An Empirical Radar Data Quality Function

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1. Introduction

The meteorological and hydrological modelling comminuties are increasingly using radar observations and place specific demands on the description of the corresponding data quality. A recent concerted effort has been the COST 717 Action Use of radar observations in hydrological and NWP model (Rossa et al. 2005). Several approaches have been proposed based on how significant the radar data quality control algorithms impact the observations (Friedrich et al. 2006; Fornasiero et al. 2006; Szturc et al. 2008). One element common to all these efforts is that a detailed knowledge of the radar systems is used to derive an error information, whereas some methods rely on extra information from complementary observations, such as disdrometers Berenguer and Zawadzki (2008) or a high-resolution rain gauge network Germann et al. (2006) which makes the task more demanding.

The fact that many NWP centres have recently taken into operations convection-permitting forecast models, many of which assimilate radar data, there is the need for a pragmatic approach to providing quality information in order to avoid that radar errors degrade the model's initial conditions and, therefore, its forecasts (e.g., Rossa and Leuenberger 2008). Such pragmatic approaches have been applied and can be as simple as parametrizing the radar data quality with range Jones and Macpherson (1997).

In this contribution a pragmatic and empirical radar data quality description is proposed to be used in radar data assimilation, more specifically for the latent heat nudging (LHN) scheme (Manobianco et al. 1994). In section 2 the data sets, the NWP, and two cases are briefly described, while section 3 is devoted to the formulation of the quality function. Results will be shown and discussed in section 4, and conclusions given in the final section.

2. Data sets, NWP model, and cases

a. Radar data

The Swiss Radar Network (SRN Germann et al. 2006) consists of three C-band Doppler radars providing full volume information every five minutes. The data are preprocessed and available on a cartesian grid with a mesh size of $2 \times 2\,km^2$ for the network composite.

The Veneto Radar Network (VRN) consists of two EEC single polarization C-band Doppler radars, one located on Mt. Grande a 470 m hill top 25 km southwest of the city of Padova, one at sea level close to the border between Veneto and Friuli in northeast Italy. Their data are post processed by the Hydrometeorological Decision Support System (Conway et al. 2007, HDSS). Here a number of quality control algorithms are applied and surface QPE is derived in the QPE-SUMS algorithm (Gourley et al. 2001). The QPE is available every 10 minutes.

b. The COSMO NWP model

COSMO-2 is the operational MeteoSwiss implementation of the high-resolution version of the non-hydrostatic weather forecasting model of the COSMO (Consortium for small-scale modelling) community presently operational at several European Weather Services (Doms and Schattler, 2002, Steppeler et al., 2003). The COSMO-2 model domain covers the Alpine arch (520 x 350 grid points, 60 vertical levels) and uses a horizontal mesh size of 2.2 km. Its forecasts are driven by the regional COSMO-7 model with 6.6km mesh size and covering central Europe, which in turn is nested in the global IFS model of ECMWF. The COSMO-2 model uses a data assimilation system based on a nudging technique (Schraff, 1997) for conventional observations from surface stations, radiosondes, aircrafts and wind profiler.

c. Radar rainfall assimilation

Radar surface rainfall observations are assimilated by the Latent Heat Nudging scheme (Jones and Macpherson 1997). The main principle of LHN is to correct the model's latent heating at each time step by a factor derived from the ratio of observed and model-estimated surface precipitation based on the basic assumption that the vertically integrated latent heating is proportional to the surface rain rate. This is accomplished by adding an extra term to the prognostic temperature equation, result-

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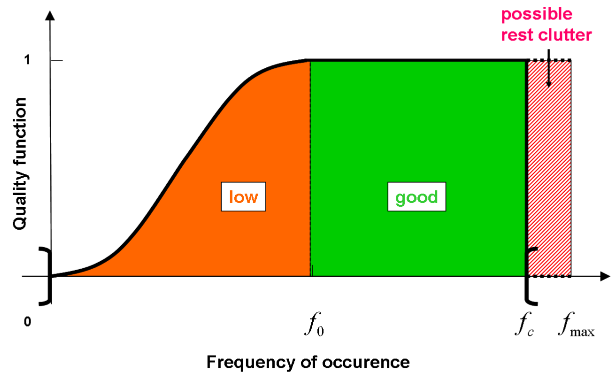


Fig. 1. Conceptual definition of the radar data quality function. Rest clutter identification is performed on the very high-frequency pixels, which then are set to zero. Pixels with frequency higher than f_0 are set to one, while the quality is lowered for frequencies below f_0. See text for further explanations.

