Funded by
Deutsche Forschungsgemeinschaft
German Research Foundation

RealPEP P3: On the Assimilation of Polarimetry-Derived Hydrometeor Mixing Ratios in Germany

UNIVERSITÄT BONN
institut für geowissenschaften METEOROLOGIE

RealPEP-SINFONY Meeting, 28th-29th April 2022

Lucas Reimann

Background and Hypothesis

Background

- **Single-polarization** radar moments: direct cloud-precipitation microphysical information contained only in (horizontal) radar reflectivity (**Z_H**)
  - ➥ Z_H is **insufficient** to describe these microphysics alone
- **Dual-polarization** radar moments contain additional information about cloud-precipitation microphysics compared to Z_H

Hypotheses

The assimilation of dual-polarization radar observations in NWP models via estimators of hydrometeor mixing ratios (HMRs) can improve quantitative precipitation forecasts (QPFs) with respect to the assimilation of Z_H alone

General Approach

1. **Derivation** of HMRs as liquid/ice water contents (**LWCs**/**IWCs**)
   - from observations of DWD's dual-polarization C-band radar network
   - via the LWC(Z_H,Z_{DR},A_H,K_{DP})-estimator adjusted to the German climatology suggested by Reimann et. al 2021 and the IWC(Z_H,Z_{DR}, K_{DP})-estimator suggested by Carlin et al. 2021

2. "**Superobing**" of derived data: spatial elevation-wise pie-piece averaging of LWC/IWC data to Cartesian grid with 10km resolution

3. **First guess** LWC/IWC projected, linearly interpolated and superobed onto same superobing grid

4. **Assimilation** of superobed LWCs/IWCs with first guess counterparts and preliminary observation error of log(LWC/IWC)=0.5 (based on DSDs) with KENDA in DWD's ICON-D2 model

5. **Evaluation** of produced QPFs

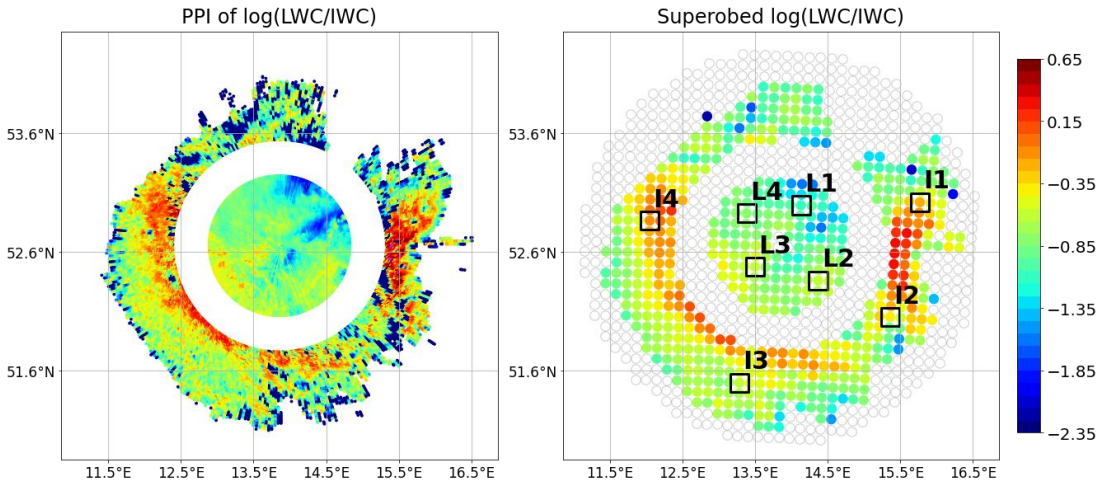
Assimilation Strategy

LWC/IWC assimilation difficulties

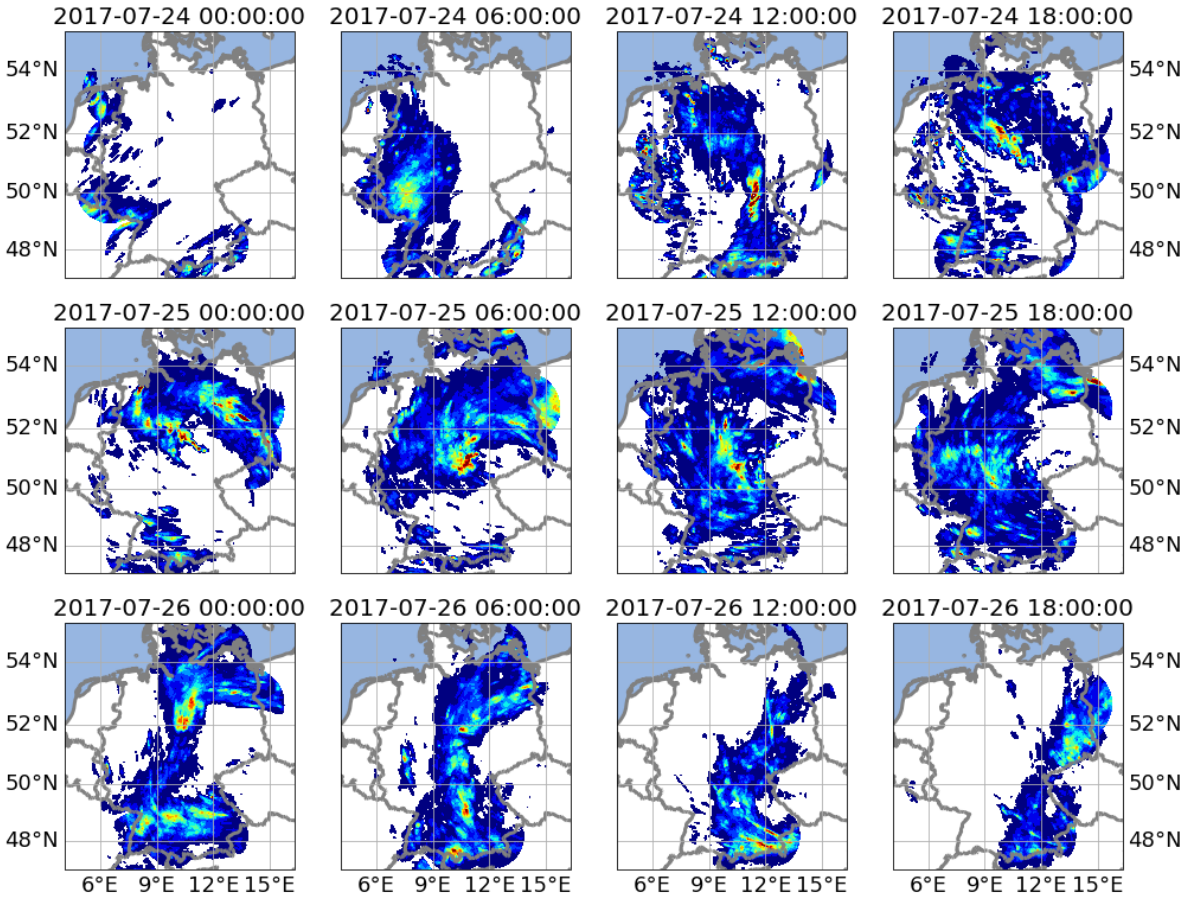
- LWC/IWC estimates only usable if data has sufficient quality (RHO_{HV}>0.85/0.90)
  - ➥ no LWCs/IWCs available in low-intensity precipitation far from the radar or in precipitation-free regions
- Used LWC/IWC-estimators partially based on Z_H
  - ➥ assimilation of LWCs/IWCs in parallel with Z_H at same superobing points not straightforward due to possibly non-zero co-variances

