OPERA BUFR guidelines

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1 Introduction

BUFR is a very flexible way of transmitting and archiving meteorological information. This flexibility, added to the fact that radar data has received so far little attention from the BUFR creator (WMO), can lead to some improper interpretation of a BUFR message containing radar data. Hence the need of some additional coding rules specific to radar data.

OPERA has recommended such rules, but these are currently split in several documents. The present paper aims to be an entry point to that documentation, by providing appropriate references. As a byproduct of that goal, it can also be seen as a summary of the OPERA coding rules for BUFR.

After studying this document, the reader should be able to :

1. code in a BUFR message the official radar products recommended by OPERA
2. decode and interpret properly a message coded following the previous guidelines

The reader is supposed to have some background about BUFR. If this is not the case, he is adviced to read first some documentation on this subject. A good starting point is [1] and the definitive reference is [2].

2 Technical prerequisites

A BUFR coding/decoding software is needed. The OPERA group has subcontracted to Graz University the development of such a package, and the use of that software is recommended (but not at all required) for the following reasons :

- the specific BUFR tables of the OPERA group are in a format readable by this software; a transcoding may be needed if some other coder/decoder is used
- the image compression requested in the OPERA BUFR message is already a feature of this OPERA software; it needs to be added to any other coder/decoder

The user guide of the software will also be needed. In the case of the OPERA coder/decoder, this document [3] covers a lot of the practical details, with examples, and is so useful to read even if another software is used.

The OPERA group maintains a set of local BUFR descriptors tables to compensate for the lack of corresponding radar descriptors in the current WMO tables. Any user of OPERA BUFR messages needs a copy of these tables, which are available at the OPERA WEB server (at : **"http://www.knmi.nl/opera/bufr/tables-OPERA-20080428.zip"**). These tables can be updated by the OPERA group to fullfill new needs.

3 General aspects of the OPERA BUFR

3.1 Value of originating center

In BUFR language, every «originating center» (in practice every NMS and some international bodies, e.g. ECMWF, are originating centers) has the right to define its own local set of descriptors. A given number identifies such an originating center. OPERA is not recognized as such a center, and so has not his assigned number.

This is a problem if OPERA needs to define radar specific descriptors. It is not possible to ask each OPERA member to add the OPERA descriptors to their local tables, as this leads to conflicts. For instance descriptor 3 21 192 is in OPERA a 4 bit reflectivity image, and in France it is used for calibration results.

The solution devised so far by OPERA was to piggyback on the missing value for the originating center field in the message. This value is 255 or 65535 depending on the BUFR edition used (see 3.3).

Since summer 2008, WMO has allocated 247 as the official «originating center» for OPERA. It is not decided currently how OPERA members will handle the transition.

3.2 Naming scheme for descriptors files and their format

Local or WMO descriptors tables can have release numbers, to handle evolutions. It is common practice to have a file corresponding to a table of a given combination local/release/type[1]. The file is read by the BUFR software when a message to be coded or decoded declares to use the corresponding table.

BUFR does not mandate a given format for these descriptors files. The consequence is that in practice, every BUFR software has its own format. OPERA has choosen recently to use a conversion from the Word tables of the original WMO documents to the so-called CSV format.

The naming scheme of the files containing the tables is as follows :

Local tables: Let Y be the originating center and X a release number for that center. The file name for the descriptors of category Z is then : **localtabZ_Y_X.csv**. Human readable forms of these tables exist also : **localtabZ_Y_X.pdf** for a PDF version and **localtabZ_Y_X.doc** for a Word version. The Word version is similar to what WMO publishes. The value of Z can be b,d or c (this last one corresponds to codes and flags table and exists only in human readable form).

WMO tables: The naming scheme is **bufrtabZ_X.csv** as Y makes no sense here. The human readable form is similarly **bufrtabZ_X.pdf** for a PDF version and **bufrtabZ_X.doc** for the original Word version.

3.3 BUFR edition

BUFR itself is an evolving format, and here also we have a release number called «edition number». The current one is 4, but OPERA messages are still using 2 or 3. The edition number concept applies to meta-information in the messages (e.g. date and time...). So it is not relevant for the descriptors.

[1] Notice that ECMWF's own BUFR software does not currently separate local tables from WMO ones

BUFR edition 2 had the «originating center» coded on 16 bits. In edition 3 that field was split in two 8 bit values : an originating center and a sub-center. So depending on the BUFR edition used, your OPERA compliant message may contain the value 255 or 65535 for the originating center. It leads the software to read files **localtabZ_255_X.csv** or **localtabZ_65535_X.csv**. These files should have identical content, and the best way to ensure it is to symlink (or hardlink) one to the other.

