An assessment of the Doppler measurements with a Ku-band spaceborne precipitation radar

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Abstract

Currently, a future satellite mission of precipitation observations is discussed in Japan. From a low-orbit satellite, it is difficult to directly observe temporal evolution of precipitating clouds. The dynamical structure of precipitation helps better understandings of the lifecycle of precipitating clouds. Thus, the Doppler capability of a spaceborne precipitation radar is expected to provide global information of the motion for various precipitating clouds. However, the Doppler measurements of precipitation from space is challenging because of a fast-moving platform and a radar's finite field of view (FOV). Since the radar onboard the spacecraft quickly passes above precipitating clouds, the decorrelation of precipitation signals due to the beam broadening effect degrades the Doppler measurement accuracy. Moreover, a spatial variability of precipitation within the FOV causes mixing of the motion between precipitating particles and spacecraft, which is called as an effect of the non-uniform beam filling (NUBF). This study investigates the Doppler capability of the spaceborne precipitation radar based on simulation experiments by using the high-spatial resolution ground radar and numerical model data. Here, we discuss two Ku-band Doppler radar systems: A) a large one antenna system and B) a two-antenna system. Since the contamination of the platform motion is proportional to the platform velocity and the radar's beamwidth, the large antenna system mitigates the contamination due to the platform motion. On the other hand, the two-antenna system adopts the displaced phase center antenna (DPCA) technique. A signal processing with two antennas cancels out the platform motion so that mitigation of the beam broadening and NUBF effects is expected even if the FOV is coarse than the large antenna system. A quantitative evaluation between the two systems is conducted. For the large antenna system (FOV of 2.5 km), the mean Doppler velocity error of precipitation (> 15 dBZ) is evaluated in the range from 2.3 to 5 .0 m/s. Although the large error is originated from a residual error of the imperfect NUBF correction, the error is mitigated from 0.7 to 1.5 m/s when a 5-km average in the along-track direction is applied. For the two-antenna system (FOV of 5 km), the error is evaluated in the range from 0.6 to 1.1 m/s.

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Purpose

A future satellite mission of precipitation observations is discussed in Japan. From a low-orbit satellite, it is difficult to directly observe temporal evolution of precipitating clouds. The dynamical structure of precipitation helps better understandings of the lifecycle of precipitating clouds. Thus, the Doppler capability of a spaceborne precipitation radar is expected to provide global information of the motion for various precipitating clouds. However, the Doppler measurements of precipitation from space is challenging because of a fast-moving platform and a radar's finite field of view (FOV). Since the radar onboard the spacecraft quickly passes above precipitating clouds, the decorrelation of precipitation signals due to the beam broadening effect degrades the Doppler measurement accuracy. Moreover, a spatial variability of precipitation within the FOV causes mixing of the motion between precipitating particles and spacecraft, which is called as an effect of the non-uniform beam filling (NUBF).

This study investigates the Doppler capability of the spaceborne precipitation radar based on simulation experiments by using the high-spatial resolution ground radar and numerical model data. Here, we discuss two Ku-band Doppler radar systems: A) a large single antenna system and B) a double antenna system. Since the contamination of the platform motion is proportional to the platform velocity and the radar's beamwidth, the large antenna system mitigates the contamination due to the platform motion. On the other hand, the two-antenna system adopts the displaced phase center antenna (DPCA) technique (Durden et al., 2007). A signal processing with two antennas cancels out the platform motion so that mitigation of the beam broadening and NUBF effects is expected even if the FOV is coarse than the large antenna system.

