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REPORT ON BIRD HAZARD ALGORITHM

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by

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Illinois Natural History Survey

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Abstract

The Illinois Natural History Survey is developing algorithms for real-time bird hazard warnings to aircraft. The algorithms will allow the NEXRAD weather radar to discriminate bird echoes from other echoes and report the presence of birds hazardous to aircraft.

Since our last report in December, 1987, we have enhanced the ability of the Illinois Natural History Survey X-band tracking radar to identify waterfowl targets at long range; gathered further radar data on waterfowl, especially Canada Geese (*Branta canadensis)*, American Crows (*Corvus brachyrhynchos)*, blackbirds (*Agelaius, Eupahgus, Quiscalus, Molothrus)*, and European Starlings (*Sturnus vulgaris)*; enhanced our ability to deal with data from weather radars; written and used computer programs to emulate the NEXRAD radar with data from any of several research radars; further investigated the Spectral Width parameter; and virtually completed a new working algorithm to detect morning roost departures by blackbirds and locate the roosting sites geographically.

No data are yet available from the NEXRAD radar itself because the data are not being made available until final testing of the first unit is completed. Data are scheduled to be made available September 1989.

Data collection, personnel developments, and project history.

Birds are a well-known hazard to aviation (Blokpoel 1976). Work since 1982 at the Illinois Natural History Survey to develop algorithms to detect birds hazardous to aircraft is described in previous reports (Larkin 1983; Larkin and Quine 1987; Quine and Larkin 1987). The algorithms will run on the Next Generation Weather Radar (Durham 1983).

Data collected in 1988 through February 1989 were entirely from the CHILL radar operated by the Illinois State Water Survey. Additional data were given to us by M.I.T. Lincoln Laboratory. During 1988 and early 1989 a series of hardware problems and upgrades occurred, nearly all of which affected the appearance of bird targets on the radar. These hardware-related events necessitated spending appreciable time on data-quality issues and writing special software to correct or exclude data from certain periods. Unavailability of Z_{DR} (Guli 1986) during most of the 1988-1989 cold months may affect our ability to apply these data to questions involving circular polarization or possible polarization diversity on NEXRAD in the future.

Date	CHILL hardware-related event
19 Jan 88	Video amplifier installed
10 Feb 88	Video amplifier removed; velocity bias improved
ca. 10 Apr 88	Notch filter inserted to reduce bias
Sep 88	New focus coil installed

30 Sep 88	Problem with 800-μsec P.R.T.s discovered
14 Oct 88	Failure of antenna drive motor; unavailable
17 Oct 88	Variable attenuators removed
20 Oct 88	4 dB attenuator installed; offset tried
14 Jan 89	Receiver relocated to reduce noise
12 Feb 89	New receiver power supply
ca. 1 Mar 89	New attenuators installed
ca. 1 Apr 89	New antenna drive motors; Z_{DR} available again

To accommodate these and other changes in software and to integrate our software facilities for reading and manipulation data from research weather radars, Dr. Quine has implemented several Computer Assisted Software Engineering tools (Appendix I). The result of spending this considerable effort is that maintenance of the programs is less demanding and is placed on a surer footing because the system can be instructed to revert to an earlier incarnation of a program if a modification is faulty. In the near future, Universal Format tapes will be generated by the NEXRAD OSF from Archive Level II data (Anon 1984), so that this format will become the focus of the extensive software facilities we have developed.

In November, 1988, in the midst of ongoing data collection in the field, Dr. Quine accepted a lucrative offer from private industry and left the project after over four years of loyal service. Considerable disruption ensued following the departure of the only full-time employee on the project. Coincidentally, several serious computer hardware failures occurred during this time, so that research and work on migratory birds and waterfowl nearly stopped in favor of technical and administrative activities. The computer failures, the first serious ones in the history of the project, included intermittent failure of a 660-MB hard disk necessitating factory repair, a 3-month series of troubles with a tape drive followed by a 3-month factory repair, failure of the laboratory's old line printer, problems with two terminals, and temporary loss of a tape controller card. Happily, the computer problems seem to be mostly resolved and a new full-time employee, Mr. Gregory Tillman, has taken up Dr. Quine's work.

Tracking radar improvements to support studies of waterfowl. The trailer housing the Natural History Survey tracking radar was modified by moving the axles rearward, increasing stability on the road, particularly in high winds, and creating additional room inside for another instrument rack. Maintenance difficulties with the old minicomputer used to gather data from the tracking radar created considerable trouble; all three disk units attached to this computer have failed in the last two field seasons and two of them are so obsolete that commercial companies cannot repair them. The tracking radar itself experienced problems, mainly related to weathering severe cold during goose migration in early winter. The telescope mount was not used during 1988.

Software for the tracking radar was significantly upgraded in two ways. Synchro-to-digital converters were brought into operation, providing increased accuracy and freedom from drift.

These characteristics were especially useful in tracking waterfowl at long distances. The same application necessitated doubling the range at which wing beat signatures could be taken. In 1988, waterfowl signatures were recorded out to about 3300 meters slant range.

Data from the tracking radar have been entered into a large database by undergraduate assistants Tom Choy and Dan Zimmerman. The variables in the database are given in Appendix II. A summary of target identity data from wing beat signatures during the Fall 1987 season is shown in Figures 1 and 2. Targets with relatively low wing beat frequencies usually fly in groups (multiple targets) and/or fly with uninterrupted, steady wing beats (steady flappers); these are waterfowl with some additional large passerines and miscellaneous large birds. Targets with higher wing beat frequencies are apt to have flap-coast wing beat patterns; these are apt to be smaller passerine birds. "Wing beat" frequencies of about 27-33 Hz are a tracking radar artifact. Frequencies of about 60 Hz are North American line current noise leaking into the system. These latter non-biological frequencies often predominate when insects (i.e. most "non-bird-like" targets) are tracked.

Spectral width.

Spectral width is one of the three product fields of the NEXRAD RDA. It is poorly understood even by those who use weather radars to study weather, partly because it has become available on such radars only recently and partly because estimation of spectral width has been fraught with difficulties whenever it has been implemented in actual hardware. Spectral width is essentially the same quantity as Variance; the two are simple arithmetic functions of each other.

In an earlier report (June 1987 Appendix II), we described a puzzling and ultimately fatal artifact in Variance data from one of the research weather radars from which we acquired data on birds. Since 1987 we have acquired data from the CHILL radar; these data have had similarly troublesome artifacts associated with spectral width. In the following paragraphs we demonstrate that (i) spectral width still holds great promise as a variable with which to discriminate birds from meteorological and ground targets and (ii) spectral widths available thus far from CHILL are, at best, difficult to interpret definitively or, at worst, afflicted with artifacts to the same degree Variance from other radars had been.

Spectral width is computed from Variance:

$$\text{spectral width} = \sqrt{|\sigma^2|}$$

, where σ^2 is the Variance. Spectral width is measured in the same units as velocity, ms^{-1}. Negative real values for σ are mathematically impossible; therefore, negative values for spectral width are mathematically impossible. However, when radar electronics produce negative Variance for any reason, spectral width is also set negative by convention. On NEXRAD (as of 29

February 1988, Anon. 1988) and on many research radars, estimates of spectral width that are negative are set to zero, obfuscating potential artifacts if they exist.

Note that converting Variance to spectral width involves a squaring operation; this squaring will reduce the proportion of values near zero (but not equal to zero) and will thus create a widening of the distribution of values near zero, or even produce a bimodal distribution of spectral width from a unimodal low distribution of Variance.

Using pulse-pair processors, one of two estimators is usually used to generate values for Variance, which is then effectively converted to spectral width using the above relationship. The first is called SW1 in CHILL data and $\sigma_2{}^2$ in equation (2), Srivastava et al. (1979):

$$\sigma_2{}^2=\frac{\lambda^2}{8\pi^2\tau^2}\left[1-\frac{|R(\tau)|}{R(0)}(1+\mathrm{SNR}^{-1})\right],$$

, where λ is wavelength, τ is the pulse repetition time, R is the autocorrelation function, and SNR is the system signal-to-noise ratio.

The second is called SW2 in CHILL data and $\sigma_3{}^2$ in equation (9) Srivastava et al. (1979):

$$\sigma_3{}^2=\frac{\lambda^2}{24\pi^2\tau^2}\ln\left|\frac{R(\tau)}{R(2\tau)}\right|$$

SW1 and SW2 were found by Srivastava et al. (1979) to be quite similar theoretically when SNR > 5 dB. Data from the CHILL radar in 1988-1989 contain SW2 directly on the tapes; much 1988-1989 data also contain noise-corrected power, allowing us to convert SW2 to SW1 if necessary to conform to NEXRAD convention. At this point, sufficient uncertainties surround spectral width that the difference between SW1 and SW2 is not yet important for our work on birds. We expect to investigate this difference after the more immediate question of negative widths is resolved.

Figure 3 shows spectral width for geese and for typical clutter during daytime migration of Canada Geese. The color scale is designed to highlight differences among negative spectral widths (black), zero or low widths (salmon, orange) and higher widths typical of ground clutter and precipitation (green, blue). Sirmans (1988) reports spectral widths for precipitation with a wide mode centered at 4-5 ms^{-1}. The large flocks of Canada Geese have widths that are largely low or negative, with only few exceptions (large echo blobs especially common to the N and SSE). The exceptions are suspected to be partly problems with CHILL estimation of spectral width. In contrast to the bird echoes other echoes are predominately 3 ms^{-1} or higher. Note ground clutter (especially at close range), noncoherent noise from another transmitter (line of blue echoes at about 265°), and traffic on Interstate Highway 74 (scattered blue echoes in a line toward the NW). Spectral width is clearly helpful in recognizing bird targets.

During 1988 through early 1989, spectral widths on CHILL were invalid or suspected to be invalid due to bias in velocity, changes in the attenuator circuits, an error in the signal processor at low pulse-repetition times, and several actual and suspected misadjustments of the gains on the I (unshifted) and Q (90° shifted in phase) channels. Personnel in our project were heavily involved for a time in assisting those at the CHILL to diagnose and characterize the problems with the radar. CHILL data are currently afflicted with heavily negative spectral widths at velocities of plus and minus Nyquist/2. The cause for this concentration of negative spectral widths at certain velocities is not known, but may involve further slight recurring maladjustments of the I and Q phases. As of this writing, CHILL personnel are using a software simulation written by Dusan Zrnic to investigate the effect of unequal average I and Q signals on computation of spectral width at different velocities. Meanwhile, spectral width remains a most promising yet not quite reliable variable for helping to separate birds from other targets on Doppler radar.

Crows, starlings, and "blackbirds"

As described in previous reports, the term "blackbird" is commonly used to denote either European Starlings (*Sturnus vulgaris*) or any of a number of species in the subfamily Icterinae. The blackbirds often roost together in multi-species roosts that change species composition (Caccamise, et al 1983, Caccamise and Fischl 1985) but last for many months when the birds are not breeding. Vegetation and exposure are important factors in roost site selection by blackbirds (Lyon and Caccamise 1981).

The densely-populated roosts occupied by blackbirds in the nonbreeding season create hazards for aviation when the birds fly to and from the roosts, but also in midday when birds feed on airdromes (Gilmer and Burtt 1974). In 1988 and early 1989 we have developed a nearly complete algorithm to locate such roosts automatically via weather radar. This algorithm is called the Blackbird Algorithm; it functions only during the early morning period when the birds depart from the roosts in nearly-circular waves, generating so-called ring angels on the PPI display (Plank 1959, Eastwood et al. 1962, Eastwood 1967, Larkin 1983). In some circumstances, locating the roost via morning observations alone will allow prediction of hazardous conditions when birds return to the roost in the evening, without actually following the return movement on radar (see below).

A related class of targets is the American Crow (*Corvus brachyrhynchos*), which, although less abundant than it was in the days of mixed agriculture in central Illinois (Black 1941), nevertheless regularly roosts in large numbers. A crow roost of 50,000 birds has been reported in recent years at Fort Cobb, Oklahoma; even in central Illinois we have two roosts of about 400 birds each. Crows in numbers as small as 400 do not form ring angels when departing the roost. However their large body size and their potential importance as hazards to aircraft make it worthwhile to collect basic data on crow movements and the parameters of crows on weather radar for possible future use and so that the Blackbird Algorithm can be configured not to reject crows as hazardous targets. It should be possible to collect data from a large crow roost elsewhere in a future season.

We have attempted to collect data of several sorts with which to test the Blackbird Algorithm. Because the Blackbird Algorithm is not designed to operate when it is windy, we have concentrated our efforts on mornings when winds were forecast to be calm or light. Sometimes forecasts were incorrect or ring angel activity was not present for some reason. In these situations, the data can be used to provide negative cases for tuning the Blackbird Algorithm's sensitivity. Similarly, by turning off time-of-day logic in the Blackbird Algorithm, various other non-blackbird targets such as predawn ground clutter and anomalous propagation, migrating birds, insects, and weather can be used as negative cases.

Table 1 summarizes periods when radar and field observations were made on roosting birds. Data in 1986 recorded under the direction of Dr. Ron Rinehart were kindly provided by the M.I.T. Lincoln Laboratory; all other data in Table 1 were collected at the CHILL radar of the Illinois State Water Survey. No effort has been put into collecting radar data on late afternoon return of blackbirds to the roost because the return movements are not well-enough organized to provide distinctive patterns on the radar display, at least in our experience in 1987-1989. Late afternoon visual observations, though, have helped greatly in locating roosts and in characterizing the species and numbers of birds in a roost.

Table 1. Radar and visual observations of blackbirds and crows, 1982 through February 1989.

Date	Times	Tape numbers CHILL	Tape numbers NHS	Surface wind* Speed	Surface wind* Dir	Field observers
18 Nov 82	0630-0650					S Urbana
	1600-1620					Windsor Rd
29 Nov 82	1630-1720					SHRC
30 Nov 82	1615-1630					S Champaign
1 Dec 82	0623-0700					Champaign
	1625-1640					NHS Annex, Kraft
2 Dec 82	0610-0652					Eisner warehouse
	1615					Eisner warehouse
6 Dec 82	0615-0704	2BRD007 (data bad)			W	Eisner warehouse
7 Dec 82	0615-0704	2BRD008	201	calm		Eisner warehouse
29 Jul 89						Huntsville, AL
10 Dec 87	0635-0725	87IL033	209			Willard
12 Dec 87	0610-0729	87IL036	206	8 ms^{-1}	W	Willard
	1600-1630					Tuscola
14 Dec 87	0643-0722	88IL038		LT	NE	Tuscola
8 Feb 88	0644-0748	88IL05-6 (CHILL down?)		calm		Tuscola
10 Feb 88	0630-0725	88IL007-8	605-606	LT	NE	Tuscola
23 Sep 88	0615-0731	88IL126				none
7 Oct 88	2130-0800	88IL129-143				none
14 Oct 88		antenna failed				none
20 Oct 88	~0630-0740	88IL147-148		VLT	SE	Willard
24 Oct 88	0655-0720					North Champaign
25 Oct 88	1720-1810					Lake of the Woods
26 Oct 88		EL failed		LT	W	Lincoln & Windsor
23 Nov 88	0615-	88IL149	211			none
9 Dec 88	0636-0707	88IL158-159 (no VEL)		STR		none
22 Dec 88	0605-0705	88IL162	213	7 ms^{-1}	SE	Rantoul
4 Jan 89	~0635-0724	88IL001		calm		Rantoul
	1652-1712			LT	S	Kraft
5 Jan 89	0635-0705			6 ms^{-1}	S	Kraft
18 Jan 89	0614-0720	89IL010	214	LT	SW	Kraft
25 Jan 89		CHILL down				none
12 Feb 89	0600-0722	89IL042	624-626	LT	NW	Parkland College
	dusk			LT	SE	Big Ditch
13 Feb 89	1718-1747			LT	S	Pesotum
21 Feb 89	1650-1725					Pesotum
24 Feb 89	0600-0644	89IL066		calm		Rantoul, Pesotum
25 Feb 89	0555-0630			MOD	S	Big Ditch

* Wind directions are directions from which the wind is blowing. LT = light, MOD = moderate, VLT = very light.

With this background, we may describe the Blackbird Algorithm. The Blackbird Algorithm is designed to work without operator assistance, generating text output and/or graphic output (e.g. a geographic situation map). It is compute-intensive but will be restricted to running only about 40 minutes/day. The scan rates of NEXRAD in normal mode (Mahapatra and Zrnic 1983) will be low, so that only a few scans will be conducted during a 40 minute period. Output will not be required until ca. 22 hours later. Thus, it can run as a low-priority job in a batch queue.

