The FlySafe project: How weather radars can improve the en-route bird strike warning system.

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In civil aviation the majority of bird strikes occur below 1000 ft, thus civil bird strikes predominantly occur on and around aerodromes. In military aviation, however, the problem is two-fold. Coupled with the threat on and around airbases, lower operational altitudes create significant risks en-route, particularly during the migration season. While the local problem is tackled by reducing the number of birds around an airport, the en-route problem can only be addressed by avoiding extreme bird densities in flight. This is realised by radar-based BIRDTAMs, already issued for decades in north-western Europe. Although BIRDTAMS are successful, they may considerably restrict operations in space and time during mass migration events. Since training missions are costly, timely forecasts and more accurate altitude information are needed. These issues were partly addressed in the BAM and FlySafe projects between 2002 and 2009. During this time operational migration forecast models were developed as well as a bird recognition algorithm for weather radars.

Recent research aims to use weather radars to (1) develop improved bird migration prediction models; (2) develop altitude profiles of bird migration and (3) explore the extension of these activities to neighbouring countries.

This paper gives a broad overview of research activities related to en-route bird strike risk reduction and the operational implementation of the system for the Belgian and Netherlands Air Forces. We also provide an update on the potential for the European weather radar networks (OPERA, BALTRAD) to provide bird migration information throughout Europe, which would greatly facilitate a large-scale European bird warning system.

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Introduction

In civil aviation the majority of bird strikes occur at low altitude, indicating civil bird strikes predominantly occur on and around aerodromes. In a study on height distribution of civil aviation over a period of 15 years in the United States Dolbeer (2006) found 74% of the strikes below 500ft, 95% of all strikes occurred below 4000ft. In military aviation, however, the problem is two-fold. Coupled with the threat on and around airbases, lower operational flight altitudes of jet fighters create significant risks en-route, particularly during the migration season (Dekker & Van Gasteren 2005). While the local problem is tackled by reducing the number of birds around an airport (summarised in IBSC Best Practice Guides, www.int-birdstrike.org), the en-route problem can only be addressed by avoiding extreme bird densities in flight (e.g. Dekker et al. 2008). This is realised by radar-based BIRDTAMs, already issued for decades in north-western Europe and based on information of air-defence radars. Although BIRDTAMS are successful, they may considerably restrict operations in space and time during mass migration events. Since training missions are costly, timely forecasts and more accurate altitude information are needed. These issues were partly addressed in the Bird Avoidance Model (BAM) project between 2002 and 2005 (Shamoun-Baranes et al. 2008). Within this project the first operational autumn migration prediction model for flight safety was developed (van Belle et al. 2007).

Inspired by the development of the operational prediction model for flight safety in the BAM project by the University of Amsterdam (UvA), the Dutch Centre for Field Ornithology (SOVON) and the RNLAF, the European Space Agency (ESA) started the FlySafe project in 2007, a collaboration between various international research partners and air forces (Dekker et al. 2008, van Gasteren et al. 2008a, Ginati et al. 2010). The aim of the FlySafe project is to reduce the impact of bird strikes on military aviation, with the potential to expand the services to civil aviation and focused on three objectives (1) airport vicinity; (2) automated bird density measurements and now casts and (3) automated local bird intensity prediction models. A detailed description of the three objectives and the onset of the project was presented by Dekker et al. (2008). In this paper we will present the results of the en-route topics (objective 2 and 3) and the operational implementation of the system for the Belgian and Dutch air force. The great potential of weather radars as sensors for bird migration activity has resulted in shifting recent research activities to weather radars as bird sensors. New research activities initiated by the RNLAF, called FlySafe-2, are aimed to (1) develop bird migration prediction models, but now based on both air-defence and weather radars in The Netherlands and Belgium; (2) develop altitude profiles of bird migration based on weather radars and (3) explore the potential to tailor the bird detection algorithm to the weather radars from neighbouring countries. FlySafe-2 started in April 2011 for a three year period as a research project with the University of Amsterdam (UvA) and Royal Netherlands Meteorological Institute (KNMI). We also provide an update on the potential for the European Weather radar networks (OPERA, BALTRAD) to provide bird migration information over Europe, which would greatly facilitate a large scale European warning system.

Bird strikes

Bird strikes are unfortunately a regular returning phenomenon both in civil and military aviation. The distribution of bird strikes with military jet fighters in Europe over speed (figure 1) demonstrates the two-fold problem facing the militaries, with peaks around take-off/landing and typical low-level cruising speeds for military jets. Furthermore birdstrikes at high speeds en-route caused more than twice the amount of damage than lower speeds at landing or take-off phase (inset), 48% for en-route, respectively 23% for local birdstrikes (based on EURBASED data 1975-2009).

