P361

RECENT IMPROVEMENTS TO THE QUALITY CONTROL OF RADAR DATA FOR THE OPERA DATA CENTRE

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1. Introduction

OPERA is the operational programme for weather radar networking within EUMETNET, the grouping of European meteorological services. The current programme of activities, OPERA4, started in April 2013, after the successful completion of the OPERA3 programme, and is described further in a poster at this conference (P364) by Saltikoff et al. (2013).

In 2009, an OPERA3 project started to develop the OPERA Data Centre (ODC), which was undertaken jointly between Météo-France (MF) and the UK Met Office (UKMO). It was to become the successor to the OPERA Pilot Data Hub (PDH), which ran from 2006 to 2011 and provided radar rainfall composites at 4km resolution, with 15 minute updates and with a domain covering the whole of Europe. In 2011, the ODC project culminated in the delivery of an operational service, called Odyssey, which is now hosted jointly at UKMO and MF and provides European radar composites on the same domain as the PDH but at 2km resolution with 15 minute updates. Unlike the PDH, which received Cartesian radar products, it ingests volumetric radar data, including Plan Position Indicator (PPI) scans. It also benefits from the use of a newer radar data exchange format known as the OPERA Data Information Model (ODIM), developed by Michelson et al. (2008), which defines strict rules for the encoding of radar data and associated meta-data in either of the HDF5 or WMO BUFR file formats. Presently 18 National Met Services (NMSs) are supplying ODIM-compliant radar data to Odyssey and this includes volumetric data from over 130 radars, most of which operate at C or S-band frequencies.

Three different types of composite are produced at each 15-minute time step as shown in Table 1. The names `RATE`, `DBZH` and `ACRR` correspond to the ODIM names for the types quantity which are encoded.

Table 1: Composite product types.

Name	Description	Units
`RATE`	surface rainfall rate	$mm\,h^{-1}$
`DBZH`	column maximum reflectivity	dBZ
`ACRR`	1hr accumulation	mm

For an example of the `RATE` product please see

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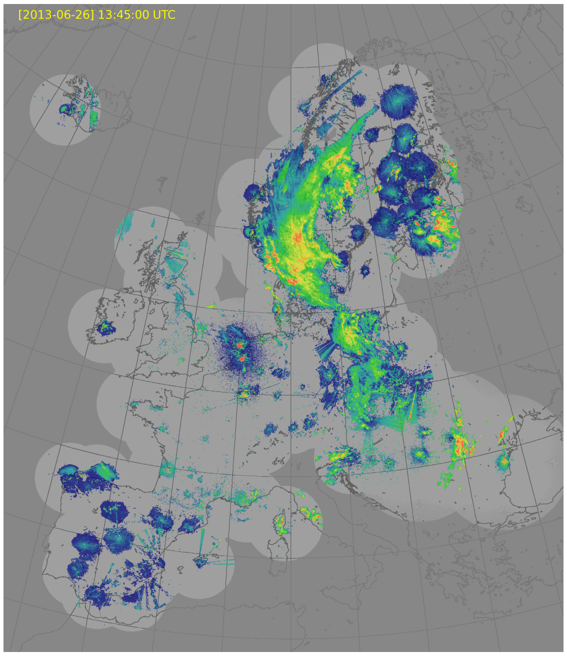
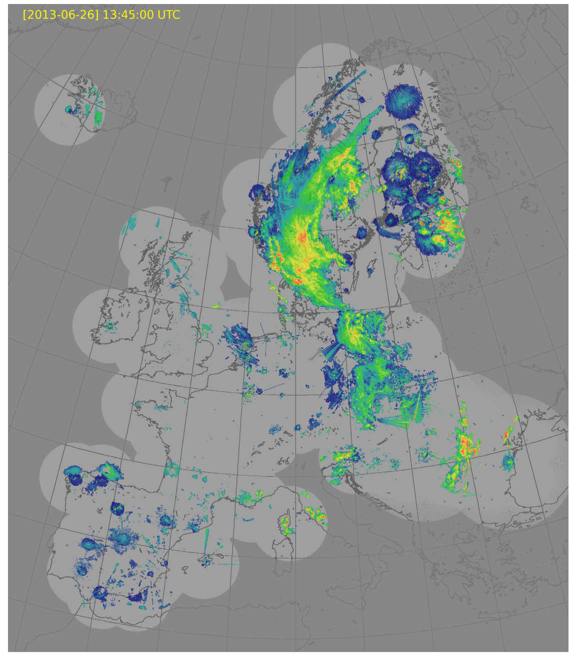


