Assessment of ground-based cloud liquid water profiling retrieval techniques

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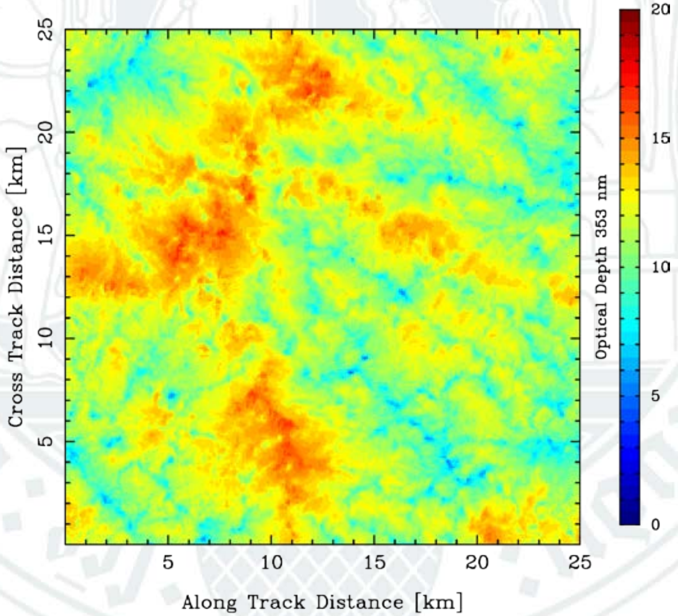


weatherreport.com

European COST action EG-CLIMET

European Ground-based Observations of Essential Variables for Climate and Operational Meteorology

EG-CLIMET: ES-0702 www.eg-climet.org 2008-2012
16 countries, 13 national weather services

MISSION

*To recommend an optimum **European network** of economical and unmanned **ground-based profiling stations** for observing winds, humidity, temperature and **clouds** (together with associated erorrs) for use in **evaluating climate and NWP models** on a global and high resolution (typically 1km) scale and ultimately for **assimilating into NWP**.*

Objective of this study

Evaluate current liquid cloud profiling techniques

- identify errors and discuss assumptions
- correct for errors

→ recommendations for an optimal retrieval method

Simulation case

- "truth" known
- direct evaluation
- need to simulate measurements

ECSIM (EarthCareSimulator)

- radar, lidar, microwave radiometer
- SW, LW fluxes

Real case

- application to real measurements
- evaluation with radiation closure

Overview of measurements and parameters

... measurements which are used ...

Lidar/cloud radar: cloud base & top (Cloudnet TC)

Z: cloud radar reflectivity factor (dBZ)

MWR: brightness temperature TB (K)

LWP: MWR liquid water path (gm^{-2})

... parameters to be retrieved ...

LWC: liquid water content (gm^{-3})

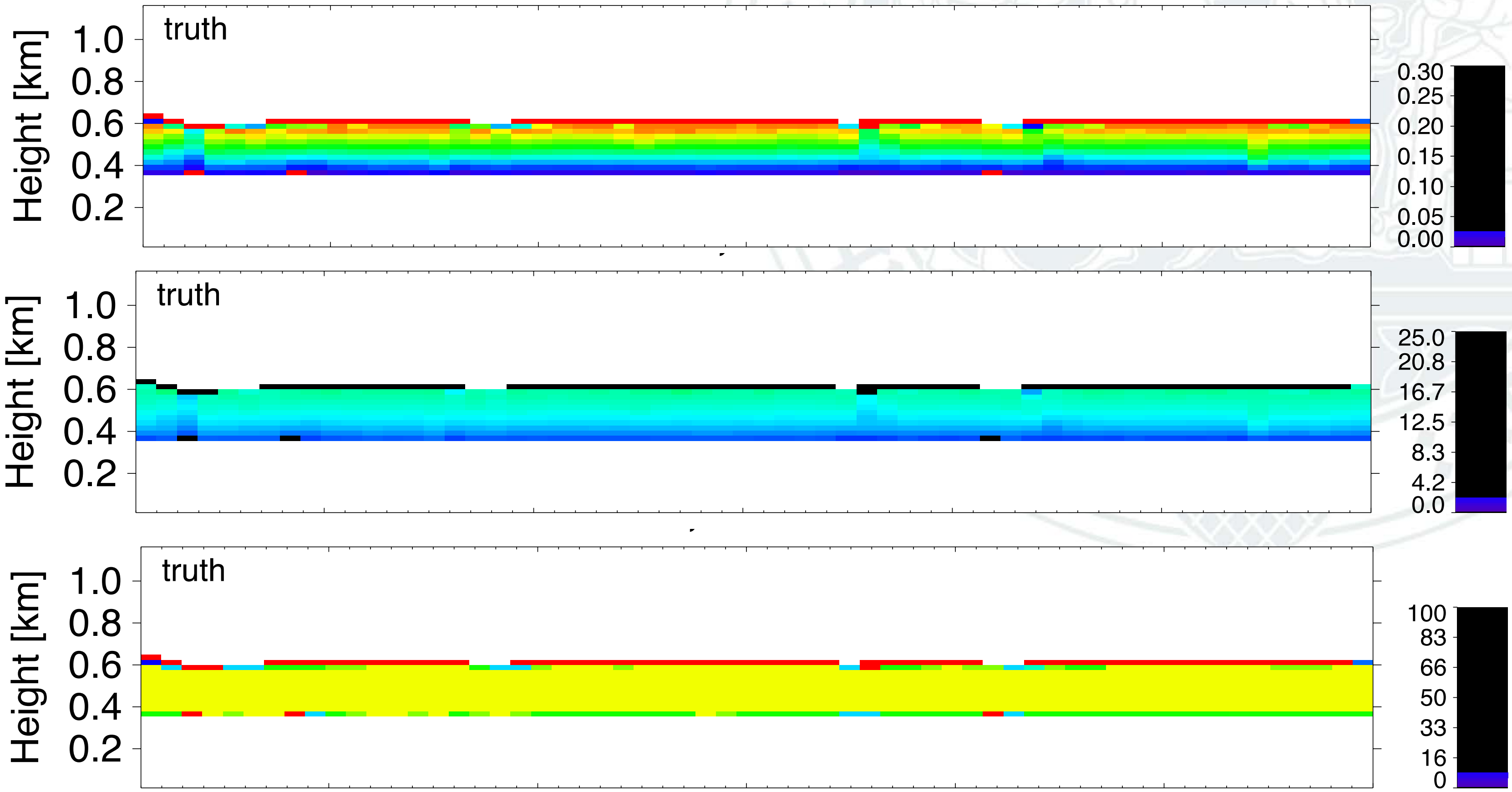
Reff: cloud droplet effective radius (µm)

N_0: cloud droplet concentration (cm^{-3})

Example of two simulated cases

One continental case simulated with LES

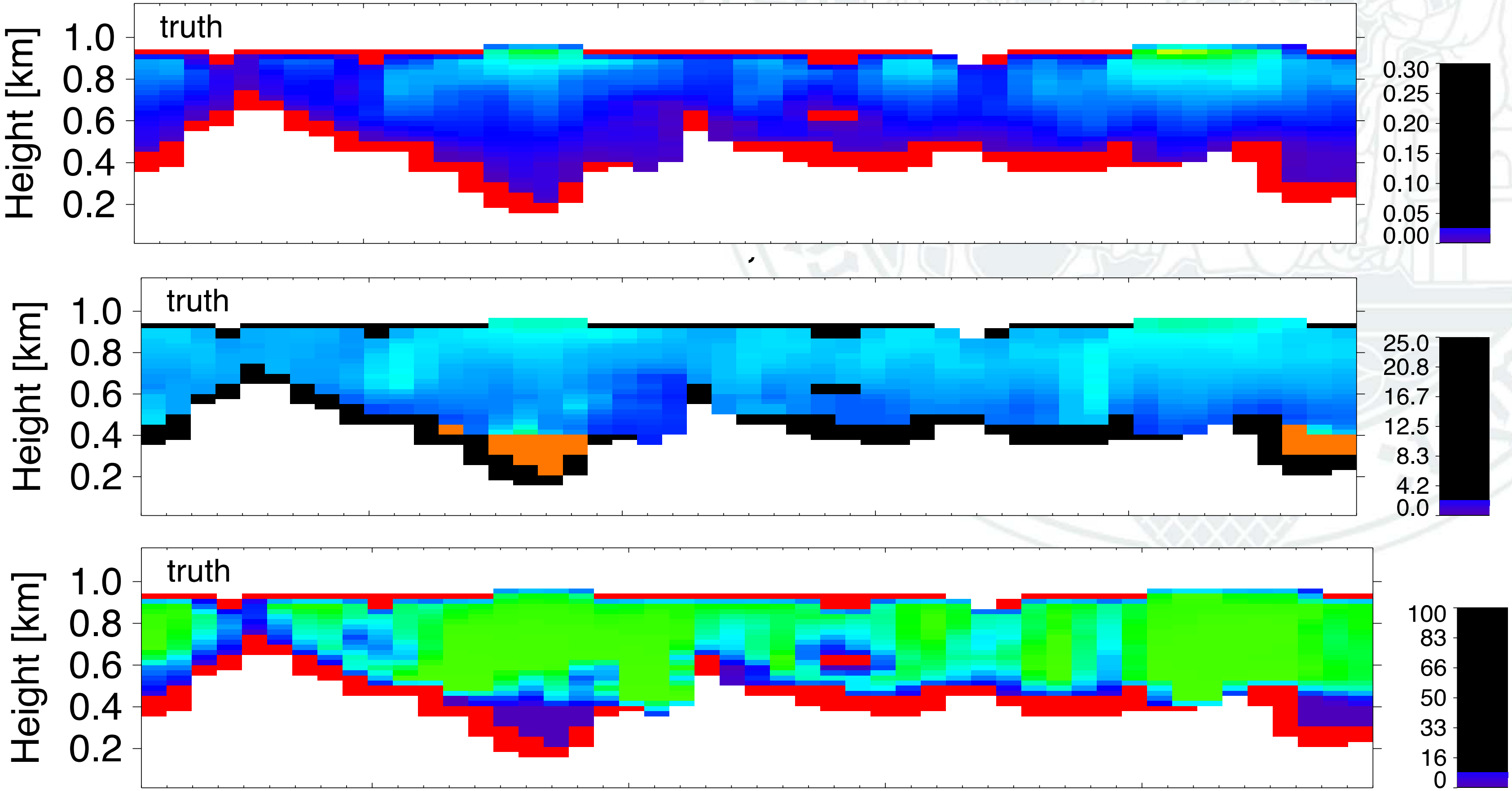
- **CABAUW:** only bulk microphysics (LWC), reasonable drop size distribution assumed (uni-modal), non-drizzling, only liquid



