Cloud Observations from Ground and Space

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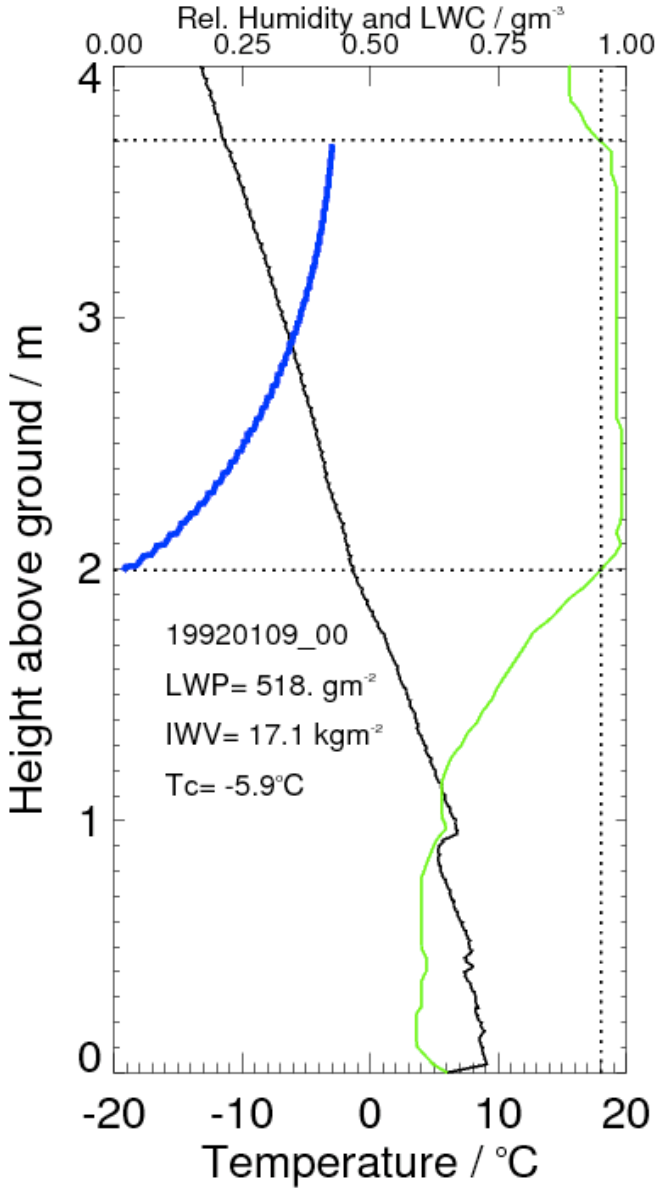
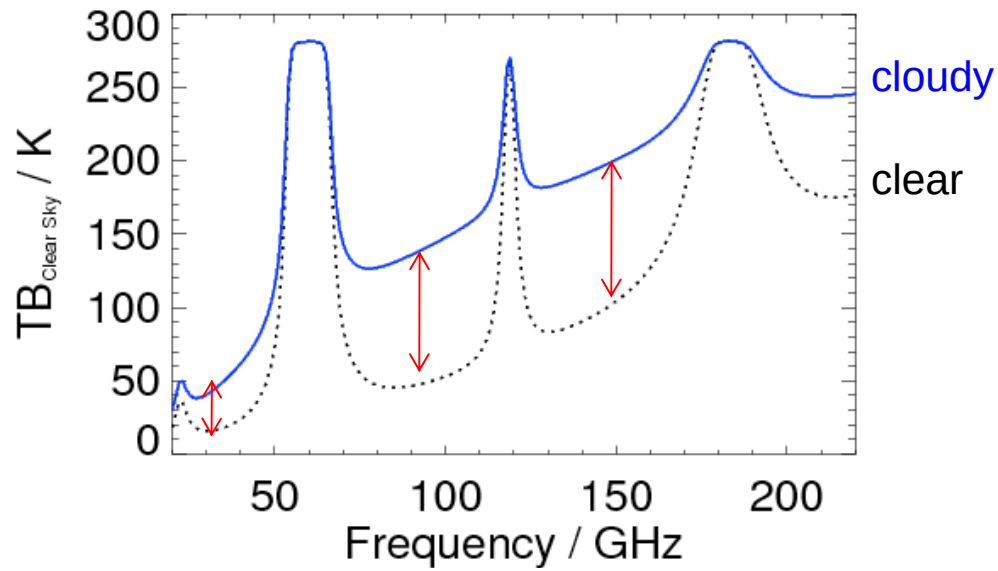
ARM Mobile Facility
Murgtal, Schwarzwald

2 April – 31 December 2007

The advantage of passive microwaves: LWP

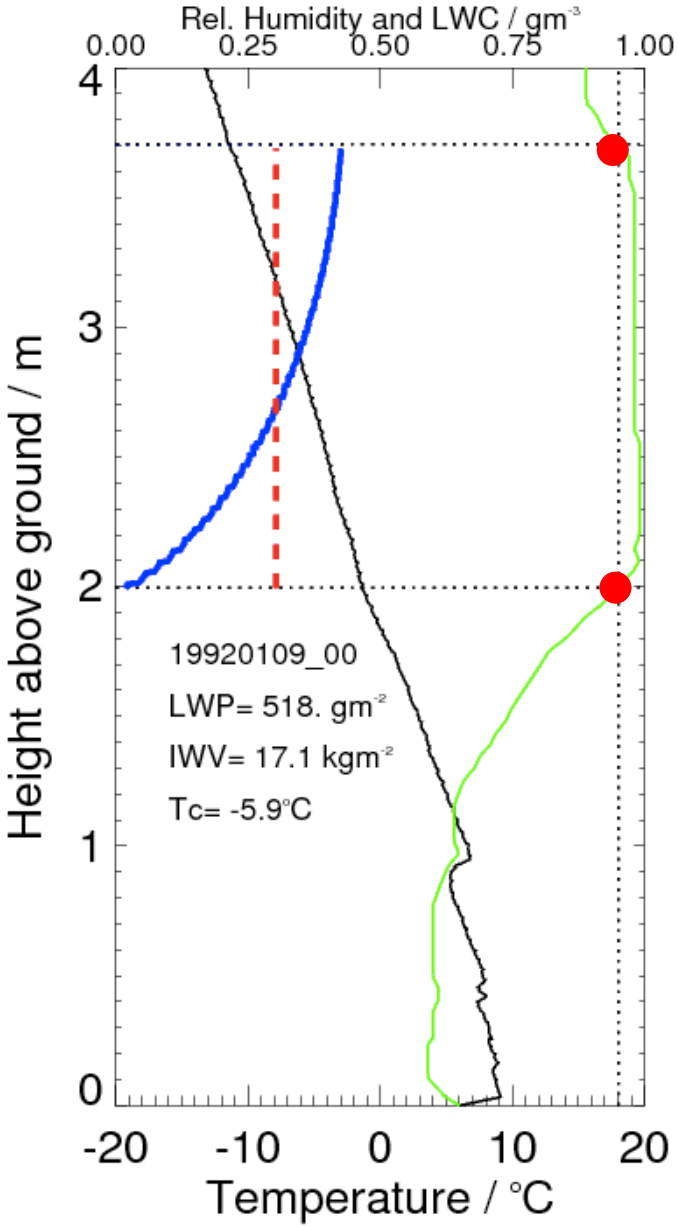


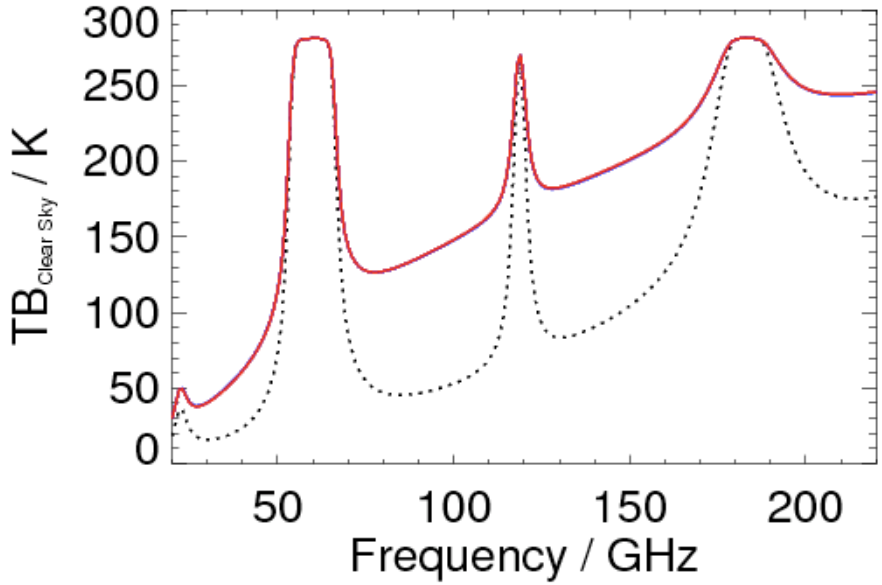


Liquid water path (LWP) can be retrieved accurately from the ground and satellite (over ocean)

