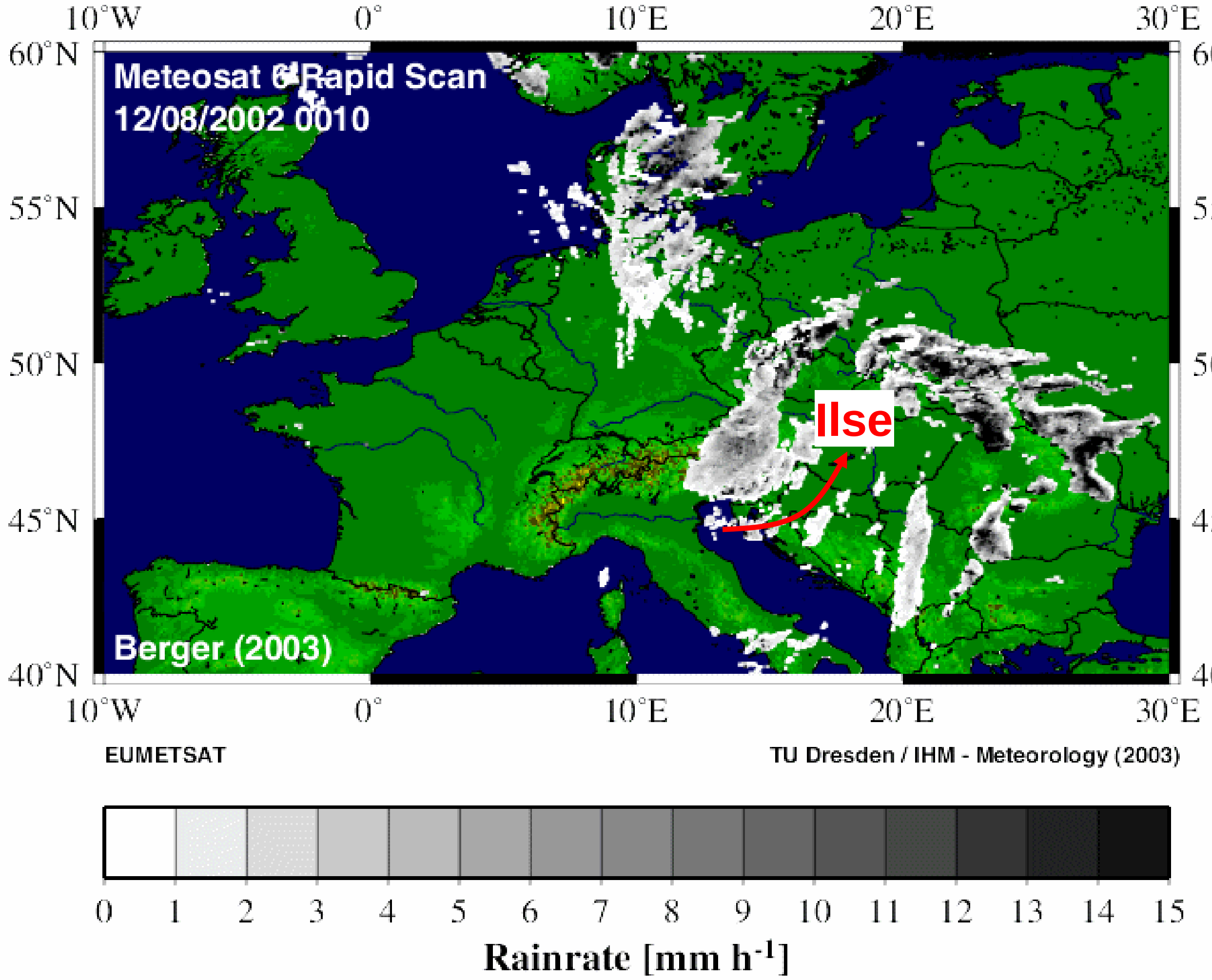
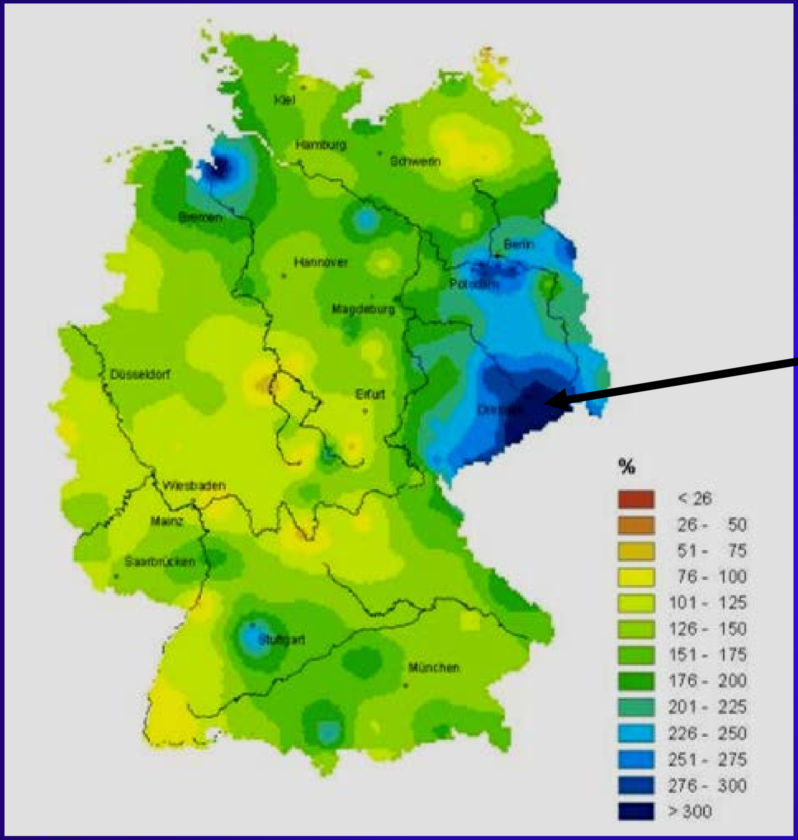
August 2002, Saxonia



Precipitation amount in August 2002



German Meteorological Service (DWD), Klimastatusbericht 2002

Largest ever measured precipitation in Germany: Zinnwald-Georgenfeld 312 mm/24h

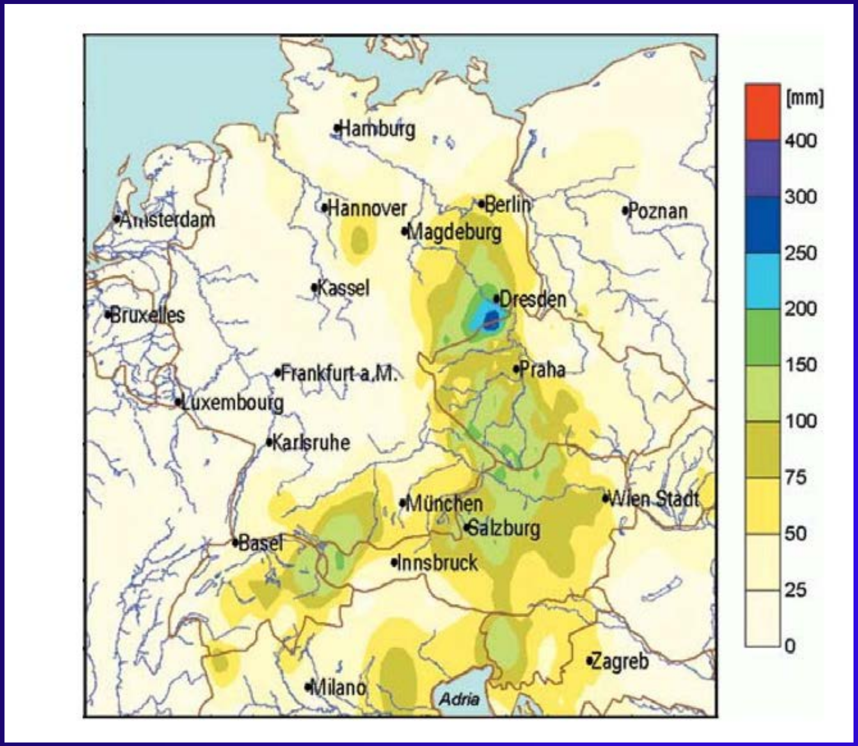
The high precipitation amount was due to orographic enhancement, flooding was amplified due to saturation of soil moisture by previous precipitation events.

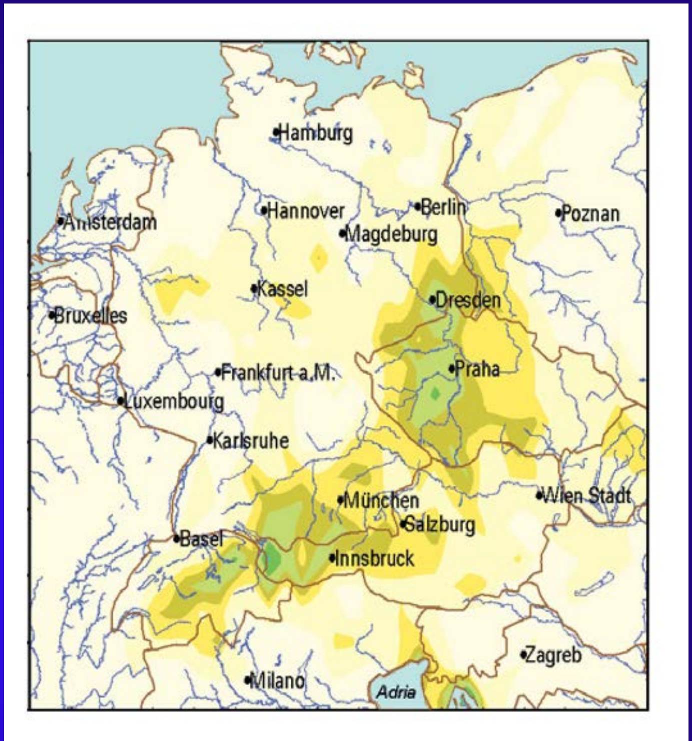
Flood disaster, Saxonia, August 2002

Economic loss: about US$18.500.000.000

(Annual Report 2002, Munich Reinsurance Company)

Performance of Local Model of DWD





DWD, Klimastatusbericht 2003

Left panel: obs. precip between 10.08.-13.08.2002, 6 UTC, right panel: LM forecast

Area-averaged precipitation was predicted reasonably well. However, prediction of location and intensity of precipitation maximum was not accurate enough for supporting hydrological models.

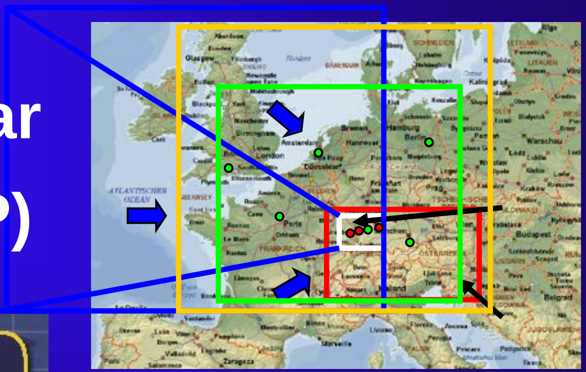
The Convective and Orographically-induced Precipitation Study (COPS): A unique application of the AMF

Volker Wulfmeyer, Institute of Physics and Meteorology (IPM), UHOH, Stuttgart, Germany
Susanne Crewell, Meteorological Institute (MIM), LMU, Munich, Germany
Richard Ferrare, NASA LaRC, USA
Jost Heintzenberg, IfT, Leipzig, Germany
Anthony Illingworth, University of Reading, UK
Alexander Khain and Mark Pinsky, Hebrew University of Jerusalem, Israel
Christoph Kottmeier, IMK, Karlsruhe, Germany
Ulrike Lohmann, ETH Zurich, Switzerland
Herman Russchenberg, Delft University, The Netherlands
David D. Turner, University of Madison-Wisconsin, USA
Ed Westwater, NOAA, Boulder, USA

Outline

1. The German research program on Quantitative Precipitation Forecasting (QPF)

2. Design of COPS and the PQP 1-year General Observations Period (GOP)



3. The key role of the AMF

The German Priority Program „QPF“

Improve QPF by the

- identification of the physical and chemical processes responsible for deficits
- exploration and application of existing and new data sets for improved representation of relevant processes
- determination of the predictability of precipitation using statistical-dynamical analyses

Basic information

www.meteo.uni-bonn.de/projekte/SPPMeteo/

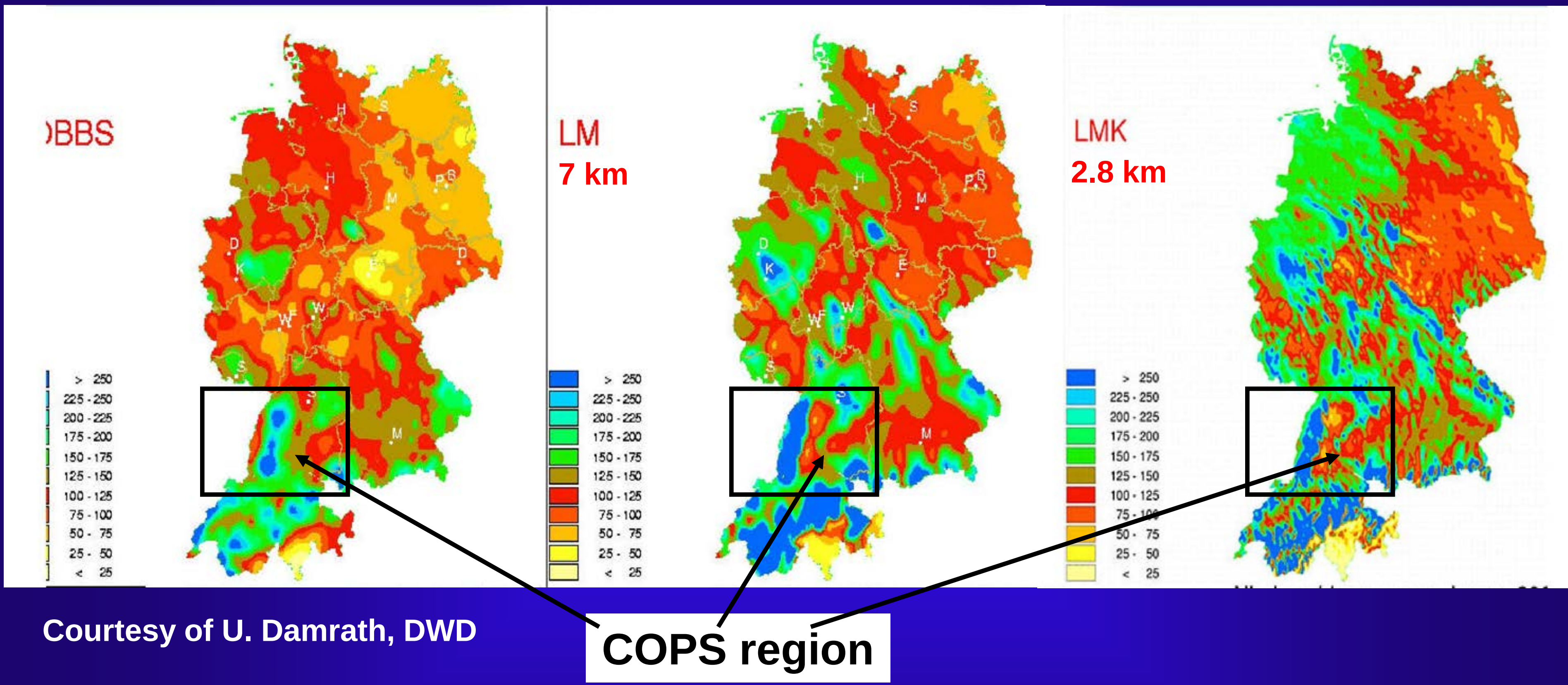
	April 2004-2005	April 2005-2006	April 2006-2007	April 2007-2008	April 2008-2009	April 2009-2010
Year	1	2	3	4	5	6
	Period 1		Period 2		Period 3	
GOP				One year		
IOP	Phase 1: Preparation			Phase 2: Performance: Summer 2007	Phase 3: Data analysis	

GOP: General Observations Period

IOP: Intensive Observations Period → COPS

- **Participants:**
  - **- 11 universities**
  - **- 3 research centers**
  - **- 2 weather services**
- **Projects:**
  - **- 3 Verification**
  - **- 2 Theory, numerics**
  - **- 3 Nowcasting**
  - **- 2 Orography**
  - **- 3 Microphysics**
  - **- 2 Parameterization**
  - **- 6 Data assimilation**
  - **- 3 GOP, IOP**

LM/LMK performance in January 2004 with prognostic precipitation



Courtesy of U. Damrath, DWD

Windward / Lee problem remaining though convection parameterization removed and resolution increased in LMK.

COPS (Convective and Orographically-induced Precipitation Study)

