Near-Surface Sublimation Below the CPR Blind Zone: Implications for EarthCARE Snowfall Surface Estimation in Coastal Antarctica

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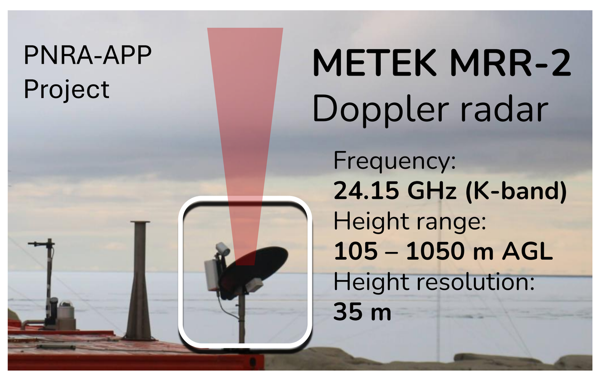
Motivation: satellite-based snowfall products rely on the assumption that radar reflectivity observed aloft is representative of the precipitation reaching the surface, an assumption that is particularly critical in the lowest layers of the Antarctic atmosphere. Ground-based radar observations indicate that this assumption is frequently violated in coastal Antarctica since precipitation detected by satellite radars may partially or entirely sublimate before reaching surface (virga event), leading to a systematic overestimation of surface snowfall accumulation in satellite retrievals.

Experimental setup:



Dataset: four years (2020, 2021, 2023, 2024) of vertical profiles of radar reflectivity (Ze [dBZ]) at 1-min resolution, MRR raw data is processed with **ImProToo** ver. 0.107 (Maahn & Kollias, 2012) to obtain reflectivity (Ze), Doppler velocity (W) and spectral width (sW) profiles with snowfall-specific filtering and de-aliasing of the Doppler spectrum.

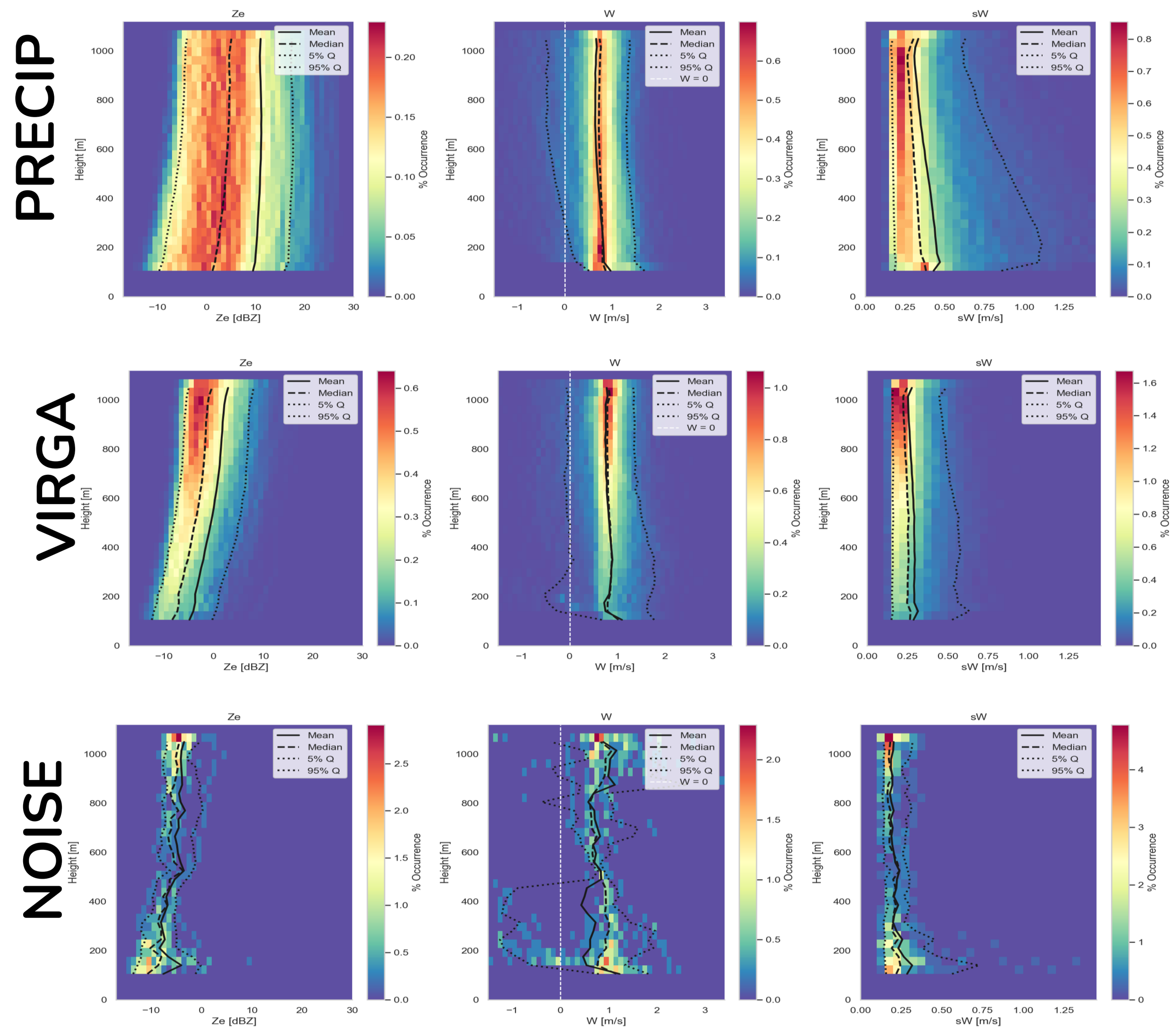
Objectives:

1. Identify virga and surface-reaching snowfall from MRR vertical profiles
2. Quantify CPR-missed virga within the near-surface blind zone from MRR observations
3. Estimate the contribution of virga to missed snowfall accumulation
4. Provide observation-based constraints on ERA5 snowfall sublimation bias

1. Classification of the profiles

based on whether the minimum detectable echo reaches the lowest range gate towards the ground.

- **No signal**: MRR detects no echoes;
- **Virga**: valid signals in the vertical column but missing in the lowest considered range gate (105 m);
- **Precipitation**: signal detected in the lowest considered range but also in the first two closely adjacent;
- **Noise (excluded)**: isolated echoes that fail the continuity check over at least two contiguous range gates;



Aggregated profiles confirm the expectations: during precipitation, the reflectivity (Ze) remains constant along the whole column and the Doppler spectral width (sW) increases as the hydrometeors grow towards the ground, while during virga events the sublimation reduces both occurrence and intensity of the reflectivity profiles and there is no growth signature in sW. The noise is concentrated near the ground with a mirror image at the highest gate, consistently with the low reliability areas indicated by Maahn & Kollias (2012).

2. Quantification of blind zone impact

2. Quantification of blind zone impact to virga identification and reflectivity derived snowfall estimation: how much will the incidence of events classified as virga change if the height of the lowest range gate is changed?

Height (m)	Precip Count	Precip %	Precip change from est. at 490m	Virga Count	Virga %	Virga change from est. at 490m	Noise Count	Noise %
105	26599	58.9	**-5.87 (%)**	18037	39.94	**+7.68 (%)**	524	1.16
315	27976	61.95	-2.82 (%)	15923	35.26	+3.00 (%)	1261	2.79
490	29252	64.77	0 (%)	14568	32.26	0 (%)	1340	2.97

The MRR detects hydrometeor echoes about 12% of the time, but only ~7% of all samples show precipitation reaching the lowest reliable radar bin at 105 m a.g.l., while virga accounts for ~4.8% of all samples (~40% of all radar-detected columns).

When the lowest considered range gate is raised to 490 m a.g.l. (close to EarthCARE radar lowest reliable bin), the estimated virga fraction decreases by more than 7%, implying that EarthCARE's CPR may systematically miss a substantial share of precipitation sublimation occurring between 500 and 100 m.

