Effect of clutter interference in surface rainfall estimates at off-nadir scan angles

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Introduction

The long-term TRMM PR data have resulted in high-resolution rainfall climatology, revealing striking regional characteristics of the orographic and coastal rainfalls, and a spatially fixed bias caused by some factors such as the differing main-lobe clutter interferences (Hirose et al. 2012, JTECH). GPM DPR has been accumulated for approximately 5 years, providing new information including retrieval uncertainties in the high-latitudes. Overall, the long-term mean spaceborne radar data is useful in view of the geographical dependence in the retrieval at different surface types; however, the regional uncertainty remains to be solved. This study investigates observation discrepancies in rainfall estimates with focus on the influence of varying clutter-free levels. It aims to achieve internal consistency of the TRMM PR and GPM DPR rainfall statistics among the incidence angles.

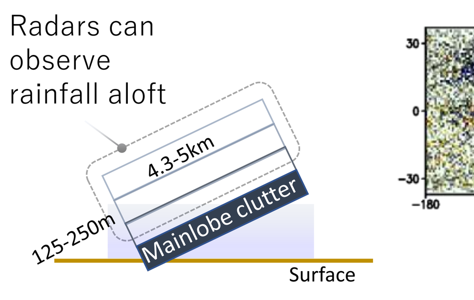


Fig. 1 Near-surface observation interfered by mainlobe clutter

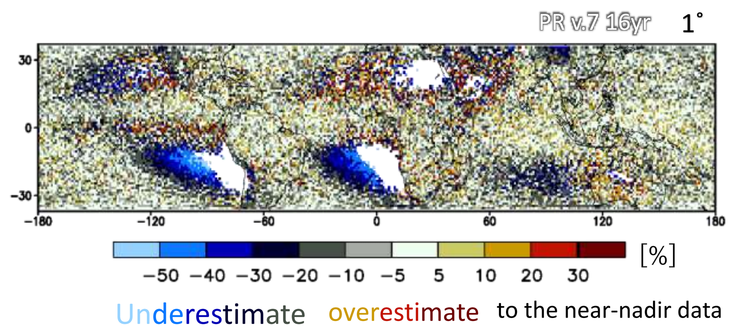


Fig. 2 Anomaly of rainfall amount to the near-nadir statistics

R > 0.1 mm/day, Near nadir: 21-23 & 27-29 bin

Clutter free bottom level and the incidence angle dependency

The clutter depth from the surface (**Clutter Free Bottom**; **CFB** level) is approximately 1,000 and 2,000 m at the near-nadir and swath edge, respectively. Along the Himalayan range, the clutter interference levels are increased by 750–1,000 m. CFB level for DPR is generally high over land as compared with that of PR.