A field experiment within the German QPF Program PQP

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

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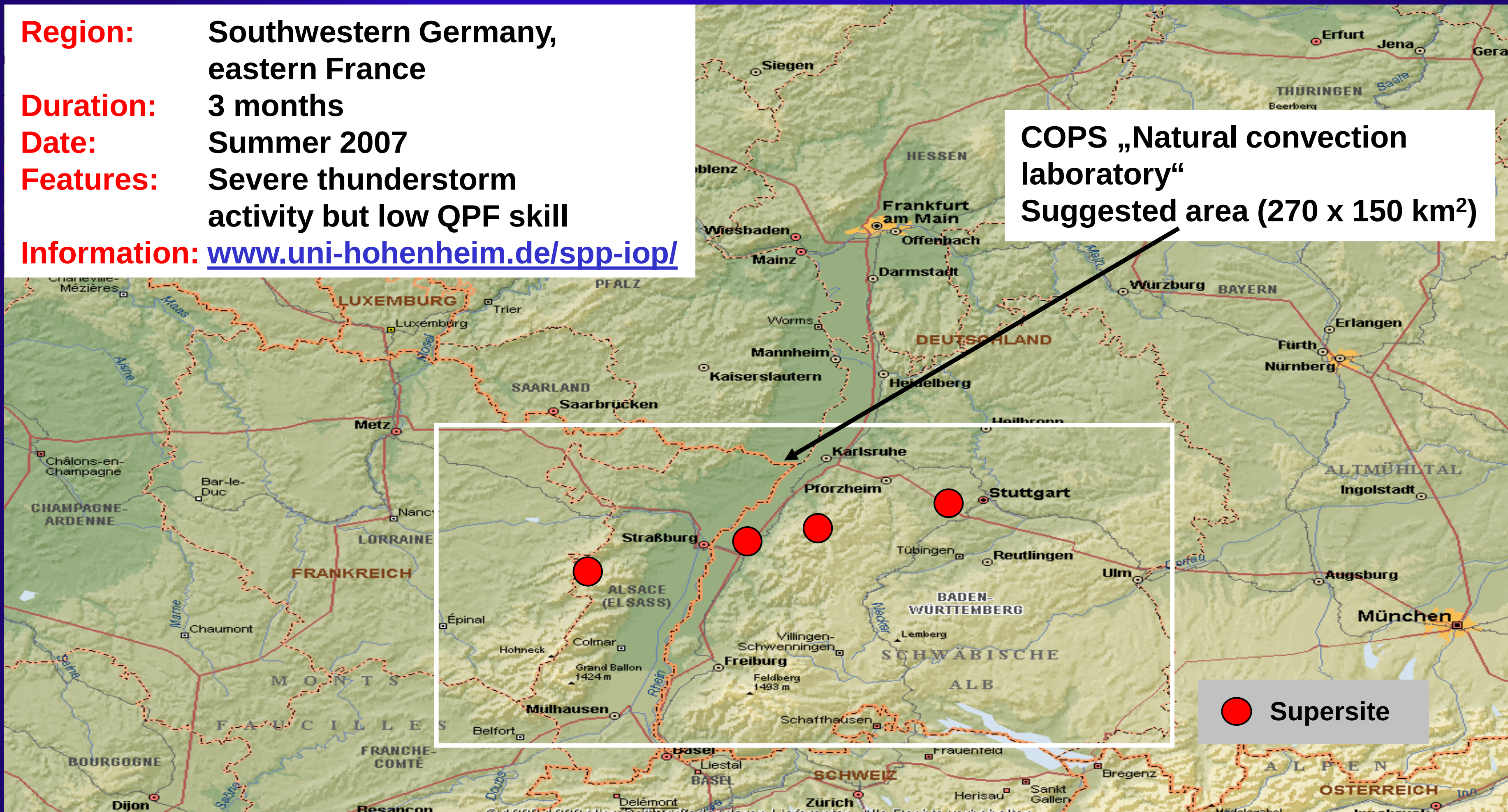
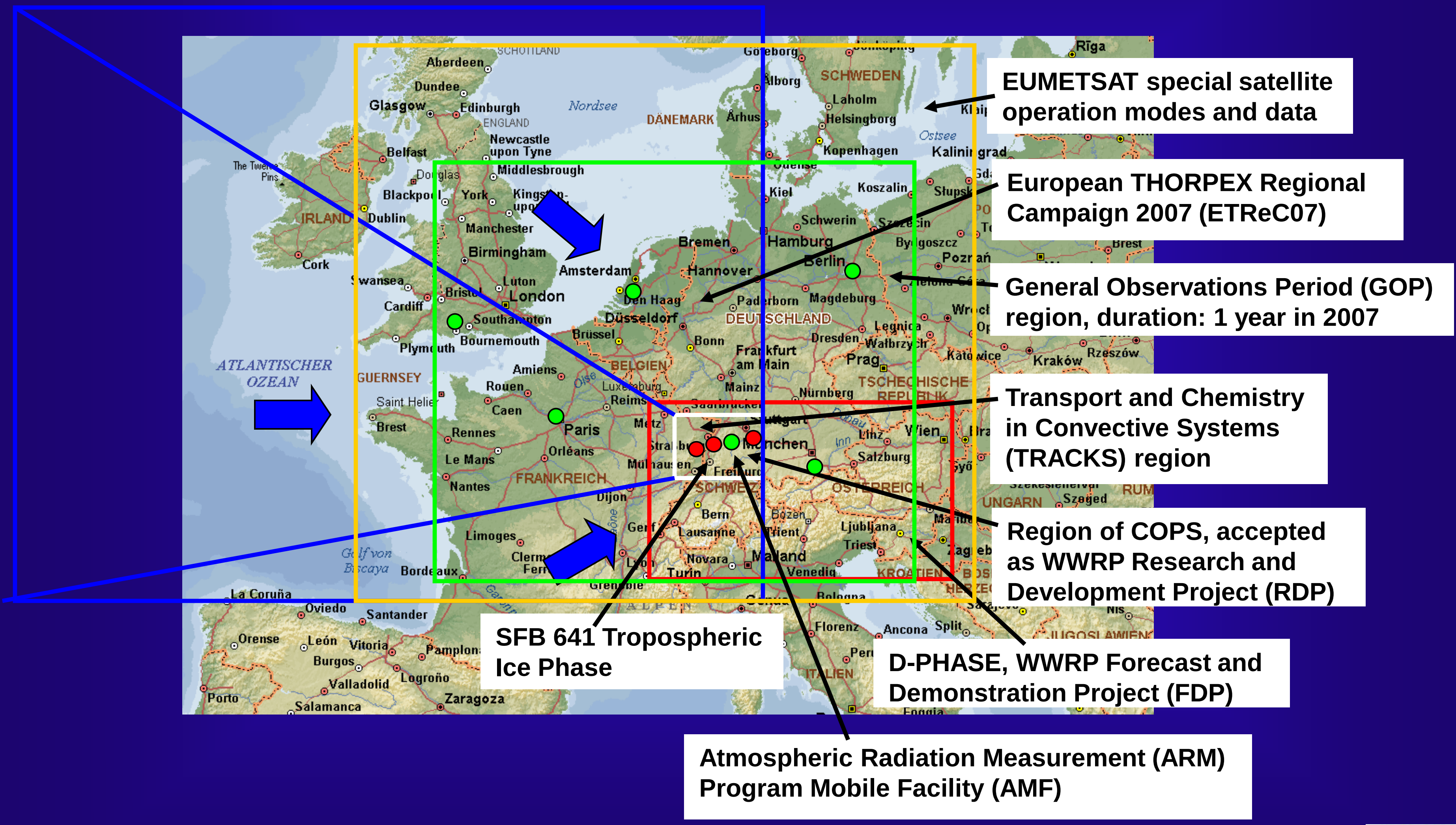
Region: Southwestern Germany, eastern France
Duration: 3 months
Date: Summer 2007
Features: Severe thunderstorm activity but low QPF skill
Information: www.uni-hohenheim.de/spp-iop/

COPS „Natural convection laboratory“
Suggested area (270 x 150 km^2)



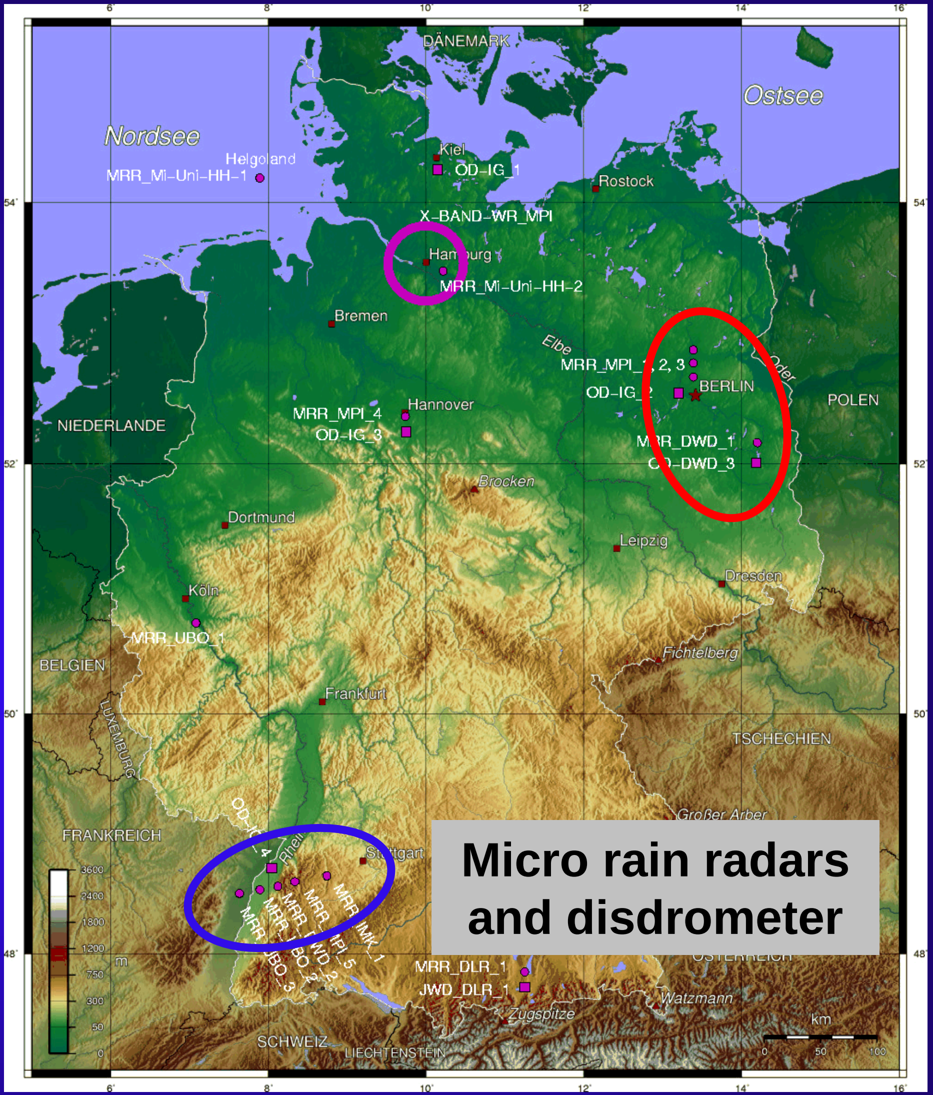
International collaboration: European Summer Experiments 2007



GOP organization and performance

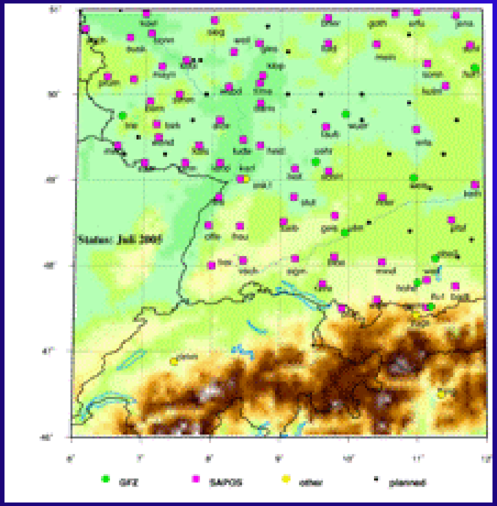
The **General Observations Period** — January to December 2007 — encompasses **COPS** in time and space

- to provide information of all kinds of precipitation types
- to identify systematic model deficits
- to select case studies for specific problems
- to relate the COPS results to a broader perspective (longer time series and larger spatial domain)



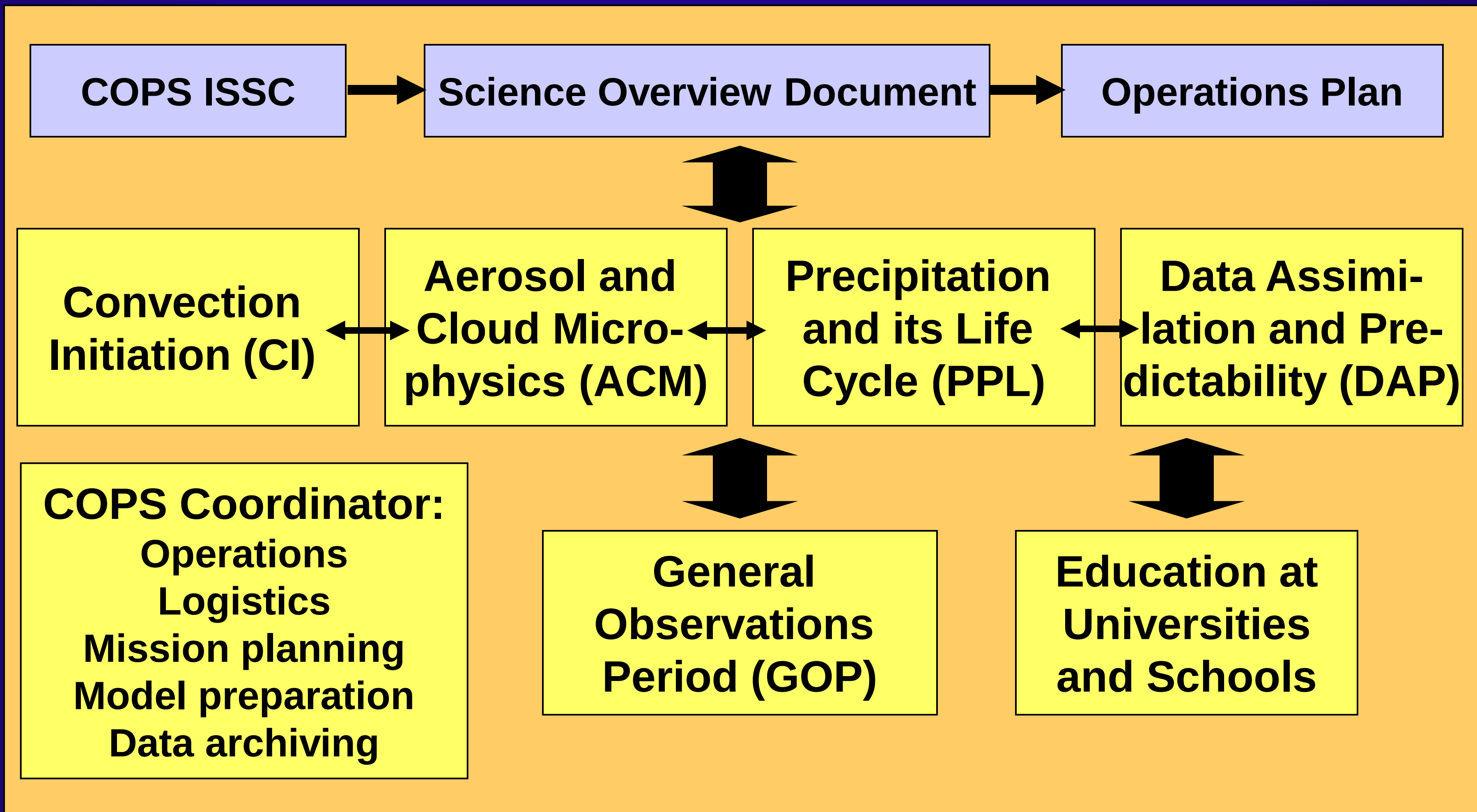
Investigation of differences in precipitation microphysics between flat and orographically structured terrain

GOP ingredients



- Rain gauges: several hundred independent observations by water authorities, environmental agencies etc.
- Meteorological stations
- Weather radar network
- Drop size distribution with micro rain radar
- Lidar, EARLINET stations, about 100 lidar ceilometer stations in Germany
- GPS network
- Satellite observations of cloud properties, water vapor, aerosol from MSG, MODIS, MERIS, AMSU, METOP, CLOUDSAT, CALIPSO

PQP field programs organizational structure



COPS science hypotheses

- Upper tropospheric features play a significant but not decisive role for convective-scale QPF in moderate orographic terrain. ⇒ ETReC07, CI, GOP, DAP
- 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 ⇒ D-PHASE, CI, ACM, PPL, DAP
- Location and timing of CI depends critically on the structure of the humidity field in the planetary boundary layer
- Continental and maritime aerosol type clouds develop differently over mountainous terrain leading to different intensities and distributions of precipitation ⇒ TRACKS, SFB 641, ACM, PPL
- Novel instrumentation during COPS can be designed so that parameterizations of sub-grid scale processes in complex terrain can be improved (ALL)
- Real-time data assimilation of key prognostic variables such as water vapor and dynamics is routinely possible and leads to a significant better short-range QPF (CI, DAP, GOP)

COPS preparation

Example: MM5 high-resolution modeling study of June 19, 2002 (6-18 UTC)

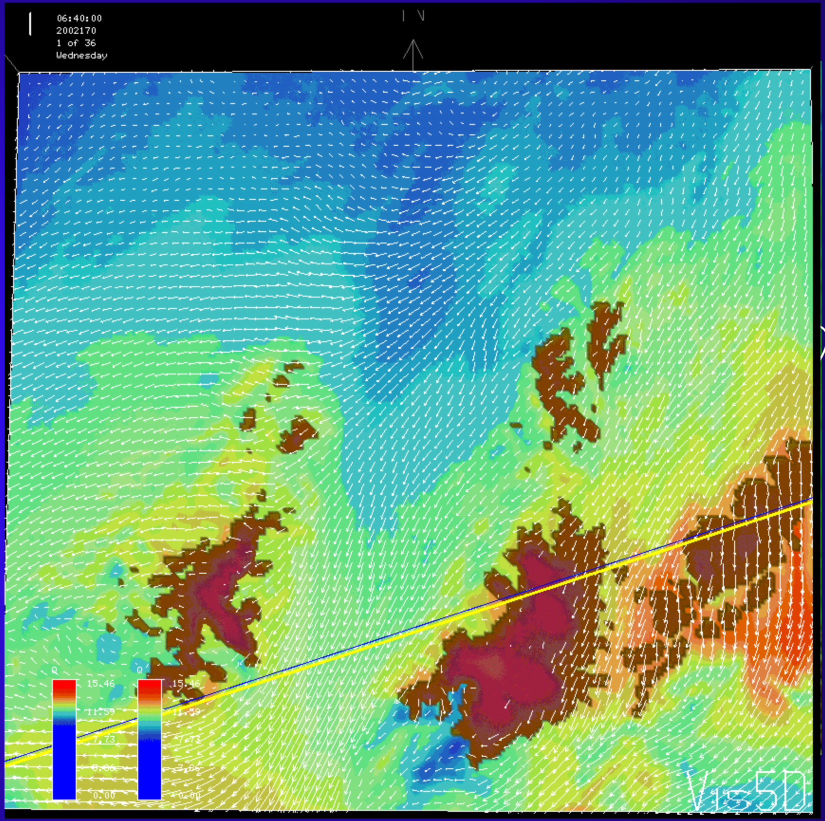
Phase 1: Pre-convection

Phase 2: Convection initation, cloud formation considering aerosol-cloud interaction

Phase 3: Development of convection, onset of precipitation

Phase 4: Maintenance and decay of precipitating system

Simultaneous large-scale and small-scale synergetic 4D observations of key variables essential.



ARM and QPF research is strongly related, as in both cases properties of clouds are critical.

Observation strategy

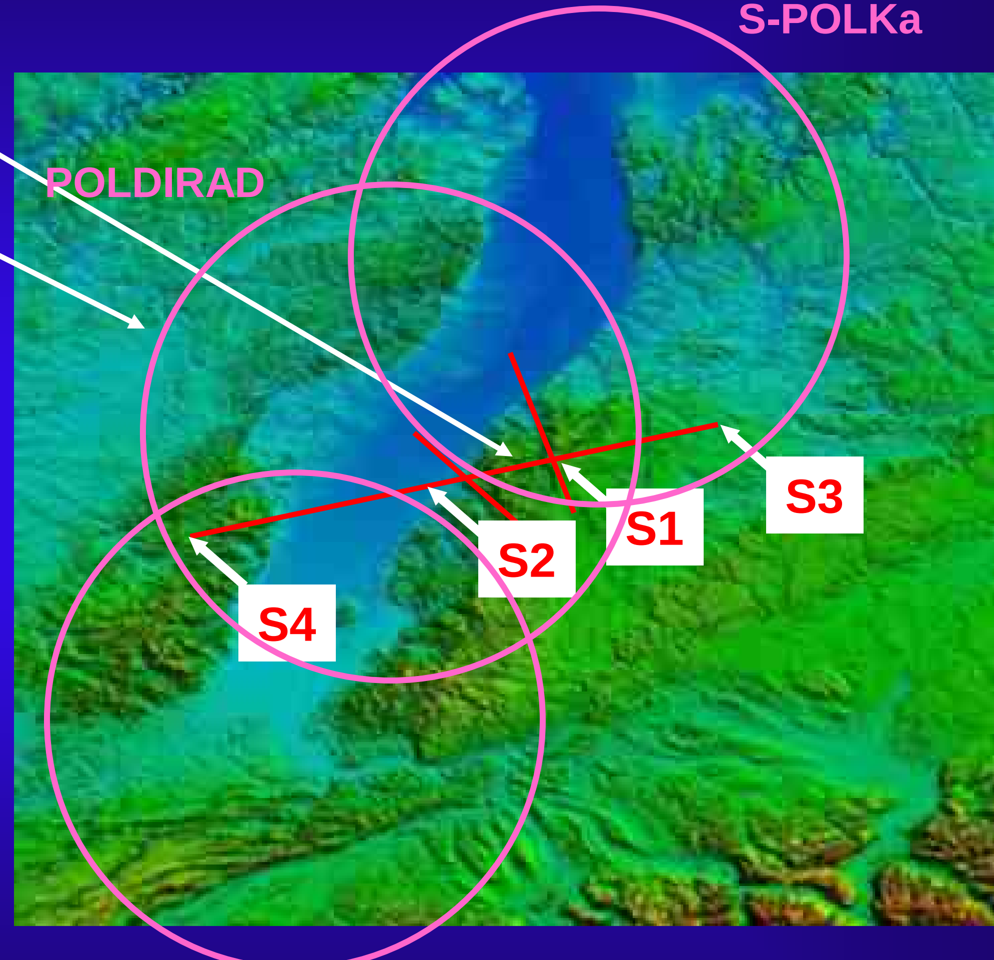
Transect with supersites

Optimization of radar coverage

Large-scale and mesoscale observations provided by Falcon aircraft.

