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DOPPLER RADAR SIGNATURES OF MIGRATING BIRDS

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1. INTRODUCTION

Biological targets such as birds are a rather common example of clutter affecting weather radars operation, especially during seasonal migrations. On the other side, the identification of echoes from birds is of great interest for ornithologists and helps to reduce a potential hazard for aircraft security.

In this paper we report the results of observations of nocturnal migrating birds flying over the Pianura Padana (northern Italy) by means of a weather radar. The most favourable period for radar measurements of birds in the above region occurs during March-May and September-November, in correspondence of seasonal movements of migrants: at springtime they leave their winter areas located in Africa and move to the breeding grounds of central and northern Europe; the opposite happens during autumn. The individuals observed over the Pianura Padana are those who meet the biological requirements (flight capability, direction of migration with respect to the Alps, fat reserves) that make them capable to cross the Alps (Bruderer and Jenni, 1990), provided that favourable weather conditions are encountered (wind direction and wind strength above all). Although individuals of all species pass over the Alps in variable amounts, it has been found that the majority of birds captured during night are long-distance migrating passerines (Bruderer and Jenni, 1990).

2. RADAR MEASUREMENTS

Birds movements were monitored by an S-band meteorological Doppler radar located at Spino d'Adda, 20 km east of Milan, Italy. The radar operates at 2.8 GHz, with a peak power of 500 kW and a PRF of 1000 Hz. The duration of the transmitted pulses is 0.5 μs corresponding to a radial resolution of 75 m. The antenna is a parabolic reflector having a 2° beamwidth. Vertical polarisation has been used. The radar worked in the "fixed-beam" mode of operation: antenna's elevation and azimuth were 10° and 45° (clockwise from North), respectively; the above azimuth direction was chosen since observation of PPIs during migratory activity usually highlighted preferential flight routes directed from SW to NE (during spring); hence, Doppler velocities measured by the radar (radial component) are roughly coincident with the preferential direction of migrants. Sequences of 4096 pulses were recorded once every 15 minutes from sunset to sunrise; 122 consecutive range gates have been considered from r=3.937 km up to r=13.012 km. The relatively small maximum range was established due to radar sensitivity bounds: assuming a minimum tale-view cross section for passerine birds of 0.5 cm^2 (Edwards and Houghton 1959), straightforward application of the radar equation for isolated targets shows that the associated echo power falls below the receiver noise level (-102 dBm) if r≥13 km.

The data set we refer to in this paper was collected during the spring migration over a night free of precipitation where PPI inspection showed intense migratory movements. The measurement started on 30 March 2000 at 16:35:50 UTC and went through the night to end on 31 March 2000 at 06:46:00 UTC.

3. DATA PROCESSING

Off-line data processing was subsequently carried out, through the following steps: a) a classification of targets was performed based on Doppler spectra analysis: after clutter rejection in the frequency domain (Passarelli, 1981), birds were identified where a spectral peak was present at least 20 dB above the noise level. This simple algorithm allowed us to isolate signals “strong” enough to show the temporal signature that is typical of birds (see next section); b) mean power, mean Doppler velocity and spectral width were computed by means of an adaptative technique based on a window of variable length centred around the spectral peak previously detected. The above technique was adopted since returns from birds are relatively weak signals with a narrow Doppler band (when compared e.g. to rain), therefore it is very important to select properly the signal frequency interval in order to avoid heavy errors on moments estimates. c) finally, we derived an estimate of the wingbeat frequency of birds computing the peak of signal power spectrum.

4. RESULTS

Fig. 1 shows the scattergram reflectivity-Doppler velocity relative to the 1069 targets that were classified as birds. Doppler velocity convention here is positive when objects are moving away from the radar. Positive values of velocity were almost exclusively found; moreover, about 65% of targets were travelling with radial velocity comprised between 8.3 m/s (30 km/h) and 16.7 m/s (60 km/h). Reflectivity values were

