CONVECTION-ALLOWING SIMULATIONS OF COLD POOLS IN THE NORTHWESTERN SAHARA

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OUTLINE

Introduction

– The Saharan Mineral Dust Experiment (SAMUM)
– Observations of cold pools

Model Experiments

– Motivation
– Model set-up
– Evaluation of control simulation
– Sensitivity to microphysics, turbulence & time step

Summary & Conclusions
PROPOSED MECHANISM

from Knippertz et al., JGR, 2007
31 May 2006: SYNOPTIC SITUATION

Upper-trough over Morocco and weak surface low

$Z_{500\text{hPa}}$ & SLP at 12 UTC
31 May 2006: SATELLITE VIEW

Meteosat infrared loop
1100 – 2345 UTC
31 May 2006: SATELLITE VIEW

Meteosat VIS image 1800 UTC
31 May 2006: MEASUREMENTS TINFOU

- Dew point jump
- Weak temperature decrease
  ← sensible heat fluxes
- Wind acceleration & direction change
- Drop in visibility
OTHER EXAMPLE: 25 May 2006

Meteosat infrared loop
1100 – 2345 UTC
SUMMARY OBSERVATIONS

- On 8 out of 30 days we observed density currents.
  → Part of regional climate
  → Important for dust mobilization & moisture transport

- Propagation in direction of local topographic gradient with a velocity of 5 – 7 m/s.

- Leading edge sometimes exceeding 400 km.

- Clear diurnal cycle: initiation during the afternoon and decay in the course of the night.
  → Lifetime ~10 hours

- Precipitation in High Atlas on most density-current days.

- Relation to upper-troughs (destabilization, wind shear)
COSMO EXPERIMENTS: MOTIVATION

- Cold pools play an important role in convective dynamics, e.g. for the organization to larger scales.

- Convection-allowing simulations offer new insight into cold pool evolution.

- Northwestern Saharan cold pools are an ideal testbed:
  - Robust trigger Atlas Mountains
  - Large evaporational cooling in dry, hot desert air
  - Relatively undisturbed propagation, no new convection
CONTROL RUN: MODEL SET-UP

- COSMO Version 4.0
- Nested simulations: GME analysis – COSMO 7km – COSMO 2.8 km
- Resolution: 2.8 km horizontal, 50 levels
- Simulation time: 00 UTC 03 June – 00 UTC 04 June 2006
CASE STUDY: SYNOPTIC SITUATION

Geopotential height & wind speed at 300 hPa

upper trough

upper ridge
cold air

upper trough

03 June 2006
12 UTC
CONTROL RUN
03 JUNE 01 UTC

Precipitation near-surface wind with 10 m/s isotach
Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 03 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 05 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
CONTROL RUN
03 JUNE 06 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
CONTROL RUN
03 JUNE 07 UTC

Precipitation near-surface wind with 10 m/s isotach
Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 09 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
CONTROL RUN
03 JUNE 10 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 11 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
CONTROL RUN
03 JUNE 12 UTC

Precipitation
near-surface wind
with 10 m/s isotach

IR satellite image
CONTROL RUN
03 JUNE 13 UTC

Precipitation
near-surface wind
with 10 m/s isotach
CONTROL RUN
03 JUNE 14 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN

03 JUNE 15 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 16 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 17 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 18 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
CONTROL RUN
03 JUNE 19 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 20 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 21 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
03 JUNE 22 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
Precipitation
near-surface wind
with 10 m/s isotach
CONTROL RUN
04 JUNE 00 UTC

Precipitation
near-surface wind
with 10 m/s isotach
3-D STRUCTURE OF COLD POOL

03 June
22 UTC

specific humidity [g/kg]

w > 4 m/s

Atlas

θ=306 K surface

SE

SW

NW

NE
The passage of the cold pool is associated with– cooling – moistening – wind acceleration – backing – pressure rise
COMPARISON WITH SURFACE STATIONS

- The model generates generally realistic signals
- Model ca. 1 hour too early
- Front somewhat “too sharp”
ACCUMULATED PRECIPITATION

24-h precipitation [mm]: 00 UTC 03 to 00 UTC 04 June 2006

COSMO

TRMM

> 10 m/s
SENSITIVITY EXPERIMENTS

- Variation of the size distribution of rain droplets
- Variation of the turbulent mixing length
- Impact of the time step

\[
N(D) = N_0 D^\mu \exp(-\Lambda D)
\]
SENSITIVITY EXPERIMENTS

I) Droplet Size

CTRL: $\mu = 0.5, \lambda = 500m$

$\mu = 0, \lambda = 500m$

24-h precipitation [mm]: 00 UTC 03 to 00 UTC 04 June 2006
SENSITIVITY EXPERIMENTS

I) Droplet Size

CTRL: $\mu = 0.5$, $\lambda = 500m$  
$\mu = 1$, $\lambda = 500m$

24-h precipitation [mm]: 00 UTC 03 to 00 UTC 04 June 2006
SENSITIVITY EXPERIMENTS

II) Mixing Length

CTRL: $\mu = 0.5$, $\lambda = 500\text{m}$

$\mu = 0$, $\lambda = 150\text{m}$

> 10 m/s

24-h precipitation [mm]: 00 UTC 03 to 00 UTC 04 June 2006
SENSITIVITY EXPERIMENTS

III) Time Step

CTRL: \( \mu = 0.5, \lambda = 500m \)

\( \Delta t = 10s \)

24-h precipitation [mm]: 00 UTC 03 to 00 UTC 04 June 2006
CONCLUSIONS

- Evaporationally generated cold pools are part of northwestern Saharan climate relevant for dust emission and moisture transport.
- Ideal testbed for cold pool simulations with convection-allowing numerical models.
- Control simulation shows satisfactory reproduction of cold pool characteristics, but not a perfect match.
- Sensitivity runs demonstrate acceleration of cold pool with increasing evaporational efficiency $\mu$ and decreasing turlen $\lambda$. 

THANK YOU FOR YOUR ATTENTION!
VERTICAL STRUCTURE

Log p - skew T diagram at 21 UTC 03 June 2006

Location:
29.5°N, 3.5°W
ahead of
density current
VERTICAL STRUCTURE

Log p - skew T diagram at 21 UTC 03 June 2006

Location:
29.5°N, 3.5°W ahead of density current
28.5°N, 3.5°W within density current
OUTLOOK

- Comparison of different runs with other objective criteria
  - propagation speed
  - buoyancy
- Other case studies
31 May 2006: AEROSOL CONCENTRATION TINFOU

Units are relative to campaign average
Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
04 JUNE 02 UTC

Precipitation near-surface wind with 10 m/s isotach

IR satellite image
Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN
04 JUNE 04 UTC

Precipitation
near-surface wind
with 10 m/s isotach

IR satellite image
CONTROL RUN
04 JUNE 05 UTC

Precipitation
near-surface wind
with 10 m/s isotach

IR satellite image
CONTROL RUN
04 JUNE 06 UTC

Precipitation near-surface wind with 10 m/s isotach
CONTROL RUN: MODEL SET-UP

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- Nested simulations: GME – COSMO 7km – COSMO 2.8 km
- Resolution: 2.8 km horizontal, 50 vertical levels
- Simulation time: 00 UTC 03 June – 06 UTC 04 June 2006
- Initial and Boundary data: GME Analysis