Weather radar capabilities for OSCAR

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1 Introduction

The purpose of this document is to present a method for determining weather radar capabilities for the WMO Observing Systems Capability Analysis and Review Tool (OSCAR). In this first version, we acknowledge that such radar capabilities may not necessarily align completely with OSCAR's requirements. The challenge lies in expressing radar capabilities in a way that remains consistent with the way radar systems observe the atmosphere while hopefully adding value in an OSCAR context. Doing this addresses aspects related to observing geometry and the physical parameter measured, in this case radar reflectivity factor most commonly expressed in dBZ. A simple method used to determine radar capabilities is presented and exemplified, and metadata requirements in relation to the WMO Weather Radar Database are clarified.

2 Weather radar characteristics

2.1 Geometry

Weather radars scan the lower atmosphere with the antenna at different elevation angles relative to the horizon. A series 360° scans at different elevation angles constitutes the radar's scan strategy. Such scan strategies are vastly different throughout the world; although they are often identical for several radars in a national network, even differences at the national level are known to exist.

Apart from the elevation angle, the spatial resolution differs as well: this is expressed in rays per scan and bins per ray. Combined these two dimensions are the polar geometry (spherical coordinates) in which radar observations are made. In expressing weather radar capabilities for OSCAR, knowledge of each radar's scan strategy is essential. Knowing the lowest scan's elevation angle is critical as a starting point if the complete scan strategy is not available. If the polar geometry (rays x bins) is not known, it can be assumed to be 360 rays with a 1° half-power beam width and 250 x 1km bins, giving a maximum range of 250 km for C and S bands, otherwise 60 x 1km bins for X band.

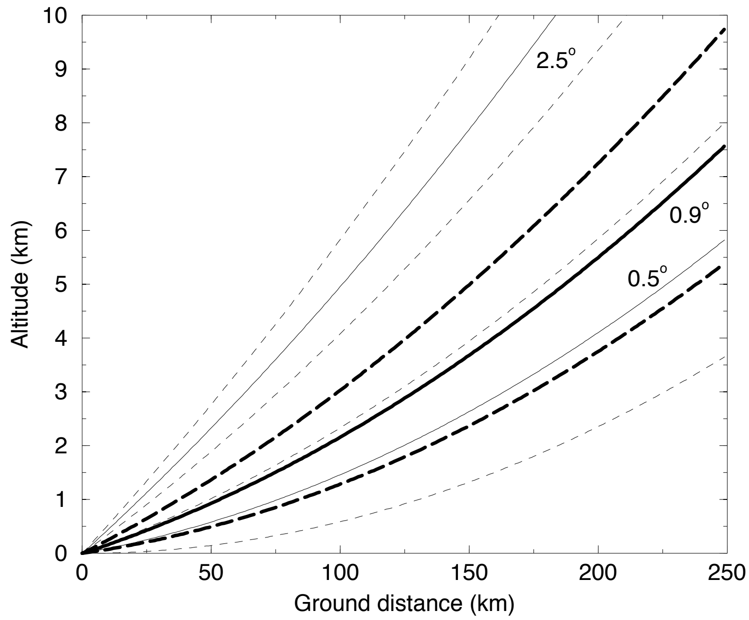

Figure 1. Assumed standard propagation of radar beams with 1° widths. Solid lines show the centre of each of three beams at the given elevation angles. Dashed lines show the upper and lower limits of the half-power beam widths.

The radar beam broadens with increasing range from the radar, and the beam does not follow the Earth's surface but is instead assumed to propagate according to a 4/3 Earth radius which means that the beam's altitude above the surface increases with range. These two factors combined imply that the observation geometry of an individual bin can be several kilometers deep at distant ranges (Figure 1). The assumption we normally make, and that we also make for OSCAR, is a standard atmosphere with normal propagation conditions.

The practical implications of beam propagation and broadening is that the radar will underestimate precipitation with increasing range, especially where the beam is above the melting layer which is common for all radars sited outside the tropics.

2.2 Radar quantities

We start with radar reflectivity factor *Z*, most commonly expressed on the decibel scale as dBZ. This is the radar's "native" observable, a measure of the power of the received echo.