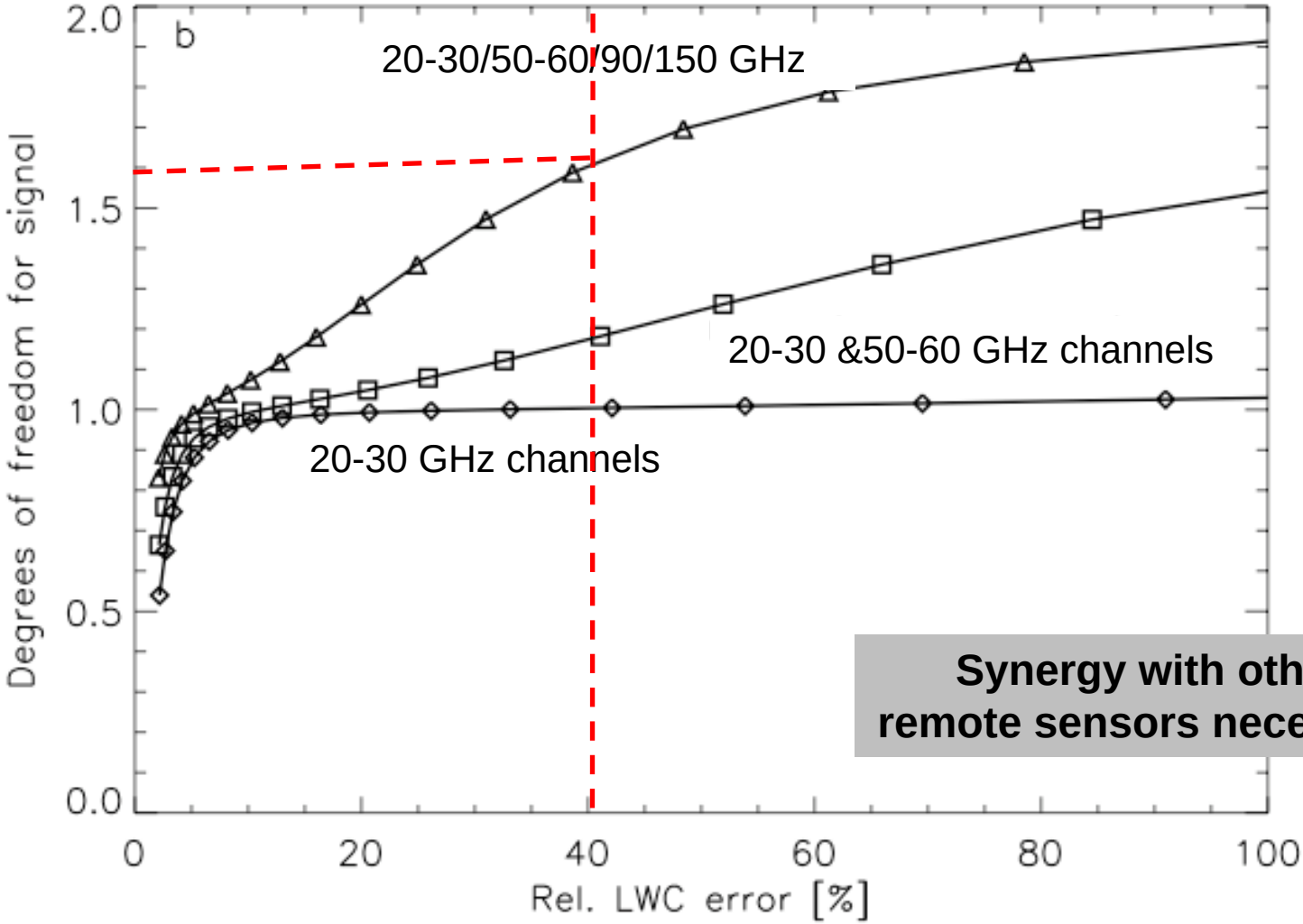
What about profiles of liquid water content (LWC)?

The limiation of passive microwaves: LWC





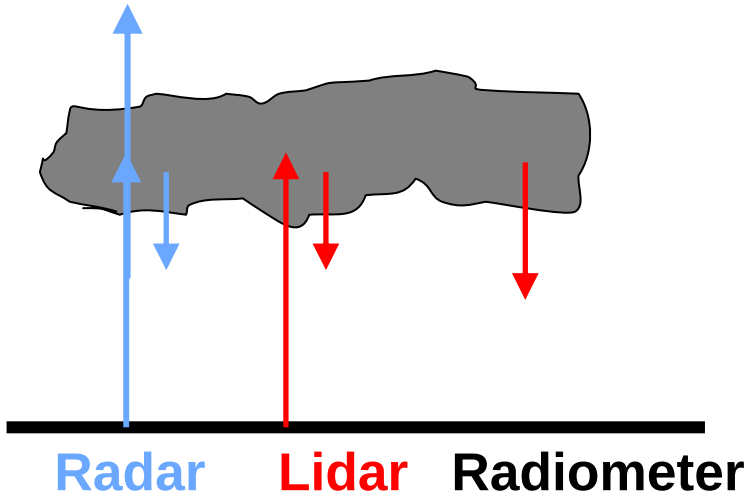
Profiling of cloud water

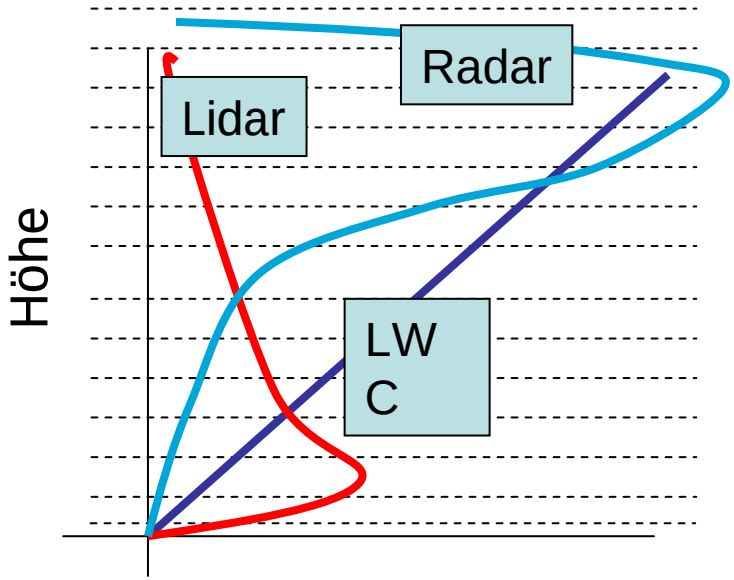


Synergy with other remote sensors necessary

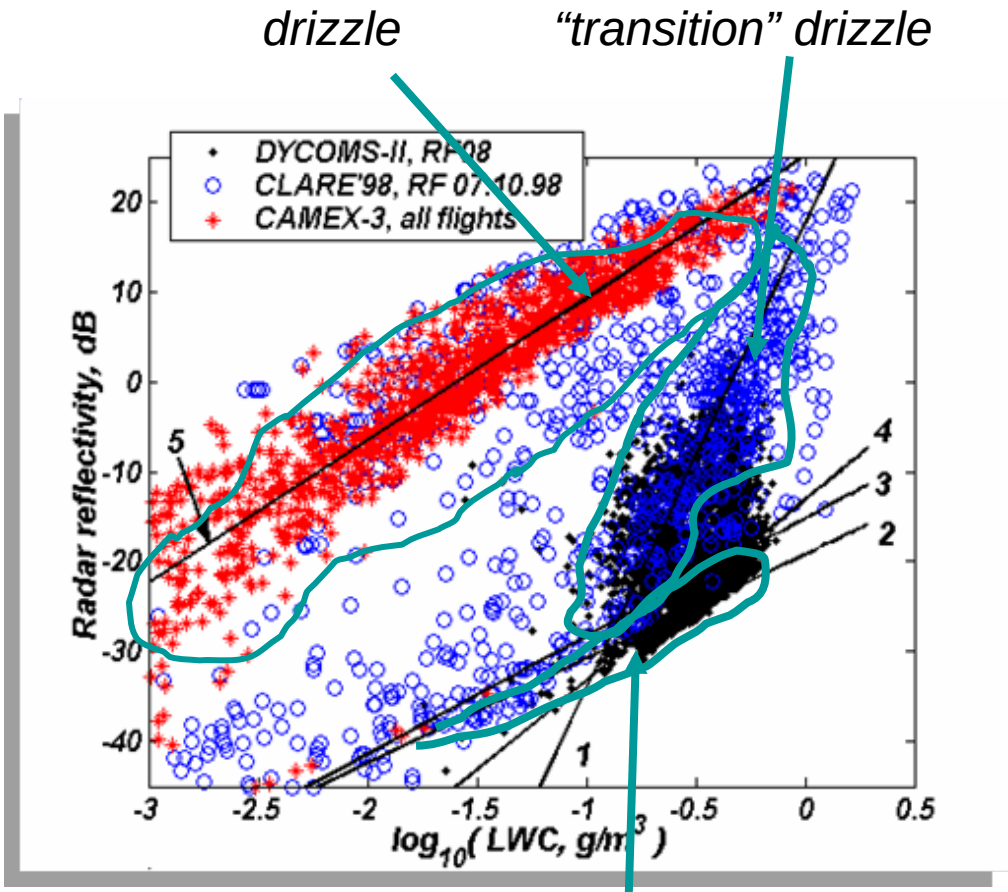
Remote Sensors for Synergy

- **Cloud radar**
  - radar reflectivity factor **Z**
  - Doppler-Spectrum
  - lineare depolarisation **LDR**
  - influence of insects and drizzle
- **Lidar**
  - backscatter coefficient prop. **r^2**
  - depolarization information for phase
  - strong extinction by water clouds
- **Infrared spectrometer**
  - water vapour and temperature
  - high sensitivity for thin clouds
  - information on effective radius
- **Microwave radiometer**
  - liquid water path **LWP**





Problem: Drop size distribution N(r)



H. Russchenberg

liquid water content
(3. moment)

$$LWC \propto \int_0^\infty D^3 N(D) dD$$

radar reflectivity
(6. moment)

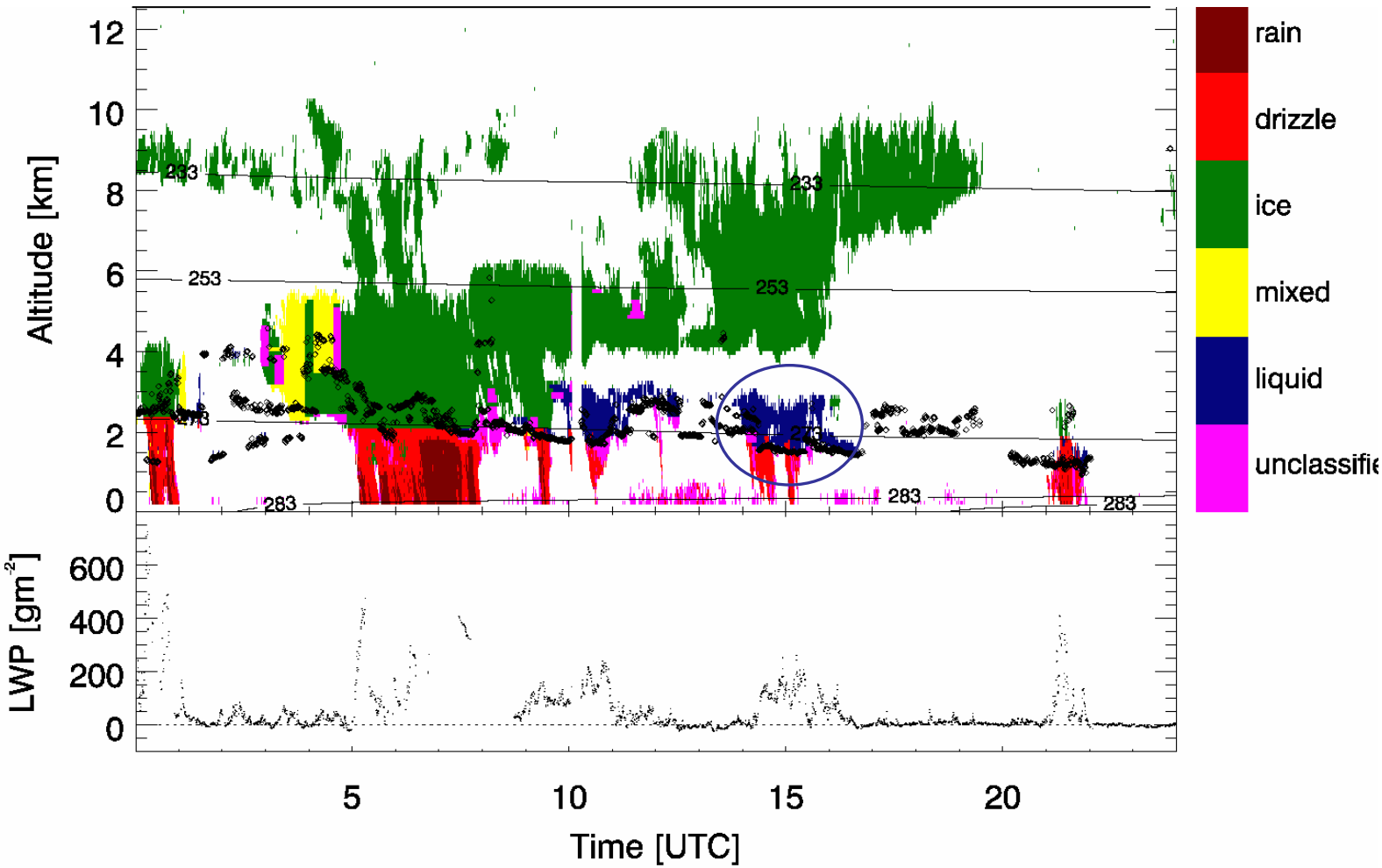
$$z = \int_0^\infty D^6 N(D) dD \, [mm^6 / m^3]$$

