Statistical Retrieval of Thin Liquid Cloud Microphysical Properties Using Ground-Based Infrared and Microwave Observations

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1. Characteristics of Thin Liquid Water Clouds

Thin liquid water clouds: liquid water path (LWP) below 100 g/m²

- **Frequently occurring** in most climate regimes (over 50 % at midlatitudes [2])
- **Large sensitivity** of the shortwave down- and upwelling flux to the LWP (Fig. 1)
- **High uncertainties** of widely used Microwave Radiometer (MWR) retrievals (20-30 g/m²)

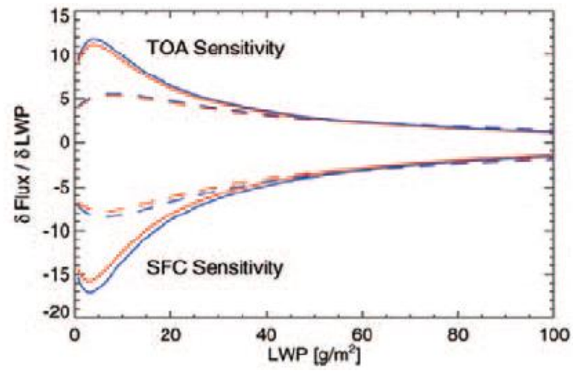


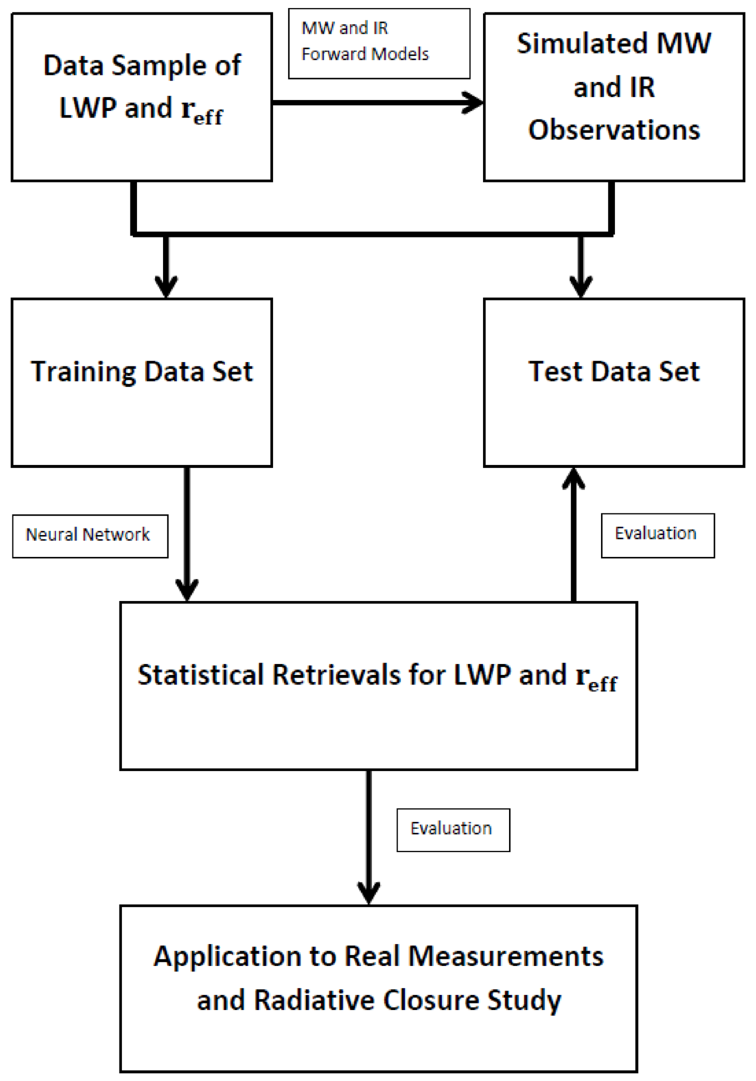
Fig. 1: *Simulated sensitivity of the shortwave fluxes to the LWP at the surface (SFC) and top of the atmosphere (TOA) [3]*

