Sinergia fra Osservatorio Meteo-Climatologico Antartico e progetto PNRA-APP per lo studio delle precipitazioni a MZS

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40 anni dell'Osservatorio Meteo-Climatologico Antartico

Centro Ricerche ENEA di Frascati (Roma) - 15 Aprile 2026

Outline

- Rationale
- Instrumentation for solid precipitation monitoring: a synergistic approach
- Synergy between IAMCO and APP: Quantitative Precipitation Estimation (QPE) at MZS
- Synergy between IAMCO and APP: Snow microphysics, classification, and improved QPE at MZS
- Ongoing synergistic activities

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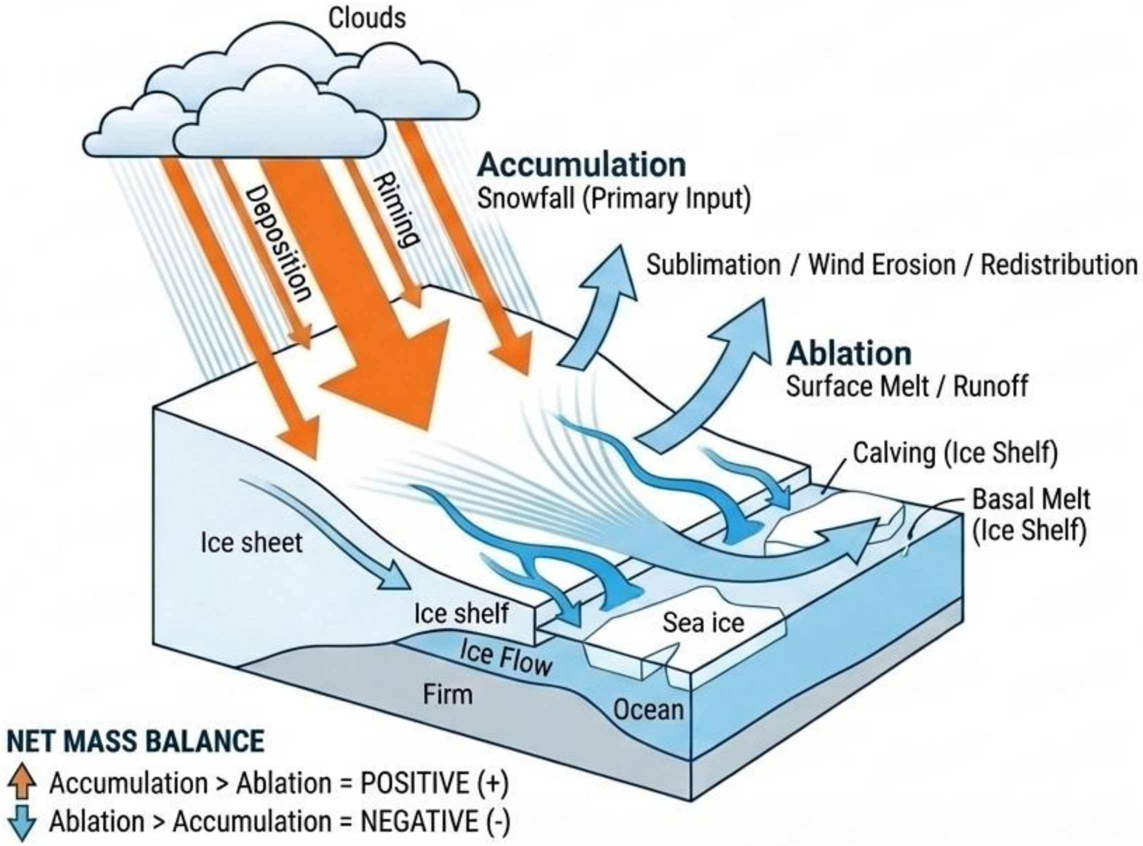
Why this matters

Snowfall is the main positive mass input to the Antarctic Ice Sheet, but it remains difficult to observe and quantify.

Surface Mass Balance of Antarctic Ice Sheet (AIS)

- During precipitation and deposition, mass accumulates at the surface
- Snow can also be redistributed by the wind (erosion/deposition) and/or sublimate, either from the surface or from drifting snow particles
- Mass is lost when meltwater is not retained in the firn by refreezing and leaves the ice sheet as runoff

Snowfall is the primary mass input to the AIS, and its variability strongly affects the ice-sheet mass balance.



Observing and Modeling Ice Sheet Surface Mass Balance
(10.1029/2018RG000622)

