DEFENCE DÉFENSE

Overview of Experimental Pulse-Doppler Radar Data Collected October 1999

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Defence R&D Canada

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 2000-114
December 2000

National Defence Défense nationale

Canada

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ABSTRACT

The Defence Research Establishment Ottawa has designed and constructed an experimental air-to-air radar system as the first step in demonstrating an air-to-air surveillance capability for the Canadian Forces' CP-140 Maritime Patrol Aircraft. Initial flight trials of the experimental radar system were conducted in October 1999. The resulting data set includes measurements of ground clutter, water clutter, urban clutter, and returns from targets of opportunity. These data will be used to support the development of new signal processing and target detection algorithms that will form the basis of the CP-140 air-to-air surveillance capability. The data will also be used to support the validation of radar simulation models with site-specific clutter.

RÉSUMÉ

Le Centre de recherches pour la défense Ottawa a conçu et fabriqué un système radar expérimental air-air au cours de la première étape d'une démonstration portant sur les fonctions de surveillance air-air de l'avion de patrouille maritime CP-140 des Forces canadiennes. Les premiers essais en vol du système radar expérimental ont eu lieu en octobre 1999. L'ensemble des données résultantes comprend des mesures du fouillis de sol, du fouillis d'eau, du fouillis urbain et des échos de cibles de passage. Ces données serviront à établir de nouveaux algorithmes de traitement des signaux et de détection des cibles, sur lesquels reposeront les fonctions de surveillance air-air du CP-140. Ces données seront également utilisées pour valider des modèles de simulation radar avec le fouillis existant à l'emplacement.

EXECUTIVE SUMMARY

The role of the CP-140 Maritime Patrol Aircraft is expected to evolve to include new activities such as air-to-air surveillance in support of drug interdiction and other civil and military missions. The AN/APS-506 radar on the CP-140 is unsuitable for use in the air-to-air surveillance role, as it was designed for detecting small targets on the ocean surface. To help address this deficiency, the Defence Research Establishment Ottawa has developed an experimental pulse-Doppler radar system as the first step in demonstrating an air-to-air surveillance capability for the CP-140. This system will give the CP-140 the ability to detect and track small, slow, low-flying aircraft.

This document is an overview of data collected with the experimental radar system during its first flight trials in October 1999. These data will be used to support the development of new signal processing and target detection algorithms that will form the basis of the CP-140 air-to-air surveillance capability. The data will also be used to support the validation of radar simulation models with site-specific clutter.

The experimental radar system was installed on the National Research Council's Convair 580 aircraft. Four sorties were flown: one each on 21, 22, 25, and 28 October 1999. Nearly 80 gigabytes of useful data were collected. The data set includes measurements of ground clutter, water clutter, urban clutter, returns from targets of opportunity.

The experimental radar system operates in one of two modes. The conventional pulse-Doppler mode uses four different pulse repetition frequencies (PRFs): 6.593 kHz, 7.659 kHz, 8.828 kHz, and 9.827 kHz. The phase-agile pulse-Doppler mode, in which each radar pulse is encoded with a random change of phase, uses only two pulse repetition frequencies: 6.593 kHz and 9.827 kHz. The advantage of the phase-agile mode is the elimination of the range ambiguities that normally plague the operation of medium PRF radar systems.

The experimental radar system will be modified to correct the deficiencies discovered during the October 1999 trials. The next flight trials are scheduled for late June 2000, at which time more ground and water clutter data will be collected and the system will be calibrated.

Hughes, Steven J., Overview of Experimental Pulse Doppler Radar Data Collected October 1999. Defence Research Establishment Ottawa, DREO TM 2000-114, December 2000.

SOMMAIRE

Le rôle de l'avion de patrouille maritime CP-140 devrait évoluer de manière à englober de nouvelles activités, comme la surveillance air-air à l'appui de missions de lutte contre le trafic des drogues et d'autres missions civiles et militaires. Le radar AN/APS-506 du CP-140 convient mal à la surveillance air-air, car il a été conçu pour détecter de petites cibles à la surface de l'océan. Afin de combler cette lacune, le Centre de recherches pour la défense Ottawa a mis au point un système radar Doppler expérimental à impulsions au cours de la première étape d'une démonstration portant sur les fonctions de surveillance air-air du CP-140. Ce système permettra au CP-140 de détecter et de suivre de petits aéronefs lents et bas.

Ce document donne une vue d'ensemble des données qu'a fournies le système radar expérimental durant ses premiers essais en vol d'octobre 1999. Ces données serviront à établir de nouveaux algorithmes de traitement des signaux et de détection des cibles, sur lesquels reposeront les fonctions de surveillance air-air du CP-140. Elles seront également utilisées pour valider des modèles de simulation radar avec le fouillis existant à l'emplacement.

Le système radar expérimental a été installé à bord de l'appareil Convair 580 du Conseil national de recherches. Quatre sorties ont eu lieu, soit une par jour les 21, 22, 25 et 28 octobre 1999. Près de 80 giga-octets de données utiles ont été recueillis. L'ensemble de données comprend des mesures de fouillis de sol, de fouillis d'eau, de fouillis urbain et d'échos de cibles de passage.

Le système radar expérimental peut fonctionner dans deux modes différents. Le mode Doppler à impulsions ordinaire utilise quatre fréquences de répétition d'impulsions (FRI) différentes : 6,593 kHz, 7,659 kHz, 8,828 kHz et 9,827 kHz. Le mode Doppler à impulsions agile en phase, dans lequel chaque impulsion radar est codée par une variation aléatoire de phase, utilise seulement deux fréquences de répétition d'impulsions : 6,593 kHz et 9,827 kHz. L'avantage du mode agile en phase tient à l'élimination des ambiguïtés en distance qui gênent normalement le fonctionnement des systèmes radar à FRI moyenne.

Le système radar expérimental subira des modifications visant à corriger les lacunes découvertes durant les essais d'octobre 1999. Les prochains essais en vol, prévus pour la fin de juin 2000, permettront de recueillir d'autres données de fouillis de sol et d'eau ainsi que d'étalonner le système.

Hughes, Steven J., Overview of Experimental Pulse Doppler Radar Data Collected October 1999. Centre de recherches pour la défense Ottawa, DREO TM 2000-114, décembre 2000. (en anglais)

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ACKNOWLEDGEMENTS

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1. INTRODUCTION

The role of the Canadian Forces' CP-140 Maritime Patrol Aircraft, the *Aurora*, is expected to evolve to include new activities such as air-to-air surveillance in support of drug interdiction and other civil and military missions. Unfortunately, the AN/APS-506 radar on the CP-140 is unsuitable for use in the air-to-air surveillance role, as it was designed for detecting small targets on the ocean surface. To help address this deficiency, the Defence Research Establishment Ottawa has developed an experimental pulse-Doppler radar system as the first step in demonstrating an air-to-air surveillance capability for the CP-140. This system will give the CP-140 the ability to detect and track small, slow, low-flying aircraft.

This document is an overview of data collected with the experimental radar system during its first flight trials in October 1999. These data will be used to support the development of new signal processing and target detection algorithms that will form the basis of the CP-140 air-to-air surveillance capability. The data will also be used to support the validation of radar simulation models with site-specific clutter.

The experimental radar system was installed on the National Research Council's Convair 580 aircraft in October 1999. Four sorties were flown: one each on 21, 22, 25, and 28 October 1999. The first sortie was used as a "shake-down" flight, and the last three sorties were used to collect data. Approximately 80 gigabytes of useful data were recorded. These data include ground clutter from the area around Ottawa, water clutter from Lake Ontario, urban clutter from the City of Ottawa, returns from ground moving targets on Highway 401, and returns from air and surface targets of opportunity.

The experimental radar system operates in one of two modes. The first mode, the conventional pulse-Doppler mode, is a modification of the design discussed in [1]. This mode uses four different pulse repetition frequencies (PRFs), and has a maximum unambiguous range of about 500 kilometers for targets detected on any three of the four PRFs. The second mode uses the phase-agile pulse encoding technique discussed in [2]. This mode uses only two PRFs, but encodes each pulse with a random binary phase to eliminate the range ambiguity.

Chapter 2 describes the high-level design and operation of the experimental air-to-air radar system to provide a context for the rest of the document. This chapter also shows the azimuth and elevation beam patterns for the AN/APS-506 antenna to highlight the sidelobes that may be responsible for some of the unusual features seen in the range-Doppler maps presented in Chapters 5 through 9.

Chapter 3 describes the overall aims of the October 1999 flight trials and expands upon the specific goals and achievements of each of the four sorties that were flown. The goal of the first sortie was to verify the correct operation of the entire radar system. The second sortie was used to record ground clutter returns from the area between Ottawa and

Mirabel and to record returns from ground moving targets on Highway 401. The goal of the third sortie was to record water clutter returns from Lake Ontario and urban clutter returns from the City of Ottawa. The goal of the fourth sortie was to record returns from ground moving targets on Highway 401.

Chapter 4 provides a brief overview of the October 1999 data set. More detailed descriptions of the data set are found in the subsequent chapters. Chapter 5 describes data recorded during the take-off, transit, and landing portions of each sortie. Chapter 6 describes the ground clutter data. Chapter 7 describes the data gathered from ground moving targets. Chapter 8 describes the water clutter data. Chapter 9 describes the urban clutter data.

Chapter 10 discusses the problems and deficiencies of the experimental radar system, and outlines potential solutions. Chapter 11 describes future work and Chapter 12 presents the summary and conclusions.

2. SYSTEM DESCRIPTION

This chapter describes the high-level design and operation of the experimental air-to-air pulse-Doppler radar system to provide a context for understanding the rest of the document. A more complete and detailed description of the design will be the subject of a separate publication. This chapter also shows the azimuth and elevation beam patterns for the AN/APS-506 antenna to highlight the sidelobes that may be responsible for some of the unusual features seen in the range-Doppler maps presented in Chapters 5 through 9.

2.1. SYSTEM DESIGN

The experimental air-to-air pulse-Doppler radar system is shown schematically in Figure 2-1. The antenna and its servo system are standard subsystems from the AN/APS-506 radar system that is installed on the CP-140 aircraft.

The radar transmitter, labeled "TX" in the figure, is a 20-kWatt device manufactured by Raytheon TI Systems (formerly Texas Instruments Defense Systems & Electronics). This transmitter is a derivative of the AN/APS-137B(V)5 transmitter. It operates at 9.75 GHz with pulse repetition frequencies up to 10 kHz and a maximum duty cycle of one percent.

The exciter/receiver, labeled "XCTR/RX" in the figure, is a custom-built subsystem that supplies a transmit gate to the transmitter and mixes the return signal to an intermediate frequency of 6.25 MHz.

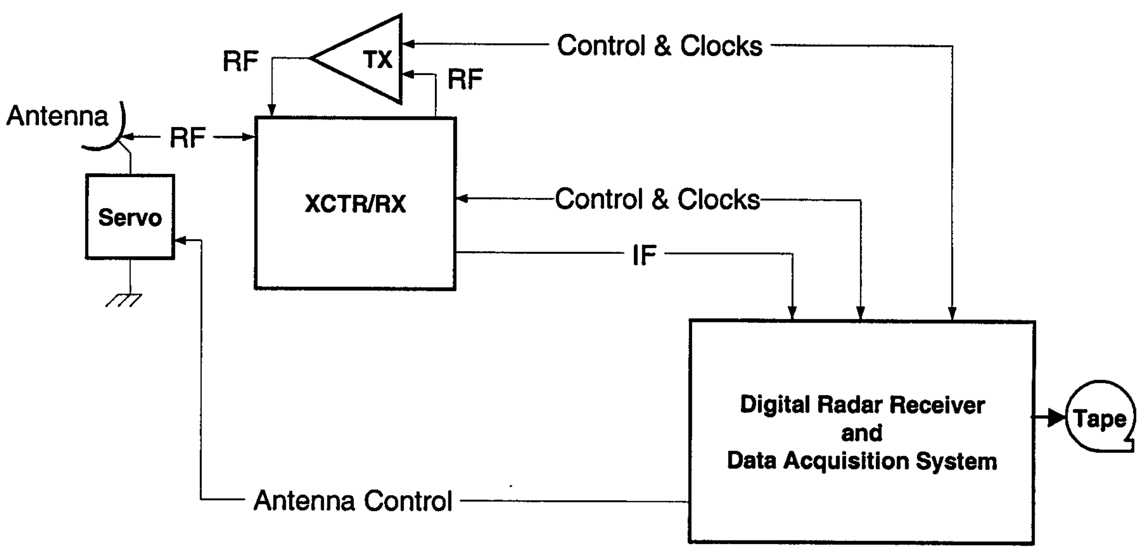

Figure 2-1 Block Diagram of the Experimental Radar System

The "Digital Radar Receiver and Data Acquisition System" is a collection of commercial and custom VME hardware, with custom software running on an embedded computer and on a digital signal processing card. This system digitizes and demodulates the radar signal to baseband. Range-Doppler maps are displayed on an operator console and the raw radar data are written to magnetic tape for off-line analysis. There is no real-time signal processing performed on the radar data. The "Digital Radar Receiver and Data Acquisition System" was originally built under contract by DSP*Con* Inc [3], and has been extensively modified under contract by MultiDev Communications JDL Inc. [4].

2.2. SYSTEM OPERATION

All timing and control signals in the experimental radar system are synchronized with a 50 MHz master clock located within the Digital Radar Receiver and Data Acquisition System. In particular, the transmitter reference clock of 8.33 MHz is derived from the master clock by dividing by six, resulting in a clock period of 120 nanoseconds. The transmitter is driven by a pulse that is five clock-periods long, giving a nominal pulse width of 600 nanoseconds.

The master clock is divided by eight to produce the intermediate frequency of 6.25 MHz. The output of the exciter/receiver is sampled at 25 MHz, which is four times the intermediate frequency. The digital receiver performs quadrature demodulation and lowpass filtering before decimating the data by a factor of sixteen to produce complex *I*n-phase and *Q*uadrature-phase (I&Q) data. The range gate period for the I&Q data is 640 nanoseconds.

The pulse repetition frequencies (PRFs) are generated in hardware by selecting the desired number of range gates. The number of range gates and the resultant PRF are given in Table 2-1 for each operating mode.

Table 2-1 Number of Range Gates and Pulse Repetition Frequencies

N_{rg}	*PRF* (kHz)	Operating Mode
237	6.593	Conventional and Phase-Agile
204	7.659	Conventional
177	8.828	Conventional
159	9.827	Conventional and Phase-Agile

2.3. ANTENNA BEAM PATTERNS

The azimuth and elevation beam patterns for the AN/APS-506 antenna are shown in Figure 2-2. The figure shows the relative one-way gain of the antenna as a function of azimuth angle (the upper plot) and elevation angle (the lower plot) over the range ±120 degrees. Note that the antenna patterns are truncated at –35 dB relative gain. This is the lower measurement limit for the elevation pattern.

The 3-dB beamwidth is 2.2 degrees in azimuth and 4.0 degrees in elevation; the 10-dB beamwidth is 3.9 degrees in azimuth and 6.9 degrees in elevation.

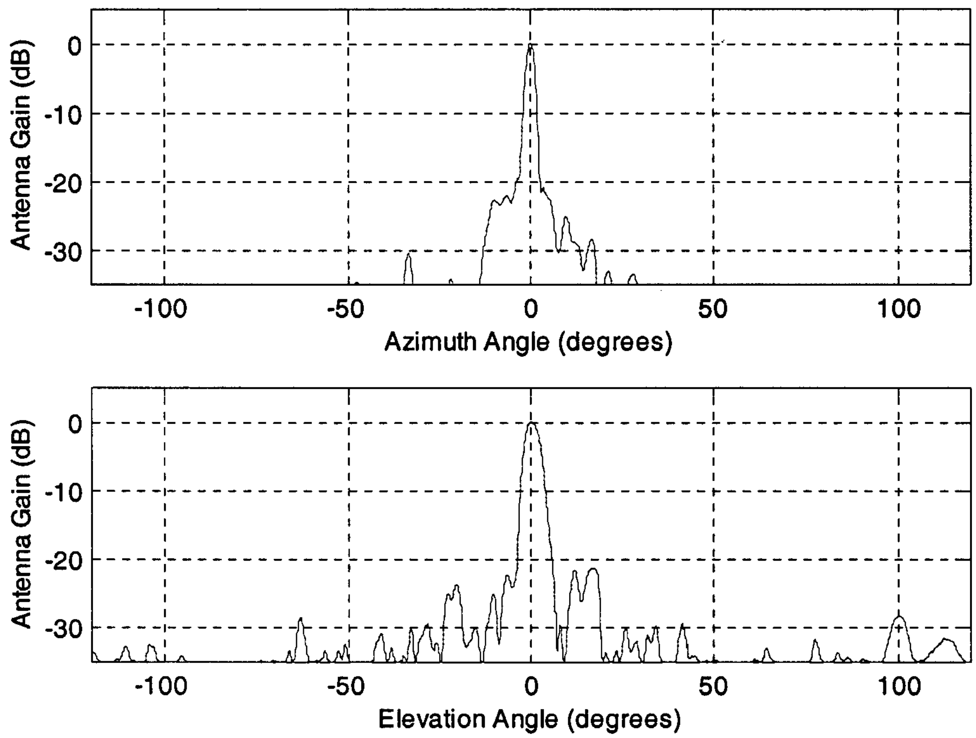

Figure 2-2 Antenna Beam Patterns

Note the azimuth sidelobe near 10 degrees and the elevation sidelobes near -104 and -24 degrees. Some of the range-Doppler maps shown in Chapters 5 through 9 exhibit unusual features that are consistent in range and Doppler frequency with returns that might be associated with these sidelobes.

3. FLIGHT TRIALS OVERVIEW

The first flight trials of the experimental air-to-air pulse Doppler radar system took place from 21 to 28 October 1999. The system was installed on the National Research Council's Convair 580, a twin-engine, long-range turboprop aircraft. The aims of the flight trials were:

1. to verify the operation of the experimental radar system;
2. to collect surface clutter returns at various antenna elevation angles over different types of terrain; and
3. to collect radar returns from slow-moving ground targets and other targets of opportunity.

The rest of this chapter discusses the specific goals and achievements of the four different sorties on 21, 22, 25, and 28 October 1999. The data collected during these sorties are discussed in Section 4.

3.1. FIRST SORTIE

The first sortie took place on 21 October 1999. The purpose for the flight was to verify the correct operation of the entire radar system. This goal was accomplished in less time than expected, so the decision was made to use the rest of the flight for collecting data.

Unfortunately, the software often crashed shortly after starting a new recording, forcing the operator to restart the software and re-enter a number of parameters. By default, the software starts writing data to the tape at the "beginning of media" rather than at the "end of data". The operator forgot to over-ride this default after the last software crash, effectively erasing the tape and losing all the data that had been recorded during the flight. Greater care was taken in subsequent flights to minimize the possibility of accidentally erasing the tape.

3.2. SECOND SORTIE

The second sortie took place on 22 October 1999. The purpose of this sortie was to record ground clutter data from the area between Ottawa and Mirabel. There was enough flight time left over to record returns from vehicular traffic on Highway 401 between Cornwall and Brockville. Data were recorded on three tapes. One small tape contains the data recorded during take-off and landing. One large tape contains the first half of the ground clutter data. A second large tape contains the second half of the ground clutter data and the vehicle returns.

The data recorded during take-off and landing were an attempt to capture returns from targets of opportunity near the Ottawa airport. The antenna elevation angle was +3 degrees during take-off and -2 degrees during landing. (Positive elevation angles are looking up; negative elevation angles are looking down.)

The flights between Ottawa and Mirabel were flown at four different nominal altitudes: 6000 meters (20,000 feet), 2700 meters (9,000 feet), 1250 meters (4,000 feet), and 750 meters (2,500 feet). The antenna elevation angles were -14, -7, -4, and -2 degrees, respectively. The variations in altitude and elevation angle kept the center of the antenna beam at a ground range of about 22.5 kilometers. The flights over Highway 401 were flown at a nominal altitude of 750 meters (2,500 feet) with an antenna elevation angle of –14 degrees.

3.3. THIRD SORTIE

The third sortie took place on 25 October 1999. The purpose of this sortie was to record water clutter data from Lake Ontario and urban clutter data from the City of Ottawa. Data were recorded on three tapes. One small tape contains the data recorded during take-off. One large tape contains the water clutter data. A second large tape contains the urban clutter data and the data recorded during landing.

As with the first sortie, the data recorded during take-off and landing were an attempt to capture returns from targets of opportunity near the Ottawa airport. The antenna elevation angle was +2 degrees during take-off and -2 degrees during landing.

The flights above Lake Ontario were flown at four different nominal altitudes: 6000 meters (20,000 feet), 2700 meters (9,000 feet), 1250 meters (4,000 feet), and 750 meters (2,500 feet). The antenna elevation angles were -14, -7, -4, and -2 degrees, respectively. The variations in altitude and elevation angle kept the center of the antenna beam at a ground range of about 22.5 kilometers.

The urban clutter data were collected during circular flights around the City of Ottawa. The antenna beam was pointed abeam the aircraft at Parliament Hill, which is located in the center of the built-up urban area. The flights around the City of Ottawa were flown at nominal altitudes of 2700 meters (9,000 feet) and 1500 meters (5,000 feet), with antenna elevation angles of -14 and -7 degrees respectively.

3.4. FOURTH SORTIE

The fourth sortie took place on 28 October 1999. The purpose of this sortie was to record returns from vehicular traffic on Highway 401. Data were recorded on two tapes. One small tape contains the data recorded during take-off and landing. One large tape contains the vehicle returns.

The data recorded during take-off and landing were an attempt to capture returns from targets of opportunity near the Ottawa airport. The antenna elevation angle was +3 degrees during take-off and zero degrees during landing.

The flights over Highway 401 were flown at a nominal altitude of 750 meters (2,500 feet). The antenna elevation angle was -5 degrees.

4. DATA OVERVIEW

During the trials of the experimental air-to-air radar system, radar, navigation, and ancillary data were recorded on Sony Digital Tape Format (DTF) tapes. There are two sizes of DTF tape: the small tapes have a capacity of 12 GB, while the large tapes have a capacity of 42 GB. At a nominal recording rate of 6.25 megabytes per second, the small tapes provide about 32 minutes of recording time, while the large tapes provide about 112 minutes.

The tapes have been labeled according to the date and time of the first recorded data. The label format is *YYYY-MM-DD-hh-mm*, where *YYYY-MM-DD* is the date (year, month, and day of the month), and *hh-mm* is the time (hour and minute, Universal Coordinated Time).

The entire data set for the trials is recorded on eight tapes: three small tapes and five large tapes. Table 4-1 summarizes the label, size, and contents of each tape.

Table 4-1 Summary of Data Tapes

Tape Label	Tape Size	Scenario	Sortie
1999-10-22-14-28	Small	Take-off, Transit, and Landing	2
1999-10-22-14-45	Large	Ground Clutter	2
1999-10-22-16-29	Large	Ground Clutter, Transit, and Vehicle Returns	2
1999-10-25-14-55	Small	Take-off and Transit	3
1999-10-25-15-30	Large	Water Clutter	3
1999-10-25-17-49	Large	Transit, Urban Clutter, and Landing	3
1999-10-28-15-14	Small	Take-off and Landing	4
1999-10-28-15-30	Large	Vehicle Returns and Transit	4

Chapters 5 through 9 present a more detailed description of the data recorded during the October 1999 flight trials. The presentations include examples of range-Doppler maps derived from the recorded data. Range-Doppler maps are images that show the intensity of the radar signal plotted as functions of range gate (horizontal axis) and Doppler frequency (vertical axis). Each range-Doppler map shows the data for one coherent processing interval (CPI). The CPI is a collection of 256 consecutive radar pulses, all with the same pulse repetition frequency (PRF). The CPI is the period over which the radar signal can be integrated coherently.

The range-Doppler maps are color-coded according to the scale shown in Figure 4-1. This scheme maps the full dynamic range of the radar system from dark blue (-100 dB relative to full scale) to dark red (0 dB relative to full scale). Full scale is defined as a ±1 volt sinusoidal input at the output of the exciter/receiver.

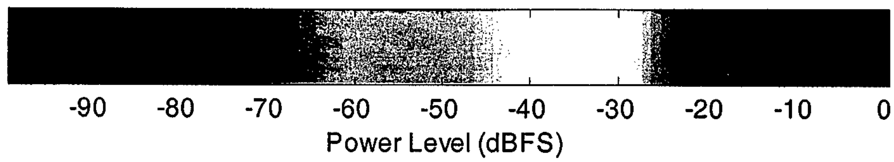

Figure 4-1 Range-Doppler Map Color Mapping Scheme

Also included in Chapters 5 through 9 are figures showing the aircraft location superimposed on Digital Terrain Elevation Data (DTED) maps of the area. The DTED maps are typically plotted in increments of 1 degree of latitude and longitude. The axes are labeled as kilometers east and north of the Ottawa airport. The DTED maps use the color-coding shown in Figure 4-2. This scheme maps lower altitudes to green, middle altitudes to red, and higher altitudes to white.

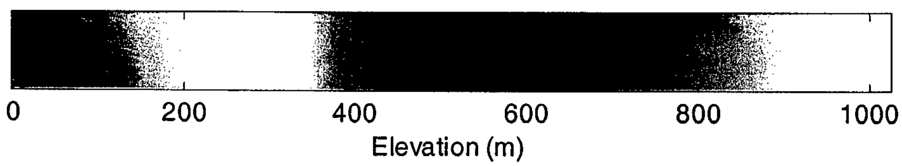

Figure 4-2 DTED Elevation Color Mapping Scheme

5. TAKE-OFF, TRANSIT, AND LANDING DATA

Radar data were recorded during the take-off, transit, and landing portions of each sortie. The intention was to capture data for targets of opportunity, particularly near the Ottawa airport. Table 5-1 summarizes the data that were recorded during these portions of the sorties. The table includes the tape label, the file number, the type of data, the number of recorded CPIs, the antenna elevation angle, and the antenna azimuth angle.

Table 5-1 Summary of Take-off, Landing, and Transit Data

Tape Label / File Number	**Type of Data**	**Number of CPIs**	**Antenna Elevation** (degrees)	**Antenna Azimuth** (degrees)
1999-10-22-14-28				
File001	Take-off	6988	+3	±10
File002	Transit	6238	-14	±105
File004	Transit	8171	-2	±10
	Landing	4602	-2	±10
1999-10-22-14-45				
File001	Transit	2590	-14	±105
1999-10-22-16-29				
File006	Transit	3882	0	±105
1999-10-25-14-55				
File001	Take-off	3917	+2	±10
	Transit	16538	-2	±10
1999-10-25-17-49				
File001	Transit	15370	-14	±105
	Landing	10198	-2	±10
1999-10-28-15-14				
File001	Take-off	5633	+2	±10
	Transit	3608	-2	±10
		11414	-5	±10
File002	Landing	2784	0	±10
1999-10-28-15-30				
File009	Transit	1650	0	±60
			0	±10

5.1. SECOND SORTIE TAKE-OFF, TRANSIT, AND LANDING

Tape 1999-10-22-14-28 is a small tape containing four data files. File001 contains data recorded during the take-off for the second sortie. File002 contains data recorded during the transit away from the Ottawa airport. File003 is a short file that is the result of a software crash. File004 contains data recorded during the transit back to the Ottawa airport and the landing. The contents of these files are discussed in the following sections.

5.1.1. Take-Off

File001 on Tape 1999-10-22-14-28 contains data recorded on 22 October 1999 during the take off from Ottawa airport for the second sortie. The file contains 6988 CPIs of conventional and phase-agile data. There are 5661 conventional CPIs in 6 segments and 1327 phase-agile CPIs in 5 segments. The antenna elevation angle is +3 degrees. The antenna azimuth scan is ±10 degrees. The flight path for this file is shown in Figure 5-1.

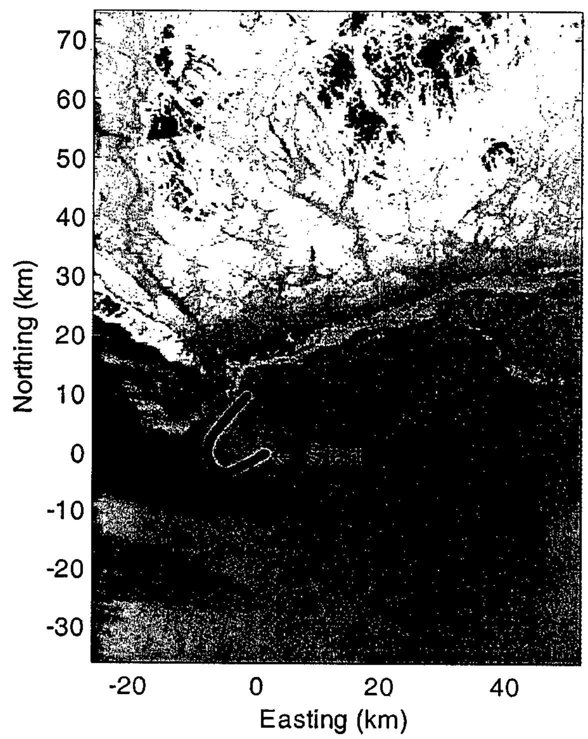

Figure 5-1 Flight Path for the Second Sortie Take-Off

5.1.1.1. Phase-Agile Data

An example of phase-agile data recorded during the take-off for the second sortie is shown in the range-Doppler map in Figure 5-2. This is CPI number 1930, which was recorded at 14:30:45 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 401 meters above mean sea level, the antenna elevation angle is +3 degrees, and the antenna azimuth is zero degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is +5.6 kHz. The data have been processed for the first range interval.

The figure shows weak mainlobe clutter at all ranges. Although the antenna is pointing upwards, the elevation beamwidth is wide enough and the altitude is low enough to produce the mainlobe clutter. The power level of the mainlobe clutter is about 25 dB above the power level of the background noise.

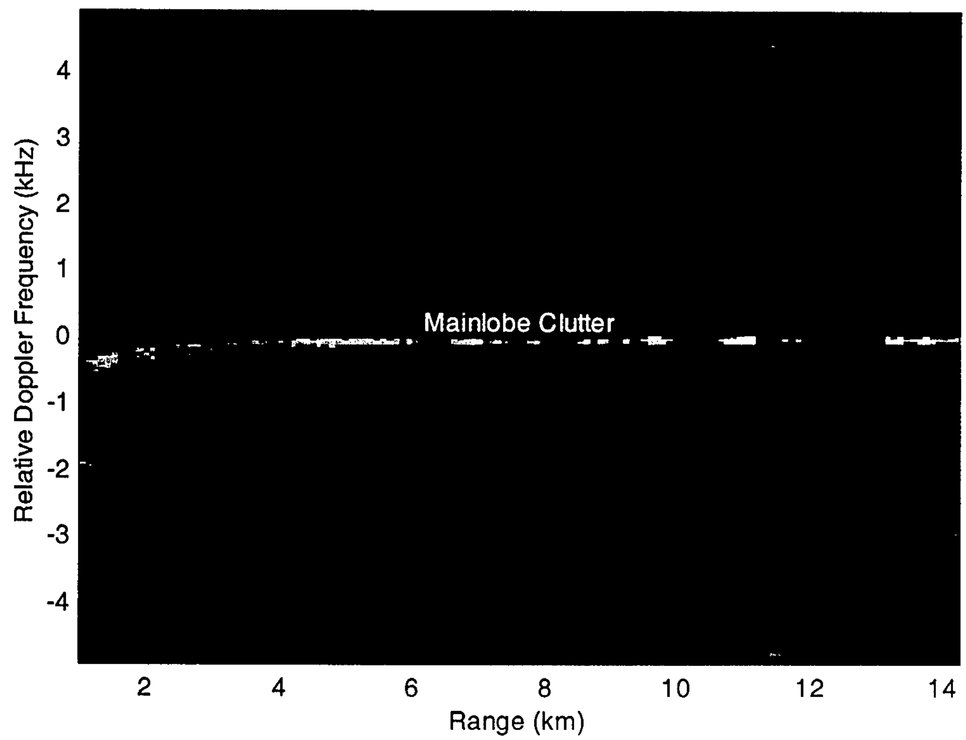

Figure 5-2 Phase-Agile Data from the Second Sortie Take-Off

5.1.1.2. Conventional Data

An example of conventional data recorded during the take-off for the second sortie is shown in the range-Doppler map in Figure 5-3. This is CPI number 2918, which was recorded at 14:31:21 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 776 meters above mean sea level, the antenna elevation angle is +3 degrees, and the antenna azimuth is -2.5 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.3 kHz.

As was the case for the phase-agile data above, the figure shows weak mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 15 dB above the power level of the background noise. The figure also shows a target of opportunity at an apparent range of 4.9 kilometers and an apparent relative frequency of 2.4 kHz. The range and frequency ambiguities can be resolved by locating the target in CPIs with other pulse repetition frequencies. The unambiguous range is 4.9 kilometers and the unambiguous relative frequency is -7.4 kHz, which corresponds to a target velocity component of -412 kilometers per hour. The speed of the target implies that it is an aircraft.