One million droplets with 10 µm radius give same radar reflectivity as on drop with 100 µm radius

$$z = a LWC^b$$

Different regimes with different Z-LWC relations and different error characteristics

Cloudnet *Target* Classification



Ewan O'Connor, Reading

Microwave radiometer

- HATPRO
- DPR 90/150

Cloud radar

- reflectiviy
- Doppler velocity
- spectral width

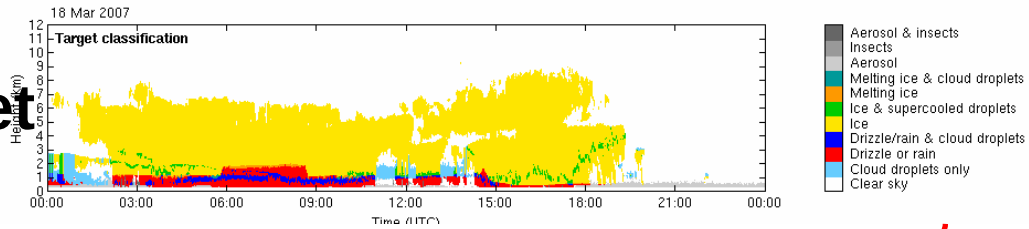
Micro pulse lidar Ceilometer

- extinction
- cloud base height

A prori information

- radio sondes
- climatology
- short-term-NWP

1. Cloudnet target classification



2. Integrated Profiling Technique (IPT)

Bayesian approach

$$\mathbf{x}_{i+1} = \mathbf{x}_i + (\mathbf{S}_a^{-1} + \mathbf{K}_i^T \mathbf{S}_e^{-1} \mathbf{K}_i)^{-1} \cdot [\mathbf{K}_i^T \mathbf{S}_e^{-1} (\mathbf{y} - \mathrm{F}(\mathbf{x}_i)) - \mathbf{S}_a^{-1} (\mathbf{x}_i - \mathbf{x}_a)]$$

physically consistent profiles of

- temperature
- humidity
- liquid water content + *effective radius*
- *ice water content + effective radius*

+errorr

Statistical evaluation

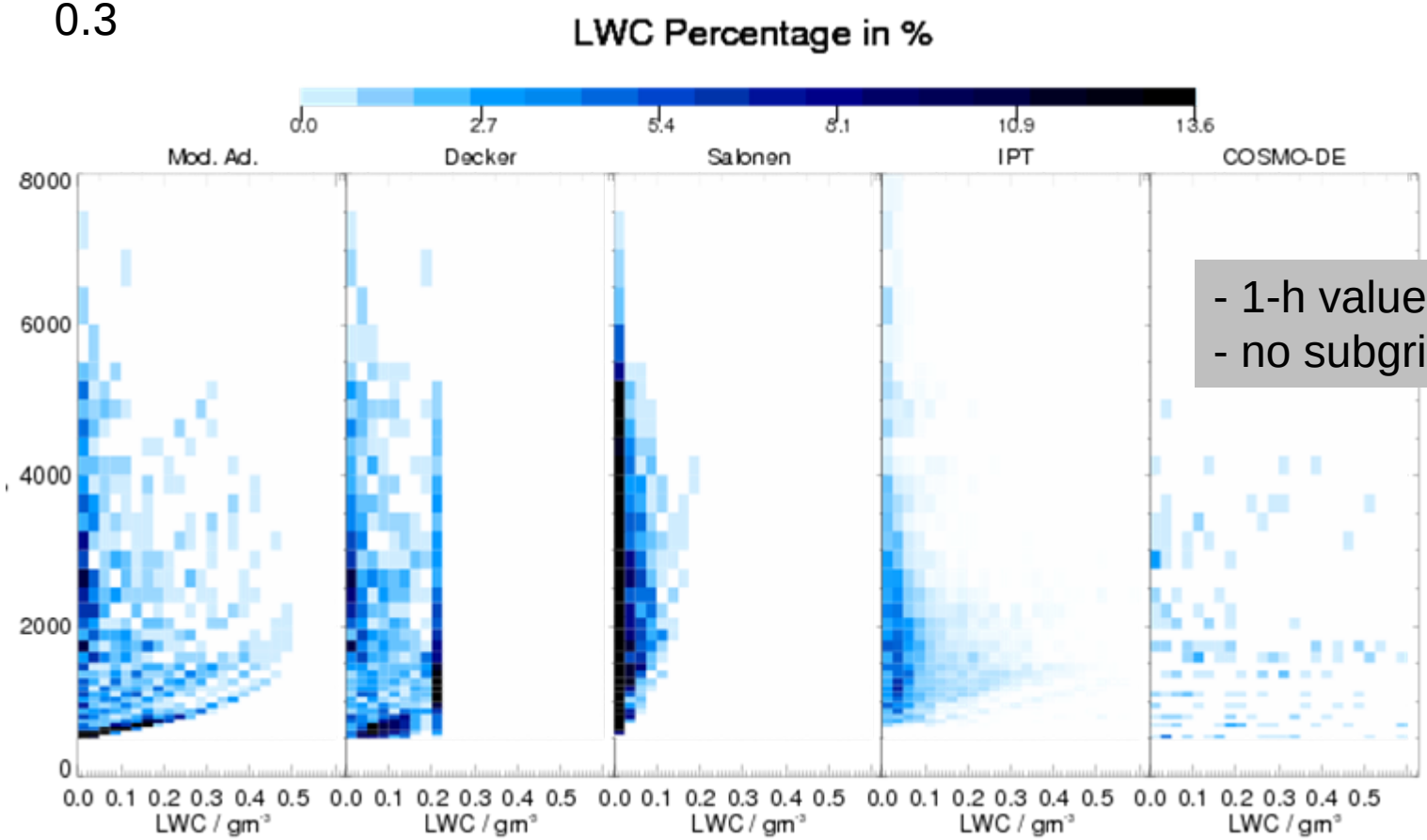
- Weather forecasts
- Radiation schemes

Löhnert et al., 2004, 2007, 2008

Cloud Liquid Water Profiles

Application of Integrated Profiling Technique to AMF deployment in Black Forest

43 (23)% single layer water clouds (no drizzle) LWP- cloud thickness correlation 0.3



