A parameterization of convective dust storms for models with mass-flux convection schemes

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Focus: convective dust storms (haboobs)

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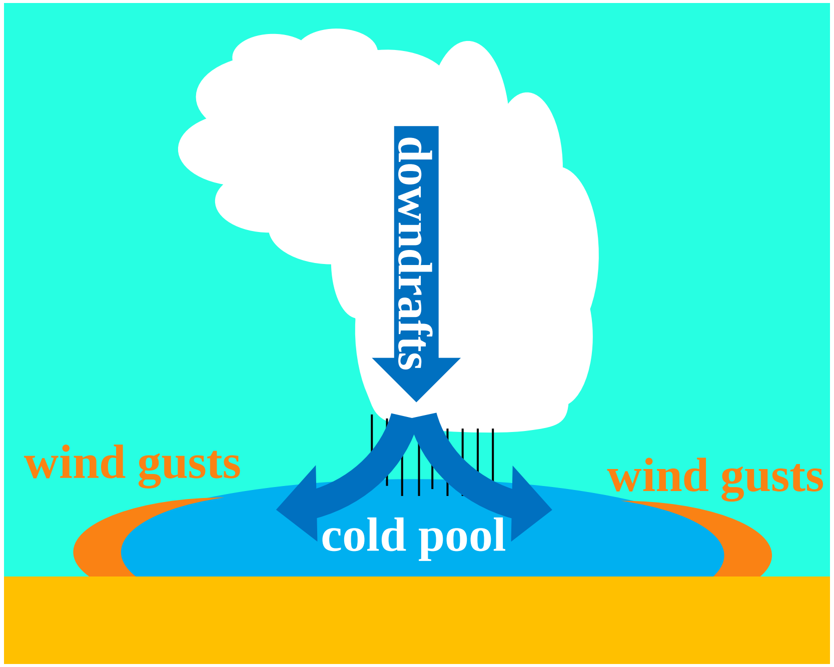
Formation related to moist convection

- Origin in **convective downdrafts** driven by evaporation of precipitation
- A **cold pool** spreads quickly as a density current
- A front of **wind gusts** lifts dust into the cold pool



Dust emission from convective storms

- **Important contribution** in Summer over West Africa
  (Heinold et al. 2013, JGR; Marsham et al. 2013, JGR)
- But **missing** in global models which do not resolve convection

(Marsham et al. 2011, GRL; Garcia-Carreras et al. 2013, GRL)

Need for a parameterization!
Idea: use the convective downdrafts described as **downdraft mass flux** in many convection schemes

Data: the Cascade project

Set of simulations for West Africa
with the UK Met Office Unified Model

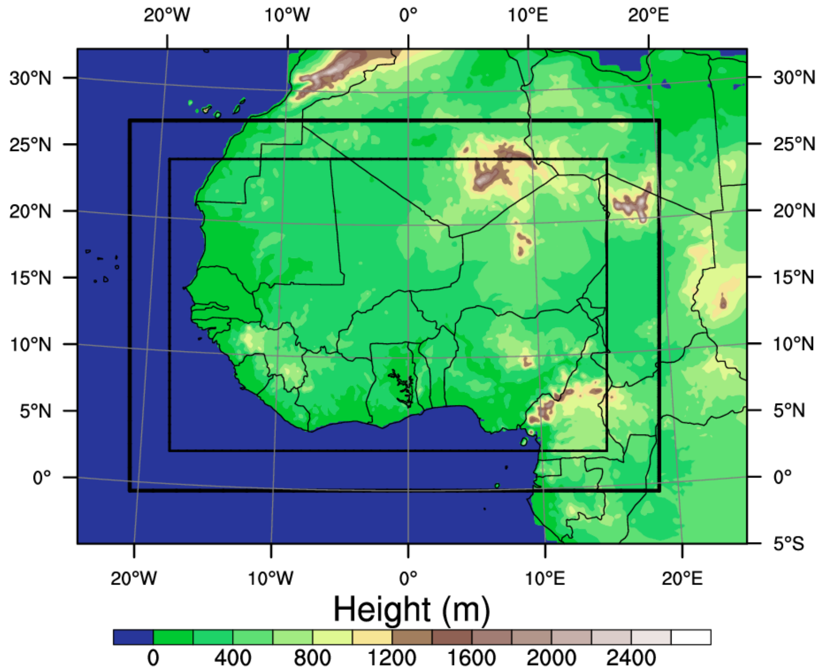
June-July 2006, different grid spacings

- 12 km: **parameterized convection**
- 4 km: **explicit convection**
- 1.5 km (10 days): **explicit convection**