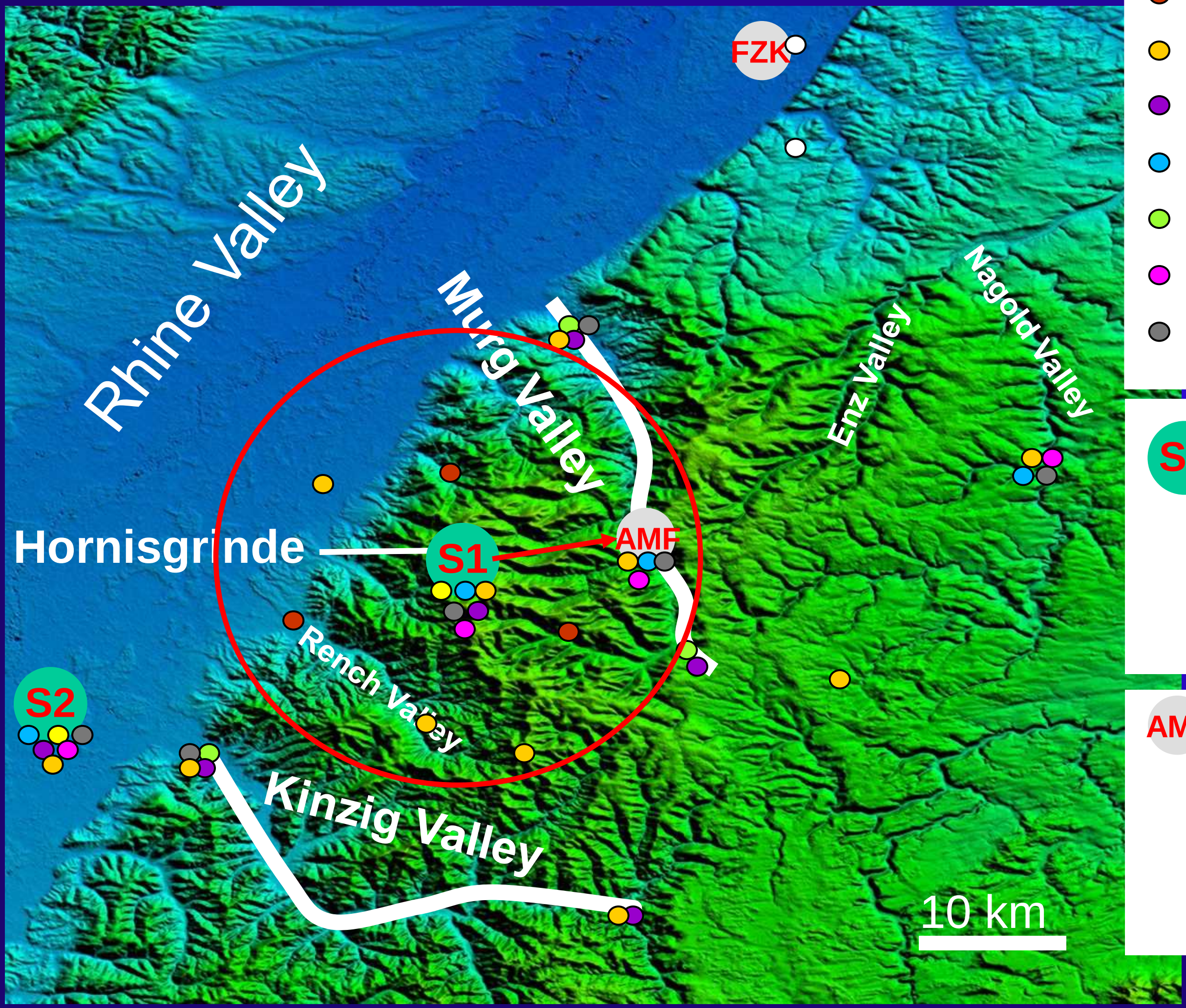
Regional observations between supersites performed by Do-128 aircraft.

Cloud microphysics with UK BAE 146 and French CNRS/INSU Falcon 20 aircrafts.



Montancy (F), 2006

Zoom in view in Northern Black Forest



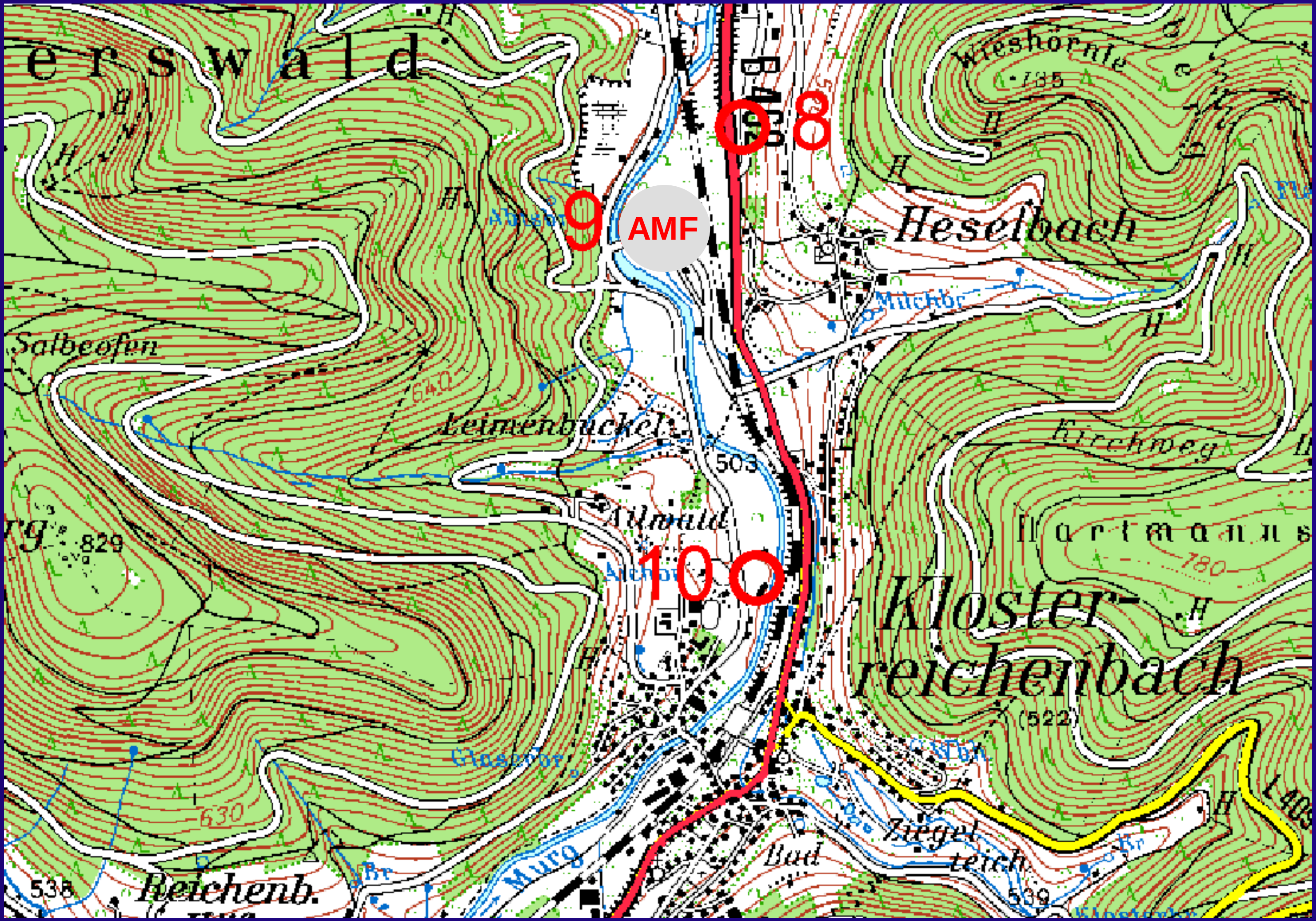
- Energy balance stations
- Flux stations (turb. towers)
- Radiation turbulence clusters
- Soil moisture sensors
- Mesonet
- Radiosonde stations (RS)
- Sodars
- MRRs
- GPS

S1:
UHOH WV DIAL
UHOH RRL
Windtracer
UHOH X-band

AMF:
AMF
HATPRO + 90/150 GHz
MWL & WiLi (incl. RS)
FZK cloud radar

The Black Forest AMF Site: From dust to snow, March 8, 2006

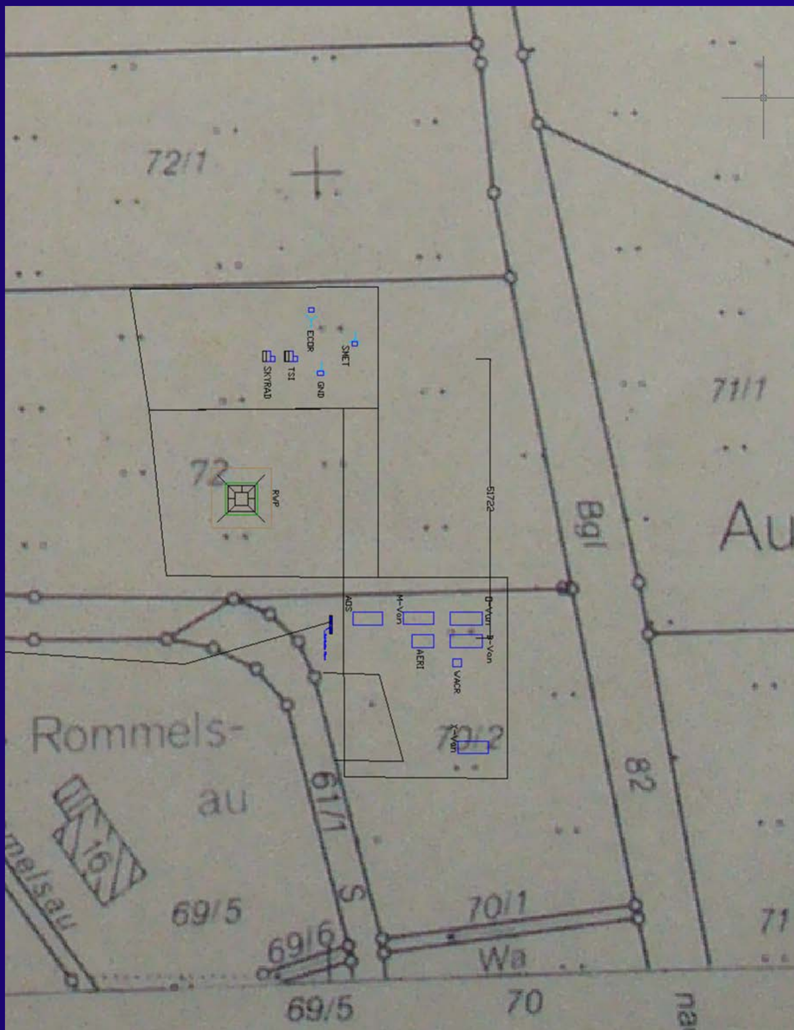
The Black Forest AMF Site



48° 32' 22'' N, 8° 23' 43'' E

The Black Forest AMF Site

The Black Forest AMF Site



- 14 channel scanning microwave radiometer HATPRO (LMU)
- 90/150 GHz radiometer (LMU)
- Online implementation for Integrated Profiling Technique (IPT) Löhnert et al. 2004 & COST 720:
  - Profiles for T and q, LWP, IWV, r_{eff}
  - Online model evaluation for AMF and Cloudnet stations
- 36-GHz scanning cloud radar (FZK)
- Micro rain radar (UHH)
- Multi-wavelength lidar (IfT)
- Doppler lidar (IfT)
- Scanning water vapor DIAL (UHOH)
- Scanning rotational Raman lidar (UHOH)
- Scanning Doppler lidar (FZK)

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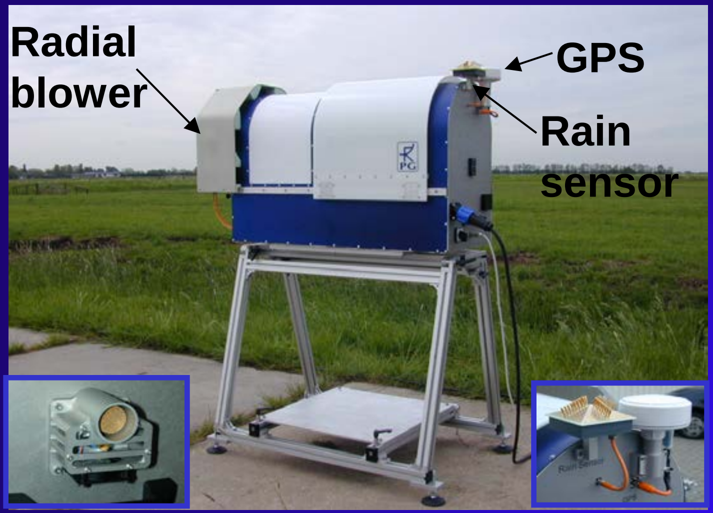
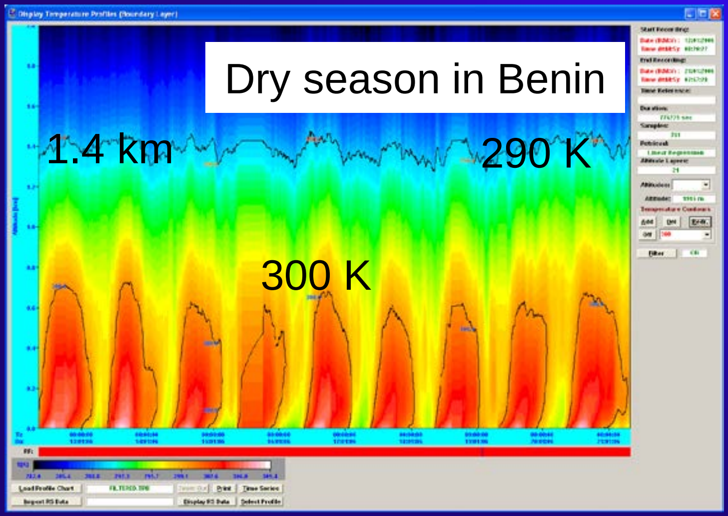
LMU Humidity and Atmospheric Profiler (HATPRO)

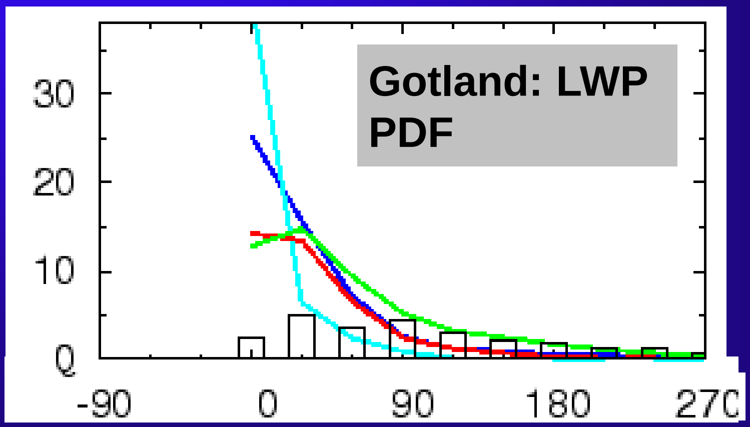


Rose, T. at al. Atmos. Res. 2005



- Design based on BBC results
- LWP, IWV, humidity and temperature profile
- Rain sensor, GPS, clock
- Environmental humidity, pressure and temperature

CLIWA-NET and Cloudnet products



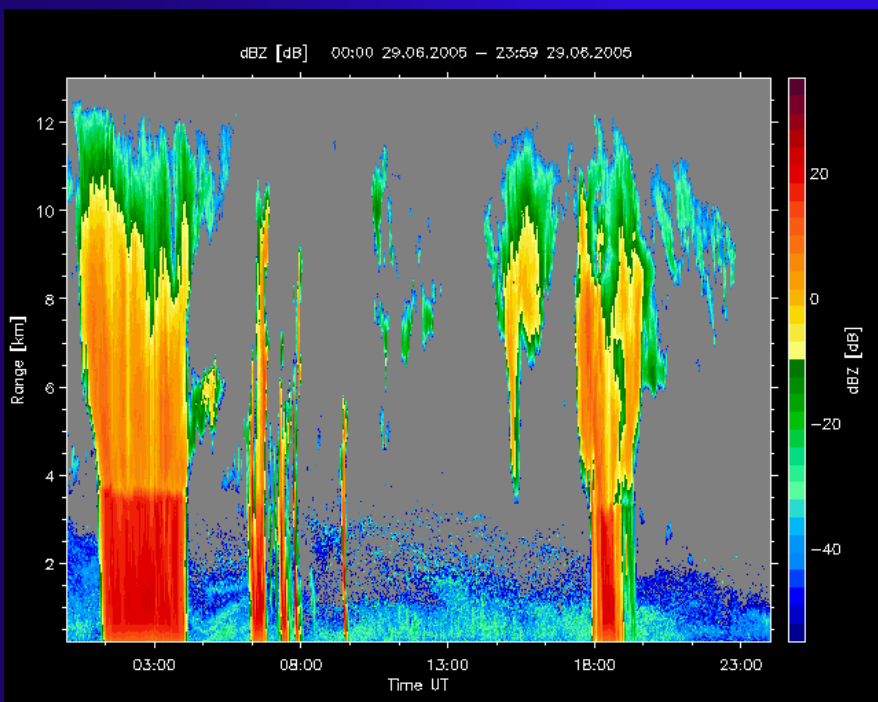
OBS
ECMWF
LM
RCA
RACMO

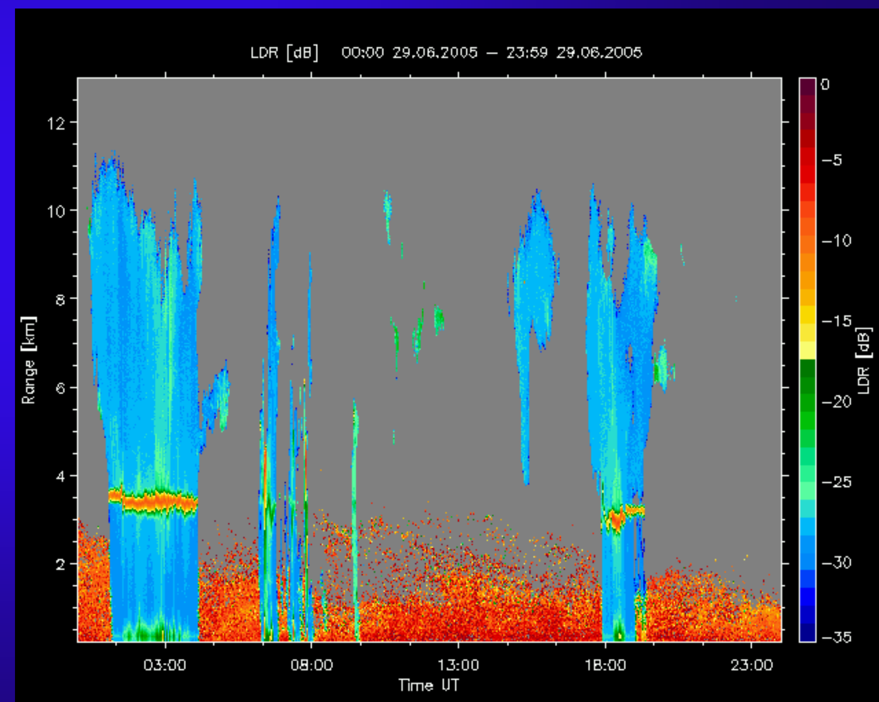
Van Meijgaard and S. Crewell, Atmos. Res. 2005

