COPS science questions revisited: What have we learned so far from COPS?

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„Golden“ COPS thunderstorm:
15 July 2007, IOP8b

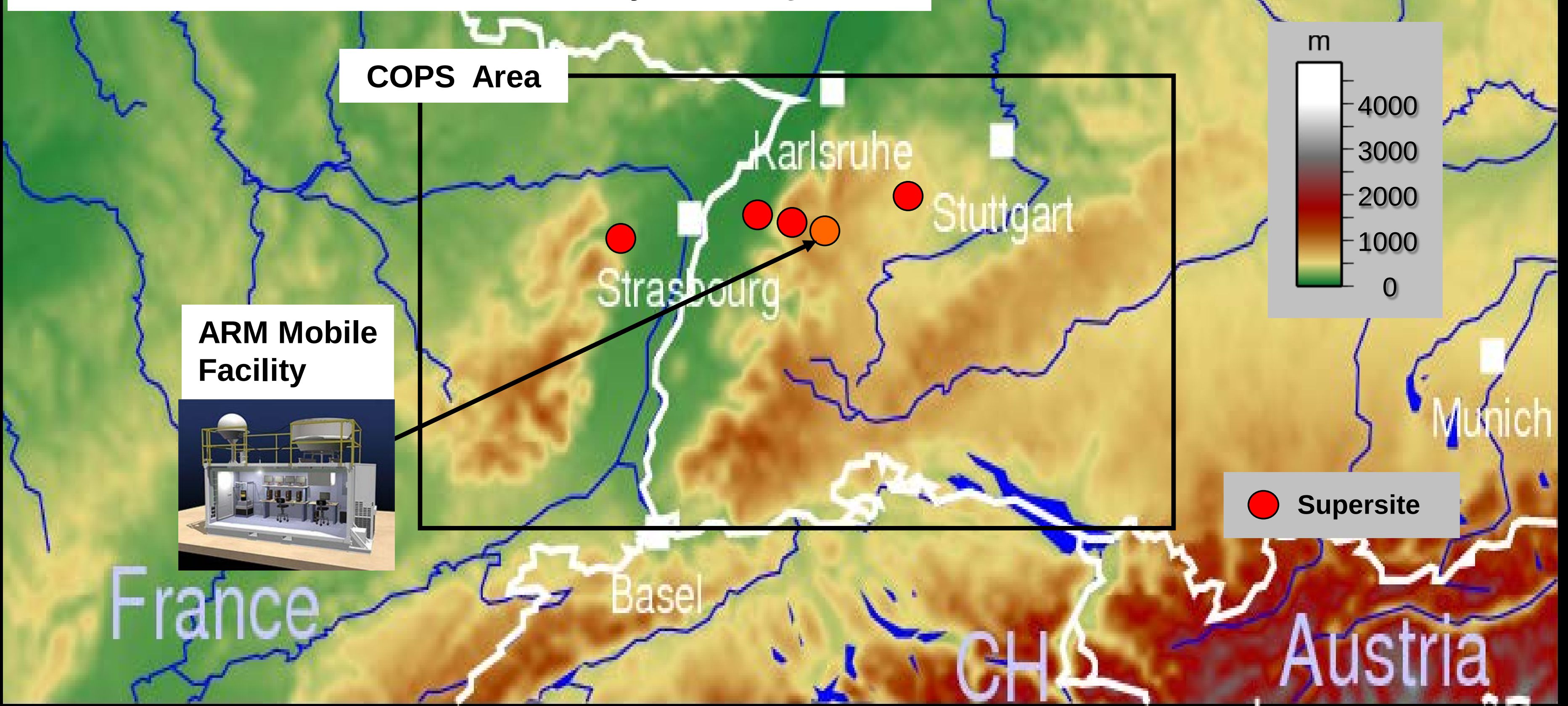
COPS (Convective and Orographically-induced Precipitation Study)

WWRP WORLD WEATHER RESEARCH PROGRAMME

PQP Praecipitationis Quantitativae Praedictio

Goal: **Advance the quality of forecasts of orographically-induced convective precipitation by 4D observations and modeling of its life cycle**

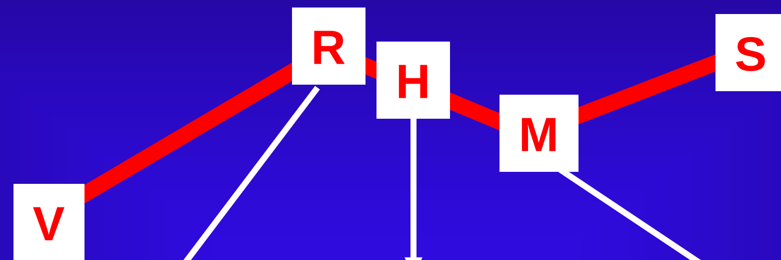
Region: Southwestern Germany, eastern France
Date: 1 June – 31 August 2007
Features: Severe thunderstorm activity but low QPF skill



- Lidars
- Cloud radars
- Precip. radars
- Radiometers
- Radiosondes
- Sodars

Supersite Instrumentation

POLDIRAD



- FZK WTR
- MICCY (scan.)
- UV MRR
- UV radiosondes
- UV tethersonde
- UV AWS network
- GFZ GPS receiver
- FZK soil moisture

- CNRS WV Raman lidar
- CNRS TRESS = Aerosol Raman Lidar IR radiometer, sun ph.
- LaMP X-band (scanning)
- LaMP K-band (vertical)
- MF radiosondes
- MF surf. flux stations (3)
- MF soil moisture (1-3)
- MF UHF prof., sodar
- GPS receiver

- UHOH WV DIAL (scanning)
- UHOH RR lidar (scanning)
- FZK WindTracer (scanning)
- FZK cloud radar (45° scan)
- UHOH X-Band (vertical)
- UHH MRR
- TARA
- UK radiosondes
- ADMIRARI (scanning)
- CNR MW radiometer (scan.)
- UK aerosol in-situ analysis
- GFZ GPS receiver
- FZK soil moisture

- AMF: RS, MWR, AERI, RWP, WACR, aerosol in-situ analysis
- HATPRO
- 90/150 GHz
- IfT MWL
- IfT WILI
- UHH MRR
- GFZ GPS receiver
- FZK soil moisture

- UNIBAS Raman lidar
- UK Doppler lidar
- UK wind profiler
- UK MWR
- UHH cloud radar
- UK radiosondes
- UK sodar
- UHH MRR
- GFZ GPS receiver
- FZK soil moisture

- FZK and UBT sodars (entrance of Murg and Kinzig V.)
- UF sodar (entrance of Rench V.)
- UK sodar (Murg Valley)

