Enhancing Satellite Validation in Antarctica: A Novel K2W Methodology for Comparing Ground-Based Measurements at K-band with Spaceborne Radar Observations Collected at W band

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Motivations

- Knowledge of precipitation amounts is particularly significant in Antarctica as precipitation is the most considerable positive term of the surface mass balance of the Antarctic Ice Sheet
- Ground-based snowfall observations over Antarctica are rare due to the harsh environment and high logistical, equipment maintenance, and operational costs. Therefore, satellite measurements are crucial to provide continent-wide precipitation estimates
- Satellite products require extensive validation in Antarctica, both to verify assumptions underlying retrievals and quantify uncertainties. Ground-based validation is not trivial because of differences in sampling areas, blind zones, and the rarity of overpasses during precipitation

Goals

- ❑ Developing a conversion methodology (K2W) to simulate the W band radar reflectivity and Doppler profiles from ground based Micro Rain Radar at 24 GHz and laser disdrometer observations, relatively common precipitation instruments available at Antarctic research stations, differently from imaging disdrometer or KA or W band profilers
- ❑ Assessing the performance of our approach by comparing the observed CloudSat radar reflectivity profiles
- ❑ Obtaining vertical Doppler profiles at W band that could be beneficial for validating measurements from the incoming ESA/JAXA EarthCARE satellite mission

Antarctic Site and Instruments

- The Italian research station "Mario Zucchelli" (MZS), managed by the National Antarctic Research Program (PNRA), is located at Terra Nova Bay along the Ross Sea coast of Northern Victoria Land.
- Micro Rain Radar 2 (MRR) is a K-band (24 GHz) profiling Doppler radar, typically used in vertical pointing mode that operates at the K-band (24 GHz) to derive Doppler power spectra in 64 bins over 32 vertical range bins. MRR has been set to a vertical resolution of 35 m, which makes it possible to obtain the first trustworthy measurement just 105 m above the surface.
- Particle Size and Velocity (Parsivel) is an optical laser disdrometer that simultaneously measures the sizes and fall velocities of the hydrometeors (binned in 32 × 32 diameter/speed classes).
- NASA CloudSat mission was launched in 2006 carrying the CPR, a 94 GHz (W-band) nadir-pointing radar, which measures the radar reflectivity factor of clouds and precipitation. In this work, we used the 94 GHz CloudSat 2B-GEOPROF (release P1 R05) radar reflectivity data.

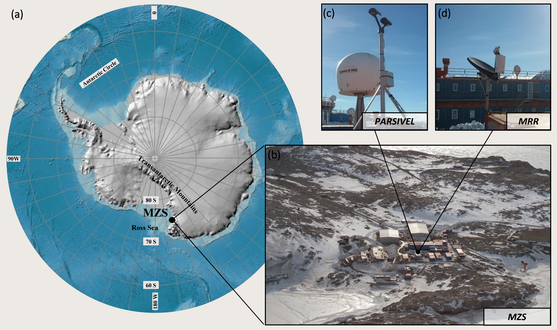


Figure 1.
(a) Geographic map of the Antarctic continent with the locations of Mario Zucchelli research station (MZS) (credit: Earthstar Geographics-PGC-UMN-Esri); (b) Aerial view of the Mario Zucchelli research station (credit: PNRA.aq) with the position of the co-located instrumentation used in this study: disdrometer (c) and radar (d).

K2W Methodology

K2W simulates W-band spectra from MRR K-band spectra using appropriate backscattering cross-sections $C_{bk}(D)$ and $v_t(D)$ terminal velocity-diameter relationship for precipitation with the aid of disdrometer observations

K2W

MRR Retrieval

I. Spectral reflectivity density with respect to Doppler velocity: $\eta_v(v_s, \mathrm{R}) = \frac{\eta(\mathrm{s},\mathrm{R})}{\Delta v}$

II. Particle size distribution is obtained by: $\eta_D(\mathrm{D}) = \eta_v(\mathrm{v})\frac{\partial v}{\partial \mathrm{D}}$
   I. Spectral reflectivity density with respect to particle diameter
   II. Dividing by backscattering cross-section $\mathrm{N(D)} = \frac{\eta_D(\mathrm{D})}{C_{bk}(\mathrm{D})}$