Convective dust storms *(Marsham et al. 2011, GRL)*

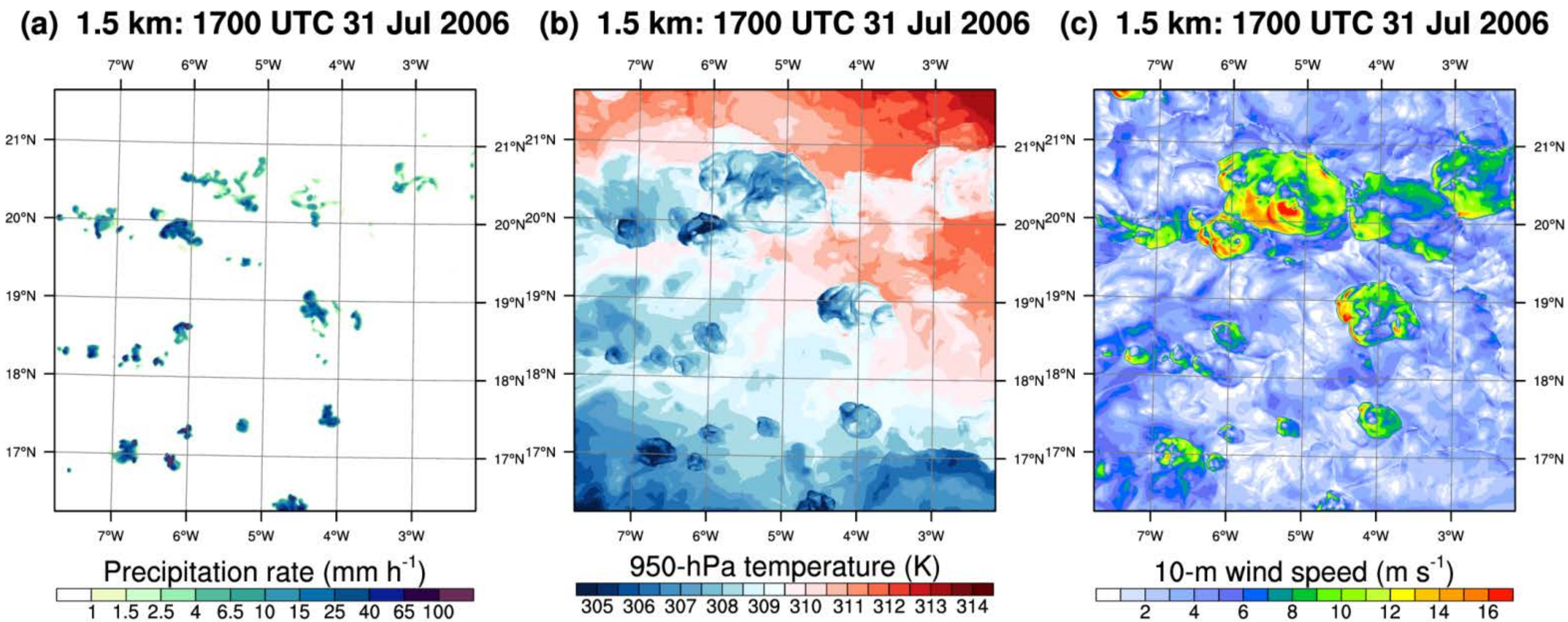
- resolved with explicit convection
- missing with parameterized convection