2. Retrieval Setup Using Simulated Observations

Data Sample: One year (2012) of single layer liquid water clouds detected by a cloud classification scheme (**Cloudnet** [1]) at the Jülich Observatory for Cloud Evolution (**JOYCE**) http://www.joyce.cloud

Cloud property	Mean value	STDDEV
Cloud base height	1769.6 m	889.9 m
Cloud thickness	337.9 m	185.6 m
LWP	51.2 g/m²	71.1 g/m²
LWC	0.2 g/m³	0.2 g/m³
r_{eff}	6.2 μm	2.2 μm

Table 1: *Main cloud properties of the data sample*



Instruments: **MWR** using 7 channels (22 - 32 GHz); equipped with a Infrared Radiometer (**IR**): broadband wavelength bands at 11.1 μm and 12 μm

Atmospheric Emitted Infrared Interferometer (**AERI**): 13 micro-windows (771 - 998 cm^{-1})

- High spectral resolution
- Sensitive to changes in LWP until 60 g/m²

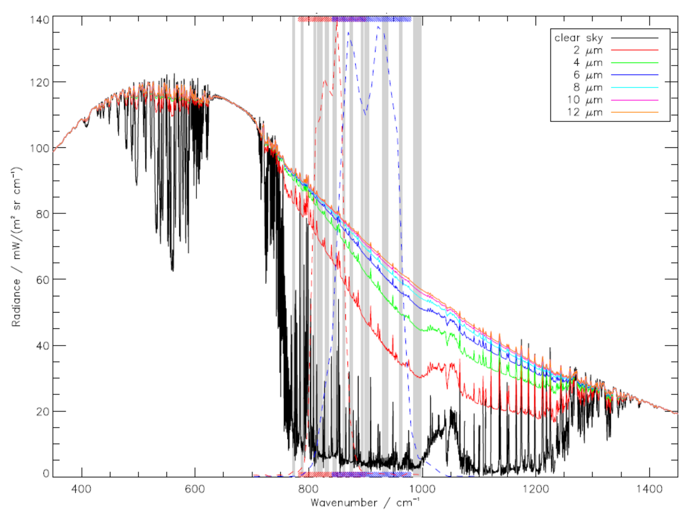


Fig. 2: *Simulated AERI radiances for different effective radii. Grey bars denote the 13 micro-windows and dashed colored lines the IR band-passes.*

3. Neural Network Retrieval Results

Scientific Goals:

- Assess the benefit of combining microwave and infrared observations
- Determine the difference between the broadband and highly spectral resolved infrared information for LWP and effective radius

