Advanced weather radar networking with BALTRAD+

Daniel Michelson

Daniel Michelson[1], Jarmo Koistinen[2], Tuomas Peltonen[3], Jan Szturc[4], Michael R. Rasmussen[5]

[1]*Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, dbm@baltrad.eu*

[2]*Finnish Meteorological Institute, Helsinki, Finland, jarmo.koistinen@fmi.fi*

[3]*Radiation and Nuclear Safety Authority, Helsinki, Finland, tuomas.peltonen@stuk.fi*

[4]*Institute of Meteorology and Water Management, Katowice, Poland, jan.szturc@imgw.pl*

[5]*Department of Civil Engineering, Aalborg University, Aalborg, Denmark, mr@civil.aau.dk*

(Dated: 29 May 2012)

1. Introduction

The BALTRAD project was carried out between February 2009 and January 2012. With funding from the EU's Baltic Sea Region Programme, eight partners in seven countries created the latest-generation network of weather radars, not as a prototype or proof-of-concept, but as an element of regional infrastructure. There was no funding for new radars in BALTRAD; instead the focus was on linking up all existing weather radars in the region, which was successfully accomplished. The concept that was implemented is decentralized, where partners exchange data on a peer-to-peer basis and then process all data locally, according to local needs, using a common "toolbox" containing data processing algorithms.

One of the pillars of the BALTRAD project was that it needed to demonstrate real added value to various end uses of radar data and products. Two pure end-user organizations were represented in the partnership. Through the creation of an Application Case Log, the value of radar to various uses and applications was documented, and real value of radar-based information from BALTRAD was demonstrated for general forecasting, aviation, radiation and nuclear safety, flooding and disaster management, and urban hydrology.

Starting in late January 2012, the BALTRAD+ project has taken over where BALTRAD left off. We now have a so-called extension-stage project with additional funding designed to implement transnational investments, ie. make outputs from BALTRAD fully operational. This paper presents the BALTRAD+ partnership and scope, and we also provide some highlights that have emerged from the BALTRAD project while looking ahead to what will emerge from BALTRAD+.

2. The partnership and project organization

BALTRAD+ consists of 13 partners in 10 countries (Table 1), most of which are the national weather and hydrological services. There are over 60 C-band weather radars in this partnership, several of which are modern dual-polarization systems. Additionally, we are transferring our radar networking and data processing technology to X-band systems for use in urban applications such as water management. Two such X-band systems are being trialed in Denmark. Associated with the partnership, but not a direct member, is the University of Hamburg that will also be trailing BALTRAD software for use with data from a network of X-band radars in Germany.

Table 1. The BALTRAD+ partnership.

Country	Partner	Main tasks
Norway	Norwegian Meteorological Institute	Software integration
Sweden	Swedish Meteorological and Hydrological Institute	Lead Partner
Finland	Finnish Meteorological Institute (FMI) Radiation and Nuclear Safety Authority (STUK)	FMI: Communications, algorithm documentation STUK: radiation and nuclear safety applications
Estonia	Estonian Meteorological and Hydrological Institute	Communications, software development
Latvia	Latvian Environment, Geology and Meteorology Agency	Leads the testing team
Lithuania	Lithuanian Hydrometeorological Service	Testing
Belarus	Republican Hydrometeorological Center	Testing
Poland	Institute of Meteorology and Water Management	Software development, Data quality management, End-user interaction
Germany	German Weather Service	WMO Information System integration
Denmark	Danish Meteorological Institute (DMI) Aalborg University, Dept. Civil Engineering (AAU) Aarhusvand A/S	DMI: software integration AAU: urban hydrology proof-of-concept Aarhusvand: urban hydrology proof-of-concept

BALTRAD+ has a budget of around 1.9 M€ and a two-year lifetime, ending on 31 December 2013. The co-funding responsibility ranges from 5-25%, where overhead costs are not eligible. So in practice, each partner co-funds a large proportion of its budget itself.

The project is organized into the following four work packages:

1. Administration. This is a mandatory work package designed to manage the project.
2. Communications. This is also mandatory, and geared towards facilitating both internal and external communications, e.g. with users of our system and its products, and giving presentations at conferences.
3. Realization of transnational investments. In a typical EU Interreg project, this would involve investing in physical objects like structures and related infrastructure. In our case, these investments comprise a small amount of computer hardware and a large amount of work effort designed for the partnership to create a permanent operational system that will live on through its own critical mass. One can say that this investment is in building the collaborative structure and its expertise.
4. Pilot investment and real-world use. The first part deals with transferring BALTRAD outputs from the main-stage project to X-band systems supporting applications at the municipal scale. The second part demonstrates the added value of this technology transfer through application in a multi-scale environment. We also have four so-called User Forum events in this work package, where we train and inform both technical users and end users of the information produced by the network and its system.

