EarthCARE 2026 Science and Validation workshop

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EarthCARE Doppler velocity measurements in convection: impact of multiple scattering

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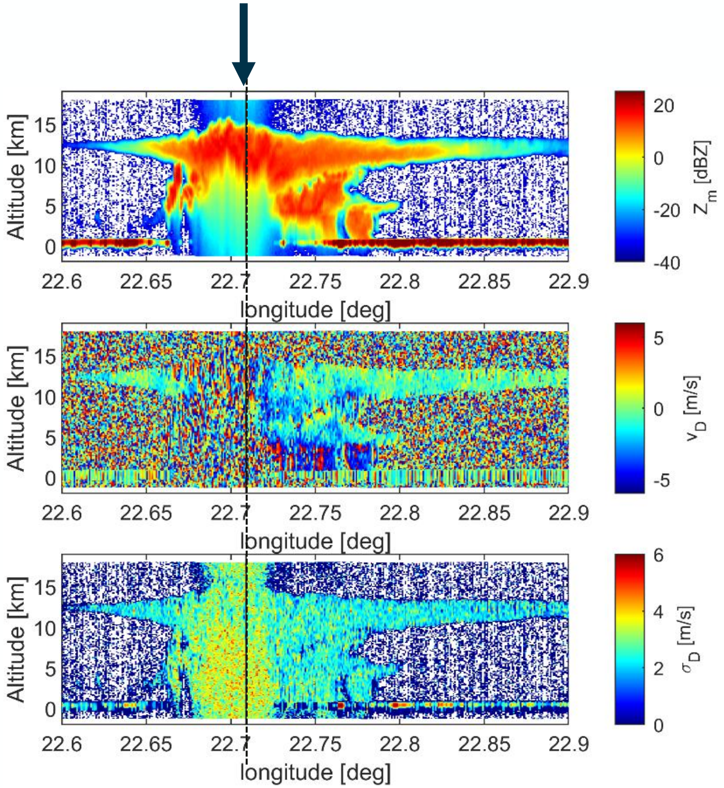
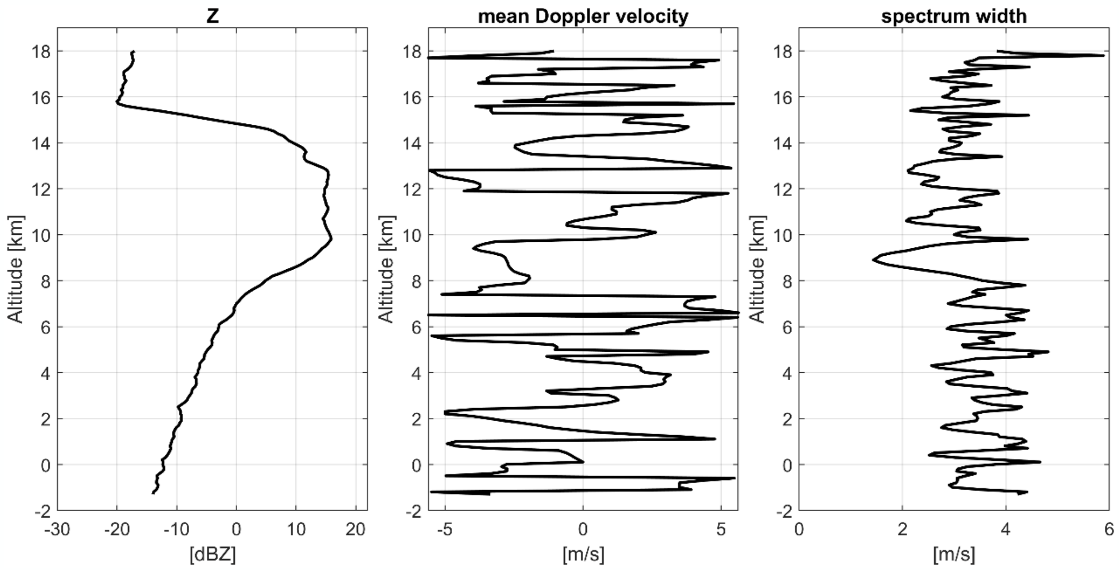
Motivation and objective

Doppler from space in convection is challenging because:

- Convection is characterized by large wind velocity variability and hydrometeor variability within short distances → Non-uniform beam-filling
- Large amount of dense ice particles → multiple scattering (MS)
- Small Nyquist velocity (5.65 m/s for EarthCARE) → aliasing, many foldings in convection.