FZK

- FZK RS station

„Burgundische Pforte“

- FZK RS station

Collected Data

10 000 surface stations = Joint D-PHASE COPS (JDC) Data Set

New/densified Networks: soil moisture, energy balance, GPS, MRR,…

2 700 Radio soundings

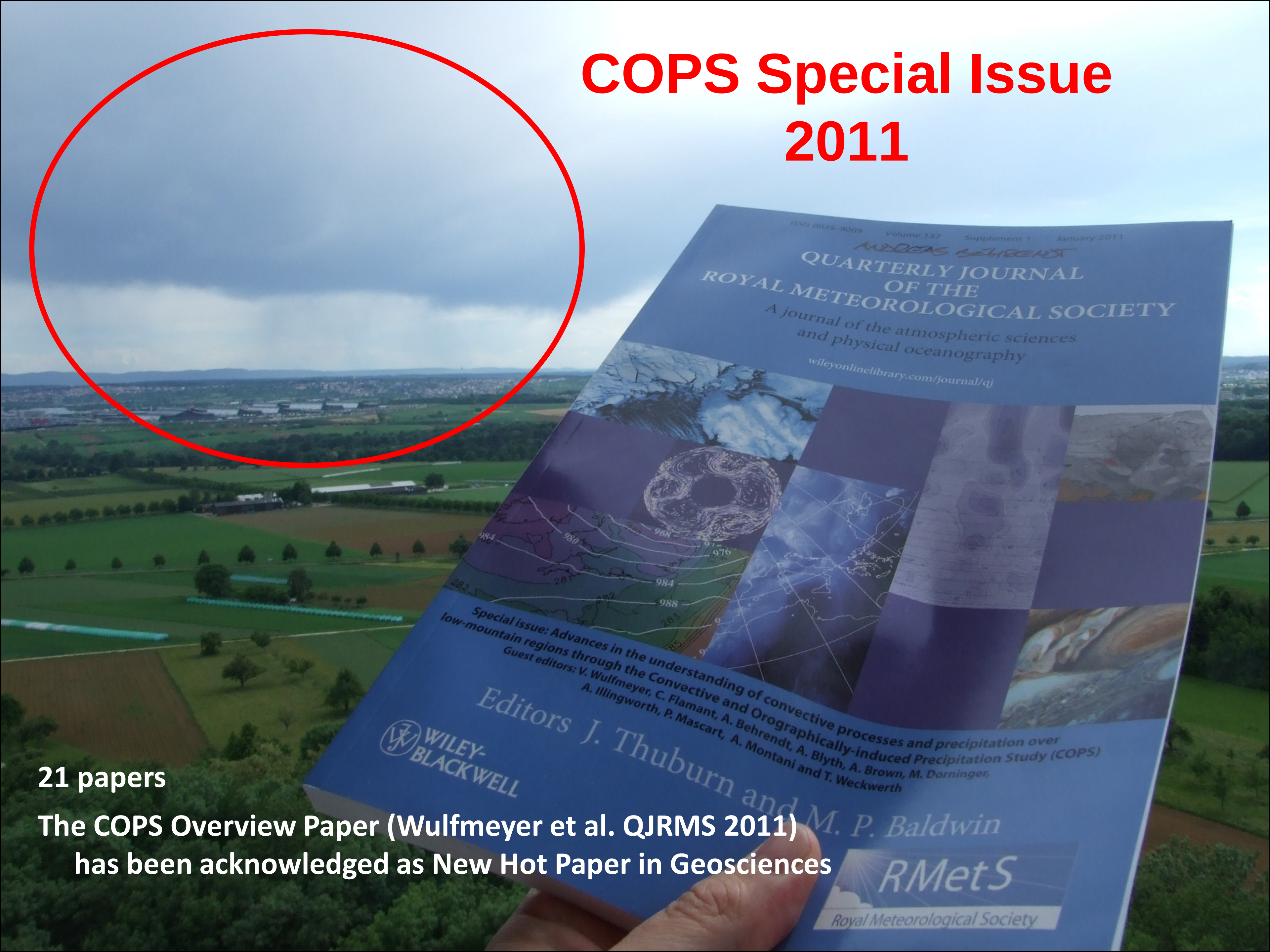
11 000 h of lidar data

400 h of aircraft data (9 aircraft + 1 Zeppelin)

10 000 model runs, 50 000 000 model fields and plots

18 Intensive Observations Periods, 30 IOP days

COPS Special Issue 2011

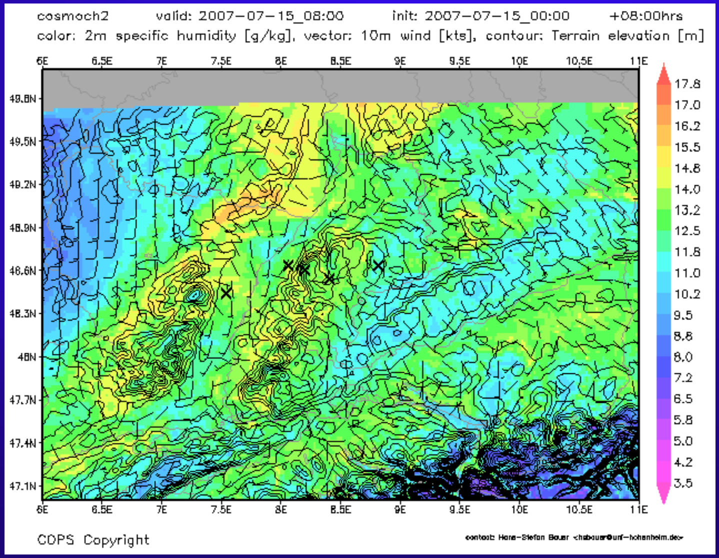


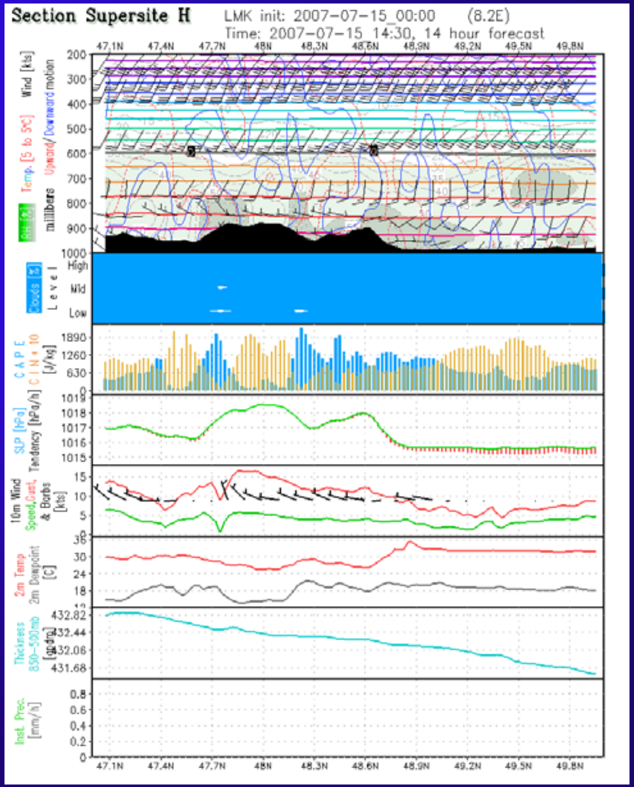
21 papers

The COPS Overview Paper (Wulfmeyer et al. QJRMS 2011) has been acknowledged as New Hot Paper in Geosciences