Example of two simulated cases

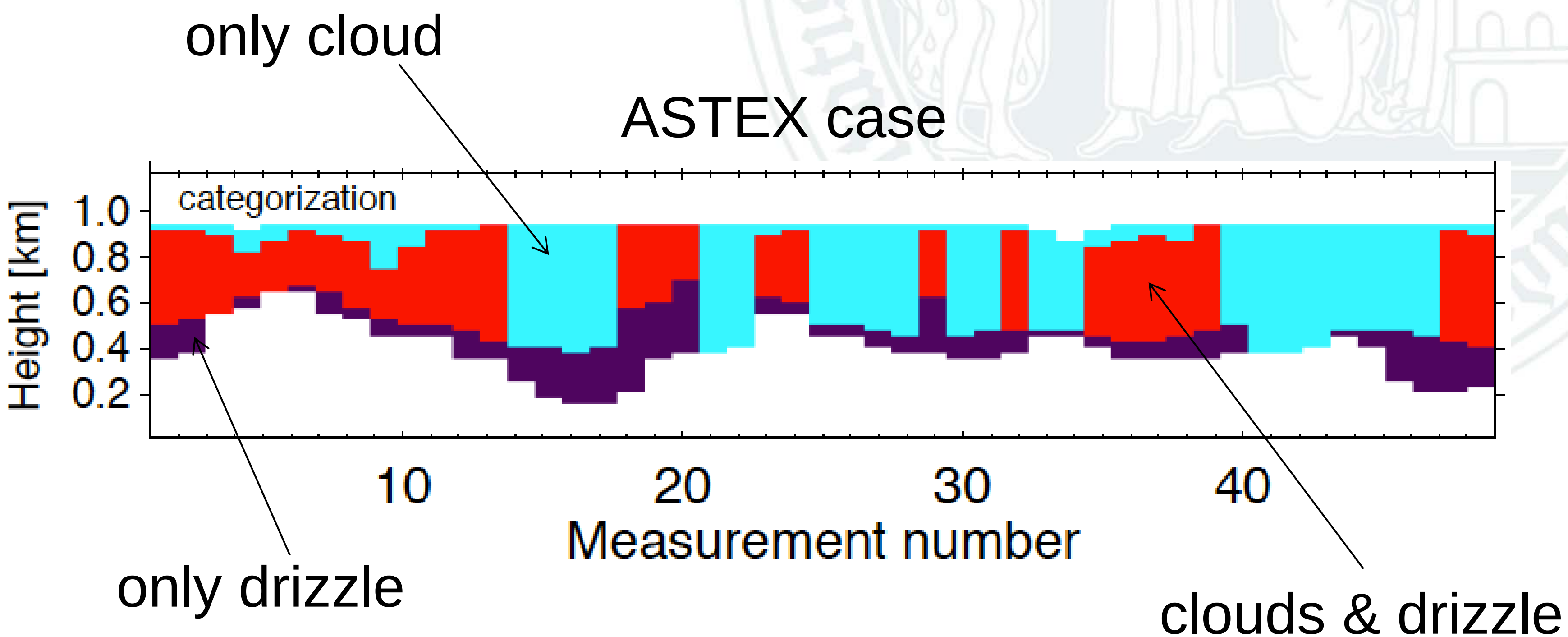
One maritime case simulated with LES

- **ASTEX:** spectrally resolved microphysics, low LWP (< 100 gm^{-2}), partially drizzling, only liquid



Prior categorization of clouds

Cloudnet scheme following Hogan & O'Connor (Univ. of Reading)
•discriminate between thermodynamic phase of water
•precipitating (drizzle) / non-precipitating
•cloud particle detection vs. aerosol and insects



Retrievals

Cloudnet (O'Connor et al.) → retrieve LWC(z)

•*input*: MWR LWP, cloud boundaries & temperature

•linearly scaled adiabatic LWC, non-drizzle

BRANDAU (Brandau et al. / Frisch et al.) → retrieve LWC(z), Reff(z) and N_0

- *input*: MWR LWP and radar Z, cloud boundaries
- uni-modal drop size distribution
- relation between moments (2nd and 3rd) of DSD (Brenguier et al. 2011)

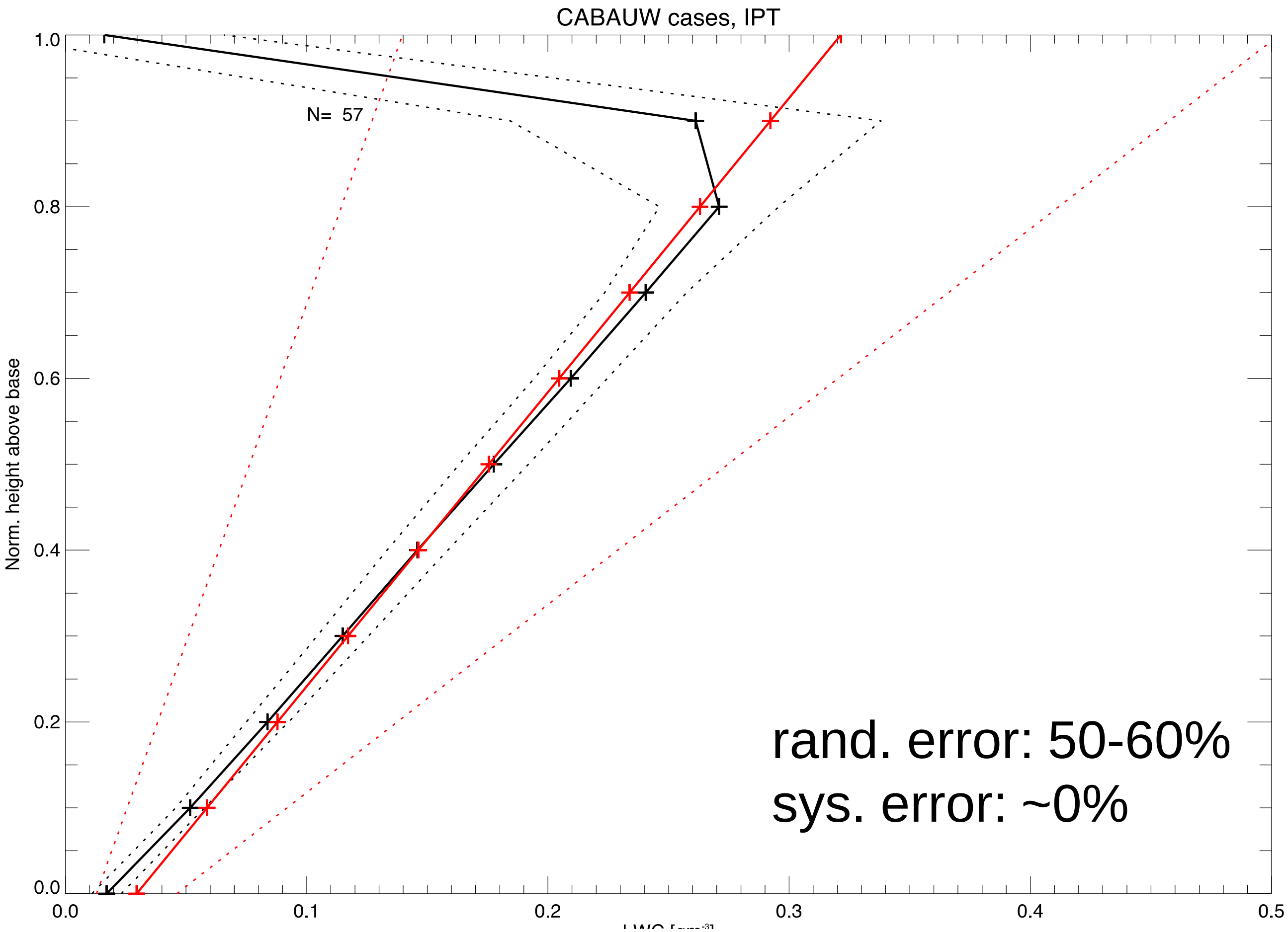
IPT (Löhnert et al. / Ebell et al.) → retrieve LWC(z), Reff(z)

•*input*: MWR TB, radar Z and a priori LWC, cloud boundaries, cloudnet TC

•minimize cost function to meet TB, LWC a priori profiles and radar Z-LWC relation, Reff accoring to Frisch et al. (2002)

