Definition of Product Quality Descriptors

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1 Introduction

The objective of OPERA is to harmonize and improve the operational exchange of weather radar information between National Meteorological Services. In order to fulfill this objective, a consistent set of data of agreed quality has to be exchanged. Current radar systems vary in their standards of operation and, therefore, information on the quality of the exchanged radar data is of crucial importance. OPERA aims at the production of a set of standards defining those aspects of data collection from radars, including quality, that affect the proposed products for international exchange. The work plan of OPERA foresees for working group 1, which is covering the “Production of radar data”, a project to “develop and standardize appropriate quality control procedures” (project 1c). This project has been split into three subprojects:

1. Description of the currently applied quality-ensuring procedures (see working document WD_9_99)

2. Set-up of a library (database) describing calibration methods used for each radar (in preparation)

3. Definition of a list of quality descriptors (this document)

The purpose of the last subproject (1c3) is to come up with a review of how the physical problems of the observation technique impinge on our ability to accurately measure the observed quantity. It will propose ways to account for inherent limitations in the technique like clutter and beam shadows as well as the variable behavior of the technique for things like bright band and anomalous propagation. It should also deal with the variable performance of the equipment and algorithms used to generate different data products. Ultimately, a set of appropriate BUFR-parameters to encode the current and recommended/standardized quality information into the BUFR-message for international exchange has to be defined.

Apart from being of general interest, the quality descriptions indicators can be used during the production of radar composites and the assimilation of radar data in hydrological and atmospheric models. This subproject, therefore, has an evident connection with the activities of COST-717 action on “Use of Radar Observations in Hydrological and NWP Models”.

In this subproject a review of all aspects of “quality” and how certain performance factors impinge on the “quality” of the final products has been performed. It was recognized that there are different factors that have bearing on performance. There are, for instance, static factors that relate to permanent conditions. These can be global, and relate to the fundamental technique (deficiencies in choice of operating frequency, i.e. attenuation, etc.), and/or they can relate to the particular installation (local interference, both physical and electrical, and the particular hardware employed). There are also changing factors that relate to variable performance of the equipment and the ability of the technique to cope with changes in the environment that it is trying to sample. These can be long-term trend type changes or very rapid dynamic changes.

From the review of the quality aspects, quality descriptors are deduced for basedata, surface rainfall product, and the wind profile product. The quality descriptors are divided into static, global dynamic, and local dynamic descriptors. “Global” refers to descriptors that are valid for all data points, and “local” refers to descriptors which are given per pixel or altitude. “Static” is used to denote descriptors that are constant and only depend on the radar equipment, radar siting, or product algorithm, while "dynamic" descriptors vary for each observation.

From the obtained quality descriptors a list of proposed BUFR quality descriptors is deduced. Only global static quality descriptors are proposed, because it is not feasible to implement more complicated quality description within the lifetime of the current OPERA program.

2 Review

In this chapter we will enumerate the various components that directly or indirectly may influence the quality of the measured and processed radar data. Brief descriptions of the various topics are given and argumentations for the definition of quality related descriptors are illustrated.

2.1 Radar Acquisition System

This section will handle the setup operation of a radar measuring station as well as the components of a radar system starting from the transmission of the electromagnetic microwave pulses up to the building of the observation value (range gate) in form of a digital quantity.

2.1.1 Siting

The location where a radar station is placed is selected upon many different criteria like logistic aspects, political considerations and observation quality for a specified target of users. This last aspect will be taken into consideration in our context. A site can be selected in order to maximize the coverage of a given territory where a network of radar stations exists or to best observe a predefined region for the prevention of hydrometeorological and geological risks. The geographic coordinates and the altitude of the radar station characterize in a fundamental way the station site. A more particular and very helpful indication, which is strongly related to the quality of the observed data, is the occultation map, which describes the obstacles surrounding the horizon of a radar antenna. This could be expressed as a set of horizon maps, one for each nominal elevation of the operational scan strategy, delivering range-azimuth value pairs where the antenna beam axis is blocked by obstacles (non meteorological objects).