Domains of the Cascade runs



Ideal set of simulations to develop a parameterization

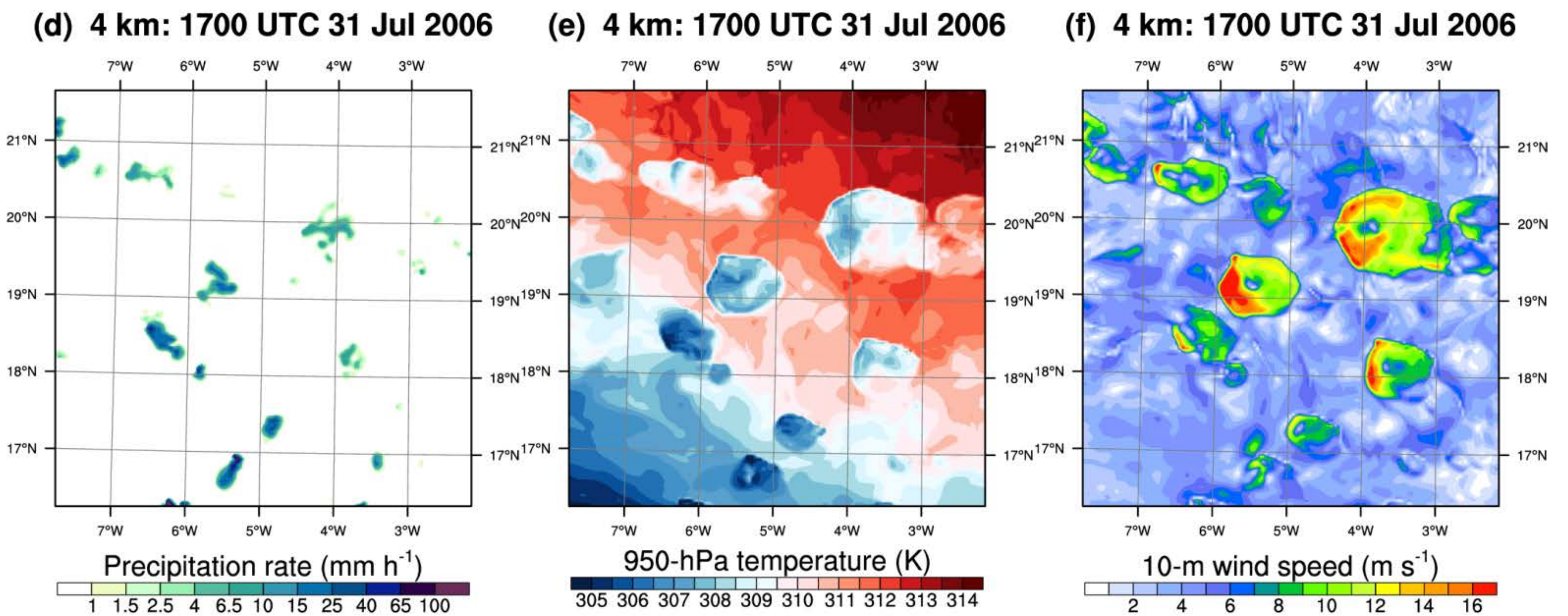
Example: 1.5 km with explicit convection



Convective precipitation → Cold pools → Strong surface winds

The 1.5-km run **resolves** convective dust storms but not enough data… (10 days)

Example: 4 km with explicit convection



Convective precipitation → Cold pools → Strong surface winds

The 4-km run **resolves** convective dust storms
→ reference for the parameterization!

Example: 12 km with parameterized convection

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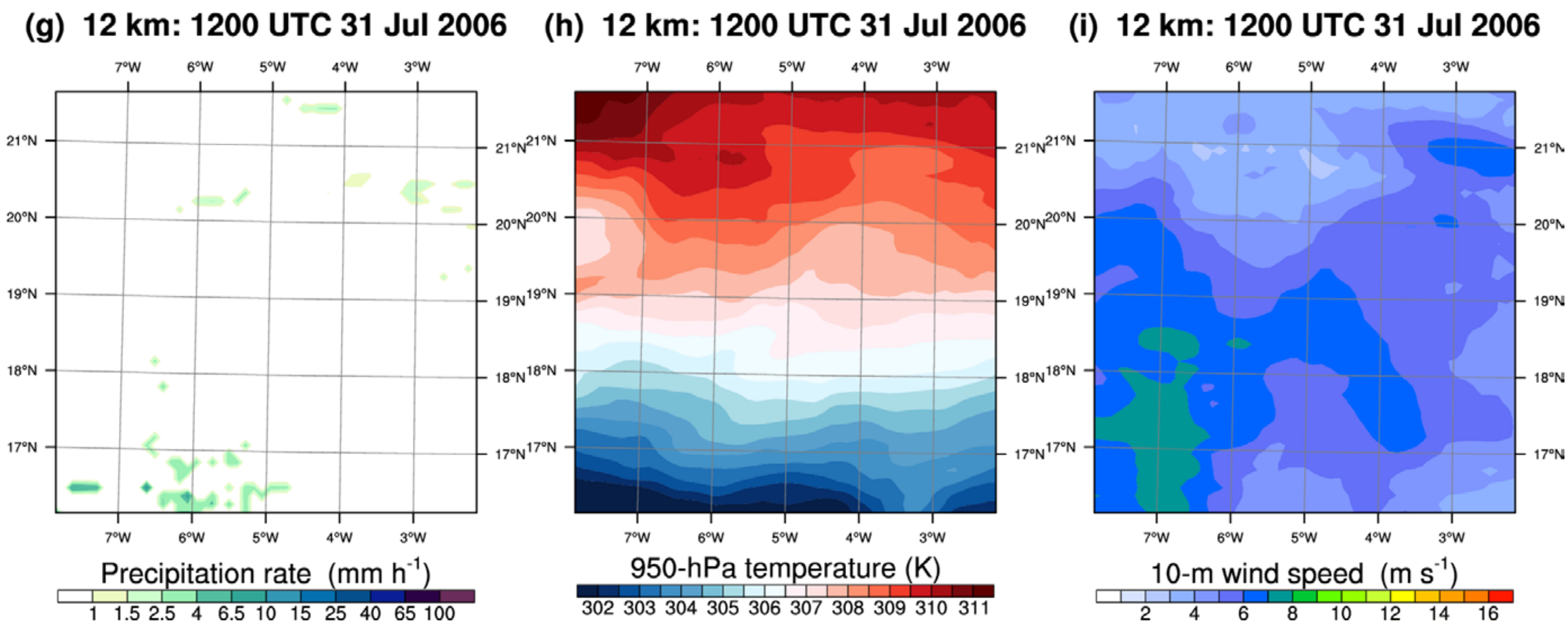


