

Identifying Doppler Velocity Contamination Caused by Migrating Birds. Part I: Feature Extraction and Quantification

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ABSTRACT

Radar echoes from migrating birds can severely contaminate Doppler velocity measurements. For meteorological applications, especially quantitative applications in radar data assimilation, it is necessary to remove bird-contaminated velocity scans by using an automated identification technique. Such a technique should be also useful for ornithologists in selecting bird echoes automatically from radar scans. This technique can be developed in two steps: (i) extract the main features of migrating-bird echoes from reflectivity and Doppler velocity images and find proper parameters to quantify these features; (ii) utilize these parameters to develop an automated quality control procedure to identify and flag migrating-bird-contaminated Doppler velocity scans (sweeps). The first step is accomplished in this study (Part I) by identifying possible migrating-bird echoes in the level II data collected from the Oklahoma KTLX radar during the 2003 spring migrating season. The identifications are further verified by polarimetric radar measurements from the National Severe Storms Laboratory (NSSL) KOUN radar, Geostationary Operational Environmental Satellite (GOES) IR images, and rawinsonde measurements. Three proper parameters are found, and their histograms are prepared for the second step of development (reported in Part II).

1. Introduction

It is well recognized that radar signal returns from flying birds, especially from migrating birds, can contaminate Doppler radar velocity measurements (O'Bannon 1995; Jungbluth et al. 1995; Gauthreaux and Belser 1998; Gauthreaux et al. 1998). 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^{-1} (Gauthreaux et al. 1998; Collins 2001; Bi et al. 2002). Investigations at the National Centers for Environmental Prediction (NCEP) also showed

that the velocity azimuth display (VAD) winds could be most frequently contaminated by migrating birds in the nighttime during the migrating seasons (Collins 2001). The problem showed as a north–south wind component that was too strong from the south in the spring and too strong from the north in the fall within preferred limits of altitude and temperature. These statistical features and related biases were similar to those detected from the wind profiler data (Jungbluth et al. 1995). Based on these statistical features and related climatology, and built on the experiences with the wind profiler data quality control (QC) (Collins 1993), a QC technique was developed to deal with the Doppler velocity data quality problems, including those caused by migrating birds (Collins 2001). In this QC, the bird contamination is identified mainly based on the observed increment (difference between the VAD wind and 6-h forecast wind interpolated to the observation location) together

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with the wind speed and height–time residual (difference between the VAD wind and a velocity interpolated from other wind data at nearby heights and times). This technique is currently used at NCEP for VAD wind QC.

The existing VAD wind QC is inadequate and will become completely outdated as soon as NCEP starts to assimilate the full-volume and full-precision level II wind data from the 120 National Weather Service (NWS) Weather Surveillance Radar-1988 Doppler (WSR-88D) radars into their operational numerical weather forecast (NWP) systems. A simple QC has been developed for level II radar data assimilation (Xu et al. 2004; Gu et al. 2001) with the U.S. Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS; Hodur 1997), but it deals with the velocity aliasing problem only. Although its dealiasing capability has been improved recently (Gong et al. 2003), this QC does not deal with complex data quality problems such as those caused by migrating birds. Gauthreaux and Belser (1998) and Gauthreaux et al. (1998) examined the appearance of birds on level II reflectivity and velocity images and presented some useful ideas and techniques to identify bird influences. While their QC techniques were designed mainly for accurate interpretations and human forecast applications, the main features of bird echoes and related ideas reported in their studies laid a foundation for the current study (see sections 3a and 3b herein). Quantitative applications of level II Doppler velocity data, especially radar wind assimilation with an operational NWP system, require high-standard data quality and reliability. To meet the required high standard, it is necessary not only to leverage the existing QC techniques but also to develop new techniques for level II wind QC. This is the motivation of this study. The goal is to develop a statistically reliable technique for automated detection of migrating-bird-contaminated level II Doppler velocity fields. Such an automated technique should also be useful for ornithologists in selecting bird echoes from radar scans. In particular, ornithologists regard the weather as the contaminant, not the birds, and they could make good use of the identified bird-contaminated scans in their studies of bird migration.

