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Assessing the benefits of specific attenuation for quantitative precipitation estimation with a C-band radar network

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Application of A for QPE using the ZPHI method (Testud et al. 2000)

- Inherit the advantages of $R(K_{DP})$ but less noisy in light rain and suffer less from spatial degradation.
- Previous studies at S band show a significant **sensitivity of $\alpha_{H/V}$ to DSD (Drop Size Distribution) variability**

  → the dependence of $\alpha_{H/V}$ on **rain type**.

  → **the change of Z_{DR} with $Z_{H/V}$** ($\frac{\Delta Z_{DR}}{\Delta Z_H}$ or the slope $K_{H/V}$ in the relationship of $Z_{DR} = K_{H/V}Z_{H/V}$ + constant) (Wang et al. 2017, 2019; Zhang et al. 2020).

  → This so-called Z_{DR} slope is immune to a **potential radar system bias**.
- **$R(A_V)$** was proved to be even **less sensitive to DSD variability** and may provide higher accuracy in areas of strong attenuation compared to $R(A_H)$.

Application of A for QPE using the ZPHI method **at C band**

- The susceptibility of $\alpha_{H/V}$ to DSD variability is **more pronounced** compared to S band Trömel et al. (2014). The dependence of $\alpha_{H/V}$ on Z_{DR} is **non-monotonic**, and its assessment is further complicated by **stronger (differential) attenuation and resonance effects**.

- The enhanced sensitivity of **the coefficients in R($A_{H/V}$)** relations to DSD characteristics

  → In tropical Taiwan, R($A_{H/V}$) relations are derived depending on rain types (Wang et al. 2017).

  → In the mid-latitudes, **R-K_{DP}** scatter plots can be much narrower than those of R-$A_{H/V}$ for **heavier continental rain** dominated by large raindrops originating from large graupel or hail (Thompson et al. 2018).

- The combination of **R(K_{DP})** and R($A_{H/V}$) relations

  → the generally better applicability of R(K_{DP}) **at shorter wavelength**.

  → shortcomings of the R($A_{H/V}$) algorithms in **rain mixed with hails**.

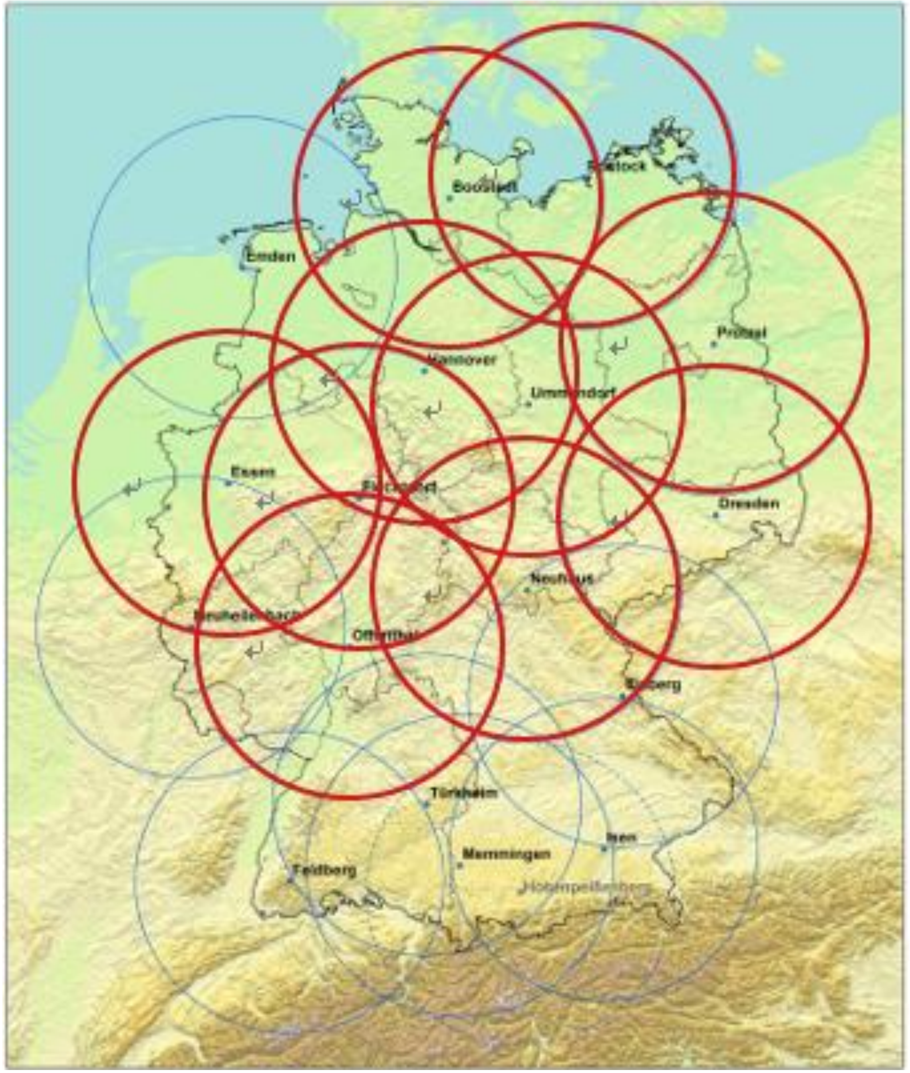
Data

- Thies disdrometer
  - ✓ from DWD (the German Meteorological Service)
  - ✓ from the Institute for Geosciences - Section Meteorology at the Uni Bonn

