364 **OPERA 4 - THE NEW PHASE OF OPERATIONAL WEATHER RADAR NETWORK IN EUROPE**

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1. INTRODUCTION

The operational weather radar network in Europe is quite extensive: In July 2013, OPERA's 30 members had 178 weather radars. The radar network is heterogeneous both in hardware and signal processing, thus making it fundamentally different from the NEXRAD network, also because the density of weather radars is roughly two times higher.

OPERA is the operational programme for weather radar networking within EUMETNET, the grouping of European Meteorological Services. Its two objectives are, to provide a European platform wherein expertise on operationally-oriented weather radar issues is exchanged, and to develop, generate and distribute high-quality pan-European weather radar composite products on an operational basis.

OPERA started in 1999. It gets its funding via EUMETNET from the member organizations. The work is planned as projects or phases, lasting 3-5 years. The present phase, OPERA 4 will run 2013-2017, and it will focus in data quality and users of radar data. Coordinating member is Finnish meteorological Institute (FMI). Each national institute can decide whether it wants to join the optional programmes, but OPERA has more members than any other EUMETNET optional project or operational service.

This paper will tell about OPERAs achievements during the first 13 years, and plans and challenges of the new phase.

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1. HISTORY

"*In the beginning of Nexrad, there was an empty map and a lot of money. In beginning of Opera, there was a map of existing radars and no money*." To be more precise, the existing WSR-57 and WSR-74 existing radars of U.S. were not used in construction of the NEXRAD, and the radar sites were selected in a careful process of identifying propriety areas of dense population, and then considering meteorological and geographical facts (Leone et al, 1989).

Nobody ever drew a plan for European radar network, instead each country acquired radars mainly for its local needs. The first radars were analog, typically located at or very near the main airport to provide a display for the local forecaster. Arrival of digital radars allowed networking, first nationally and then data exchange with nearest neighbours. In the beginning of OPERA, regional exchange programs and their data formats already existed (Collier and Chapuis, 1990).

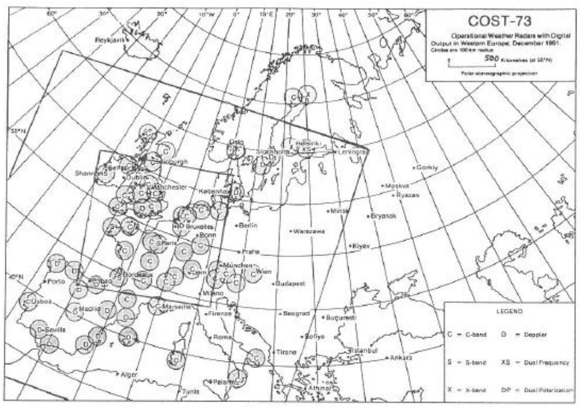

Figure 1: Radar networks in Europe by 1991 and areas for which COST images are produced

Fig 1: Radar networks in Europe 1991, 8 years before the first OPERA.

Although the location of radar sites is primarily a national responsibility, the sites are distributed rather evenly, also across the national borders. The median distance between two neighboring radars in the network is 128 km (80 miles)

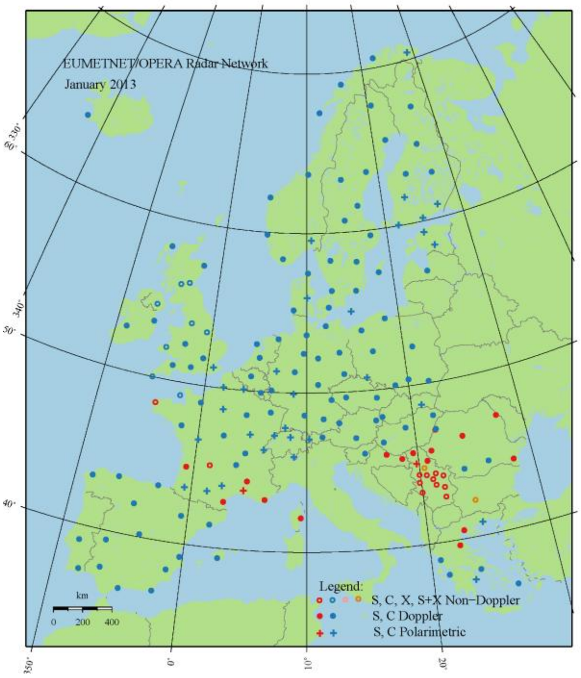

Fig 2: OPERA radar network 2013.