Objective: analyze the behaviour of the Doppler spectra and the estimators of spectral moments in convection.





Methodology for simulating Doppler spectra in EarthCARE in presence of MS

- **Single scattering** is simulated analytically.

- **Higher orders of scattering** are simulated with an importance sampling based Monte-Carlo algorithm that solves the scalar RTE in 3D atmosphere.

At *k*-th scattering:

1. the radiation stream interacts with an ensemble of particles whose velocity is gaussian distributed;
2. radiation undergoes a **mean Doppler shift** and a **spectral broadening**

$$\Delta v_D^k = (\boldsymbol{u}_{\mathrm{k}-1} - \boldsymbol{u}_k) \cdot (-v_T(\Theta)\boldsymbol{i}_z + \mathbf{v}_{\mathbf{wind}})$$

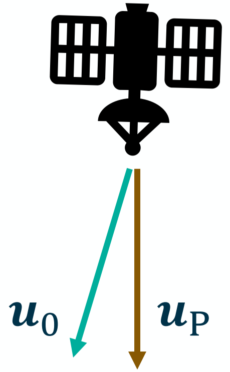
$$\Delta\Sigma_D^k = [(\boldsymbol{u}_{\mathrm{k}-1} - \boldsymbol{u}_k)^2]^T \operatorname{diag}\left(\sigma^2_{wind,x}, \sigma^2_{wind,y}, \sigma^2_{wind,z} + \sigma^2_{hydro}(\Theta)\right)(\boldsymbol{u}_{\mathrm{k}-1} - \boldsymbol{u}_k)^2$$

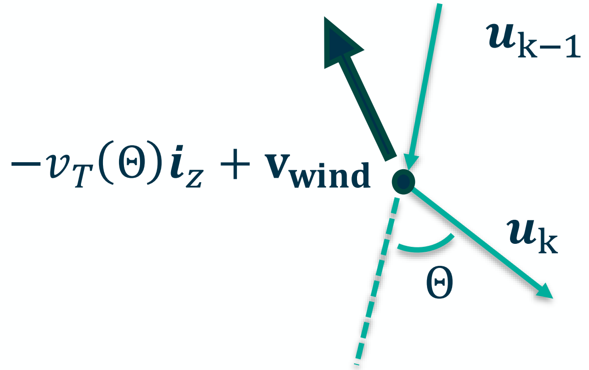
3. The contribution of the k-th order of scattering is

$$v_D^k = \frac{1}{2}\left[\left(\sum_{k=1}^{n} \Delta v_D^k\right) - \boldsymbol{v}_{SC} \cdot (u_{\mathbf{0}} - u_{\boldsymbol{n}})\right] - \boldsymbol{v}_{SC} \cdot \boldsymbol{u}_P \qquad \Sigma_{D_k} = \frac{1}{2}\left[\sum_{k=1}^{n} \Delta\Sigma_{D_k}\right]$$