ing in a gradual adjustment of the other fields according to the full, nonlinear model. The introduced change in buoyancy provokes an enhancement or dampening of the vertical velocity and the associated cloud and precipitation processes. The vertical shape of the applied forcing is taken from the model latent heating, ensuring consistency with the microphysical parametrisation. At each grid point with non-zero temperature increments, the specific humidity is also adjusted such that the relative humidity is conserved. Latent Heat Nudging has proven to work well in the kilometre-scale COSMO model for idealized and real convection cases (Leuenberger and Rossa 2007). When precipitation is treated as a prognostic model variable and is advected in all three space dimensions, a basic assumption of the LHN scheme is violated. Stephan et al. (2008) proposed a modified LHN scheme to take into account the spatial and temporal separation of the rate of change in latent heating and surface precipitation and make the LHN algorithm more compatible with the prognostic precipitation scheme of the COSMO model. This improved LHN scheme is part of the operational implementation of COSMO-2 and used for all experiments presented in this study.

d. Case studies

. In this section a brief description of the cases is given along with the impact of the LHN on the analysis, in order to be able to assess the impact of the quality function on the LHN analyses.

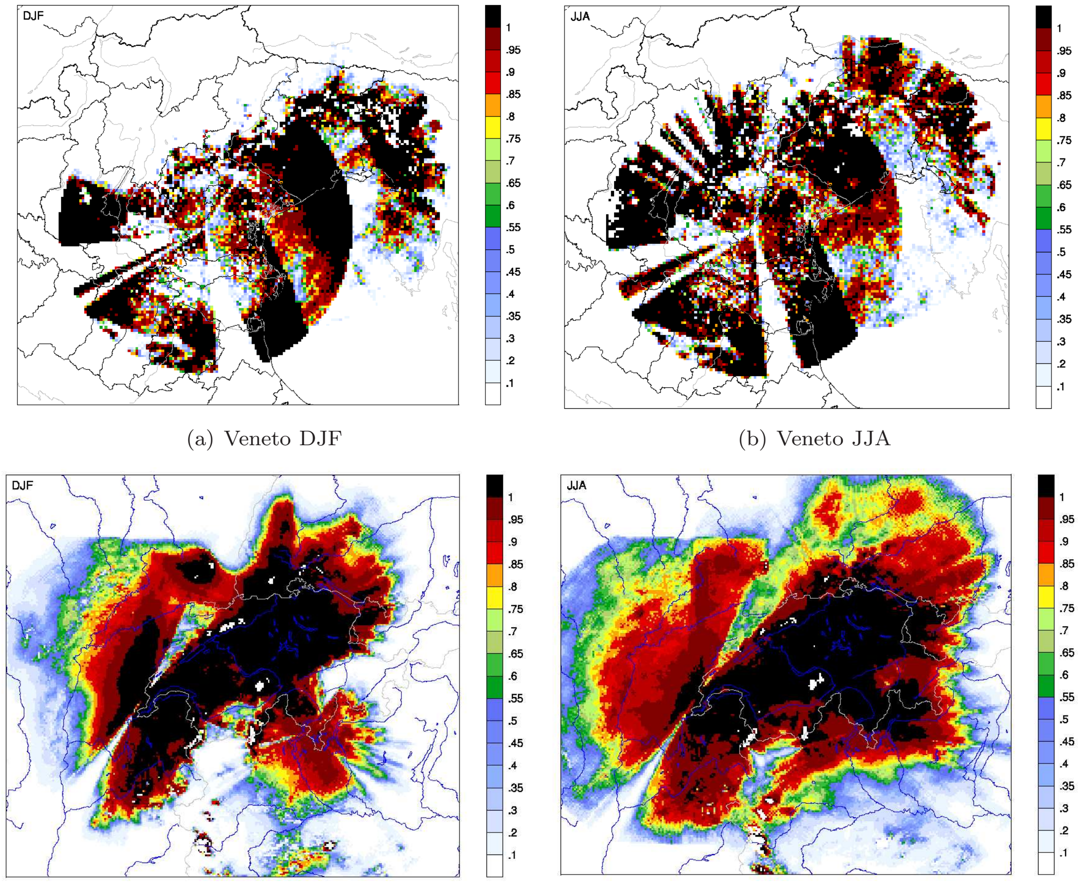
1) Veneto case 26 September 2007

This rainfall event was exceptional in terms of rainfall intensities and accumulations (up to 120 mm in 1 hour, 90 mm in 30 min, and 24 mm in 5 min), and overall accumulation 320 mm in 6 h and caused flooding of the urbanized area of Venice Mestre. A surface low located on the Gulf of Genoa was associated with an upper-level trough which advected cold air from Northern Europe towards the Alps and subsequently onto Veneto, giving rise to organized convective activity.