Major COPS Results and Conclusions

1) **Logistics:**
   - Surface data collection, harmonization, and quality control
   - GRIB1 Tigge+ table for CP models, common visualization tools
   - Common lidar and radar data formats
   - Air traffic control
   - Data base





Major COPS Results and Conclusions

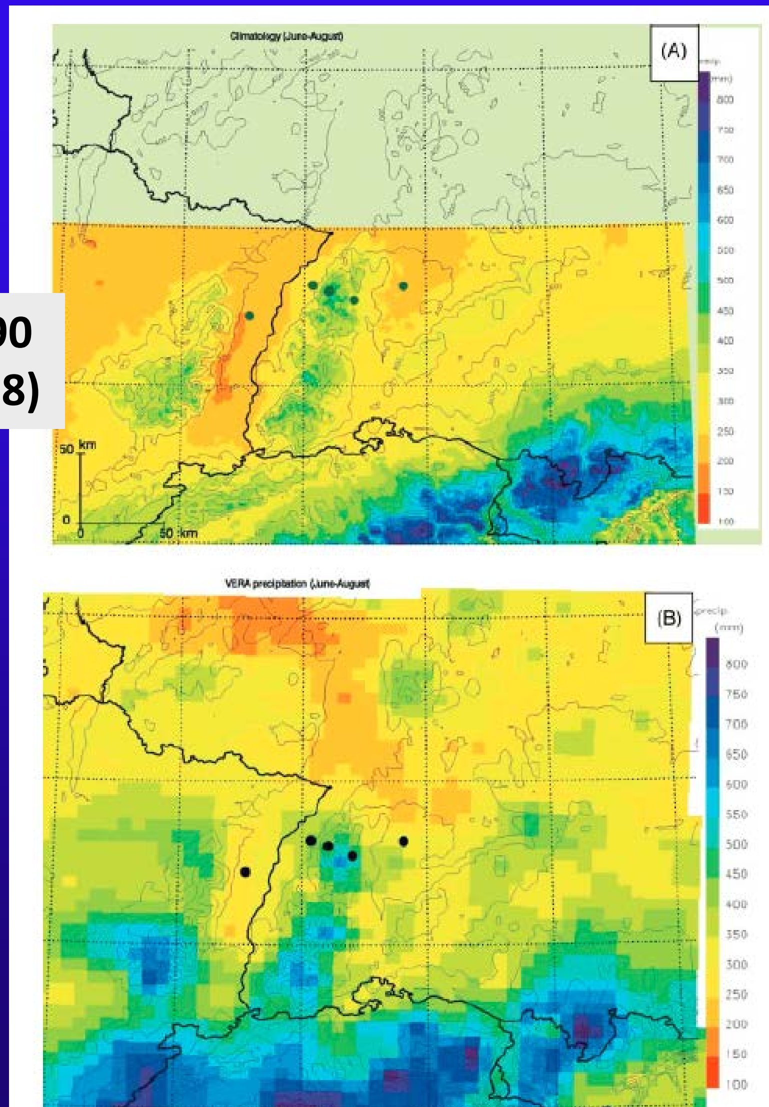
2) **Processes:**

- **Evapotranspiration nearly independent of soil moisture, thus mainly controlled by vegetation.**
- **CAPE higher (moisture convergence), CIN lower over mountain ranges.**
- **Thermodynamically-induced flow decisive for <u>convection initiation</u> and modification of frontal systems under all forcing conditions.**
- **<u>Diurnal cycle of precipitation</u> is likely due to a preconditioning of lower troposphere by shallow convection leading to more severe convection in the late afternoon (less coupled to mountain flow).**

Precipitation: Climatology vs. COPS

Summer 1971 – 1990 (Frei and Schär, 1998)

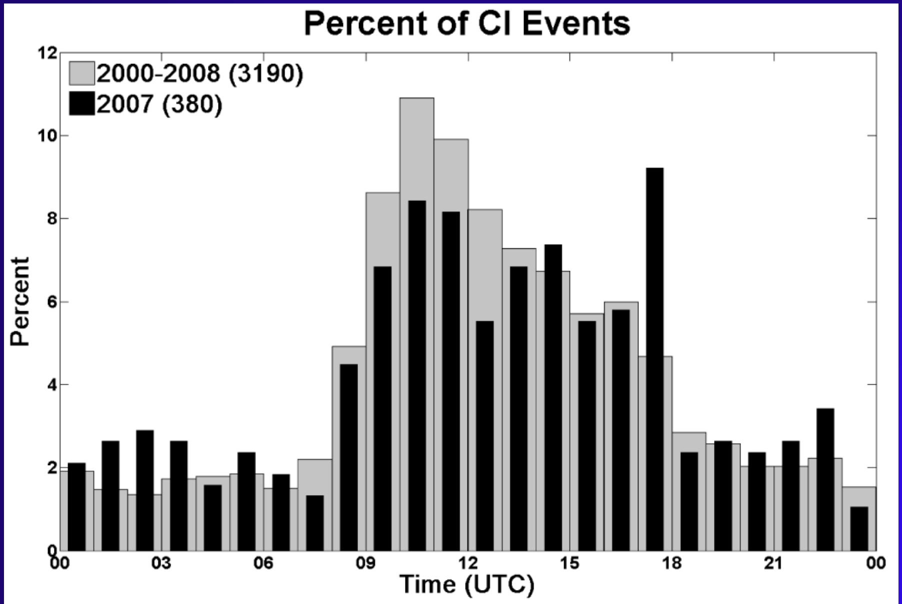
COPS (VERA data)