2.1.2 Radome

The presence of a radome (radar dome) and his "goodness" (e.g. surface quality, degree of cleanness, age, etc.) contribute to the quality of the signal (attenuation). The radome can, affect the radar beam in several ways: via absorption and phase shifting by the dry radome wall, via scattering from the radome joints, via the geometrical distribution of the radome joints, and via absorption by rain or snow on the radome (Manz et al., 1998). It is very complicated to describe in a quantitative way the effects of a radome of given characteristics being dependent from many parameters (like the wind direction, the precipitation intensity, the degree of wetness of his surface, etc.) so that we suggest, for the time being, to just indicate if a radome is present or not.

2.1.3 Wavelength

The wavelength λ influences three important parameters:

- The attenuation (greater losses with shorter λ)
- The sampling volume by a given antenna size (increases with λ^2)
- The reflectivity from hydrometeors (decreases with λ^4)
- The clutter intensity (increases with λ^4)

Again this is an entity very complicatedly related to the goodness of the data so that it should not be directly taken as a specific quality indicator.

2.1.4 Antenna

The antenna gain, beam width, radiation characteristics etc. influences the degree of goodness, sharpness (tangential resolution in space) and accuracy of the performed measures but these parameters will not be directly taken as quality indicators.

2.1.5 Alignment

In order to ensure an accurate geographical referencing of observations two main aspects should be covered: the correctness of the antenna pointing in absolute and relative way. The absolute antenna alignment should be checked periodically e.g. during actions of preventive maintenance. The relative alignment accuracy depends the system characteristics and mainly concerns the precision attainable when a predefined antenna elevation is to be actuated. The date of the last performed check on alignment is taken as an indirect indicator of the data quality.

2.1.6 Transmitter

The transmitter power is a specific characteristic of radar equipments. Together with other quantities it defines the sensitivity of the instrument at a nominal distance from the antenna (typically 100 km), which is the ability to detect a minimal precipitation rate at such distance. This is not a quality related quantity but its stability in time indicated by a typical drifting value could be. With the state of the art of modern technology the drift value is so low that usually it will not be taken into consideration. Due to short time defects the transmitted power can be out of tolerance so that an indicator of this feature can be given as related to the quality.

2.1.7 Receiver

The noise level, which is a typical characteristic of the receiver part of the radar hardware, influences the value of the minimum detectable signal. It will not directly be taken as quality indicator but if its intensity is higher than a predefined threshold value than a flag influencing the overall quality index should be issued.

2.1.8 Waveguide losses

Knowing the transmitted power and recording the reflected power in a given point of the signal circuit it is possible to check if the power attenuation along the signal path is within tolerances when the nominal value of the total losses is known. A flag indicating that the total waveguide loss is below a predefined threshold can be used as quality indicator.

2.1.9 Repair and preventive Maintenance

The interventions at the radar site should be indicated by means of the date when those operations have been performed the last time; it should differentiate between checking actions with possible adjustment of the levels causing minor effects and repair where components are changed with possible major consequent changes in the quality of the signal. If data products are generated during such interventions a particular indicator should be given.

2.1.10 Calibration

Calibration has to compensate for short-term variations of the radar equipment, i.e., to provide stable conditions for precipitation measurements. It is the basis for long-term adjustments with rain gauges. Calibration may also be needed after component replacement to ensure that no relative change in sensitivity has occurred. Absolute calibration is neither required nor easy or cheaper to be achieved. Relative accuracy defines our ability to reproduce in the future the values we presently measure. The date of the last calibration can be indirectly associated to the degree of confidence of the measurements and thus to their quality. With high-quality hardware and thorough calibration, it should be possible to keep the absolute calibration error of the radar equipment below 2 dB (30% of equivalent rain rate) (Smith, 2001).

2.2 Environment

The quality of weather radar data is determined to a large extent by the environment of the radar. Finding a suitable location for weather radar in mountainous or urban areas is rather painstaking. The first measure for the quality of a radar site is a so-called occultation map showing the limiting range or lowest usable elevation as a function of range. In the framework of the COST-73 action an European map of radar coverage has been produced using these occultation maps (Newsome, 1992). The height of the antenna feed (above the surface) is an important parameters as well: it determines both the coverage of the radar and the quality of the precipitation estimates. The presence of permanent clutter and the probability of anomalous propagation clutter are also important factors. Mountains are notorious for their permanent clutter, and a nearby sea or frequent passages of fronts can result in a high probability of anomalous propagation clutter. Permanent clutter can be removed using a clutter map which is recorded under dry weather conditions. Anomalous propagation clutter can be suppressed/removed based on signal fluctuation statistics or Doppler filtering.