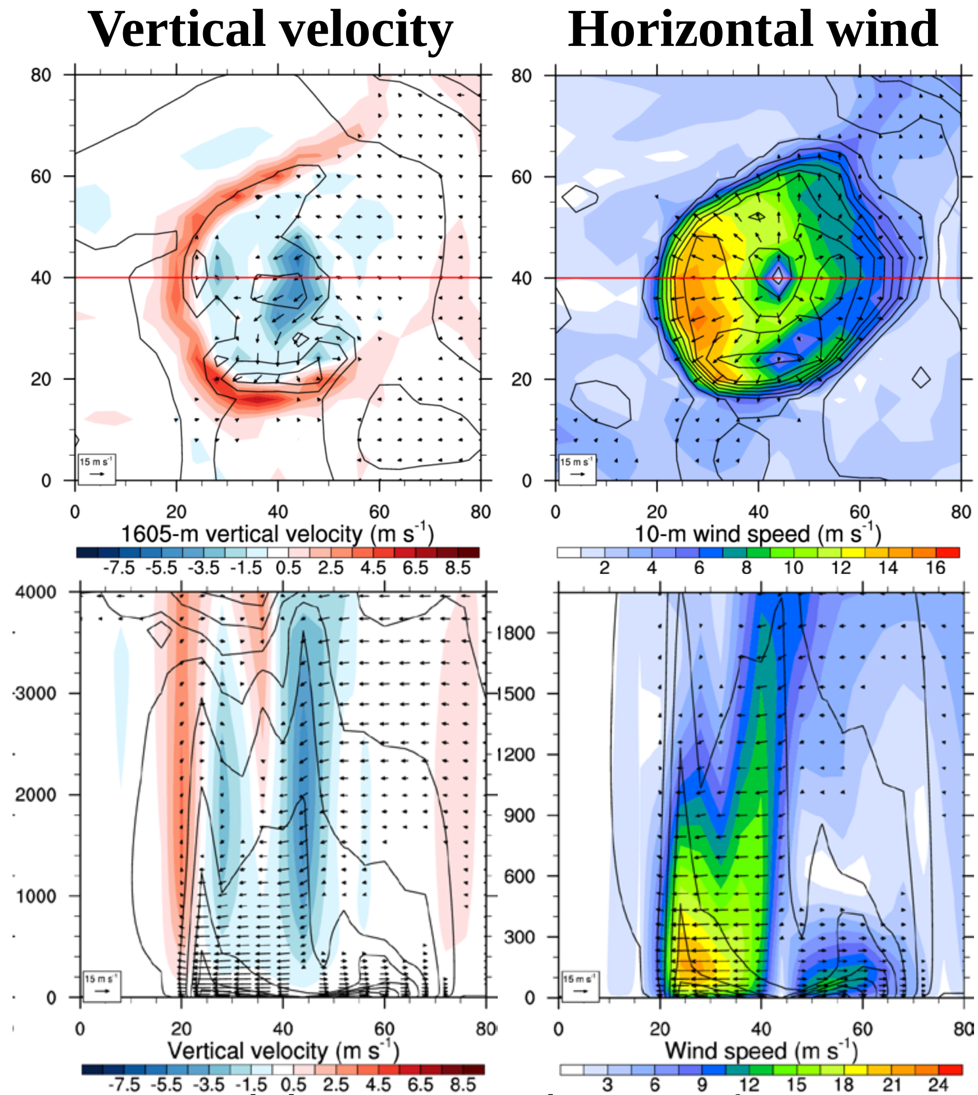
Widespread precipitation → No distinct cold pools → Weak surface winds

The 12-km run **lacks** convective dust storms
→ test for the parameterization!

