Precipitation amount in August 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.

German Meteorological Service (DWD), Klimastatusbericht 2002
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

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
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/

- **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

---

<table>
<thead>
<tr>
<th>Year</th>
<th>GOP</th>
<th>IOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Phase 1: Preparation</td>
</tr>
<tr>
<td>2</td>
<td>One year</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Phase 2: Performance: Summer 2007</td>
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<tr>
<td>4</td>
<td></td>
<td>Phase 3: Data analysis</td>
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<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
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</tr>
</tbody>
</table>

**GOP:** General Observations Period  
**IOP:** Intensive Observations Period → COPS
LM/LMK performance in January 2004 with prognostic precipitation

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

Courtesy of U. Damrath, DWD
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

**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/](http://www.uni-hohenheim.de/spp-iop/)

COPS „Natural convection laboratory“
Suggested area (270 x 150 km²)

Supersite
International collaboration: European Summer Experiments 2007

- European Summer Experiments 2007
- Region of COPS, accepted as WWRP Research and Development Project (RDP)
- D-PHASE, WWRP Forecast and Demonstration Project (FDP)
- Transport and Chemistry in Convective Systems (TRACKS) region
- European THORPEX Regional Campaign 2007 (ETReC07)
- General Observations Period (GOP) region, duration: 1 year in 2007
- SFB 641 Tropospheric Ice Phase
- EUMETSAT special satellite operation modes and data
- Atmospheric Radiation Measurement (ARM) Program Mobile Facility (AMF)
Investigation of differences in precipitation microphysics between flat and orographically structured terrain

- 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)

GOP organization and performance

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

Micro rain radars and disdrometer
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 ISSC → Science Overview Document → Operations Plan

Convection Initiation (CI) ← Aerosol and Cloud Microphysics (ACM) ← Precipitation and its Life Cycle (PPL) ← Data Assimilation and Predictability (DAP)

COPS Coordinator:
Operations Logistics
Mission planning
Model preparation
Data archiving

General Observations Period (GOP)

Education at Universities and Schools
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 initiation, 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.
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

UHOH WV DIAL
UHOH RRL
Windtracer
UHOH X-band

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

+ 14 channel scanning microwave radiometer HATPRO (LMU)
+ 90/150 GHz radiometer (LMU)
+ Online implementation for Integrated Profiling Technique (IPT)
  Löhner et al. 2004 & COST 720:
  - Profiles for T and q, LWP, IWV, $r_{\text{eff}}$
  - 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)
LMU Humidity and Atmospheric Profiler (HATPRO)

- 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

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

March 30, 2006 16th ARM Science Team Meeting, Albuquerque, NM, USA
FZK scanning 36-GHz polarization, Doppler cloud radar

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

![Image of radar equipment]

March 30, 2006 16th ARM Science Team Meeting, Albuquerque, NM, USA
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
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 in regions with significant orography.
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 postprocessing, 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

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Christoph Kottmeier, IMK, Karlsruhe, Germany, Co-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

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

Courtesy of U. Damrath, DWD, Bechthold et al. QJRMS 2004, among others
**Hypothesis:** Windward/Lee problem due to inadequate convection parameterization

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
Coordination of WWRP Projects

Phase 1
- April 2004
- April 2005
- April 2006

Phase 2
- April 2007
- April 2008
- April 2009
- April 2010

Phase 3
- April 2009
- April 2010

Projects:
- THORPEX ERC
- WWRP SSC
- COPS
- GOP
- ETReC07
- MAP FDP
- MEDEX
- TIGGE
- B08 FDP, Vancouver 2010 FDP
- Data archive, MPIfM Hamburg
- MAP and IHOP_2002 experiences
Proposed synergy of observing systems

Precipitation radars

X-, C- or S-band,
\( \lambda \approx 3–10 \text{ cm, } \nu \approx 10–3 \text{ GHz,} \)
\( \Rightarrow \) Reflectivity, velocity, refractivity, precip, clouds

Cloud radars

Ka- or W-band
\( \lambda \approx 3–9 \text{ mm, } \nu \approx 100–35 \text{ GHz} \)
\( \Rightarrow \) near-range reflectivity, velocity in clouds, depol. \( \delta \)

Lidars

\( \lambda \approx 0.3–2 \text{ \( \mu \)m, } \nu \approx 10^{15}–1.5 \times 10^{14} \text{ Hz} \)
\( \Rightarrow \alpha_{\text{par}}, \beta_{\text{par}}, \text{ depol. } \delta, q, T, \)
velocity in clear air, aerosols and thin clouds

Microwave and FTIR radiometers

\( \Rightarrow \) LWC, q, T, ...

The full potential of synergetic measurements is not explored yet, e.g.:
- \( R_{\text{eff}} \) 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

Training of ensemble

Verification of ensemble forecasts

Production of mesoscale ensemble prediction system
Precipitation in Germany

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

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

Frühling

Sommer

Herbst

Winter

Jahr

DWD Klimastatusbericht 2001
Lokal-Modell (LM) at different resolutions (Braun et al. 2003)
4-D variational data assimilation (4DVAR)

Cost function

\[ J = \sum (x - x_b)^T (x_b - x) + \sum (y - Hx)^T R^{-1} (y - Hx) \]

State vector

\( x \)

Background field vector

\( x_b \)

Background error covariance matrix

\( R \)

Observations

\( y \)

Forward operator

\( H \)

Observation error covariance matrix

\( R \)

Initialization by ECMWF analysis

Only LASE data have been used.

18 UT Data assimilation window 21 UT

4DVAR optimally uses the information content of lidar data.