FZK scanning 36-GHz polarization, Doppler cloud radar

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Sensitivity: -40dBZ at 5km,
averaging time: 0.1s





PQP Praecipitationis Quantitativae Praedictio

AMF proposal science questions

- What are the processes responsible for the formation and evolution of convective clouds in orographic terrain?
  CI + ARM + D-PHASE + PQP scientists

- What are the microphysical properties of orographically induced clouds and how do these depend on dynamics, thermodynamics, and aerosol microphysics?
  ACM + ARM + GOP + PQP scientists

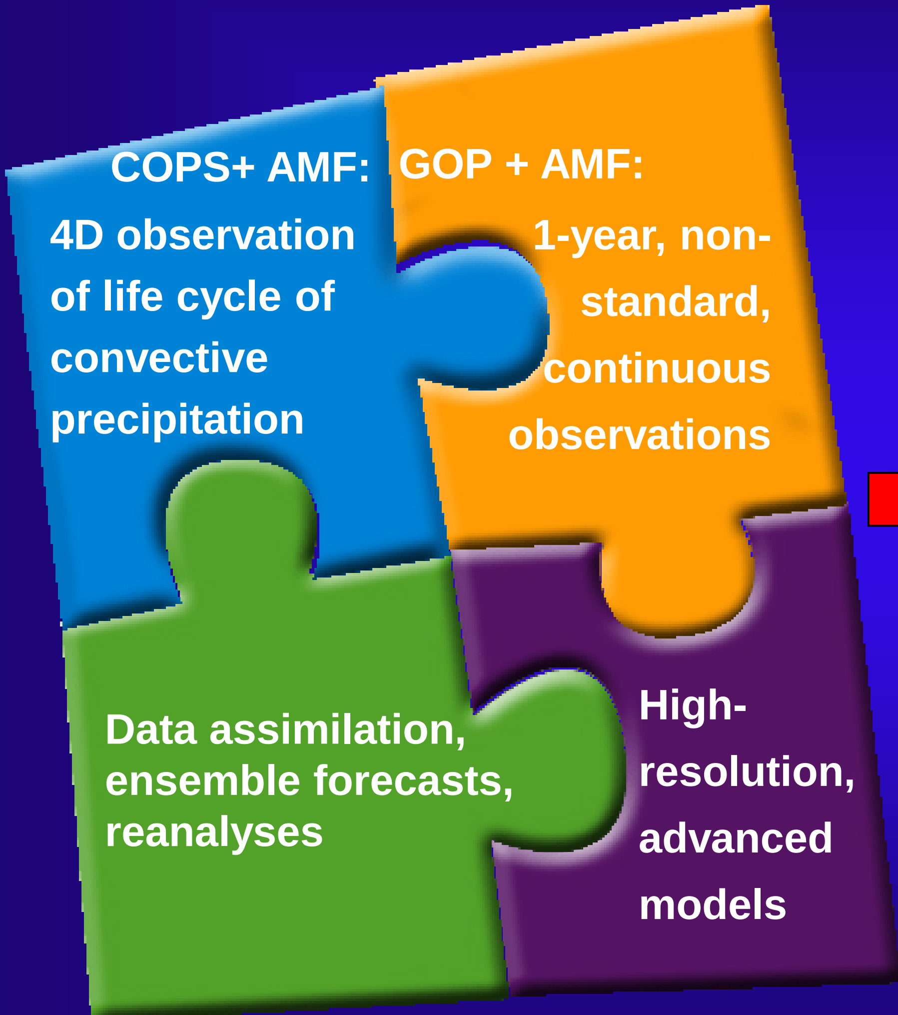
- How can convective clouds in orographic terrain be represented in atmospheric models based on AMF, COPS, and GOP data?
  Coordination of all efforts

PQP Praecipitationis Quantitativae Praedictio

Expected scientific results

- Detailed insight in the **performance of the AMF** with respect to atmospheric variables (q,T,aerosols & clouds) and instruments (MWR, radar).
- Improved understanding of the **representativeness of AMF** measurements in orographic terrain from high-resolution mesoscale models to the scale of GCMs.
- Development of strategies for determining **cloud climatologies in complex terrain**. Comparison of the microphysical properties of convective clouds with maritime locations (NL, UK) and continental flat regions (Lindenberg).
- Investigation of clouds with **low LWP**.
- Understanding of the relation between dynamics, thermodynamics, aerosol properties, and cloud microphysics in complex terrain.
- Test and development of novel parameterization schemes for convection in regions with significant orography.
- Test and development of novel parameterization schemes for cloud microphysical variables n in regions with significant orography.

Research Vision



Separate, quantify, and reduce QPF errors due to initial fields and parameterizations, study their effect on predictability

Data assimilation, closing the gap between observations and modeling:

Real-Time Assimilation of Observations of Key Prognostic Variables and the Development of Aerosol Operators (RAPTOR)

Operator development

- Generalization of the existing operators
- Develop operators for:
  + scanning lidar systems
  + Doppler lidar and radar
  + ZTD, slant path GPS
- Tests and assimilation experiments for selected cases

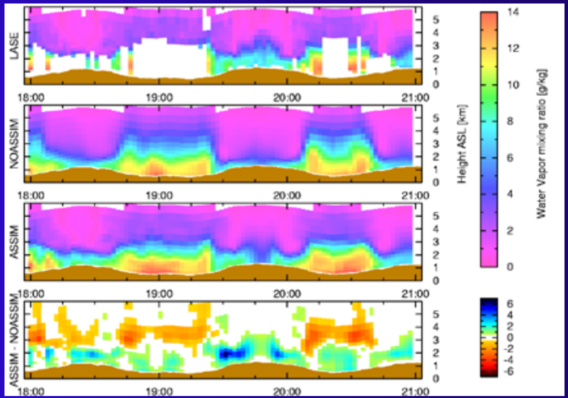
Real-time assimilation

- Automatization of the system consisting of pre- and postproces-sing, assimilation, and model forecast
- Creation of forecast products for the COPS operation center
- Testing resp. using the system during COPS

Aerosol operators

- Set up of WRF and WRF-Chem
- Feasibility study for the assimilation of selected aerosol observations
- Development of forward operators for selected aerosol observations
- Tests and case studies

Mesoscale forecast system based on MM5 / WRF providing the possibility of assimilation novel meteorological data and in future aerosol information in real-time



Clear improvement of modeling of convection initiation and precipitation by 4DVAR of LASE data, Wulfmeyer et al., MWR 2006

PQP and COPS International Science Steering Committee

Volker Wulfmeyer, IPM, UHOH, Germany, Chair

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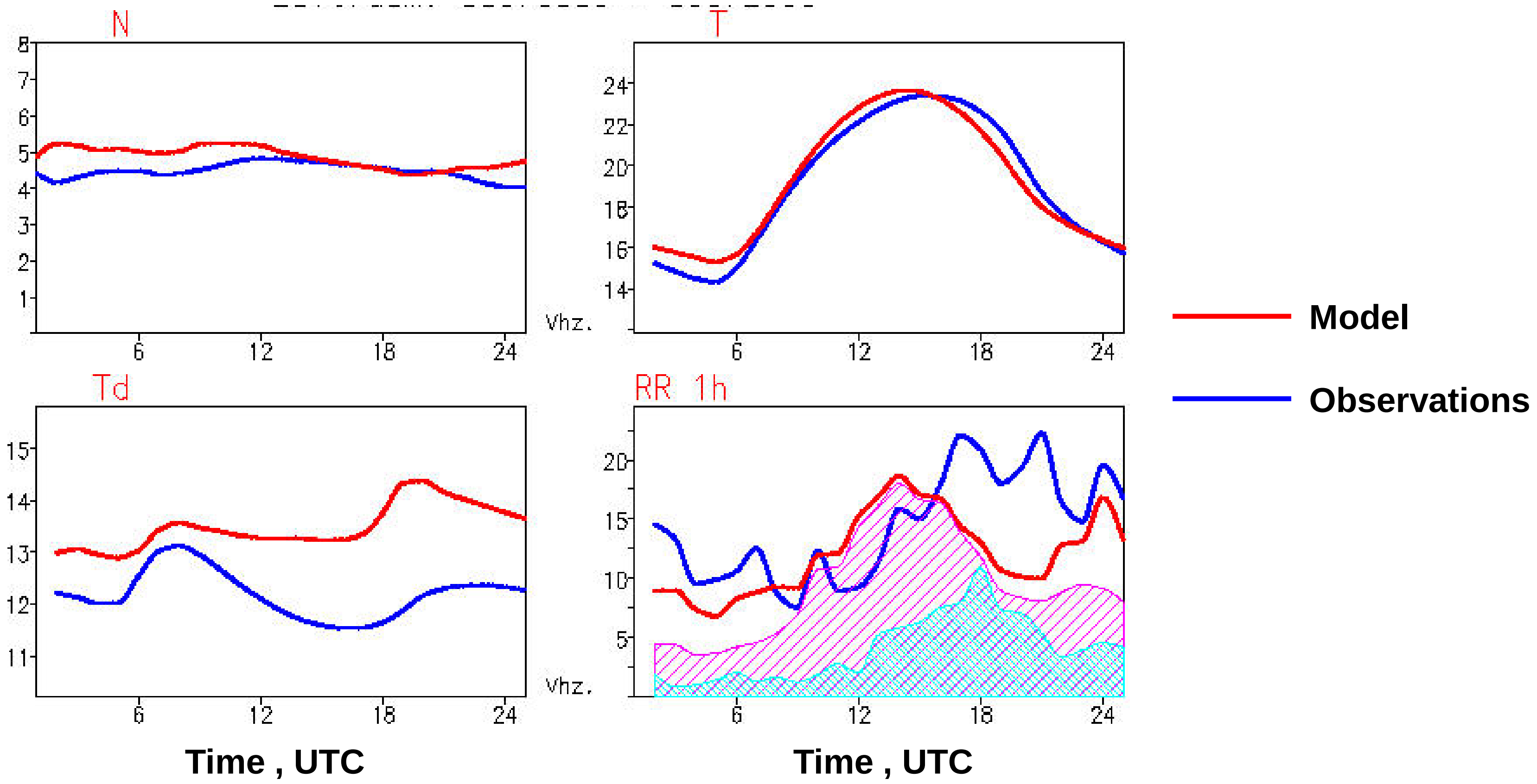
Clemens Simmer, Institute of Meteorology, University of Bonn, Germany

Reinhold Steinacker, Department of Meteorology and Geophysics, University of Vienna, Vienna, Austria

Tammy Weckwerth, EOL, NCAR, Boulder, Colorado, USA

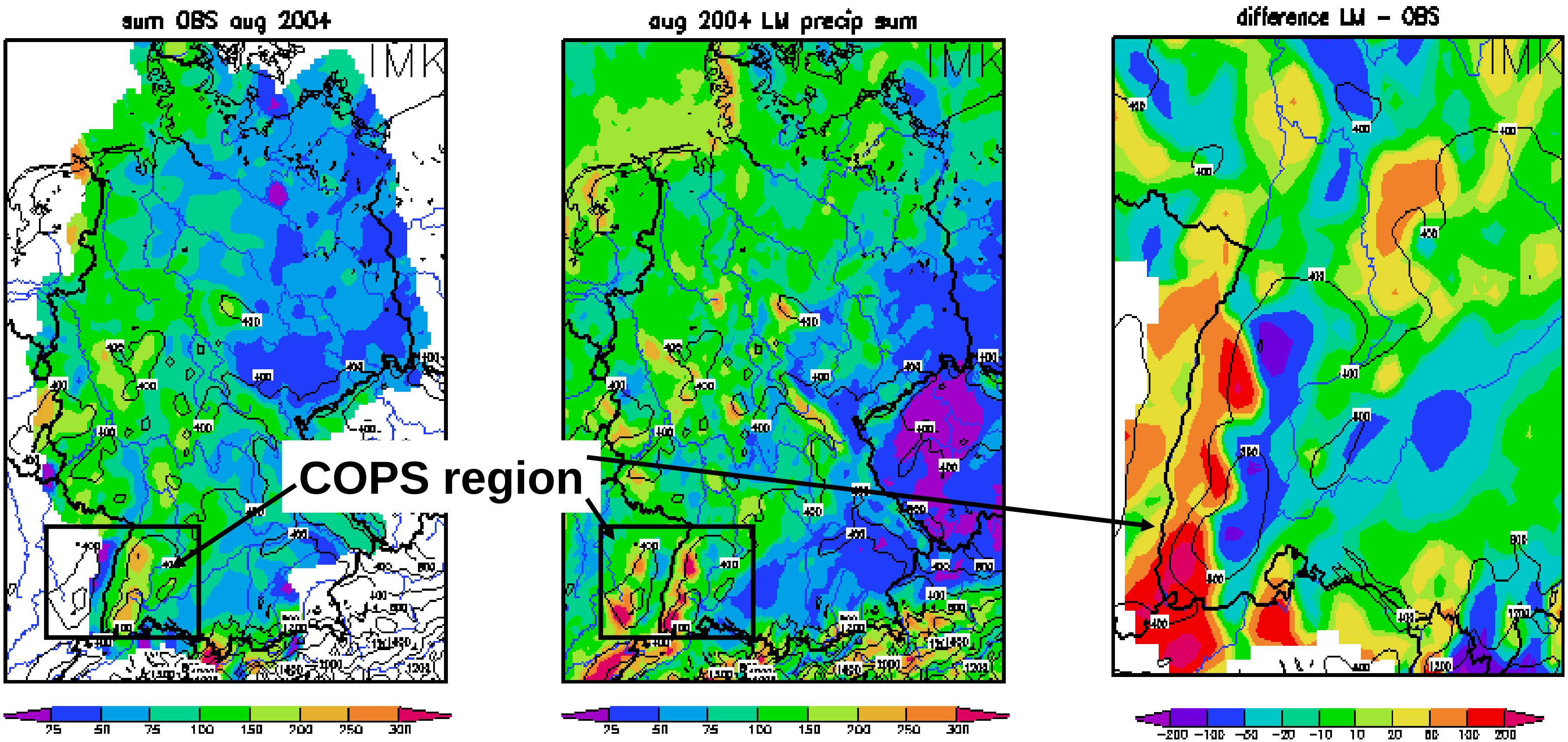
Diurnal cycle of precipitation averaged between 03.07.-29.07.2003 and 6.5-15E, 47.3-54N



Courtesy of U. Damrath, DWD, Bechthold et al. QJRMS 2004, among others

Systematic deviations in diurnal cycle of precipitation and of boundary layer variables are evident.

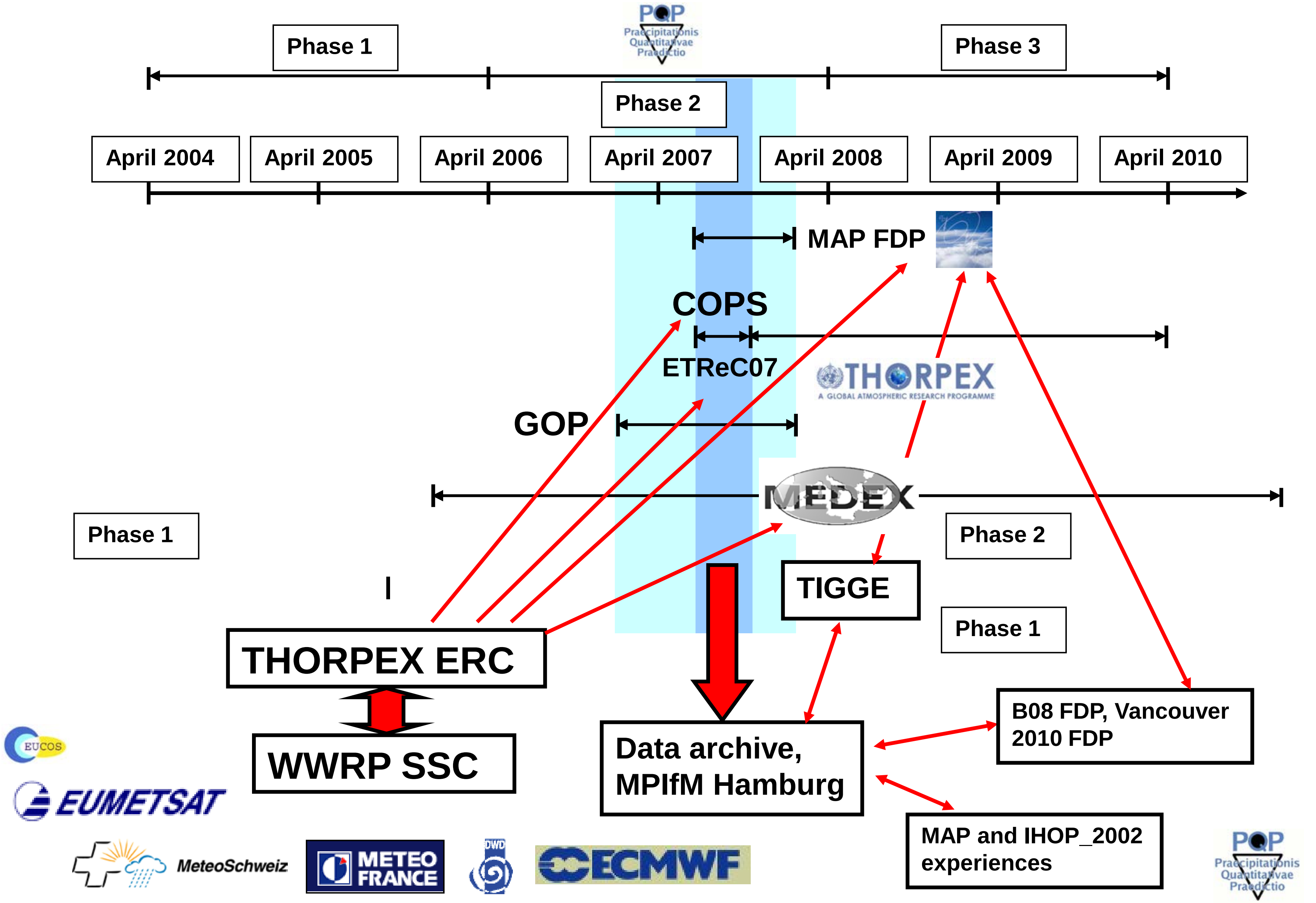
LM performance in August 2004 using prognostic precipitation



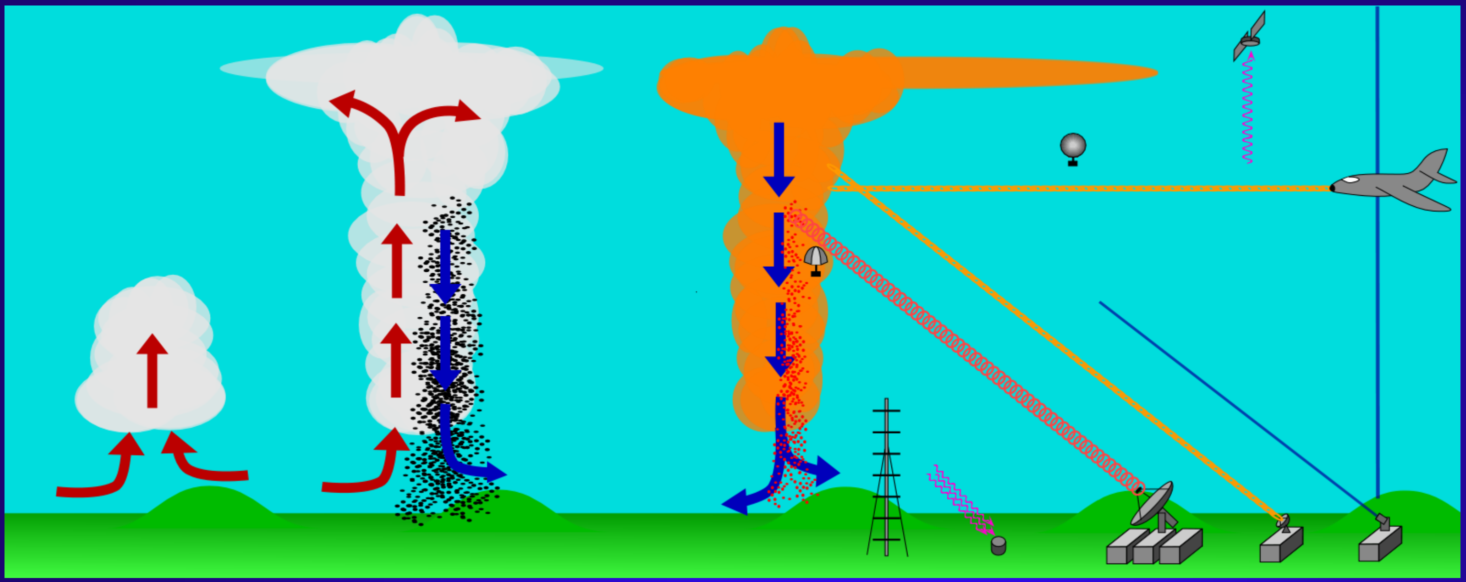
Left: observations, middle: LM forecast, right: difference. Courtesy of L. Gantner, FZK, see also v. Lipzip et al. 2005

Hypothesis: Windward/Lee problem due to inadequate convection parameterization

Coordination of WWRP Projects



Proposed synergy of observing systems



Precipitation radars

X-, C- or S-band,
$\lambda \approx$ 3–10 cm, $\nu \approx$ 10–3 GHz,
⇨ Reflectivity, velocity, refractivity, precip, clouds

Cloud radars

Ka- or W-band
$\lambda \approx$ 3–9 mm, $\nu \approx$ 100–35 GHz
⇨ near-range reflectivity, velocity in clouds, depol. δ

Lidars

$\lambda \approx 0.3$–$2\ \mu m$, $\nu \approx 10^{15}$–1.5×10^{14} Hz
⇨ α_{par}, β_{par}, depol. δ, q, T, velocity in clear air, aerosols and thin clouds

Microwave and FTIR radiometers

⇨ LWC, q, T, ...