The Blackbird Algorithm first executes a series of conditional statements that make sure a sweep could contain blackbird echoes. Then follow another series of conditionals that confine the algorithm to only certain regions of the radar sweep and to certain pulse volumes within the regions. The contents of these pulse volumes are cast into Cartesian coordinate arrays and one or more iterations of a modified Hough Transform are performed to generate a large Accumulator Array (Figure 4). The Hough Transforms locate circles of departing blackbirds in the Cartesian arrays, in this case also using reflectivity and velocity information to tailor the transform to the known characteristics of ring angels. After each iteration, if any candidate blackbird roosts are located, information on the largest roost is stored. Then the pulse volumes that contribute to the largest roost are erased from the Cartesian arrays and another iteration of the Hough Transform is executed on the whole Cartesian array. This process is continued until all roosts have been located. The intermediate output for each sweep is a list of roost centers (if any) and the radius of the region of departing birds from each center, in decreasing order of size. For each day's sweeps, the list of roost centers is compared with a master list of roost centers for recent days. Then (a) known roosts are updated in time, size and location and (b) tentative new roosts are entered in the master list, to be converted into known roosts if they persist in time over days. The locations, sizes, times of day of activity, and geographical area of influence of known roosts, if any, constitute the final daily outputs of the algorithm.

Details of the Blackbird Algorithm follow. In these paragraphs, "roost" will be understood to mean "roost large enough to be detected on radar".

Wind and the Blackbird Algorithm. Wind conditions near the ground have several important effects upon the appearance of blackbird echoes on radar. As explained below, birds flying upwind often will be underrrepresented or absent because they fly very low. If they are detected, their speeds relative to the ground will be lower than their True Airspeeds; likewise, birds flying downwind will have higher speeds relative to the ground. These considerations result in distortion of the classic ring angel bulls-eye pattern, often leaving only a fast-moving comma-shaped line of echo on the downwind side. Because such patterns are much harder to recognize, even for the human expert, than the ring angel pattern, the Blackbird Algorithm is not designed to function when surface winds are strong. However, if low winds are available every few days, the Blackbird Algorithm should function adequately because it identifies roosts by their presence over many days' time, not on the basis of each individual morning's echo pattern.

We note that no independent mechanism is currently available for incorporating either surface winds or winds aloft into NEXRAD algorithms. In this case, the VAD algorithm will not be dependable at low heights because many of the echoes will be birds, not passive windborne scatters. VAD's at higher elevations will often be corrupted by the presence of early-morning remnants of nocturnal migration. We have recorded volume scans with departing starlings present at the lowest elevation simultaneously with late-Fall migrants at higher elevations.

Restriction of algorithm invocation. A series of conditional tests restricts the algorithm to possible roost-departure events and to possible blackbird echoes within those possible events.

At a given geographical location large roosts of blackbirds occur at some times of the year but not at others. At northern latitudes where blackbirds are not present in midwinter because they migrate south, roosting occurs during the periods before and after the migration, sometimes lasting into May in Canada (Greenwood and Weatherhead 1982). In the southern contiguous United States, roost occupation centers on the winter months. Days of the year when the Blackbird Algorithm may be invoked will be a site-specific adjustable parameter.

As seen in Figures 5 and 6, the Blackbird Algorithm need run only during a specific time of day, between about 30 minutes before and about 30 minutes after Civil Sunrise. That is to say, the algorithm will not run on any volume scan whose lowest-elevation sweep is not within this time frame. Time of day of departure from the roost may be earlier early in the roosting season; further data in another season is needed to decide this issue. Similarly, times of roost departure may be more variable at higher latitudes where dawn is less well defined in terms of light level. Peak numbers of departing birds are present 10-15 minutes before Civil Sunrise in most cases in Illinois. This portion of the algorithm requires computation of Civil Sunrise as an input.

When there is appreciable wind, blackbirds departing the roost in an upwind direction fly low, often as low as 1-2 m AGL in open country. Such birds are too low to be detected on large radars in most circumstances. When flying downwind or when winds are nearly calm, blackbirds generally fly at heights of about 50 m AGL, approximately double the height of mature trees. In these situations (see our 1987 Report), the birds are usually visible except when among or obscured by tall structures. In any case, only the lowest elevation sweep in a volume will contain blackbird echoes except close to the radar, where the second-lowest sweep will also contain echoes. To create Cartesian arrays for the Blackbird Algorithm, a 0-50 m CAPPI is created using only the lowest two elevation sweeps and is converted to a Cartesian array. We shall refer to XY positions in this array as pixels (picture elements).

Depending on cloud cover and other factors, a maximum range can be specified for the Blackbird Algorithm. It will be less than the 230-km maximum range for velocity in NEXRAD. The maximum range will sometimes be greater than that computed from the earth's curvature because of the prevalence of anomalous propagation around dawn. Because we have not found blackbird roosts at long ranges near Champaign, Illinois, the exact value for this adjustable parameter of maximum range is presently unknown, but is probably safely put at 75-100 km or less.

If weather algorithms indicate precipitation at higher elevations, the Blackbird Algorithm will not run because precipitation will necessarily obscure bird echoes at lower elevations.

To be cast into the Cartesian arrays, individual radar pulse volumes must contain a minimum reflectivity corresponding to a few blackbirds (see Rinehart 1986). The minimum reflectivity will differ according to whether roosting crows are present in the area.

Spectral width (see preceding section) should be within the range seen in departing blackbirds.

Radial velocity is important to the Blackbird Algorithm. Although we do not yet have full data on the range of species included in the "blackbirds" category, these birds all fly with a mean True Airspeed of ca. 20 ms^{-1}. With individual variation and measurement error, about 24 ms^{-1} might be a reasonable value to use as an upper bound. Therefore, in calm conditions one may expect all blackbird targets on radar to have |velocity| less than 24 ms^{-1}. Targets with >24 ms^{-1} are either non-blackbird targets or are flying in winds that give them a faster speed relative to the ground than their True Airspeed. Such targets are discarded when casting a volume scan into Cartesian arrays.

The modified Hough Transform. Because rings of blackbirds departing a roost are seldom continuous figures, shape-recognition schemes (e.g. Bryant and Bryant 1987) are inappropriate for blackbirds. Instead, we use the Hough Transform, which searches the radar image globally and is statistical in nature rather than requiring continuous boundaries. It is invoked after casting the data from the lowest sweeps of one volume scan into a Cartesian array. The Cartesian array has a resolution of 0.5 km x 0.5 km; the resolution may of course be coarser for reflectivity in NEXRAD. The Cartesian array has a plane for reflectivity and a plane for Doppler velocity.

The Hough algorithm is a standard technique in computer vision used to recognize generalized curves in images. For this application it has been modified to recognize circles of the form

$$r^2 = (x - a)^2 + (y - b)^2$$

, where a and b are the location of the center and r is the radius. It does this by looking at all the points in the image and considering all possible circles that best explain the data. Each pixel in the image is examined if it exceeds threshold criteria. Using the above equation, the algorithm determines the possible circles of which each pixel could be a part (Figure 7). Because the number of circles is potentially infinite, the circles considered are limited to those that have their centers within the image array.

For each potential circle determined, an element in an accumulator array is incremented. The accumulator array is a three dimensional matrix indexed by the a and b coordinates of the circle center and the radius. This has the effect of "keeping score" of which potential circles are common to the most pixels. When there are several points in the image that all lie on the same circle, as shown in Figure 8, that circle will be incremented more times in the accumulator array than any of the others. Once all the pixels in the image have been considered, the accumulator array is searched for local maxima and these points indicate the center and radius of circles formed by the pixels on the image. Centers of Hough-located circles are tentative roost centers; radii are estimates of the size of expanding rings of departing blackbirds, which is a function of the distance blackbirds travel from the roost to feed (Stewart 1978; Angerbjorn, et al 1984).

Remaining steps for a complete Blackbird Algorithm.

(a) Convert remaining (1989) CHILL data and construct NEXRADized (Larkin and Quine 1988) Universal Format files. Complete testing the algorithm on the test files.

(b) Resolve difficulties with CHILL spectral width (see section above).

(c) Set the adjustable parameters for central Illinois.

(d) Run a full set of tests of the algorithm, readjusting parameters if necessary.

(e) Prepare the algorithm for formal submission to the NEXRAD OSF. An inquiry about the mechanism for accomplishing this step has been made.

(f) At a later stage, develop site-specific parameters for other sites than central Illinois (probably necessary at other latitudes at least).

Migrating Waterfowl.

During the fall and early winter of 1987 and again in 1988-1989, one of our goals was to study the migration of large waterfowl on CHILL, using both tracking radar and visual observations to characterize the echoes detected by CHILL. Our December 1987 report (Quine and Larkin 1987) contains a brief description of the rationale, goals, and overall method of the 1987 waterfowl effort.

The CHILL radar was configured in 1988-1989 and in most of 1987 to have a maximum range of 153 km. As seen in Figure 9 (a 150 km radius from CHILL), this range covers a large part of Illinois and some of Indiana. This 300-km diameter circle intercepts the fall migration routes of two numerous species, the Lesser Snow Goose (*Chen caerulescens*) and the Canada Goose (*Branta canadensis*).

Many Lesser Snow Geese--the species includes the Blue Goose, which is considered a race--breed on and near Baffin Island, Canada and stop over on fall migration around James Bay, Canada (Blokpoel 1974; Blokpoel and Gauthier 1975; Bellrose 1976; Blokpoel and Richardson 1978). Sometime about the last week in October or the first week in November, often in one extended movement, the Snow Geese fly from James Bay to the Gulf Coast in Louisiana. Except for a few tens of thousands of Snow Geese that stop en route on the

Illinois River and at other places, most of the approximately 250,000 Snow Geese make the trip in one continuous flight. Snow Geese migrate high, from 700 to roughly 3000 m AGL.

Geographically, the CHILL is ideally suited to observe this huge migration. In both 1987 and 1988 we sought to record the Snow Goose migration but failed to record large numbers of targets. Although we have some indications of goose-like targets having been detected on some evenings, the mass migration was not recorded partly because of some CHILL hardware problems in 1987 but principally because the geese evidently leave James Bay unobserved by humans, probably at night, and so colleagues in Canada who were ready to report the departure of the geese failed to detect it. Success in observing Snow Geese on radar in a future fall season will likely result from using the radar nearly continuously when weather in Canada has been favorable for initiation of migration or from detecting the birds' calling.

Canada Geese proved easier to observe on CHILL. The largest "population" of Canada Geese, the Mississippi Valley Population, breeds near the southern lip of Hudson Bay and James Bay, Canada and winters mainly on and near several large lakes in southern Illinois and adjoining states (Bellrose 1957, 1968, 1976; Paine and Tacha 1987). Although some of the Canada Geese stop in the western part of the Lower Peninsula of Michigan near Fenville and although in some years weather events cause the geese to make temporary stopovers in southern Canada or northern Wisconsin or Michigan, most of the population stops over in south central Wisconsin. Horicon National Wildlife Refuge was formerly the stopover site for the great majority of the birds; presently they appear to disperse over a somewhat wider area in Wisconsin. The CHILL can observe this migration of Mississippi Valley Canada Geese unless the birds pass too far to the west.

Fall migration of Canada Geese is thought to be made likely by snow cover becoming deep enough to prevent feeding and by freezing of lakes (Bellrose 1976). As in many bird species, the actual time of takeoff is correlated with weather factors, especially wind direction (Bellrose 1974; Blokpoel 1980; Blokpoel and Gauthier 1980; Wege and Raveling 1983). Circumstances favoring nighttime versus daytime migration are not clear from the literature.

In both 1987 and 1988 a concentrated effort was made to record Canada Geese during their migration from Wisconsin through Illinois. Partly with the generous cooperation of personnel at the Wisconsin Department of Natural Resources and the Fish and Wildlife Service and partly by local monitoring of geese during the daytime, we succeeded in recording what appeared to be the largest movements of Canada Geese in 1987 and in 1988. As seen for 1988-89 in Figure 10, radar observations took place during periods of movement of Canada Geese into their wintering areas and the numbers of geese involved are large. The chart is typical of Canada Goose movements, with a minority of the geese reaching southern Illinois in September followed by a period of almost no major movements and ending in a mass movement of several hundred thousand geese in December. The period of highest passage rate of Canada Geese was monitored in both seasons, with about 2 gigabytes of data recorded in 1988 and slightly less in 1987. In addition to these mass movements, several lesser movements were recorded.

Canada Geese migrate as high as 3,000 m but most often at 600-800 m AGL (Bellrose 1967; Myres and Cannings 1971). Figure 11 shows that this height happens to be excellently suited for low-elevation detection of the geese on weather radar; however, at the longer ranges in an adiabatic atmosphere the curvature of the earth limits the detection of Canada Geese. (Canada Geese sometimes fly very low beneath snow or dense cloud cover, but weather echoes would limit their detectability anyway, as NEXRAD is presently configured.) In both 1987 and 1988 some Canada Goose flocks were detected to the limit of CHILL range. At close range, sweeps at higher elevations will detect geese, allowing measurement of their height albeit with low resolution and with the assumption that their height distribution near the radar is representative of their height distribution elsewhere.

Binocular observations during the mass movements of 1987 and 1988 show the flock sizes of the daytime-migrating Canada Geese to be large (Figure 12). Canada Geese usually migrate in long skeins, echelons, or vees (Williams et al 1976). This allows rough estimation of the spatial size of Canada Goose flocks from the measurements of their numbers. Assuming the mean spacing between members of a flock to be 3.5 m (Heppner 1974), the estimated spans of the flocks often exceeded 1 km and sometimes exceeded 2 km (Figure 13). We expect these estimates are roughly correct, with the observed bunching and doubling of lines of geese reducing the size on radar and the inevitable overlapping into adjacent range gates and radials providing some compensatory enlargement of the echoes. Therefore many individual flocks in a mass movement of migrating Canada Geese will be visible on NEXRAD despite dot-echo rejection on NEXRAD (see next section). The detailed structure of Canada Goose flocks will not be visible on NEXRAD because of the 1 km range resolution in reflectivity.

Flight speeds of geese are about 70 km hr^{-1} (Bellrose and Crompton 1981; Wege and Raveling 1984). Depending on wind conditions in which the birds are flying, their speeds relative to the ground are usually high enough to allow Doppler velocity to be used directly in assisting to recognize geese on weather radar.

In both 1987 and 1988, the mass movements of Canada Geese passed over Champaign toward the SSE or even toward the SE; in 1987 the Wabash Valley in Indiana was "black with Canada Geese" the day after the birds migrated (Don Staggs, personal communication). The radar data are further confirmed by reports of Canada Geese arriving on refuges in southern Illinois from the east. We tentatively attribute this obvious misdirection to strong winds out of the NW on both days (Figure 14). Wind drift, common in migrating waterfowl even during the daytime (Bergman 1964; Bergman and Donner 1971; Wege and Raveling 1984) seemed to result in large geographic displacement, causing these geese to vary their "flyways" and even their immediate destinations by hundreds of miles. In such cases, NEXRAD's potential of monitoring goose movements in real time will be superior to the current approach of relying on static "flyways" marked on maps.

Estimation of numbers of Canada Geese from reflectivities and flock sizes will be possible after matching flocks seen with binoculars with flocks observed on CHILL. The geese/dB relationship can certainly be described statistically by comparing distributions from binocular counts with distributions of reflectivities and echo areas. We are also making the comparison directly by matching a number of individual flocks observed both visually and with radar, a time-consuming process that is in progress. We are entering the era of routine counting of geese with radar.

Emulation of NEXRAD using data from research radars.

Although NEXRAD was defined in the NEXRAD Technical Requirements in 1983, implementation of this formal definition continues to evolve. Insofar as the technical characteristics of NEXRAD are implemented in firmware and software, they will continue to change. (In fact, they may be and will be altered during operation to accommodate different conditions, for instance "clear air" versus storm conditions.) Because recognition of birds on NEXRAD as presently configured is sensitive to these technical characteristics, we have been diligent in attempting to develop Bird Hazard Algorithms in an environment as close to NEXRAD itself as possible. In spring, 1988 Larkin and Quine visited the NEXRAD Joint System Project Office in Silver Springs, Maryland to be briefed on the exact technical details of NEXRAD. Because NEXRAD is unlike most research radars in characteristics such as gate spacing, polarization, and dot-echo rejection, we then wrote software (called EMULATE_NEXRAD) that allows data collected on research radars to be used in place of data from an actual NEXRAD, data from which continue to be unavailable. EMULATE_NEXRAD is described in general terms in Larkin and Quine (1988). It takes as input data from any of several research radars and generates as output Universal Format data with the abovementioned and other characteristics as close as possible to what NEXRAD itself would produce. The time required to run the Bird Hazard Algorithm on NEXRADized data is not excessive even on a modest minicomputer (Figure 15).