3.4 Image compression

Radar data can be huge and a method to compress it is needed. BUFR, conceived to replace short messages of the SYNOP type, has for the moment a very poor performing compression facility. Hence the OPERA group has devised a more efficient one, which definition lies outside BUFR itself, and so is beyond the scope of a pure BUFR software. In practice the BUFR coder must be fed with the compressed image pixel array, and on the other side the decoder retrieves only the compressed data stream.

Clearly some mid-level software layer is needed to perform the compression/decompression step. For the moment, only the OPERA BUFR software has this layer. DWD is working on this and France has it already one-way. The description of the compression scheme can be found in the OPERA software documentation [3].

3.5 Section 1 content

Octet 10 of this section is a data sub-type. It is currently not used by OPERA. It could provide a priori information to distinguish between local radar data, composites or vertical profile data, instead of relying on descriptor 0 30 031.

4 Mandatory content of an OPERA BUFR message for surface radar rainfall intensity

The reference documents are [4], [5] and [6] for this kind of product. The definitive interpretation of the descriptors is given by the WMO tables [2] and the OPERA tables (available at : **"http://www.knmi.nl/opera/bufr/tables-OPERA-20080428.zip"**).

Descriptor	Signification	Comment
3 01 001	WMO block and station number	
3 01 19Y	Meta information about the product	YY=2 or YY=4; see tables below; 3 01 194 exists only for tables 6 and above
3 01 022	Latitude, longitude and height of station	Present only for individual radar data and for tables 5 and below
0 30 196	Image type	0 for local radar, 1 for composite; present only for tables 6 and above
3 01 193	Geographic projection information	See table below; present only for tables 6 and above
0 30 031	Image type	0=PPI; 1=composite; 2=CAPPI
0 29 002	Co-ordinate grid	0 for cartesian
0 33 003	Quality information	Needs WMO table 11 at least; present only for local radar data
3 21 250	Radars included	Present only for composites
3 21 008	Z to R conversion	Present only if a rain scale is used below
3 13 0YY	Reflectivity or rain intensity scale	YY=09 for reflectivity; YY=10 for rain intensity
3 21 19Y	Horizontal pixmap	The bit resolution of a pixel is determined by Y; Y can be set to 2 (4 bits) or 3 (8 bits)

Table 1: content of reflectivity product

Descriptor 3 01 192 seems to be used by few countries, instead its equivalent is coded. This practice is not recommended, as it can lead to ambiguous determination of the 4 corner coordinates of the image (if for instance another 3 21 023 descriptor is used after of before these corners to code the radar position). It is recalled that BUFR does not impose an order on descriptors, but using a 3 XX YYY sequence descriptor implicitly gives such an order. Here the equivalent content of 3 01 192 and its high resolution replacement 3 01 194 defined in tables 6:

3 01 192		
Descriptor	Signification	Comment
3 01 011	Date of measurement	
3 01 012	Time of measurement	
3 01 023	Latitude, longitude	NW corner (coarse accuracy)
3 01 023	Latitude, longitude	NE corner
3 01 023	Latitude, longitude	SE corner
3 01 023	Latitude, longitude	SW corner
0 29 Y01	Projection type	Y=2 for recent local tables; Y=0 for old ones
0 05 002	Latitude of radar	Missing value for composite (coarse accuracy)
0 0X 002	Longitude of radar	Missing value for composite; X=6 for recent tables; X=5 for old tables (typo)
0 05 033	Pixel size along the x-axis of the image	
0 06 033	Pixel size along the y-axis of the image	
0 30 021	Number of pixels per row	
0 30 022	Number of pixels per column	

Table 2: list of descriptors equivalent to 3 01 192

3 01 194		
Descriptor	Signification	Comment
3 01 011	Date of measurement	
3 01 012	Time of measurement	
3 01 021	Latitude, longitude	NW corner (high accuracy)
3 01 021	Latitude, longitude	NE corner
3 01 021	Latitude, longitude	SE corner
3 01 021	Latitude, longitude	SW corner
0 29 201	Projection type	
0 05 001	Latitude of radar	Missing value for composite (high accuracy)
0 06 001	Longitude of radar	Missing value for composite
0 07 001	Height of station	
0 05 033	Pixel size along the x-axis of the image	
0 06 033	Pixel size along the y-axis of the image	
0 30 021	Number of pixels per row	
0 30 022	Number of pixels per column	

