Revisiting liquid water content retrievals in warm stratified clouds: The „modified Frisch“

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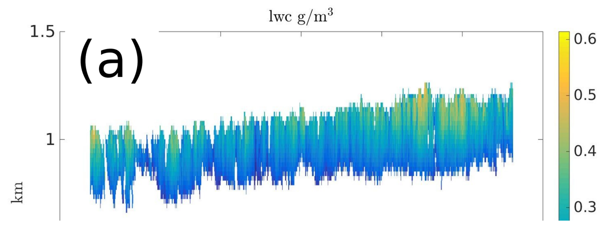
1. Motivation

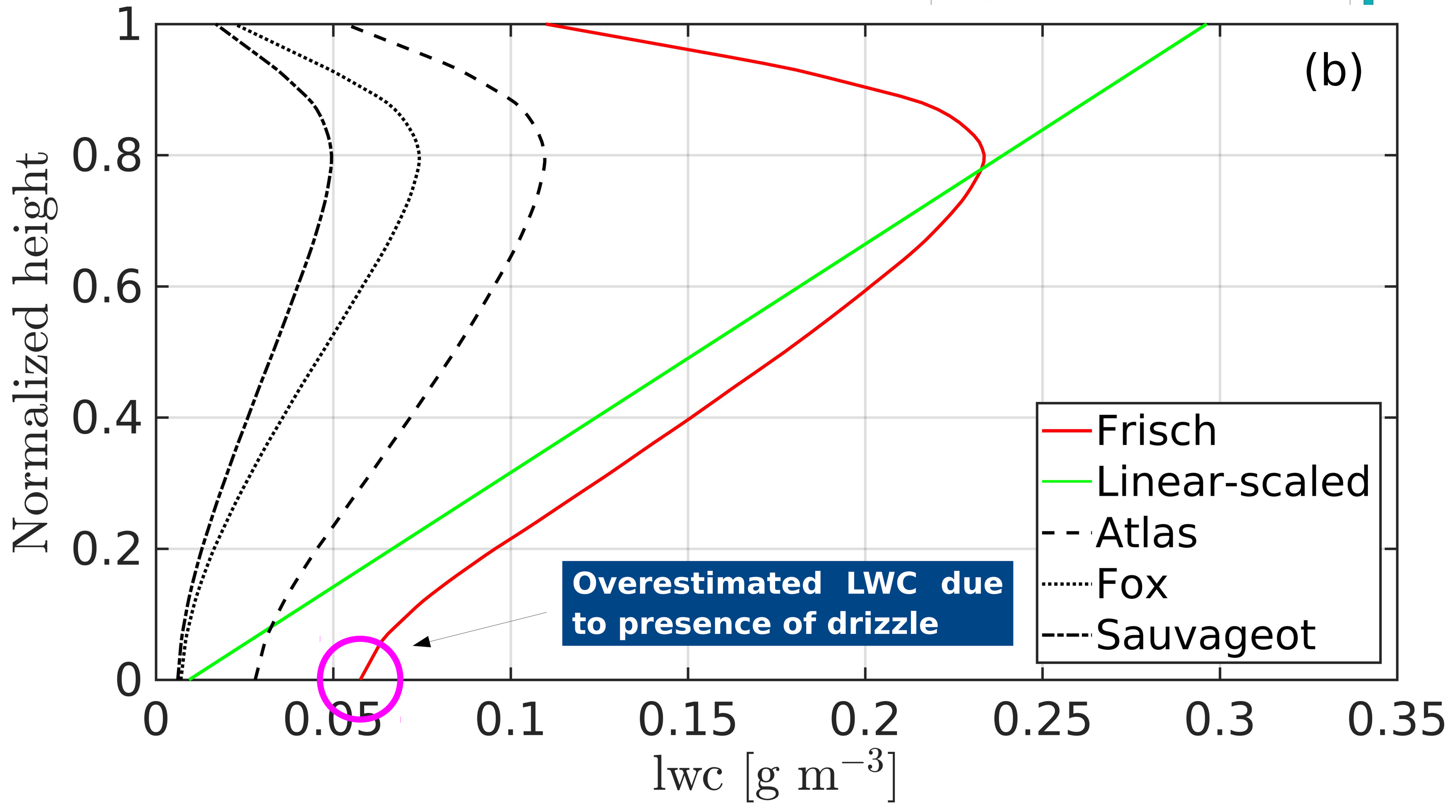
Stratocumulus and stratus clouds cover on average about 46 % of the planet [1] and therefore strongly influence the Earth's radiation budget. However, they are major **uncertainty sources** in numerical **models**. To evaluate models, **accurate measurements** of cloud properties are **needed** as references.