To achieve the above-mentioned goal, a real-time level II data process and wind analysis system is developed and used to monitor data quality problems and collect related information to permit discrimination of bird echoes (Liu et al. 2003). The level II reflectivity and Doppler velocity data collected from the Oklahoma KTLX radar during the 2003 spring migrating season is used herein to study the data quality problems caused by migrating birds. In addition, because polarimetric radar is able to discriminate bird echoes from meteorological scatterers (Zrnic and Ryzhkov 1998), observations from the National Severe Storms Laboratory (NSSL) KOUN polarimetric radar are used to verify the identification of migrating-bird contamination on level II data. Clear-sky satellite nighttime IR images and rawinsonde observations are also used, whenever available and necessary, to identify the presence of migrating birds. Note that polarimetric radar observations have not been used in operational observations so far, satellite nighttime IR images are not useful in the presence of clouds, and rawinsonde observations are available only twice per day. For operational applications, the QC technique must be designed to rely primarily on the information provided by the high-resolution level II reflectivity and Doppler velocity fields. Due to lack of independent measurements other than radar, it will be very difficult to detect bird contamination gate-by-gate or beam-by-beam for operational applications. A feasible approach is to detect bird contamination sweep-by-sweep or volume-by-volume. For the reason explained in the beginning of section 2, our study is focused on the lowest sweeps at the 0.5° elevation angle. The QC should be designed to utilize as much as possible the information provided by the high-resolution level II data fields, but it must be also sufficiently simple and computationally efficient for operational applications. To develop such a QC, we need to extract the main features of bird echoes in level II data fields (at 0.5°) and find proper QC parameters to quantify the extracted main features. The detailed processes and results are reported in this paper, organized as follows. The data collection and the verification of the existence of birds are described in the next section. The main features of bird echoes and related QC parameters and their histograms are presented in section 3. Conclusions follow in section 4.

2. Dataset and verification information

The coverage of WSR-88D is 460 km for reflectivity and 230 km for Doppler velocity. Based on the radar ray range–height equation (Doviak and Zrnic 1993), the 0.5° radar beam reaches 4 km at about 200 km away from radar under standard atmospheric conditions. Migrating birds usually fly at altitudes between 0.4 and 4 km (Gauthreaux et al. 1998), so WSR-88D measurements at the 0.5° elevation angle provide more information on bird echoes than measurements of higher elevation angles. Thus, as mentioned in the introduction, this study will be focused on bird contamination in level II Doppler velocity fields at the lowest elevation angle (0.5°).

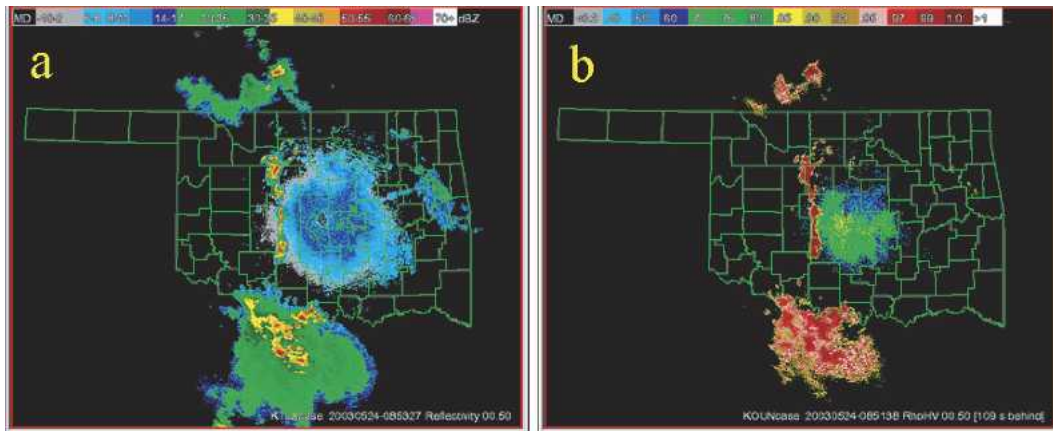


FIG. 1. (a) Reflectivity observed by KTLX and (b) correlation coefficient observed by KOUN at 0.5° elevation angle at 0000 UTC 24 May 2003.

Data quality problems in level II data from the Oklahoma KTLX radar have been continuously monitored and recorded via various quality indices (including the three QC parameters presented in section 3) since June 2002 by our real-time system (Liu et al. 2003). The level II reflectivity and Doppler velocity data collected over the entire 2003 spring bird migrating season (15 April–15 June) are processed together with the recorded quality indices. The processed data contains a total of 12 591 volume scans. Since migrating birds fly mostly at night, migrating-bird contamination is not detected from daytime scans among the 12 591 volume scans. Thus, only 5782 nighttime scans at the lowest tilt (0.5°) are selected in this study. High-resolution and high-fidelity images of reflectivity and Doppler velocity are produced from the selected nighttime scans at the lowest tilt. The produced image fields are then combined into movie loops. By animating these movie loops for each night, possible migrating-bird contamination is screened together with the recorded quality indices (especially the three QC parameters). Every field subject to possible migrating-bird contamination is flagged at this preliminary stage, and this is done entirely by visual inspections based on the criteria described by Gauthreaux and Belser (1998) and accumulated human experiences (O'Bannon 1995; Jungbluth et al. 1995; Collins 2001; Bi et al. 2002; Zhang et al. 2002, 2003). Then, observations from KOUN polarimetric radar, satellite, and rawinsonde are used to confirm the identifications. By cross-examining all the information obtained from these observations, the scans with bird contamination are finally identified.

