P5.13 DETECTION OF BIRDS AND INSECTS USING POLARIMETRIC RADAR OBSERVATION

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1. INTRODUCTION

It has been known that polarimetric radar can discriminate biological and meteorological scatterers. Furthermore, Zrnic and Ryzhkov (1998) have shown that the polarimetric properties of small Rayleigh scatterers like insects and large non-Rayleigh scatterers like birds are significantly different. Vaughn (1985) has stated that prolate spherical water drops are a better model of birds and insects than spherical water drops (Riley, 1985). Usually the ratios of width-to-length are between 1:2 and 1:3 for birds and between 1:3 and 1:10 for insects (Vaughn, 1985). Due to the difference in shape and size, the polarimetric signatures of insects and birds are different. Birds have higher differential phase and lower differential reflectivity than insects. Thus, it is possible to develop an algorithm to distinguish between birds and insects using polarimetric variables.

These advantages of polarimetric radar can significantly improve the current radar applications. First benefit is for quantitative precipitation estimation; non-meteorological echoes caused by birds and insects can be identified and removed to prevent contamination of rainfall estimates. Second, birds can contaminate Doppler radar velocity measurements (Jungbluth et al. 1996; Gauthreaux et al. 1998a,b). In the presence of migrating birds (mostly nighttime during the migrating seasons), radar measured velocities can be very different from the air velocities (projected along the radar beams) and the differences are typically in the order of 10 m/s (Gauthreaux et al. 1998b; Collins 2001; Bi et al. 2002). On the other hand, insects as passive tracers of air motions are usefull for wind measurements in most of cases. Third, for flight safety purpose, it might be possible to issue bird strike advisories (bird strikes to aircraft are a growing problem in world).

A classification algorithm that enables identification of different types of meteorological and non-meteorological echo has been developed at NSSL using observations with the polarimetric prototype of the WSR-88D radar. Discrimination between insects and birds will be part of this algorithm. In this paper, several examples of birds and insects observed by the polarimatric KOUN radar are presented in sections 2 and 3. The discussions and conclusions are in section 4.

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2. OBSERVATIONS OF TRANSITION BETWEEN INSECTS AND BIRDS

Continuous observations of polarimetric KOUN radar from 00:00UTC 9 May 2004 to13:00UTC 10 May 2004 provide unique opportunity to study the transition between insects and migrating birds during sunrise and sunset in spring over Oklahoma. The sunset time on 9 May 2004 and sunrise time on 10 May 2004 are 01:22UTC and 11:30UTC respectively.

During the observation period (from 00:00UTC to 01:15UTC on 9 May 2004) some scattered storms appeared about 100 km away from the KOUN radar. Insects, birds, and ground clutter were present near the radar. Using the classification algorithm we have separated and removed storm echoes and ground clutter from biological scatterers. Measurements of differential reflectivity Z_{dr} were corrected at low signal-to-noise ratio (SNR). Also, the observations with low cross-correlation coefficient (less than 0.3) were excluded from analysis.

Fig.1 shows the reflectivity, differential reflectivity, and differential phase of biological echoes observed with the KOUN radar at 0.5^{o} elevation angle at 01:19 UTC and 02:35 UTC on 10 May 2004. It is clearly evident that the clear air echoes in the upper panels (before sunset, Fig. 1) are significantly different from the echoes in the lower panels (after sunset). The extent of radar echoes increases from 50 km (first range ring in Fig.1) before sunset to almost 100 km (second range ring) after sunset. The disk-like and central symmetric shapes of reflectivity fields Z (Fig. 1a and d) indicate horizontal homogeneity of the scattereres. The azimuthal dependencies of differential reflectivity Z_{dr} and differential phase ϕ_{dp} are clearly pronounced in Fig.1b, c, e, and f). In order to investigate the evolution of the polarimetric characters of these two different kinds of echoes, the average values of the radar observed polarimetric variables are estimated. The average is made over all range gates with valid observations at 0.5^{o} elevation angle.

It is worth noting that the differential phase ϕ_{dp} is a sum of backscatter differential phase δ and a propagation component. Zrnic and Ryzhkov (1998) found that δ dominates ϕ_{dp} in the observations of biological scatterers and the propagation component can be neglected. Henceforth, ϕ_{dp} is assumed to equal δ in our observations of birds and insects.