(a) Without QC



(b) With QC

Figure 1: Odyssey `SURF` composite with and without QC.

Figure 1. This is based on a weighted average of dBZ over all radar pixels within a specified horizontal range of each composite grid cell centre. A fixed $Z-R$ relationship is used to convert the averaged dBZ into $mm\,h^{-1}$.

Most NMSs provide data with the least possible pre-processing applied. This is recommended by OPERA because it allows the Quality Control (QC) to be done in a consistent and centralized way on Odyssey. To date two QC methods have been added to process each PPI scan before compositing. Firstly, a simple climatology-based clutter filter was introduced in 2011. Secondly, a suite of anomaly detection algorithms, provided by BALTRAD[1], was introduced in March 2013. Figures 1a and 1b show an example of the SURF composite both with and without the QC applied. Further details of these algorithms are given in the next few sections.

[1]BALTRAD is the Baltic Sea Region Programme (2007-2013) part-financed by the European Union, European Regional Development Fund and European Neighbourhood and Partnership Instrument.

2. Odyssey clutter filter

Figure 1a demonstrates that there is a significant amount of residual clutter in the composite near to many of the radar sites. The clutter filter's purpose is to mask out these echoes while retaining the genuine rainfall signals as much as possible.

A set of monthly echo count images are updated when new PPI scans are processed by Odyssey. For each known PPI scan configuration there is one echo count image stored which is indexed by a combination of the year, month, radar site code and elevation angle (with a tolerance of 0.01° to allow for drift).

Figure 2 shows a monthly echo count image for the UK Clee Hill radar scan at 1.0° elevation, which extends to 250km range. The image shows widespread regions of permanent ground clutter (where the echo count is at or near 100%) within the first 100km of the radar site.

By combining a clutter filter with the compositing algorithm it becomes possible to reject pixels entirely from a radar image and yet retain

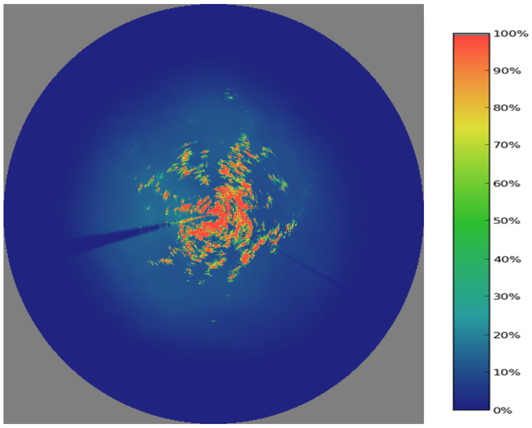


Figure 2: Normalized monthly echo count accumulation for Clee Hill radar (1.0° elevation).

valid data in the composite by substituting nearby radar pixels from the same radar or a different radar. Radar pixels are rejected when the normalized echo count (a value between 0% and 100%) exceeds a predetermined clutter threshold which is defined on a site-by-site basis. The normalization factor is equal to the highest recorded echo count in the image (divided by 100).

a. *Evaluation*

The first version of Odyssey used a clutter threshold which was set conservatively at value of 90% for all radars. Work was done later within OPERA to evaluate the impact of the filter and the effect of the choice of the threshold.