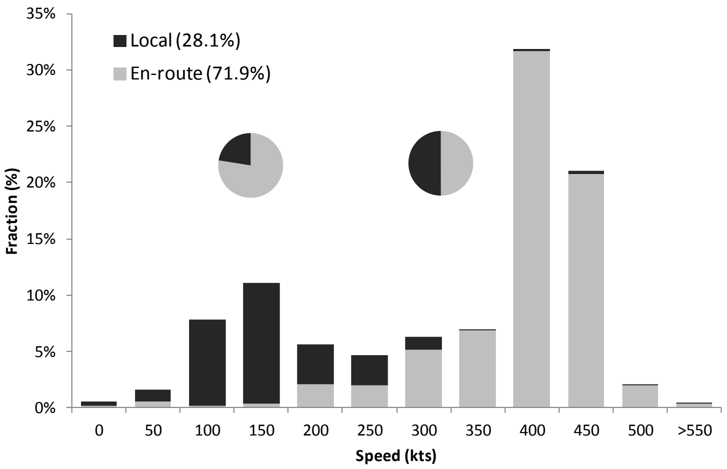

Figure 1 Proportional distribution of local and en-route birdstrikes over speeds of military fast jets (N 17,732). The proportion of damage for the two different classes is indicated by the dark part of the inserted circles. Data taken from the European Bird Strike Database (Dekker & Buurma, 1990), for the years 1975-2009.

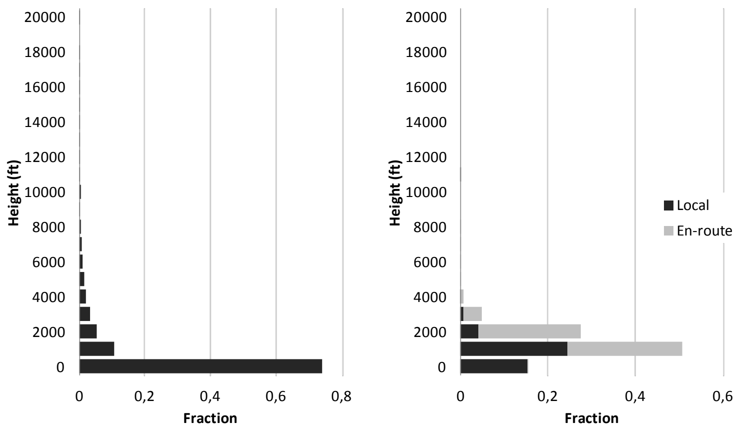

Figure 2 Proportional height distribution of bird strikes with civil aircraft (left) and per flight phase for military aircraft (right). Flight phase from civil aircraft is unknown, but dominated by local bird strikes. Data from civil aircraft taken from the United States from 1990-2004 (N 38,949), (Dolbeer, 2006). Data from military aircraft taken from RNLAF, 1976-2011 (N 2,210).

Steep climbing angles up to altitudes above 20,000ft and higher or descending from these high altitudes to an airport indicate the limited amount of time civil aircraft generally spent in the height layer where most of the bird movements occur and bird strikes happen. Typical altitudes for local bird movements are below 1,000ft and for bird migration up to 10,000ft. Military jet aircraft can operate at very low altitudes, depending on the type of exercise. Minimum flight altitude for jet fighters in The Netherlands, for example, is 1,200ft, while low-level routes can be flown at 250ft. The time spent in the altitude where the birds are is much larger in these military flights, which is indicated by the high frequency of en-route birdstrikes in figure 1. Nearly 85% of the military en-route birdstrikes occur in the height band of 1,000 – 3,000ft, figure 2. Unfortunately figures on the time aircraft spent in different height layers is unknown for military aircraft. Nevertheless, the striking difference in height distribution of birdstrikes between civil and military aviation indicates a big difference in operational use of these height layers.

The consequences of facing a birdstrike is also different between civil and military aviation. The indirect costs can increase rapidly in civil aviation when aircraft are grounded due to bird strikes and passengers are delayed and need to stay overnight. The costs of birdstrikes in civil aviation, including the effects of cancelled flights and delays, has been estimated at 1 – 1.5 billion USD per year worldwide in the early 2000's (Allan 2002). The data Allan (2002) was using, showed that 12% were direct costs due to damage to aircraft, while the other 88% were indirect costs of cancelations and delays. For military aircraft these indirect costs are less clear, but loss of mission time is costly and grounded aircraft cannot be used. McCloud (1992) calculated for the year October 1989 – September 1990 that the total downtime for the Royal Air Force was the equivalent to 14.4 aircraft being permanently grounded.

The FlySafe-1 project

FlySafe is one of the first pilot projects of the European Space Agency's (ESA) Integrated Applications Promotion (IAP) programme. In Europe, air forces issue BIRDTAM warnings (BIRD notice To AirMan) to their military pilots based on ground-based radar systems. Daily BIRDTAM warnings are issued in Germany, The Netherlands and Belgium. Until recently also Denmark issued daily BIRDTAM warnings. In The Netherlands alone, for example, daily BIRDTAM warnings resulted in a decrease of 45% of the en-route birdstrikes since the early 1990's. The aim of the FlySafe I project is therefore not primarily to reduce the number of birdstrikes, but to concentrate on (1) making the existing system automatic, person independent, robust and 24/7 operational; (2) add more reliable altitude information to the BIRDTAM warnings; (3) add more (ground-based) sensors to get a better geographical coverage and expandable to other European countries; (4) increase the temporal and spatial resolution of bird migration predictions and (5) couple bird migration models and measurements into nowcasts.