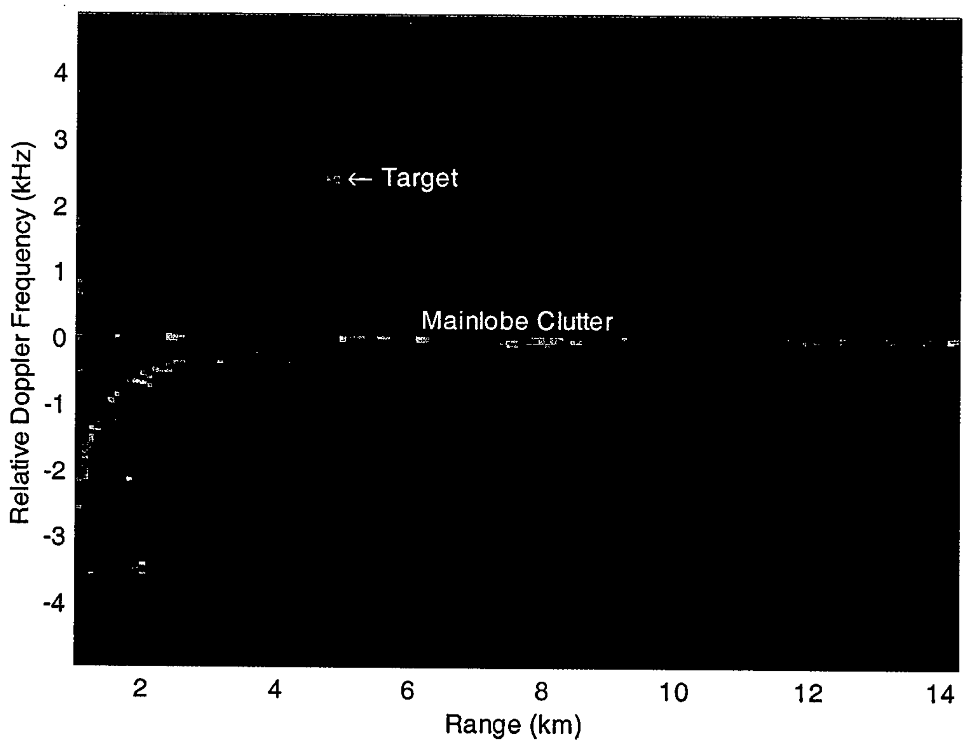

Figure 5-3 Conventional Data from the Second Sortie Take-Off

5.1.2. Transit Away From Ottawa

File002 on Tape 1999-10-22-14-28 contains data recorded on 22 October 1999 during the second sortie transit from the Ottawa airport toward Mirabel. The file contains 6238 CPIs of conventional and phase-agile data. There are 4432 conventional CPIs in two segments and 1806 phase-agile CPIs in one segment. The antenna elevation angle is -14 degrees. The antenna azimuth scan is ±105 degrees. The flight path is shown in Figure 5-4.

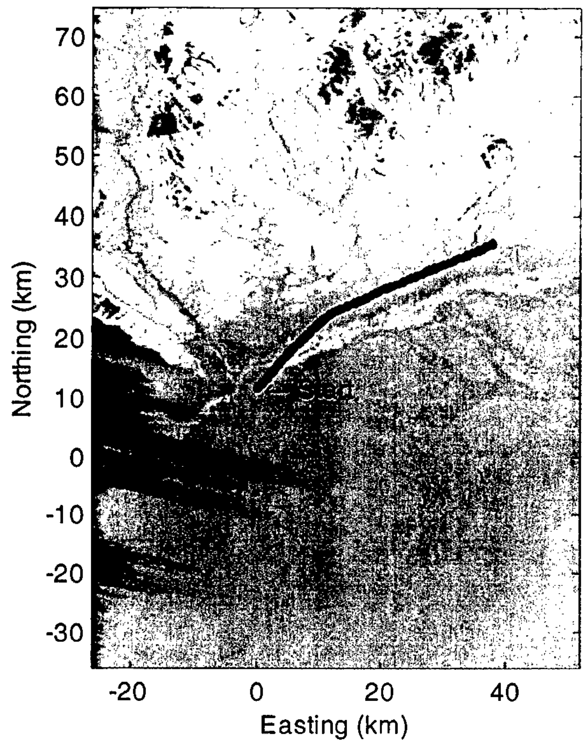

Figure 5-4 Flight Path for the Second Sortie Transit away from Ottawa

5.1.2.1. Conventional Data

An example of conventional data recorded during the transit away from Ottawa for the second sortie is shown in the range-Doppler map in Figure 5-5. This is CPI number 132, which was recorded at 14:34:18 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 2219 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is +75.2 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 1.8 kHz.

The figure shows strong mainlobe clutter at ranges from about 7 kilometers to 12 kilometers. The power level of the mainlobe clutter is about 50 dB above the power level of the background noise. The altitude return is seen at a range of 2.2 kilometers. The feature near 3.4 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.5 kHz is the superposition of two artifacts: a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz and a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter. Note that these two artifacts are not normally coincident. See Section 11.3 for a discussion of these artifacts.

The figure also shows two targets of opportunity, with apparent relative frequencies of +0.5 kHz (Target 1) and –1.1 kHz (Target 2). Both targets are at an apparent range of 9.6 kilometers. The unambiguous range for both targets is 24.9 kilometers. The unambiguous relative Doppler frequency for Target 1 is +0.5 kHz and for Target 2 is –1.1 kHz. These frequencies correspond to velocity components of +29 kilometers per hour for Target 1 and -62 kilometers per hour for Target 2. Target 1 is moving toward the radar; Target 2 is moving away from the radar. The speeds and ranges imply that the targets might be surface vehicles.

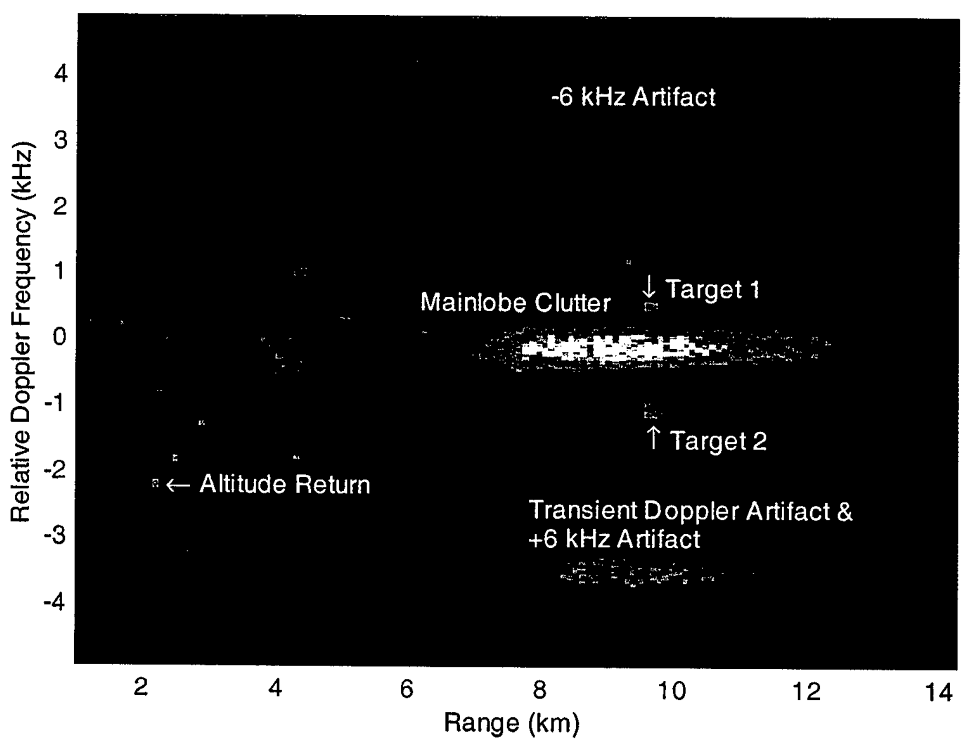

Figure 5-5 Conventional Data from the Second Sortie Transit away from Ottawa

5.1.2.2. Phase-Agile Data

An example of phase-agile data recorded during the transit away from Ottawa for the second sortie is shown in the range-Doppler map in Figure 5-6. This is CPI number 3900, which was recorded at 14:36:34 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 2978 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -20.6 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.9 kHz. The data have been processed for the first range interval.

The figure shows strong mainlobe clutter at ranges from about 9 kilometers to 14 kilometers. The power level of the mainlobe clutter is about 50 dB above the power level of the background noise. The altitude return is seen at a range of 3.0 kilometers. The feature near 3.6 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.4 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz. The feature near -4.2 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter. The feature near -1 kHz out to a range of about 8 kilometers is sidelobe clutter due to the strong elevation sidelobe at about -24 degrees.

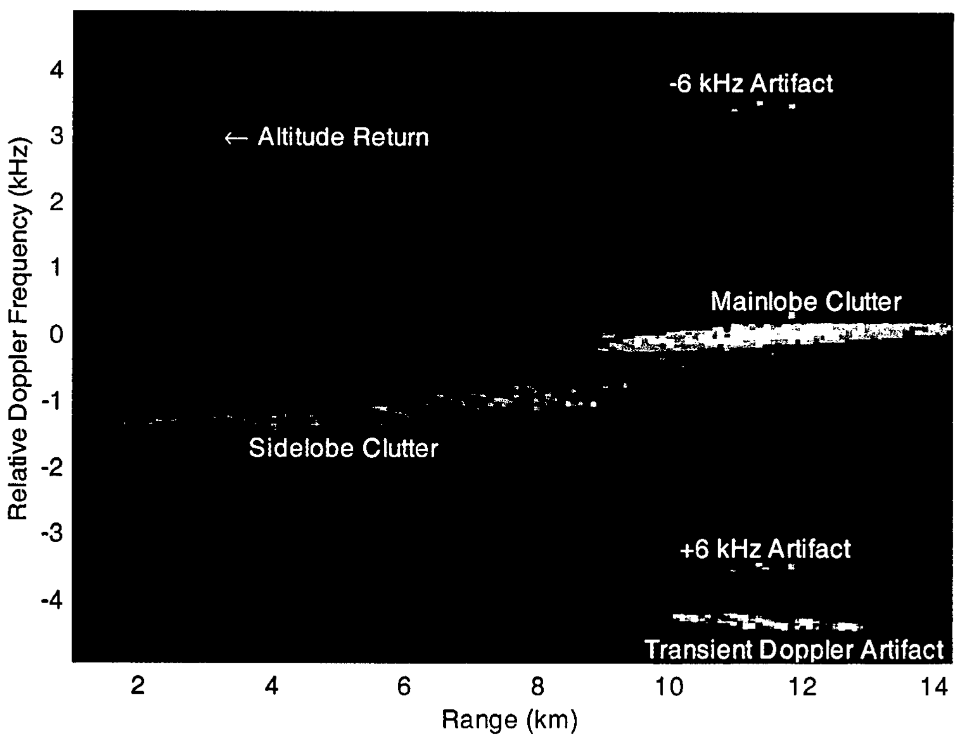

Figure 5-6 Phase-Agile Data from the Second Sortie Transit away from Ottawa

5.1.3. Return Transit

File003 on Tape 1999-10-22-14-28 contains data recorded on 22 October 1999 during the second sortie return transit to the Ottawa airport. Due to a software crash, the file contains only 376 CPIs of data. The file will not be discussed further.

5.1.4. Return Transit and Landing

File004 on Tape 1999-10-22-14-28 contains data recorded on 22 October 1999 during the second sortie return transit to and landing at the Ottawa airport. The file contains 12773 CPIs of conventional data, with 8171 CPIs in the transit segment and 4602 CPIs in the landing segment. The antenna elevation angle is -2 degrees. The antenna azimuth scan is ±10 degrees. The flight path is shown in Figure 5-7.

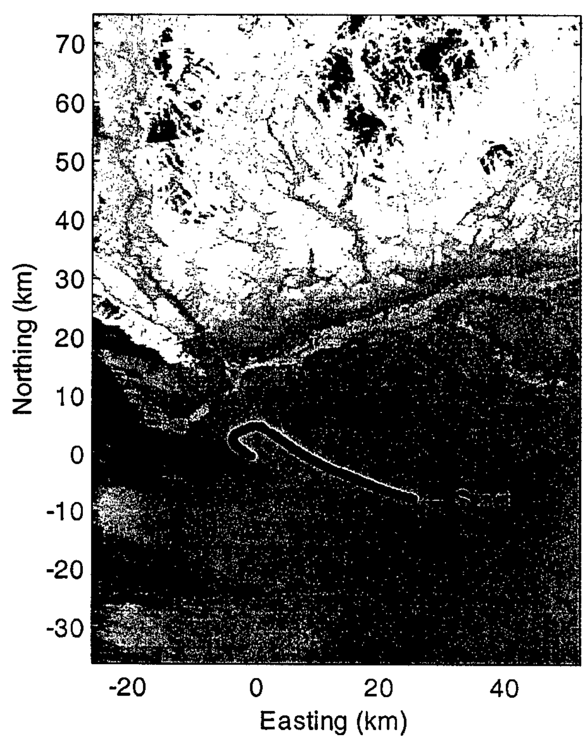

Figure 5-7 Flight Path for the Second Sortie Return Transit and Landing

An example of the data recorded during the landing at Ottawa airport at the end of the second sortie is shown in the range-Doppler map in Figure 5-8. This is CPI number 6439, which was recorded at 18:44:30 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 291 meters above mean sea level, the antenna elevation angle is -2 degrees, and the antenna azimuth is -14.6 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.9 kHz.

The figure shows strong mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 45 dB above the background noise. The features near -4.0 and +3.9 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz. The feature near -2.1 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows two targets of opportunity, with apparent relative frequencies of +0.4 kHz (Target 1) and –0.6 kHz (Target 2). Both targets are at an apparent range of 12.4 kilometers. The unambiguous range for both targets is 27.7 kilometers. The unambiguous relative Doppler frequency for Target 1 is +0.4 kHz and for Target 2 is –0.6 kHz. These frequencies correspond to velocity components of +24 kilometers per hour for Target 1 and -34 kilometers per hour for Target 2. Target 1 is moving toward the radar; Target 2 is moving away from the radar. The speeds and ranges imply that the targets might be surface vehicles.

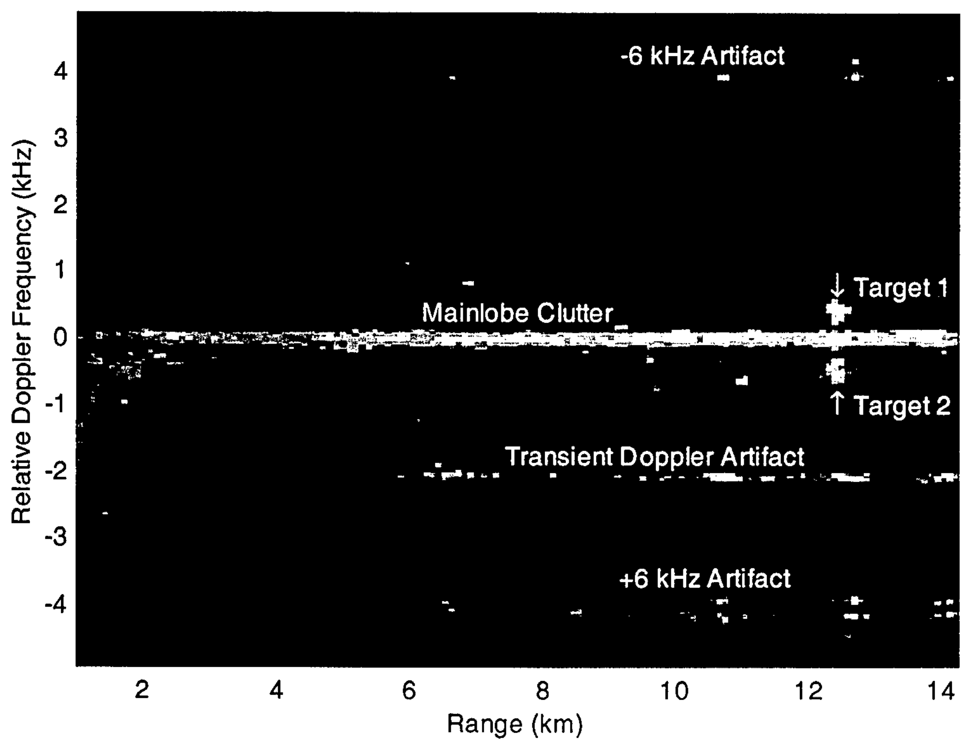

Figure 5-8 Conventional Data from the Second Sortie Landing

5.2. SECOND SORTIE TRANSIT TO MIRABEL

Tape 1999-10-22-14-45 is a large tape containing seven files of data. File001 contains data recorded during the second sortie transit from Ottawa to Mirabel. The file contains 2590 CPIs of conventional data. The antenna elevation angle is -14 degrees. The antenna azimuth scan is ±105 degrees. The altitude above mean sea level varies from 5346 meters at the beginning of the file to 6003 meters at the end. The mean ground speed is 480 kilometers per hour, with a standard deviation of 3 kilometers per hour. The flight path is shown in Figure 5-9.

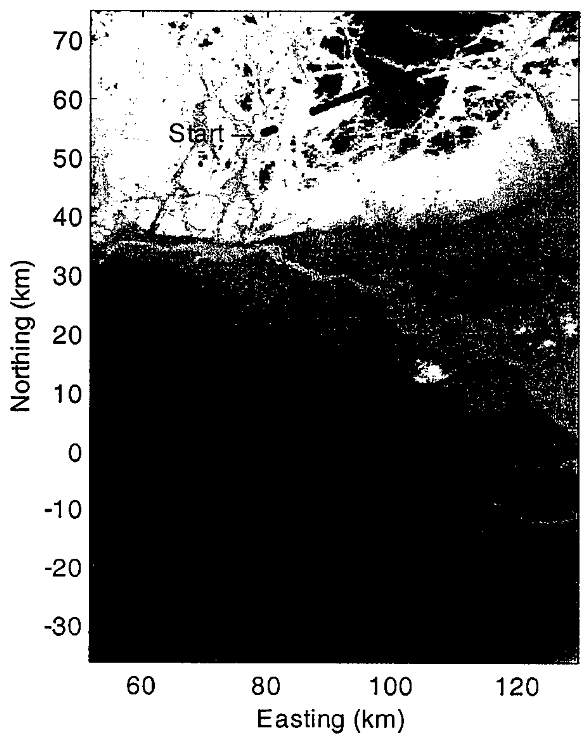

Figure 5-9 Flight Path for the Second Sortie Transit to Mirabel

An example of the data recorded during the transit to Mirabel for the second sortie is shown in the range-Doppler map in Figure 5-10. This is CPI number 5930, which was recorded at 14:50:10 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 6003 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is 100.9 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -1.6 kHz.

The figure shows strong mainlobe clutter at ranges from about 5 kilometers to 14 kilometers. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The feature near 3.2 kHz is the superposition of two artifacts: an artifact offset from the mainlobe clutter by about -6 kHz and a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter. These two artifacts are not normally coincidental in relative frequency. The feature near -3.3 kHz is an artifact offset from the mainlobe clutter by about +6 kHz.

The figure also shows a target of opportunity, with apparent relative frequency of -1.3 kHz and at an apparent range of 13.3 kilometers. The unambiguous range is 28.5 kilometers. The unambiguous frequency is –1.3 kHz. This frequency corresponds to a target velocity component of -75 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

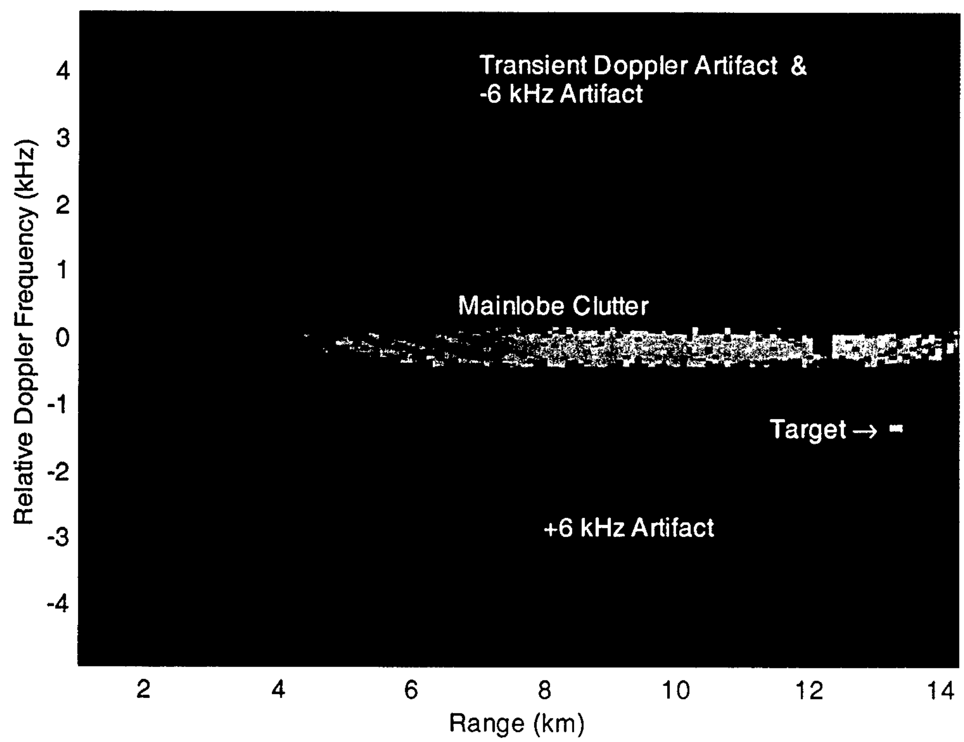

Figure 5-10 Conventional Data from for the Second Sortie Transit to Mirabel

5.3. SECOND SORTIE TRANSIT TO HIGHWAY 401

Tape 1999-10-22-16-29 is a large tape containing ten files of data. File005 through File007 contain data from the second sortie transit from Ottawa to Brockville for flights over Highway 401. These data are discussed in the following sections.

5.3.1. Ottawa to Brockville, Part 1

File005 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the second sortie transit to Brockville for flights over Highway 401. Due to a software crash, the file contains only 376 CPIs of data. The file will not be discussed further.

5.3.2. Ottawa to Brockville, Part 2

File006 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the second sortie transit to Brockville for flights over Highway 401. The file contains 3882 CPIs of conventional data. The antenna elevation angle is zero degrees. The antenna azimuth scan is ±105 degrees. The mean altitude is 747 m above mean sea level with a standard deviation of 15 m; the mean ground speed is 284 kilometers per hour with a standard deviation of 5 kilometers per hour. The flight path is shown in Figure 5-11.

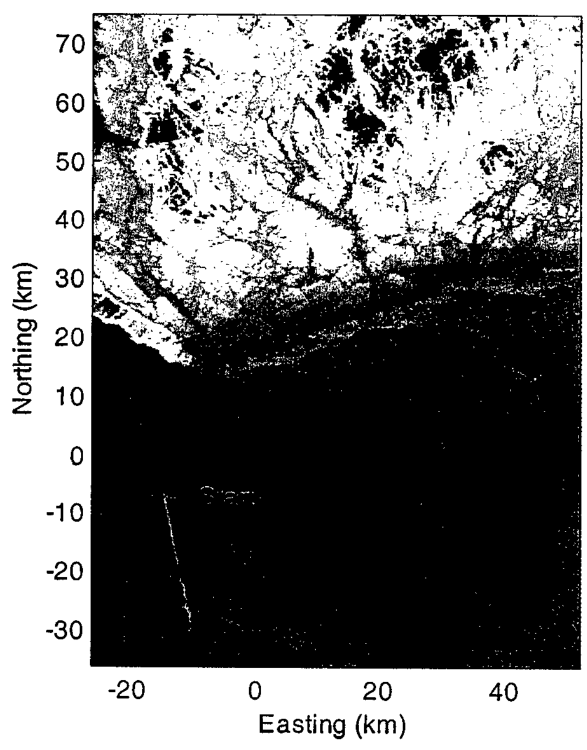

Figure 5-11 Flight Path for the Second Sortie Transit to Brockville

An example of the data recorded during the second sortie transit to Brockville is shown in the range-Doppler map in Figure 5-12. This is CPI number 453, which was recorded at 17:42:11 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 756 meters above mean sea level, the antenna elevation angle is zero degrees, and the antenna azimuth is +23.3 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 4.7 kHz.

The figure shows strong mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The feature near 3.9 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.9 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz. See Section 11.3 for a discussion of these artifacts. The feature between about 1 and 2 kHz and extending across all ranges is of unknown origin.

The figure also shows a target of opportunity, with apparent relative frequency of -1.4 kHz and at an apparent range of 10.4 kilometers. The unambiguous range is 10.4 kilometers. The unambiguous frequency is –1.4 kHz. This frequency corresponds to a target velocity component of -79 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

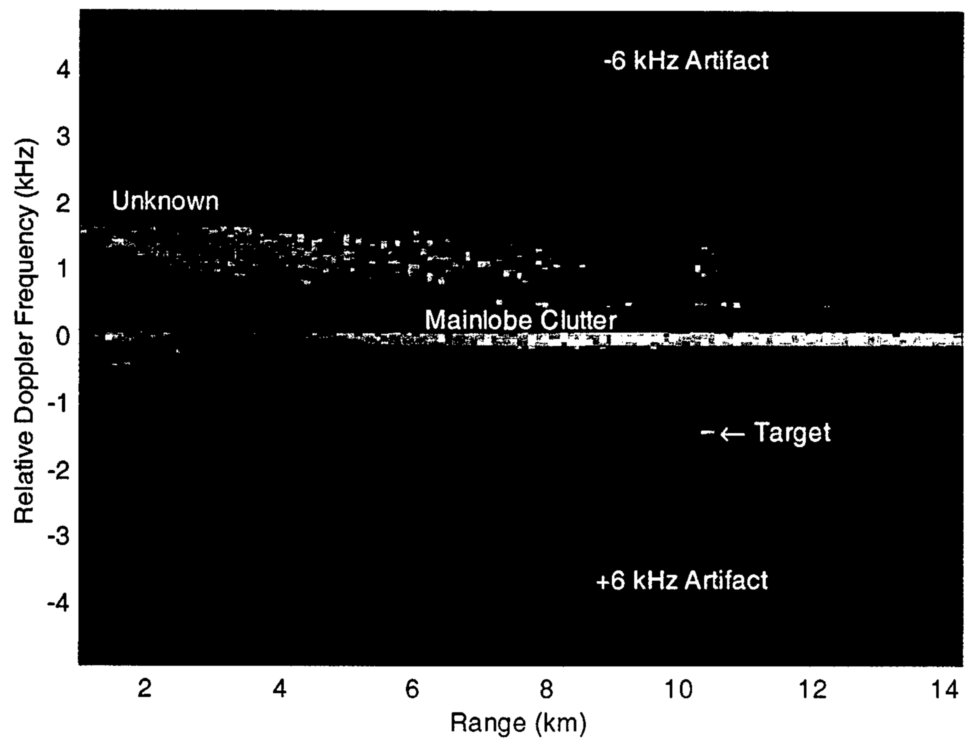

Figure 5-12 Conventional Data from the Second Sortie Transit to Brockville

5.3.3. Ottawa to Brockville, Part 3

File007 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the second sortie transit from Ottawa to Brockville for flights over Highway 401. Due to a failure of the radar transmitter, the file contains only 1293 CPIs of data. The file will not be discussed further.

5.4. THIRD SORTIE TAKE-OFF AND TRANSIT TO LAKE ONTARIO

Tape 1999-10-25-14-55 is a small tape containing one file of data. File001 contains data recorded on 25 October 1999 during the take-off and transit to Lake Ontario for the third sortie. The file contains a total of 20455 CPIs of conventional data, 3917 CPIs in the take-off segment and 16538 CPIs in the transit segment. The antenna elevation angle is +2 degrees during take-off and -2 degrees during transit. The antenna azimuth scan is ±10 degrees during both segments. The flight path is shown in Figure 5-13.

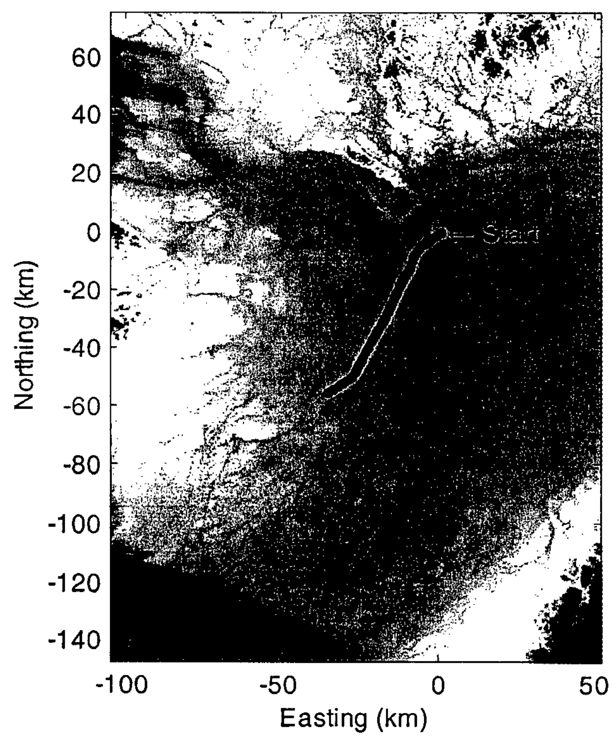

Figure 5-13 Flight Path for the Third Sortie Take-Off and Transit to Lake Ontario

An example of the data recorded during the third sortie transit to Lake Ontario is shown in the range-Doppler map in Figure 5-14. This is CPI number 10292, which was recorded at 15:03:20 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 2749 meters above mean sea level, the antenna elevation angle is -2 degrees, and the antenna azimuth is 7.0 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.2 kHz.

The figure shows mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 30 dB above the power level of the background noise. The altitude return is seen at a range of 2.7 kilometers. The feature near -2.5 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows a target of opportunity, with apparent relative frequency of -1.7 kHz and at an apparent range of 13.8 kilometers. The unambiguous range is 44.3 kilometers. The unambiguous frequency is –1.7 kHz. This frequency corresponds to a target velocity component of -95 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

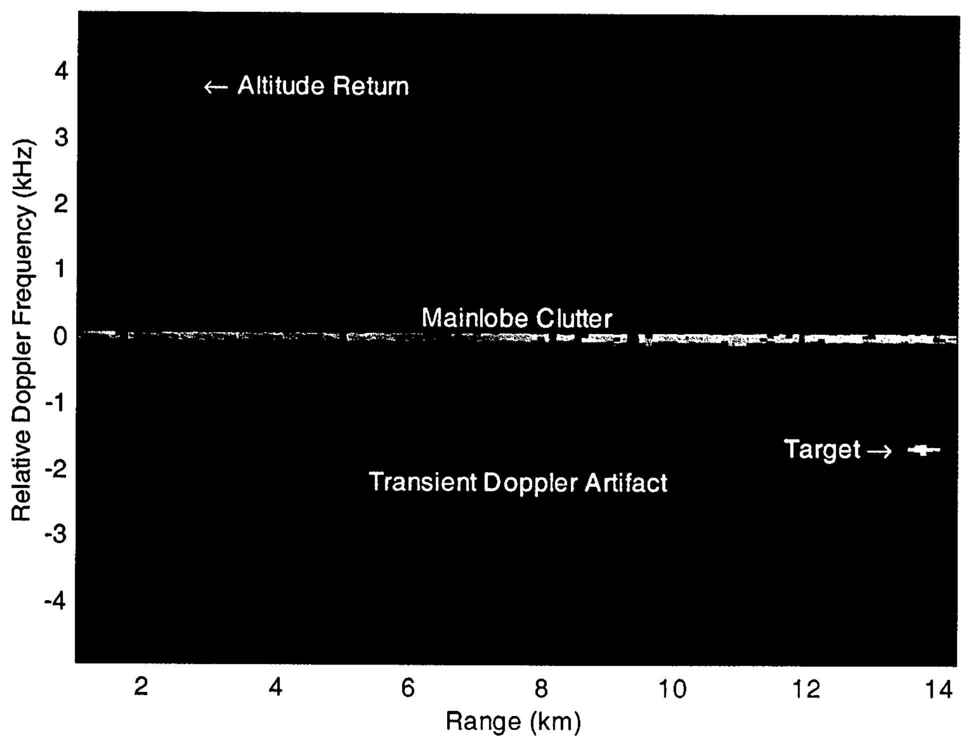

Figure 5-14 Conventional Data from the Third Sortie Transit to Lake Ontario

5.5. THIRD SORTIE TRANSIT FROM LAKE ONTARIO TO OTTAWA

Tape 1999-10-25-17-49 is a large tape containing one file of data. File001 contains data recorded during the third sortie transit from Lake Ontario to Ottawa and the landing at Ottawa airport. These data are discussed in the following sections.

5.5.1. Transit Segment

File001 on Tape 1999-10-25-17-49 contains data recorded on 25 October 1999 during the third sortie transit from Lake Ontario to Ottawa. The transit segment of the file consists of 15370 CPIs of conventional data, from 17:50:49 UTC to 18:06:42 UTC. The antenna elevation angle is -14 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude is 2702 m above mean sea level with a standard deviation of 14 m; the mean ground speed is 442 kilometers per hour with a standard deviation of 24 kilometers per hour. The flight path is shown in Figure 5-15.