Here, we present a retrieval technique that contributes to solve a **problem** that has been challenging the remote sensing community for several decades: Retrieving **liquid water content** (LWC) **profiles** combining radar and microwave radiometer (MWR) measurements in both **drizzling** and non-drizzling **clouds**.

2. The problem

***Fig. 1**: a) Stratocumulus cloud observed at the Jülich Observatory for Cloud Evolution - Vertical Column. b) Different state-of-the-art LWC retrievals: From radar only (black); from microwave radiometer only (green); combining radar and radiometer (red).*

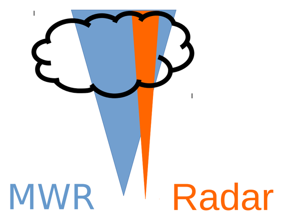




- Current LWC **retrievals differ** strongly.
- LWC retrievals **relating radar reflectivity to LWC**, i.e. relating the 6th moment (~D⁶) of the drop size distribution to the 3rd (~D³), **only** work in the **absence of drizzle**.
- The presence of **drizzle** leads to an **overestimation** (underestimation) **of LWC** at **cloud base** (cloud top).

3. The „modified Frisch"

The "original Frisch" [2] retrieves the **LWC** scaling the integrated **liquid water path** (LWP) from the MWR with the **radar reflectivity** profile (Z_e) with vertical resolution Δz:



$$LWC_i = LWP \frac{\sqrt{Z_e(i)}}{\Delta z \sum_{j=1}^{N} \sqrt{Z_e(j)}} \quad (1)$$

The method conserves the LWP; however, once **drizzle** is present, which generally **weakly contributes to LWC** (~D³) but strongly **influences the reflectivity** (~D⁶), the **LWC** is (heavily) **overestimated**. This usually happens at cloud base, especially, in marine stratified clouds.

