Evaluating ECMWF global model cloud and precipitation fields with observed radar reflectivity: How do we ensure a fair comparison?

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1. Introduction

- An improved representation of clouds and precipitation is a key area for Numerical Weather Prediction (NWP) and climate models.
- Radar reflectivity from ground-based (ARM) and space-borne (CloudSat) radars provide an opportunity to evaluate cloud and precipitation in the ECMWF global NWP model (IFS).
- It is vital to ensure we compare "like-with-like" to highlight real model deficiencies rather than artefacts of the comparison.

2. A fair comparison?

Issues that need to be addressed for a fair comparison of equivalent radar reflectivity between model and observations:

- Co-location in space and time

Radar reflectivity forward model

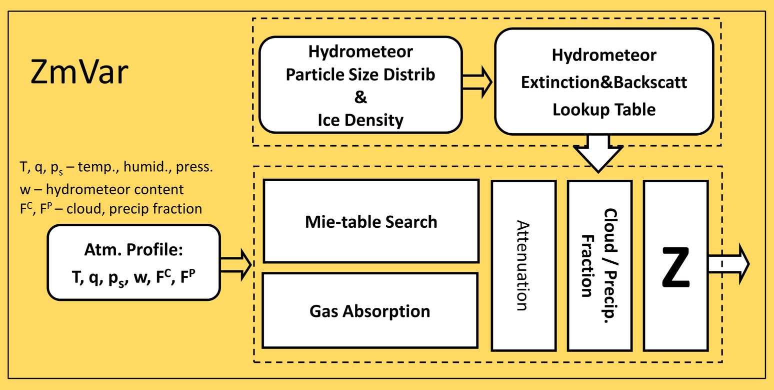
- Discrete hydrometeor categories versus continuum
- Microphysical assumptions (e.g. particle size distributions) and electromagnetic properties (scattering, absorption)
- Limitations of the observations, (e.g. thresholds, attenuation)

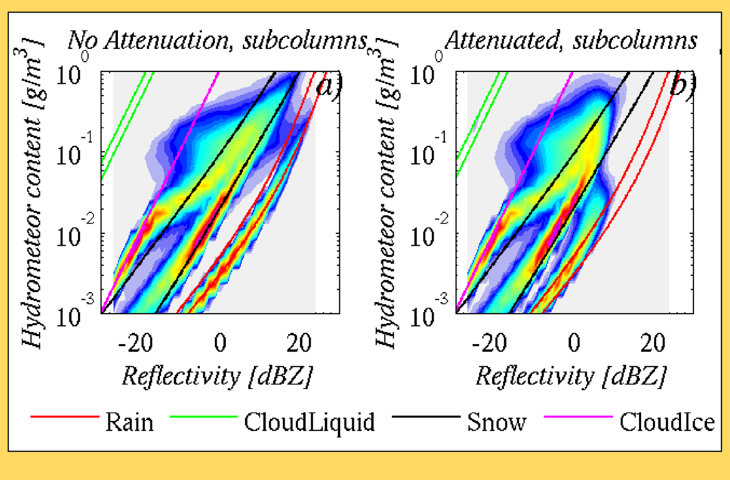
Sub-grid model

- Mismatch of spatial resolution and sampling 1D versus 2D
- Sub-grid cloud and precipitation fractions and overlap

3. Radar reflectivity forward model

- ZmVar radar reflectivity forward model based on Di Michele et al., (2009) to simulate reflectivities from the IFS (efficient, flexible, adjoint available for assimilation) for the four model hydrometeor categories (cloud liquid, rain, cloud ice, snow).





Particle size distributions (PSD) and single particle electromagnetic properties (EP) for each model category:

Liquid	PSD: lognormal (Miles et al. 2000)
Rain	PSD: exponential (Marshall and Palmer, 1948) EP: t-dependent permittivity (Liebe et al. 1991)
Ice	PSD: gamma function (Marchand et al. 2009) EP: hexagonal columns (Liu, 2008)
Snow	PSD: temp-dependent (Field et al. 2007) EP: aggregates of columns (Hong et al. 2008)

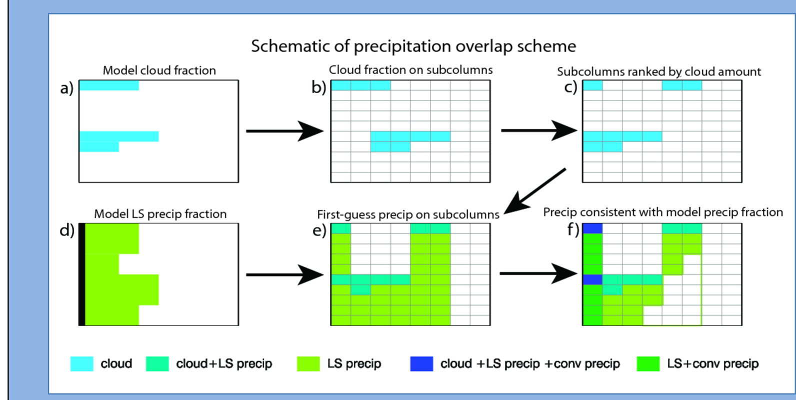
Hydrometeor mass vs. ZmVar reflectivity

Lines - relationships in ZmVar for each hydrometeor type (double lines for liquid, rain, and ice indicate two limits for temperature dependence).