Process: formation convective dust storm

Developing cold pool in 4-km run

- A strong convective downdraft **spreads out radially** in a cylindrical cold pool
- The cold pool outflow creates **strong surface winds** and triggers new convective cells
- The downdraft transports horizontal momentum and makes the wind **asymmetric**



Black contours: potential temperature θ

Parameterization: conceptual model

The parameterization is based on the **downdraft mass flux** M_{dd}

- M_{dd} spreads out radially in a cold pool of radius R and height h
- The cold pool propagates with radial speed $C = M_{dd} / 2\pi\rho Rh$
- The radial wind increases linearly with radius and peaks at height z_{max}
- The cold pool is steered with speed $C_{st} = 0.65\ U_{env}$

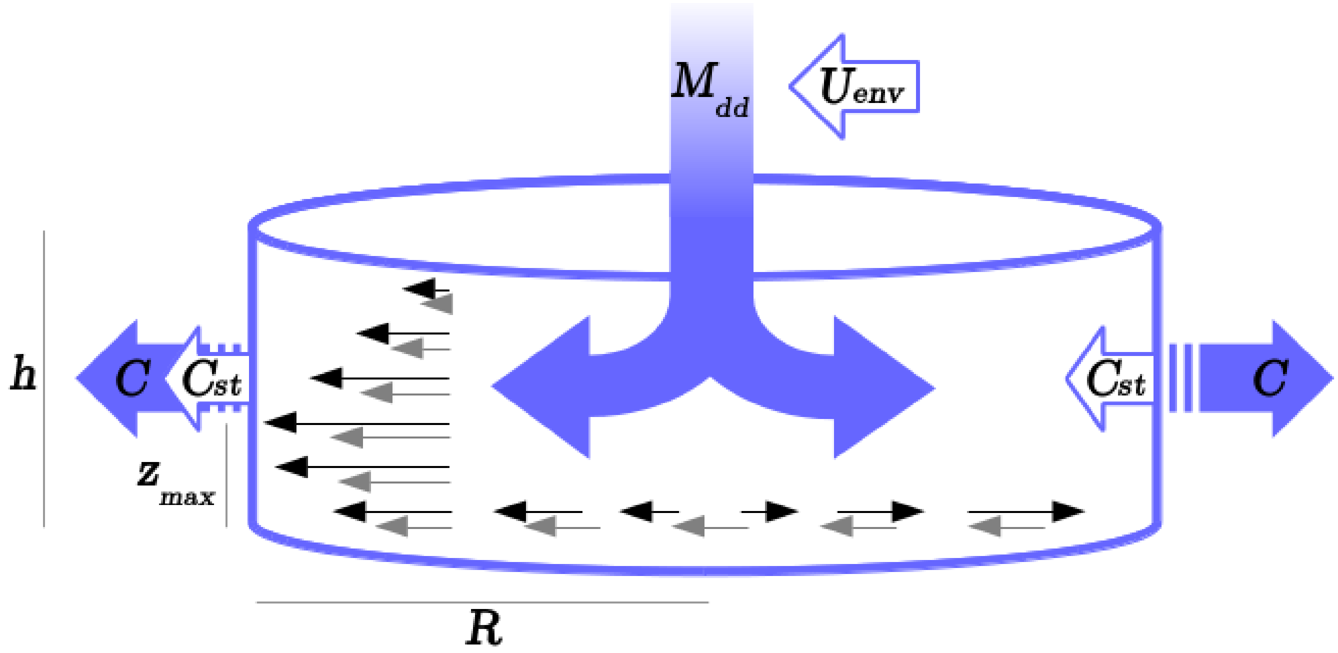


Illustration: developing cold pool

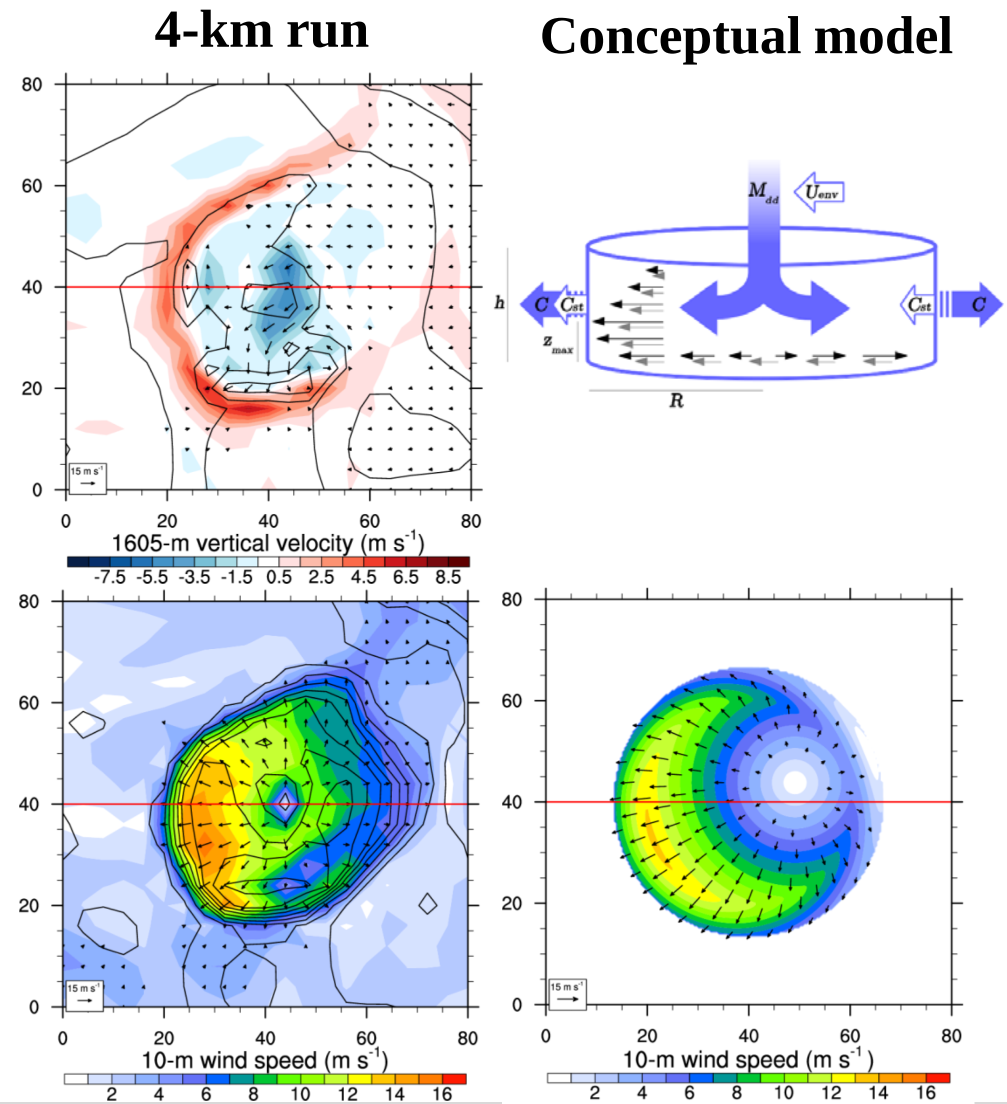
The simple assumptions

- Capture the magnitude and asymmetry of surface wind
- Miss fine-scale processes only

The conceptual model **matches the typical structure** of a cold pool outflow

Further constraints

- **Static** cold pool: avoids coupling convection scheme
- **Fixed geometry** cold pool: single tuning parameter R
- M_{dd} calibrated with **factor 10**