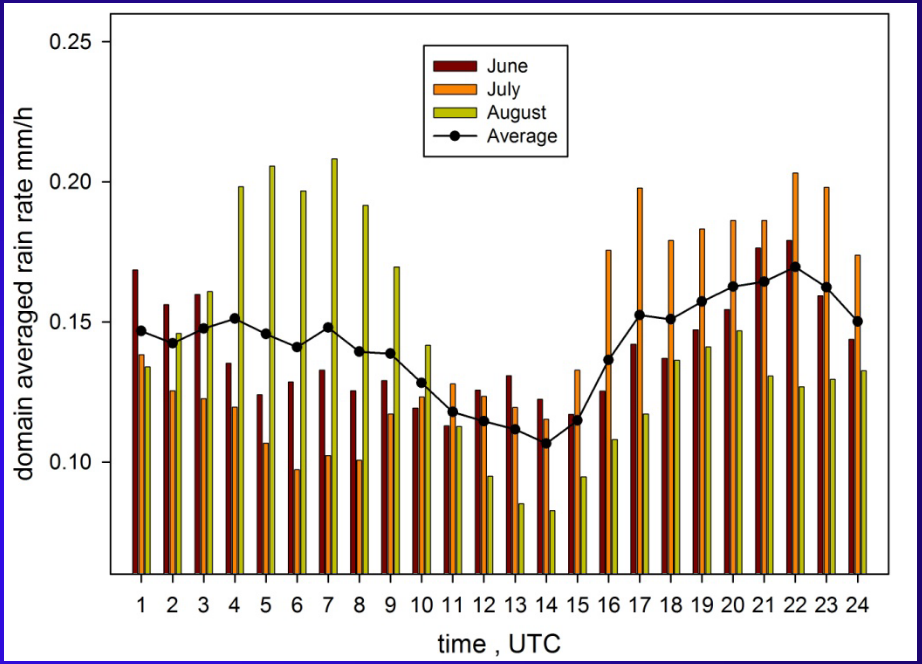
COPS was wetter than climatology

Wulfmeyer et al., QJRMS, 2011
…and also
Wernli et al., MetZ, 2010

The COPS Summer in Perspective



Diurnal cycle of convection initiation (Weckwerth et al. QJRMS 2011).

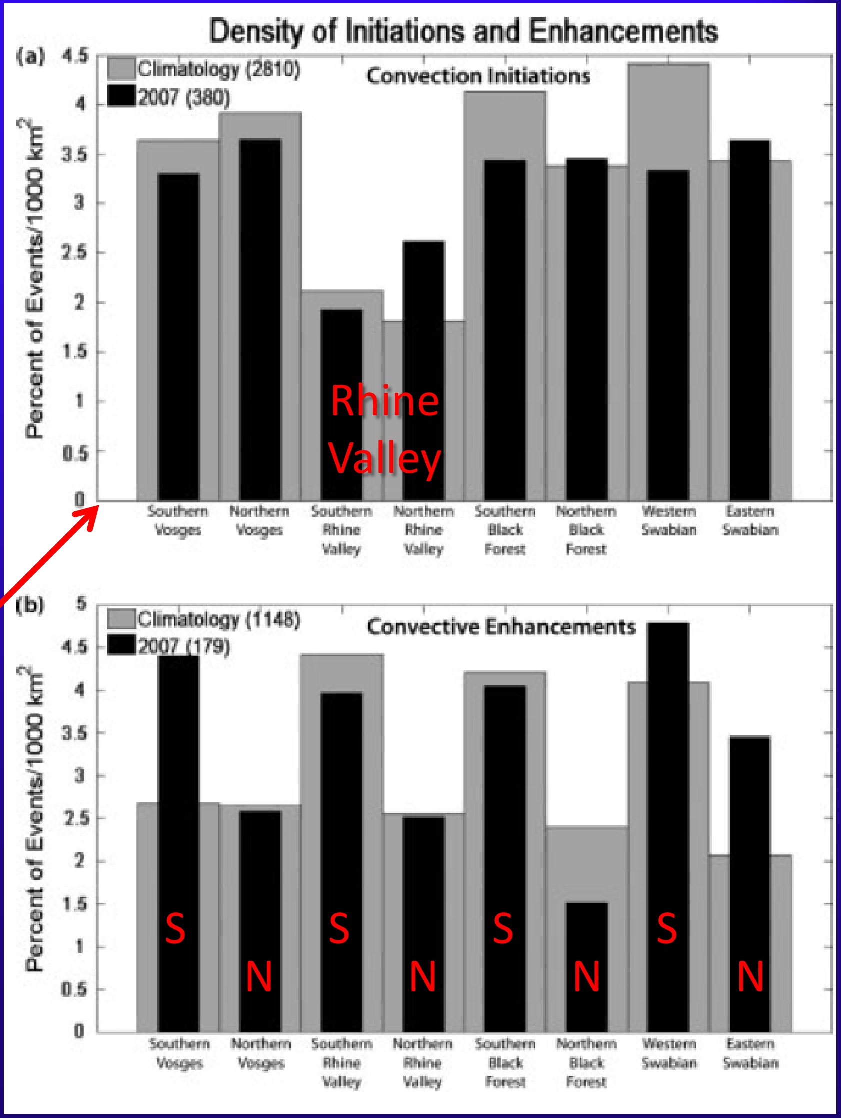


Diurnal cycle of precipitation for June, July, and August, as well as average.

Diurnal cycle in good agreement with climatology. Phase shift between CI and precipitation maximum amounts to about 10 h (Wulfmeyer et al. QJRMS 2011).

CI & CE Statistics from Radar Composites

PPL Hypothesis:
“The life cycle of single cells is affected by orography but not the one of larger systems.”



Mountain CI > Valley CI

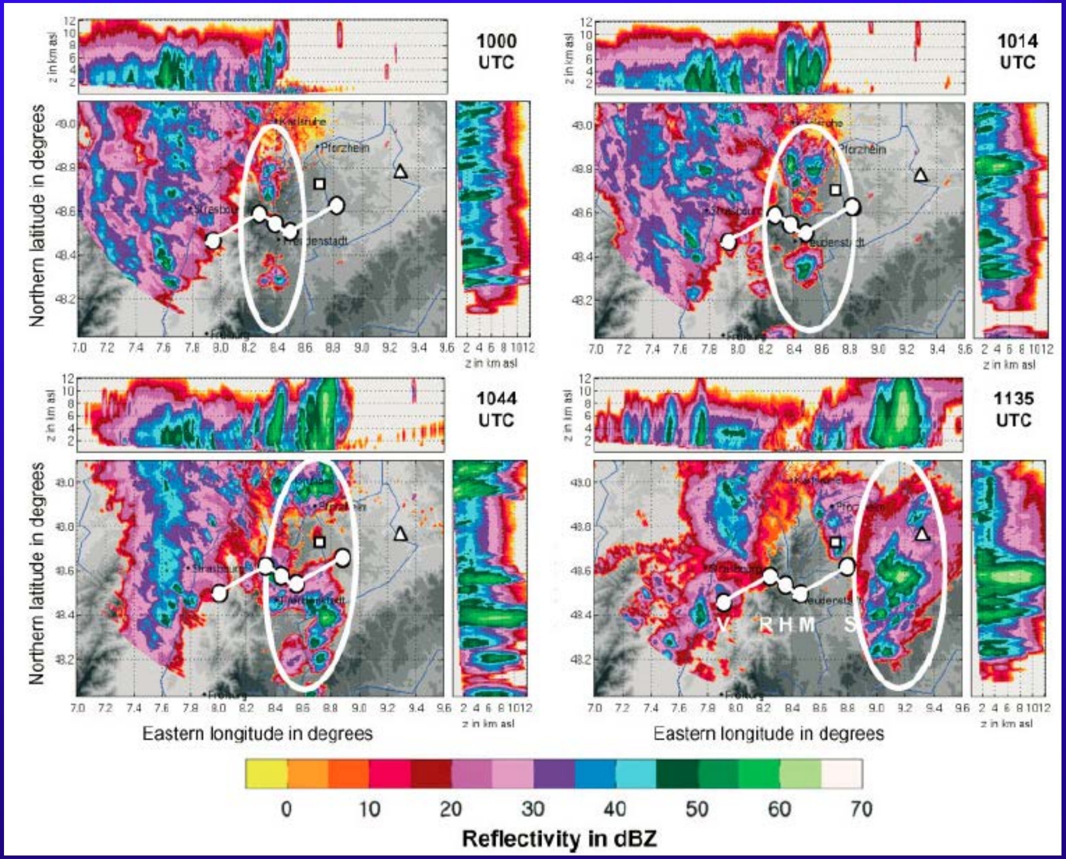
Mountain CE ≈ Valley CE , but
CE in <u>Southern</u> COPS area > <u>Northern</u> COPS Area