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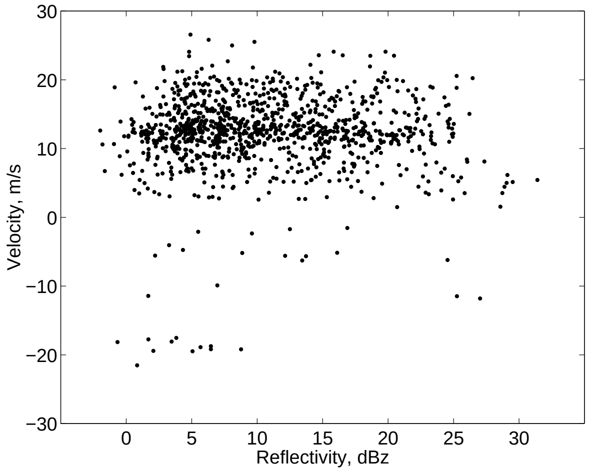

Figure 1: *Scattergram reflectivity-Doppler velocity for the 1069 targets identified as birds. Positive values of velocity are associated to targets moving away from the radar.*

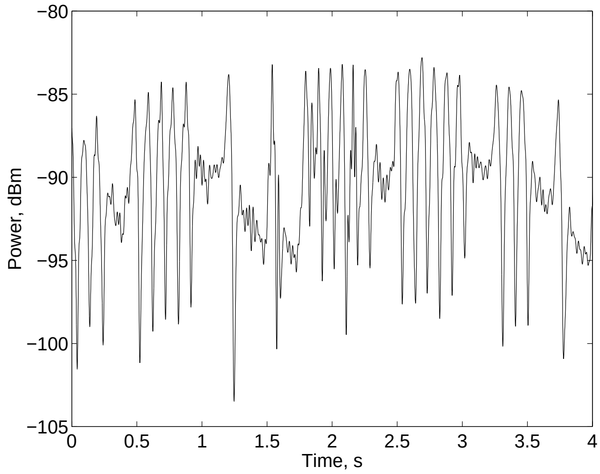

Figure 2: *Time signature of a bird. Intervals where a quasi-sinusoidal pattern is present correspond to the scattering cross section modulation during wingbeating. The wingbeat frequency is 10.3 Hz.*

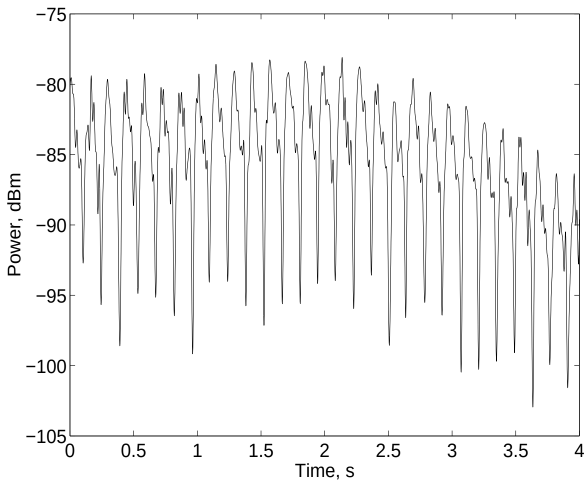

Figure 3: *Time signature of a bird that is flapping its wings without any pause. The wingbeat frequency is 7.2 Hz.*

all below 30 dBZ, being mostly distributed between 0 dBZ and 15 dBZ. As a term of comparison, the reflectivity measured in light rain (1 mm/h) is about 23 dBZ. It is to note that, if the majority of birds are flying roughly along the radial direction, their cross section is minimum (tail-view). Higher values of cross section, hence of reflectivity, would be measured when looking at birds from a direction normal to their flight (side-view). Not shown here is the distribution of spectral widths: we found that more than 90% of Doppler spectra of birds exhibited values not in excess of 1 m/s.

We remark that the above estimates were the results of averages performed over an observation time of ~4s: it is also interesting to evaluate the temporal fluctuations of the signal within the above interval. As pointed out by several authors (see Vaughn (1985) for a review), time histories of echoes associated to birds exhibit a characteristic amplitude modulation due to wingbeating. Figs. 2 and 3 confirm the previous studies, showing two examples of time power signals, obtained by filtering the row data with a moving average over 9 samples: in the former we see a regular, “quasi sinusoidal” wingbeat pattern during flapping flight with small intervals of gliding flight between successive bursts; these pause intervals are absent in the latter signature. We found that the extent of power variations during flapping bursts can be up to 20 dB. Signals like those shown above are obtained when a single bird is flying inside the resolution volume. We also found more complicated “shapes” probably produced by two or more targets (with comparable cross section) present at the same time, that make it difficult to detect any flight pattern. As far as possible, we tried to separate these spurious signals, discarding Doppler spectra with more than one relevant peak.

