QUANTITATIVE PRECIPITATION ESTIMATION IN ANTARCTICA USING DIFFERENT ZE-SR RELATIONSHIPS BASED ON SNOWFALL CLASSIFICATION COMBINING GROUND OBSERVATIONS BY RADAR AND DISDROMETER

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1. Motivation of the work

- Snow has a primary impact on climate and weather influencing the energy budget and the hydrological cycle of the Earth directly. Hence the need for continuous observations of snowfall both on local and global scales.
- Remote sensing techniques are necessary to ensure spatial and temporal coverage. However, quantifying the snowfall amount is quite demanding due to the changing features of solid hydrometeors.
- Estimations by weather radar exploit power-law relationships connecting radar equivalent reflectivity factor (Ze) and liquid-equivalent snowfall rate (SR). Relationship choice is not univocal, as it comprises many assumptions of peculiar precipitation characteristics such as particle density, habit, and shape.
- During snowfall, the microphysical features of falling hydrometeors can modify in a very small timescale. Hence, the use of a static Ze-SR relation seems to be limiting and not well representative of the natural variability of ice particles.
- Antarctica represents a perfect training ground for studying and investigating microphysical characteristics and processes of solid precipitation. Also, the knowledge of the spatial and temporal distribution and variability of snowfall in Antarctica and its effects on the mass balance is fundamental to define the impact of the Antarctic ice sheet on sea-level rise.
- Since November 2018, a vertical pointing Micro Rain Radar (MRR) and a Parsivel disdrometer have been operating simultaneously at the "Mario Zucchelli" Italian Antarctic station (MZS).
- In this framework, we investigated the snowfall amount at MZS during two Antarctic summer seasons by using an adjustable Ze-SR relation based on the prevailing falling particles. Six Ze-SR relationships, optimized for MZS, were parameterized, the proper relation to be used is chosen comparing radar and disdrometer observations, in terms of Ze, in a 10-minutes time window.

4. Precipitation Dataset @MZS

Precipitation measurements by Parsivel and co-located MRR (at **100 meters height**, first exploitable gate) were used in this work.

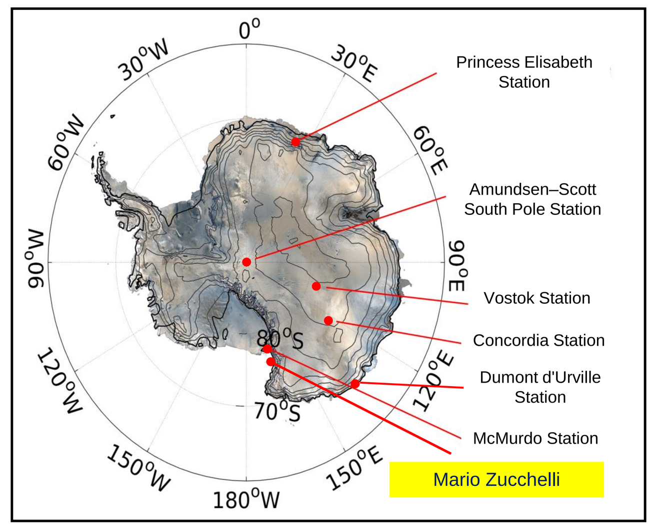
Data range from Nov. 2018 to Mar. 2019, and from Nov. 2019 to Feb. 2020. Only days with at least 1 hour of continuous precipitation were considered valid for the analyses, for a total of 54 days of precipitation.

A set of criteria were laid out to filter the database due to intrinsic limits of instruments:

- **Reflectivity threshold:** a value of -5 dBZ for radar minute measurements was chosen. MRR observations below such threshold could be flawed;
- **Wind threshold:** an upper limit value of 7 m/s was set for the reliability of Parsivel measurements. Disdrometer accuracy can be lower in case of strong wind, while MRR observations are not in principle affected by horizontal winds;
- **SR threshold:** minutes with calculated SR value less than 0.01 mm/h were discarded since disdrometer observations can not be completely trusty.

The first criterion was applied to the whole dataset to test the consistency of Parsivel and MRR measurements: **23555 minutes** were available for the analysis.
All the criteria were applied for the Ze-SR estimation, reducing the database to 16712 minutes of precipitation.