Weckwerth et al., QJRMS, 2011

..., e.g., IOP9c proves otherwise.

PPL Hypothesis:
"The life cycle of single cells is affected by orography but not the one of larger systems."

Falsified.
(as expected)



Corsmeier et al., QJRMS, 2011

Major COPS Results and Conclusions

3) Model performance and verification:

- Indications that models overestimate transpiration at low soil moisture (root depth, root water uptake).
- Boundary layer to deep over mountains, probably too strong vertical mixing.
- Thermodynamically-induced flows partly resolved, vertical wind too low in convergence zones
- Windward-lee effect due to incorrect simulation of flow distorsion in low-mountain regions and resulting displacement of convergence zone triggering CI at wrong locations.
- Clear improvement of diurnal cycle of precipitation and QPF by CP models.
- Main remaining systematic errors in QPF due to deficiencies of aerosol-cloud-precip microphysics?

Soil Moisture

CI1: What is most relevant for the heterogeneity of the boundary layer fields of key prognostic variables (differences in soil moisture, surface characteristics, orography, …)?

In the modell (COSMO-DE):
…considerable impact on convection–related parameters
…but no systematic influence on convective precipitation

In the observations:
…latent heat flux, CBL characteristics, and convective parameters barely/weakly dependent on soil moisture

Do the models overestimate the impact of soil moisture?
Future work: more realistic representation of soil moistute

(Hauck et al., QJRMS, 2011)
(Kalthoff et al., QJRMS, 2011)

On a specific day, surface characteristics govern fluxes, not altitude differences.

(Eigenmann et al., QJRMS, 2011)

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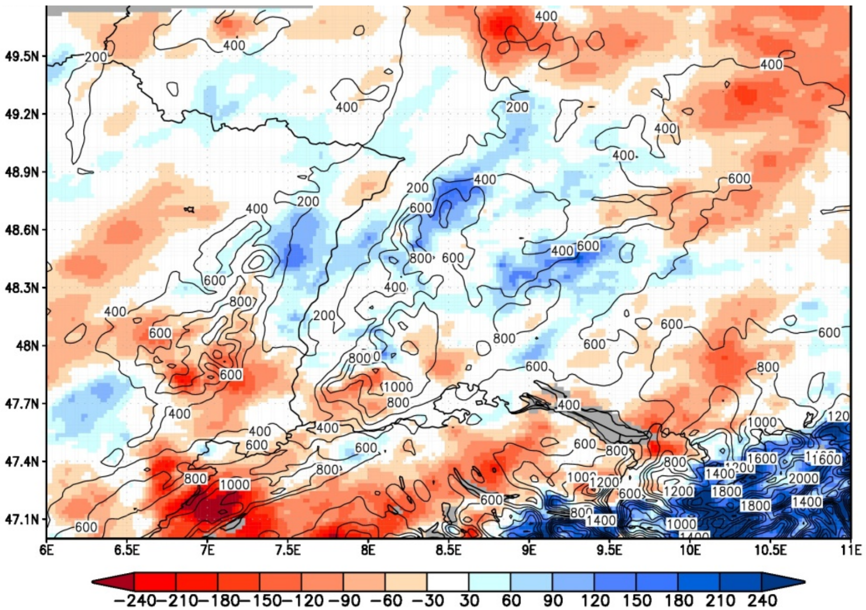
Model Grid-Size

Accurate modeling of the orographic controls of convection is essential and only possible with advanced mesoscale models having a resolution of the order of a few kilometers.

Meteo Swiss COSMO2 without parameterization of deep convection, 2.2 km grid resolution



3-month integrated precipitation of model - observations.

Can the windward/lee problem be solved by high-resolution mesoscale modeling without convection parameterization?

Yes.

Models tend to be too wet.

Large differences in diurnal cycle.

Even 2-km models are not yet capable of reproducing the necessary fine-scale circulation details.

(Bauer et al., QJRMS, 2011)

…more case studies required!

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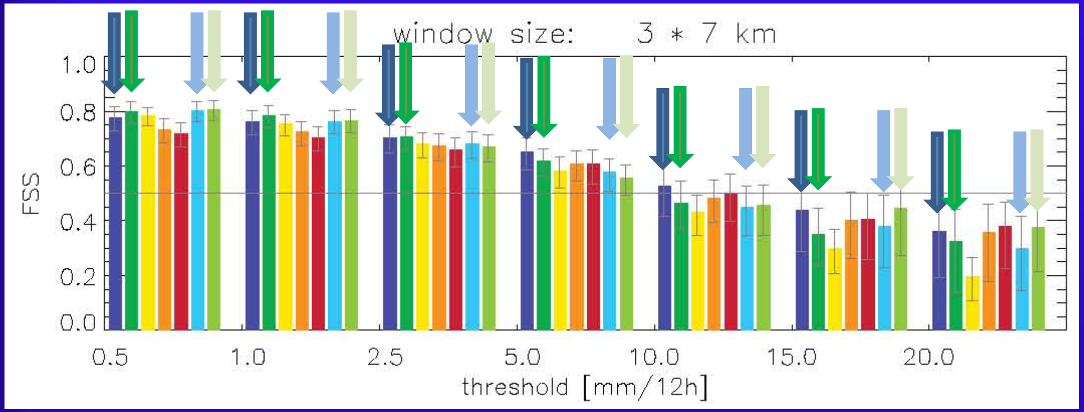
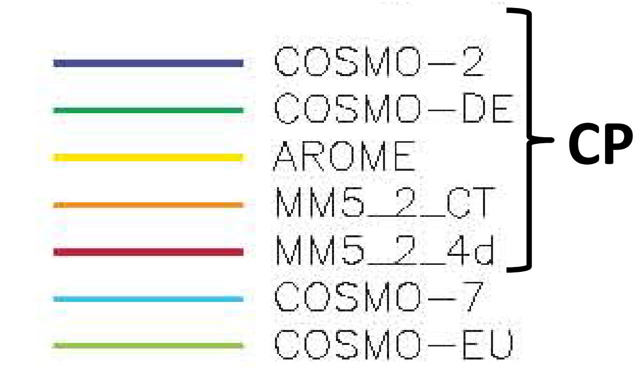
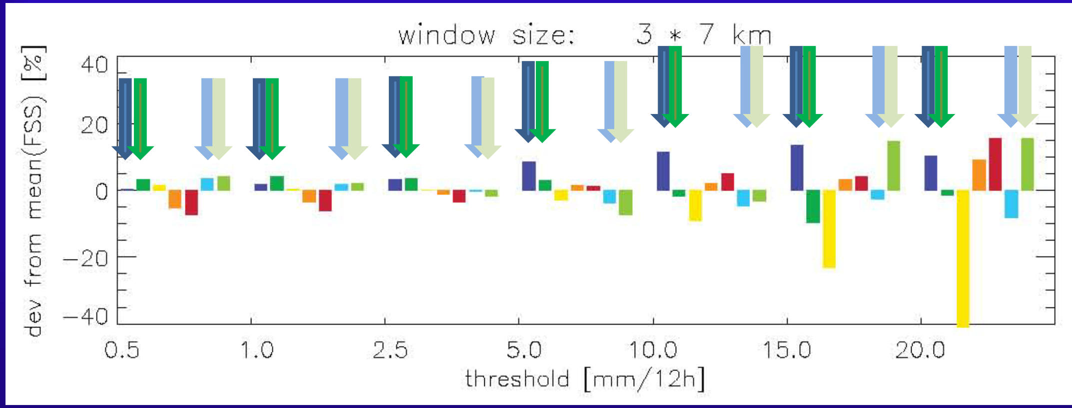
Verification Study of Convection-Permitting (CP) Models