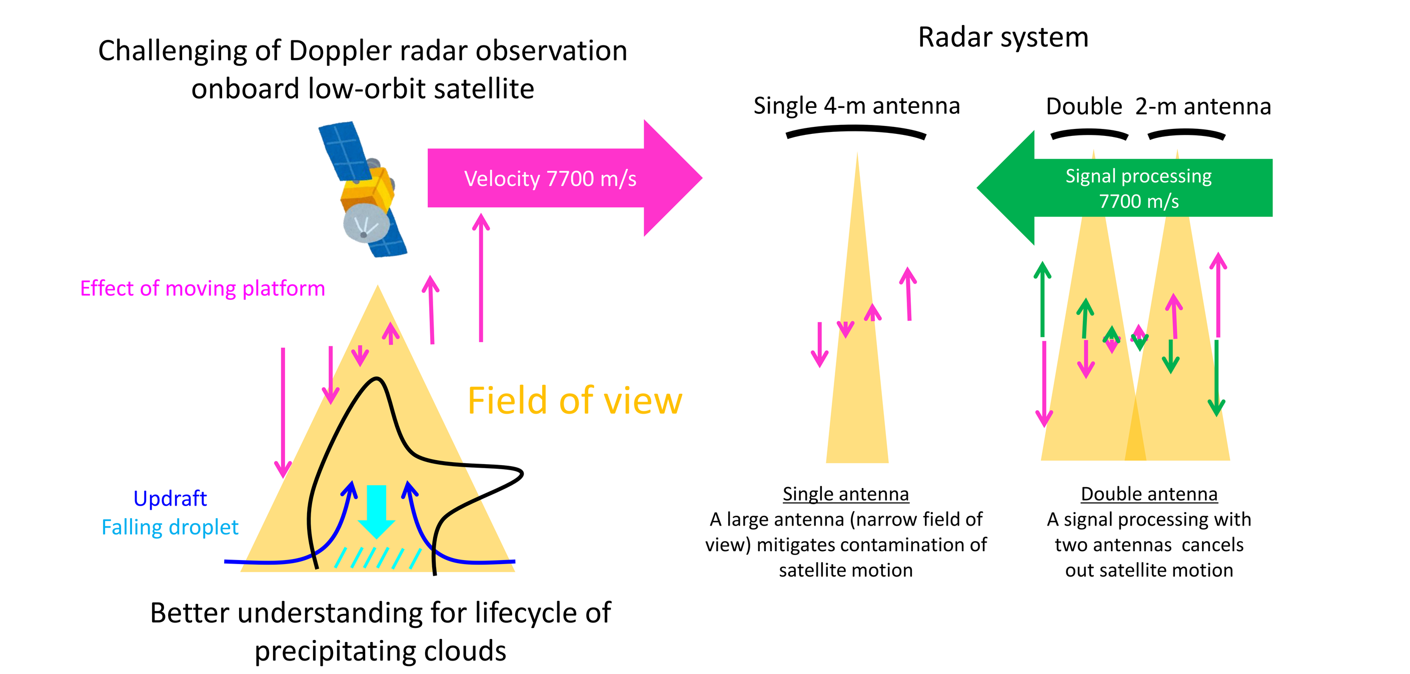


Figure: Schematic of radar antenna system for spaceborne Doppler radar

Table: Used parameters in this study

Satellite height: 400 km

	Single antenna	Double antenna
FOV (Along-track & cross-track)	2.5 km x 5 km	5 km x 5 km
Nyquist velocity	40.2 m/s	38.6 m/s
Pulse number for an FOV	256	128
Radar echo sensitivity (Doppler observation: >10 dBZ)	~0 dBZ	~3 dBZ
Apparent satellite velocity	7600 m/s	200 m/s
Along-track sampling interval	0. 625 km	

Doppler scan is only conducted at the nadir.
Cross-track scan w/o Doppler measurement is conducted during the Doppler scans.

Data and method

1) FOV-averaged values of Doppler mean velocity and radar reflectivity are computed from high-resolution data of the ground radar (XRAIN) and the numerical simulations (Kollias et al., 2014, 2018).
2) Contamination of satellite velocity and random error of signal are simulated (Schutgens 2008).
3) NUBF's velocity bias in the simulated radar data is removed by a correction algorithm (Sy et al. 2014).
4) Corrected data are evaluated with true (FOV-averaged) Doppler mean velocity.
5) Error evaluation for 5-km size is also co to the difference in FOV size between two antenna systems.