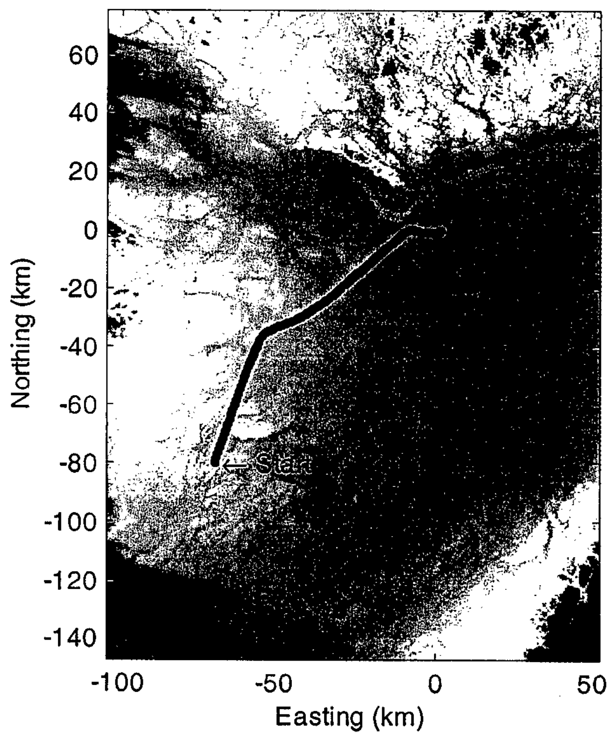

Figure 5-15 Flight Path for the Third Sortie Transit from Lake Ontario

An example of the data recorded during the third sortie transit segment is shown in the range-Doppler map in Figure 5-16. This is CPI number 2, which was recorded at 17:50:49 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 2715 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -99.2 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -1.3 kHz.

The figure shows strong mainlobe clutter at ranges from about 9 kilometers to 14 kilometers. The power level of the mainlobe clutter is about 35 dB above the power level of the background noise. The altitude return is seen at a range of 2.5 kilometers. The feature near 3.8 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.7 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz. The feature near 2.5 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

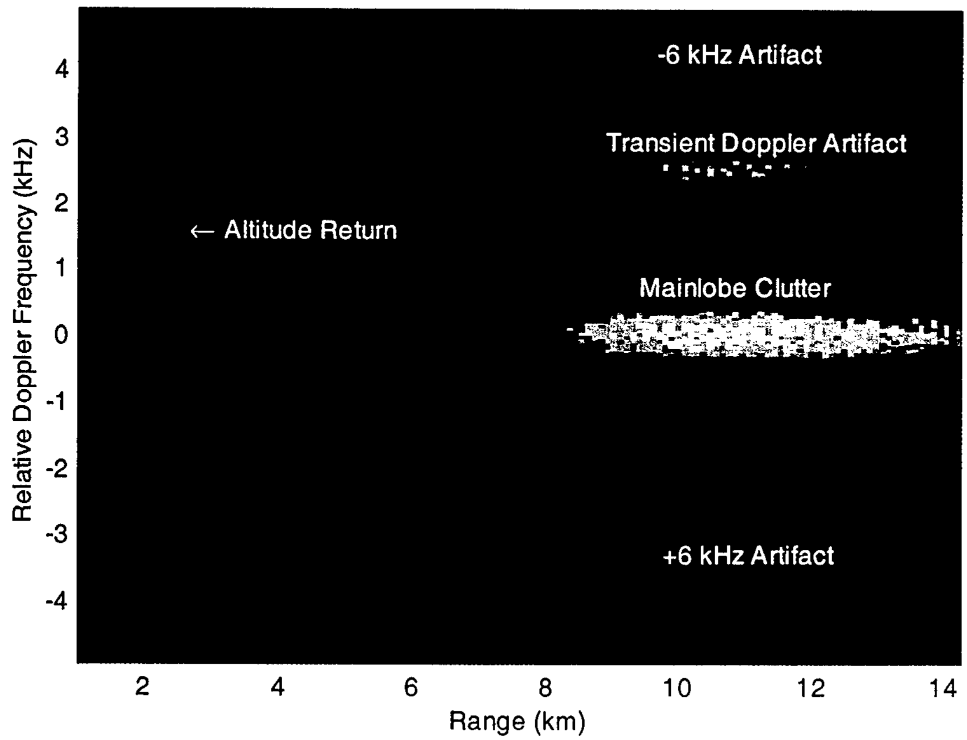

Figure 5-16 Conventional Data from the Third Sortie Transit from Lake Ontario

5.5.2. Landing

File001 on Tape 1999-10-25-17-49 also contains data recorded during the third sortie landing at Ottawa airport. This segment of the file consists of 10198 CPIs of conventional data, from 18:35:30 UTC to 18:41:50 UTC. The antenna elevation angle is -2 degrees. The antenna azimuth scan is ±10 degrees. The flight path is shown in Figure 5-17.

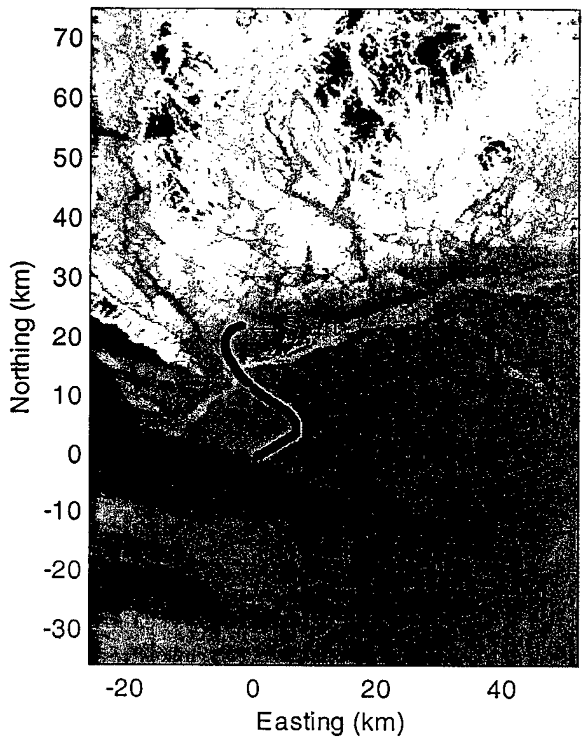

Figure 5-17 Flight Path for the Third Sortie Landing

An example of the data recorded during the landing segment of the third sortie is shown in the range-Doppler map in Figure 5-18. This is CPI number 84202, which was recorded at 18:41:31 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 145 meters above mean sea level, the antenna elevation angle is -2 degrees, and the antenna azimuth is +5.3 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is +4.0 kHz.

The figure shows weak mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 20 dB above the background noise. The mainlobe clutter feature at a range of 2.6 kilometers is a very strong stationary target on the ground, perhaps a building at the airport. The feature at 1.8 kHz and 2.6 kilometers is a transient Doppler artifact at the negative Doppler frequency of the ground target. The broadband noise associated with the ground target is probably due to saturation of the radar receiver. The noise peaks are about 45 dB below the level of the ground target. This is well above the frequency sidelobes of the Doppler processing.

The figure also shows a potential target at an apparent range of 5.1 kilometers and an apparent relative frequency of 4.0 kHz Doppler. The apparent relative frequency corresponds to a target velocity component of +220 kilometers per hour. The speed implies that the target is probably another aircraft.

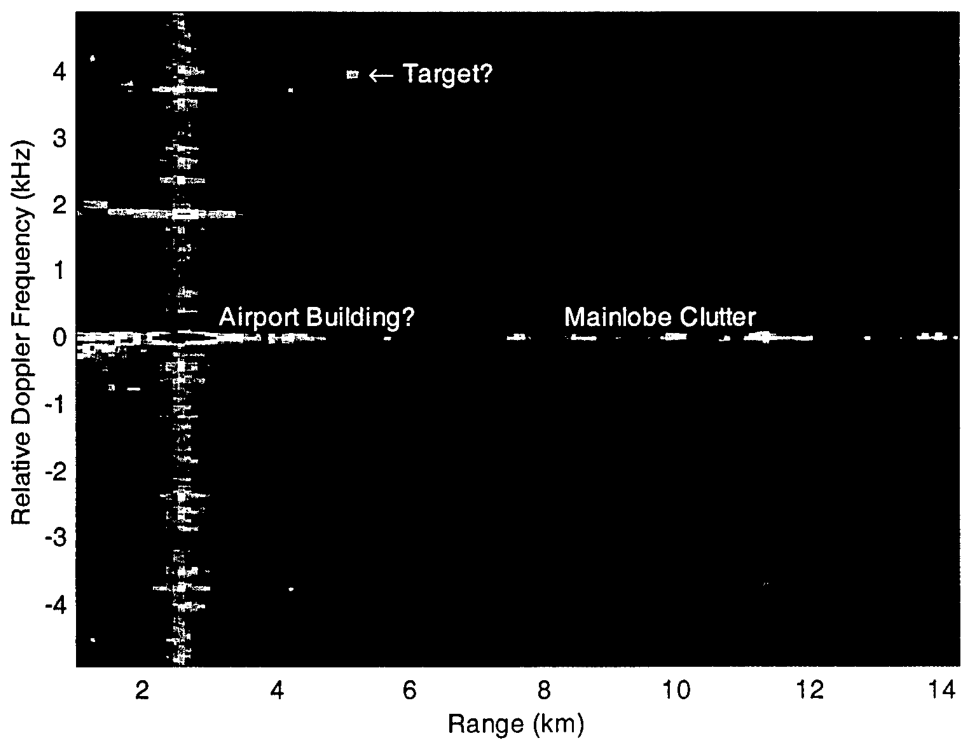

Figure 5-18 Conventional Data from the Third Sortie Landing

5.6. FOURTH SORTIE TAKE-OFF, TRANSIT, AND LANDING

Tape 1999-10-28-15-14 is a small tape containing two files of data. File001 contains data recorded during the fourth sortie take-off from Ottawa airport and the transit to Highway 401 to record returns from vehicular traffic. File002 contains data recorded during the landing at Ottawa airport. These data are discussed in the following sections.

5.6.1. Take-Off and Transit to Brockville

File001 on Tape 1999-10-28-15-14 contains data recorded on 28 October 1999 during the take-off for the fourth sortie and the transit to Highway 401 near Brockville. The file contains 20655 CPIs of data, 15229 conventional CPIs in the first segment of the file and 5426 phase-agile CPIs in the second segment. The antenna elevation angle is +2 degrees during take-off and -2 degrees during transit. The antenna azimuth scan is ±10 degrees during both segments. The flight path is shown in Figure 5-19.

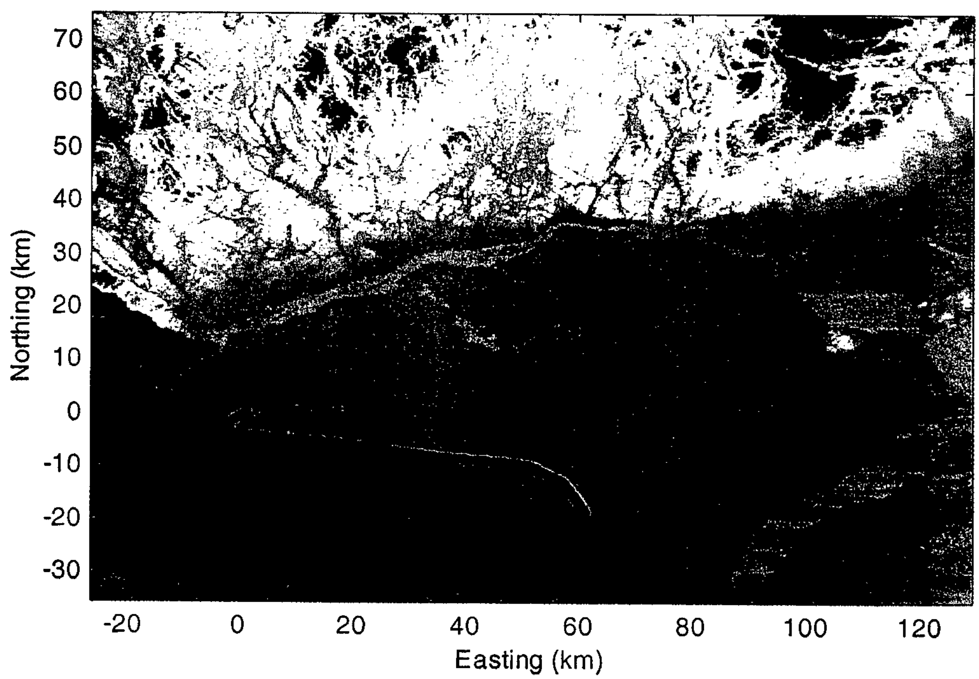

Figure 5-19 Flight Path for the Fourth Sortie Take-Off and Transit to Brockville

5.6.1.1. Conventional Data

An example of conventional data from the fourth sortie transit segment is shown in the range-Doppler map in Figure 5-20. This is CPI number 12330, which was recorded at 15:23:48 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 714 meters above mean sea level, the antenna elevation angle is -5 degrees, and the antenna azimuth is +13.3 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.2 kHz.

The figure shows strong mainlobe clutter at ranges from about 4 kilometers to 12 kilometers. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The feature near 3.4 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.4 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -2.6 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

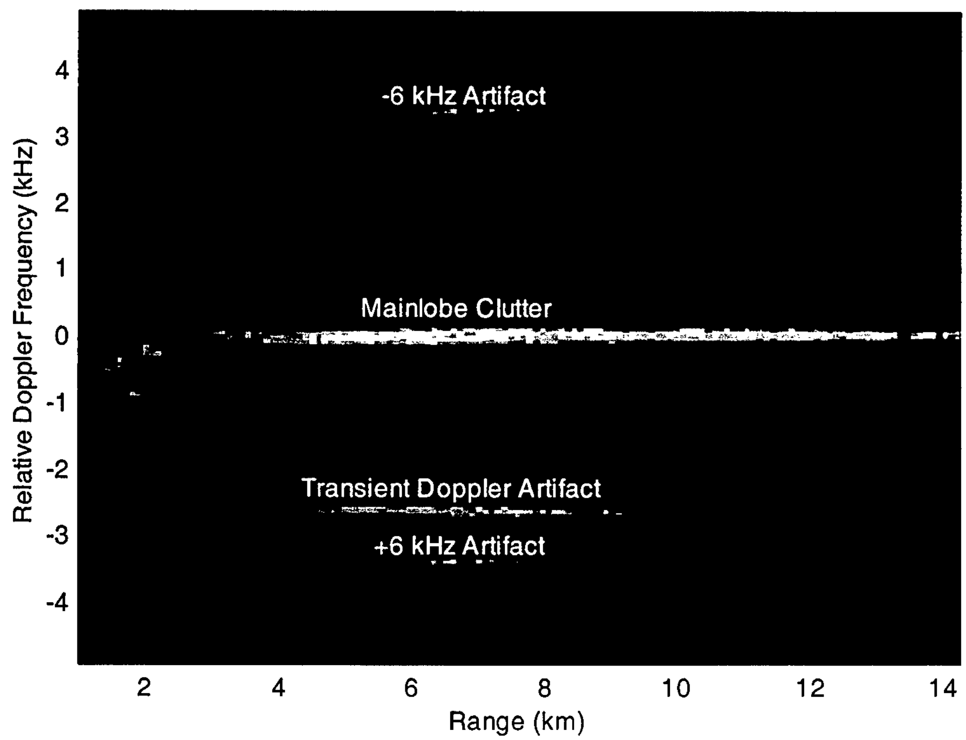

Figure 5-20 Conventional Data from the Fourth Sortie Transit to Brockville

5.6.1.2. Phase-Agile Data

An example of phase-agile data from the fourth sortie transit segment is shown in the range-Doppler map in Figure 5-21. This is CPI number 18370, which was recorded at 15:27:27 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 738 meters above mean sea level, the antenna elevation angle is -5 degrees, and the antenna azimuth is +4.4 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.9 kHz. The data have been processed for the first range interval.

The figure shows strong mainlobe clutter at ranges from about 4 kilometers to 12 kilometers. The power level of the mainlobe clutter is about 40 dB above the background noise. The features near ±3.4 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz. The feature near -2.0 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows a target of opportunity, with apparent relative frequency of -1.1 kHz and at an unambiguous range of 6.5 kilometers. The frequency ambiguity can be resolved by locating the target in CPIs with other pulse repetition frequencies. The unambiguous frequency is –1.1 kHz. This frequency corresponds to a target velocity component of -63 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

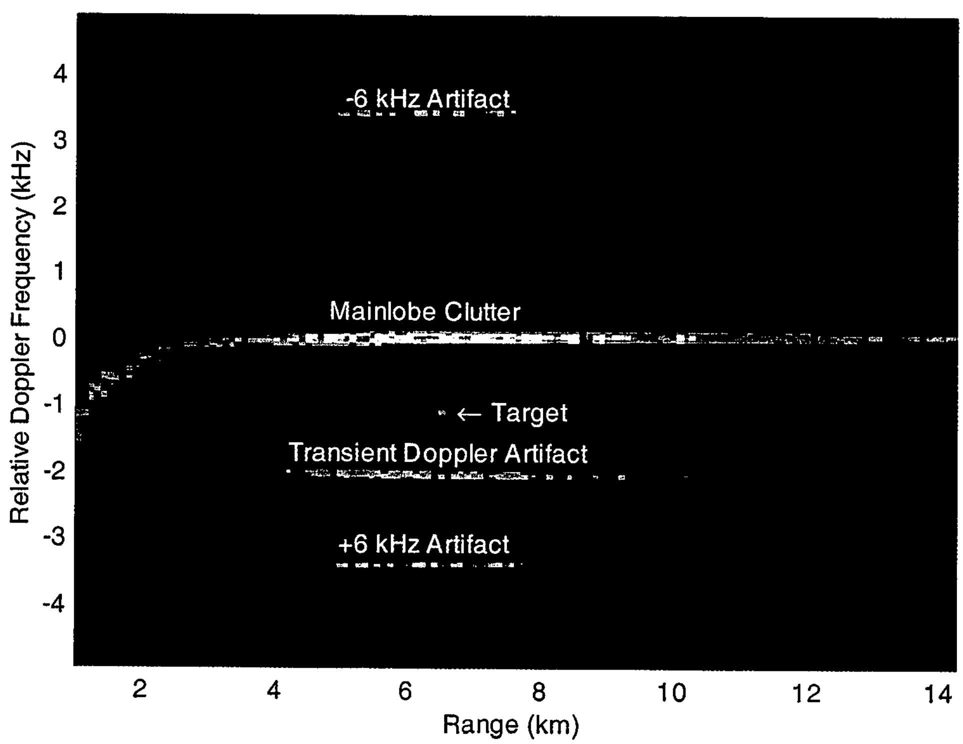

Figure 5-21 Phase-Agile Data from the Fourth Sortie Transit to Brockville

5.6.2. Landing

File002 on Tape 1999-10-28-15-14 contains data recorded on 28 October 1999 during the fourth sortie landing at Ottawa airport. The file contains 2784 CPIs of conventional data. The antenna elevation angle is zero degrees. The antenna azimuth scan is ±10 degrees. The flight path is shown in Figure 5-22.

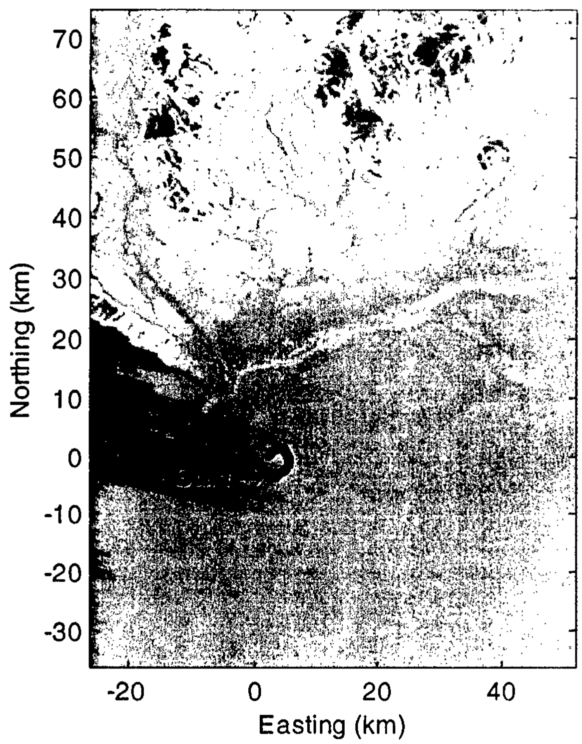

Figure 5-22 Flight Path for the Fourth Sortie Landing

An example of the data recorded during the fourth sortie landing is shown in the range-Doppler map in Figure 5-23. This is CPI number 36, which was recorded at 17:01:42 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 2749 meters above mean sea level, the antenna elevation angle is zero degrees, and the antenna azimuth is -3.4 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.4 kHz.

The figure shows strong mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The feature near -0.9 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows two targets of opportunity, with apparent relative frequencies of +0.7 kHz (Target 1) and –0.7 kHz (Target 2). Target 1 is at an apparent range of 8.2 kilometers, while Target 2 is at 8.4 kilometers. The unambiguous range for Target 1 is 23.5 kilometers and 23.7 kilometers for Target 2. The unambiguous frequency for Target 1 is +0.7 kHz and for Target 2 is –0.7 kHz. These frequencies correspond to velocity components of +40 kilometers per hour for Target 1 and -40 kilometers per hour for Target 2. The speeds and ranges imply that the targets might be surface vehicles.

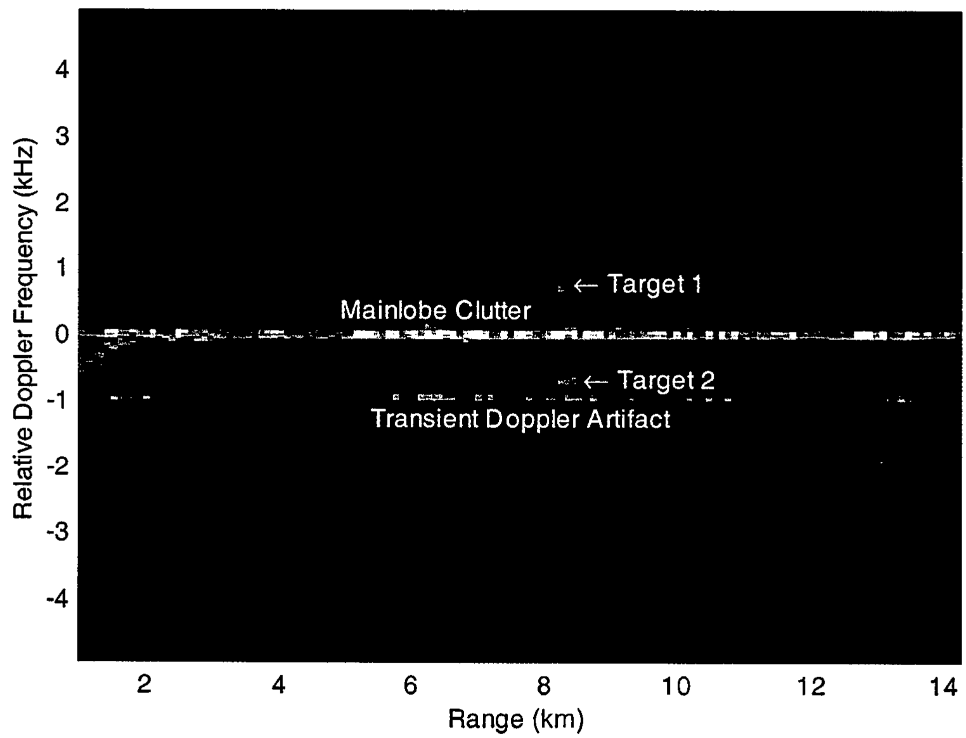

Figure 5-23 Conventional Data from the Fourth Sortie Landing

5.7. FOURTH SORTIE TRANSIT FROM HIGHWAY 401

Tape 1999-10-28-15-30 is a large tape containing nine files of data. File008 and File009 contains data recorded during the fourth sortie transit to Ottawa airport for landing. These data are discussed in the following sections.

5.7.1. Transit, Part 1

File008 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the fourth sortie transit from Highway 401 to Ottawa. Due to a failure of the radar transmitter, the file contains only 905 CPIs of data. The file will not be discussed further.

5.7.2. Transit, Part 2

File009 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the fourth sortie transit from Highway 401 to Ottawa. The file contains 1650 CPIs of conventional data. The antenna elevation angle is zero degrees. The antenna azimuth scan is ±60 degrees to 16:54:40 UTC and ±10 degrees thereafter. The mean altitude is 735 m above mean sea level with a standard deviation of 16 m; the mean ground speed is 304 kilometers per hour with a standard deviation of 20 kilometers per hour. The flight path is shown in Figure 5-24.

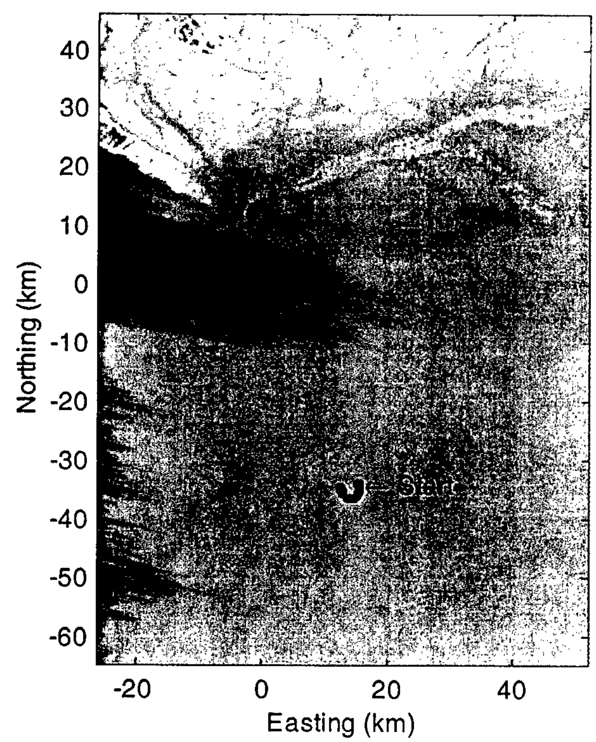

Figure 5-24 Flight Path for the Fourth Sortie Transit from Highway 401

An example of the data recorded during the fourth sortie transit to Ottawa from Highway 401 is shown in the range-Doppler map in Figure 5-25. This is CPI number 121, which was recorded at 16:54:15 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 762 meters above mean sea level, the antenna elevation angle is zero degrees, and the antenna azimuth is +5.4 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.7 kHz.

The figure shows strong mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The feature near -1.6 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows a target of opportunity, with an apparent relative frequency of +1.7 kHz and an apparent range of 4.6 kilometers. The unambiguous range is 19.9 kilometers. The unambiguous frequency is +1.7 kHz. This frequency corresponds to a velocity component of +95 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

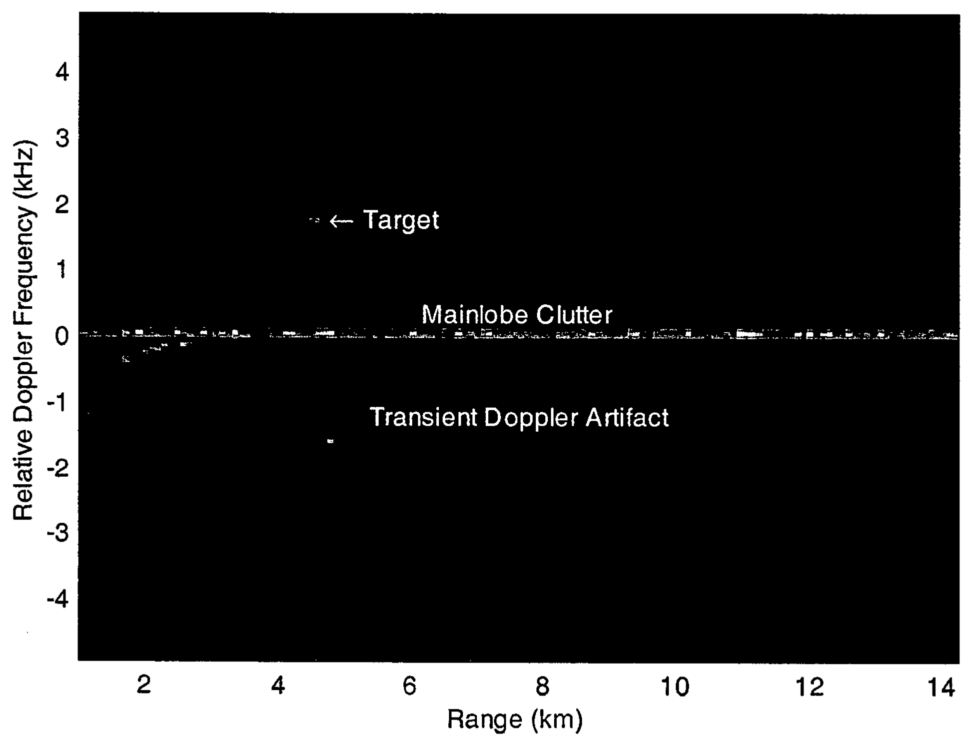

Figure 5-25 Conventional Data from the Fourth Sortie Transit from Highway 401

6. GROUND CLUTTER DATA

Ground clutter data were recorded during the second sortie, on 22 October 1999, during flights between Ottawa and Mirabel. The intention was to capture returns from the same geographical area for a number of different antenna elevation angles. The nominal aircraft altitude was set for each antenna elevation angle such that the ground range to the center of the radar beam would be about 22.5 kilometers. Table 6-1 summarizes the ground clutter data that were recorded. The table includes the tape label, the file number, the radar mode, the number of coherent processing intervals, the mean altitude (meters above mean sea level), and the antenna elevation angle.

Table 6-1 Ground Clutter Data

Tape Label / File Number	**Mode**	**Number of CPIs**	**Mean Altitude** (meters)	**Antenna Elevation** (degrees)
1999-10-22-14-45				
File003	Phase-Agile	16671	6254	-14
File004	Conventional	10690	6258	-14
File006	Conventional	12698	2738	-7
File007	Phase-Agile	6527	2725	-7
1999-10-22-16-29				
File001	Conventional	13268	1205	-4
File002	Phase-Agile	14666	1179	-4
File003	Conventional	3403	744	-2
File004	Phase-Agile	11486	773	-2

In general, the area to the north of the flight line between Ottawa and Mirabel is hilly and forested, with a number of lakes and small rivers. The area to the south of the flight line is the relatively flat floor of the Ottawa Valley, with some forested areas and some farmland. Except for the greater Ottawa area, neither area has significant urban populations, although the southern area does have a number of small rural communities and a significant network of roads.

6.1. SECOND SORTIE GROUND CLUTTER, HIGHER ALTITUDES

Tape 1999-10-22-14-45 is a large tape containing seven data files. File003 and File004 contain phase-agile and conventional data respectively at a nominal altitude of 6000 meters and an antenna elevation angle of -14 degrees. File005 is a short file that is the result of a software crash. File006 and File007 contain conventional and phase-agile data respectively at a nominal altitude of 2700 meters and an antenna elevation angle of -7 degrees. These data are discussed in the following sections.

6.1.1. Phase-Agile Data at 6000 Meters

File003 on Tape 1999-10-22-14-45 contains data recorded on 22 October 1999 during the first flight from Mirabel to Ottawa. The file contains 16671 CPIs of phase-agile data. The antenna elevation angle is -14 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 6254 meters with a standard deviation of 13 meters; the mean ground speed is 342 kilometers per hour with a standard deviation of 10 kilometers per hour. The flight path is shown in Figure 6-1.

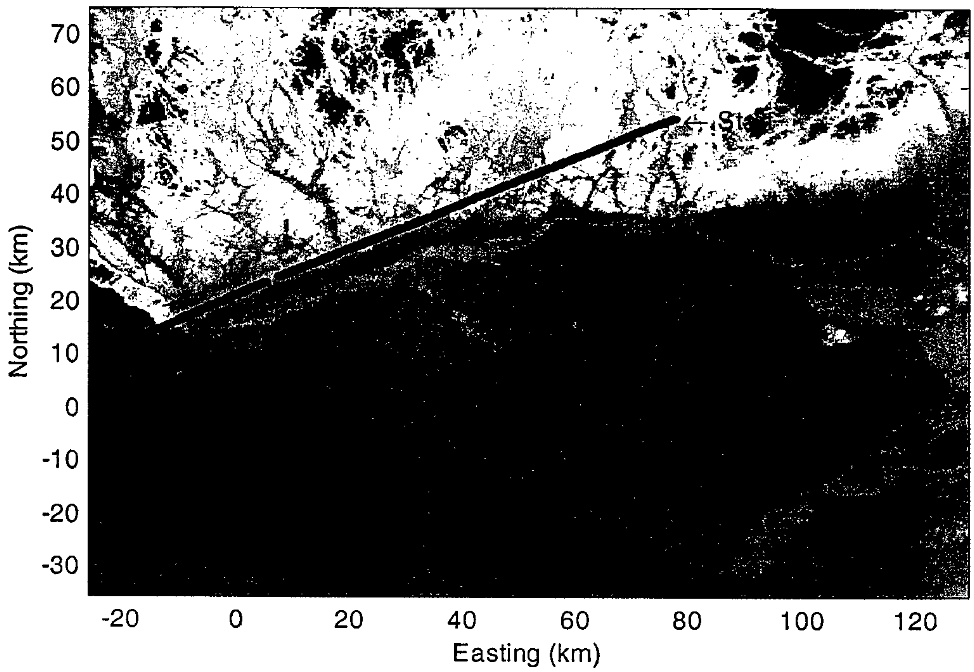

Figure 6-1 Flight Path for the First Flight from Mirabel to Ottawa

An example of the data recorded during the first flight from Mirabel to Ottawa is shown in the range-Doppler map in Figure 6-2. This is CPI number 57, which was recorded at 14:57:53 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 6268 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -94.0 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -0.5 kHz. The data have been processed for the second range interval.

The figure shows strong mainlobe clutter at ranges from about 21 kilometers to 30 kilometers. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise.