Why this matters

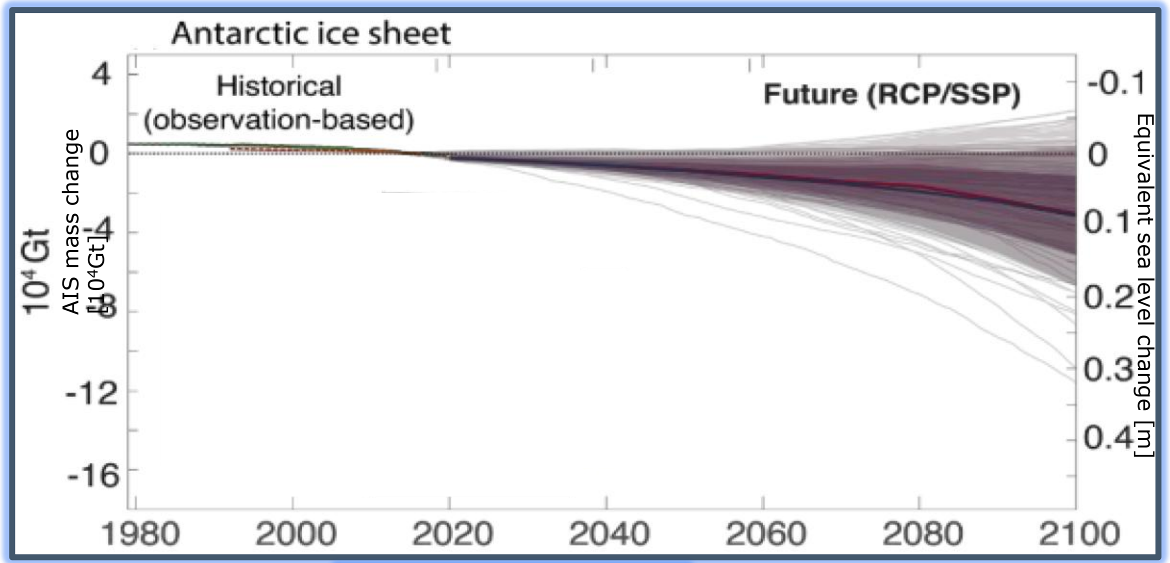
Snowfall is the main positive mass input to the Antarctic Ice Sheet, but it remains difficult to observe and quantify.

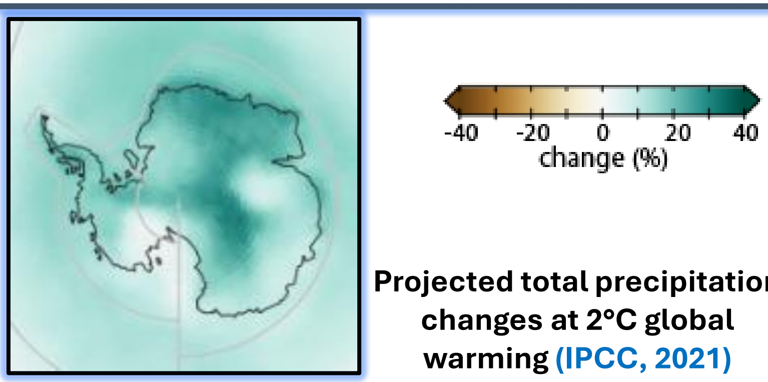
Recent and Future changes in the AIS (IPCC)

- There is high confidence that glaciers have lost mass in all polar regions since 2000 and will continue to lose mass at least for several decades, even if global temperature is stabilized
- AIS has been losing mass since at least 1990, with the highest rate during 2010-2019 and it is projected to continue to lose mass
- There is high confidence that mean precipitation and precipitation intensity will increase and that rainfall will increase with respect to snow over the coastal regions

This highlights the need for continuous observations and monitoring of Antarctic precipitation

Sixth Assessment Report - AR6 2021
IPCC





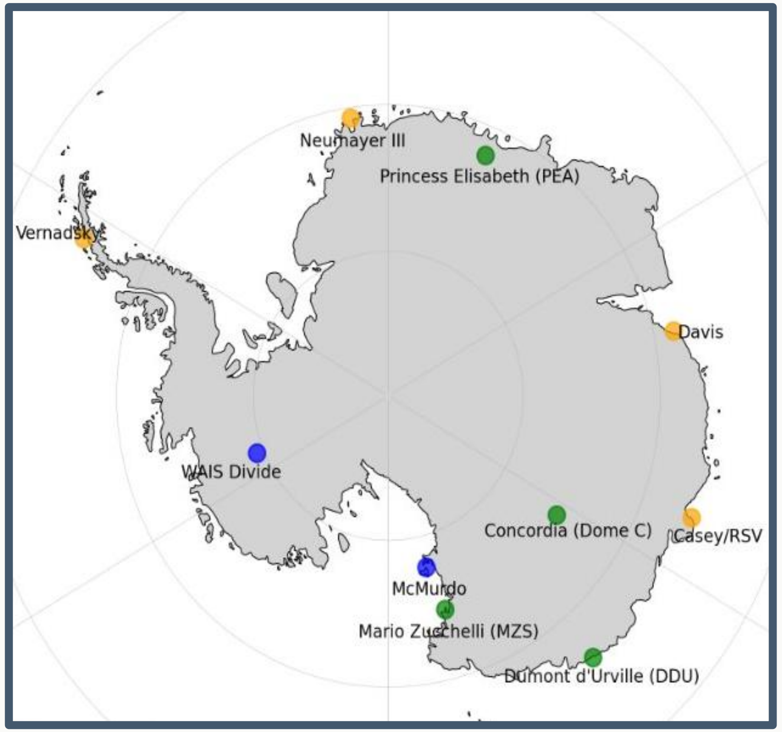
Projected total precipitation changes at 2°C global warming (IPCC, 2021)

What do we know about Antarctic precipitation?