Radar reflectivity is related to rain rate (intensity) through the drop-size distribution (DSD). Radar reflectivity is usually assumed to the sum of the diameters of the drops to the sixth power per unit volume. Contrasting this is rain rate, which is assumed to be related to the cubed sum of the drops per unit volume. This means that small differences in radar reflectivity will give large differences in rain rate, as illustrated in Figure 2. This also means that errors expressed natively in dBZ will vary tremendously in terms of rain rate.

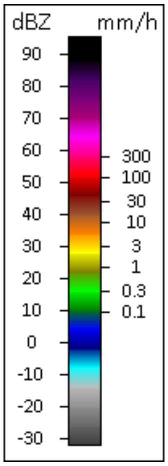

Figure 2. Typical dynamic range of radar reflectivity factor (dBZ) in radar data, and how it relates to rain rate (mm/h) illustrated through a display legend.

Radar reflectivity factor (*Z*) is related to rain rate (*R*) quantitatively through the *Z-R* relation that reads $Z=AR^b$, where *A* and *b* are coefficients, the most common of which are *A*=200 and *b*=1.6 according to Marshall & Palmer (1948).

It should be noted that conditions and relations are different for solid phase precipitation, which will be excluded from consideration here for the time being for the sake of simplicity.

2.3 Representing weather radar data quality

International efforts to harmonize the practices of characterizing and representing weather radar data quality emerged from the European COST Action 717 (Michelson et al., 2004). These formulations were subsequently pulled through to an operational context in EUMETNET OPERA (Holleman et al. 2006), where a so-called "quality indicator" was formulated to represent various types of data quality generated from different algorithms in a standardized way. This representation encodes qualities within the range 0 (lowest quality) to 1 (highest quality). Two intuitive examples of such quality indicators are 1) the probability that an echo is not precipitation, and 2) percent beam blockage caused by topography.

In recent years, data processing chains have been established that have implemented these concepts and this standardized data quality representation, for example through the BALTRAD (Osrodka et al. 2010) and BALTRAD+ (Szturc et al. 2012) projects in the Baltic Sea Region, and through OPERA's Odyssey data centre for Europe (Norman et al. 2010).

3 Weather radar capabilities

Capabilities for OSCAR are based on the following algorithms that all operate in the radar's original polar space at the individual bin level, thereby outputting a array that matches each scan's polar geometry:

1. Beam blockage by topography. If the radar beam is partly or entirely blocked by hills and mountains, then information on how much the beam is blocked (%) is of critical importance. We propose that the algorithm openly documented in the BALTRAD cookbook be used[1]. Areas with blockage above 70% will be considered to have lowest quality, ie. data in such areas are unusable. This algorithm uses the global digital elevation model GTOPO30 that has a spatial resolution of around one km. It can both identify blockage and correct for it. For OSCAR, only the blockage identification will be used.
2. Analysis of beam propagation and broadening characteristics. As mentioned above in Section 2.1, knowledge of the size and depth of the radar beam is directly related to data quality. Quality will therefore decline with increasing range from the radar because the pulse volume increases. We propose that the algorithm openly documented in the BALTRAD cookbook be used[2]. This algorithm is purely descriptive; it does not correct.
3. Knowledge of the height of the main axis of the radar beam is also very useful as a quality indicator, as quality will decrease with increasing height, especially if the radar observation is being considered representative at the surface. Calculated heights will be relative to the radar's altitude. A cap of 10 km will be used, above which data will be considered unusable. In cases with negative elevation angles, negative beam heights will be set to zero when deriving this indicator.
4. A measure of "total quality" has also been developed and openly documented in the BALTRAD Cookbook[3]. We select the minimum quality information from steps 1-3 above, as their minimum determines the quality of each polar bin.
5. Based on the total quality from point 4 [0-1], the information will be scaled to the interval 1-5 dBZ, where a 1 dBZ error is considered highest quality and 5 dBZ error considered lowest quality. Note that this measure of "radar capability" represents data quality aloft, ie. at the altitude at which the radar data are acquired. Radar bins with the highest error are considered unusable. This type of "error" is more of a qualitative uncertainty than a quantitative error bar.
6. For radar capabilities to be assumed representative for the Earth's surface, the uncertainty from point 5 is multiplied by a scaling factor that itself scales linearly between 1 and 3, corresponding with uncertainties aloft of 1 and 5 dBZ respectively.