As mentioned in the introduction, polarimetric radar observations can be used to discriminate nonmeteorological scatterers from meteorological scatterers (Doviak and Zrnic 1993). Polarimetric radar can also

be used to discriminate bird echoes from insect echoes (Zrnic and Ryzhkov 1998). Insects usually are considered as passive tracers that can represent the air motion. This is the reason that only bird echoes are treated as contamination for air velocity measurements by using Doppler radar. An example is shown in Fig. 1b, in which the KOUN radar is located at the center of the image. As displayed by the field of correlation coefficient between horizontal and vertical polarization (at 0.5°) in Fig. 1b, bird echoes are clearly colored (green and blue) very differently from the thunderstorm echoes (red and yellow). Note that the correlation coefficient is very close to 1 over the red and yellow areas but is around 0.7 over the green and blue areas. This correlation coefficient indicates the similarities of scatterer property between horizontally and vertically polarized echoes. The similarity is high and close to 1 for raindrops and hail in a thunderstorm because these hydrometeors are nearly spherical. The similarity is relatively low for bird echoes because birds are not spherical but have elongated shapes. This explains why and how bird echoes (green and blue) can be identified from the correlation coefficient field as shown in Fig. 1b. For the same time period, the level II reflectivity field (at 0.5°) observed by the KTLX WSR-88D (located about 20 km away from KOUN) is displayed in Fig. 1a. As shown, bird echoes in the vicinity of the radar site are colored in the same range as the thunderstorm cells patches along the south–north-oriented dryline to the west side of the radar site. Thus, as experienced by the authors and many other investigators, identifying bird echoes from level II data alone often requires considerable skills and experiences and is not always possible. Because of this, KOUN polarimetric radar observations in the same observation period are used extensively to check the presence of birds in order

to reexamine the level II Doppler velocity fields, especially those flagged in the above preliminary stage. This improves the accuracy of the verification information.

Clear-sky satellite nighttime IR images (over the Oklahoma area) and rawinsonde observations from the Oklahoma OUN sounding station are also used, whenever available and necessary, to further verify the presence or nonpresence of migrating birds. If the nighttime satellite IR image shows clear sky over the Oklahoma area during the migrating season but the KTLX radar reflectivity displays a disklike echo around the radar, then the radar echoes are very likely to be caused by migrating birds. Rawinsonde observations from OUN are also used to compare with KTLX VAD winds around the synoptic times (0000 and 1200 UTC). Large difference between the rawinsonde and VAD winds can occur in the presence of migrating birds. The difference between the rawinsonde and VAD winds can quantify how severely the level II Doppler velocities are influenced by migrating birds. The detailed method and some of the results are reported in Bi et al. (2002).

After the above reexamination, all the sweeps of level II Doppler velocities are classified into two groups: (i) noncontaminated and (ii) contaminated (finally flagged) sweeps. Note that nesting bird echoes are not considered as contamination for two reasons. First, these echoes usually have relatively small sizes, often too small to be detected (by the QC developed based on the statistics of this and follow-up studies). Second, nesting birds fly in all different directions and thus do not significantly contaminate the level II Doppler velocities. On the other hand, all migrating birds fly nearly in the same direction, and they can severely contaminate the level II Doppler velocities. Thus, even when migrating bird echoes are identified only locally or coexist with weather echoes, the entire level II Doppler velocity field is still flagged. In total, 2457 out of 5782 nighttime lowest-sweep scans are flagged. The nonflagged scans are completely free of migrating bird echoes.

3. Main features of bird echoes and related QC parameters

As explained in the introduction, to develop a sweep-by-sweep QC technique, we need to extract the main features of bird echoes in level II reflectivity and Doppler velocity fields (at 0.5°) and find proper QC parameters that can be efficiently computed from level II data to quantify the extracted main features for each sweep. Gauthreaux and Belser (1998) showed several main features of bird echoes in level II data, such as en-

hanced reflectivity with an annular or disklike shape and enhanced velocity coverage. These main features are also observed from the level II data collected by our real-time system (Liu et al. 2003), including the data used in this study (see section 2). Additional features are also sought to further characterize bird echoes. Among all the additional features so far extracted, the most significant feature is the enhanced gate-to-gate velocity fluctuations. To quantify this and the aforementioned two main features, a number of QC parameters have been considered, and three of them are found practically most useful. The details are presented in the following subsections.

a. Mean reflectivity

The radar ornithological studies of Gauthreaux and Belser (1998) and Gauthreaux et al. (1998) showed that most migrating birds fly at night from approximately south to north in spring and from approximately north to south in fall, and they fly in favor of a tailwind usually. Their induced radar echoes enhance the reflectivity and often display a disklike or annular pattern centered at the radar site. Such a pattern with bird-enhanced reflectivity is also frequently observed from KTLX radar during migrating seasons. But the pattern becomes complicated when large lakes or mountains are present. An example is presented in Fig. 2a (see also Fig. 1b). Due to the presence of migrating birds (nighttime, at 0421 UTC 3 May 2003), the reflectivity in Fig. 2a exhibits a disklike pattern and the maximum reflectivity is enhanced (by about 20 dBZ in comparison with the clear-air reflectivity). These features are distinctive for migrating-bird echoes in comparison with thunderstorm echoes and clear-air echoes (not shown).

