Estimation of Ice Water Content using single-, dual-, and triple-frequency radar

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Upper-tropospheric ice clouds play an important role in the global radiation budget and climate system, affecting precipitation formation processes and, consequently, the global water cycle. Estimating, at global scale, variables like the Ice Water Content (IWC), i.e. the ice mass per unit volume of atmospheric air, is therefore mandatory to understand the global radiation budget [1]. Multiple frequency radars are expected to provide solutions to retrieve IWC with higher accuracy than that achievable using single frequency reflectivity methods that obtain IWC using power laws between IWC and the radar reflectivity factor. Using multi-frequency radar, dual-frequency ratio (DFR) can be defined as the ratio of the equivalent radar reflectivity factors at two different frequencies, provided that for at least one of them, scattering is not in the Rayleigh-Gans regime. IWC algorithms using DFR are supposed to be more robust with respect to the variability of properties of ice particles. Multi-frequency radars are considered for the future satellite missions, following the NASA/JAXA Global Precipitation Measurement (GPM) mission, the first one using a dual-frequency (Ku and Ka bands) radar. To investigate different combinations of frequencies, many campaigns were conducted using properly instrumented aircrafts. Data of this study are from the OLYMPEX campaign [2], particularly those from the NASA airborne triple-frequency radar (Ku-, Ka-, and W-band), as well as from a second aircraft equipped with probes for in situ measurements. Measurements used are from the NCAR Particle Probes for Particle Size Distributions (PSD) and from Cloud Droplet Probe for Cloud Liquid Water Content (CWC). The IWC reference estimate is obtained by the difference between Total Water Content from the Nevzorov probe and the Liquid Water Content from the King probe [3]. The IWC radar algorithms examined are based both on single- frequency reflectivity factor measurements, and on combinations of Ku-band reflectivity with DFR_{aou}, DFR_{woa}, DFR_{wou}, and DFR_{aou} jointly with DFR_{woa}, where subscripts *aou*, *woa*, *wou* indicates Ka-band over Ku-band, W-band over Ka band, and W-band over W-band, respectively. An analysis was performed using IWC measurements and radar measurements simulated from PSDs by modelling particles as horizontally-aligned oblate spheroids with axial ratio equal to 0.6 and a mass-size relation optimized for OLYMPEX measurements whose coefficients depend on CWC. It was found that the performance of IWC algorithms, in terms of normalized bias, normalized standard error, and the correlation coefficient, in general, improves as the number of parameters of the algorithms increases. More important, the performance depends on CWC, so that it is preferable to use algorithms optimized for specific CWC classes. This property was confirmed also using actual radar measurements coincident with in situ measurements. Unfortunately, CWC is not operationally available and a substitute must be searched. Three CWC classes (*dry* for $CWC<10^{-4}$ g m^{-3}, *wet* for $CWC> 10^{-2}$ g m^{-3}, *moist* otherwise) were chosen and the corresponding (DFR_{woa}, DFR_{aou}) pairs were considered. It was observed that the slope of least square line of (DFR_{woa}, DFR_{aou}) pairs increased with decreasing CWC. This suggested to define the *Sl* (slope) parameter as the ratio between $\log_{10}DFR_{aou}$ and $\log_{10}DFR_{woa}$ as a proxy of CWC. In terms of *Sl*, *dry*, *moist* and *wet* are defined by $Sl>0.469$, $0.361<Sl<0.469$, $Sl<0.361$, respectively [4]. The effectiveness of using *Sl* was tested using collocated radar and PSD measurements. The interesting result is that, combining algorithms with parameters obtained for the three *Sl* class intervals, a much better performance of is achieved with respect to algorithms developed using all the data available, regardless of *Sl*.

References

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