The full potential of synergetic measurements is not explored yet, e.g.:
- R_{eff} in clouds using lidar and cloud radar (Donovan et al. 2001)
- Cloud condensation nuclei using lidar, cloud radar and microwave radiometer (Feingold et al. 1997)

Key tool for research on QPF and predictability:
Mesoscale limited-area ensemble forecasting

Ensemble of boundary conditions

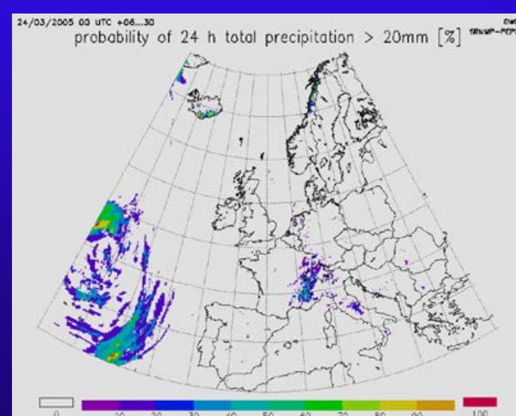
Model background error
Observations
} Initial conditions

High-quality, high-resolution, high-intensity combined observations

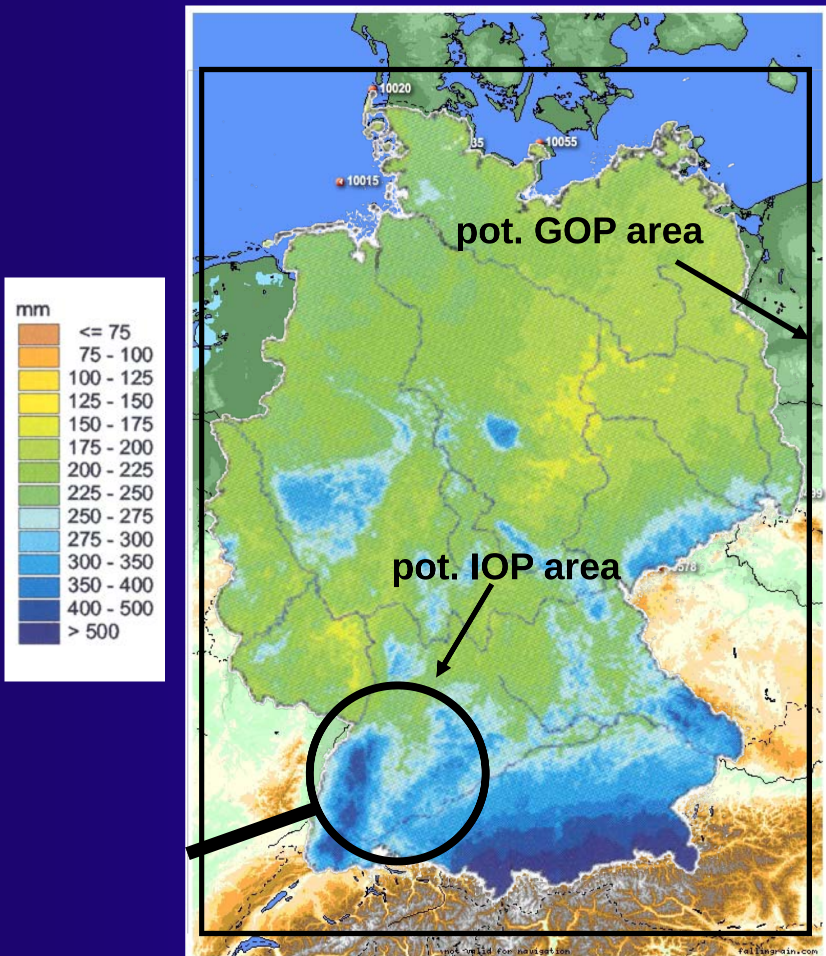
Model physics

Verification of ensemble forecasts ⟺ Training of ensemble

Production of mesoscale ensemble prediction system



Precipitation in Germany



Orography in Germany.
Overlay: Mean precipitation amounts in Summer, average between 1901 and 2000 (DWD Klimastatusbericht 2001)

GOP role and data:

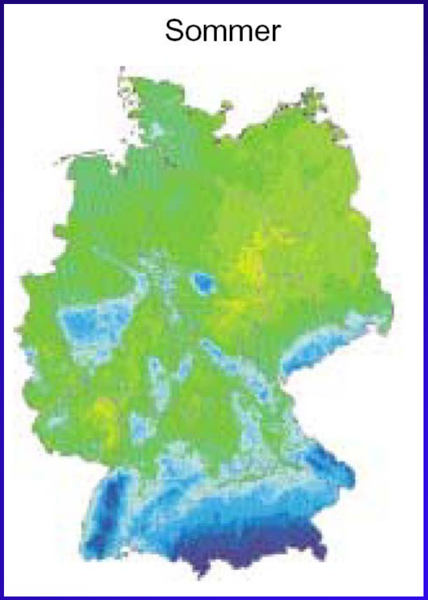
Extend conventional data sets by providing increased coverage and statistics of key variables

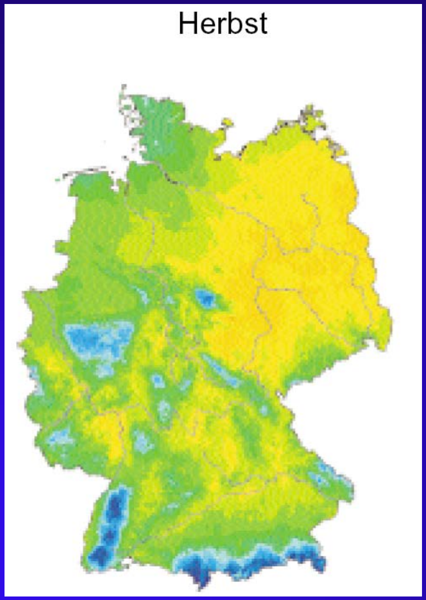
Envisioned data:

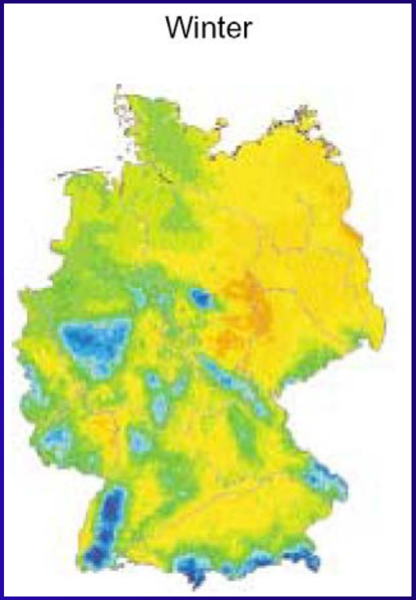
- **Collected on a routine basis by operational instruments**
- **Data quality control possible**
- **Operational algorithms producing key variables**
- **Special operation modes of observatories (Cabauw, Lindenberg)**
- **Existing data sets of other projects (e.g. BALTEX, EU Activities)**

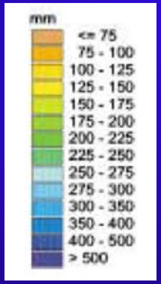
Duration: 1 year, 2007, coverage at least Germany

Distribution and trends of precipitation

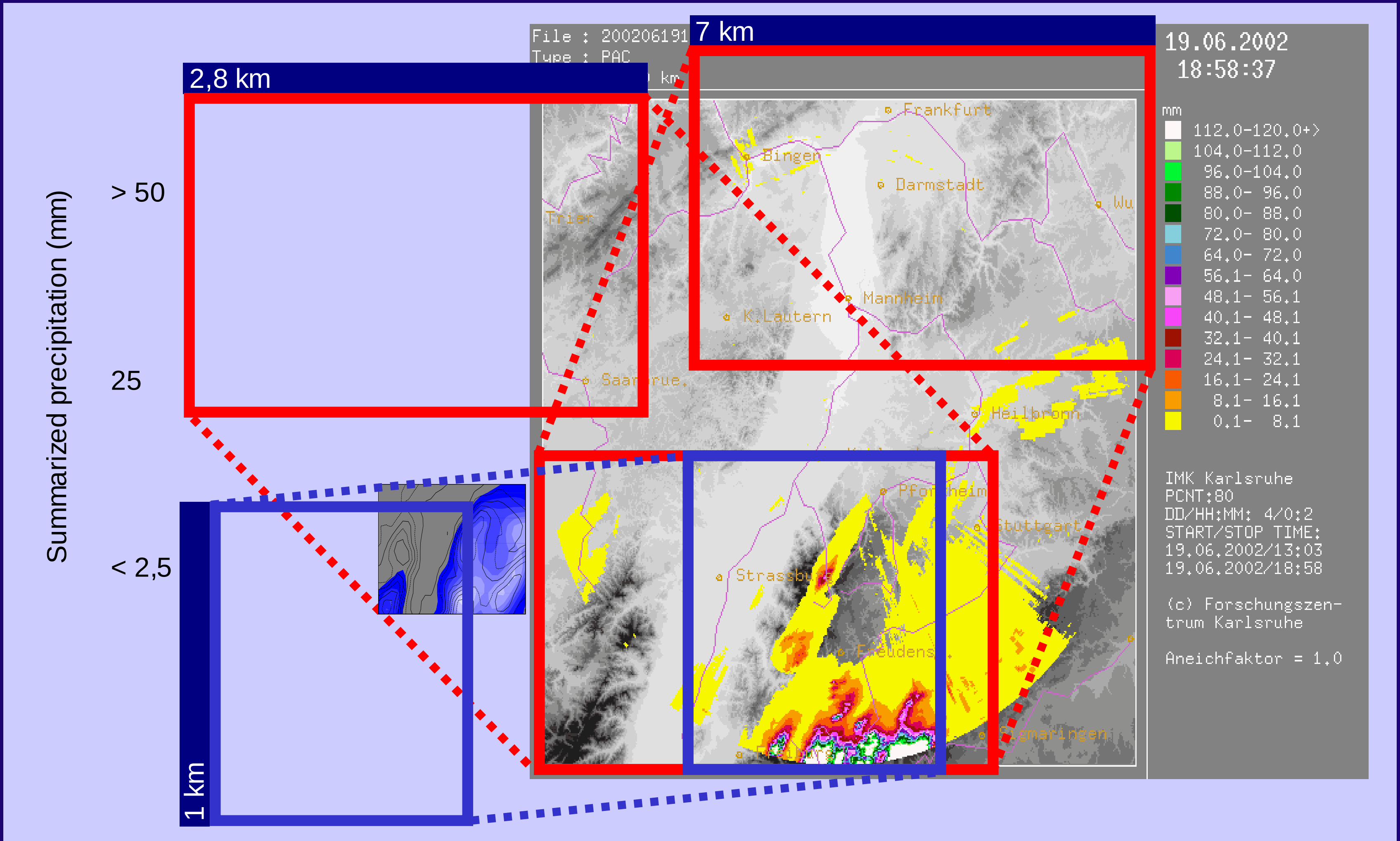






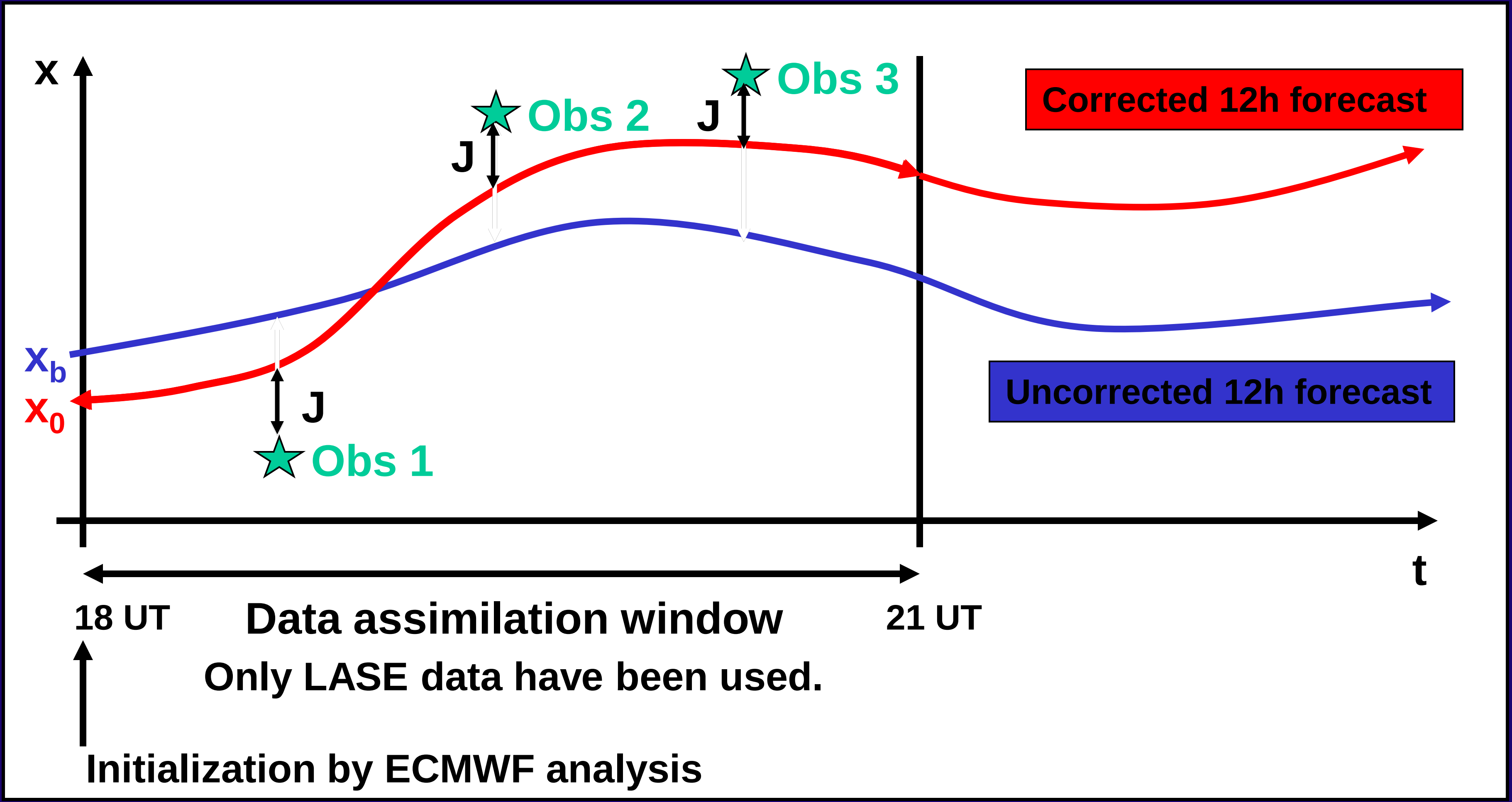


DWD Klimastatusbericht 2001



Lokal-Modell (LM) at different resolutions (Braun et al. 2003)

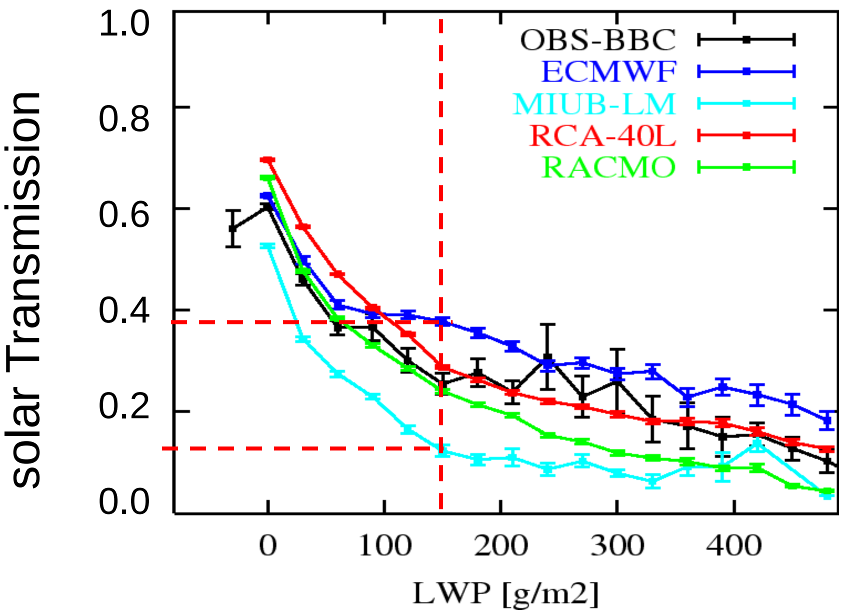
4-D variational data assimilation (4DVAR)



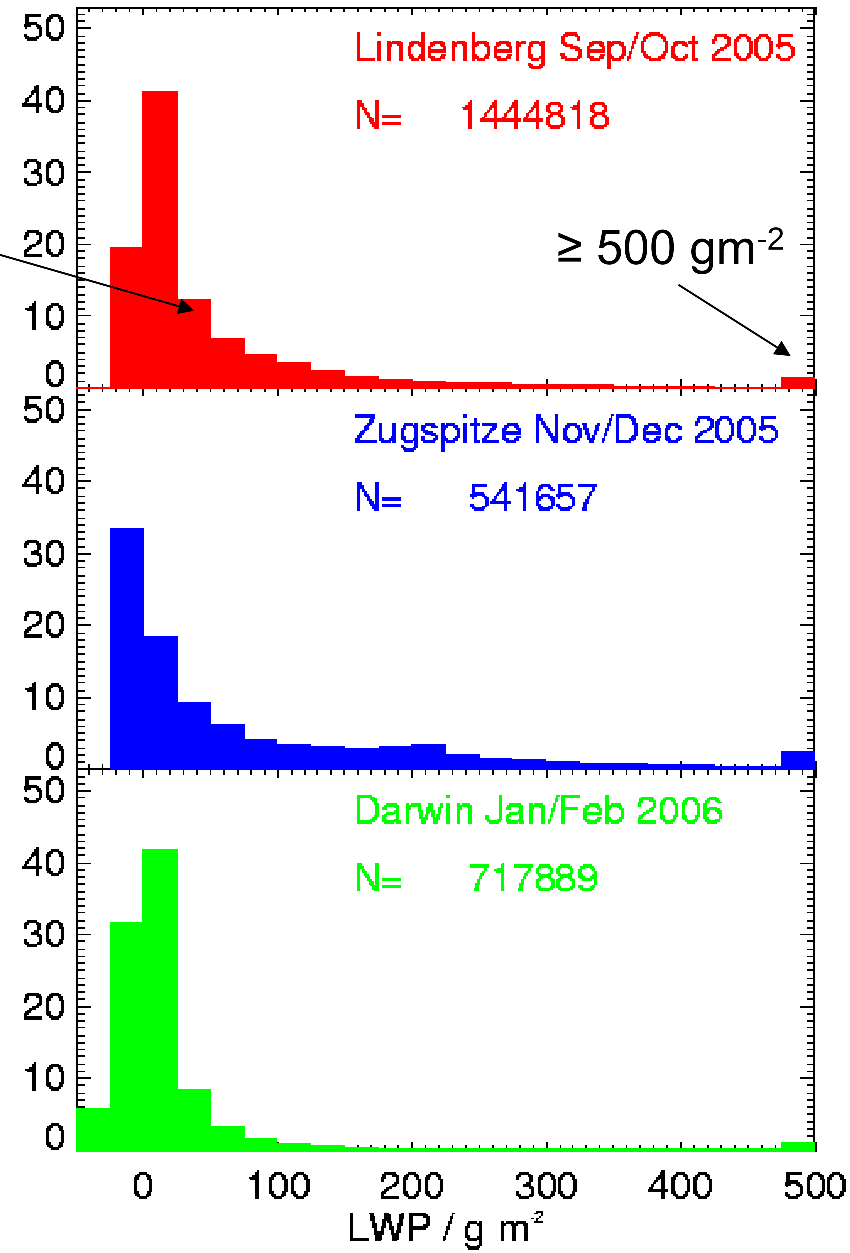
4DVAR optimally uses the information content of lidar data.