- 1-h values only
- no subgrid LWC

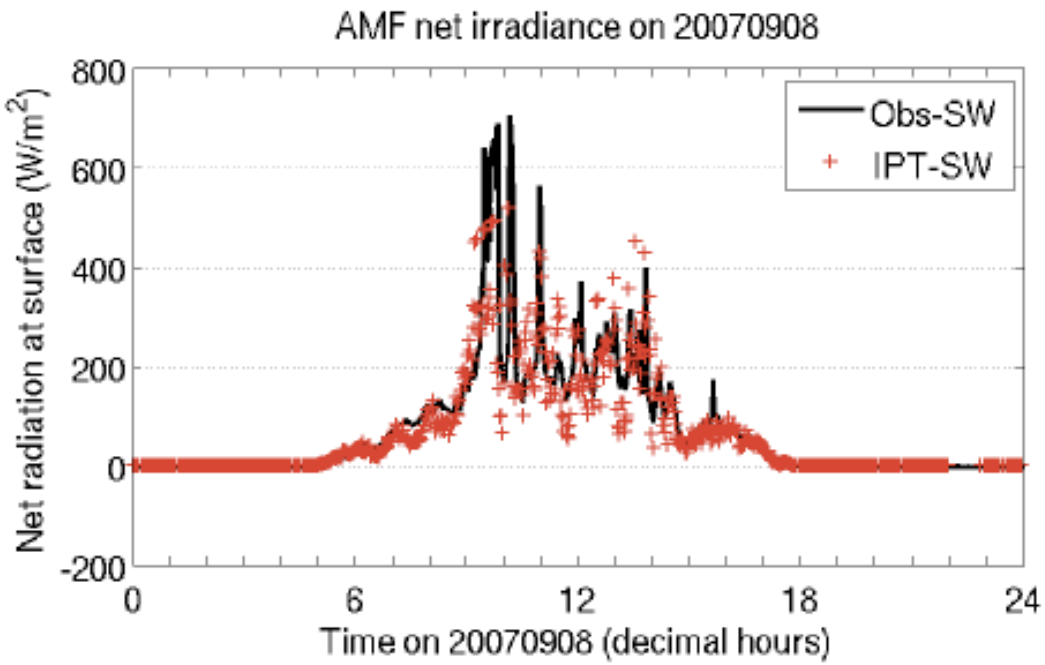
IPT

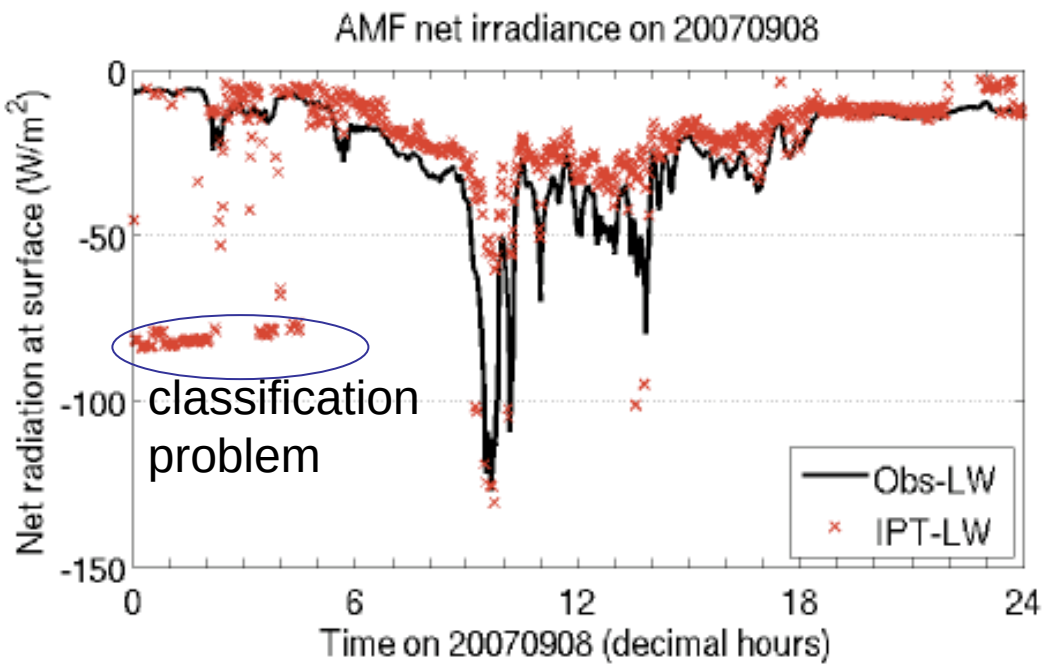
Modelling from RS profiles

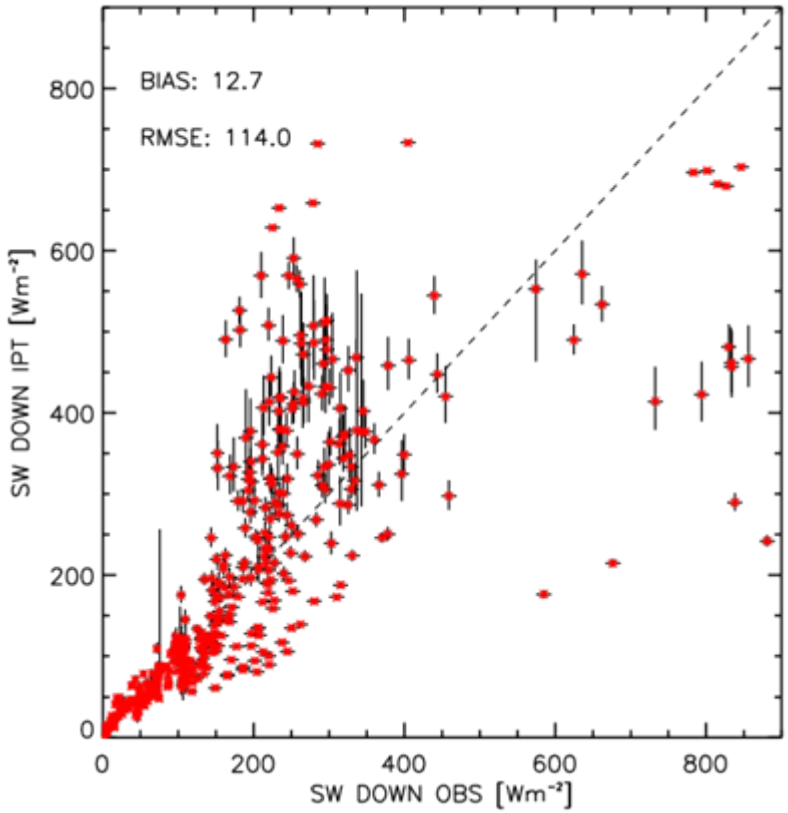
Kerstin Ebell

Cloud radiation interaction

Use IPT (and error characteristics) as input for flux calculations



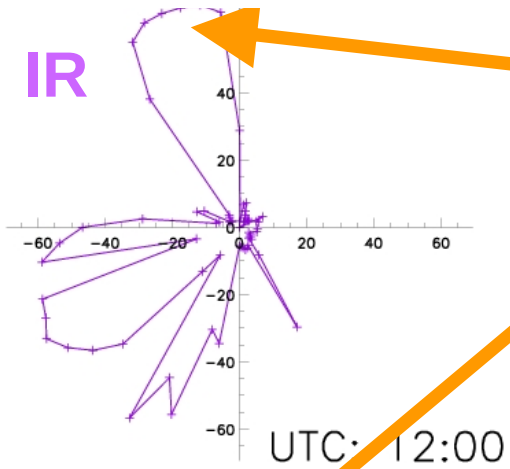


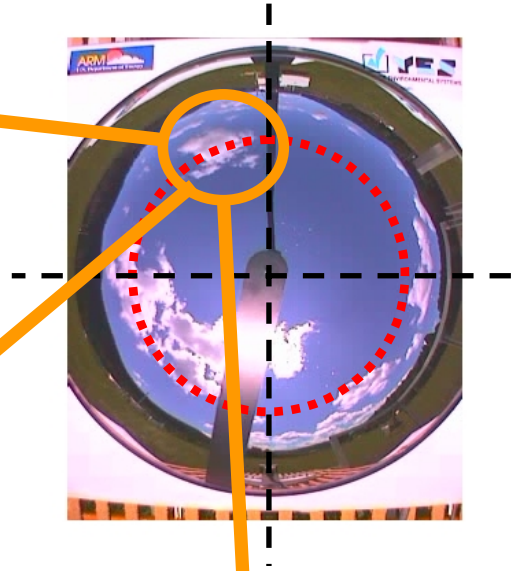


Discrepancies through 3D effects

Effects of Spatial Inhomogenity

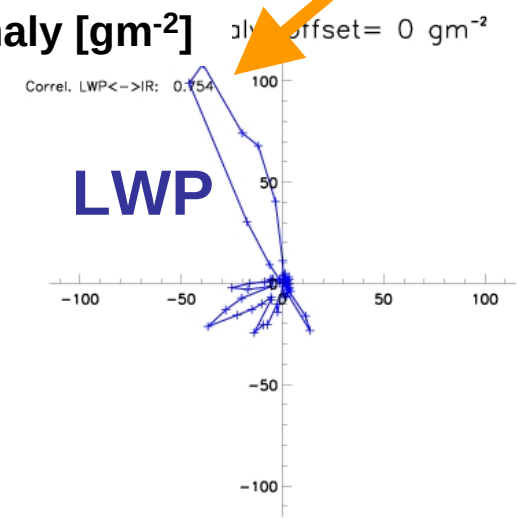
Infrared-anomaly [K]



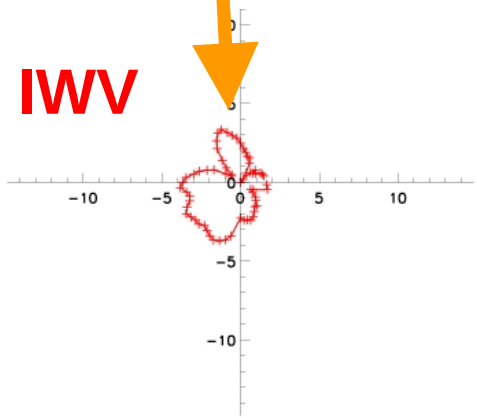


Use of scanning microwave observations for characterising 3D structure of LWP field

Liquid water anomaly [gm^{-2}]



Water-vapor-anomaly [kgm^{-2}]

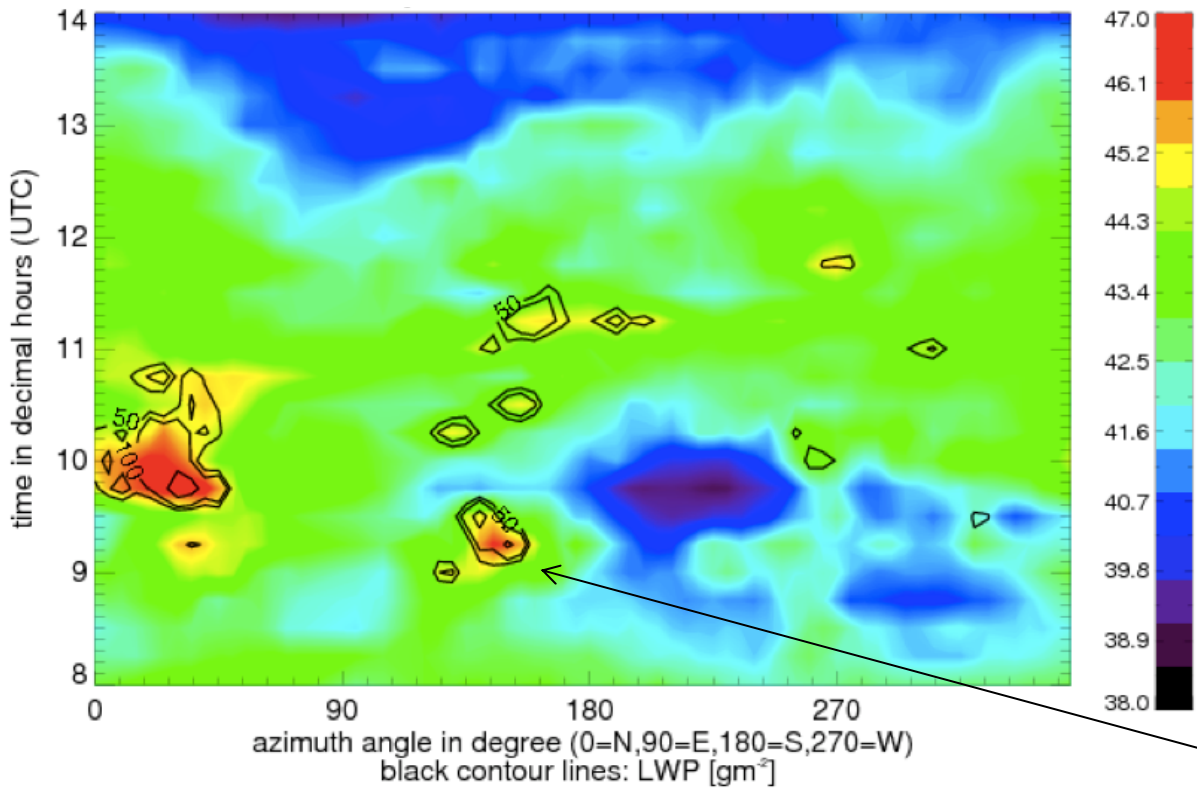


Kneifel et al., 2009

Spatial Inhomogeneity

Time

integrated water vapor on 4. August 2007



North East South West contour lines of LWP

Conclusions: Ground-based remote sensing

- **Ground-based reference stations**
  - provide the most complete view on the atmospheric state
  - testing of new instrumentation
  - more stations in different climate regions
    ➔ integration of different *communities*
  - accompanying model evaluation
    ➔ test of new parametrisatins
    ➔ evaluation of column models