This evaluation was carried out in 2012 by comparing UK Met Office hourly gauge reports, from a network of tipping-bucket rain gauges, to the radar accumulation (`ACRR`) composites, for a domain covering the UK, for a trial period of three months. This included 2160 hourly time steps at each of approximately 300 co-located radar / gauge pairs. Using the categories of "rain" and "no-rain" for each of the two observation types, a 2x2 contingency table was constructed (see Table 2) and then the Peirce's Skill Score, as described in Jolliffe and Stephenson (2003), was calculated according to Equation 1.

Table 2: Construction of contingency table.

Radar	Gauge		
	Rain	No Rain	Total
Rain	A	B	$A+B$
No Rain	C	D	$C+D$
Total	$A+C$	$B+D$	$A+B+C+D$

$$\texttt{PSS} = \frac{AD - BC}{(A+C)(B+D)} \tag{1}$$

The trial was repeated for each of 5 different clutter threshold settings and the PSS is shown for each threshold in Table 3. Based on these skill scores, it was concluded that the clutter filter has a beneficial effect on the composite and that for the UK Met Office radars, a threshold of 60% is optimal.

Table 3: Peirce's Skill Score for different clutter thresholds.

Threshold	PSS
100%	0.51
90%	0.59
60%	0.6
40%	0.59
20%	0.55

It was noted that the scores can be sensitive to the method of combining radar pixels in the compositing algorithm. For example, when calculating the weighted average to arrive at a composite pixel value, if there is at least one "rain" echo in the average, even if the other pixels are mostly "no rain" echoes, the composite pixel will be treated as a "rain" pixel.

As a result of this study, a first-guess value of 60% was set for the whole of the European radar network but ideally site-specific tuning would be done for all radars because each radar has different characteristics; many have been processed with Doppler clutter filters and / or have minimum dBZ thresholds applied, effectively filtering out some of the clutter. The potential for further tuning using this method will be limited by the availability of recent rain gauge data from dense rain gauge networks in the regions of interest but it is possible that the NMSs themselves will supply their own values for the thresholds.

3. bRopo QC algorithms

The BALTRAD software module known as bRopo became available in 2012 and included a suite of anomaly detection algorithms which were developed originally at FMI by Peura (2002). This software was deployed on the operational Odyssey system in March 2013.

The algorithms included are listed individually in Table 4. Odyssey currently employs the `SPECK`, `EMITTER` and `SHIP` algorithms but for efficiency reasons only the `SPECK` filter is used for PPI scans above 2.0° elevation.

Each filter contributes to an overall quality indicator (a value between 0 and 255) which is subsequently used with a chosen quality threshold to decide which pixels are to be rejected before compositing.

Further details of the `SPECK`, `EMITTER` and `SHIP` algorithms are given in the following sections.

Table 4: bRopo filters.

Name	Type of Anomaly
`BIOMET`	birds and insects near the radar
`SPECK`	noise; distinct specks
`EMITTER`	line segments
`SUN`	long line segments
`SHIP`	ships (and aircraft)
`VERT GRAD`	sea waves and ducting effects
`METEOSAT`	suspiciously warm data
`DOPPLER`	non-continuous Doppler data

a. *`EMITTER` filter*

Interference from Radio Local Area Networks (RLANs) can have a serious impact on the quality of the measured reflectivity data. These effects are usually obvious and take the form of radial spokes, e.g. see Figure 3a. bRopo deals with this problem by using a *computer vision* method to detect line segments within the image (Peura (2002)). Figure 3b shows some examples of spokes, marked as red, which have been identified in unprocessed radar data. A useful feature of this algorithm is its ability to allow some pixels within an identified sector, i.e. those that are more likely to be meteorological echoes, to be preserved.