Shading - relative occurrence of the reflectivity vs. *total* hydrometeor content from the global model.

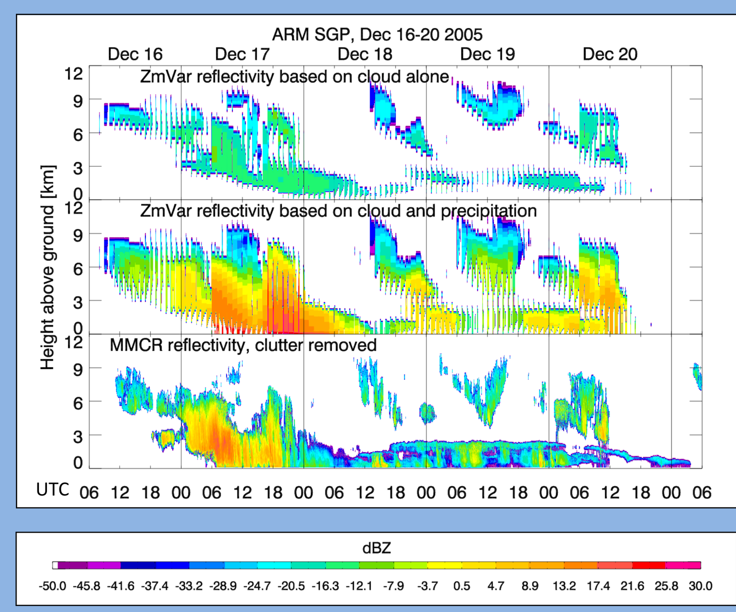
4. Accounting for sub-grid variability

- The IFS model provides information on sub-grid cloud fraction (liquid, ice) and precipitation fraction (rain, snow) and overlaps.
- Need to take account of this for signal attenuation and a fair comparison with the high-spatial/temporal resolution radar data.
- A sub-grid column approach (SCOPS, Webb et al., 2001) is used. ZmVar is applied to each sub-column separately.



Schematic of cloud and precipitation fractions and overlap on sub-columns.

- Precipitation overlaps maximally with cloud.
- First guess assumes no reduction in precipitation fraction due to evaporation (centre) – as SCOPS.
- IFS model does assume reduction of precipitation fraction with evaporation (left & right panel).
- Convective precipitation in cloudiest part of grid-box.