After spending considerable time writing EMULATE_NEXRAD, using it to generate a quantity of Universal Format test data, and working to make the Bird Hazard Algorithms operate properly on the "NEXRADized" data, we have recently discovered that the NEXRAD technical characteristics have changed materially (Anon 1988). Dot-echo rejection, probably gate depth, and other crucial characteristics are changed. We must start over with new, revised specifications on what NEXRAD is. Continued unavailability of data from the NEXRAD prototype imposes a hardship on developers of algorithms sensitive to differences between NEXRAD and research radars, especially relating to topics such as circular polarization and point-target rejection.

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Figures

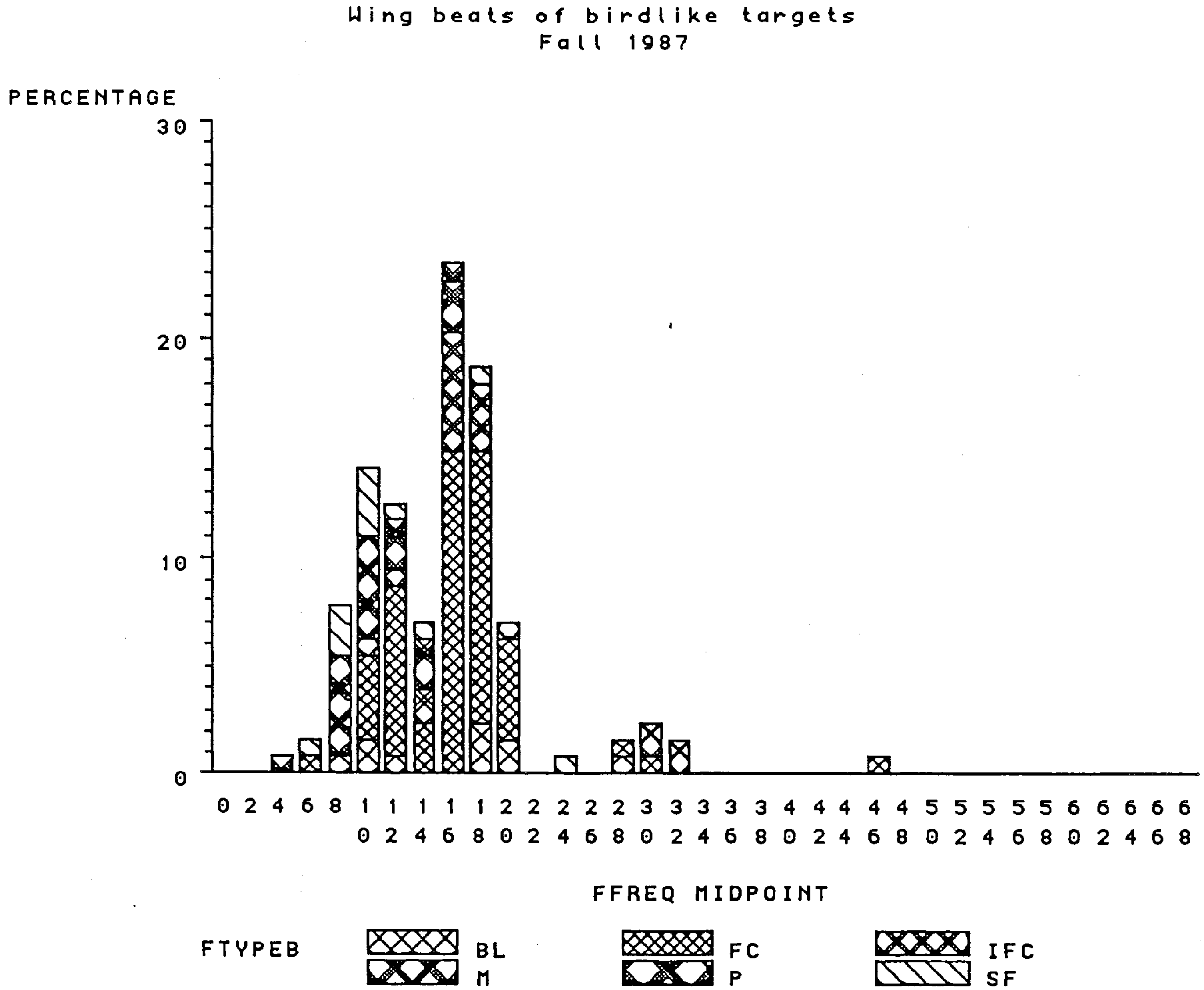

Figure 1. Wing beat frequencies measured with tracking radar. BL=bird like, FC=flap coast, IFC=intermittent FC, M=multiple echoes in one trackable target, P=pulsing target, SF=steadily flapping target.

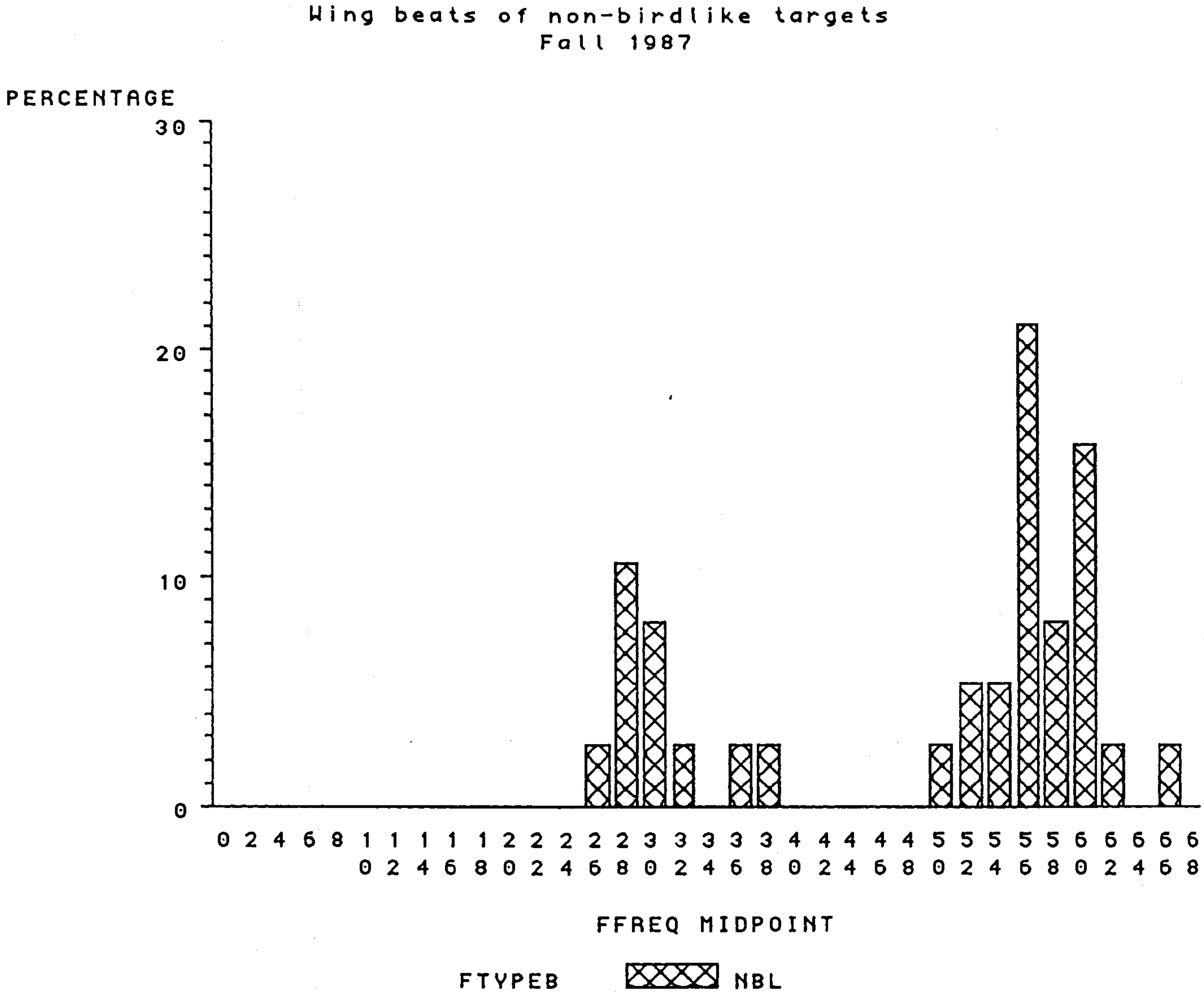

Figure 2. "Wing beat" frequencies of NBL (non-bird like) targets, that is, targets showing no discernible wing beat modulations.

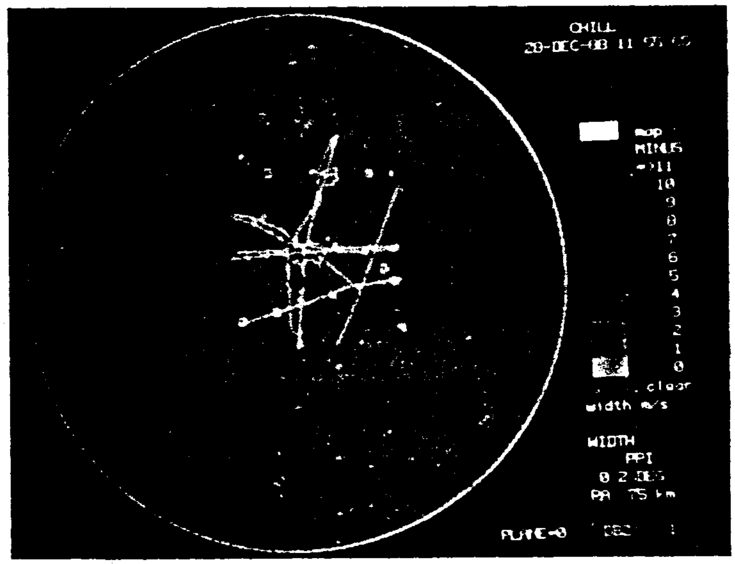

Figure 3. PPI at elevation 0.2° at midday on 28 December 1988. Image is spectral width field (SW2) of large flocks of Canada Geese distributed generally over the display but especially to the N and SE. Most, but not all, goose flocks are readily apparent because their spectral widths are near-zero or negative (salmon or black), wheras road traffic and other clutter has a greater width (green or blue). The white map in the center of the display is Champaign County, showing towns, Interstate highways, and railroad lines.

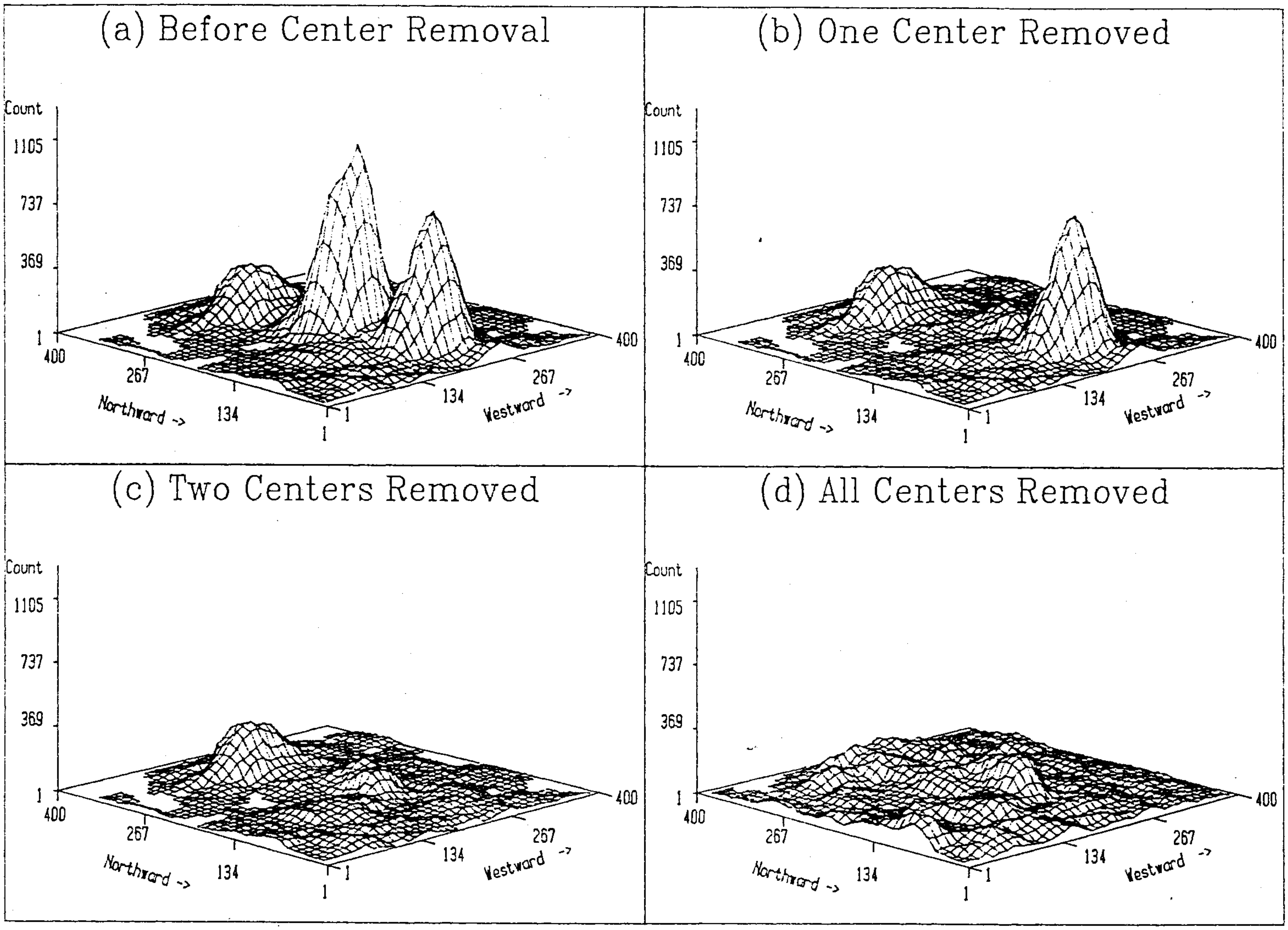

Figure 4. Accumulator Array of roost centers with N=3 roosts in the original image (a) and after the three roost centers have been located by the Blackbird Algorithm (b-d).

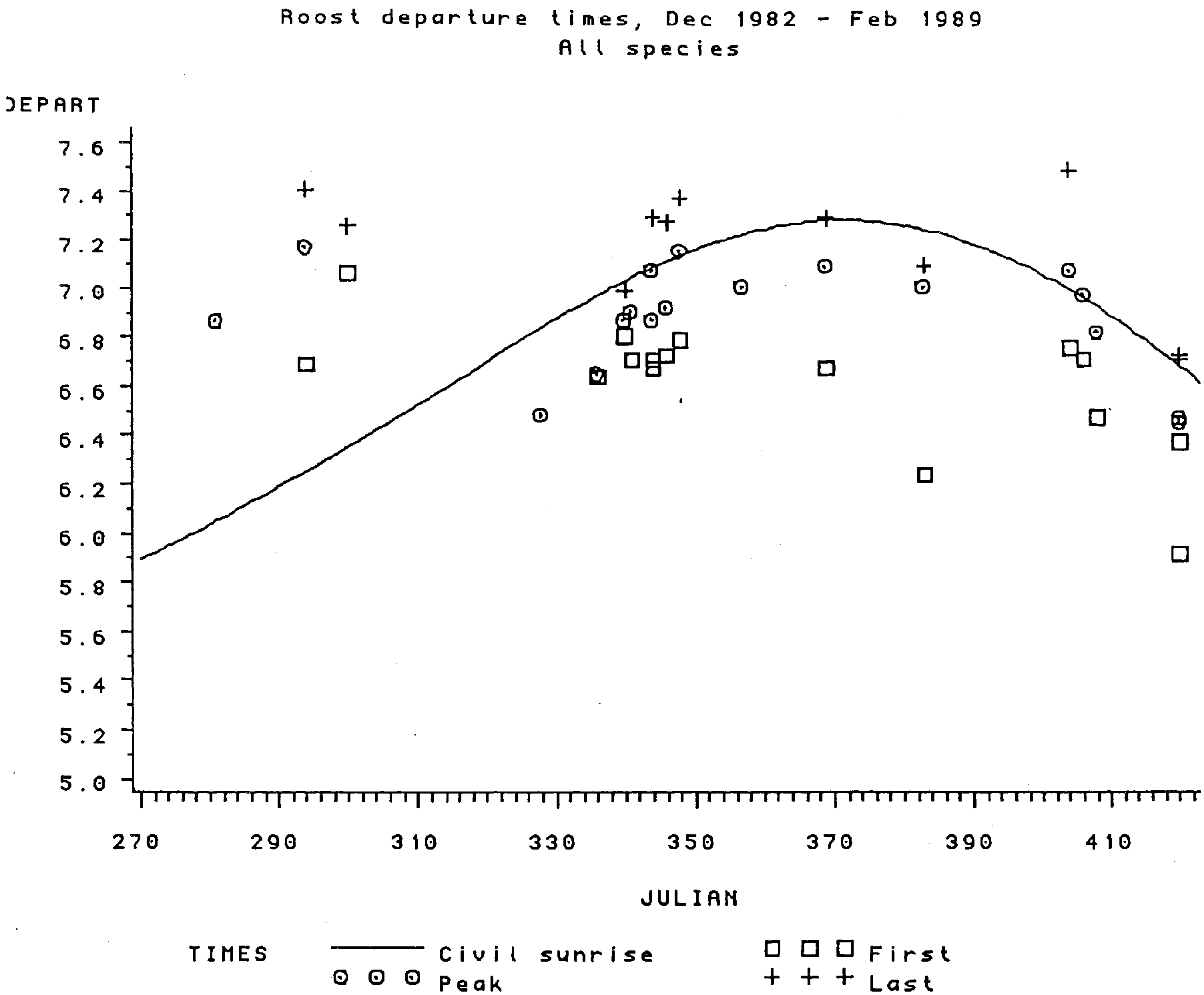

Figure 5. Radar and direct visual observations of the times of first, peak, and last roost departures near Champaign, Illinois. The vertical axis is local time in decimal hours; the horizontal axis is day of the year, with 365 added to days in January-March. The solid line is the calculated time of Civil Sunrise.