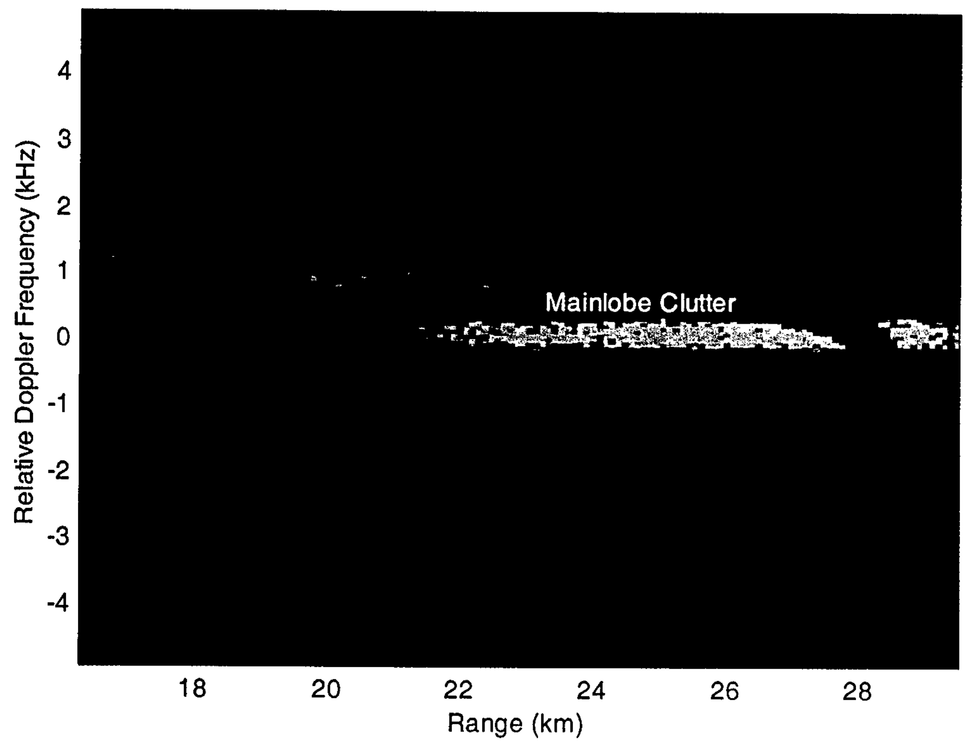

Figure 6-2 Phase-Agile Ground Clutter Data at 6000 Meters Altitude

The mainlobe clutter shown in Figure 6-2 has a break from about 27.3 kilometers to 28.4 kilometers range. Figure 6-3 shows the locations of the aircraft and the mainlobe beam for this data set. The figure shows that the beam intersects the Ottawa River. Figure 6-4 shows the terrain elevation through the centerline of the mainlobe clutter. The figure shows a depression, which is the Ottawa River, from 26.9 to 27.8 kilometers slant range. The slant range of the river is within 0.5 kilometers of the location of the mainlobe clutter break. Therefore, the break is probably due to reduced backscatter from the water surface compared to the surrounding terrain.

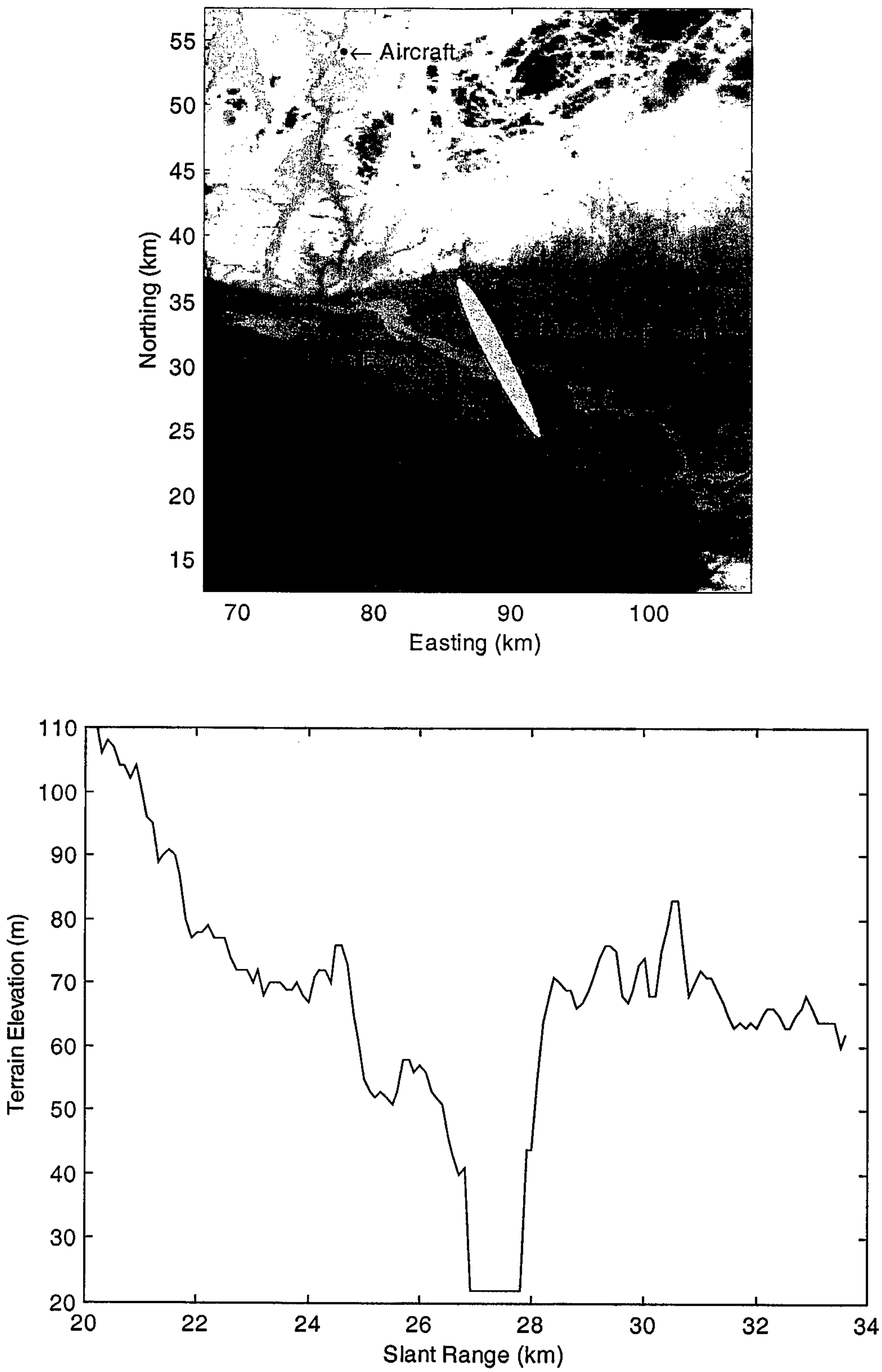

Figure 6-4 Terrain Elevation through Mainlobe Clutter for Data in Figure 6-2

6.1.2. Conventional Data at 6000 Meters

File004 on Tape 1999-10-22-14-45 contains data recorded on 22 October 1999 during the first flight from Ottawa to Mirabel. The file contains 10690 CPIs of conventional data. The antenna elevation angle is -14 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 6258 meters with a standard deviation of 8 meters; the mean ground speed is 502 kilometers per hour with a standard deviation of 5 kilometers per hour. The flight path is shown in Figure 6-5.

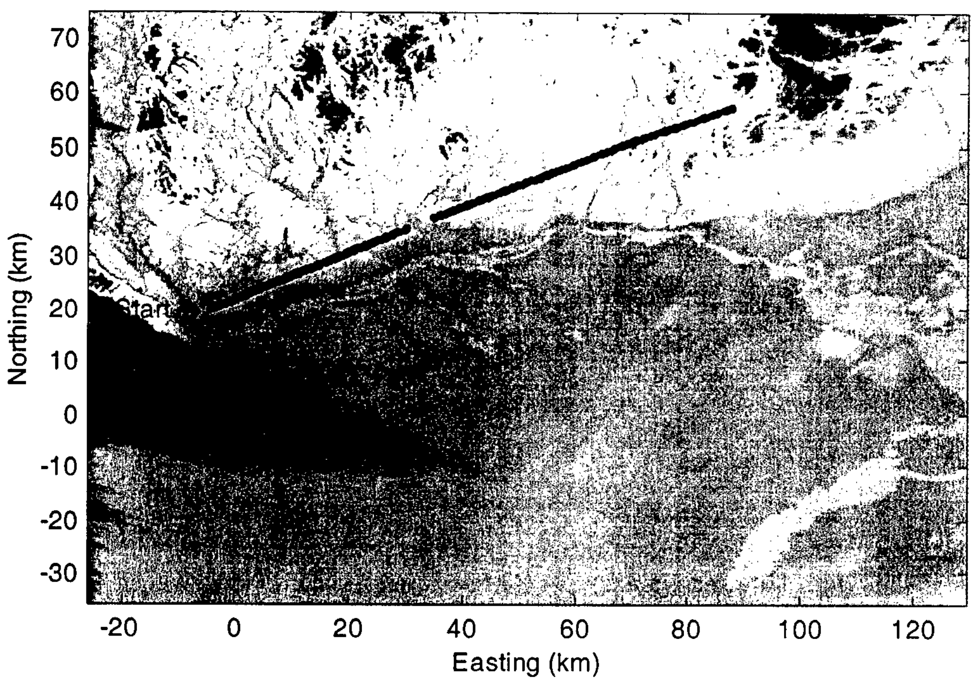

Figure 6-5 Flight Path for the First Flight from Ottawa to Mirabel

An example of the data during the first flight from Ottawa to Mirabel is shown in the range-Doppler map in Figure 6-6. This is CPI number 279, which was recorded at 15:19:59 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 6258 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -36.3 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.9 kHz.

The figure shows strong mainlobe clutter at apparent ranges from about 4 kilometers to 14 kilometers. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The feature near -4.1 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter. The feature near -1.3 kHz for all ranges is probably sidelobe clutter due to the elevation sidelobe at about -24 degrees.

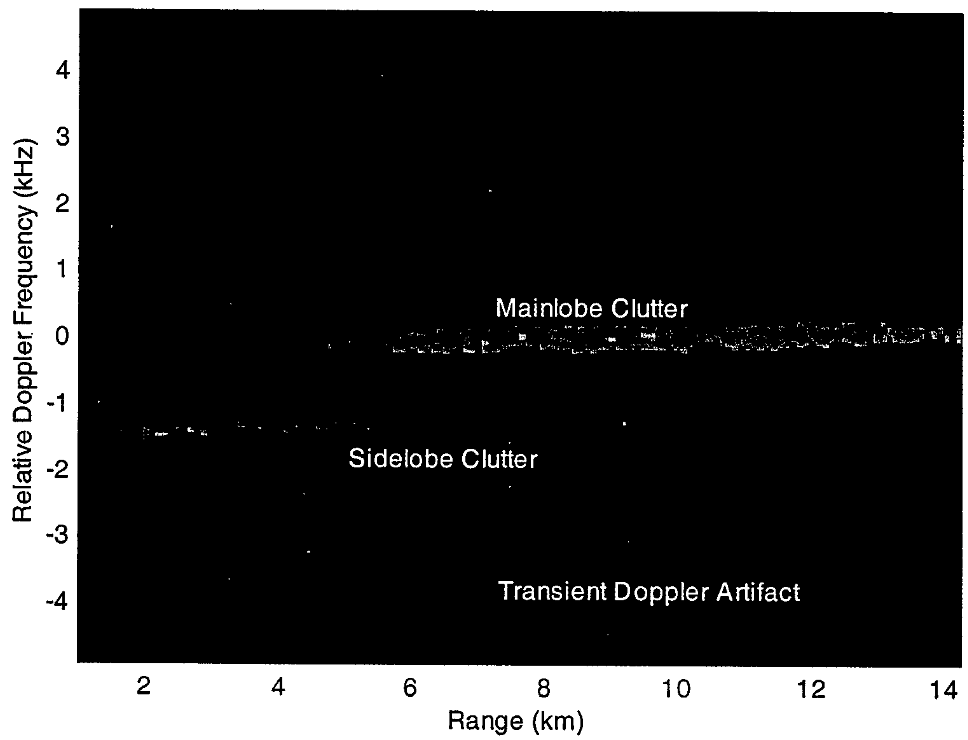

Figure 6-6 Conventional Ground Clutter Data at 6000 Meters Altitude

6.1.3. Conventional Data at 2700 Meters, Part 1

File005 on Tape 1999-10-22-14-45 contains data recorded on 22 October 1999 during the second flight from Mirabel to Ottawa. Due to a software crash, the file contains only 1479 CPIs of data. The file will not be discussed further.

6.1.4. Conventional Data at 2700 Meters, Part 2

Tape 1999-10-22-14-45 File006 contains data recorded on 22 October 1999 during the continuation of the second flight from Mirabel to Ottawa. The file contains 12698 CPIs of conventional data. The antenna elevation angle is -7 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 2738 meters with a standard deviation of 6 meters; the mean ground speed is 311 kilometers per hour with a standard deviation of 10 kilometers per hour. The flight path is shown in Figure 6-7.

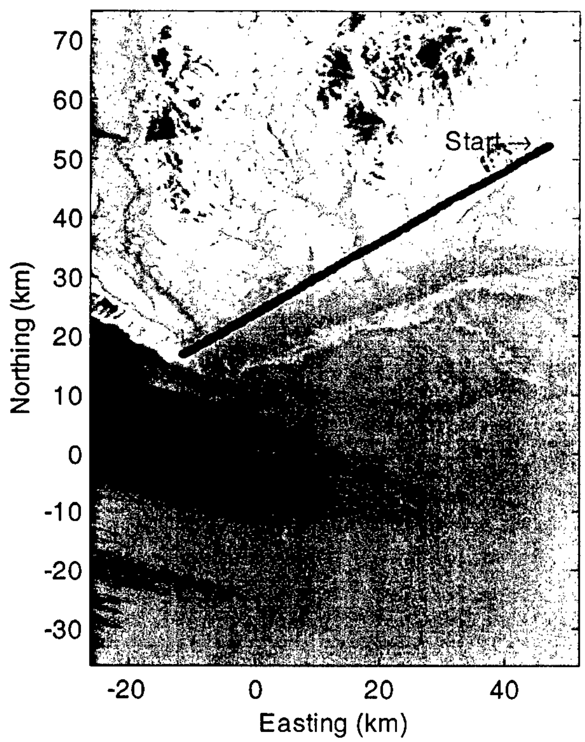

Figure 6-7 Flight Path for the Second Flight from Mirabel to Ottawa

An example of the data recorded during the second flight from Mirabel to Ottawa is shown in the range-Doppler map in Figure 6-8. This is CPI number 74, which was recorded at 15:44:21 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 2722meters above mean sea level, the antenna elevation angle is -7 degrees, and the antenna azimuth is -95.7 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -0.5 kHz.

The figure shows strong mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The altitude return is seen at a range of 2.5 kilometers. The feature near 1 kHz and at all ranges is located at a frequency that is consistent with a return due to the antenna's azimuth sidelobe at 10 degrees. Other aspects of this feature, particularly its extent in range and its amplitude are not well understood and will be the subject of future study.

The figure also shows a target of opportunity, at a relative frequency of -1.3 kHz and at an apparent range of 5.1 kilometers. The unambiguous range is 20.3 kilometers. The unambiguous frequency is -1.3 kHz. This frequency corresponds to a target velocity component of -75 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

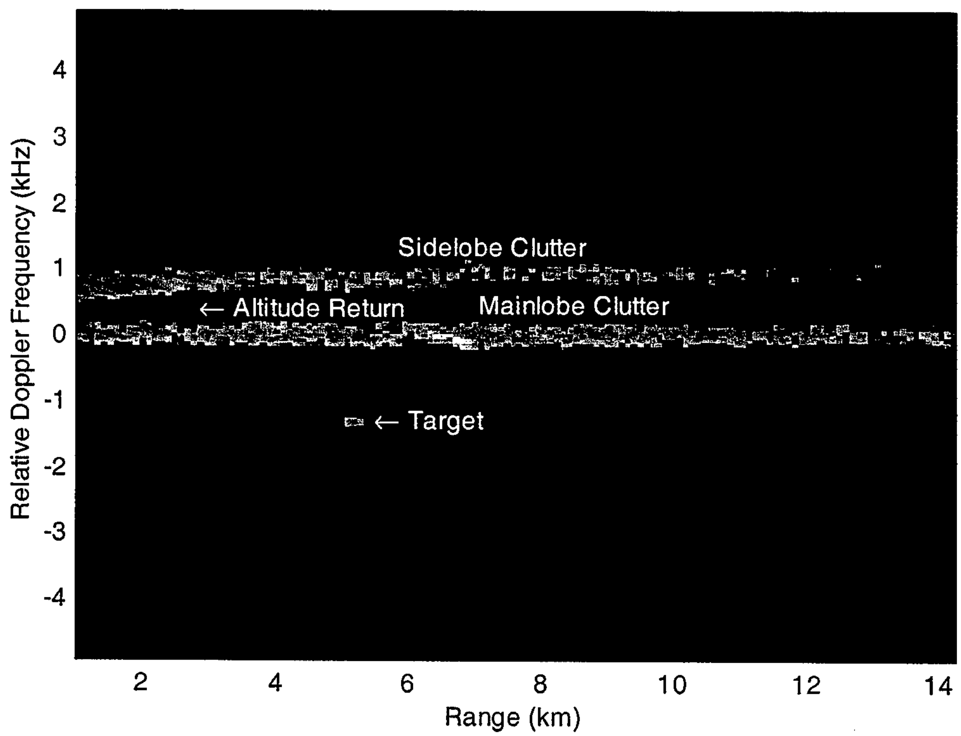

Figure 6-8 Conventional Ground Clutter Data at 2700 Meters Altitude

6.1.5. Phase-Agile Data at 2700 Meters

File007 on Tape 1999-10-22-14-45 contains data recorded on 22 October 1999 during the second flight from Ottawa to Mirabel. The file contains 6527 CPIs of phase-agile data. The antenna elevation angle is -7 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 2725 meters with a standard deviation of 18 meters; the mean ground speed is 449 kilometers per hour with a standard deviation of 3 kilometers per hour. The flight path is shown in Figure 6-9.

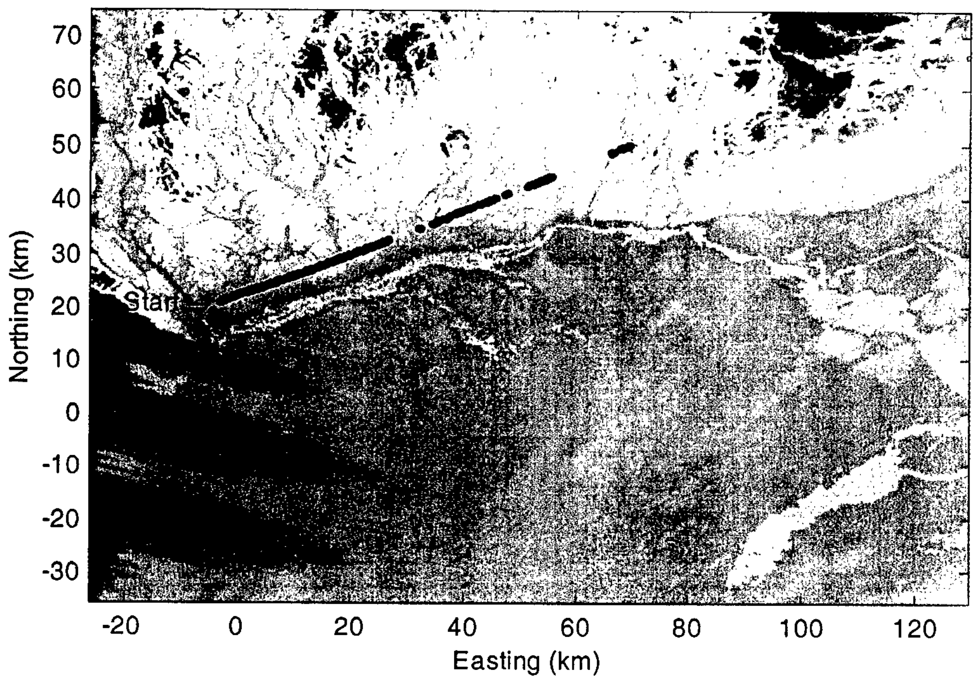

Figure 6-9 Flight Path for the Second Flight from Ottawa to Mirabel

An example of the data recorded during the second flight from Ottawa to Mirabel is shown in the range-Doppler map in Figure 6-10. This is CPI number 209, which was recorded at 16:02:24 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 2734 meters above mean sea level, the antenna elevation angle is -7 degrees, and the antenna azimuth is -79.0 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 1.5 kHz. The data have been processed for the second range interval.

The figure shows mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 35 dB above the power level of the background noise. The feature near -3.1 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter. Note the strong variation in the mainlobe clutter as a function of range.

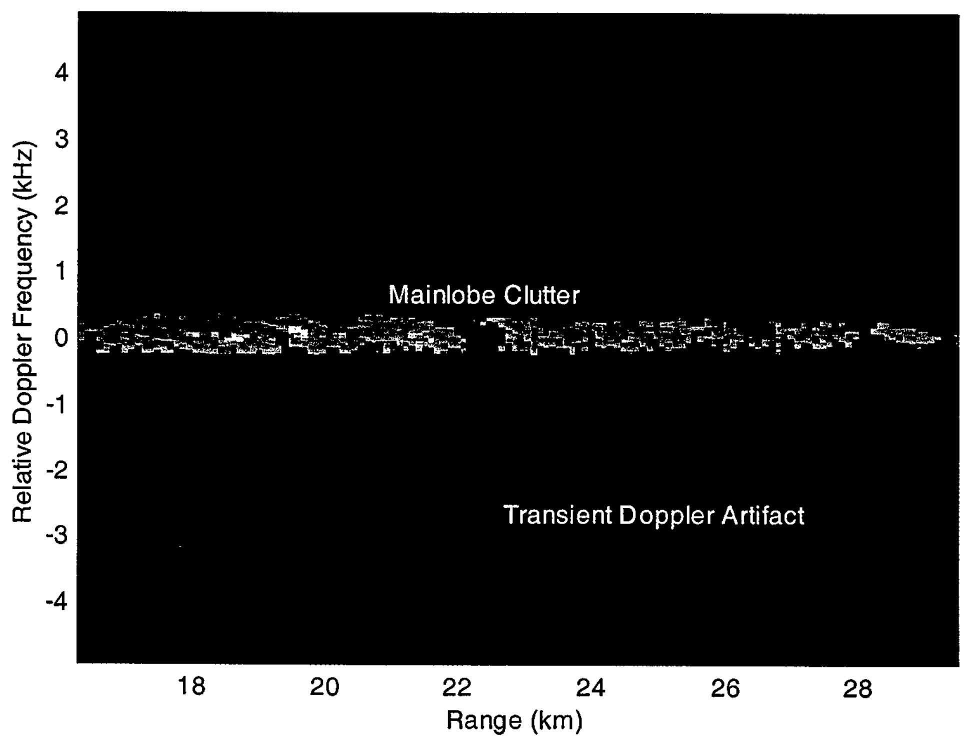

Figure 6-10 Phase-Agile Ground Clutter Data at 2700 Meters Altitude

Figure 6-11 shows the locations of the aircraft and the radar beam for the data shown in Figure 6-10, showing that the beam illuminates an area of topographical roughness. Figure 6-12 shows terrain elevation along the centerline of the beam. This figure shows depressions at slant ranges of 22.1, 26.5, 28.0, and 29.3 kilometers, corresponding to the breaks in the mainlobe clutter. The structure seen in the mainlobe clutter is probably due to these topographical variations.

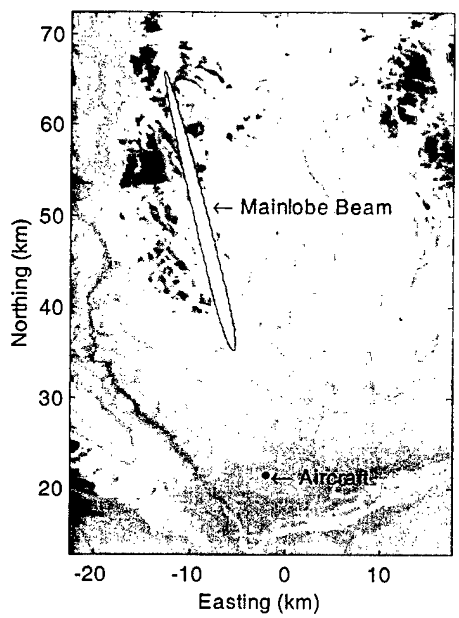

Figure 6-11 Aircraft and Mainlobe Beam Locations for Data in Figure 6-10

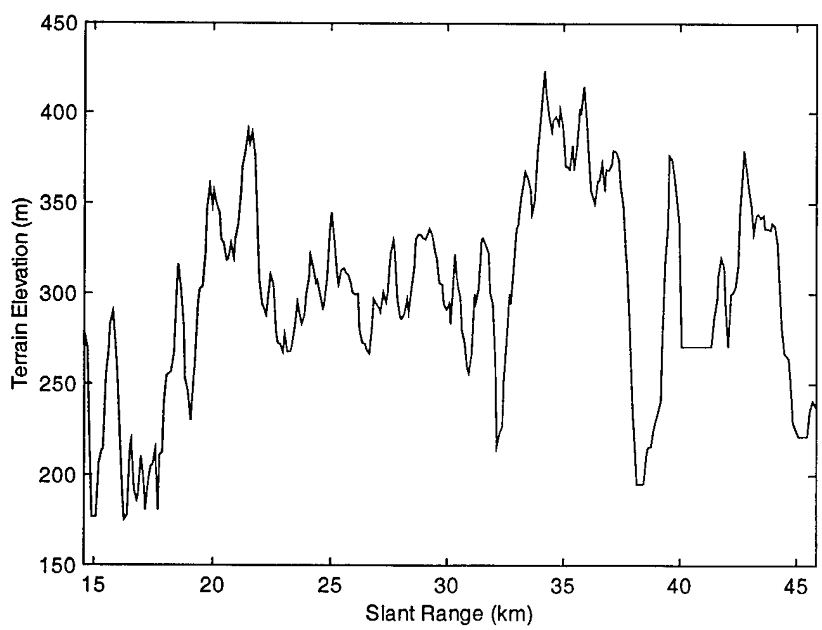

Figure 6-12 Terrain Elevation Through Mainlobe Clutter for Data in Figure 6-10

6.2. SECOND SORTIE GROUND CLUTTER, LOWER ALTITUDES

Tape 1999-10-22-16-29 is a large tape containing ten files of data. File001 and File002 contain conventional and phase-agile data at a nominal altitude of 1250 meters and an antenna elevation angle of -4 degrees. File003 and File004 contain phase-agile and conventional data at a nominal altitude of 750 meters and an antenna elevation angle of -2 degrees. These data are discussed in the following sections.

6.2.1. Conventional Data at 1250 Meters

File001 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the third flight from Mirabel to Ottawa. The file contains 13268 CPIs of conventional data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 1205 meters with a standard deviation of 3 meters; the mean ground speed is 302 kilometers per hour with a standard deviation of 9 kilometers per hour. The flight path is shown in Figure 6-13.

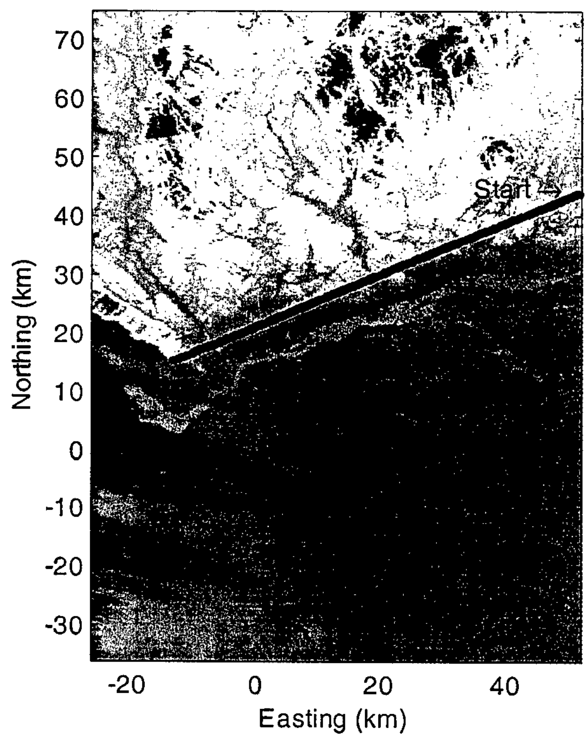

Figure 6-13 Flight Path for the Third Flight from Mirabel to Ottawa

An example of the data recorded during the third flight from Mirabel to Ottawa is shown in the range-Doppler map in Figure 6-14. This is CPI number 1146, which was recorded at 16:31:12 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 1207 meters above mean sea level, the antenna elevation angle is -4 degrees, and the antenna azimuth is -11.42 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.0 kHz.

The figure shows mainlobe clutter at all ranges. The peak power level of the mainlobe clutter is about 50 dB above the background noise. The altitude return is seen at a range of 1.1 kilometers. The features near ±3.8 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz.

The figure also shows at least three targets of opportunity, with apparent relative frequencies of -1.5 kHz (Target 1), -1.8 kHz (Target 2), and –1.9 kHz (Target 3). The targets are at apparent ranges of 6.5, 6.4, and 6.4 kilometers respectively. The unambiguous ranges are 21.8, 21.7, and 21.7 kilometers, and the unambiguous frequencies are -1.5 kHz, -1.8 kHz, and –1.9 kHz, respectively. These frequencies correspond to velocity components of -84 kilometers per hour for Target 1, -99 kilometers per hour for Target 2, and -105 kilometers per hour for Target 3. All three targets are moving away from the radar. The speeds and ranges imply that the targets might be surface vehicles.

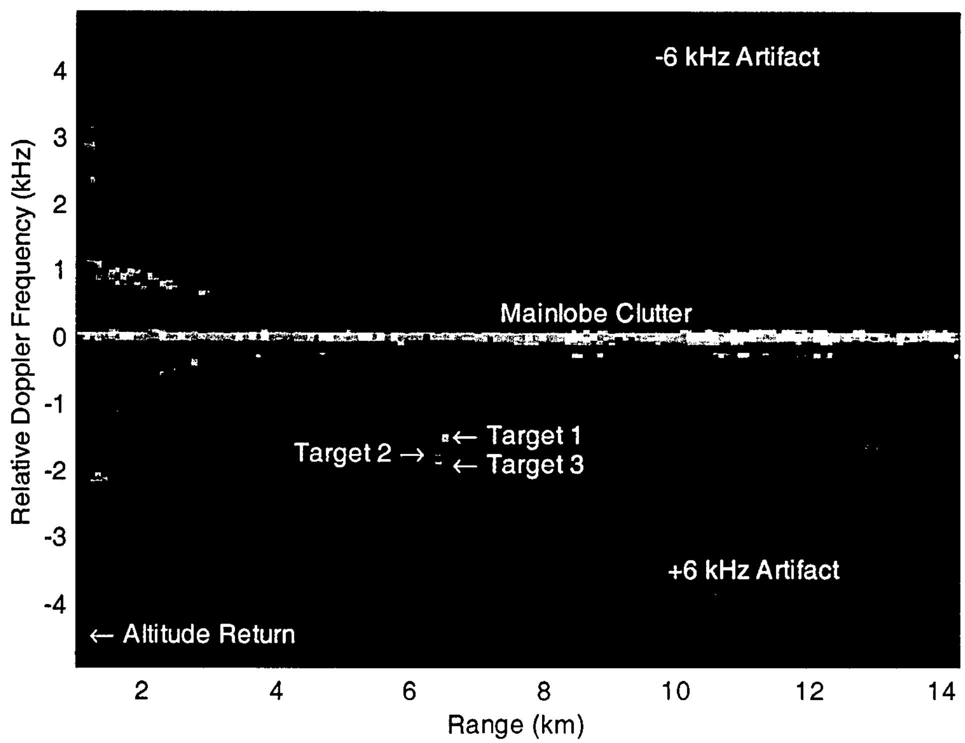

Figure 6-14 Conventional Ground Clutter Data at 1250 Meters Altitude

6.2.2. Phase-Agile Data at 1250 Meters

File002 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the fourth flight from Ottawa to Mirabel. The file contains 14666 CPIs of phase-agile data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 1179 meters with a standard deviation of 16 meters; the mean ground speed is 354 kilometers per hour with a standard deviation of 9 kilometers per hour. The flight path is shown in Figure 6-15.

