1. Introduction

The fundamental objective of OPERA (Operational Programme for the Exchange of weather RAdar information) is to provide a European platform wherein expertise on operationally-oriented weather radar issues is exchanged and holistic management procedures are optimised (Huuskonen et al., 2010). The OPERA Programme is now in its third phase (2007-2011) and will be extended by one year. A central objective of this third phase is to develop, implement and run an operational data centre (ODC), able to collect and process radar data volumes, originating from European Meteorological Services (NMSs), and to produce and deliver quality controlled composite products on a pan-European scale. During its previous phase, the OPERA Programme established a Pilot Data Hub (PDH) that has been operated by the Met Office since 2006 (Harrison et al., 2006). The PDH was the first step in demonstrating the full potential of a European Weather Radar Network. It currently gathers data from approximately 100 radars together with 11 national composites. Although the input data are Cartesian products and not harmonized, the PDH has demonstrated that a European domain composite is possible both technically and politically.

To reach the OPERA-3 central objective of establishing an ODC, a team consisting of OPERA delegates from France, Germany, the Netherlands, Sweden, and the United Kingdom prepared a specification document. The team reviewed existing operational observational data hubs, and collected the requirements of the main users (core meteorological service forecasting and nowcasting, Numerical Weather Prediction (assimilation and verification), civil and military aviation and hydrology). The specification document was approved by the whole OPERA group, expressing a preference for 2D composites of ‘raw’ volume data. A call for proposals was issued in November 2008 amongst the OPERA members, who represent 30 European NMSs.

In response, three proposals were submitted to OPERA, from KNMI, SMHI and DWD, and Météo France and the Met Office. The OPERA Programme Manager then established a subgroup of OPERA (RMI, KNMI, FMI, TU-Graz, and EARS) to perform a technical evaluation of the proposals. The final selection took place during the 36th EUMETNET Council, where Météo France and the Met Office were elected as Responsible Members for this exciting challenge.

2. The Partners’ offer

2.1 General characteristics

The key elements of the joint Météo France - Met Office proposal, with an operational centre running in parallel in Toulouse and Exeter (see Figure 1), are a high level of resilience and maximum availability of radar products.
The IT communications design is based on existing and new developments within Europe (e.g. RMDCN and vGISC (virtual Global Information System Centre)). Together with a full compliance to all mandatory requirements, and a budget within the OPERA envelop, the Partners’ offer fully meets OPERA’s main objective of “establishing the weather radar networking as a solid element of the European infrastructure”.

2.2 Deliverables

The deliverables of the ODC are listed in the table below. Three different composites will be produced from harmonized polar volume data: a maximum reflectivity composite, a surface rainfall composite and a one-hour accumulated product. These composites will have a resolution of 2 km and a frequency of 15 minutes.

<table>
<thead>
<tr>
<th>Description of the deliverable</th>
<th>Comment</th>
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<tbody>
<tr>
<td>1 Operational software which are modular and portable.</td>
<td>Transferable to another responsible member</td>
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<tr>
<td>2 Full documentation including algorithms and system overview</td>
<td>In English</td>
</tr>
<tr>
<td>3 3 composites: reflectivity, surface rainfall and one-hour accumulated precipitation</td>
<td>Base on agreed algorithms</td>
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<tr>
<td>4 A redistribution of input data</td>
<td>Via the V-GISC, for NWP</td>
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<tr>
<td>5 Statistics per radar on availability, timeliness and quality of volume data</td>
<td>Through a FTP server</td>
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<td>6 An operational service</td>
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<td>7 A list of procedures for taking radars out of the network</td>
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<tr>
<td>8 An assistance to the members to supply their data</td>
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<td>9 A development plan</td>
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<td>10 Project status reports</td>
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</table>

2.3 Activities

The functional breakdown of the ODC tasks is shown in Figure 2.

Fig. 2 Functional modules and management package

2.3.1 FM1 Input and decode

The first module consists of ingesting and decoding polar volume data from the European NMSs.

2.3.2 FM2 Pre-processing

Pre-processing consists of checking and qualifying the raw volume data received from the NMSs. The output of this module will remain as single scan data with quality information.

2.3.3 FM3 Projection and compositing

The third module is divided into 3 sub-activities: mapping the polar data into the Cartesian composite grid; compositing the data and archiving the products.
2.3.4 FM4 IT Communication.

The IT communication is a transverse module that builds, as far as possible, on existing tools or on new developments within the WIS (WMO Information System). Its 2 main sub-activities are finalising the flow and mechanisms by which data moves from suppliers, between Toulouse and Exeter and to users, and giving advice to NMSs on their bandwidth requirements.

2.3.5 FM5 System management and monitoring.

System management and monitoring is another transversal module and considers how the data centre will be managed and monitored once operational. Numerous sub-activities are to be taken into account such as system monitoring (input data, product generation, data and products dissemination, real-time system monitoring), automatic warning of non-delivery of data, visualisation of input data, site removal procedures, display of logs and statistics.

