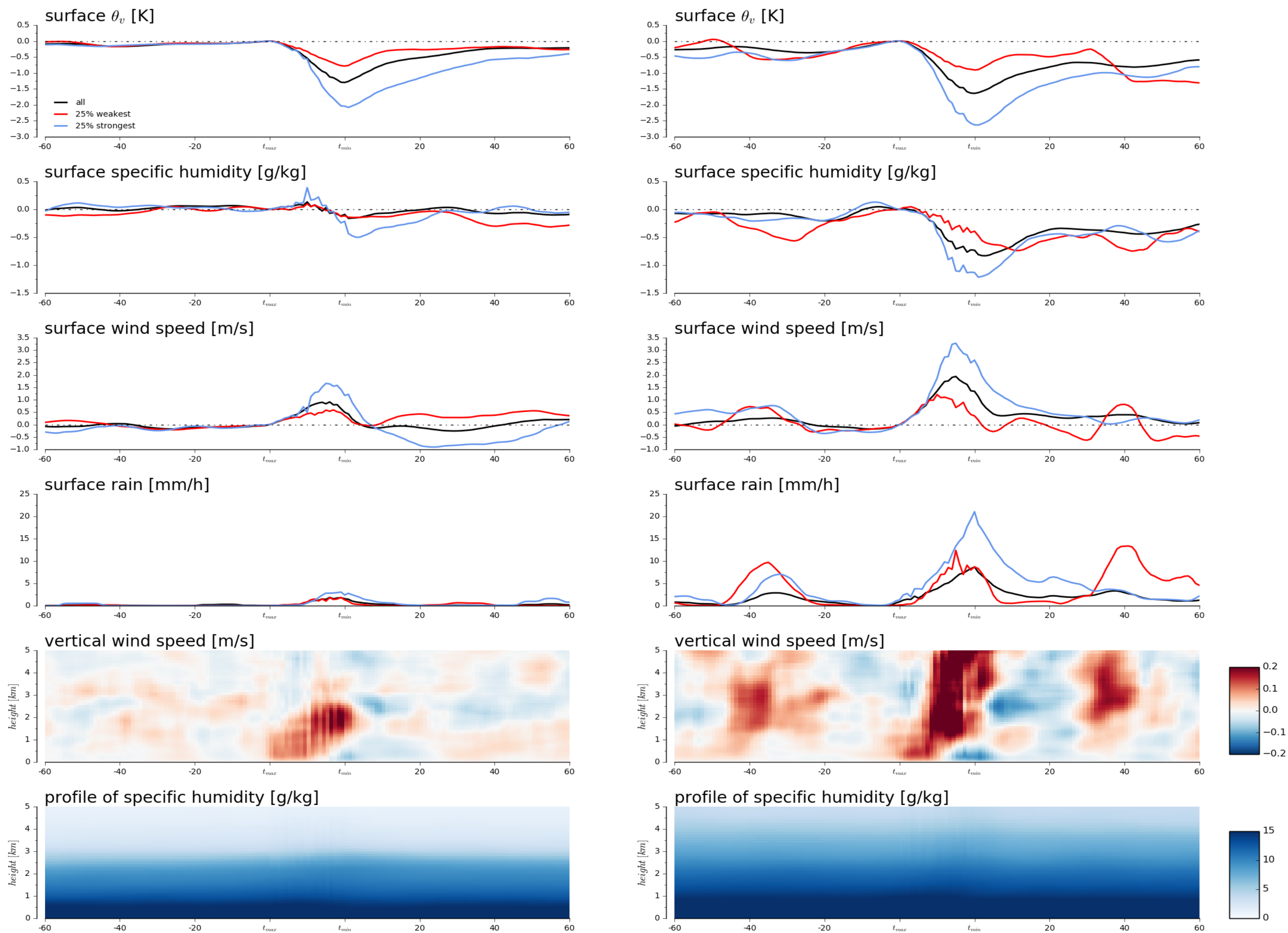
ICON 300 meters LES at meteogram points - 132 cold pools analyzed





ICON 300 meters LES at meteogram points - Shallow convective events - 74 cold pools analyzed

ICON 300 meters LES at meteogram points - Deeper convective events - 58 cold pools analyzed