To quantify the above features, several QC parameters were tried and tested. The experiences so far obtained indicate that it is difficult to effectively quantify the annular and disklike patterns caused by bird echoes, but it is relatively easy to quantify the bird-enhanced reflectivity. Based on the experiences acquired from our visual inspections on radar reflectivity images displayed in dBZ units, a proper QC parameter for the latter is the mean reflectivity (MRF), in dBZ, defined by

$$\text{MRF} = \sum_n \text{Ref}(n) / N_{\text{ref}}, \quad (1)$$

where $\text{Ref}(n)$ is the radar reflectivity (in dBZ) at the n th data point, the summation $\sum_n$ is over n (from 1 to N_{ref}), and N_{ref} is the number of reflectivity observations (including those with 0 dBZ) on the concerned sweep

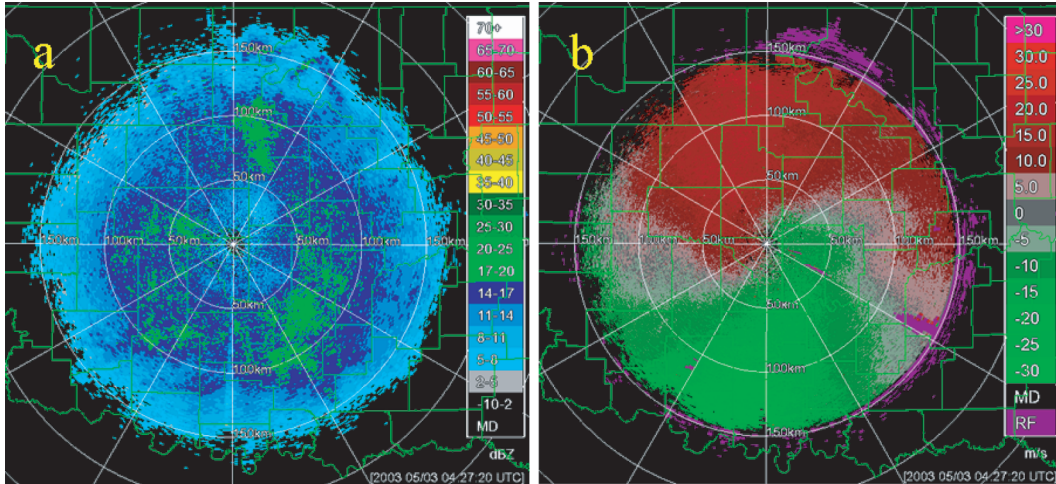


FIG. 2. (a) Reflectivity and (b) Doppler velocity observed by KTLX at 0.5° elevation angle at 0421 UTC 3 May 2003.

(at 0.5°). Here, the bird-echo enhanced reflectivity is quantified by MRF – the averaged reflectivity, in dBZ (which is obtained by averaging the dBZ values of the reflectivity rather than averaging the echo intensity and then converting the average in dBZ units). How to effectively quantify the annular and disklike bird echoes is still under investigation.

The MRF is computed for each sweep in the consolidated dataset (see section 2). The noncontaminated and contaminated (flagged) sweeps are binned separately into equally divided MRF intervals (bin width = 1 dBZ). The resulting histograms are plotted in Figs. 3a and 3b. The two histograms exhibit quite different frequency distributions between the contaminated and noncontaminated sweeps. The maximum frequency is 480 at MRF = 4 dBZ for the noncontaminated sweeps, which is well separated from the maximum frequency (=500) at MRF = 8 dBZ for the contaminated sweeps. Thus, statistically, MRF can be selected as a QC parameter to quantify the enhanced reflectivity by migrating birds.

Note that pure bird echoes are normally around 4 dBZ, which is lower than the median (6.8 dBZ) and averaged value (7.1 dBZ) of MRF for the contaminated sweeps in Fig. 3a. The reason is that many contaminated sweeps contain high-reflectivity thunderstorm echoes. As these thunderstorm echoes are mixed with bird echoes, the MRFs are raised in these sweeps and become significantly stronger than normal clear-sky bird echoes (around 4 dBZ). Many noncontaminated sweeps also contain high-reflectivity thunderstorm echoes. This explains why the two histograms overlap considerably on the high-MRF side. Regardless of this partial overlap, the maxima of the two histograms are well

separated, as shown in Fig. 3. Thus, MRF can be a useful QC parameter, and it is used statistically, in combination with other two QC parameters introduced in the next two subsections, to discriminate contaminated sweeps from noncontaminated sweeps.

b. Velocity data coverage

Another important feature of bird echoes described in Gauthreaux and Belser (1998) is the enhanced velocity coverage. This bird-related feature is also seen from KTLX level II data. An example is presented in Fig. 2b for the same case as in Fig. 2a. As shown, due to the presence of migrating birds, the Doppler velocity measurements cover nearly the entire scope of radar scans at 0.5° elevation angle. This feature is quite unique and different from scattered thunderstorm echoes and clear-sky echoes in the absence of migrating birds.