The big achievement of the OPERA 1 was to improve and promote the common data format BUFR, and software for its encoding and decoding. Before OPERA, if one wanted to create an international composite, one usually had to write input and output procedures for each radar manufacturer's software separately. One by one, all the manufacturers started to provide option for data output in the OPERA's promoted format to be used in international exchange. (OPERA's BUFR tools and documentation can be freely downloaded from OPERA Website). OPERA 3 introduced ODIM, a data model, which has been implemented in BUFR and in HDF5. The industry has also started to provide this format in the radar systems for sale. BUFR is WMO format, HDF5 is Open Software. The main reason to continue supporting two formats is that, in many member institutes, the existing infrastructure can support only one format or the other.

2. USEFUL SOFTWARE AND DATA COLLECTIONS

Data describing the radars has been collected in a radar database. It allows searches for typical values or extremes of such parameters as radar height or measurement range. Rinehart's classical book on radar meteorology has a drawing called radar envy: is his radar larger than mine? In addition to envy and curiosity, the radar database helps radar experts to find colleagues facing similar challenges: if you plan your first ever radar in the mountain range, you perhaps want to see what kind of solutions others have applied, and even get the contact information of those experienced radar owners.

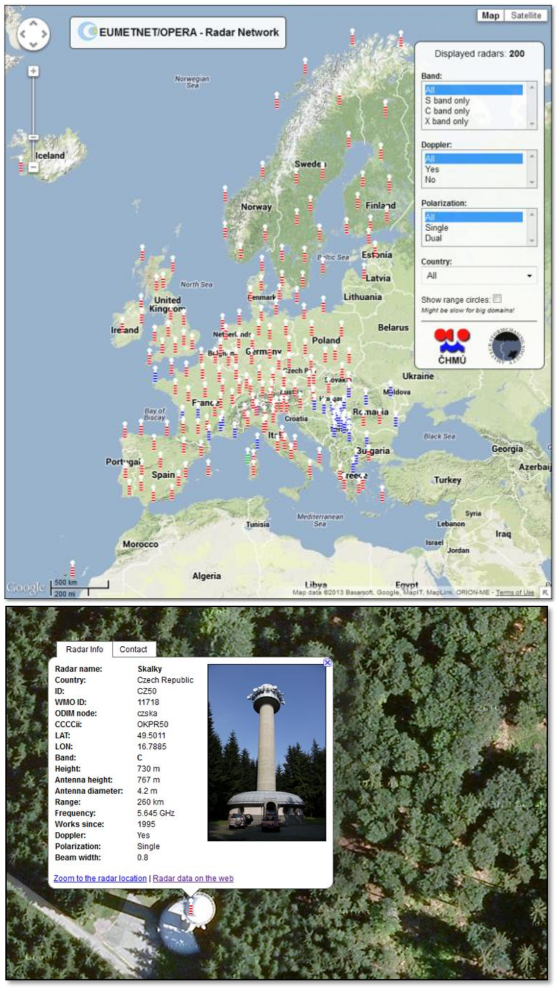

Fig 3 (left). Example of the use or radar database application in Google maps. Network overview (top), zoom to the individual radar location and display of its metadata. Courtesy of Google Maps TM.