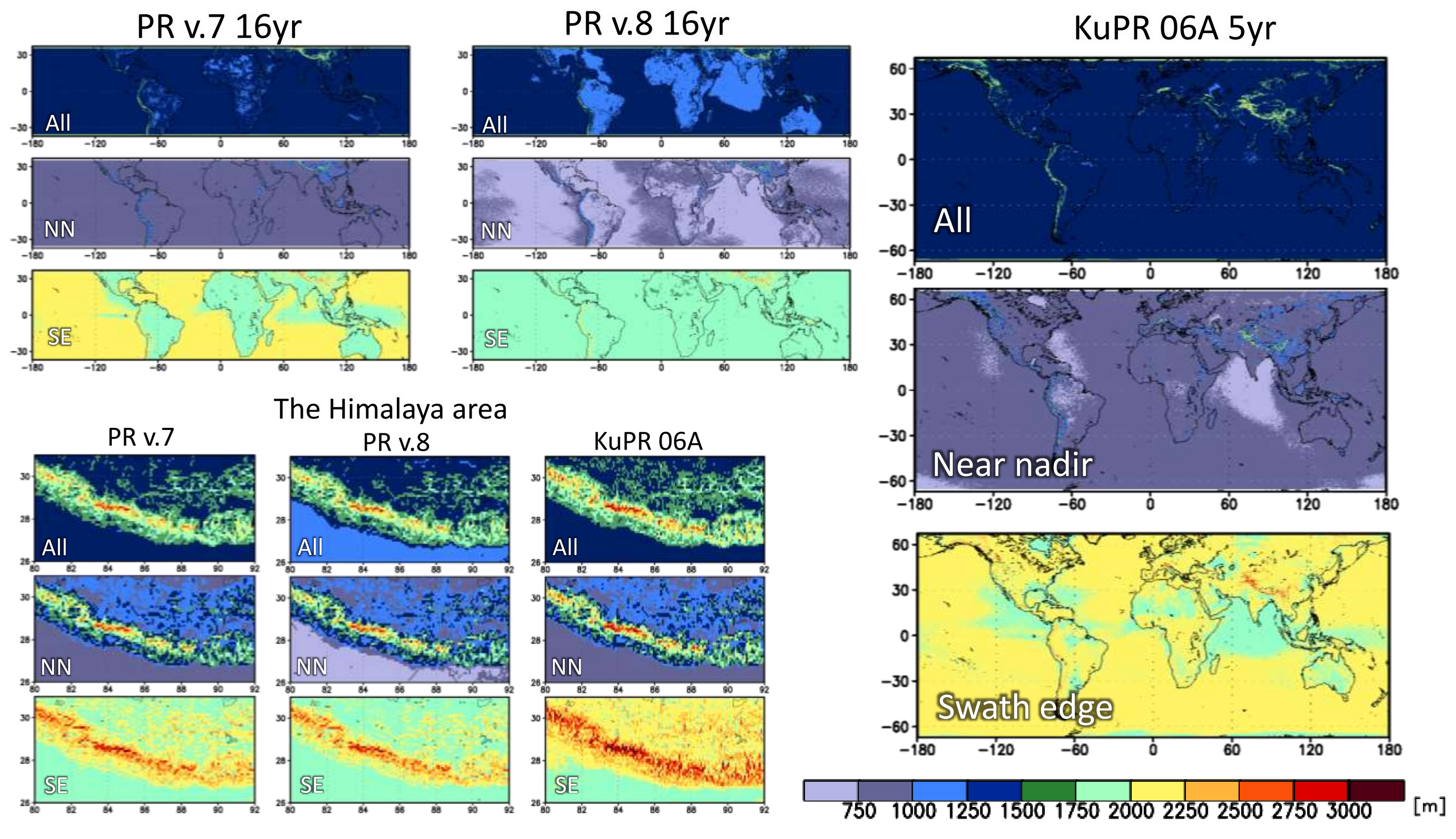


Fig. 3 Levels of Clutter Free Bottom from surface

All: 1-49 angle bins, near nadir (NN): 23-27 bins, and swath edge (SE): 1-2, 48-49 bins

Surface rainfall estimated by PR and DPR is **underestimated** at its **off nadir.** Singular overestimates at nadir over land result from retrieval uncertainty on rainfall > 50 mm/h. This is a controversial issue in conjunction with uncertainties of σ^0 in the attenuation estimates.

The **near-nadir** statistics are assumed to be of the highest quality in terms of observation limitation. An obvious retrieval error can be observed in the incidence-angle dependency as shown in Fig. 4 and Table 1.

Approximately **7%** and **2%** of the rainfall over **land** and **oceans** (70°N-S) is **smaller** than the near-nadir statistics (21-23rd and 27-29th angle-bin data out of 49 bins) for KuPR 06A, respectively. At latitudes higher than 60°, the KuPR data are considerably lower than the near-nadir data. This study attempts to reduce the retrieval bias by mitigating the per-angle inconsistency of low-level precipitation profiles.