2.3 Basedata

This section will handle the components of a radar system starting from the observational value up to the generation of the basic data, which is generally denoted, as polar or elevation data. In the NEXRAD terminology “data in spherical coordinates provided at the finest resolution available”.

2.3.1 Scan strategy

The scan strategy is the collection of the principal parameters related to the operated volumetric observation procedure. For the sake of simplicity we will consider following parameters as pertaining to the scan strategy (we assume that the antenna rotates 360° in azimuth for each single elevation):

- Elevation sequence
- Azimuthal rotation speed (eventually elevation dependent)
- Time positioning of antenna elevation (may be elevation dependent)
- The pause between successive scans, or duration of scanning scheme (Ending minus starting time)

Each radar system has his own scan strategy dictated by various motivations like the field of use of the radar data or the environmental conditions (mountainous versus flat land). For example one radar station can have the task to scan the atmosphere as widely, fast, or accurately as possible. The scan strategy together with other parameters like the spatial dimension of the illuminated volume for the range cell and the timing of the scan influence the product quality, which is specific to each product.

2.3.2 Signal processing

Range bins of the same range gate are averaged in order to reduce the influence of the signal fluctuation for the reflectivity; the number of averaged bins is related to the accuracy of the estimated reflectivity (Rosa Dias, ????).

2.3.3 Aliasing

Multi-trip echoes may occur by a given pulse repetition frequency (PRF) beyond the maximum unambiguous range. The PRF should therefore be known in order to judge the potential severity of range aliasing problems. The tendency to set the PRF to a low value in order to achieve a large unambiguous range, which is high enough, is often counterbalanced by the desire to keep the PRF as high as possible to get a high Nyquist velocity (Doppler aliasing). Details on aliasing are given in section 2.5. As a quality indicator a flag marking the correction for range and/or velocity aliasing should be foreseen.

2.3.4 Clutter treatment

Ground echoes: it is not easy to quantify the quality of clutter suppression in an objective and intersystem comparable way. The residual clutter left after having applied clutter removal algorithms can be qualified for example by analyzing radar data produced under dry weather conditions. We propose to give following indicators:

1. The number of clutter contaminated pixels in percent of the total number of pixels present in the product image
2. The mean value of the intensity of all clutter contaminated pixels

Side lobes, highly depending from the radiation characteristics of the antenna are also a source of potential residual clutter that fluctuate in time more heavily than that originated from the main lobe. The side lobe rejection factor with respect to the main lobe is related to the data quality.

Anomalous propagation: this kind of clutter contamination can be treated analogous to ground clutter. The potential of his occurrence can be modeled if the vertical profile through the atmosphere for temperature and humidity parameters is known with enough vertical spatial resolution. Gradients in the refractivity index of radar microwaves can be taken as a good indicator of the potentiality for anomalous propagation.

2.3.5 Attenuation

There are two main types of attenuation effects for a propagating microwave signal: the radome damping and the signal energy absorption and scattering due to the interaction with the water vapor and atmospheric aerosols (gaseous attenuation). As quality indicator we can specify a flag that marks the use of a corrective factor to compensate for the gaseous attenuation in addition to those proposed in the two sections concerning the "Radome" and the "Wavelength".

2.4 Surface Rainfall Product

Reflectivity values as observed at a certain range and height have to be converted to rainfall rates at ground level. This conversion introduces errors in the resulting rainfall map because of the variability of the Z-R relationship, bright band effects, vertical reflectivity profile and incomplete beam filling.

2.4.1 Z-R relationship

The variability of the Z-R relationship originates from differences in the droplet-spectrum which depends on the precipitation situation and climatological circumstances. Many different Z-R relationships of the general form $Z = aR^b$ with Z in mm^6/m^3 and R in mm/h can be encountered in literature (Collier, 1989), but $Z = 200R^{1.6}$ is widely accepted. The parameters of the Z-R relationship (a, b) should be given in BUFR message.

2.4.2 Vertical Profile of Reflectivity

Gradients in the vertical reflectivity profile (VPR) are believed to be the major source of errors in radar measurements of surface rainfall. Possible causes of strong vertical reflectivity gradients are interaction between droplets, updrafts and downdrafts, evaporation and accretion of drops under the cloud base, and melting precipitation (bright band). As a result, the observed reflectivity will depend on the beam-height due to strong reflectivity enhancement at the melting layer (bright band), reflectivity reduction when the radar beam samples the snow region, and non-detection at far ranges where the radar beam overshoots the cloud tops.