The database contains the following information of each radar location, type (Doppler and or dual polarization), frequency band (X, C, S), max range, starting year, antenna height and diameter, beam width, gain, frequency in GHz. In OPERA4, members use a table in the internal wiki service to update this information, and the resulting tables are published regularly in the OPERA website.

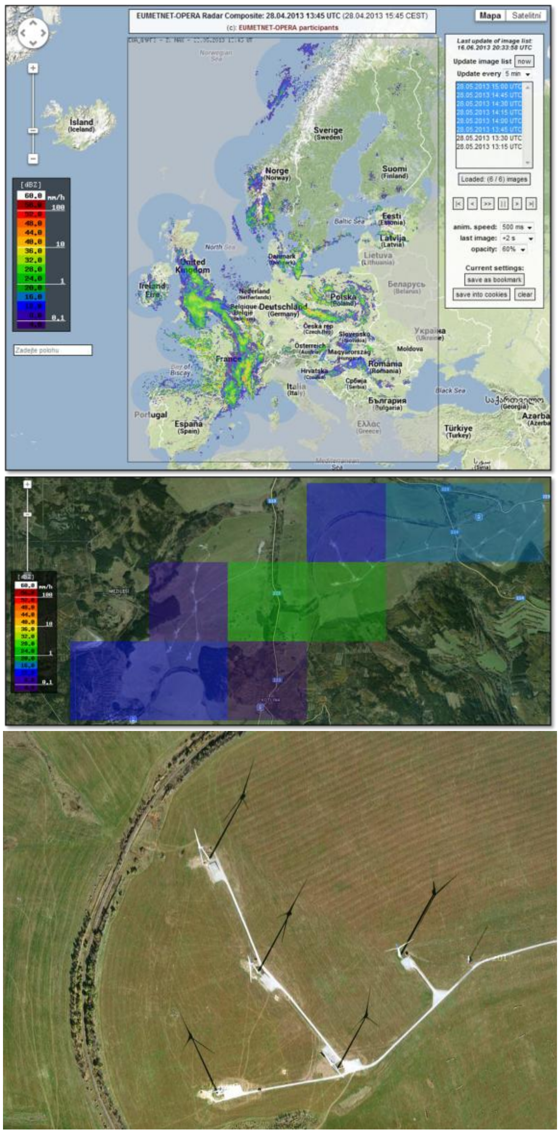

Fig 4. Examples of the application for visualization of radar data in Google maps. Visualization of OPERA composite (top), zoomed to the level of individual radar pixels, non-meteorological radar echo caused by wind turbines (middle), zoomed to wind turbines recognizable by their shadows (bottom). Courtesy of Google Maps ^{TM}.

The first Pilot hub was creating a mosaic of images and national composites. The real data hub, Odyssey, is building a composite from raw data volumes, allowing use of centralized cleaning and compositing methods. The compositing software and other parts of the Odyssey are described more in detail in paper by Scovell et al in the same conference.

A web-based tool that utilize Google Maps API was developed for visualization of radar locations from OPERA Radar Database and related metadata available on EUMETNET- OPERA webserver (Fig. 3).

A demonstration of visualizing the actual radar data in Google maps is shown in Figure 4. Utilization of Google Maps API is helpful in checking of metadata information of individual radars and also for identification of possible sources of decreased quality of radar data (e.g. remaining ground clutter caused by wind farms or partial beam blocking by mountains).

3. PROTECTION

OPERA is not only about exchanging radar data with your neighbours, which is illustrated by the fact that our members include Iceland (which has no neighbours) and Luxembourg (which has no radars). It is equally important, that it provides a platform where operational radar users can openly discuss plans and compare experience. Two topics which have been most actively discussed are windmills and frequency protection.

