Proceedings of ERAD (2004): 320–323

ERAD 2004

Radar system for bird observation

L. Dinevich, Y. Leshem, and O. Sikora

George S. Wise Faculty of Natural Sciences, Dept. of Zoology, Tel-Aviv University, Ramat Aviv, 69978, Israel

Abstract. When bird flight is monitored by a radar, the coordinates of bird radio echo centers form almost a straight line over certain route legs. A set of techniques developed in the presented study enables to use this distinctive characteristic in order to distinguish bird echo against the background of motionless or chaotically moving objects, such as ground clutter, clouds, precipitation, atmospheric inhomogeneities etc. The algorithm based on this characteristic enables to analyze the motion of bird echoes on the basis of the following movement patterns: a) straightforward, but not uniform; b) both straightforward and uniform; c) non-uniform, with significant deviations from the direct line and d) chaotically directed movement.

The data on the pattern of signal movement were used to calculate flight vectors, i.e. direction and velocity, both of individual birds and bird groups.

Usage of MRL-5 radar allows to simultaneously obtain both ornithological and meteorological data, which are processed by a specially designed algorithm and serve as the basis for mapping that integrates weather and bird monitoring.

1 The main idea

The character and the pattern of radio echo shifts is considered to be the main characteristic for selecting bird echoes against the background of other signals.

Figures 1a and b show bird radio echo fields obtained with the help of a photo camera from the radar screen. The photographing was performed during horizontal scanning at a fixed tilt angle, operating two recording modes: a) within the same scan, the objective being open during the entire survey, and b) the objective being open over 18 scans (3 min). Figure 1c shows the same echo field after the digital signal processing and summing-up over 18 scans.

Correspondence to: L. Dinevich
(dinevich@barak-online.net)

As can be seen in the figures, one of the main characteristics of a bird echo is its movement, as a result of which dotted echoes (Fig. 1a) are transformed into relatively rectilinear streaks (Figs. 1b, c). The increment in the length of a streak is caused by the forward shift of the echo with time.

Within most bands, the number of dotted echoes that form a streak is smaller than the number of scans, and the rectilinear pattern is often broken by a change in direction.

Identification of Bird Echo: the Method and the Algorithm

The method of the present study is based on conclusions and results of numerous long-term studies (Bruderer, 1992; Dinevich et al., 2000; Dinevich et al., 2004; Chernikov, 1979; Zavirucha et al., 1977; Gauthreaux et al., 1998; Zrnic and Ryzhkov, 1998). The main elements of the method are as follows:

1. Radar reflectivity fields obtained by summing-up a preset number of scans at different antenna tilts (Fig. 1c) are the main source of data for isolating bird echoes against the background. The duration of a single scan is 20 s.

2. While plotting the radar reflectivity field for each signal, a preliminary signal processing is performed, including removal of noise by the lower power threshold.

3. In the present study, eight scans were performed at each tilt angle. In case of fewer scans, some relevant information remains unavailable, while increasing the number of scans does not yield more relevant data, at the same time enlarging significantly the calculation time.

4. The number of preset tilt angles was chosen so as to encompass all the altitudes where birds are flying, at the given beamwidth.