The above feature can be properly quantified by the velocity data coverage (VDC) that is defined by

$$\text{VDC} = N_{\text{vr}}/N_{\text{max}}, \quad (2)$$

where N_{vr} is the number of Doppler velocity observations on the concerned sweep (at 0.5°), $N_{\text{max}} = I_{\text{gt}} \times J_{\text{bm}}$ is the maximal number of velocity observations on one sweep, $I_{\text{gt}} = 920$ is the total number of gates of along each beam, and $J_{\text{bm}} (=367)$ is the total number of beams (at 0.5°).

The VDC is computed for each sweep in the consolidated dataset. The noncontaminated and contaminated sweeps are binned separately into equally divided VDC intervals (bin width = 4%). The two resulting histograms are plotted in Figs. 4a and 4b and exhibit very

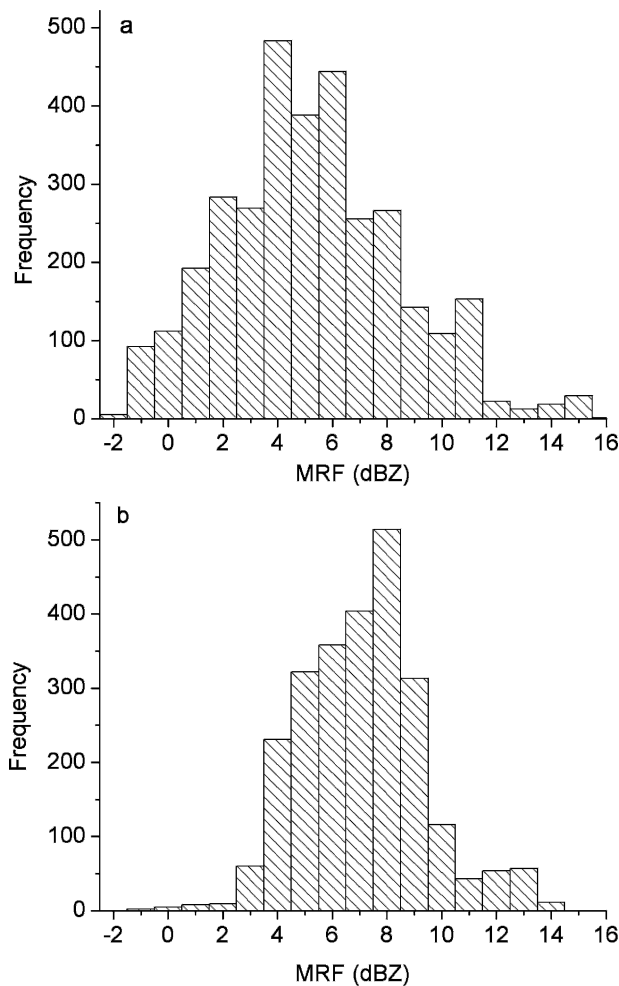


FIG. 3. Histogram of MRF (dBZ) for (a) noncontaminated and (b) bird-contaminated sweeps.

different frequency distributions between the contaminated and noncontaminated sweeps. The maximum frequency is 500 at VDC = 45% for the noncontaminated sweeps, which is far apart from the maximum frequency (=480) at VDC = 65% for the contaminated sweeps. Thus, statistically, VDC should be a good QC parameter.

c. Along-beam perturbation velocity sign changes

In addition to the above-mentioned important features, it is noted that in the presence of migrating birds the textures of level II reflectivity and velocity imagery are quite grainy in the finescale but rather smooth and uniform in the grand pattern in comparison with those in the absence of birds. This feature can be seen if the reflectivity in Fig. 2a or the velocity in Fig. 2b is zoomed in (not shown). Figure 5a displays the level II velocity imagery of overcast stratiform precipitation