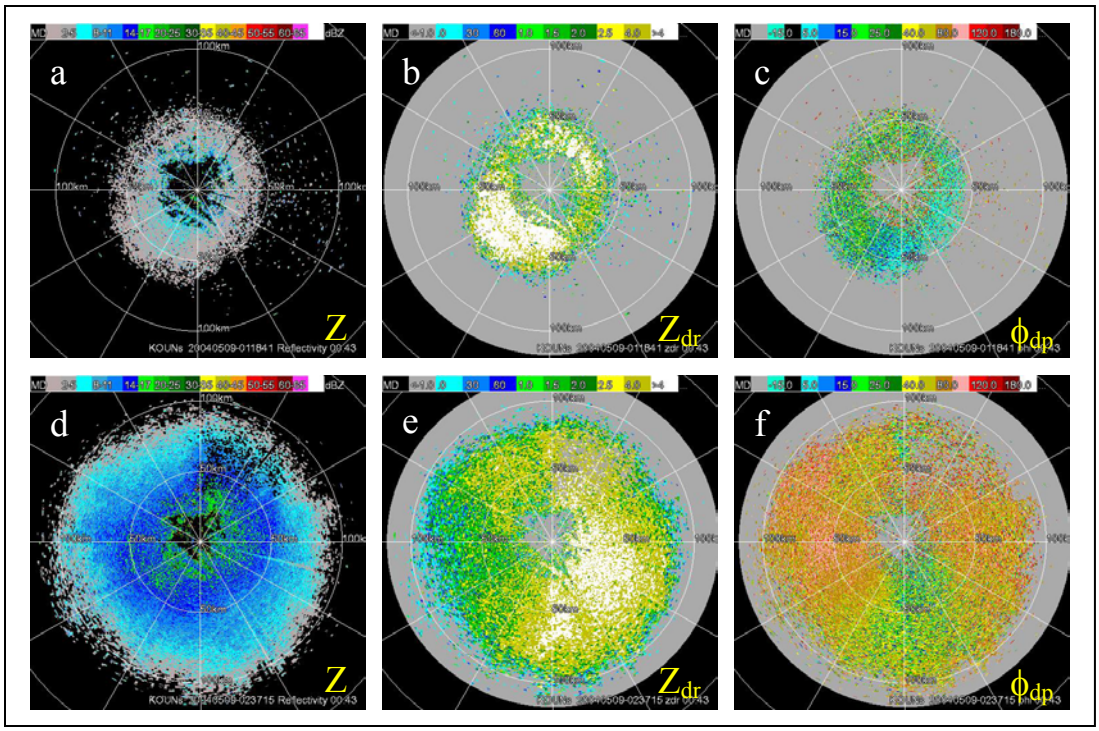

Fig.1. The upper three panels (a), (b), and (c) are reflectivity Z, differential reflectivity Z_{dr}, and differential phase f_{dp} observed by KOUN at 0.5^{o} elevation angle at 01:19UTC on 9 May 2004. The lower three panels (d), (e), and (f) are the same as (a), (b), and (c), except at 02:35 UTC on 9 May 2004. The radar is at the center of each image. The white rings indicate range 50 km and 100 km from the radar.

The time series of average reflectivity $\overline{Z}$, average differential reflectivity $\overline{Z}_{dr}$, and average differential phase $\overline{\phi}_{dp}$ over a twenty-four hour period are displayed in Fig. 2. These three variables exhibit dramatic changes around sunset and sunrise time. Between 02:30 UTC and 11:00 UTC, $\overline{Z}_{dr}$ and $\overline{\phi}_{dp}$ are at almost constant levels 2.2 dB and 70° respectively, as birds were primarily responsible for the echoes. The values of $\overline{Z}_{dr}$ and $\overline{\phi}_{dp}$ agree with the results of previous polarimetric radar observations of birds (Zrnic and Ryzhkov, 1998). In the daytime periods (00:00UTC to 01:UTC and 12:00UTC to 24:UTC), $\overline{\phi}_{dp}$ is about 30° that is evidently smaller than 70° of bird echoes. But $\overline{Z}_{dr}$ gradually increases from 0 dB at about 14:20UTC to its peak 3.5 dB at 01:00UTC. For 10 cm wavelength polarimetric radar, 3 dB and 30° are typical values of Z_{dr} and ϕ_{dp} for insects (Zrnic and Ryzhkov, 1998). The reason for the increase of $\overline{Z}_{dr}$ from the morning to afternoon (14:00UTC to 24:00UTC) is unknown. This result indicates that migrating birds cause clear air echoes in the night and insects are major contributors to the clear echoes in the late afternoon. $\overline{Z}$, $\overline{Z}_{dr}$, and $\overline{\phi}_{dp}$ reach their local minimums at about 01:40UTC right after sunset at 01:22UTC and then sharply reach their plateau value in about an hour. At about 11:00UTC (half hour before the sunrise) $\overline{Z}$, $\overline{Z}_{dr}$, and $\overline{\phi}_{dp}$ experience a significant drop from 12.5 dBZ, 2.2 dB, and 70° to 2 dBZ, 0.1dB, and 40° respectively in about three hours. Obviously, the transition from birds to insects at sunrise is considerably slower than the transition from insects to birds at sunset. In less than about 1.5 hour, insects are replaced by birds in the boundary layer. Similar phenomena are observed by the KTLX radar for a whole migrating season of the spring 2003 (Zhang et al., 2004).