[1] http://git.baltrad.eu/trac/wiki/cookbook/BEAMB
[2] http://git.baltrad.eu/trac/wiki/cookbook/RADVOL-QC_BROAD
[3] http://git.baltrad.eu/trac/wiki/cookbook/QIT

This information can be generated for each scan in the scan strategy, as long as the elevation angles are available. It is assumed that the capabilities array for each scan will be stored in a database for OSCAR. The location of each polar bin in space (longitude, latitude, altitude) does not need to be output explicitly and stored in the database along with the capabilities output, because the radar site position, elevation angle, and polar geometry provides all the information required to calculate this information on-the-fly when the capabilities are being used. However, this information is given anyway according to Section 4.3 below.

4 Requirements on the WMO Weather Radar Database

4.1 Metadata

Table 1 contains information on which metadata are currently available in the WMO Weather Radar Database (WRD), and which metadata could be added to enhance the weather radar capabilities for OSCAR.

Table 1. Metadata required to determine weather radar capabilities for OSCAR. Mandatory metadata are required to achieve basic capabilities. Metadata that are not mandatory can be used to achieve enhanced (more complete and accurate) capabilities.

Information content	***Unit***	***Mandatory***	***In WRD***
Radar site coordinates: longitude, latitude, altitude	Decimal degrees, meters above sea level	YES	YES
Lowest elevation angle	Degrees relative to horizon	YES	YES
Additional elevation angles - complete scan strategy	Degrees relative to horizon	NO	NO
Half-power beam width	Degrees	YES	YES
Number of rays per scan	Integer value	NO	NO
Number of bins per ray	Integer value	NO	NO
Bin length: the distance between two successive range bins	Meters	NO	NO
Pulse width	Microseconds	NO	YES

4.2 Software for determining capabilities

In order for the WRD to generate capabilities for new and existing radars, the hosts of the WRD would have to acquire and run associated software. This can be achieved by implementing new software based on the algorithm descriptions in the BALTRAD Cookbook and the information in Section 3 above. Alternatively, the WRD host could run the BALTRAD Toolbox software and incorporate this into their WRD operations. BALTRAD software is Open Source, and it is available from a publicly accessible repository[4], so there are no formal restrictions that prevent such a deployment.

The current status of the beam blockage package in BALTRAD is that the software is prepared to perform analyses for any radar located in Regional Association (RA) VI (Europe and the Middle East), most of RA I (Africa), part of RA V (South-West Pacific), and a small part of RA II (westernmost Eurasia). These areas correspond to one or more GTOPO30 tiles. The software needs to be prepared to read and manage remaining tiles to achieve full global coverage. This is not a significant effort, but would need to be planned and carried out.

A command-line executable program has been written for generating capabilities for OSCAR using the BALTRAD Toolbox. This script is available online[5].

4.3 Capabilities representation for the WRD

It is envisaged that weather radar capabilities are written to text file (ASCII), from which the information is ingested into the OSCAR database. The program referred to above writes files with the following structure:

- A header three rows long, containing information identifying the site's location and characteristics, ie. the metadata in Table 1.
- One row, six columns, per capability location.

Capabilities need to be identifiable by radar site and elevation angle. This can be done either by reading the metadata from the file header, or through assigning file names with appropriate site names.

Typical file sizes are 772 kilobytes for an X-band radar scan (360 rays x 60 bins), and 3.3 megabytes for a C or S-band radar scan (360 rays x 250 bins).

5 Example

A working example is given to illustrate the concepts and methods. An existing C-band radar operated by MeteoSwiss at Monte Lema in southern Switzerland is used. This site is well suited to the task, as the radar's coverage is blocked in part by the Swiss alps. Another interesting characteristic is the radar's negative elevation angle (-0.2°) for the lowest scan in the scan strategy.