The COSMO-2 analysis cycle confirms the heavy precipitation but with incorrect timing and extension (Fig.3). A first of two passages took place in the morning hours and hit a much larger area. In the late afternoon the second passage brought even larger intensities over the region. The analysis cycle produced a local precipitation maximum which is quite close to the observed but, on top of that, a number of even stronger and larger maxima were simulated which were not observed (e.g. just east of Mestre over the coast line, and some 50 km northwest of Mestre).

Figure 3 panel b) shows that the latent heat nudging (LHN) of the Veneto radar data managed to reduce the incorrect precipitation to a large extent, for instance reducing values of more than 100 mm in the the area northwest of Mestre to under 40 mm (20 mm) for the greenish (blueish) colors, values that are in line with the rain gauge measurements (not shown). The highest accumulations simulated just to the east of Mestre were almost entirely suppressed in the LHN run. On the other hand, it successfully tiggers the precipitation in the area where it was observed with about the right accumulation.

In summary, the LHN has a very large impact on the simulation in analysis mode featuring a very efficient drying of the excess precipitation and excellent triggering of the observed convection. There is a clear response of the low-level wind and convergence field illustrating that the LHN method is able to modify the microscale circulation around the precipitation systems.



(a) Veneto DJF

(b) Veneto JJA

(c) Swiss DJF

(d) Swiss JJA

FIG. 2. Radar data quality function for VRN and SRN for winter and summer period.

2) SWISS CASE 11 AUGUST 2008

The case studied over the SRN domain is a less exceptional case of the passage of several frontal rain bands over Switzerland. On 11 August 2008 an extensive long wave trough was situated over Western Europe. An associated low pressure system over the Brithish Isles with a core of 990 hPa was associated to a warm and a cold frontal passage in central Europe on that and the following day. On 11 August in the afternoon, a first rainband associated with the warm front crossed Switzerland, causing up to 18 mm of precipitation. In the night the coldfront enterd the SRN domain from west and passed slowly over Switzerland during the 12 August. This coldfront led to heavy frontal and convective rainfall with sums up to 70 mm in northern Switzerland.

In this case, the overall effect of the LHN was to insert the main convective activity observed over northern Switzerland, along with a significant drying over the main Alpine crest in central Switzerland, where evident convective activity was suppressed (Fig. 4 panels a and b). Even on the minor precipitation peaks the LHN managed to improve the precipitation analysis.

3. Empirical radar data quality function

Simple, economical schemes for cloud-scale radar data assimilation, one of which is Latent Heat Nudging (LHN), have recently received considerable attention for deployment in rapid update cycles, and were reported to produce beneficial results (Ducrocq et al. 2002; Dixon et al. 2009, e.g.). There is, however, no explicit accounting of the observation quality in LHN, a fact which makes the scheme vulnerable, for instance to non-rain echoes which may be significantly amplified in convectively unstable environments (Rossa and Leuenberger 2008).

Another typical situation which can lead to problems in the assimilation cycle are areas in which the radar has a greatly reduced visibility or is 'blind'. Suppose that the model has precipitation in an area which are badly seen by the radar. Without accounting for this reduced radar quality the LHN scheme tries to reduce or suppress the

Table 1. Assimilation experiments for the assessment of the impact of the radar data quality function on the LHN scheme.

experiment	description	Swiss case	Veneto case
REF	without LHN	48h analysis	24h analysis
REF_R	with LHN, without quality function	starting	starting
REF_RQ	with LHN, with quality function	11 Aug 2008 00UTC	26 Sep 2007 00UTC

model precipitation by cooling the profile, which can induce subsidence. If this happens close to a boundary of the radar domain such a subsidence can act to produce an outflow boundary which, in turn, can create a low-level convergence able to trigger precipitation.