5. Observations of bird echo movements on the radar screen and the analysis of the digital data processing

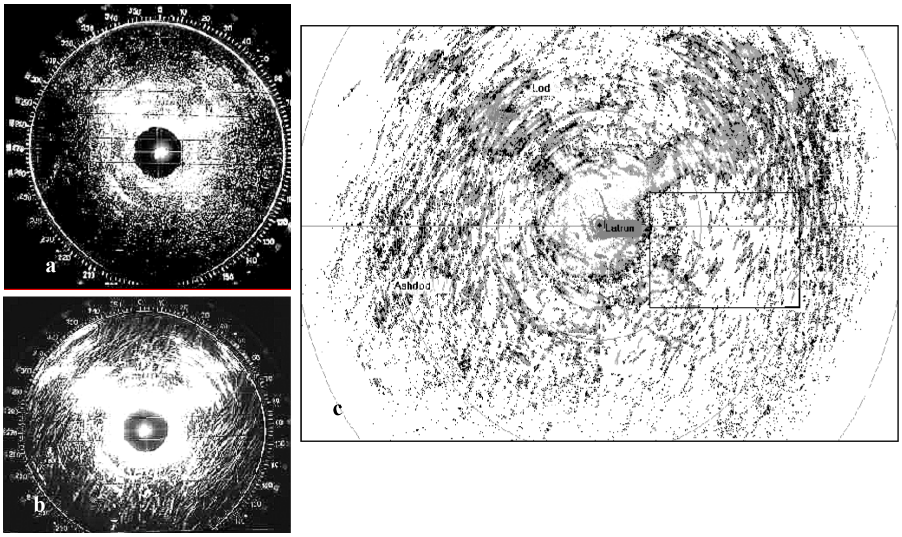

Fig. 1. The Radar screen photographs of radio echo fields a) over a single scan; b) over 18 scans at a fixed tilt angle c) the same radio echo as in 1 b) after digital processing of bird echoes and flight tracks. The lines formed by dotted echoes are bird flight tracks, the rest of the echoes are reflections from hills.

showed that within a series of 8 scans (160 s) at a fixed tilt the radar registered bird signals only once, due to the fact the birds were moving. In 15% of cases two signals, and in 3% of cases three signals were registered. The phenomenon of registering bird echo at the same coordinate position depends on the volume of MRL-5 radar surveillance (Abshaev et al., 1980), as well as on potential flight velocities and the parameters of digital processing performed on the echo fields (60 m in length and 0.176° in radius).

6. As to non-bird signals (ground clutter and clouds), their echoes are registered, as a rule, within the most of the scans, with the exception of areas with especially weak or fluctuating echo. Those are usually areas of ground clutter/cloud edges, where radar reflectivity is low. For such areas, the echoes registered at the same coordinate position may be fewer than the number of scans, and often result in false radio echoes that can be isolated by a multi-step identification procedure. In order to identify false echoes, additional properties are considered, such as the intensity of chaotic changes in the direction of the echo movement, the size of the echo etc.

All these factors were taken into account while designing Stage 1 of bird echo identification at each coordinate position of each scan.

2 Stage 1.

For each tilt angle, two data files are built up incorporating the results obtained over 8 scans.

The first file contains the data of a simple summation of all the echoes over all the scans, used for plotting maps that represent all the reflectors and the pattern of their movements. A sample of such a map in Fig. 2 shows summed-up data at 12:56, 08.10.2002. The position of the radar is marked in the center of the map. The vertical direction is toward the north, the radius of scanning being 60 km.

The prolonged line in the west marks the sea-land border. Bird echoes are represented by: a) a prolonged band almost 100 km long oriented from the north toward the south; b) separate dots and c) short streaks oriented towards the south (in the eastern sector of the map). Radio echo of ground clutter (hills, tall buildings, electric transmission lines, highways etc.) had various shapes: areal (sites), wide or narrow radial bands, sometimes dots.

In order to estimate the current ornithological situation using such a map, it is necessary to analyze how radio echoes evolve with time, as well as to have a good knowledge of the terrain in question.

To form the second file, the parameter of echo motion is implemented, i.e. signals registered in the same coordinate position more than once are excluded from the data, thus leaving aside most of the non-bird echoes.

3 Stage 2.

A bird echo depends not only on the bird's size and dielectric properties, but also on the arrangement of the wings and spatial orientation of the body at the moment when the bird is targeted by the probing impulse (Zavirucha et al., 1977; Chernikov, 1979; Dinevich et al., 2000). If the power of the reflected signal is relatively low (e.g. the distance is long and/or the birds are of small size), the signal may appear within some scans and be not registered within others. As a result, the bird radio echo may form either a straight or a broken line.

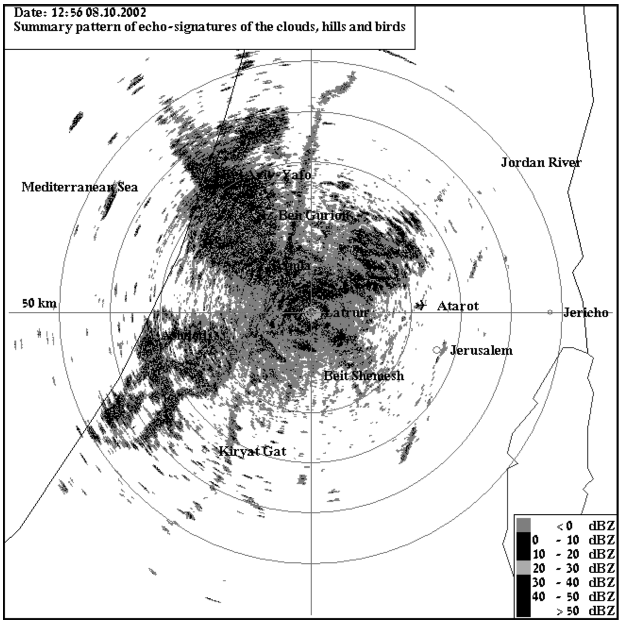

Fig. 2. Summed-up radio echo map (12.56, 08.10.2001).

