

DEVELOPMENT AND TESTING OF
TECHNIQUES FOR DIGITAL EXTRACTION
OF ICE VELOCITIES FROM HARDCOPY
REMOTE-SENSING IMAGERY

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	ii
LIST OF TABLES	iv
ACKNOWLEDGEMENTS	v
1. INTRODUCTION	1
2. IMAGE PROCESSOR DESCRIPTION, HARDCOPY PROCESSING MODIFICATION STRATEGY AND STRUCTURE	5
2.1 THE IOS IMAGE PROCESSOR	5
2.2 STRATEGY AND CHOICE OF METHOD FOR HARDCOPY PROCESSING	8
2.3 HARDCOPY IMAGERY PROCESSING, OVERALL STRUCTURE	11
3. HARDCOPY PROCESSING, APPLICABLE IMAGERY AND SYSTEM MODULES, FUNCTIONS AND DESCRIPTION	13
3.1 INTRODUCTION, DISCUSSION OF STARTING POINT IMAGERY TYPES	13
3.2 OPT (OPTICAL DISTORTION) MODULE	14
3.3 VHR2 (RECTIFICATION AND MAPPING) MODULE	15
3.4 VHR3 BACKGROUND REMOTE MAPPING MODULE	27
3.5 AFFINE MODULE	28
3.6 ICE MODULE	29
3.7 MOVIE MODULE	31
4. PILOT PROJECT TESTING	32
4.1 INTRODUCTION	32
4.2 LANCASTER SOUND STUDY	37
4.3 DAVIS STRAIT STUDY	43
4.4 BAFFIN BAY STUDY	54
5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	59
5.1 SUMMARY AND CONCLUSIONS	59
5.2 RECOMMENDATIONS	62
6. REFERENCES	65
APPENDIX A: DIGITIZING HARDCOPY IMAGERY AND ICE TRACKING: AN OPERATOR'S MANUAL	67
APPENDIX B: APPLICATIONS TO RADAR HARDCOPY IMAGING	135
APPENDIX C: CALCULATION OF ORBITAL AND IMAGE PARAMETERS	137

LIST OF FIGURES

	<u>Page</u>	
Figure 2-1:	Block diagram of the IOS image processor.	6
Figure 2-2:	The NC-66SLX instrumentation camera and hardcopy mounting stage.	7
Figure 2-3:	Organization of hardcopy processing and linkage of modules.	12
Figure 3-1:	The assumed orbital subtrack great circle (O) and an orthogonal great circle (S) containing the scanned surface arc (shaded area).	16
Figure 3-2:	The satellite (x'',y'',z''), intermediate (x',y',z'), and geocentric (x,y,z) coordinate systems and rotation angles.	17
Figure 3-3:	A typical line printer output after a 5 control-point rectification.	25
Figure 4-1:	Study areas covered in pilot studies 1, 2 and 3.	34
Figure 4-2:	Approximate stable positions of the winter ice edge in eastern Parry Channel, 1961-1982.	35
Figure 4-3:	Representative ice trajectories in Lancaster Sound for the indicated time intervals. The squares denote measured floe positions after the initial start of each trajectory.	44
Figure 4-4:	Ice velocity vectors averaged over the study period in the indicated zones. Numbers of ice velocity values included in each average are indicated.	45
Figure 4-5a:	Time series representation of the average daily ice velocities in the NW quadrant of Lancaster Sound.	46

	<u>Page</u>
Figure 4-5b:	Time series representation of the average daily ice velocities in the NE quadrant of Lancaster Sound. 47
Figure 4-5c:	Time series representation of the average daily ice velocities in the SE quadrant of Lancaster Sound. 48
Figure 4-5d:	Time series representation of the average daily ice velocities in the SW quadrant of Lancaster Sound. 49
Figure 4-5e:	Time series representation of the average daily ice velocities for East Devon Island. 50
Figure 4-6:	Representative ice trajectories in Davis Strait for the indicated time intervals. 52
Figure 4-7:	Ice velocity vectors averaged over the study period in the indicated zones. Rectangles centred on the heads of the vectors have side lengths equal to twice the corresponding standard deviations of the observed velocity components. 53
Figure 4-8:	Ice point locations on March 8, 1983 (blue square), March 14, 1983 (yellow square) and March 21 (red square), superimposed on March 21 image (video monitor photograph). 56

LIST OF TABLES

	<u>Page</u>
Table 1-1: Remote-imagery systems commonly used in ice dynamical studies.	3
Table 1-2: Archival-and real time-sources of hard-copy imagery, types and contents of images.	4
Table 3-1: Forms of the AFFINE module polynomials for the (x,y) (x',y') transformation using n control points where $3 < n < 7$. Extension to n values > 7 follows the established pattern for adding new terms.	29
Table 4-1: Control point errors for nominally aligned and rotated hardcopy images.	38
Table 4-2: Displacements along the x- and y-axes as measured for points 1-8 (Figure 4-8) for the March 8-14, 1983 and March 14-21, 1983 time intervals.	58

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1. INTRODUCTION

Canada's intention to safely exploit its Arctic and offshore resources has placed a high priority upon the development of new methods for locating and characterizing sea ice. Existing or planned programs are in place which can or will provide all-weather ice observations from either high-altitude aircraft (by SLAR or SAR) or from the highly specialized Radarsat satellite. The high development and operational costs of the new observation systems have, in turn, created an equivalently urgent need for improved, more detailed, ice forecasting in order to reduce the reliance on all-weather observation to economically affordable levels and to allow longer range offshore and transport planning.