3. Technical solutions

The BALTRAD technical platform has been presented and described previously by Henja et al. (2010). This section serves to provide an update. The most fundamentally important aspect that hasn't changed is that BALTRAD software is developed for 64-bit Linux using the C/C++, Java, and Python programming languages. Exchanged data are in ODIM_H5 (HDF5) format, which is the modern European standard (Michelson et al. 2011).

The entire BALTRAD "node" concept, comprising communications, database, and product generation subsystems, will be organized into a resilient solution, meaning that multiple instances of the node will provide redundancy, thereby providing a solution with the highest possible uptime and availability.

3.1 Core subsystems

The data exchange subsystem is a Java Web Application using the Spring framework and a Tomcat server. Compared to its status in 2010, it has been simplified by dropping the use of the Hibernate framework. In early 2012, data exchange functionality was complemented with mechanisms for ensuring secure communications. This functionality is based on the use of exchanged public keys that are managed by Google's Keyczar package. It's worth noting that communications are secure in the sense that sensitive information is encrypted (as it should be), but that the connection between peer nodes in the network remains unencrypted. This brings the advantage that our communications solution can be used in environments where encryption using e.g. SSL is not allowed, while still ensuring that communications remain secure. During BALTRAD+, this functionality will continue to be refined.

The subsystem responsible for managing all data locally, called the BDB, uses a Postgres database to represent all metadata and store all ODIM_H5 files. The purpose of the BDB is to store all data consistently, and access them quickly and efficiently, without the complexity of SQL semantics. This achieved by mapping database-specific functionality to ODIM_H5 metadata groups and attributes, and through the use of high-level APIs. The original BDB was written in C++, but in late 2011 it was rewritten as a Python server with Python and Java clients. This rewrite brought with it the major advantage of easier code maintenance at the expense of a minor performance hit.

We have a subsystem written in Java called The Beast that is used for managing/scheduling data processing jobs and a few other things. The Beast operates on the concept of "adapters" and "routes", where the former is a way of communicating information and the latter is a set of criteria that must be fulfilled in order to use an adapter. The implementation imposes virtually no limitation on adding new adapters/routes. Most routes are simple and triggered on an event basis, but we have non-trivial routes as well, e.g. for generating polar volumes from a set of scans, and for generating composites from polar data sets.

3.2 Data processing

Data processing is performed using the so-called BALTRAD toolbox. This is a collection of software packages that centre around a common framework that offers harmonized functionality (written in C) for processing data. We are already exchanging conventional Doppler and dual-polarization data, so the ability to process all kinds of data is of central importance. See Gill et al. (2012) on how polarimetric moments are being treated. The toolbox's core functionality contains common routines for reading and writing ODIM data and manipulating them in various ways. During the BALTRAD project, we planned that the toolbox would have both Java and Python frameworks, needed for integration with the other subsystems, but in practice there was only demand for the one written in Python. However, during BALTRAD+, the Java framework is being developed that accesses the same underlying C functionality.

The toolbox has been created as an optional subsystem, acknowledging that some partners have other data processing solutions and are only using BALTRAD to exchange data. Software developed for the toolbox must nevertheless fulfill certain criteria in order for it to integrate properly in the overall system. This toolbox compliance can be achieved in three different ways:

- Integration using the toolbox APIs. This integration can be as simple as using only the routines for reading/writing ODIM data. The important thing is that these routines are used because it enables algorithms from different contributors to be run efficiently in memory, forming data processing chains without intermediate file I/O.
- External server. In this case, it's up to the contributor to provide an adapter for the Beast subsystem, so that it knows how to communicate with the external server. Similarly, the contributed external server must contain a so-called data injector, so that results generated by the server can be injected into the BALTRAD node.
- Shell-escape plugin. This is little more than example functionality, showing how the node can run an external binary on the command line. This is a suboptimal solution allowed in extreme cases where the user has no control over the external binary itself. It is then up to the user to formulate appropriate routes for this plugin, and ensure that results are injected back into the BALTRAD node.