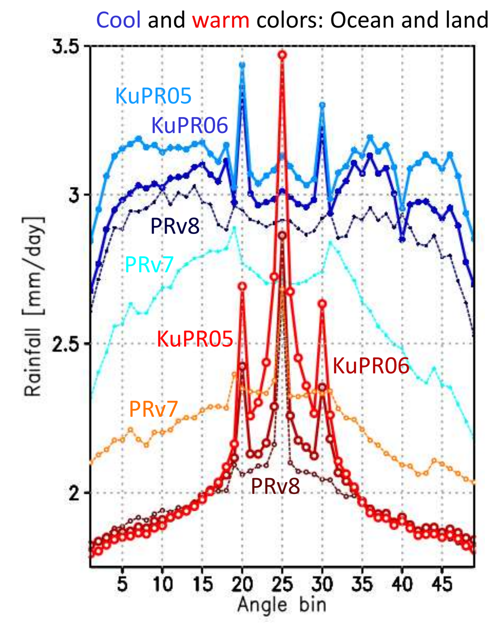
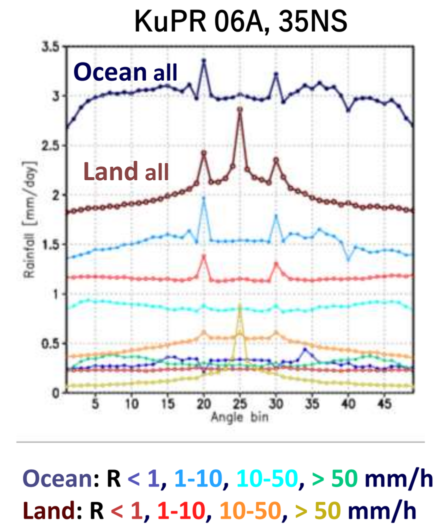


Fig. 4 Estimated surface rainfall at different incidence angles, 35°N-S



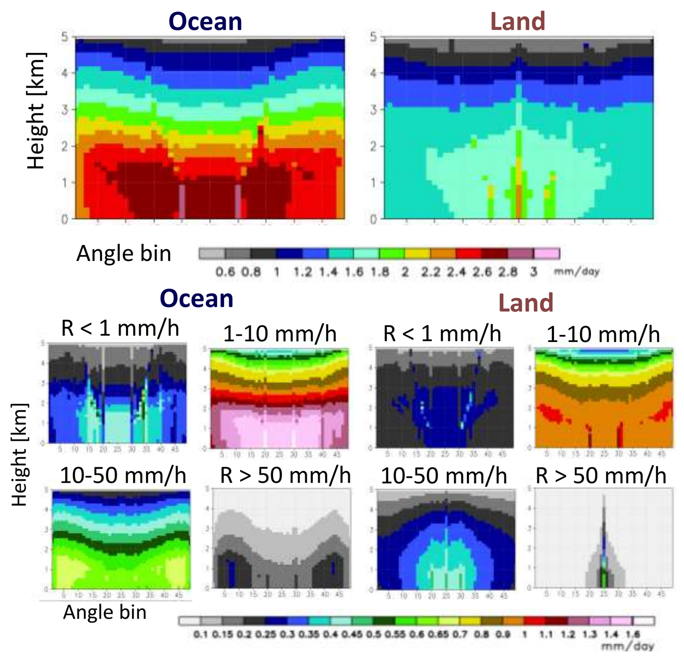


Fig. 6 KuPR 06A rainfall at levels below 5 km, 70°N-S

Table 1 Rainfall between 35°S-35°N (35°-70°) and the anomaly to the near-nadir statistics

	Ocean				Land			
	PR v.7	PR v.8	KuPR 05A	KuPR 06A	PR v.7	PR v.8	KuPR 05A	KuPR 06A
Rainfall [mm/day]	2.6	2.9	3.1 (1.9)	3.0 (1.8)	2.2	2.0	2.1 (1.1)	2.0 (1.0)
Anomaly [%]	**-4.0**	-0.2	1.7 (**-7.9**)	0.7 (**-11.6**)	**-4.7**	**-5.1**	**-11.8** (**-11.6**)	**-6.4** (**-8.8**)

Mitigation of underestimation bias at off-nadir angles

The underestimation bias is mainly attributable to 1) the deficiency of the profile model below the clutter-free bottom level and 2) the effect of missing shallow storms.