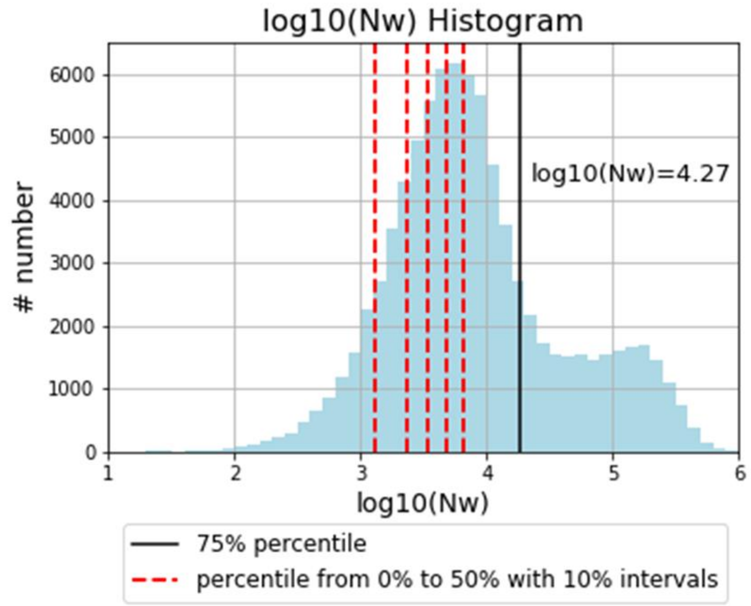
→ 84,169 1-minute DSDs

- OTT Pluvio Rain gauge measurements
- RODOLAN (RAdar-OnLine-Aneichung) RW
  - ✓ DWD's operational 1 km-resolution, hourly QPE product, which is **based on reflectivities** only but **adjusted to rain gauge measurements**.

- DWD C-band polarimetric radars
  - ✓ terrain-following elevation angle
- Four convective events on (12-24UTC)
  - ✓ 19th July 2017
  - ✓ 28th July 2018
  - ✓ 9th August 2018
  - ✓ 20th July 2019
- A stratiform event on 25th July 2017 (0-24UTC)



Methodology - Scan-based α deriving from Z_{DR} slopes



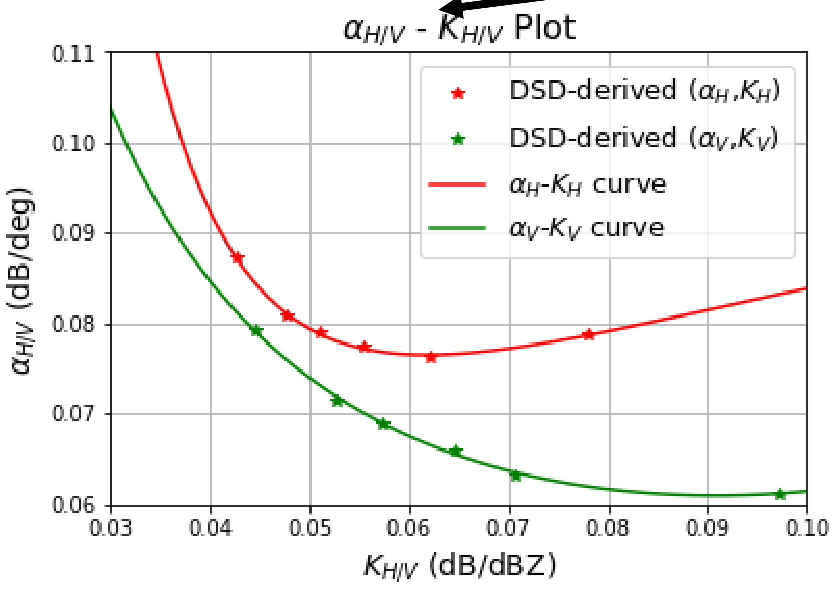
Nw (normalized raindrop concentration) as a proxy for different precipitation classes, for which different Z_{DR} slopes and $\alpha_{H/V}$ values are expected to define their relationship.

