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

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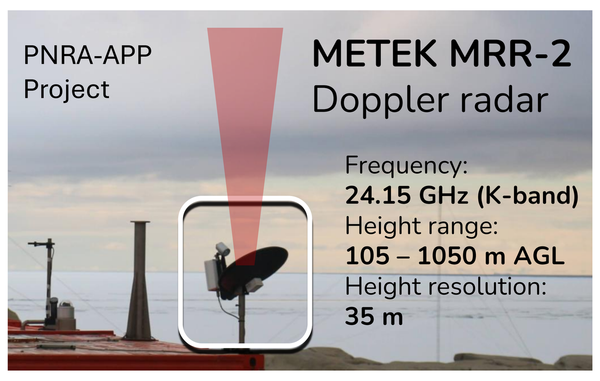
Motivation: satellite-based surface snowfall products rely on the assumption that radar reflectivity observed aloft is representative of the precipitation reaching the ground, an assumption that is particularly critical in the lowest layers of the Antarctic atmosphere.

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

RESULTS

1. **Classification of the radar vertical 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 (isolated signals, removed)**: echoes that fail the continuity check over at least two contiguous range gates are removed from the dataset

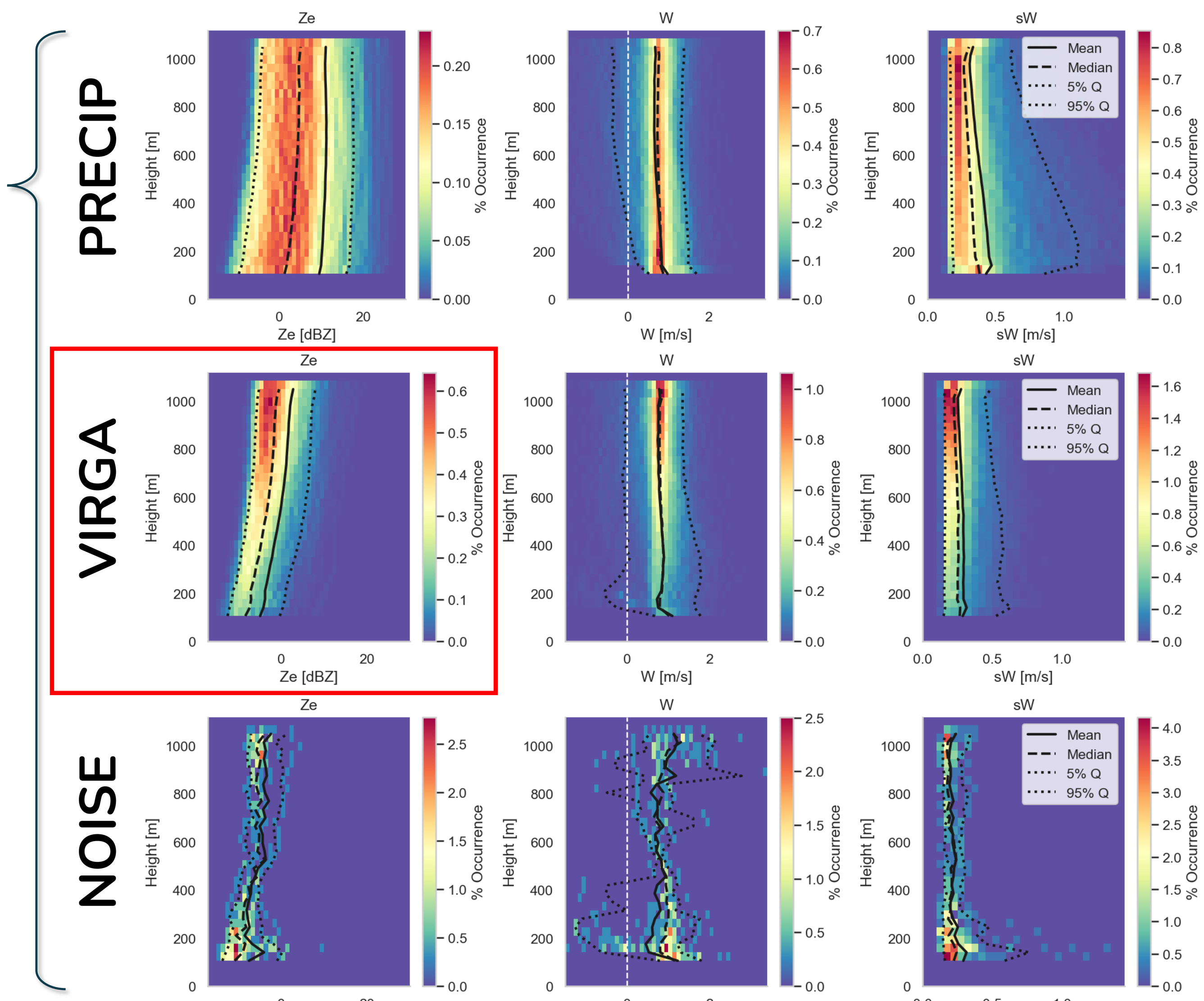
2. **Quantification of blind zone impact** to virga identification and reflectivity derived snowfall estimation: how much will the incidence of events classified as virga change if the height of the lowest range gate is changed?