Uncorrected 12h forecast

Corrected 12h forecast

Initialization by ECMWF analysis

4DVAR optimally uses the information content of lidar data.
low LWP < 100 gm$^{-2}$
very important for "cloud forcing"

van Meijgaard [2004]

Climatologies
Microphysical properties of clouds

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

Meteosat Second Generation Comparison: July 2004

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

RMSE cloud cover (%)

0 3 6 9 12 15 18 21
0 5 10 15 20 25 30

Sea, Alps, flat land, low mountain, Poldirad, COPS
Model evaluation

Horizontal structure

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

Vertical structure

- LM control

van Lipzig et al. [2006]

Schroeder 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

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.
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.

Lean et al. 2005: UK Met Office / University of Reading Technical Report No. 466
Diurnal cycles of precipitation in JJA averaged between 2001-2003 in Germany: Observations versus LM

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

Courtesy of Marcus Paulat, Uni Mainz, PQP VERIPREG Project
COPS/GOP Performance and Data Archiving

COPS Operations Center (OC)
Operate webbased data management system as fast and user-friendly interface to
• Visualize and discuss all forecasts and operational data available
• Select missions of the day
• Guide operations of the instruments
• Visualize and discuss COPS measurement data

NINJO
Fast and user-friendly interface for visualizing
• DWD forecasts
• operational data of DWD

COPS Instruments

COPS/GOP Data Archive
Operate data bank for
• COPS data
• GOP data
• Operational forecasts and analyses
• Research forecasts and analyses

DWD
EUMETSAT
MAP-FDP/D-PHASE
ETReC07
GTS

March 30, 2006 16th ARM Science Team Meeting, Albuquerque, NM, USA
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.
COPS Preparation

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

Phase 1: Pre-convection
Phase 2: Convection initiation, 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)

Time, UTC

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)

- **N**: Model
- **T**: Observations
- **Td**: Model
- **RR 1h**: Observations

Time, UTC
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

<table>
<thead>
<tr>
<th>Model</th>
<th>Mesh-size</th>
<th>Forecast range</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ensemble prediction systems</strong></td>
<td></td>
<td></td>
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<tr>
<td>COSMO-LEPS</td>
<td>10 km</td>
<td>132h</td>
<td>ARPA-SIM, DLR</td>
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<tr>
<td>MOGREPS</td>
<td>25 km</td>
<td>36h</td>
<td>UK Met Office</td>
</tr>
<tr>
<td>GEM-LAM</td>
<td>10 km</td>
<td>48h</td>
<td>Environment Canada</td>
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<tr>
<td>PEPS</td>
<td>7 km</td>
<td>48h</td>
<td>EUMETNET SRNWP</td>
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<td><strong>Deterministic high-resolution models</strong></td>
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</tr>
<tr>
<td>aLMo</td>
<td>2-3 km</td>
<td>18h</td>
<td>MeteoSwiss</td>
</tr>
<tr>
<td>LAMI</td>
<td>2.8 km</td>
<td>48h</td>
<td>ARPA-SIM</td>
</tr>
<tr>
<td>LAMI</td>
<td>7 km</td>
<td>48h</td>
<td>ARPA-SIM</td>
</tr>
<tr>
<td>LAMI-CNMCA</td>
<td>3 km</td>
<td>48h</td>
<td>UGM-CNMCA</td>
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<tr>
<td>MOLOCH</td>
<td>2 km</td>
<td>24-36h</td>
<td>ISAC-CNR, ARPAL-CMIRL</td>
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<tr>
<td>MM5 and WRF</td>
<td>1 km</td>
<td>36h</td>
<td>University of l’Aquila-CETEMPS</td>
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<tr>
<td>QBOLAM</td>
<td>10 km</td>
<td>48h</td>
<td>APAT</td>
</tr>
<tr>
<td>AROME</td>
<td>2.5 km</td>
<td>48h</td>
<td>Météo-France, University Paul Sabatier</td>
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<tr>
<td>LMK</td>
<td>2.8 km</td>
<td>18h</td>
<td>DWD</td>
</tr>
<tr>
<td>MM5 and/or WRF</td>
<td>1 km</td>
<td>12-24h</td>
<td>University of Hohenheim</td>
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<td>ALADIN-Austria</td>
<td>9.6 km</td>
<td>48h</td>
<td>ZAMG</td>
</tr>
<tr>
<td>GEM-LAM</td>
<td>2.5 km</td>
<td>24h</td>
<td>Environment Canada</td>
</tr>
</tbody>
</table>
The full potential of synergetic measurements is not explored yet, e.g.:
- LWC, IWC, $R_{\text{eff}}$ in clouds using microwave radiometer, lidar and cloud radar (Donovan et al. 2001, Feingold et al. 1997, Löhner et al. 2004, Cloudnet and COST 720 algorithms)

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. $\delta$

**Lidars**

- $\lambda \approx 0.3$–2 µm, $\nu \approx 10^{15}$–1.5×10^{14} Hz
  - $\alpha_{\text{par}}, \beta_{\text{par}},$ depol. $\delta,$ q, T,
  - velocity in clear air, aerosols and thin clouds

The full potential of synergetic measurements is not explored yet, e.g.:
- LWC, IWC, $R_{\text{eff}}$ in clouds using microwave radiometer, lidar and cloud radar (Donovan et al. 2001, Feingold et al. 1997, Löhner et al 2004, Cloudnet and COST 720 algorithms)
1) Data base and retrievals
2) Assimilation and stat. dyn. methods
3) Processes and model physics
4) Operational test environment

GOP and IOP

VALIDATION

DFG Priority Program

Universities and research institutes

NWP models

DWD