Unfortunately, not much

Raingauges (>3000)

Truesize Italy vs Antartica



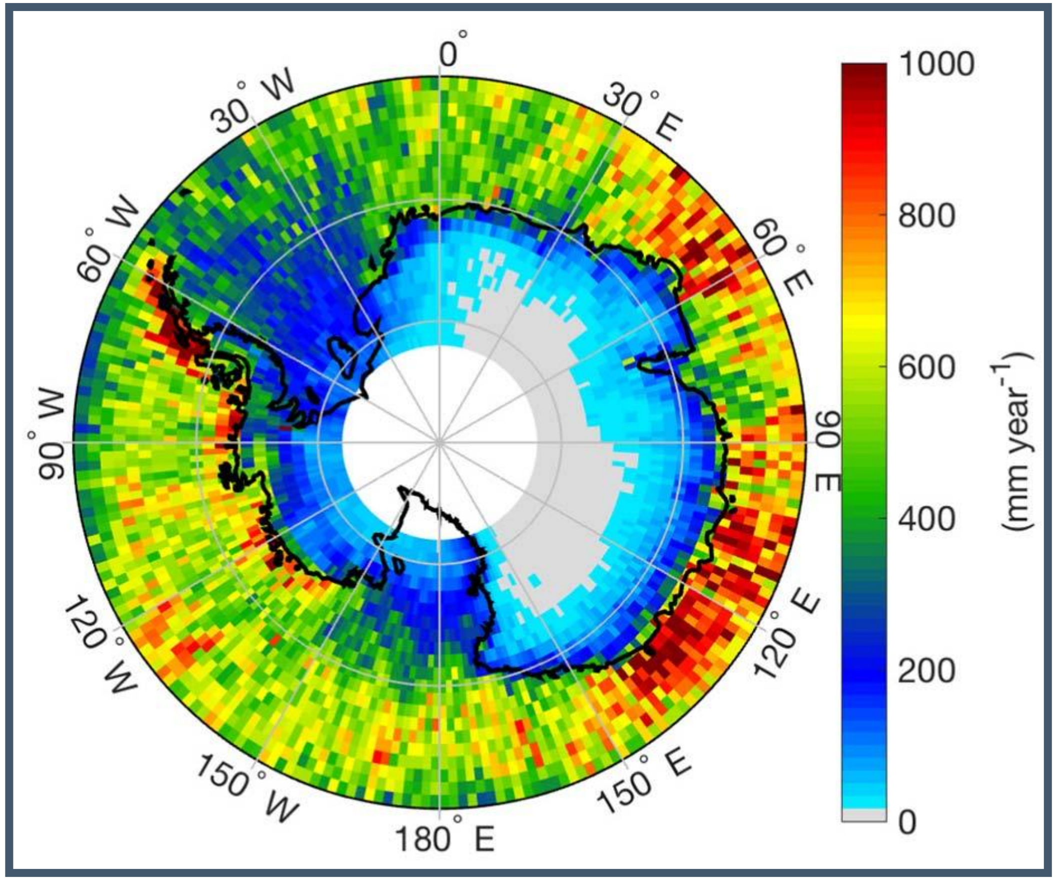
Research stations
(precipitation monitoring)

What do we know about Antarctic precipitation?

Unfortunately, not much

- Ground-based precipitation observations over Antarctica are still very sparse, due to logistical constraints, harsh conditions, and difficult instrument deployment and maintenance.
- Ground observations are essential to validate satellite products and numerical models, and to improve precipitation parameterizations.
- Antarctic precipitation is still poorly constrained, both in terms of amount and microphysical properties.

A substantial improvement is still needed in our understanding of Antarctic precipitation, especially in terms of microphysics and QPE.



CloudSat: Mean annual snowfall
(Milani et al., 2018)

The Microphysical Challenge of Solid Precipitation

The Problem of Uniqueness
Unlike spherical raindrops, each snow particle is shaped by complex growth processes, including diffusional growth, riming, and aggregation.

Variable Factors
Tremendous morphological variability exists in habit, shape, fall behavior and density.

Temporal Instability
Microphysical properties can shift within a few minutes during a single snowstorm.

This microphysical variability strongly affects the accuracy of both remote-sensing and in situ measurements of snowfall.

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MZS solid precipitation observatory: strengths and limitations of individual instruments

Metek MRR - Radar

- **Specs:** 24 GHz, 1-min resolution,105- 1050m vertical range.
- **Provides:** Radar reflectivity (Ze), Doppler velocity, Spectral width.
- **Limitation:** converting Ze into snowfall rate requires microphysical assumptions (Ze–SR relationship).

Optical Disdrometer

- **Specs:** 1-min resolution.
- **Provides:** Dimensions, Terminal velocity v(D), Particle Size Distribution N(D).
- **Limitation:** point measurement, strongly affected by high winds and blowing snow.

Alter-Shield Weighing Gauge

- **Specs:** 1 min resolution.
- **Provides:** Accumulated mass, precipitation intensity.
- **Limitation:** provides no information on snow microphysics and requires intensive maintenance.

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Synergy!

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Quantitative Precipitation Estimation (QPE) at MZS

- Summer snowfall was analyzed at Mario Zucchelli Station, Terra Nova Bay over four Antarctic campaigns: 2015–16 to 2018–19.
- Precipitation was estimated by combining MRR vertical radar, optical disdrometer, snow gauge, and automatic weather station data.

