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USING MRL-5 RADAR FOR IDENTIFYING RADAR ECHO OF MIGRATING BIRDS AND PLOTTING RADAR ORNITHOLOGICAL CHARTS

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The computerized radar ornithological system based on MRL-5 meteorological radar enables to perform automatic 24-hour monitoring of bird flights. The MRL-5 capacity of simultaneously obtaining both the meteorological and ornithological data made it possible to design an algorithm for plotting superposed weather and ornithological charts and to provide them every 15–20 min online to be used by air traffic control services.

Introduction. The progress of aviation, high density of aircraft over relatively small areas (especially in the vicinity of large airports), as well as striving for higher speeds using the lightest possible aircraft constructions – all these factors have inevitably created a conflict between the technological advancement and the nature. The most serious manifestation of this conflict is collisions between aircraft and birds (Ganja et al.,1991). The main routes of bird migration from Europe to Asia and Africa and back lie over Israel (Leshem and Yom-Tov, 1998). It was shown (Bruderer, 1992) that during the migration period the average number of birds over a cubic km of the air may exceed 500. As the airspace over Israel is also dense with aircraft, collisions are not rare during vigorous spring and autumn migrating bird flows, resulting in loss of bird life and sometimes human casualties (Bahat and Ovadia, 2005). Bird-aircraft collision are not rare in other regions (Thorpe, 2005). This situation calls for development of operational techniques aimed at assessment and control over the ornithological status in order to ensure air traffic safety.

The main idea underlying the algorithm

Tables 1 and 1(a) present the typical characteristics of migrating birds' radar echoes.

Table 1

Typical characteristics of radar echoes of migrating birds

Typical characteristics of radar echo	Studies*
– relatively low power. Reflectance coefficient (Z < 30dBZ), – forward and relatively linear movement – maximum amplitude fluctuations within the low frequency range (below 10 dB in 2–50 Hz frequency range). – MRL-measured σ are greater on the 10 cm wave length than those on the 3 cm wavelength – polarization characteristics of the signal are typical of horizontally-oriented targets. Differential reflectance as the ratio of horizontally-oriented signal (with pulse horizontally polarized) to vertically-oriented signal (with pulse vertically polarized) exceeds the unity significantly ($dP = P_{\parallel}/P_{\perp} >> 1$). For small droplets within clouds and precipitation this value is close to unity. – in the λ wave-length range of 3 to 100 cm, σ of both birds and insects decrease noticeably as the radar wavelength increases. At the same time, there is a distinct maximum of the σ (λ) frequency dependency that occurs at λ = 10 cm wave-length. – high dispersion of experimental data at λ = const (from few tens of cm^2 at λ = 3 см to σ = 10^{-1} cm^2 at λ = 100 cm). σ values for some bird species with wings folded are presented in Table 1(a). – the mean σ-values of different bird spices at the value of radar wavelength from less than 10 cm^2 (Sparrow) up to 400 cm^2 (Albatross). – σ-values of birds are approximately by order of 2–3 greater than σ-values of insects	Edwards, Houghton, 1959; Salman, Brilev, 1961; Schaefer, 1966; Chernikov and Schupjatsky, 1967; Skolnik. 1970; Chernikov, 1979; Bruderer and Joss, 1969; Bruderer, 1992; Ganja et al. 1991; Buurma, 1999; Larkin et al., 2002; Gudmundsson et al., 2002; Gauthreaux and Belser, 2003; Zavirucha et al., 1977; Zrnic and Ryzhkov, 1998.

N o t e s : * – Table presents only a small part of the numerous studies of bird echo characteristics. ** – ESA (σ) – effective scattering area

Table 2

ESA (σ) values for various bird species with wings folded and bodies set at different angles relative to the radar

Bird species	Dimensions of bird σ ($m^{2)}$ obtained at exposure to the radar at various angles		
	Side	Head	Tail
Rook	$2{,}5\cdot10^{-2}$	–	–
Pigeon	$1{,}0\cdot10^{-2}$	$1{,}1\cdot10^{-4}$	$1{,}0\cdot10^{-4}$
Starling	$2{,}5\cdot10^{-3}$	$1{,}8\cdot10^{-4}$	$1{,}3\cdot10^{-4}$
House sparrow	$7{,}0\cdot10^{-4}$	$2{,}5\cdot10^{-5}$	$1{,}8\cdot10^{-5}$

ESA parameters of the same bird may vary as much as by factor of 10 depending on its orientation relative to the radar (Houghton, 1964; Bruderer and Joss, 1969). According to a study where ESA was measured in a anechoic chamber at different angles relative to the radar beam (Zavirucha et al., 1977), the maximum echo values were found within the range of 65–115° relative to the beam, which corresponds to the bird's lateral exposure (while 0° corresponds to the radar beam directed at the bird's beak). In addition, ESA variations can be caused by the bird's wingbeat. In these cases, the ESA values may increase up to 10-fold or drop almost to zero, the frequency of the fluctuations reaching 2–24 Hz (Chernikov, 1979). Hence, ESA of a bird depends on its size, its orientation relative to the radar beam and on the instantaneous position of its beating wings. In the resent study, we managed to establish a number of other characteristics typical of bird echoes.

