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Detection of Birds by Radar

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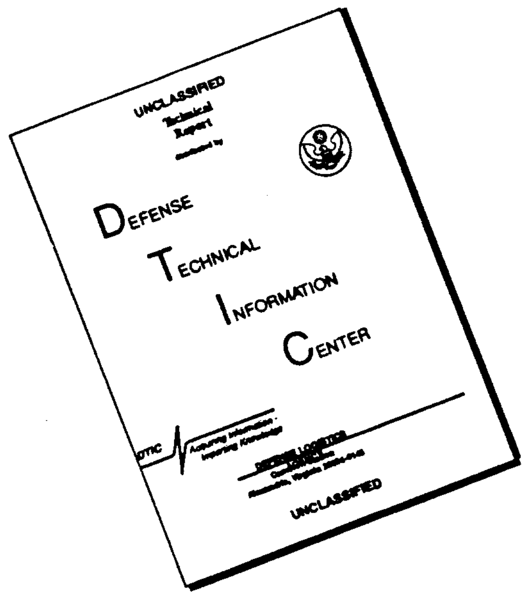

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Hoewel vogels slechts een kleine radardoorsnede (Radar Cross-Section, RCS) hebben kunnen ze met radar over een beperkt afstandsbereik worden gedetecteerd en gevolgd.

Radarwaarneming van vogels kan een doel op zich vormen maar ook ongewenst zijn. Het trekpatroon van vogels geeft informatie aan biologen maar ook aan piloten die hun route hieraan kunnen aanpassen. Vogels kunnen ook valse tracks veroorzaken waardoor het observeren van vliegbewegingen wordt bemoeilijkt.

Voor een tweetal generieke radarsystemen wordt aangegeven tot welke afstand vogels kunnen worden waargenomen. Registraties van vogels zijn verkregen met metingen van Signaal's SCOUT Continuous Wave radar en van Signaal's zoek en track systeem Flycatcher. Het spectrum als functie van de tijd (SCOUT data) alsmede de vogeltracks en radiale Doppler snelheid (Flycatcher data) worden onderzocht.

Contents

LIST OF SYMBOLS

B	bandwidth of the receiver [Hz]
c	velocity of light [m/s]
F	noise figure of the receiver
$f_{Doppler}$	Doppler frequency [Hz]
f_t	radar transmit frequency [Hz]
G_t	transmit antenna gain [-]
G_r	receive antenna gain [-]
k	Boltzmann's constant
I_i	received SCOUT I channel [V]
I'_i	corrected received SCOUT I channel [V]
S/N	Signal to Noise ratio
P_d	probability of detection
P_{fa}	false-alarm probability
P_r	received signal power [W]
P_t	radar transmit power [W]
Q_i	received SCOUT Q channel [V]
Q'_i	corrected received SCOUT Q channel [V]
T	temperature [K]
v_r	radial velocity [m/s]
λ	wavelength of the radar electromagnetic energy [m]
σ	target Radar Cross Section [m^2]

1 INTRODUCTION

A severe threat for modern aircraft are bird strikes. Especially during bird migrations, which happen twice a year in Holland, the risk of bird strikes can be high. The damage as a result of a bird strike can be very high, and may even result in loss of aircraft. Therefore it is necessary to measure bird densities in the neighbourhood of airports and along air-traffic routes. These densities can be measured using a radar system. In this chapter some notes on such a radar system will be given.

Modern radar systems have the ability to detect and track targets with a very low Radar Cross Section (RCS). Therefore any bird could initiate a track. If this happens, the radar operator is burdened with the task to discriminate between echoes and tracks of real targets and those of birds. Classification of birds and other air targets such as aircraft and helicopters allows for distinction between these targets so that the number of bird tracks can be reduced.

During the National Technology Project (NTP) on Advanced Radar Techniques for Improved Surveillance and Tracking (ARTIST) trials were conducted in September and October 1992. Subsequent to these trails the three available systems were used for observing birds.

Bird phenomena have been studied by radar by a number of investigators. See for example Vaughn [1], which reviews the literature that describes birds and insects as radar targets. The observed phenomena provide information about the specifications of radar systems for bird observation. In this study the following subjects are investigated:

1. Radar systems for bird observations
   Birds can be detected by several types of radar: Pulse radars give the position of the bird. Continuous Wave (CW) radars give the doppler shift of the body and other moving parts of the bird. These provide a characteristic spectrum. Frequency Modulated CW radars provide the characteristic spectrum and the bird's position.
2. Analyses of the collected bird data
   The tracks and the corresponding spectra give information about the number of birds and the type of birds.

This report is organized as follows. Chapter two describes the principles of bird observation radar systems. Chapter three and four present the experimental setup and signal processing of the ARTIST data. Chapter five presents the results of the observed data. Finally, we summarize the results of the study.

2 DETECTION OF BIRDS BY RADAR SYSTEMS

The main problem in detecting birds with a radar system is the small Radar Cross Section (RCS). Theory reports for large birds an average RCS of -20 dBm2 measured at a frequency of 10 GHz (Vaughn, 1985, Eastwood, 1967). The RCS depends also on other factors, for example the size of the bird and the aspect angle. A sample calculation of the maximum detection range against birds using a generic pulsed radar system is shown in table 1.

Table 1: Sample linkbudget for a generic pulse radar.

Transmit power	1000 W	+30 dBm
Duty cycle	0.02	-17 dB
Antenna gain (twice)	30 dB	+60 dB
wavelength (twice)	0.033 m	-29.6 dB
Bird RCS	0.01 m2	-20 dB
$(4\pi)^3$	1984.4	+33 dB
kTB (B=1000 Hz)	4e-18	-174 dB
S/N (Swerling 1, $P_d = 90\%$, P_{fa} = 1e-6)		+ 21 dB
Maximum detection range	3841 m	

This received power follows directly from the radar equation (Skolnik, 1990):

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{1}$$

The singe pulse signal-to-noise ratio S/N, is given by:

$$S/N = \frac{P_r}{BFkT} \tag{2}$$

In Equations 1 is P_r the received power, P_t the transmit power, G_t and G_r are the transmit and receive antenna gain, λ is the wavelength, σ the target RCS and R the distance to the target. In Equation 2 is P_r the received noise power, k the constant of Boltzmann, T the noise temperature of the antenna, B the bandwidth of the receiver and F the noise figure (considered to be zero) of the receiver. If the signal-to-noise ratio is known one can calculate the detection probability and the false alarm rate for a given Swerling case. The Swerling case depends on the characteristics of the target. In the here given calculation Swerling case 1 is assumed. Caution must be taken when using this equation and table because many more factors influence radar performance. These tables are only given for demonstration purposes and do not represent a real radar system in a real environment. However, it gives a good indication of the possibilities of a generic pulse radar against small targets like birds.

Some improvement of this small detection range can be expected when using an FMCW radar. These radars are, just as pulsed radars, capable of detecting birds as well as determining their radial speed. Due to the higher duty cycle (almost 100%) the detection range is somewhat higher. This is shown in table 2.

Table 2: Sample linkbudget for a generic FMCW radar.

Transmit power	50 W	+17 dBm
Duty cycle	1	0 dB
Antenna gain (twice)	30 dB	+60 dB
wavelength (twice)	0.033 m	-29.6 dB
Bird RCS	0.01 m2	-20 dB
$(4\pi)^3$	1984.4	+33 dB
kTB (B=1000 Hz)	4e-18	-174 dB
S/N (Swerling 1, P_d = 90%, P_{fa} = 1e-6)		+ 21dB
Maximum detection range	4830 m	

Of course, these tables just serve for illustration properties, so the detection range will be different for different radars, environments and targets. In these calculations no attempt has been made to take the surroundings into account. However, they do show the difficulties for the detection of such small targets.

The given calculations show the detection range of a radar against one bird. When looking at groups of birds the detection range can be higher. With a radar it is possible to determine the range at which a group of birds is flying. By taking some assumptions on bird RCS the number of birds in such a group (the bird density) can be estimated. However, since the RCS of a bird depends on the kind of bird, it is very difficult to determine the bird density when the type of birds is not known a priori. This difficulty can be solved by first extracting the type of bird from the radar data. This can be done in several ways, which have their own difficulties each. Two possible ways are given here.

The first way to determine the type of a detected bird is by measuring its Doppler shift. The radar is only capable of determining the radial velocity of the bird (the velocity in the direction of the radar). Using this velocity and the measured position of the bird (requiring a rather high resolution radar) the flight pattern of the birds can be determined. It is not known by the authors whether this is a reliable way to determine the bird's type. Further research in this field will be necessary.

The second way is to determine the internal motion of the birds using a radar with a high Doppler resolution. For example, the wing beat frequency can be measured, giving an indication of the type of bird.

It is clear that much research needs to be carried out before these methods can be implemented in a radar system. The measurements presented in the next chapters give an indication of the capabilities of some radar systems for measuring bird density.

3 THE EXPERIMENTAL SETUP

The bird trials were conducted on Tuesday 29 October 1992. Three systems of Signaal were used: the SCOUT CW radar, the search-and-tracking radar system Flycatcher and the IRSCAN infra-red surveillance system.

The sensor head of IRSCAN consists of the UP 1042 thermal surveillance and tracking camera. The output video signal was recorded with IRIG-B time.

The output (I and Q) of the SCOUT radar was sampled at a rate of 100 kHz. The SCOUT radar used to make the bird measurements was modified from FM-CW mode to CW mode.

In order to aim SCOUT and IRSCAN at the same target, they were slaved by the search-and-tracking radar system Flycatcher. The Flycatcher's tracking position and velocity of the target were recorded as well. The key parameters of the SCOUT radar system are stated in Table 3.

Table 3: SCOUT system parameters.

Parameter	Value
Frequency band	X-band
Transmit frequency	9 GHz
Waveform	CW
Sample frequency (complex)	100 kHz

The Doppler frequency shift, $f_{Doppler}$ (in Hz), is calculated according to:

$$f_{Doppler} = \frac{2\, v_r\, f_t}{c}, \tag{3}$$

where: v_r is the radial velocity with respect to the radar (in m/s), c velocity of light (in m/s) and f_t the radar transmit frequency (in Hz). The frequency shift of the SCOUT can be calculated with:

$$f_{Doppler} = 60 v_r. \tag{4}$$

The recorded IRSCAN video signal provided the information of the target(s) in the radar beam. The quality of the video signal is not good enough for image processing techniques.

4 SIGNAL PROCESSING OF THE SCOUT DATA

The collected SCOUT radar data is seriously disturbed by interfering signals, see van Dorp [2]. Therefore, an interference suppressing process has been designed and implemented. Other radar signals and the infrared system on the site emit various interfering signals. These signals produce a nearly identical interference in both the I and Q channel. Therefore the interfering signals are removed by substracting the Q channel from the I channel:

$$I'_i = I_i - Q_i. \tag{5}$$

With I_i and Q_i the i-th input samples and I'_i the corrected signal.

The advantages of this method are:

1. simple and quick
2. causes a good reduction of the strongest inferfering signals.

The greatest disadvantage is: the spectrum gives no information about the flight direction (outbound or inbound) anymore. This is not serious since the Flycatcher provides the radial velocity.

There are other correction methods possible as well, see van Dorp [2], but these methods have other side effects that disturb the bird tracks seriously. A good presentation of the collected data and its phenomena is our intention.