All retrievals use common "measurements" and cloud boundaries

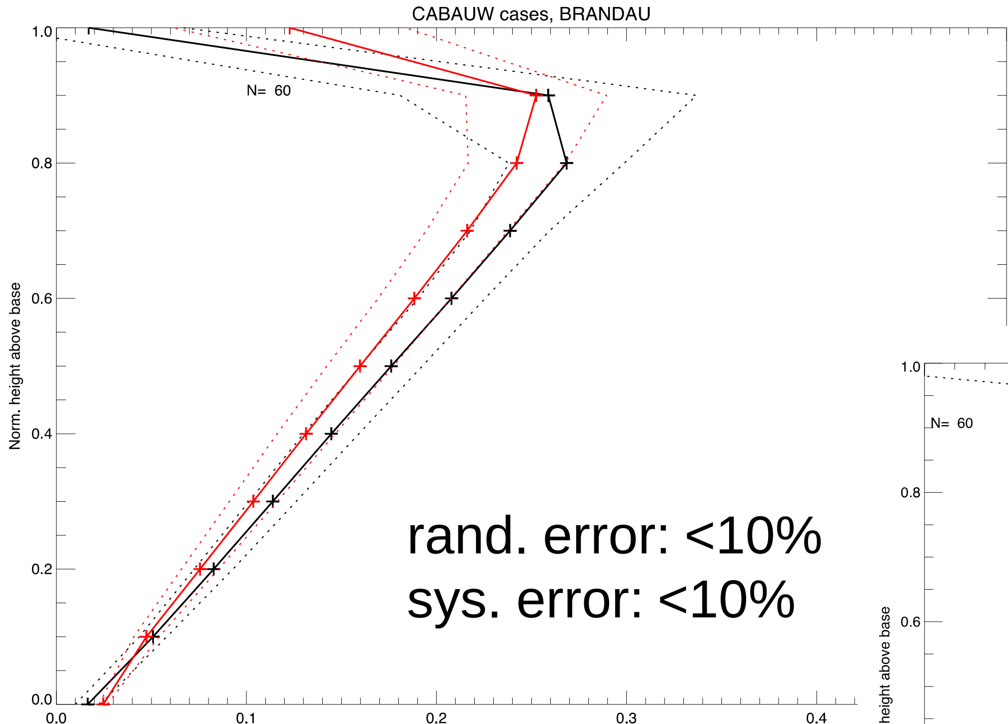
CABAUW case: Cloudnet



LWC / gm^{-3}

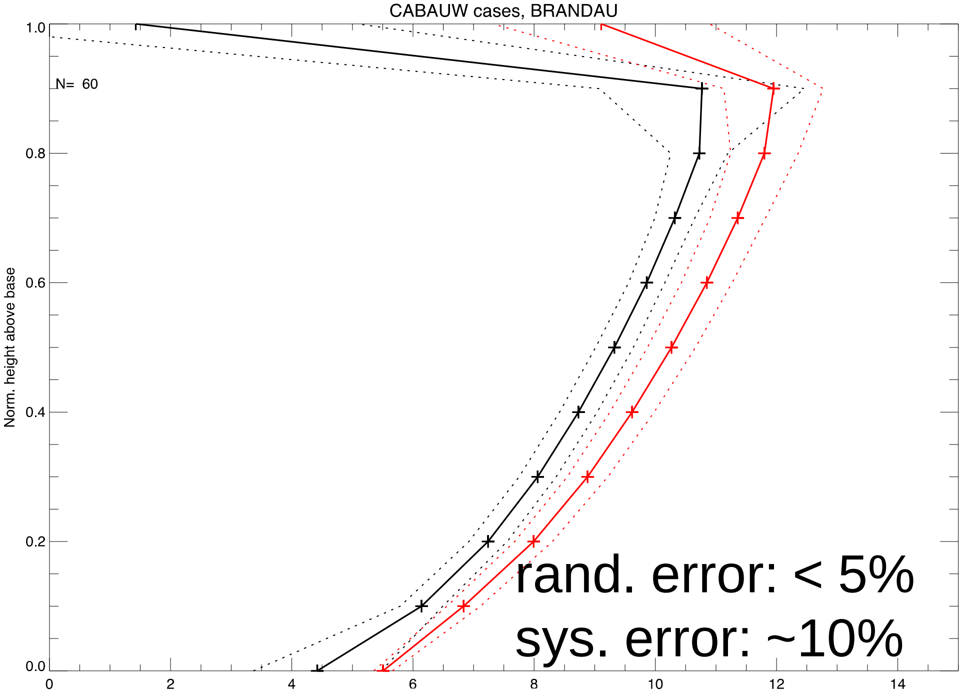
- large random error due to linear scaling