Mainlobe clutter filtering → Diff of the clutter-free bottom (CFB) levels

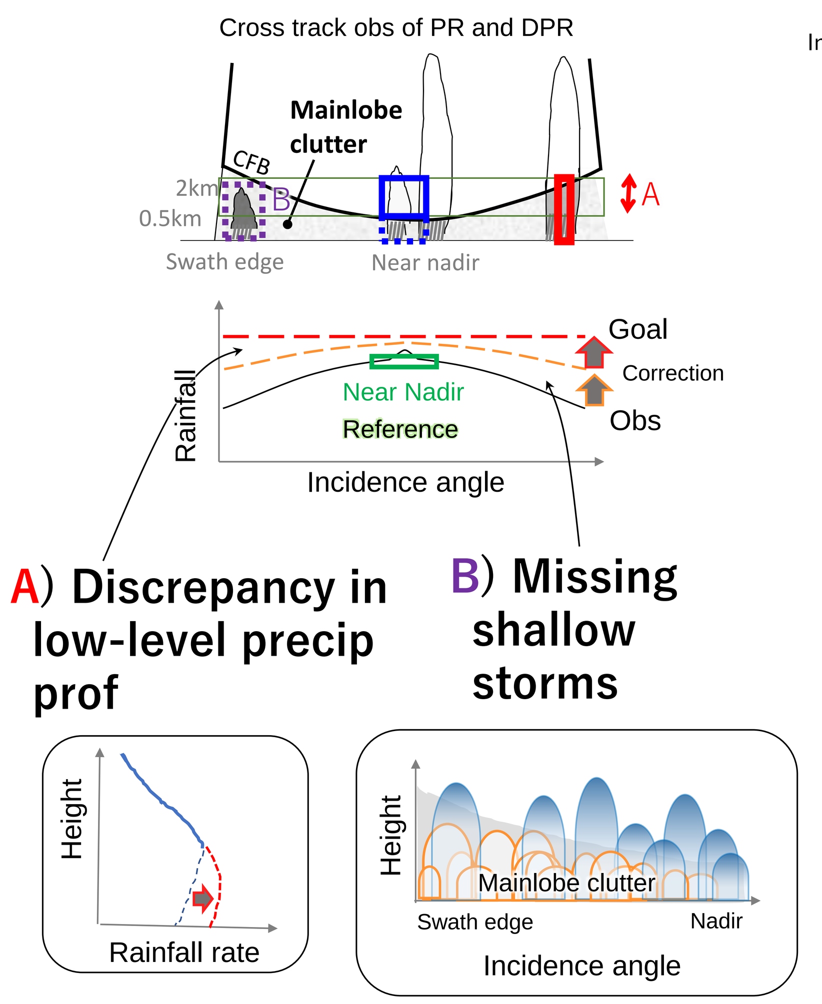


Fig. 7 Major factors of the incidence angle dependency

→ Increase off-nadir rainfall estimates

→ Improve consistency of rain statistics btw angles

A) Discrepancy in low-level precipitation profiles

A **low-level precipitation profile** (**LPP**) database was generated based on the near-nadir statistics. After an instantaneous correction by more than one thousand of a priori rainfall-rate profiles, the precipitation increased over majority of the areas (the exceptions were the dry regions).