$$Nw = \frac{4^4}{\pi \rho_w} \frac{LWC}{D_m^4}$$

$\alpha_{H/V}$ and $K_{H/V}$ of each class

$$A_{H/V} = \alpha_{H/V} K_{DP}$$

$$K_{H/V} = \frac{Z_{DR\_40} - Z_{DR\_25}}{15}$$



radar-derived $K_{H/V}$

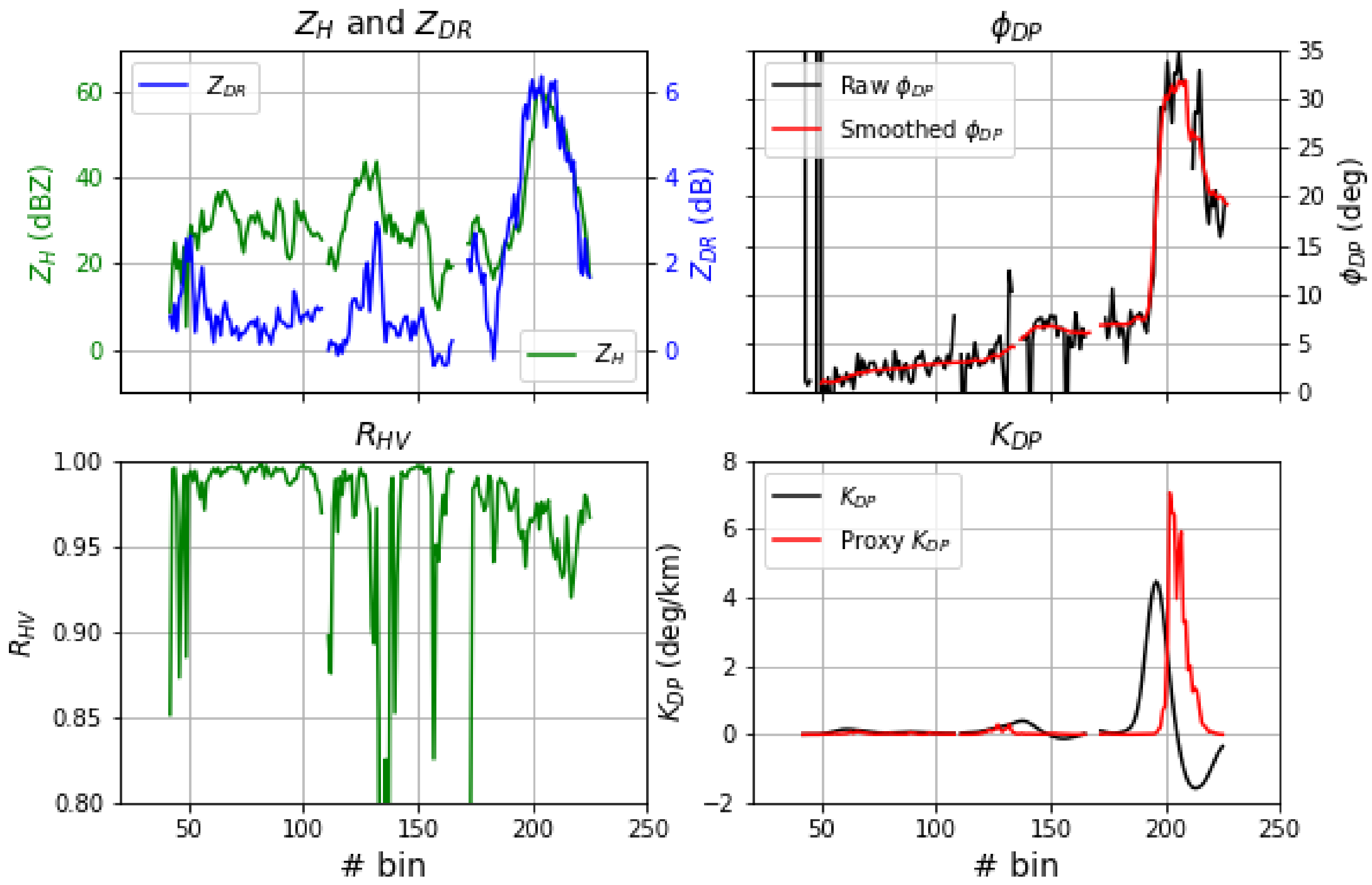
- a first-guess attenuation correction
- Φ_{DP} < 30 deg
- a linear fit to the median Z_{DR} values computed from each 1 dBZ interval in the range 25 dBZ to 40 dBZ
- renewed scan by scan

- The Φ_{DP} **bump** due to the non-uniform beam filling could be more severe at C band with the combination of the resonance effect.
- K_{DP} is replaced by K_{DP}^* as 40 dBZ < Z_H < 55 dBZ and K_{DP} < 0.25 degkm^{-1}.

$$K_{DP}{}^*(r) = \frac{\Delta\Phi_{DP}(r_1, r_2)}{2\int_{r_1}^{r_2}[Z_H(s)]^{0.84}ds}[Z_H(r)]^{0.84}$$

Zhang et al. 2013

- The ranges with **Z_H > 50 dBZ** (potential existence of hail) are excluded from the integration in the ZPHI method to prevent extremely high $A_{H/V}$ values (Wang et al., 2017 and 2019).