3 Assimilation Configurations

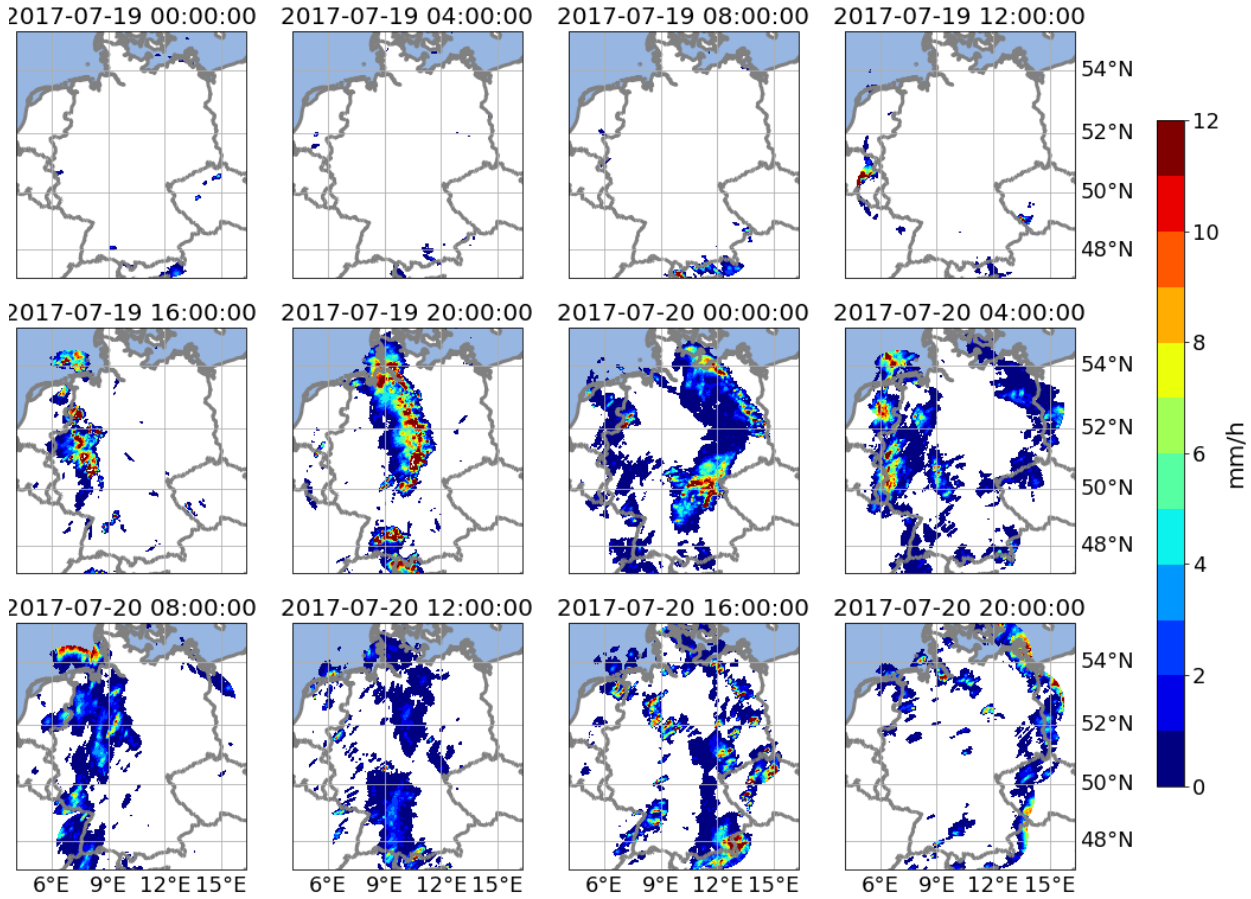
1. **CONV**: Assimilation of conventional observations only
2. **CONV+Z_H**: Assimilation of conventional observations and volumetric Z_H observations as operational
3. **CONV+Z_H+LWC/IWC**: Assimilation of conventional observations plus LWC/IWC observations where LWC/IWC data trustworthy plus Z_H data elsewhere



Considered Events



Stratiform rainfall
24th to 26th July 2017



Convective rainfall
19th to 20th July 2017

Results

Single-Observation Experiments

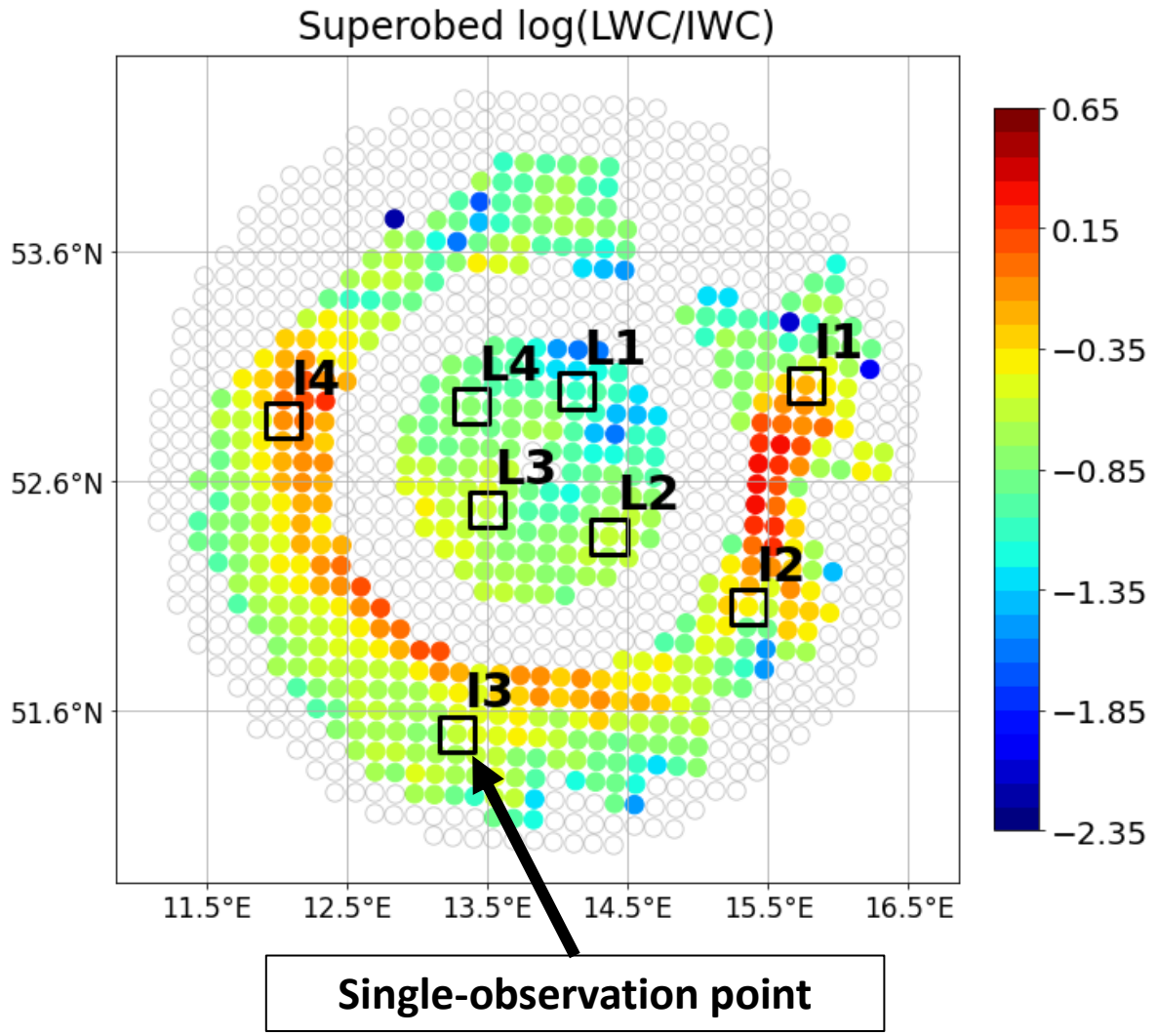
Purpose

- Answer question: does assimilation of LWC/IWC with chosen observation error and assimilation of Z_H lead to increments of comparable size?
- If not: increment “jumps” may lead to problems in the LETKF step