The toolbox APIs map closely to the organization given in ODIM. This has yielded an efficient code base with a relatively small memory footprint. Henja and Michelson (2012) show how applying the BALTRAD toolbox to all available European weather radar data improves the quality of European composite products, and they also show how the use of the toolbox scales and performs.

3.3 Software availability

All BALTRAD software is available according to Open Source principles; the bulk of the software according to the Gnu Lesser General Public License. Our public repository is found at http://git.baltrad.eu/ and this is where a frequently asked questions (FAQ) and user guide provides information on how to install and use our system. We also operate a Trac project management and bug/issue tracking system. We welcome the community to contribute by offering access to these facilities.

4. BALTRAD Cookbook

Technical implementation and uninterrupted real time dissemination of international data products has been the main goal of weather radar networks until recent years (Collier 2001). While this challenge has been realized via solutions created e.g. in BALTRAD and in OPERA, a new challenge is arising among the users – the quality of the disseminated products doesn't fulfill regularly the user's requirements (Harrison et al., 2010). Thus quality algorithms are needed for improved performance of radar production. In principle Quality control (QC) in BALTRAD+ and in any radar system must cover all phases of the weather radar process from scanning and signal processing to end user product generation. Two important levels of QC must be recognized:

1. Quality algorithms generate categorical, probabilistic or deterministic indicators associated to the measured data (quality indicator level).
2. Quality index level contains the algebra how to apply the quality indicators in the end product of a specific application with specific user-defined quality requirements.

Traditionally QC has consisted of filtering and thresholding of measured data in an irreversible process in the radar signal processor. A more flexible future system better facilitating the level 2 QC above would store much of the "raw" data as such together with a number of quality indicators which are applied not earlier than in the user-specific product generation.

In BALTRAD+ we are far from ideal level 2 QC but apply corrections and improvements commonly used in many networks. The community has agreed on terminology in which a "recipe" becomes a tested and documented quality algorithm. The collection of recipes forms the BALTRAD+ Cookbook. Recipes will be documented (with the tool Trac) on a publicly available site applying the "flow chart" approach as the minimum requirement. This approach denotes that not necessarily all quality algorithms are written as executable codes but as process documents containing descriptions of the necessary input and output data as well as all physical and meteorological parameters, constraints and derivations the algorithm contains in order to be stable. Such an approach is reasonable as the technical solutions vary between countries and even among individual radars. For example, in most cases both conventional and polarimetric options are needed for a specific quality issue. Multiple solutions for the same quality issue and radar type are also allowed (e.g. low and high level solutions). Recipes are aimed for freely selectable operational implementation and the Cookbook is open to any recipe that can be seen useful to the community. The BALTRAD+ Workshop in Helsinki in January 2012 generated preliminary requirements of the content of a recipe. Additionally, the list of algorithms was mapped with realization weight (low, medium, high) and preliminary responsibilities at each Partner were given (Table 2). Referring to Table 2 some remarks are noteworthy: Compositing can be done in several places of the physical correction steps depending on the quality needs and type of the composite and thus, is not explicitly mentioned. Corrections for wind products are not included (e.g. for wind profiles one should remove birds but keep insects). The corrections are separated to those which correct measurements *in situ* (or "bin situ") and those which correct or estimate ground level conditions.

Table 2. BALTRAD+ quality algorithms of the highest priority.

Location	Quality algorithm
bin situ	Calibration of network power levels and pointing angles
bin situ	Diagnosis of non-meteorological echoes and hail, with a probabilistic indicators
bin situ	Attenuation due to rainfall
bin situ	Diagnosis of the strength of convection (updraft effects on DSD, VPR, bright band)

bin situ	Probabilistic diagnosis of the occurrence of overhanging precipitation in the lowest elevation PPI
bin situ	Diagnosis of precipitation type and PSD in the volume scan
ground	Correction of the effects of the VPR in dBZ
ground	Modification of dBZ due to hail for QPE
ground	Horizontal motion analysis of precipitation patterns and interpolation/extrapolation applying it
ground	Hydrometeor type analysis at ground level (applies: vertical hydroclass correction, AWS, NWP, satellite)
ground	Gauge-radar adjustment & integration

5. Cooperation with weather radar end users

Work in the frame of the BALTRAD+ Work Package 4 “Pilot investment and real-world use” are the continuation of activities performed within the BALTRAD project (Szturc et al., 2012). The first task of the new project in user-related topics is to work out “Catalogue of radar-based products which end-users are interested in”. The main way to define the fields of interest has been a survey by questionnaire, review of literature of the subject, and information collected during the BALTRAD+ User Forum. The questionnaire includes questions about radar data type, format (numerical or graphical), resolution (temporal and spatial), means of access, etc.