The individual spectra contain 16K sample points. To reduce the noise, eight spectra are averaged, with each spectrum having 2K overlap. Observation time of one second contains about 6 averaged spectra. The segmentation of the sampled data is depicted schematically in Figure 1:

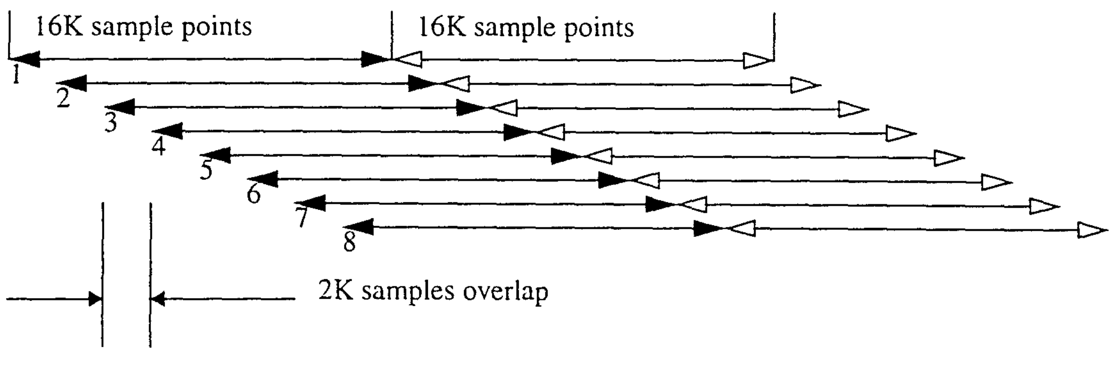


Figure 1: Segmentation of the sampled data.

5 RESULTS

In this section thirteen measurements containing data collected with the SCOUT and Flycatcher are presented.

Figure 2 shows the spectra of the SCOUT data (left) and the radial velocity of the target as measured by the Flycatcher (right). Low amplitudes are blue, medium amplitudes green and high amplitudes are red. The preprocessing causes no discrimination between inbound and outbound flights. The Flycatcher interference causes vertical lines in the spectra (right). Other radar systems cause interference when these emit in the direction of the SCOUT radar and cause peaks on harmonic frequencies. The horizontal "noise" is due to the imperfect radar registrations.
The Flycatcher's radial velocity is negative for inbound flights and positive for outbound flights. The radial velocity during the time between two tracks is not defined and gives no useful information. Time runs from top to bottom.
The Flychater's tracking positions are illustrated in Figure 3. The flight direction of the birds is indicated by a black arrow. The two tracks are labeled with a number, the first track has label 1, the second track label 2 etc. The radars are located at (0,0).

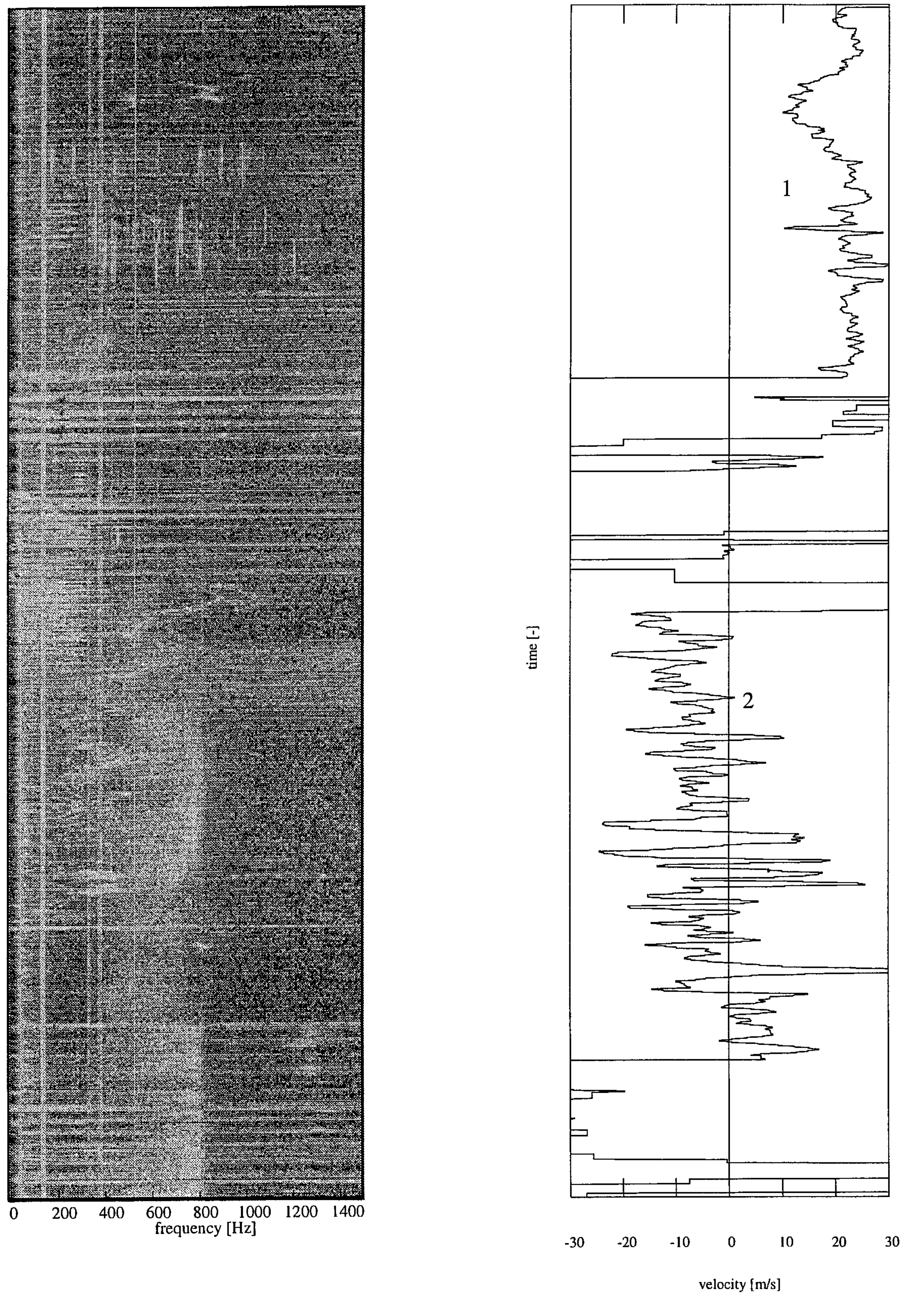


Figure 2: Spectra of Measurement 1 (left) and corresponding radial velocity (right). The measurement started at 10:11:40 for the duration of 214 s (1 cm vertical = 10.7 s).

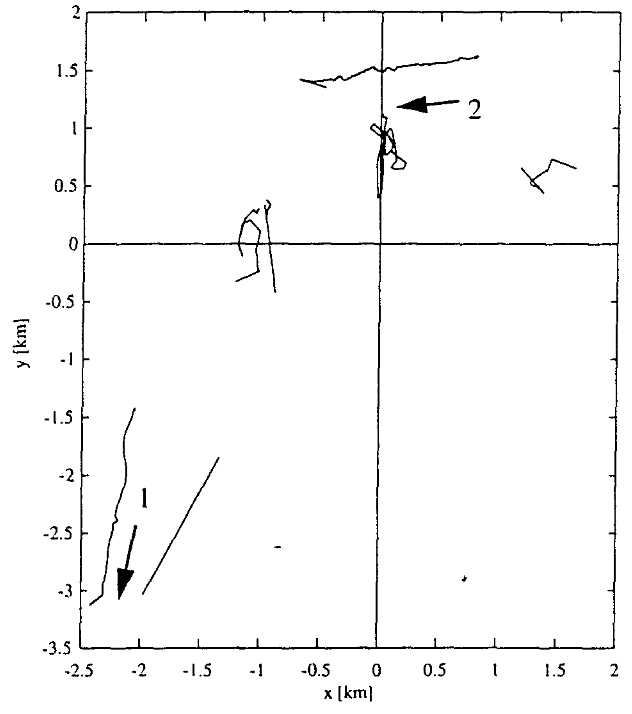


Figure 3: Tracks of Measurement 1. The measurement began at 10:11:40 for the duration of 214 s.

There is one bird in the radar beam during the first track of Measurement 1, see Figure 2 and 3. The SNR of the bodyline is low due to the relatively large range and small size of the bird. This single bird induces little deviation of the radial velocity.

The second track contains about fifteen seagulls. These seagulls cause multiple doppler frequencies in the spectra due to the different velocities and flight directions. The short range causes a better SNR of the bodyline. One particular seagull flew through the radar beam two times causing two strong frequency components of 350 Hz. This group of seagulls causes a greater deviation of the radial velocity measured by the Flycatcher than the single bird track because the radar system switched between the individual birds.

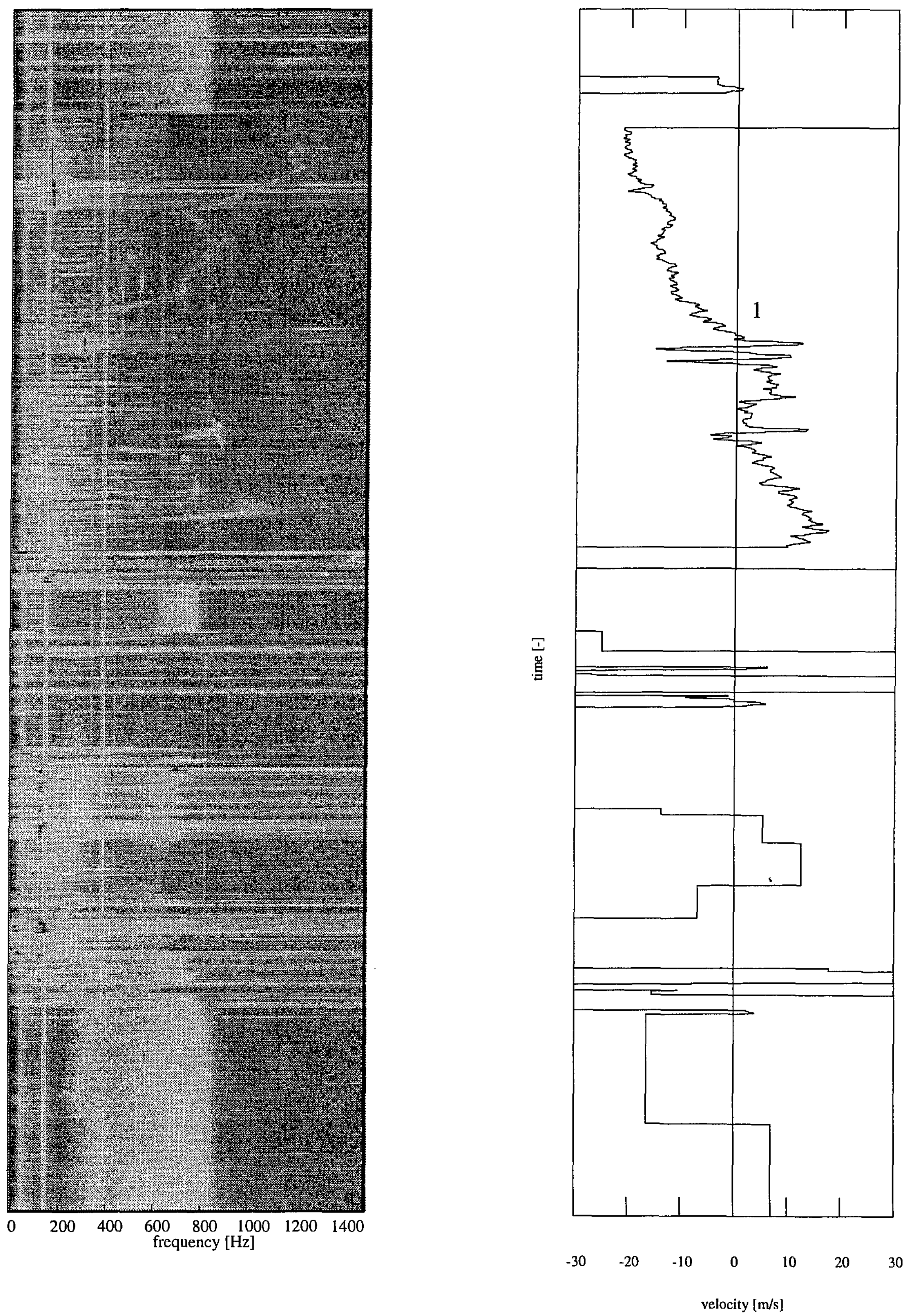


Figure 4: Spectra of Measurement 2 (left) and corresponding radial velocity (right). The measurement started at 10:15:05 for the duration of 218 s (1 cm vertical = 10.9 s).