2. Instruments @MZS



OTT Parsivel is a laser disdrometer. It measures hydrometeor size (D) and fall velocity (v). From D and v the Particle Size Distribution (PSD) can be calculated.

Parsivel	
Size/velocity classes	32
Size width	0.1-3.0 mm
Size range	0.3 -25 mm
Velocity range	0.2 -20 m s^{-1}

Metek MRR is an FM-CW portable vertically pointing radar. It provides vertical profiles of reflectivity spectra, from which reflectivity, mean Doppler velocity, and spectral width can be derived.

MRR	
Frequency	24.23 GHz
Transmit power	50 mW
Operational Temperatures	-40..+60 °C
Maximum Height	6000 m
Vertical resolution	30-200m
Number of Range gates	Up to 30

3. Methods

Combing particle size distributions, achieved by Parsivel observations, and scattering model, the disdrometer-derived reflectivities were obtained by the minute for each defined microphysical categories by:

$$Ze = 10^{18}\frac{\lambda^4}{\pi^5|K|^2}\int_{D_{min}}^{D_{max}}\sigma_b(D)N(D)dD \quad (1)$$

here λ is the wavelength of MRR (m), $|K|^2$ is related to the dielectric constant of liquid water and conventionally equals 0.92 and σ_b is the backscattering cross-section (m^2).

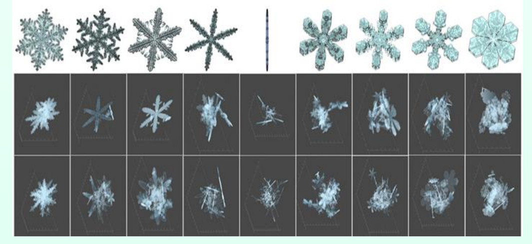
Snowfall rates for each category from disdrometer measurements were calculated by:

$$\text{SR}=\frac{3600}{\rho_w}\int_{D_{min}}^{D_{max}} m(D)v(D)N(D)dD \quad (2)$$

where ρ_w is the density of liquid water; m(D) are the mass-diameter relations of the particles and are derived from DDA database, while v(D), representing the terminal velocity relations, are taken from Locatelli and Hobbs (1974).

Discrete Dipole Approximation Database (Kuo et al., 2016)

This valuable database contains single scattering and density properties of more than 8000 "fake" solid hydrometeors, divided by main microphysical types (aggregate, pristine), which in turn are subdivided in habits (dendrites, planes, and needles).



For our purposes, these particles were grouped in 6 different categories:

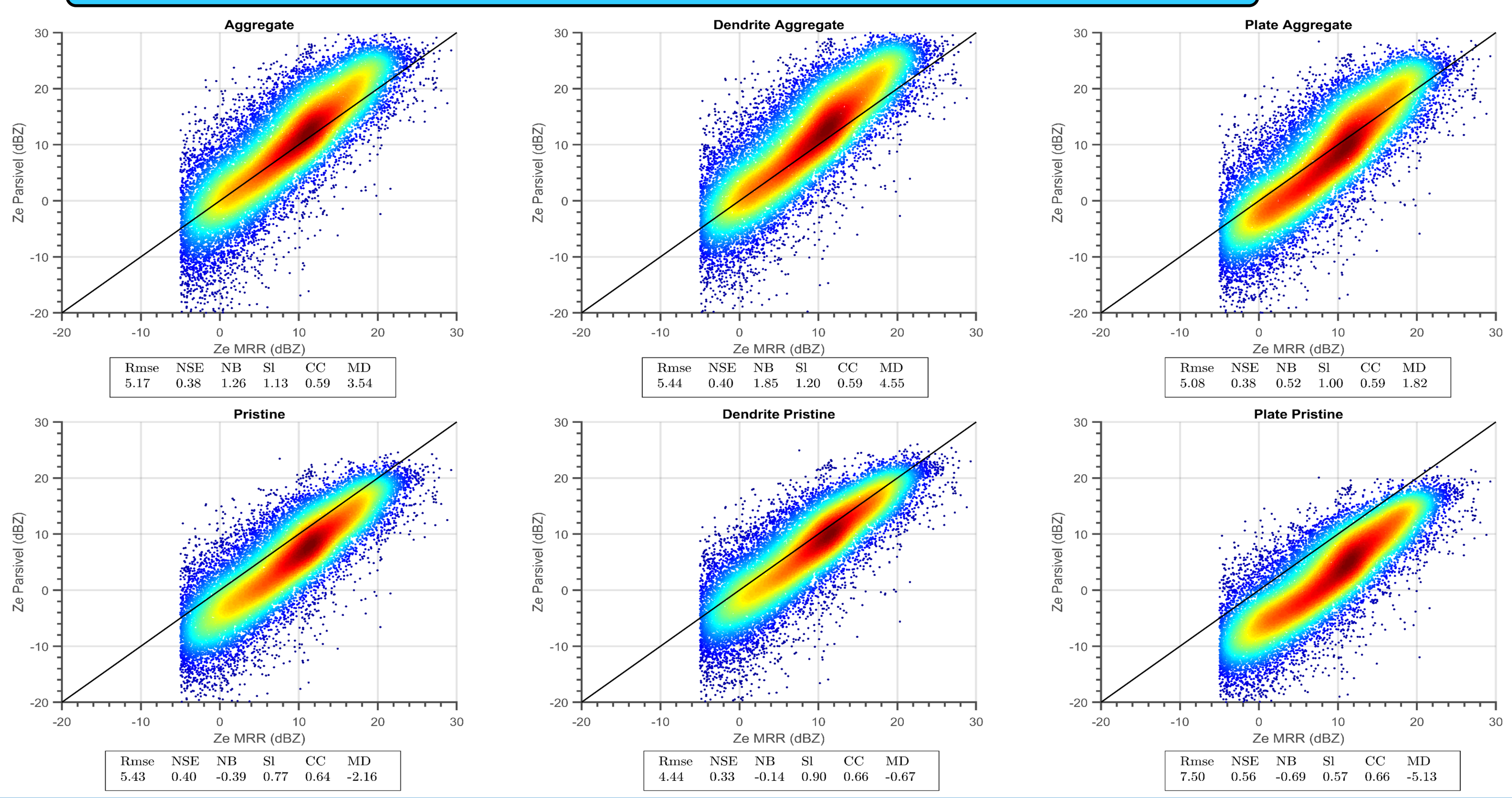
- *Aggregate* (containing aggregate-dendrites, -plates -needles),
- *Aggregate-dendrites*
- *Aggregate-plates*
- *Pristine* (containing pristine-dendrites, -plates, -needles)
- *Pristine-dendrites*
- *Pristine-plates*

For each category, disdrometer-derived Ze and SR were calculated.

Root mean square errors between MRR Ze measurements and each of 6 values of disdrometer reflectivity, one for each habit category, have been calculated in a 10-minute window. The category with the **lowest RMSE value** has been considered representative of the **prevailing type of particles** in that time window.

5. Results

5.1 Consistency of MRR and Parsivel measurements in terms of Ze



Our approach combines qualitative and quantitative analyses to test the correspondence between radar reflectivity and disdrometer-derived reflectivity with different microphysical inputs.

Overall, density scatter plots for 1-minute Ze data, show a good agreement in the case of aggregate-like types of particles for medium and low values of reflectivity. Pristine-like habits (excluding plate-pristine case) work well when high Ze values are observed. However, the density peak of Ze observations (dark red) is better approximated by aggregate type. In particular, the aggregate case seems to works properly between 0-10 dBZ radar observations, whereas dendrite-pristine performs best in reproducing high Ze values.

Dendrite-pristine achieves the lowest Rmse and mean difference values (in dBZ), also resulting in the least biased case. Correlation coefficients are around 0.6 for all categories.

In general, aggregate-like habits overestimate the observations while pristine-like underestimate, hence showing the importance of microphysical inputs in the calculation of snowfall amounts.