Investigation performed in touch with different groups of weather radar data end-users is still in progress, however some preliminary conclusions can be formulated:

- Hydrologists are more interested in forecasts than observed data. They still consider rain gauge network as more reliable data source, especially in case of the dense network.
- National meteorological services are interested in certain domains whereas other institutions (administrative, authority) in region or catchment-related data.
- Generally numerical information is desired as the most effective and flexible. Only in small number of cases other forms like graphical or text message (e.g. warning) are useful.
- Scientific users are more interested in extremely high-resolution data (1 to 5 minutes and 1 km), whereas for operational users slightly lower resolution is satisfactory (up to 10 minutes and 1-2 km).
- First of all the automatic way of data delivery is expected, such as through webpage or FTP protocol. Other ways of access to the data that require any activity from the user are not found useful.
- Quality information about radar data is highly desired. However it must be clearly and precisely defined in order to be understood.

A draft catalogue of data types that particular target groups of end-users found to be most useful was drawn up (Table 3).

Table 3. List of summarized expectation of weather radar data end-users.

Type of data	Product	End user groups
3-D data	Volumes of radar reflectivity *Z* and radial Doppler velocity *V*	Meteorologists, research, air traffic control, education, mass media
2-D precipitation products	Surface precipitation rate and accumulation *R*	Hydrologists, meteorologists, road and railway protection, radiation, hydropower, urban water, agriculture, ecology, research, education, mass media
	Type of surface precipitation *R*	Rescue services, road and railway protection, radiation, agriculture, research
	Nowcasting of surface precipitation *R*	Hydrologists, radiation, hydropower, urban water, research
2-D Doppler (wind) products	Surface wind velocity and direction **V**	Radiation, research, education, mass media
	Nowcasting of surface wind **V**	Radiation, research

Apart from the standard radar products some end-users require tailored radar-based products according to their specific expectations. The examples of the user’s dedicated products are the following:

- 3-D hazard index for air traffic control based on multi-phenomena algorithms with *Z* and *V* volumes as input data (e.g. Ośródka et al., 2010).
- Biological echo detection based on 3-D data *Z* and *V*, especially from dual-polarimetric radars (e.g. Pylkkö et al., 2008).
- Products for mass media and wide range of public (animated, colourful, etc.) (e.g. Celano et al., 2008).

7. Radiation and nuclear safety application

In the case of nuclear or radiological emergency or in exercise, a radiation protection authority has to provide an overview of the current situation and prepare countermeasure recommendations. Weather conditions are crucial when assessing environmental consequences of an accident resulting in a release of radioactive substances to the atmosphere. Airborne releases are transported by the wind, spread and diluted by turbulent atmospheric processes and deposited onto the ground by dry and wet scavenging (rain). Rain may increase deposition considerably and therefore also dose rates on the ground level.

The comparison between radiation data and rain data is also useful in routine conditions because rain brings down naturally occurring radionuclides and then higher dose rate levels are detected.

7.1 Information systems for nuclear or radiation emergency response in Finland

KETALE is a database and Web application intended to improve the collaborative decision support of Radiation and Nuclear Safety Authority (STUK) and of the Finnish Meteorological Institute (FMI) (Ammann et al. 2010). It integrates distributed modeling (weather forecasts and dispersion predictions by FMI, release and dose assessments by STUK) and facilitates collaboration and sharing of information. With the Web map component it is possible to view dose and dispersion calculations and also view and create countermeasure recommendations during accidents. BALTRAD rain data can also be viewed on the map as a separate layer. The example of viewing dispersion and rain data together is shown in the Fig. 1.