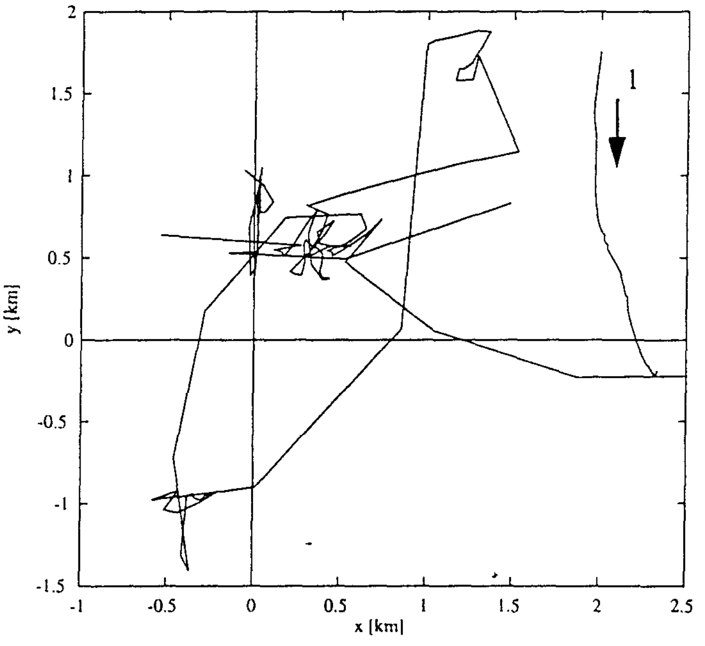


Figure 5: Tracks of Measurement 2. The measurement started at 10:15:05 for the duration of 218 s.

Measurement 2 contains one track of many birds, see Figure 4 and 5. The type of bird is not known. The bodyline is strong and there is a small shoulder on both sides of the bodyline. The second part of the recorded signal gives no useful information.

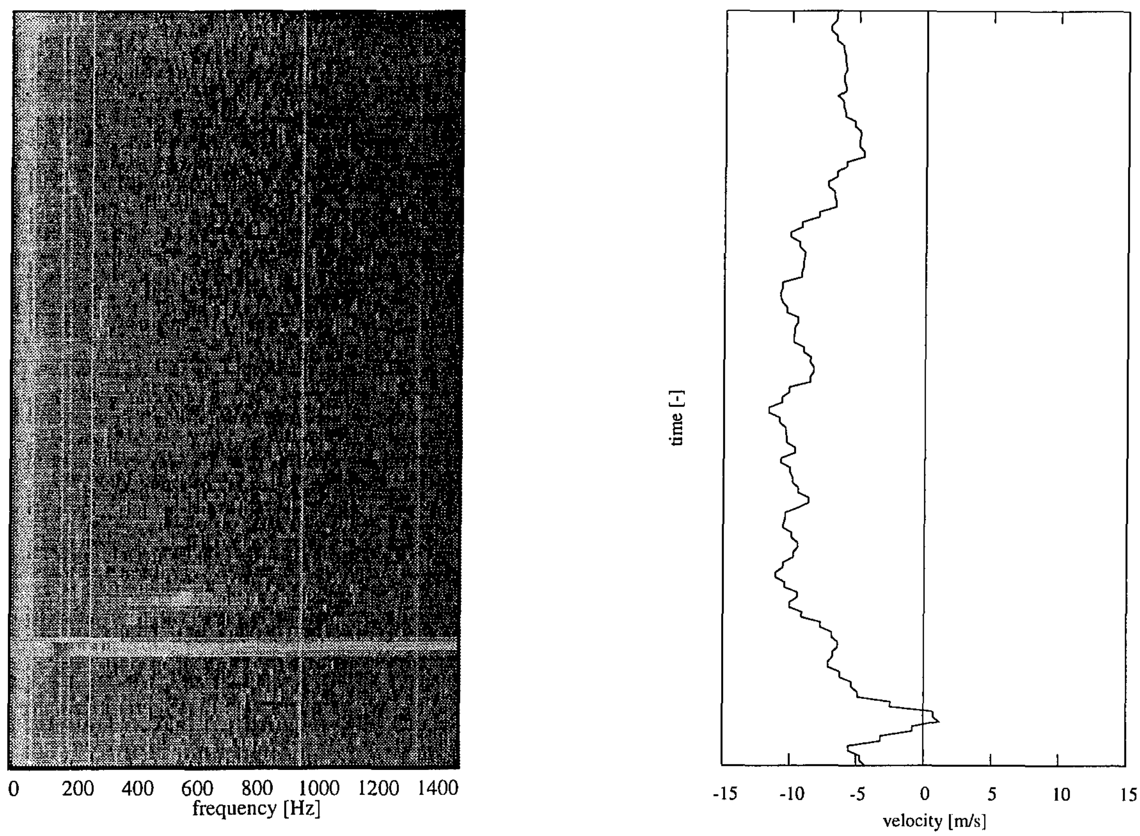


Figure 6: Spectra of Measurement 3 (left) and corresponding radial velocity (right). The measurement started at 10:41:38 for the duration of 19 s (1 cm vertical = 1.9 s).

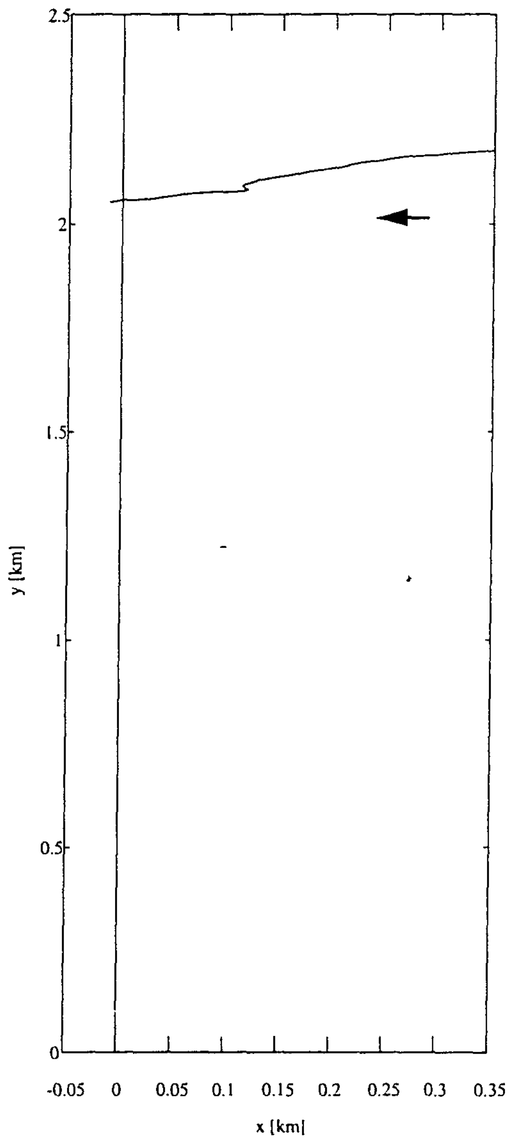


Figure 7: Track of Measurement 3. The measurement started at 10:41:38 for the duration of 19 s. The x and y scale differ in size.

Measurement 3 contains one unknown bird, see Figure 6 and 7. The bird flew one straight flight pattern from East to West. The bird has no frequency modulation imposed on the bodyline.

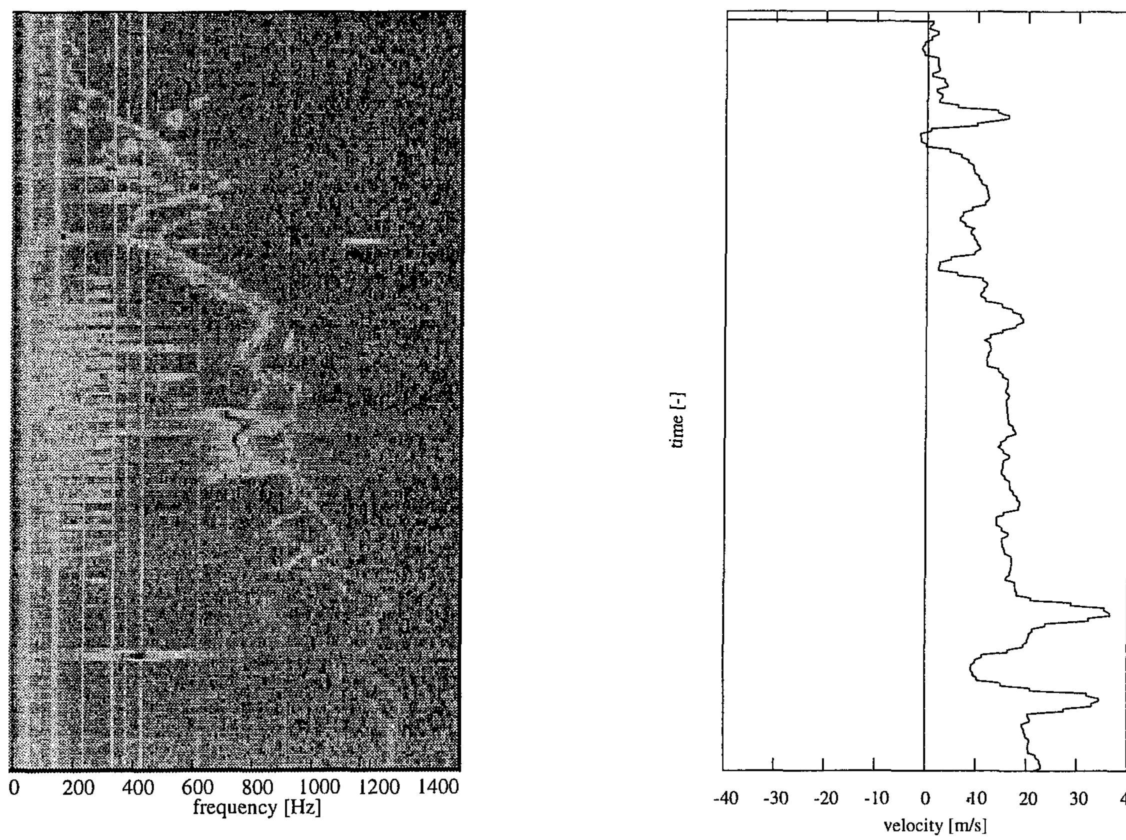


Figure 8: Spectra of Measurement 4 (left) and corresponding radial velocity (right). The measurement started at 10:42:33 for the duration of 37 s (1 cm vertical = 3.7 s).