$$s^{j,k}(r,v) = P^{j,k}(r)\,\mathcal{N}\left(v_D^{j,k}, \Sigma_D^{j,k}\right)$$

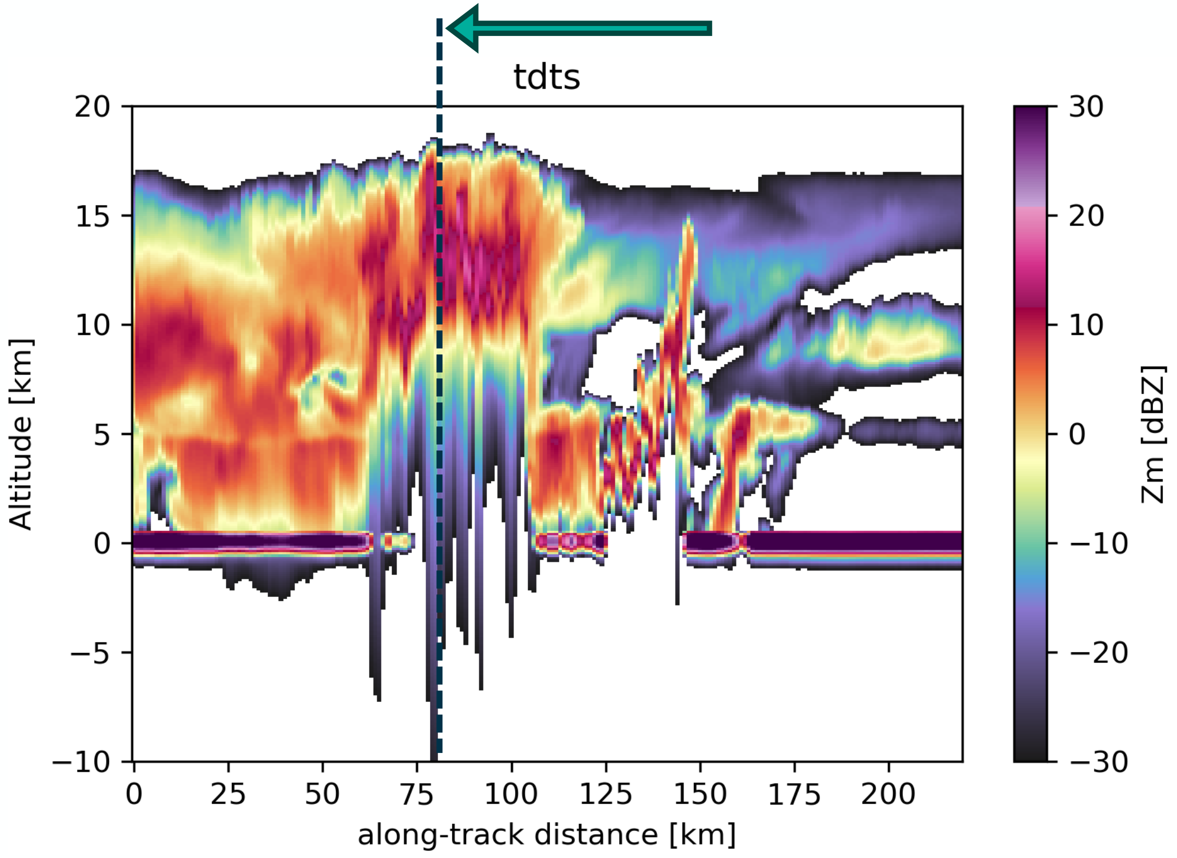
$$S^{MS}(r,v) = \sum_{j=1}^{N_T}\sum_{k=1}^{\infty} s^{j,k}(r,v)$$