Journal of Glaciology

IGS

Article

Cite this article: Scarchilli C et al. (2020). Characterization of snowfall estimated by in situ and ground-based remote-sensing observations at Terra Nova Bay, Victoria Land, Antarctica. *Journal of Glaciology* **66**(260), 1006–1023. https://doi.org/10.1017/jog.2020.70

Characterization of snowfall estimated by in situ and ground-based remote-sensing observations at Terra Nova Bay, Victoria Land, Antarctica

Claudio Scarchilli[1], Virginia Ciardini[1], Paolo Grigioni[1], Antonio Iaccarino[1], Lorenzo De Silvestri[1], Marco Proposito[1], Stefano Dolci[2], Giuseppe Camporeale[3], Riccardo Schioppo[4], Adriano Antonelli[5,6], Luca Baldini[7], Nicoletta Roberto[7], Stefania Argentini[7], Alessandro Bracci[7,8] and Massimo Frezzotti[9]

Methodological Architecture: **Deriving a site-specific Ze–SR relationship**

Step 1: Surface Microphysics (Disdrometer Inputs)

- **Input:** N(D) – Particle size distribution and fall velocity.
- **Constraint:** Removal of anomalous wind-driven fall velocities (>7 m/s).

Step 2: Backscatter Approximation (SSRGA)

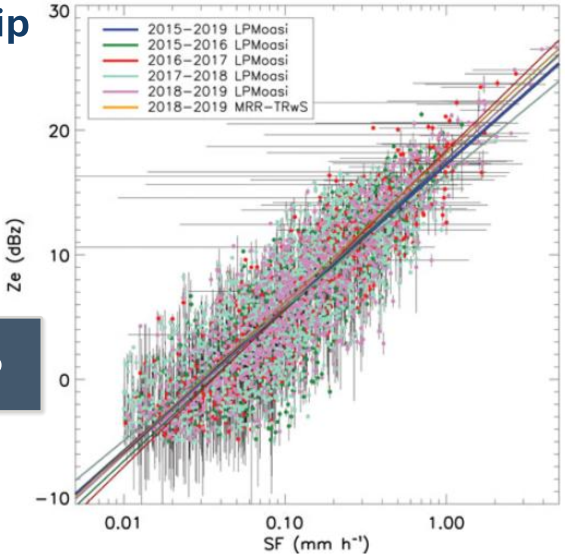
- **Input:** Self-Similar Rayleigh-Gans Approximations.
- **Function:** derives the scattering properties of complex snow particles, improving on soft-spheroid approximations

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

$$SF_{RATE} = \frac{3600}{\rho_w} \int_{D_{min}}^{D_{max}} m(D) v(D) N(D) \mathrm{d}D$$

Step 3: Site-specific Ze–SR relationship for MZS

Ze = 54 SR $^{1.15}$



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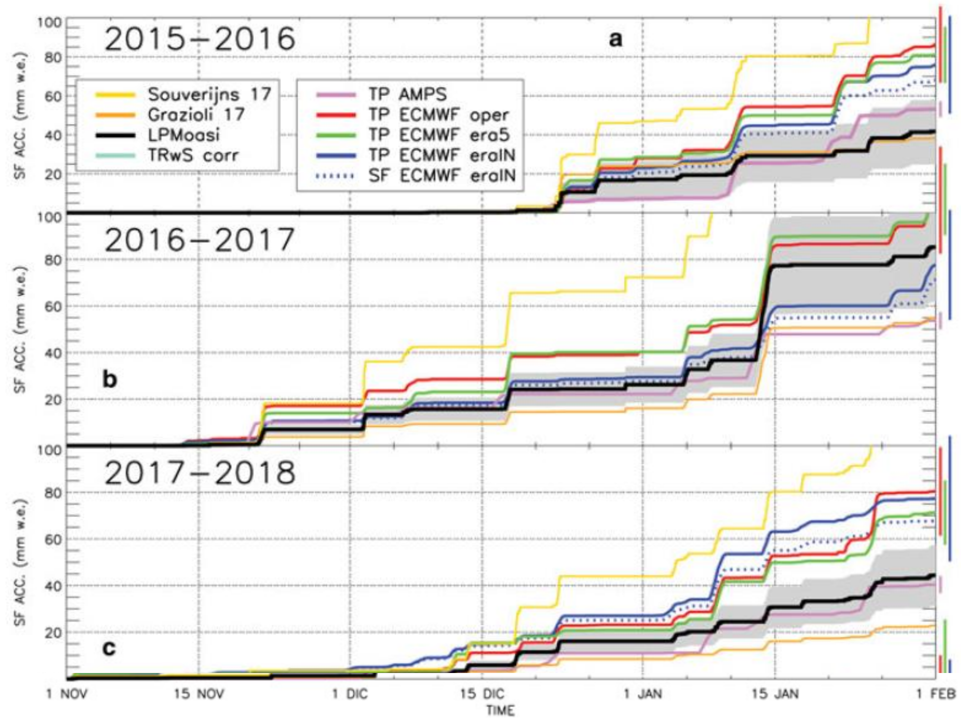
Precipitation results and model comparison

- Estimated summer snowfall ranged from about 44 to 85 mm w.e., with totals strongly influenced by a few intense events.
- ECMWF and AMPS generally captured the timing of precipitation events.
- However, they did not reproduce the amounts well during the strongest events.
- Overall, ECMWF overestimated precipitation, whereas AMPS underestimated it.