References

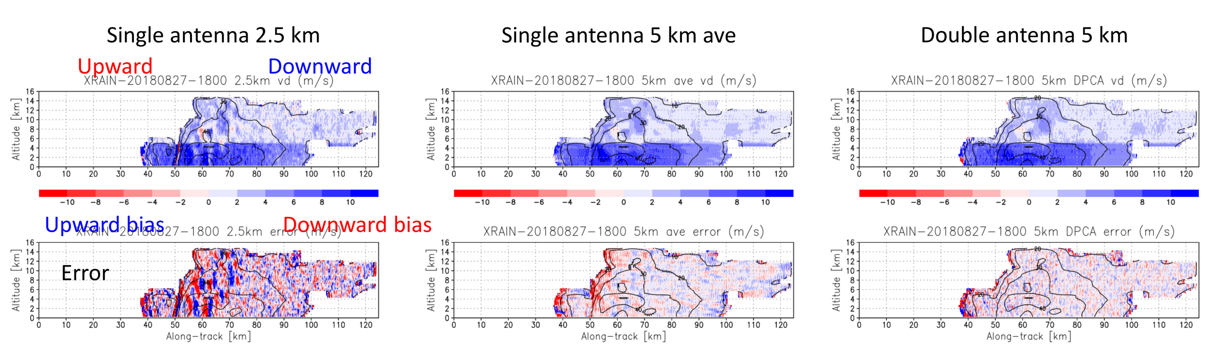
Schutgens (2008) https://doi.org/10.1175/2007JTECHA956.1, Sy et al. (2014) https://doi.org/10.1109/TGRS.2013.2251639, Kollias et al. (2014) https://doi.org/10.1175/JTECH-D-11-00202.1, Kollias et al. (2018) https://doi.org/10.1117/12.2324321, Durden et al. (2007) https://doi.org/10.1109/LGRS.2006.887136, Doviak and Zrnic (1993) Textbook 2nd ed.

Summary

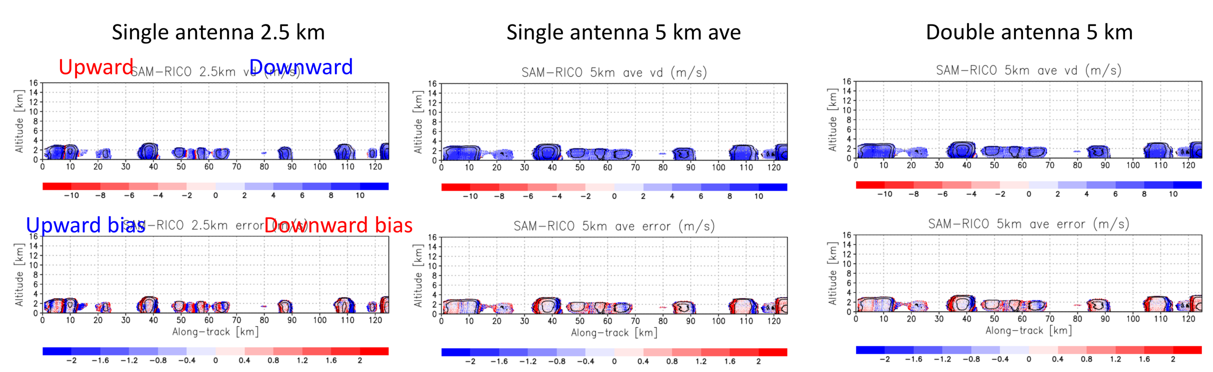
A quantitative evaluation between the two systems is conducted. For the large antenna system (FOV of 2.5 km), the mean Doppler velocity error of precipitation (> 15 dBZ) is evaluated in the range from 2.3 to 5 .0 m/s. Although the large error is originated from a residual error of the imperfect NUBF correction, the error is mitigated from 0.7 to 1.5 m/s when a 5-km average in the along-track direction is applied. For the two-antenna system (FOV of 5 km), the error is evaluated in the range from 0.6 to 1.1 m/s.