The set of rainfall retrievals

With K_{DP}* replacement

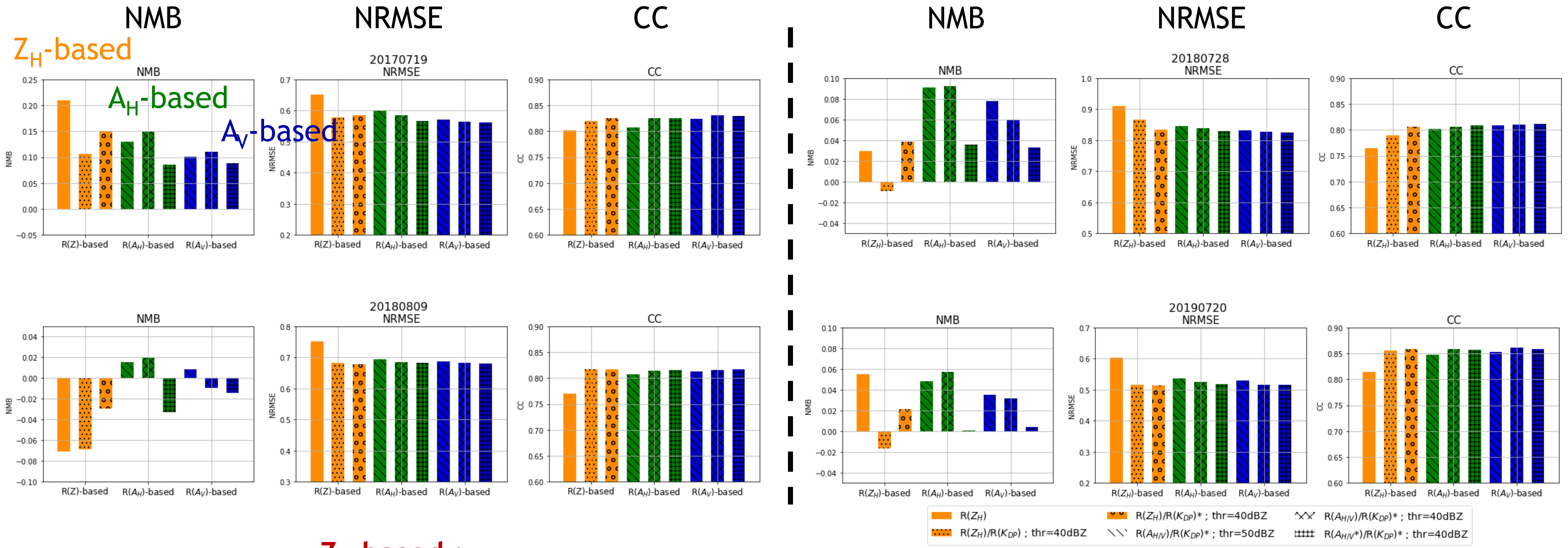
Z_H-based	$R(Z_H)$	$R(Z_H)/R(K_{DP})$ (>40 dBZ)	$R(Z_H)/R(K_{DP})^*$ (>40 dBZ)
A_H-based	$R(A_H)/R(K_{DP})^*$ (>50 dBZ)	$R(A_H)/R(K_{DP})^*$ (>40 dBZ)	$R(A_H^*)/R(K_{DP})^*$ (>40 dBZ)
A_V-based	$R(A_V)/R(K_{DP})^*$ (>50 dBZ)	$R(A_V)/R(K_{DP})^*$ (>40 dBZ)	$R(A_V^*)/R(K_{DP})^*$ (>40 dBZ)

With adjusted $\alpha_{H/V}$

The rain rate relationships derived from measured DSDs

$$R(Z_H) = 0.052{Z_H}^{0.57} \qquad R(K_{DP}) = 20.7{K_{DP}}^{0.72} \qquad R(A_H) = 121.38{A_H}^{0.74} \qquad R(A_V) = 193.17{A_V}^{0.82}$$

Result – convective cases



Z_H-based :