Towards a robust, person independent 24/7 operational system

One of the major pre-conditions of such a project is a well designed processing centre and central database, designed, developed and run by SARA Computing and Networking Services (www.sara.nl). Flat files from all ground-based radar sensors, meteorological model-data from ECMWF and bird-track data from weather radars is automatically sent, processed and added to the central database.

Once inserted in the central database, the data is ready for visualisation, model building and setting up operational services for different types of users. The database started with data from January 2006 and is still up and running. As an example of the amount of data stored in the database the individual bird tracks extracted from the Medium Power Radars of The Netherlands and Belgium are given per year in table 1.

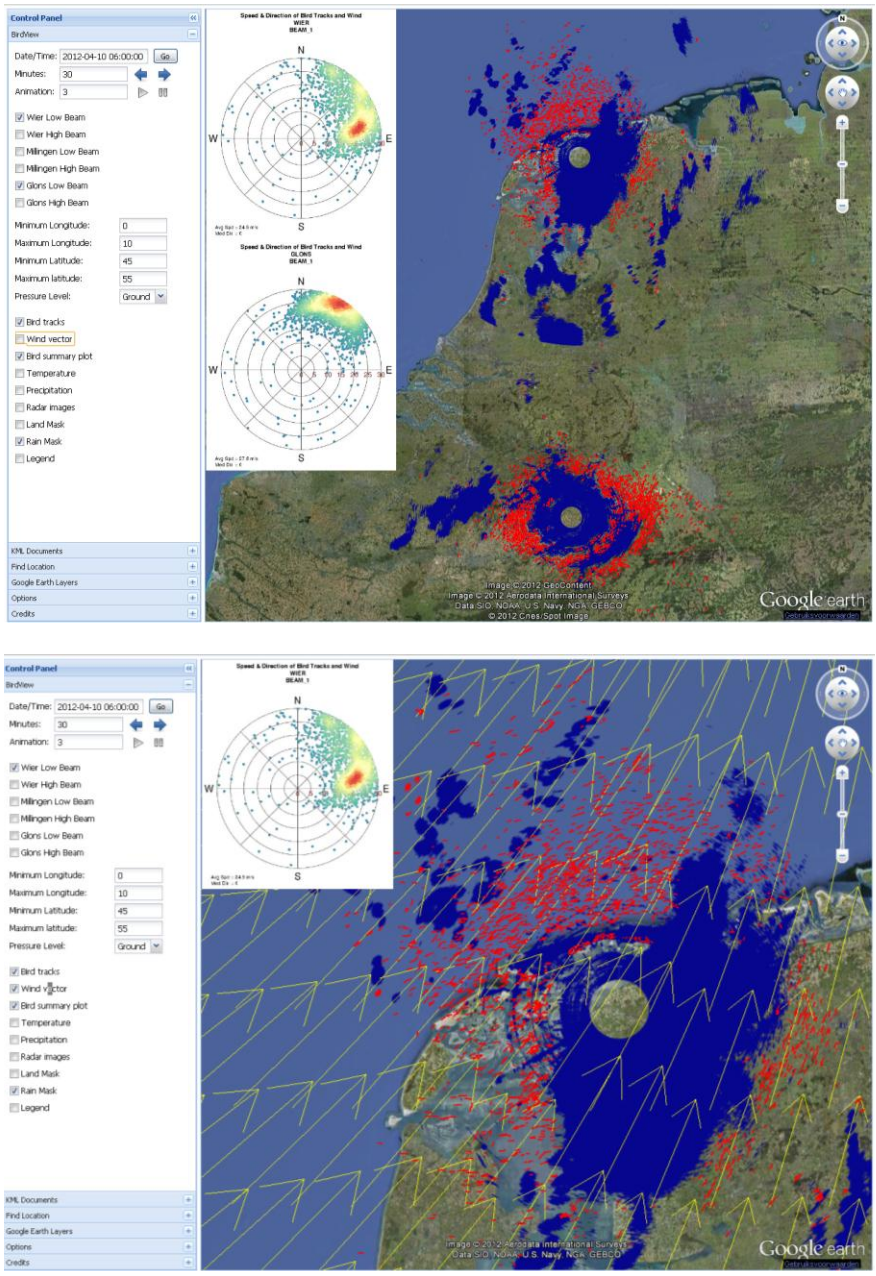

Figure 3 Birdview web service showing the information from the remote FlySafe database as different layers on the Google Earth web-browser plug-in. The top figure shows bird track data (red) from both MPR radars, together with precipitation (blue) and a bird summary plot showing the speed and direction of all tracks as a rose plot. The lower figure zooms in on the radar in the north of The Netherlands showing individual bird tracks, precipitation areas and wind vectors as different layers. The rose plot shows the scatter of speed and direction of individual tracks. 10 April 2012, 5:45 UTC.