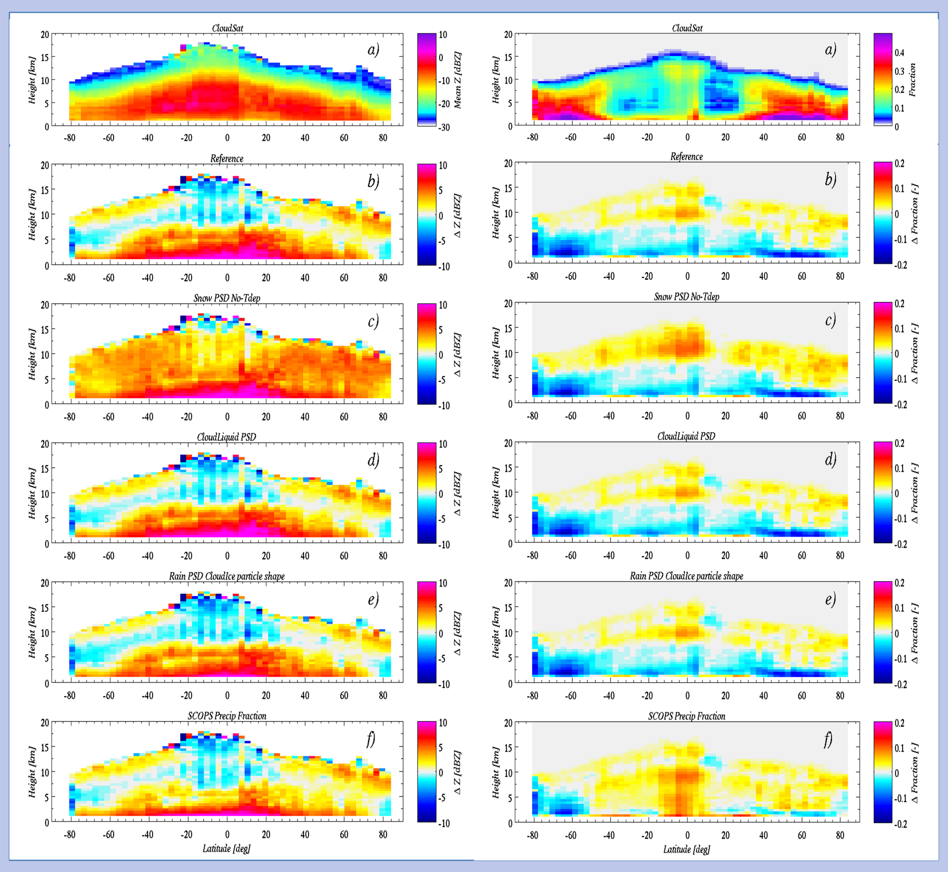


Example comparison of radar reflectivity between IFS model ZmVar sub-column and ARM SGP data. Precipitation is a dominant part of the signal.

5. Sensitivity to assumptions

Assess sensitivity of the IFS vs. CloudSat reflectivity:

- Sensitivity to uncertainties in the microphysical assumptions and electromagnetic properties in the IFS/ZmVar radar reflectivity forward model (particle size distributions, particle properties).
- Sensitivity to the specification of sub-grid cloud fraction and precipitation fraction assumptions and overlap.



Zonal mean reflectivity when present (left column) and fractional occurrence (right column) for January 2007

(a,b) CloudSat, (c-l) give the difference between ZmVar simulated and CloudSat reflectivity for different assumptions within the bounds of uncertainty in the modelling of hydrometeor properties.

(c,d) using the reference configuration;

(e,f) removing the temperature-dependence of snow aggregates PSD;

(g,h) decreasing the mean diameter of the particle size distribution;

(i,j) increasing PSD intercept for rain and changing the cloud ice habit from columns to plates;

(k,l) SCOPS precipitation fraction, rather than from IFS model.

6. Conclusions

- Radar signal is dominated by larger hydrometeors, so **important to represent precipitation profiles from the model appropriately**.
- Ice/snow properties uncertain and reflectivity is sensitive to uncertainties, less impact on occurrence. **Model limitations of discrete ice/snow categories and lack of information on particle properties limits forward model comparison.**
- However, robust results for IFS model deficiencies are an **overestimate of reflectivity in the lower troposphere** (due to rain) and **overestimate of occurrence in the upper troposphere**, (due to ice/snow in agreement with Delanoë et al., 2011)
- Future work will investigate PDFs of reflectivity profiles and regional and regime dependent variations and reasons for model deficiencies.

Bibliography

- Delanoë, J., R. J. Hogan, R. M. Forbes, A. Bodas-Salcedo and T. H. M. Stein, 2011. Evaluation of ice cloud representation in the ECMWF and UK Met Office models using CloudSat and CALIPSO data. Submitted to *Q. J. R. Meteorol. Soc.*
- Di Michele, S., O. Stiller and R. Forbes, 2009. WP-1000 Report for ESA contract 1-5576/07/NL/CB: Project QuARL - Quantitative Assessment of the operational value of space-borne radar and lidar measurements of cloud and aerosol profiles. ECMWF, UK.
- Field, P. R., A. J. Heymsfield, and A. Bansemer, 2007: Snow size distribution parameterization for mid-latitude and tropical ice clouds. *J. Atmos. Sci.*, **64,** 4346–4365.
- Hong, G., P. Yang, B. A. Baum and A. J. Heymsfield, 2008. Relationship between ice water content and equivalent radar reflectivity for clouds consisting of non-spherical ice particles. *J. Geophys. Res. – Atmospheres*, **113**(D20), D20205.
- Liebe, H.J., G. A. Hufford, and T. Manabe, 1991: A model for the complex permittivity of water at frequencies below 1THz. *Int. J., Infrared and millimeter waves*, **12**(7), 659-675.
- Liu, G., A database of microwave single-scattering properties for nonspherical ice particles. *Bull. Am. Met. Soc.*, **89**, 1563-1570, 2008.
- Marshall , J. S., and W.M. Palmer, 1948. The distribution of raindrops with size. *J. Meteorology*, **5**, 165-166.
- Marchand, R., J. Haynes, G. G. Mace, T. Ackerman, and G. Stephens, 2009. A comparison of simulated cloud radar output from the multiscale modeling framework global climate model with CloudSat cloud radar observations, *J. Geophys. Res.*, **114**, D00A20.
- Miles, N.L., J. Verlinde, E. Clothiaux, 2000. Cloud droplet size distributions in low-level stratiform clouds. *J. Atmos. Sci.*, **57**, 295-311.
- Webb, M., C. Senior, S. Bony, and J.-J. Morcrette, 2001. Combining ERBE and ISCCP data to assess clouds in the Hadley centre, ECMWF and LMD atmospheric climate models. *Climate Dynamics*, **17**(12), 905-922.

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