

Response to community comments

Shunsuke Aoki, Takuji Kubota, Hiroaki Horie, and Yuichi Ohno: “Characteristics of multiple-trip echoes observed by EarthCARE Cloud Profiling Radar”, submitted to Atmospheric Measurement Techniques (AMT) (egusphere-2026-3256).

CC1: 'Comment on egusphere-2026-3256', V. Shcherbakov, 30 Jul 2026 reply

To my knowledge, satellite mirror images (SMIs) were not reported in the literature before the work DOI: 10.5194/egusphere-2026-3256. Therefore, comprehension of that effect is of importance. Whereas the experimental data (Fig. 3) are convincing, presented by the authors explanation of properties of Doppler velocity (Fig. 3c) is far from being sufficient.

We sincerely thank you for your insightful comments on the discussion of satellite mirror images (SMIs). We have carefully revised the manuscript and added explanations clarifying why the SMI Doppler velocity varies substantially within a single scene and why an artifact originating from the CPR electronics is unlikely. Our point-by-point responses are provided below.

I assume that $V(H_{fsc})$ and V_{Los} of Eq. (7) are `dopplerVelocityAtSurfaceBin` and `satelliteVelocityContamination` values, respectively, of CPR L1b Level 1 Product (see URL: https://www.eorc.jaxa.jp/EARTHCARE/data/L1/CPR_NOM_e.html; last access 29 July 2026). Accordingly, the properties of V_{SMI} follow the properties of those two parameters. In my opinion, the properties of $V(H_{fsc})$ should be dominating.

According to Fig. 8 of the work DOI: 10.5194/egusphere-2025-4819, the measured Doppler velocity at surface is on average within the range $[-0.4, 0.3]$ m/s. According to Fig. 4 of the work DOI: 10.5194/amt-18-5607-2025, EarthCARE CPR antenna mispointing leads to Doppler velocity bias within the range $[-0.2, 0.8]$ m/s. Consequently, the data of Fig. 3c are really exceptional and the authors must propose a working model aiming to explain observed properties.

First of all, that working model must give reliable ideas explaining why V_{SMI} (I suppose that $V(H_{fsc})$ as well) fairly increases with latitude decreasing / longitude increasing. Moreover, the increase is so high that the jump, which corresponds to doubled Nyquist-velocity, is observed at a latitude of about 78° . Roughly, the increase in V_{SMI} and $V(H_{fsc})$ is about 10 m/s.

According to the authors (lines 21 -22) “... SMIs occur almost exclusively over surfaces with near-saturated backscatter, such as melting sea ice and land with surface-water cover.” Conditions of melting sea ice or

land with surface-water cover can be associated with the specular reflection in non-uniform beam filling (NUBF) conditions. Accordingly, the question is: how NUBF, which is statistically homogeneous, can lead to the linear increase of V_{SMI} and $V(H_{\text{sfc}})$ in Fig. 3c?

Thank you for providing insightful comments. As you mention, the Doppler velocity provided in the CPR products is corrected for the satellite velocity contamination in the line-of-sight direction (V_{LOS}). On the other hand, the dominant contribution to V_{LOS} arises from vertical motion of the satellite. Because the satellite altitude varies systematically along the orbit as shown in new Figs. 5b and 5c, V_{LOS} change with amplitude approximately $\pm 30 \text{ m s}^{-1}$. When the satellite altitude is increasing, a negative Doppler component is introduced, whereas a positive component is introduced when the altitude is decreasing (Fig. 5c). This contribution can be estimated from the satellite telemetry, and stored as “satelliteVelocityContamination” variable in the CPR L1b product. We recognized that a more detailed explanation of these Doppler velocities is important for interpreting our results. We have therefore added the following explanation to the revised manuscript:

Line 304–324

Instead, the Doppler velocity at the SMI altitude, V_{SMI} , can provide a useful diagnostic. The raw Doppler velocities measured by the CPR contains a contribution from the satellite velocity in the line-of-sight direction, V_{LOS} . Because an SMI involves an additional round trip between the satellite and the surface, its Doppler velocity, V_{SMI} , contains an additional V_{LOS} contribution relative to that of the first-trip surface echo as follows:

$$V_{\text{SMI}} = (V(H_{\text{sfc}}) + V_{\text{LOS}}) \bmod 2V_N, \quad -V_N \leq V_{\text{SMI}} < V_N, \quad (9)$$

where V_N is the Nyquist velocity. The dominant contribution to V_{LOS} arises from vertical motion of the satellite associated with altitude variations along the orbit (Figs. 5b and 5c). Its magnitude can reach approximately $\pm 30 \text{ m s}^{-1}$ and can be determined from the satellite telemetry. A smaller contribution to V_{LOS} results from the CPR’s antenna beam mis-pointing caused by thermal distortion of the CPR main reflector, uncertainties in the satellite attitude determination, and residual calibration errors (Puigdomènech Treserras et al. 2025). This component also varies systematically over the orbit, but its amplitude is only about 0.3 m s^{-1} .