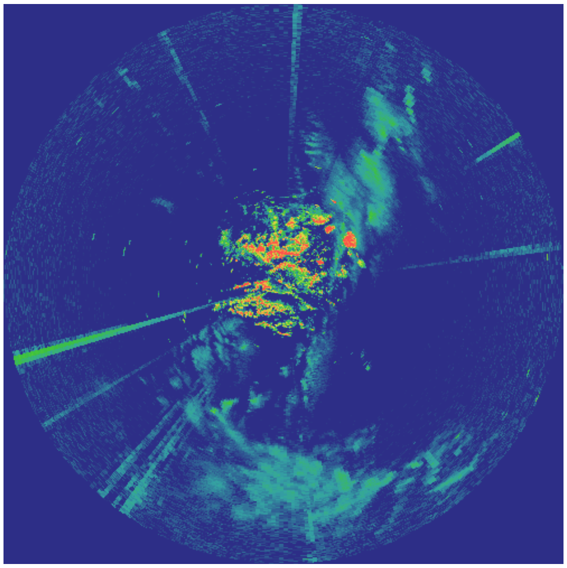
The algorithm can be configured using three parameters which constrain the identification to have i) a reflectivity above a minimum dBZ, ii) to be longer than a specified number of radial bins and iii) to be wider than a specified number of degrees.

b. *`SPECK` filter*

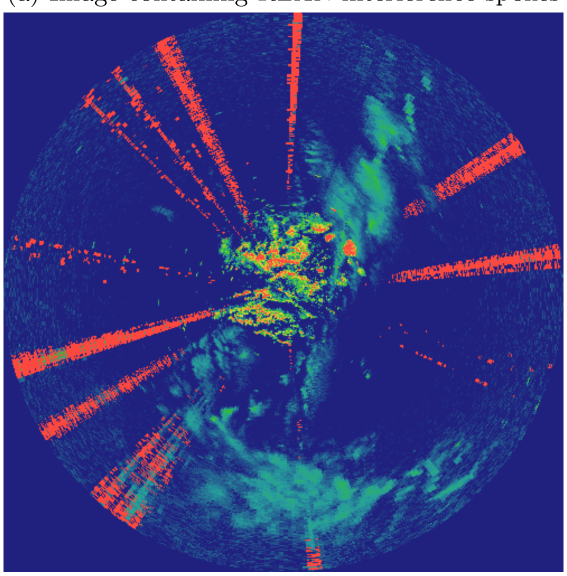
Isolated individual pixels or small clusters of pixels, known as speckle, can arise due to various sources, including noise in the radar receiver apparatus. bRopo provides an algorithm to identify speckle which is again based on the *computer vision* method of segment identification. A maximum area of the segment, in pixels, can be specified in addition to a minimum dBZ threshold.

c. *`SHIP` filter*

Some types of anomaly arise as a result of returns over the sea from highly reflective surfaces such as ships and waves. The ship anomalies are likely to occur within busy shipping channels, such as in the Gulf of Finland, the English Channel / La Manche or the Strait of Gibraltar. bRopo tries to detect these as small but intensive echoes in individual pixels by considering relative changes in dBZ between pixels, although some additional processing is required to be able to distinguish between convective storms and ship or wave echoes because they have similar signatures in the radar imagery. Figure 4a shows an example of a monthly accumulation (based on `ACRR` composite data) for a region covering the Gulf of Finland, including three Finnish radars. It can be clearly seen in this image the presence of straight lines, where the accumulation is greater, which are known to be the location of the shipping channels. The second image, Figure 4b, shows a similar accumulation but which included radar data processed using the `SHIP` filter.