To explore and visualise this amount of data, a new web service, 'Birdview', was developed to access this information directly from remote locations and interactively view multiple layers of FlySafe data (bird tracks, speed and direction plots, wind at different height layers, precipitation, temperatures). The 'Birdview' web service uses the Google Earth web-browser plug-in. The biggest advantage of using web browsers as a framework, is the possibility of advanced scripting that can be used for dynamic data querying and user interface customization, two things that are not supported in the standard Google Earth application. Examples of the 'Birdview' web service are presented in figure 3, which shows the data from April 10, 2012 at 5:45 UTC. In the north of The Netherlands birds above sea are flying on average 20 m/s with a mean track direction of 85 degrees. Above land birds fly much faster due to following winds, on average 29 m/s heading 45 degrees and in Belgium 28 m/s heading 30 degrees. In this case one can see at the same time bird migration arrivals from the UK (above sea) and France (above land). On the left the user is able to easily scroll through the data and switching on and off the different layers. The 'birdview' web service is used to explore the data, helping the user explaining the (sometimes weird) events by selecting different weather layers at different height intervals.

	2006	2007	2008	2009	2010	2011
Wier (NL)	35,594,185	39,865,910	43,661,909	41,119,602	28,069,880	31,439,863
Glons (B)	29,290,097	33,641,110	28,893,133	30,513,325	24,846,408	27,378,179

Table 1 Overview of the total number of bird tracks per Medium Power Radar per year as detected by the ROBIN bird detection system and stored in the FlySafe database. In total, about 260 million and 175 million tracks for the Wier and Glons radars respectively in 6 years time.

Local Bird migration prediction models

A bird migration prediction model for the autumn period was developed in the BAM project (2002-2005) by Van Belle et al. (2007). This model predicted bird migration intensity for the next two days and nights for the north of The Netherlands based on the MPR radar data. The disadvantage of the model was that weather data must be downloaded first, the model must be run and figures uploaded manually, furthermore it was limited to the autumn period for one location. Within the FlySafe project newly developed models should be automatic, robust, 24/7 throughout the whole year and for more locations (50 km NW and SE of both MPR radars equals to four different locations). Local forecast migration models were therefore developed to predict hourly migration intensity at four sites in the Netherlands and Belgium from local meteorological conditions (Kemp 2009). Bird density measurements from military surveillance radars (MPR) and modelled weather variables from the European Centre for Medium-Range Weather Forecast deterministic model (ECMWF), both stored in the SARA database, were used. A generic model building framework was designed to assist in data processing, model calibration and testing, and, ultimately, model selection. This framework was generic in that it was quickly adaptable to new locations and also allowed for some interactive data exploration and manipulation while maintaining a structured and consistent progression of modelling procedures. Utilizing this generic framework, models composed of multiple combinations of predictor variables were built and tested for each unique location, season, and diurnal period. The 50 best performing models for each location, season, and diurnal period were retained to provide an ensemble forecast for migration intensity up to 72 hours into the future. Migration predictions (72 hour forecast), as well as the predictions and measurements from the previous seven days, were made available on the Internet as a completely automated system, figure 4.

One of the more significant findings during the development of the local forecast models was, unfortunately, that the measured bird densities were occasionally spurious. The Robin clutter filters, which were supposed to account for sources of clutter in the calculation of bird density, were inadequate in their classification of light precipitation. Meaning that, at times, precipitation (drizzle) was interpreted as though it were birds and vice versa. This situation hampered the development of accurate models and the assessment of model performance, particularly regarding high densities, and will continue to do so until the issue of rain "contamination" is resolved. As such, significant model improvement in the future is only expected when the quality of the measurements have been considerably enhanced. In the mean time using a combination of the model and the meteorological information sufficiently facilitates the operator for day to day operations.