Forecast initial time: 0 UTC
Verification time period: 6-18 UTC
The Fractions Skill Score (FSS, Roberts and Lean MWR 2008) is an example of a fuzzy verification score useful for high-resolution models.

FSS shows consistent superior performance of convection-permitting (CP) COSMO2 over COSMO7 but no clear result for COSMO-DE and COSMO-EU (Bauer et al. QJRMS 2011).

Major COPS Results and Conclusions

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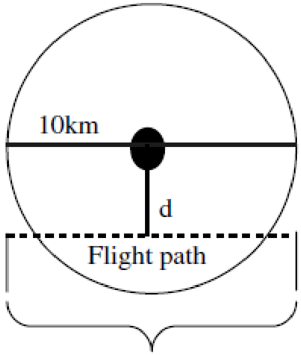
Major COPS Results and Conclusions

4) Demonstration of new Observations:

- Water-vapor and temperature lidar provided previously unachieved vertical and temporal resolution as well as accuracy.
- GPS STD and tomography very useful for studying moisture variability.
- VERA and C-band Doppler radar (partly dual-Doppler) applied for detection of convergence zones.
- Combination of ground-based and airborne sensors investigated aerosol-cloud microphysics.
- Lidar aerosol data improved the simulation of precipitation during Saharian dust outbreak over COPS area.

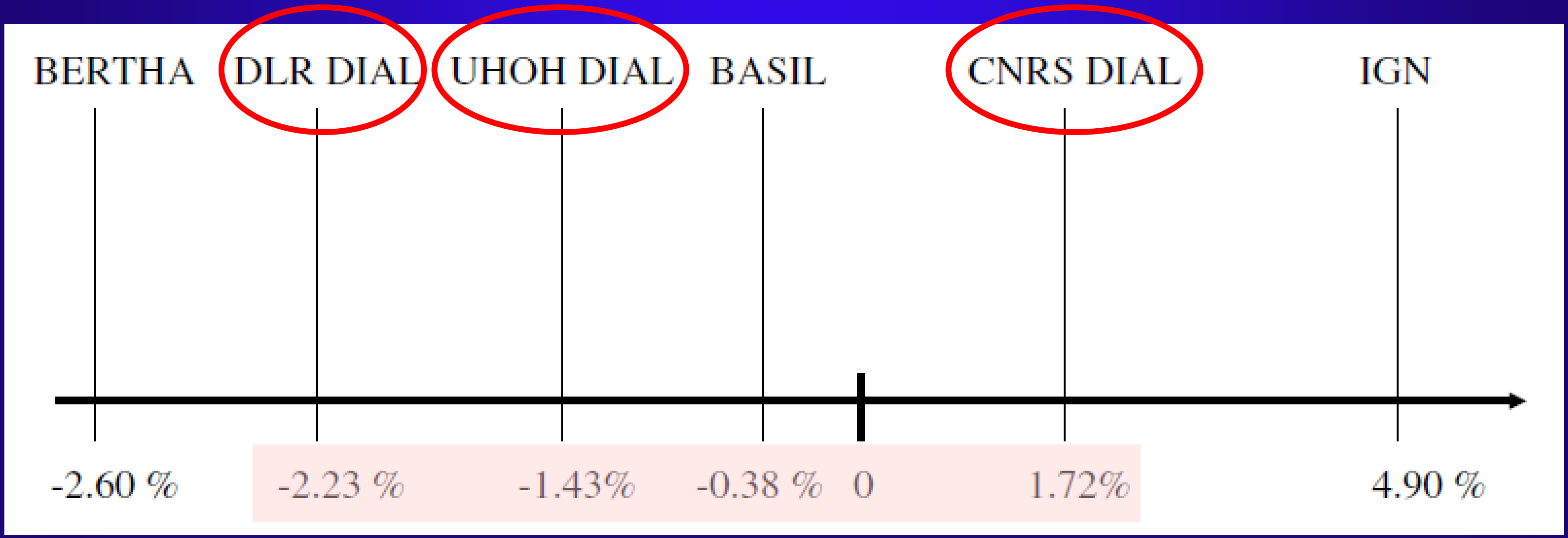
- (Still) Much more can be exploited with the COPS data set, especially ABL characteristics and microphysics.
- New lidar technology available also for long-term operational measurements.

