Bird migration monitoring across Europe using weather radar

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Abstract

It has recently been shown that weather radars can be used to monitor bird migration for single radars. Given the recent developments in the OPERA network on harmonization of radar practices and data formats, it is becoming increasingly feasible to use this technique for monitoring bird migration across Europe. Reflections from birds (around -10 dBZ) are generally much weaker and more sensitive to disturbances, such as noise and clutter, than those from weather. These disturbances vary from radar to radar, because of different radar types (e.g. signal to noise ratio) and siting (e.g. clutter). It is therefore not straightforward to apply existing algorithms for bird detection to data from different radars. This means that the extent to which different radars in the network are suitable for bird migration monitoring may vary. 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 adaptation of the algorithm will not only allow us to use networks of radars to monitor bird migration, but also to formulate requirements for radar characteristics to monitor bird migration. The adapted algorithm may be applied to volume data from the OPERA network. This is foreseen for the near future using data from the autumn of 2011 from several stations in western Europe. With the resulting data bird migration can be studied at an unprecedented scale.

1. Introduction

Operational weather radar can be used to monitor bird migration as a function of altitude and time (Dokter et al., 2010). In particular, C-band Doppler weather radars are suitable to provide automated information on bird migration (Van Gasteren et al., 2008). A network of weather radars across Europe that are prepared to measure bird densities would provide invaluable information on bird movements over large distances, both horizontally and vertically, and in time. Spatio-temporal bird density information could provide information on bird migration patterns over large areas, information on external factors impacting bird migration routes, information on bird densities as a function of altitude and time, which can help aviation safety, and information on avian-borne diseases, among others. Dense European meteorological radar networks are already available, often used for the detection of precipitation on a European-wide scale. Weather radars from the European Operational Programme for the Exchange of weather RAadar information (OPERA) network (Fig.1) may be used to implement the bird retrieval algorithm to monitor bird densities over a large area. The OPERA network consists of different types of radar. An existing bird density retrieval algorithm, developed and operated for the Dutch C-band Doppler radars in De Bilt and Den Helder can be implemented for operational C-band Doppler radars across western Europe. The main challenges to overcome for a successful implementation of this algorithm to other radar systems are the handling of noise and clutter, which can vary considerably for different radar systems. This is particularly important for bird retrieval algorithms, which are more sensitive to noise and clutter, due to the weak reflections from birds as compared to precipitation. Other challenges for the retrieval of consistent bird density profiles for all radars in the network are the harmonisation of the data formats, the data information content and the scanning strategies, which are integral issues for the OPERA network.
2. Bird density retrieval algorithm

A bird density retrieval algorithm for C-band Doppler radar was developed for the Dutch weather radars in De Bilt and Den Helder (Dokter, 2009). The algorithm uses several filters to distinguish between precipitation, insect and bird echoes.

2.1 Reflectivity filter

The reflectivity factor $Z$ from bird scattering is typically low, in the order of about -10 to 10 dBZ, for C-band radars. In general, reflectivity factors from precipitation are much higher, but both insects and precipitation can also give rise to signals similar in strength to those from birds. Therefore, additional filters are needed to distinguish birds from other scatterers.

In order to filter strong precipitation areas, a reflectivity threshold is used. All range gates with a reflectivity higher than 0 dBZ are considered to contain precipitation, with the additional criterion that at least 5 neighbouring range gates also contain a reflectivity higher than this threshold. The latter 'uniform filling' criterion ensures that only cells are selected as precipitation which are uniformly filled. This uniformity is often observed for areas with precipitation, but often not for areas with birds.

All range gates that were not (yet) identified as precipitation areas on the basis of the reflectivity threshold are further filtered on velocity variation, which is different for precipitation, birds, and insects.

2.2 Velocity variation filter

In addition to reflectivity filtering, a filter is applied to the Doppler radial velocity variation field. Typically, areas of precipitation show a radial velocity $v_r$ that is spatially continuous and locally homogenous. The speed of hydrometeors is determined by the wind field and the terminal velocity, which are usually spatially smooth variables, except in the case of strong convective systems. Similarly, insects and other, passive, scatterers that can be lifted into the air by convection during clear weather, produce radial velocities that are completely determined by the wind velocity. This is because insects have active flight speeds that are either negligible or non-directional on average.
Bird migration, on the other hand, gives rise to a much greater variation in the radial velocity field. Active flight from birds may vary in speed and direction for individual birds, while the individual direction of flight is mostly independent from the wind direction. Therefore, the radial velocity for birds has a higher degree of (local) spatial variation. Furthermore, migrating birds give rise to scattered groups of range gates with valid data, causing the radial velocity field to be inhomogeneously filled (Dokter et al., 2009).