Several algorithms have been developed for conversion of radar volume data to rainfall maps that use vertical reflectivity profile correction. Generally, averaged vertical reflectivity profiles, which are obtained from high-quality and high-resolution data at short ranges, are used to extrapolate a reflectivity measured at a certain range and height to a corrected on-ground rainfall intensity. A very important quality indicator for surface rainfall products is the height of the radar beam above the surface, and in addition a flag indicating whether a VPR correction has been performed and possibly the applied correction factor should be defined.

2.4.3 Bright Band

The bright band, a distinct feature of the VPR, with its vertical extent of less than 300 meters is only a disturbing factor at short ranges ($<$65 km) where the radar beam is narrow enough to resolve it. Methods for correction of the bright band enhancement use, for instance, NWP output (height of melting layer) or identification of the bright band in the vertical profile of reflectivity. It should be indicated when a bright band correction has been applied.

2.4.4 Gauge adjustment

To keep the radar rainfall estimates as accurate as possible, several operational radar systems are adjusted using rain gauge measurements on a regular basis. Kitchen and Blackall (1992) have recognized that adjustment methods using hourly rain gauge accumulations can introduce representativeness errors due to small scale structures present in the rainfall field. In addition, differences in timing and location can occur between the precipitation observed at high-altitude by radar and that by the on-ground rain gauges. These errors can be significant, i.e., up to 150 % for the representativeness errors, and have to be separated from possible biases in the radar rainfall estimation using long-term averages or "mean-field" bias adjustments (Fulton et al., 1998). Several different techniques for adjustment of radar rainfall estimates to rain gauge accumulations are currently employed (Michelson and Koistinen, 2000; Harrison et al., 2000). For surface rainfall products, the application of a gauge adjustment scheme, the adjustment factor, and the number of rain gauges used for this adjustment should be indicated.

2.5 Wind Profile Product

2.5.1 Aliasing

Because a Doppler radar uses phase differences to determine the radial velocity, there is a maximum velocity that can be determined unambiguously. This maximum velocity is called the Nyquist velocity and it can be expressed as:

$$V_{Nyquist} = \frac{\mathrm{PRF} \cdot \lambda}{4} \tag{1}$$

where PRF is the Pulse Repetition Frequency of the radar pulses and λ is the wavelength of the radar (5 cm for C-band). The timelag between two successive radar pulses, and thus the PRF, also determines the maximum range that can be resolved unambiguously. This leads to the fundamental equation for the maximum (Nyquist) range and maximum velocity of a Doppler radar:

$$R_{Nyquist} \cdot V_{Nyquist} = \frac{c \cdot \lambda}{8} \tag{2}$$

where c is the speed of light. For measurements with a Doppler radar, a trade-off, therefore, has to be made between the maximum velocity and the maximum range. Velocity aliasing can usually be identified in radar images by detecting abrupt velocity changes of about $2 \cdot V_{Nyquist}$ between neighboring measurements. In this case, the basic assumption is that the true wind field is sufficiently smooth and regular; this is true for the greater part of the weather situations with the exception of mesocyclones, tornado vortices or highly sheared environments.

Aliasing problems can largely be circumvented by applying different measurement techniques, like dual-PRF or staggered PRT (Pulse Repetition Time). Many operational Doppler radars in Europe have the capability of using the dual-PRF technique. During a dual-PRF measurement, radial winds are measured with alternating high and low PRFs. By combining the measured velocities at low and high PRF, the maximum unambiguous velocity can be extended by about a factor of three.

To be able to interpret Doppler velocity data information on the applied PRF(s) and on the measurement technique, e.g., single-PRF, dual-PRF, staggered PRT, should be given in the BUFR message. Furthermore, (additional) de-aliasing during post-processing of the velocity data or calculation of the wind profile should be indicated.

2.5.2 Clutter

Radial wind measurements can be heavily affected by normal or anomalous propagation clutter. Clutter signal can be suppressed to a large extent from the reflectivity and radial wind data by reducing the echo power around zero radial velocity using discrete filtering techniques in the time or frequency domains. All operational Doppler radars apply this kind of filtering before the radial velocity is determined. For a complete discussion on the problem of the bias introduced in the radar wind spectrum due to the clutter and clutter-suppression algorithms, the reader is referred to Seltmann (2000).