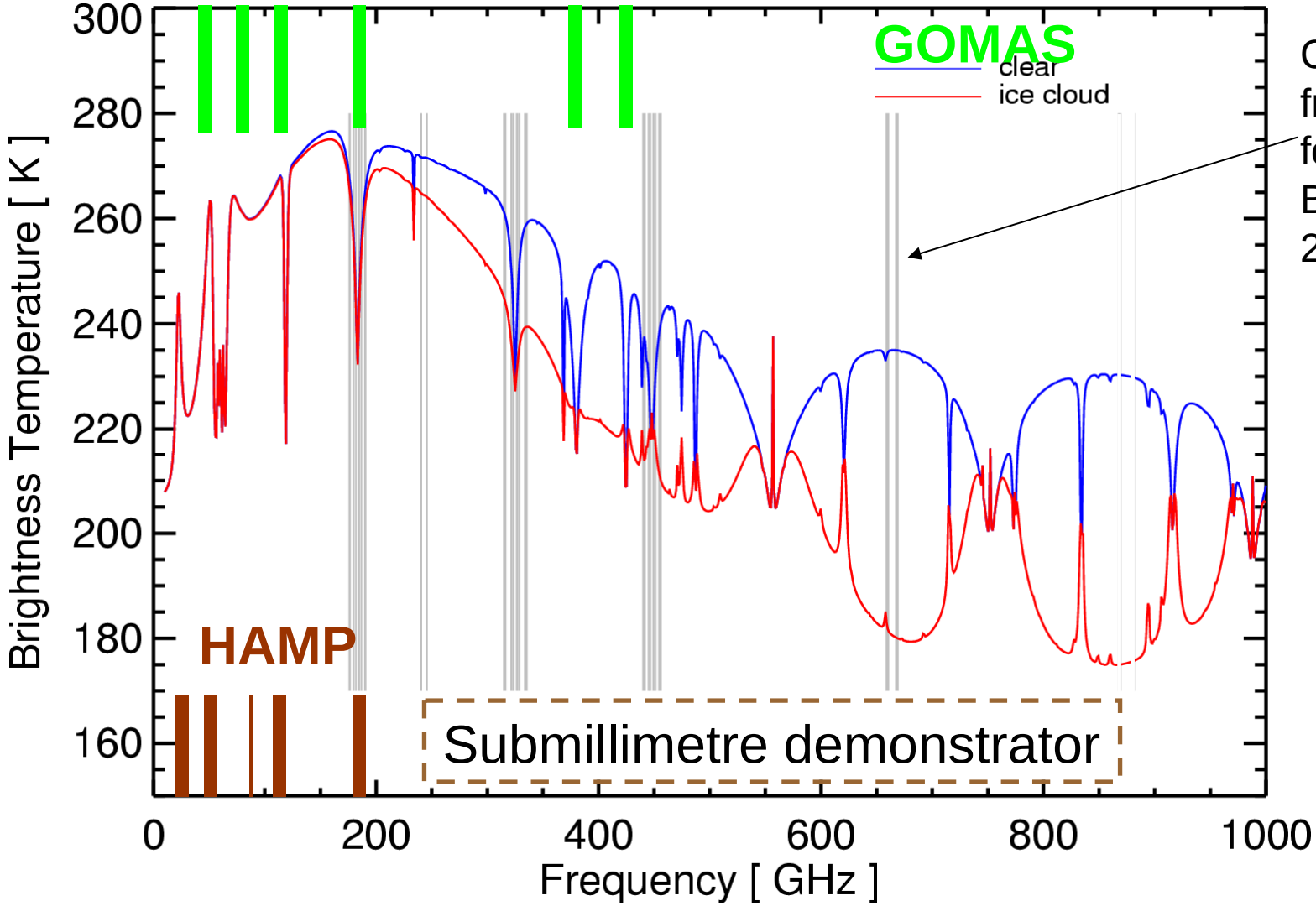
- **Sensor Synergy**
  - integrating as much instrumentation as possible
  - thorough instrument error characterisation
  - automatization

- **Moving from 1 to 3D**
  - low-cost distributed instrument packages
  - scanning instrumentation / tomography
  - small airplanes

Alberto Graciano, ESA/ESTEC

Satellite Remote Sensing of ice clouds ..

Cloud Ice Water Sub millimetre Imaging Radiometer (CIWSIR)

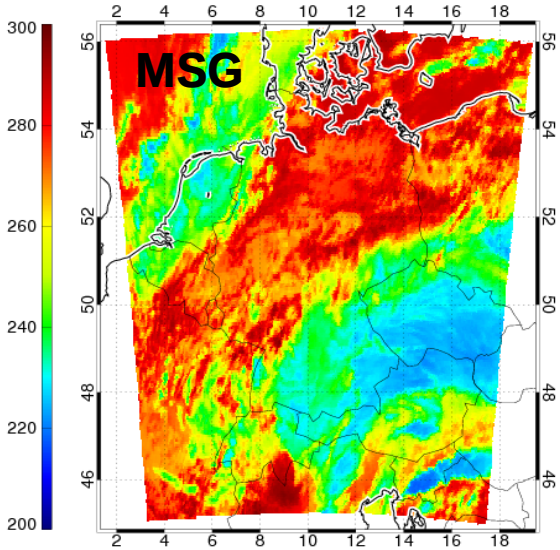


CIWSIR frequencies following Bühler et al., 2007

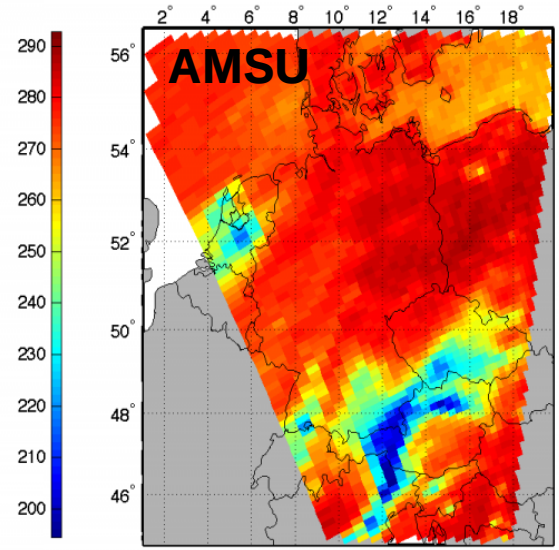
(after Bühler et al., CIWSIR Mission Proposal, 2005, figure by Viju O. John)

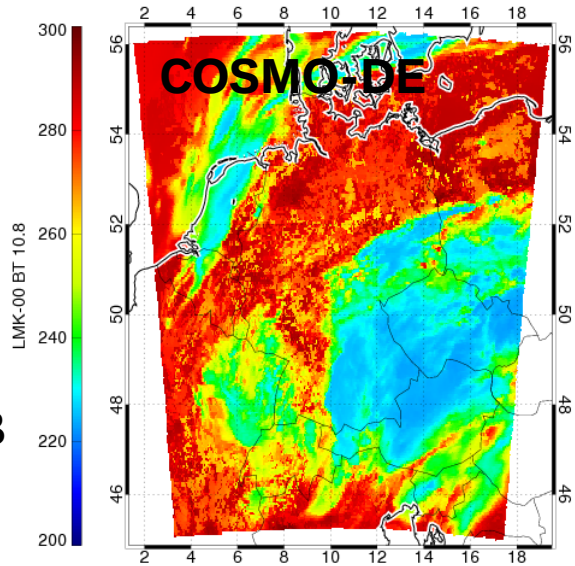
Advantage of high-frequency MW

10.8 μm



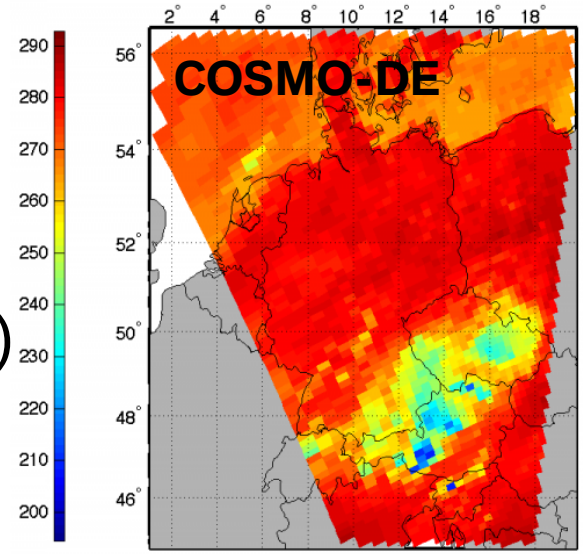
150 GHz





QUEST
project
(see poster)

3 August 2006
(Pfeifer et al., 2009)



FUB

Potential of Submillimeter Frequencies

Microwave radiative transfer model

- gas absorption
- hydrometeor interaction
- surface emissivity

Mesoscale cloud model output

- 3-dimensional fields
- detailed microphysics
- realistic situations

Simulated brightness Temperatures

- demonstrator frequencies
- instrument specifications

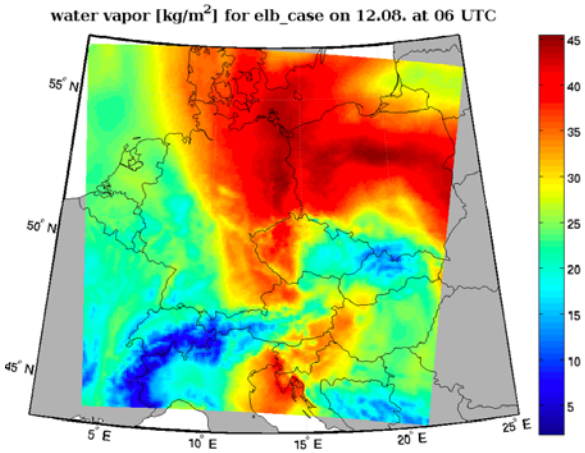
Retrieval algorithm

Ice Water Path (IWP)
Precipitation (solid&liquid)

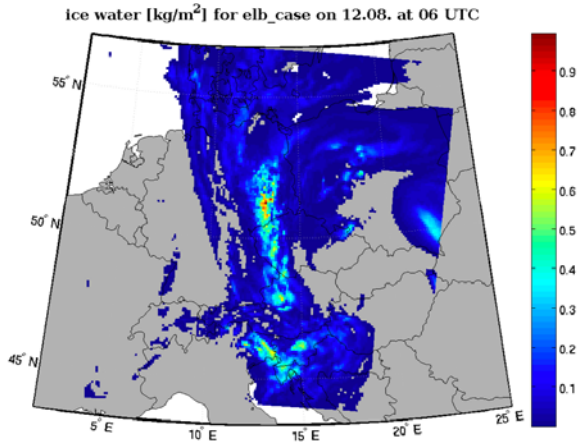
Approach after Defer et al., 2008 and Mech et al., 2007