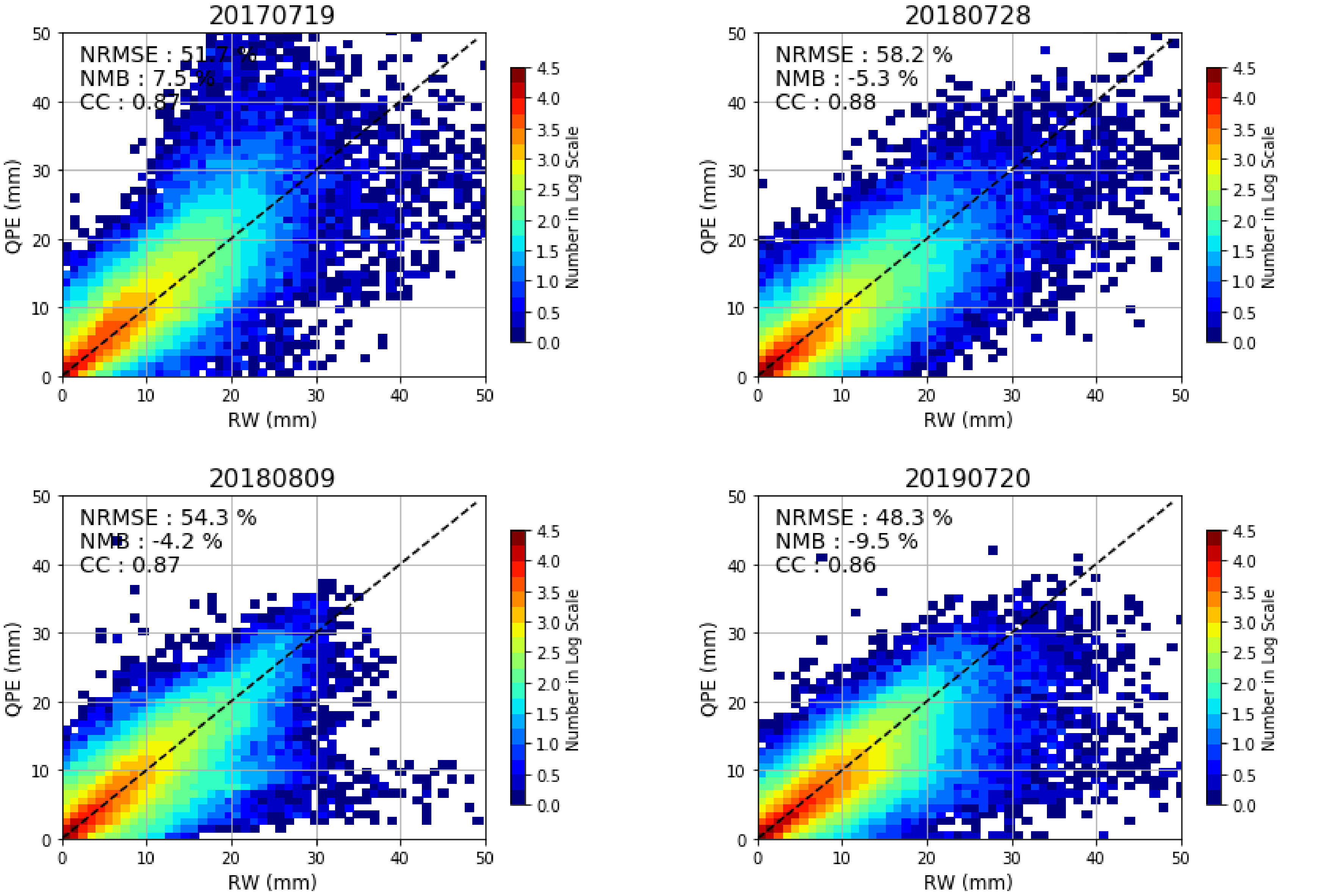
- $R(Z_H)$ algorithm shows the highest NRMSE and lowest CC.
- $R(K_{DP})$ or $R(K_{DP})^*$ further improves the scores.

$A_{H/V}$-based :

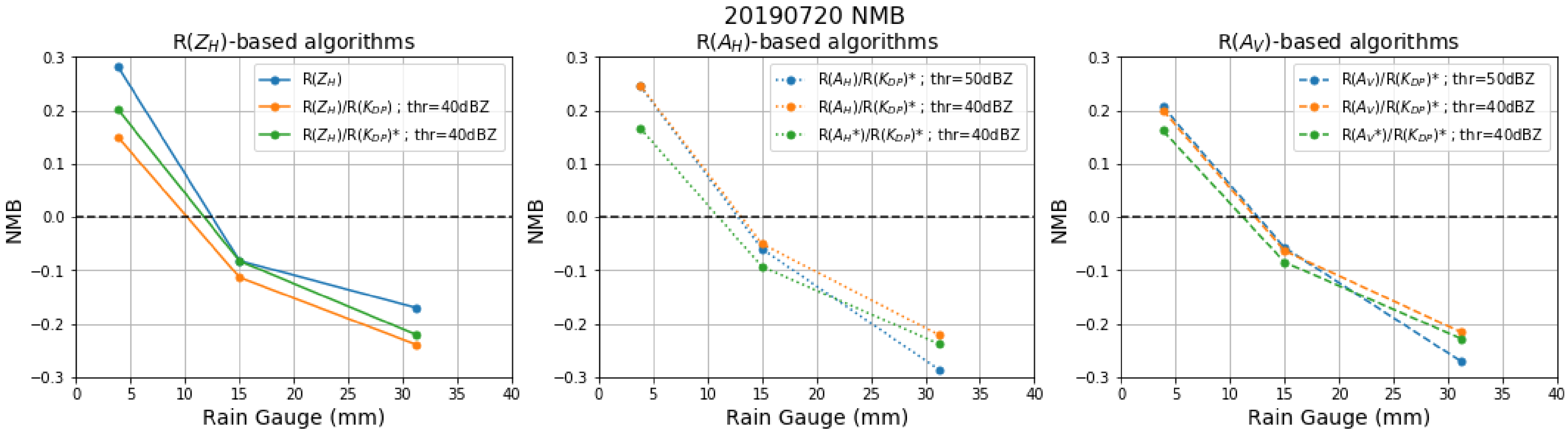
- $R(A_H)/R(K_{DP})^*$ shows larger NMB and NRMSE than $R(A_V)/R(K_{DP})^*$.
- $R(A_{H/V}^*)/R(K_{DP})^*$ reveal comparable performances.

Result – convective cases

The comparison of $R(A_V^*)/R(K_{DP})^*$ and RW products shows a good agreement.