The classical ways to clean radar images are based on two characteristics of clutter targets (e.g. mountains): the clutter is not moving (hence allowing Doppler filtering) and it has the same size all the time (allowing statistical filtering). Wind turbines are an exception; the blades move and hence give Doppler speed, and the reflectivity depends on wind direction because turbines are turned to wind. For good coverage radars should be located to places with open horizon (such as hill tops) , and unfortunately these are also places favoured for wind farms. The clutter is seen from wind turbines several tens of kilometers away. OPERA has studied the impact of wind turbines, and in 2010 OPERA published “Statement on wind turbines”. It includes recommendation which states that within 5 km of a C-band radar and 10 km of an S-band radar no wind turbines should be built, and that within 20 km (30 km for S-band) the potential development should be assessed before proceeding. The recommendation has been endorsed by both EUMETNET and WMO. Recently, the industry has questioned the status of this statement, and in the present phase the issue is discussed again in OPERA:

Weather radars are not the only users of C-band and S-band frequencies. The same frequency bands are used for WLAN (Wireless Limited Area Networks), often known as RLAN (Radio LAN).. While the “WiFi services” are the WLAN applications best known for everyday users, the point-to-point connections executed using WLAN technology are most harmful for radar interference. The interferences from WLAN are a major problem in some European countries. Example of their detrimental effect is in Figure 5. The figure is from October 2012, after that OPERA has applied post-processing methods which partially mitigate the effect (Scovell, 2013).

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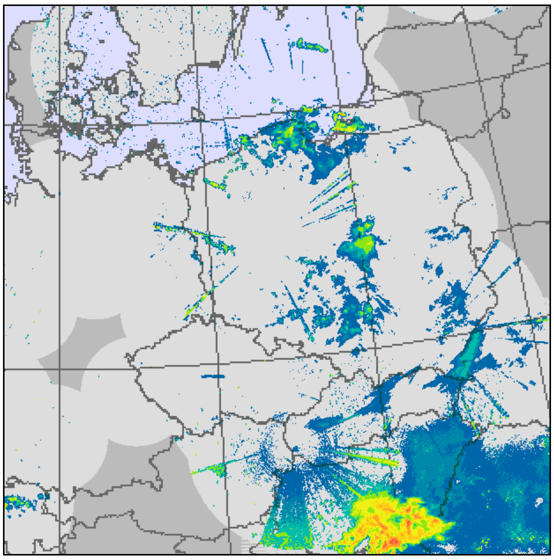

Figure 5. The spikes pointing to radar locations are caused by external emitters at the same frequency, and many of these are known to be WLAN stations.

Radio regulations should give protection to radar frequencies, but the supervision is not equally strict everywhere. EUMETNET has its own programme to protect frequencies needed for weather instruments EUMETFREQ (www.eumenet.eu/eumetfreq), and OPERA supports the work e.g. by providing examples of disturbances and increasing the awareness of the issue among its members

OPERA3 has prepared a Statement on processing RLAN interferences and Recommendation on coexistence with 5 GHz RLAN (Opera 2008 and 2009)

4. RADAR DATA USERS

Since the time of cathode ray displays, remote sensing instruments have been the devices providing pretty pictures. In 21st century, the use of radar *data* in addition or instead of radar *images* is growing fast. One big user group is the community of numerical weather prediction (NWP).

European Centre for Medium-range Weather Forecasts, ECMWF has successfully assimilated NEXRAD data in its global model, and the results show improvement in Europe on day 5 and Asia on day 8 (as the impact propagates downstream the storm track) (Lopez, 2011). They received composites from the OPERA pilot hub which were compared to other observations as well as ECMWF model data (Lopez, 2008). They have now started a similar evaluation of the more recent OPERA composites from the operational data hub, using both real time and archived data (since 2008).

The Limited Are Models (LAM) have expressed their wish to receive radial velocity data in polar volumes, and also more metadata. Metadata for velocity is rather straightforward, but important (what is the largest unambiguous speed for each sweep, how is the sign coded (positive towards or away from radar). For reflectivity, the biggest issue is different kind of zeroes: knowing between “no rain”, “no measurement” and “disregarded in quality control” makes a difference. This is where the heterogeneity of the OPERA add extra challenge: to get this metadata in the data files needs at least post-processing, often changes in settings of the signal processor, and sometimes even changes by the processor manufacturer.