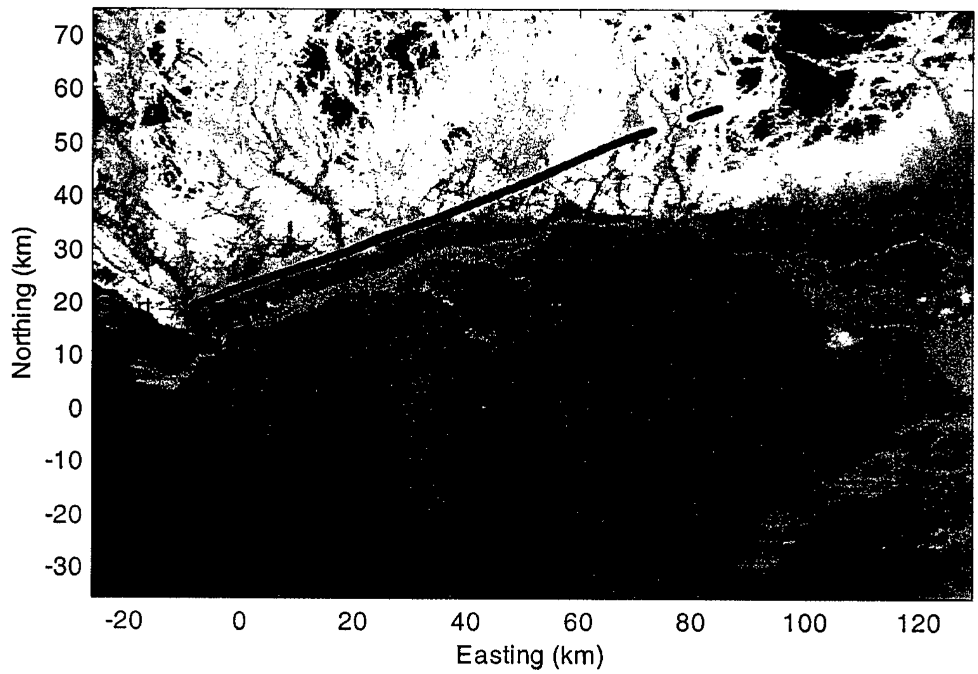

Figure 6-15 Flight Path for the Third Flight from Ottawa to Mirabel

An example of the data recorded during the third flight from Ottawa to Mirabel is shown in the range-Doppler map in Figure 6-16. This is CPI number 89, which was recorded at 16:50:07 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 1188meters above mean sea level, the antenna elevation angle is -4 degrees, and the antenna azimuth is +96.0 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -0.7 kHz. The data have been processed for the first range interval.

The figure shows strong mainlobe clutter from a range of about 9 kilometers. The wideband noise up to about 6 kilometers is actually mainlobe clutter in the second range interval and is therefore uncompressed in the first range interval. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The feature near 3.8 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.8 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz. The feature near 1.3 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

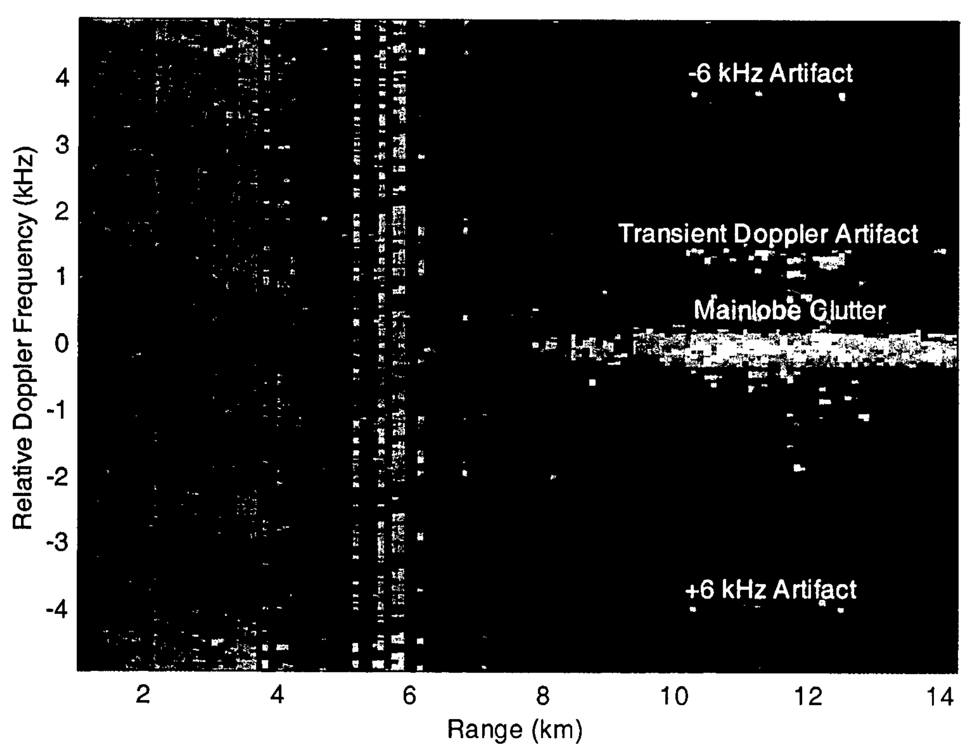

Figure 6-16 Phase-Agile Ground Clutter Data at 1250 Meters Altitude

6.2.3. Conventional Data at 750 Meters

File003 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the first part of the fourth and final flight from Mirabel to Ottawa. The file contains 3403 CPIs of conventional data. The antenna elevation angle is -2 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 744 meters with a standard deviation of 20 meters; the mean ground speed is 321 kilometers per hour with a standard deviation of 12 kilometers per hour. The flight path is shown in Figure 6-17.

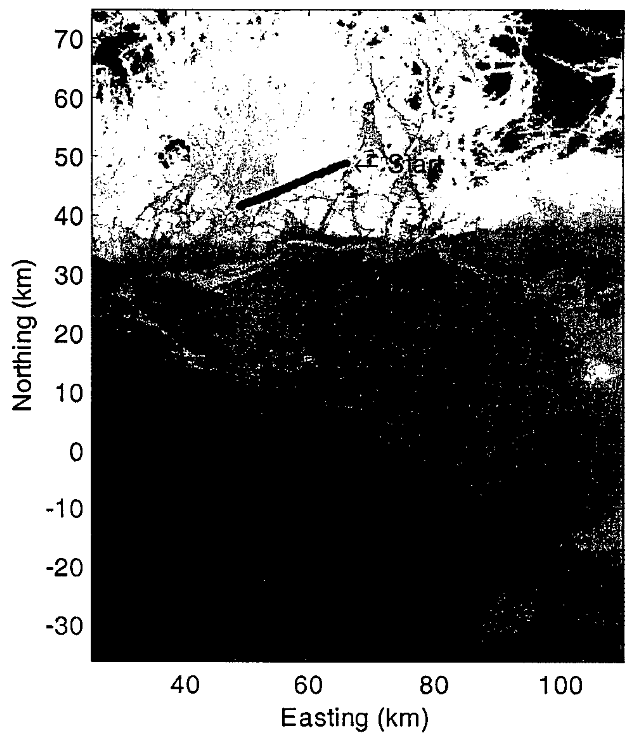

Figure 6-17 Flight Path for First Part of Fourth Flight from Ottawa to Mirabel

An example of the data recorded during the first part of the fourth flight from Ottawa to Mirabel is shown in the range-Doppler map in Figure 6-18. This is CPI number 125, which was recorded at 17:19:35 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 747 meters above mean sea level, the antenna elevation angle is -2 degrees, and the antenna azimuth is -91.8 degrees with respect to the true ground speed of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -0.2 kHz.

The figure shows strong mainlobe clutter from a range of about 2.8 kilometers. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The feature near 3.9 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.9 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz.

The figure also shows a target of opportunity with an apparent relative frequency of -1.5 kHz and an apparent range of 8.0 kilometers. The unambiguous range is 23.3 kilometers. The unambiguous frequency is -1.5 kHz, which corresponds to a velocity component of -82 kilometers per hour. The speed and range implies that the target might be a surface vehicle.

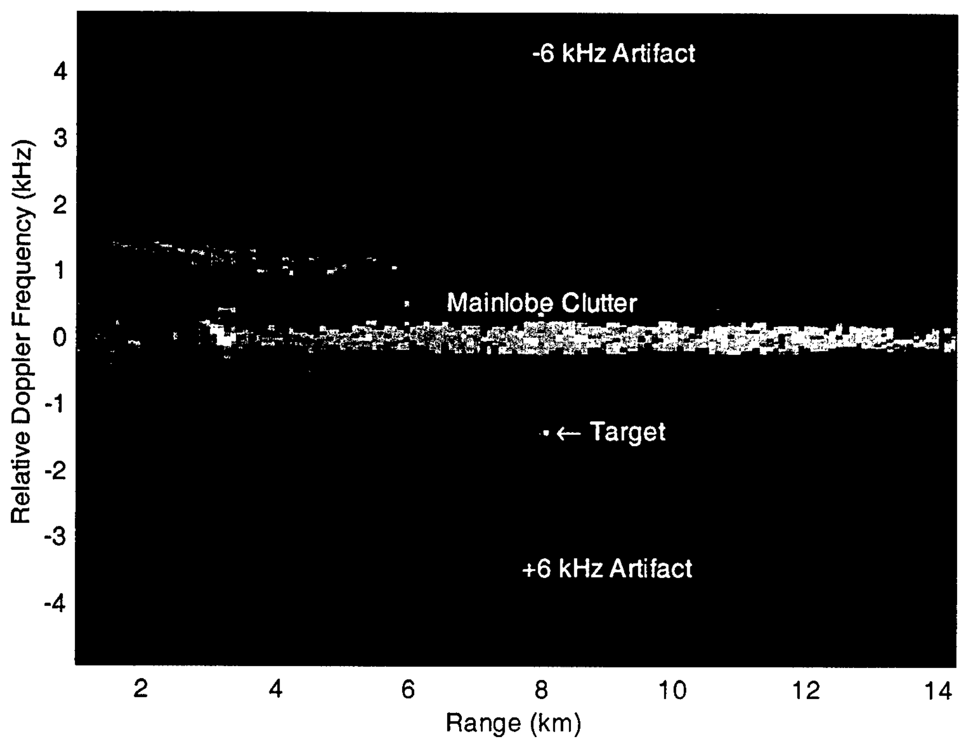

Figure 6-18 Conventional Ground Clutter Data at 750 Meters Altitude

6.2.4. Phase-Agile Data at 750 Meters

File004 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the second part of the fourth and final flight from Mirabel to Ottawa. The file contains 11486 CPIs of phase-agile data. The antenna elevation angle is -2 degrees. The antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 773 meters with a standard deviation of 7 meters; the mean ground speed is 311 kilometers per hour with a standard deviation of 11 kilometers per hour. The flight path is shown in Figure 6-19.

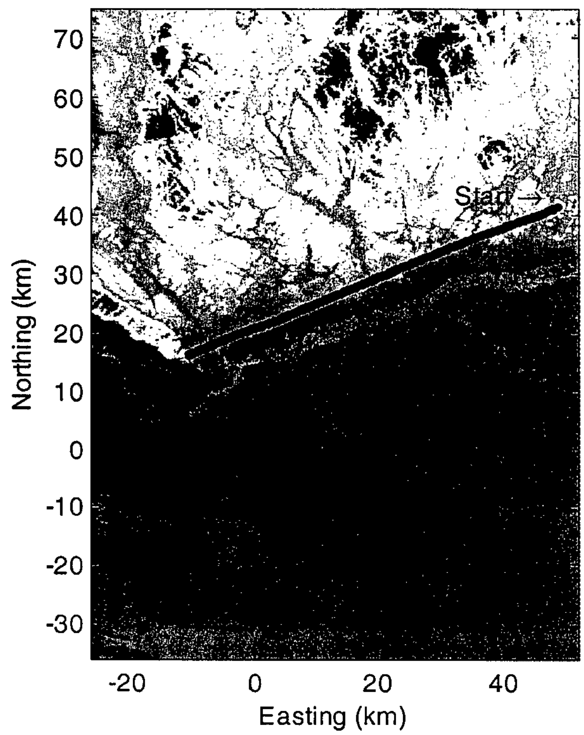

Figure 6-19 Flight Path for the Second Part of the Fourth Flight from Ottawa to Mirabel

An example of the data recorded during the second part of the fourth flight from Ottawa to Mirabel is shown in the range-Doppler map in Figure 6-20. This is CPI number 135, which was recorded at 17:23:19 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 771 meters above mean sea level, the antenna elevation angle is -2 degrees, and the antenna azimuth is +75.2 degrees with respect to the true ground speed of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 1.4 kHz. The data have been processed for the first range interval.

The figure shows patches of strong mainlobe clutter from a range of about 5 kilometers. The wideband noise is due to uncompressed mainlobe clutter energy in the second range interval. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise.

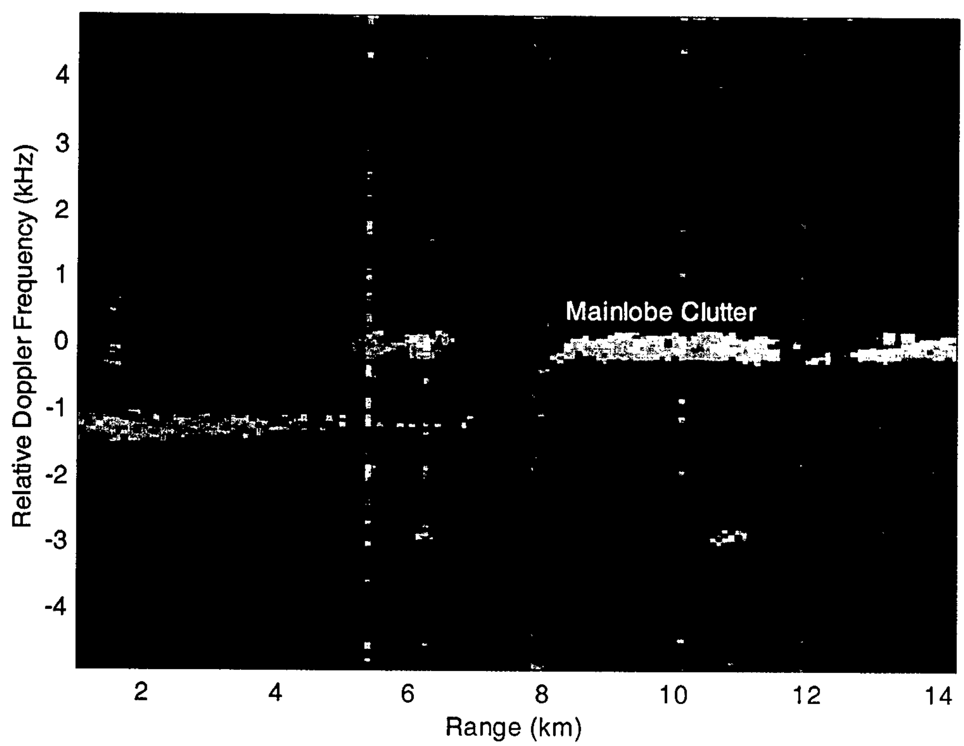

Figure 6-20 Phase-Agile Ground Clutter Data at 750 Meters Altitude

7. GROUND MOVING TARGET DATA

Data were recorded during flights over Highway 401 west of Cornwall, Ontario, on 22 and 28 October 1999. The intention was to capture returns from ground moving targets, that is vehicular traffic, on the highway. Table 7-1 summarizes the ground moving target data that were recorded. The table includes the tape label, the file number, the radar mode, the number of coherent processing intervals, the mean altitude (meters above mean sea level), and the antenna elevation angle (degrees up).

Table 7-1 Ground Target Data

Tape Label / File Number	**Mode**	**Number of CPIs**	**Mean Altitude** (meters)	**Antenna Elevation** (degrees)
1999-10-22-16-29				
File008	Conventional	6692	776	-14
File010	Phase-Agile	10664	780	-14
1999-10-28-15-30				
File001	Conventional	20608	723	-4
File002	Phase-Agile	15675	731	-4
File004	Conventional	20174	730	-4
File005	Conventional	13774	773	-4
File006	Conventional	15269	762	-4

7.1. SECOND SORTIE GROUND MOVING TARGETS

File008 through File010 on Tape 1999-10-22-16-29 contain data recorded during second sortie flights over Highway 401 between Cornwall and Brockville. These data were recorded at a nominal altitude of 750 meters above mean sea level, with an antenna elevation angle of -14 degrees, and an antenna azimuth scan of ±10 degrees. These data are discussed in the following sections.

7.1.1. Conventional Data

File008 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the second sortie flight over Highway 401 from Cornwall to Morrisburg. The file contains 6692 CPIs of conventional data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±10 degrees. The mean altitude above mean sea level is 776 meters with a standard deviation of 3 meters; the mean ground speed is 282 kilometers per hour with a standard deviation of 11 kilometers per hour. The flight path is shown in Figure 7-1.

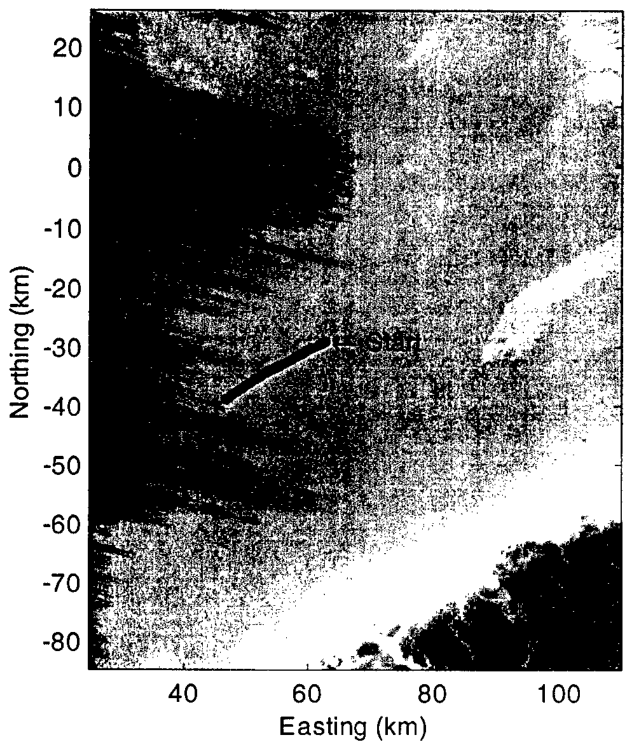

Figure 7-1 Flight Path for the Second Sortie Flight from Cornwall to Morrisburg

An example of the data recorded during the second sortie flight over Highway 401 is shown in the range-Doppler map in Figure 7-2. This is CPI number 124, which was recorded at 18:12:24 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 775 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -7.2 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.1 kHz.

The figure shows very strong mainlobe clutter from about 2 kilometers to 5 kilometers apparent range. The power level of the mainlobe clutter is about 50 dB above the background noise. The features near ±3.9 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz. The feature near -0.4 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows a number of targets, with apparent relative frequencies near 1.8 kHz (Target 1), -1.5 kHz (Target 2), and -2.2 kHz (Target 3). The targets are all at about the same apparent range of 2.6 kilometers. The unambiguous ranges are 2.6 kilometers for all targets. The unambiguous frequencies are 1.8 kHz, -1.5 kHz, and -2.2 kHz respectively. These frequencies correspond to velocity components of 101, -86, and -121 kilometers per hour respectively. The speeds and ranges are consistent with vehicular traffic on Highway 401.

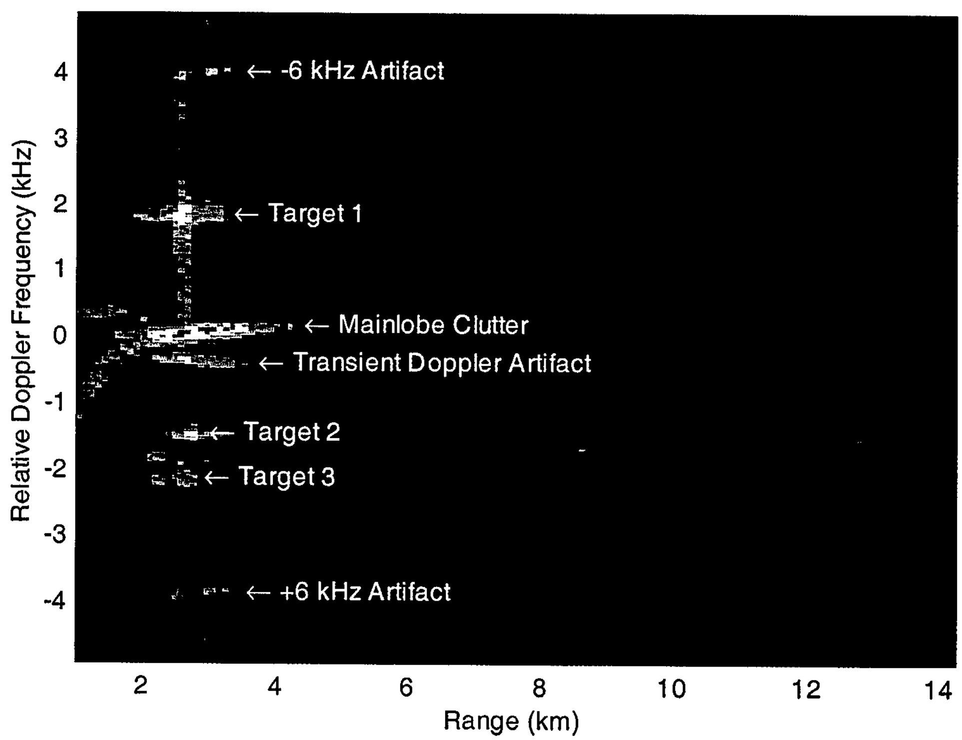

Figure 7-2 Second Sortie Conventional Ground Target Data

7.1.2. Phase-Agile Data, Part 1

File009 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the first flight over Highway 401 from Morrisburg to Cornwall. Due to a failure of the radar transmitter, the file contains only 436 CPIs of phase-agile data. The file will not be discussed further.

7.1.3. Phase-Agile Data, Part 2

File010 on Tape 1999-10-22-16-29 contains data recorded on 22 October 1999 during the continuation of the first flight over Highway 401 from Morrisburg to Cornwall. The file contains 10664 CPIs of phase-agile data. The antenna elevation angle is -14 degrees. The antenna azimuth scan is ±10 degrees. The mean altitude above mean sea level is 780 meters with a standard deviation of 5 meters; the mean ground speed is 395 kilometers per hour with a standard deviation of 15 kilometers per hour. The flight path is shown in Figure 7-3.

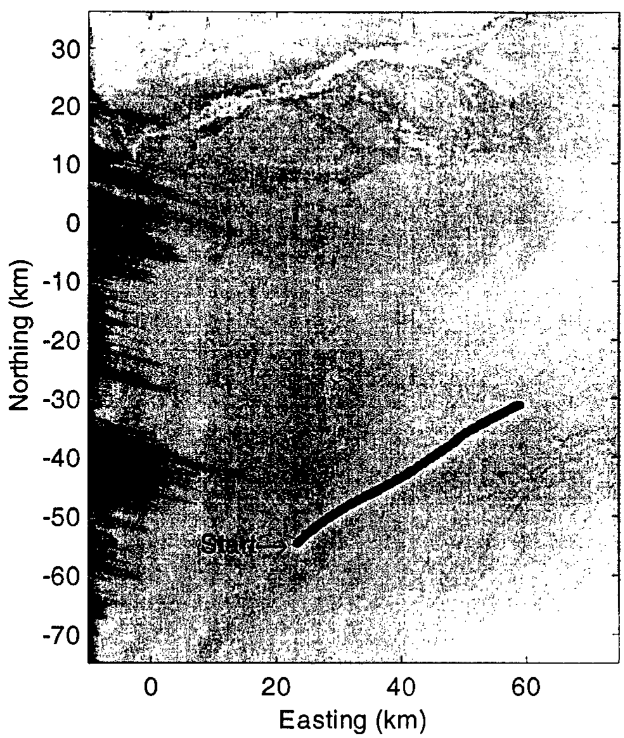

Figure 7-3 Flight Path for the Second Sortie Flight from Morrisburg to Cornwall

An example of the data recorded during the second sortie flight over Highway 401 from Morrisburg to Cornwall is shown in the range-Doppler map in Figure 7-4. This is CPI number 58, which was recorded at 18:25:32 UTC on 22 October 1999. The PRF is 9.827 kHz, the altitude is 779 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is +3.1 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 7.1 kHz. The data have been processed for the first range interval.

The figure shows very strong mainlobe clutter from about 2 kilometers to 5 kilometers range. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The features near -3.8 and 3.5 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz. The feature near -4.5 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows at least two clusters of targets, with apparent relative frequencies of 2.0 kHz (Target Cluster 1) and -2.0 kHz (Target Cluster 2). The targets are all at about the same range of 3.0 kilometers. The unambiguous frequencies are 2.0 kHz and –2.0 kHz respectively, corresponding to velocity components of 110 and -112 kilometers per hour. The speeds and ranges are consistent with vehicular traffic on Highway 401.

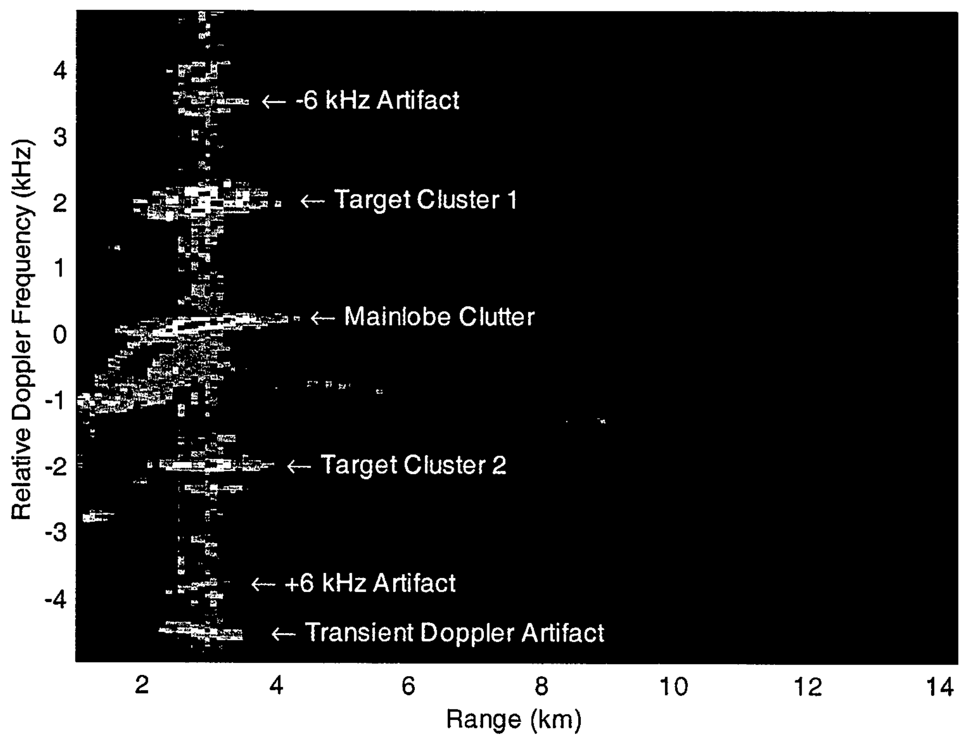

Figure 7-4 Second Sortie Phase-Agile Ground Target Data

7.2. FOURTH SORTIE GROUND MOVING TARGETS

File001 through File006 on Tape 1999-10-28-15-30 contain data recorded during fourth sortie flights over Highway 401 between Cornwall and Brockville. These data were recorded at a nominal altitude of 750 meters above mean sea level, with an antenna elevation angle of -4 degrees, and an antenna azimuth scan of ±10 degrees. These data are discussed in the following sections.

7.2.1. Conventional Data

File001 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the first flight of sortie four over Highway 401 from Cornwall to Brockville. The file contains 20608 CPIs of conventional data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±10 degrees. The mean altitude above mean sea level is 723 meters with a standard deviation of 11 meters; the mean ground speed is 274 kilometers per hour with a standard deviation of 5 kilometers per hour. The flight path is shown in Figure 7-5.

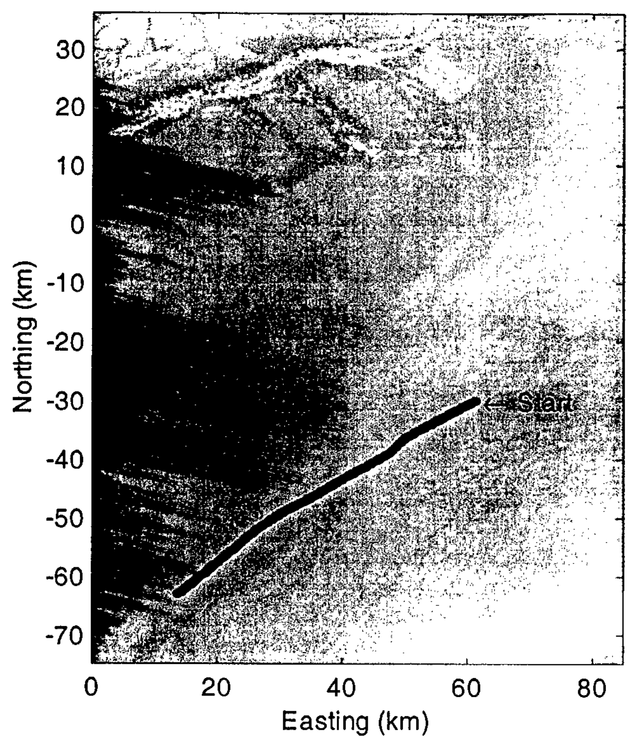

Figure 7-5 Flight Path for the First Flight of the Fourth Sortie from Cornwall to Brockville

An example of the data recorded during the first flight of the fourth sortie over Highway 401 is shown in the range-Doppler map in Figure 7-6. This is CPI number 15291, which was recorded at 15:40:53 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 739 meters above mean sea level, the antenna elevation angle is -4 degrees, and the antenna azimuth is -1.4 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 4.8 kHz.

The figure shows mainlobe clutter at all ranges, with very strong mainlobe clutter from about 5 to 13 kilometers apparent range. The power level of the mainlobe clutter is about 50 dB above the background noise. The features near ±3.5 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz. The wideband feature at 8.0 kilometers is probably due to receiver saturation from the strong target at -1.7 kHz.

The figure also shows a large number of targets, with apparent relative frequencies clustered about ±1.7 kHz. The apparent target ranges are from 3.4 to 13.6 kilometers. The range and frequency ambiguities cannot be resolved easily due to the large number of targets. The relative frequencies correspond to velocity components of ±95 kilometers per hour. The maximum target velocity is about 118 kilometers per hour. The speeds and ranges are consistent with vehicular traffic on Highway 401. The targets at 13 kilometers range are probably vehicles turning off Highway 401 onto Highway 16 near Prescott.

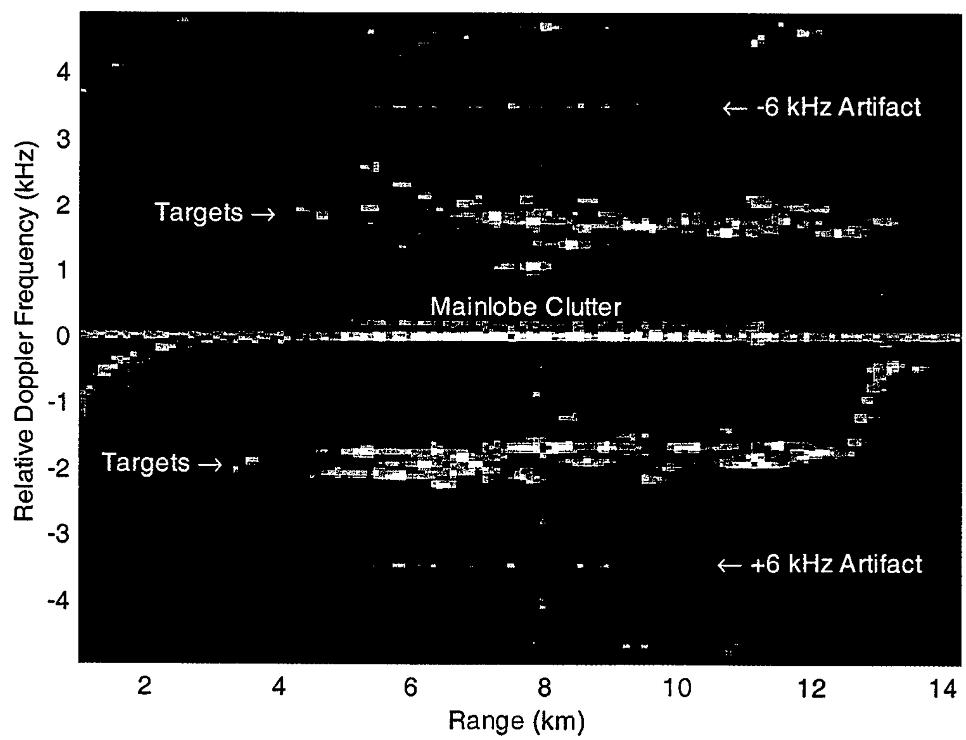

Figure 7-6 Fourth Sortie Conventional Ground Target Data

7.2.2. Phase-Agile Data, Part 1

File002 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the first flight of the fourth sortie over Highway 401 from Brockville to Cornwall. The file contains 15675 CPIs of phase-agile data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±10 degrees. The mean altitude above mean sea level is 731 meters with a standard deviation of 8 meters; the mean ground speed is 375 kilometers per hour with a standard deviation of 3 kilometers per hour. The flight path is shown in Figure 7-7.

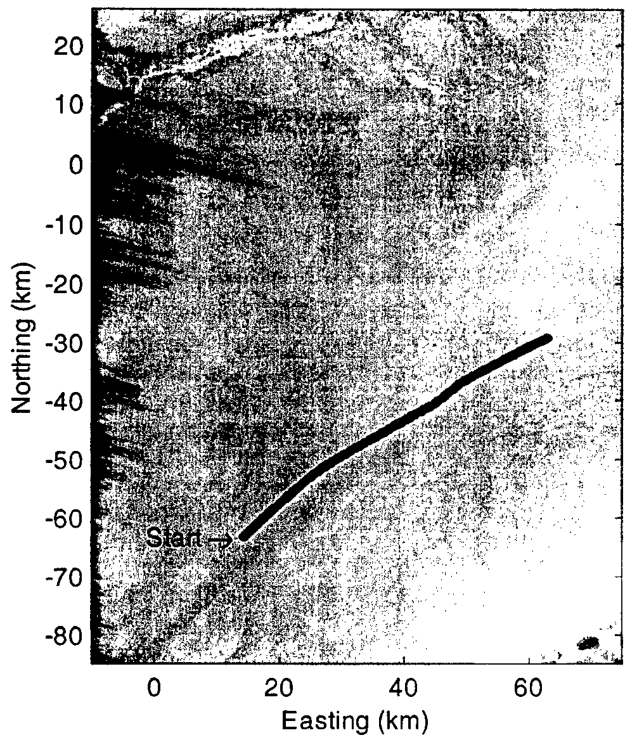

Figure 7-7 Flight Path for the First Flight of the Fourth Sortie from Brockville to Cornwall

An example of the data recorded during the first flight of the fourth sortie over Highway 401 from Brockville to Cornwall is shown in the range-Doppler map in Figure 7-8. This is CPI number 12, which was recorded at 15:46:47 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 708 meters above mean sea level, the antenna elevation angle is -4 degrees, and the antenna azimuth is +1.6 degrees with respect to the true ground speed of the aircraft. The data have been processed for the first range interval.