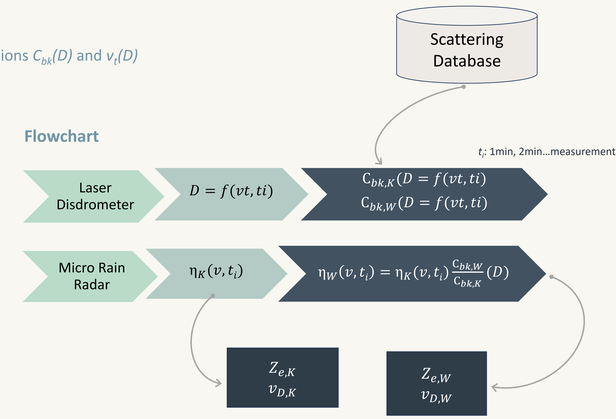
III. Making explicit the frequency dependencies:

$$\mathrm{N(D)} = \frac{\eta_{D,K}(\mathrm{D})}{C_{bk,K}(\mathrm{D})} \quad \text{as well as} \quad \mathrm{N(D)} = \frac{\eta_{D,W}(\mathrm{D})}{C_{bk,W}(\mathrm{D})} \quad \text{considering same snow habit}$$

IV. Going backwards:

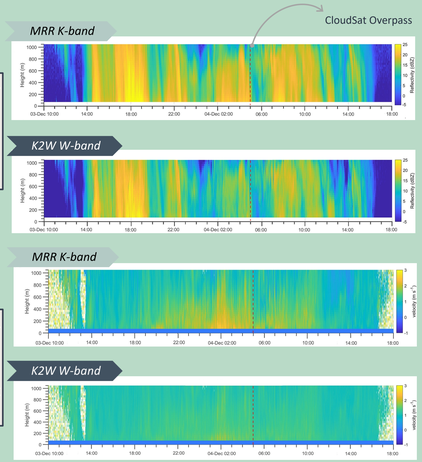
$$\eta_{v,W}(v) = \eta_{v,K}(v)\frac{C_{bk,W}(D)}{C_{bk,K}(\mathrm{D})} \qquad \eta_{v,W}(v_s) = \eta_{v,K}(v_s)\frac{C_{bk,W}(v=g(D))}{C_{bk,K}(v=g(D))} \Rightarrow \mathbf{Z_{e,W}}\ \mathbf{V_{D,w}}$$

Flowchart

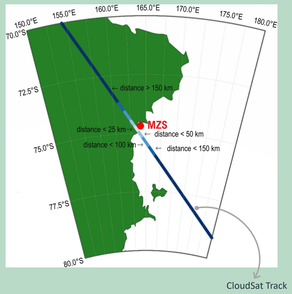


Results

Simulation of W-band Doppler Spectra



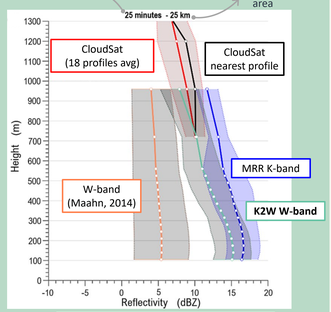
- Overpass: 5:00 UTC on 4 December 2018
- Minimum distance from MZS: 22.9 km
- Considered lowest CloudSat range gates (720, 960 m a.s.l)
- 8 MRR range gates averaged to match CloudSat vertical resolution



Comparison CloudSat-K2W profiles

Vertical profiles of W-band reflectivity obtained by K2W around the CloudSat overpass were time averaged for comparison with the horizontal averaged CloudSat Z_e within a certain distance from MZS

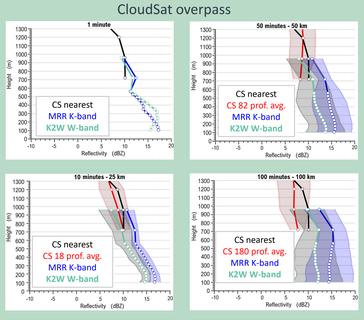
Best Result



Difference between K2W and CloudSat
0.2 dB at 760m
1 dB at 960 m

Sensitive analysis

Change averaging time window and distance from MZS to consider spatial variability of precipitation during CloudSat overpass



Narrowing
1-min: K2W not able to convert
10-min: difference ~1,4dB

Widening
Profiles start to be quite distinct
Worsening of correspondence

Conclusions

- Satellites are the major source of information about precipitation in Antarctica ⋙ development of a reliable validation strategy for the satellite measurements is in high demand
- K2W methodology combines MRR Doppler spectra and disdrometer data to simulate 94 GHz reflectivity and Doppler measurements
- K2W was assessed using CloudSat overpass over MZS for a typical snowfall event:
  - **K2W reproduces** CloudSat Ze profile with 0.2 dB mean difference at the lowest radar range bin and 0.5 dB difference on average below 1 km altitude
  - **K2W simulates** the Ze profile within the CloudSat blind zones. This unattenuated W-band profile can be used to evaluate spaceborne W-band radar retrievals
  - **K2W simulates** the W-band Doppler velocity below 1 km altitude that will be observed by EarthCARE
- Pairs of MRR-disdrometer are available in many ground observation sites worldwide and in most of the research stations in Antarctica ⋙ K2W method has a wide application

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