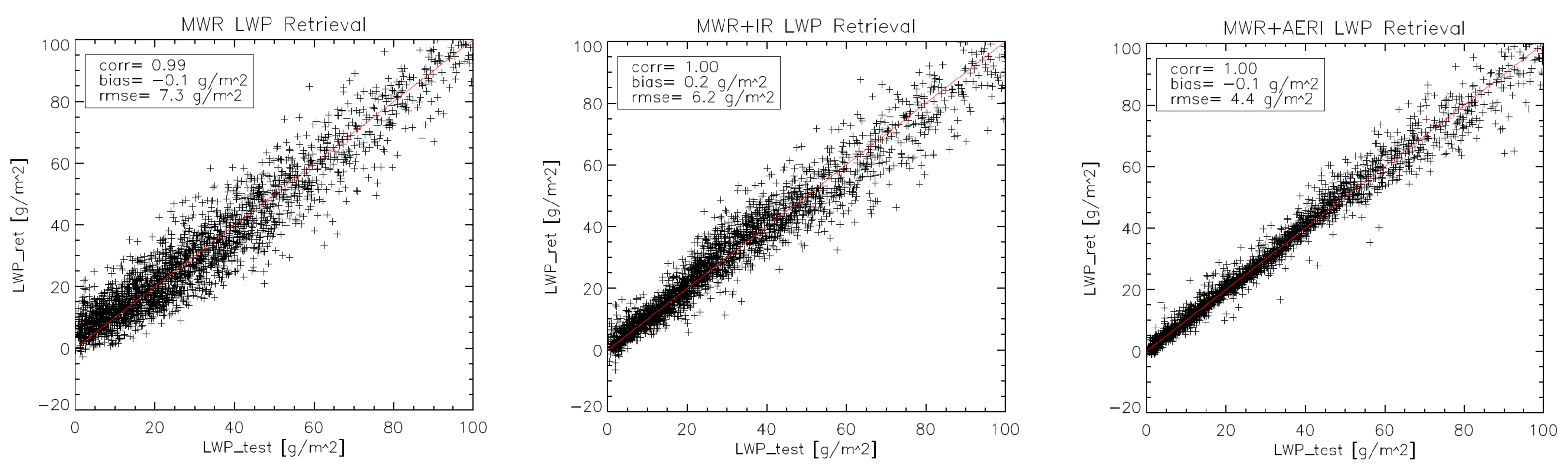


Fig. 3: *Test and retrieved LWP by the MWR (left), MWR+IR (middle) and MWR+AERI (right) retrievals*

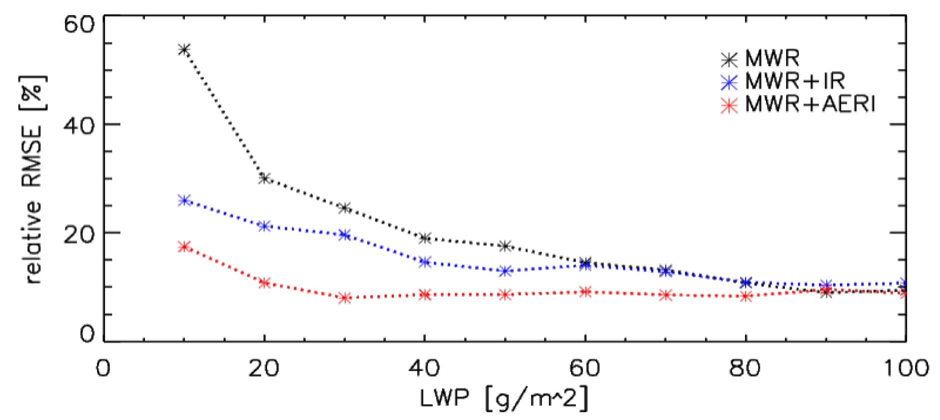


Fig. 4: *Relative root mean square error for the LWP retrievals as a function of LWP*

- Lowest relative error in LWP for the **MWR+AERI** retrieval (7-17 %)
- Up to **10 % improvement** compared to the MWR+IR retrieval