2.3.6 MP6 Overall system organisation.

The Management Package, aims at getting final agreement on how, what, where and when development takes place (definition of coding languages, hardware architecture, documentation, sharing of work between the Partners, ...).

The success of the ODC partly relies on the capability of the OPERA Members to send compliant data. A supporting work package, also led by Météo France and the Met Office, has been established to help Members ensure their data are in the correct format and contain the correct information.

2.4 Main milestones

The project was kicked-off on the 3rd of September 2009. The timetable is tight as the delivery of the ODC is due on the 1st of January 2011. The main milestones are identified in the development plan and the project Gantt chart, amongst which are:
- 03/09/09 – M1: Kick-off meeting.
- 14/10/09 – M3: Opera meeting: Agree Input format, compositing algorithms, quality indicator.
- 01/04/10 – M5: Opera meeting: Minimal processing chain in place for testing composite, agree output format.
- 01/10/10 – M7: Opera meeting: IT communication scheme ready.
- 01/01/11 – M8: ODC operational.

3. Status of the developments

3.1 Decoding, pre-processing and compositing

One assumption of the project is that all the input data arriving at the ODC is in the correct format and contains the correct (meta)data. Such assumption, as well as the more general goal of OPERA to harmonize data, led to the definition of a common information model named ODIM (OPERA Data Information Model). This work was carried out before the beginning of the ODC project. During their 2009 autumn meeting, the OPERA members agreed on 2 input formats (HDF5 and BUFR) compliant with the ODIM. These 2 formats are the only formats that are accepted by the ODC and on which assistance is provided if needed by the project team. Converters from BUFR to HDF5 and from HDF5 to BUFR have been developed by the project.

One of the key elements of the ODC software is the way to achieve the mapping between the polar pixels of the input data and the Cartesian pixels of the composite products. The challenges are both on the quality of the method, in terms of the number and pertinence of raw data pixels used to fill a Cartesian pixel, as well as on its performances, in terms of CPU and memory used. The requirement is that raw data is decoded, qualified, projected and composited in less than 5 minutes. Considering the number of European radars (in the order of magnitude of 190) and the numbers of scans performed by each radar during 15 minutes (15 as an average), the challenge is real. One of the first activities of the project has been to define and test different mapping methods.

A simple closest neighbour mapping (as used in the Pilot Data Hub) has been found to be good enough for local radar data in Cartesian format, but not satisfactory for polar data. The basic idea to solve the problem has been to associate, for a given Cartesian composite cell (index j), a set of weight \( W_i \) (where i indexes all polar cell values for all
radars and their elevations). The interpolated value at the composite cell \( j \) will be
\[
\sum x_i w_i / \sum w_i
\]
where \( x_i \) is the polar cell value. The result is that all polar input data, for all radars and all elevations for each radar, is horizontally interpolated to the vertical of the grid of Cartesian composite cells. Potentially all available polar cells contribute in the interpolation process.

But this simple approach to the problem of selecting nearby cells by iterating over all cells in the input grid, for each cell in the composite grid is not tractable for use at run-time. The number of iterations would be equal to the number of cells in the input grid multiplied by the number of cells in the composite grid. This is estimated to be approximately \(10^{14}\) iterations. However, it was possible to use this method as a baseline.

The 2 algorithms that were finally elected, after tests on fake input data, are detailed in Figure 3. The first one, called k-d tree, relies on the fact that, given a set of arbitrary points in space, it is possible to store the points in the computer memory in such a way that finding the nearest points, to a chosen point in the space, is highly efficient. The second one, called reverse mapping, takes advantage that it is easier to ask the question, “What composite grid cells lie within a radius \( \rho_{\max} \) of a point \((r, \theta)\) in the polar grid?” than it is to ask the question “What polar grid cells lie within a radius \( \rho_{\max} \) of a point \((X, Y)\) in the composite grid?”.

**FIG. 3.** Description of the polar to Cartesian mapping methods. k – d tree algorithm on the left, reverse mapping algorithm on the right.

Once the mapping from polar input data to the Cartesian composite grid is done, the compositing process takes only a few seconds. The whole of the process takes about 3 minutes. It includes, before compositing, consistency checks by comparison of some of the metadata contained in the input files with the information stored in a database and the calculation of a per pixel quality index. This quality index is the product of a ratio function of the « number of radars used » by the pre-processed pixel weight \( w_i \). Pixels with a height of less than 200 m above the radar height are not used to avoid residual clutter if any. Figure 4 shows a composite obtained with the reverse mapping method from UK and French polar data.

The Partners’ offer allows an archive of the products with a very high level of resilience. All disseminated composite products are archived in two separate places (in Toulouse and Exeter) and will be accessible through a website hosted by Météo France.

### 3.2 IT Communication

The recommendation from the ODC project team is to use, when possible, the RMDCN to send the input data to the ODC. The alternative is to use the Internet, which will not guarantee sufficient bandwidth, in particular during crisis situations where it might be important to get all data in time.