CABAUW case: Brandau LWC & Reff



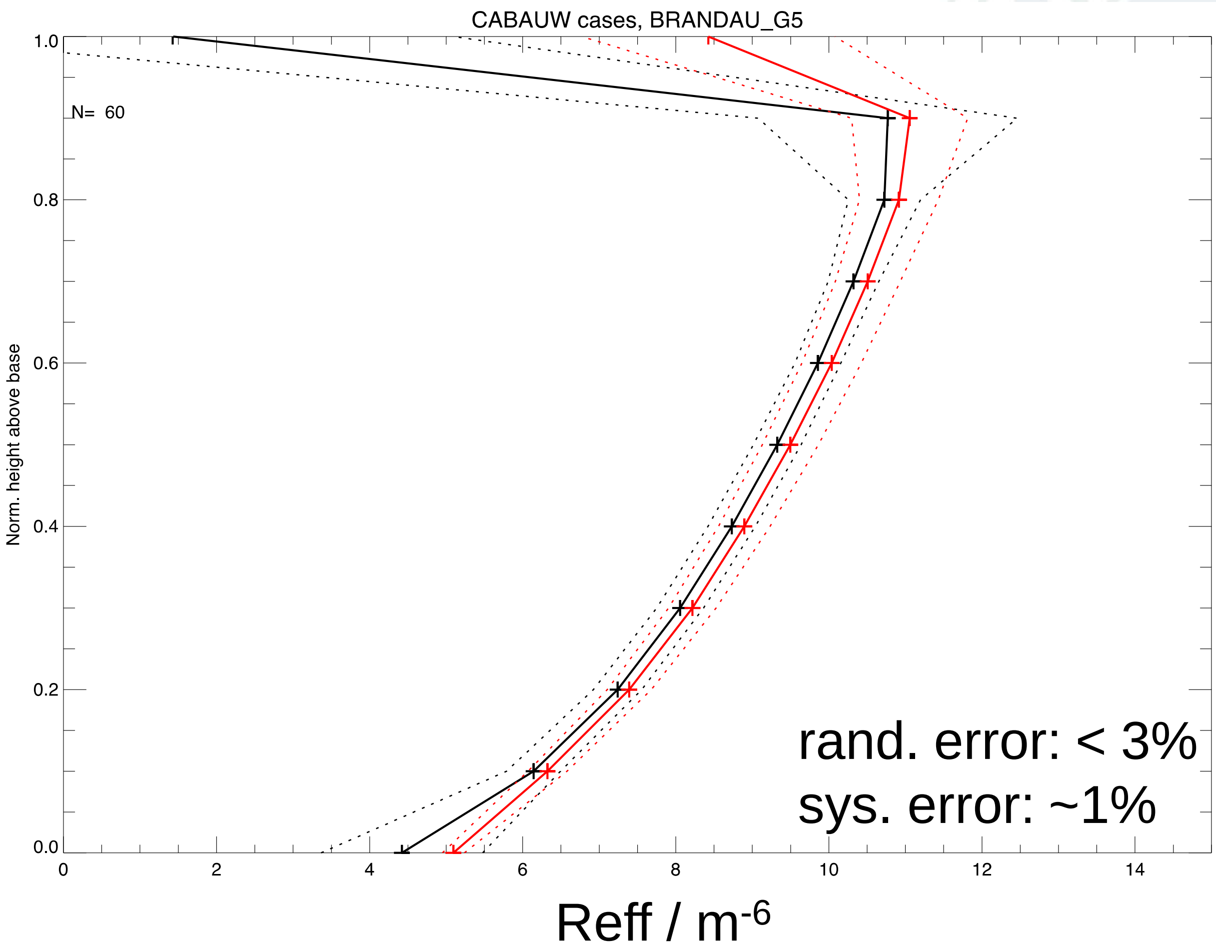
LWC / gm^{-3}

red: retrieval
black: „truth“



Reff / m^{-6}

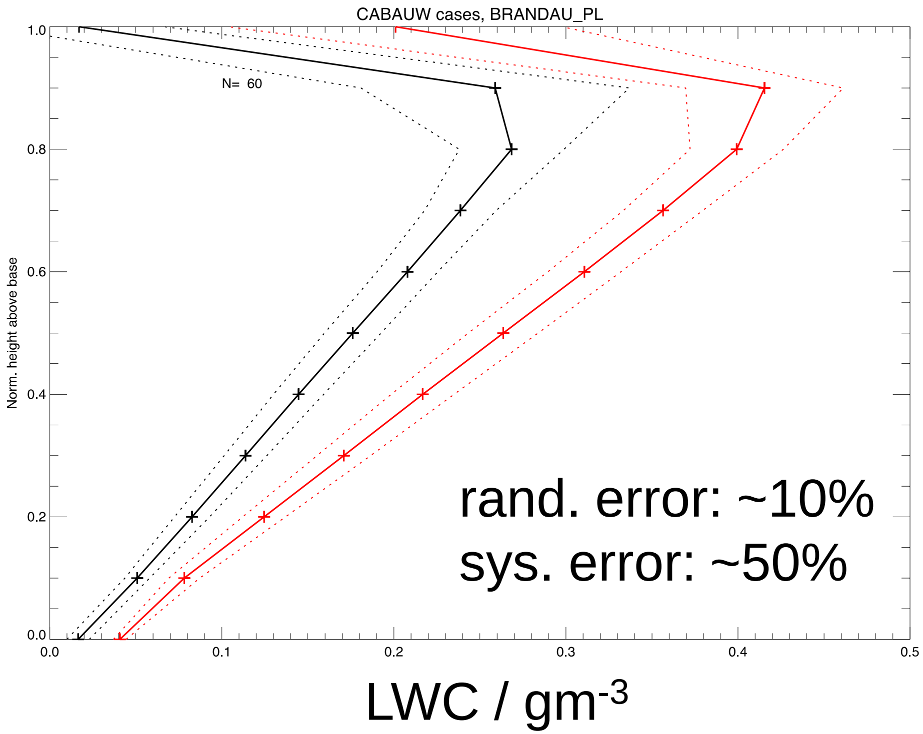
CABAUW case: „optimized“ Brandau



red: retrieval
black: „truth“

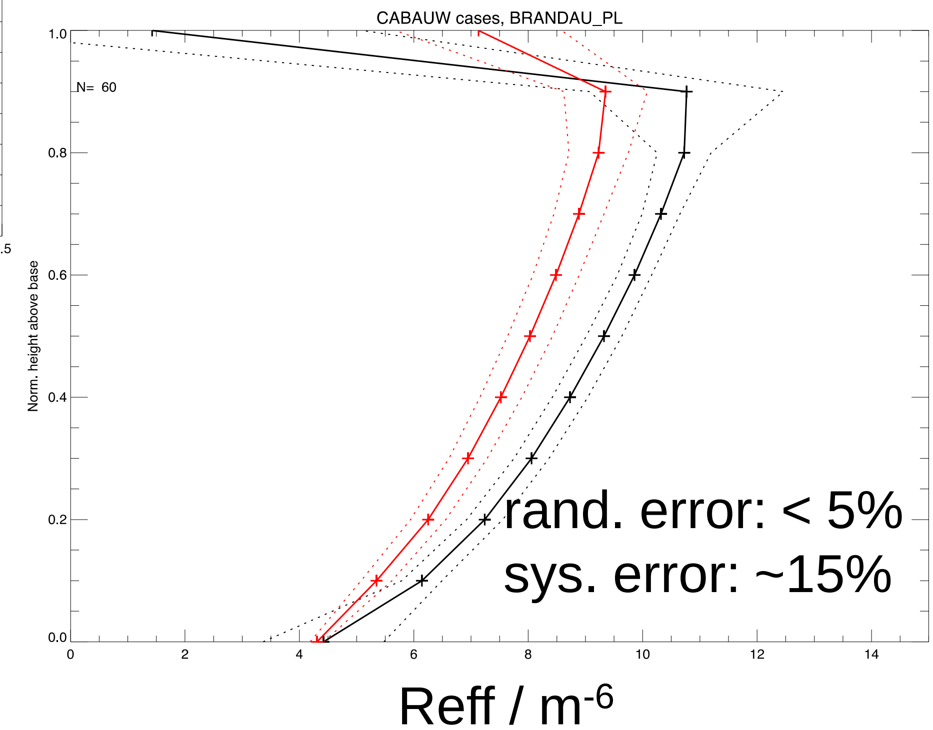
relative dispersion of DSD adapted to LES output
→ Reff (and N_0) improvement

CABAUW case: Brandau with LWP error



LWP error: +25 gm^{-2}

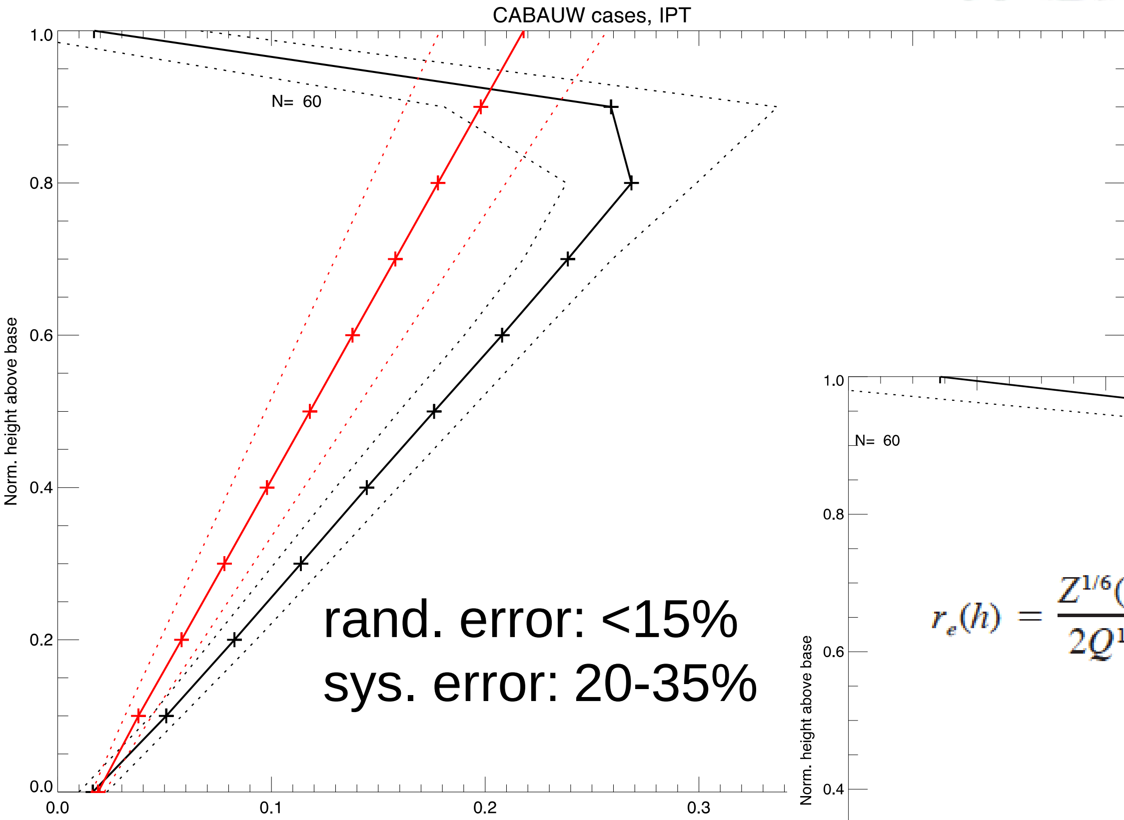
(20 < LWP < 50 gm^{-2})



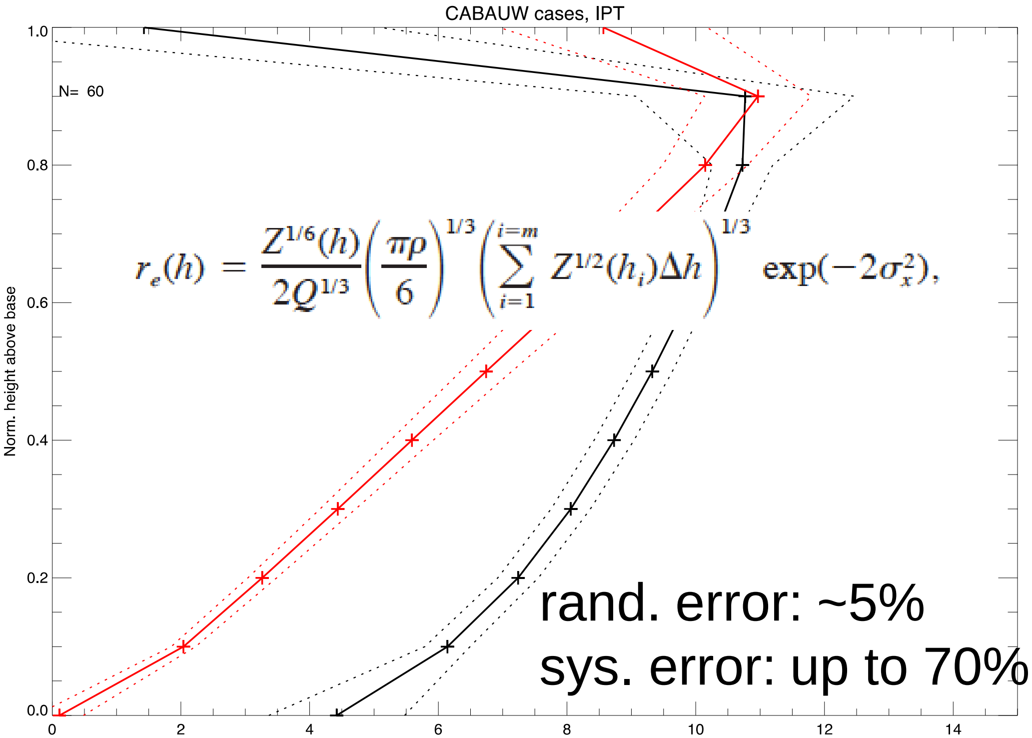
LWP accuracy crucial!