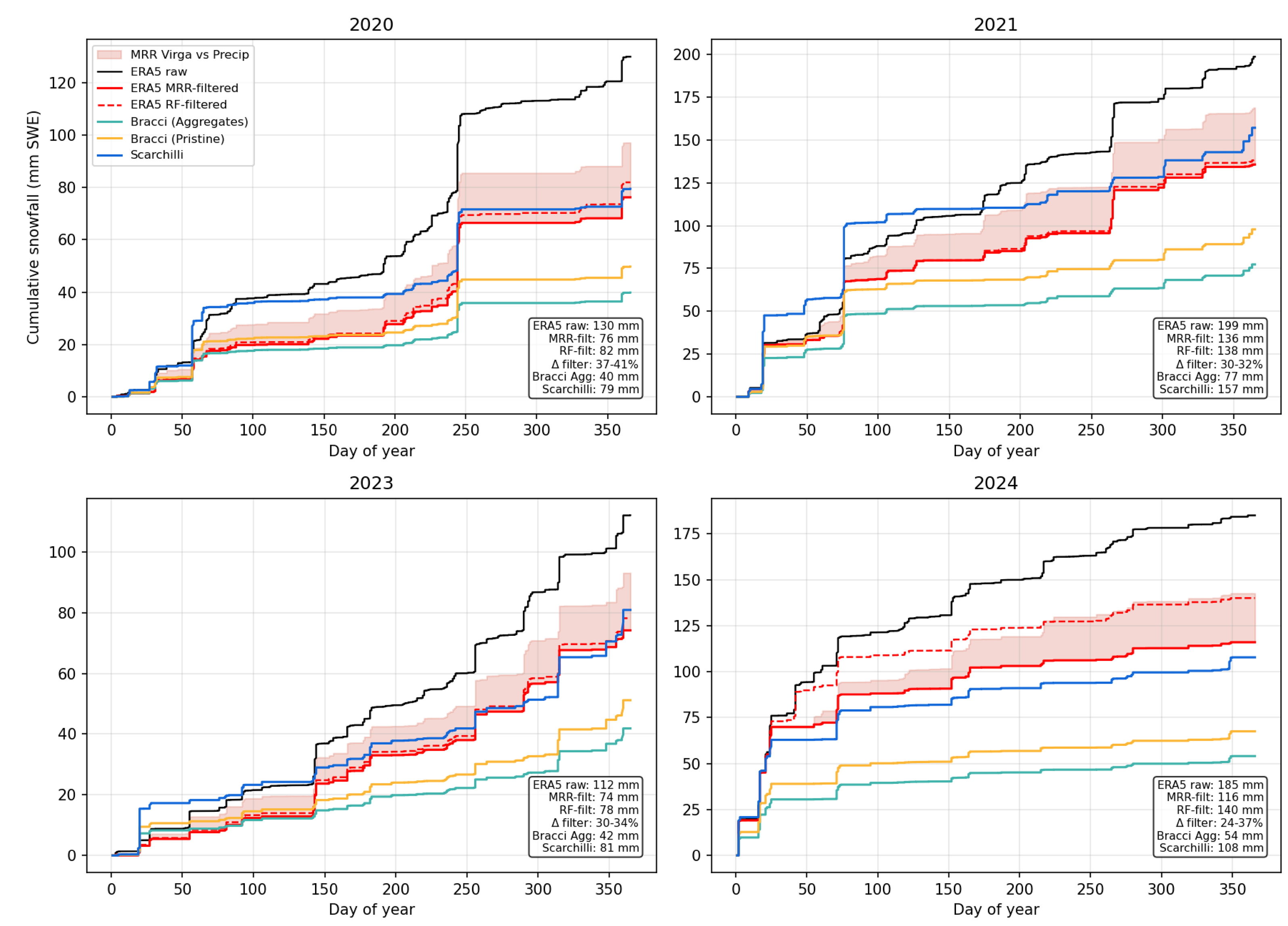
3. Snowfall mass lost to sublimation missed by CPR:

The blind zone effect propagates into surface precipitation estimates: for the year 2023, changing the lowest gate from 105 to 490 m, SWE increases annually by about 20–40 mm, more than the typical Ze–SR parameter-related uncertainty.