Some scenarios based on the dates of availability of the input data to the ODC, when known, were established. Most of them show that an increase of the RMDCN bandwidth by an amount of around 2Mb/s both in Toulouse and Exeter will be necessary in order for the ODC to receive the data and disseminate the products. Half of the input data will arrive in Toulouse, half in Exeter, and the existing message switching systems will be used to exchange the input data between the Partners as well as to disseminate the composites.

The Partners’ proposal was offering the use of the vGISC functionalities to manage the exchange of the data between the 2 centres. The main advantage being the 2 centres would appear as one from the outside. Unfortunately, the vGISC project has been delayed by more than 6 months. This delay will not prevent the ODC becoming operational but does mean more work for the ODC project team to address the communications issues.

A file naming convention, based on WMO standards, has been agreed amongst OPERA members for sending the input files to the ODC.
3.3 Monitoring

As collaboration is a major element of the ODC Project, in accordance of all OPERA members, the requirements for monitoring availability and quality have been passed to the EUCOS Quality Management Team at DWD. This means:
- the quality of radar data will be available from the same source as other observation type, the OPERA Programme being consistent with other EUMETNET observation Programmes,
- Web access to OPERA data performance,
- near real-time information,
- monitoring independent of the ODC – what the customer really got and when,
- allows for future enhancement, including NWP comparison.

Thresholds on availability and timeliness of the input data and of the output products of the ODC have been agreed by the OPERA community.

Apart from the monitoring of the data, the ODC team is developing the monitoring of the ODC system itself, together with an internal web site. This internal web site will permit the visualization of the input data and of the composites. It will also allow the operating people, on a 24/7 basis, to monitor the system and if the input data does not meet the required standards to forbid its use in composites. An email alert will be sent to the supplier in case of an outage of his input data.

3.4 Collaboration between the Partners

One advantage of the Partners’ offer was that the expertise and knowledge were not in the hands of one big NMS. This was also a potential drawback, as a lack of cooperation and coordination between the Partners during the development phase could have led to delays. This risk did not materialise and weekly meetings via telephone and videoconferences have helped reduce the risk. The choice of a common coding language, C++, and a tool to write documentation was quite straightforward and very quickly agreed.

The main difficulty came from dealing with the IT Security. As the ODC will be part of the operational environment in the Met Office and Météo France, strict IT security rules need to be applied. This is especially true when deploying software into the operational environment in Exeter and Toulouse. This is the “price to pay” for the reliability offered. It took a few months longer than planned to be able to share a common server to manage the common code, and set up the ODC hardware.

Despite this last point, the human resources spent are not well over the initial estimate. The overspend is of the order of 10 to 20%.

3.5 Data policy

Data policy is still an open issue that should be solved before the end of 2010. An expert team, made up of members of the EUMETNET council, PBObs and OPERA, has been established to consider the data policy of the ODC composite products.
4. Conclusion, perspectives and the future

Developing an operational radar centre with such a tight schedule is a challenge, particularly because the development is carried out jointly by two major NMSs, and because the ODC will be operated in two different operational environments. The challenge has been taken up enthusiastically, with some lessons already learned, especially the importance of addressing the IT security issues when building and sharing a reliable operational system. The challenge will not be completely achieved by the 1st of January 2011 because the two parts of the ODC, Toulouse and Exeter, will not yet be seen as just one centre from the outside. This is because of the delay of the vGISC project that should come into operation only in the second half of 2011, with a delay exceeding 6 months.

Collaboration is a major feature of the ODC. This is demonstrated by the monitoring of the input data and ODC composites being performed at the EUCOS Quality Management Portal (QMP), independent of to the ODC, but in full coherence with the other observation data. The door is also open for a comparison of weather radar data with NWP data at the QMP.

Improving and measuring the quality of the data in the ODC composites is probably the next big challenge to be addressed by this and future OPERA Programmes. This issue will only be comprehensively addressed by the first operational version of the ODC in January 2011. In Europe there is a fantastic level of knowledge on how to improve and measure the quality of radar data. Many processing algorithms exist at a national and regional (particularly within the BALTRAD project) level. The challenge now is to agree on what should be deployed at the ODC and should algorithms be universally or regionally applied. The current OPERA Programme is also trying to address the taxing subject of the application of quality information, through one of its work streams (Norman, et al. 2010). Pulling this work through to operations will see a major step forward for the ODC.

Another challenge will be further harmonization of the input data to the ODC. Great progress has been made, both in agreeing data formats and in production practices (Huuskonen et al., 2009). A day when every operational radar in Europe runs the same scan strategy, producing the same products, etc is something those developing the ODC can only dream of.

Having developed a solid element of the European infrastructure, the OPERA community will now have a place to test and implement new treatments and algorithms. In such a perspective, the liaison and sharing of expertise within Europe and especially the BALTRAD Project is of great importance.

References