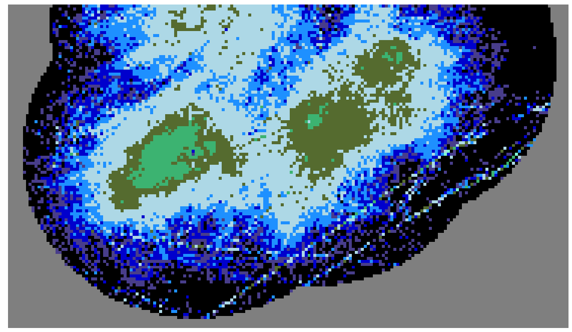


(a) Image containing RLAN interference spokes

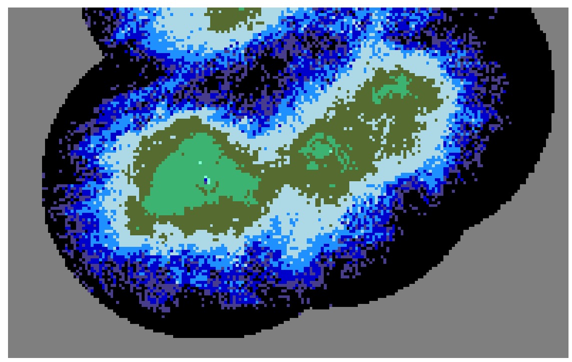


(b) Image containing identified spokes (in red)

Figure 3: Images showing the identification of RLAN interference spokes.



(a) Without QC applied.



(b) With bRopo QC filter applied.

Figure 4: Images showing the identification and removal of echoes from ships in the Gulf of Finland using monthly accumulation data derived from ACRR composites.

4. Comparison to NWP

An assessment of the PDH was carried out by Mittermaier et al. (2008) using the UKMO North Atlantic European (NAE) model as a reference. This model has a 12km resolution and a domain which completely encloses that of the PDH. The method of assessment involved the conversion of the radar data on to the NAE grid, and then an *anomaly difference* field $\Delta\eta$ was calculated between each daily model accumulation M and the corresponding daily radar accumulation R:

$$\eta_R = \frac{R - \mu_R}{\sigma_R}$$
$$\eta_M = \frac{M - \mu_M}{\sigma_M}$$
$$\Delta\eta = \eta_M - \eta_R$$

where the means μ and the standard deviations σ are based on the spatial averages over the whole domain for each single day. The daily anomaly differences were then averaged over a long time period (typically 40+ days) with the aim to remove the transient model forecast bias errors.

The results of Mittermaier et al. (2008) suggest that there were a number of unresolved problems with the quality of the PDH data. This included problems related to software compatibility issues and the intermittent availability of some radars, range effects resulting from the reduced radar detection ability at long range, seasonal biases, in particular cold season bias over the Nordic and Baltic region, deficiencies in the model to predict convective scale NWP, orographic effects seen over the Pyrenees and the west coast of Norway, Vertical Profile of Reflectivity (VPR) effects and regions affected strongly by anomalous propagation, e.g. over the North Sea in the UK. It was also noted later that there were some serious geolocation errors which arose because of the many differences in the definition of local radar coordinate systems and because, unlike Odyssey, the PDH ingested a mixture of single site data and national composites.

Figure 4 shows the results of a new study, using the same method of calculating anomaly differences, to compare Odyssey daily accumulations, derived from `ACRR` composites, to the more recent UKMO EURO4km NWP model, a 4km downscaled model which encloses the Odyssey domain. The main focus was to discover what biases, if any, are present in the data and how any such biases compare to the earlier PDH study. The areas of red indicate a positive anomaly difference (a strong model anomaly or a weak radar anomaly) while the areas of blue indicate a negative anomaly difference (a weak model anomaly or a strong radar anomaly). As can be seen in the figure, much of the area is white, where the absolute anomaly difference is less than 0.2, indicating a good agreement between radar and model. There are some strong red areas, for example over the north coast of the Iberian Peninsula, in the Scottish Highlands and on the west coast of Norway. This signature is similar to that of the PDH and is thought to correspond to cases where the model is overestimating the orographic enhancement and / or where the radar is simply not seeing this effect. There is also a strong red anomaly over the Alps but this is thought to be due to the inability of the French radars to see into this region due to the local terrain (note there are no Swiss or Italian radars in the Odyssey composite). There are some isolated blue "dots" in Eastern Europe which are thought to be due to ground clutter and there are in various places some longer blue lines which are