Example: Elbe flooding

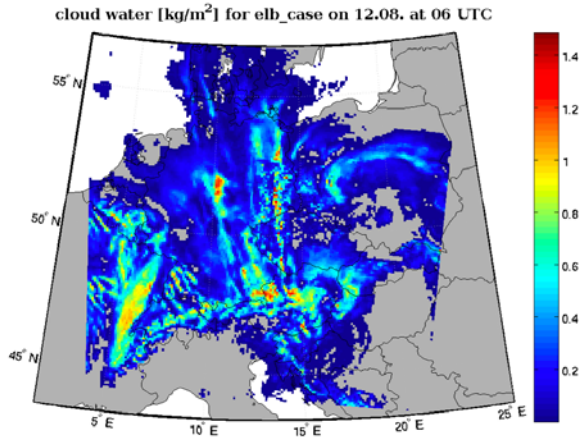
Water Vapor



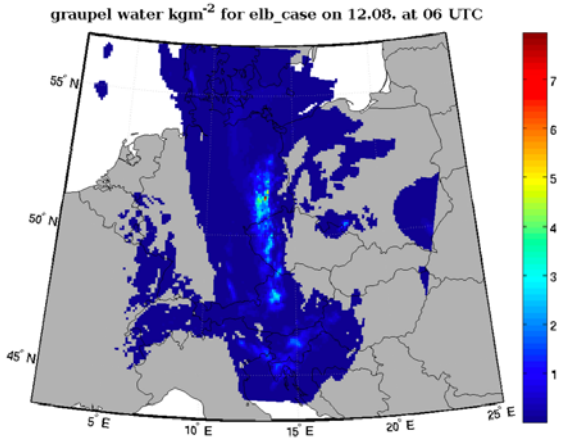
Ice Water Path (IWP)



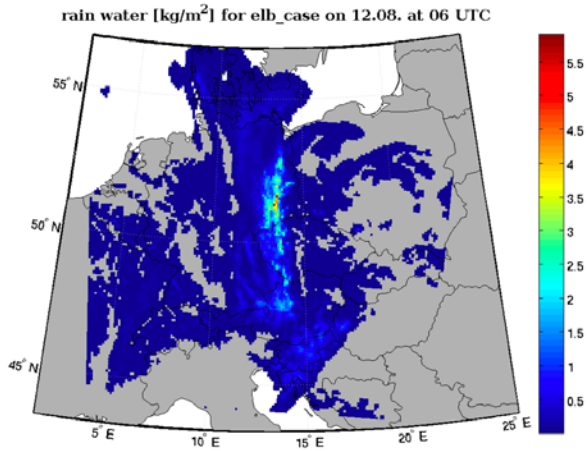
Cloud Water



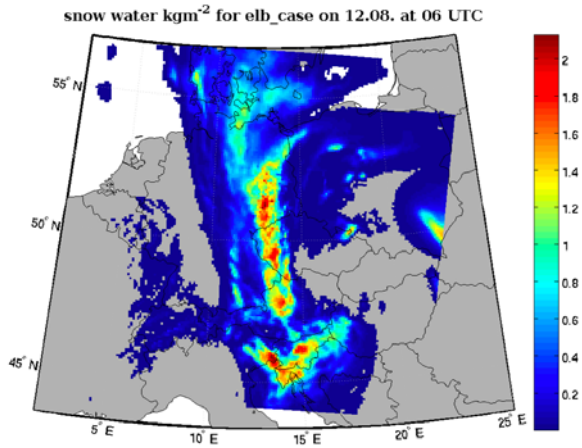
Graupel Water Path (GWP)



Rain Water Path (RWP)