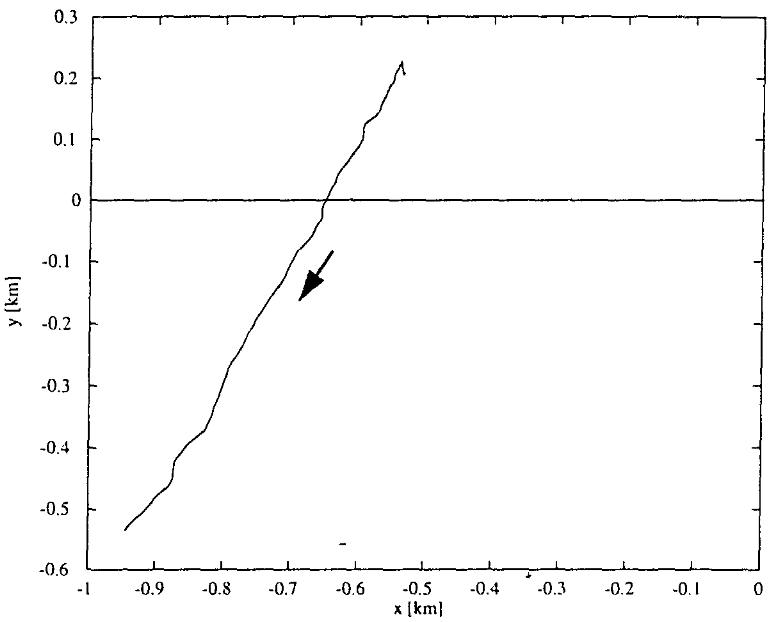


Figure 9: Track of Measurement 4. The measurement started at 10:42:33 for the duration of 37 s.

There are two small birds in track during measurement 4, see Figure 8 and 9. Half-way a third bird flew through the radar beam, inducing a strong doppler frequency of 700 Hz. The two small birds flew outbound with different velocities.

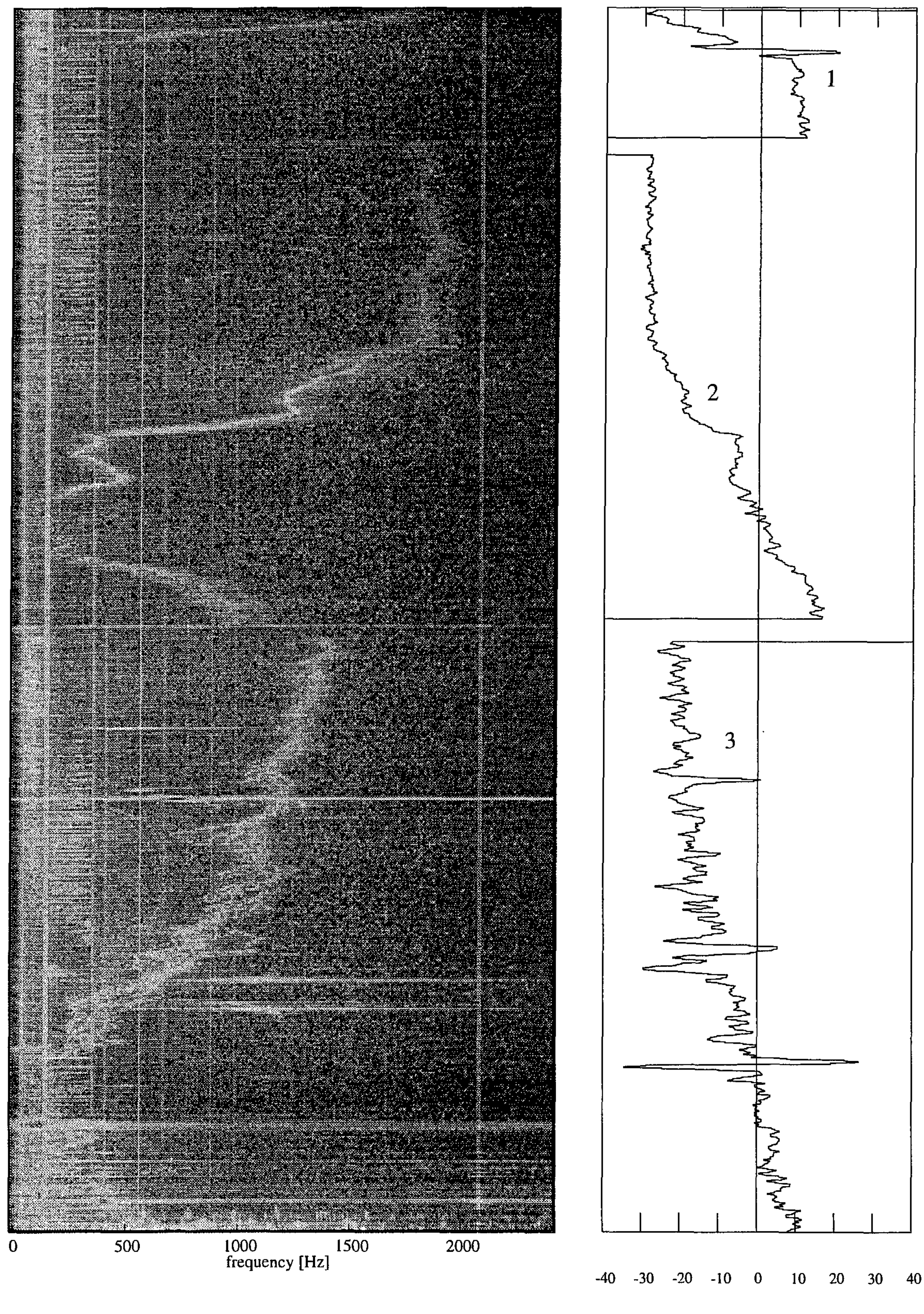


Figure 10: Spectra of Measurement 5 (left) and corresponding radial velocity (right). The measurement started at 10:43:26 for the duration of 206 s (1 cm vertical = 10.3 s).

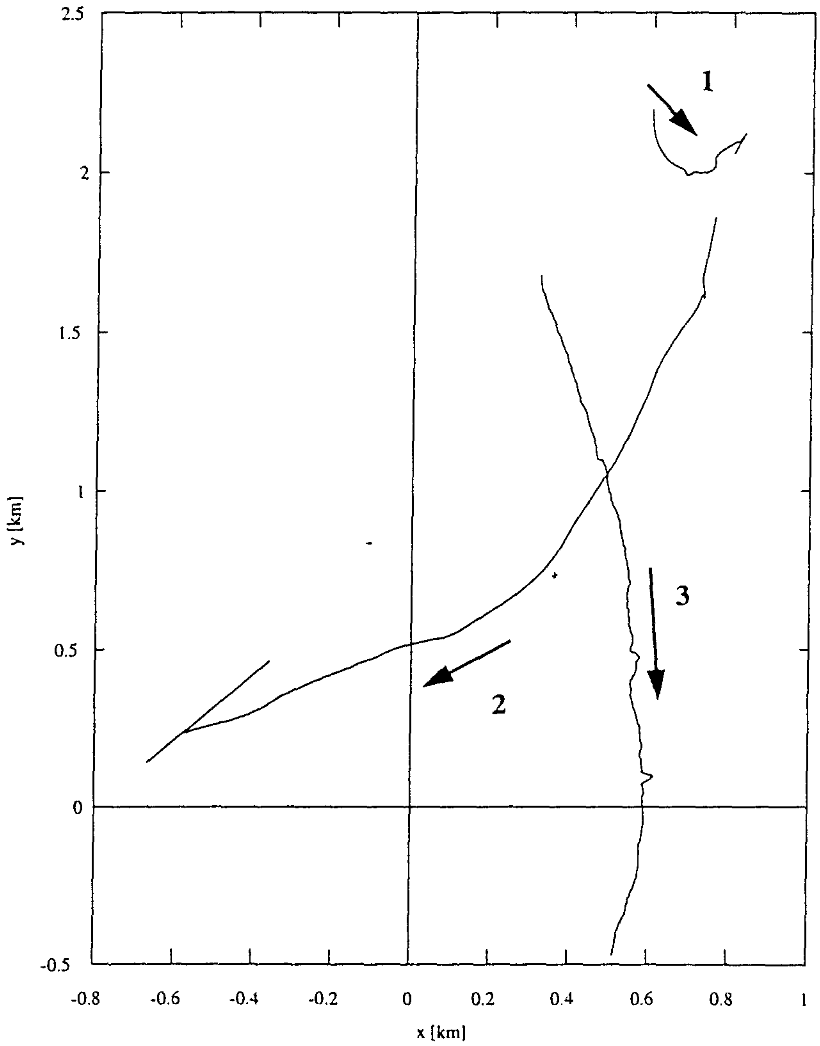


Figure 11: Tracks of Measurement 5. The measurement started at 10:43:26 for the duration of 206 s.

Measurement 5 contains three tracks, see Figure 10 and 11. There is a small group of birds with little distance between them in the radar beam during the first track. The spectra give a good doppler shift that belongs to the outbound flight. The second track belongs to one duck. This duck has little frequency shoulders on both sides of the bodyline, the shoulders and bodyline have equal doppler shifts. The shoulders are visible due to the relatively short range of the duck which induces a high SNR. The third track contains a group of thirty birds. The different velocities of the birds induce a frequency band in the spectra. Figure 12 and 13 present Measurement 6, the continuation of the last track in Measurement 5.
The deviation of the radial velocity of the group of birds is larger than the one of a single bird, because the Flycatcher switched between the birds of a group.