The variation in radial velocity is quantified by determining the local standard deviation $\sigma_v$ of $v_r$ for each considered range gate, using its 8 direct neighbours. The difference in reflectivity factor $Z$, the radial velocity $v_r$ and the local standard deviation in radial velocity $\sigma_v$ is illustrated in Fig.2 for precipitation, insects and birds.

![Figure 2](image-url)

*Figure 2. Reflectivity factor Z (left), radial velocity $v_r$ (middle) and radial velocity standard deviation $\sigma_v$ (right) Plan Position Indicators (PPIs) for a case of precipitation (a,b,c), a case of clear air without birds during daytime (d,e,f) which are probably caused by insects, and a case of intense bird migration (g,h,i) (Dokter et al, 2009).*
3. Clutter

3.1 Static clutter maps

Clutter filtering is particularly important for the correct determination of the weak bird reflections. Currently, a static clutter map is implemented in the bird retrieval algorithm, valid for De Bilt and Den Helder only. All pixels with reflectivity values exceeding a certain threshold (-10 dBZ) are identified as clutter and rejected for the retrieval of birds. This ensures that ground clutter will have a limited effect on retrieved bird densities. The static clutter map was constructed by averaging all clutter-corrected reflectivity values of a given radar pixel over a given dry period. This dry period should be carefully selected so that no significant influence of insects or birds is expected. The current clutter map was created using reflectivities averaged over 14-19 February 2008. The static clutter map should be updated regularly (e.g. once per year), as buildings may be erected or demolished. This requires manual selection of dry periods, which can be time-consuming. This is close to impossible when the method is applied to data from the approximately 200 radars in the OPERA network.

3.2 Dynamic clutter maps

An alternative method of constructing clutter maps is by using long-term statistics of reflectivity (Donaldson, 2010). The advantage of this is that it can be done automatically. The basic assumption behind this method is that at least a certain percentage of the time the radar data are not affected by precipitation, insects, or birds. The clutter map can then be defined as the 25th percentile, median (i.e. 50th percentile), or mode of the reflectivity values of each pixel. These statistics are all insensitive of the values of the higher reflectivities. We use uncorrected reflectivity for this purpose as we would like to ensure that the Doppler clutter filter applied to the data has limited influence on the retrieved bird densities.

Figure 3 shows an example of the probability density function of the uncorrected reflectivity of a pixel from the radar in De Bilt for the year 2011 and the month of April 2012. Also shown in this figure are the 25th percentile, median, and mode corresponding to the 2011 data. The figure clearly shows the peak caused by clutter around -10 dBZ, and the signals from precipitation above these values. It is also shown that the probability density over a given month is very similar to that taken over an entire year. This means that this method could be applied to 1-month statistics without losing robustness. For robustness we select the mode as the statistic to use for construction of the clutter maps. Figure 3 shows that this is very close to both the 25th and 50th percentiles.

The effect of the old static and new dynamic clutter maps is shown in Figure 4. It shows the bird density retrievals for the De Bilt radar from 25 to 31 May 2012 using (a) the old static clutter map and (b) the dynamic clutter map, that was created using the mode of all 2011 data. The effect of the dynamic clutter map is to remove all signals in the lowest elevations, so effectively the radar becomes blind to bird movements below about 200 m. These signals are mainly caused by clear-air echoes from insects in the summer months. This means that the 2011 mode is a too severe condition to serve as a clutter filter in this case.

![Fig 3. Probability density function of the uncorrected reflectivity of a radar pixel (elevation 1.1 degrees, azimuth 61 degrees, range 6.5 km) of the radar in De Bilt for the year 2011 (solid black line) and the month of April 2012 (solid grey line). The mode, median and 25th percentile for the year 2011 are shown by the dashed blue line, solid green line and solid red line, respectively.](image-url)
Conclusions

The ongoing efforts within the European OPERA weather radar network provide opportunities for bird migration monitoring across Europe. Synchronisation of data formats and scanning strategies helps the consistent retrieval of bird density estimates from various radar systems along the migration routes. Bird reflections are generally weak, so the correct filtering of clutter is particularly important for the retrieval of bird density estimates. Here, we investigated the use of a dynamic clutter map, based on the mode of all data from 2011 for each radar pixel. The effect of this clutter map was the rejection of most of the pixels near the ground and near the radar, effectively making the radar 'blind' for bird movements near the surface. Therefore, new ways for dynamic and automatic clutter filtering must be explored in order to provide reliable bird density estimates from weather radar data.

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References