Snow Water Path (SW



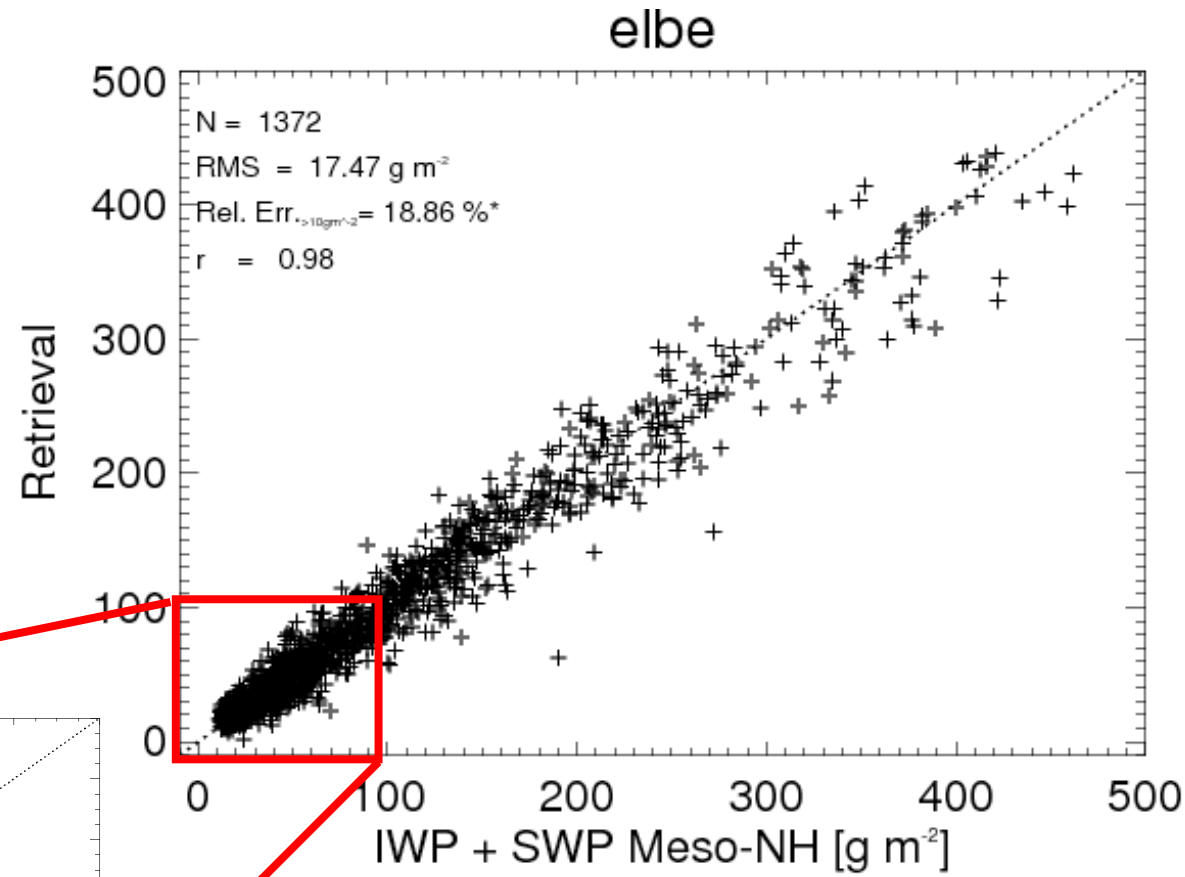
Meso-NH calculations by J.-P. Chaboureu

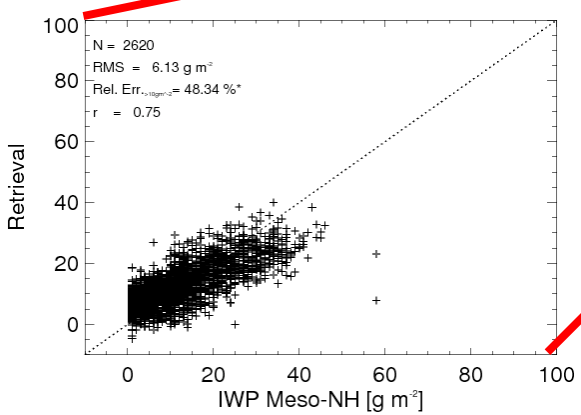
CIWSIR Retrieval Performance

Development of simple retrieval algorithm for ice clouds

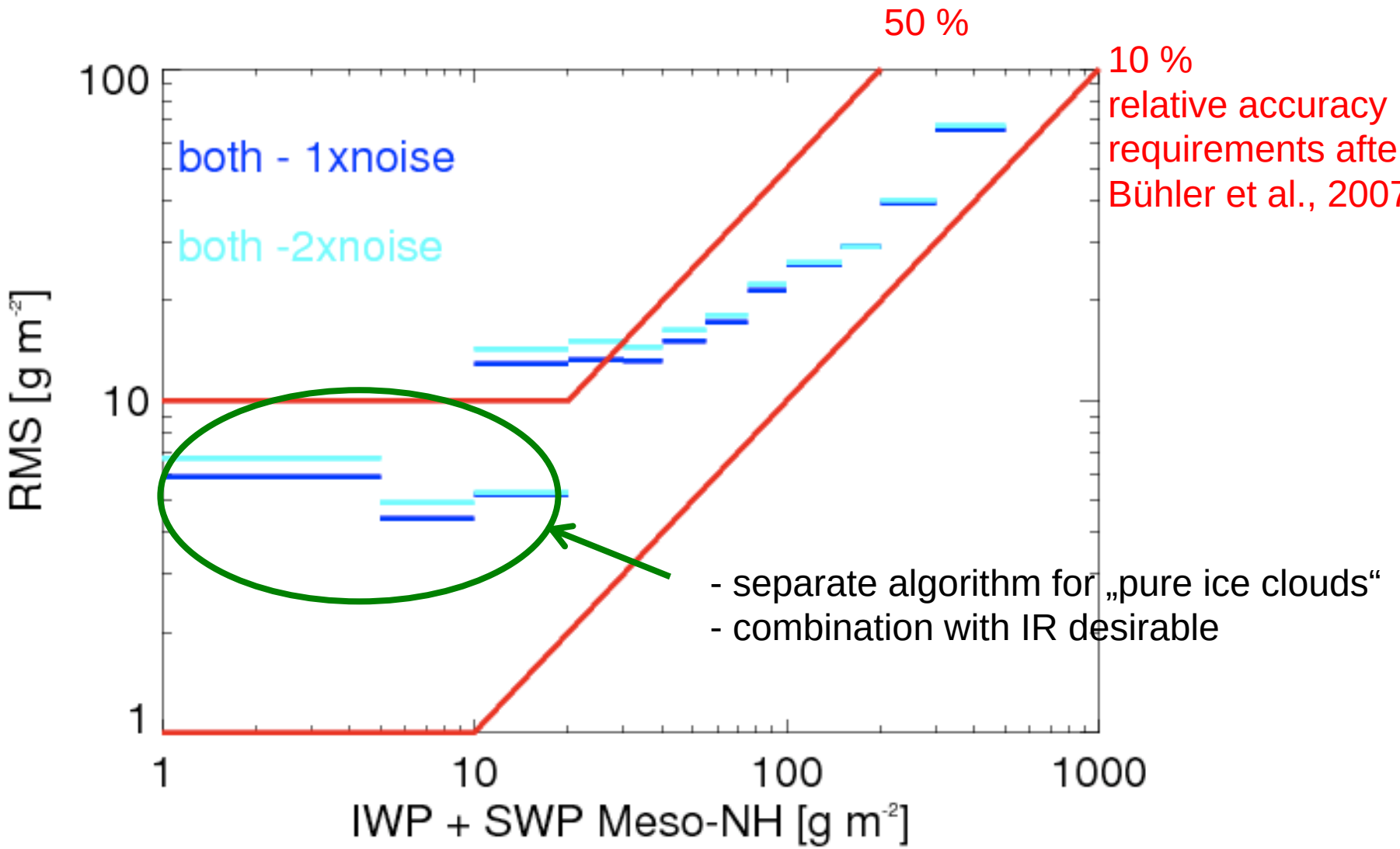
combining IWP and SWP

- no surface rain rate
- IWP > 10 gm^{-2}
- snow water path (SWP) < 500 gm^{-2}



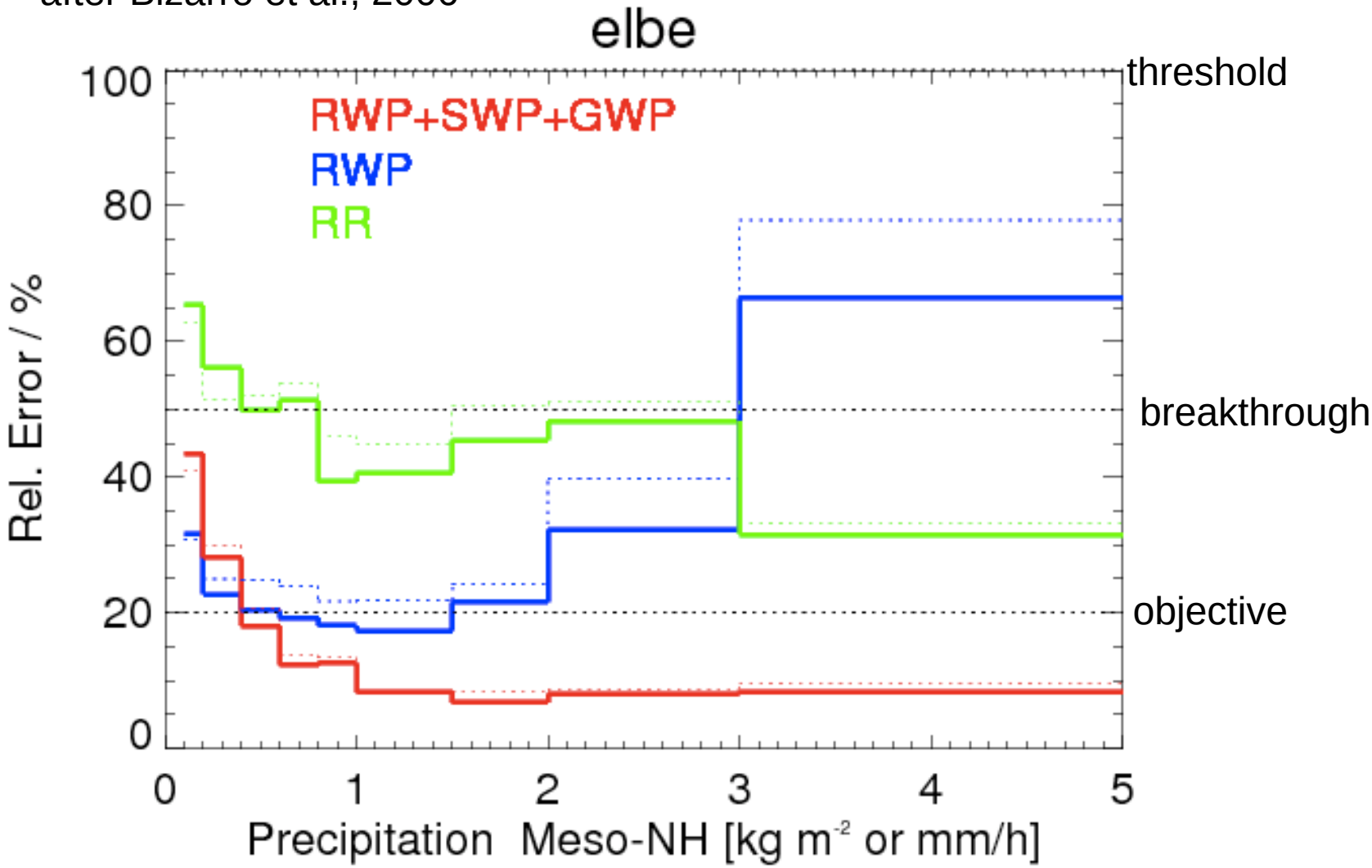


Comparison with CIWSIR Requirements



GOMAS Performance

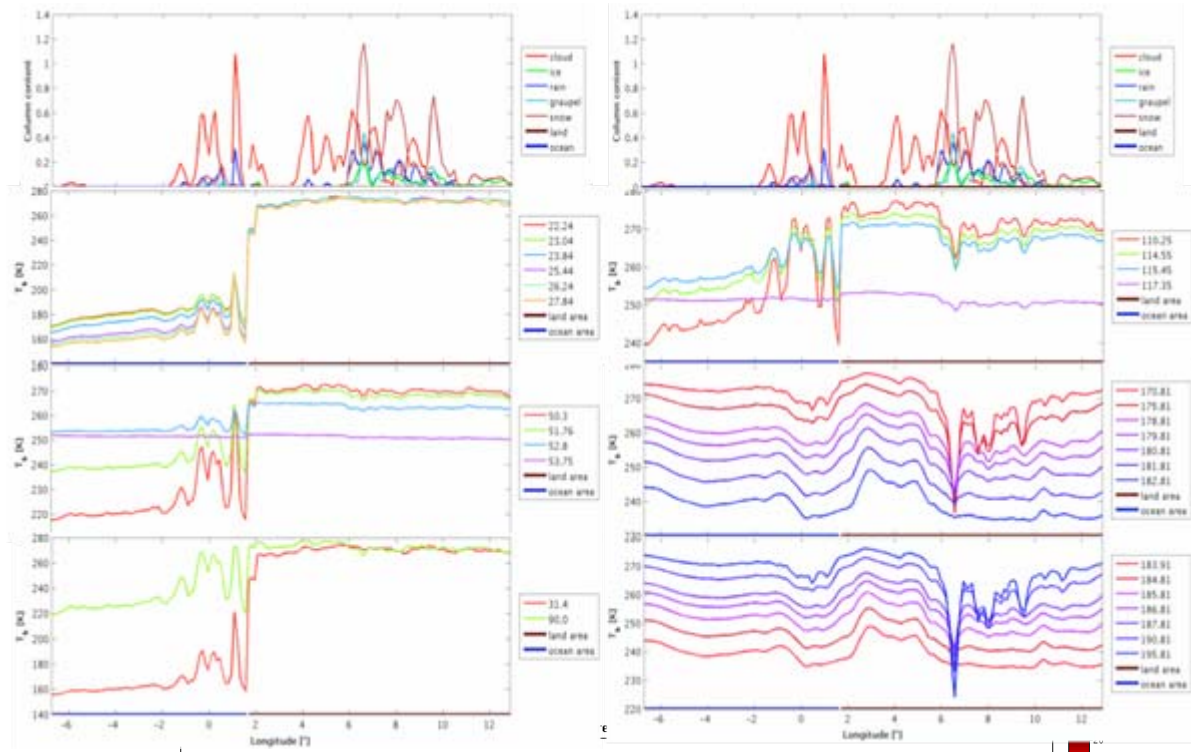
Geostationary Observatory for Microwave Atmospheric Sounding (**GOMAS**)
after Bizarro et al., 2006

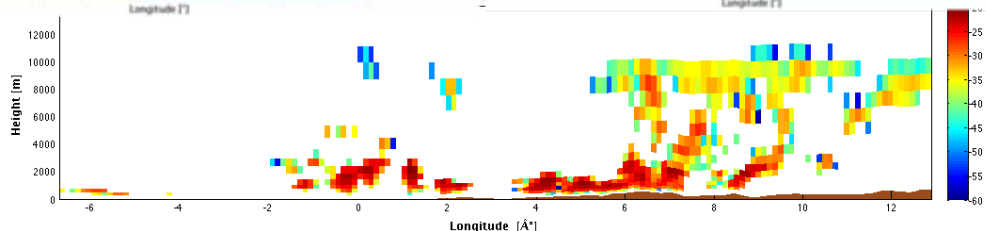


Conclusions: Satellite remote sensing

- **Millimetre / Submillimetre Frequencies**
  - high potential for hydrometeor remote sensing
  - challenge of scattering properties
    ➔ size/form/density
  - advantage of higher spatial resolution
  - combination with active sensors

- **Airborne Demonstrators**
  - HAMP - the microwave package on HALO(MPI HH)
  - performance tests
  - fine scale resolution
  - satellite validation





Conclusions: Satellite remote sensing

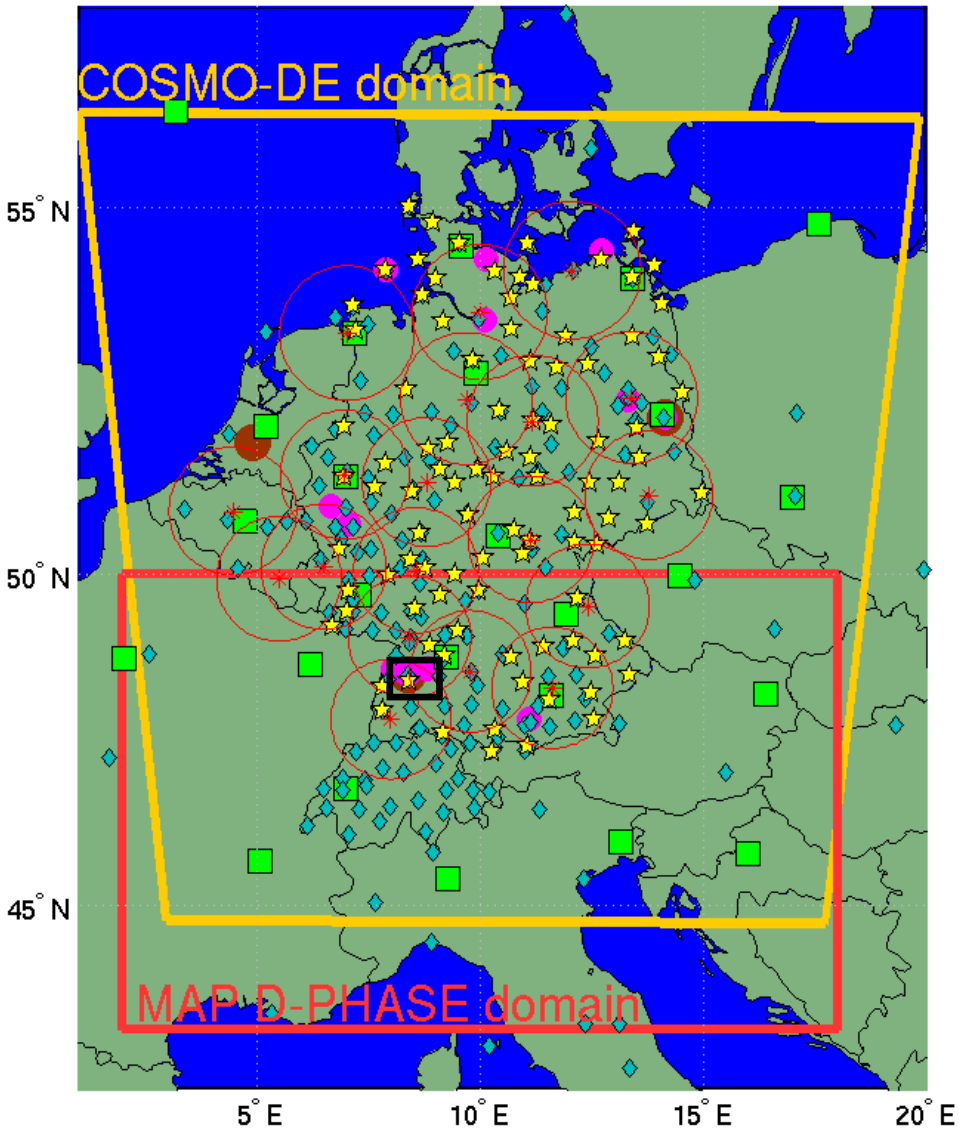
- **Which cloud parameters are mst useful for data assimilation, evaluation, satellite retrievals?**