To assess the a-priori quality of wind profiles, the application of Doppler clutter filtering and the rejection of radial wind close to zero should be indicated.

2.5.3 Birds and actively-flying insects

Non-hydrometeor targets such as insects and birds are detected by (Doppler) radar as well. While some insects can provide a help in defining the boundary layer wind, birds and actively-

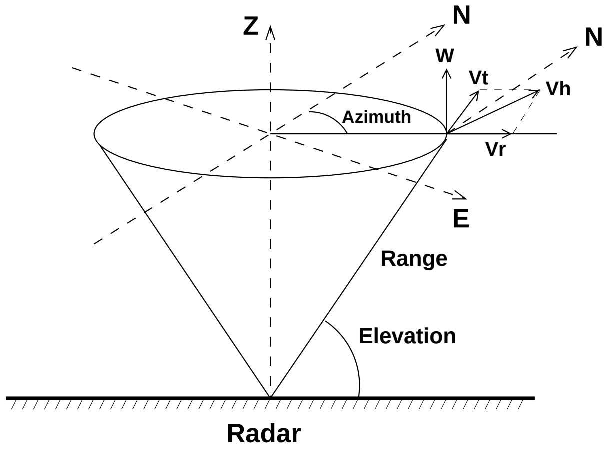

Figure 1: Radar geometry for measuring wind profiles.

flying insects are a serious problem for velocity retrieving algorithms (Koistinen, 2000). Erroneous wind data due to birds can often be recognized by inconsistency of the velocity data. The application of a bird-wind rejection algorithm should be indicated and otherwise the likeliness of bird contamination and/or preferred azimuths of migrating birds should be listed.

2.5.4 Profile retrieval

Wind profiles can be obtained from single-site radar data under the assumption of a linear wind model. In this model the wind in the vicinity of the radar (at the origin) is expressed as:

$$U(x,y,z) = u_0 + x\frac{\partial u}{\partial x} + y\frac{\partial u}{\partial y} + (z - z_0)\frac{\partial u}{\partial z} \tag{3}$$

and likewise for $V(x,y,z)$ and $W(x,y,z)$. Using this linear wind field, the radial wind can be calculated as a function of range, azimuth, and elevation. For a uniform wind field this results in:

$$V_{radial} = u_0 \cos\theta \sin\phi + v_0 \cos\theta \cos\phi + w_0 \sin\theta \tag{4}$$

When Doppler radar data is displayed at constant range and elevation (θ), the radial wind as a function of azimuth (ϕ) will have the form of a sine. The wind speed and direction can be determined from the amplitude and the phase of the sine, respectively. This technique is called Velocity-Azimuth Display (VAD), and it was introduced by Lhermitte and Atlas (1961) and Browning and Wexler (1968). The radar geometry used to measure these volume scans is shown schematically in Figure 1.

Instead of processing, for each height, a single VAD or a series of VADs, one can also process all available volume data in a certain height layer at once. This so-called Volume Velocity Processing technique (VVP) has been introduced by Waldteufel and Corbin (1979). Using equation 3 of the linear wind model, the radial wind can be calculated for all points within a layer centered at height z_0. Via a multi-dimensional and multi-parameter linear fit, the parameters of the linear wind field can be extracted. The VVP technique is typically applied to thin layers of data at successive heights to obtain a wind profile.

For wind profile products, the retrieval technique used to extract the wind profiles from the volume data, e.g., VAD, EVAD, or VVP, and the maximum range used for profile retrieval should be indicated in the BUFR message. Furthermore, quality indicators resulting from the retrieval of the wind at each height, like the number of valid points, the chi-square of the fit, standard deviations of wind speed and direction, are useful. Finally, the quality of the wind profiles is different for clear air, stratiform precipitation, or convective situations. The median reflectivity at each height could be used to indicate the meteorological situation.

3 Proposed Quality Descriptors

The proposed quality descriptors have been divided in the following way:

- Static descriptors. These indicators remain unchanged during most of the time. They are not influenced by changing external factors like environmental parameters, e.g., the weather
- Dynamic global descriptors. These indicators are time and situation dependent and thus they can change from one product to the following in time. They are, however, considered valid during a whole scan sequence and are associated to all data points contained in a given product.
- Dynamic local descriptors. These indicators are also time and situation dependent. In addition, these indicators may change within a given product from one data point to the next one.