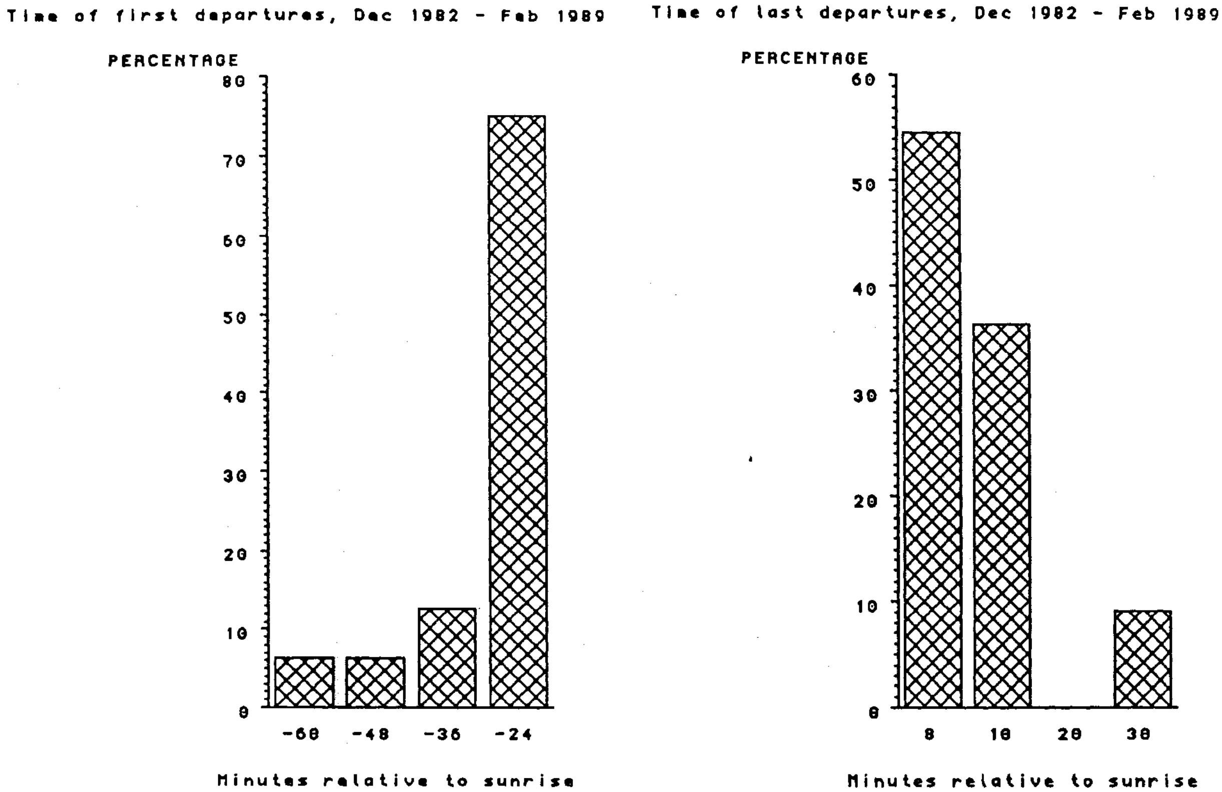

Figure 6. Times at which the first (left) and last (right) blackbirds and crows were observed to leave roosts, relative to Civil Sunrise. Data include both visual and radar observations of departures.

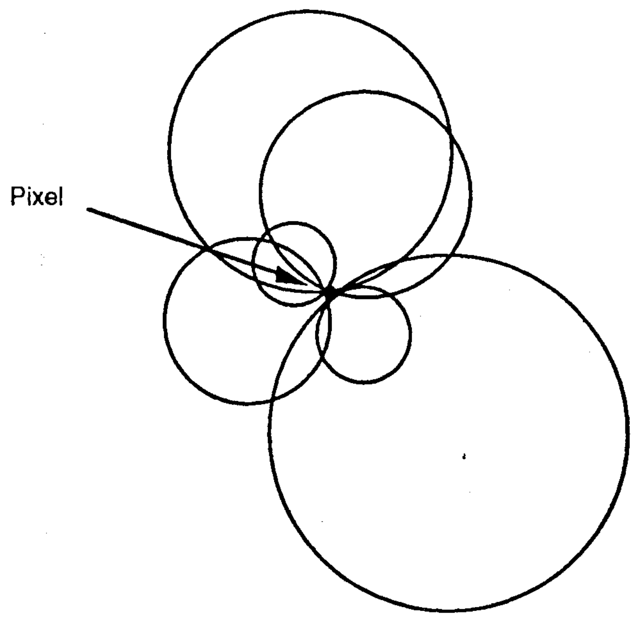

Figure 7. Possible circles for one pixel. Any circle may intersect a given radar echo.

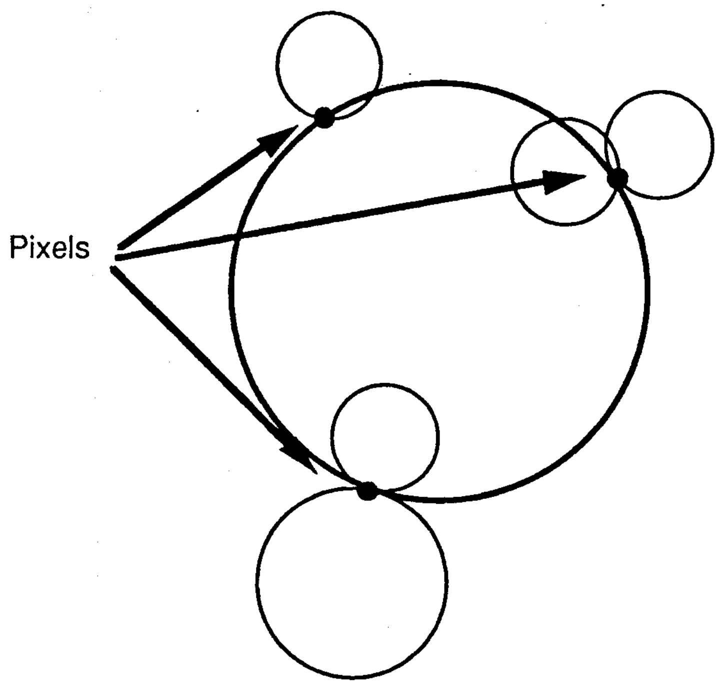

Figure 8. Only one circle may intersect three pixels. Three radar echoes implicate one possible roost center.

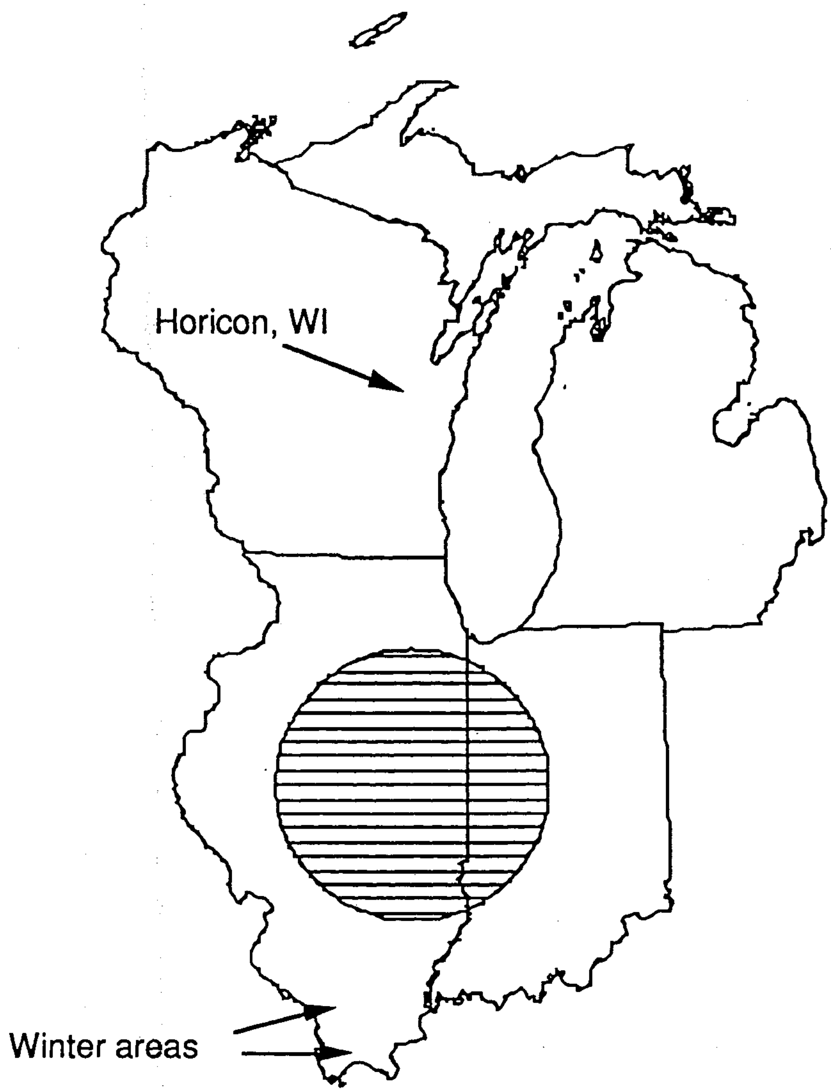

Figure 9. Coverage of CHILL radar during 1987 and 1988 studies of goose movements. The area of coverage was slightly over 150 km in radius, centered on Champaign IL. The area around Horicon, WI is the principal fall stopover for the Mississippi Valley Flock of Canada Geese and lakes in southern Illinois and nearby areas are the wintering areas.

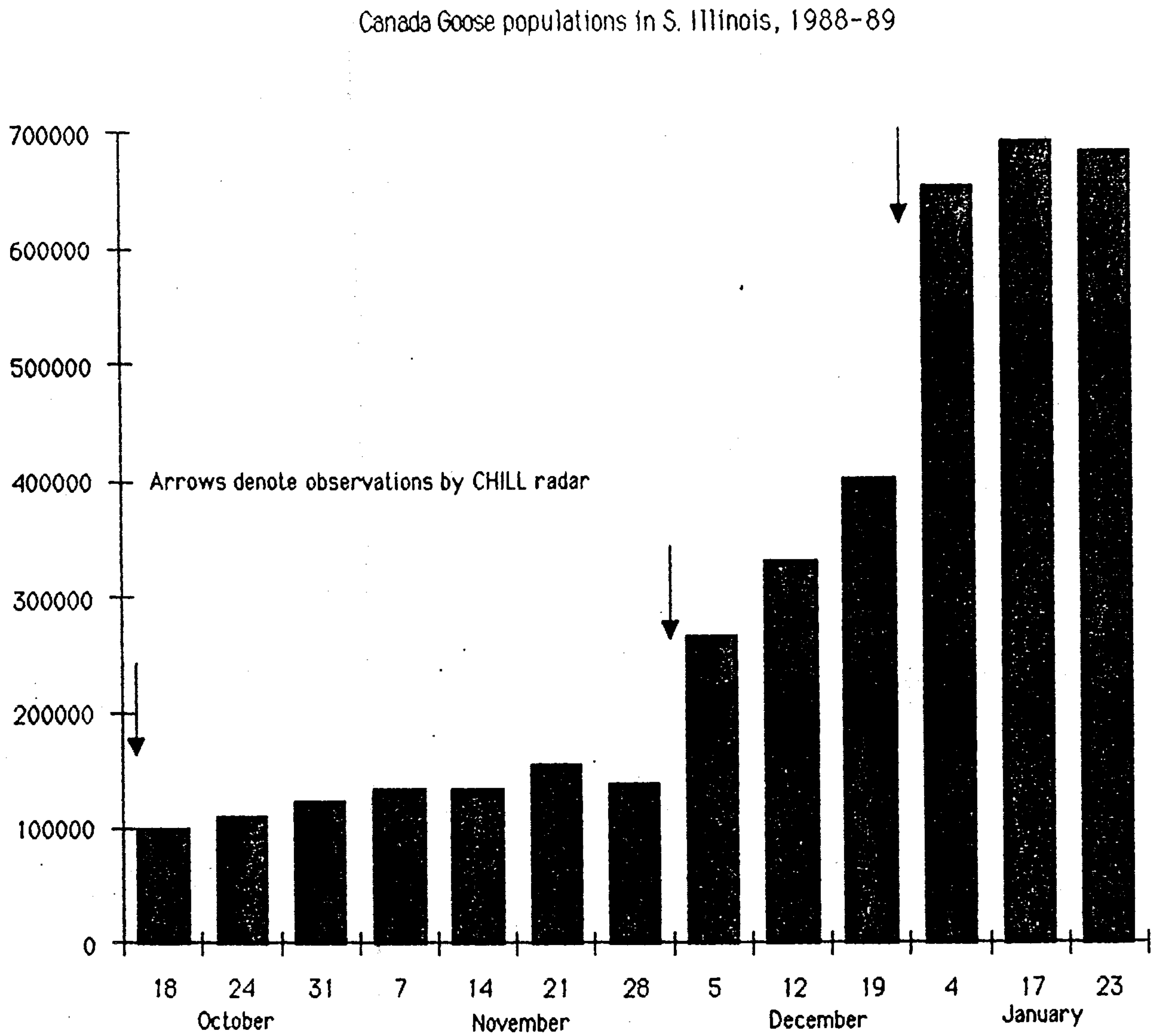

Figure 10. Illinois Department of Conservation censuses of geese in southern Illinois and periods of operation of the CHILL radar, 1988-1989.

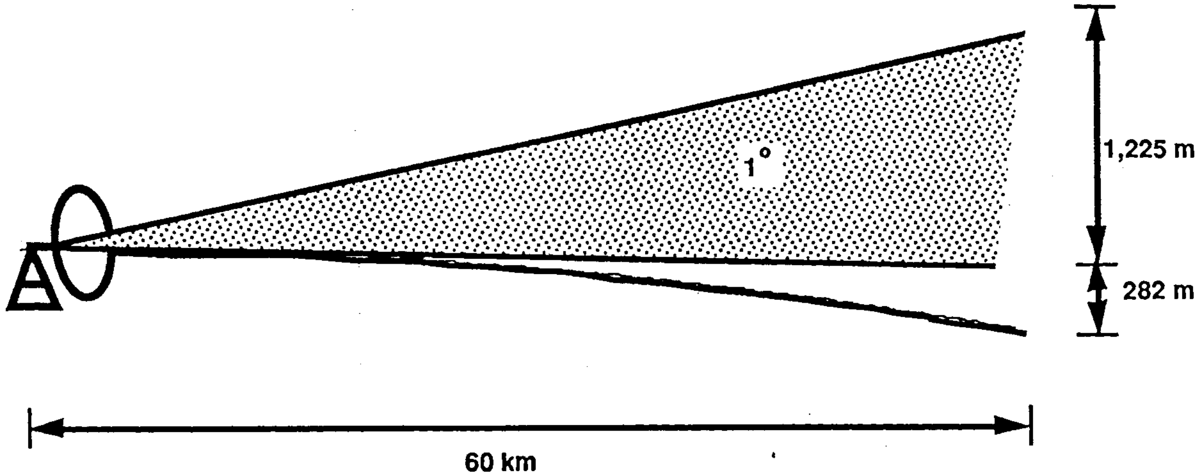

Figure 11. The effect of the curvature of the earth upon the height of the radar beam at 0.4 degrees elevation. Even though the bottom of the radar beam is angled slightly downward, the lowest heights are not observed in an adiabatic atmosphere. Almost the lowest 300 m is lost in this case, at 60 km slant range. The effect is more pronounced at greater ranges, following the relationship:

$$\text{Height in km} = R_s \times \sin(\varnothing) + R^2/12,756$$

, where R_s is slant range in km and $\varnothing$ is elevation angle.