Table 1

Height	Precip Count	Precip occurrence	Precip change from est. at 490m	Virga Count	Virga occurrence	Virga change from est. at 490m	Noise Count	Noise occurrence
105 m	26599	58.90 %	**-5.87 %**	17286	38.28 %	**+7.83 %**	1275	2.82 %
315 m	27976	61.95 %	-2.82 %	15097	33.43 %	+2.98 %	2087	4.62 %
490 m	29252	64.77 %	-	13749	30.45 %	-	2159	4.78 %

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, Tab. 1).

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 a.g.l. .



Aggregated MRR 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.

During virga events the sublimation reduces both occurrence and intensity of the Ze profiles, and there is no growth signature in sW.

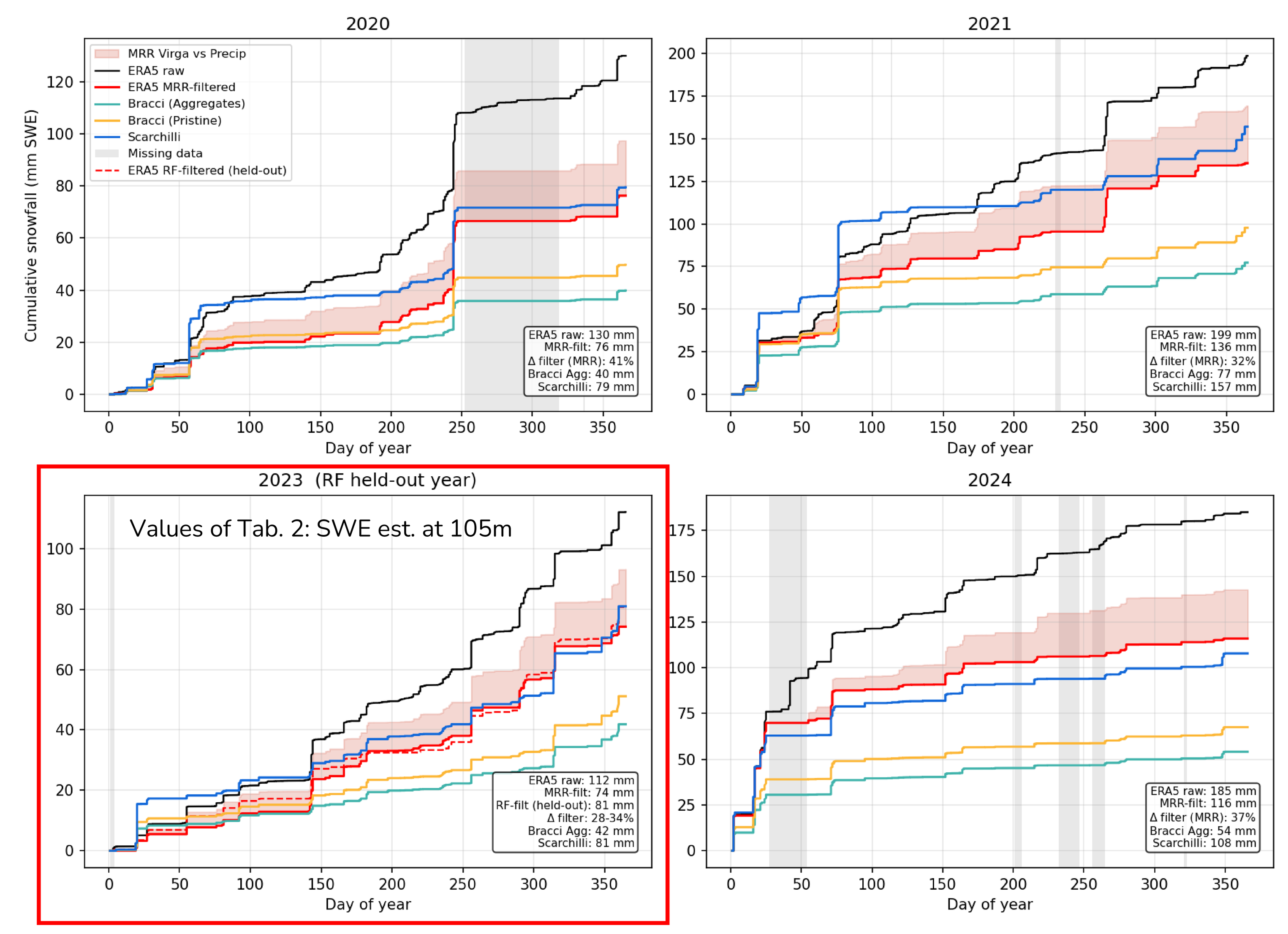
The noise is concentrated near the ground and near the highest gates, consistently with the low reliability areas indicated by Maahn & Kollias (2012).