3.1 Static descriptors

These indicators are characteristics of the radar station and remain unchanged during most of the time; they are also not influenced by external factors like environmental parameters (e.g. the type of weather) so they are defined of “overall” type.

3.1.1 Base data (polar volumes)

Siting:	Geographical position and altitude of antenna feed
	COST-73 Occultation diagram (Newsome, 1992)
Equipment:	Flag marking compensation for radome attenuation
	Flag marking the compensation for range attenuation
	Mean Frequency of radar
	Antenna 3 dB beam width
	Side lobe suppression factor
	Accuracy of elevation
	Accuracy of azimuth
	Type of receiver: coherent, coherent on receive, non-coherent
	Dynamic range of receiver
	Minimum detectable signal
	Radar constant
	Range-gate length
Maintenance:	Date of the last electronic calibration
	Date of the last alignment check
	Date of the last maintenance or repair intervention
	Table marking status of radar system
Scanning strategy:	Elevation sequence
	Time increments relative to start of first elevation
	Azimuthal antenna speed
	Pulse Repetition Frequencies (high and low)
Signal processing:	Maximum processed range
	Number of averaged range-gates
	Number of integrated/averaged pulses
	Table indicating the type of clutter treatment

Note that the radar constant is defined as the difference between reflectivity factor in dBZ at 100 km and transmitted power in dBm.

3.1.2 Surface Rainfall Product

The quality descriptors are intended for instantaneous surface rainfall product. For accumulated surface rainfall additional quality descriptors may be needed. Most of the quality descriptors defined for the base data can also be used for the surface rainfall product.

Z-R:	Coefficients (a, b) of Z-R relationship
Height:	Target height of CAPPI used for surface rainfall estimation
VPR:	Table indicating applied VPR correction method
Adjustment:	Table indicating gauge adjustment method applied

3.1.3 Wind Profile Product

For the definition of the quality indicators for Weather Radar Wind Profiles, the specification for WRWP products by Galli et al. (1999) is taken into account. Most of the quality descriptors defined for the base data can also be used for the wind profile product. Especially the type of clutter treatment is of importance for the wind profile product.

Method:	Table with Doppler wind calculation methods
Velocity range	Lowest estimable radial wind, without clutter
	Highest estimable radial wind, unambiguous velocity
Volume:	Inner radius of measured volume
	Outer radius of measured volume
Birds:	Table with “bird” removal methods

3.2 Dynamic global descriptors

These indicators are time and situation dependent and thus they can change from one product to the following in time. They are however considered valid during a whole scan sequence and are associated to all data points contained in a given product so that they are defined as “global”.

3.2.1 Base data

Hardware:	Transmitted power (out of tolerance flag)
	Receiver noise (level too high flag)
	Waveguide losses (too high flag)
Scanning scheme:	Flag marking the completeness of the scanning sequence
Hardware:	Number of averaged range bins
Clutter:	number of clutter contaminated pixels
	mean value of the intensity of all clutter contaminated pixels
	side lobe rejection
Anaprop:	Probability of anaprop from refractivity gradient

3.2.2 Surface Rainfall Product

Gauges:	Number of gauges used for gauge adjustment
FactorV:	Maximum VPR correction factor
FactorG:	Maximum gauge adjustment factor

3.3 Dynamic local descriptors

These indicators are also time and situation dependent. In addition, these indicators may change within a given product from one data point to the next one so that they are defined as “local”.

3.3.1 Surface Rainfall Product

Height:	height used for rainfall estimation at this location
FactorV:	VPR correction factor
FactorG:	Gauge adjustment factor

The following proposition is based on the internal flags to be used at Météo France (Gueguen and Urban, 2002). Nevertheless, to accommodate the different practices of the OPERA members, the addition of complementary flags is proposed.

First we give some basic information about the pixel.

- What was the elevation of the beam for this pixel ? This indicates actually the altitude of the measurement. We can have a luxury solution, where it is an index in the table of the elevations used for this radar (to be given elsewhere by another BUFR descriptor). This index needs at most 5 bits of data. We can also have a cheap solution, where on 2 bits we simply code four class of altitudes, for example:

  1. Below 2000m
  2. Between 2000m and 4000m
  3. Between 4000m and 6000m
  4. Above 6000m

- Status of the pixel. This indicates if the data is :

  1. the raw data
  2. a correction of the raw data by augmentation
  3. a correction of the raw data by diminution
  4. a reconstituted data

  So this is 2 bits of information.