Ze-SR relation	105 m	315 m	490 m
Bracci 2022 (Aggregates)	41.84 (35.03, 49.02)	52.69 (44.50, 61.30) [+26 %]	59.37 (50.50, 68.69) [+42 %]
Bracci 2022 (Pristine)	51.12 (43.06, 60.22)	64.87 (55.04, 75.84) [+27 %]	73.55 (62.77, 85.45) [+44 %]
Scarchilli 2020	80.87 (77.29, 86.06)	102.99 (98.66, 109.34) [+27 %]	117.09 (112.40, 124.07) [+45 %]
ERA5 (sf)	112.07 (estimated at the ground)		

4. ERA5 surface snowfall (sf) estimates can be corrected for the sublimation loss

4. ERA5 surface snowfall (sf) estimates can be corrected for the sublimation loss by neglecting the snow amounts outside the hours classified as precipitation by MRR (majority vote from 1min profiles).



MRR-based and RF-based corrections coincide in 3 of the 4 years (and 2024 spread originates from a single event around day 35). Corrected estimates are much closer to radar-derived accumulations from the literature (Scarchilli et al., 2020; Bracci et al., 2022)

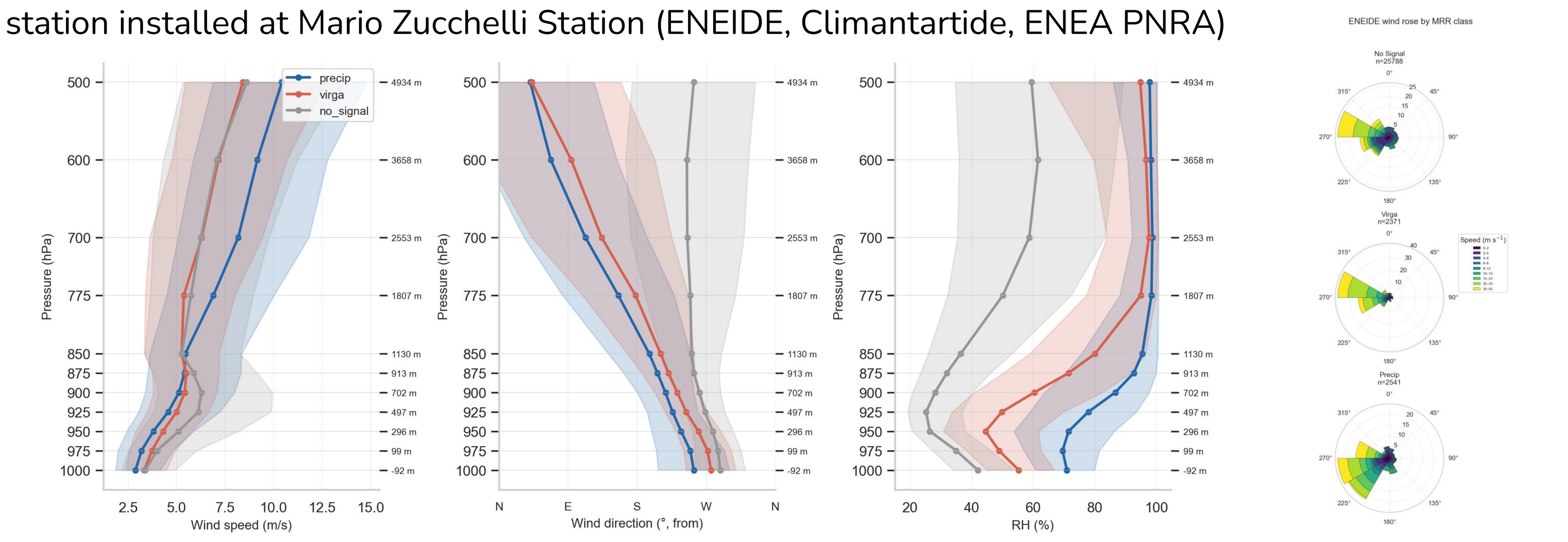
Take-home messages:

- Sublimation is frequent (40% of precipitating clouds) at MZS and more generally along the Antarctic coast
- The identification of virga event is dependent on the level height at which it is estimated
- This introduces a height-dependent bias on surface snowfall estimates which affects EarthCARE's CPR

And what if the MRR is missing?