The figure shows strong mainlobe clutter from about 4 kilometers range. The power level of the mainlobe clutter is about 50 dB above the power level of the background noise. The feature near 3.5 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.5 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz.

The figure also shows a large number of targets, with apparent relative frequencies clustered about ±1.6 kHz. The target ranges are from 4.8 to 13.8 kilometers. The relative frequencies correspond to velocity components of ±89 kilometers per hour. The maximum target velocity is about 114 kilometers per hour. The speeds and ranges are consistent with vehicular traffic on Highway 401.

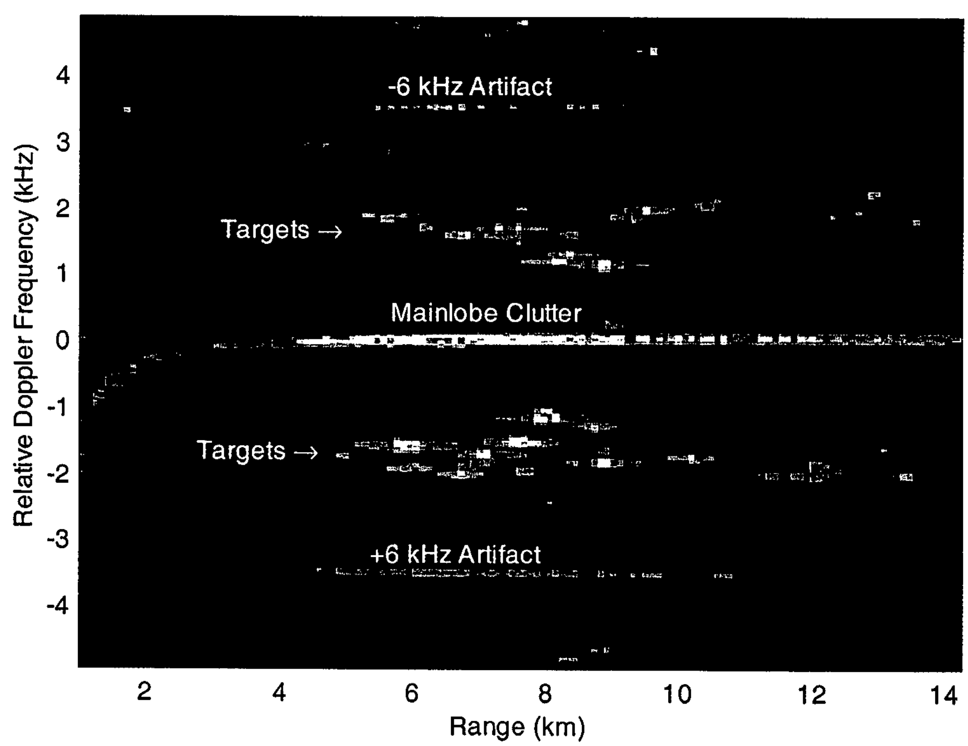

Figure 7-8 Fourth Sortie Phase-Agile Ground Target Data

7.2.3. Phase-Agile Data, Part 2

File003 on Tape 1999-10-22-16-29 contains data recorded on 28 October 1999 during the second flight over Highway 401 from Cornwall to Brockville. Due to a failure of the recording system, the file contains only 642 CPIs of phase-agile data. These data will not be discussed further.

7.2.4. Conventional Data with High-Voltage Blanking Enabled

File004 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the second flight of the fourth sortie over Highway 401 from Cornwall to Brockville. The file contains 20174 CPIs of conventional data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±10 degrees. The mean altitude above mean sea level is 730 meters with a standard deviation of 14 meters; the mean ground speed is 277 kilometers per hour with a standard deviation of 5 kilometers per hour.

The transmitter high-voltage blanking, which was normally disabled, was enabled for this data set to determine its impact on the quality of the recorded data. Analysis of the impact of the high-voltage blanking is left to future work.

7.2.5. Conventional Data with Asynchronous Transmitter Clock

File005 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the second flight of the fourth sortie over Highway 401 from Brockville to Cornwall. The file contains 13774 CPIs of conventional data. The antenna elevation angle is -4 degrees. The antenna azimuth scan is ±10 degrees. The mean altitude above mean sea level is 757 meters with a standard deviation of 9 meters; the mean ground speed is 390 kilometers per hour with a standard deviation of 5 kilometers per hour.

The 8.33 MHz synchronization clock was disconnected from the transmitter for this data set, forcing the transmitter to generate its own clock signals internally. This was done to determine the impact of clock synchronization on the quality of the recorded data. Analysis of the impact of the clock synchronization is left to future work.

7.2.6. Conventional Data with Air Target

File006 on Tape 1999-10-28-15-30 contains data recorded on 28 October 1999 during the third and final flight of the fourth sortie over Highway 401 from Cornwall to Brockville. The file contains 15269 CPIs of conventional data. The file contains two segments of data: the first to record returns from ground moving targets on Highway 401 and the second to record returns from an aircraft target of opportunity. In the first segment, the antenna elevation angle is -4 degrees and the antenna azimuth scan is ±10 degrees. In the second segment, the antenna elevation angle is +10 degrees and the antenna azimuth scan is ±20 degrees. The mean altitude above mean sea level is 762 meters with a standard deviation of 35 meters; the mean ground speed is 263 kilometers per hour with a standard deviation of 9 kilometers per hour. The flight path is shown in Figure 7-9.

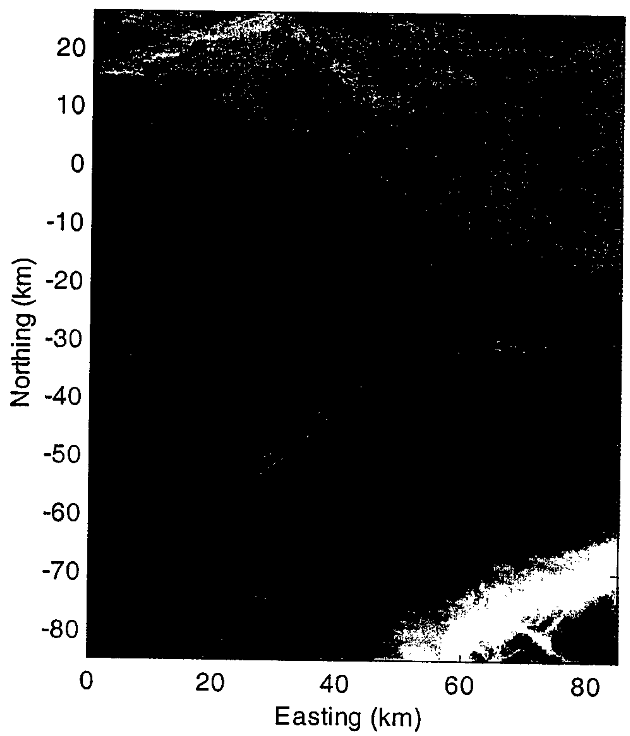

Figure 7-9 Flight Path for the Third Flight of the Fourth Sortie from Cornwall to Brockville

The returns from ground moving targets on Highway 401 are similar to those shown in Section 7.2.1. An example of the aircraft returns recorded during the third flight of the fourth sortie over Highway 401 from Cornwall to Brockville is shown in the range-Doppler map in Figure 7-10. This is CPI number 6384, which was recorded at 16:29:44 UTC on 28 October 1999. The PRF is 9.827 kHz, the altitude is 784 meters above mean sea level, the antenna elevation angle is +10 degrees, and the antenna azimuth is +17.1 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 4.3 kHz.

The figure shows weak sidelobe clutter to about 8 kilometers range. The power level of sidelobe clutter is about 15 dB above the power level of the background noise.

The figure also shows a target with a relative frequency of -3.2 kHz and an apparent range of 3.9 kilometers. The range and frequency ambiguities can be resolved by locating the target in CPIs with other pulse repetition frequencies. The unambiguous range is 3.9 kilometers and the unambiguous frequency is –3.2 kHz. This frequency corresponds to a velocity component of -176 kilometers per hour. The speed and range are consistent with the recorded observation of another aircraft.

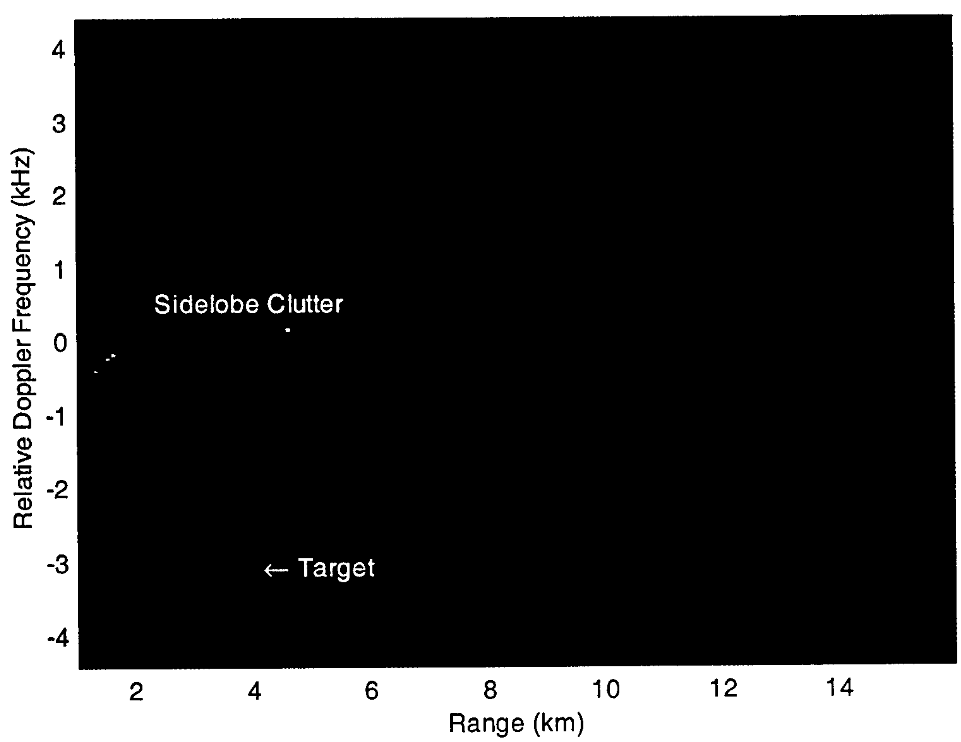

Figure 7-10 Conventional Aircraft Target Data

8. WATER CLUTTER DATA

Data were recorded during third sortie flights above Lake Ontario on 25 October 1999. The intention was to capture water clutter returns from the lake surface. Table 8-1 summarizes the water clutter data that were recorded. The table includes the tape label, the file number, the radar mode, the number of coherent processing intervals, the mean altitude (meters above mean sea level), and the antenna elevation angle (degrees up).

Table 8-1 Water Clutter Data

Tape Label / File Number	**Mode**	**Number of CPIs**	**Mean Altitude** (meters)	**Antenna Elevation** (degrees)
1999-10-25-15-30				
File001	Conventional	9982	6120	-14
File002	Phase-Agile	9573	6113	-14
File003	Conventional	3623	2694	-7
File004	Phase-Agile	8738	2706	-7
File005	Conventional	4672	1186	-4
File006	Conventional	5582	1187	-4
File008	Phase-Agile	8831	1202	-4
File009	Conventional	19142	747	-2
File010	Phase-Agile	7295	758	-2

8.1. THIRD SORTIE WATER CLUTTER

Tape 1999-10-25-15-30 is a large tape containing 10 files of data recorded during the third sortie flights above Lake Ontario. These data were recorded at nominal altitudes of 6000, 2700, 1250, and 750 meters above mean sea level, with antenna elevation angles of -14, -7, -4, and -2 degrees. The antenna azimuth scan is ±105 degrees. The end segment of File009 contains returns from an aircraft target of opportunity. This segment has an antenna elevation angle of zero degrees and an antenna azimuth scan of ±10 degrees. These data are discussed in the following sections.

8.1.1. Conventional Water Clutter Data at 6000 Meters

File001 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the first westbound flight above Lake Ontario. The file contains 9982 CPIs of conventional data. The antenna elevation angle is -14 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 6120 meters with a standard deviation of 5 meters; the mean ground speed is 369 kilometers per hour with a standard deviation of 2 kilometers per hour. The flight path is shown in Figure 8-1.

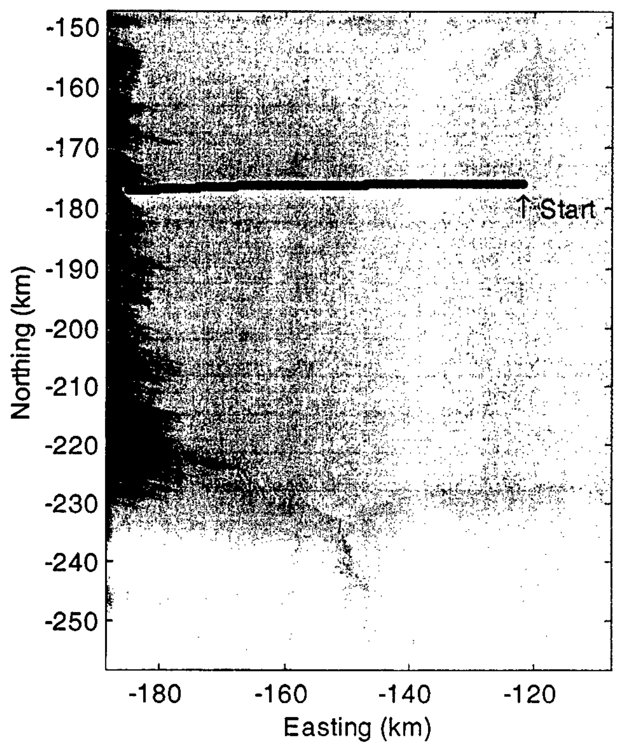

Figure 8-1 Flight Path for the First Westbound Flight above Lake Ontario

An example of the data during the first westbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-2. This is CPI number 187, which was recorded at 15:32:12 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 6115 meters above mean sea level (6040 meters above Lake Ontario). The antenna elevation angle is -14 degrees and the antenna azimuth is +5.2 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.3 kHz.

The figure shows weak mainlobe clutter from about 4 kilometers to 14 kilometers apparent range. The power level of the mainlobe clutter is about 30 dB above the power level of the background noise. The altitude return is seen at a range of 6.0 kilometers. The feature near -3 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

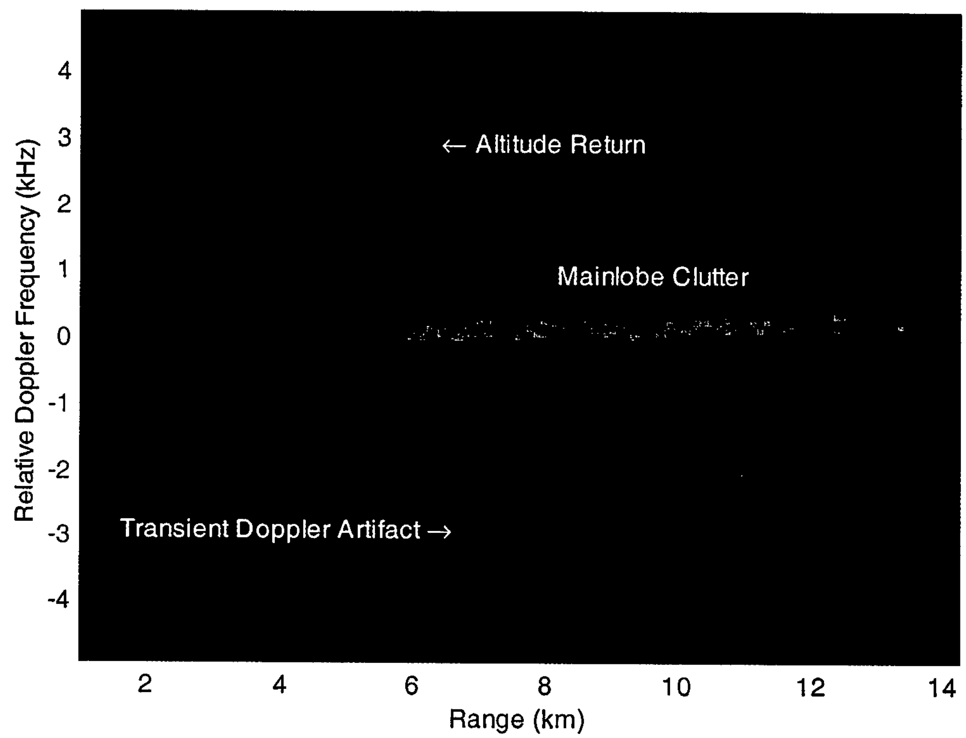

Figure 8-2 Conventional Water Clutter Data at 6000 Meters Altitude

The antenna beam illuminated a portion of the north shore of Lake Ontario whenever the antenna pointed north. An example of this is shown in the range-Doppler map in Figure 8-3. This is CPI number 247, which was recorded at 15:32:13 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 6115 meters above mean sea level (6040 meters above Lake Ontario). The antenna elevation angle is -14 degrees and the antenna azimuth is 88.2 degrees with respect to the true ground track of the aircraft.

The figure shows strong mainlobe clutter from 5 kilometers to 14 kilometers apparent range. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The altitude return is seen at a range of 6.0 kilometers.

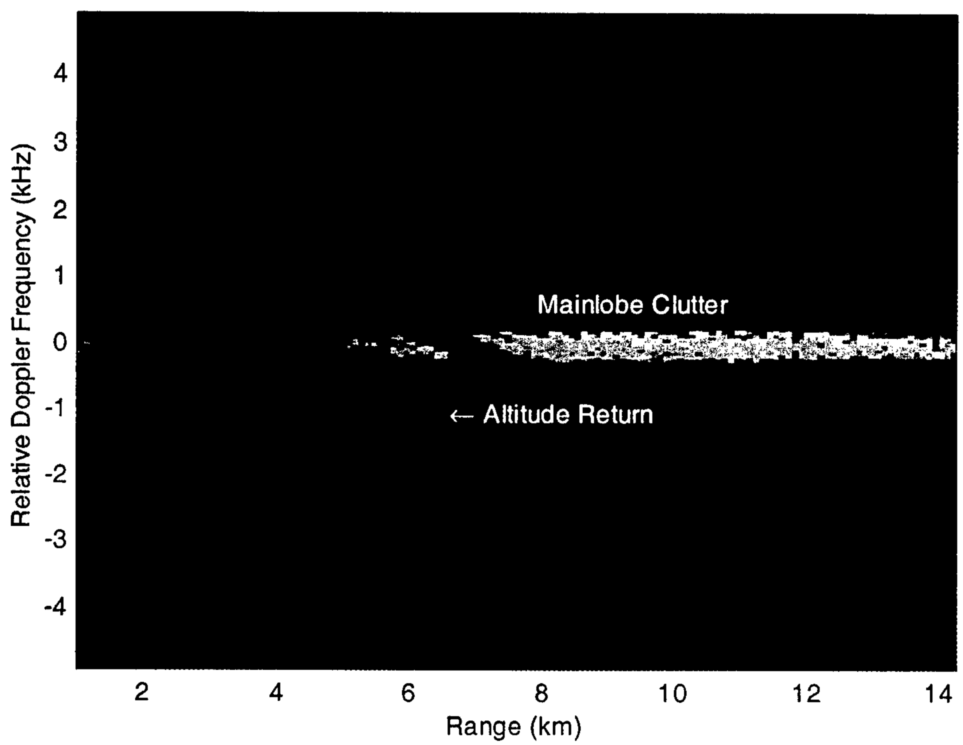

Figure 8-3 Clutter Returns from the North Shore of Lake Ontario

Note the break in the mainlobe clutter in Figure 8-3 from about 6.5 to 7.1 kilometers apparent range. Figure 8-4 shows that the mainlobe illuminates a portion of land on the north shore of Lake Ontario. The mainlobe also illuminates a bay at slant ranges from 20.8 to 21.7 kilometers. The break in the mainlobe clutter is likely due to the relatively weak radar returns from the bay or possibly due to terrain shadowing.

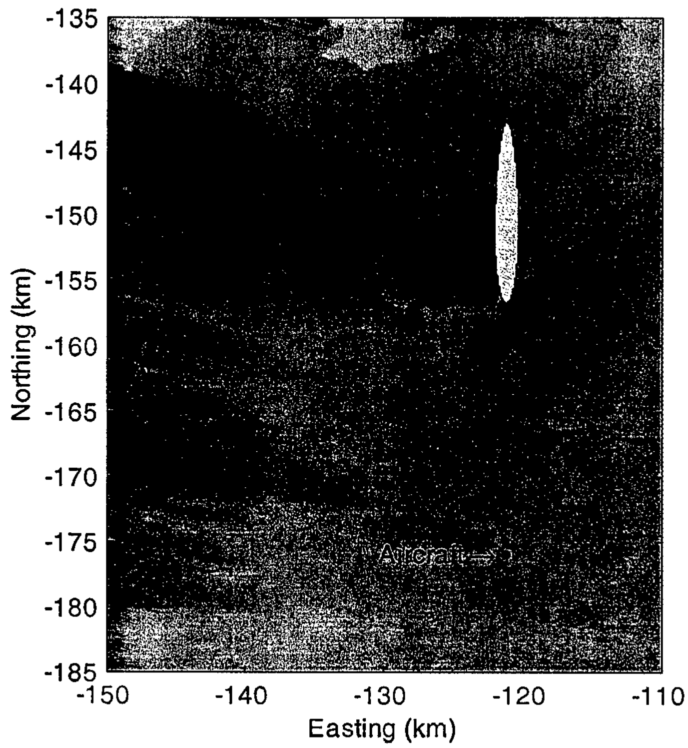

Figure 8-4 Aircraft and Mainlobe Beam Locations for Figure 8-3

8.1.2. Phase-Agile Water Clutter Data at 6000 Meters

File002 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the first eastbound flight above Lake Ontario. The file contains 9573 CPIs of phase-agile data. The antenna elevation angle is -14 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 6113 meters with a standard deviation of 8 meters; the mean ground speed is 498 kilometers per hour with a standard deviation of 3 kilometers per hour. The flight path is shown in Figure 8-5.

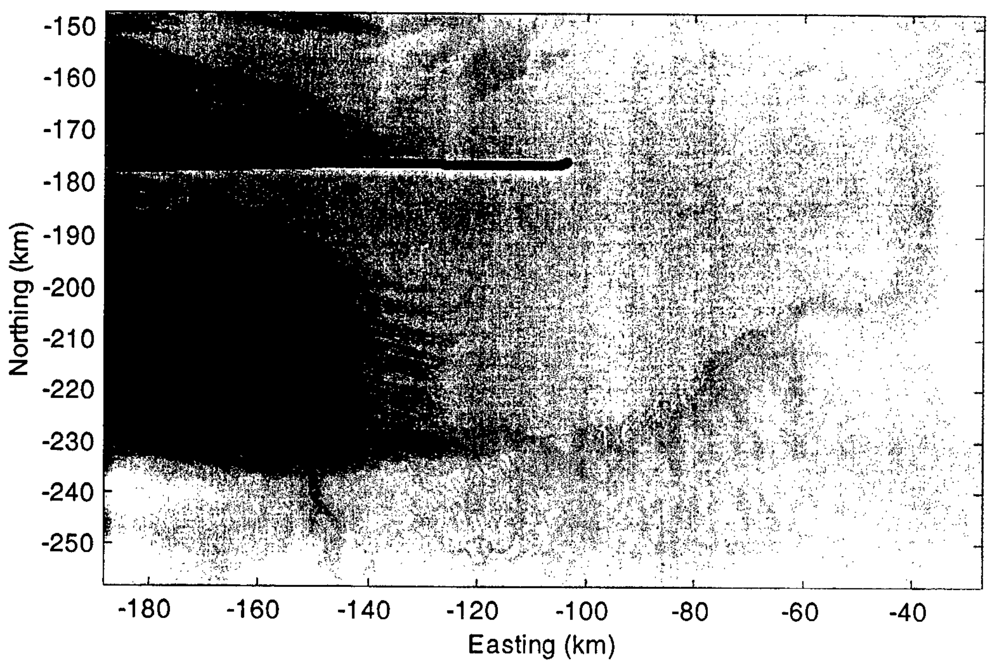

Figure 8-5 Flight Path for the First Eastbound Flight above Lake Ontario

An example of the data recorded during the first eastbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-6. This is CPI number 174, which was recorded at 15:46:07 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 6117 meters above mean sea level (6042 meters above Lake Ontario). The antenna elevation angle is -14 degrees and the antenna azimuth is -7.6 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 8.6 kHz.

The figure shows weak mainlobe clutter from about 20 kilometers range. The power level of the mainlobe clutter is about 35 dB above the power level of the background noise. The wideband noise at 21.2 kilometers range is actually the uncompressed altitude return located in the first range interval at a range of 6.0 kilometers.

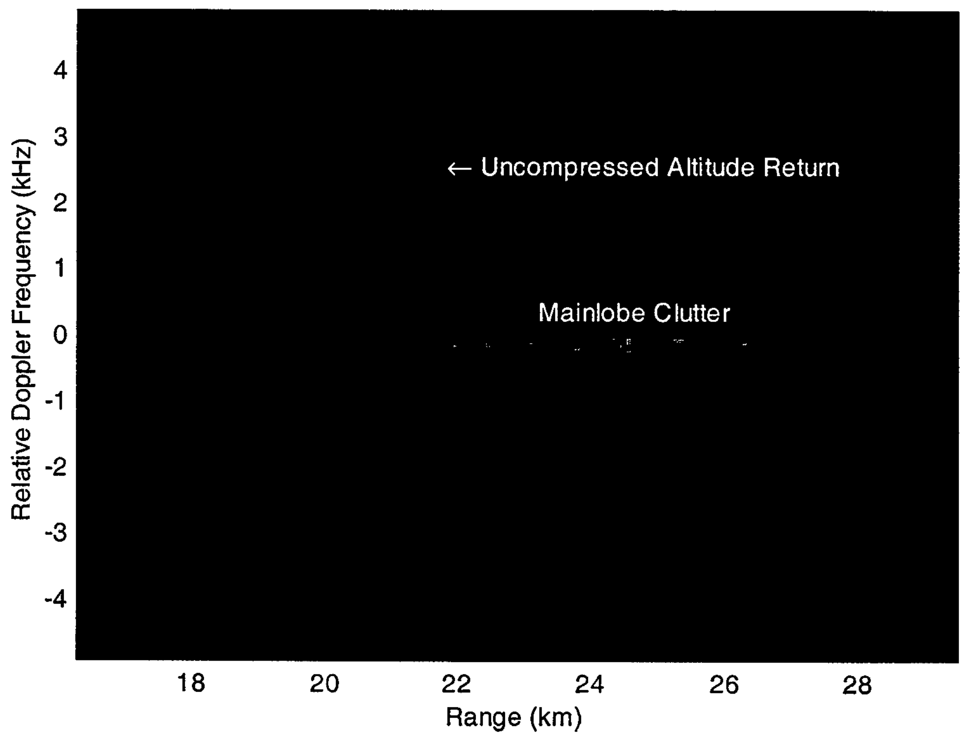

Figure 8-6 Phase-Agile Water Clutter Data at 6000 Meters Altitude

8.1.3. Conventional Water Clutter Data at 2500 Meters

File003 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the second westbound flight above Lake Ontario. The file contains 3623 CPIs of conventional data. The antenna elevation angle is -7 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 2694 meters with a standard deviation of 6 meters; the mean ground speed is 309 kilometers per hour with a standard deviation of 14 kilometers per hour. The flight path is shown in Figure 8-7.

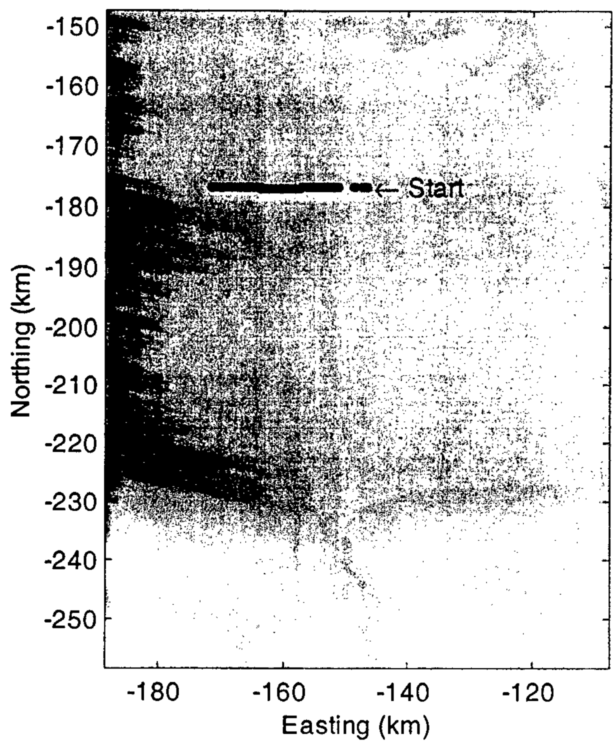

Figure 8-7 Flight Path for the Second Westbound Flight above Lake Ontario

An example of the data recorded during the second westbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-8. This is CPI number 2369, which was recorded at 16:04:44 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 2695 meters above mean sea level (2620 meters above Lake Ontario). The antenna elevation angle is -7 degrees and the antenna azimuth is +2.7 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.7 kHz.

The figure shows mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 35 dB above the power level of the background noise. The altitude return is seen at a range of 2.6 kilometers. The feature near -1.8 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

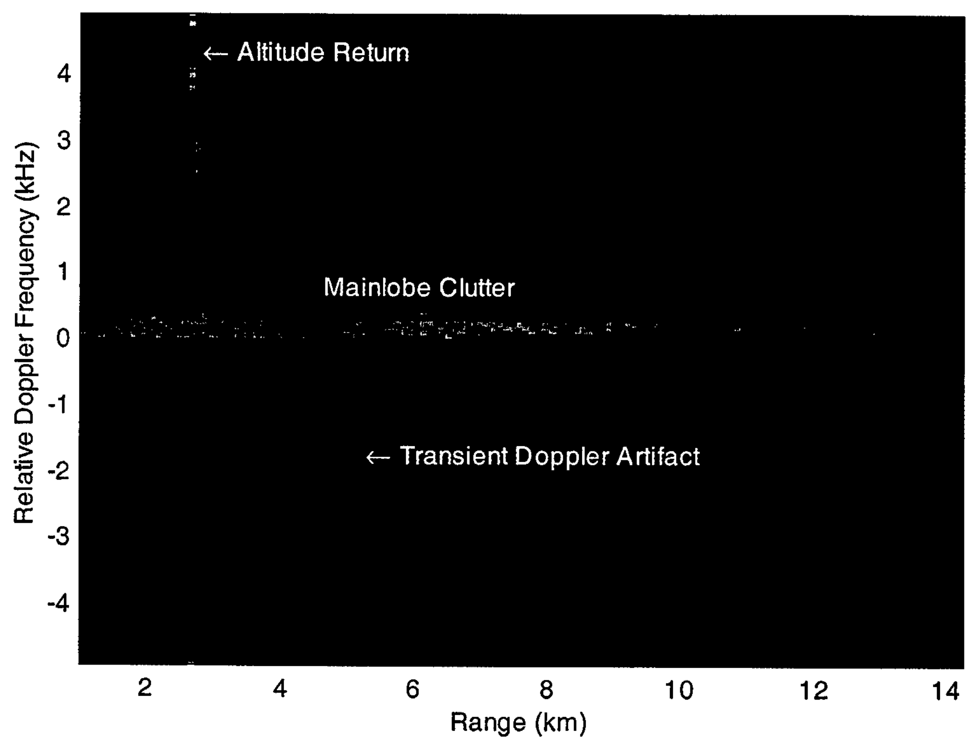

Figure 8-8 Conventional Water Clutter Data at 2500 Meters Altitude

8.1.4. Phase-Agile Water Clutter Data at 2500 Meters

File004 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the second eastbound flight above Lake Ontario. The file contains 8738 CPIs of phase-agile data. The antenna elevation angle is -7 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 2706 meters with a standard deviation of 3 meters; the mean ground speed is 434 kilometers per hour with a standard deviation of 2 kilometers per hour. The flight path is shown in Figure 8-9.