Even though majority of OPERA radars are C-band, the distance between radars is so small (in average 128 km) that we can provide a reasonable coverage of Doppler data. Most members measure different tilts or tasks with different PRF schemas, resulting in different unambiguous velocities (Nyquist velocities). The typical lowest Nyquist velocities are 5-10 m/s, while the largest measurable velocities go up to 60 m/s.

The diversity of Nyquist velocities adds needs for metadata collection and it use in the assimilation end: it is not enough for the assimilation process to keep track of maximum unambiguous velocity by radar, and not even by elevation, but each task must be recognized. First assimilation tests have also shown, that there is no general standard of expressing whether negative velocities are towards or away from radars, each manufacturer has its own default values and in many cases even the user can set this. Hence, the sign must be included in metadata.

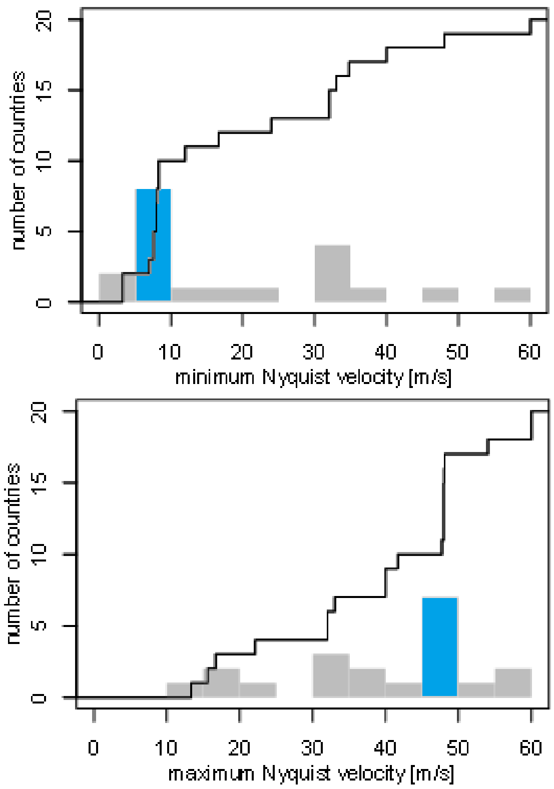

Fig 6. Distributions of minimum (upper panel) and maximum (lower panel) Nyquist velocities over countries. Grey bars show the distribution in classes of 5 m/s, blue bars show the most populated class and the black lines show the cumulative distribution

5. PLANS UNTIL 2017

OPERA4 consists of 25 separate tasks, each of them executed by 1-6 member institutes. The first 12 have started from 2013. Most of them focus on improving, planning and maintaining the Odyssey data hub. One task aims at preparing the future of Odyssey: future technical architecture, future quality codes and their future use. In 2015, the remaining tasks start building applications to be integrated to the architecture created in the first phase. OPERAs focus is on operational applications, it does not fund ambitious research projects, but it tries to bridge the academical innovations to operational work. The possibility to discuss applications and recommendations among 30 experts with different backgrounds and experience of different climates, hardware and software solutions gives both quality and credibility to results of OPERA:.

6. LESSONS LEARNED

OPERA 4 as just started, so there has not been many lessons to be learned yet.

The practical advice we got from OPERA 3 was to nominate a reviewer for each task, who will at least browse though deliverables before they are discussed in expert team meetings, pointing out the details which require wider attention.

By observing the success of earlier OPERA phases we have noticed the importance of open atmosphere in discussions. We devote a part of each meeting for national reports, and in these the members tell not only success stories but also about less fortunate experiments. “Learning from negative examples” (not making the same errors than others) has probably saved considerable amounts of resources among the members.

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The opera deliverables are available at http://www.eumetnet.eu/opera-documents

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