Effective Radius Retrieval

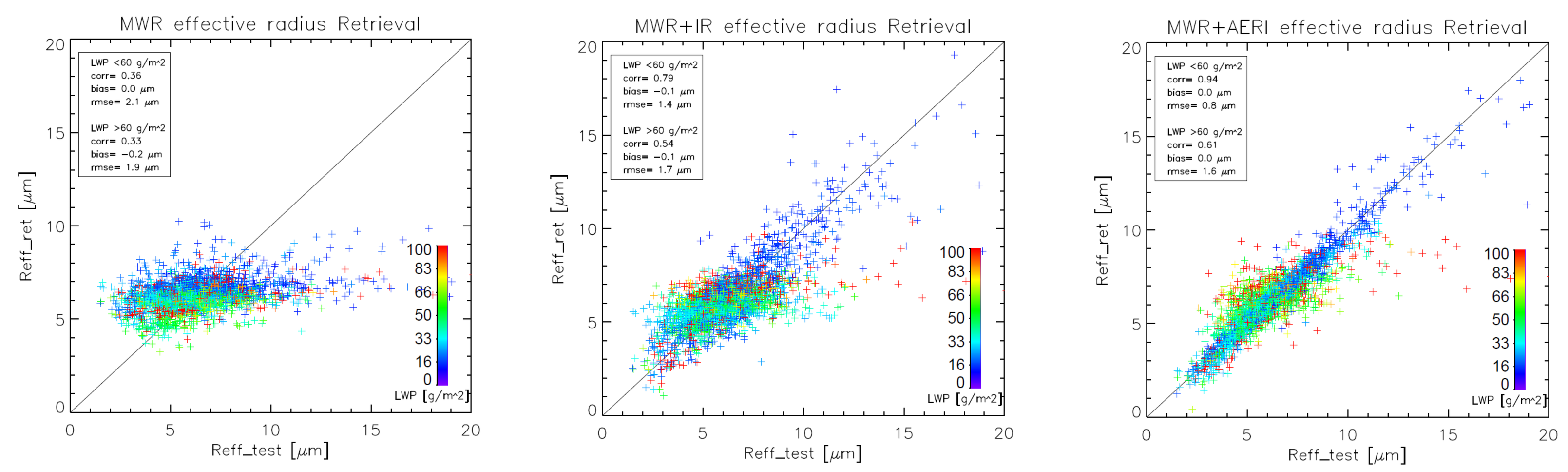


Fig. 5: *Test and retrieved effective radius by the MWR (left), MWR+IR (middle) and MWR+AERI (right) retrievals*

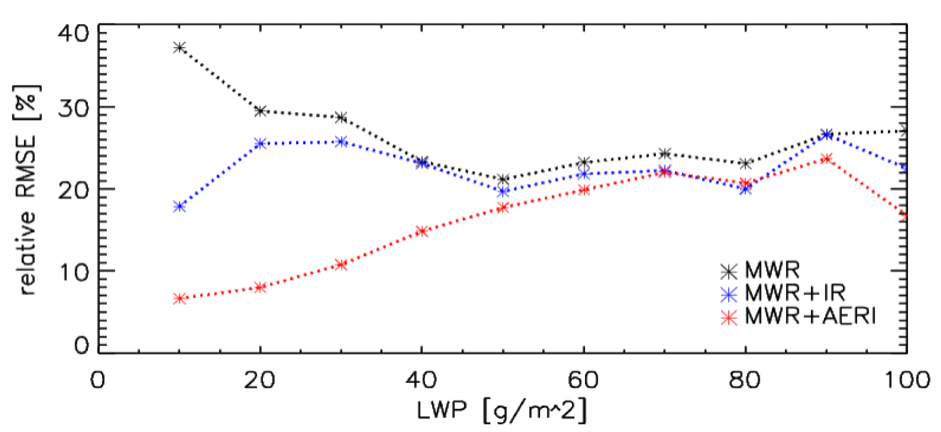


Fig. 6: *Relative root mean square error for the effective radius retrievals as a function of LWP*

- MWR retrieval reveals **no sensitivity** to the effective radius
- MWR+AERI retrieval shows best performance **up to 60 g/m²** (relative error below 20 %)

4. Application to Real Measurements

Shortwave Radiative Closure Study

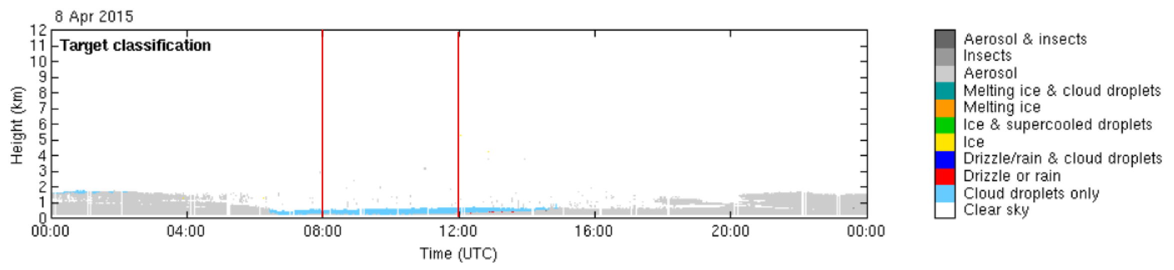


Fig. 7: *Cloudnet Target Classification: 8 Apr 2015; red lines indicate the selected time period for the closure study*