For the moment, we have consumed 7 bits of data (4 in the cheap case). The following depends of the status of the pixel flag. For more details, see document “Quality flags for local radar and composite images to be exchanged internationally” by Gueguen and Urban (2002).

3.3.2 Wind Profile Product

Scanning:	Antenna azimuthal speed
	Pulse Repetition Frequency (PRF)
	Pulse width
Birds:	Bird contamination likely or not
	Preferred azimuths of migrating birds
Retrieval:	Number of valid points
	Flag for re-run without outliers
	Reflectivity factor in retrieval volume
	Spectral width in retrieval volume
	Chi-square of retrieval
	Standard deviation of wind speed
	Standard deviation of wind direction

4 Recommendations

It is highly recommended to include in the BUFR messages both the static descriptors and dynamic global descriptors for base data quality. The implementation of the dynamical descriptors in the operational processing will, however, not be straightforward because it requires real-time extraction and conversion to BUFR of system parameters.

For the surface rainfall products, a number of flags (both static and dynamic) should be included in the BUFR messages which refer to the application of several processing steps, like VPR correction and gauge adjustment. Apart from the processing, the quality of surface rainfall products is highly determined by the height above the surface of the radar observation. The height of the radar observation can be made available in several ways:

1. by reconstruction from elevation and range. For this, the height and geographical position of the antenna feed and the elevation sequence used to collect the base data need to be provided.

2. by sending height maps, visibility/occultation maps, and ground clutter maps in BUFR format along with the precipitation product on a regular basis, for instance once a month.

3. by inclusion of a quality indicator for each pixel in every surface rainfall product (Météo France model). This quality indicator indicates for each pixel the height of the observation and the presence of clutter.

The options have been listed in order of increasing effort and data transmission load.

For the interpretation of radar wind profiles knowledge on base data (elevations, PRFs, etc.), the retrieval algorithms used, and the quality of the fit of the wind model is a pre-requisite. The wind profile BUFR message should contain static information on the wind profile retrieval algorithm, the elevation sequence, and the maximum range. For each wind vector, dynamic information on the quality of the data and model fit (see previous section). Finally, bird contamination is a serious problem for radar wind profile retrieval. Flags indicating the type algorithms used to remove migrating bird contamination should be included in the BUFR messages.

5 Proposed BUFR descriptors

In this section the BUFR quality descriptors are listed for the base data. surface rainfall, and wind profile products. The table entries corresponding to BUFR descriptors referring to tables are listed below.

5.1 Base data

A list of the proposed quality descriptors of radar base data is given.

F	X	Y	Element name	Unit	Scale	Reference	Width
0	05	002	Latitude (coarse accuracy)	Degree	2	-9000	15
0	06	002	Longitude (coarse accuracy)	Degree	2	-18000	16
0	07	001	Height of station	Meter	0	-400	15
1	03	000	Delayed replication of 3 descriptors				
0	31	001	Replication factor (Num. azimuths)				
0	02	135	Antenna beam azimuth	Degree	2	0	16
0	02	135	Antenna elevation (minimum)	Degree	2	-9000	15
0	06	021	Distance (Maximum range)	m	-1	0	13
0	25	015	Radome attenuation correction	Flag	0	0	2
0	25	012	Range attenuation correction	Table	0	0	2
0	02	121	Mean frequency	Hz	-8	0	7
0	02	106	3-dB beamwidth	Degree	1	0	6
0	02	107	Sidelobe suppression	dB	0	0	6
0	02	yyy	Accuracy of elevation	Degree	2	0	8
0	02	yyy	Accuracy of azimuth	Degree	2	0	8
0	02	yyy	Receiver type	Table	0	0	2
0	02	130	Dynamic range	dB	0	0	7
0	02	129	Minimum detectable signal	dB	0	-150	5
0	02	100	Radar constant	dB	1	0	12
0	25	001	Range-gate length	m	-1	0	6
0	xx	yyy	Date last electronic calibration				
0	xx	yyy	Date last alignment check				
0	xx	yyy	Date last maintenance/repair				
0	xx	yyy	Status radar system	Table	0	0	4

Table is continued on next page.