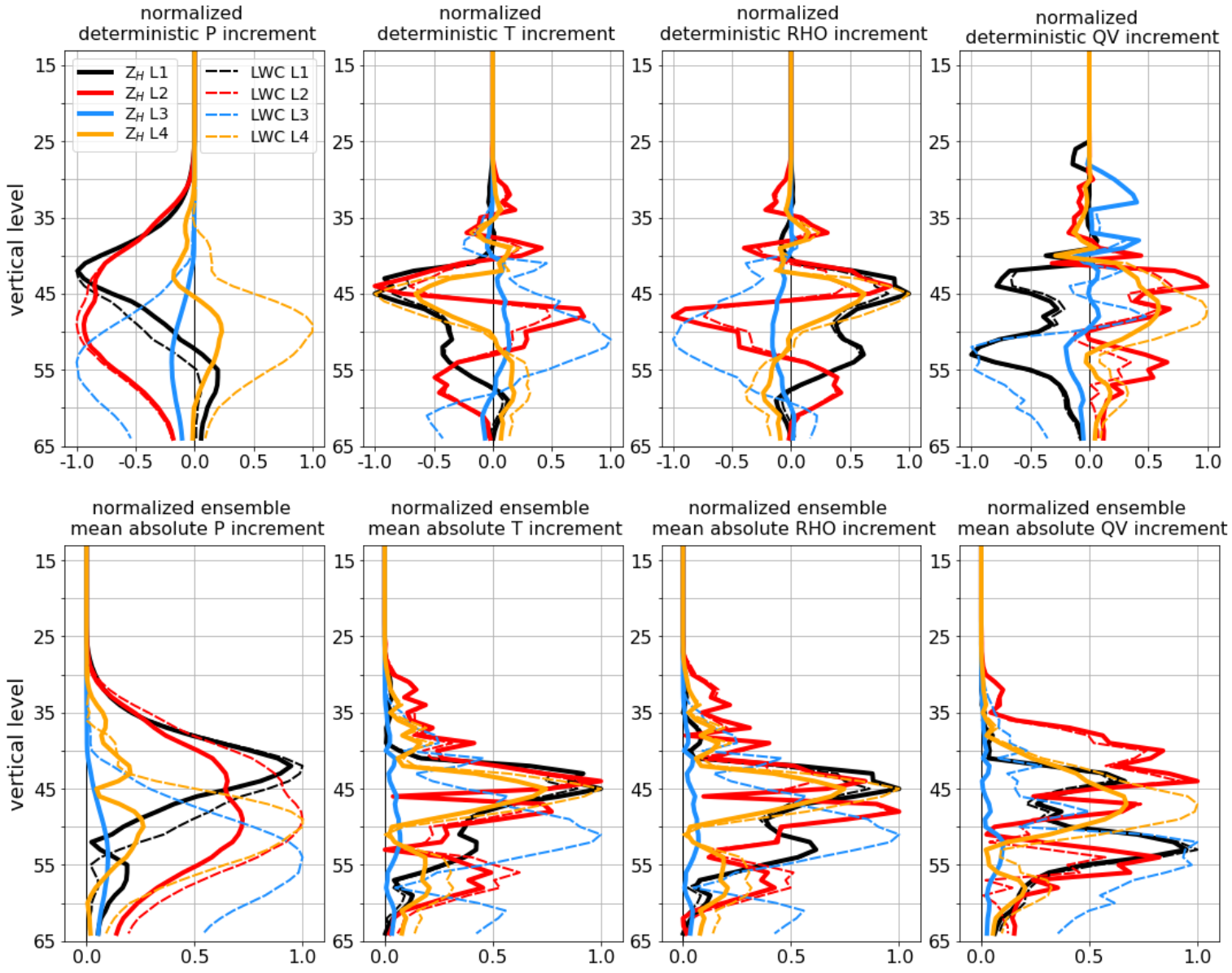
Strategy

- Assimilation of **exclusively** one superobing point (L1, L2, … , I1, I2, … in right figure) at a time. 4 LWC, 4 IWC.
- For each point assimilation of corresponding Z_H or LWC/IWC
- Comparison of increments produced by Z_H and LWC/IWC

Radar Prötzel, 1.5° elevation, 25-07-2017 2 UTC

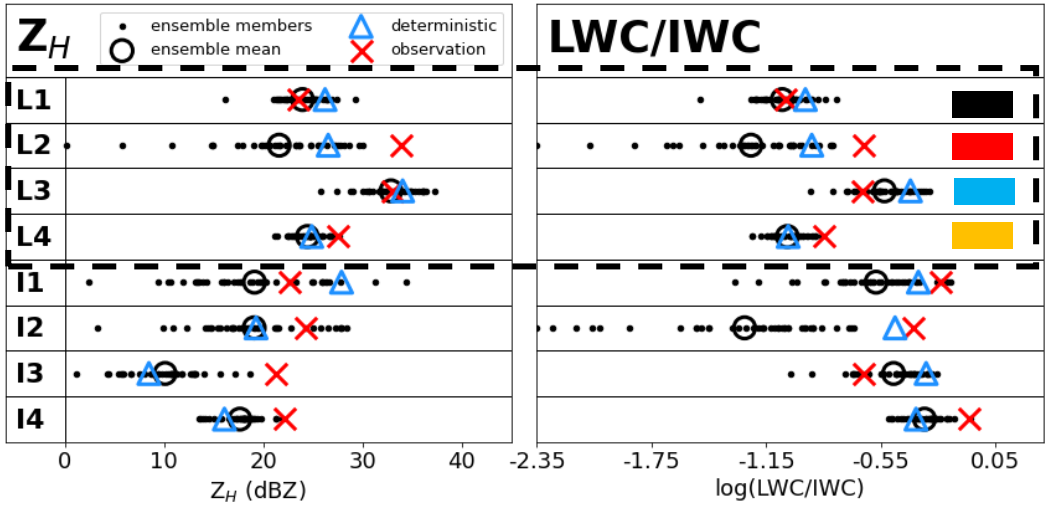


Single-Observation Experiments: LWC

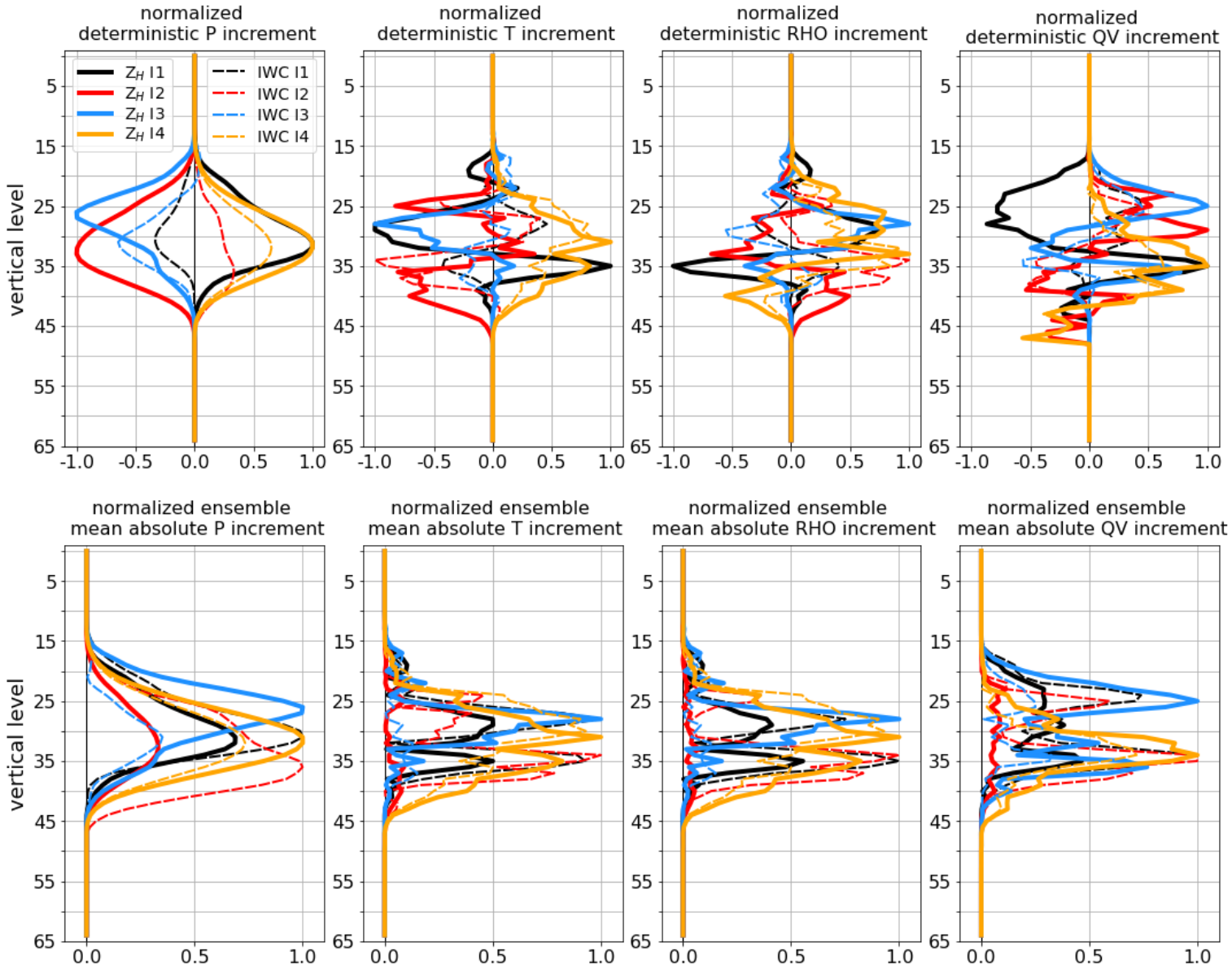


Findings:

- **Relative positions** of deterministic first guesses, ensemble means & observations similar
- **Deterministic** (upper row left figure): if relative positions of first guess and observation similar for Z_H and LWC the produced increments are similar (e.g. black and red curves)
- **Ensemble mean** (lower row left figure): if relative absolute differences between first guess ensemble mean and observation are similar the ensemble mean absolute increments are similar