CABAUW case: IPT LWC & Reff

red: retrieval
black: „truth“



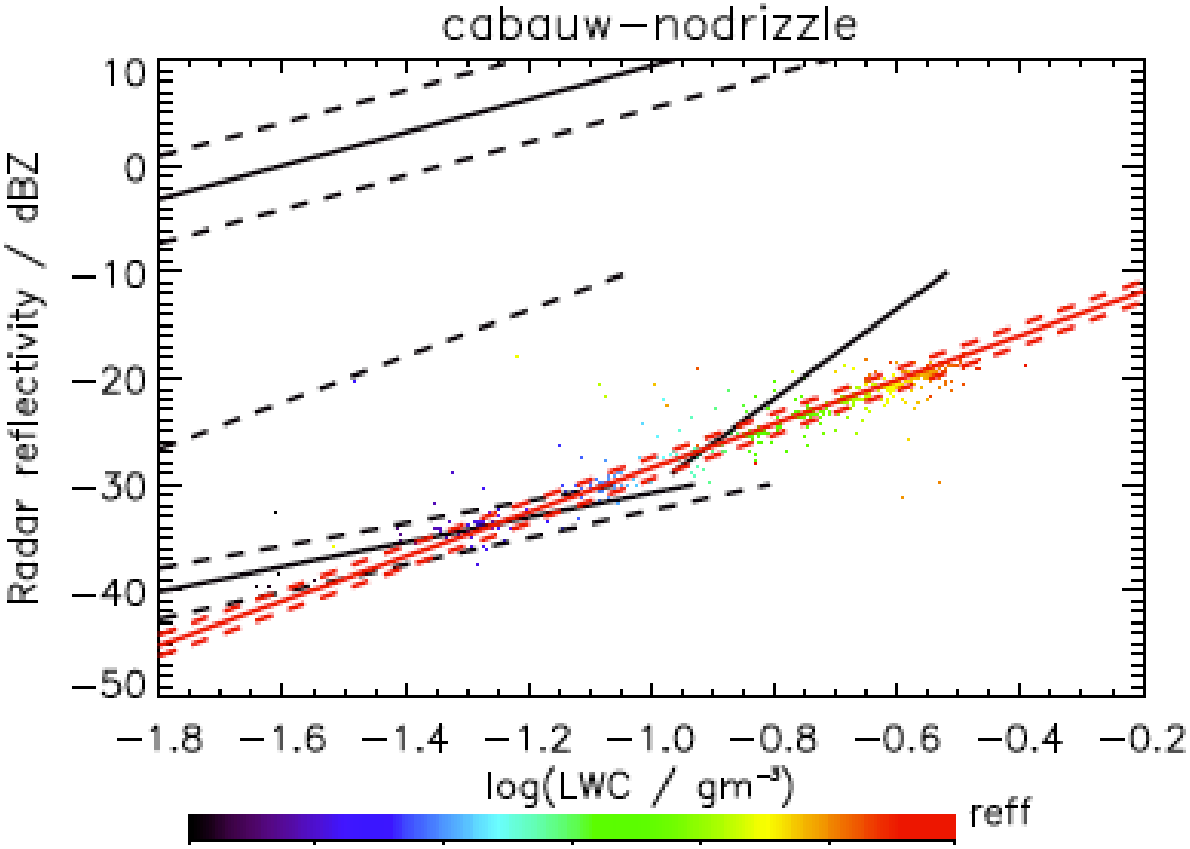
rand. error: <15%
sys. error: 20-35%



$$r_e(h) = \frac{Z^{1/6}(h)}{2Q^{1/3}}\left(\frac{\pi\rho}{6}\right)^{1/3}\left(\sum_{i=1}^{i=m} Z^{1/2}(h_i)\Delta h\right)^{1/3} \exp(-2\sigma_x^2),$$