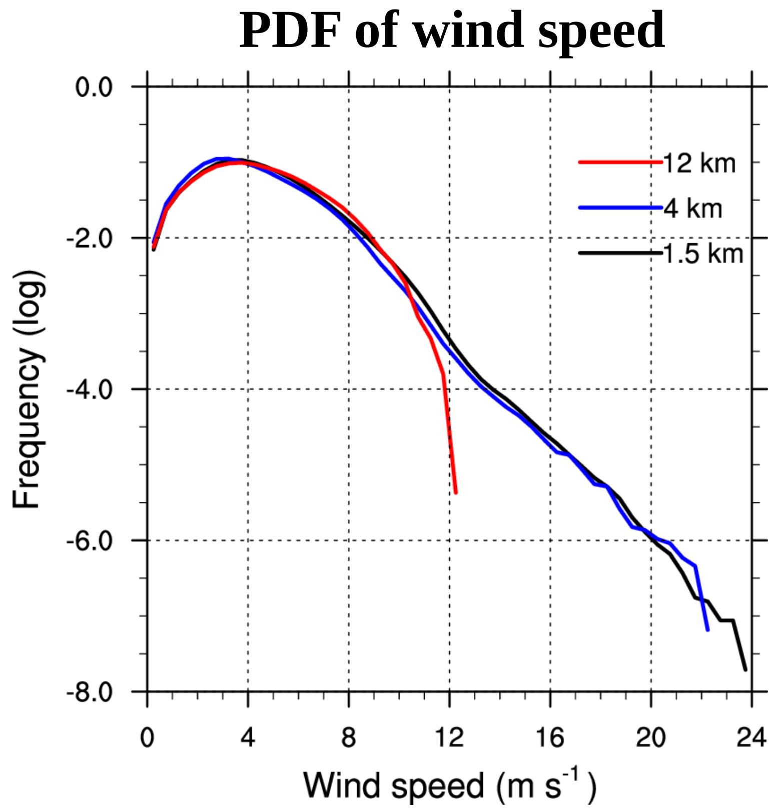
Calibration: estimate of dust emissions

"Dust Uplift Potential" *(Marsham et al. 2011, GRL)*

$DUP = v\, U^3 (1 + U_t/U)(1 - U_t^2/U^2)$

- v: fraction of bare soil
- U: 10-m wind
- U_t=7m/s: threshold for dust uplift

→ *Very sensitive to the tail of distribution*



Identification cold pools

in reference 4-km run

- Cooling below -1 K/h
- Vertical velocity above 0.5 m/s

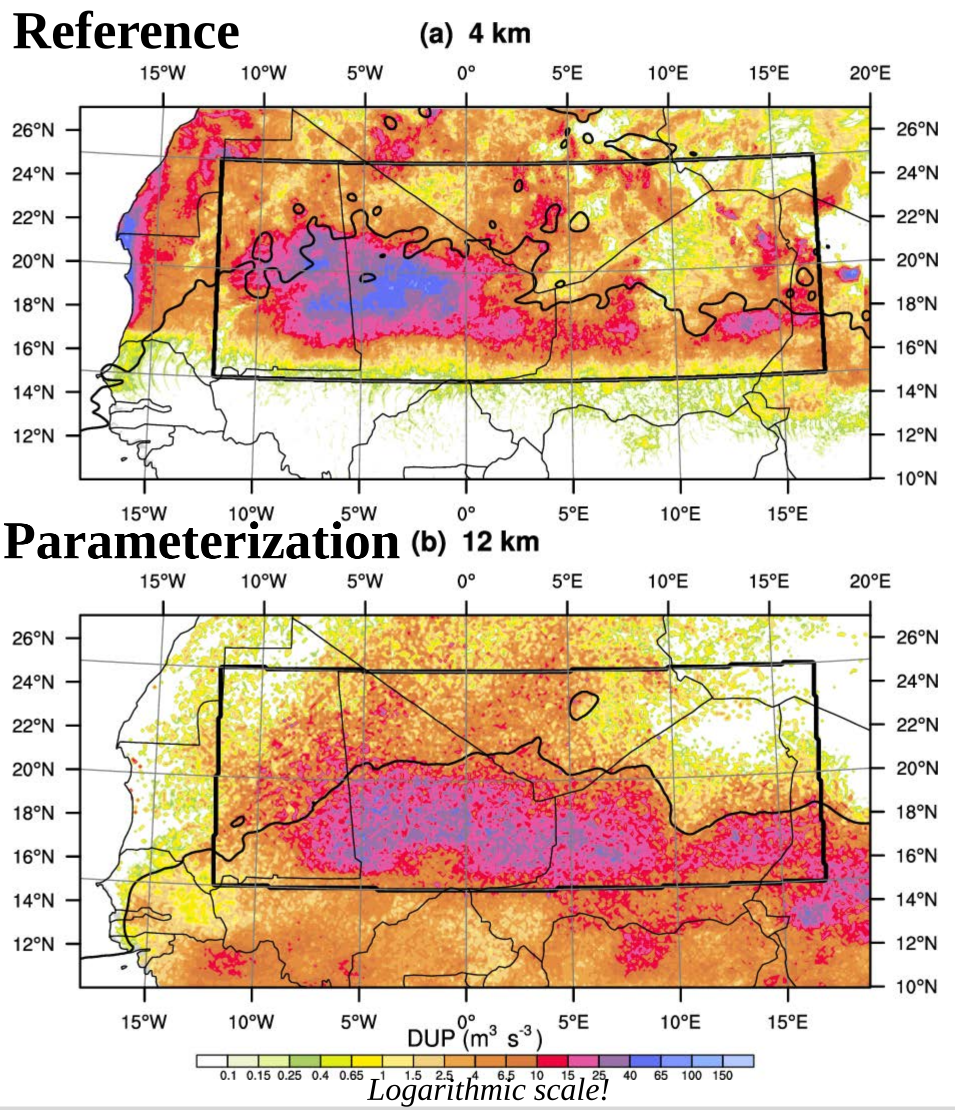
→ *No unique identification* *(Heinold et al. 2013, JGR)*