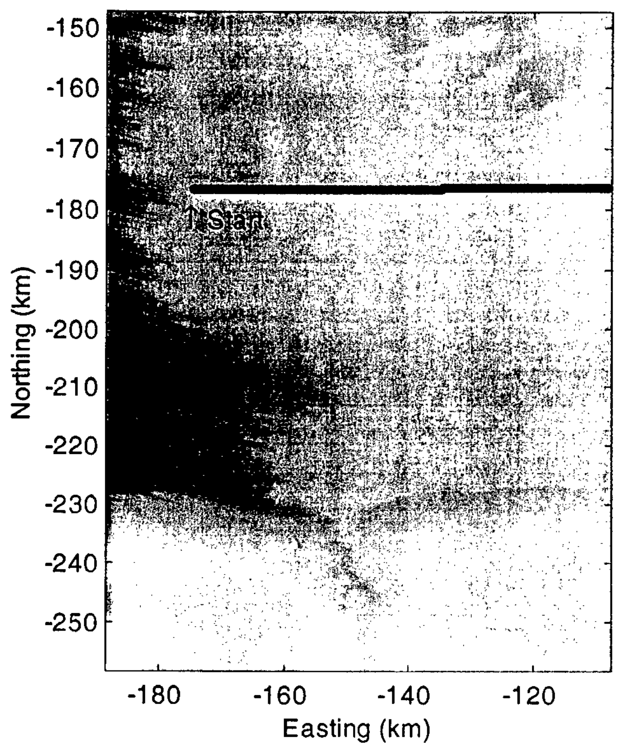

Figure 8-9 Flight Path for the Second Eastbound Flight above Lake Ontario

An example of the data recorded during the second eastbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-10. This is CPI number 172, which was recorded at 16:15:56 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 2704 meters above mean sea level (2629 meters above Lake Ontario). The antenna elevation angle is -7 degrees and the antenna azimuth is -4.5 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 7.1 kHz. The data have been processed for the second range interval.

The figure shows weak mainlobe clutter for all ranges. The power level of the mainlobe clutter is about 30 dB above the power level of the background noise. The wideband noise at 17.9 kilometers range is the uncompressed altitude return at a range of 2.6 kilometers.

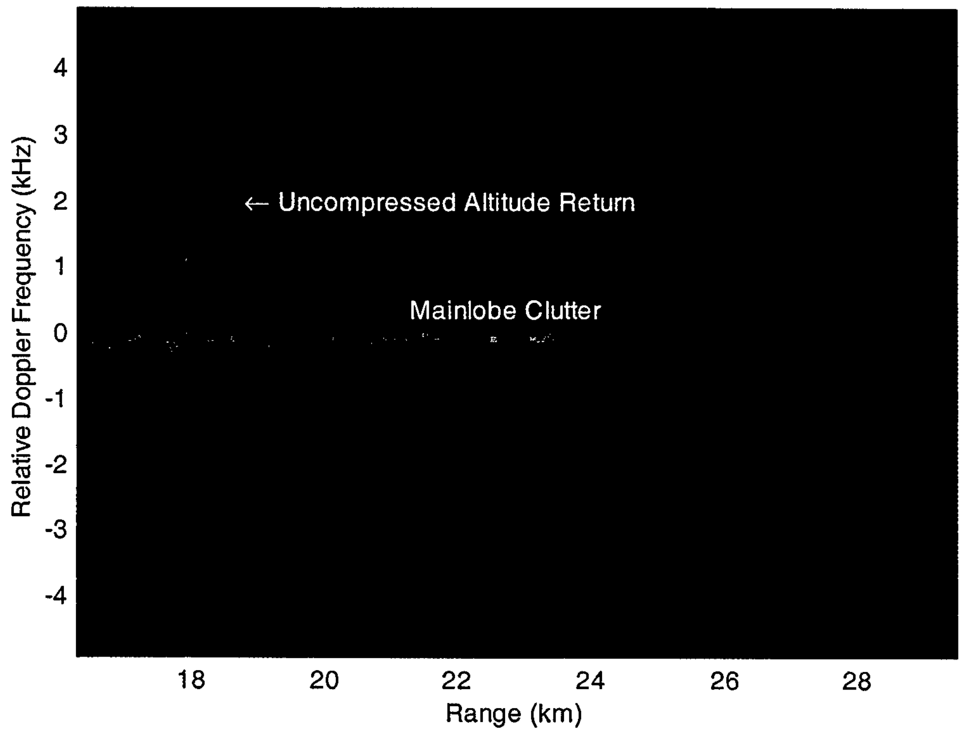

Figure 8-10 Phase-Agile Water Clutter Data at 2500 Meters Altitude

8.1.5. Conventional Water Clutter Data at 1250 Meters, Part 1

File005 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the first part of the third westbound flight above Lake Ontario. The file contains 4672 CPIs of conventional data. The antenna elevation angle is -4 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 1186 meters with a standard deviation of 3 meters; the mean ground speed is 293 kilometers per hour with a standard deviation of 7 kilometers per hour. The flight path is shown in Figure 8-11.

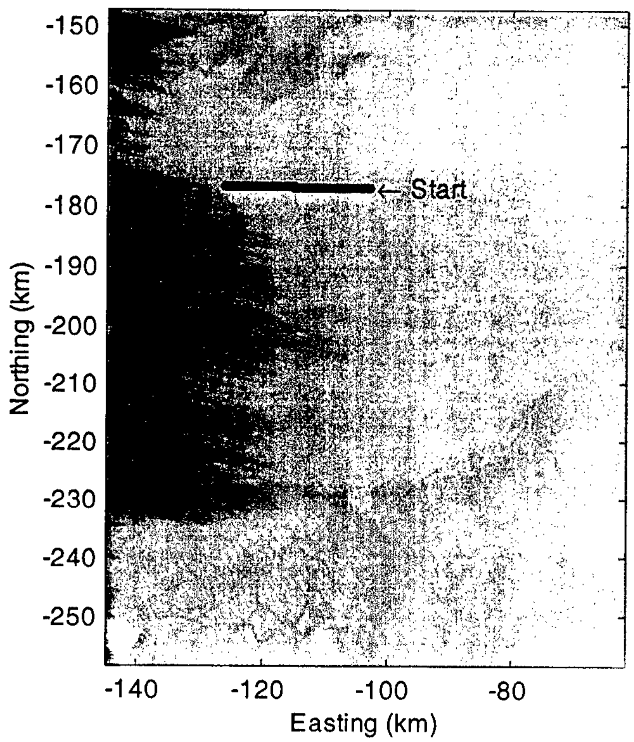

Figure 8-11 Flight Path for the First Part of the Third Westbound Flight above Lake Ontario

An example of the data recorded during the first part of the third westbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-12. This is CPI number 95, which was recorded at 16:30:39 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 1190 meters above mean sea level (1115 meters above Lake Ontario). The antenna elevation angle is -4 degrees and the antenna azimuth is -0.8 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.6 kHz.

The figure shows mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The altitude return is seen at a range of 1.2 kilometers. The feature near -1.5 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

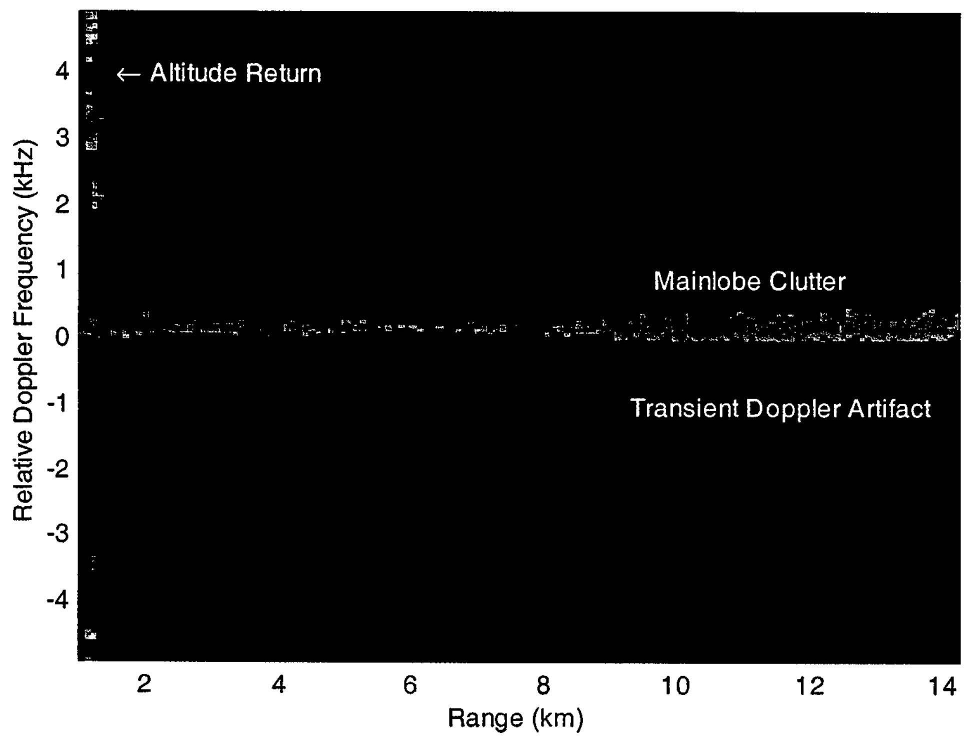

Figure 8-12 Conventional Water Clutter Data at 1250 Meters Altitude

8.1.6. Conventional Water Clutter Data at 1250 Meters, Part 2

File006 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the second part of the third westbound flight above Lake Ontario. This file was created inadvertently as the result of a failure of the radar transmitter. The file contains 5582 CPIs of conventional data. The antenna elevation angle is -4 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 1187 meters with a standard deviation of 5 meters; the mean ground speed is 282 kilometers per hour with a standard deviation of 2 kilometers per hour. The flight path is shown in Figure 8-13. The data in this file are similar to those shown above in Figure 8-12.

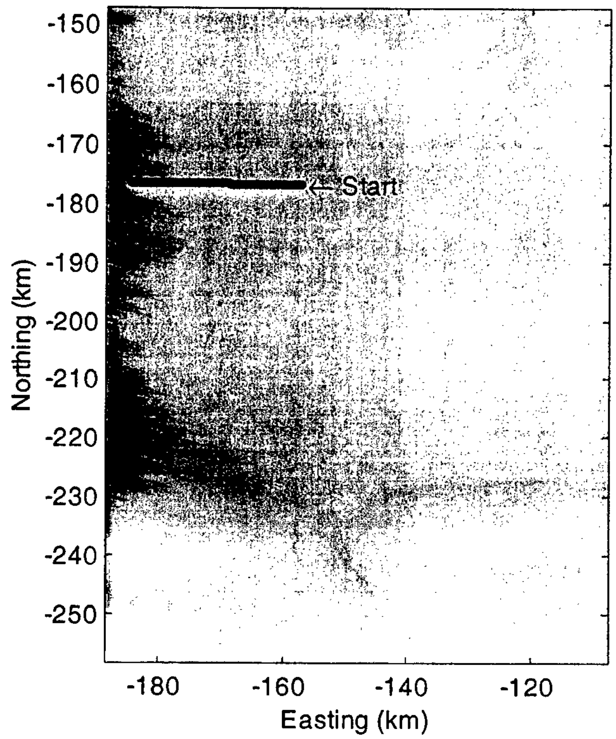

Figure 8-13 Flight Path for the Second Part of the Third Westbound Flight above Lake Ontario

8.1.7. Phase-Agile Water Clutter Data at 1250 Meters, Part 1

File007 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the first part of the third eastbound flight above Lake Ontario. Due to a failure of the radar transmitter, the file contains only 320 CPIs of phase-agile data. The file will not be discussed further.

8.1.8. Phase-Agile Water Clutter Data at 1250 Meters, Part 2

File008 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the second part of the third eastbound flight above Lake Ontario. The file contains 8831 CPIs of phase-agile data. The antenna elevation angle is -4 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 1202 meters with a standard deviation of 1 meter; the mean ground speed is 402 kilometers per hour with a standard deviation of 3 kilometers per hour. The flight path is shown in Figure 8-14.

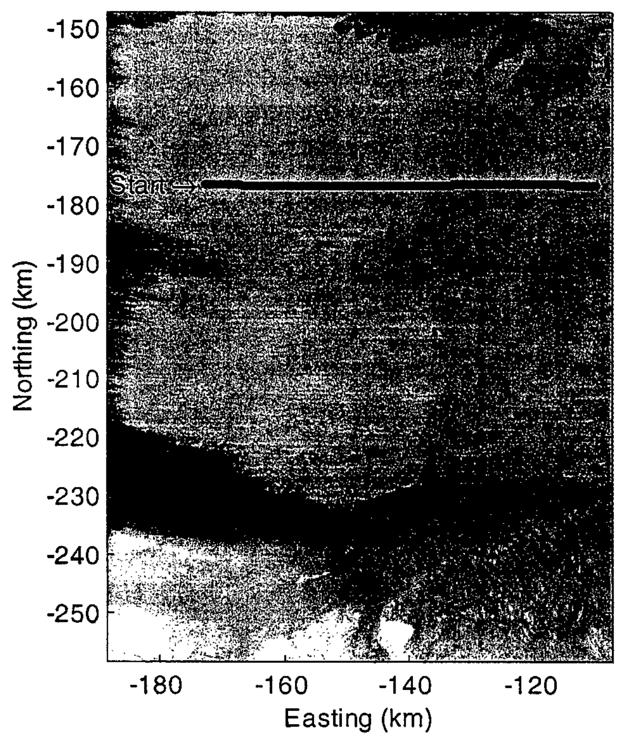

Figure 8-14 Flight Path for the Second Part of the Third Eastbound Flight above Lake Ontario

An example of the data recorded during the second part of the third eastbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-15. This is CPI number 403, which was recorded at 16:53:35 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 1200 meters above mean sea level (1125 meters above Lake Ontario). The antenna elevation angle is -4 degrees and the antenna azimuth is 27.2 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.3 kHz. The data have been processed for the first range interval.

The figure shows mainlobe clutter from a range of about 8 kilometers. The power level of the mainlobe clutter is about 30 dB above the power level of the background noise. The altitude is seen at a range of 1.2 kilometers. The feature at an apparent relative frequency of -3.1 kHz and a range of 13.3 kilometers is a transient Doppler artifact at the negative Doppler frequency of the target.

The figure also shows a target of opportunity, with an apparent relative frequency of 0.3 kHz and a range of 13.3 kilometers. The unambiguous frequency is 0.3 kHz, which corresponds to a velocity component of 16 kilometers per hour. The speed and range of the target is consistent with the recorded observation of a ship traversing Lake Ontario.

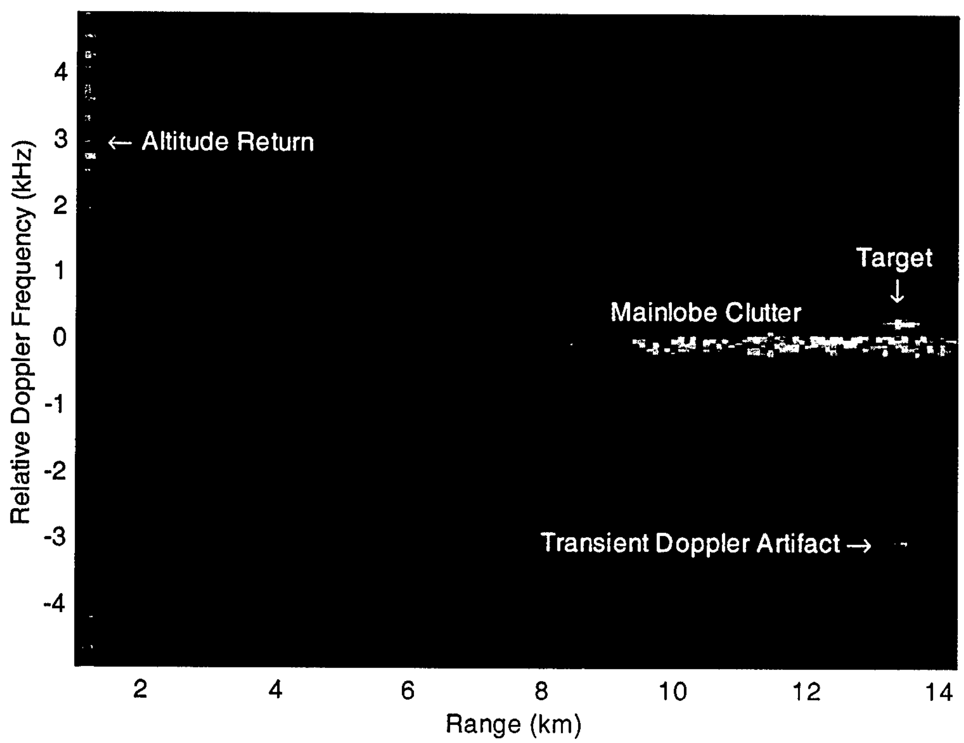

Figure 8-15 Phase-Agile Water Clutter Data at 1250 Meters Altitude

8.1.9. Conventional Water Clutter Data at 750 Meters

File009 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the fourth westbound flight above Lake Ontario. The file contains 19142 CPIs of conventional data. The file consists of two segments. In the first segment, the antenna elevation angle is -2 degrees and the antenna azimuth scan is ±105 degrees. In the second segment, the antenna elevation angle is zero degrees and the antenna azimuth scan is ±10 degrees. The second segment was flown to capture returns from an aircraft that was observed flying a parallel course to the north. The mean altitude above mean sea level is 747 meters with a standard deviation of 5 meters; the mean ground speed during the first segment is 279 kilometers per hour with a standard deviation of 7 kilometers per hour. The flight path is shown in Figure 8-16.

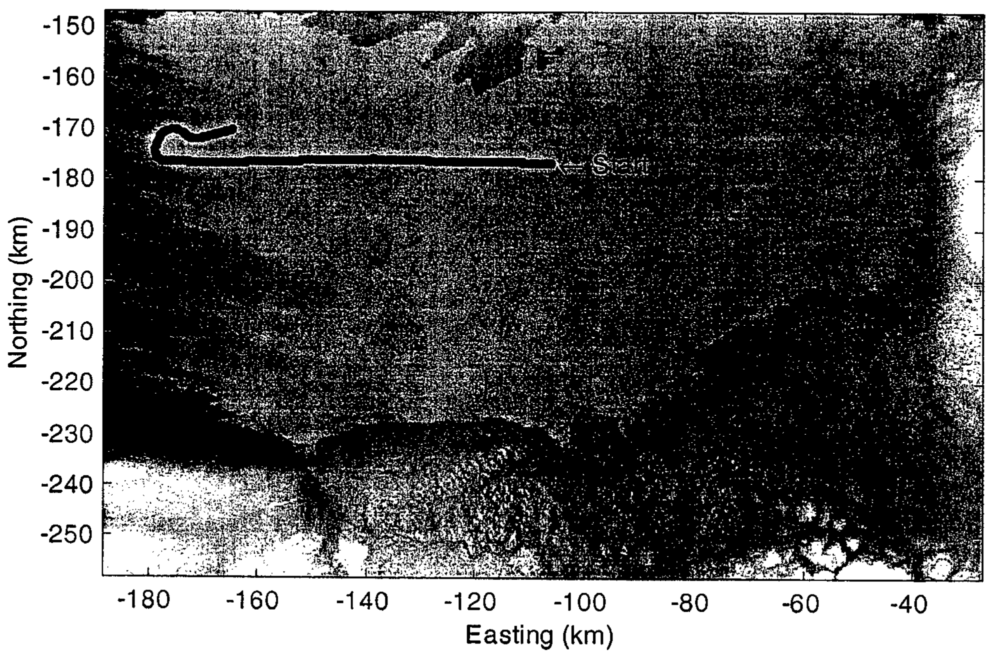

Figure 8-16 Flight Path for the Fourth Westbound Flight above Lake Ontario

An example of the data from the first segment of the fourth westbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-17. This is CPI number 273, which was recorded at 17:07:47 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 750 meters above mean sea level (675 meters above Lake Ontario). The antenna elevation angle is -2 degrees and the antenna azimuth is 1.6 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 5.3 kHz.

The figure shows mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 40 dB above the power level of the background noise. The feature near -1.0 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

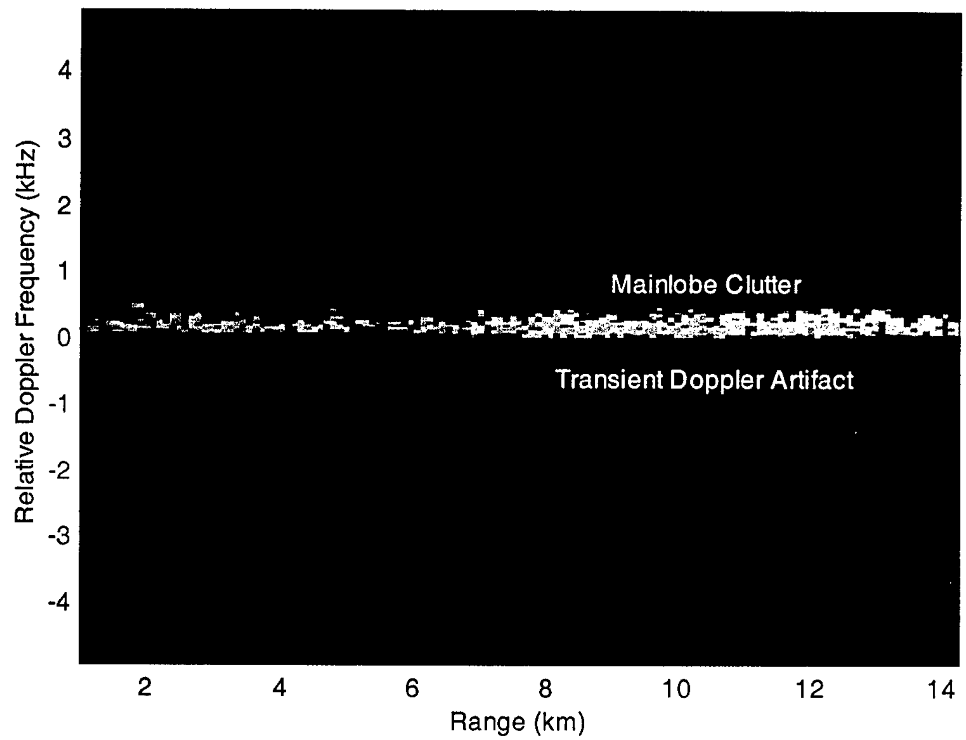

Figure 8-17 Conventional Water Clutter Data at 750 Meters Altitude

An example of the data from the second segment of the fourth westbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-18. This is CPI number 29921, which was recorded at 17:25:36 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 746 meters above mean sea level (671 meters above Lake Ontario). The antenna elevation angle is zero degrees and the antenna azimuth is 0.5 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 6.8 kHz.

The figure shows weak mainlobe clutter at all ranges. The power level of the mainlobe clutter is about 30 dB above the power level of the background noise.

The figure shows a target with an apparent relative frequency of 0.4 kHz and an apparent range of 4.4 kilometers. The unambiguous range is 111.2 kilometers. The unambiguous frequency is 0.4 kHz, which corresponds to a velocity component of 20 kilometers per hour. This target might be another aircraft that was observed flying a parallel course to the north.

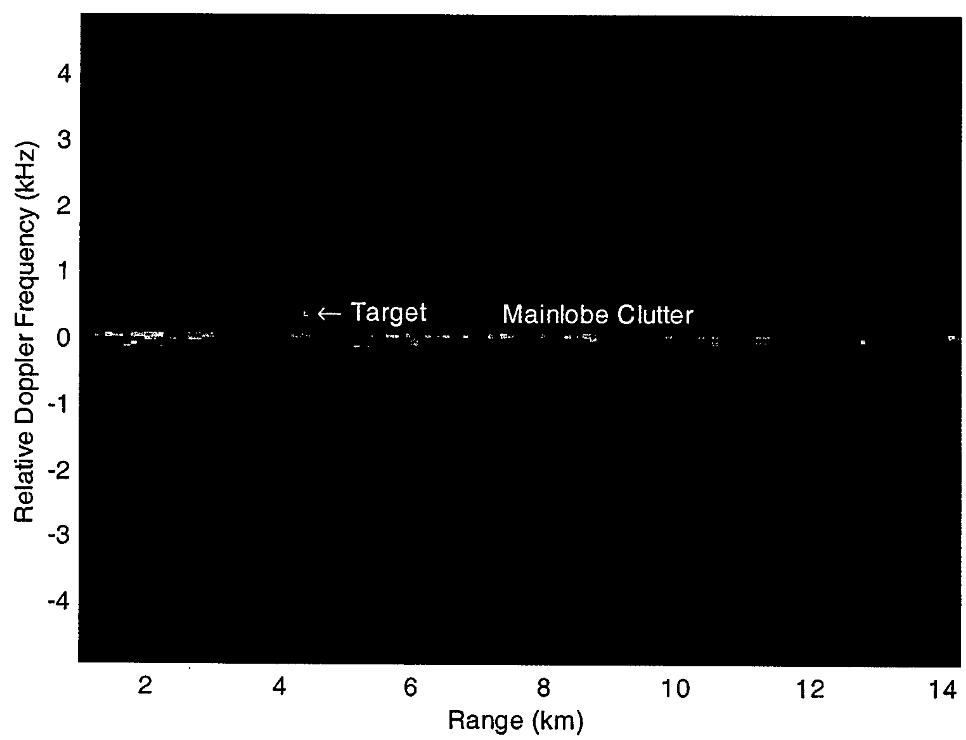

Figure 8-18 Conventional Data Showing Aircraft Target of Opportunity

8.1.10. Phase-Agile Water Clutter Data at 750 Meters

File010 on Tape 1999-10-25-15-30 contains data recorded on 25 October 1999 during the fourth and final eastbound flight above Lake Ontario. The file contains 7295 CPIs of phase-agile data. The antenna elevation angle is -2 degrees and the antenna azimuth scan is ±105 degrees. The mean altitude above mean sea level is 758 meters with a standard deviation of 4 meter; the mean ground speed is 390 kilometers per hour with a standard deviation of 7 kilometers per hour. The flight path is shown in Figure 8-19.

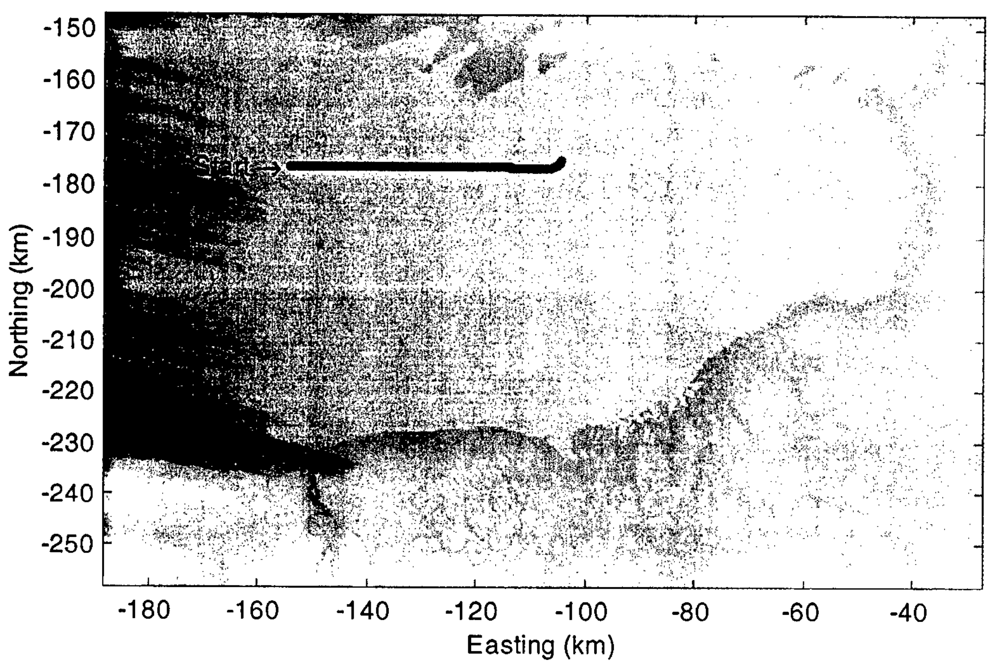

Figure 8-19 Flight Path for the Fourth Eastbound Flight above Lake Ontario

An example of the data recorded during the fourth and final eastbound flight above Lake Ontario is shown in the range-Doppler map in Figure 8-20. This is CPI number 262, which was recorded at 17:28:48 UTC on 25 October 1999. The PRF is 9.827 kHz and the altitude is 754 meters above mean sea level (679 meters above Lake Ontario). The antenna elevation angle is -2 degrees and the antenna azimuth is 5.4 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is 7.0 kHz. The data have been processed for the first range interval.

The figure shows mainlobe clutter from a range of about 6 kilometers. The power level of the mainlobe clutter is about 30 dB above the power level of the background noise.

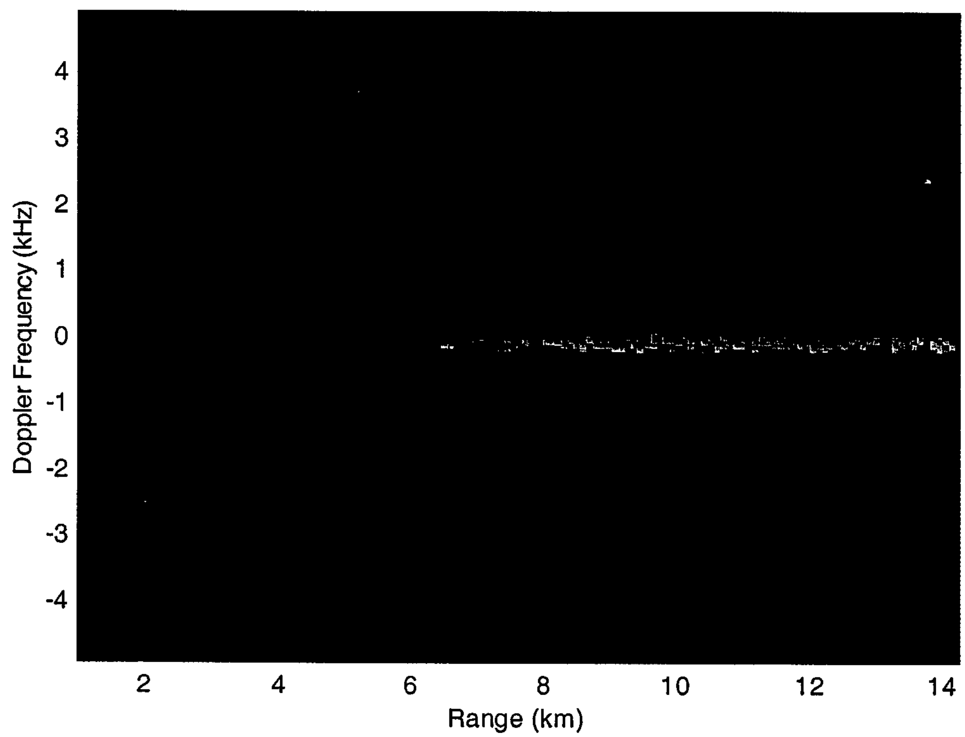

Figure 8-20 Phase-Agile Water Clutter Data at 750 Meters Altitude

9. URBAN CLUTTER DATA

Data were recorded during circular flights around the City of Ottawa on 25 October 1999. The intention was to capture ground clutter returns from an urban area. Table 9-1 summarizes the urban clutter data that were recorded. The table includes the tape label, the circle number, the radar mode, the number of coherent processing intervals, the mean altitude (meters above mean sea level), and the antenna elevation angle (degrees up).

Table 9-1 Urban Clutter Data

Tape Label / Circle Number	**Mode**	**Number of CPIs**	**Mean Altitude** (meters)	**Antenna Elevation** (degrees)
1999-10-25-17-49				
Circle 1	Conventional	14096	2676	-14
Circle 1	Phase-Agile	3268	2676	-14
Circle 2	Conventional	15072	1477	-7
Circle 2	Phase-Agile	8128	1477	-7

9.1. THIRD SORTIE URBAN CLUTTER

Tape 1999-10-25-17-49 is a large tape containing one data file. The file includes urban clutter data from two and one-half circular flights that were flown counterclockwise around the City of Ottawa. The flights were at nominal altitudes of 2500 and 1500 meters above mean sea level and with antenna elevation angles of -14 and -7 degrees respectively. The antenna azimuth scan was from -100 to -80 degrees, with the center of the scan pointed nominally at Parliament Hill in the center of Ottawa. The circle radii were about 11 kilometers. These data are discussed in the following sections.

9.1.1. Urban Clutter at 2500 Meters

Data from the first circular flight around the City of Ottawa consist of 17364 CPIs in five segments: 14096 CPIs in three segments of conventional data and 3268 CPIs in two segments of phase-agile data. The antenna elevation angle is -14 degrees and the antenna azimuth scan is -100 to -80 degrees. The mean altitude above mean sea level is 2676 meters with a standard deviation of 7 meter; the mean ground speed is 356 kilometers per hour with a standard deviation of 49 kilometers per hour; the mean radius of the circle is 11.0 kilometers. The flight path for the first circular flight is shown in Figure 9-1. The figure also indicates the segments during which phase-agile data were recorded (red 'X's) and the location of Parliament Hill ('+").