Motivated by Germann and Joss (2004) who pointed out the structural similarity of the long-term radar QPE accumulation with the visibility map of the radar, an empirical radar data quality function is proposed here based on a long-term frequency analysis of precipitation occurrence f, which counts for each radar pixel the number of times when precipitation is observed. The main idea is to attribute quality to these pixels as follows (Fig. 1):

- pixels which are seen too many times are likely to be rest clutter and are assigned $w(x, y) = 0$ for $f \geq f_c$;
- pixels which are regularly seen are likely to be of sufficient quality to be taken verbatim, i.e. $w(x, y) = 1$ for $f_0 \leq f \leq f_c$;
- pixels which are rarely seen are likely to be in blocked areas and are assigned $w(x, y) = g(f) \to 0$ for $f \to 0$;

The lag correlation of the time series for each pixel is found to discriminate clutter pixels from rain pixels, in that the decorrelation length is shorter for the former. This is used to identify plausible values of f_c. The function $g(f) = 1 - 1/(1 + e^{0.7f-4})$ is chosen such as to provide a smooth transition between the good and the still acceptable pixels.

In the perspective of updating such an analysis by adding the latest day while taking out the oldest in the data set, the length of the period should be long enough to avoid too large day-by-day variability, while it should be short enough to allow for at least seasonal differences. One-month periods proved to be rather short, while three-month periods seem more adequate. Figure 1 upper panels shows the results for the summer and the winter seasons for the Swiss radar network. It can be easily seen that the main and well known error prone areas are reproduced by the quality function, i.e. the scarse visibility in the valleys like the Valais and the Engadin, the cones due to nearby obstacles of the La Dole radar, the range effect in all three radars, as well as a number of small scale clutter-prone areas.

The seasonal variability is also plausible in that in summer the precipitation systems are higher-reaching than in winter so that they are seen at longer ranges in summer yielding better quality. In particular, in winter the quality at long ranges is reduced, the orographic blocking as well as the cone of the La Dole radar extending to the northeastmuch much more pronounced. The rest clutter pixels (white wholes) are remarkably stable and tend to be larger in winter than in summer.

For the Veneto radar network (Fig. 1 lower panels) the cones due to two closeby hill peaks are well visible in the quality function, as are the shielded areas behind the pre-Alpine chain to the north. The range effect, however, is inverted especially for the Mt. Grande radar, showing good quality at longer and reduced quality in large patches at shorter ranges. The lower quality regions close to the radar occur mostly over completely flat terrain and still require explanation. Also, there is a significant difference between the two radars of the network, with the Concordia Sagittaria radar exhibiting a frequency of occurrence which is significantly lower than for the Mt. Grande radar. This fact is unlikely to depend on differences in the precipitation climatology but is expression of differences in the performance of the two radars.

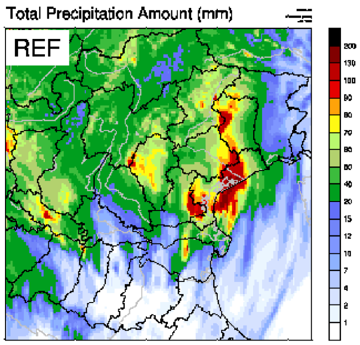
The seasonal differences are well in line with those found for the SRN. Most evident features include the longer ranges over the mountains to the north. Again, the maximum quality is found out to the border of the radar domain in summer.

4. Impact of the quality function on radar data assimilation

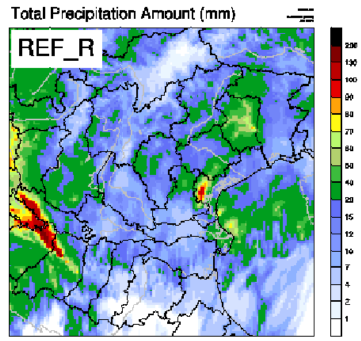
In order to assess the impact of the quality function on the LHN scheme assimilation experiments were run as listed in Tab. 1. In the following two subsections this impact is described for the cases presented in Section 3.

a. *Veneto case 26 September 2007*

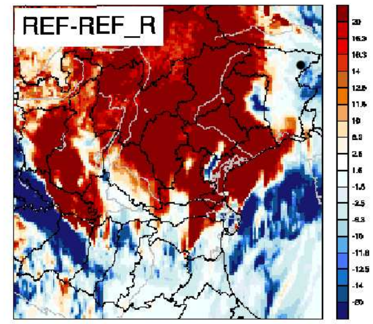
The main impact of the quality function in experiment REF_RQ as compared to REF_R is the reduced dipolar structure at the western border (Fig. 3 panels d and f) of the radar domain and, most prominently, the differences in the blind cones of the Mt. Grande radar. In fact, here the