Results

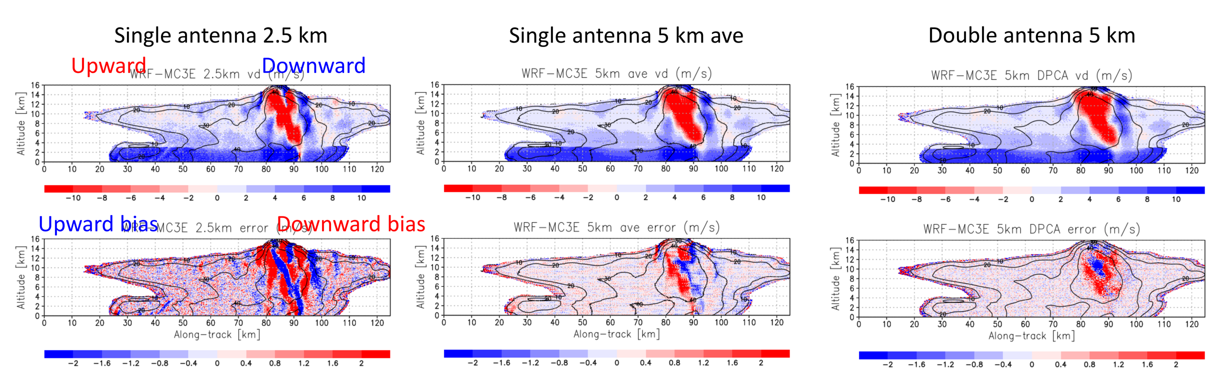
XRAIN (ground radar: 250 m spatial resolution)



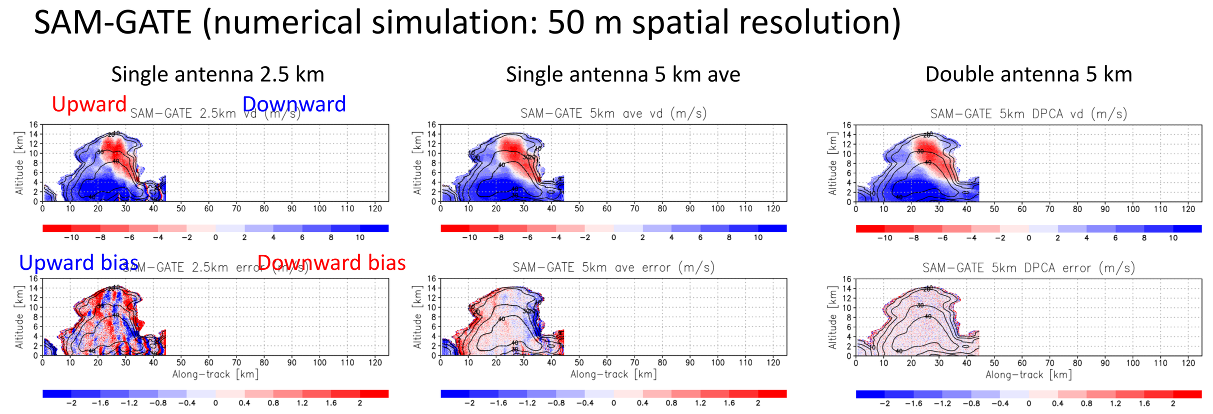
SAM-RICO (numerical simulation: 50 m spatial resolution)