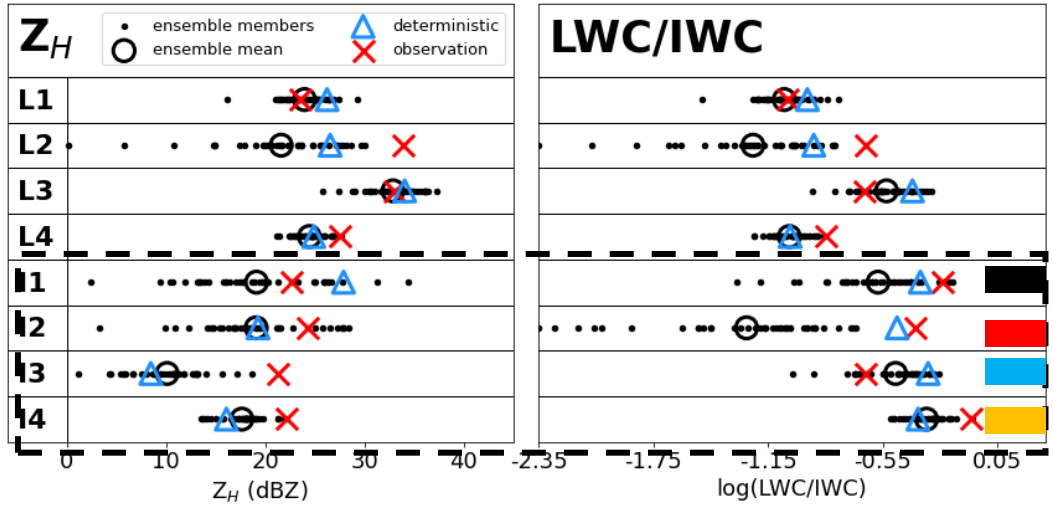


Single-Observation Experiments: IWC



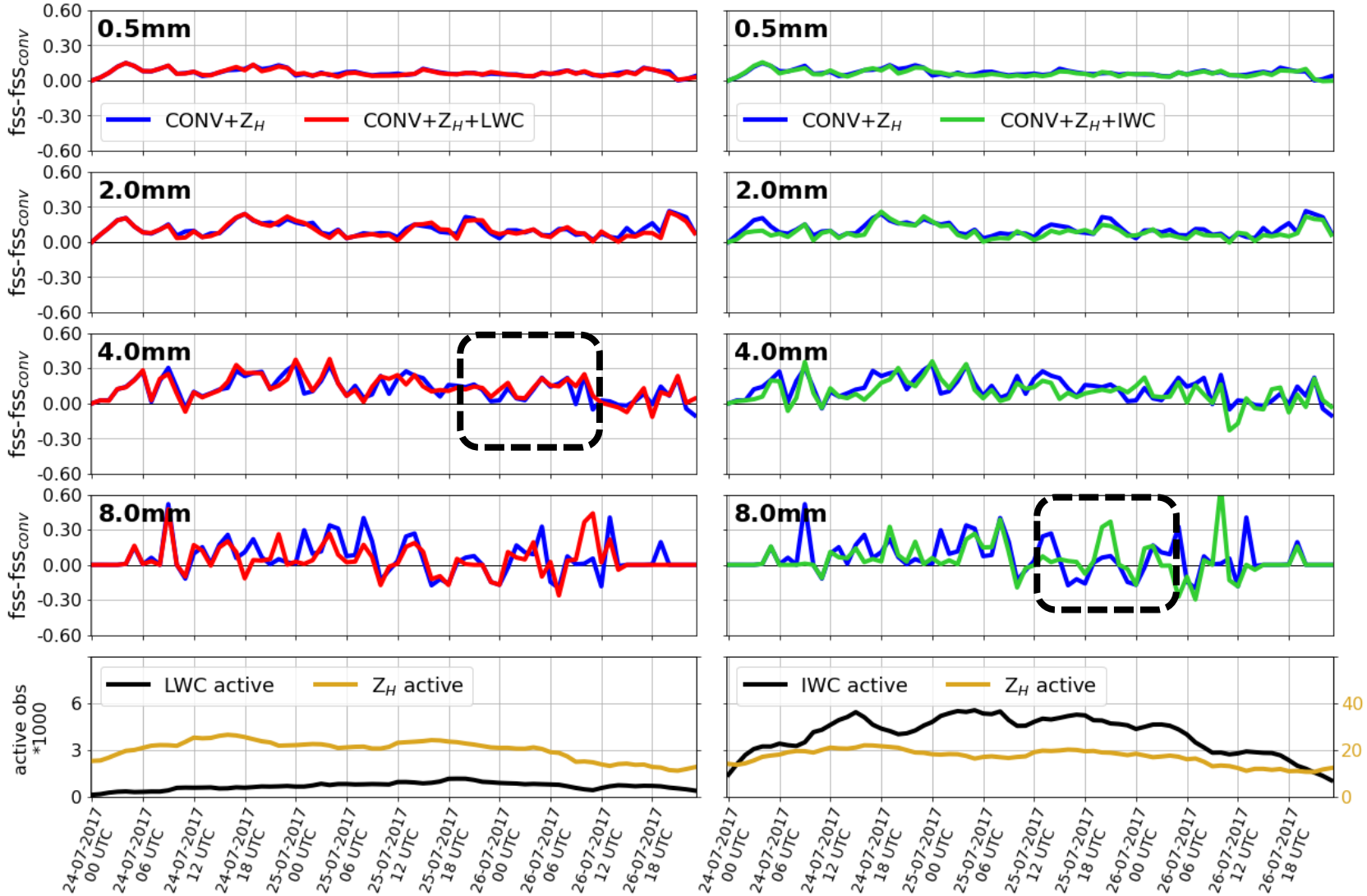
Findings:

- **Relative positions** of deterministic first guesses, ensemble means & observations different
- **Deterministic** (upper row left figure): if relative difference between first guess and observation similar for Z_H and IWC the produced increments are similar (e.g. orange curve)
- **Ensemble mean** (lower row left figure): if relative absolute difference between first guess ensemble mean and observation is similar the ensemble mean absolute increments are similar



First Guess Evaluation: Stratiform Event

Deterministic First Guess



Percentual differences in fss timeseries means (CONV+Z_H+HMR minus CONV+Z_H)

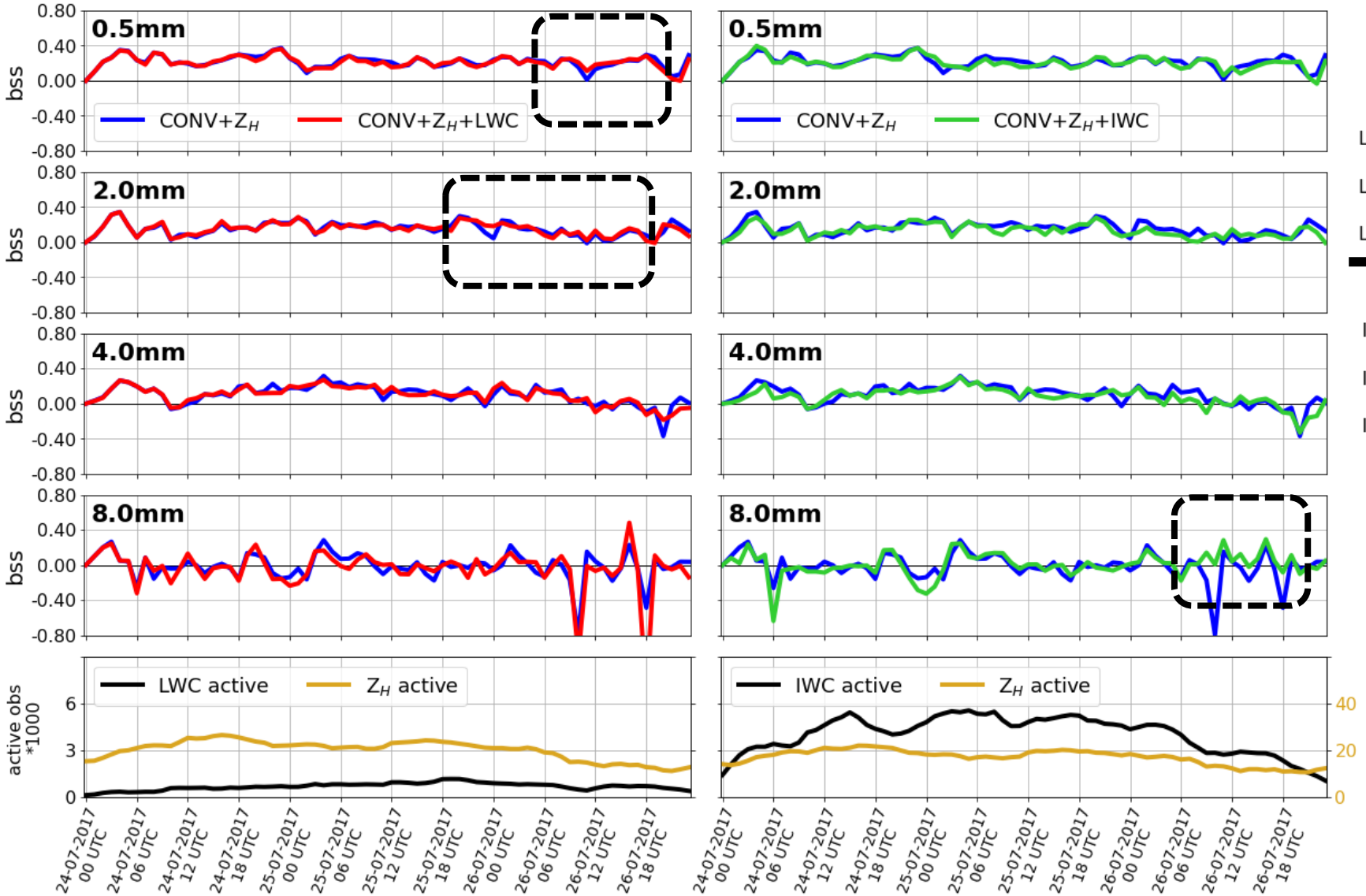
	0.1	0.5	1.0	2.0	4.0	8.0
LWC full	-0.24	-0.23	-0.46	-0.91	1.28	-9.04
LWC day 1	-0.32	-0.09	-0.12	-0.38	-1.08	-4.74
LWC day 2	-0.39	-0.33	-0.06	-0.49	1.62	-29.39
LWC day 3	-0.02	-0.28	-1.16	-1.82	3.40	7.32
IWC full	-0.42	-0.67	-1.06	-3.31	-5.17	-10.09
IWC day 1	-0.39	-0.65	-0.71	-3.32	-7.15	-13.20
IWC day 2	-0.66	-0.77	-0.87	-3.35	-3.83	2.15
IWC day 3	-0.20	-0.59	-1.57	-3.27	-4.52	-19.24