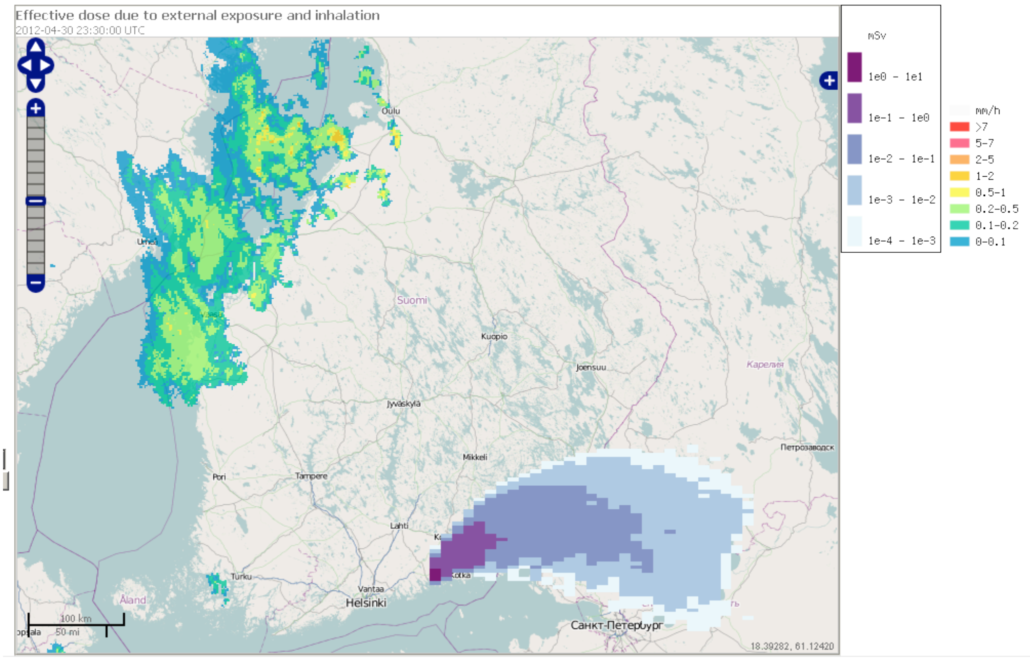

Figure. 1 KETALE map view within a browser. The map consists of three image layers: a background map, the dose prediction, and rain information from BALTRAD. The map can be interactively zoomed and panned. It is possible to bind the timestamp of dispersion layer with radar layer but layers can also be treated as separate.

BALTRAD data is also integrated to the national radiation monitoring Web application USVA. The Web map of USVA offers a spatial visualization of dose rate readings, their averages over the municipalities of Finland, and the time series of past dose rate measurements for example. It has the same map component with KETALE system and therefore USVA can use the same service to fetch radar images.

7.2 BALTRAD WMS interface

STUK has implemented WMS interface to view BALTRAD radar data. WMS (Web Map Service) is a standard protocol for serving georeferenced images over the Internet developed and published by the Open Geospatial Consortium (OGC®). Images are generated on the server side. In KETALE and USVA systems, WMS requests are generated by the Web map component that is built on top of the OpenLayers JavaScript API. OpenLayers supports multiple data layers from different sources. Image layers form a view handled by the Web browser. The layer technology speeds up zooming and panning the map and makes it possible to request data from different sources. There are available a lot of software that has support for WMS, Quantum GIS and Google Earth for instance.

BALTRAD radar layer is created using Mapserver software with Python bindings. With Python HDF5 libraries it is possible to extract numeric data from HDF5 and this information can be visualized. Mapserver can then handle data reprojection and other GIS-related tasks and then generate an image. In addition, WMS requests include information on geographic boundaries, style etc.

BALTRAD WMS interface is distributed within the BALTRAD software package. It is tested in some Linux distributions including BALTRAD development environment but in principle it is platform-independent. It is also independent of BALTRAD node and requires only HDF5 files to create radar images. BALTRAD WMS package will be further developed in BALTRAD+ project.

8. Transfer to X-band in support of urban hydrology

As a new activity in BALTRAD, Local Areal Weather Radar (LAWR) data are injected into the BALTRAD system. The small, short-range X-band radars are primarily used for urban hydrology. Their spatial resolution is 100 meters and the temporal resolution is 1 minute. This type of weather radar input is used to make short-term nowcasts for real-time control of storm drainage systems.