LMDZ environment and motivation

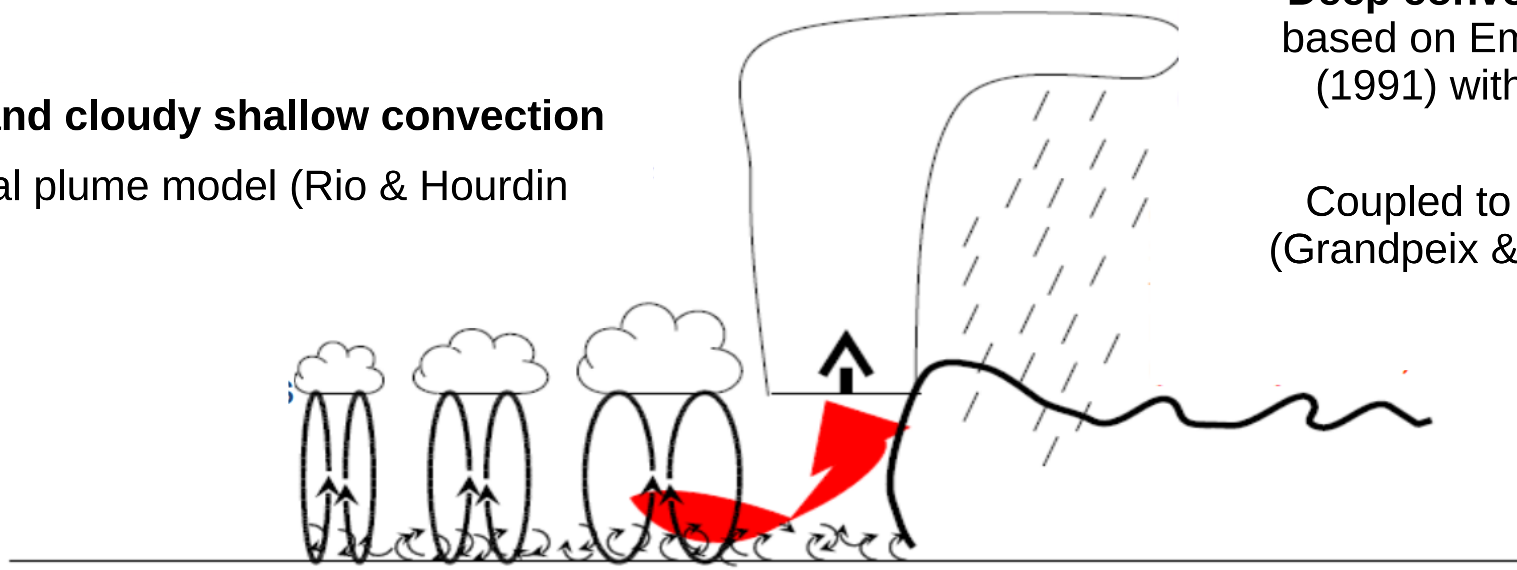
Two convective schemes in LMDZ6

- Emanuel's convective scheme, used to represent deep convection
- The thermal plume model (Rio and Hourdin 2008) to represent dry and cloudy shallow convection

→ cold pools are coupled with the deep convective scheme only

Dry and cloudy shallow convection

Thermal plume model (Rio & Hourdin 2008)



Deep convective scheme based on Emanuel scheme (1991) with ALP closure

Coupled to **cold pools** (Grandpeix & Lafore 2010)

In observations (especially in the trade wind regions), presence of cold pools below shallow cumuli as well (Zuidema et al. 2012)

→ coupling cold pools with the shallow convective scheme in LMDZ6

Brief overview of the cold pool scheme in LMDZ

Standard version of the "wake model"