threshold (mm)

Findings:

- FSS very similar for **CONV+Z_H** and **CONV+Z_H+LWC** configuration, no systematic differences. Improvements in some situations for e.g. 4 mm threshold
- **CONV+Z_H+IWC** configuration rather leads to FSS reduction, systematic deterioration for e.g. 2 mm threshold. Though, some improved situations for 8.0 mm threshold

First Guess Evaluation: Stratiform Event



Differences in bss timeseries means
(CONV+Z_H+HMR minus CONV+Z_H; *100)

	0.1	0.5	1.0	2.0	4.0	8.0
LWC full	-0.96	-0.49	-0.03	-0.02	-0.24	-2.76
LWC day 1	-0.79	-0.43	-0.03	0.34	-0.23	-0.99
LWC day 2	-1.53	-0.79	-0.39	-0.47	-0.04	-2.54
LWC day 3	-0.56	-0.25	0.33	0.09	-0.45	-4.74
IWC full	-1.96	-1.08	-0.88	-2.15	-2.34	1.78
IWC day 1	-1.07	-0.66	-0.32	-0.78	-2.38	-3.35
IWC day 2	-1.85	-0.65	0.02	-2.57	-1.13	-0.46
IWC day 3	-2.97	-1.95	-2.36	-3.11	-3.52	9.16

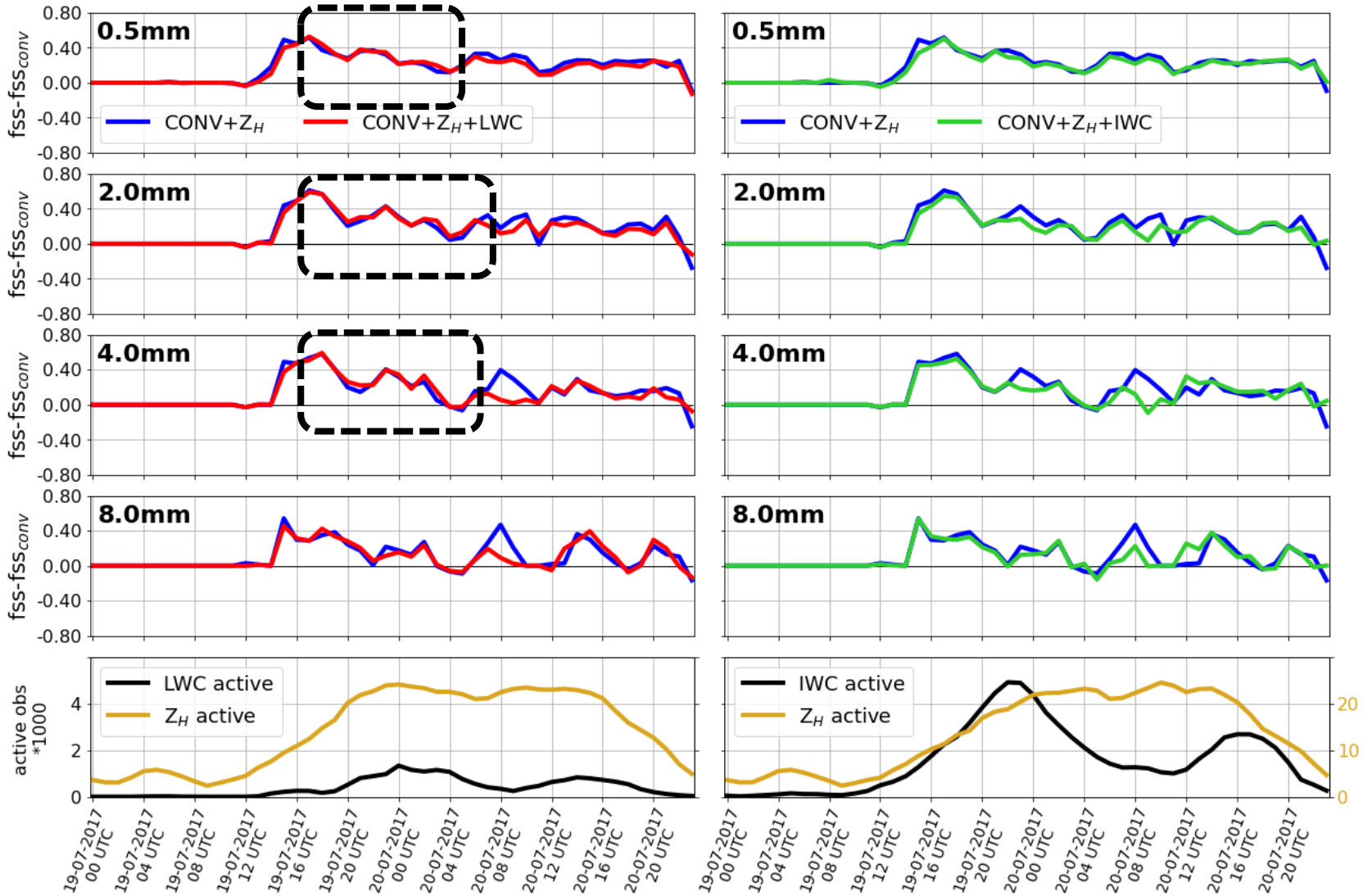
threshold (mm)

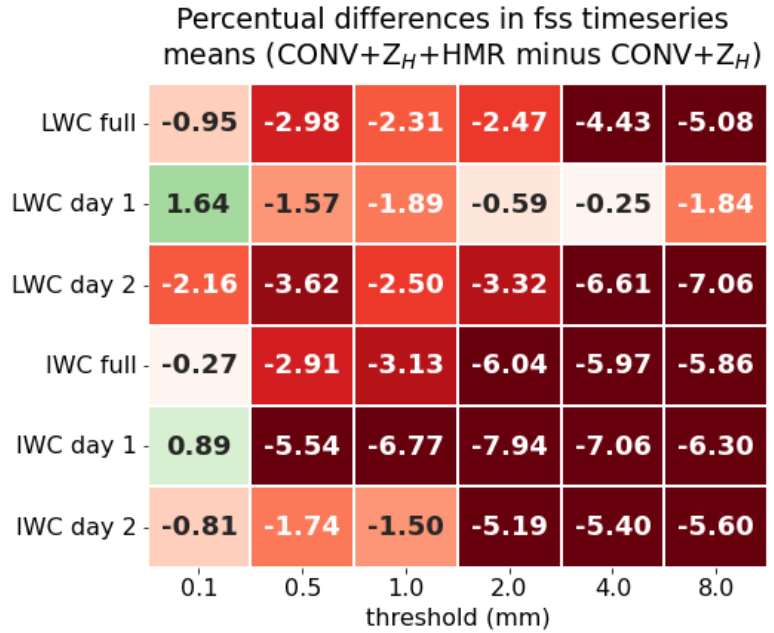
Findings:

- BSS very similar for **CONV+Z_H** and **CONV+Z_H+LWC** configuration, no systematic differences. Improvements in some situations for e.g. 0.5/2 mm threshold
- **CONV+Z_H+IWC** configuration rather leads to FSS reduction, systematic deterioration for e.g. 2 mm threshold. Though, some improved situations for 8.0 mm threshold

First Guess Evaluation: Convective Event

Deterministic First Guess

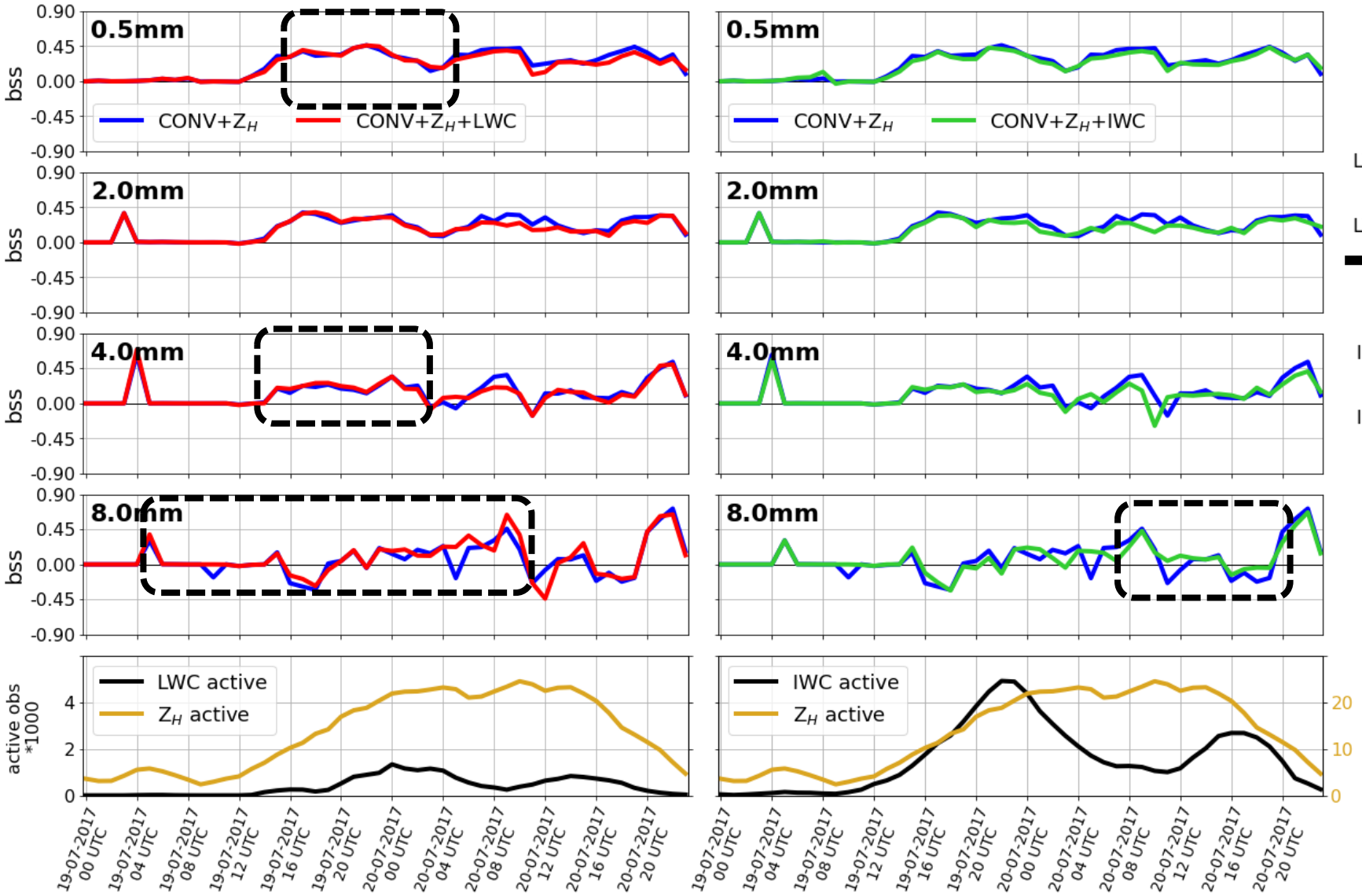


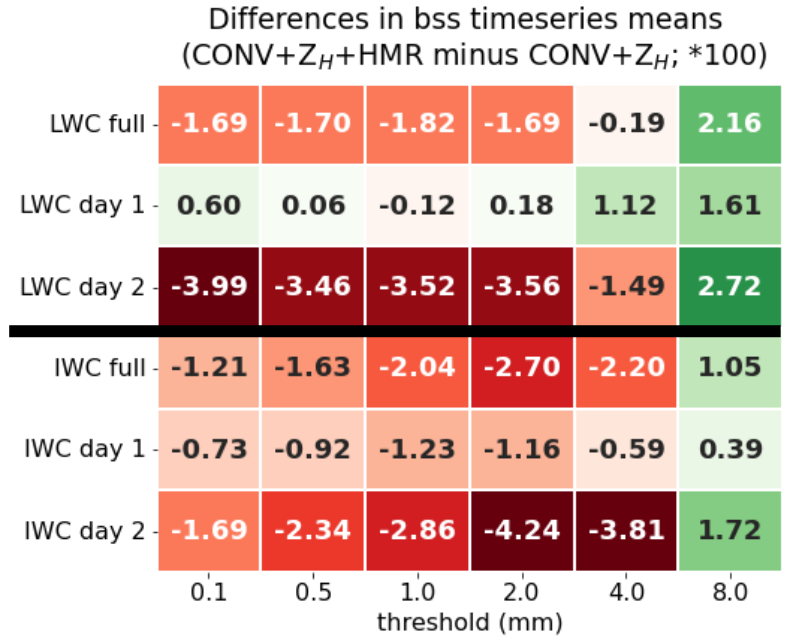


Findings:

- FSS for **CONV+Z_H+LWC** configuration enhanced towards middle of period where most observations active, systematically deteriorated towards second half of period especially for lower thresholds
- **CONV+Z_H+IWC** configuration rather leads to systematic FSS deterioration for e.g. 0.5/2 mm threshold.

First Guess Evaluation: Convective Event





Findings:

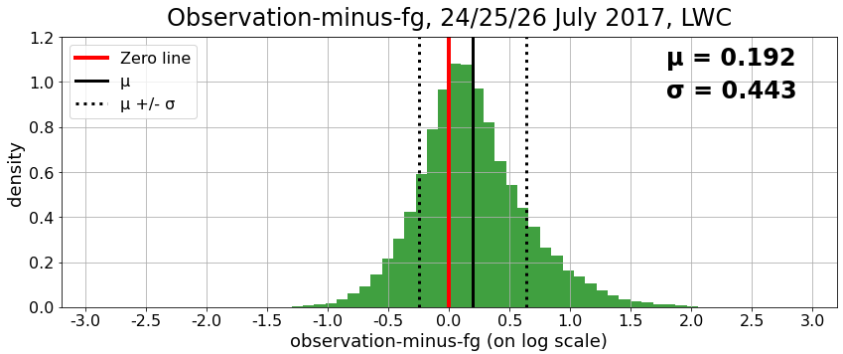
- BSS for **CONV+Z_H+LWC** configuration improved towards middle of period for higher thresholds. Deterioration towards second half of period for lower thresholds
- **CONV+Z_H+IWC** configuration rather leads to FSS reduction, systematic deterioration for e.g. 2 mm threshold. Though, some improved situations for 8 mm threshold