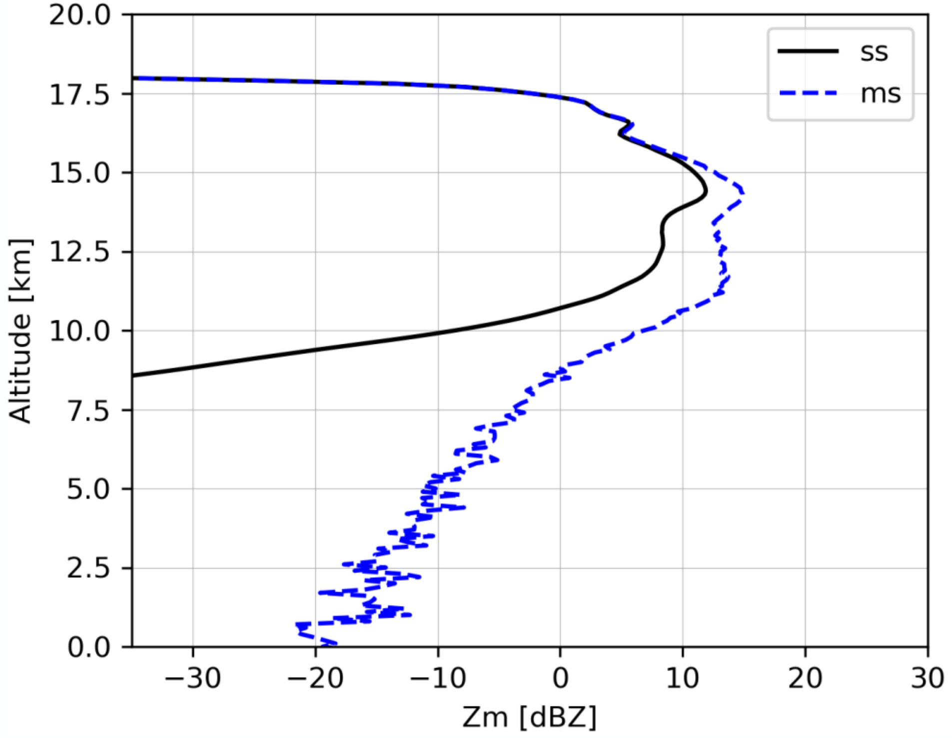




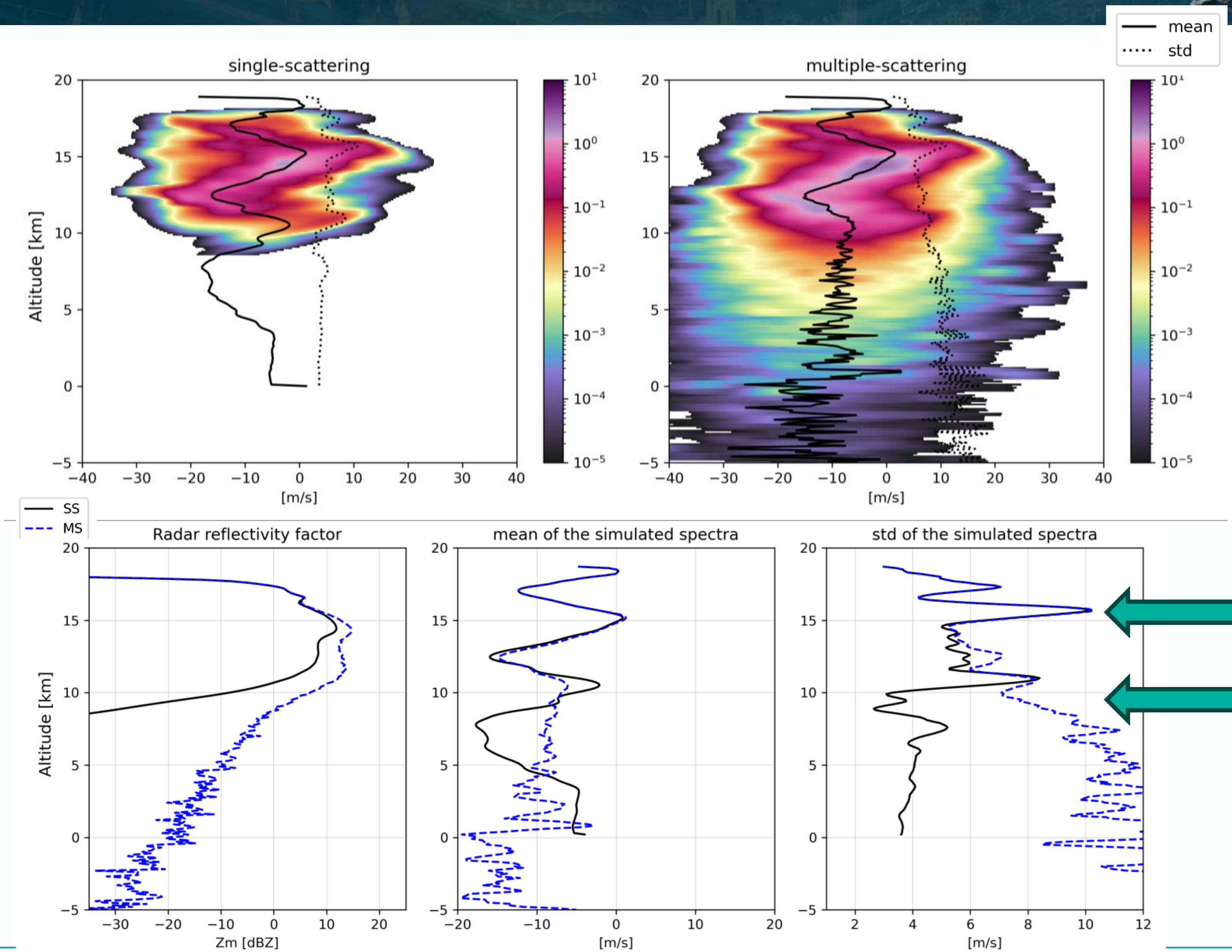
Simulation of MS effects

Case study: convective cell over Australia (RAMS simulations from Marinescu et al. 2026)