Climatologies

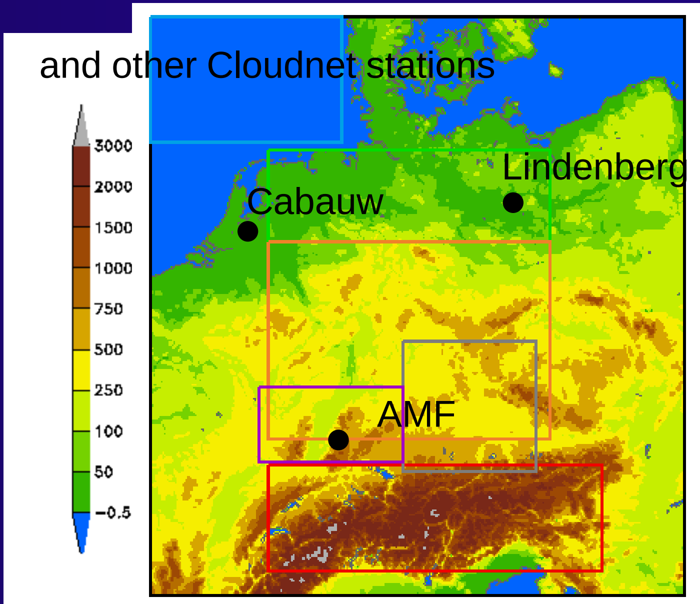
low LWP < 100 gm^{-2} very important for "cloud forcing"

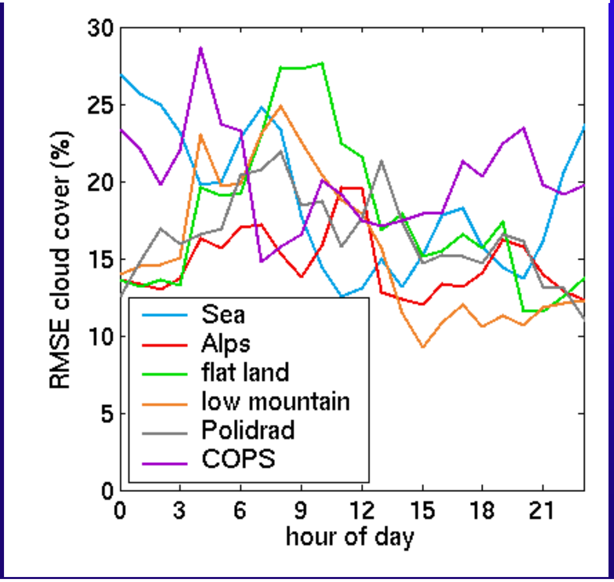


van Meijgaard [2004]



Microphysical properties of clouds





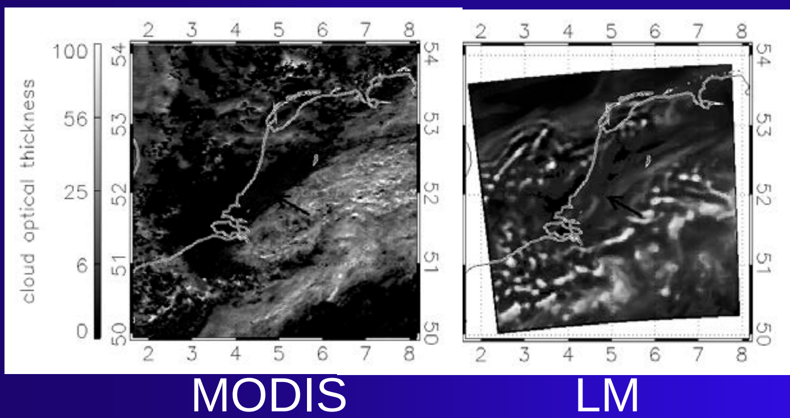
Meteosat Second Generation Comparison: July 2004

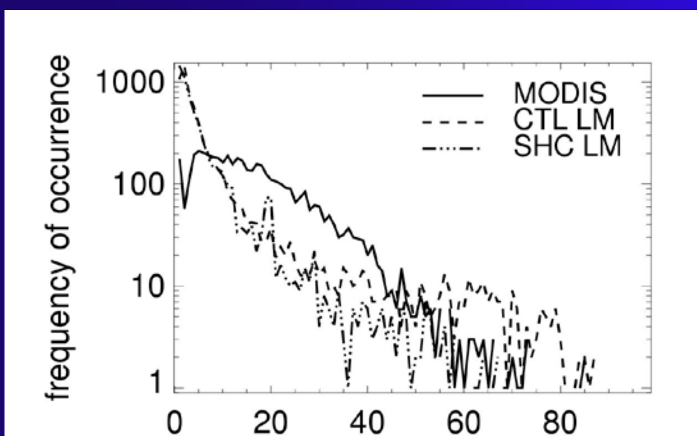
Cloud cover (%) LMK00 / LMK12	BIAS (%)	STD (%)	Correlation
LMK total	8 / 5	9 / 9	0.80 / 0.80
Sea	**9 / 8**	17 / 17	0.72 / 0.70
Alps	6 / 2	14 / 15	0.78 / 0.81
Flat land	**9 / 7**	17 / 17	0.68 / 0.70
Low mountain	7 / 5	15 / 16	0.68 / 0.67
Poldirad domain	5 / 2	17 / 17	0.72 / 0.75
COPS domain	4 / 0	**22 / 20**	**0.49 / 0.61**

- separate weather regimes
- cross correlation of radiation/cloud/precip
- compare different Cloudnet station statistics
- investigate representativity of colum for model gridbox

Model evaluation

Horizontal structure

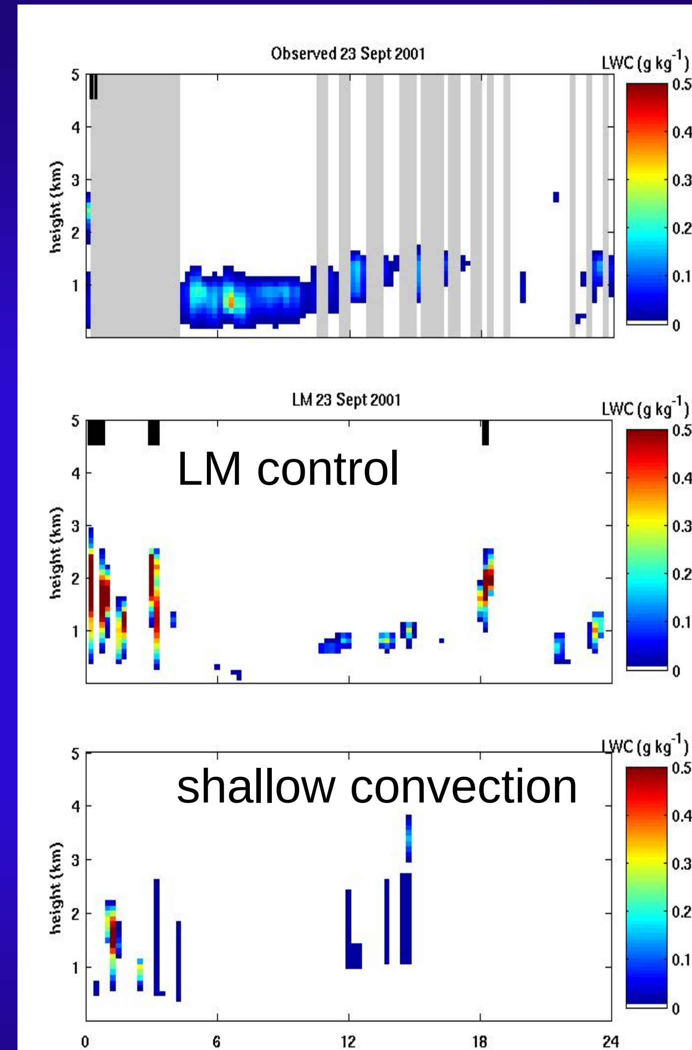




Schroeder et al. [2006]

- refine cloud pattern decriptors
- cross correlate different variables (precip./cloud/vapor)
- test 3D-turbulence & new shallow convection param.

Vertical structure

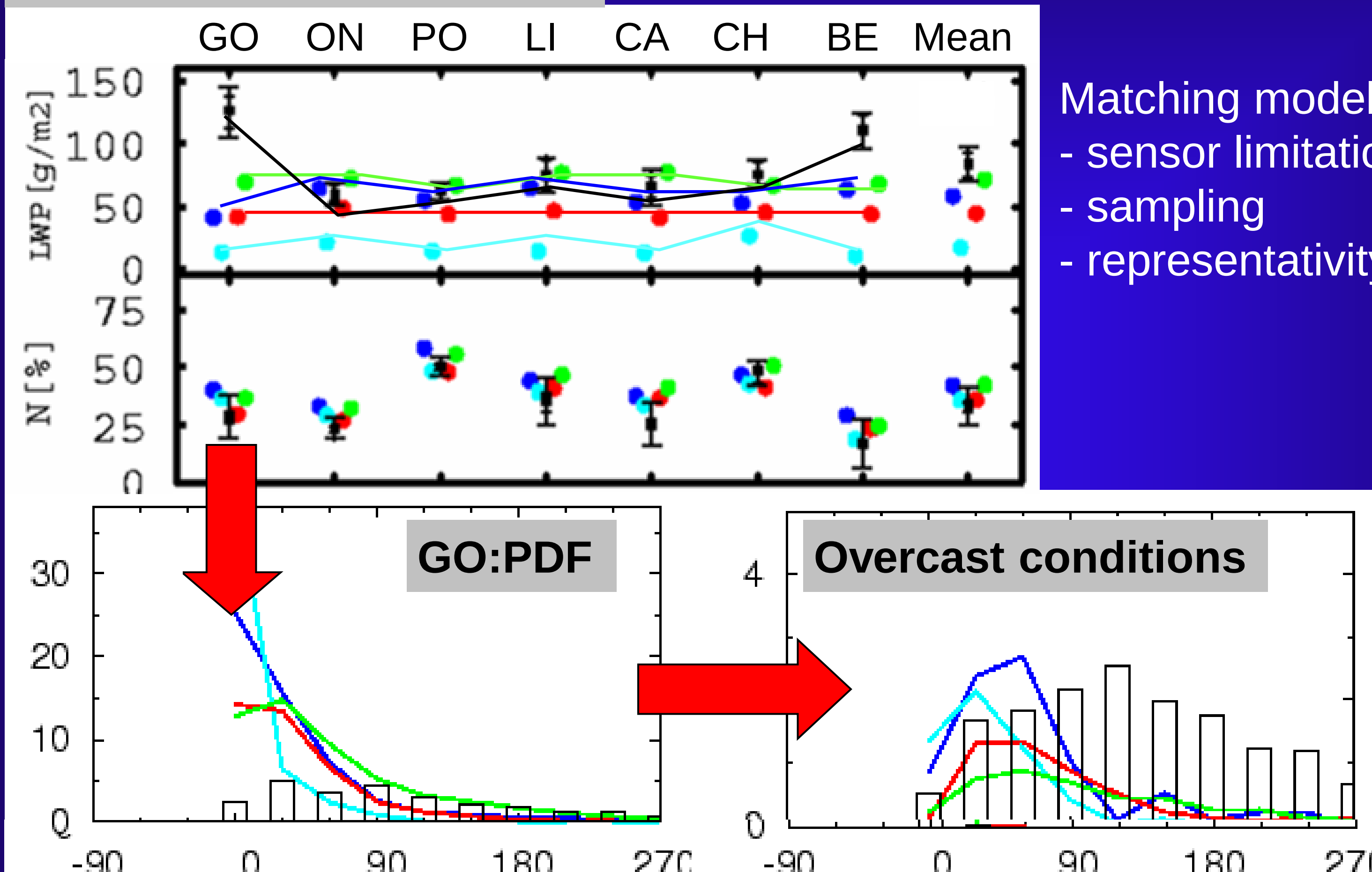


van Lipzig et al. [2006]

Identification of model deficits

Example based on long-term observations at 7 stations from Gotland (GO) to Bern (BE)

Mean liquid water path



Matching model and observations:
- sensor limitations
- sampling
- representativity

OBS
ECMWF
LM
RCA
RACMO

Meijgaard, E. van, and S. Crewell, 2005: Comparison of model predicted liquid water path with ground-based measurements during CLIWA-NET, *Atmos. Res*., 75(3), 2005.

Representativity of Observations

Typically a constant advection velocity is assumed and column observations are averaged over a certain time to match model resolution

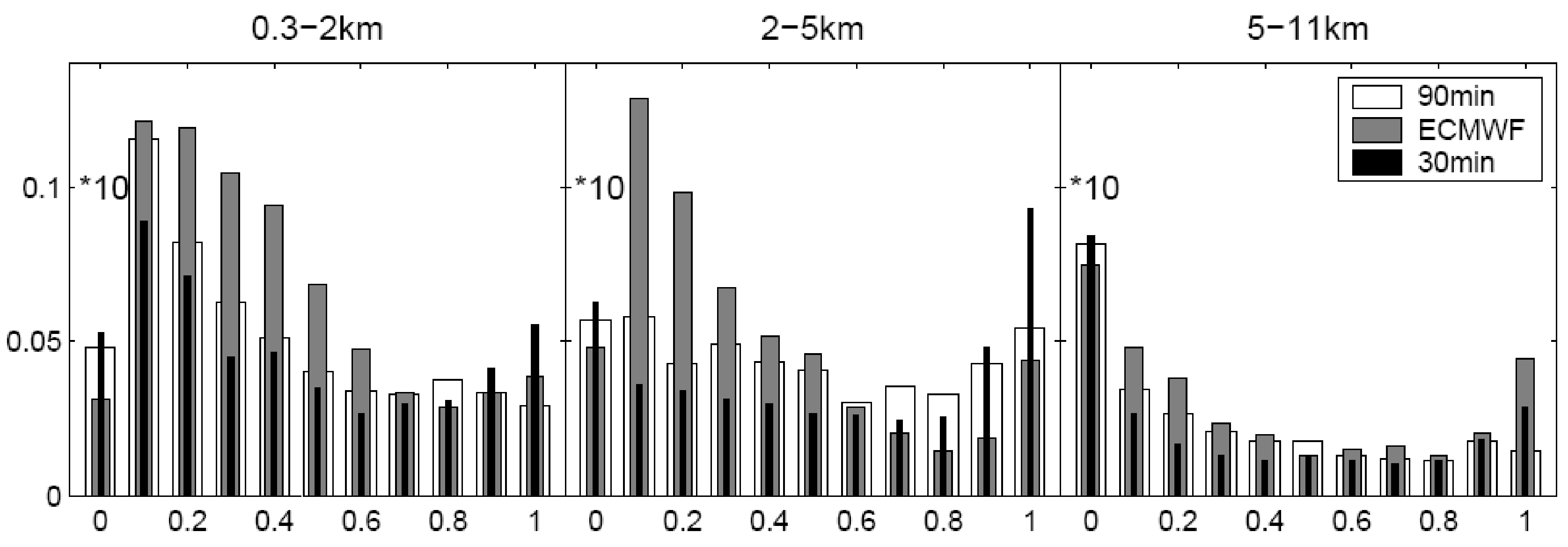


Figure 3: Frequency distribution of the cloud fraction for ECMWF, with the corresponding radar observations for low, mid and high clouds. The model distribution (grey bars) are compared to the observations averaged according to their minimum (white bars) and maximum (black columns) advective time scales. The first group of bars, the clear-sky values should be multiplied by 10.