Water vapour lidar intercomparison



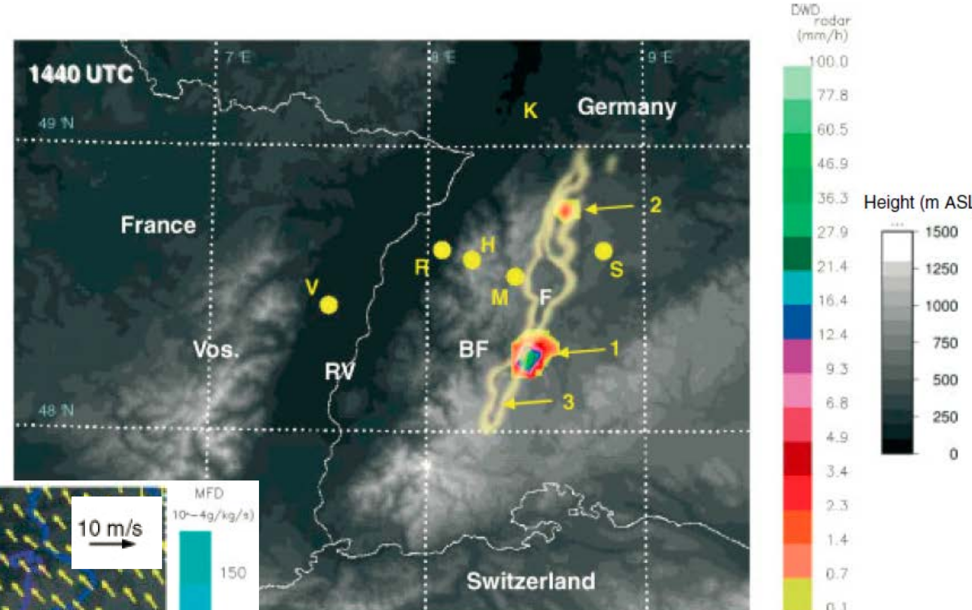
integration time = 50 sec for *DLR DIAL and* 80 sec for *CNRS DIAL*
hor. integration length ~ 10 km for both *DLR DIAL and CNRS DIAL*

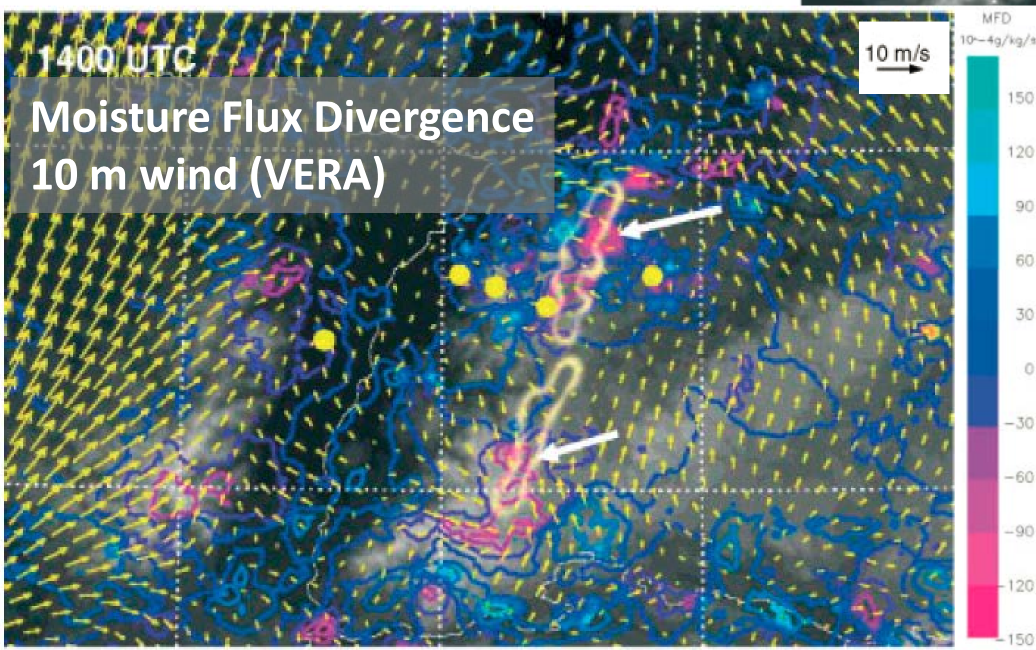
WV DIAL Systems
are within 4 %



Bhawar et al., QJRMS, 2011

IOP 8b, 15 July 2007: **Convection Initiation**



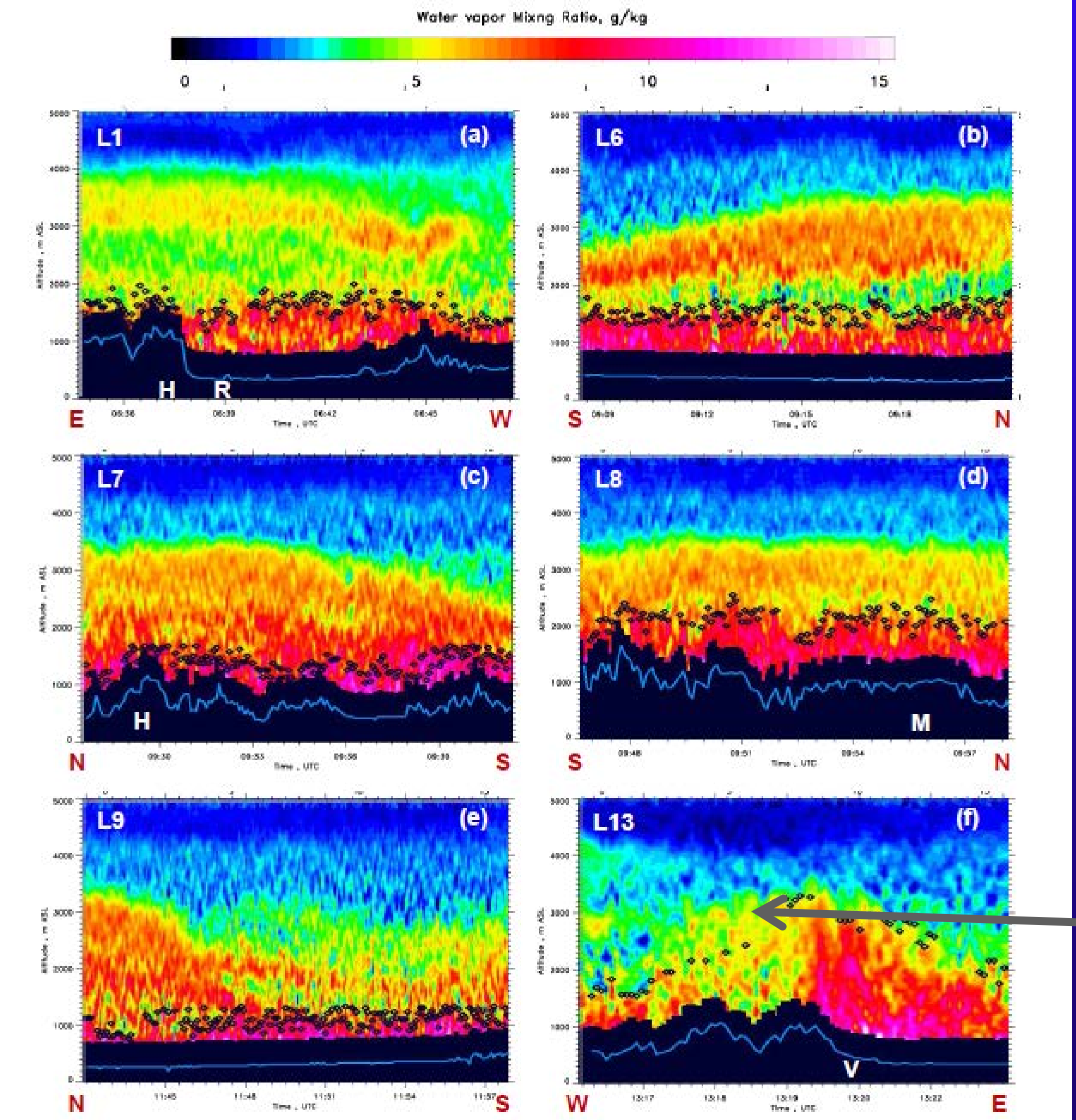


In the presence of sufficient moisture and CAPE and low CIN **local convergence zones** were were decisive.