Simulation of Doppler spectra



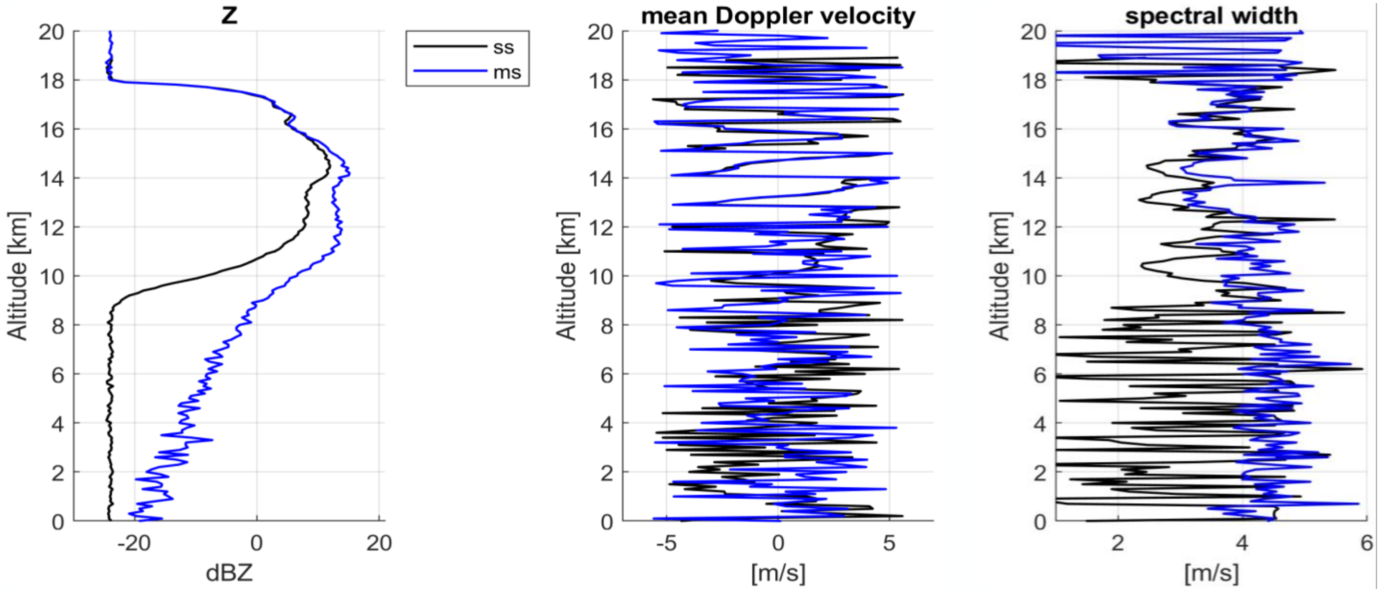
The spectral broadening can be due to MS and multi-modality of the spectra (NUBF):