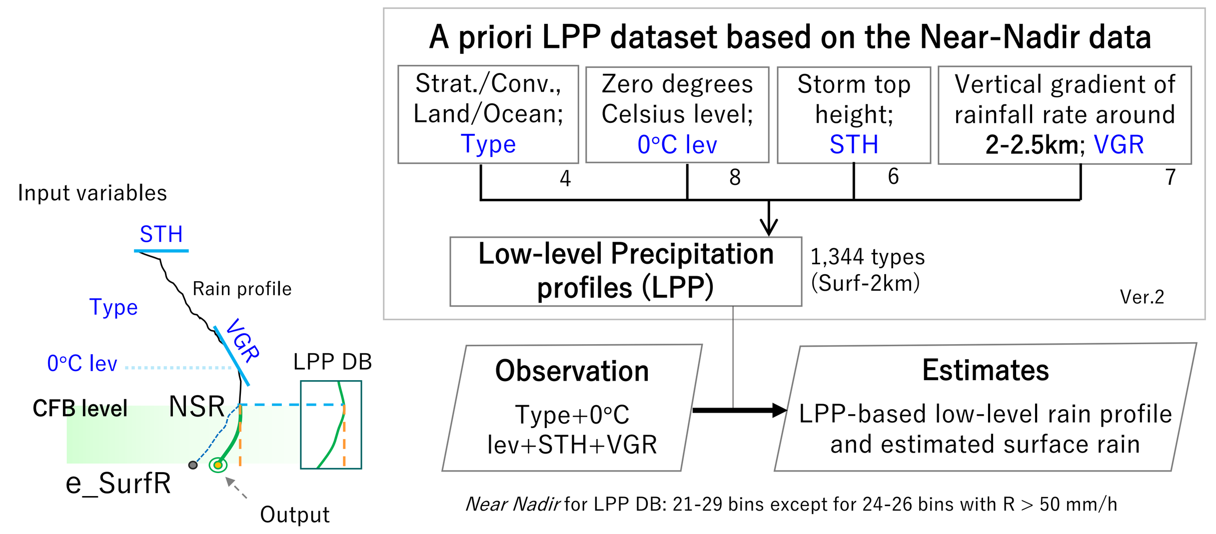


Fig. 8 Correction of surface rainfall estimates based on the referential LPP DB

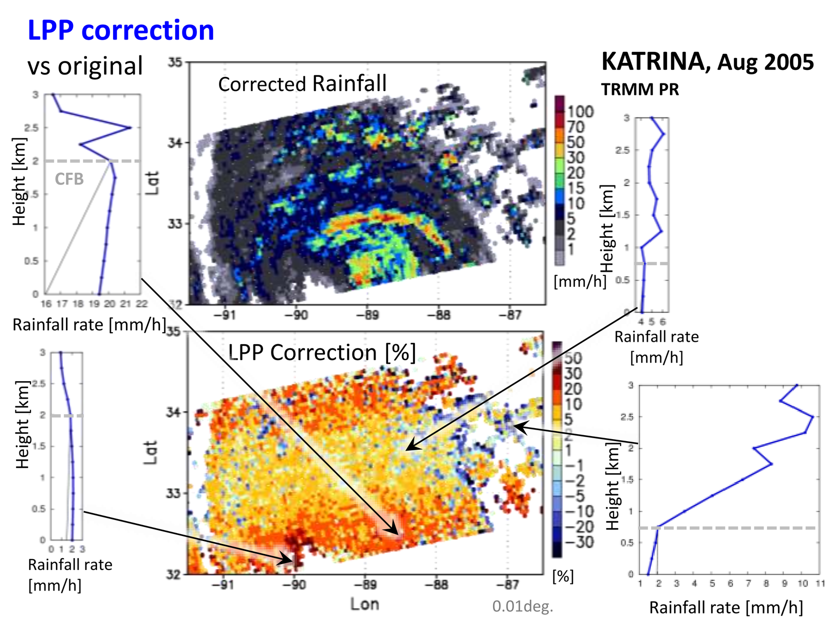


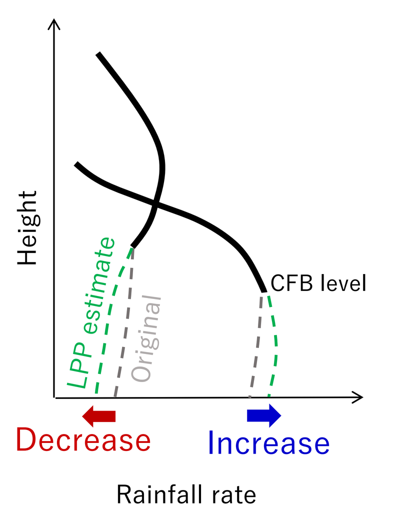
Fig. 9 A case of rainfall rate and the effect of the low-level profile correction on surface precipitation estimates.

This effect was significant in **mountainous areas**, where the clutter-free bottom level is high, and at **high latitudes** dominated by shallow storms. The prevailing low-level profile patterns differ by regions and season; however, this correction generally increases surface rainfall as indicated by cool color shading in Fig. 10.

For example, the 0.01°-scale maximum rainfall around the Cherrapunji valley, India, was increased from 28.9 to 31.5 mm/day (+9%).

Assumption of the evaporation effect for stratiform rain over land is different between PR v.7 and current DPR algorithms.

The impact of LPP correction is relatively small for KuPR data but non-negligible in mountainous areas and in the high latitudes. In average, on the basis of the 5-year KuPR data, the LPP correction increased rainfall by **4%** for all domain and **13%** at 55°-65°S.