- **What important cloud parameters are missing from satellte observations?**

- **Spatial and temporal coverage needed?**

- **Which model improvements are needed?**

GOP Area and Instrumentation

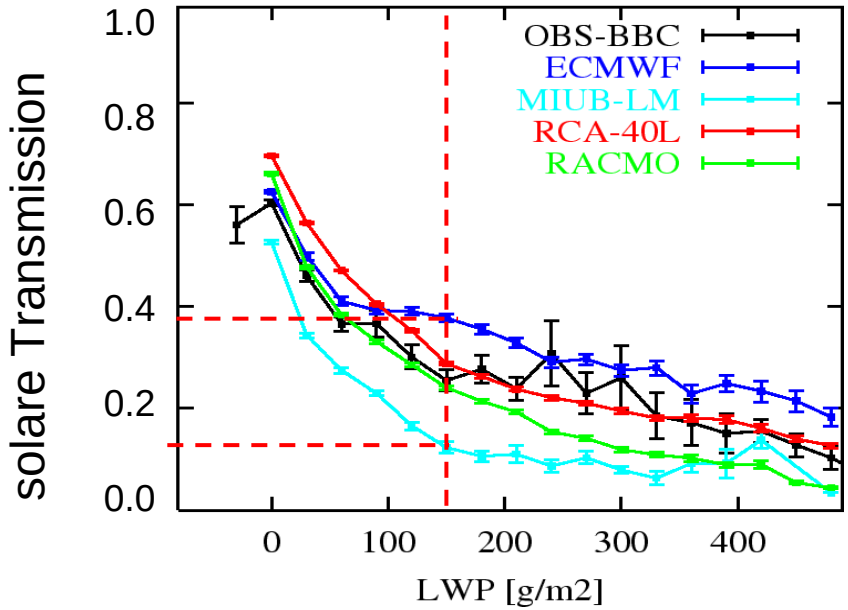


- Radiosonde
- Cloudnet
- Micro Rain Radar
- GPS
- Ceilometer
- Weather Radar

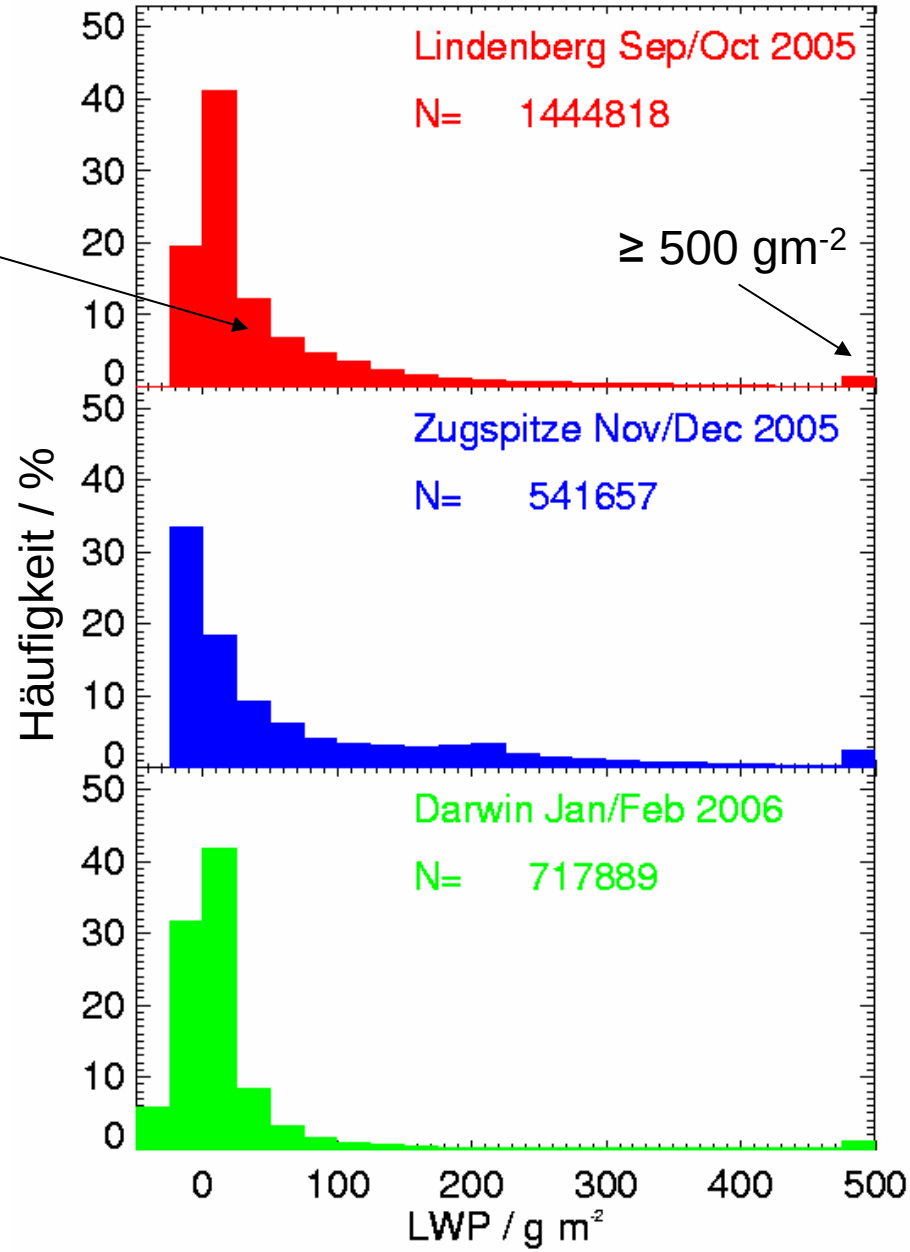
and Satellites

Wechselwirkung Wolken Strahlung

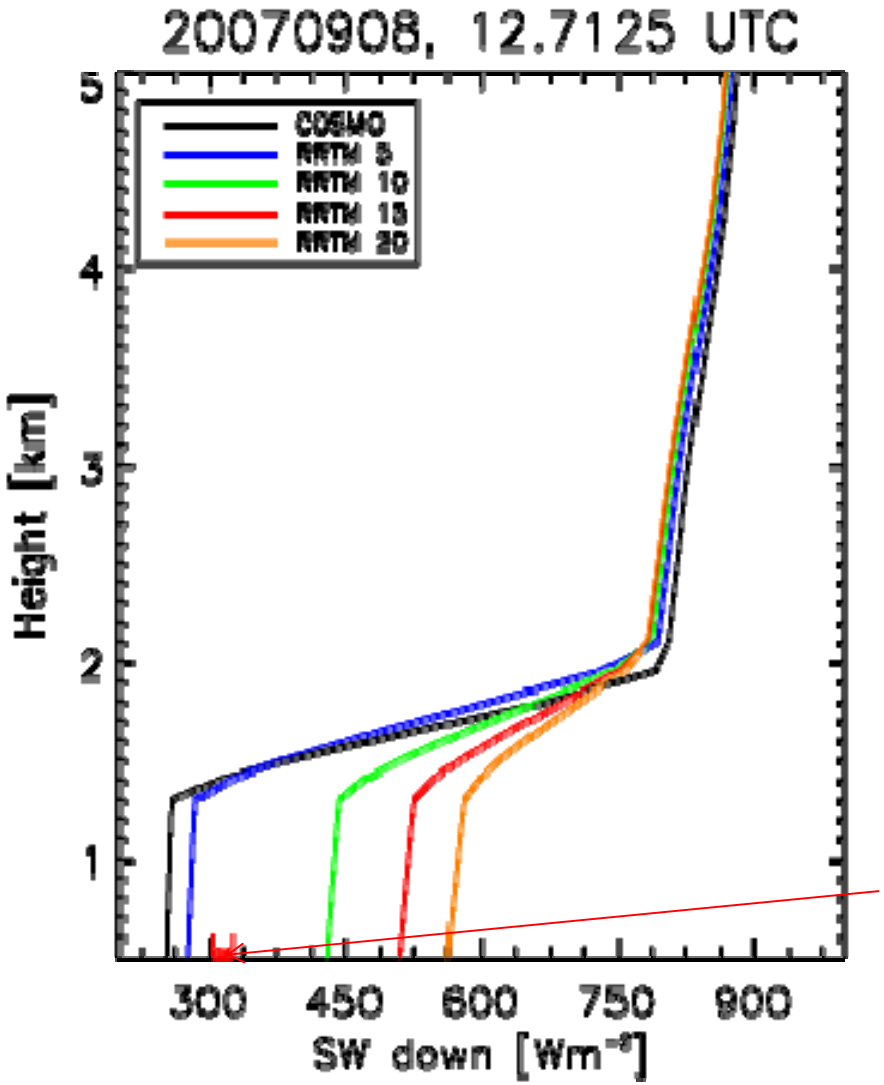
geringer Flüssigwasserpfad (LWP) < 100 gm^{-2} wirkt stark auf den Strahlungshaushalt



Eu Project Cliwanet



Wechselwirkung Wolken Strahlung



Beobachtungen

Bei Wolken mit geringem Flüssig-wassergehalt (hier LWP ca. 50 gm^{-2}) hat effektiver Radius starken Einfluss

$$r_{eff} = \frac{\int n(r) r^3 dr}{\int n(r) r^2 dr}$$

Verbesserte Beobachtungen für LWC und Effektivradius gerade für dünner Wolken notwendig

The advantage of passive microwaves

- **Wechselwirkung von Wolken und Strahlung**

  ➔ Betrieb der ARM Mobile Facility im Schwarzwald 2007

  Sensorsysnergie mit Hilfe der Integrated Profiling Technique (IPT)

- **Entstehung von Niederschlag**

  ➔ Schwerpunktprogramm „Quantitative Niederschlagsvorhersage“

  Identifikation von Modelldefiziten mittels Fernerkundungsmethoden

Prozessverständnis und Entwicklung neuer Beobachtungsmethoden gehen Hand in Hand