NUBF

Significant MS broadening starts where $Z_m^{MS} - Z_m^{SS} > \sim 8\, dB$

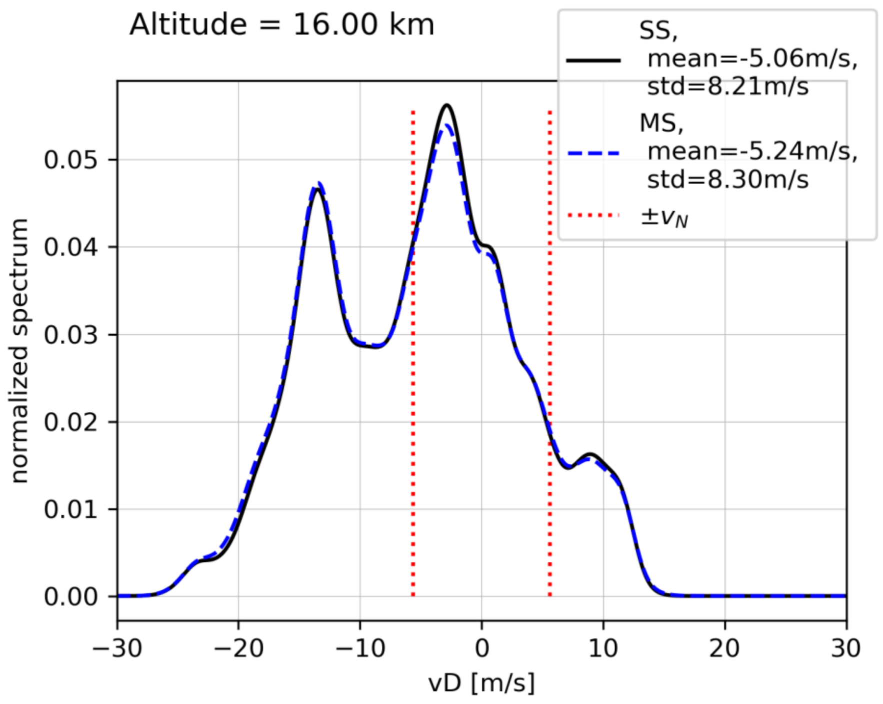
I&Q Processing and estimator

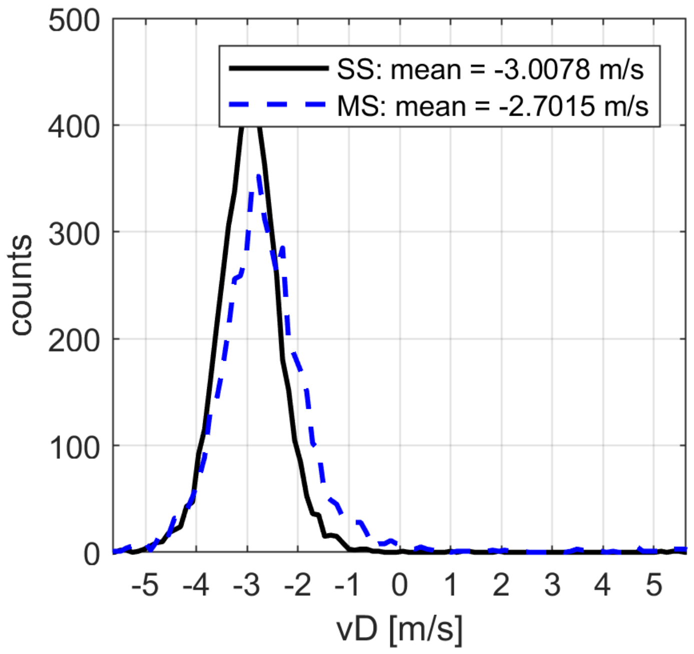
1. Synthetic I&Q signals are obtained by simulating the correlation at different lags from the Doppler spectra (*Battaglia et al., 2025)* with EC sampling characteristics.
2. I&Q signals are processed through PPP estimators to retrieve the estimate of Z, mean Doppler velocity and spectral width:
   - $\hat{R}_1 = \frac{1}{N_b}\sum_{b=1}^{N_B} R_1^b,$ with $R_1^b = \frac{1}{M-1}\sum_{k=1}^{M-1} \tilde{V}_k \tilde{V}_{k+1}^*$
   - $\hat{V}_D = -\frac{V_N}{\pi}\arg(\hat{R}_1)$, $\hat{\sigma}_D^2 = \frac{2V_N^2}{\pi^2}\ln\left(\frac{R_0 - N_f}{|R_1|}\right)$
   - Where $\hat{R}_1$ is the Pulse-Pair covariance estimate at lag 1.
3. Assumption: the spectra are constant along-track for the M (=22) consecutive pulses used for the estimation of the spectral moments.