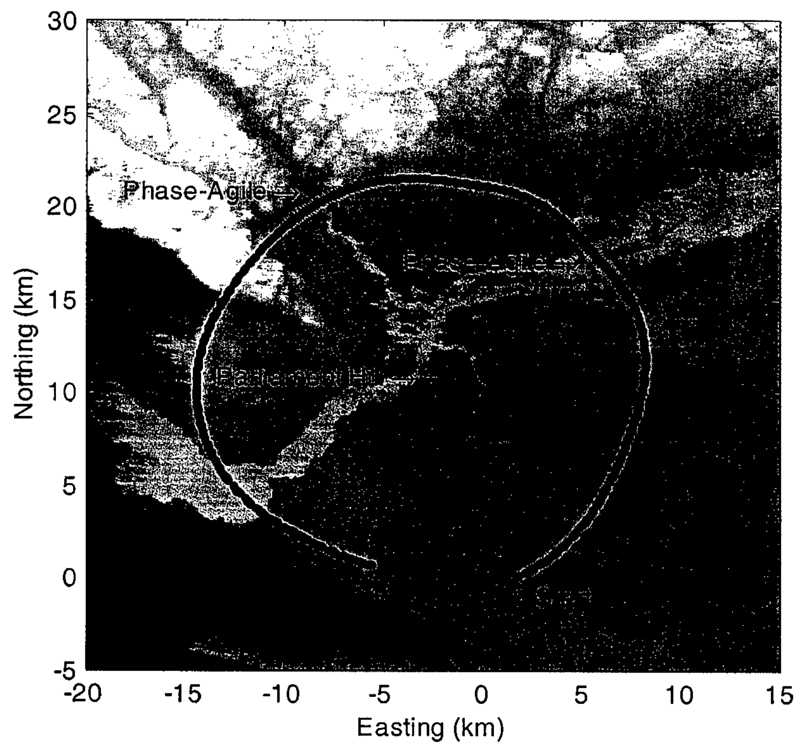

Figure 9-1 Flight Path for the First Circular Flight around Ottawa

An example of conventional data from the first circular flight around the City of Ottawa is shown in the range-Doppler map in Figure 9-2. This is CPI number 30598, which was recorded at 18:09:12 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 2660 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -99.4 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -0.9 kHz.

The figure shows very strong mainlobe clutter from about 9 kilometers to 14 kilometers apparent range. The power level of the mainlobe clutter is about 45 dB above the power level of the background noise. The feature near 3.6 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.8 kHz is an artifact offset from the mainlobe clutter by about +6 kHz.

The figure also shows a large number of targets, with apparent relative frequencies clustered about ±0.8 kHz and ±1.8 kHz. The apparent target ranges are from 9 kilometers to 14 kilometers. The relative frequencies correspond to velocity components of ±45 and ±100 kilometers per hour. The maximum target velocity is about 140 kilometers per hour. The speeds and ranges are consistent with vehicular traffic on city streets and on Highway 417, which runs east west through Ottawa.

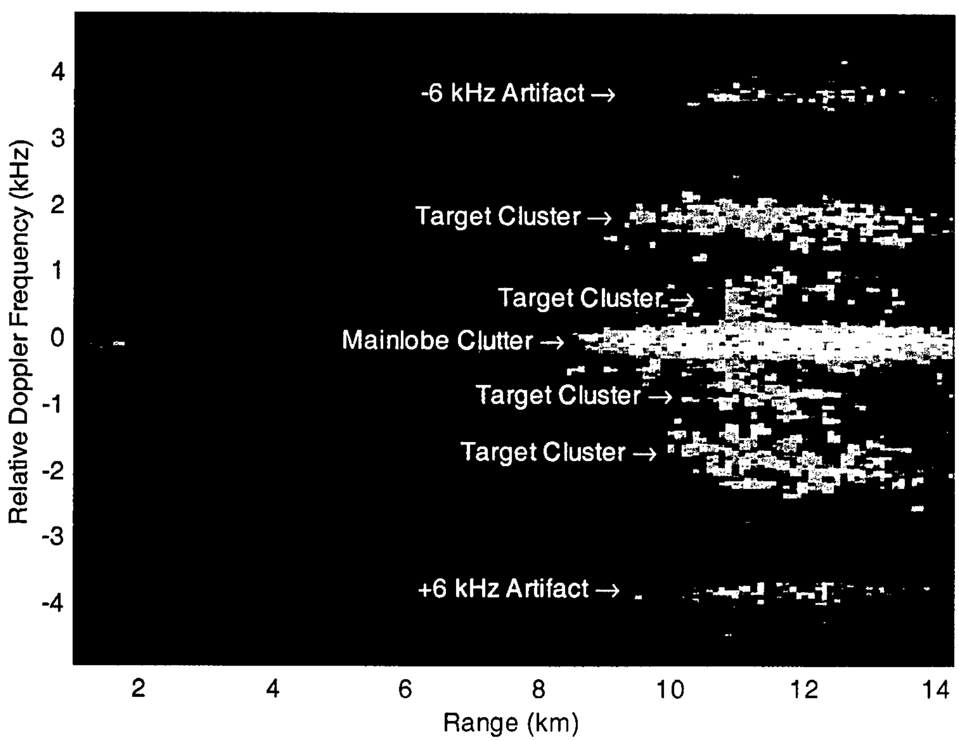

Figure 9-2 Conventional Urban Clutter Data at 2500 Meters Altitude

An example of phase-agile data from the first circular flight around the City of Ottawa is shown in the range-Doppler map in Figure 9-3. This is CPI number 31148, which was recorded at 18:09:32 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 2678 meters above mean sea level, the antenna elevation angle is -14 degrees, and the antenna azimuth is -86.7 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is +0.4 kHz. The data have been processed for the first range interval.

The figure shows very strong mainlobe clutter from about 9 kilometers to 14 kilometers range. The power level of the mainlobe clutter is about 55 dB above the background noise. The features near -3.9 and 3.7 kHz are artifacts offset from the mainlobe clutter by about ±6 kHz. The feature near -0.6 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter.

The figure also shows a large number of targets, with apparent relative frequencies clustered about +0.5 kHz. The target ranges are from 10 kilometers to 13 kilometers. The relative frequency corresponds to velocity components of +28 kilometers per hour. The maximum target velocity is about 45 kilometers per hour. The speeds and ranges are consistent with vehicular traffic on city streets. Note that the transient Doppler artifact associated with the mainlobe clutter masks any targets that might be expected with frequencies near -0.5 kHz.

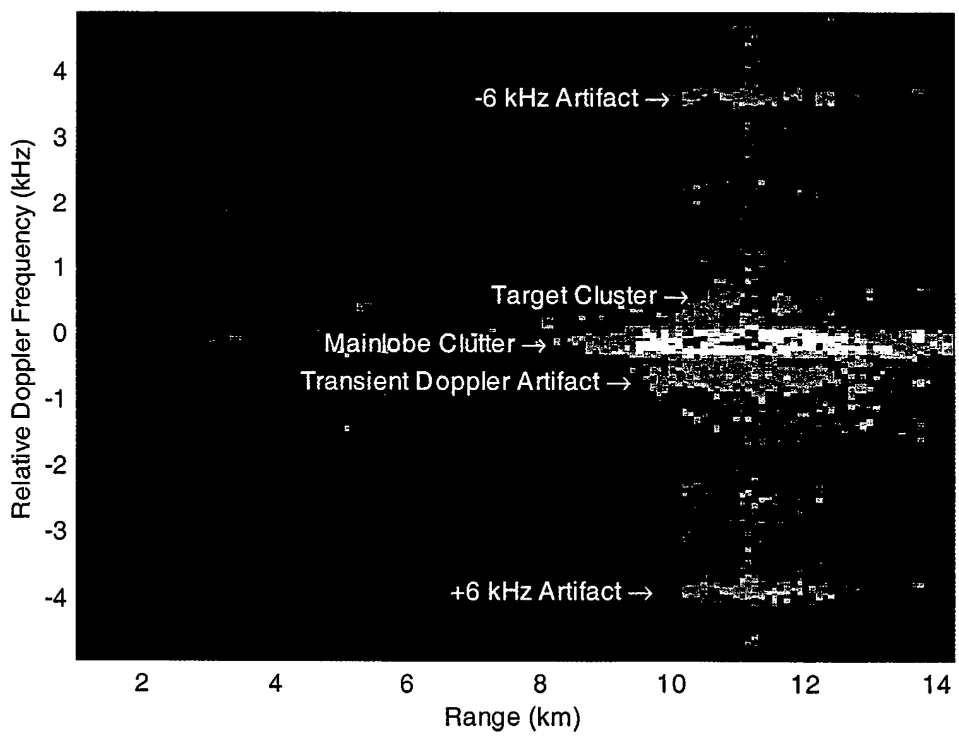

Figure 9-3 Phase-Agile Urban Clutter Data at 2500 Meters Altitude

9.1.2. Urban Clutter at 1500 Meters

Data from the second circular flight around the City of Ottawa consist of 23200 CPIs in five segments: 15072 CPIs in three segments of conventional data and 8128 CPIs in two segments of phase-agile. The antenna elevation angle is -7 degrees and the antenna azimuth scan is from -100 to -80 degrees. The mean altitude above mean sea level is 1477 meters with a standard deviation of 8 meters; the mean ground speed is 340 kilometers per hour with a standard deviation of 34 kilometers per hour; the mean radius of the circle is 11.1 kilometers. The flight path for the second circular flight is shown in Figure 9-4. The figure also indicates the segments during which phase-agile data were recorded (red 'X's) and the location of Parliament Hill ('+").

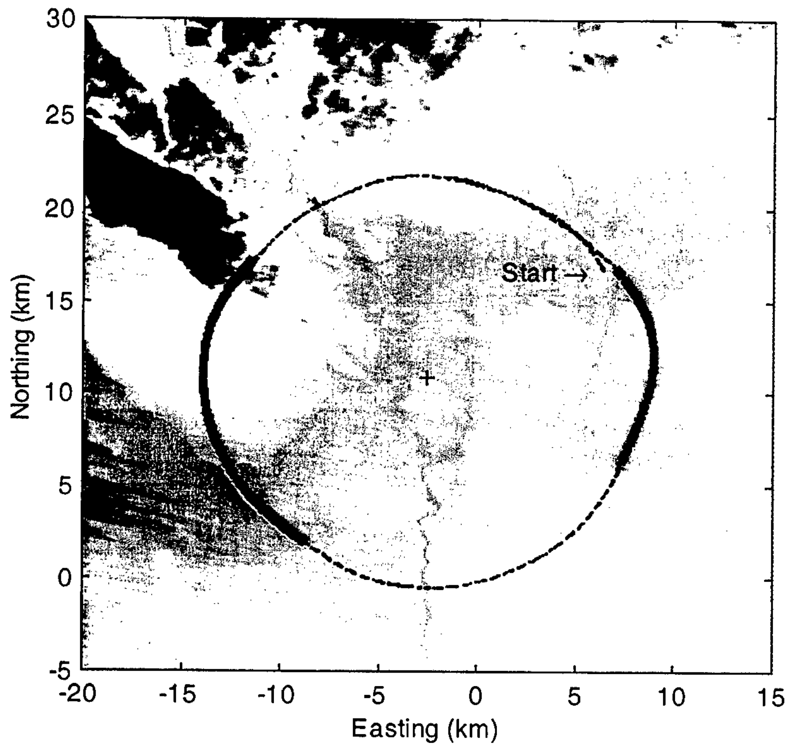

Figure 9-4 Flight Path for the Second Circular Flight around Ottawa

An example of phase-agile data from the second circular flight around the City of Ottawa is shown in the range-Doppler map in Figure 9-5. This is CPI number 62608, which was recorded at 18:28:31 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 1473 meters above mean sea level, the antenna elevation angle is -7 degrees, and the antenna azimuth is -87.7 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is +0.3 kHz. The data have been processed for the first range interval.

The figure shows very strong mainlobe clutter from about 7 kilometers range. The power level of the mainlobe clutter is about 55 dB above the power level of the background noise. The wideband noise out to an apparent range of 4.5 kilometers is the uncompressed mainlobe clutter from the second range interval. The feature near 3.6 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.9 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz.

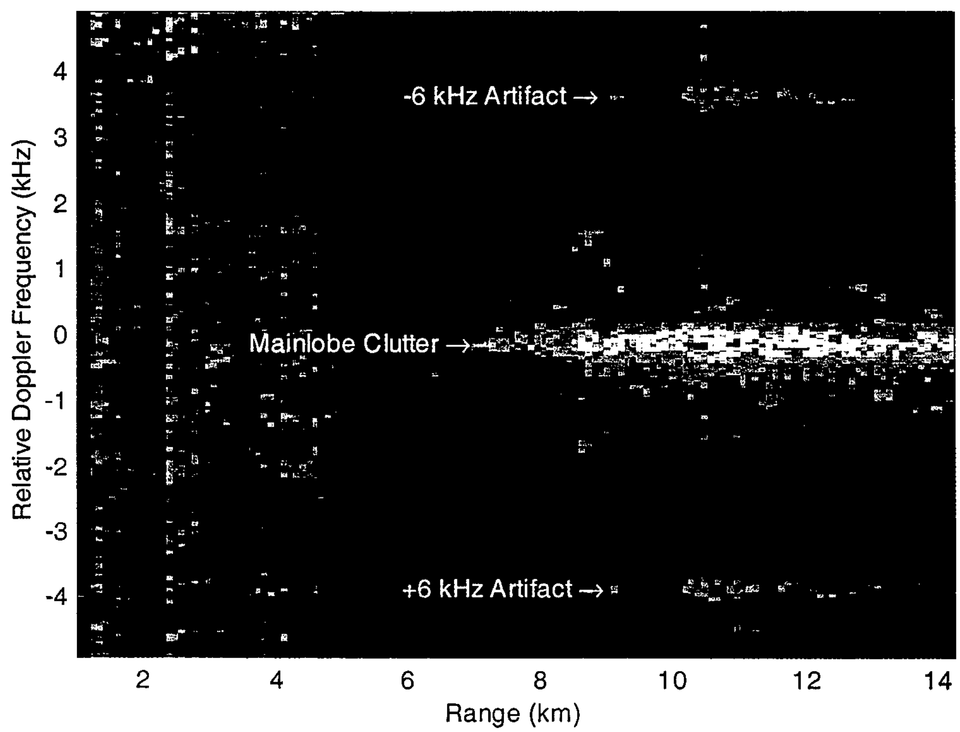

Figure 9-5 Phase-Agile Urban Clutter Data at 1500 Meters Altitude

An example of conventional data from the second circular flight around the City of Ottawa is shown in the range-Doppler map in Figure 9-6. This is CPI number 62618, which was recorded at 18:28:31 UTC on 25 October 1999. The PRF is 9.827 kHz, the altitude is 1473 meters above mean sea level, the antenna elevation angle is -7 degrees, and the antenna azimuth is -97.0 degrees with respect to the true ground track of the aircraft. The calculated Doppler frequency of the mainlobe clutter is -0.8 kHz.

The figure shows strong mainlobe clutter at all apparent ranges except near 7 kilometers. The mainlobe clutter actually starts at about 8 kilometers and extends to about 22 kilometers. The power level of the mainlobe clutter is about 50 dB above the power level of the background noise. The feature near 3.8 kHz is a spurious receiver artifact offset from the mainlobe clutter by about -6 kHz. The feature near -3.7 kHz is a spurious receiver artifact offset from the mainlobe clutter by about +6 kHz. The feature near 1.5 kHz is a transient Doppler artifact at the negative Doppler frequency of the mainlobe clutter. Note that the wideband noise at 11.4 kilometers range is probably due to receiver saturation associated with the very strong return in the mainlobe clutter.

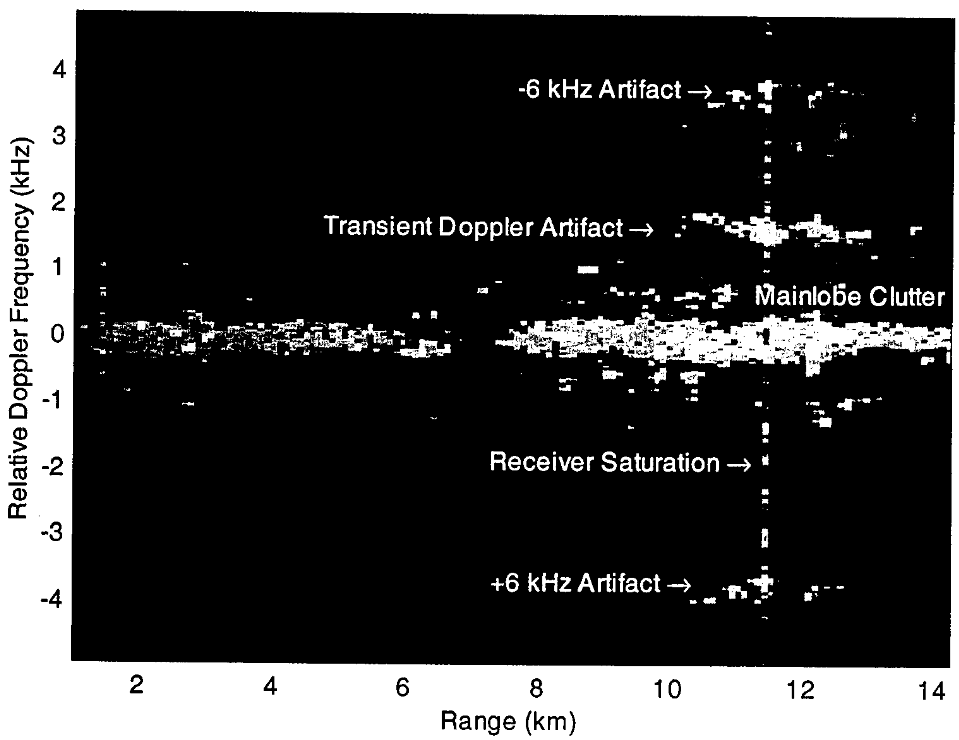

Figure 9-6 Conventional Urban Clutter Data at 1500 Meters Altitude

10. PROBLEMS AND DEFICIENCIES

There were a number of problems and deficiencies encountered during the October 1999 flight trials of the experimental air-to-air radar system. These are discussed in the following sections.

10.1. RECORDING SYSTEM

10.1.1. Software Crashes

The recording system often crashed shortly after starting a new recording process. The recording system would post an error message stating that the tape drive was not ready. Meanwhile, the tape drive and the graphical display under the error message window appeared to operate normally. Unfortunately, the only way to recover from this error was to shut down the recording system and restart the software. The operator would then have to re-enter a number of operational parameters. This led to a number of recording errors, particularly for the antenna elevation angle.

10.1.2. Write To Beginning Of Media

The recording system starts writing new data at the "beginning of media" rather than at the "end of data". This mode of operation may be suitable for test purposes in the laboratory, but can – and does – lead to loss of data during flight trials. The operational difficulties presented by this action were compounded by the tendency of the system to crash shortly after starting up the recording process.

10.2. PHASE DECODING

There is a problem with decoding the phase-agile data. Consider the data in CPI number 3896 from File002 on Tape 1999-10-22-14-28. Figure 10-1 shows the raw range-Doppler map for these data, processed for the first range interval. The broadband noise to the left of the radar pulse at Range Gate 32 is the continuation of the main lobe clutter. It ought to be compressed in range interval one.

The same data, but processed for the second range interval, are shown in Figure 10-2. Note that the portion of the main lobe clutter to the left of the radar pulse is now compressed. This is incorrect; this portion of the mainlobe clutter should be compressed only when processed for range interval one.

The figures showing phase-agile data in this document have been produced by:
1. Processing the portion to the right of the radar pulse for the range interval of interest;
2. Processing the portion to the left of the radar pulse for the next range interval; and
3. Combining the left and right portions to form a composite image.

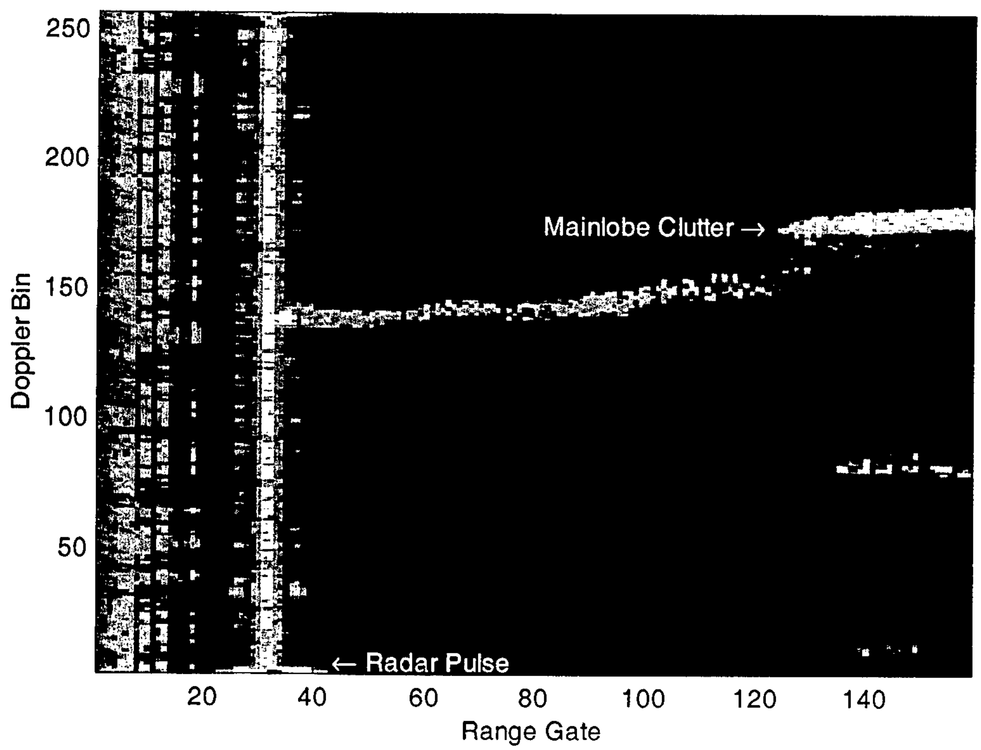

Figure 10-1 Phase-Agile Data Processed for First Range Interval

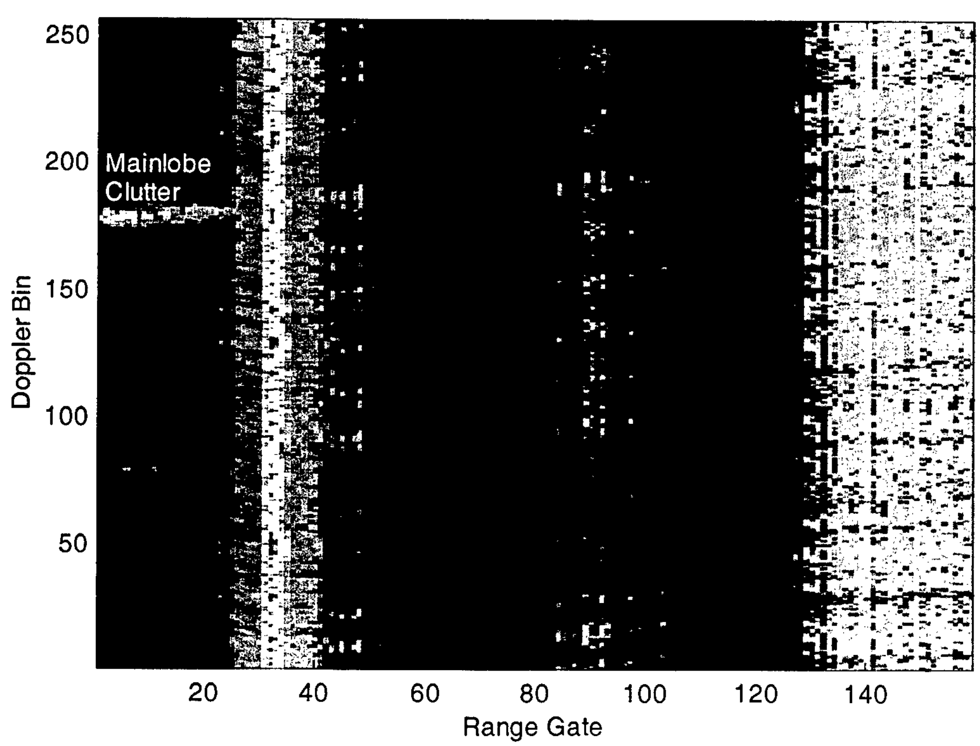

Figure 10-2 Phase-Agile Data Processed for Second Range Interval

10.3. DOPPLER ARTIFACTS

Two kinds of Doppler artifacts have been observed in the data collected in October 1999. One kind of artifact is a transient Doppler artifact [5] at the negative Doppler frequency of impulsive signals. This artifact is associated with the transient response of the lowpass filter used in the demodulation process to the leading and trailing edges of the radar pulses. The second artifact is due to oscillator sidelobes caused by power supply interactions. These sidelobes are offset from the carrier frequency by about ±6 kHz and mix with the radar signal to produce artifacts.

An example of the two types of Doppler artifacts is shown in the range-Doppler map in Figure 10-3. This is the same data shown previously in Figure 5-16, but is not translated in frequency to place the mainlobe clutter at zero frequency. The mainlobe clutter is located at a Doppler frequency of about 8.6 kHz. Recall that the pulse repetition frequency (PRF) is 9.827 kHz. The transient Doppler artifact associated with the mainlobe clutter is located at (-8.6 kHz *mod* PRF) = 1.2 kHz. The ±6 kHz artifacts are located at ((8.6 kHz + 6.0 kHz) *mod* PRF) = 4.8 kHz, and at ((8.6 kHz - 6.0 kHz) *mod* PRF) = 2.6 kHz.

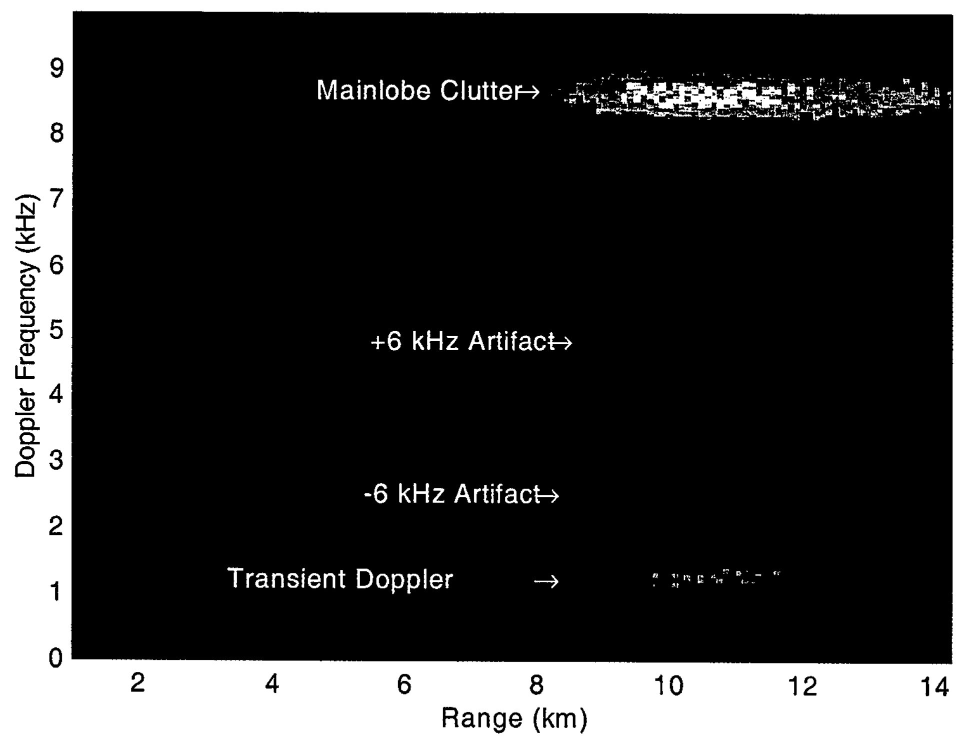

Figure 10-3 Conventional Data Showing Doppler Artifacts

A cross section in Doppler frequency through the mainlobe clutter and the Doppler artifacts is shown in Figure 10-4. The figure shows the locations and relative strengths of the artifacts. The transient Doppler artifact is 27 dB below the mainlobe clutter. The ±6 kHz artifacts are about 35 dB below the mainlobe clutter.

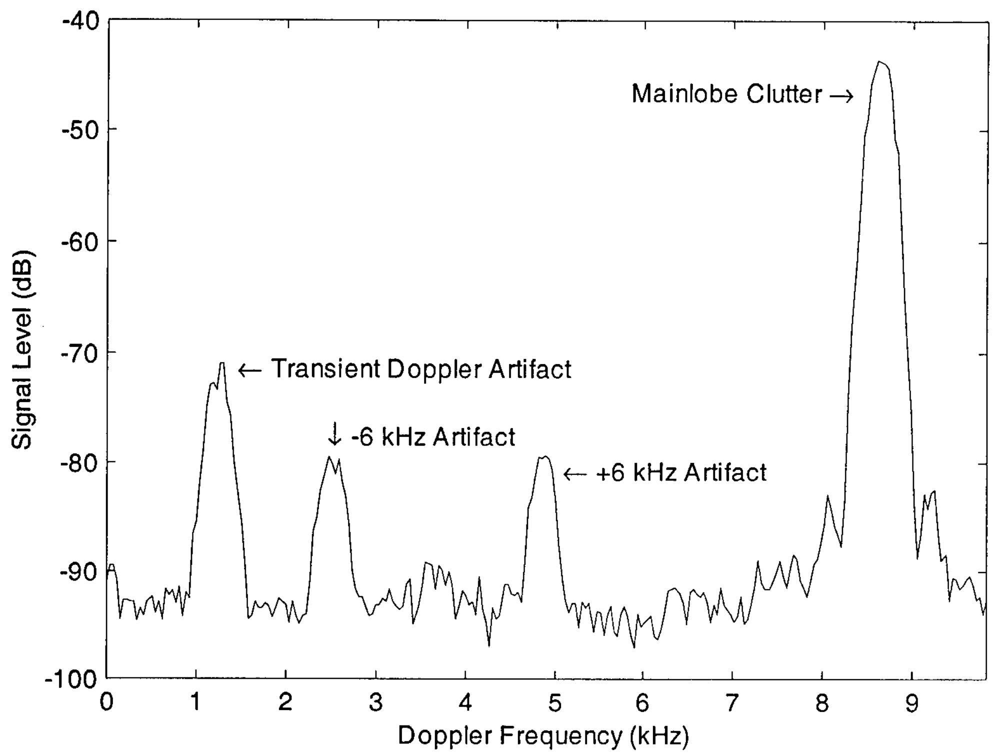

Figure 10-4 Mean Cross Section through Mainlobe Clutter and Doppler Artifacts

11. FUTURE WORK

The next flight trials for the experimental air-to-air radar system are scheduled for late June 2000. The purpose of these trials will be:

1. To collect additional ground and water clutter data free from the artifacts observed in the October 1999 data set;
2. To calibrate the radar system by recording returns from a radar test generator; and
3. If possible, to collect returns from a cooperative and instrumented aircraft target.

Prior to the June 2000 flight trials, the known deficiencies of the current hardware and software will be addressed. This will include the following:

1. The recording software will be analyzed to identify the source of and to rectify the time-out error while writing data to the tape;
2. The recording software will be modified so that the default action will be to write new data at the "end of data" rather than the "beginning of media";
3. The problems with phase decoding and range interval processing will be identified and rectified;
4. The source of the ±6 kHz sidelobes will be identified and modifications will be made to reduce or eliminate these sidelobes;
5. The recording software will implement a Variable Frequency Offset (VFO); and
6. The recording software will be modified to permit direct control over the operating parameters of the radar antenna.

Beyond the June 2000 flight trials, research activities will continue in the following areas:

1. Implementing mainlobe clutter filtering for the phase-agile data [2];
2. Refining existing and creating new Constant False-Alarm Rate (CFAR) algorithms [1] for target detection;
3. Investigating the site-specific characteristics of the ground clutter;
4. Determining target detection performance for the experimental air-to-air radar system; and
5. Implementing real-time processing and display of air targets.

12. SUMMARY AND CONCLUSIONS

The Defence Research Establishment Ottawa has designed and constructed an experimental air-to-air radar system as the first step in demonstrating an air-to-air surveillance capability for the Canadian Forces' CP-140 Maritime Patrol Aircraft. Initial flight trials of the experimental radar system were conducted in October 1999 on the National Research Council's Convair aircraft, operated by the Institute for Aerospace Research.

The experimental radar system operates in one of two modes. The conventional pulse-Doppler mode uses four different pulse repetition frequencies: 6.593 kHz, 7.659 kHz, 8.828 kHz, and 9.827 kHz. The phase-agile pulse-Doppler mode, in which each radar pulse is encoded with a random change of phase, uses only two pulse repetition frequencies: 6.593 kHz and 9.827 kHz. The advantage of the phase-agile mode is the elimination of range ambiguities. Both modes employ coherent processing intervals that are 256 pulse periods long.

Nearly 80 gigabytes of radar data were collected on 22, 25, and 28 October 1999. The data set includes measurements of ground clutter, water clutter, urban clutter, and returns from targets of opportunity. These data will be used to support the development of new signal processing and target detection algorithms that will form the basis of the CP-140 air-to-air surveillance capability. The data will also be used to support the validation of radar simulation models with site-specific clutter.

The experimental radar system will be modified to correct the deficiencies discovered during the October 1999 trials. The next flight trials are scheduled for late June 2000, at which time more ground and water clutter data will be collected and the system will be calibrated.

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5 Hughes, S.J. (1999). Mitigation of Transient Doppler Artifacts in Airborne Pulse Doppler Radar. (DREO TR 1999-125). Defence Research Establishment Ottawa.

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The Defence Research Establishment Ottawa has designed and constructed an experimental air-to-air radar system as the first step in demonstrating an air-to-air surveillance capability for the Canadian Forces' CP-140 Maritime Patrol Aircraft. Initial flight trials of the experimental radar system were conducted in October 1999. The resulting data set includes measurements of ground clutter, water clutter, urban clutter, and returns from targets of opportunity. These data will be used to support the development of new signal processing and target detection algorithms that will form the basis of the CP-140 air-to-air surveillance capability. The data will also be used to support the validation of radar simulation models with site-specific clutter.

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experimental radar
radar data
radar clutter
ground clutter
water clutter
urban clutter
site-specific clutter