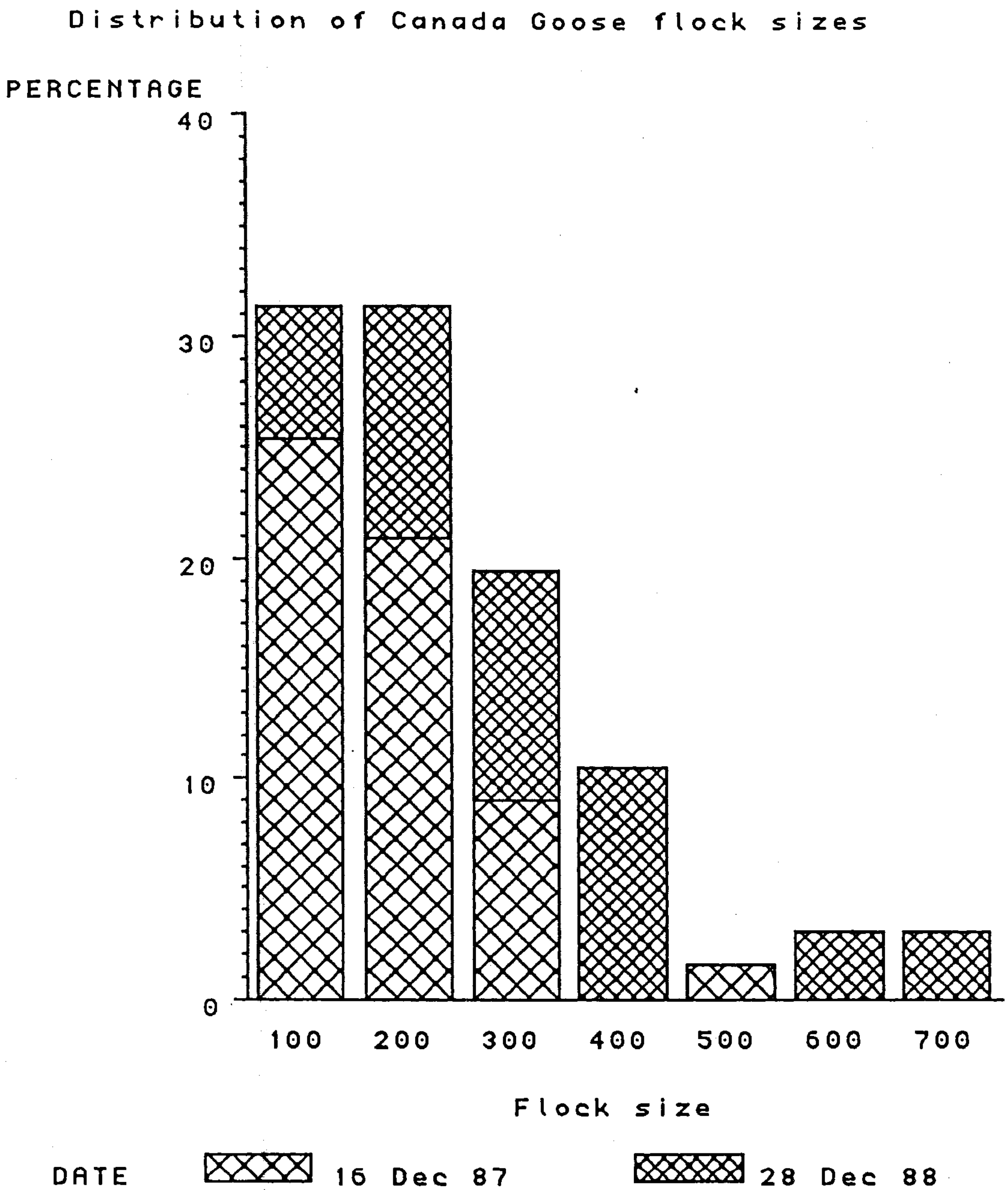

Figure 12. Counts of Canada Goose flocks as seen by observers at the Monticello Road Field Site of the Department of Electrical and Computer Engineering of the University of Illinois.

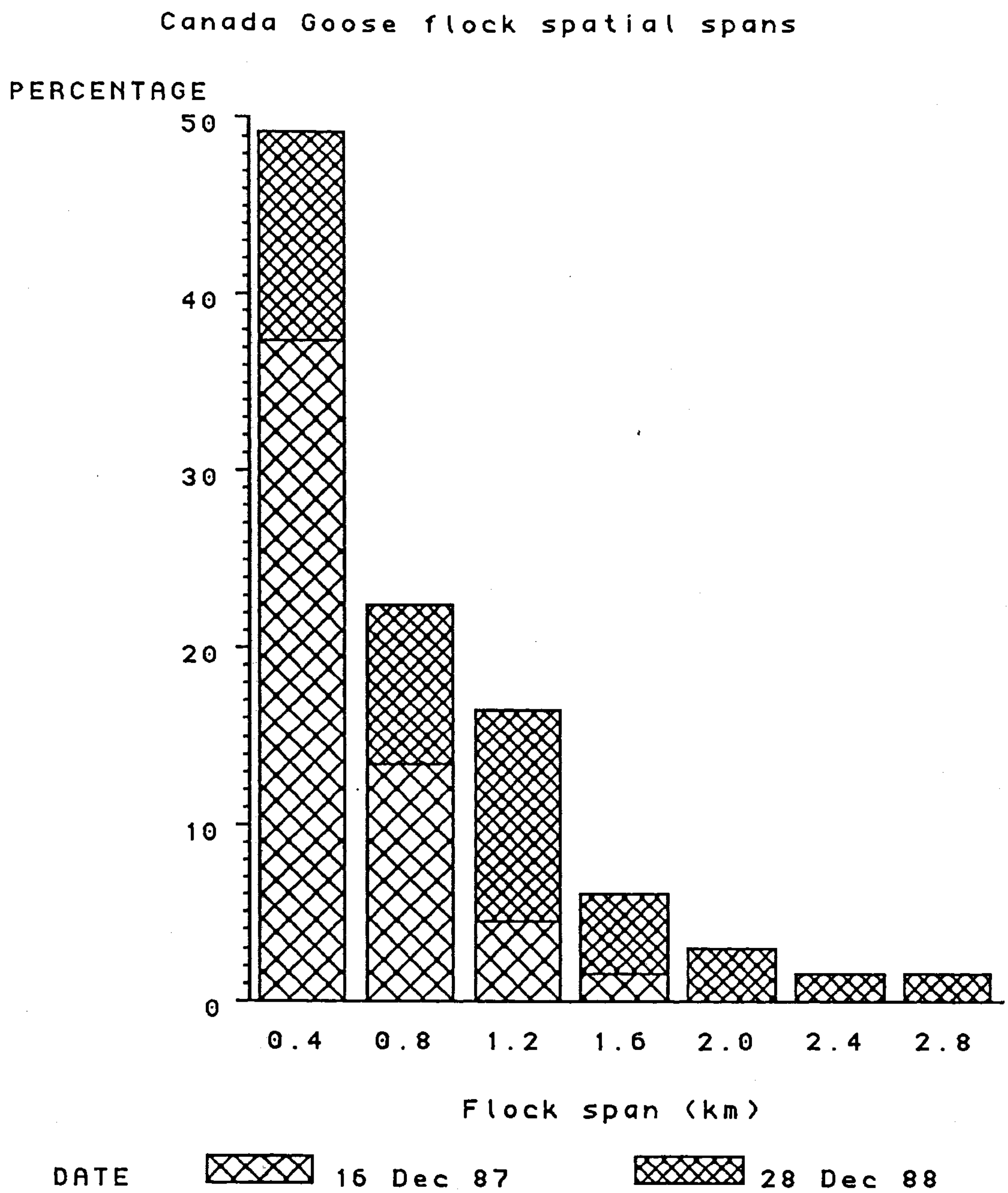

Figure 13. Maximum distance across individual flocks of Canada Geese migrating in daytime, based on an average 3.5 m distance between centers of flying geese.

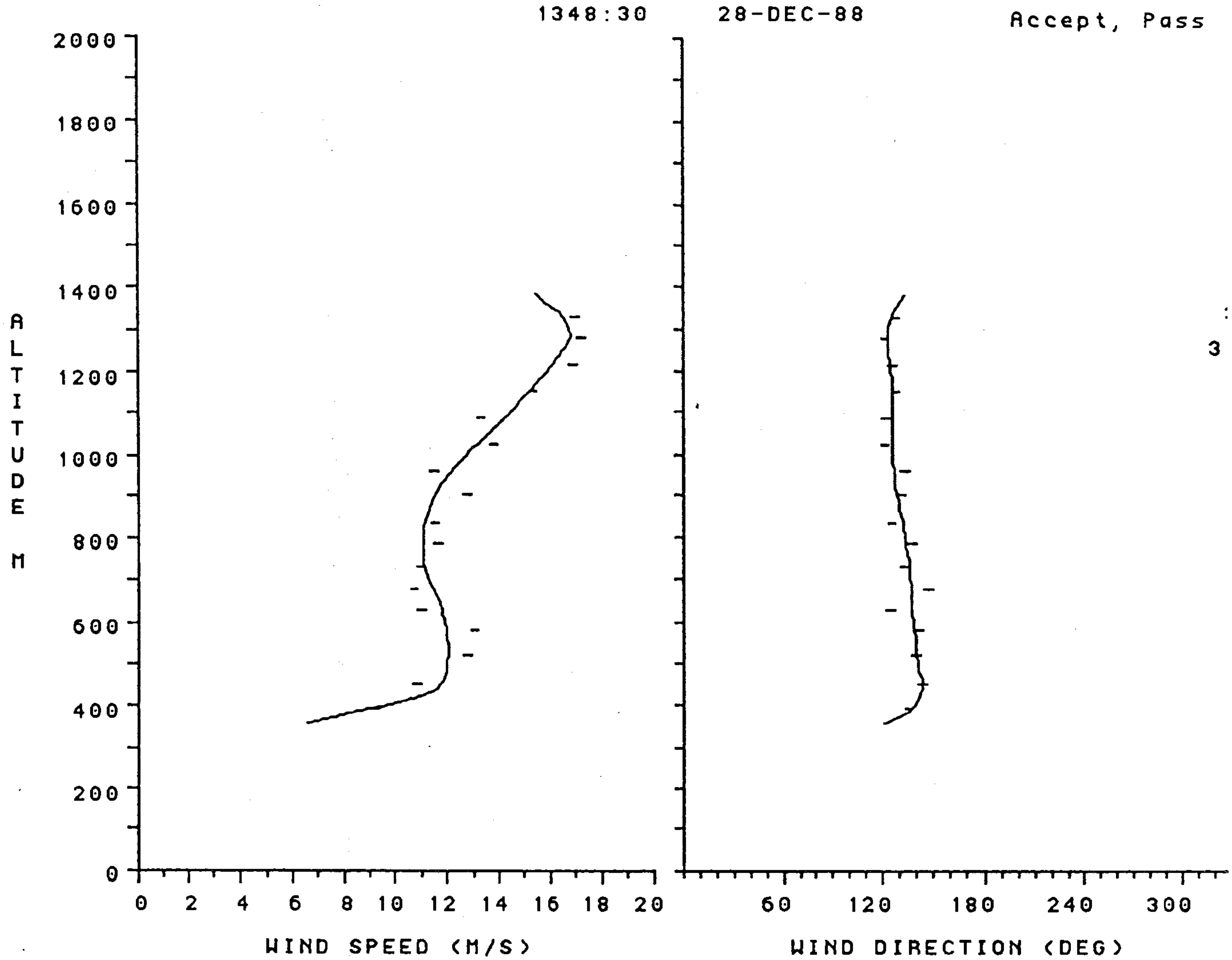

Figure 14. Wind profile during large fall Canada Goose migration of 1988. The birds flew in appreciable (ca. 25 kt) winds blowing toward (*sic*) SE; the winds increased later in the afternoon.

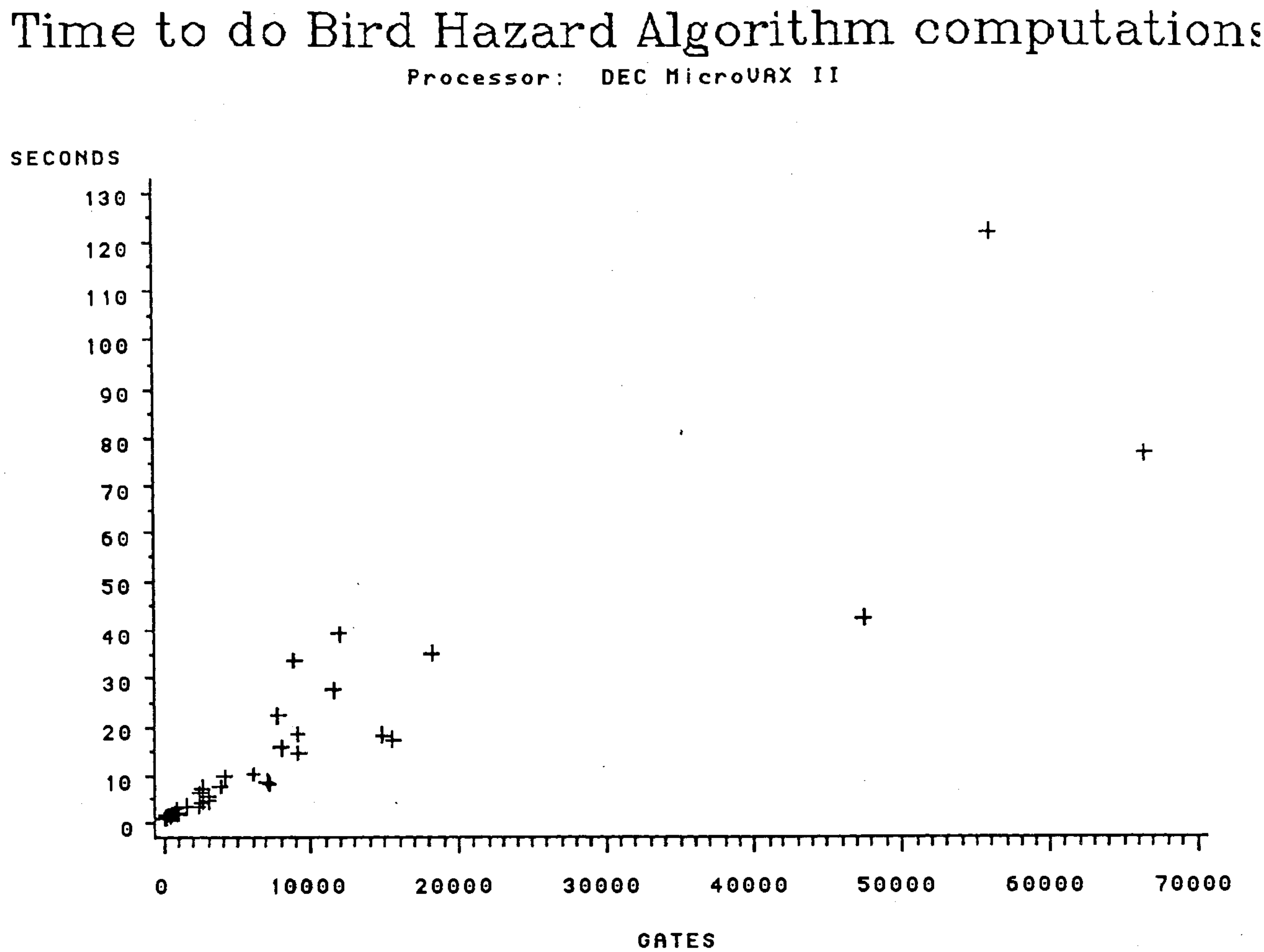

Figure 15. Time required to perform the FORTRAN test algorithm for migrating birds and waterfowl, on an unaugmented Digital Equipment Corp. minicomputer. Included are all test patches presently available. The largest patches are about 360 radials by about 200 range gates in size.