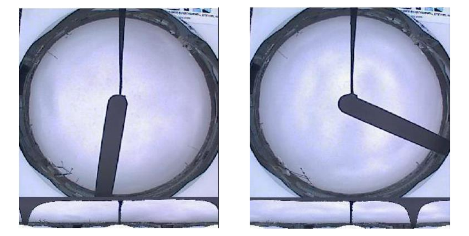


Fig. 8: *Total Sky Imager: 8 Apr 2015; 8 UTC (left), 12 UTC (right)*

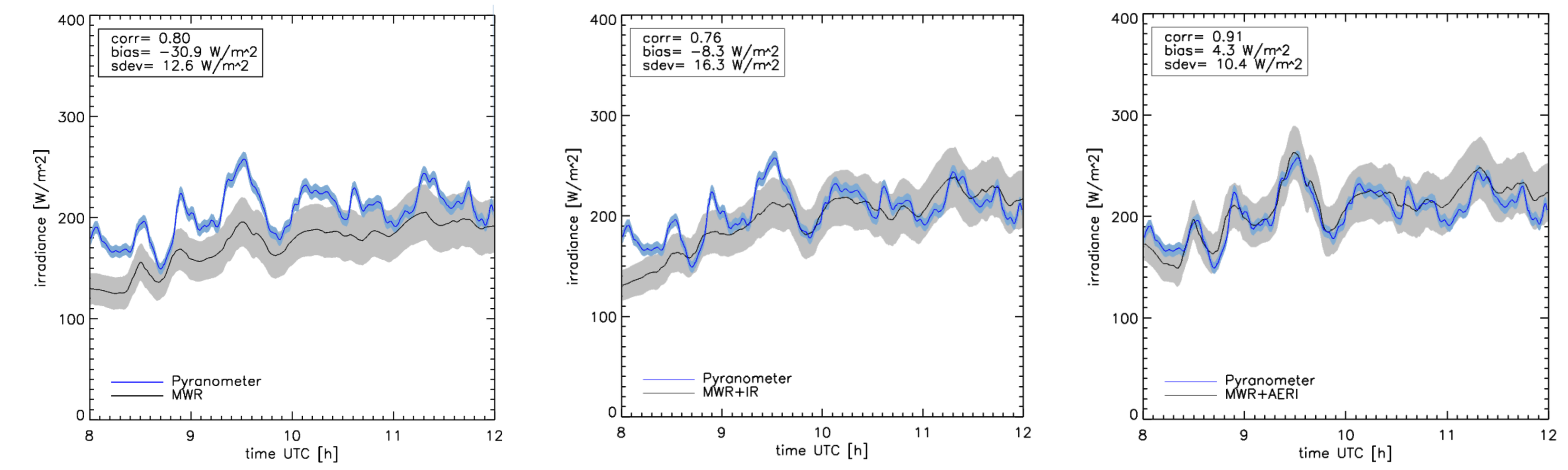


Fig. 9: *Shortwave downwelling fluxes measured by a pyranometer (blue) and simulated by a forward model (grey), using the effective radius and LWP retrievals (left MWR, middle MWR+IR, right MWR+AERI) on 8 Apr 2015, 8-12 UTC*

5. Summary and Conclusions

- The neural network approach provides a robust and fast applicable statistical retrieval algorithm.
- Infrared observations significantly improve the accuracy of the LWP for thin liquid water clouds compared to a MWR retrieval.
- Combination of infrared and microwave observations provides the best retrieval performance for the entire LWP range.
- Highly spectral resolved infrared observations are beneficial compared to the broadband information, especially for retrieving the effective radius.

References:

[1] *Illingworth, A. J., and Coauthors, 2007: Cloudnet: Continuous evaluation of cloud profiles in seven operational models using ground-based observations. Bull. Amer. Meteor. Soc., 88, 883-898.*

[2] *Marchand, R., T. Ackerman, E. D. Westwater, S. A. Clough, K. Cady-Pereira, and J. C. Liljegren, 2003: An assessment of microwave absorption models and retrievals of cloud liquid water using clear-sky data. J. Geophys. Res., 108, 4773.*

[3] *Turner, D. D., and Coauthors, 2007: Thin liquid water clouds their importance and our challenge. Bull. Amer. Meteor. Soc., 88, 177–190.*

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