Calibration 12-km run: best match 4-km run with tuning parameter **R = 2.0 km**

Results: geographical distribution

DUP in reference 4-km run

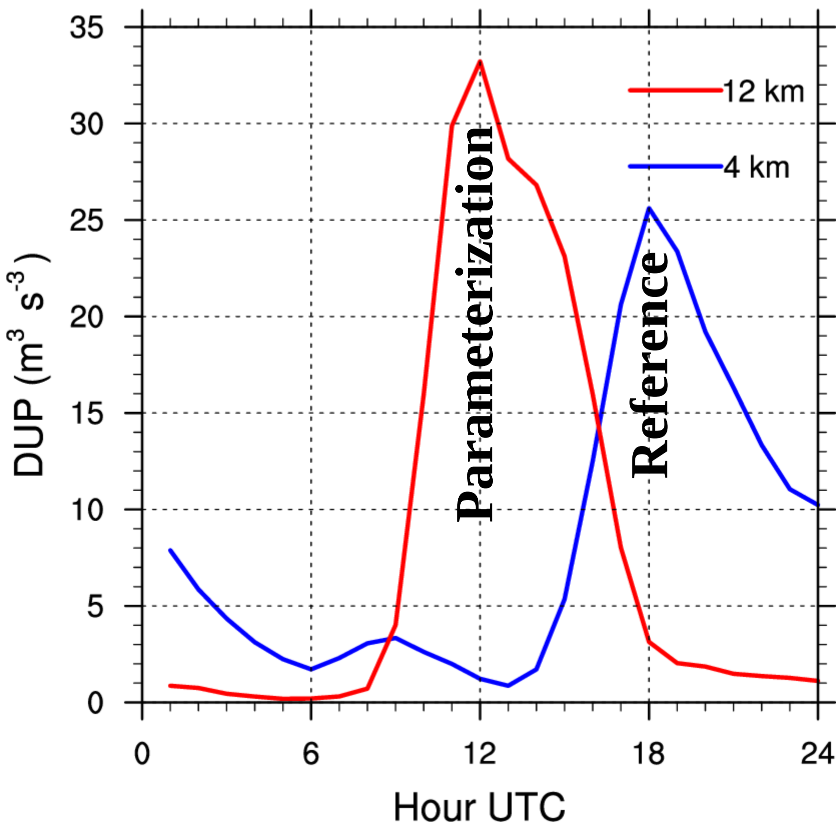
- Highest over South Sahara: **successfully captured by parameterization** although shifted eastward with monsoon flow
- High near mountain ranges: **missed by parameterization** due to relative lack convection
- High along the Atlantic coast: not related to convection
- Weak over Sahel: missing in reference run!?



Results: diurnal cycle

DUP in reference 4-km run

- Strong amplitude:
  captured by parameterization
- Triggering in the afternoon:
  too early in parameterization
  like parameterized convection
- Long-lasting peak:
  too short in parameterization
  like parameterized convection



Main biases in parameterization
due to **biases in convection scheme**

Conclusions

Convective dust storms are a key ingredient to dust emission

- Large fraction of dust emission in Summer over West Africa
- But missing in global models that do not resolve convection

We suggest a parameterization based on a simple conceptual model: the downdraft mass flux spreads out radially in a cylindrical cold pool

The parameterization is applied to a set of model runs for June-July 2006

- The parameterization successfully lifts dust over South Sahara
- The main biases are due to biases in the convection scheme

Parameterization and results available in Pantillon et al. 2015, JAS, early online release

Work in progress: **sensitivity tests** to the period, resolution and model
Perspectives: **implementation** in global weather and climate models

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Thank you!

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