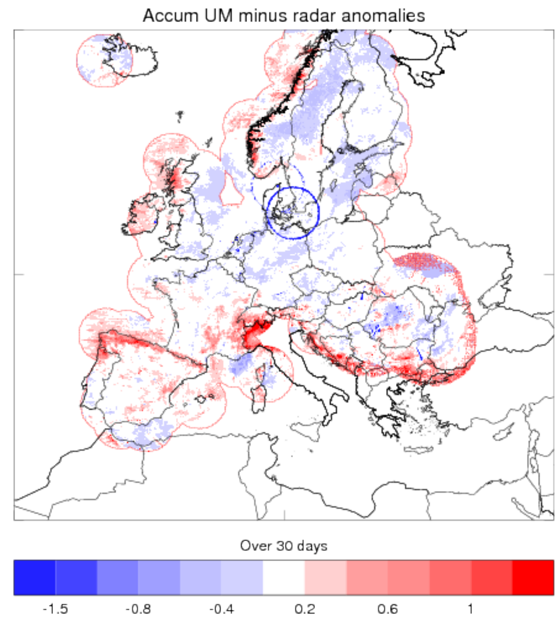
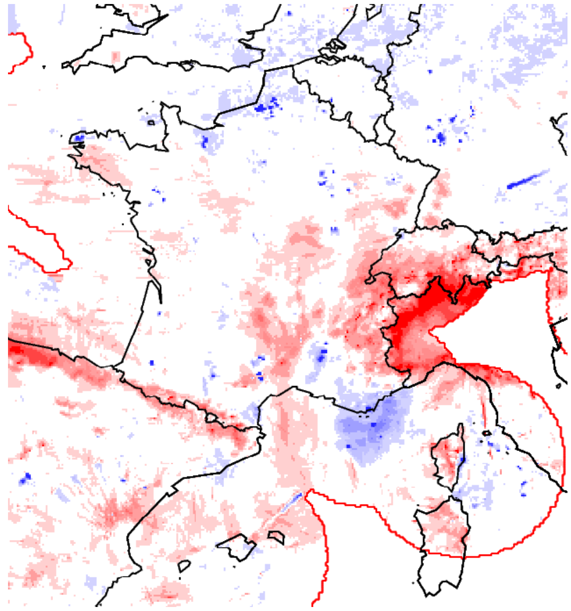


Figure 5: Anomaly differences for April 2013 averaged over a 30 day period.

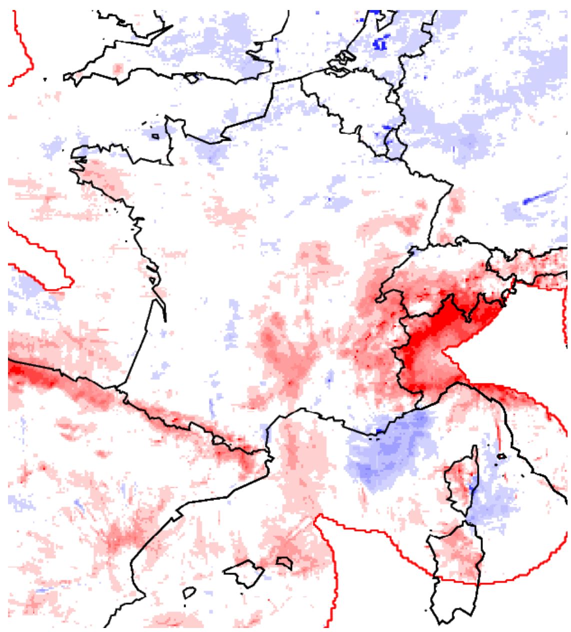
likely to be due to RLAN interference. Also noteworthy is a blue ring around some of the Danish radars - the cause is not known but the effect appears to have been resolved since the study was done. Please note also that there is an edge effect around the Romanian radars which appears in red but is not a positive anomaly difference. It results from the inability of the composite to properly interpolate S-band radar data at long range.