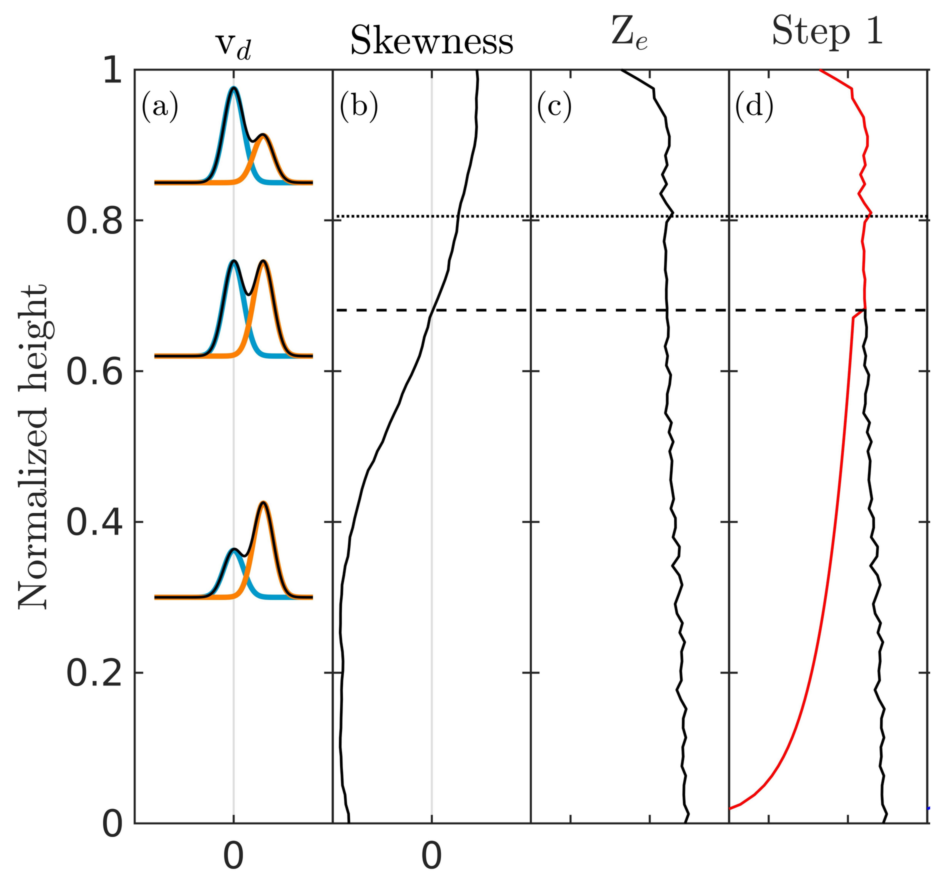


***Fig. 2**: Sketched modified Frisch. a) Exemplary Doppler spectra (black) of a warm cloud with cloud droplets (light blue) and developing drizzle profile (orange). b) Skewness profile of Doppler spectra. c) Integrated reflectivity of Doppler spectra. d) Step 1: Modified reflectivity signal (red) using the original signal above zero-skewness-height (dashed horizontal line) and assuming a linear decrease of the √Z_e to cloud base. Note that the shape is parabolic as only the x-coordinate is plotted in log-space..*

The „modified Frisch" overcomes the „drizzle problem" by

- **identifying** which region of the Z_e profiles is dominated by **drizzle**;
- **modifying** the Z_e **profile** in the contaminated region assuming a linear increase of LWC starting from cloud base;
- **retrieving** the **LWC** profile according to Eq. (1) using the modified reflectivity signal.

4. Results

To test the „modified Frisch", we simulated radar and MWR measurements with PAMTRA [3] for **different LWC profiles** obtained from a bin micro-physical model [4; modified] varying cloud LWP, autoconversion schemes, cloud droplet number concentration and embryonic drizzle sizes.