Fig. 1 shows the echo field after computer processing of signals obtained from 18 scans, which has a distinct dot structure. Analysis of the photos shows that a major characteristic of a bird echo is movement, which leads to transforming the dot-made echoes into strips. The enlarged fragments of the strips (1, 2, 3, 4) demonstrate their straightforwardness. The increments to the strip length take place due to the transitional movement of an echo in time. Aspecial software designed as part of our study enabled to analyze the structure of 270 randomly selected echo strips. Each experimental strip was obtained over summation of 8 scans at a fixed antenna vertical angle. The software enables to trace the process of strips' formation from scan to scan. The findings show that the recurrence of a bird echo at the same coordinate point (over 8 scans, the total duration of 80 s) in at least 90 % of cases does not exceed two. This result is due not only to the pattern of a bird flight, but also to the technical parameters of the radar system, with its narrow pulse and the narrow symmetric beam. The recurrence of echoes from other reflectors (ground clutter, clouds and some kinds of atmospheric inhomogeneities) follow a different pattern, with their echoes usually reoccurring over all of or most of the scans, and thus are easily filtered out. The only exception is heavily fluctuating week signals reflected from friable clouds and precipitations. In case the concentration of such objects is relatively high, it creates an illusion of change in their spatial position, i.e. of a movement. At the same time, due to the origin and behavior of these objects, their typical feature is a chaotic character of the direction of adjacent echoes caused by the pseudo-movement. Hence, the vectors formed in the process are chaotically directed, in contrast to bird echoes.

The detailed description of the method for bird echo identification against the background of other types of atmospheric echoes, as well as the technique for designing and plotting ornithological charts can be found in other papers by the authors (Dinevich and Leshem, 2007; 2008;2010; 2011). Examples of ornithological charts of different types are presented in Fig. 2–7. Fig. 8 shows the cloud echo chart. Fig. 9 features the external look of the radar and a group of school students who came to take a class in radar ornithology. Fig. 10 gives the internal view of the display booth of the radar ornithological station.

On the potential development and increasing the accuracy of the system

1. The ratio of radar echo power at the two wavelengths

The ratio of radar echo power at the two wavelengths of MRL-5 radar depends entirely on the parameters of a target (Abshaev et al., 1980). Chernikov (1979) showed that the power of an insect echo at the 3 cm wavelength is twice as large as that at the 10-cm wavelength. This ratio is inverse for bird echo as well as for small-drop clouds and precipitation (Stepanenko, 1973). Therefore, the ratio of the two reflection coefficients at the two wavelengths ($Z_{dBZ3,2sm}/Z_{dBZ10sm} > 1$ for "non-bird echo") can serve as an additional indication while identifying bird echoes and eliminating false vectors.

2. Polarization parameters of a radar echo.

As was shown by Shupiyatsky (1959), the values of depolarization and differential polarization are functionally connected only to the shape of a target and its orientation in space and do not depend on any other parameters, including the dielectric conductivity of the target, signal attenuation along the track etc. Using the two polarization components Δ*Px* and *dP*, one can calculate a bird's orientation in space as well as its shape, i.e. the ratio of its length to its width. The formula for calculation of a bird's orientation in space is $tg2\theta = 2dP^{1/2}\Delta P^{1/2}[dP^{1/2} - 1]$, where θ is the angle of the orientation. It is important that the differential reflexivity value makes it possible to identify birds against the background of various atmospheric inhomogeneities whose nature does not imply formation of visible hydrometeors and whose differential reflexivity value is close to unity. As the differential reflexivity values of bird echoes is much larger than unity, it means that this feature of a reflected signal can be used for filtering out undesired signals. It was also shown (Dinevich et al., 1994) that differential reflexivity values of small drops are close to unity. Taking this into account, signals with parameters ≤ 30 dBZ and $dP \approx 1$ are characteristic of small drop echoes, while signals with parameters ≤ 30 dBZ and $dP >> 1$, in combination with other typical characteristics (fluctuation patterns, mobility in space etc.) are likely to be bird echoes.