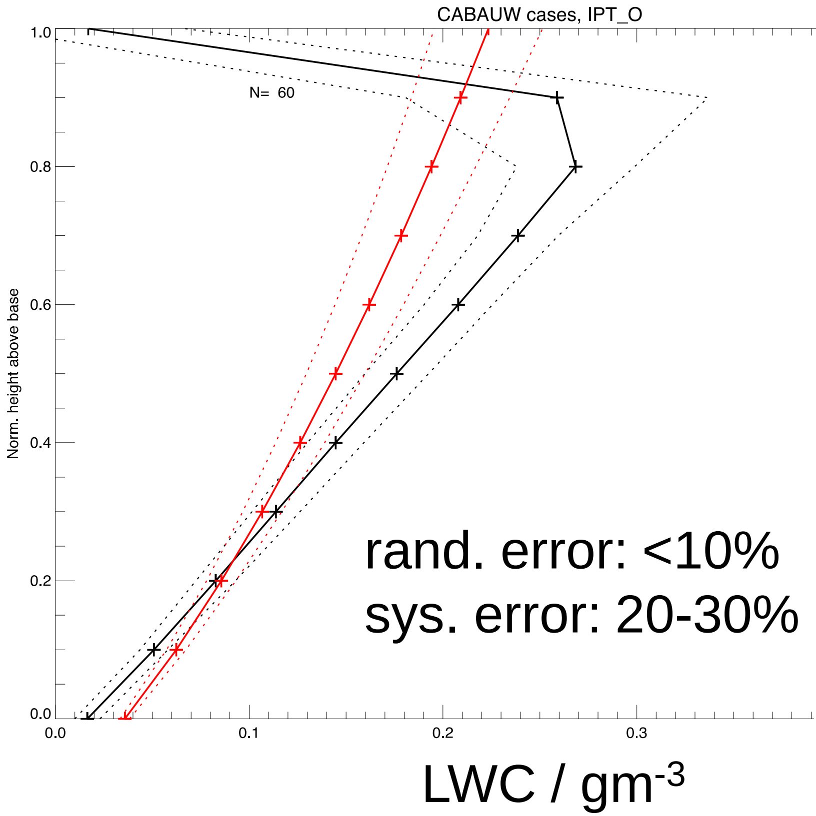
rand. error: ~5%
sys. error: up to 70%

CABAUW case: „optimize“ IPT

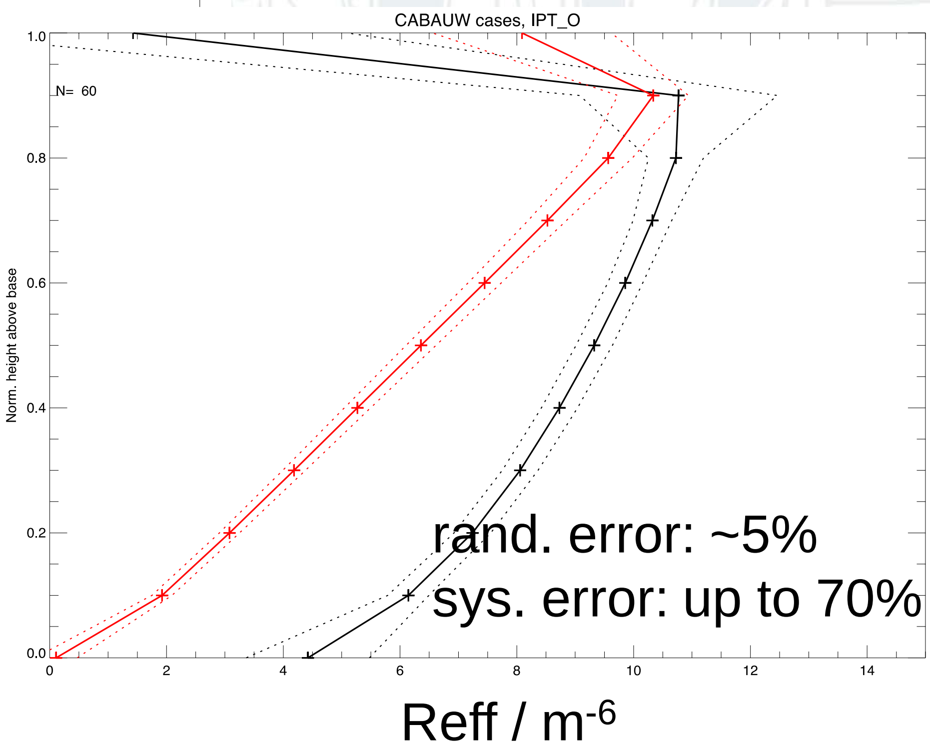


black: original IPT Z-LWC relations
red: to LES output adjusted Z-LWC relations

CABAUW case: IPT „optimized“

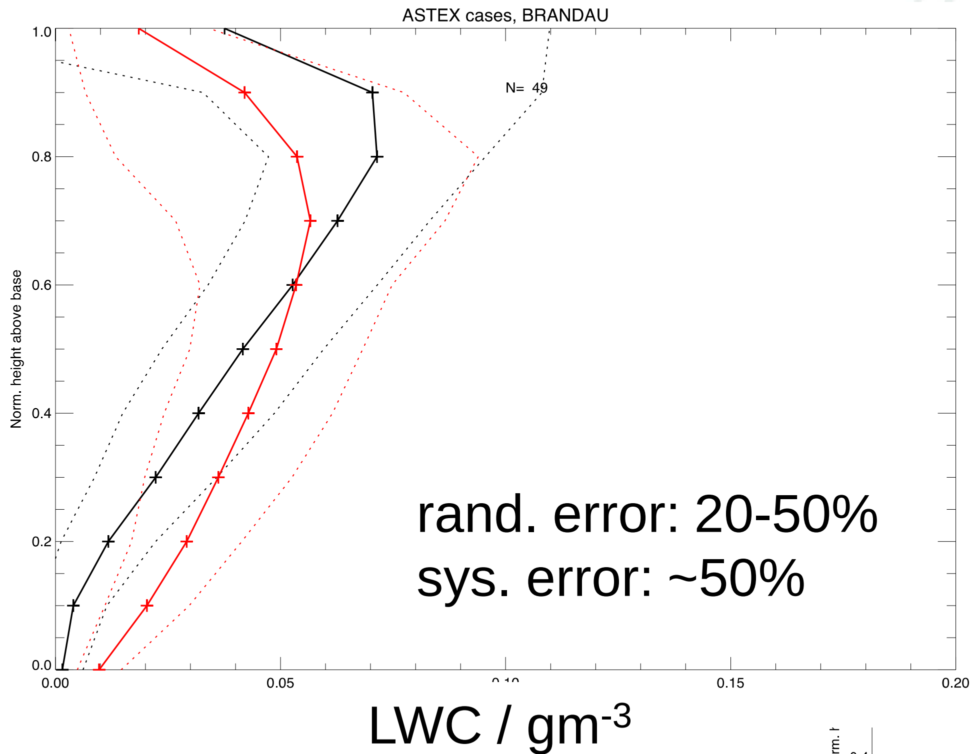


red: retrieval
black: „truth“

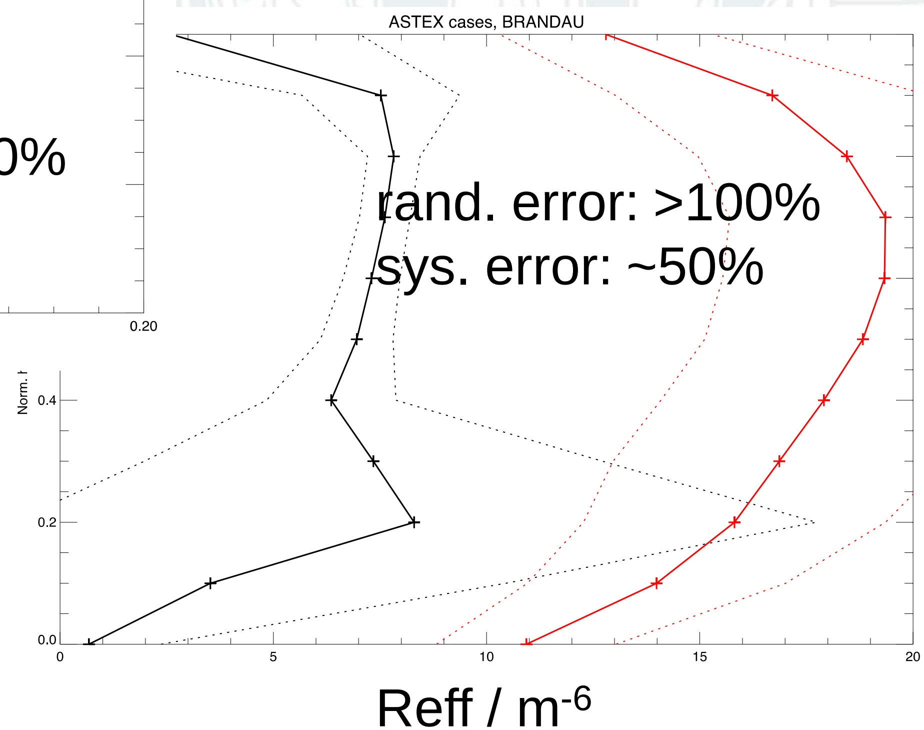


no significant improvement
→ IPT dominated by LWC a priori profile

ASTEX: Brandau



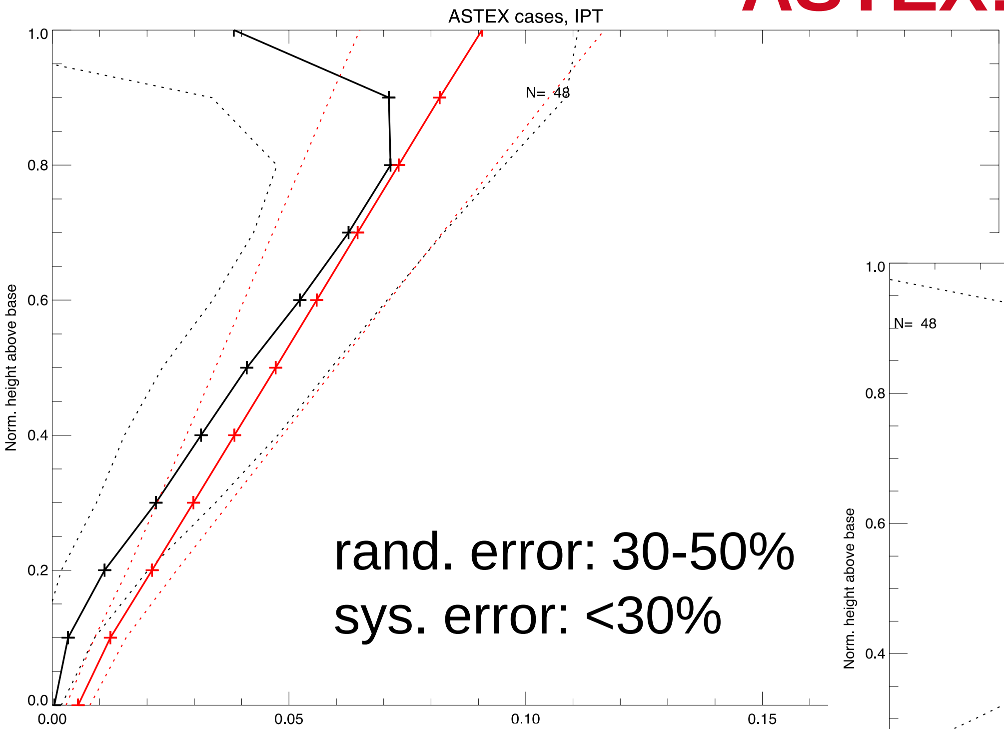
red: retrieval
black: „truth“



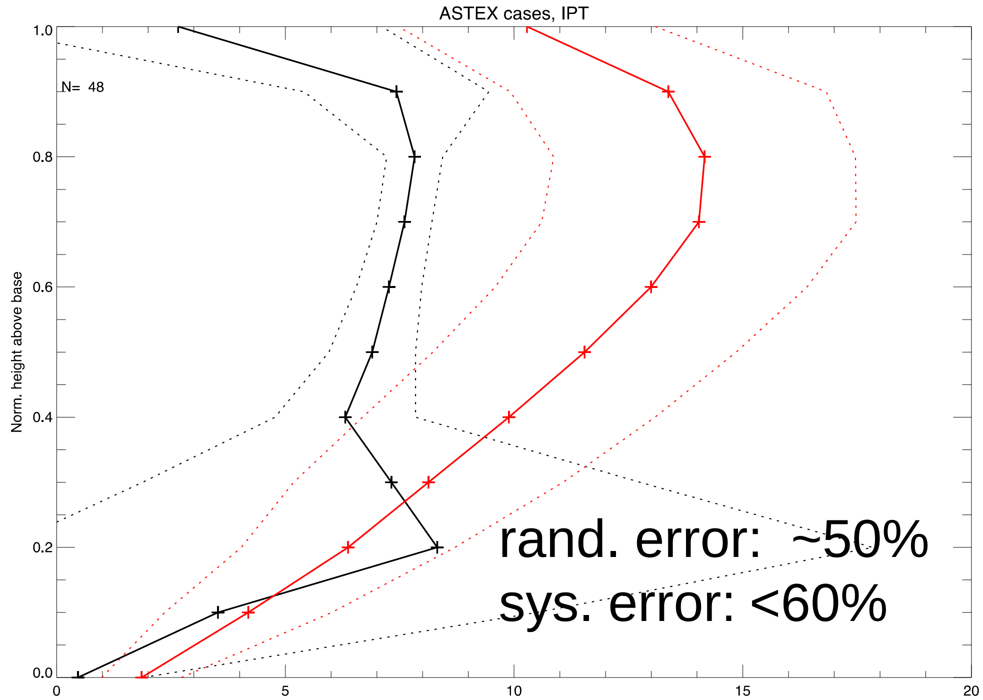
- drop size distribution no longer uni-modal → small number of drizzle droplets lead to Reff overestimation