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Snow microphysics, classification, and improved QPE at MZS

- Snowfall at MZS was analyzed during the 2018–2019 and 2019–2020 using a large set of coincident radar and surface observations.
- Snow-classification-based radar QPE method was developed combining MRR and disdrometer data and snow-particle scattering simulations to apply different Ze–SR relationships for different hydrometeor types.

remote sensing MDPI

Article

Quantitative Precipitation Estimation over Antarctica Using Different *Ze-SR* Relationships Based on Snowfall Classification Combining Ground Observations

Alessandro Bracci [1,2], Luca Baldini [1,*], Nicoletta Roberto [1], Elisa Adirosi [1], Mario Montopoli [1], Claudio Scarchilli [3], Paolo Grigioni [3], Virginia Ciardini [3], Vincenzo Levizzani [4] and Federico Porcù [2]

Methodological Architecture: **Variable Ze–SR retrieval based on snow classification**

Step 1: Surface Microphysics (Disdrometer Inputs)

- **Input:** N(D) – Particle size distribution and fall velocity.
- **Constraint:** Removal of anomalous wind-driven fall velocities (>7 m/s).

Step 2: Category-based simulation

- Apply the 6 snow categories from Kuo's DDA database
- Derive:
  - 6 simulated reflectivities (Ze_{disd})
  - 6 snowfall rates (SR)
  - 6 category-specific Ze–SR relationships

Step 3: Reflectivity matching

- Compare observed Ze_{MRR} with the 6 simulated Ze_{disd}
- Compute RMSE in a 10-min window

Step 4: Hydrometeor classification

- Select the category with the lowest RMSE
- Identify the prevailing snow particle type

Step 5: Adaptive QPE

- Apply the corresponding Ze–SR relationship
- Retrieve snowfall rate and accumulated precipitation

Snow microphysics, classification, and improved QPE at MZS

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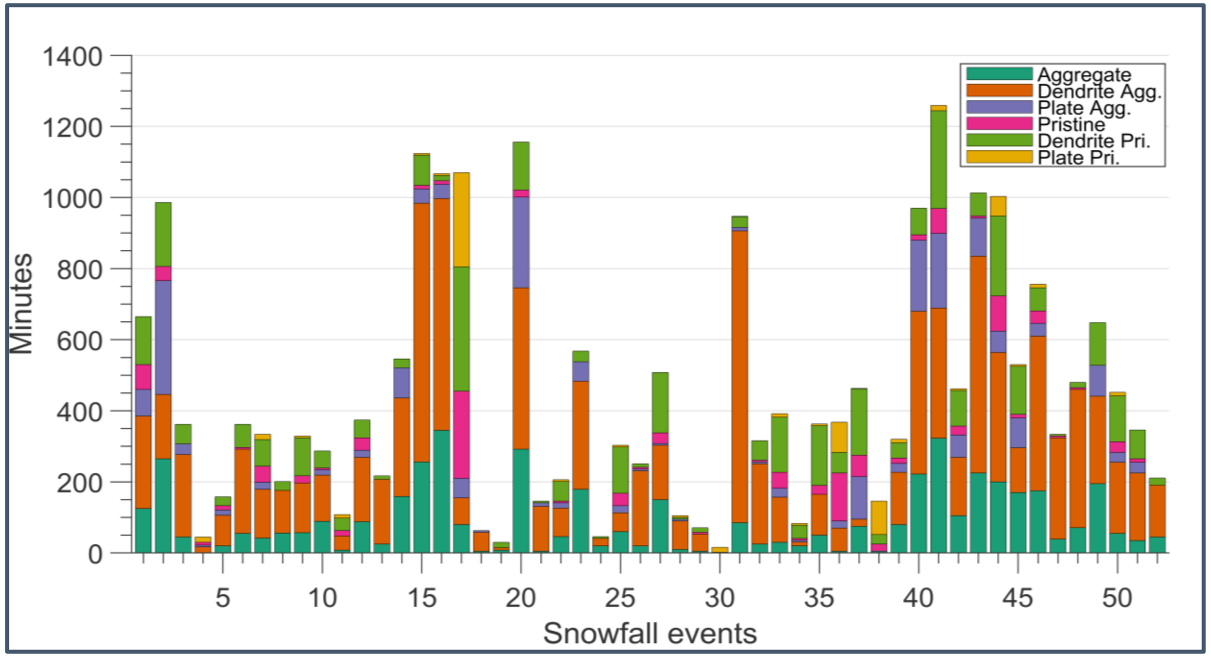
Snow classification results

- The classification shows that aggregate-like particles dominate snowfall at MZS, accounting for more than 75% of all precipitation minutes.
- Dendrite aggregates are the most frequent class, representing about 45% of the total database, followed by the more generic aggregate category at about 20%.
- Most snowfall events exhibit a mixture of particle types, with both aggregate and pristine signatures, whereas events dominated only by pristine particles are rare.