The anomaly difference information is useful for planning future improvements to the quality control and corrections. With this in mind, anomaly differences were calculated for the April 2013 case both i) without bRopo + clutter QC and ii) with bRopo + clutter QC. Figures 6a and 6b show a region over the west of Europe, primarily over France, before and after the QC. In the uncorrected difference field, there are some strong isolated negative anomaly differences which are known to be due to wind farms. These were, by choice, not removed from the PPI scan data received on Odyssey. In the second image, these signatures appear to have been removed.

Based on the images shown, it was concluded that the effect of the QC is generally localised, as might be expected, i.e. the widespread regions of red or blue anomaly differences were largely untouched and the main differences were seen in terms of the removal of the isolated regions of strong negative anomaly difference, likely to be permanent clutter or RLAN interference. Also, it was noted from the images that the filters do not perform as well as might be expected in some regions, e.g. the RLAN interference in Figure 6a is not modified in figure 6b. However, this may be corrected with further tuning of the bRopo algorithms, which has not yet been done for radars outside the Baltic Sea Region.



(a) Without QC applied.



(b) With QC applied.

Figure 6: Images showing the impact of clutter and bRopo QC on the anomaly differences for a region in the west of Europe. Note that some of the strong negative anomalies (blue) are thought to be due to wind farms.

5. Further Work

In the OPERA4 programme there are a number of activities starting which aim to improve the both the QC and the Quantitative Precipitation Estimation (QPE) of Odyssey. This includes improvements to the compositing algorithm, VPR corrections, solar monitoring (for elevation and azimuth pointing corrections) and improvements to the way quality information is shared and subsequently used to give appropriate weightings to radar data that is used in the composite. There are also plans to repackage single-site data, which has undergone QC, into single-volume files which will then be redistributed to NWP users.

The findings described in this report suggest that further tuning of the bRopo and clutter filters on a site-by-site basis would be effective and that a more rigorous verification study would better identify areas where improvements to the QC are needed.

Odyssey `SURF` composites have recently been used for input into European nowcasting models as part of the Hazard Assessment based on Rainfall European Nowcasts (HAREN) project (*http://haren-project.eu/*).

REFERENCES

Jolliffe, I. and D. Stephenson, 2003: *Forecast Verification: A Practitioner's Guide in Atmospheric Science*. John Wiley and Sons, 50-51 pp.

Michelson, D., R. Lewandowski, M. Szewczykowski, and H. Beekhuis, 2008: EUMETNET OPERA Weather Radar Information Model for Implementation with the hdf5 File Format. Available online from: http://www.eumetnet.eu/sites/default/files/OPERA_2008_03_WP2.1b_ODIM_H5_v2.1.pdf.

Mittermaier, M., B. Macpherson, M. Naylor, R. Scovell, D. Harrison, and P. Earnshaw, 2008: Assessing the OPERA Pilot Data Hub European Radar Composite for NWP Applications. Met Office Technical Report No. 521. Availabile online from: http://research.metoffice.gov.uk/research/publications/papers/technical_reports/reports/521.pdf.

Peura, M., 2002: Computer vision methods for anomaly removal. *Proceedings of the Second European Conference on Radar Meteorology (ERAD)*, Delft, Netherlands, 312–317.

Saltikoff, E., H. Leijnse, and P. Novak, 2013: OPERA 4 - THE NEW PHASE OF OPERATIONAL WEATHER RADAR NETWORK IN EUROPE. *Proceedings of the 35th AMS Conference on Radar Meteorology*, Breckenridge, Colorado, USA.