The fact that the morning transition starts before the sunrise time (11:30UTC) on the ground is likely due to the altitude of the migrating birds; at 2 km aloft the migrating birds see the sun before it can be observed on the ground and start their descent.

Usually polarimetric signatures of insects and birds exhibit a well-pronounced azimuthal dependence that is determined by their fight direction. Zrnic and Ryzhkov (1998) have plotted the azimuthal dependencies of Z_{dr} and ϕ_{dp} for reflections from birds and compared these to model results for oblate spheroids. The azimuthal dependencies of Z_{dr} from insects were observed by Mueller and Larkin (1985) and Achtemeier (1991b). Fig. 3 shows the azimuthal distributions of Z_{dr}, ϕ_{dp} and Doppler velocity V_r for insects and birds in our observations. Z_{dr}, ϕ_{dp} and V_r in Fig.3 are averaged over radial distances from 30 km to

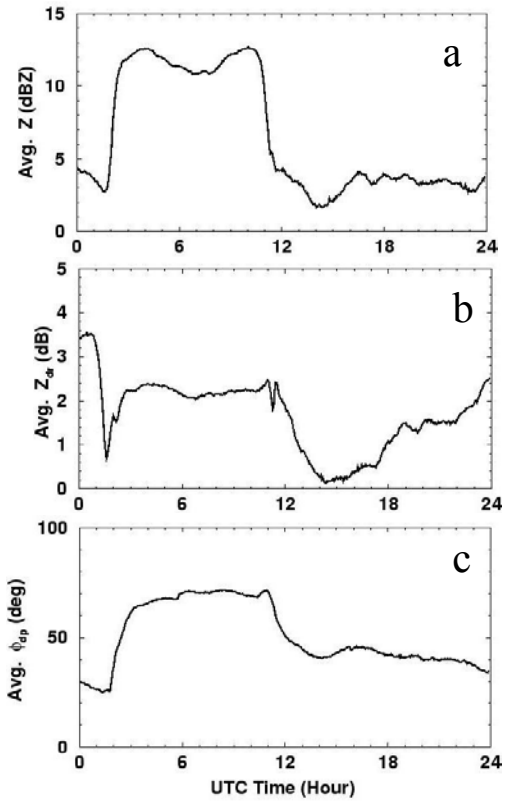

Fig. 2. The evolution of (a) $\overline{Z}$, (b) $\overline{Z}_{dr}$, and (c) $\overline{\phi}_{dp}$ observed by KOUN radar at 0.5^{o} elevation angle in the period from 00:00UTC to 24:00UTC on 9 May 2004.

45 km (60 range gates). Rawinsonde observations on 9 May 2004 indicate that the wind is from the south that is consistent with V_r obtained from insects in Fig. 3a. The magnitude of V_r obtained from birds in Fig.3b is larger because the migrating birds fly with their favorite tail-wind. There are no obvious systematic azimuthal dependencies in Z_{dr} and ϕ_{dp} for insects (Fig.3a). For migrating birds (Fig.3b), ϕ_{dp} exhibits a symmetric pattern with respect to wind direction. It is consistent with the theoretical and observation results of Zrnic and Ryzhkov (1998). However, only to the west of the radar (i.e. azimuth 10° –180 ^{o}, see Fig. 3b), Z_{dr} shows azimuthal dependency.