- circular cold pools (the wakes) with vertical frontiers
- the wakes are cooled by the precipitating downdrafts, the air outside the wakes feeds the convective saturated drafts
- D_{wk} – the wake density – is uniform; the density of wakes is the same for all grid columns where the wake model is activated
- 3 wake state variables: 1) their fractional coverage σ_w 2) the potential temperature difference $\delta\theta(p)$ and (3) the specific humidity difference $\delta q_v(p)$ between the wake and its environment
- Wakes being denser than their environment, they spread with a rate

$$\partial_t \sigma_w = 2 C_* \sqrt{\pi D_{wk} \sigma_w}$$

  with C_* proportional to the square root of the wake potential energy (von Karman 1940)
- The spreading induces a vertical velocity difference (assumed piecewise linear) between wakes and their environment
- Wakes activate and feed the deep convective scheme through its closure

Ongoing improvements

1. Planetary boundary layer splitting

- The turbulent scheme is applied separately in the wakes and in their environment
- At the interface, surface exchange laws connect the two regions
- At the surface, the assumption is made that the temperature is the same in both regions

2. Dynamics of cold pool population

- Goal: represent a population of cold pools, with lifetime considerations
- Two categories of cold pools: active cold pools (continuously fed by convective downdrafts) and inactive cold pools, which collapse
- The total density of cold pools and their fractional coverage vary with the birth rate of cold pools, the collapse of inactive cold pools and the collisions between cold pools

(More details in Grandpeix & Lafore 2010)

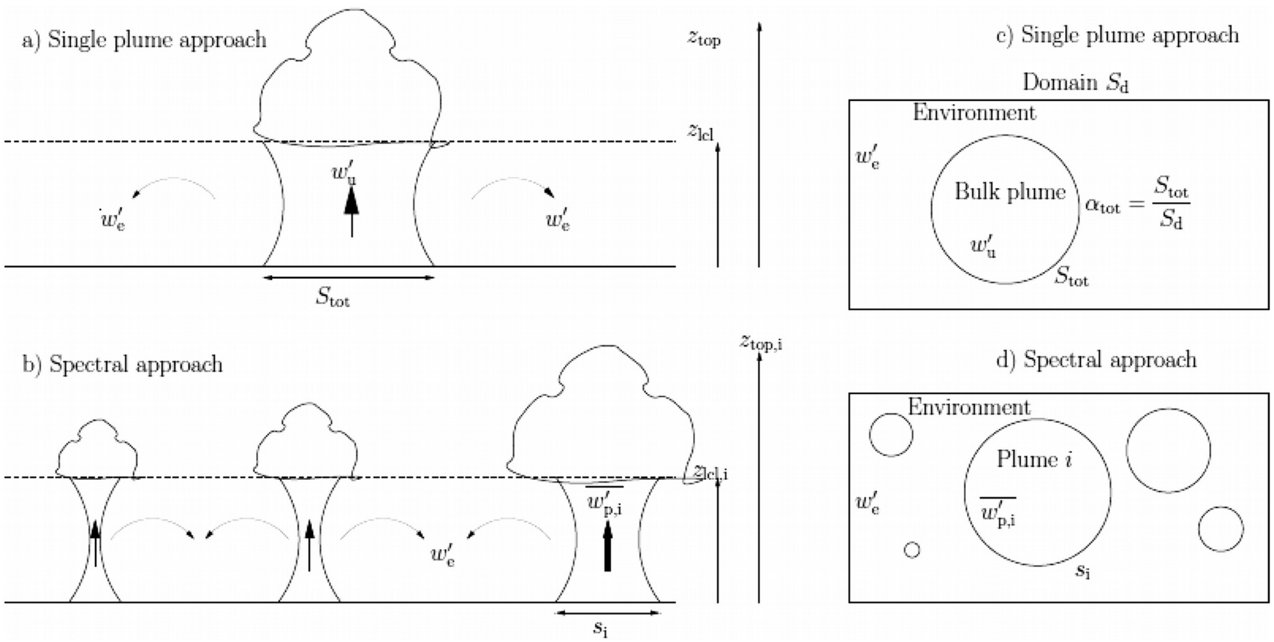
Coupling cold pools with the shallow convective scheme – original idea

Only the "**deepest shallow cumuli"** may precipitate and therefore create cold pools

→ use the cross-section spectrum of Rochetin 2012 to select only the shallow cumuli "deep enough"

$$\sqrt{s_2} = a(\langle z_{top}\rangle - \langle z_{lcl}\rangle) + b\langle z_{lcl}\rangle$$

$$P_2(s) = \frac{1}{s_2}\exp\left(\frac{-s}{s_2}\right)$$



Rochetin et al., JAS 2014

Assumptions:

1) clouds start to precipitate when $s > s_{trig} = 5\ km^2 \rightarrow s_{tot} = \int_{s_{trig}}^{\infty} \frac{N_2}{s_2}\exp(-s/s_2)$

2) The cooling and moistening due to the evaporation of precipitation is homogenized below cloud base

3) The thermals are present only outside cold pools

SCM preliminary results in the Rico case

I) Case description

- Data used to build the case obtained during the “Rain in Cumulus over the Ocean” (RICO) measurement campaign, which took place near the Carribean islands Antigua and Barbuda during Dec 2004 – Jan 2005
- Composite case based on a three week period with typical trade wind cumuli and a fair amount of precipitation
- The area averaged amount of rain during the three week trade wind cumulus period is about **0.3 mm/day**

(B. Stevens)

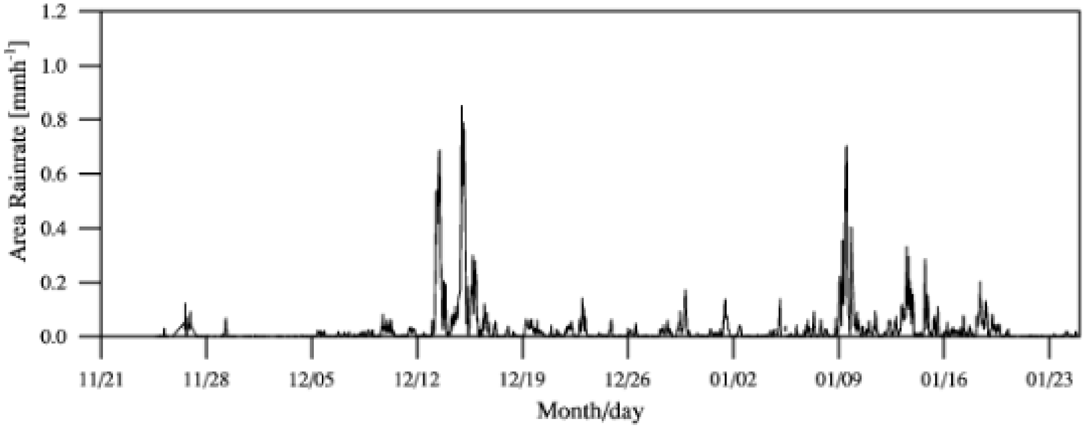
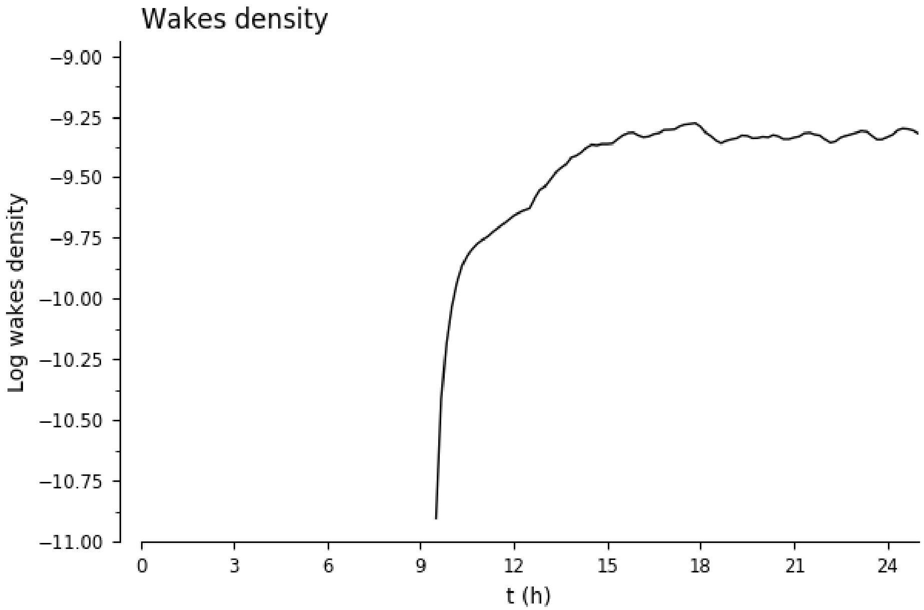
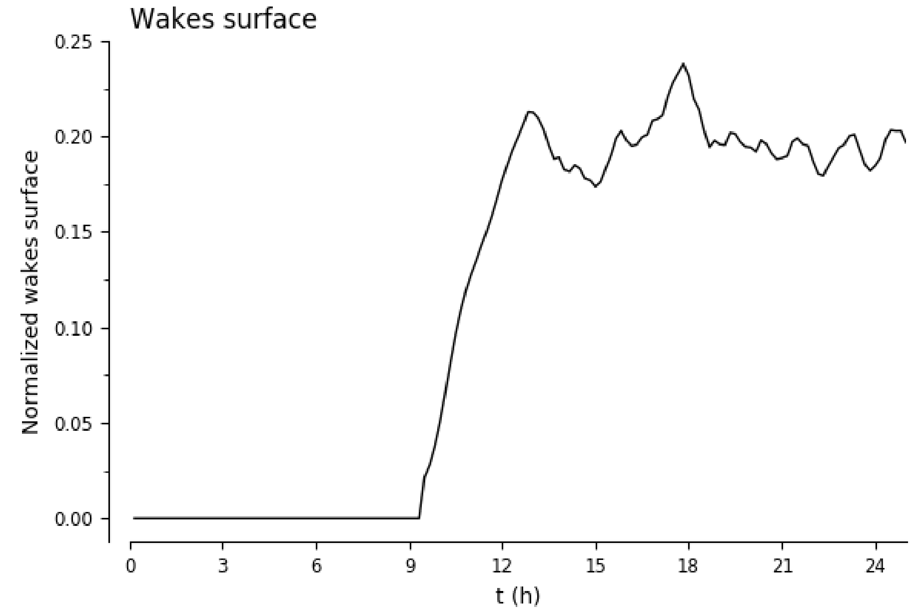