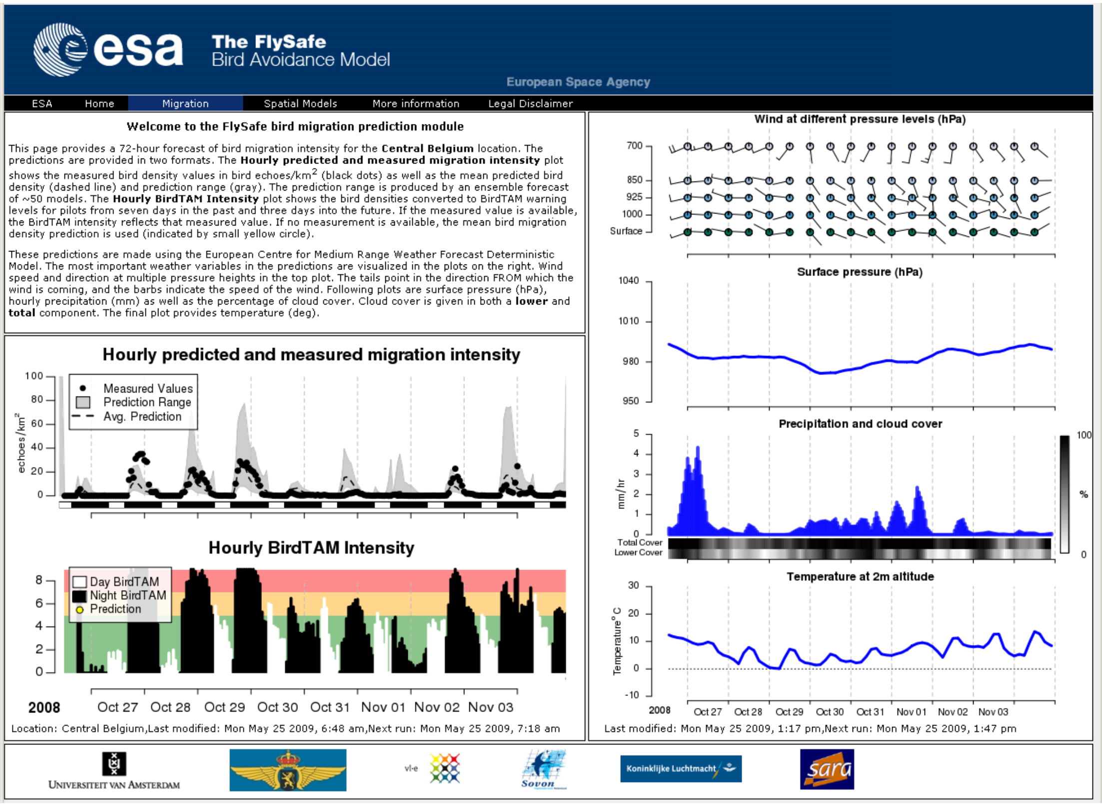

Figure 4 The FlySafe Bird migration prediction module for the location central Belgium, 27 October – 3 November 2008. On the top left the hourly predicted (dashed line with range in gray) and measured (black dots) migration intensity plot with the bird densities converted to BIRDTAM warning levels for pilots down left. The most important weather variables in the predictions are visualized in the plots right.

We tested the overall reliability of the 24-hour model compared to that achieved by the earlier 'van Belle model' (van Belle et al. 2007). Especially for the more relevant, higher densities, the overall accuracy of the new models was better than the 'van Belle model' (Kemp 2009).

The use of weather radars as bird sensors

Wind measurements by Doppler weather radars and wind profilers have been introduced in the early 1990's in meteorology. Already from the first measurements contaminations by birds and insects were found (Wilson et al. 1994, Martin & Shapiro 2007). A Doppler weather radar measures the pulse volume and reflectivity-weighted radial component of the velocity of scatterers, i.e. the velocity towards the radar. Birds flying homogeneous into one direction will result on the radar screen as a sine curve with peaks into the azimuth direction; birds are flying towards or away from the radar. The wind speed and direction can be determined from the amplitude and the phase of the sine, respectively. This well known technique is called velocity–azimuth display (VAD) (Lhermitte & Atlas 1961, Browning & Wexler 1968). The amount of scatter around this sine curve can be quantified

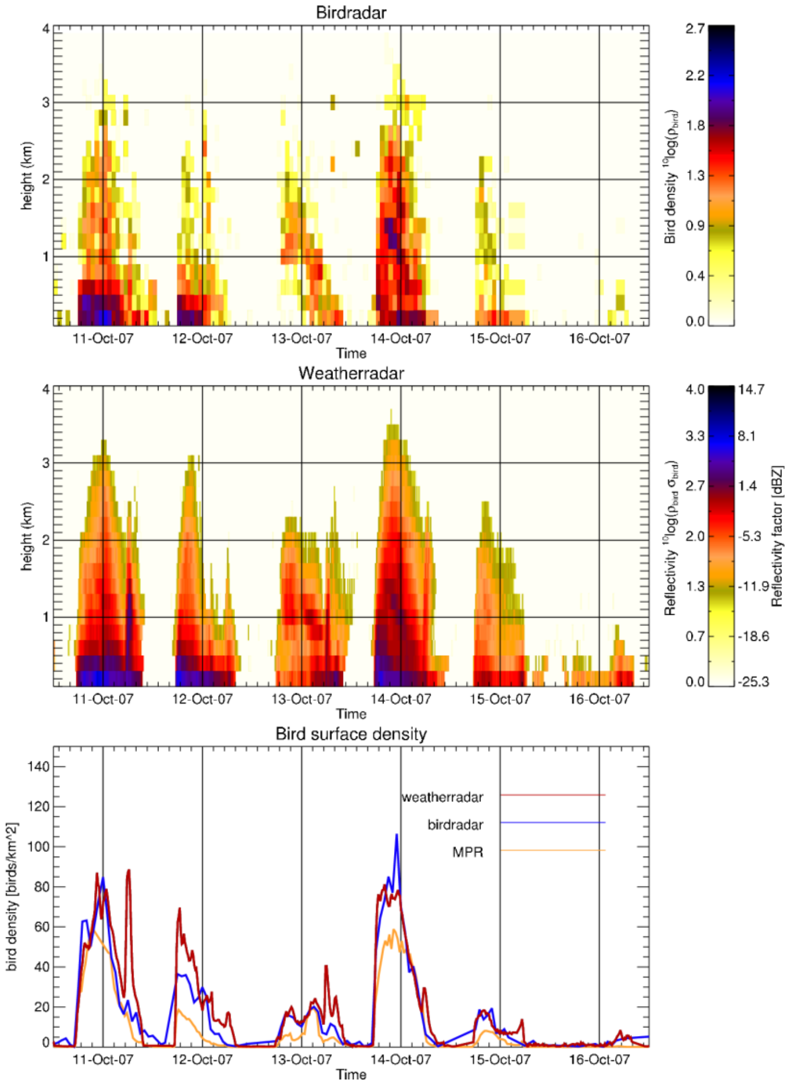

Figure 5 Retrieved time-height profiles by bird radar (top) and weather radar (middle). The vertical integrated bird densities are shown in the lower panel. The bird densities (colors) are given along a logarithmic scale. Yellow/gray equals 1 bird per km^3, red starts with 10 birds per km^3 and blue indicates values of 100 birds per km^3 and up.