Table 3: list of descriptors equivalent to 3 01 194 (exists in tables 6 and above only)

And the equivalent content of 3 01 193 :

3 01 193		
Descriptor	Signification	Comment
0 29 199	Semi-major axis of rotation ellipsoid	a
0 29 200	Semi-minor axis of rotation ellipsoid	$b = a\sqrt{1-e^2}$, e the ellipsoid excentricity
0 29 193	Longitude Origin	λ
0 29 194	Latitude Origin	θ
0 29 195	X-Offset	X-coordinate of the upper left corner of the upper left pixel of the image
0 29 196	Y-Offset	Y-coordinate of the upper left corner of the upper left pixel of the image
0 29 197	1st Standard Parallel	θ_1
0 29 198	2nd Standard Parallel	θ_2

Table 4: list of descriptors equivalent to 3 01 193

In section 6, some technical information is given about how to use the projection information of descriptors 0 29 ZZZ.

4.1 Coding rules

- Radar products for exchange within Europe are top view of :
  - Instantaneous surface rainfall intensity
  - Low level equivalent radar reflectivity factor in dBZ
- An individual image pixel value is interpreted according to the slicing table given by 3 13 0YY. It may be at resolution 4-bit or 8-bit.
- Row means the vertical co-ordinate from the top of the image starting at 0 for the first row. Column means the horizontal co-ordinate from the left of the image starting at 0 for the first column.
- The co-ordinates 3 01 023 of the corners of the image are given at the center of the pixel corners.
- Overlays such as maps, coastlines, roads, text, colour scales, must not be included in the image.
- Pixels in 3 21 19Y when decompressed must be presented in order from the top left, row by row, to the bottom right.
- All pixels within the area of an image, but beyond the range of any radar, must be coded as ‘no data available’.

4.2 Coding recommendations

- As great a number of level slices as possible should be used, with a recommended minimum of 15 levels.
- Images for exchange should contain the minimum amount of clutter possible.

- The time shown in section 1 of the BUFR message is the actual observation time, taken as the mid-scan time (or the start scan time if not available) for radar site data; it is a nominal time for composite images.
- Observation and nominal times at which radar data should be recorded and composites produced are H+00, H+15, H+30 and H+45, where H is hours UTC.
- The observation window for data to be included in a composite should be as narrow as possible and should not be greater than the nominal composite image time + or - 5 minutes. Data with an observation time outside of this window should not be included in the composite image.
- If data is being exchanged over the GTS, the time shown in the GTS header should be the same as in section 1.

BUFR coders are also free to add other information to the above minimal message, as long as descriptors from the WMO or local tables are used. For instance, adding an elevation angle (WMO descriptor 0 02 135) or a height (OPERA local descriptor 0 21 200) would indicate a scan at the given elevation or a CAPPI product.

Other types of messages (rainfall accumulation, side-view, etc…) are presented in the exemples in [3], but they are currently not officially endorsed.

5 Mandatory content of an OPERA BUFR message for wind profile products

The reference document is [7].

Descriptor	Signification	Comment
3 01 001	WMO block and station number	
3 01 011	Date of measurement	
3 01 012	Time of measurement	
3 01 022	Latitude, longitude and height of station	
0 02 003	Type of measuring equipment used	Radar = 3
1 06 000	Delayed replication of 6 descriptors	
0 31 001	Delayed descriptor replication factor	Number of levels
0 07 007	Height	
0 11 001	Wind direction	
0 11 002	Wind speed	
0 33 002	Quality information	0=ok, 1=suspect, 3=missing
0 11 006	w-component	
0 33 002	Quality information	0=ok, 1=suspect, 3=missing

Table 5: content of WRWP product

Notice that only WMO descriptors are used here, so the local table release value is set to 0 and the country originating center can be used instead of 255 or 65535. WMO table release 11 or higher should be used, as below the presence of quality descriptors 0 33 YYY is not certain.

6 Use of geographic projection information

Table 4 at page 6 shows that the reflectivity product contains geographic projection information to localize the pixels of the image. In the following, the mathematical notation for the descriptor value given in the “Comment” column of that table will be used.

As geographic projection is a specialized technical subject, it may be interesting to show on examples how to derive from X-Offset and Y-Offset the 4 corner coordinates needed in 3 01 192. To be concrete, let us take the case of the PROJ library of geographic projections.