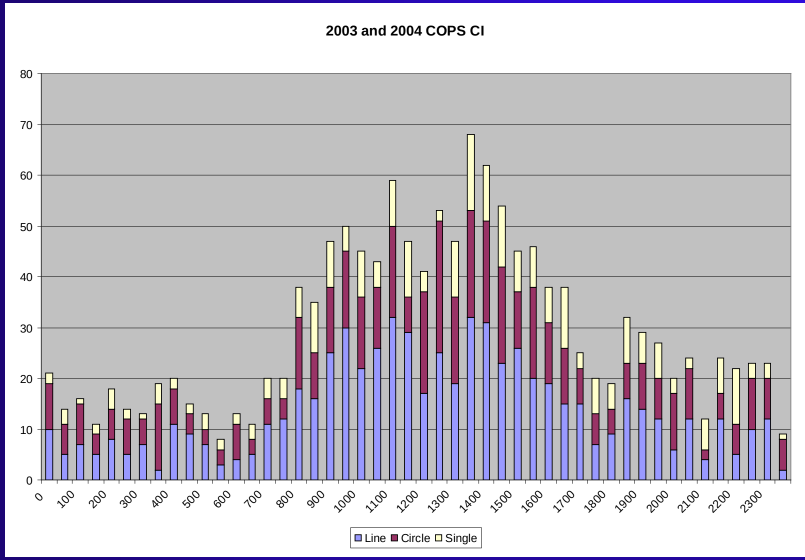
➡ **need to describe sub-grid variability and anisotropy**

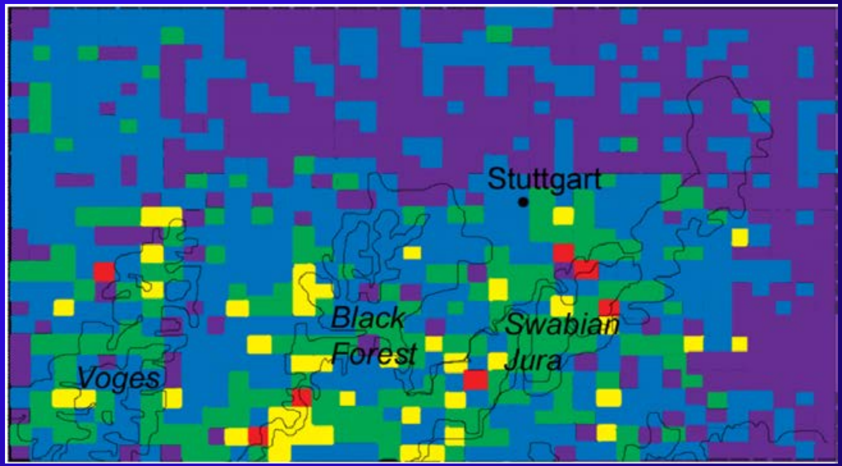
Willen, U. and S. Crewell, 2004: Comparison of model and radar derived cloud vertical structure and overlap, 14th International Conference on Clouds and Precipitation (ICCP), Bologna, Italy, 18 to 23 July 2004

Weather Characteristics of COPS Region

Events with large amounts of precipitation are mainly

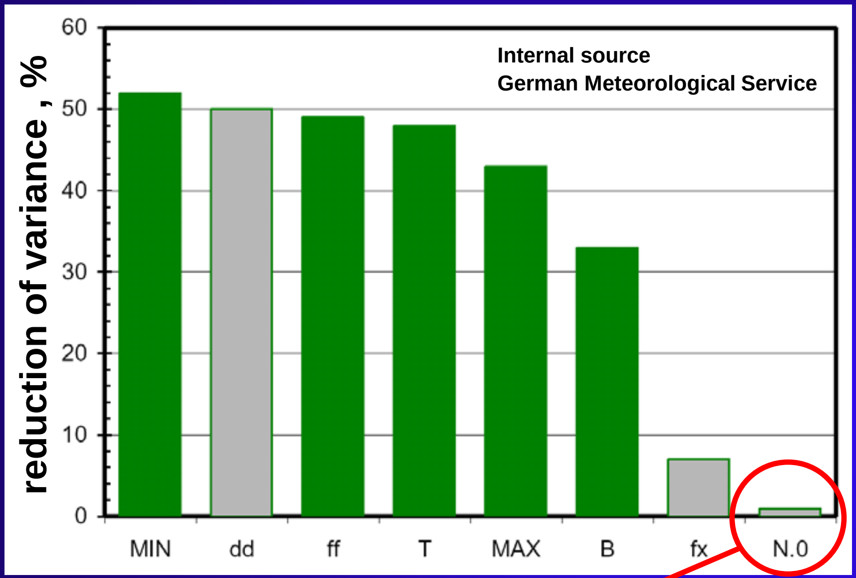
- **forced/frontal: Convection imbedded in frontal line**
- **forced/non-frontal: synoptic-scale ascent, but no surface front**
- **air mass convection (non-forced/non-frontal)**

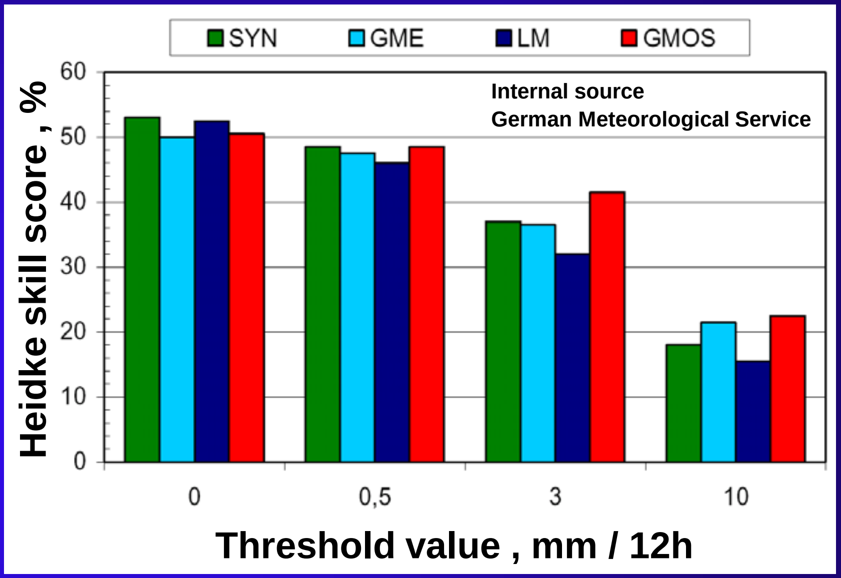




Convection initiation climatology in the COPS domain. Left panel: Diurnal variation. Blue indicates linearly-organized convection; maroon is cluster form organization and yellow is single-cell initiation. Local noon is at ~12:35 UTC. Right panel: Initiation distribution. Purple is 0-3; blue is 4-7; green is 8-11; yellow is 12-15 and red is 16-20 CI events. The black lines indicate topography.

Reduction of variance and forecast skill in Quantitative Precipitation Forecast (QPF)

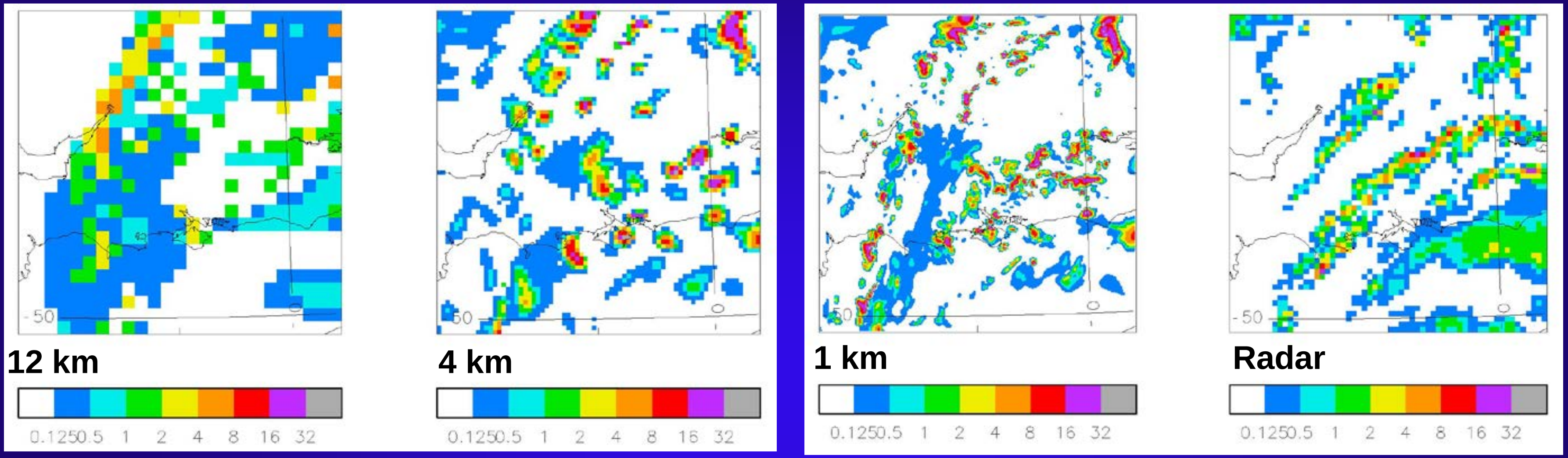




No improvement in the prediction of precipitation during the last 16 years.

Models perform worse with increasing amount of precipitation.

UK Met Office high-resolution modeling trial runs for 2004 cases. Example: August 20, 2004

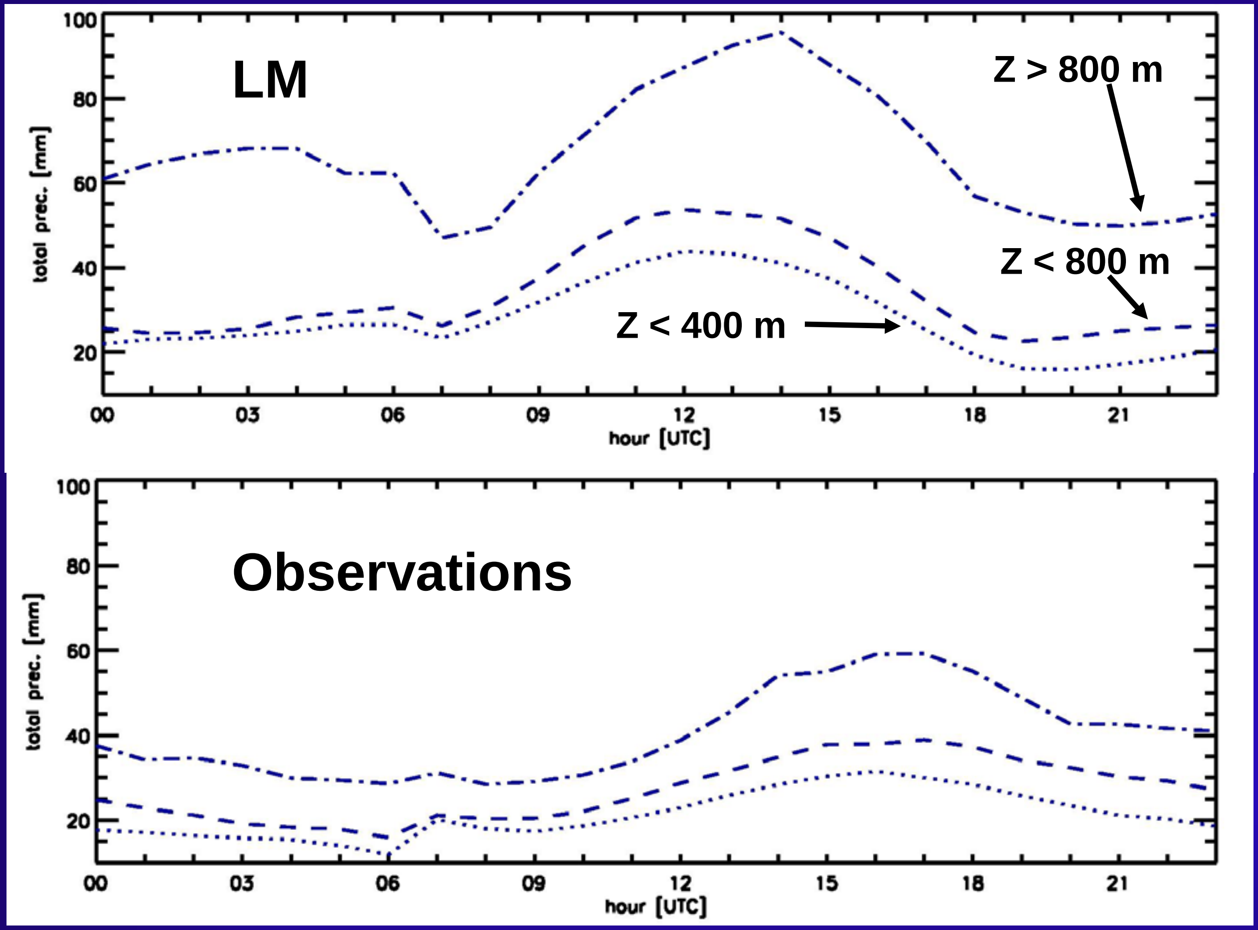


Lean et al. 2005: UK Met Office / University of Reading Technical Report No. 466

- Evidence of better spatial and temporal distribution of precipitation in high-resolution runs
- Significant overprediction most likely due to deficiencies in the data assimilation system and model physics.

Increase of resolution and shutdown of convection parameterization do *not* necessarily improve model performance.

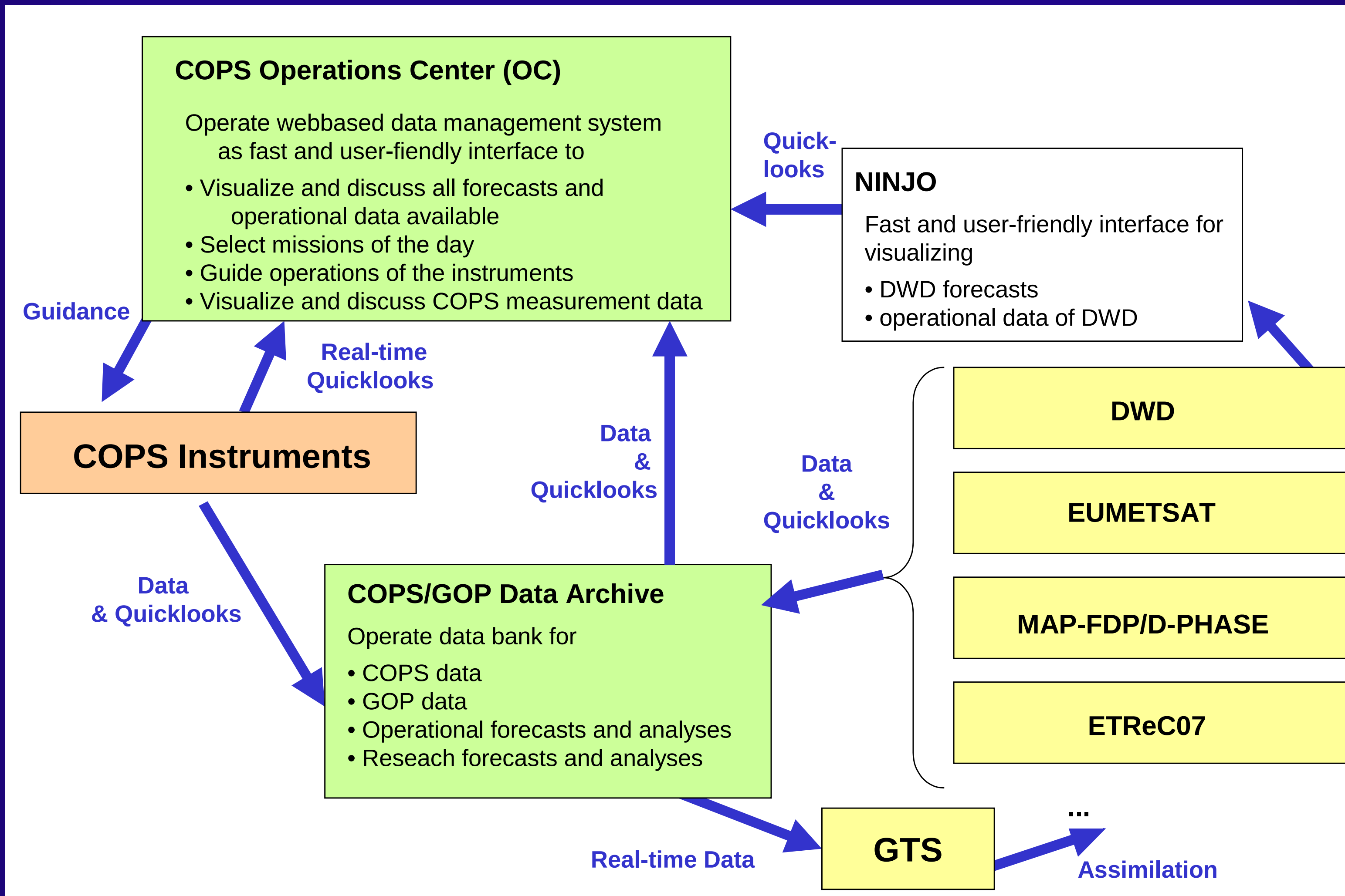
Diurnal cycles of precipitation in JJA averaged between 2001-2003 in Germany: Observations versus LM



Courtesy of Marcus Paulat, Uni Mainz, PQP VERIPREG Project

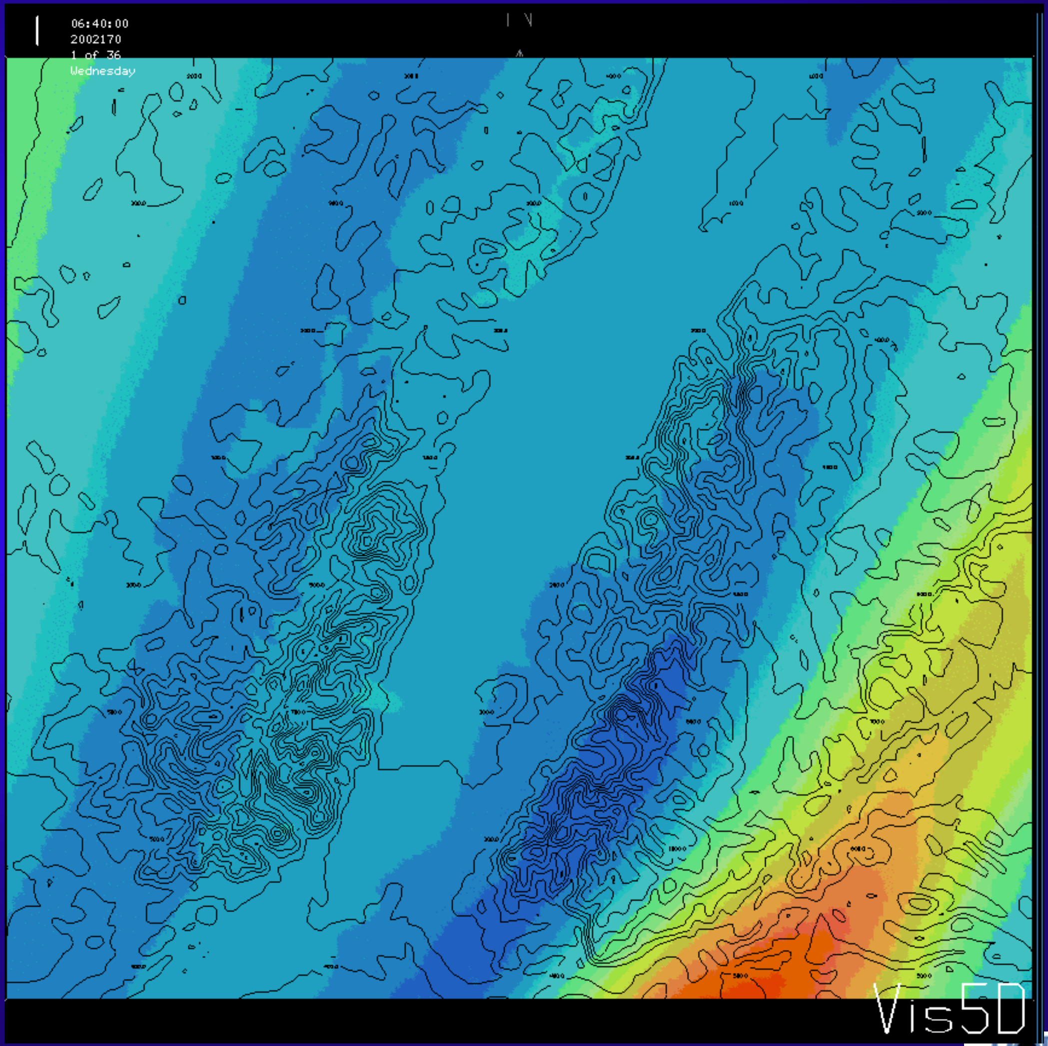
Phase errors in diurnal cycle of precipitation are evident, which are also visible in boundary layer variables.

COPS/GOP Performance and Data Archiving



COPS Preparation

Example: MM5 high-resolution modeling study of June 19, 2002 (6-18 UTC)



Water-vapor mixing ratio and cloud field at 6 km in region of large-scale upper-level trough.