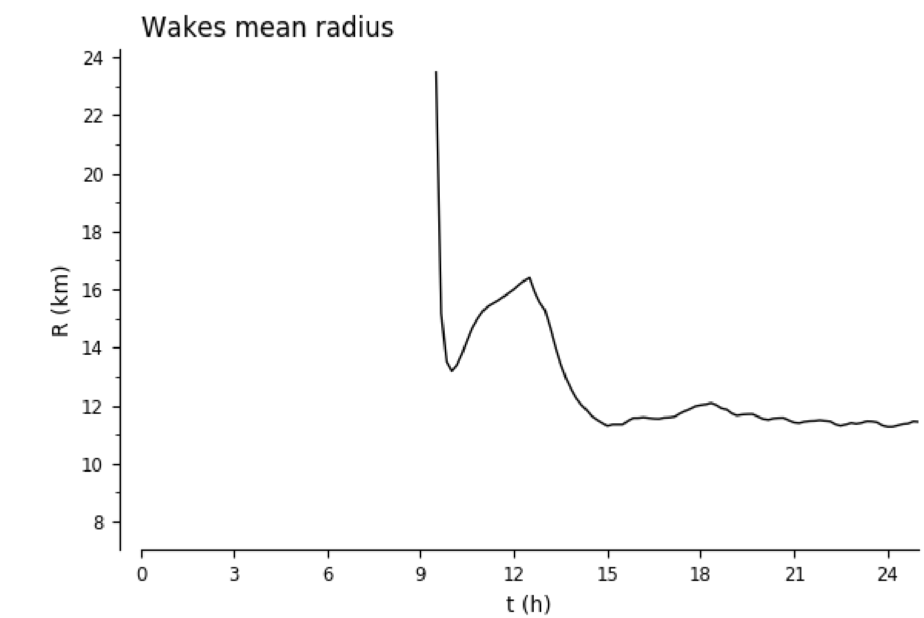
Figure 1. Time series of area rainfall during RICO, derived from SPol radar observations.