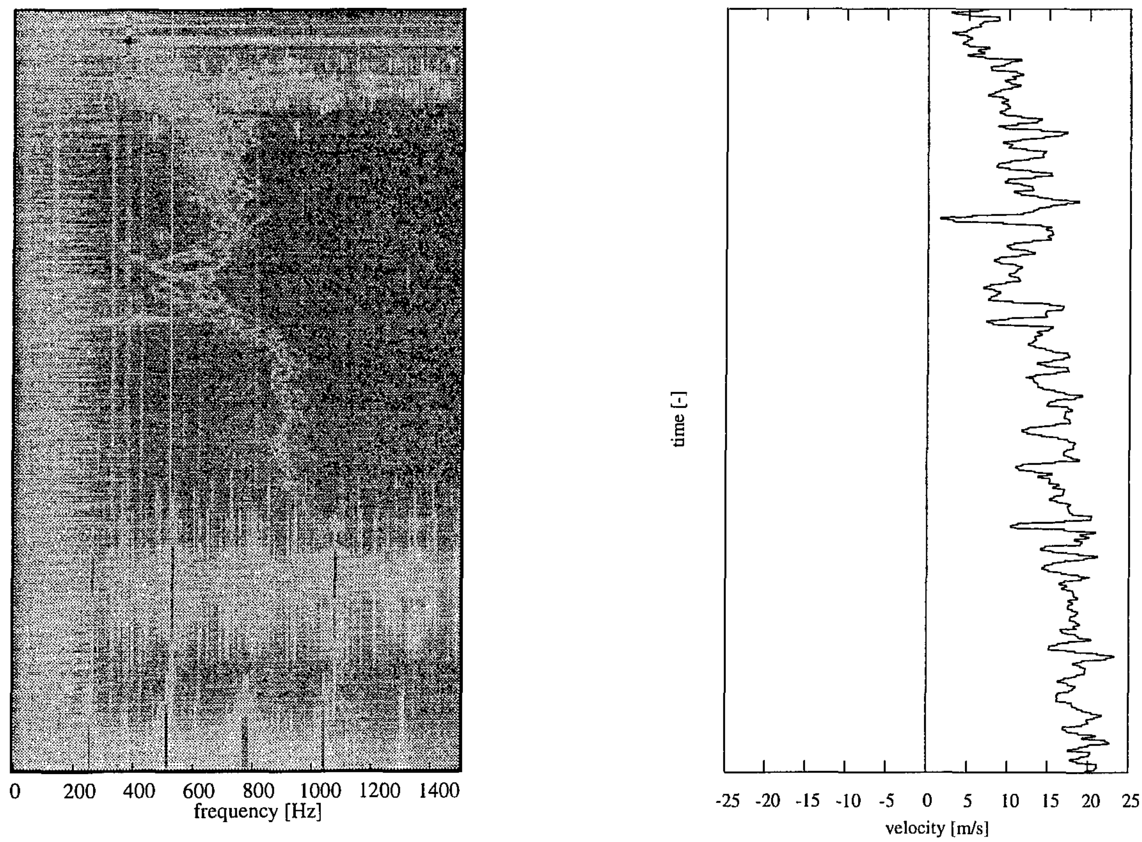


Figure 12: Spectra of Measurement 6 (left) and corresponding radial velocity (right). The measurement started at 10:46:43 for the duration of 81 s (1 cm vertical = 8.1 s).

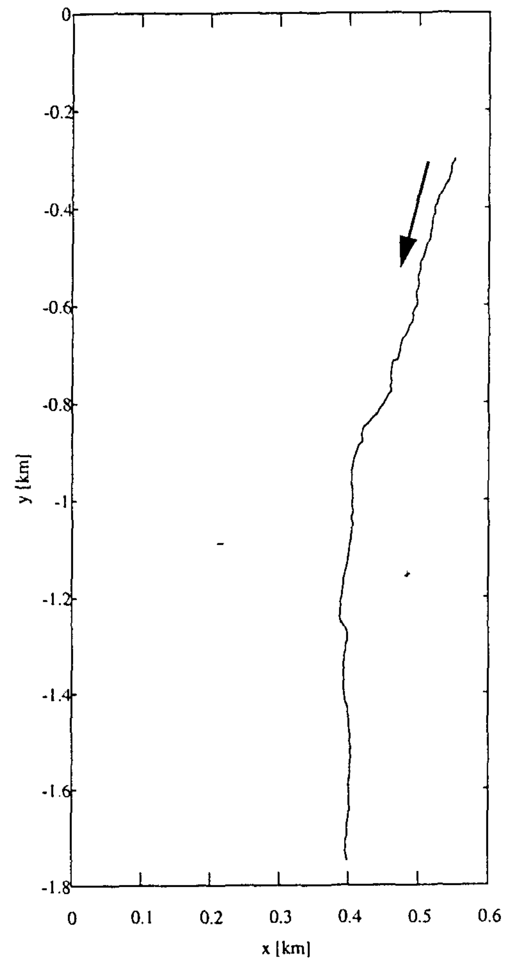


Figure 13: Track of Measurement 6. The measurement started at 10:46:43 for the duration of 81 s. The x and y scale differ.

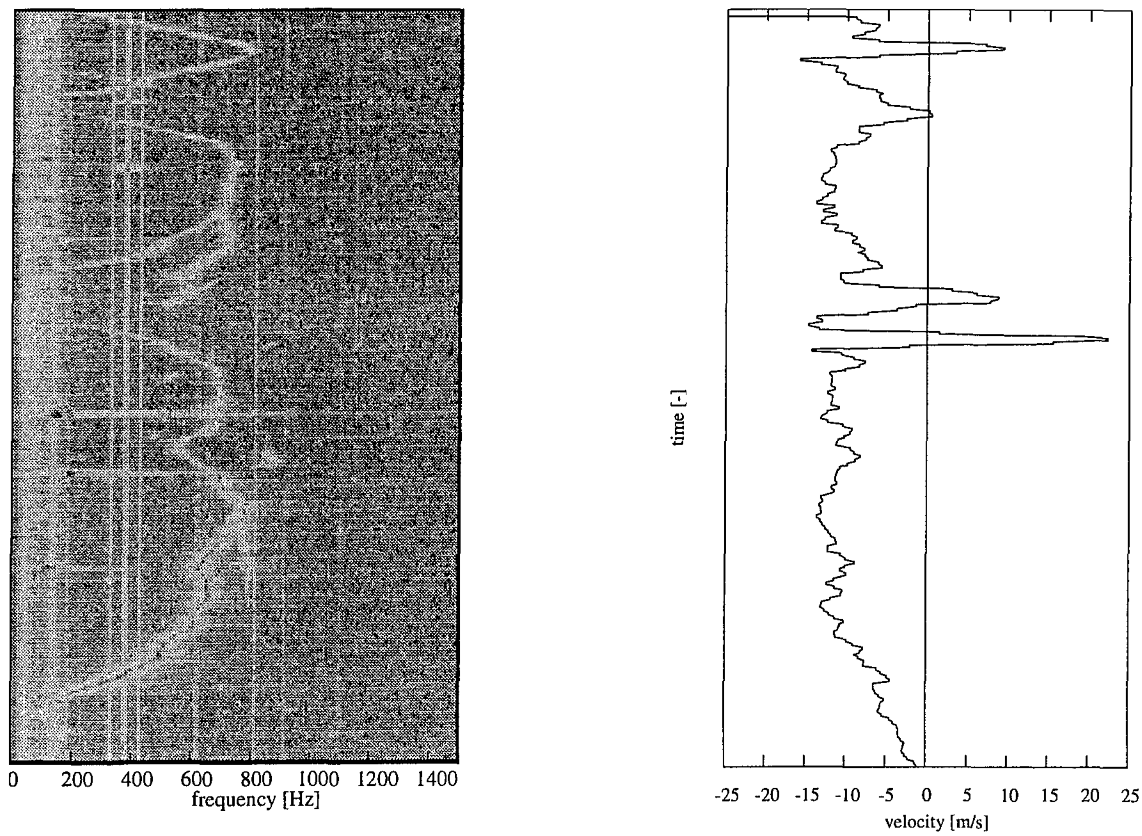


Figure 14: Spectra of Measurement 7 (left) and corresponding radial velocity (right). The measurement started at 10:50:14 for the duration of 51 s (1 cm vertical = 5.1 s).

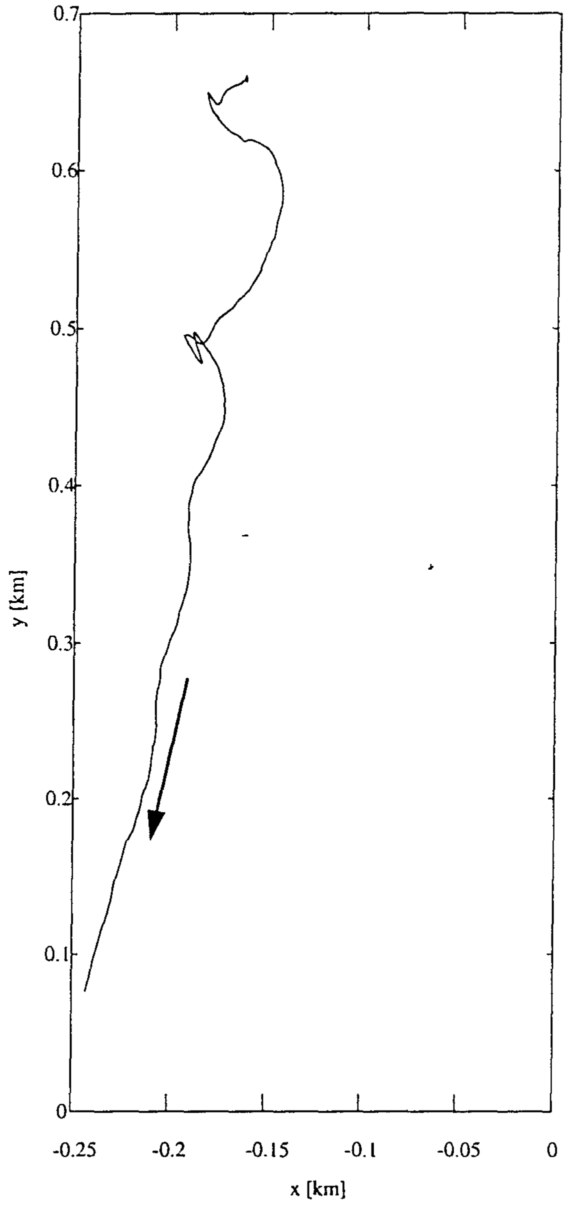


Figure 15: Track of Measurement 7. The measurement started at 10:50:14 for the duration of 51 s. The x and y scale differ.

There is one seagull in the radar beam during Measurement 7, see Figure 14 and 15. The track shows a pattern that indicates a hovering seagull. Two other birds flew through the radar beam, where two bodylines appear in the spectrum. The Flycatcher switched between the tracked bird and the one who crossed the radar beam. The Flycatchet tracked the bird with the largest RCS.