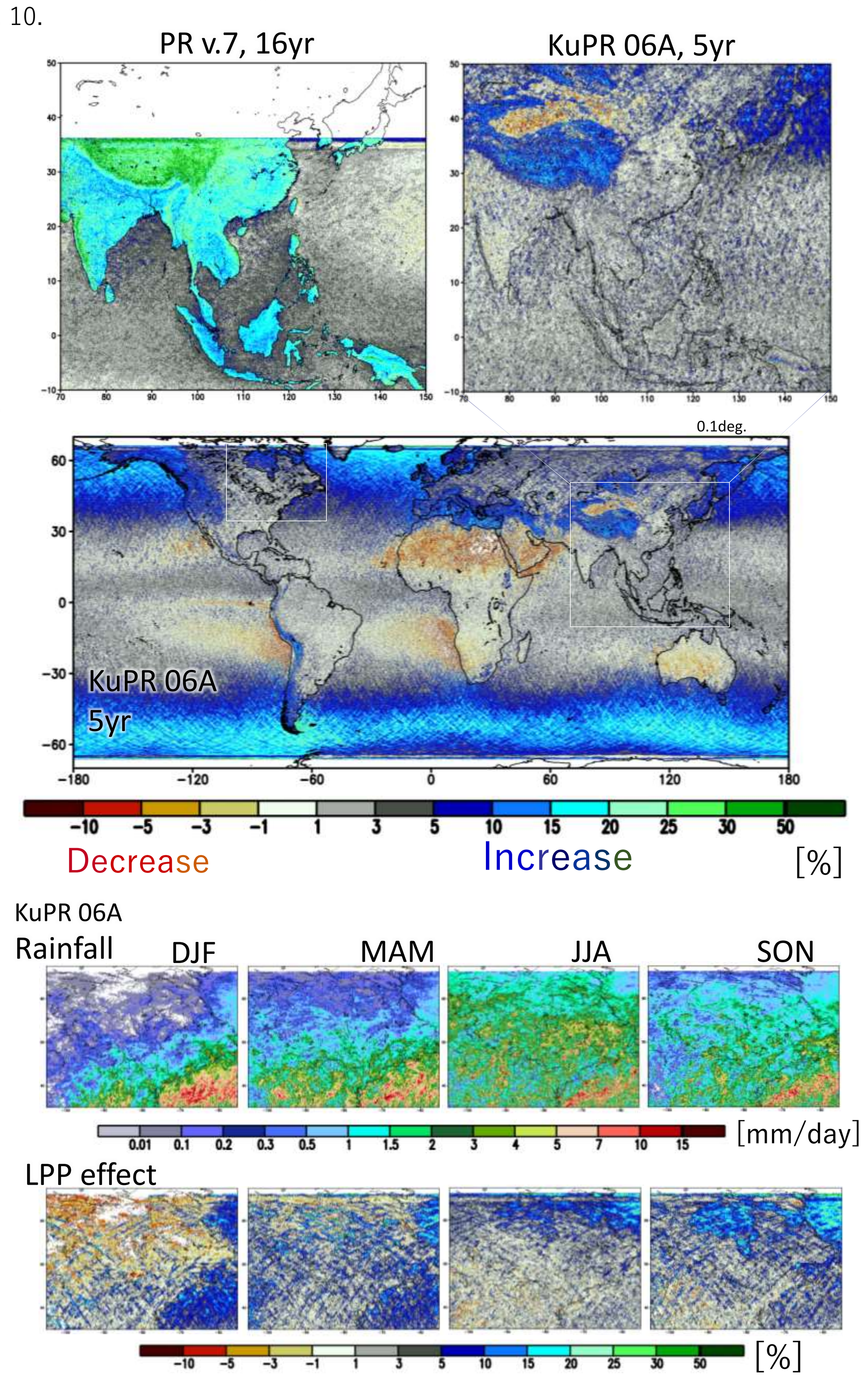


Fig. 10 Effect of LPP correction for PR v.7 and KuPR 06A rainfall

B) Missing shallow storms

The discrepancy arising from the shallow storm deficiency with respect to the observation limit can be estimated from the number of per-level storms and their corresponding rainfall rates (Hirose et al. 2012, JTECH).

Shallow rain deficiency; Missing rain by lesser # of shallow storms

$$\frac{\sum_{i=1}^{49}\sum_{h=surf}^{2.5km}\left(N(i,h)-N(nn,h)\right)\cdot\overline{R_s}(nn,h)}{\sum_{h=surf}^{top}N(nn,h)\cdot\overline{R_s}(nn,h)}$$

The missing ratio of rainfall from the shallow storms (< 2.5 km) interfered with the surface clutter (i.e., shallow rain deficiency) is closely related with the shallow rain fraction and clutter free bottom levels. After a statistical correction, the rainfall dramatically increased over **the low-rainfall oceans**, **at high latitudes**, **over the Tibetan plateau**, and **over high mountains**. The zonally averaged shallow rain deficiency had its peak around 20°S, including the ocean off Peru and Angola, and the southern edge of the observation domain. More than **50%** of the rainfall was missed there.