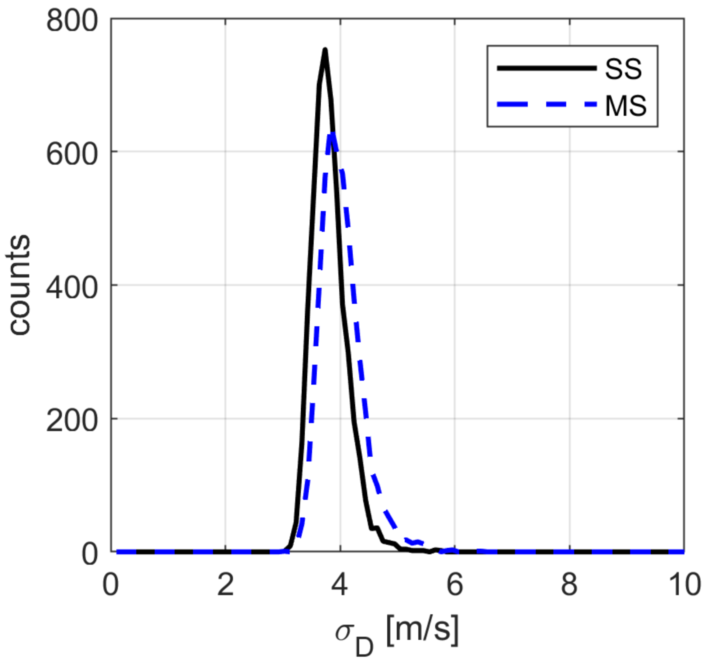


Example of estimates from 1 random I&Q relization

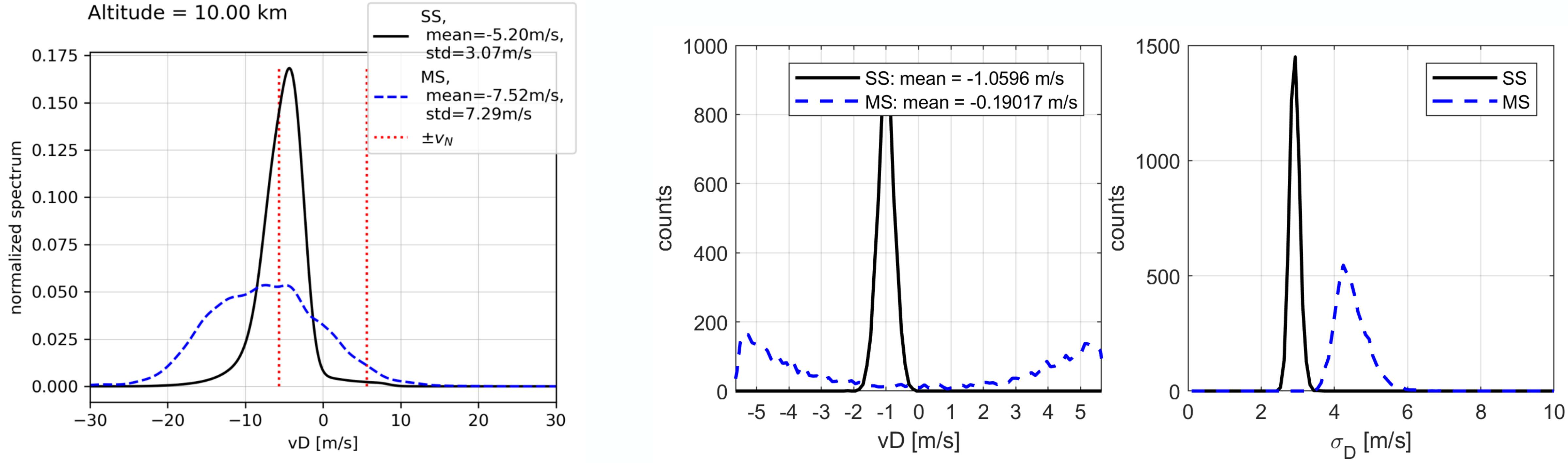
Estimator: example at altitude = 16 km







Estimator: example at altitude = 10 km

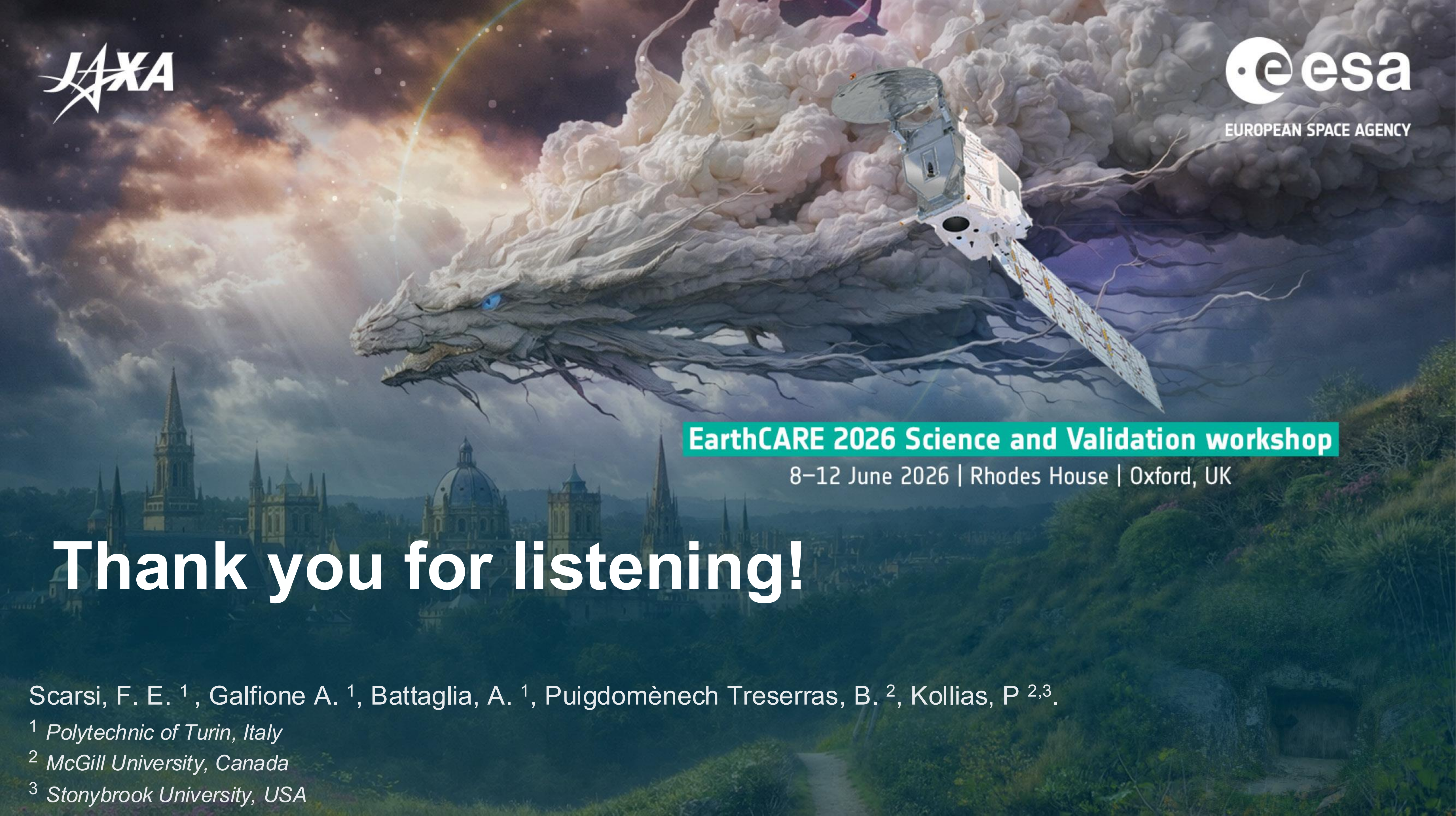


Conclusions and future work

1. In convection, Doppler spectra are often non-gaussian (multi-modal) due to the large inhomogeneity in the hydrometeor distributions and wind field in the convective cell and backscattering volumes.
2. Multiple scattering tends to broaden the spectra, however this effect is low in regions where $Z_m^{MS} - Z_m^{SS} < \sim 8\ dB$
3. Broadening and multimodality associated with the narrow Nyquist velocity range tend to strongly bias velocity estimates.

Future work

1. Because of the difficulty in the interpretation of the Doppler signal in deep convection the best strategy is to flag these areas and do not consider them in statistical analysis (which can only be sensibly performed only in mild convection).
2. A clustering analysis of deep convective areas based on the scrambled Doppler signal could provide information about global climatology of deep convection (where does it occur? how wide are convective cells, ...)



Thank you for listening!

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