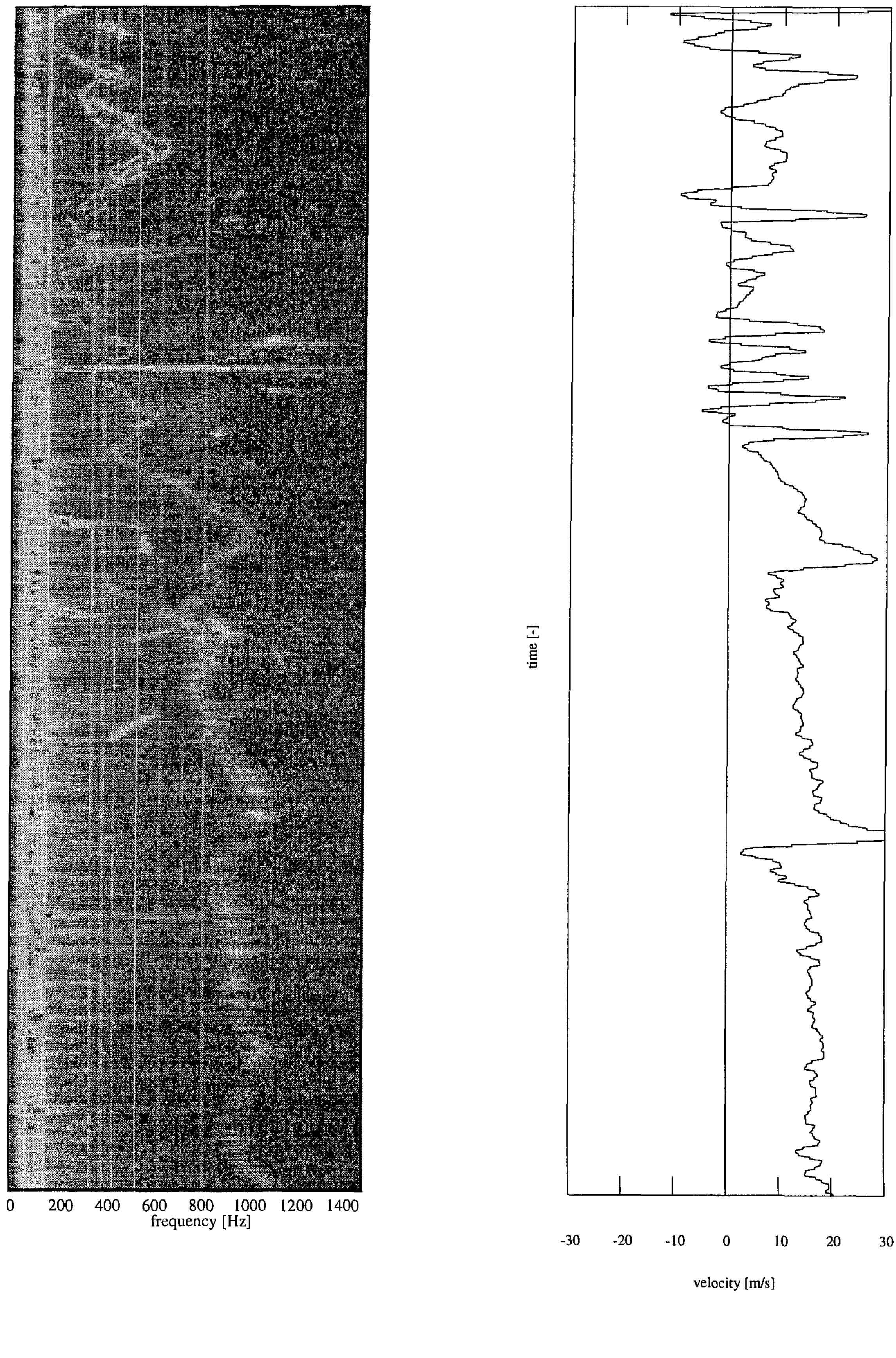


Figure 16: Spectra of Measurement 8 (left) and corresponding radial velocity (right). The measurement started at 10:54:44 for the duration of 90 s (1 cm vertical = 4.5 s).

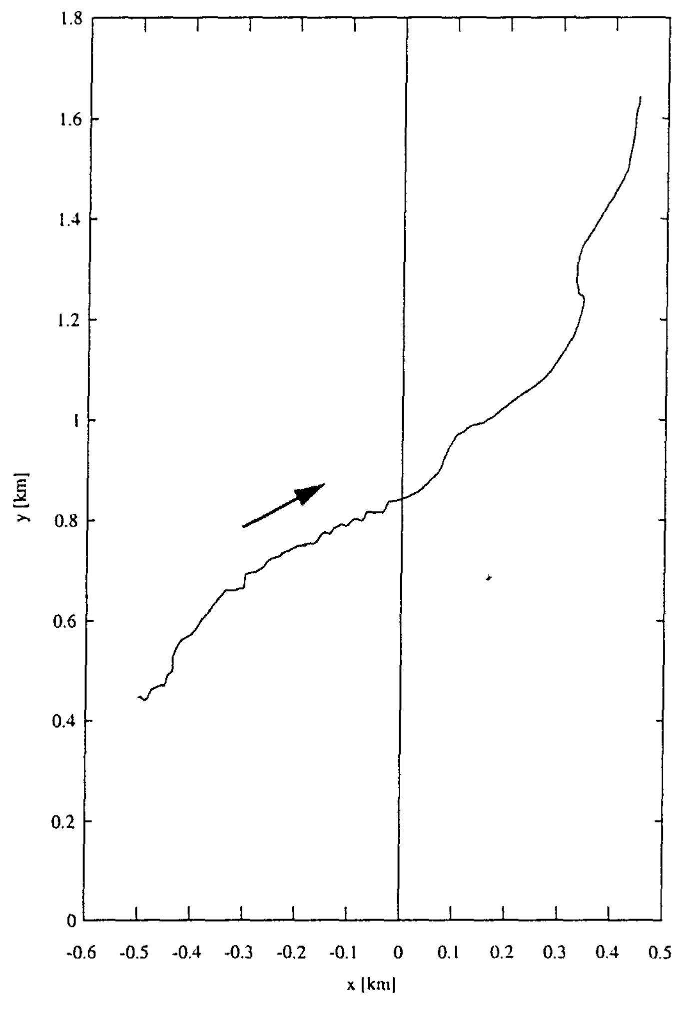


Figure 17: Track of Measurement 8. The measurement started at 10:54:44 for the duration of 90 s.

Figure 16 and 17 show Measurement 8. It contains three ducks in the first half of the track and one duck in the second half. The first half shows some little shoulders on both sides of the bodyline, the second half shows an irregular bodyline pattern. The source of this irregular bodyline pattern is not known. A number of different birds flew through the radar beam during this track.
The radial velocity and spectra show that the duck looses radial speed when hovering.

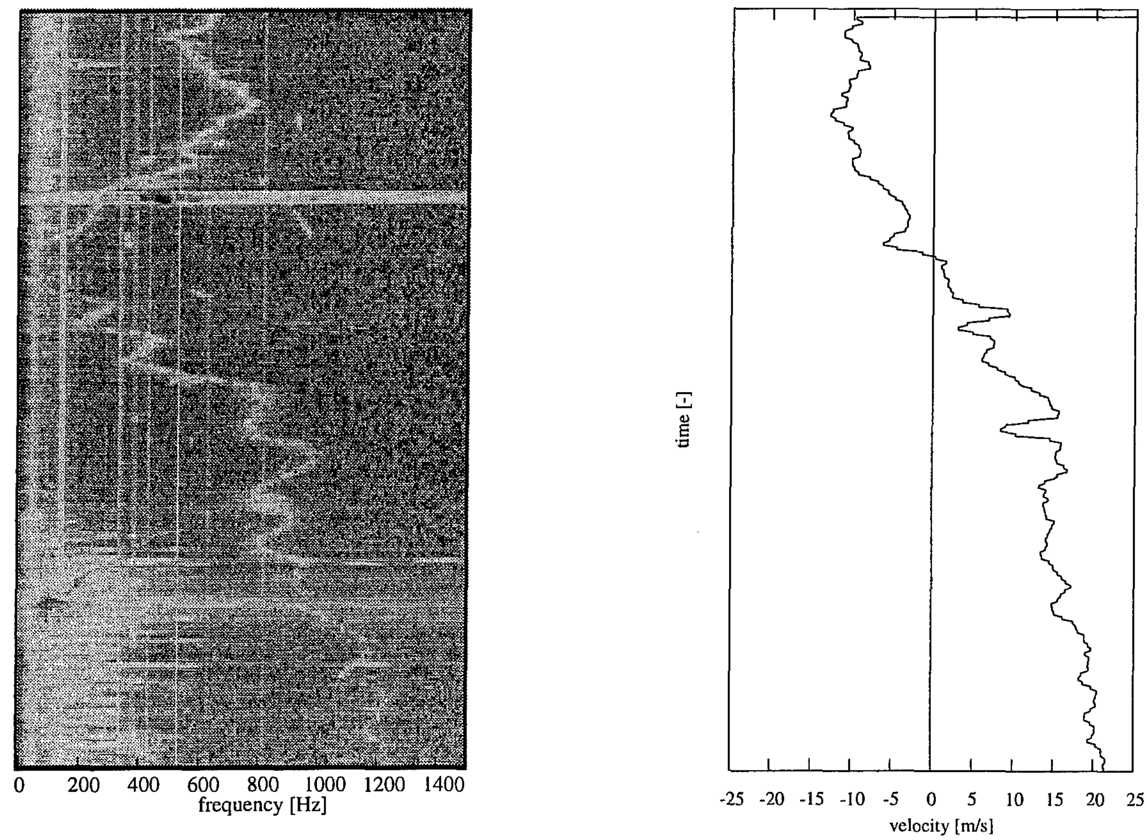


Figure 18: Spectra of Measurement 9 (left) and corresponding radial velocity (right). The measurement started at 10:56:32 for the duration of 43 s (1 cm vertical = 4.3 s).

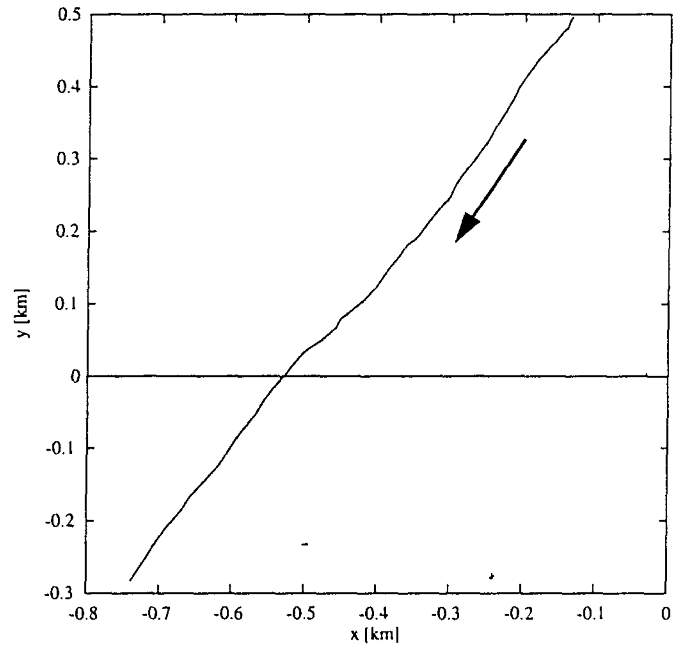


Figure 19: Track of Measurement 9. The measurement started at 10:56:32 for the duration of 43 s.

Measurement 9 contains one duck, see Figure 18 and 19. The range is small and induces a good SNR of the bodyline. This SNR decreased for increasing ranges. There are small shoulders on both sides of the bodyline. The bodyline frequency shows the acceleration and deceleration of the bird.