Ideally, $V(H_{\text{sfc}})$ would be zero after V_{LOS} -correction. In practice, however, small residual velocities on the order of 0.1 m s^{-1} remain because of uncertainties in V_{LOS} and variations in surface scattering properties, including effects associated with nonuniform beam filling (NUBF) and the strong incidence-angle dependence of specular reflection. We therefore use the observed $V(H_{\text{sfc}})$ explicitly rather than assuming it to be zero.

Figures 4d and 7d compares the V_{SMI} predicted from Eq. (9) with the observed Doppler velocity, $V_{\text{obs}}(H_{\text{SMI}})$, demonstrating that the predicted and observed values are in good agreement. In Fig. 4d, the expected and observed V_{SMI} gradually shifts toward more positive velocities from the left to the right side, with folding at V_N near 78°N . This feature results from the variation in satellite altitudes as shown in Fig. 5c. Relatively weak noise contamination in V_{SMI} and the corresponding $V(H_{\text{sfc}})$ may also indicate specular reflection, because only the portion of the radar beam directed very close to the specular direction contributes to the received signal, thereby effectively narrowing the beamwidth.

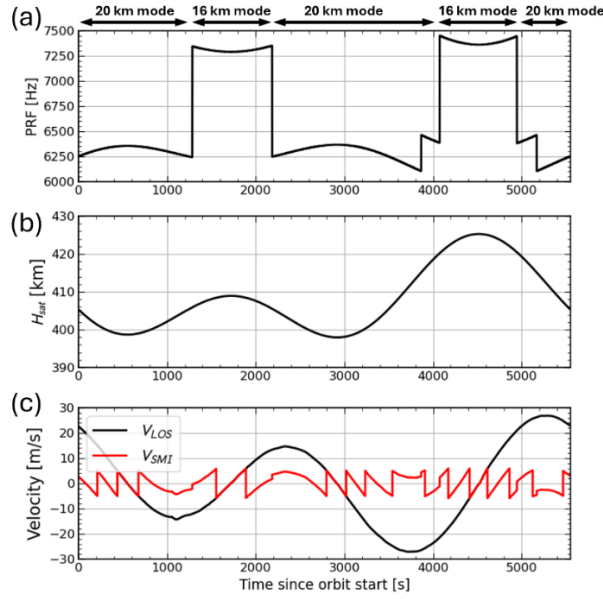


Figure 5: (a) PRF; (b) H_{sat} ; and (c) V_{LOS} and expected V_{SMI} calculated assuming $V_{\text{sf}} = 0$ during one orbit of orbit number 06198 on 1 July 2025.

There is another possibility related to the fact of the “near-saturated backscatter”. The SMIs data in Fig. 3 could be an artefact due to the CPR electronics operating in near-saturated conditions. The authors should provide explanations why the possibility of the electronics artefact was discarded.

Thank you for raising this important possibility. We consider it unlikely that the observed echoes originate from the CPR electronics. In addition to the agreement in Doppler velocity, the clearest evidence is the dependence of the echo altitude on surface elevation. As shown in the new Fig. 7, spurious echoes occasionally appear near 10 km over the Andean Plateau, consistent with the altitude predicted from the SMI propagation geometry. Such a systematic dependence on surface elevation would not be expected for a generic electronic artifact associated with receiver saturation. This behavior therefore provides strong evidence that the echoes result from the SMI mechanism, involving two round trips between the spacecraft and the surface. We have added an explanation of this point to the revised manuscript as follows:

Line 282–289

SMIs can also occur over elevated inland water surfaces. Figure 7 shows SMIs generated over the Salar de Uyuni in the Andean Plateau. Because the surface is located at an elevation of approximately 3.7 km, the SMIs appear at about 10 km, as predicted by Eq. (6). Additional echoes suggestive of SMIs are also seen over the foothill region on the left side of the figure, which coincide with the locations of inland water bodies. The strong surface returns may raise the possibility of unanticipated instrumental artifacts associated with receiver saturation, including compression or clipping of the received signal and a possible delayed electronic response. However, the observed echo altitudes are consistent with the predicted SMI geometry, supporting the interpretation that these echoes are generated by the proposed SMI mechanism rather than by a saturation-related instrumental artifact.