5.2 Ze-SR relationships

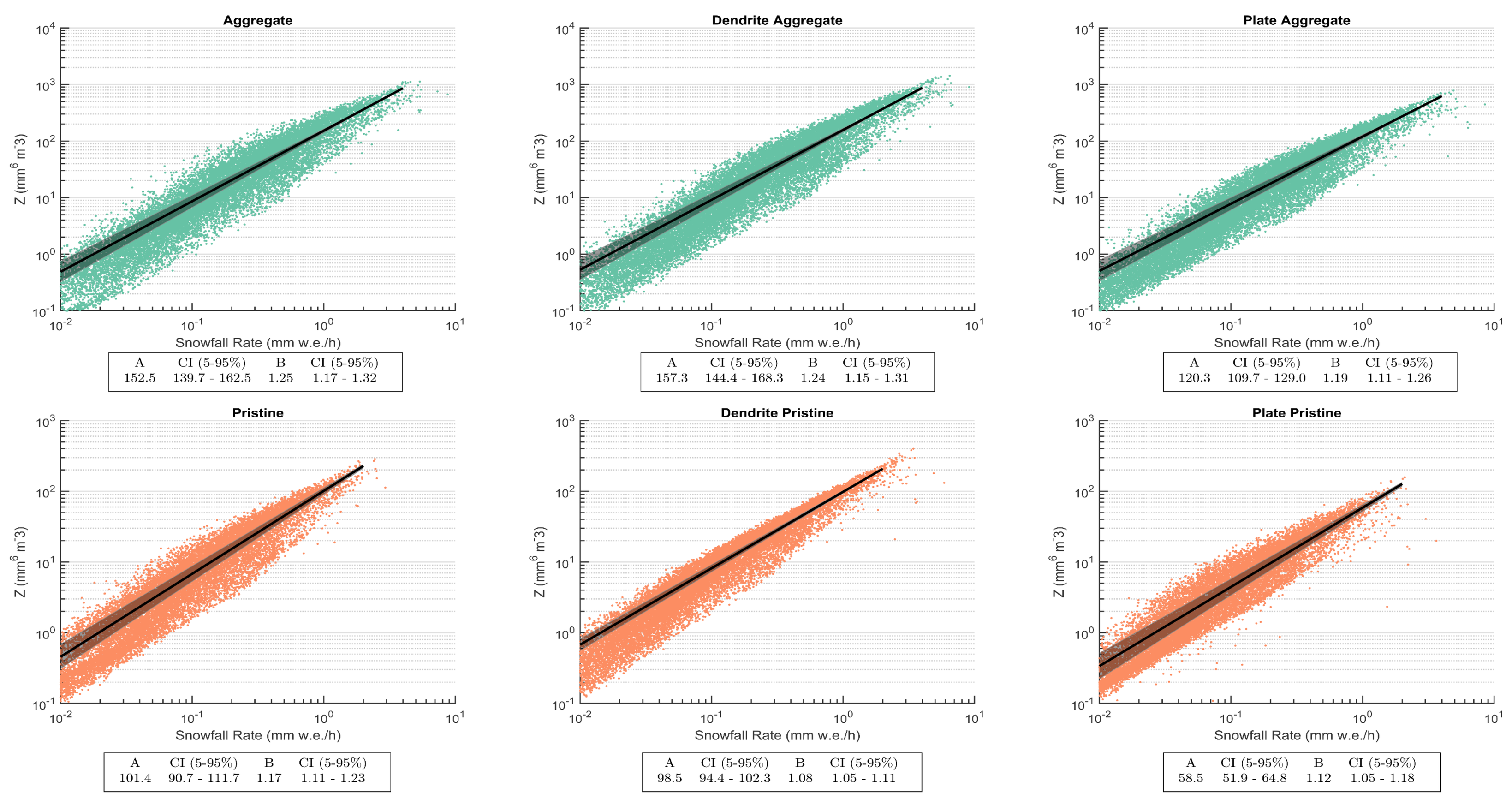
Ze-SR relationships were derived through non-linear least square regression between the 6 estimations of snowfall rate from disdrometer, and the radar observations. The relations are in the power-law form (i.e. Ze=A*SR^B), and the uncertainties of prefactor A and exponent B were evaluated employing a bootstrapping approach.

Results show significant variability of prefactor A, while the exponent B is almost constant.

A is higher in *aggregate-like* cases, ranging from 157.3 of dendrites to 120.3 of plates.

In contrast, A is lower for *pristine* cases, in particular in *plate-pristine*. Such results are not unexpected: A is linked to the diameter of the particles, and usually, aggregate snowflakes reach larger dimensions than pristine particles.