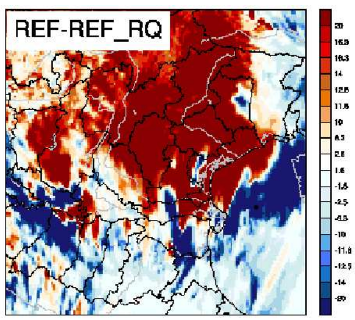
(a) REF



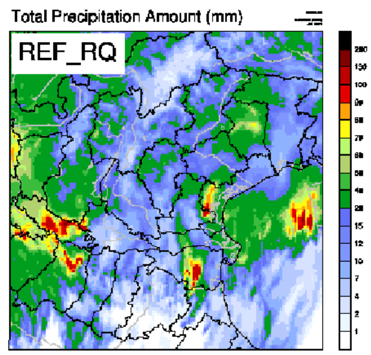
(b) REF_R



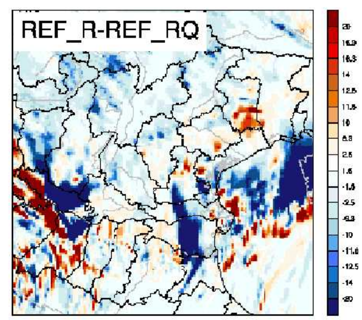
(c) REF-REF_R



(d) REF-REF_RQ



(e) REF_RQ



(f) REF_R-REF_RQ

FIG. 3. 24-hour precipitation accumulation for Veneto case 26 September 2007 00 UTC the experiments listed in Table 1 (panels a, b, and e), as well as the corresponding differences (panels c, d, and f). The arrangement of the panels has been chosen to help the comparison of the accumulation and their differences. The accumulation classes are 1, 2, 4, 7, 10, 12, 15, 20, 40, 50, 60, 70, 80, 90, 100, 130, 200 mm, while the accumulation differences are -20, -14, -12.5, -11.8, -10, -6.3, -2.5, -1.6, 1.6, 2.5, 6.4, 10, 11.6, 12.5, 14, 16.3, 18.3, 20 mm.

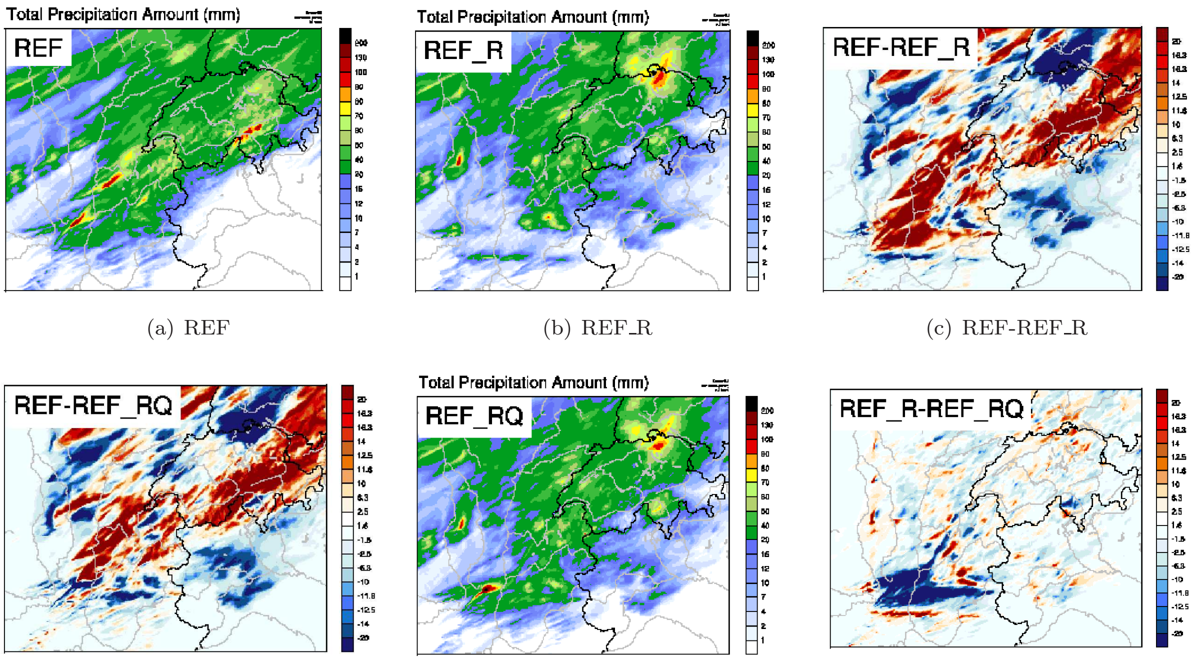
quality function allows for the model precipitation to stay in the simulation. More subtly, and due to the fact that the quality function of the Veneto radar network is one in this area, the cone constitutes a border between the areas where the radar is assigned zero and full quality. In this case, the erroneous model rainfall is suppressed by inducing subsidence, but not in the cone, so that the resulting low-level outflow produces a convergence and, therefore, enhanced rainfall. This effect is evident in the difference plots REF - REF_RQ and REF_R - REF_RQ (Fig. 3 panels c and f).

