Dynamic assignment of RADAR reflectivity uncertainty forcing data assimilation in WRF numerical model

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Meteorological Radar observations are precious sources of information for numerical prediction models, and indeed suitable software packages have been developed to assimilate such data. In particular, the Weather Research and Forecasting (WRF) model supports a data assimilation (DA) system with specific operators H_Z and H_v which allow to pass from any model atmospheric state x to the corresponding predicted radar reflectivity, $Z = H_Z(x)$, and radial velocity, $v_r = H_v(x)$. As known the analysis state x is found from a first guess or background state x_B, minimizing a cost function J which is a quadratic form of the analysis-background and the predicted-measured data difference. In this process of minimization, both the background error and the uncertainty of the observations play a key role.

Whereas some methods exist to compute the former, the latter is usually assigned taking as reference the measurement error and extending it by some factor to include the so called "representation error" (to account for the fact that the quantity measured by the instrument does not represent exactly the quantity computed by the model state through the operator H). Since the theory leading to a quadratic cost function, i.e. Gaussian errors, works better when the difference between observed and predicted values is at most of the same order of magnitude of their assumed standard error s, WRF-DA allows the user to set not only s but also an upper limit D = ns for the acceptance of the data to be assimilated. By default such a limit is set to n=5, so that, if retained, all the observations farther than 5s are discarded. Thus the choice of a suitable value for the standard error becomes of great importance: if s is too small, as usually happened taking it equal to the instrumental uncertainty, then it is highly probable that a large number of observations will be discarded; if it is chosen too large, then a large number of observations will be assimilated, but with a very low weight and, probably, with negligible effect. Alternatively one can fix s to a reasonable estimate and extend the tolerance limit, setting n to higher values, also permitting the assimilation of data farther away from the first guess value. The question of which strategy to follow becomes even more important for radar reflectivity, whose dynamic is usually high, spanning many orders of magnitude. If on one hand the instrumental uncertainties can be of a few dBZ, on the other hand the differences between observed and predicted values can reach tens of dBZ, especially where the model fails to predict a rain that actually happened. Unfortunately those are precisely the situations in which assimilation would be more useful for adjusting a model forecast. To overcome such a limitation, a dynamic assignment of uncertainty for the RADAR observations can be accomplished with a reasonable computational cost. This strategy consists of the following steps: at first a very large fictitious error, say 25 dBZ, is assigned to all the observations, so that none of them is discarded and the WRF-DA process performs a comparison between the observed Z and the corresponding $H_Z(x_B)$ reflectivity values, saving their differences $Z\text{-}H_Z(x_B)$ in a dedicated diagnostic file. Then the DA process is stopped and the differences is read by an external software, which provides to reassign all the observation uncertainties, setting them to the values $s = |Z\text{-}H_Z(x_B)|/n$. Finally a second WRF-DA process is launched, to produce the final analysis. In this way no radar reflectivity is discarded, and any observation is assimilated with the highest weight compatible with the acceptance limit D = ns and the instrumental error. This method has been successfully applied to a couple of case studies, for which the operational WRF model (without radar data assimilation) was not able to correctly predict the heavy rain actually occurred. The so obtained accumulated precipitation has been compared with the ones resulting from two others error assignment strategies, i.e. fixed *s* uncertainties with either D = 5*s* or D = *ns*, with *n* fixed large enough to ensure the assimilation of all the reflectivity observations.

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