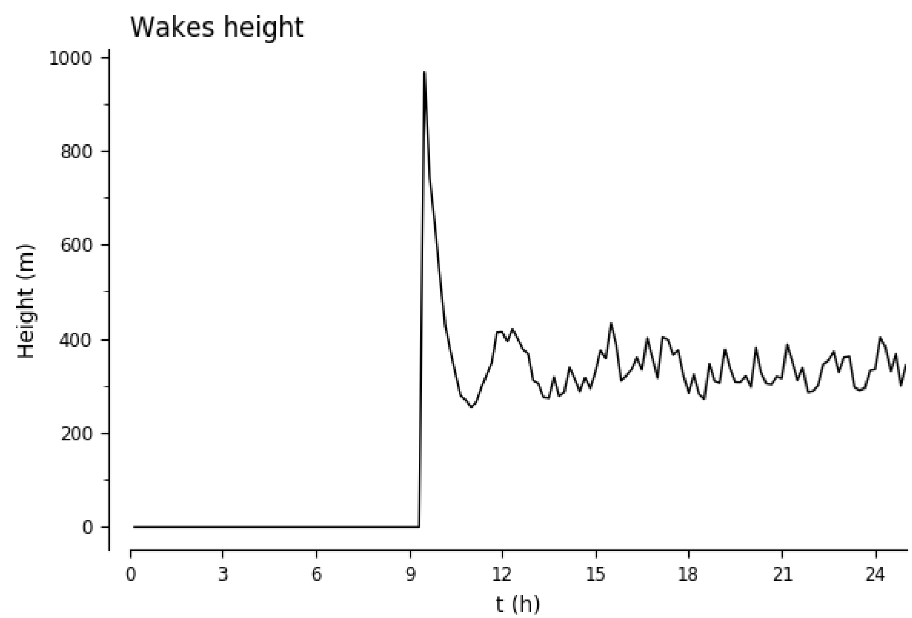
SCM preliminary results – Rico case

II) Wakes characteristics







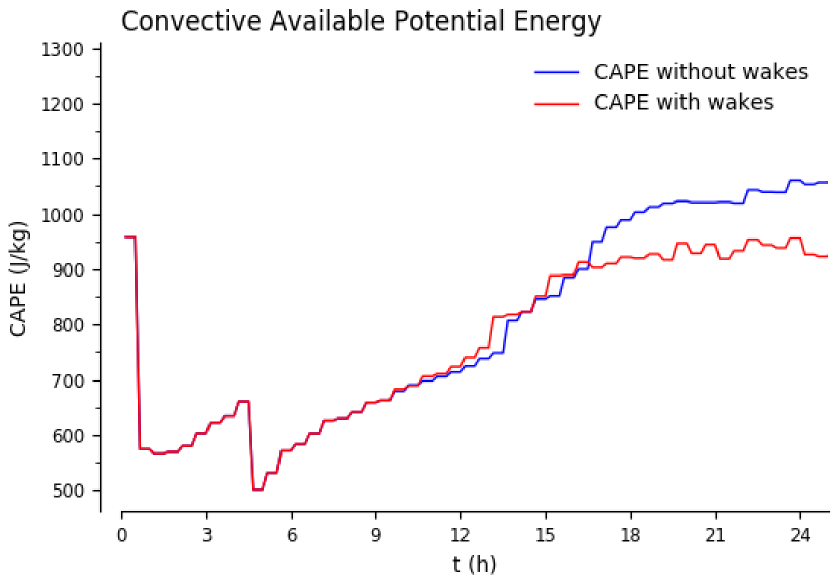


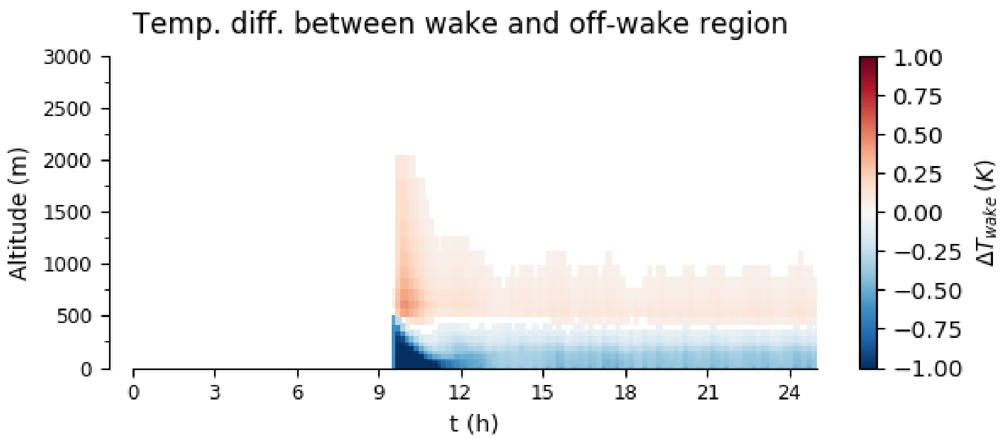
SCM preliminary results – Rico case

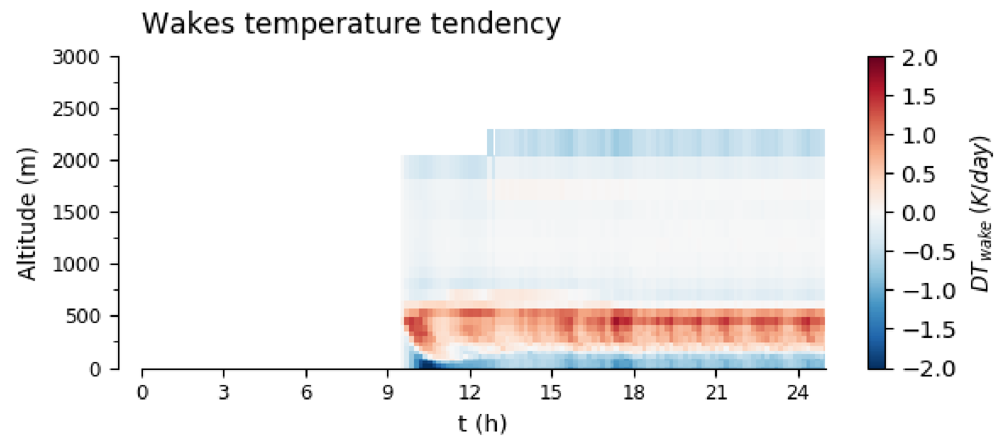