b. Swiss case 11 August 2008

The most evident feature of the LHN run REF_R for this case is the artificially looking structure in the south-western border of the SRN domain (Fig. 4). Infact, the SRN quality is close to zero in this area due to a visibility cone of the La Dole radar and a progressive range effect. The model analysis simulated significant precipitation in this area which the LHN sucessfully reduced. Just outside the SRN domain, on the other hand, there are precipitation bands along the border. Again, these are compatible with the mechanism discussed above. The quality function recognizes this as an area in which the radar data should not have a strong impact on the model. Accordingly, the run with the quality function REF_RQ strongly reduces the artifacts, both within the radar domain and just across its border. On the rest of the SRN domain the quality function has a minor impact on the LHN scheme, as the model did not produce preciptiation in areas of low radar data quality.

5. Summary and discussion

In this contribution a novel, yet simple, empirical quality description of radar-derived quantititive precipitation estimates (QPE) was proposed. It was constructed using a long-term frequency of occurrence of precipitation analysis. Hereby frequent (rare) occurrence of precipitation is assessed as 'good' ('bad') quality, while rest clutter was



(a) REF (b) REF_R (c) REF-REF_R

(d) REF-REF_RQ (e) REF_RQ (f) REF_R-REF_RQ

Fig. 4. As in Fig. 3 but for the Swiss case 11 August 2008 and 48-hours accumulation period.

identified and assigned quality zero. How and for what frequencies the quality descreases from one to zero is tunable to some extent, and can be conceived as an overall weight one subjectively intends to assign to the radar observation. The empirical radar data quality function proposed with a moving 90-day accumulation window has the following characteristics:

- it is conceptually simple and easy to construct;
- it reproduces the main error structures and is, therefore, a plausible way to account for the average problems in radar QPE;
- it has a sufficiently smooth day-to-day evolution for an Alpine climate;
- it accounts for the seasonal variability of the radar QPE;
- it is, to some extent, generic, in that it can 'easily' be evaluated for different radar networks (here for two) and, potentially, also for heterogeneous networks in that it does not rely on specifics of the radar processing.

The impact of the proposed quality function on the LHN assimilation has been found to be beneficial in that it:

- reduces artifacts which can be induced close to boundaries of the radar domain;
- constitutes an additional means to reduce rest clutter and its potentially harmful impact on the analysis;
- does not artificially interfere with the model precipitation in areas where the radar is (almost) blind;

The limitations of such an empirical radar data quality description are recognized in that:

- it is empirical and not physically based and does, therefore, describe the effects of the error sources without taking them into account explicitly;
- it is an average, rather than a instantaneous quality description and thus accounts for average errors, rather than actual real time errors;
- the present formulation will yield good (bad) quality in case of precipitation occurrence much higher (lower) than climatology, hence not reflecting effective radar data quality;
- the quality is described as a weight between 0 and 1, i.e. an index, rather than in units of the precipitation and is, therefore, not directly applicable to statistical data assimilation schemes as ensemble Kalman filters, for instance, nor does it, in its present form, account for error covariances.

In a radar network single radars may be missing occasionally, or for longer periods, a fact which is not easily accounted for in the presented approach. A solution to this problem could be performing the analysis on the single radars and then composited following the compositing procedure of the network. Alternatively, the quality information thus obtained could be used in support of the compositing method, preferring the radar with the best quality for a given pixel.

An obvious extention of this work is to apply the quality function to longer assimilation periods and assess its impact more systematically. Also, its impact on the free forecasts has yet to be addressed. In view of the OPERA efforts to make radar data available on a European scale this approach could be a candidate method to pragmatically deal with the inevitably very heterogeneous radar data quality in the framework of assimilation methods like LHN.

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