Snow microphysics, classification, and improved QPE at MZS

CNR ISAC

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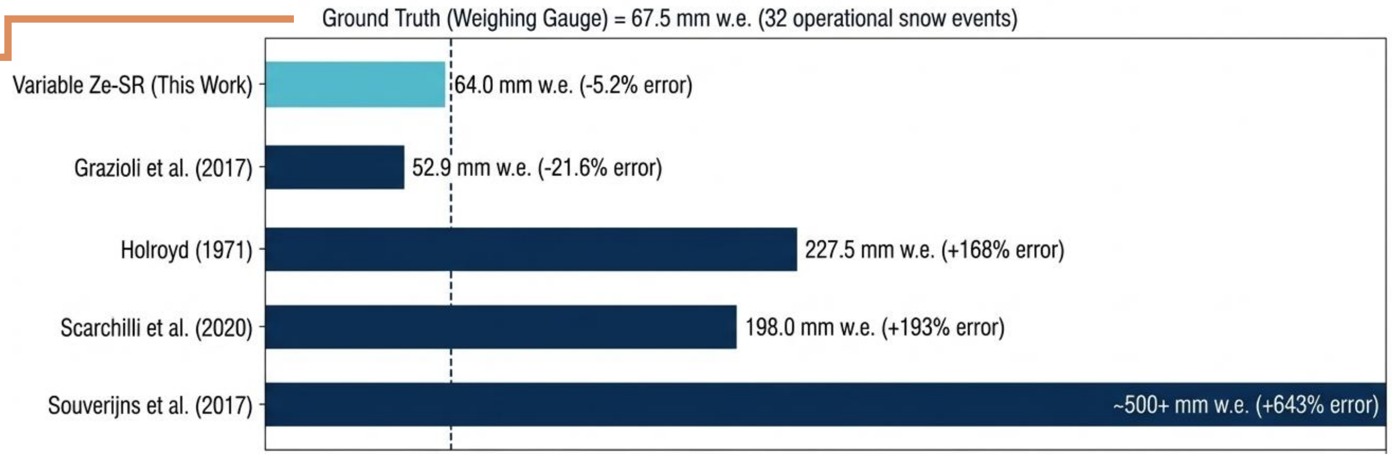
Benchmark against fixed Ze–SR relationships: **the variable Ze–SR approach performs best**



Conclusion: Using fixed relationships for Antarctic QPE can lead to large errors. Hydrometeor classification is essential.

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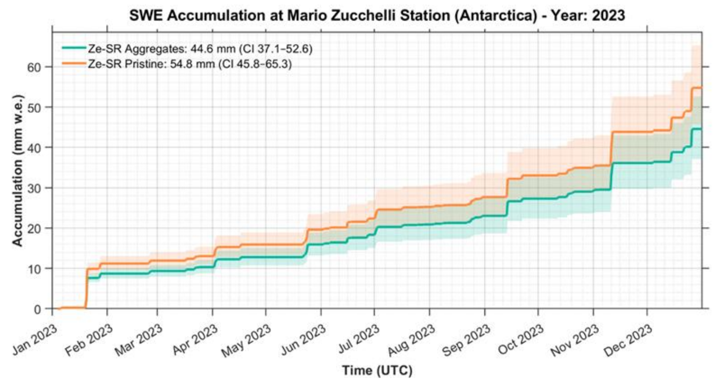
Towards Antarctic-wide precipitation products

Extension through WMO - Antarctic Regional Climate Center

- The WMO / AntRCC consensus statement proposes MRR as a practical basis for harmonized snowfall-rate and accumulation products in Antarctica.
- The baseline concept is simple: near-surface reflectivity, category-dependent Ze-SR relationships, and explicit uncertainty ranges.
- Where a disdrometer is co-located, the same framework can be refined at selected supersites.
- This is realistic because MRR systems are already available at a growing number of Antarctic sites.