PQP Praecipitationis Quantitativae Praedictio

COPS Preparation

Example: MM5 high-resolution modeling study of June 19, 2002 (6-18 UTC)

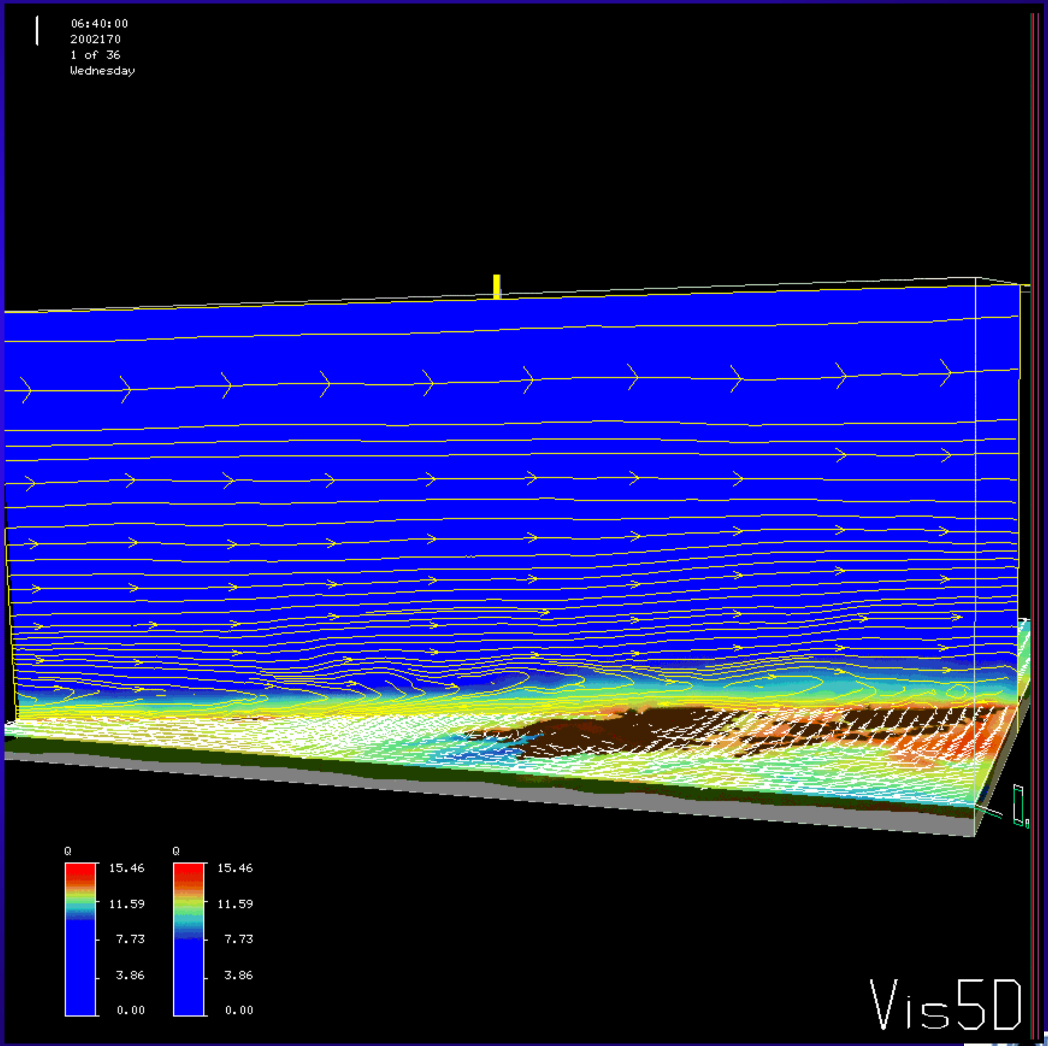
Phase 1: Pre-convection

Phase 2: Convection initation, cloud formation considering aerosol-cloud interaction

Phase 3: Development of convection, onset of precipitation

Phase 4: Maintenance and decay of precipitating system

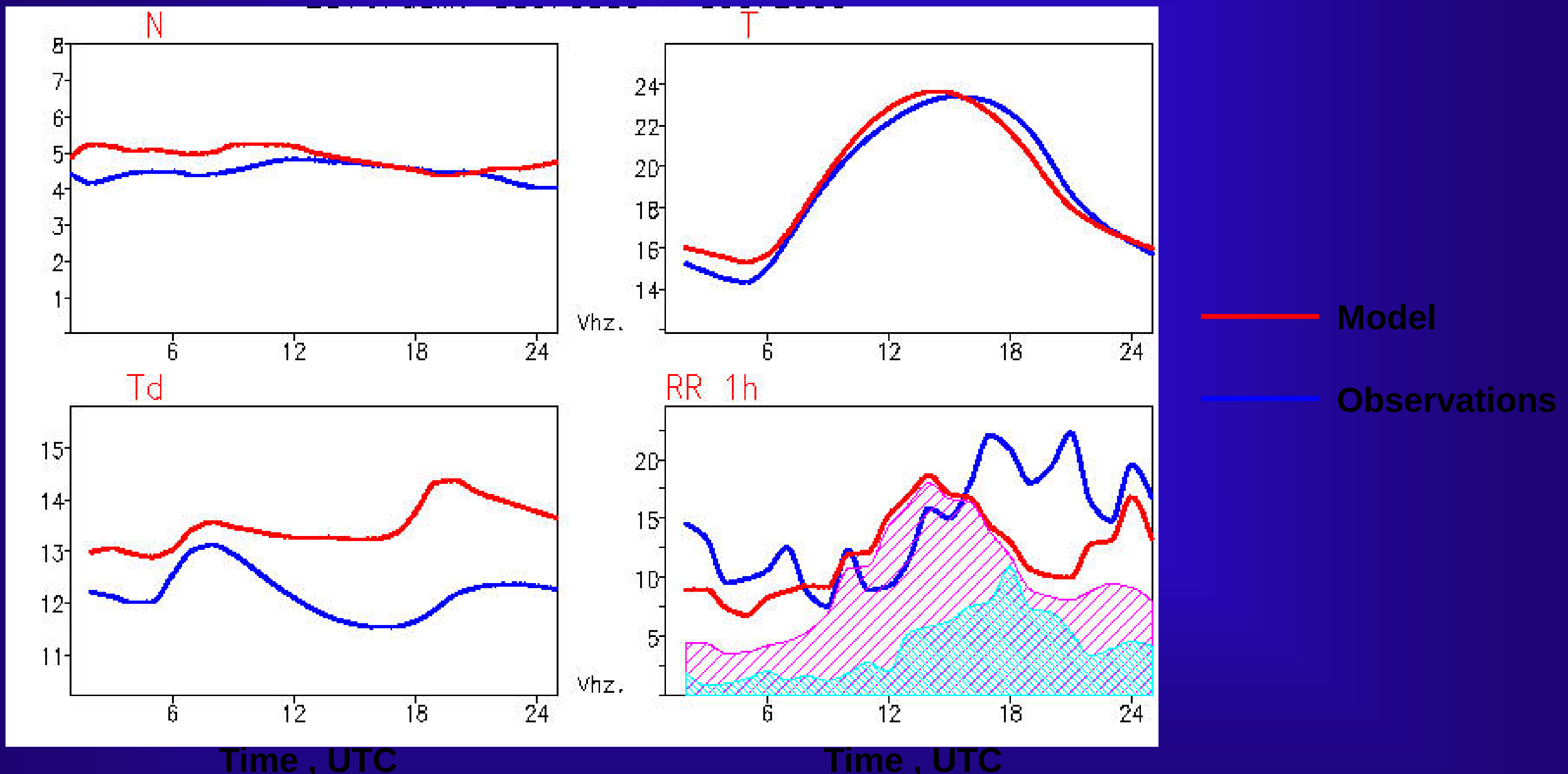
Simultaneous large-scale and small-scale synergetic 4D observations of key variables.



Boundary layer water-vapor mixing ratio, wind, cloud, and precipitation fields.

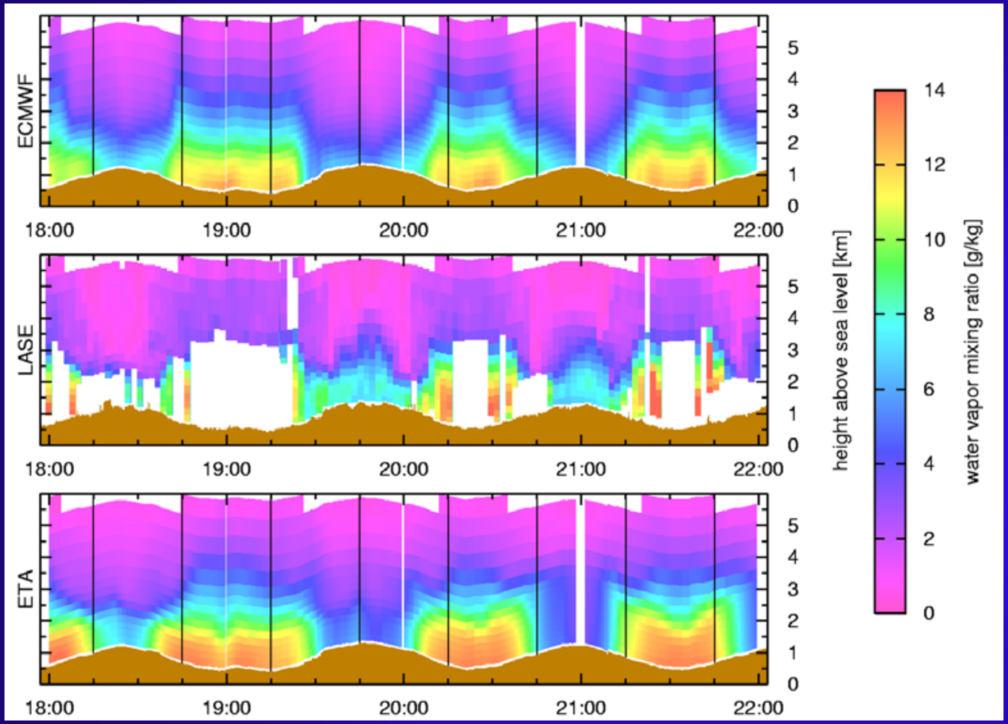
The phase error in the diurnal cycle of precipitation: A key problem in quantitative precipitation forecasting

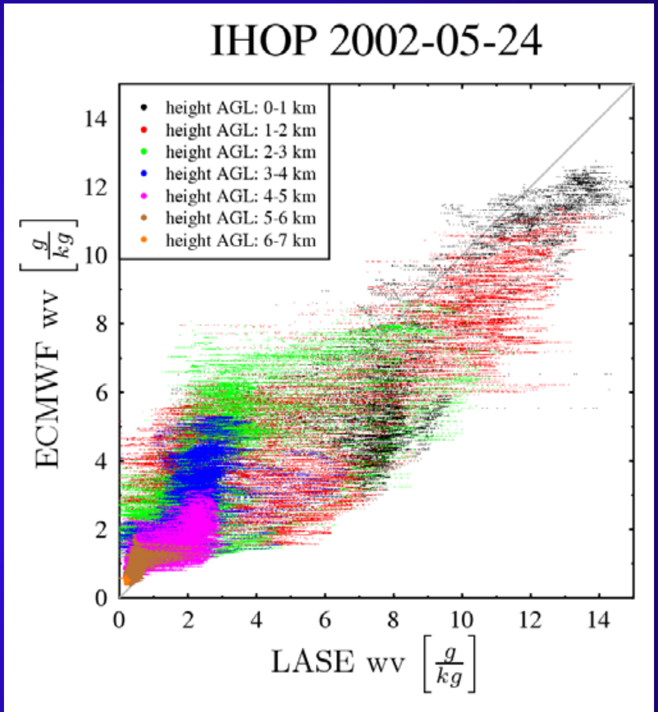
Diurnal cycle of precipitation averaged between 03.07.-29.07.2003 and 6.5-15E, 47.3-54N using the Lokalmodell (LM) of the German Meteorological Service (DWD)



Courtesy of U. Damrath, DWD, Bechthold et al. QJRMS 2004, among others

ECMWF and ETA initial conditions investigated by airborne water vapor differential absorption lidar (NASA LASE) during IHOP_2002





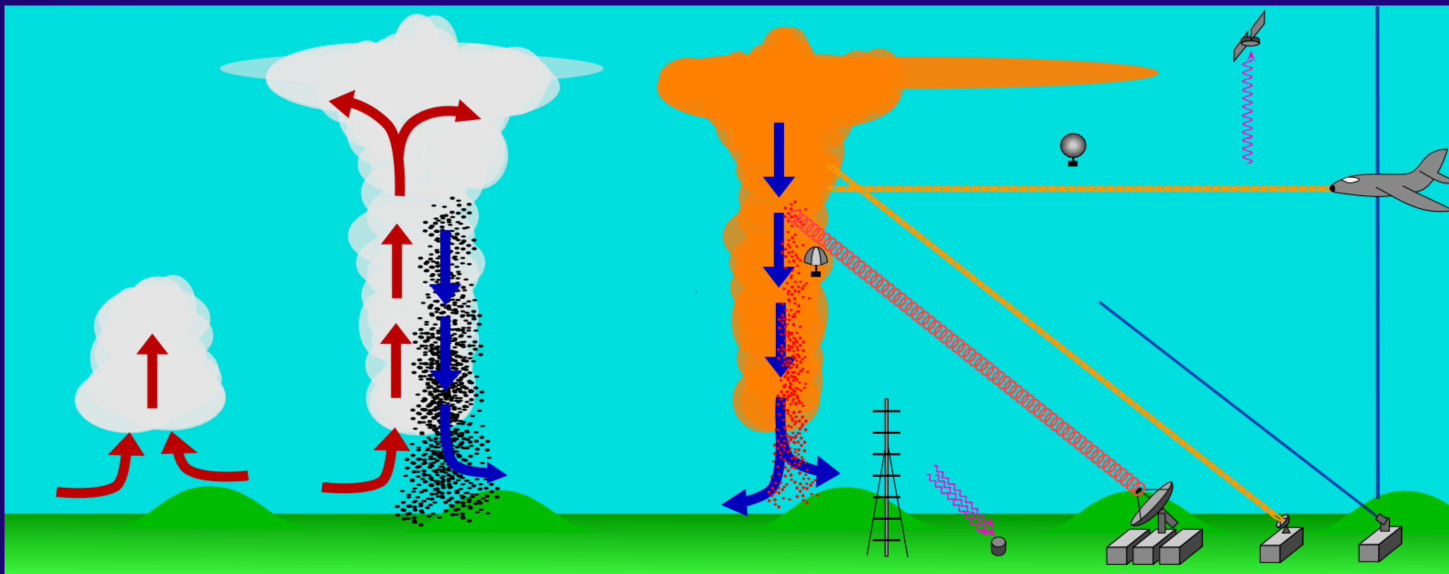
Wulfmeyer et al., MWR, Jan. 2006

Significant errors in ECMWF and ETA initial water-vapor fields detected.

Models operated during COPS and D-PHASE

	Model	Mesh-size	Forecast range	Institution
Ensemble prediction systems	COSMO-LEPS	10 km	132h	ARPA-SIM, DLR
	MOGREPS	25 km	36h	UK Met Office
	GEM-LAM	10 km	48h	Environment Canada
	PEPS	7 km	48h	EUMETNET SRNWP
Deterministic high-resolution models	aLMo	2-3 km	18h	MeteoSwiss
	LAMI	2.8 km	48h	ARPA-SIM
	LAMI	7 km	48h	ARPA-SIM
	LAMI-CNMCA	3 km	48h	UGM-CNMCA
	MOLOCH	2 km	24-36h	ISAC-CNR, ARPAL-CMIRL
	MM5 and WRF	1 km	36h	University of l'Aquila-CETEMPS
	QBOLAM	10 km	48h	APAT
	AROME	2.5 km	48h	Météo-France, University Paul Sabatier
	LMK	2.8 km	18h	DWD
	MM5 and/or WRF	1 km	12-24h	University of Hohenheim
	ALADIN-Austria	9.6 km	48h	ZAMG
	GEM-LAM	2.5 km	24h	Environment Canada

Proposed synergy of observing systems



Precipitation radars

X-, C- or S-band,
$\lambda \approx$ 3–10 cm, $\nu \approx$ 10–3 GHz,
⇨ Reflectivity, velocity, refractivity, precip, clouds

Cloud radars

Ka- or W-band
$\lambda \approx$ 3–9 mm, $\nu \approx$ 100–35 GHz
⇨ near-range reflectivity, velocity in clouds, depol. δ

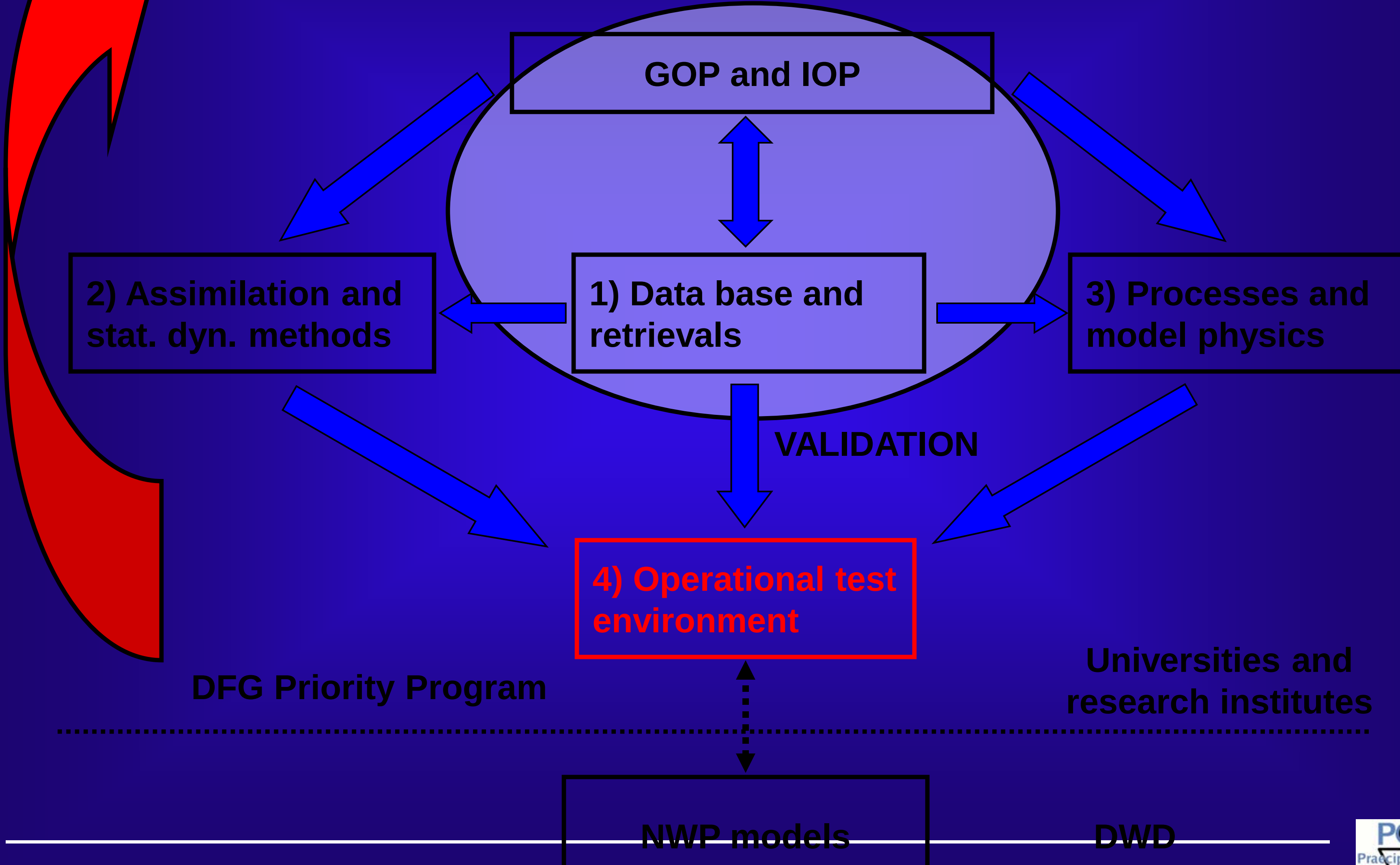
Lidars

$\lambda \approx$ 0.3–2 μm, $\nu \approx 10^{15}$–1.5×10^{14} Hz
⇨ α_{par}, β_{par}, depol. δ, q, T, velocity in clear air, aerosols and thin clouds

Microwave and FTIR radiometers

⇨ LWC, q, T, ...

The full potential of synergetic measurements is not explored yet, e.g.:
- LWC, IWC, R_{eff} in clouds using microwave radiometer, lidar and cloud radar (Donovan et al. 2001, Feingold et al. 1997, Löhnert et al 2004, Cloudnet and COST 720 algorithms)


GOP and IOP
1) Data base and retrievals
2) Assimilation and stat. dyn. methods
3) Processes and model physics
VALIDATION
4) Operational test environment
DFG Priority Program
Universities and research institutes
NWP models
DWD