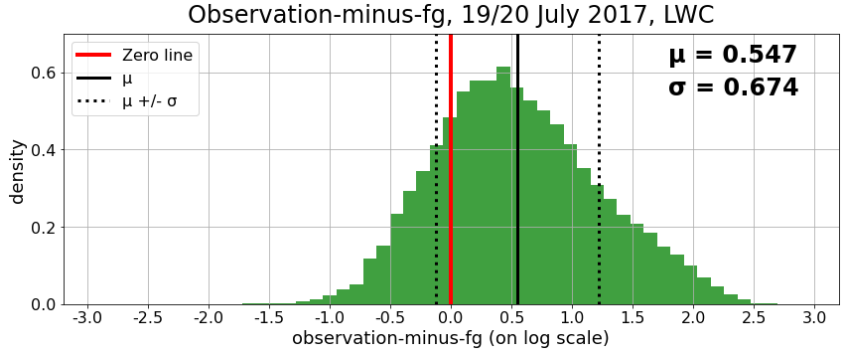
Observation-Minus-FirstGuess Statistics

Stratiform event

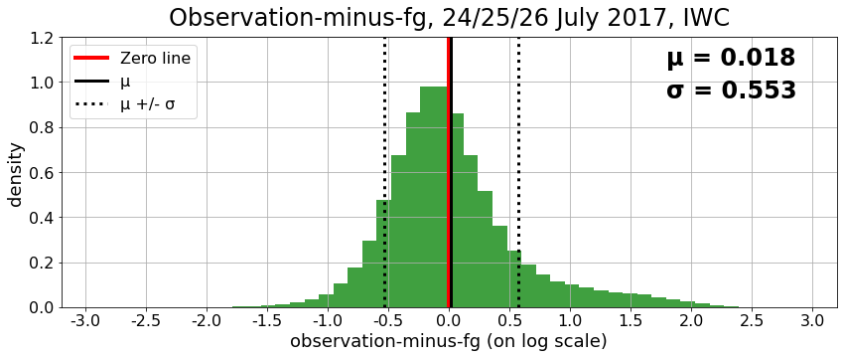
Convective event

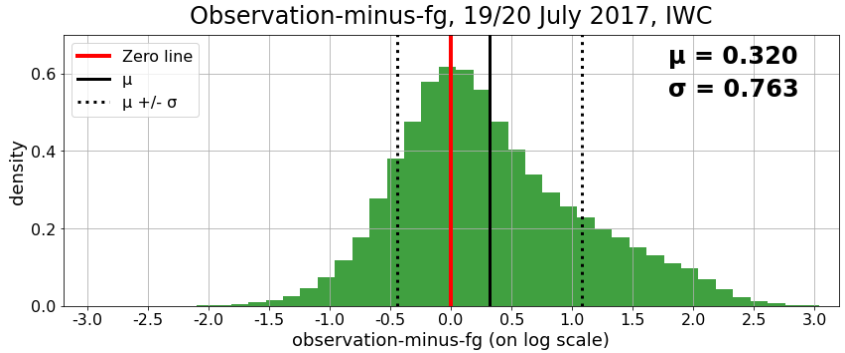
LWC





IWC



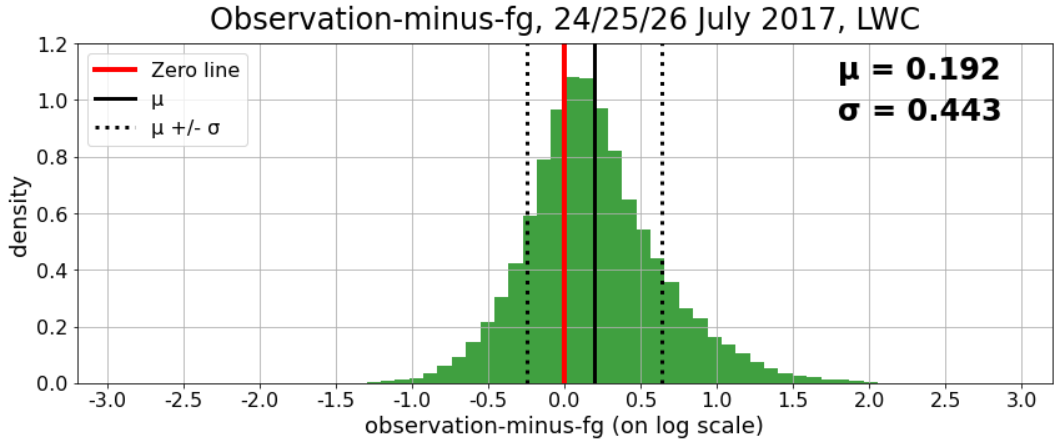


- **Stratiform event**: LWC distribution quite symmetric but small positive bias; IWC distribution exhibits tail to positive values; without tail small negative bias
- **Convective event**: LWC distribution has tail to positive values and positive bias; IWC distribution has tail to positive values, without tail no considerable bias

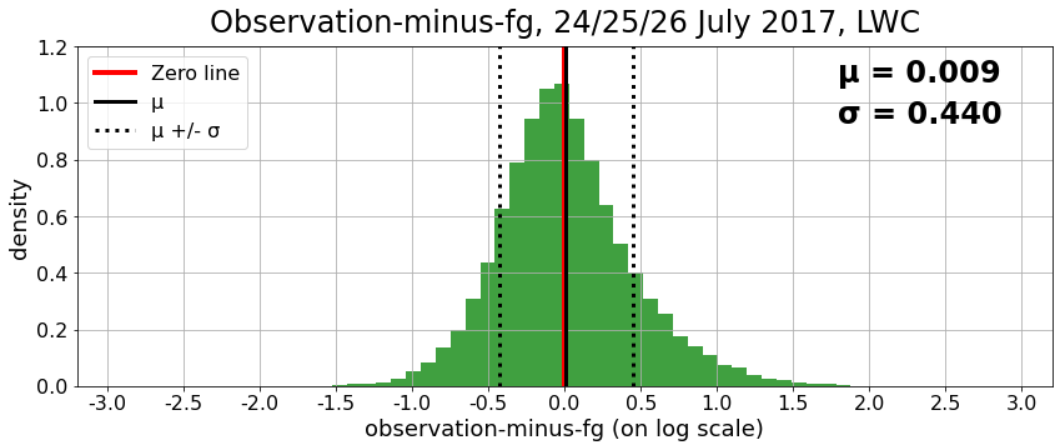
First Guess Evaluation with Bias Correction

Stratiform event, LWC

No correction



Bias correction



FSS

Percentual differences in fss timeseries means (CONV+Z_H+HMR minus CONV+Z_H)

	0.1	0.5	1.0	2.0	4.0	8.0
No Correction full	-0.24	-0.23	-0.46	-0.91	1.28	-9.04
No Correction day 1	-0.32	-0.09	-0.12	-0.38	-1.08	-4.74
No Correction day 2	-0.39	-0.33	-0.06	-0.49	1.62	-29.39
No Correction day 3	-0.02	-0.28	-1.16	-1.82	3.40	7.32
Bias Correction full	-0.12	-0.07	-0.26	-0.54	-0.09	-16.50
Bias Correction day 1	-0.49	-0.23	-0.48	-0.55	-2.54	-7.17
Bias Correction day 2	-0.00	-0.09	-0.01	-0.44	2.20	-15.38
Bias Correction day 3	0.11	0.09	-0.31	-0.65	-0.00	-29.76

threshold (mm)

BSS

Differences in bss timeseries means (CONV+Z_H+HMR minus CONV+Z_H; *100)

	0.1	0.5	1.0	2.0	4.0	8.0
No Correction full	-0.96	-0.49	-0.03	-0.02	-0.24	-2.76
No Correction day 1	-0.79	-0.43	-0.03	0.34	-0.23	-0.99
No Correction day 2	-1.53	-0.79	-0.39	-0.47	-0.04	-2.54
No Correction day 3	-0.56	-0.25	0.33	0.09	-0.45	-4.74
Bias Correction full	-0.36	0.32	0.98	0.76	-0.01	-4.28
Bias Correction day 1	-0.73	-0.08	0.14	0.68	0.48	-0.40
Bias Correction day 2	-0.07	0.58	1.88	1.30	-0.37	-1.92
Bias Correction day 3	-0.27	0.47	0.92	0.30	-0.15	-10.52

threshold (mm)

- **FSS**: bias correction leads to improvement for full period for lower thresholds 0.1-2.0 mm
- **BSS**: bias correction leads to improvement for full period for all thresholds except for 8.0 mm and to even better BSS for thresholds 0.5-2.0 w.r.t. CONV+Z_H configuration

Conclusions

- Single-observation experiments suggest that if deterministic & ensemble mean first guess & observations are distributed similarly for Z_H and LWC/IWC the increments are similar
  - ➥ The preliminary chosen observation error of log(LWC/IWC)=0.5 appears to be reasonable
- Configuration CONV+Z_H+LWC leads to
  a. no systematic improvements in FSS/BSS over configuration CONV+Z_H for stratiform rainfall event, though in some situations improvements are visible
  b. improvements in FSS/BSS over configuration CONV+Z_H especially for first day of convective period (squall line pass-through) and especially for BSS at higher thresholds
- Configuration CONV+Z_H+IWC leads to partly systematic deterioration in FSS/BSS over configuration CONV+Z_H for stratiform & convective events, though in few situations improvements are visible
- Obs-minus-fg distributions show biases and partly tails to positive values for both LWC & IWC. Bias correction for stratiform event in configuration CONV+Z_H+LWC overall improves results