From the point of view of radar meteorologists, since fast scan capabilities are required, operative radars often produce estimates based on very short time intervals (typically, in the order of one tenth of a second or less): when a bird is flying inside a resolution cell, a high dispersion of reflectivity estimates has to be expected, according to the position of the sampling interval with respect to the overall temporal pattern. As an example, we broke the 4096 long sequences of Figs. 2 and 3 into 64 sub-sequences of 64 samples each and computed the corresponding reflectivity: we found values spread all over the interval 8.2-22.8 dBZ (the mean value was 19.2 dBZ) in the former, and comprised between 9.6 dBZ and 18.8 dBZ (mean value of 16.1 dBZ) in the latter respectively.

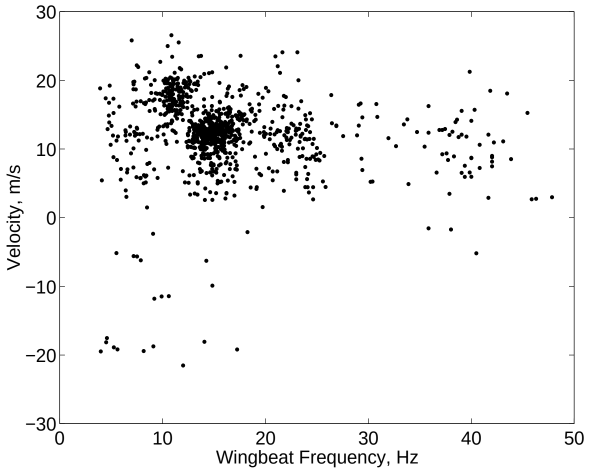

Figure 4: *Scattergram Wingbeat Frequency-Doppler velocity.*

By inspection of Figs. 2 and 3 we also argued that the wingbeat frequency is rather constant, at least during the observation time. The above characteristic was usually found in our data set. Ornithological studies (Pennycuick, 1996) confirm that the wingbeat frequency of a bird in steady cruising flight should be close to a "natural" frequency determined by its mass and wing morphology and by other environmental parameters (e.g. air density). Fig. 4 shows the scattergram wingbeat frequency-velocity of our data set: 90% of values are in the interval 5-25 Hz. Note that the majority of points in Fig. 4 is concentrated in two separated areas: a densely populated spot occurs at frequencies in the interval 13-17 Hz and velocities between 10 and 15 m/s, while another one falls in the ranges 10-13 Hz and 15-20 m/s respectively. A third region seems to be present at 20-25 Hz and around 10 m/s but it is much less evident. Assuming that the radial velocity is close to the effective one, we argued a correlation between wingbeat frequency and velocity: birds that are flying faster seem to flap their wings at a lower rate. Given this different frequency-velocity behaviour it could be inferred that the two spots correspond to birds of different species. Though, we found no evidence in literature about to what extent the above parameters remain unchanged when considering many individuals (with different mass, wing length, etc.) of the same species.
Additional information that could prove helpful to distinguish between different species regards flapping and gliding flight intervals: although for cases in which both phases of flight are present the duration of each interval is largely variable, the absence of pause intervals was found in correspondence of wingbeat frequencies typically below 10 Hz, (e.g. 7.2 Hz in Fig. 3).

5. CONCLUSIONS

We presented here the results of Doppler weather radar measurements of migrating birds, performed in the "fixed-beam" mode of operation. The observation time window of each resolution cell (~4s), much longer than in the case of operative weather radars, allowed to provide accurate estimates of reflectivity and Doppler moments: reflectivity values were mainly comprised between 0 and 15 dBZ (tail-view according to prevalent migratory direction observed on PPIs). Velocities were basically within the interval 8.3-16.7 m/s (30-60 km/h), while measured spectral widths were usually below 1 m/s. Time histories of associated echoes showed the typical amplitude modulation associated to wingbeating. 90% of wingbeat frequencies were in the interval 5-25 Hz: two distinct groups with a different combination wingbeat frequency-velocity were visible, suggesting the idea that faster birds flap their wings at a lower rate.
In order to gather more information about reflectivity values associated to birds, further measurements are needed considering different view angles; in view of species identification, correlation of velocity and wingbeat with additional variables like the presence or absence of gliding flight intervals, the extent of signal amplitude modulation, the time and height of flight could prove useful.

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