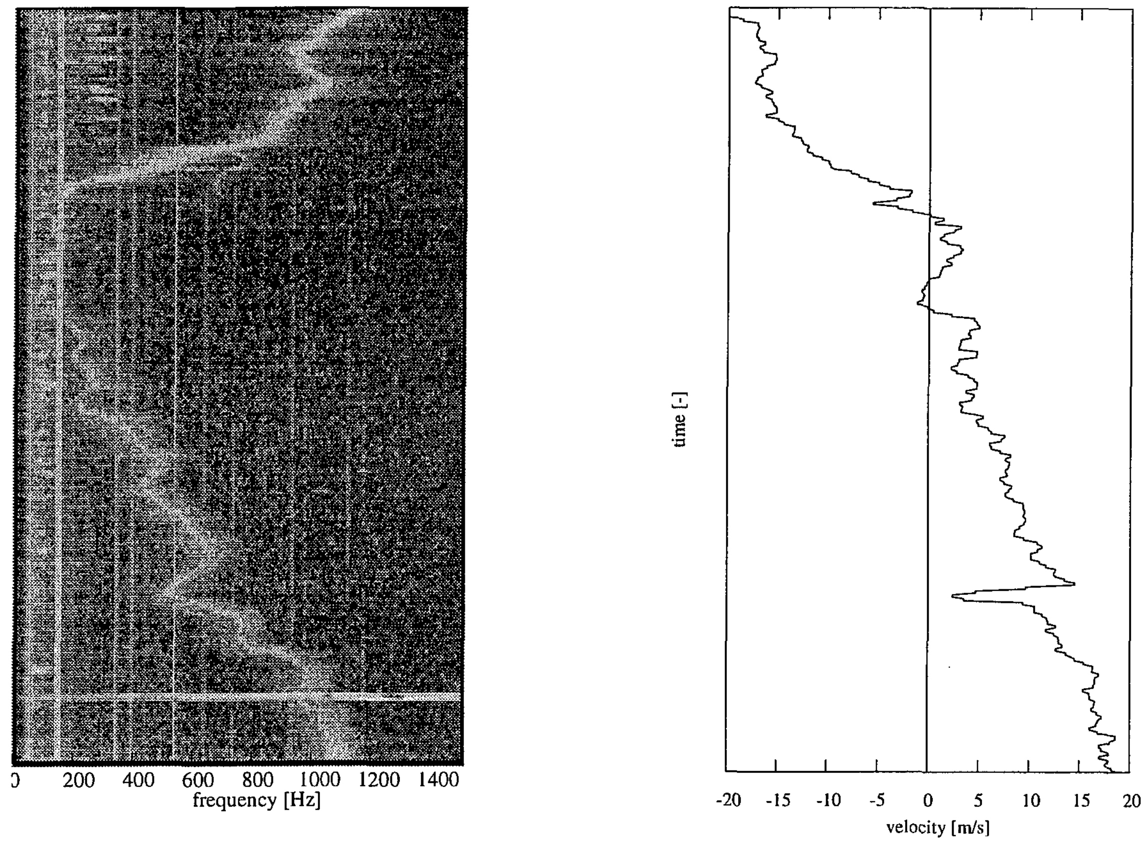


Figure 20: Spectra of Measurement 10 (left) and corresponding radial velocity (right). The measurement started at 11:01:08 for the duration of 50 s (1 cm vertical = 5 s).

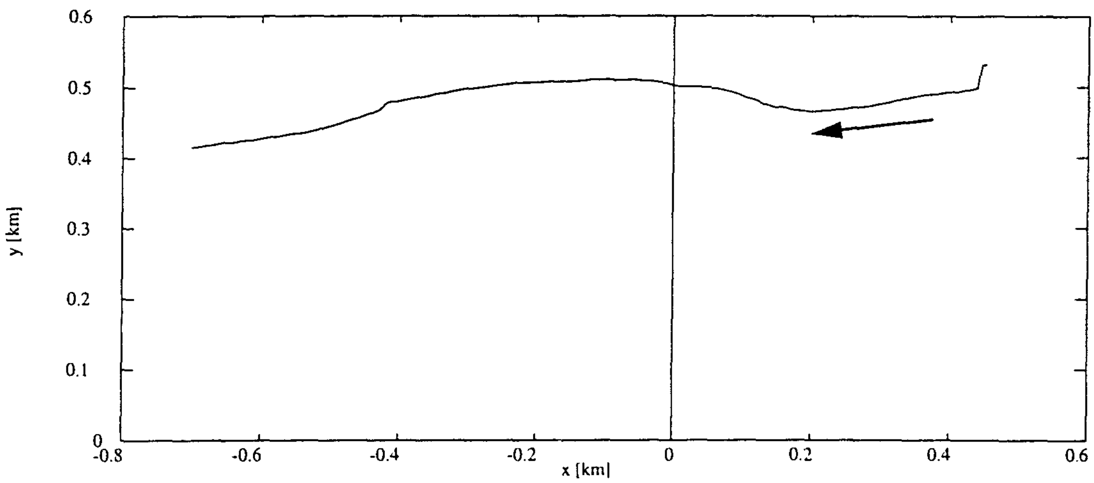


Figure 21: Track of Measurement 10. The measurement started at 11:01:08 for the duration of 50 s.

There is one duck in the radar beam during this Measurement. The spectrum has shoulders of 75 Hz on both sides of the bodyline. The frequency modulated signal belongs to a particular movement of the duck. The frequency modulation increases with increasing radial velocity. The shoulders are visible due to the short range during this flight.

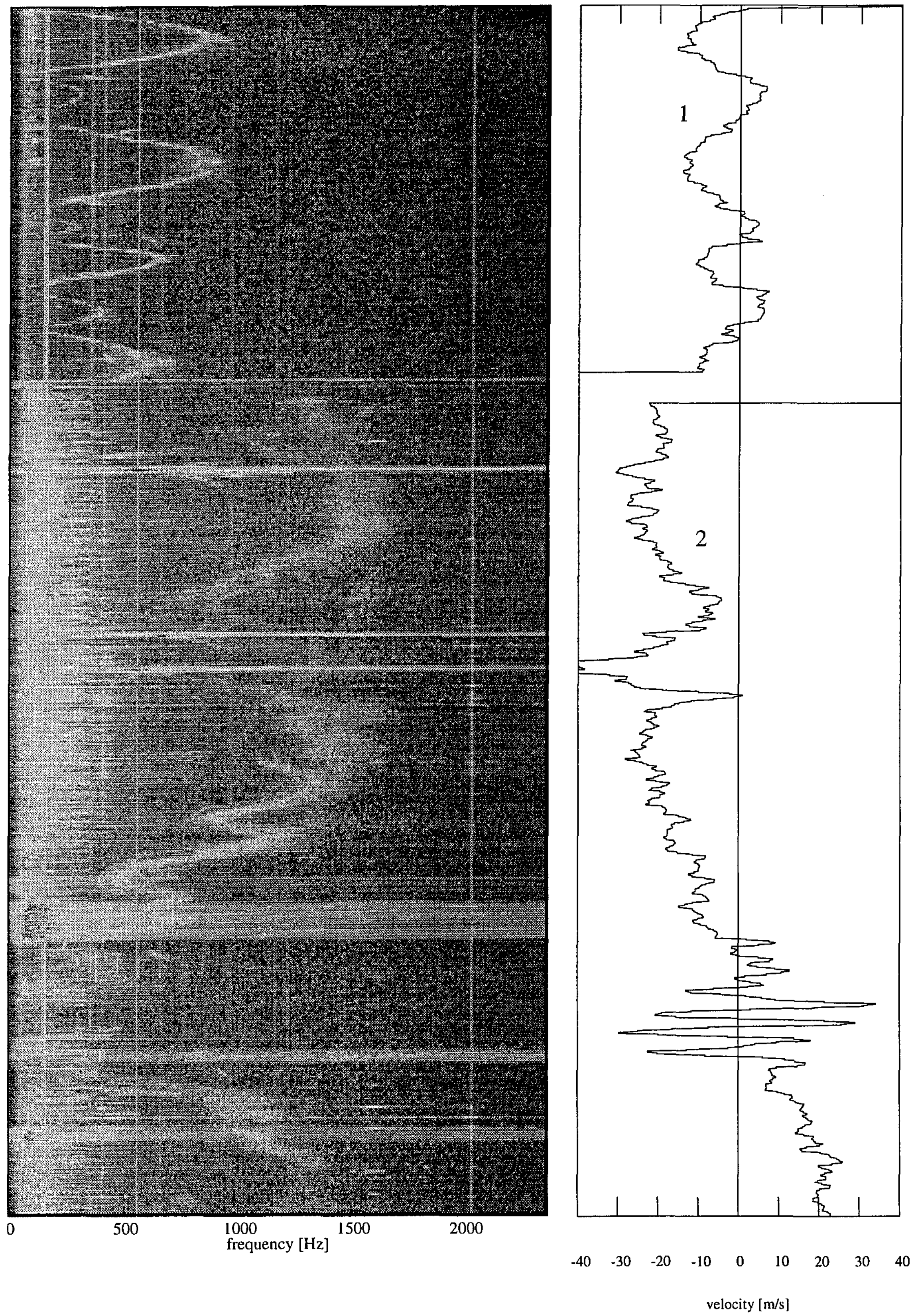


Figure 22: Spectra of Measurement 11 (left) and corresponding radial velocity (right). The measurement started at 11:02:51 for the duration of 164 s (1 cm vertical = 8.2 s).

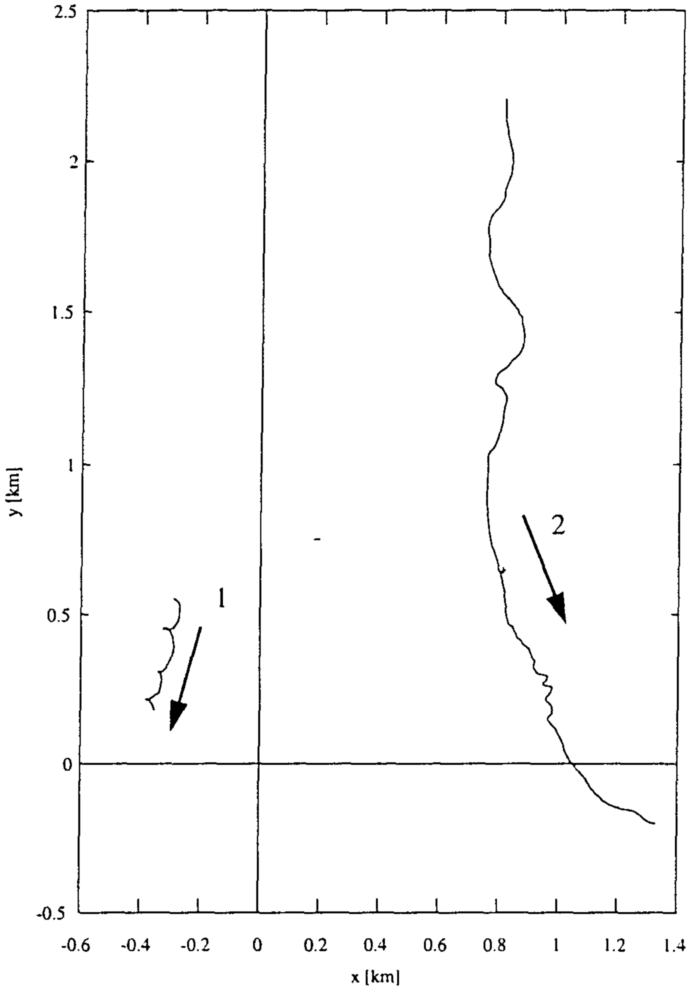
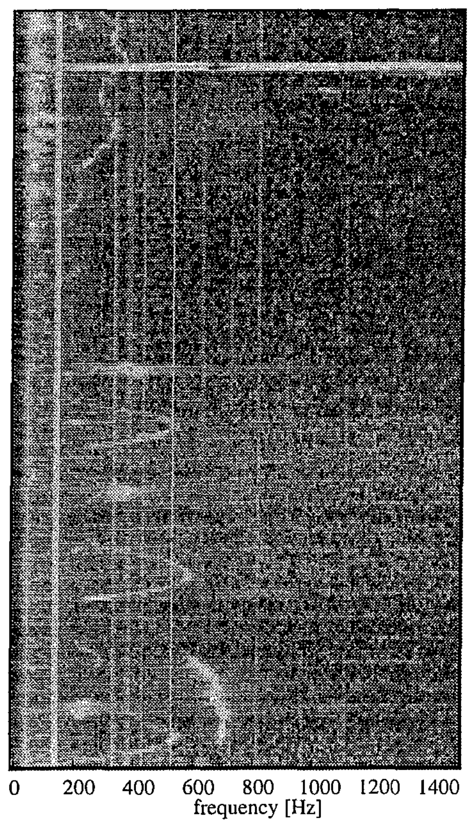


Figure 23: Tracks of Measurement 11. The measurement started at 11:02:51 for the duration of 164 s.