F	X	Y	Element name	Unit	Scale	Reference	Width
1	05	000	Delayed replication of 5 descriptors				
0	31	001	Replication factor (Num. elevations)				
0	04	016	Time increment (Seconds)	Seconds	0	-4096	13
0	02	135	Antenna elevation	Degree	2	-9000	15
0	02	109	Antenna speed (azimuth)	Degree/s	2	0	12
0	02	125	Pulse Repetition Frequency (high)	Hz	-1	0	8
0	02	125	Pulse Repetition Frequency (low)	Hz	-1	0	8
0	25	yyy	Maximum processed range	m	-3	0	10
0	25	002	Number of gates averaged	Numeric	0	0	4
0	25	003	Number of integrated pulses	Numeric	0	0	8
0	25	010	Clutter treatment	Table	0	0	4

5.2 Surface Rainfall Product

A list of the proposed quality descriptors of (instantaneous) surface rainfall product is given.

F	X	Y	Element name	Unit	Scale	Reference	Width
0	25	007	Z to R conversion factor	Numeric	0	0	12
0	25	008	Z to R conversion exponent	Numeric	2	0	9
0	21	200	Height of CAPPI	m	0	-1000	15
0	xx	yyy	VPR correction method	Table	0	0	4
0	xx	yyy	Gauge adjustment method	Table	0	0	4

5.3 Wind Profile Product

A list of the proposed quality descriptors of radar wind profile product is given.

F	X	Y	Element name	Unit	Scale	Reference	Width
0	25	yyy	Doppler wind calculation method	Table	0	0	4
0	25	yyy	Lowest estimable radial wind	m/s	1	0	10
0	25	yyy	Highest estimable radial wind	m/s	1	0	10
0	25	yyy	Inner radius of volume	m	-2	0	10
0	25	yyy	Outer radius of volume	m	-2	0	10

5.4 BUFR Table Entries

The entries for the table with the range attenuation correction (0 25 012) methods are given below.

Code	Meaning
0	Hardware
1	Software
2	Hardware and Software
3	Missing value

The entries for the table with the receiver types (0 02 yyy) are given below.

Code	Meaning
0	non-coherent
1	coherent on receive
2	coherent
3	Missing value

The entries for the table with the status of the radar system (0 xx yyy) are given below.

Code	Meaning
0	Okay
1	Running uncalibrated
2	Overestimation of reflectivity
3	Underestimation of reflectivity
4	Unstable receiver
5	Unstable transmitter
15	Missing value

The entries for the table with the type of clutter treatment (0 25 010) are given below.

Code	Meaning
0	None
1	Map
2	Insertion of higher elevation data and map
3	Analysis of the fluctuating logarithm signal (clutter detection)
4	Extraction of the fluctuating part of linear signal (clutter suppression)
5	Clutter suppression - Doppler
6	Multi-parameter analysis
7	Doppler time-domain filtering
8	Doppler frequency-domain filtering
9	Doppler frequency-domain filtering with spectral reconstruction
15	Missing value

The entries for the table with the VPR correction methods (0 xx yyy) are given below.

Code	Meaning
0	None
1	Bright-band correction
2	Climatogical profiles
3	Pre-selected profiles
4	Nearby profiles
5	Locally extracted profiles
6	Modeled profiles
15	Missing value

The entries for the table with the gauge adjustment methods (0 xx yyy) are given below.

Code	Meaning
0	None
1	Mean field
2	Range correction
3	Spatial correction
15	Missing value

The entries for the table with the Doppler wind calculation methods (0 25 yyy) are given below.

Code	Meaning
0	VAD
1	Linear wind
2	Uniform wind
3	VVP
4	MVVP
5	EVAD
15	Missing value

6 Conclusions

For surface rainfall products, different ways of providing quality information have been proposed. Especially for the most luxurious option, the amount of overhead with the data can increase significantly. At some point, we may end up having more information in the quality flag than in the data itself. Interpretation of radar wind profiles requires additional information of quality and retrieval algorithms. BUFR files containing radar wind profiles are generally very small, so there is no problem in expanding the amount of static and dynamic quality information here. The main problem is the implementation and transfer of the dynamical information in the operational process. It is clear, however, that quality information for both surface rainfall products and radar wind profiles is extremely important for all applications, e.g., compositing of radar data, assimilation in radar observations in numerical weather prediction models, and use of radar data for hydrology. The issue of the selection of mandatory quality descriptors has not been addressed in this project. This issue will be left to the follow-on of the current OPERA program.

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