Appendix I. Radar data error detection, correction, and code maintenance.

by Douglas B. Quine

Development of a bird hazard algorithm for NEXRAD requires a broad base of data from weather radars. Until data are available in 1989 from the prototype NEXRAD system being setup at NSSL, we have depended on data gathered from several research radars located around the country. Such research radars are operated independently by different institutions with different research objectives and therefore, not surprisingly, gather different kinds of data in several different formats. The Air Force Geophysical Laboratory (AFGL), University of Chicago/ University of Illinois (CHILL), Massachusetts Institute of Technology (MIT) and National Center for Atmospheric Research (NCAR) radars each store their data in different formats. These radar formats reflect the tradeoffs between highly compressed data (such as CHILL and MIT) and uncompressed formats (such as AFGL and NCAR's Universal Format) which store individual rays of data separately and for which errors on the data tapes typically result in the loss of only one ray. In addition for special applications, such as our recent intensive studies of spectral width at the CHILL radar, special storage formats may be employed. In this case, the data were stored as complex numbers to permit us to compute different estimates of spectral width based on R0, R1, and R2 (lags 0, 1, and 2).

Much our effort at the Illinois Natural History Survey over the past several years has been devoted to developing code to read and rebuild these various radar formats. "Universal Format" (UF) defines some seventy different housekeeping variables (Table I-1) which are stored to aid in the identification and interpretation of the radar data. Most other radar formats store less comprehensive information regarding the radar data.

Nature of errors and omissions in radar data

Seven different classes of errors or omissions occur. First, the data may have been stored with some MANDATORY COMPONENTS MISSING. Missing components may occur when the processor is getting ahead of the storage medium and the data are stored without the proper header block. We have also observed cases in which the mandatory end-of-tape marks are missing. Such problems represent especially difficult cases because such errors violate the basic assumptions of the format. Such cases invariably require that special purpose code be written to recover these data (if they are sufficiently important) and they invariably involve careful integration of these patches into the larger working system.

Second, the standard radar data format itself may have been designed with INSUFFICIENT HOUSEKEEPING INFORMATION for accurate automated processing of the radar data. Even the exhaustive UF format fails to store some header information; this has spawned a new UF superset format, UR (Oye and Mueller, 1986), which provides more header information. In UF format the gate spacing is stored with only 1-m resolution. Over 1000 range gates, a 50-cm gate spacing error accumulates to represent a position error of several gates at the end of the ray! The new UR format stores gate spacing with mm resolution to resolve this problem. Other formats often lack such basic information as the year, site, time zone (this can be a problem at sites which do not observe daylight savings time), latitude and longitude.

Third, the radar data may FAIL TO CONFORM to the standards set for the particular format. Research installations, unlike production systems, are often in a state of continuing development and data are gathered hastily using interim storage formats and conventions. "In house" and "working" data sets unfortunately have a way of becoming essential data sets when they contain exciting or novel observations. Furthermore, as new functions are added for which provisions were not made, the formats may be modified or only those radar parameters for which there is immediate need may be stored. UF format, for instance specifies a maximum record length of 4095 16-bit words; when radars record long rays of several radar parameters (reflectivity, velocity, spectral width, ZDR) then this record length is insufficient and the limit is often ignored. Utility programs designed to read these data then fail to work, sometimes in spectacular ways, and must be modified or rewritten to remain functional. Some of these violations are obvious, wheras others are subtle and are observed only when standard programs start to return unexpected results. We have also observed cases in which mandatory file marks between volume scans are lacking.

Fourth, the radar data may have MISSING VARIABLES within the structure set for the particular format. UF makes provisions for items to be left out of the housekeeping header blocks as well as providing a hierarchy of header blocks (MANDATORY HEADER BLOCK, OPTIONAL HEADER BLOCK, LOCAL USE HEADER BLOCK) which provides some local flexibility. When data are left out of these header blocks, independent external information may be needed in order to interpret the radar data. When the mandatory missing data flag is not utilized to indicate this condition, or indeed when the missing data flag itself is missing, then the data can be quite difficult to recover without minutely specialized routines and operator intervention.

Fifth, radar data may also have INCORRECT VARIABLES stored in the housekeeping blocks. Such errors may be due to software errors (e.g. time in hours = 30) but more often are associated with setup or hardware failures. The azimuth and elevation angles, for instance, may not have been properly calibrated when the radar was installed, leading to a slight tilt of the system. In such cases the PPI display may have a pronounced bias due to the tilt of the radar against the ground. (For instance, a 0.5 degree tilt of the radar represents a 50% error in height of echoes when a scan is made at nominal 1 degree elevation.) When the azimuth and elevation encoders fail, much more dramatic errors occur in which the azimuth may jump suddenly during smooth rotations. Azimuth or elevation bit errors can make for especially complex apparent motions which are most easily observed by inspection of a plot of the azimuth steps; periodic patterns of reversals and uneven step sizes are often clear indicators of such errors and they may indeed point to the exact bits at fault.

Sixth, there may be SYSTEMATIC ERRORS in the data fields (the data associated with each of the range gates for each of the radar parameters). The polarity of a signal may be reversed resulting in sign errors for velocity, the calibration values may be incorrect for the radar configuration, or hardware failures in the radar or the data storage systems may result in improper data being stored. Incomplete tape initialization may result in tapes with initialization headers on the tape, which in turn may prevent tape drives from automatically determining the density of the tape, resulting in fatal drive errors or an apparent inability to read an otherwise satisfactory tape.

Finally, there may be isolated failures associated with some data fields or some range gates. If the processing system becomes overloaded under some conditions, data fields may drop out, incomplete data may be written, or old data may be retained in the rays of data reported by the radar.

MULTISTAGE DATA CORRECTION HIERARCHY

We have developed a multistage technique for correcting errors and omissions in radar data (Figure I-1). Whenever data are read from computer tape, a lookup file of radar definitions (RADAR_*.DEF) for that particular site or format is read to preset the values of those variables that are otherwise unavailable in the particular data format. Such variables often include the radar wavelength, latitude, and site altitude. This lookup file is also used to overrule lingering incorrect values from previous radar systems. The implementation of the lookup file is flexible; a file can be configured in a few minutes when after we obtain information about a new radar system and site. A lookup file of definitions can be updated if better information becomes available. For instance, more accurate information on the geographical location of the radar sometimes becomes known after the initial location information has already been recorded on the data tapes.

The combination of the radar definitions file and the data read from tape make possible the second stage of data correction. At this case certain corrections and enhancements can be made from the available data. The actual Nyquist velocity, for instance, can be computed from the wavelength of the radar and the pulse repetition rate using Formula 1.

Formula I-1: NYQUIST = PULSE_REP_FREQ *WAVELENGTH_METERS /4

Many sites have either similar standard updates that can be derived from available data or that correct data which are known to be in error or add values which are otherwise missing. Some repairs of azimuth errors can be achieved using measurements of the observed rotation rate of the radar and a model of the known defects in the azimuth encoders. Likewise, when the radar is actually performing an RHI scan but the data are flagged as a PPI scan data the code can correct the flags and proceed normally.

The third stage of the data update and correction process involves code written to deal with specific errors on specific data tapes. Often these are conditional corrections depending on several different factors which cannot be achieved simply by substituting values within the radar definition files. Specific errors include isolated problems such as the elevation angle being improperly reported on a specific series of data tapes from one site, the need to use an alternative source for particular values, or the incorrect number of range gates being reported. The need for these corrections is generally based on errors in writing the original data tapes.

The fourth stage of data correction requires human interaction with the data. For instance, when the azimuth encoders develop severe bit errors and report improper azimuths, especially when PPI/RHI flags are missing as well, then automatic correction of the data is as likely to exacerbate the situation as to improve it. In such a case the program should provide as much data as possible to the user (e.g. the trend of azimuths and elevations) to enable an intelligent decision to be made as what azimuth, elevation, and sweep mode to define for the radar sweep. This is the last stage of error correction that is available online (without modification of the computer program itself).

The final stages of the error correction process involve debugging techniques and tools for evaluating the radar data and for modifying the computer code to deal with newly discovered bad data tapes. We have a variety of tools to debug problems in radar data tapes. A recently developed TAPEEXAM utility provides the first stage of attack on a problem tape. This utility makes it possible to determine the structure of the tape (block lengths, starting characters in each block, file marks, logical end of tape, physical end of tape). Once the intended structure of the data tapes is known, such information makes it possible to distinguish header blocks from data blocks and to identify which blocks of data warrant further examination.

When a particular block of data is identified for detailed examination, the VAX DUMP utility can produce printouts of raw data directly from tape. Such dumps are necessary in the early stages of deciphering badly corrupted data on tape or disk. Such approaches are especially valuable when working with poorly documented radar formats or when trying to resolve ambiguities in the description of these formats.

The NCAR Universal Format tape dumping program (UFDUMP) is used to examine tapes in the UF format and to check values in different fields. In-house augmentations to this program (UFEXAM) have made it more robust and have added the capability of examining disk files as well as tape files. Our augmented version can help determine the cause of UF problems rather than merely serving as a data dumper and test of conformation to the standards. CHILL format (both old and new) radar tapes can be examined using the CHILL TEST utility; in-house modifications to this utility have also enhanced its capabilities for such debugging purposes.

Finally, insights from such approaches are used to make modifications to our programs to read radar data and the process can then start from the top again. The techniques involved in modifying of radar reading programs are discussed below.

CODE DEVELOPMENT and MAINTENANCE SYSTEM

A complex and interrelated set of programs have been developed in our laboratory for the reading, display, and analysis of radar data. When one program module is modified there are often implications and repercussions for a number of the other modules. As new radar formats are encountered, or as we obtain radar data tapes with errors which require correction, it is often necessary to modify this radar processing code. Furthermore the nature of our scientific endeavor ensures that the analysis code is likewise in a state of flux and development. We use software supplied by the manufacturer of our computer, Digital Equipment Corp. (DEC), as well as in-house test code and procedures, to prevent code modifications from creating unexpected problems down the line. These precautions are outlined in Figure I-2.

First we have a DEC Source Code Analyzer (SCA) and Database which is used to store much of the new radar analysis and processing code developed in our laboratory. This facility maintains a reference copy of the source code as well as maintaining a database of all routines, symbols and variables. If a programmer needs information about the use of a particular variable, it can be obtained here. Likewise if modules need to be studied or the structural relations within the code need to be reviewed this system provides the necessary information.

The next layer of the code management process is the DEC Code Management System (CMS). It maintains archival copies of all code. When modules are removed for modification, they are rigorously tracked and the resulting history may be examined to follow the fate of particular modules. This system prevents such problems as multiple programmers modifying the same code at the same time (a not-unlikely development in a complex system). It also allows reconstructing previous versions of code if necessary. Lastly it provides a central repository for the source code and a central object library for the compiled modules to accelerate the linking of programs.

The third layer of the process is the DEC Module Management System (MMS). MMS tracks the various dependencies in each module of the program. When an up-to-date version of a particular program is needed, it will check the dates on all of the components of the program and determine which components have been updated and the changes that are necessary to make a current version. This third layer maintains the integrity of both the SCA and the CMS systems and automatically keeps them up-to-date. The computer instructions required to implement MMS on a large program are intricate (Figure I-3).

Finally, in-house test procedures have been developed which perform a series of tests on known radar data sets and examine the results. A program developed on our image processor can detect a problem if only one of the 311,000 displayed points on an image is not the same value as a reference version of the same data. The reference versions are updated only if the new code provides a more accurate version of the data than the original code. This final stage of verification helps reduce the number of unexpected surprises when changes to code have unexpected effects.

Table I-1. UF variables and observed errors

----- MANDATORY HEADER BLOCK -----

1. Tape format
2. Bytes per record
3. Pointer original header
4. Pointer local use header
5. Pointer data header
6. Physical record number
7. Volume number
8. Ray number
9. Records per ray
10. Sweep number
11. Radar name
12. Site name
13. Latitude
14. Longitude
15. Altitude
16. Year
17. Month
18. Day
19. Hour
20. Minute
21. Second
22. Time zone
23. Azimuth angle
24. Elevation angle
25. Sweep mode (ppi/rhi)
26. Fixed angle
27. Sweeprate
28. Year of tape
29. Month of tape
30. Day of tape
31. Tape generator facility
32. Missing data code

----- optional header block -----

33. Project name
34. Baseline azimuth
35. Baseline elevation
36. Hour of volume start
36. Minute of volume start
36. Second of volume start
37. Tape name
38. Gate spacing flag

----- local use header block -----

------- DATA HEADER BLOCK -------

39. Fields per ray
40. Records per ray
41. Fields per record

42. Field names (1 ... Fields per ray)
43. Pointers to field headers (1 ... Fields per ray)

------- GENERAL DATA HEADER BLOCK -------

44. Position of first dataword (1 ... Fields per ray)
45. Data scale factor
46. Range to first gate
47. Adjust to center of first gate
48. Sample volme spacing
49. Number of sample volumes
50. Sample volume depth
51. Horizontal beam width
52. Vertical beam width
53. Receiver bandwidth (MHz)
54. Polarization transmitted
55. Wavelength
56. Number of samples used in field estimate
57. Threshold field
58. Threshold value
59. Threshold scale factor
60. Edit code
61. Pulse repetition time
62. Bits per sample volume

------ VELOCITY DATA HEADER BLOCK ------

63. Nyquist velocity
64. Bad velocity flag

---- REFLECTIVITY DATA HEADER BLOCK ----

65. Radar constant
66. Noise power
67. Receiver gain
68. Peak power
69. Antenna gain
70. Pulse duration

Figure I-1. MULTISTAGE DATA CORRECTION HIERARCHY

```
********************************
****   Original DATA TAPE   **** <----------!
********************************            !
               !                            !
               !                            !
               V                            !
********************************            !
****  RADAR.DEF definitions ****            !
********************************            !
               !                            !
               !                            !
               V                            !
********************************            !
****  Standard Programmed   ****            !
**  Corrections + Derivations **            !
********************************            !
               !                            !
               !                            !
               V                            !
********************************            !
*** Tape Specific Programmed ***            !
**  Corrections + Derivations **            !
********************************            !
               !                            !
               !                            !
               V                            !
********************************            !
*** Online User Corrections  ***            !
********************************            !
               !                            !
               !                            !
               V                            !
        ********************************    !
        ****  Tape Debugging Tools  ****    !
        ********************************    !
               !                            !
               !                            !
               V                            !
        ********************************    !
        ****  Program Modifications **** ----
        ********************************
```

Figure I-2. Code development and maintenance system

```
  ---->         Modification and Development of Programs
  |                                   |
  |                                   |
  |                                   V
  |--->     DEC SCA (Source Code Analyzer) Library and
Database
  |                                   |
  |                                   |
  |                                   V
 |---> DEC CMS (Code Management System) Source Code Library
and Database
 |                                   |
 |                                   |
 |                                   V
 |--->     DEC CMS (Code Management System) Object Code
Library
 |                                   |
 |                                   |
 |                                   V
 ----     DEC MMS (Module Management System) Object Code
Library
 |                                   |
 |                                   |
 |                                   V
 ----                         TESTING OF CODE
```