as the radial velocity standard deviation, which is a good indicator to discriminate between weather, insects and birds (Holleman et al. 2008, Van Gasteren et al. 2008b). This algorithm was successfully applied in a study to profile bird migration (Van Gasteren et al. 2008b). It was shown in this study that altitude layers with a high standard deviation of radial velocity occurred on height layers where bird migration was detected by an independent bird radar. Reliable quantification of bird migration with altitude could not be demonstrated owing to the large distance between the weather radar and bird radar (80 km).

The big breakthrough came from a follow on study in the FlySafe project where Doppler weather radar data have been validated against simultaneous and co-located bird density measurements by a high precision bird radar (Dokter et al. 2009, 2011). The mobile bird tracking radar has been stationed next to weather radars in The Netherlands, Belgium and France in autumn 2007 and spring 2008. In this study it was found that Doppler weather radar was highly successful in determining quantitative bird density profiles. The detection probability was very high (99%) and the fraction of false alarms low (2%). See figure 5 for an example of the validation of the bird radar against the weather radar. To get an idea of the number of birds which pass the radar screen during a night or more precise a 1 km line during the peak passage in the night of October 14, 2007 (see figure 5) bird densities must be multiplied by 3.6 * mean groundspeed, which equals 6338 birds per km front per hour or more than 57,000 birds per night over 1 km front. Assuming homogenous bird migration over the Ardennes (the location of the weather radar) this equals to nearly 6 million birds in one night over a 100 km wide front, which is small compared to normal broad front migration in NW-Europe.

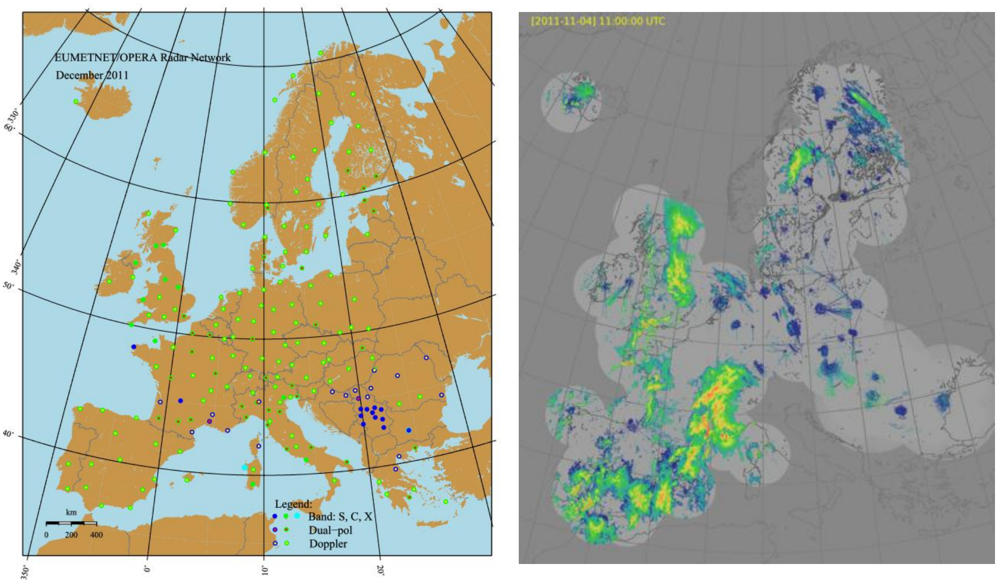

Figure 6 Distribution of all weather radars in Europe (left) and an example of the radar composite (right) from those countries which joined the OPERA and BALTRAD project. Now only weather is shown in the radar composite, which will hopefully be replaced by a dedicated bird movement composite in near future. See www.knmi.nl/opera.

Many European air forces have no en-route bird risk reduction programme at all and it's not foreseen that many more air defence radars will be accessible in the near future. Up scaling bird migration detection by radar to a European wide scale based on weather radars offers an excellent opportunity, see figure 6 for the distribution and coverage of weather radars in Europe. Many countries are a member of the Operational Program on Exchange of Radar data (OPERA) running within EUMETNET or BALTRAD (an advanced weather radar network for the Baltic Sea Region, www.baltrad.eu), which provides a framework to enable the weather services to work together. The establishment of the OPERA data centre in 2011 (Dupuy et al. 2010) can easily improve access to the radars in different countries. Apart from highly improved bird strike warnings over large parts of Europe (!), such a network would yield invaluable information for scientific research on bird migration. Anticipating to this wealth of unique data the RNALF initiated a research project with the UvA and KNMI, called FlySafe 2. The objectives and first results of this project are presented in the next chapter.