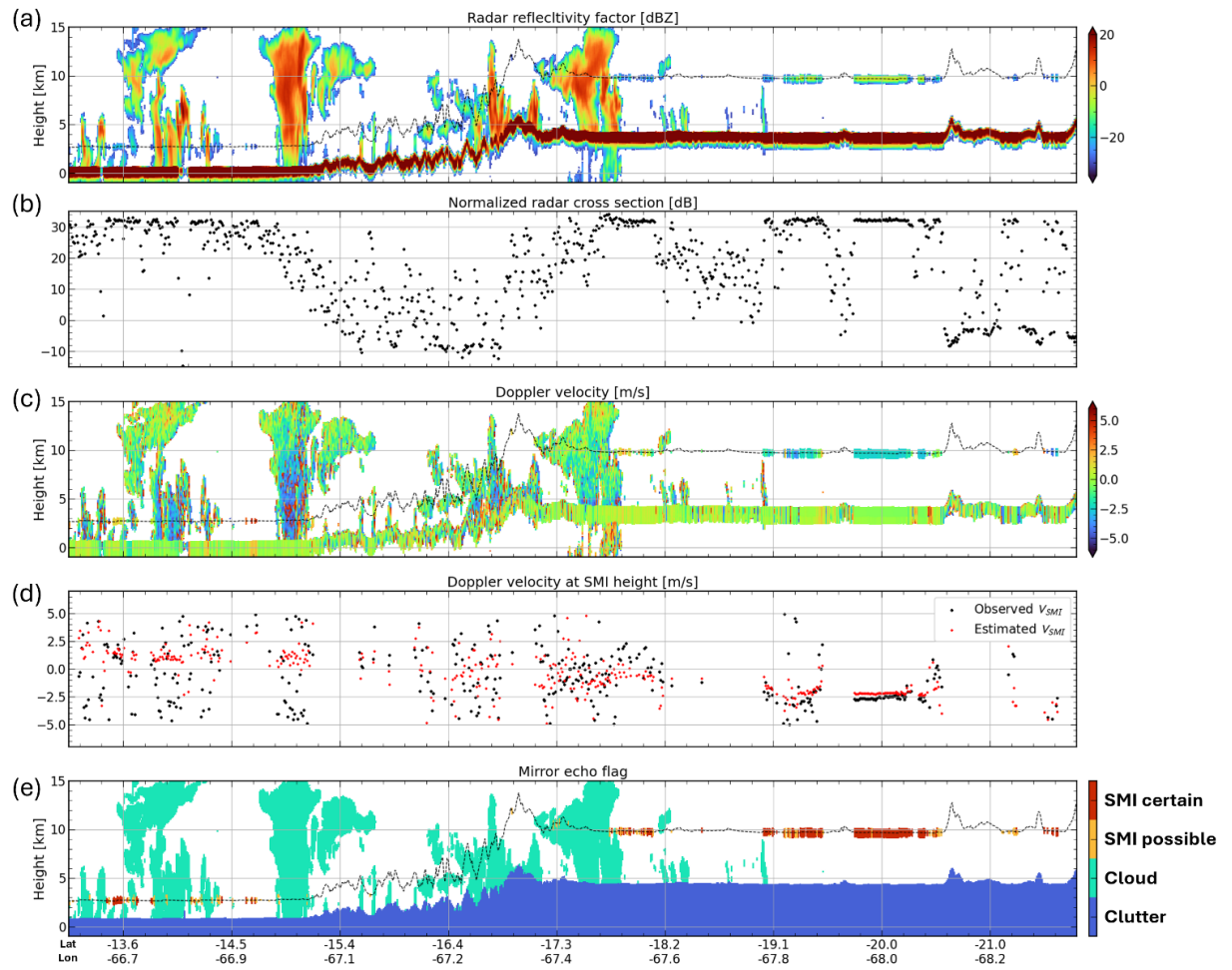


Figure 7: Same as Fig. 4, but for a case on 16 March 2025 (frame 04540E).