3. OBSERVATIONS OF LOCALIZED FLOCKS OF BIRDS

By carefully examining the radar observations, we found persistent flocks of nesting birds above certain areas near rivers. We have selected two areas of localized birds echoes (see Fig. 4) and examined the evolutions of average reflectivity $\overline{Z}_1$, average differential reflectivity $\overline{Z}_{dr1}$ and average differential phase $\overline{\phi}_{dp1}$ corresponding to these two areas from 19:00 to 21:00UTC (14:00 to 16:00CDT) (see Fig.5). The area 1 (flock 1) is bounded by 241° and 248 ^{o} in azimuthal directions, and from 43 km to 47 km in range. The area 2 (flock 2) is bounded by 286° and 290 ^{o} in azimuthal directions, and from 44

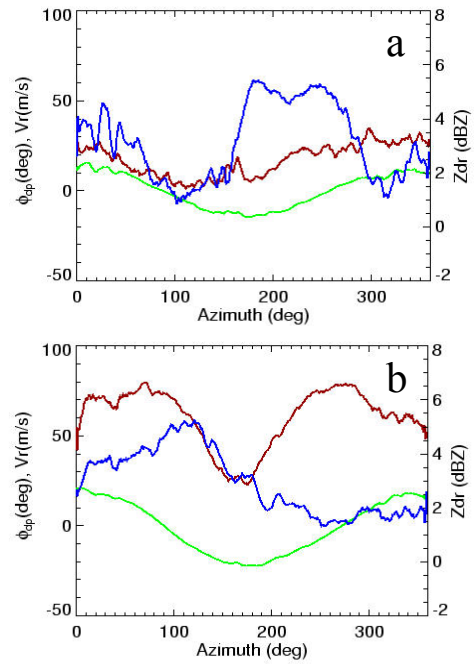

Fig.3. Azimuthal dependencies of Z_{dr} (blue), ϕ_{dp} (red), and Doppler velocity V_r (green) at 0.5^{o} elevation angle for reflection from (a) insects at 01:18UTC and (b) birds at 02:57UTC.

km to 48 km in range. Fig. 5 displays the $\overline{Z}_1$, $\overline{Z}_{dr1}$ and $\overline{\phi}_{dp1}$ for flock 1 as function of time. The evolutions of these variables for flock 2 (not shown) are similar to flock 1.

$\overline{Z}_1$ and $\overline{\phi}_{dp1}$ fluctuate around 10dBZ and 70 ^{o} respectively during the two hours. These values are well above the background value of $\overline{Z}$ and $\overline{\phi}_{dp}$ (4 dBZ and 40° correspondingly) during the same period of time. $\overline{Z}_{dr1}$ of about 0 dB is well below the 1.5 dB of background $\overline{Z}_{dr}$. In general, birds are larger than insects and have larger backscattering cross sections than insects. High $\overline{Z}_1$ and $\overline{\phi}_{dp1}$ are consistent with returns from birds whereas low $\overline{Z}_{dr1}$ implies that these birds might be more randomly oriented in the region 1 compared to migrating birds. We label the birds in the region 1 as nesting birds because the corresponding Doppler velocities scattered around zero (Fig. 6) indicating that the birds do not fly in the same direction as migrating birds do. Further this also confirms that

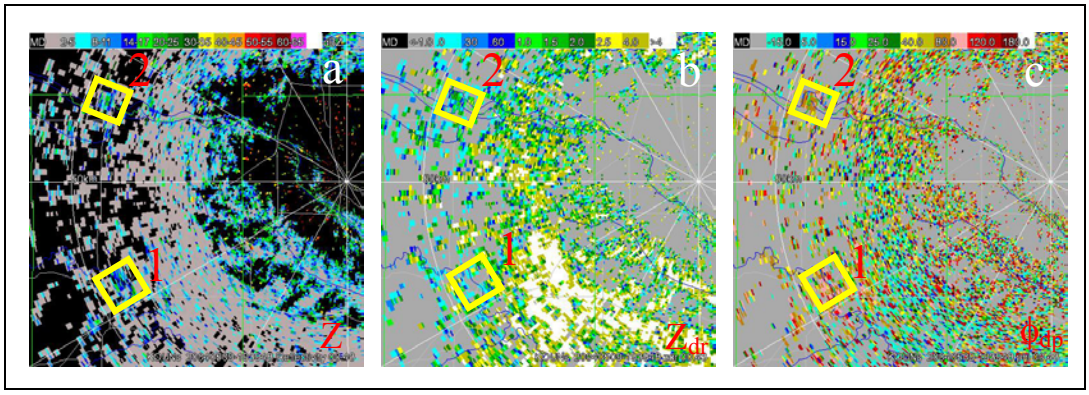

Fig. 4. Z (a), Z_{dr} (b), and f_{dp} (c) observed at by KOUN at 0.5^{o} elevation angle at 19:39 UTC on 9 May 2004. Radar is on the cross point of white lines. Yellow boxes mark the sections where nesting birds observed. White range ring indicates 50 km.