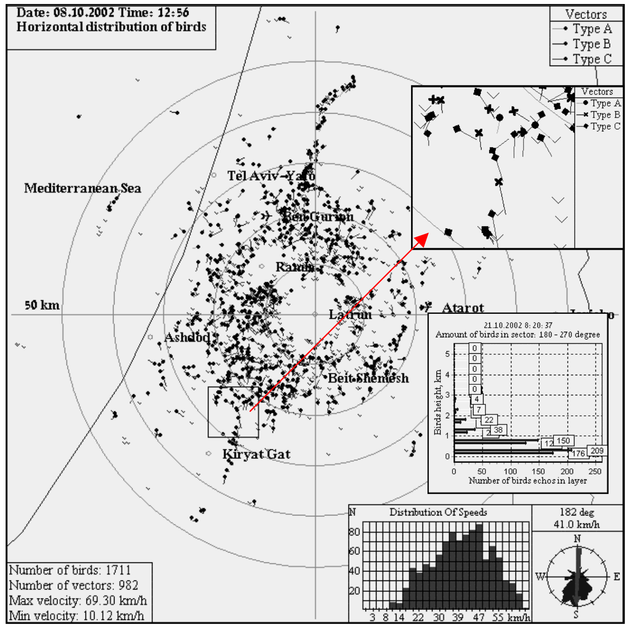

Fig. 3. Horizontal distribution of birds in the layer from the ground to the upper level of their flight. Date: 08.10.2002. Time: 12:56.

Taking this fact into account, the algorithm for bird echo identification implies the following three procedures to be implemented at each vertical angle.

Procedure #1: *Plotting segments of a straight line by a preset number of dots obtained during intermediate scans.*

For each radio echo, the first coordinate of its center obtained in a scan is considered to be the first coordinate that can be used to draw n straight lines. The terminal coordinate of the line is to lie within the range of distances that can be reached by a bird if it flies at the maximum/minimum velocity. The minimum (Vmin) and maximum (Vmax) values are determined over the data obtained during 160 s (8 scans). According to our experience, taking into account the wind speed, those values are usually in the range of 8–70 kmh.

As a result of the procedure, we obtain a bundle of straight lines originating from the point that is the center of each initially registered radio echo. Out of n lines, we select m lines on which, provided certain conditions, not less than k signals will fall during intermediate scans (it was experimentally obtained that $k \geq 4$).

Procedure #2: *Determining the criterion of the uniform echo motion*

Out of m lines that were plotted in relation to each initially registered signal, only those are selected where the distance between the echo centers in the first scan and the echo centers in the subsequent scans increases with time (i.e. with scan number). $l_1 < l_2 < l_3 < \ldots l_n$, l_i being the distance between radio echo centers in two adjacent scans. The ratio $l_1, l_2, \ldots l_n$ among adjacent scans enables to estimate the uniformity of bird flight velocities and to establish the corresponding criteria values.

In our study we implemented the following conditional criteria: motion is defined as a uniform one if, at least within a single flight leg, the deviation from the average velocity does not exceed 20%, otherwise the motion is defined as a non-uniform one.

Procedure #3: *Determining the criterion of motion straightforwardness*

Out of the set of straight lines that remained after Procedure #2 selection, a single line is selected where the transverse deviations of radio echo centers in the subsequent scans do not exceed the prescribed values of the motion linearity criterion. The diametral deviations of radio echo centers in subsequent scans from the straight line connecting the first and the last scans should not exceed a certain prescribed fraction of this line's length.

In our study, three conditional values were chosen for these purpose, namely: under 10% for straightforward movement; 10–30% and 30–40% for the two types of non-straightforward movement. The problem is solved by selecting, out of the lines remaining after Procedure #2, the single line on which the centers of echoes selected in the intermediate scans are located at minimum distances from the abovementioned connecting line.

4 Stage 3: Isolation and exclusion of false line segments

Even after the second phase of filtering, a certain amount of false line segments remains. According to multiple observations, false line segments are usually formed of echoes in areas of weak signals, such as clouds, sub-inversion termics, visually non-observable mesofronts etc.