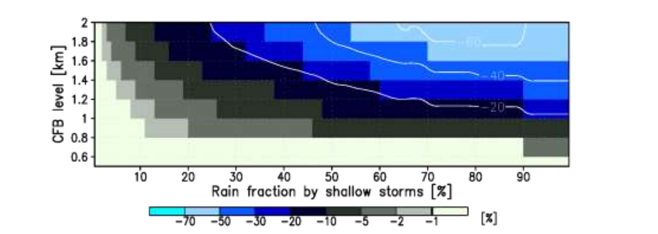


Fig. 12 KuPR shallow rain deficiency averaged for rain fraction by shallow storms (abscissa) and clutter free bottom level (ordinate)

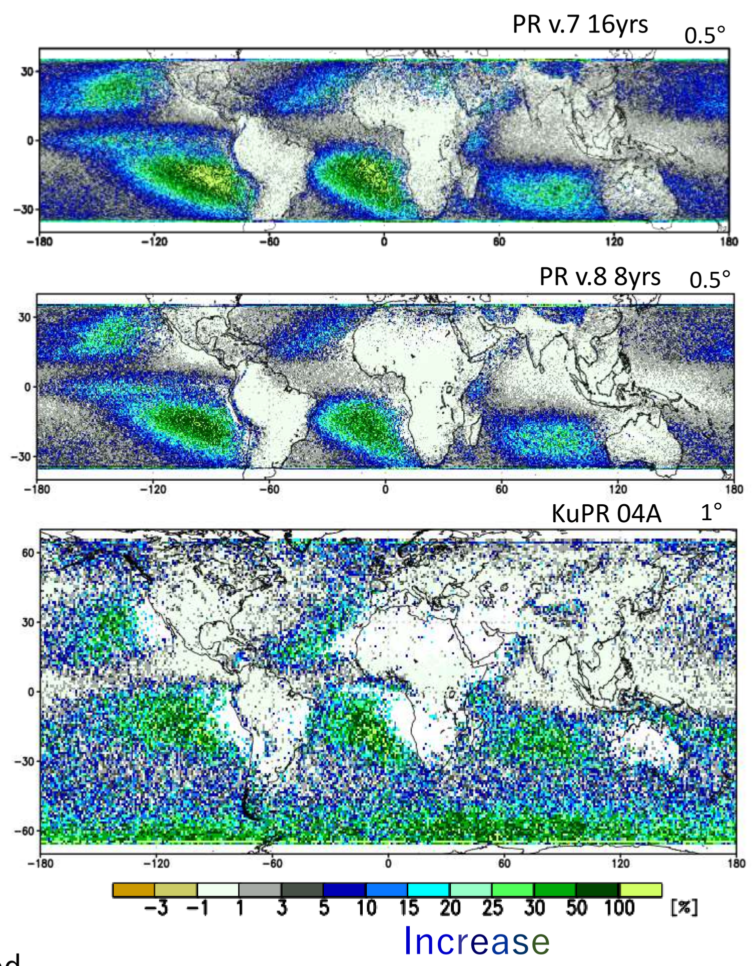


Fig. 11 Effect of correction for shallow rain deficiency of PR and KuPR

Conclusion

In specific areas such as the Tibetan plateau, low-rainfall oceans, and in the middle and high latitudes, the correction on the incidence angle dependency increases PR and DPR rainfall by **tens of percent**. Accordingly, the **off-nadir underestimation** was substantially **reduced.** The long-term dataset that was corrected for **internal consistency** provides a better spatial reference.

However, further examination with other instruments is needed on the detectability of echoes near the ground surface to ensure accurate understanding of high rainfall concentration on mountainous slopes. More detailed investigations on the remaining differences such as the off-nadir overestimation over ocean and the near-nadir statistics between algorithms are necessary to ensure the robustness and continuity of the two spaceborne radar data.