Figure 22 and 23 show Measurement 11. It contains two tracks: the first track belongs to one seagull and the second track belongs to about fifty birds. The flight pattern of the hovering seagull has a corresponding shape as the one of Measurement 7. There are little bodyline shoulders when the radial velocity has its maximum deviation. The group of birds causes a number of different bodyline frequencies. The group has equivalent apparent acceleration and deceleration.



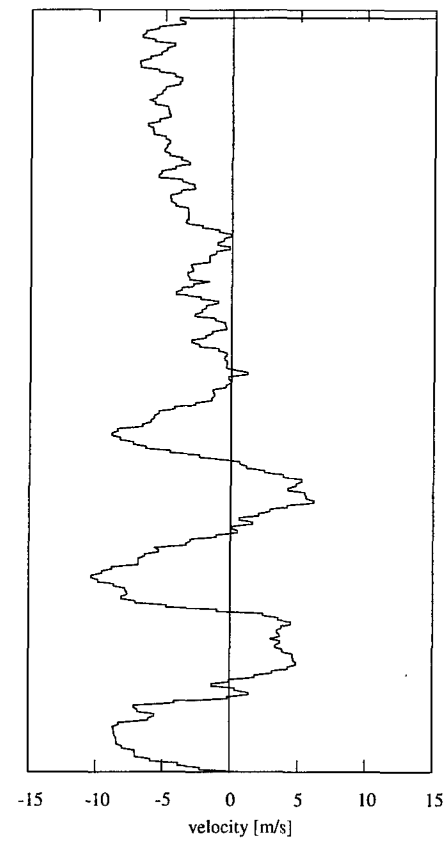


Figure 24: Spectra of Measurement 12 (left) and corresponding radial velocity (right). The measurement started at 11:07:29 for the duration of 45 s (1 cm vertical = 4.5 s).

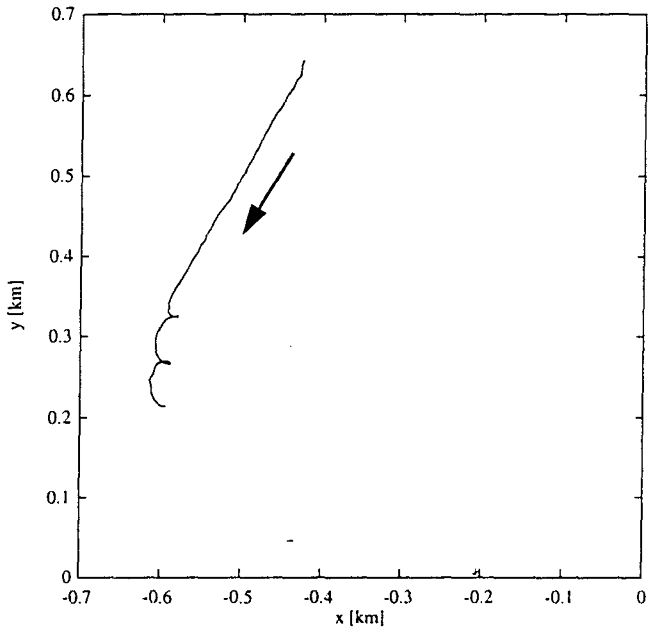


Figure 25: Track of Measurement 12. The measurement started at 11:07:29 for the duration of 45 s.

Figure 24 and 25 show Measurement 12. There is one seagull in the radar beam during this flight. The flight pattern of the sea gull shows a similar mirrored shape as the one of Measurement 11.

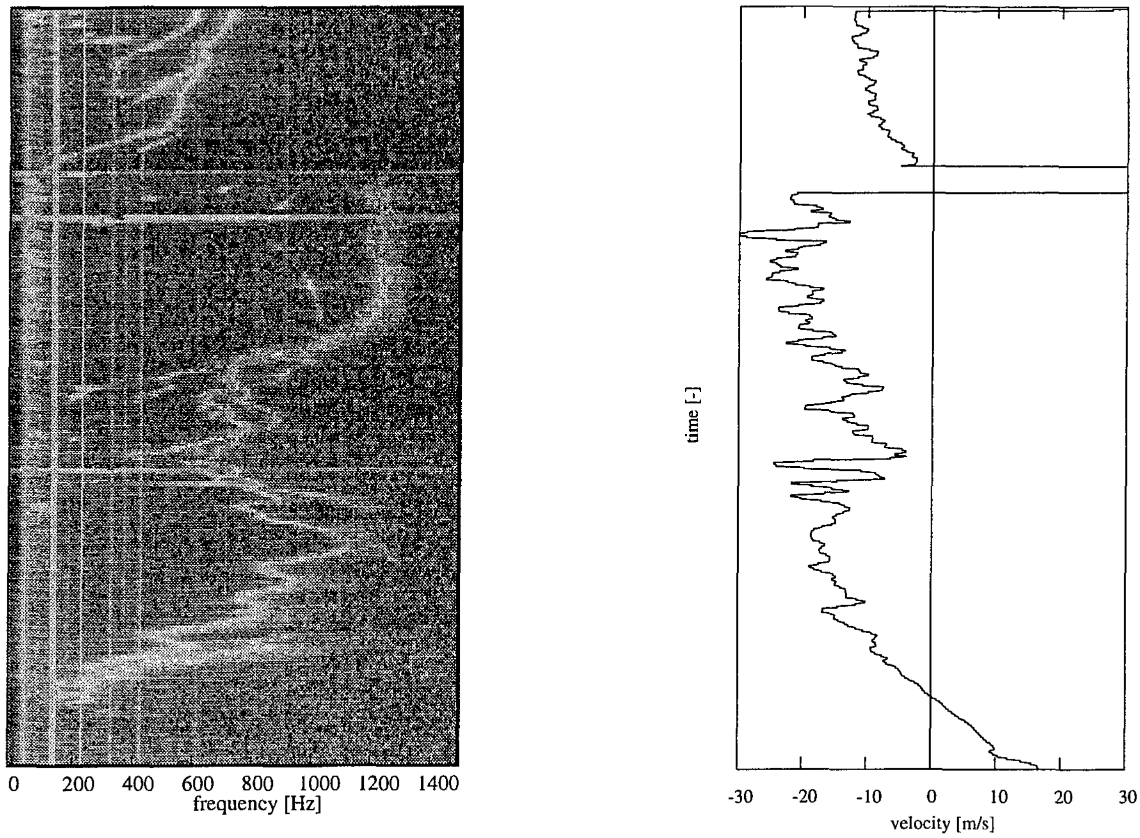


Figure 26: Spectra of Measurement 13 (left) and corresponding radial velocity (right). The measurement started at 11:11:22 with a duration of 77 s (1 cm vertical = 7.7 s).

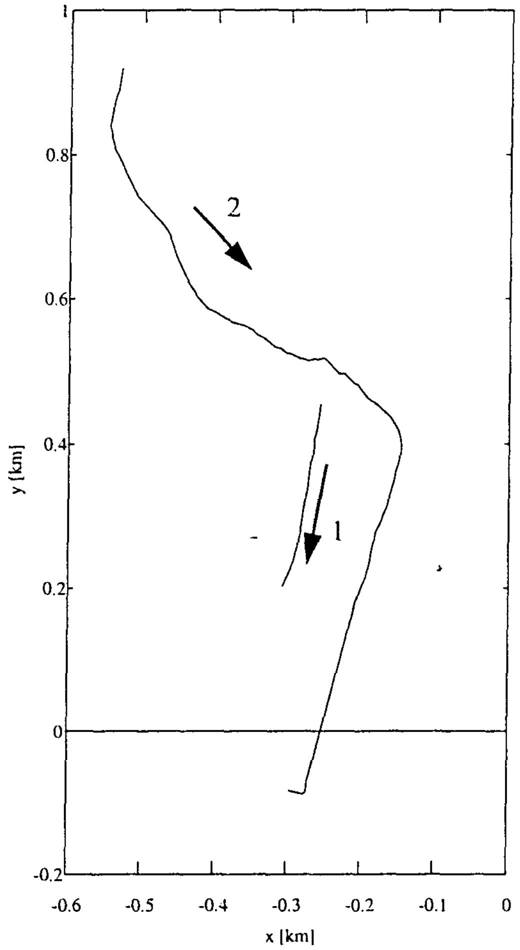


Figure 27: Tracks of Measurement 13. The measurement started at 11:11:22 with a duration of 77 s.

Figure 26 and 27 show Measurement 13. Measurement 13 contains two tracks: The first small track belongs to two sea gulls. The track started with two birds and ended with one bird in the radar beam. There are small shoulders on both sides of the bodyline.

The second track belongs to a large group of small birds. The birds display different radial velocities. The number of birds in the radar beam differs during the track. There is one bird in the radar beam during the last part of this track. This bird causes small shoulders on both side of the bodyline.

6 CONCLUSIONS

It has been shown that it is possible to detect birds using a radar system. Some sample calculations of the performance of a generic radar system have been given, showing the detection range. Classification of birds however is not an easy task, due to the small Radar Cross Section of the birds and the incomplete knowledge of radar characteristics of birds. Some methods to classify birds are mentioned but further research is still necessary.

Also some observations can be made:

1. It has been shown that interfering signals disturb the signal of interest. It is very likely that better results would be obtained without this interference. As a consequence only a limited dynamic range is left for the signal of interest.
2. The birds produce a doppler shift in the spectra due to the radial velocity of their bodies. A group of birds causes different doppler frequencies due to the individual velocities and directions.
3. Seagulls hovering and flapping produce a characteristic flight pattern.
4. Some birds have small frequency components on both sides of the bodyline. The origin of these are not known.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

In this report current radar technology for the detection and tracking of birds is described. The RCS and a simple model for the calculation of the maximum detection range is given. Some measurements of birds are shown. These measurements are obtained using the SCOUT continuous radar and the Flycatcher search and track radar. The spectra as a function of time and the tracks and radial velocity are investigated.

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