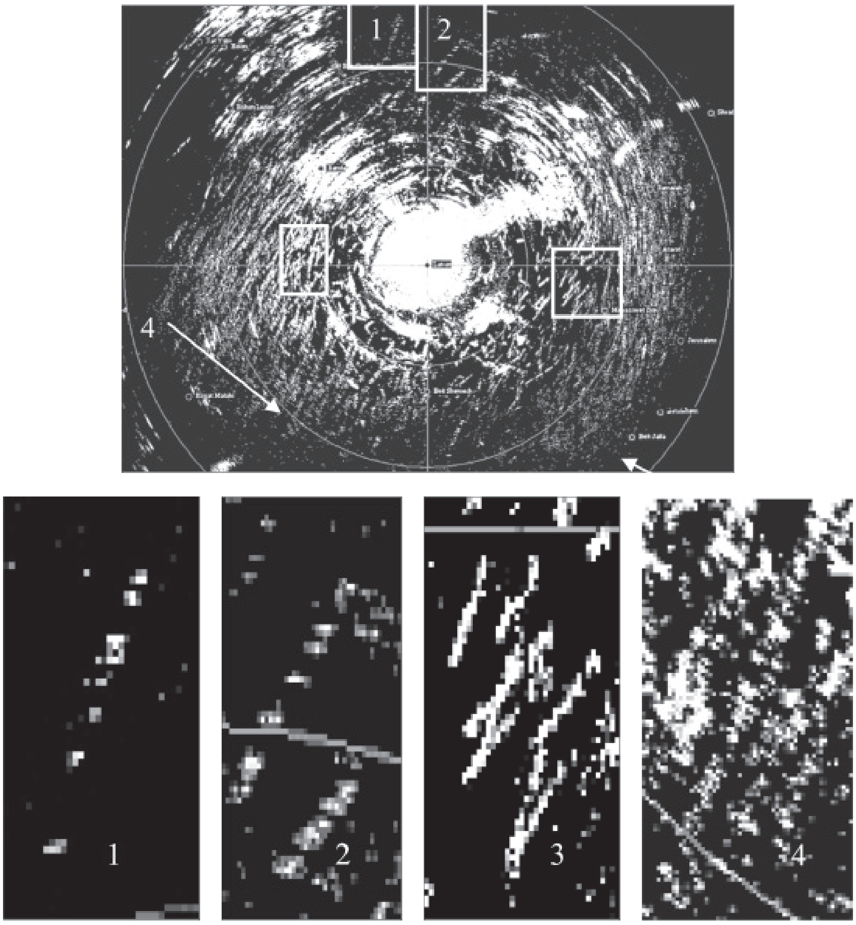

Fig. 1. The echo field after computer processing of signals obtained from 18 scans. 1,2,3 and 4 present enlarged fragments of the field

3. Fluctuation characteristics of echo from various target reflectors

On the basis of our research in fluctuation parameters of signals (Dinevich et al., 2004), a special device was designed that enables to analyze fluctuation characteristics. With the antenna in the "halt mode" and within the preset 200 m-long strobe, the device analyzes each pulse to isolate the signal of the maximum amplitude and to store it in memory, as well as to accumulate and plot the spectra of amplitude and frequency on the basis of 10–20 s samples. Given the frequency of MRL-5 sounding pulse (500 pulses per sec.), each sample contains spectra of power changes and frequency of maxima repetitions for 5–10 thousand signals. A low-frequency filter that underwent special tuning enabled to separate fluctuation amplitude spectra into "bird/not bird" categories at the accuracy of at least 80 %. In cases when the signal is reflected from a single bird the accuracy exceeds 95 %.

Conclusions

– Radar echo parameters determined for various purposes were used as the basis for designing an algorithm that enables to identify bird echoes and to perform on-line plotting of vector fields that represent bird movements, including the height parameters.