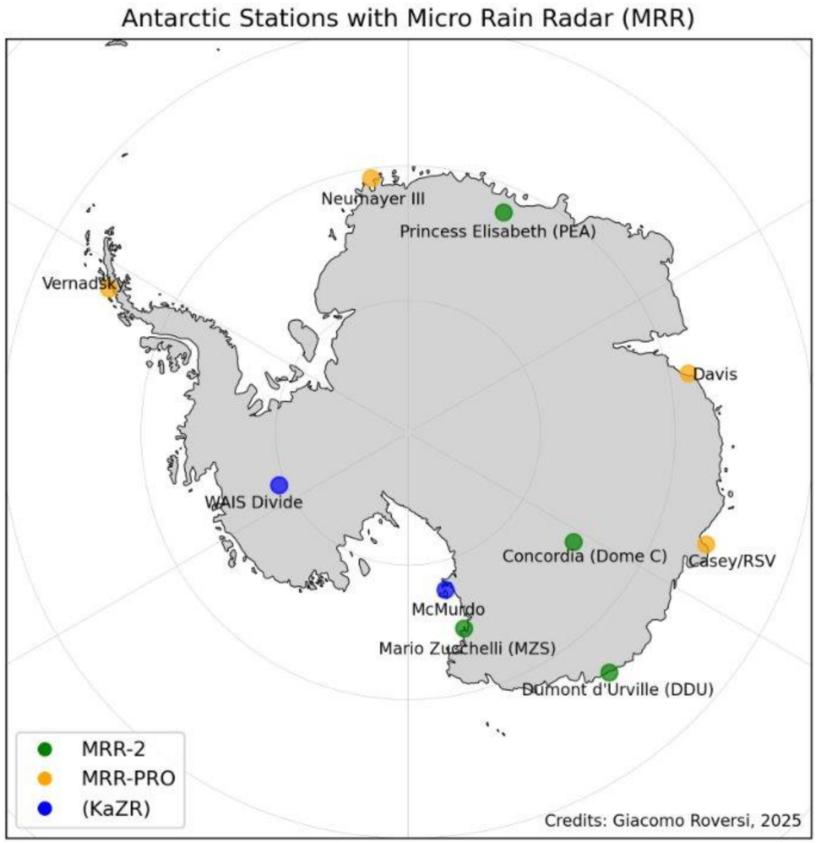
Example cumulative SWE product



Operational message

MZS can act as a calibrated supersite, while an MRR-only baseline remains broadly deployable across the wider Antarctic network.

Existing MRR footprint

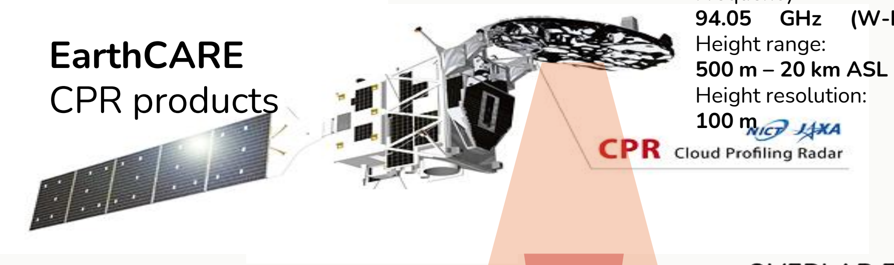


Ongoing synergistic activities

Ground-based support for EarthCARE validation

Why ground validation is needed

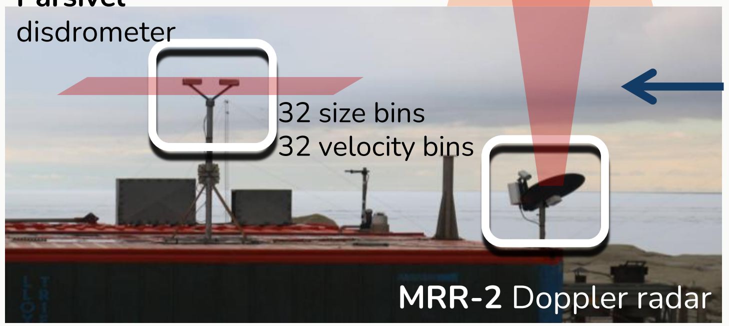
- EarthCARE (ESA-JAXA) CPR cannot fully observe the lowest layer above the surface because of ground clutter and the blind zone.
- At MZS, co-located MRR and Parsivel measurements help fill this observational gap and interpret near-surface snowfall processes.
- Through the K2W methodology, ground observations allow the reconstruction of satellite-like W-band variables and direct comparison in the overlap region.



Frequency:
94.05 GHz (W-band)
Height range:
500 m – 20 km ASL
Height resolution:
100 m

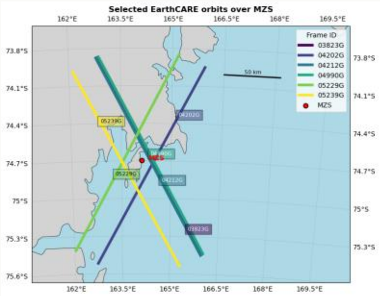
OVERLAP FOR VALIDATION

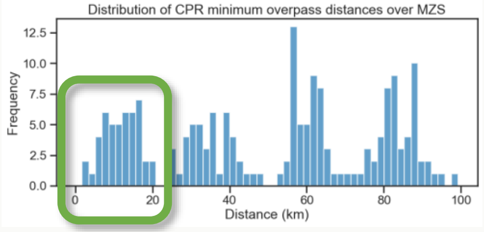
ADDITIONAL INFORMATION

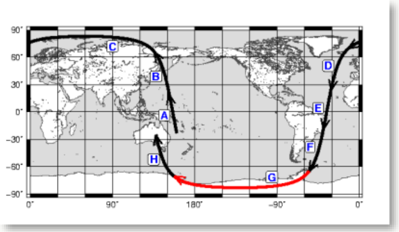


Frequency:
24.15 GHz (K-band)
Height range:
105 – 1050 m AGL
Height resolution:
35 m

EarthCARE overpasses at MZS





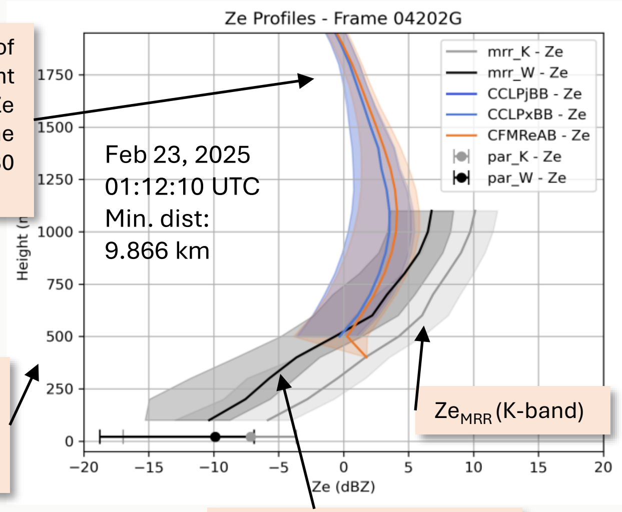


EarthCARE validation at MZS

Radar Reflectivity

Average profiles of CPR equivalent reflectivity factor Ze (dBZ) during the selected windows (30 km)