Result - convective cases



- **Z_H-based** : the NMBs of the algorithms with **R(K_{DP})***
  - → at each rain intensity are between or smaller than the other two
  - → always have lower error than R(Z)/R(K_{DP}) in moderate and heavy rain

based on 3-h accumulated rainfall
Light : 0-7.5 mm
moderate : 7.5-22.5 mm
Heavy : >22.5 mm

- **$A_{H/V}$-based** :
  - → **R($A_{H/V}$)/R(K_{DP})* with the threshold of 40 dBZ** result in smaller NMBs **in heavy rain** than the ones with **the threshold of 50 dBZ**
  - → when compared to the R($A_{H/V}$)/R(K_{DP})* algorithms, **R($A_{H/V}$*)/R(K_{DP})*** reduce again the error **in light rain**

The improvement is achieved only by reducing the bias

a scan-based $\alpha_{H/V}$ represents an **average value** but cannot take care of the various precipitation types occurring within a scan, and thus hampers the improvement of NRMSE and CC.

→ ray-based $\alpha_{H/V}$

- **Z_H-based** : the NMBs of the algorithms with **$R(K_{DP})^*$**

  → at each rain intensity are between or smaller than the other two

  → always have lower error than $R(Z)/R(K_{DP})$ in moderate and heavy rain

- **$A_{H/V}$-based** :

  → **$R(A_{H/V})/R(K_{DP})^*$ with the threshold of 40 dBZ** result in smaller NMBs **in heavy rain** than the ones with **the threshold of 50 dBZ**

  → when compared to the $R(A_{H/V})/R(K_{DP})^*$ algorithms, **$R(A_{H/V}^*)/R(K_{DP})^*$** reduce again the error **in light rain**

based on 3-h accumulated rainfall
Light : 0-7.5 mm
moderate : 7.5-22.5 mm
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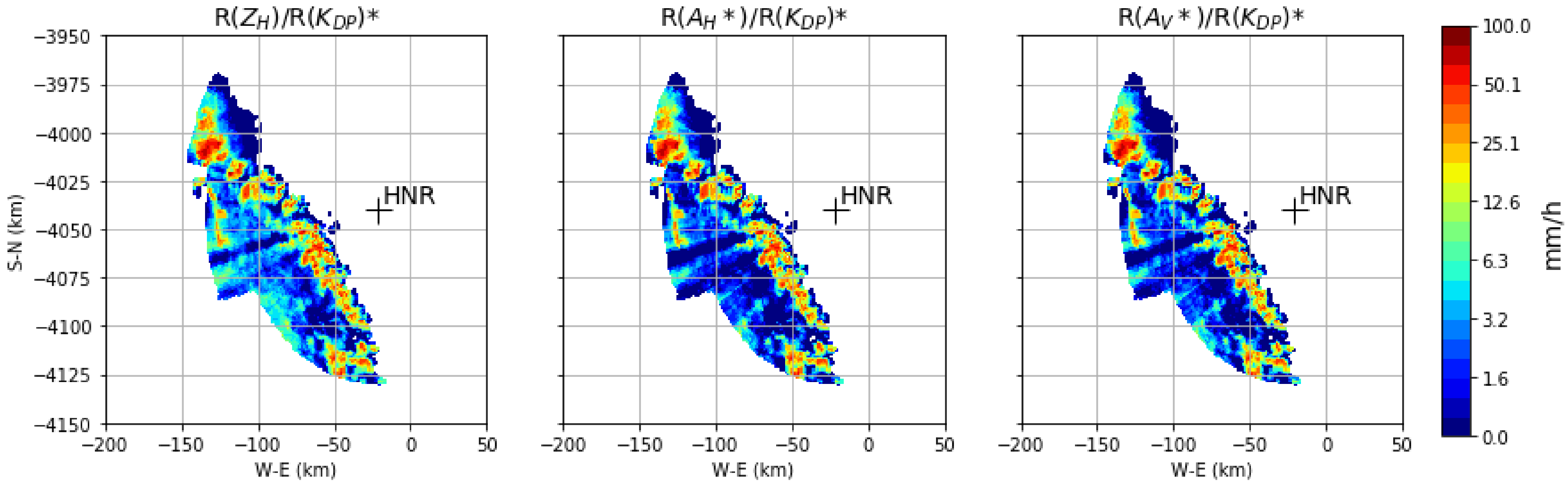
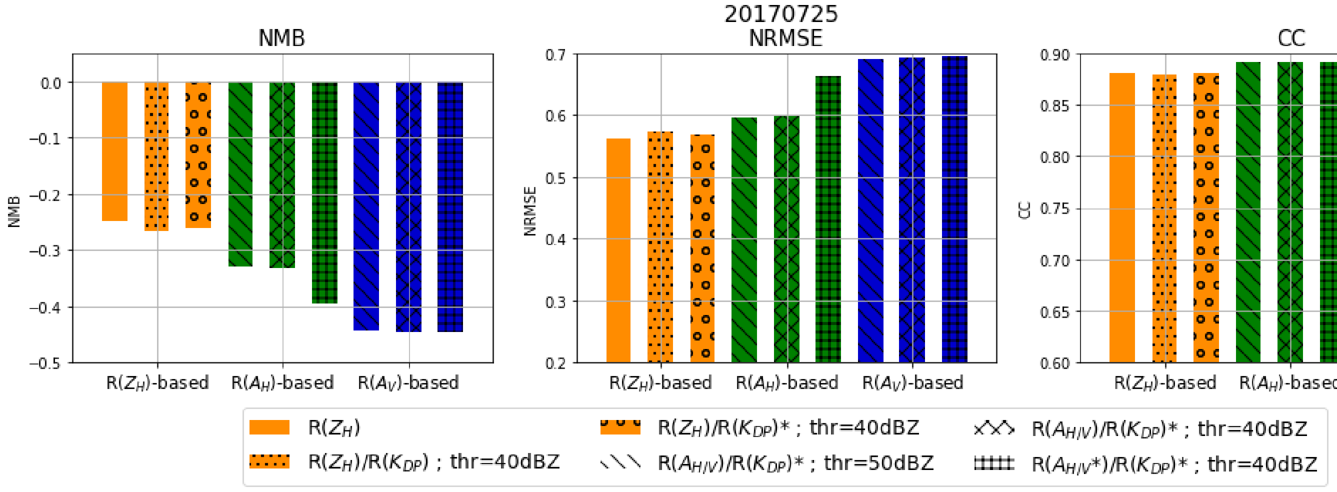
Result – convective cases