FlySafe-2 project, aims and first results

While FlySafe-1 predominantly focused on bird migration density predictions based on military air defense radars in The Netherlands and Belgium, FlySafe-2 will work towards expanding the radar network spatially by including more operational European weather radars to monitor and predict migratory bird movements over a much larger area. Taking the bird migration algorithm for weather radars developed by Dokter et al. (2011) as a starting point for new research, the activities are divided into three work packages:

1. **Develop bird migration prediction models, based on weather radars in The Netherlands and Belgium**. Bird migration prediction models in the BAM- and FlySafe-1 project are based on military air defence radars from The Netherlands and Belgium. This work package will develop comparable bird migration prediction models, using bird migration densities from three weather radars (2 in The Netherlands, 1 in Belgium). The generic model framework developed in FlySafe-1 will be used to expand to the two other Belgium weather radars when at least three years of data is available. The contamination, due to inadequate classification of light rain in the air defence bird migration densities, is much better classified as such in weather radar data. It's therefore expected that the new set of bird migration prediction models will perform much better at high bird densities, which are the high risk situations where BIRDTAM's are issued for.

2. **Develop altitude profiles of bird migration based on the weather radars in The Netherlands and Belgium**. In all current bird migration prediction models, no information on altitude is available. Detailed altitude information of bird migration is not available in military air defence radars, but is in weather radars. The algorithm developed in the FlySafe-1 project (Dokter et al. 2011) created a dataset of two Spring and Autumn seasons for the weather radars in The Netherlands and one Autumn season in Belgium. These bird migration profiles will be used to develop altitudinal bird migration predictions.

3. **Explore the potential to tailor the bird detection algorithm to weather radars from neighbouring countries**. Even the daily operations of the Royal Netherlands Air force go beyond the coverage of our own (bird) radars. We therefore need to expand bird migration measurements and predictions spatially by incorporating radar measurements from neighbouring countries. Within the FlySafe-2 project an inventory of potential weather radars on the axis from Scandinavia towards SW-Europe are the most important ones to explore this first step. The existing bird algorithms will be tested against at least 6 weather radars on this axis. The weak signals of birds are sensitive to disturbances, such as noise and clutter, than those from weather. Furthermore they vary from radar to radar and it's therefore not straightforward to apply the existing algorithms for bird detection to data from different radars. The challenge is to adapt the existing algorithm so that it can cope with

these varying radar characteristics and yield consistent bird migration data for all radars in the network.

The starting point for the FlySafe-2 project is far from setting up a new project, it was more like jumping on a (slowly) moving train after a period of three years. Both the SARA processing centre as well as the core of the UvA and KNMI researchers were familiar with the data and the project. At this moment we passed the exploration phase in the last two work packages. The first results on the prediction of the altitude distribution of migrating birds, during nocturnal peak migration three hours after sunset, are encouraging and a paper has already been submitted (Kemp et al, submitted). One remarkable finding was that nocturnal migrants in the mid-latitude area generally decreases non-linearly with altitude. Factors such as tailwind in relation to surface head winds and temperature do influence flight altitude as well. Under very specific conditions layering events, i.e. when peak densities occur at higher altitudes (with lower densities below), do occur, particular in Spring.

The third work package concentrated on adapting the existing algorithm so that it can cope with varying radar characteristics and yield consistent bird migration data for all radars in the network. Current work is concentrated on defining dynamic clutter maps, in a selection of radars from figure 7.

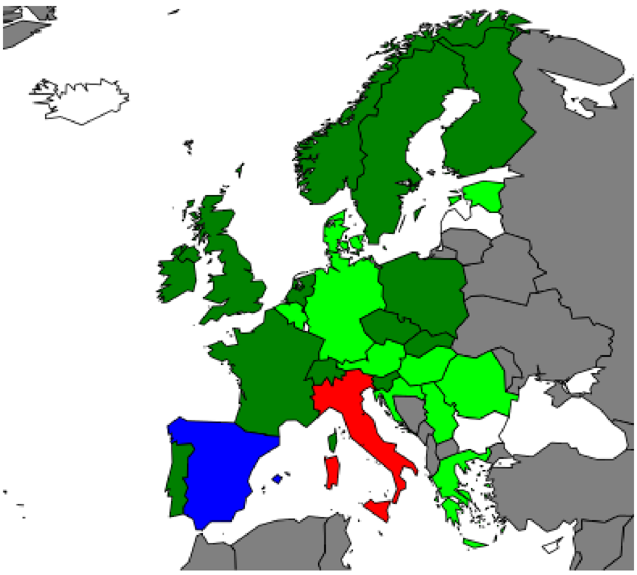

Figure 7 Countries contributing weather radar data (green) for a test period. Spain did not reply yet and Italy cannot supply data (update November 2011).

The FlySafe products

Both FlySafe-1 and FlySafe-2 are research projects. All sensor data, visualizations and products are stored on a research project server, which will finally close after the projects. This would also hold for the bird migration predictions (figure 4). The FlySafe research products will therefore be moved to a sustainable, operational, automatic, 24/7 service which will be hosted outside the FlySafe projects. The ESA, BAF and RNLAF initiated this phase, called FlySafe operational service centre, in 2011. The goal of the project is to establish this service in an operational setting. The importance of weather in bird migration prediction models, the cooperation between the RNLAF and the KNMI as well as the 24/7 operational infrastructure at the weather service made the KNMI a good host for the sustainable bird migration services. Apart from these bird migration predictions and BIRDTAM intensities for four different locations (figure 4), also the height density profiles from five operational weather radars (3 in Belgium, 2 in The Netherlands) will be provided according to the bird migration algorithms for weather radars as developed by Dokter et al. (2011). This new web service is available at www.flysafe-birdtam.eu, figure 8 and will replace the website currently running at SARA (see figure 4).