Figure I-3. MMS code to maintain BABEL program

```
! $ MMS /DESCR=BABEL_CMS                    /CMS /OVERRIDE /VERIFY /OUT=BABEL_MMS.LOG
!                                                    .... REGENERATES BABEL.EXE
!
! $ MMS /DESCR=BABEL_CMS /MACRO=DEBUGS /CMS /OVERRIDE /VERIFY /OUT=BABEL_MMS.LOG
!    (note $(LINK), not LINK is used below)
!    (uses DEBUGS.MMS                                .... GENERATES BABEL.EXE /DEBUG
!
!
!  BABEL_CMS.MMS DESCRIPTION FILE FOR BABEL.EXE   DOUGLAS QUINE   12-AUG-1988
!
.FIRST
              SHOW TIME
              SET DEFAULT [QUINE.MMS]
!
!       SPECIFY LINK LIST FOR EXECUTABLE TARGET
!
!        (DIR$BABEL:BABEL.OPT:
!                 lists all known items with no implied library references)
!
!        N.B. FOLLOWING MODULES LEFT OUT - NO SOURCE CODE
!                 DIR$CHILL:RADARLIB(CHILL2),-        (missing include file)
!                     DIR$CHILL:RADARLIB(CHILL2)  : DIR$CHILL:CHILL2.C
!                 DIR$CHILL:RADARLIB(CHLGET),-        (compiler errors)
!                     DIR$CHILL:RADARLIB(CHLGET)  : DIR$CHILL:CHLGET.C
!                 DIR$CHILL:RADARLIB(CHLGET3),-       (missing include file)
!                     DIR$CHILL:RADARLIB(CHLGET3) : DIR$CHILL:CHLGET3.C
!                 DIR$CHILL:RADARLIB(CHLVELSUB),-     (missing include file)
!                     DIR$CHILL:RADARLIB(CHLVELSUB) : DIR$CHILL:CHLVELSUB.C
!
!
BABEL.EXE : [BH_LIBRARY]BH(ADJUST_DAY),-
 [BH_LIBRARY]BH(ADJUST_GATE),-
 [BH_LIBRARY]BH(AFGL_FIND),-
 [BH_LIBRARY]BH(AFGL_SCAN),-
 [BH_LIBRARY]BH(ASCHD),-
 [BH_LIBRARY]BH(ASCRAY),-
 [F77]F77(ASK_FS),-
 [F77]F77(ASK_FS_ERROR),-
 [F77]F77(ASK_FS_ERROR_NEW),-
 [BH_LIBRARY]BH(BABEL),-
 [BH_LIBRARY]BH(BEAMBAB),-
 [BH_LIBRARY]BH(BLOCKBAB),-
 [F77]F77(BUFF_EMPTY=TV_ACCESS.OBJ),-
 [BH_LIBRARY]BH(CENSOR=EMULATE_NEXRAD.OBJ),-
 [BH_LIBRARY]BH(CHECK_BABELINC),-
 [BH_LIBRARY]BH(CHECK_GATE=EMULATE_NEXRAD.OBJ),-
 [BH_LIBRARY]BH(CHECK_RGB_INC),-
 [BH_LIBRARY]BH(CHECK_SIGMET),-
 [BH_LIBRARY]BH(CHILL_AUTO_CTERM),-
```

```
[BH_LIBRARY]BH(CHILL_CAL),-
[BH_LIBRARY]BH(CHILL_CHECK_NEW),-
[BH_LIBRARY]BH(CHILL_CHECK_OLD),-
[BH_LIBRARY]BH(CHILL_CHECK_OLD2),-
[BH_LIBRARY]BH(CHILL_CHECK_OLD3),-
[BH_LIBRARY]BH(CHILL_CHECK_TIME),-
[BH_LIBRARY]BH(CHILL_CTERM),-
[BH_LIBRARY]BH(CHILL_FIND),-
[BH_LIBRARY]BH(CHILL_INIT),-
[BH_LIBRARY]BH(CHILL_READ),-
[BH_LIBRARY]BH(CHILL_READ1),-
[BH_LIBRARY]BH(CHILL_SCAN),-
[BH_LIBRARY]BH(CHILL_SW),-
[BH_LIBRARY]BH(CHILL_VEL_NEW),-
[BH_LIBRARY]BH(CHILL_VEL_OLD),-
[BH_LIBRARY]BH(CHILL_ZDR),-
[BH_LIBRARY]BH(CHNO),-
[BH_LIBRARY]BH(CODE_UFSITE),-
[BH_LIBRARY]BH(COMPSET),-
[F77]F77(COMPRESS=TVSAVESUB.OBJ),-
[BH_LIBRARY]BH(COMPUTE_UF_NRG),-
[BH_LIBRARY]BH(COPYC),-
[F77]F77(CTRLC_TRAP=TVDRV.OBJ),-
[F77]F77(DAYLIGHT),-
[F77]F77(DB),-
[BH_LIBRARY]BH(DCSITE),-
[BH_LIBRARY]BH(DCSITENAME),-
[BH_LIBRARY]BH(DCTYPE),-
[BH_LIBRARY]BH(DC_UFSITE),-
[BH_LIBRARY]BH(DEBUG_AZIMUTH),-
[BH_LIBRARY]BH(DECINFO),-
[BH_LIBRARY]BH(DECODEAFG),-
[BH_LIBRARY]BH(DISKRD),-
[BH_LIBRARY]BH(DISKWR),-
[BH_LIBRARY]BH(DRAWMAP),-
[BH_LIBRARY]BH(EMULATE_NEXRAD),-
[BH_LIBRARY]BH(FILE_MARK),-
[BH_LIBRARY]BH(FIND_END),-
[BH_LIBRARY]BH(FINDTYPAN=COMPSET.OBJ),-
[F77]F77(FINISH_FILLING=TVDRV.OBJ),-
[BH_LIBRARY]BH(FIRST_TAPECALL),-
[F77]F77(FORTRAN_IOSTAT),-
[BH_LIBRARY]BH(GETDAY=NAME.OBJ),-
[BH_LIBRARY]BH(GETELEV=NAME.OBJ),-
[BH_LIBRARY]BH(GETMO=NAME.OBJ),-
[BH_LIBRARY]BH(GETREC),-
[BH_LIBRARY]BH(GETTIME=NAME.OBJ),-
[BH_LIBRARY]BH(GETTYPE=NAME.OBJ),-
[BH_LIBRARY]BH(HEADERAFG),-
[BH_LIBRARY]BH(HEADERBAB),-
[BH_LIBRARY]BH(HEADERBAB1),-
[BH_LIBRARY]BH(IGET16),-
[BH_LIBRARY]BH(INDEXC),-
[BH_LIBRARY]BH(INV_DCSITE),-
```

```
[BH_LIBRARY]BH(INV_OPENTAPE),-
[F77]F77(JPIMODE),-
[BH_LIBRARY]BH(KPAKBAB),-
[BH_LIBRARY]BH(LANDRO),-
[BH_LIBRARY]BH(LOCDATA),-
[F77]F77(LOGICAL_UNIT),-
[BH_LIBRARY]BH(MAKBAC),-
[BH_LIBRARY]BH(MAKE_FIX_KM),-
[BH_LIBRARY]BH(MAXKM=EMULATE_NEXRAD.OBJ),-
[F77]F77(MINUS_BLANKS),-
[BH_LIBRARY]BH(MIT_COMMENTS),-
[BH_LIBRARY]BH(MIT_FIND),-
[BH_LIBRARY]BH(MIT_RAYHEAD),-
[BH_LIBRARY]BH(MIT_RAYLOOP),-
[BH_LIBRARY]BH(MIT_RAYLOOP1),-
[BH_LIBRARY]BH(MIT_RAYS),-
[BH_LIBRARY]BH(MIT_RAY_UNDO),-
[BH_LIBRARY]BH(MIT_SCAN),-
[F77]F77(MKLOGNM),-
[F77]F77(MONTH_NAME),-
[BH_LIBRARY]BH(MORE_SWEEP),-
[F77]F77(MOVEWORDS=TVDRV.OBJ),-
[BH_LIBRARY]BH(MOV_ASCII),-
[BH_LIBRARY]BH(MVBLANKS=WRLST.OBJ),-
[BH_LIBRARY]BH(MVREC),-
[BH_LIBRARY]BH(MVTAPE),-
[BH_LIBRARY]BH(MW=EMULATE_NEXRAD.OBJ),-
[BH_LIBRARY]BH(NAMCONV),-
[BH_LIBRARY]BH(NAME),-
[BH_LIBRARY]BH(NEXRAD_UF_CLEANUP),-
[BH_LIBRARY]BH(OPENFIL),-
[BH_LIBRARY]BH(OPENINB),-
[BH_LIBRARY]BH(OPENOUTB),-
[BH_LIBRARY]BH(OPENTAPE),-
[BH_LIBRARY]BH(OPEN_FILES),-
[BH_LIBRARY]BH(OUTSIZE=EMULATE_NEXRAD.OBJ),-
[BH_LIBRARY]BH(OVERRIDE_AFG),-
[BH_LIBRARY]BH(OVERRIDE_CHI),-
[BH_LIBRARY]BH(OVERRIDE_MIT),-
[BH_LIBRARY]BH(OVERRIDE_UF),-
[BH_LIBRARY]BH(OVERRIDE_UR),-
[BH_LIBRARY]BH(POINT=EMULATE_NEXRAD.OBJ),-
[BH_LIBRARY]BH(POSITION),-
[BH_LIBRARY]BH(POSTODATA),-
[BH_LIBRARY]BH(PPIBAB),-
[BH_LIBRARY]BH(PPI_CHAR_DV),-
[BH_LIBRARY]BH(PPI_CHAR_RZ),-
[BH_LIBRARY]BH(PREPROCESS),-
[BH_LIBRARY]BH(PUT16),-
[BH_LIBRARY]BH(RANGEBAB),-
[BH_LIBRARY]BH(RDCHBLK),-
[BH_LIBRARY]BH(RDSET),-
[BH_LIBRARY]BH(READBAB),-
DIR$CHILL:RADARLIB(READBLK),-
```

```
[BH_LIBRARY]BH(READCOLORS),-
[BH_LIBRARY]BH(READDISK),-
[BH_LIBRARY]BH(READTAPE),-
[BH_LIBRARY]BH(REPORT_INV),-
[BH_LIBRARY]BH(RGB_CLOSE),-
[BH_LIBRARY]BH(RGB_CONVERT),-
[BH_LIBRARY]BH(RGB_LABEL),-
[BH_LIBRARY]BH(RGB_LABEL1),-
[BH_LIBRARY]BH(RGB_LABEL2),-
[BH_LIBRARY]BH(RGB_LABEL_D_Z),-
[BH_LIBRARY]BH(RGB_LABEL_HISTO),-
[BH_LIBRARY]BH(RGB_LABEL_REF),-
[BH_LIBRARY]BH(RGB_LABEL_SW),-
[BH_LIBRARY]BH(RGB_OPEN),-
[BH_LIBRARY]BH(RGB_OPEN1),-
[BH_LIBRARY]BH(RGB_RAYPPI),-
[BH_LIBRARY]BH(RGB_RAYPPI1),-
[BH_LIBRARY]BH(RGB_RAYRHI),-
[BH_LIBRARY]BH(RGB_SELECT),-
[BH_LIBRARY]BH(RGB_SELECT1),-
[BH_LIBRARY]BH(RGB_SELECT5),-
[BH_LIBRARY]BH(RGB_SELECT6),-
[BH_LIBRARY]BH(SELDATA),-
[BH_LIBRARY]BH(SELECT_INPUT),-
[BH_LIBRARY]BH(SELECT_INPUT1),-
[BH_LIBRARY]BH(SELECT_OUTPUT),-
[BH_LIBRARY]BH(SELECT_OUTPUT1),-
[BH_LIBRARY]BH(SELECT_THRESHOLD),-
[BH_LIBRARY]BH(SETUP_BABELINC),-
[BH_LIBRARY]BH(SHUT_FILES),-
[BH_LIBRARY]BH(SKIPFILE),-
[RECIPE]RECIPE(SORT),-
[BH_LIBRARY]BH(SPACE_GATES=EMULATE_NEXRAD.OBJ),-
[F77]F77(STARIN),-
[F77]F77(STRINGUP),-
[BH_LIBRARY]BH(SUBBAC),-
[BH_LIBRARY]BH(SWAPPOSE),-
[F77]F77(TRIMLEAD),-
[F77]F77(TVBACK=TVDRV.OBJ),-
[F77]F77(TVBUFS=TVDRV.OBJ),-
[F77]F77(TVFRD=TVDRV.OBJ),-
[F77]F77(TVFREC=TVDRV.OBJ),-
[BH_LIBRARY]BH(TVHISTO),-
[F77]F77(TVLINE=TVDRV.OBJ),-
[F77]F77(TVMAP=TVDRV.OBJ),-
[F77]F77(TVPLANE_COLOR),-
[F77]F77(TVPRAY=TVDRV.OBJ),-
[F77]F77(TVPWRP=TVDRV.OBJ),-
[F77]F77(TVPWRP_NOCOORD=TVDRV.OBJ),-
[F77]F77(TVRCRM=TVDRV.OBJ),-
[F77]F77(TVREAD=TVDRV.OBJ),-
[F77]F77(TVREL=TVDRV.OBJ),-
[F77]F77(TVSAVESUB),-
[F77]F77(TVSETC=TVDRV.OBJ),-
```

```
[BH_LIBRARY]BH(TVSHOW_HISTO),-
[F77]F77(TVSTAT=TVDRV.OBJ),-
[F77]F77(TVTYPE=TVDRV.OBJ),-
[F77]F77(TVWCRM=TVDRV.OBJ),-
[F77]F77(TV_ACCESS),-
[F77]F77(TV_DIAGNOSE=TVDRV.OBJ),-
[F77]F77(TV_PID),-
[BH_LIBRARY]BH(UFHEADEROPT),-
[BH_LIBRARY]BH(UFHEDSBAB),-
[BH_LIBRARY]BH(UFHEDSIN),-
[BH_LIBRARY]BH(UFHEDSIN1),-
[BH_LIBRARY]BH(UFHEDSIN2),-
[BH_LIBRARY]BH(UFHEDSIN3),-
[BH_LIBRARY]BH(UFHEDSIN4),-
[BH_LIBRARY]BH(UFREADDATA),-
[BH_LIBRARY]BH(UFREADIN),-
[BH_LIBRARY]BH(UFWRITDATA),-
[BH_LIBRARY]BH(UFWRITHEAD),-
[BH_LIBRARY]BH(UF_AZ),-
[BH_LIBRARY]BH(UF_DATAFLD),-
[BH_LIBRARY]BH(UF_DATAFLD_LOOP),-
[BH_LIBRARY]BH(UF_FIELDHEAD),-
[BH_LIBRARY]BH(UF_PRESET),-
[BH_LIBRARY]BH(UF_PRESET1),-
[BH_LIBRARY]BH(UF_SCAN),-
[BH_LIBRARY]BH(UF_TIME_ZONE),-
[BH_LIBRARY]BH(UF_UPDATEI),-
[BH_LIBRARY]BH(UF_UPDATER),-
[BH_LIBRARY]BH(UNITY=EMULATE_NEXRAD.OBJ),-
[BH_LIBRARY]BH(UNMONTH),-
[BH_LIBRARY]BH(UNNAMESUB),-
[BH_LIBRARY]BH(UNTYPE),-
[BH_LIBRARY]BH(UNYEAR),-
[BH_LIBRARY]BH(UPDATE_MEAN),-
[BH_LIBRARY]BH(UPDATE_RAY),-
[BH_LIBRARY]BH(UPDATE_RAY1),-
[F77]F77(UPPER),-
[BH_LIBRARY]BH(UR_TO_UF),-
[BH_LIBRARY]BH(UR_TO_UF1),-
[BH_LIBRARY]BH(UR_TO_UF2),-
[BH_LIBRARY]BH(UR_TO_UF_DFH),-
[BH_LIBRARY]BH(UR_TO_UF_MAND),-
[BH_LIBRARY]BH(VIDEOSAVESUB),-
[F77]F77(WAIT_TIME),-
[F77]F77(WHEN),-
[BH_LIBRARY]BH(WRITE_UFTAPE),-
[BH_LIBRARY]BH(WRLST),-
[BH_LIBRARY]BH(WRSET),-
SYS$LIBRARY:VAXCRTL.OLB
!
!       LINK COMMAND
!
     $(LINK) $(LINKFLAGS) DIR$BABEL:BABEL/OPT
!
```

```
!       OBJECT FILES AND THEIR SOURCES ["must" start in column 1]
!
[BH_LIBRARY]BH(ADJUST_DAY)   : ADJUST_DAY.OBJ
ADJUST_DAY.OBJ               : ADJUST_DAY.FOR
[BH_LIBRARY]BH(ADJUST_GATE)  : ADJUST_GATE.OBJ
ADJUST_GATE.OBJ              : ADJUST_GATE.FOR, DIR$BABEL:BABELINC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR,INC:DEVICE.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR, DIR$CHILL:CHILLCOM.FOR
[BH_LIBRARY]BH(AFGL_FIND)    : AFGL_FIND.OBJ
AFGL_FIND.OBJ                : AFGL_FIND.FOR, DIR$BABEL:BABELINC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR, INC:DEVICE.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR
[BH_LIBRARY]BH(AFGL_SCAN)    : AFGL_SCAN.OBJ
AFGL_SCAN.OBJ                : AFGL_SCAN.FOR, DIR$BABEL:BABELINC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR,INC:DEVICE.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR
[BH_LIBRARY]BH(ASCHD)        : ASCHD.OBJ
ASCHD.OBJ                    : ASCHD.FOR, DIR$BABEL:BABELINC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR, INC:DEVICE.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR
[BH_LIBRARY]BH(ASCRAY)       : ASCRAY.OBJ
ASCRAY.OBJ                   : ASCRAY.FOR, DIR$BABEL:BABELINC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR, INC:DEVICE.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR
[F77]F77(ASK_FS)             : ASK_FS.OBJ
ASK_FS.OBJ                   : [F77]ASK_FS.FOR
[F77]F77(ASK_FS_ERROR)       : ASK_FS_ERROR.OBJ
ASK_FS_ERROR.OBJ             : [F77]ASK_FS_ERROR.FOR
[F77]F77(ASK_FS_ERROR_NEW)   : ASK_FS_ERROR_NEW.OBJ
ASK_FS_ERROR_NEW.OBJ         : [F77]ASK_FS_ERROR_NEW.FOR
[BH_LIBRARY]BH(BABEL)        : BABEL.OBJ
BABEL.OBJ                    : BABEL.FOR, DIR$BABEL:BABEL_DOC.FOR,-
                             DIR$BABEL:BABELINC.FOR, DIR$SIGMET:RGB_INC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR, INC:DEVICE.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR, DIR$BABEL:BABEL_TABLE.FOR
[BH_LIBRARY]BH(BEAMBAB)      : BEAMBAB.OBJ
BEAMBAB.OBJ                  : BEAMBAB.FOR, DIR$BABEL:BABELINC.FOR,-
                             DIR$BABEL:BABEL_COMMON.FOR, INC:DEVICE.FOR, -
                             DIR$BABEL:BABEL_LOCAL.FOR, DIR$BABEL:MIT_INC.FOR
[BH_LIBRARY]BH(BLOCKBAB)     : BLOCKBAB.OBJ
BLOCKBAB.OBJ                 : BLOCKBAB.FOR, DIR$BABEL:BABELINC.FOR, -
                             DIR$BABEL:BABEL_COMMON.FOR,-
                             DIR$BABEL:BABEL_LOCAL.FOR, INC:DEVICE.FOR
```

(19 pp. of similar definitions deleted.)

```
.LAST
       PURGE [QUINE.MMS] /LOG
       RENAME BABEL.EXE DIR$USER_EXE:
       COPY DIR$USER_EXE:BABEL.EXE DIR$BABEL:
       SHOW TIME
```

Appendix II. Description of the database from the INHS tracking radar, used in characterization of targets.