Real time weather radar data has only to a limited extent been available to urban drainage applications, due to the complexity of processing and delivering real time weather radar products (Einfalt et al, 2004). The LAWR data will be injected into the BALTRAD system though a specialized urban drainage node. Although, for all practical purposes, identical to all other nodes, the node preprocesses LAWR data into ODIM_H5 format before the data are injected into the node database. Also, data from other radars in the BALTRAD network are run though the BALTRAD toolbox and subsequently processed into a format readable by hydrological models. The objective is to make quality-controlled and processed weather radar data easily available for end users with urban drainage applications. LAWR data are used for analyzing historical events, while a combination of X-band and C-band data are used for nowcasting. The predicted precipitation patterns are used to model runoff, flooding and discharge of storm water into receiving waters. Based on an analysis of the consequences within the next few hours, a real-time control strategy is utilized to manage rainwater storage basins throughout the city. This will be demonstrated though the involvement of Aarhus Water Utility, which will integrate a BALTRAD node into their urban drainage management system.

A number of derived data, such as precipitation intensities, statistical return periods and accumulated precipitation are combined to produce a risk assessment map. This map makes is easy to process a large amount of weather radar information in a short time and decide which part of the city will have the highest risk of flooding. The map can be used to prioritize the resources in a response to flooding or to evaluate the severity of the event.

The BALTRAD software is in Denmark intended to be the primary system for delivering weather radar data to end-users within urban hydrology. The flexible and decentralized structure makes it well suited for the needs of water utilities.

Figure 2. Direct comparison between the LAWR X-band radar and the DMI Dualpol C-band radar at Virring near Aarhus, Denmark

Acknowledgment

BALTRAD+ is part funded by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument).

References

Ammann, M., Peltonen, T., Lahtinen, J., Vesterbacka, K., Summanen, T., Seppänen, M., Siljamo, P., Sarkanen, A. & Rantamäki, M., 2010: KETALE Web application to improve collaborative emergency management. *Proc.* International Conference on Information Systems for Crisis Response and Management 2010.

Celano, M., Siviero, F., Poli, V., Alberoni, P.P., and Di Giuseppe, F., 2008. Using Google Earth visualization platform to support the analysis of severe weather case studies. *Proc*. ERAD 2008, Helsinki, Finland

Collier,C.G. (Ed.), 2001: COST Action 75, Advanced weather radar systems 1993-97. Final report. European Commission, Brussels, 362 pp.

Einfalt, T., K. Arnbjerg-Nielsen, C. Golz, N. -E Jensen, M. Quirmbach, G. Vaes, and B. Vieux. 2004. Towards a Roadmap for use of Radar Rainfall Data in Urban Drainage. *Journal of Hydrology* 299 (3-4): 186-202.

Gill R. S., Soerensen M.B., Boevith T., Koistinen J., Peura M., Michelson D., and Cremonini R., 2012: BALTRAD dual polarization hydrometeor classifier. *Proc.* ERAD 2012 (this volume)

Harrison, D. L., Hafner, S., Peura, M., Dupuy, P., and Boscacci, M., 2010: Radar data quality management in operational environments. *Proc*., ERAD 2010, Sibiu, Romania.

Henja A., Szewczykowski M., Ernes S., and Michelson D., 2010: The BALTRAD technical platform. *Proc*. ERAD 2010. Sibiu, Romania

Henja A. and Michelson D., 2012: Improving the quality of European weather radar composites with the BALTRAD toolbox. *Proc.* ERAD 2012 (this volume)

Michelson D.B., Lewandowski R., Szewczykowski M., Beekhuis H., 2011: EUMETNET OPERA weather radar information model for implementation with the HDF5 file format. OPERA Working Document WD_2008_03, Version 2.1

Ośródka, K., Jurczyk, A., Dziewit, Z., Szturc, J., Korpus, L., 2010. MeteoFlight: System of weather hazard monitoring for air traffic control. *Proc*. ERAD 2010, Sibiu, Romania.

Pylkkö, P., Koistinen, J., Markkula, I., Ojanen, H., Tiilikkala, K., Raiskio, S., Leskinen, M., and Ooperi, S., 2008. Alarm system for insect migration using weather radars. *Proc*. ERAD 2008, Helsinki, Finland.

Szturc, J., Ośródka, K., Szewczykowski, M., Jurczyk, A., Lahtinen J., 2012. *Report on Application Case Log*. BALTRAD Project document W703 (see also BALTRAD project webpage: http://baltrad.eu/what-baltrad-offers-you).

Szturc J., Michelson D., Koistinen J., Haase G., Peura M., Gill R., Sørensen M., Ośródka K., and Jurczyk A., 2012: Data quality in the BALTRAD+ project. *Proc*. ERAD 2012 (this volume)