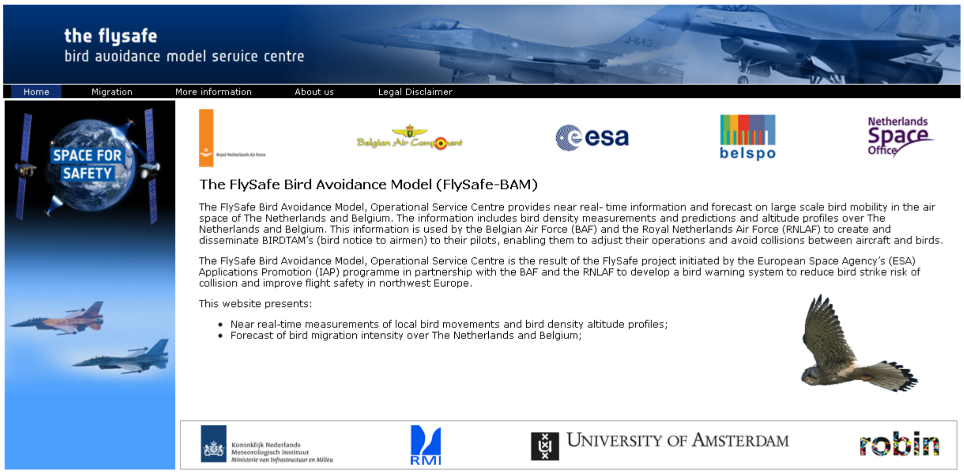

Figure 8 The new operational FlySafe bird avoidance model service centre (www.flysafe-birdtam.eu) providing near real time information and predictions on large scale bird movements in the air space of Belgium and The Netherlands. Furthermore, altitude density profiles of birds extracted from operational weather radars, indicate the altitude at which bird strike risk is highest.

Future products from the FlySafe research project(s) will be made available through this new service too.

Applying the principles to local bird strike prevention

Long term local birdstrike ratio's in The Netherlands show that the introduction of professional bird control reduced the birdstrike ratio considerably (figure 9). Despite all efforts there seems to be a lower limit in local bird strikes based on traditional bird strike prevention involving bird control and habitat management, mentioned as bird control 1.0 and 2.0 (Dekker et al 2011). Considering the increasing number of aircraft movements in the near future, the worldwide birdstrike problem can not be ignored. Particular looking at increasing geese populations in both Europe and the US an increase in the proportion of serious incidents is to be expected. Can we apply the principle of intervention in flight operations, as is done in en-route bird strike prevention, to the local situation? In other words, can radar or any other 24/7 automatic sensor, bring the local bird strike ratio further down on top of the current efforts mentioned above? The local bird strike prevention has always been focused on the reduction of birds on an airport or in the airport vicinity, but never on intervention in flight operations. Dedicated bird radars are on the market now. The next step should be set on small or medium airports to develop specific concepts-of-operations for different types of users (bird controllers, air traffic controllers and possibly even pilots).

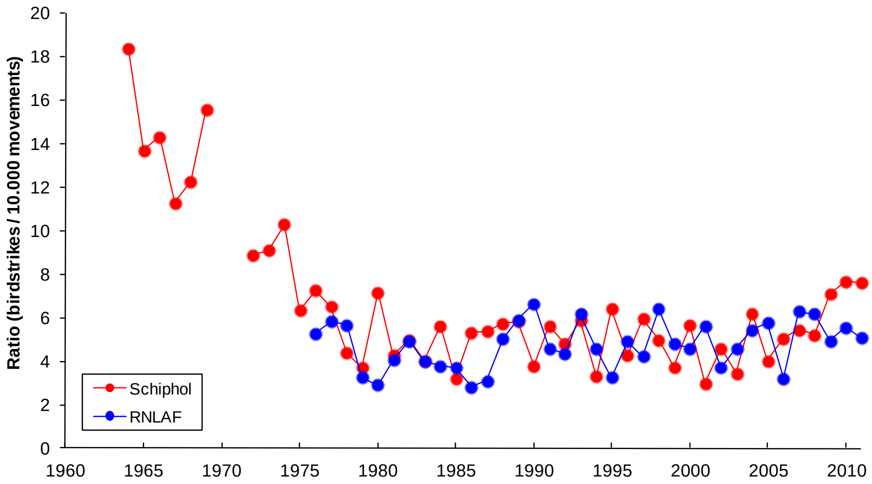

Figure 9 Long term local birdstrike ratio (birdstrikes per 10,000 movements) in The Netherlands on civil (Schiphol) and all military airports (RNLAF). Since 2007 the Schiphol figures are provided by the main airliner company, responsible for 60-70% of the movements.

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