Example capabilities for OSCAR are illustrated in Figure 3. The minimum quality field [0-1] is scaled to error/uncertainty aloft [1-5 dBZ] and also for the surface in the text output also given below.

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[4] http://git.baltrad.eu/

[5] https://github.com/DanielMichelson/oscar

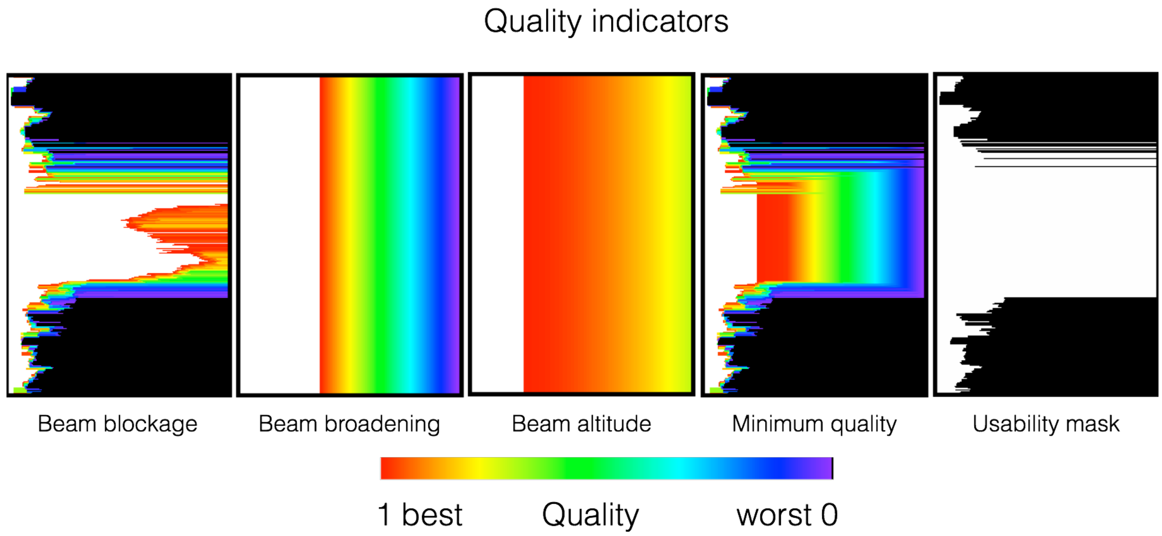

Figure 3. Four quality indicators and usability mask for the lowest scan of data from Monte Lema, Switzerland, based on the content of the WMO Weather Radar Database. Minimum quality is based on the three beam-related quality indicators, and this is the information that is scaled to capabilities for OSCAR. The radar's native polar geometry is displayed in the form of a B-scan, where rays are ordered clockwise starting from North on the Y-axis, and range bins starting from the radar left-to-right on the X-axis.

Example text output is displayed in Figure 4, where the first three rows are header, and the following rows containing capabilities are selected from the first ray pointing North. The beam's altitude drops with increasing range at first, which is normal for a negative elevation angle; at more distant range, the altitude increases (not shown). The dominant quality factor in this case is beam blockage, which becomes 70% or higher relatively close to the radar, at which point the error/uncertainty expressed in dBZ is highest and the bin is flagged as unusable.

```
Lon=8.833889 Lat=46.041944 Alt=1625.0 Rays=360 Bins=250 Scan=-0.2
Beamwidth=1.00 Binlength=1000.0 Pulsewidth=0.50
Lon         Lat         Alt         Aloft Surf  Unusable
8.833889    46.095926   1606.2      1.0   1.0   0
8.833889    46.266870   1574.6      1.1   1.2   0
8.833889    46.275867   1574.1      4.4   11.7  0
8.833889    46.284864   1573.8      4.5   12.2  0
8.833889    46.302858   1573.4      5.0   15.0  1
```

Figure 4. Output file format expressing selected capabilities for the Monte Lema radar in Switzerland. The "Aloft" column contains the error/uncertainty aloft (dBZ), whereas the "Surf" column contains the error/uncertainty at the surface (dBZ). The "Unusable" column contains a boolean value (1=unusable). One row for each polar bin in a radar scan.

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