While values of B are in line with previous studies for Antarctic sites, only the prefactor A of the *plate-pristine* case results in agreement. However, in section 5.1 appears clearly that disdrometer-derived reflectivity with *plate-pristine* inputs significantly underestimates MRR observations.

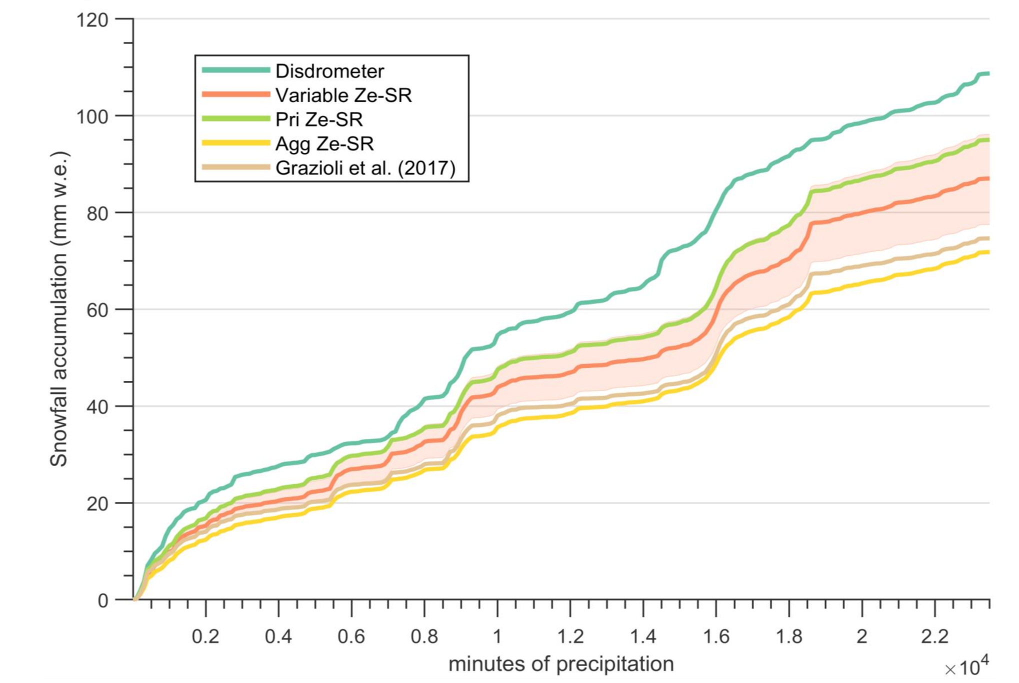


5.3 Snowfall total amount

15.3% of the 23565 precipitation minutes were recognized as aggregate, 33.3% dendrite-agg, 7.3% plate-agg, 12.5% pristine, 24% dendrite-pri, 7.6% plate-pri.

Disdrometer-line represents the SR calculation based only on Eq.2. The orange line stands for the quantification of snowfall by using the variable Ze-SR relation. Light green and yellow lines show the quantification using static Ze-SR relationships, whereas the brown line employs a relationship tailored to Dumont d'Urville site (DDU).

Accumulated snowfall computed by disdrometer is 108.7 mm w.e., whereas with static relations for aggregate and pristine categories and for DDU site amount to 71.8, 95 and 74,6 mm, respectively. Finally, variable Ze-SR accounts for 87 mm [77.9 – 96.5].



6. Outlook

As the limitations of using fixed Ze-SR relationships are known, new and variable Ze-SR relationships optimized for an Antarctic site (MZS) have been derived and evaluated. The next step is to compare retrievals with satellite products and numerical weather models.

Investigations are ongoing to apply Ze-SR relations on radar measurements at Concordia Station (Antarctic Plateau), where an MRR was installed in December 2018 in the framework of PNRA-Firclouds project and where small dimensions of precipitation particles make snowfall estimations decisively challenging.

Acknowledgements

The APP and Firclouds projects are funded by Italian National Antarctic Research Programme (PNRA) directed by the Ministry of Education, University and Research.

Logistic service provided by UTA- ENEA is warmly acknowledged for instrument installation and data management at MZS. This work is built up in collaboration with Malox and Italian Antarctic Meteo Climatological Observatory (IAMCO), PNRA projects that provide meteorological data at MZS.

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