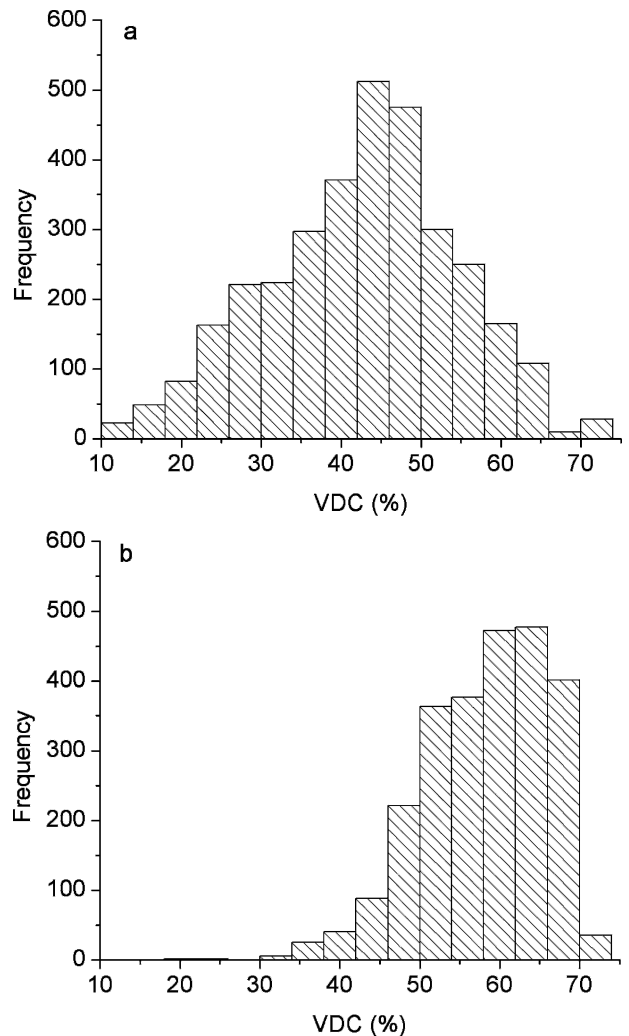


FIG. 4. Histogram of VDC (%) for (a) noncontaminated and (b) bird-contaminated sweeps.

observed at the 0.5° elevation angle from the Pittsburgh KPBZ radar on 5 November 2002, while Fig. 5b is the level II velocity imagery mainly of migrating birds observed at 0.5° from KTLX radar on 4 November 2002. As shown, in the presence of stratiform precipitation but the absence of birds, the velocity imagery is relatively smooth (Fig. 5a). In the presence of migrating birds but absence of precipitation, the velocity imagery is relatively grainy (Fig. 5b).

To quantify the grainy-texture feature, several QC parameters were tried and tested. As reported originally in Zhang et al. (2003), a potentially useful QC parameter could be the percentage of velocity sign changes, which is defined by $P_{sc}(j) = I_{sc}(j)/I_{vr}(j)$ as a function of j (associated with the azimuthal angle). Here, $I_{sc}(j)$ is the number of Doppler velocity V_r sign changes, $I_{vr}(j)$ is the number of Doppler velocity (V_r)

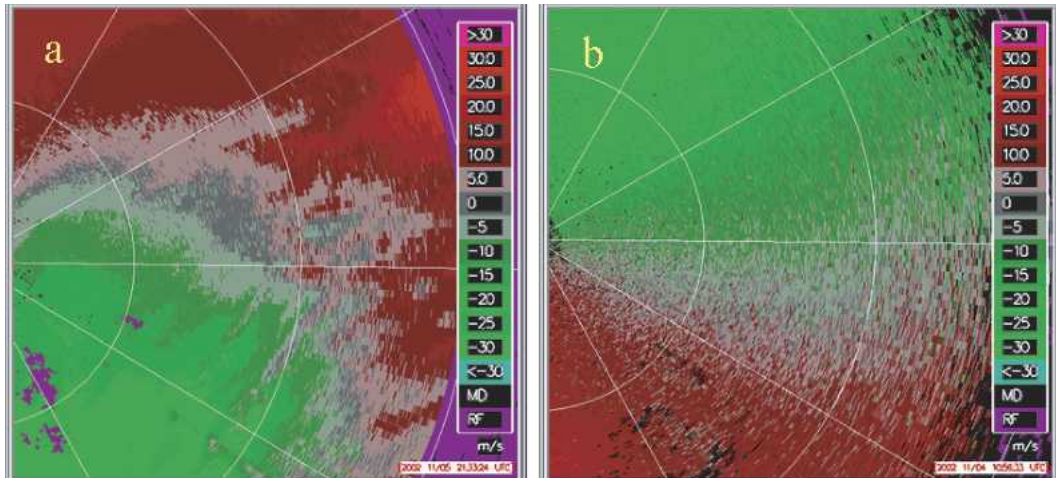


FIG. 5. Doppler velocity fields of (a) overcast stratiform precipitation observed by KPBZ on 5 Nov 2002 and (b) migrating birds by KTLX on 4 Nov 2002. Radar sites are located at the center of range rings. The interval of range rings is 50 km. Warm/cold color stands for Doppler velocity away from/toward the radar. Gray color means zero Doppler velocity.