And what if the MRR is missing? Are there proxies inside ERA5 that can help reproduce the classification?

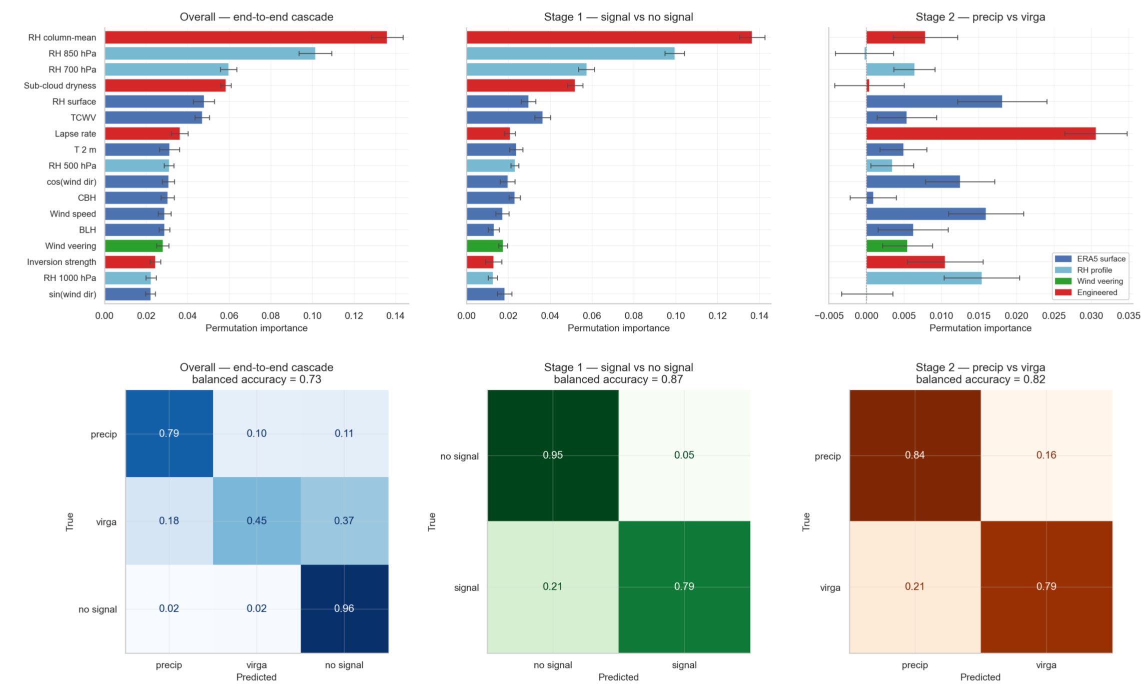
a) Search for **proxies** of the MRR classification in the ERA5 profiles and in the data from the weather station installed at Mario Zucchelli Station (ENEIDE, Climantartide, ENEA PNRA)



No signal: clear signature of katabatic events with wind directions from 285° (W, inland, Antarctic plateau) and increased wind speeds in the lower levels.
Precipitation: moist air coming from the opposite direction in the mid atmosphere, then the wind rotates towards the ground (veering). Slowest wind speeds and highest RH at the ground.
Virga: shares the same conditions of precipitation at high altitudes but then shifts toward no signal close to the ground. The separation in the RH profiles is the clearest, larger than the standard deviations and the variability of the annual and seasonal average profiles (not shown).

b) Train a **random forest** model to reproduce the classification without the MRR profiles

Binary cascade approach: first discriminate between signal and no signal (**Stage 1**, dominated by information from upper levels), then divide in virga and precipitation (**Stage 2**, dominated by humidity close to the ground, wind speed and lapse rate).



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