III) Wakes profile and tendencies

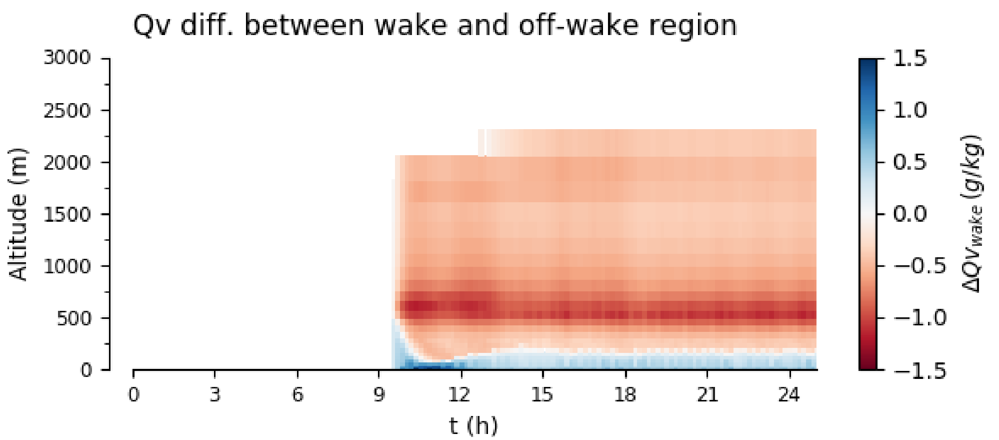
- At first, thermals are enhanced by wakes, because they are initialized in the off-wake region (warmer than the mean grid cell)
- Then, wakes drying tendency diminish the intensity of thermal plumes