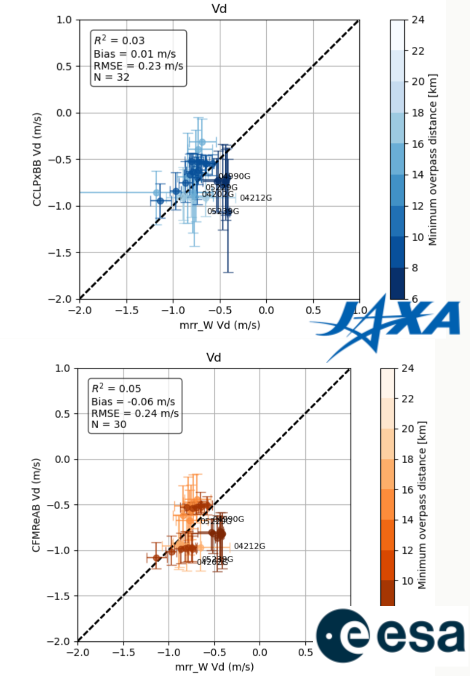
Profiles are resampled on a **uniform vertical grid**, spaced 100 m



Ze_{MRR} (K-band)

Ze_{MRR} (W-band)
Reconstructed with **K2W**

Doppler Velocity

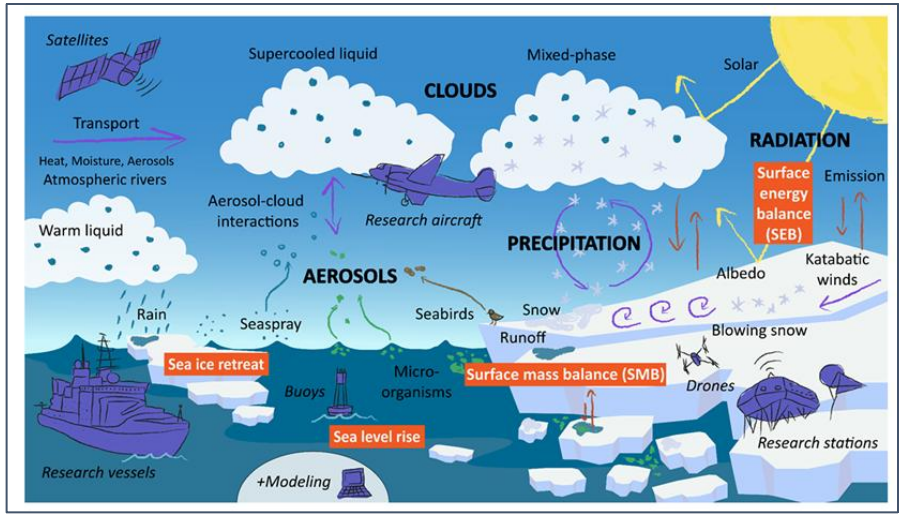


Ongoing synergistic activities
Antarctica InSync

ANTARCTICA INSYNC

CNR ISAC

Aerosol-cloud-precipitation interactions and radiative feedbacks



- Theme 6 identifies cloud and precipitation properties as still insufficiently observed and understood.
- Priority observations explicitly include precipitation at the surface and vertical profile / size-distribution information.
- The white paper stresses the value of integrating ground-based, airborne, and satellite data for validation and upscaling.
- This makes Antarctic snowfall measurements a natural contribution to the InSync legacy.

Knowledge Gap 2 – White Paper
"Characterizing cloud and precipitation properties"

Theme 6: Essential variables ANTARCTICA INSYNC

Topic	Priority 1	Priority 2	Priority 3	Knowledge gap
Blowing Snow		particle size distribution	images, velocity, habit	
Biology	In situ sea-surface Chlorophyll-a General description of nearby animal population (e.g. bird colonies)	particulate organic carbon and total organic carbon of surface sea water taxonomic groups of phytoplankton	Sea-surface microlayer samples Ocean surface mixed-layer samples(<1 m depth)	
Clouds	**Remote Sensing** Cloud cover Fog identification Cloud base height Vertical profile of backscatter	**Remote sensing** Cloud phase, LWC, LWP, IWC, IWP (radar, lidar, radiometer) Cloud particle vertical velocity	**Remote sensing** Multi-frequency / dual-polarisatioon cloud radar **In situ (balloons, aircraft)** Cloud particle size distribution Cloud particle images	**Determining cloud and precipitation properties and moisture sources (KG 2, 4)**
Precipitation	**At surface** daily total, hourly rate, phase	Vertical profile Size distribution	**Sampling** chemical composition, INP and stable water isotopes of falling rain and snow, chemical composition, INP, salinity, pH of surface snow	

Take-home message: The real added value lies in the synergy between CNR and ENEA: this experience has shown how joint work on Antarctic precipitation can build a broader collaboration, supporting shared activities from Antarctica to the Mediterranean.

Thank you!

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