According to our findings, the lines segments formed by signals reflected from such objects are of chaotic spatial orientation (Dinevich et al., 2001). Sometimes the echoes have a common shift trend that coincides with the wind direction. This characteristic, that we called the criteria of the state of chaos, is the basis for identifying those problematic areas and carrying out additional search for bird echoes that might sit within them

5 Determining bird flight velocities and designing flight vectors

Having performed Stage 1 and Stage 2 filtering, we obtain line segments. They are plotted on the basis of the prescribed number of shifting echo centers over a prescribed period of time. Several conclusions can be drawn from the plotting method, namely:

a) in case echoes form a straight line while shifting, and the line meets abovementioned requirements, those are echoes of an individual bird or bird group

b) in case the lines have a distinct orientation in relation to co-ordinates with the initial point in the scanning on the radar screen, this orientation represents the flight direction

c) in case both the coordinates and the registration time data are obtained for each echo center forming a straight line, the velocity and the direction of bird flight can be determined over each flight leg and an assessment can be made of the straightforwardness and uniformity of each echo movement.

d) the values of X_i, Y_i, t_i in two echo centers are used to build up root-mean- square linear regression dependencies *X(t)*, *Y(t)*. The first point is related to time t_1 and the second point to time t_2, t_2¿t_1.

The average direction of bird migration flow is determined as the geometrical mean of all the vectors and calculated by the method of composition of vectors. A bird flight velocity, in relation to the radar and calculated in the proposed way, is a sum of two components, namely, the bird's own velocity created by wing flapping, and the velocity of the wind flow in relation to the bird's flight direction.

Graphic representations of bird flight data, some of them including the terrain and atmospheric background.

Having performed all the three stages signal filtering, we obtain a file containing exclusively bird echoes at each tilt angle. After summing up all the files for all the angles, we obtain a summed-up projection of all the birds (in the shape of vectors) onto the horizontal plane. If then we mark on this plane the scale cursors, the highway scheme, the urban locations, the coastline etc., we obtain a map that can be called an ornithological map. A sample of such a map is shown in Fig. 3, representing the situation at 12.56, 08.10.2001. This map describes the same situation as the map in Fig. 2, but after the filtering of echoes that are given in the vector form. The radius of surveillance is 60 km, the band containing birds being about 100 km long. The band is composed of segments of varying vector density. The total number of bird and bird groups is 1711; 982 of them were flying in stable direction, according to the vectors. In the top right corner of Fig. 3 the velocity spectrum and the direction rose are shown. For a more detailed vie, the framed section A presents a fragment of the figure on a larger scale. Within this section, vectors with typical directions are shown, being marked with different symbols.

The same data base is used to design the graph showing bird distribution over different altitudes within a chosen observation area. A sample of such a graph is shown in Fig. 3 (section C), the X-axis showing the number of birds (bird groups), and the Y-axis showing the altitude.

References

Abshayev, M., Burtsev, I., Vaksenburg, S., and Shevela, G.: Guide for use of the MRL-4, MRL5 and MRL-6 radars in urban protection systems. L.,"Hydrometeoizdat" (RUS), 1980.

Bruderer, B.: Radar studies on Bird migration in the south of Israel, BSCE/21, Jerusalem, pp. 269–280, 1992.

Chernikov, A.: Radar clear sky echoes. Leningrad, Hydrometeoizdat, 3–40, (RUS), 1979.

Gauthreaux Jr., S. A., Mizrahi, D. S., and Belser, C. G.: Bird Migration and Bias of WSR–88D Wind Estimates, Weather and Forecasting 13:465–481, 1998.

Dinevich, L., Leshem, I., Gal, A., Garanin, V., and Kapitannikov, A.: Study of birds migration by means of the MRL-5 radar, J. Scientific Israel – Technological Advantages, Vol. 4, 2000.

Dinevich, L., Leshem, Y., Pinsky, M., and Sterkin, A.: Detection of Flying Birds and Estimation of their Velocity Vectors by MRL-5 Meteorological Radar, in press, 2004.

Zavirucha, V., Saricev, V., Stepanenko, V., and Shepkin, U.: Study of the dispersion characteristics of the meteorological and ornitological objects in echo-free cameras, Proc. Main Geophysic Observatory, #395, 40–45, 1977.

Zrnic, D. S. and Ryzhkov, A. V.: Observations of insects and birds with a polarimetric radar, Ieee Transactions on Geoscience and Remote Sensing 36 (2): 661–668, 1998.