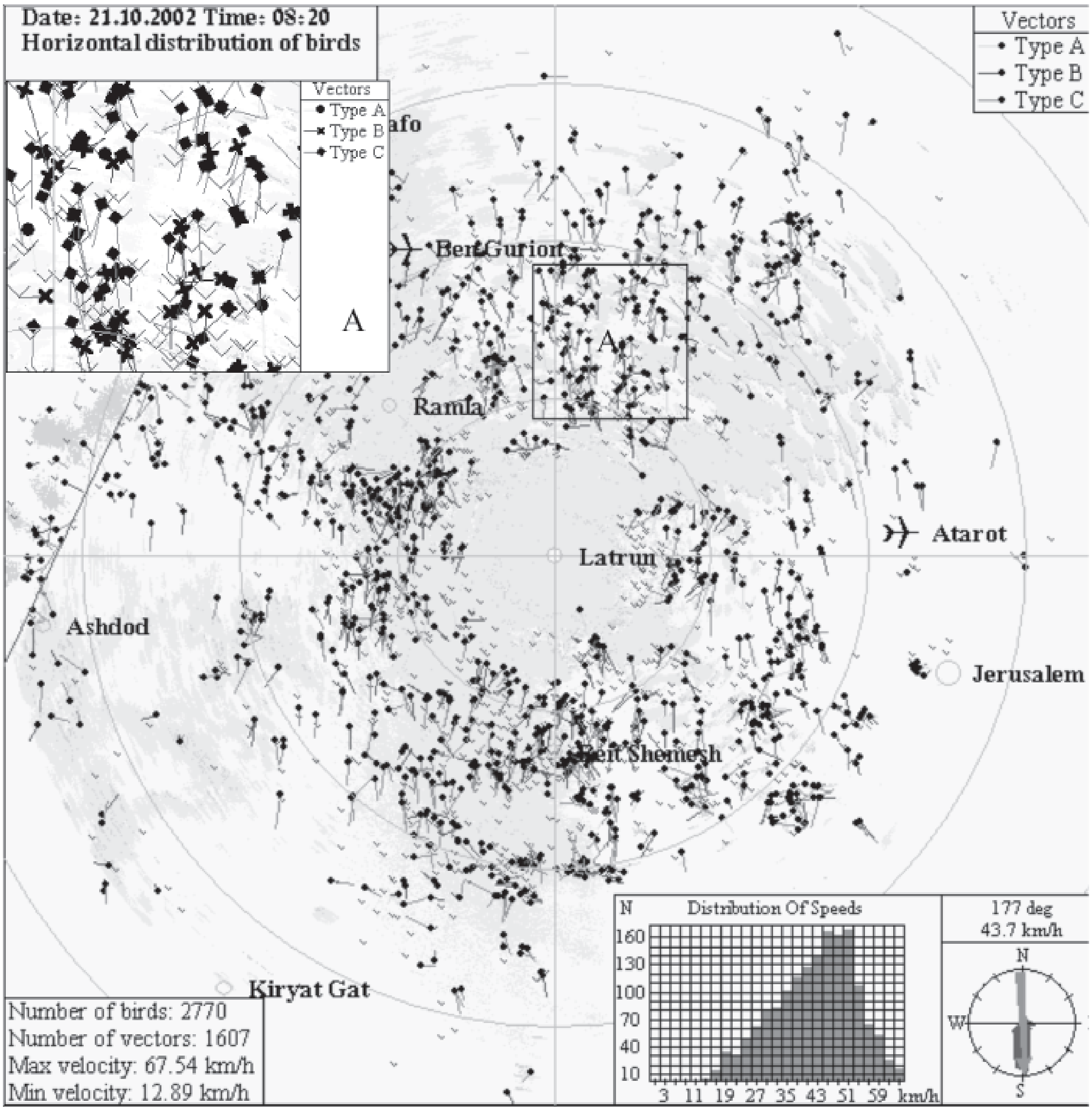

Fig. 2. Ornithological chart. Bird migration on October 21, 2002, 08.20 a.m. The actual charts are made in color. Vectors indicating the directions and velocities of bird flights (both single birds and flocks) are of three types and differ in colors. In the Figure, cloud and ground clutter reflections are colored pale gray (blue color in actual charts). Fragment A presents an enlargement where all the three types of vectors are distinctly seen, representing different patterns of flights for various bird species. Charts of this type, as well as charts of vector distribution over height and bird volume distribution during seasonal migration, are sent online to air traffic control operators every 15-20 min

– The technique of vector field plotting enables to classify birds, on the basis of their movement patterns, into several categories, among them birds flying with frequent shifts in flight direction (local birds), birds flying straightforwardly at steady velocities or at varying velocity, and those flying with repeating deviations from a straight line and at variable velocities.

– Radar ornithological charts plotted on the basis of the algorithm data enable to obtain the following information within the area of 60 km radius from the radar position, including:

1) the total quantity of birds;

2) distribution of birds' mass over height;

3) the spectra of flight directions and velocities, including the sum direction vector;

4) vector fields of bird movement juxtaposed with current meteorological status and local terrain;

5) bird distribution by the flight pattern (the degree of straightforwardness and velocity steadiness);

6) data on clouds, precipitation and visually unobservable atmospheric inhomogeneities and their parameters.

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