observations along the j th beam, and $P_{sc}(j)$ is computed beam-by-beam for the two sweeps in Fig. 5. The results are plotted in Fig. 6, where the circles are for the non-contaminated sweep in Fig. 5a and the triangles are for the bird-contaminated sweep in Fig. 5b. As shown in Fig. 6, the beam-to-beam variations of $P_{sc}(j)$ reveal a major difference between the bird-contaminated sweep (Fig. 5b) and noncontaminated sweep (Fig. 5a). Note that the mean wind was northerly (southerly) over KTLX (KPBZ) as shown in Fig. 5b (Fig. 5a). The vertical shear of the horizontal wind is quite weak in both cases. The Doppler velocity is nearly zero along the beams in the vicinities of 90° and 270° azimuths, as indicated by the yellow dashed lines in Figs. 5a and 5b. This explains why $P_{sc}(j)$ increases sharply around 90° and 270° in the presence of migrating birds (see triangles in Fig. 6) but not so in the presence of rain only (see circles in Fig. 6). Thus, as a function of j , $P_{sc}(j)$ can be an effective QC parameter, but it requires the following two conditions: (i) the winds are nearly unidirectional with weak vertical shear, and thus near-zero velocity beams can exist; (ii) the sweep is not partially contaminated by migrating birds outside the near-zero velocity beams. These limit the usefulness of $P_{sc}(j)$. Besides, for the sweep-by-sweep detection considered in this paper, $P_{sc}(j)$ must be integrated into a single QC parameter (or a small number of QC parameters). This could be simply the mean value computed by $MP_{sc} = (J_{bm})^{-1} \sum_j P_{sc}(j)$, where $J_{bm} (=367)$ is the total number of beams, as in (2). This simple QC parameter is tested and found to be not as effective as the QC parameter introduced below in Eq. (3). It is possible to make MP_{sc}

more effective if the mean [competed by $(J_{bm})^{-1} \sum_j$] is limited to near-zero velocity beams only (see Figs. 5 and 6). Selecting near-zero velocity beams, however, cannot always be successful, especially when the first condition (i) is not satisfied. Because of this and the limitation posed by the second condition (ii), $P_{sc}(j)$ is dropped for further consideration [but Liu et al. (2003) found MP_{sc} to be useful to identify the noisy velocity field].

Inspired by the above findings, a much-improved QC parameter is found to quantify the grainy-texture feature caused by migrating birds. This QC parameter is

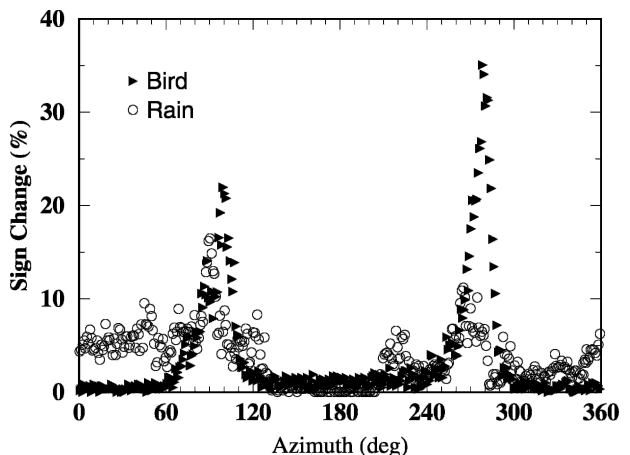


FIG. 6. Azimuthal distribution of percentages of Doppler velocity sign changes along each beam at 0.5° elevation angle at range 50 km over the azimuthal directions 360° in the presence of migrating birds (filled triangle) and rain (empty circle).

the averaged percentage of along-beam perturbation velocity sign changes (VSC) and is defined by

$$\text{VSC} = (J_{\text{bm}})^{-1} \sum_j [I_{\text{psc}}(j)/I_{\text{vr}}(j)], \quad (3)$$

where $I_{\text{psc}}(j)$ is the number of perturbation Doppler velocity sign changes along the j th beam, and $I_{\text{vr}}(j)$ and J_{bm} are the same as in Eq. (2). The summation is over J_{bm} . Here, the perturbation Doppler velocity is the Doppler velocity minus its along-beam nine-point median value. Previously, the averaged standard deviation of Doppler velocity was used to quantify the grainy-texture feature caused by bird echoes (Zhang et al. 2002). This parameter is not further considered in this paper, as it plays roughly the same role as VSC defined in Eq. (3), but it is slightly less effective statistically and less efficient computationally than VSC. As mentioned earlier, the textures of bird-contaminated reflectivity in Fig. 2a are also grainy in the finescale (not shown). This grainy texture can be quantified by the averaged percentage of along-beam perturbation reflectivity sign changes, which is defined similarly to that in Eq. (3) except that $I_{\text{psc}}(j)$ should now represent the number of perturbation reflectivity sign changes along the j th beam. This QC parameter, however, is found to be less effective than VSC in Eq. (3), mainly because the reflectivity gate resolution (1 km) is 4 times as coarse as the velocity gate resolution (0.25 km). Thus, VSC is selected in this paper as a proper QC parameter to quantify the grainy-texture feature caused by migrating birds.