6.1 Initialization

First, the initialization of the library must be done by giving the following arguments to the “proj” executable or to the initialization function “pj_init_plus()” :

- Gnomonic (value 0 of descriptor 0 29 Y01 in 3 01 192):

  `+proj=gnom +lat_0=`θ `+lon_0=`λ `+a=`a `+es=`e^2

- Stereographic (value 1 of descriptor 0 29 Y01 in 3 01 192):

  `+proj=stere +lat_0=`θ `+lon_0=`λ `+lat_ts=`θ_1 `+a=`a `+es=`e^2

- Lambert conical (value 2 of descriptor 0 29 Y01 in 3 01 192):

  `+proj=lcc +lon_0=`λ `+lat_1=`θ_1 `+lat_2=`θ_2 `+a=`a `+es=`e^2

- Oblique Mercator (value 3 of descriptor 0 29 Y01 in 3 01 192):

  `+proj=omerc +lat_0=`θ `+lon_0=`λ `+lat_1=`θ_1 `+a=`a `+es=`e^2

- Azimutal equidistant (value 4 of descriptor 0 29 Y01 in 3 01 192):

  `+proj=aeqd +lat_0=`θ `+lon_0=`λ `+a=`a `+es=`e^2

- Lambert azimutal equal area (value 5 of descriptor 0 29 201 in 3 01 192):

  `+proj=laea +lat_0=`θ `+lon_0=`λ `+a=`a `+es=`e^2

6.2 From the geographical coordinates of the upper left corner to X-Offset and Y-Offset

The C code fragment to do it is :

```
double rterre = 6370997; /* radius of some spheric earth */
char str[100];
projPJ pj;
projUV p;

/* a polar stereo exemple */
sprintf(str, "+proj=stere +lat_0=%g +lon_0=%g +lat_ts=%g +a=%g +es=0",
        90, 0, 45, rterre);
if (!(pj = pj_init_plus(str))) {
  fprintf(stderr, "FATAL: error init proj %s\n", pj_strerrno(pj_errno));
  return 0;
}
/* lat_NW latitude of upper left corner of upper left pixel */
p.v = lat_NW*DEG_TO_RAD;
/* lon_NW longitude of upper left corner of upper left pixel */
p.u = lon_NW*DEG_TO_RAD;
p = pj_fwd(p,pj);
/* Now p.u = X-Offset end p.v = Y-Offset */
```

6.3 From X-Offset and Y-Offset to the coordinates of the four image corners

Another C code snippet which could follow the previous one :

```
projUV pout;
p.u += ncols*dx; /* ncols number of columns and dx horizontal pixel size */
pout = pj_inv(p,pj);
/* pout.v / DEG_TO_RAD latitude NE corner */
/* pout.u / DEG_TO_RAD longitude NE corner */

p.v -= nrows*dy; /* nrows number of rows and dy vertical pixel size */
pout = pj_inv(p,pj);
/* pout.v / DEG_TO_RAD latitude SE corner */
/* pout.u / DEG_TO_RAD longitude SE corner */

p.u -= ncols*dx;
pout = pj_inv(p,pj);
/* pout.v / DEG_TO_RAD latitude SW corner */
/* pout.u / DEG_TO_RAD longitude SW corner */
```

References

[1] H. D. Clifford, C. Sanders, E. Cervena, C. Long, J. Ator, and M. Dragosavac. Guide to WMO Table-Driven Code Forms: FM-94 BUFR and FM-95 CREX. Technical report, WMO, January 2002. Clic here for the electronic version.

[2] WMO. *FM 94-XIII Ext. BUFR Binary universal form for the representation of meteorological data*, 2007. Clic here for the electronic version.

[3] K. Köck, H. Paulitsch, and J. Fuchsberger. FM94-BUFR Encoding and Decoding Software. Technical report, EUMETNET/OPERA, December 2007. User Guidelines version 1.5 (for software release 3.0).

[4] P. Le Berre, D. Bizic, M. Divjak, M. Rosa Dias, G. Galli, A. Huuskonen, D. Kotlarikova, J. Kracmar, J. Nagy, and W.K. Wheeler. Definition of the Currently Agreed Set of Data for International Exchange in Near Real-Time. Technical report, EUMETNET/OPERA, November 2000. Clic here for the electronic version.

[5] EUMETNET/OPERA. *Rules and recommandations for setting up radar products for international exchange within Europe*, 2001. Clic here for the electronic version.

[6] EUMETNET/OPERA. *Time stamps in radar products*, 2001. Clic here for the electronic version.

[7] G. Galli, J. Koistinen, J. Kracmar, J.-L. Maridet, and K. Köck. Specifications for Weather Radar Wind Profile products of ”simple type”. Technical report, EUMETNET/OPERA, October 2001. Clic here for the electronic version.