3. **Snowfall mass lost to sublimation missed by CPR** (during 2023, the only year without missing data): The blind zone effect propagates into surface precipitation estimates: for the year 2023, changing the lowest gate from 105 to 490 m, snowfall water equivalent (SWE) accumulation increases annually by about 20–40 mm, which is more than the typical Ze–SR parameter-related uncertainty.

Table 2

Ze-SR relation	SWE est. at 105 m	SWE est. at 315 m	SWE est. at 490 m
Bracci 2022 (Aggregates)	41.84 mm (36.54, 47.64)	52.69 mm (44.50, 61.30) [+26 %]	59.37 mm (50.50, 68.69) [**+42 %**]
Bracci 2022 (Pristine)	51.12 mm (44.41, 58.48)	64.87 mm (55.04, 75.84) [+27 %]	73.55 mm (62.77, 85.45) [**+44 %**]
Scarchilli 2020	80.87 mm (76.99, 84.90)	102.99 mm (98.66, 109.34) [+27 %]	117.09 mm (112.40, 124.07) [**+45 %**]
ERA5 (sf)	112.01 mm (estimated at the ground)		

4. **ERA5 surface snowfall (sf) estimates can be corrected for the sublimation loss** by neglecting the snow amounts falling outside of the hours classified as precipitation by MRR (majority vote from 1min profiles). These are the cumulated time series of snowfall estimates at MZS for the four years:



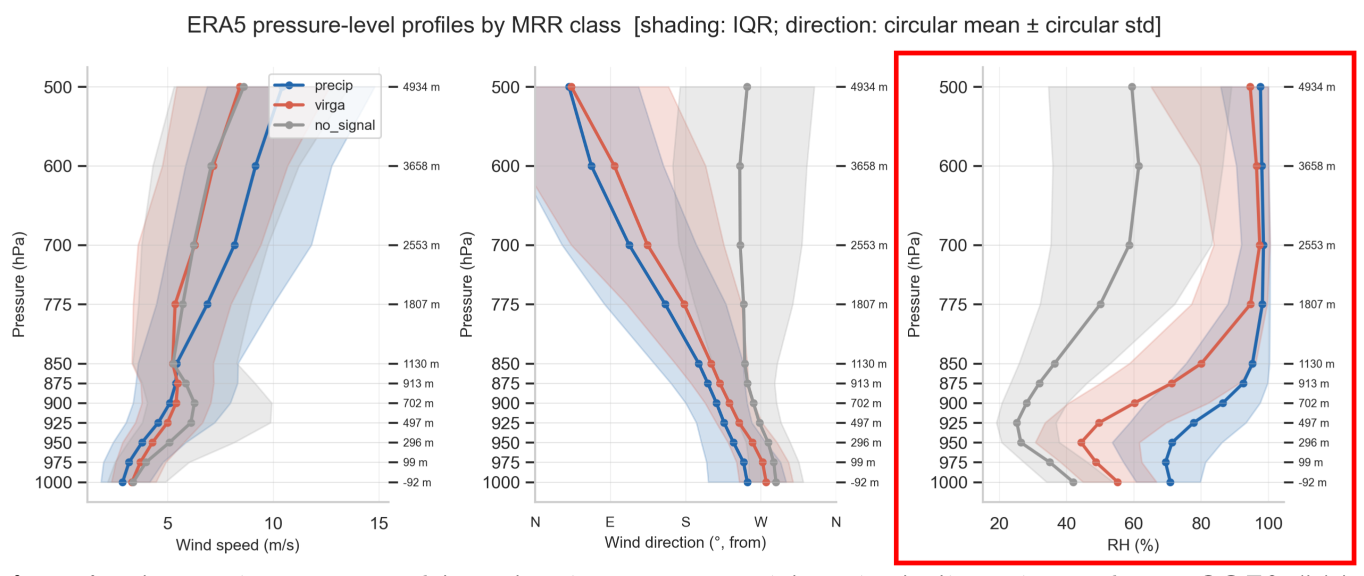
MRR-based and RF-based corrections for 2023 (the year left out from the training/test set of the random forest) are almost coincident (red lines). Corrected estimates are much closer to radar-derived accumulations from the literature (Scarchilli et al., 2020; Bracci et al., 2022)