ASTEX: IPT

red: retrieval
black: „truth“



LWC / gm^{-3}



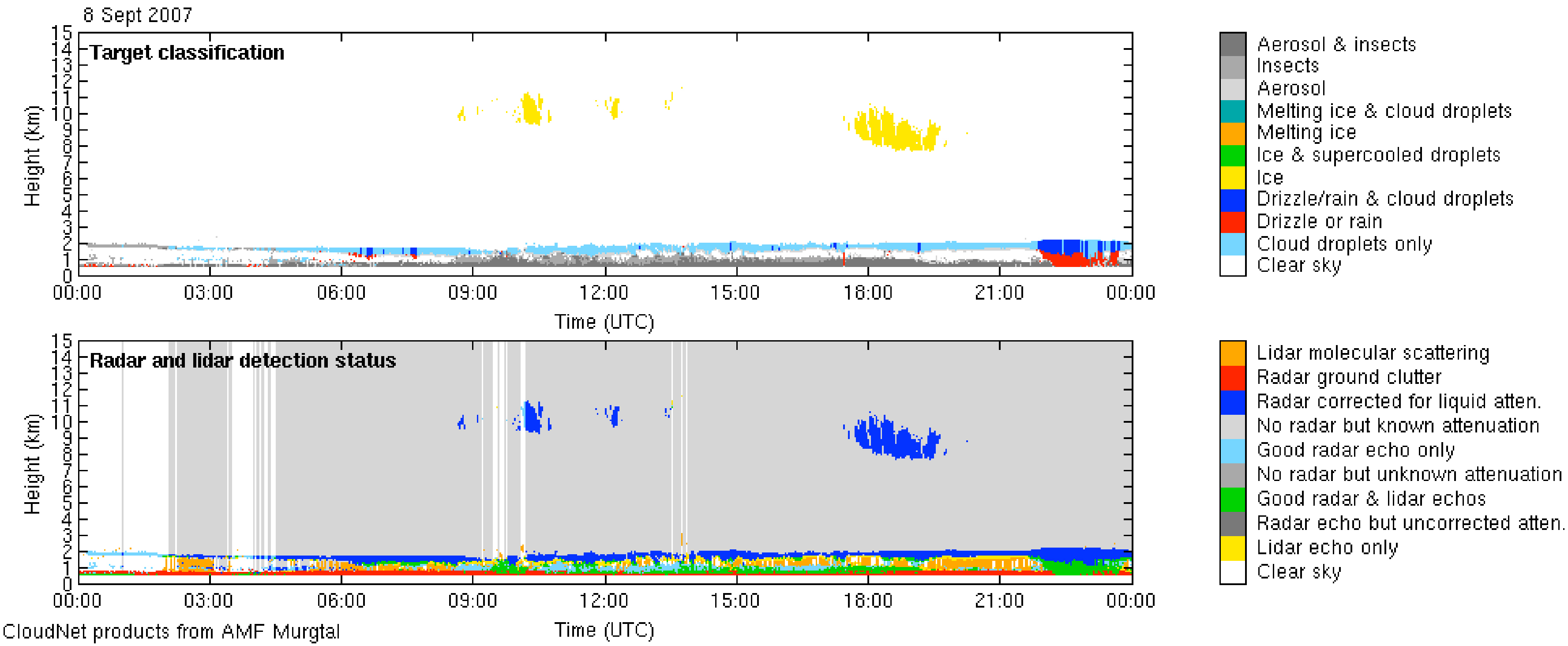
Reff / m^{-6}

- fairly robust LWC profile in drizzle „contaminated“ region

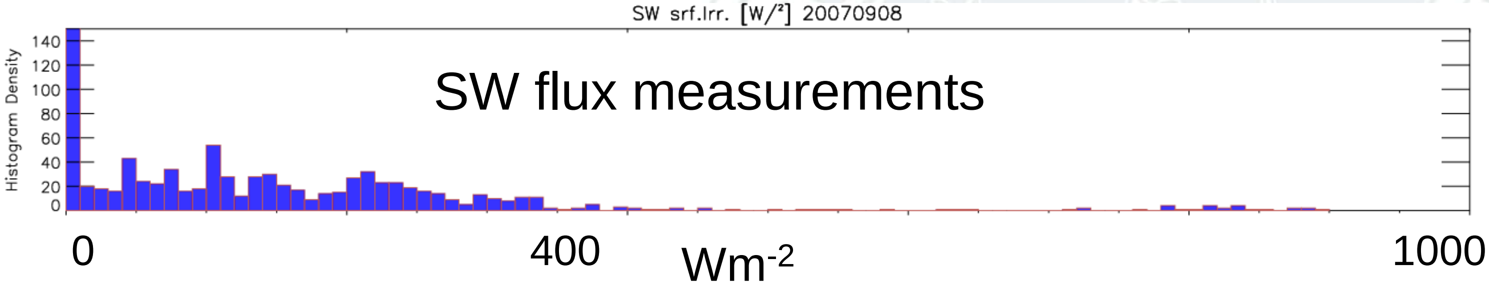
Real measurements

2007 ARM mobile facility COPS (Black Forest) deployment

→ 8.9.07: *uniform stratus cloud deck* (non-precipitating) with LWP up to 400 gm^{-2}



Application to real data: radiative closure study



Summary

- correct cloud categorization is essential for all retrieval approaches!
- for uni-modal case (CABAUW)
  - CLOUDNET: bias OK, large random error (50-60% in LWC)
  - BRANDAU & IPT: acceptable LWC accuracies (10-30%)
  - BRANDAU shows good Reff performance (10-15%)
  - accurate LWP retrieval essential for BRANDAU
  - IPT a prioi assumptions significantly determine shape of LWC profile (bias probem)
- for drizzle case (ASTEX)
  - systematic overestimation (underestimation) of Reff (N_0)
  - however, LWC „robust“

Outlook

- carry out longer-term radiative closure experiments
- adjust physical constraints within the algorithm depending on situation (e.g. non-drizzle/drizzle)
- implement more realistic a priori assumptions
- employ higher moments or full spectra from Doppler cloud radar
- 1DVAR retrieval combining different retrieval approaches
- trans-Atlantic cooperation…

Retrieval workshop

EU / DOE Ground-based Cloud and Precipitation Retrieval Workshop
13-14 May 2013, University of Cologne, Germany

Workshop Objective:
Advance algorithm development and uncertainty quantification for retrieving cloud and precipitation properties from ground-based remote sensors through international scientific collaboration and data sharing.

Workshop Outcomes:
- Identify common algorithm frameworks and paths forward for improving and/or implementing retrieval algorithms across EU and ARM observing stations.
- Identify common algorithm evaluation approaches that will be used for algorithm development and uncertainty quantification.
- Identify geophysical variables that can be commonly retrieved and shared across the EU and ARM observing stations through a data portal.

Retrieval workshop

Suggested Agenda Topics:

- Retrieval algorithm frameworks
- Prior information datasets
- Forward models
- Retrieval algorithm uncertainties
- Initial and final data products
- Web-based project management system

Workshop format:

Before the workshop, participants will fill out a 1-page form that describes their background, the retrieval method they are applying (evaluating) and the salient details about it (prior information, assumptions, forward model, etc…) and upload these to a common area at least one week prior to the workshop for all to read beforehand. Each agenda topic will start off with a short presentation from an expert in the field that is designed to identify key approaches and issues, and will help guide participant discussion. Most time will be spent on discussion and identification of key action items under each topic.

Sensitivity summary IPT

LWC prior
dominates radar; can
create bias

robust LWC in
drizzle

IPT

need better LWC
prior (level to level
covariances)

Reff according to
Frisch, mono-modal,
LWP_{IPT} dependent, fixed
dispersion

Sensitivity summary BRANDAU

only mono-modal
(LWC robust, Reff not)