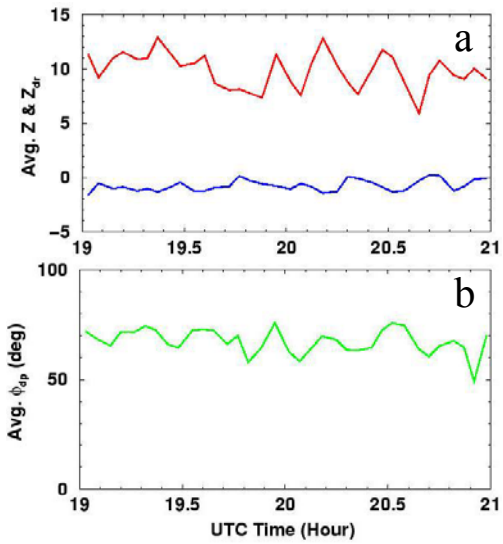

Fig. 5. Evolution of $\overline{Z}_1$ (red), $\overline{Z}_{dr1}$ (blue), and $\overline{\phi}_{dp1}$ (green) for the flock 1 (marked 1 in Fig.4) from 19:00UTC to 21:00UTC.

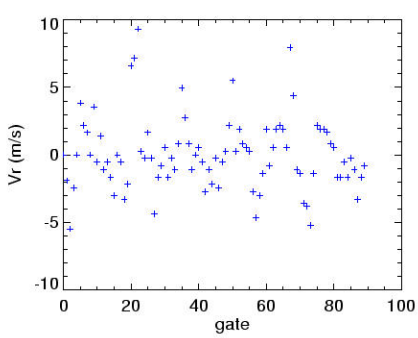

Fig. 6. Scattergrams of Vr in area 1 at 20:11UTC.

the echoes are not ground clutters because in general the Doppler velocities of ground clutters are zero.

The magnitudes of $\overline{Z}_1$ and $\overline{\phi}_{dp1}$ are consistent with $\overline{Z}$ and $\overline{\phi}_{dp}$ for nocturnal migrating birds (from 03:00 to 11:00UTC in Fig. 2), but $\overline{Z}_{dr1}$ is clearly below $\overline{Z}_{dr}$. We believe the nesting birds are different species with different sizes from the migrating birds. The relatively simple model shows that prolate spheroids with different sizes can have similar values of differential phase but different differential reflectivity (see Fig. 6 and 7 in the paper of Zrnic and Ryzhkov, 1998).

The observations of these two nesting bird flocks demonstrate the capability of polarimetric radar to provide accurate information about the location of relatively small flock of birds. In this case the area where birds reside is about 16 km^2. Such information might be useful to the aviation community because encounters with birds can damage the windshield or extinguish jet engines.

4. DISCUSSION AND CONCLUSION

The results of case study presented herein are consistent with the previous studies on the polarization-dependent radar characteristics of insects and birds (Hajovsky et al., 1966; Riley, 1975; Zrnic and Ryzhkov, 1998). The polarimetric radar is a powerful tool not only to discriminate between biological and meteorological scatterers, but also to discriminate between birds and insects. Continuous observations with the KOUN radar have shown the rapid changes of polarimetric variables like Z_{dr} and ϕ_{dp}, at sunset and sunrise time as the occupancy of the planetary boundary layer shifts between insects and birds. It has also been demonstrated that polarimetric radar can detect localized flocks of birds in a relative small area.

But there are still some unanswered questions such as gradual increase of $\overline{Z}_{dr}$ with time during the day, asymmetry of the Z_{dr} azimuthal profiles

with respect to the direction of bird migration, etc. Thus, more polarimetric radar observations and investigations of insects and birds are required to develop a reliable automatic classification procedure to distinguish between birds and insects.

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