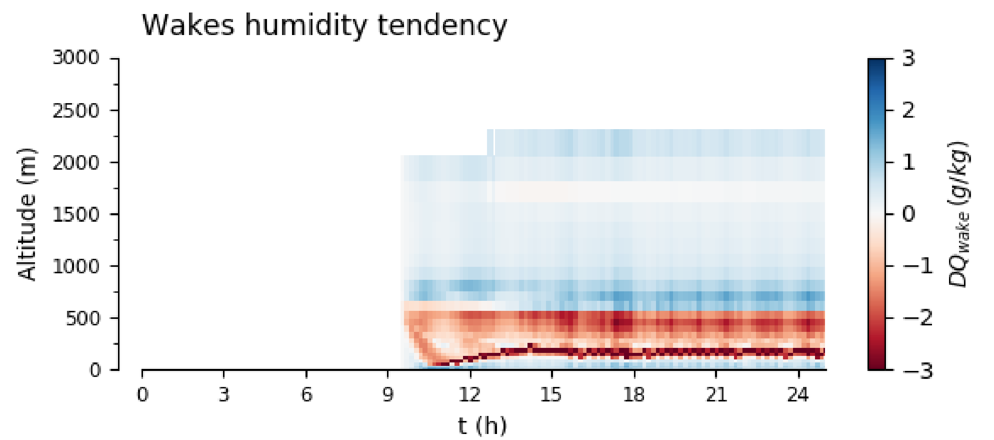
  → probably due to the vertical velocity profile above wakes









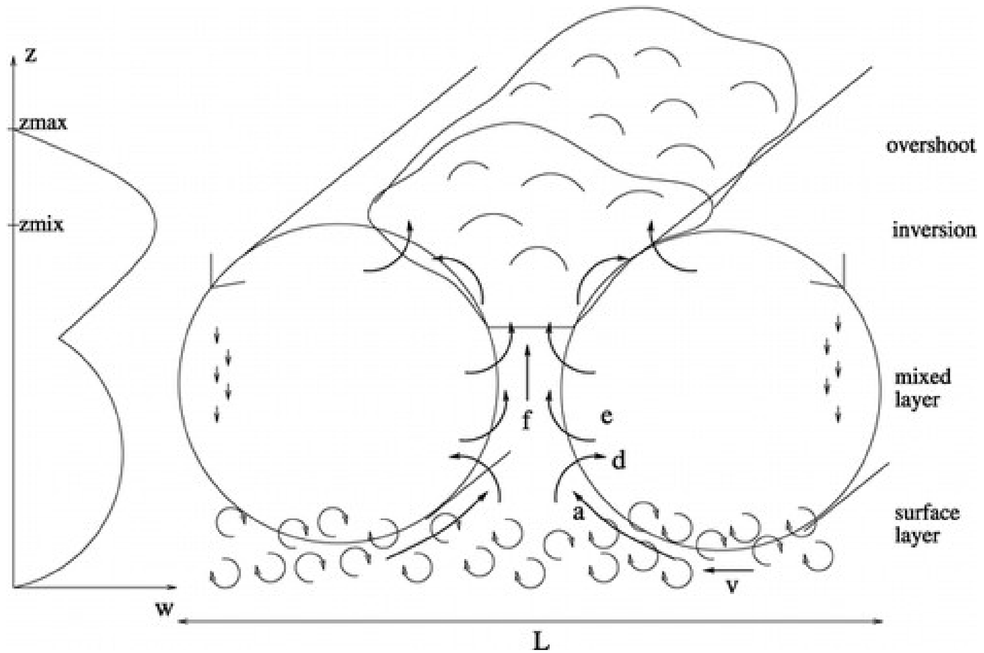


Perspectives

1) Is it necessary to represent the effect of downdrafts in the thermal plume model and how?

- thermal plume model consists of a mean plume with its compensating subsidence

- it handles neither condensation/precipitation nor downdrafts



2) How to parameterize the activation of shallow convection by cold pools?

- inspiration from deep convection: cold pools trigger and feed the deep convective scheme through an Available Lifting Energy (ALE) and Available Lifting Power (ALP) – two quantities used in the closure of the deep convective scheme

- similarly, should the closure of the thermal plume model be modified in order to take into account the effect of cold pools?

3) What improvements does the coupling of a shallow convective scheme with a cold pool scheme offer for LMDZ?

- use cold pools to represent better the aggregation of shallow convection? Its propagation?

Questions?