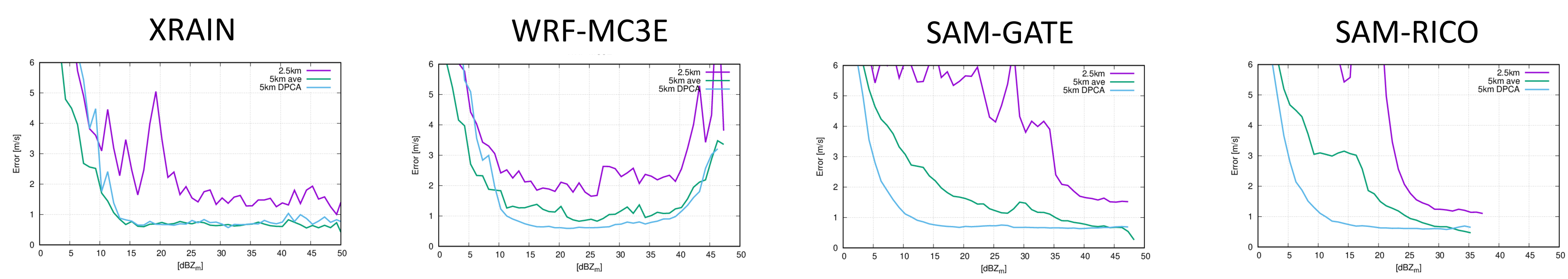
WRF-MC3E (numerical simulation: 250 m spatial resolution)



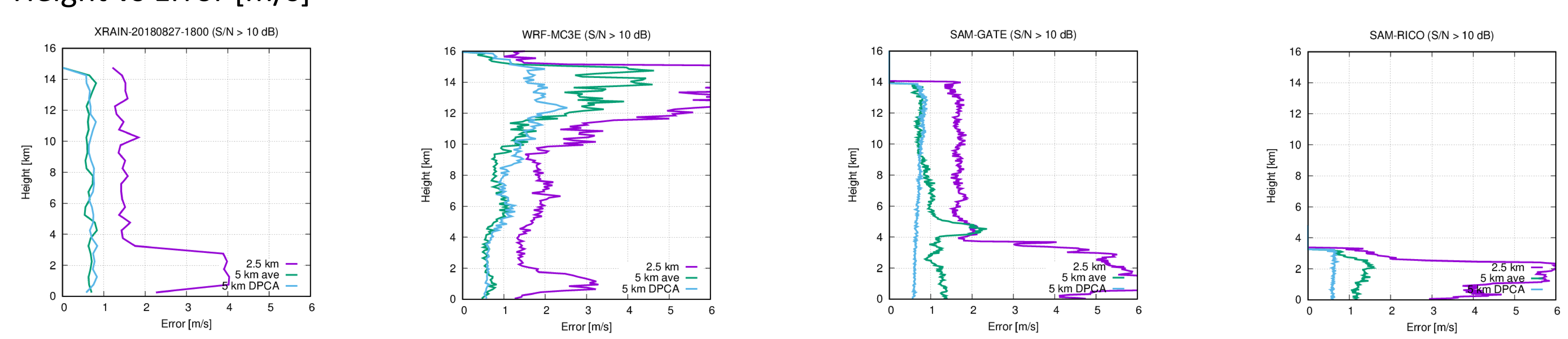
SAM-GATE (numerical simulation: 50 m spatial resolution)



Z_m vs Error [m/s]



Height vs Error [m/s]



Singe antenna 2.5 kma
Single antenna 5 km ave
Double antenna 5 km

	Single antenna 2.5 km	Single antenna 5km ave	Double antenna 5 km
Doppler error (assuming uniform rain)	1.47 m/s	0.66 m/s	0.45 m/s
XRAIN	2.25 m/s	0.69 m/s	0.71 m/s
WRF-MC3E	2.68 m/s	1.34 m/s	1.10 m/s
SAM-GATE	3.78 m/s	1.16 m/s	0.68 m/s
SAM-RICO	4.95 m/s	1.53 m/s	0.63 m/s

Expected error is assumed for SNR 10 dB of pulse pair (Doviak and Zrnic, 1993)

Sampled data where Z_m > 15 dBZ

Single antenna:
Z_{noise} 6.3 dBZ (15 dBZ = S/N 8.7 dB)
Double antenna:
Z_{noise} 9.3 dBZ (15 dBZ = S/N 5.7 dB)

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