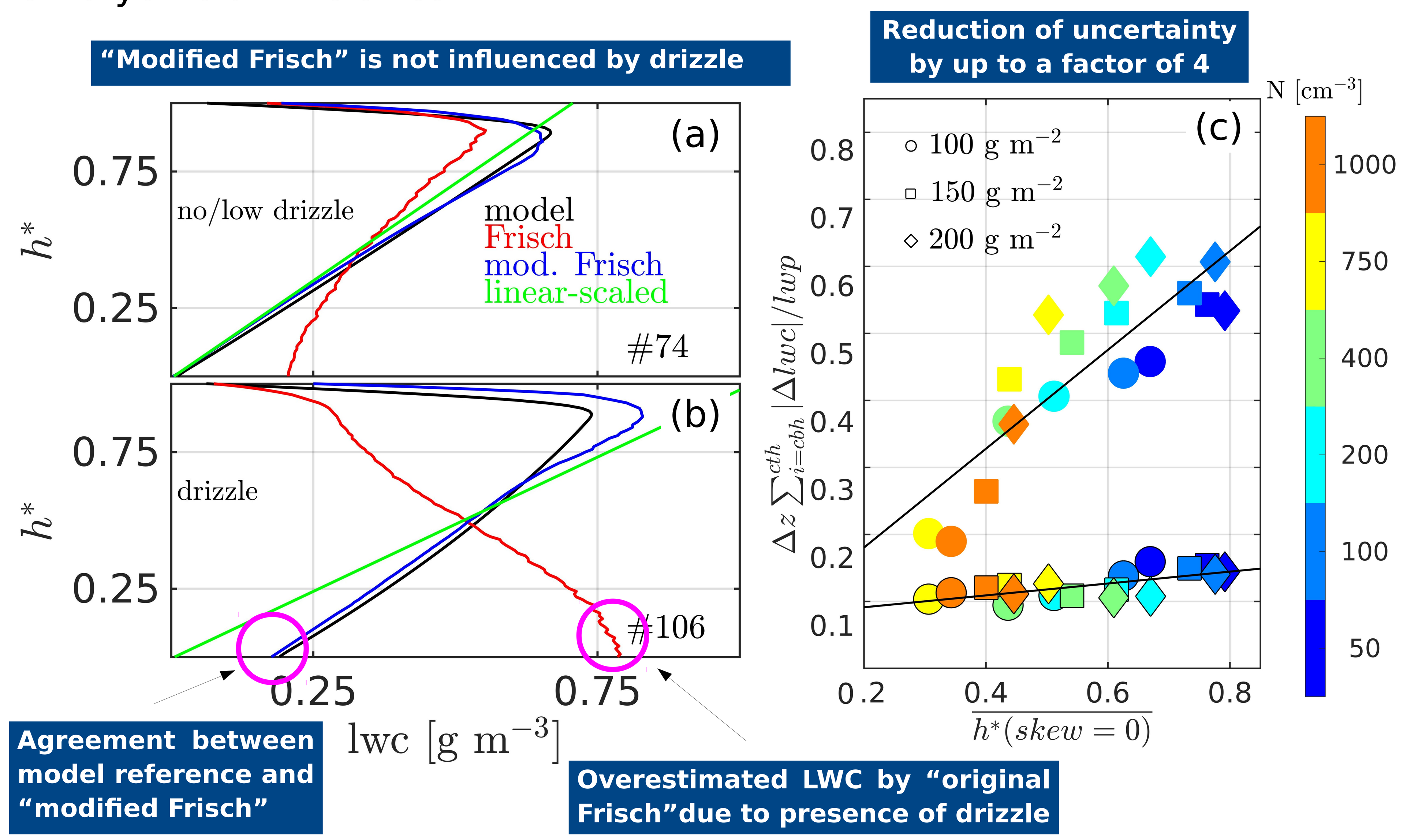


***Fig. 3**: Comparison of mean normalized LWC profiles of different retrieval techniques. a) The linear-scaled method (green; used by CLOUDNET), the „original Frisch" (red) and the „modified Frisch" (blue) versus the model reference (black) for no/low drizzling clouds. The 0 on the y-axes indicates cloud base, 1 indicates cloud top. b) As a) but for drizzling clouds. c) Mean normalized cumulative LWP error with respect to the model reference versus height where skewness is zero (h*(skew=0)), i.e. drizzle starts to dominate Z_e The mean values are separated depending on cloud LWP and cloud droplet number concentration. The "original Frisch" in colored points without edges; the "modified Frisch" colored points with edges.*

5. Conclusion

- The „modified Frisch" provides **accurate** estimates of **LWC profiles** in both **drizzling and non-drizzling clouds**.
- The **error** is **reduced by** up to a **factor of 4** comparing to the „original Frisch".
- The uncertainty increases with increasing LWP (increasing accretion rate) and decreasing number concentration (Twomey effect).

References:

[1] Rossow, W. B., and R. A. Schiffer (1999), Advances in Understanding Clouds from ISCCP, Bulletin of the American Meteorological Society, 80 (11), 2261–2287.

[2] Frisch, A. S., G. Feingold, C. W. Fairall, T. Uttal, and J. B. Snider (1998), On cloud radar and microwave radiometer measurements of stratus cloud liquid water profiles, Journal of Geophysical Research: Atmospheres, 103 (18), 23,195–23,197.

[3] Maahn, M. (2015), Exploiting Vertically Pointing Doppler Radar for Advancing Snow and Ice Cloud Observations, Ph.D. thesis, University of Cologne, URL: http://kups.ub.uni-koeln.de/6002/1/thesis_mmaahn_pub.pdf

[4] Kollias, P., W. Szyrmer, J. Rémillard, and E. Luke (2011), Cloud radar Doppler spectra in drizzling stratiform clouds: 2. Observations and microphysical modeling of drizzle evolution, Journal of Geophysical Research Atmospheres, 116 (13), 1–14.

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