The VSC is computed for each sweep in the consolidated dataset. The noncontaminated and contaminated sweeps are binned separately into equally divided VSC intervals (bin width = 2%). The resulting histograms are plotted in Figs. 7a and 7b. The two histograms exhibit very different frequency distributions between the contaminated and noncontaminated sweeps. For the noncontaminated sweeps, the maximum frequency is 580 at VSC = 38%. For the contaminated sweeps, the maximum frequency is 1200 at VSC = 41%. Although the two maxima are not far apart from each other, the frequency distribution for the contaminated sweeps is sharply peaked at VSC = 41%, while the frequency distribution for the noncontaminated sweeps spreads mostly over the range between VSC = 30% and 40%. Thus, statistically, VSC is an acceptable QC parameter.

4. Conclusions

In this paper, level II reflectivity and Doppler velocity data collected by the Oklahoma KTLX radar during the 2003 spring bird migrating season (15 April–15 June) are used to investigate Doppler velocity contami-

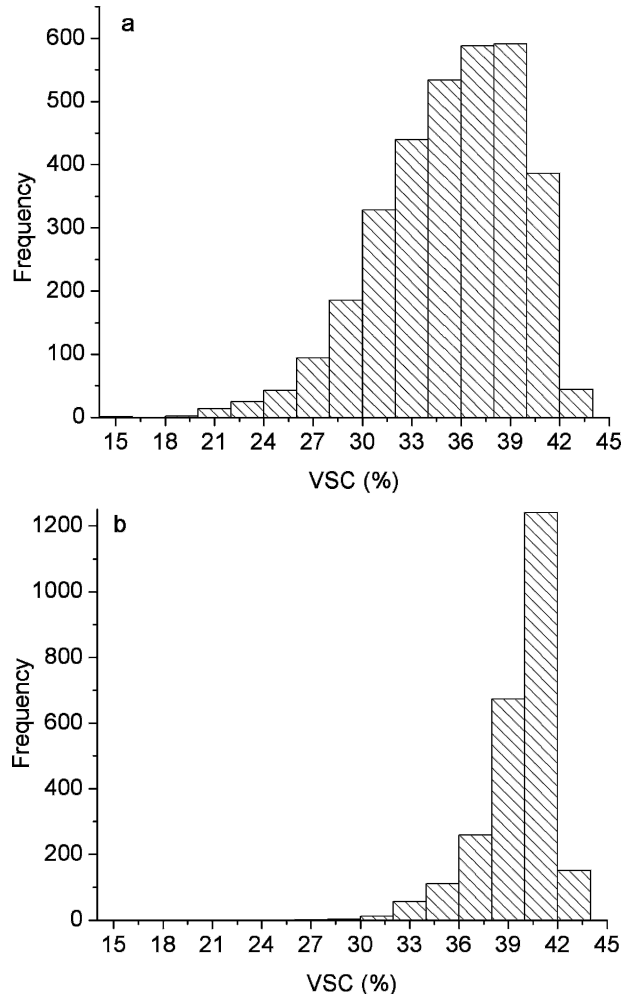


FIG. 7. Histogram of VSC (%) for (a) noncontaminated and (b) bird-contaminated sweeps.

nation caused by migrating birds. The observations of the NSSL KOUN polarimetric radar, Geostationary Operational Environmental Satellite (GOES) IR images, and rawinsonde measurements over the same time period are used for the verifications. Based on previous radar ornithological studies (Gauthreaux and Belser 1998), three main features of bird echoes are extracted from the collected data. These main features can be characterized as (i) enhanced reflectivity with an annular or disklike shape, (ii) enhanced Doppler velocity coverage, and (iii) enhanced grainy texture in the velocity imagery, respectively. Three QC parameters are then designed to properly quantify these important features. These three QC parameters are the mean reflectivity (MRF), the velocity data coverage (VDC), and the along-beam perturbation velocity sign changes (VSC) [see Eqs. (1)–(3)].

The histograms of the above three QC parameters

(Figs. 3, 4, and 7) show that the frequency distributions for bird-contaminated sweeps are very different from those for noncontaminated sweeps. In particular, for MRF, the maximum frequencies are well separated (by 4 dBZ) between the bird-contaminated and noncontaminated cases. For VDC, the maximum frequencies are also well separated (by 20%) between the bird-contaminated and noncontaminated cases. For VSC, the two maxima (41% for bird-contaminated and 38% for noncontaminated) are closer to each other. But the VSC frequency distribution for the bird-contaminated case is narrow and sharply peaked (at 41%), which is very different from the widespread frequency distribution (20%–43%) for the noncontaminated case. These histograms suggest that it is feasible to develop a bird identification technique based on these QC parameters. The detailed technique will be presented in a follow-up paper (Liu et al. 2005).

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