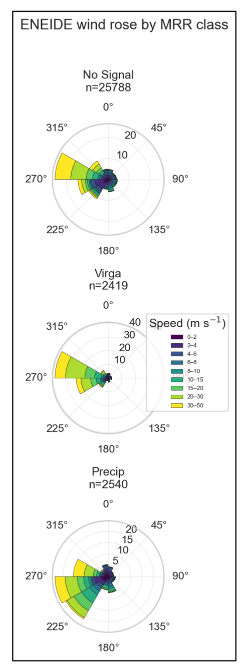
TAKE-HOME MESSAGES

- **Sublimation** of the precipitation is frequent (40% of precipitating clouds) at MZS and more generally along the East Antarctic coast (Wiener et al., 2024)
- The identification of **virga events** is dependent on the height at which it is estimated
- This introduces a blind-zone-height-dependent **bias on surface snowfall estimates**, which for EarthCARE's CPR is expected to be around -7% in virga occurrence and +40% in SWE mass
- ERA5 surface snowfall estimates can be **corrected locally** for sublimation (~ -30%)

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):





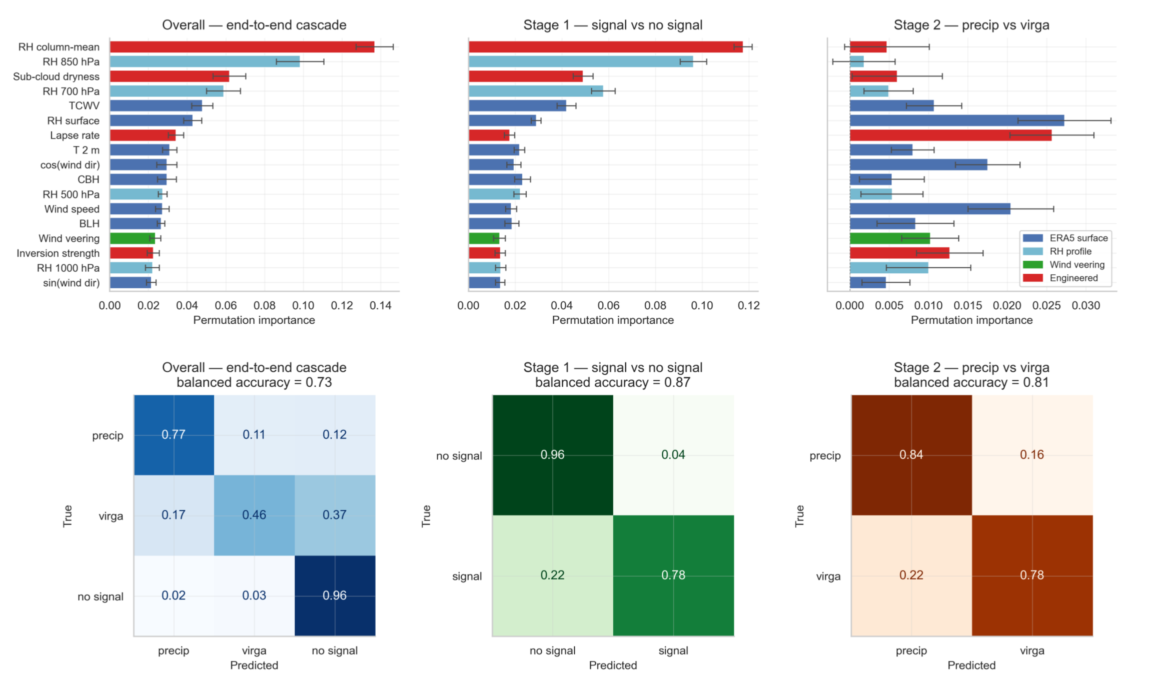
No signal: clear signature of katabatic events with wind directions from 285° (W, inland, Antarctic plateau) and increased wind speeds in the lower levels.

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 both the interquartile ranges (IQR) and the variance of annual and seasonal average profiles (not shown).

b) Train a **random forest** model on three years (2020, 2021, 2024) 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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