LWC very LWP sensitive

BRANDAU

rather insensitive to dispersion and Z

cloud boundaries need to be well characterized

Sensitivity summary BRANDAU

high random uncertainty

LWC very LWP sensitive

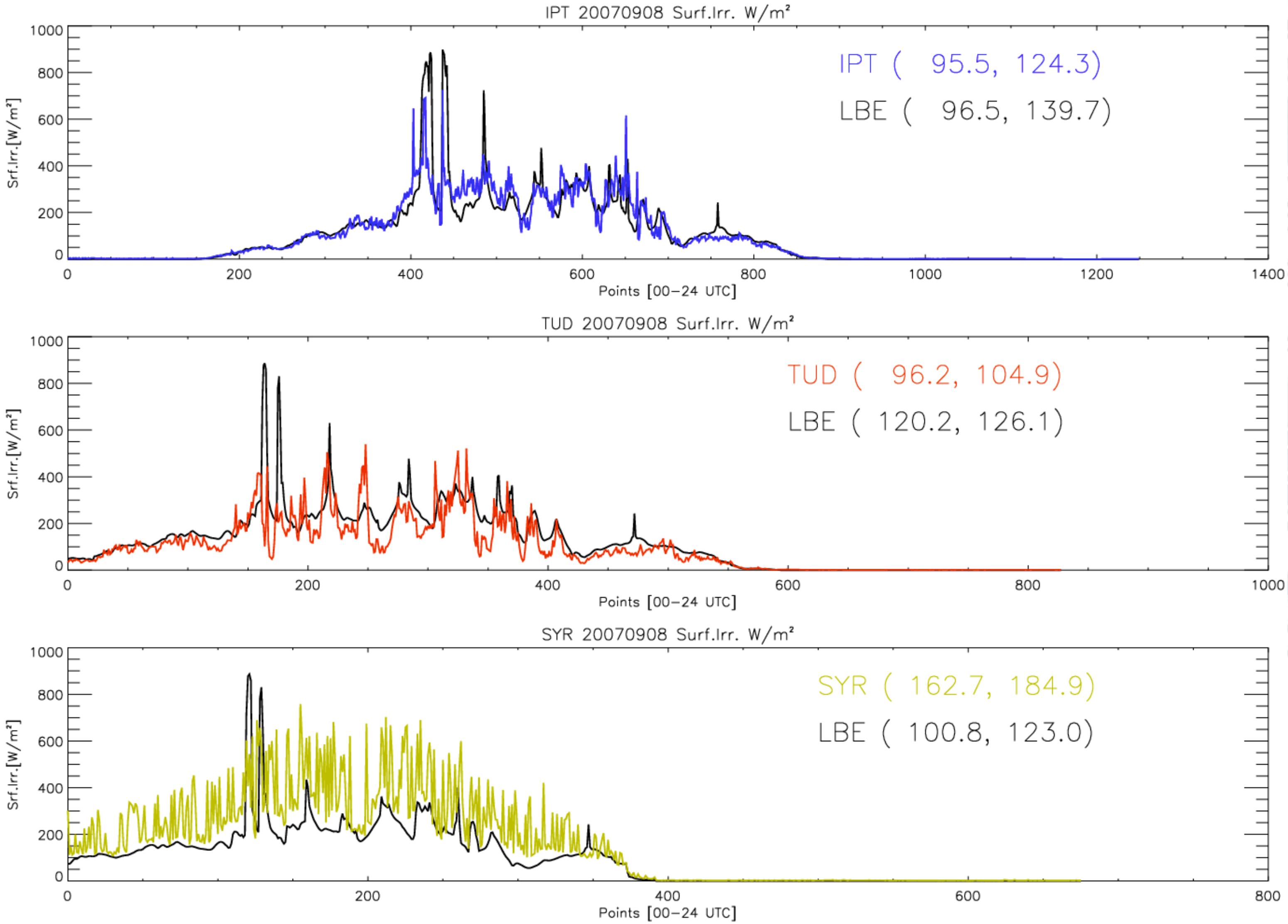
CLOUDNET

linear profile

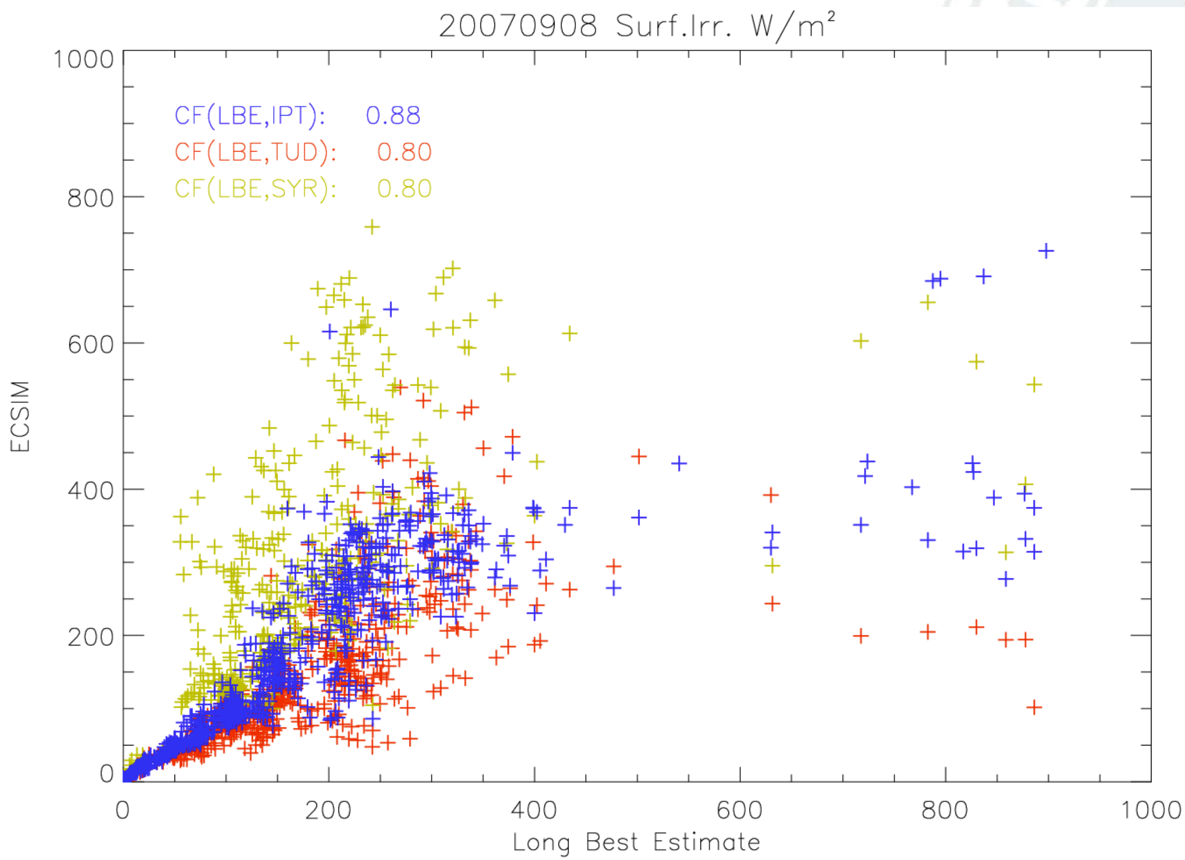
Overview of algorithms & cases

	ASTEX	FIRE	CABAUW	CABAUW_driz
Cloudnet	lwp lwpp25 lwpm25	lwp lwpp25 lwpm25	lwp lwpp25 lwpm25	lwp lwpp25 lwpm25
Brandau	lwp_g87 lwp_g5 lwpm25_g87 lwpp25_g87 zm05_g87 zp05_g87	lwp_g87 lwp_g5 lwpm25_g87 lwpp25_g87 zm05_g87 zp05_g87 zp05_g5	htrue_g5 lwp_g87 lwp_g5 lwpm25_g87 lwpp25_g87 zm05_g87 zp05_g87	lwp_g87 lwp_g5 lwpm25_g87 lwpp25_g87 zm05_g87 zp05_g87
IPT	ipt_stand ipt_opti	ipt_stand ipt_opti	ipt_stand ipt_opti	ipt_stand ipt_opti
SYRSOC	lwp lwpp25 lwpm25	lwp lwpp25 lwpm25	lwp lwpp25 lwpm25	lwp lwpp25 lwpm25

Real data: radiative closure 20070908

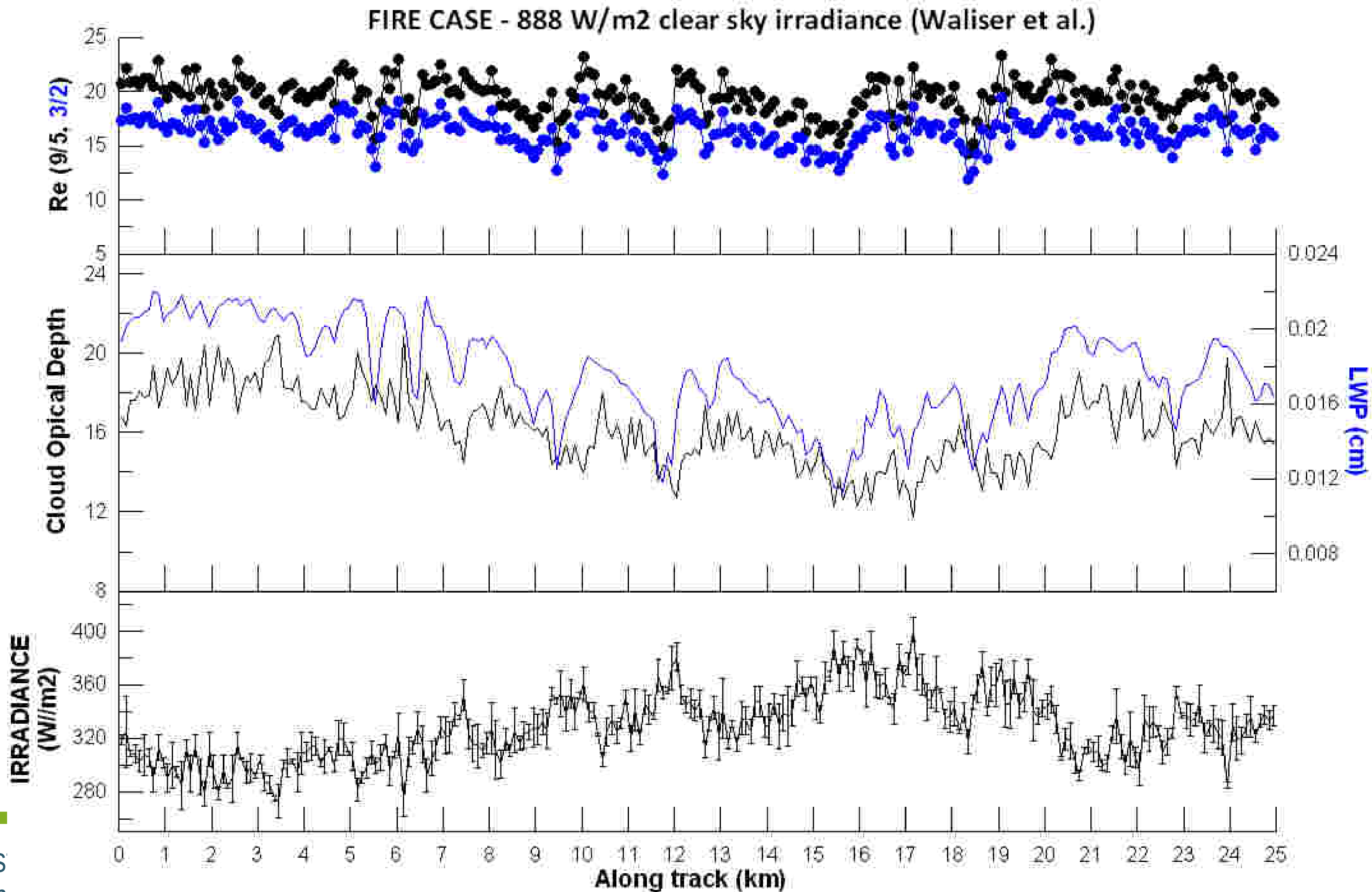


Real data: radiative closure 20070908

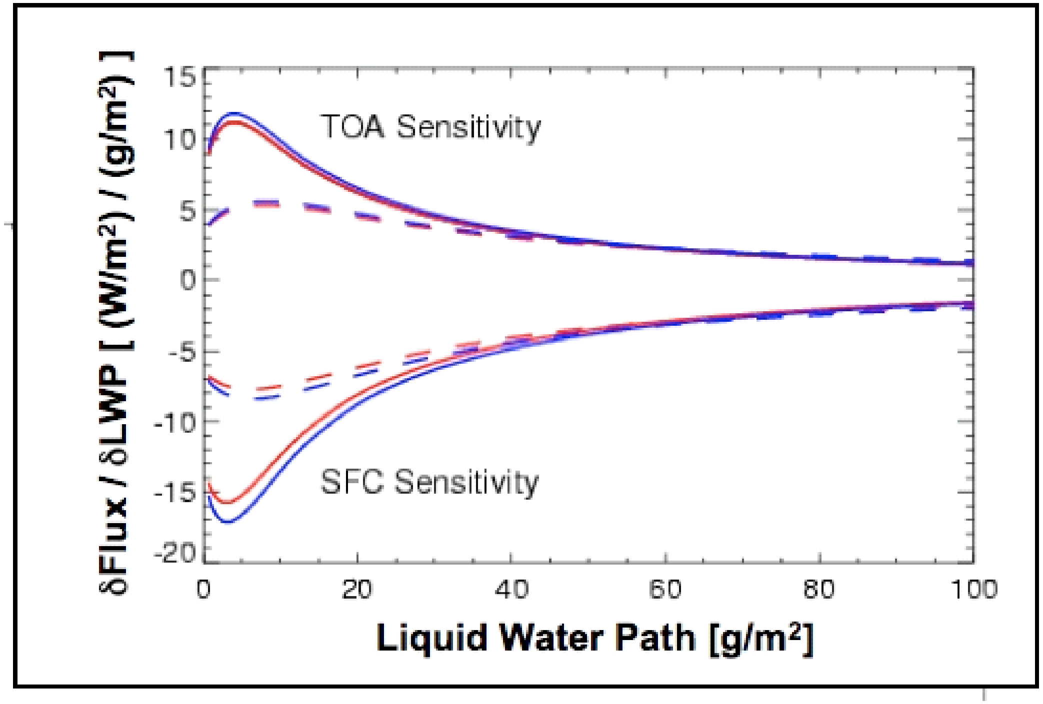


- closed cloud deck (20070908) shows acceptable SW closure for IPT and TUD (~80 Wm^{-2} STDEV, BIAS close to zero)
- SYRSOC shows overestimation due to lower LWC and Reff values, cloud boundary issue?
- keep in mind inhomogeneity
- broken cloud case from June shows much larger differences ...

FIRE CASE: estimation of cloud optical depth by SW broadband data.



Why focus on pure liquid water clouds?



Turner et al. 2007

- they ocurr very frequently and significantly influence solar radiative forcing

→ large climate impact!

- however, these clouds are difficult to measure and model

→ especially in global climate models!

Turner et al. 2007