The database includes 6,033 tracks collected in Illinois, Massachusetts, and Michigan. The number includes a few balloons, ground targets used for calibration purposes, aircraft, and other miscellaneous subjects, but the vast majority are flying birds. All tracks of birds engaged in natural behavior are described by linear equations describing their paths through space (Larkin and Thompson, 1980). Most tracks have associated time series of echo strength (wing beat signatures in the case of bird tracks), along with autocorrelations of the time series and subjective records of individual wing beats, if any. The database consists of one observation per track, with the more detailed information having been extracted by programs written in FORTRAN and summarized for inclusion in the database.

The database allows extraction of information important for characterization of targets, such as height distribution, taxonomic composition (waterfowl, passerine, insect), direction and speed of movement, etc. Both statistical descriptions of these parameters over the seasons and their particular values while the weather radars are taking data have proven useful. In the latter case, the information is used to establish "ground truth" in a sample of the airspace observed by the large weather radars.

The first letter in the name of each variable indicates the source of the variable in the original detailed data files.

Variable	Description
CBALLOO	A Balloon Track?
CFLGS	Flags Appearing in Track, CATCH
CMAX1	E-most Point of Whole Track, CATCH
CMAX2	N-most Point of Whole Track, CATCH
CMAX3	Maximum Height of Whole Track, CATCH
CMIN1	W-most Point of Whole Track, CATCH
CMIN2	S-most Point of Whole Track, CATCH
CMIN3	Minimum Height of Whole Track, CATCH
CN	No. points in whole track, from CATCH
CNBAD	No. Bad Points, WC CATCH
CWBALLOO	A Balloon Track?
CWFLGS	Flags Appearing in Track, WC CATCH
CWMAX1	E-most Point of Whole Track, WC CATCH
CWMAX2	N-most Point of Whole Track, WC CATCH
CWMAX3	Maximum Height of Whole Track, WC CATCH
CWMIN1	W-most Point of Whole Track, WC CATCH
CWMIN2	S-most Point of Whole Track, WC CATCH
CWMIN3	Minimum Height of Whole Track, WC CATCH
CWN	No. Points in Whole Track, WC CATCH
CWNBAD	No. Bad Points, WC CATCH
DATE	Starting Date of Session
FFREQ	Principal Frequency, Hz
FFREQ2	Secondary Frequency, Hz
FNOTES	Notes Relating to Target Signature
FREST	Other Notes re Target Signature
FTYPEB	Target Type from Signature, FC
FTYPEBQ	Question Mark re Type from FC Analysis
FTYPEN	Target Type from Radar Notes, FC
FTYPENQ	Question Mark re Type from Radar Notes
NARTIF	Artifacts Noted
NBINOC	No. Seen in Binoculars

NCALIB	Calibration Performed
NCLOUD	Cloud Cover, %
NCMOON	Moon Behind Cloud
NCOLOR	Color Seen Visually
NCOMGEN	General Comments about the Session
NCOMTRK	Comments About Particular Tracks
NLIGHT	Light Source Used for Observations
NMOON	Moon
NN_A	No. Peaks on A-scope
NOBSERV	Observer(s)
NON	Was Spotlamp turned on?
NPRECIP	Precipitation
NRX	Reaction? (e.g to Spotlamp)
NSCOP	No. of Targets Seen in Telescope
NSCOPOP	Telescope Used
NSEQ	Sequence No. in NOTES File
NSHAPE	Shape Seen Visually
NSIZE	Size Seen Visually
NSIZ_A	Size Estimated on A-scope
NSOUNDR	Acoustic Sounder On?
NSPECIES	Species
NTCDRY	Dry Bulb Temperature, C
NTCWET	Wet Bulb Temperature, C
NTODIR	Surface Wind Direction, Degrees Toward
NTYPE	Target Type from A-scope or Notes
NUE	No. Seen with Unaided Eye
NWINSPD	Surface Wind Speed, m/s
SDIR	Direction of Segment re Ground, degrees
SDURA	Duration of Segment
SLAG	Segment Lag from Start of Track, s
SMETER	Length of Segment, m
SN	No. Points in Segment
SSEG	Segment
SSPD	Speed re Ground, m/s

SWDIR	Heading, degrees
SWDURA	Duration of WC Segment
SWLAG	Segment Lag from Start of WC Track, s
SWMETER	Length of WC Segment, m
SWN	No. Points in WC Segment
SWSEG	WC Segment
SWSPD	True Airspeed, m/s
SWX_A	X at Start of WC Segment, m/s
SWX_B	Eastward Component of WC Segment, m/s
SWX_SE	S.E. of Eastward WC Component, m.s
SWY_A	Y at Start of WC Segment, m
SWY_B	Northward Component of WC Segment, m/s
SWY_SE	S.E. of Northward WC Component, m/s
SWZ_A	Height at Start of WC Segment, m
SWZ_B	Rate of Climb of WC Segment, m/s
SWZ_SE	S.E. of Height for WC Segment
SX_A	X at Start of Segment, m/s
SX_B	Eastward Component of Segment, m/s
SX_SE	S.E. of Eastward Component, m/s
SY_A	Y at Start of Segment, m
SY_B	Northward Component of Segment, m/s
SY_SE	S.E. of Northward Component, m/s
SZ_A	Height at Start of Segment, m
SZ_B	Rate of Climb of Segment, m/s
SZ_SE	S.E. of Height for Segment
TIME	Local Time

Appendix III. Using velocity to restrict the area of search in the Blackbird Algorithm.

Velocity and azimuth information available from the radar will enable the algorithm to limit the spatial scope of the search when trying to determine centers of roosts. On a general level, we note that targets approaching the radar cannot originate from any roost between the radar and the target. In fact, the roost must lie at some point beyond the tangent to the radar at the point of the target (Figure III-1). Conversely, a target receding from the radar cannot originate from a roost whose center lies beyond that same tangent.

More specifically, because blackbirds fly at about 20 ms^{-1} True Air Speed, the velocity given by the Doppler radar can be used to narrow the search space. We treat the case of 20 ms^{-1}, the case of lower velocities, and the case of zero velocity. We know that Doppler radar measures only that component of speed along the radial direction. Therefore, if blackbird echoes are measured receding or approaching at high speed ($\geq$ about 20 ms^{-1}), then they must be traveling along a radial and the roost must lie on or near the radial. This is the narrowest possible area to search for the roost. If blackbird echoes are measured flying at a lower speed ($\ll$ 20 ms^{-1}) then they are traveling at an angle to the radar. The angle can be determined by normalizing the speed with respect to the maximum speed and taking the SIN^{-1} function. This angle and the reflection of this angle about the radial describe the two possible directions the birds might be flying relative to the radar. Targets travelling at zero velocity take the tangent described in the previous paragraph.

The angle should be relaxed slightly to account for the possibility of wind affecting the speed of the birds. Therefore the two lines and their reflections are calculated using the radar velocity plus or minus 4 ms^{-1}. The areas described by these two velocity and angle is shown in Figure III-3. To determine the possible directions from which the birds are flying given their radial velocity one uses:

$$\text{Direction} = \text{SIN}^{-1}((\text{VEL}-4)/20)$$

and

$$\text{Direction} = \text{SIN}^{-1}((\text{VEL}+4)/20).$$

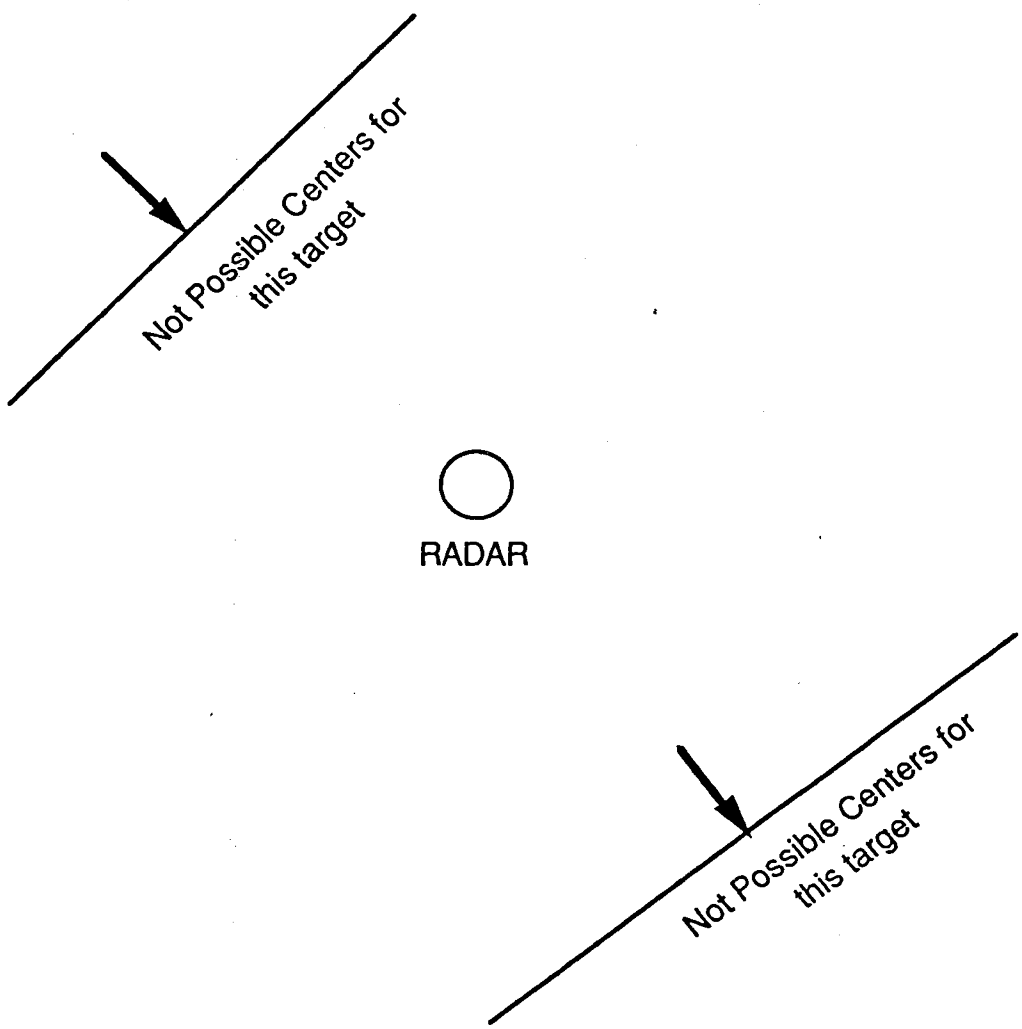

Figure III-1. Tangent lines delimit areas where a roost center cannot lie, for a target at a given location with velocity of a given sign.

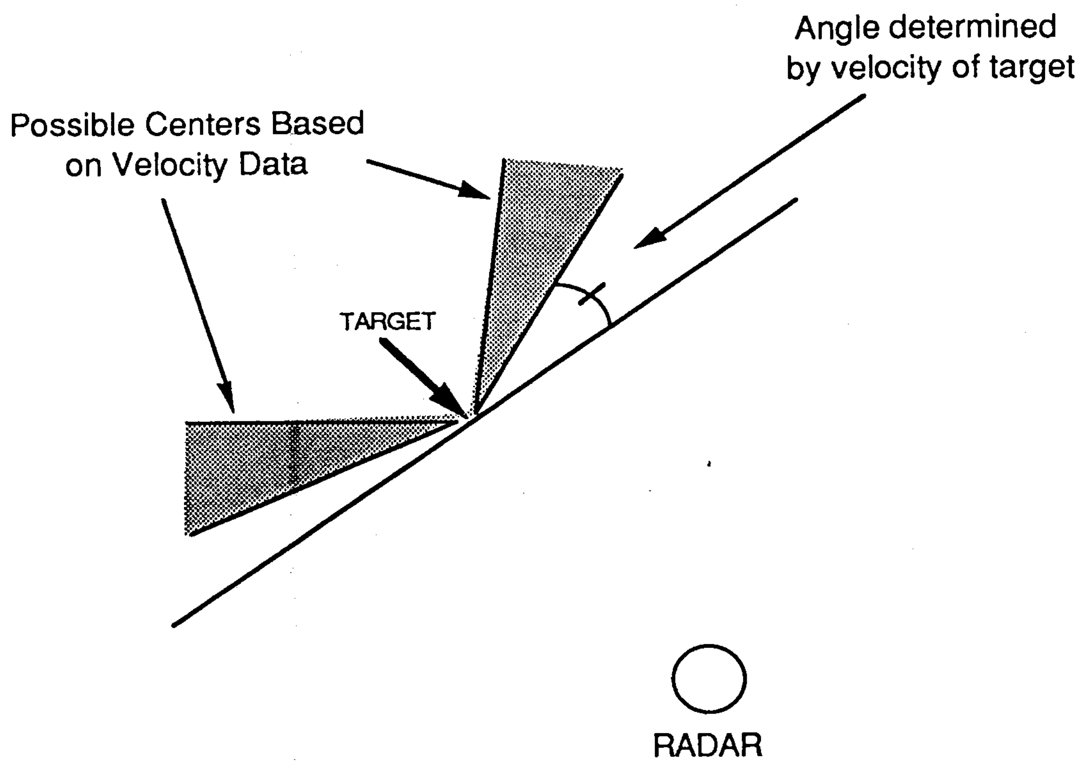

Figure III-2. Directions of possible roost centers based on velocity.

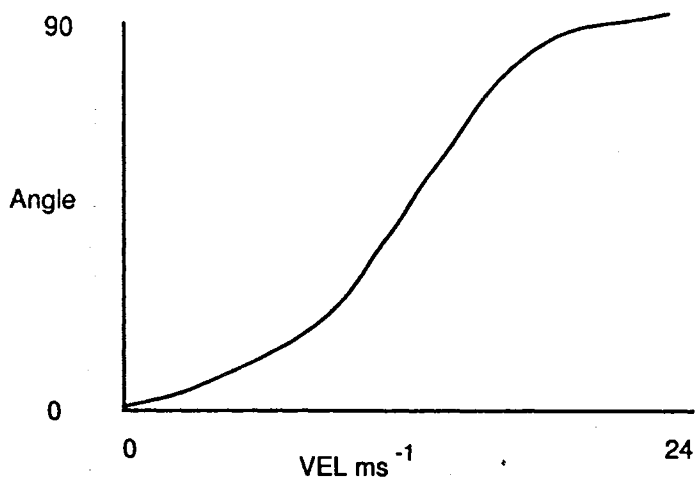

Figure III-3. Functional relationship between the angle of Figure II-2 and velocity.

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