Ground-based Microwave Radiometry for

- investigating spatial variability
- towards sensor synergy

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The Challenge: Humidity variations

Small scale variations of water vapor and clouds

Water vapor mixing ratio [ig/kg] along S-SW (210°)—N-NE (30°) transect

30° scans
Δx = 5 km
at PBL height

Microwave radiometry measures thermal emission along slant path
Scanning in Different Spectral Regions

Azimuth scan at 30° elevation

Liquid water path (LWP) [gm⁻²]

Infrared TB anomaly [K]

Total Sky Imager

Microwave radiometry can reveal cloud water ➔ good matching of beams is required
Process Studies

- assessment of individual clouds
  ➔ dynamic component from Doppler wind lidar
- analysis of 3D radiation effects
Statistical information

Murg Valley aligned in north – south direction

Water vapor

- azimuth scans show maximum differences between individual directions up to \(4 \text{ kgm}^{-2}\)
- largest mean differences occur in north–south with \(-0.18 \text{ kgm}^{-2}\) and in east–south with \(-0.14 \text{ kgm}^{-2}\)

Liquid water path

- azimuth scans show more than \(20 \text{ gm}^{-2}\) higher LWP above hill crests
- not straightforward comparable to zenith observations

Mean LWP in \(\text{gm}^{-2}\)
Water Vapor Gradients

- airmass corrected integrated water vapor \( W \)

Linear horizontal gradient in water vapor density \( \rho_v \) in the direction of the gradient \( x \)

\[
\rho_{v_0}(x) = A_0 + A_1 x
\]

\[
\rho_v(x, z) = \begin{cases} 
\rho_v(x) & z \leq h \\
\rho_v(x) \cdot \exp\left(-\frac{z-h}{L}\right) & z > h 
\end{cases}
\]

- \( A_0 \) water vapor above site
- \( A_1 \) gradient strength
- \( h \) boundary layer height
- \( L \) scale height

Radiosonde profile
Water Vapor Gradients

The amplitude factor corresponds to the gradient distribution between PBL and free troposphere

\[ W_1 = A_1 \left( \frac{1}{2} h^2 + Lh + L^2 \right) \]

The offset of the cosine wave corresponds to the vertical column above the instrument site

\[ W_o = A_o (h + L) \]

\[
W = W_0 + W_1 \tan \theta \cos(\alpha + \varphi)
\]

The units for water vapor are kg m\(^{-2}\).

**Legend:**
- \( \alpha \) azimuth angle
- \( \theta \) zenith angle
- \( \varphi \) gradient direction
- \( A_1 \) gradient strength

• Crosses show gradient direction derived for individual elevation angles.
• Line gives direction obtained from fit to full volume data.
Linear Water Vapor Gradients

Model validation: 20 April 2009

COSMO
$\Delta x=400m$

6 UTC

12 UTC

16 UTC

HATPRO

Annika Schomburg, Christoph Selbach
Temporal development

problems of high-resolution modelling: correct description of boundary conditions and advection

COSMO with Δx=400m

scan variability
Towards Sensor Synergy

cloud radar distracts raven from MWR
**Integrated Profiling Technique (IPT)**

a 1DVar approach towards multi-instrument retrieval

Measurements = INPUT

- passive RS – measurement + error
- active RS – measurement + error
- in-situ measurement + error
- a priori information + error

Integration

- e.g. 1DVAR

OUTPUT

- atmospheric composition: temperature, humidity, hydrometeors + errors

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What about profiling of clouds?

Inclusion of higher MWR frequencies doubles information content.
How does radar help?

Ebell, K., U. Löhnert, S. Crewell, D. Turner, On characterizing the error in a remotely sensed liquid water content profile, Atmospheric Research, 98(1), 57-68. DOI:10.1016/j.atmosres.2010.06.002
Conclusions

- Microwave radiometer (MWR) can provides continuous spatial informations on column water vapour and cloud distribution
  - process studies
  - long-term statistics (site representativeness)

- Water vapour gradients can be automatically determined
  - advection often occurs in distinct jumps
  - investigate how residual WV field can be related to convective activity

- For model evaluation it is important to match observations and models not only in space and in time but also to mimic instruments
  - observation simulators

- Optimal estimation theory is a powerful tool to investigate information content
  - no liquid water profiles can be determined from MWR alone
  - cloud radar provides additional informations
Uncertainty implication for radiation

sensitivity of retrieval to additional microwave brightness temperatures
→ include 90 / 150 GHz channels

→ effect on LWP results: ± 20 gm⁻²
→ strong effect on solar flux: variations from -40 to +20 Wm⁻²
Volume scanning

IWV

θ = 57°

mean+/−std dev = 11.5+/−0.3

min, max, N = 11.1, 12.6, 326

θ = 76°

mean+/−std dev = 0.0+/−0.2

min, max, N = −0.6, 0.8, 326

LWP

09.09.2009 00:09:48 - 00:18:06 [dur=08:18]
Ideas and Questions for our Action

- many other promising instrument combinations
  - Radar + Lidar (e.g. Univ. of Reading)
  - MWR + Lidar (e.g. Univ. of Bern, IfT Leipzig)
  - IR + Lidar (??)
  ...

- Where do we need/want to go?
  - Identify combinations which are easy to handle & robust, bring forth straight-forward results and are relatively "cheap" → Network-suitability (WG1 & 4)
  - **Ceilometer, GPS, IRT, MWR combinations** …

  → Develop methods for dedicated "anchor stations" for a most complete picture of the atmospheric profile + errors (WG3 & 4)
  - **Lidar, FTIR, cloud radar, wind profiler combinations** …

- What are some of the pending problems?
  - calibration & instrumental error issues (WG1)
  - absorption model uncertainties!!! (which WG??)
  - radar discrepancy (WG4)