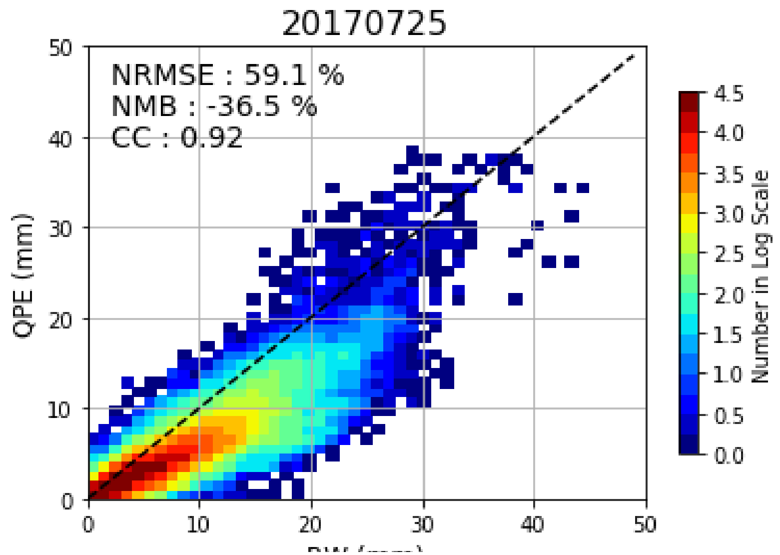


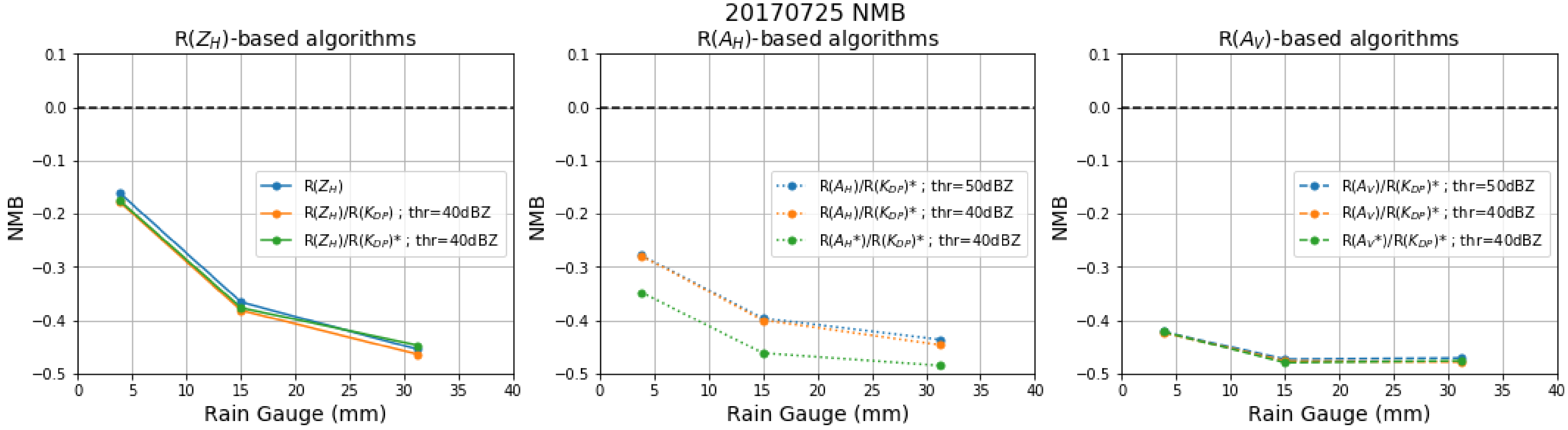
In areas right behind the hail core with strong attenuation, all the products show several underestimated bands along the rays.

→ the integral process should be reset in each pure-rain **segment** for the ZPHI method.