Behrendt et al., QJRMS, 2011
Barthlott et al., QJRMS, 2011
Richard et al., QJRMS, 2011

IOP 8b, 15 July 2007: **Moisture in the ABL**

Airborne Water Vapour DIAL Leandrell



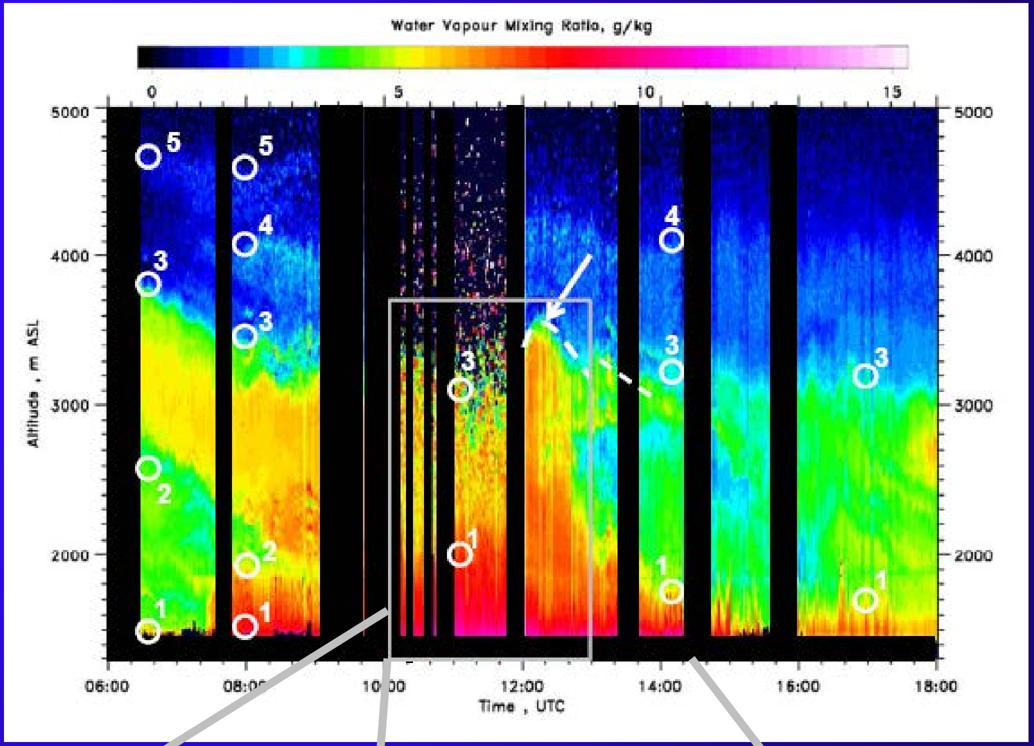
Low moisture west of Vosges explains differences between Black Forest and Vosges Mountains: deep and shallow convection, respectively.

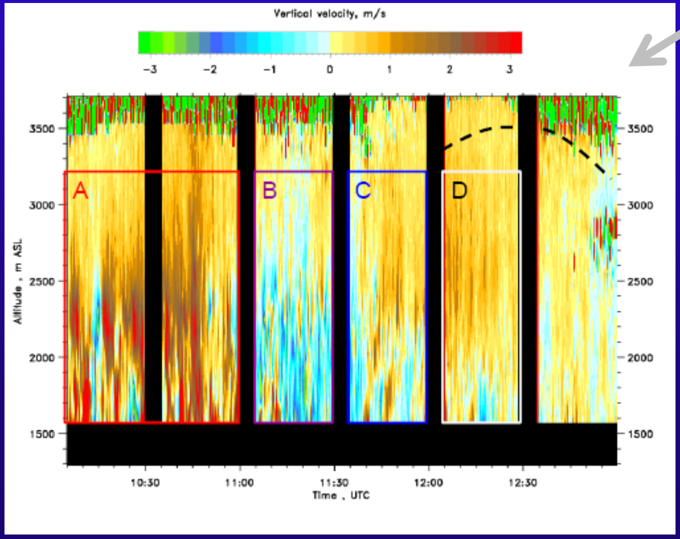
Behrendt et al., QJRMS, 2011

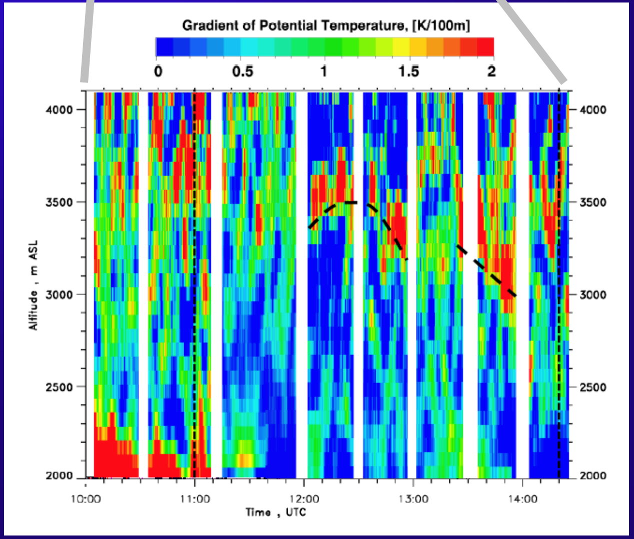
IOP 8b, 15 July 2007: **Thermodynamic structure of a local convergence zone**

Water Vapour DIAL
Rotational Raman Lidar
Doppler Lidar at Hornisgrinde

Low CIN, high latent heat flux but no CI because of capping lid.







Behrendt et al., QJRMS, 2011

Major COPS Results and Conclusions

5) **Data assimilation and predictability:**

- Positive impact of the assimilation of GPS STD on QPF.
- Positive impact of Doppler radar and reflectivity.
- 3DVAR provides benchmark for DA systems on the CP scale
- Orography can increase the predictability of convection.
- The lead time is not limited by the lifetime of convective cells but by the lifetime of the forcing conditions leading to convection.
- Multi-model ensemble provided improved simulation of convective cells (14 h lead time).

- COPS and D-PHASE data can be used as DA testbed and IMRE but test and comparison of different DA techniques still open.
- More impact studies possible.
- COPS-D-PHASE data set unique for verification studies.