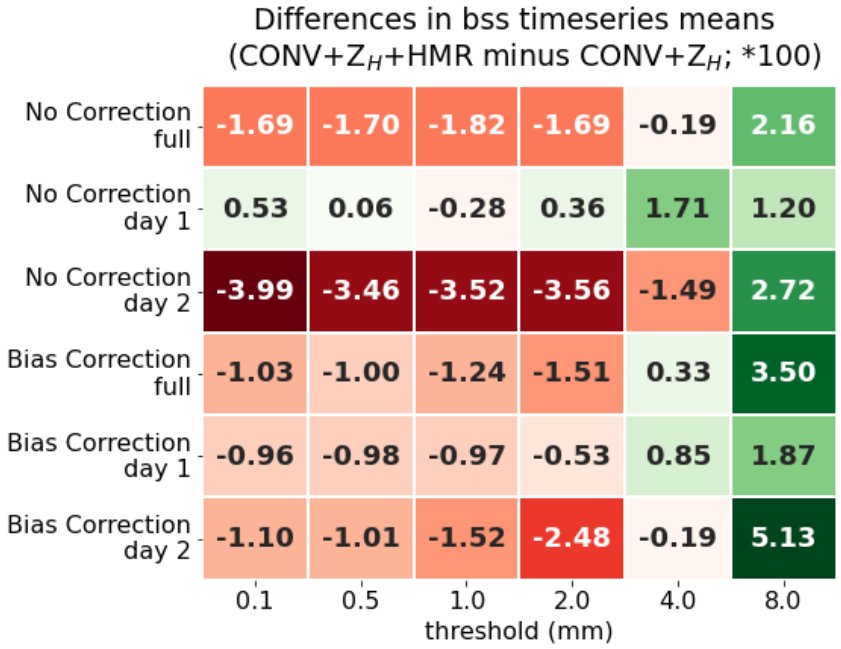
Near-Future Work

- Test influence of obs-minus-fg distribution modification on the other experiments
- Produce and evaluate 24h-forecasts
- Include heavy stratiform rainfall event in connection with low-pressure system “Bernd” from 13th to 14th July 2021 (4 times higher radar range resolution)
- …..

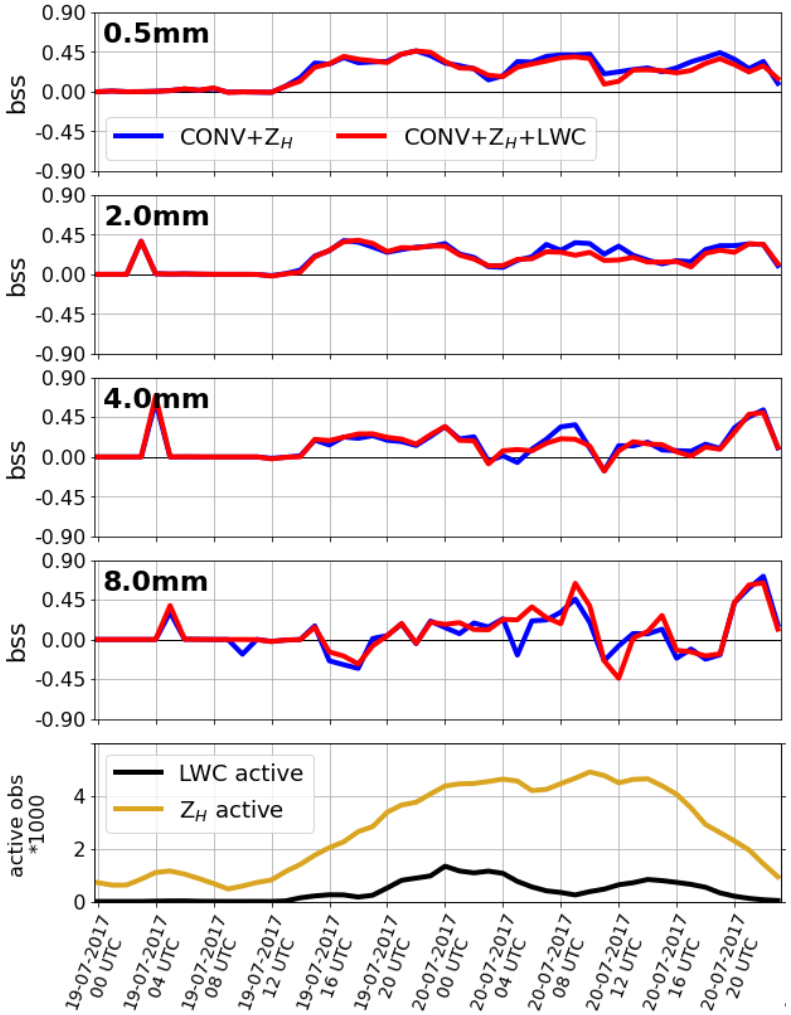
Thank you!
Questions?

Appendix

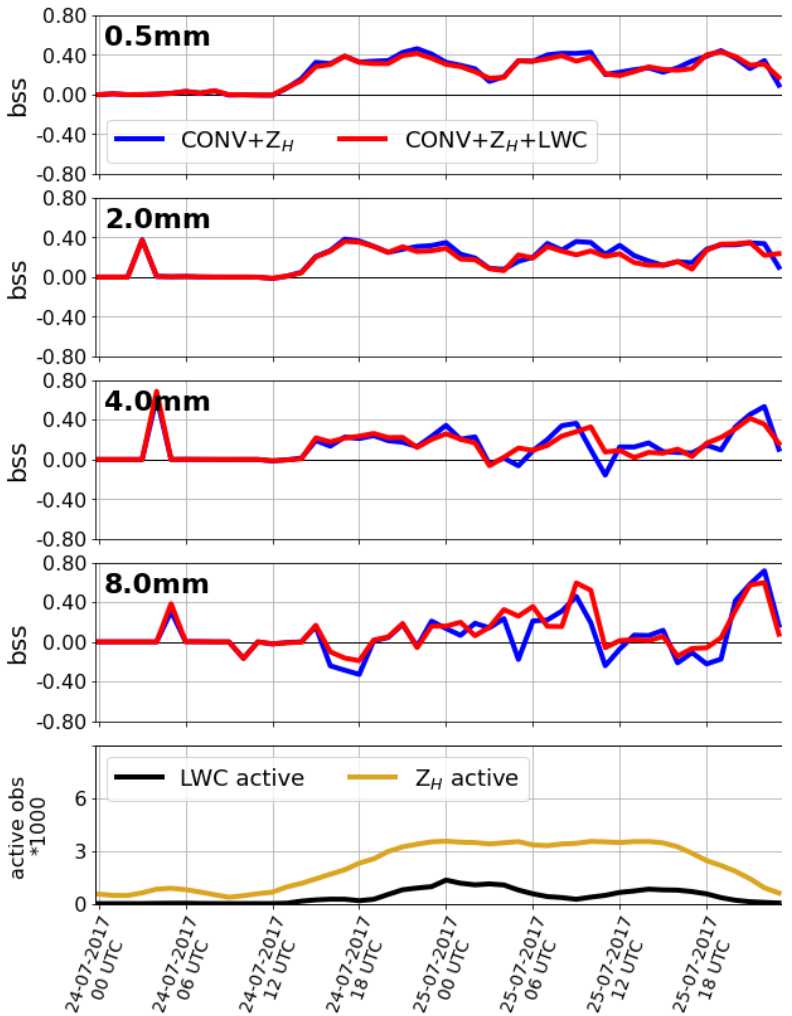
Convective event obs-minus-fg distribution bias correction

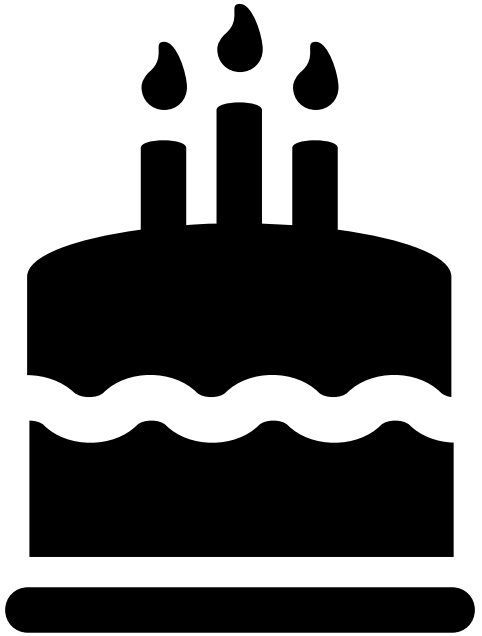


before correction



after correction





Surprise, surprise …

HAPPY BIRTHDAY, CLEMENS!