Result - stratiform



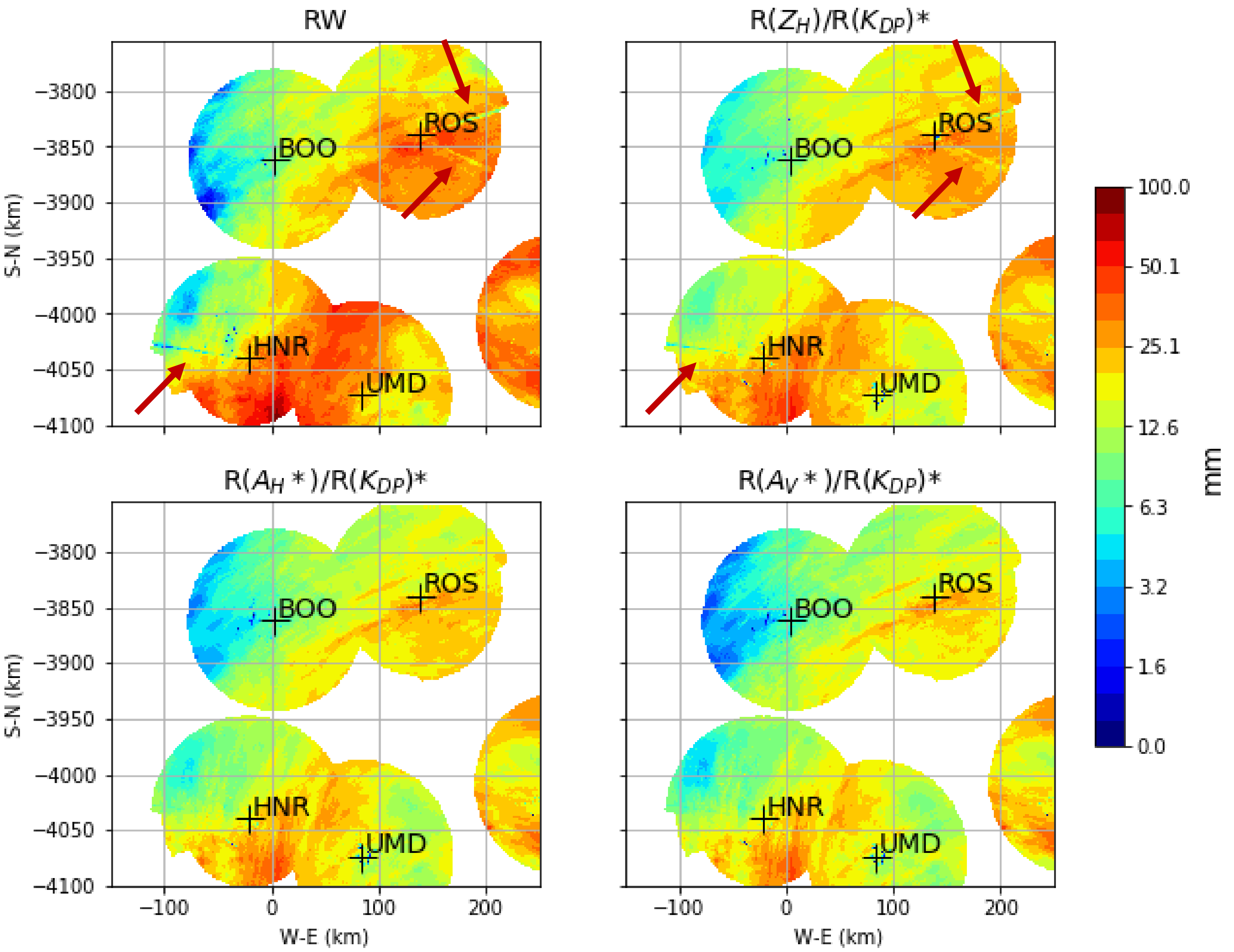




Underestimation →

Less sensitive Φ_{DP}, smoothing process of Φ_{DP}, too low $\alpha_{H/V}$ values

Result - stratiform



Conclusions and future work

- The Z_H-based algorithms with **$R(K_{DP})^*$** show **lower NMBs in moderate and heavy rain** compared to $R(K_{DP})$.
- **After the adjustments**, NMBs are decreased and the QPE performances of **$R(A_H^*)/R(K_{DP})^*$ and $R(A_V^*)/R(K_{DP})^*$ are comparable**.
- The derived hybrid QPE products are quite **consistent with** the **RW** product.
- **$A_{H/V}$-based** rainfall retrievals further mitigate the **PBB** problem.

Conclusions and future work

- An average **scan-based $\alpha_{H/V}$** value cannot satisfy the case when the rain within a scan is inhomogeneous, and thus **limits the improvement of NRMSE and CC**.

  → an optimization of **net $\alpha_{H/V}$ along the ray or within the segment**

- Ignoring Φ_{DP} from the cell and directly connecting pure rain segments into a path will miss the attenuation from the cell which should propagate to the bins behind, and lead to underestimated $A_{H/V}$ (rainfall) in the latter segment.

  → the **segmentation of a ray** in the case of heavy rain containing large drops or hail

- The performance of $A_{H/V}$-based products in **stratiform rain** is worse than that of Z_H-based products, which should be addressed with great care in ongoing and future research.

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