The required forecasting improvements must necessarily come from an understanding of the dynamics of the sea ice cover. Efforts are now underway in several public and private sector research laboratories to provide such understanding through the development of ice and water circulation models. To be effective, these models must be made consistent with observational data obtained from conventional meteorological and oceanographic measurements in conjunction with ice drift data extracted from satellite-tracked drifter positions and digital satellite imagery.

The present report describes the development and testing of a new capability for economically extracting ice position and velocity data from hardcopy satellite imagery which could greatly expand the data base available to such research efforts. This expansion would facilitate the addressing of important questions concerning year-to-year and shorter term variability, "upstream" influences and other factors. The particular significance of the hardcopy capability arises from the circumstance that, to date, only the hardcopy imagery archives have had sufficient continuity and historical reach to support quantitative ice dynamical studies in all possible areas of interest. The origins of this preference for paper or film hardcopy have been largely economic. Nevertheless, certain disadvantages, of the most popular hardcopy storage form, namely paper, have tended to limit applications. These disadvantages include:

- a) the deterioration and damaging of images during storage and use;
- b) the great dependence of image content on the grey-scale selection (the image brightness/satellite recorded light level relationship) made at the time of hardcopy production; and

- c) the need to use time-consuming manual or optically assisted methods to remove image distortions and to extract and display data.

The described research and development effort was directed at the production of a facility with a demonstrated capability for using modern digital techniques to extract research-quality information from a wide variety and quality of hardcopy products. Installation of the resulting system on the Adage (Ikonas) Image Processor of the Remote Sensing Group, at the Institute of Ocean Sciences, Sidney, B.C. was a key feature of the development program which allowed detailed evaluation of the data retrieval process and the demonstration of both traditional and previously little-used, film strip methods for data display.

The emphasis in the testing program was given to the products available from the VHRR and AVHRR (Very High and Advanced Very High Resolution Radiometer) instruments mounted on board the NOAA and Tiros-N series of satellites. This type of imagery (see Table 1-1) provides, by far, the largest volume of hardcopy products relevant to ice studies. The high productivity of this imagery results from the large observational swaths of the VHRR and AVHRR instruments which allow the imaging of a given Arctic surface point as much as six times daily per operational satellite (under normal circumstances two NOAA-type satellites are operational at any one time). The consequently high frequency of repeat observations and the availability of thermal infrared channels, which allow night and Arctic winter observations, provide the continuity of coverage necessary for the documentation of complex ice-dynamical processes. Nevertheless, the developed techniques were designed to be sufficiently general to allow application to less frequently obtained but higher spatial resolution imagery forms (Landsat, SLAR etc., Table 1-1). A similar flexibility was necessary with regard to imagery sources in order to account for the different types of processing applied between the recording of the raw satellite data and the production of the hardcopy image (see Table 1-2).

The main body of the report begins, in Section 2, with an overall description of the developed processing system including summaries of the basic details of the host image processor and software packages, and the hardware changes associated with the critical first (redigitization) step of the hardcopy processing (Sections 2.1 and 2.2). These basic background elements are then followed by a discussion and presentation of justifications for the specific approach taken in achieving image rectification (Section 2.3) prior to a block-diagram and flow chart summary of

the evolved processing procedure in terms of function and software components which are derived and/or described in detail in Section 3. The pilot project study results are presented in Section 4 and are followed by a closing summary, in Section 5, of system performance and capabilities together with recommendations for further improvements in processing and image storage procedures. Suggestions are also offered for useful applications of the developed capability. An operator's manual is included in Appendix A.

Table 1-1: Remote-imagery systems commonly used in ice dynamical studies.

Remote-System	Instrument	Spectral Ranges	Repetition Rate at 74°	Spatial Resolution (at nadir)
NOAA-1,...,8 Satellites	VHRR, AVHRR	1 visible band, 3 near & thermal infrared bands	5 times daily per satellite	1.1 km
Tiros-N Satellite	AVHRR	1 visible band, 3 near & thermal infrared bands	5 times daily per satellite	1.1 km
Landsat 1-5 Satellite	MSS Thematic Mapper (TM) & Return Beam Vidicon (RBV) available for highly specialized applications	2 visible & 2 near infrared MSS bands	Once daily per satellite for 4 consecutive days followed by a 12-14 (satellite-dependent) dark period	80 m
SLAR & SAR Airborne Images	All weather microwave imagers	Monochromatic	Determined by costs & aircraft availability	25-100 m

Table 1-2: Archival- and real time-sources of hardcopy imagery, types and contents of images.

Source	Imagery Types	Processing
AES, Ice Forecasting Central, Ottawa, ON	Full-swath & full resolution (blowup) NOAA imagery. Positive transparencies of AES SLAR tracks.	Stretching corrections for earth curvature applied, pixel dropout in full swath images.
AES, Arctic Weather Centre, Edmonton, AB	Full-swath & full resolution (blowup) NOAA imagery.	Stretching corrections for earth curvature applied, pixel dropout in full swath images.
Canada Centre for Remote Sensing, PASS Centre, Prince Albert, SK	Full swath NOAA & Landast imagery.	Curvature & radiometric corrections applied to NOAA & Landsat images. All recorded pixels printed.
Environmental Data & Information Service, Washington, DC (US)	NOAA & Tiros-N imagery, full swath imagery.	Pixels near periphery of swath eliminated from image, stretching corrections applied to images obtained from NOAA 6, 7 & 8.
EROS Data Center, Sioux Falls, SD (US)	Landsat MSS & other products.	Radiometric & curvature corrections.

2. IMAGE PROCESSOR DESCRIPTION, HARDCOPY PROCESSING MODIFICATION STRATEGY AND STRUCTURE

2.1 THE IOS IMAGE PROCESSOR

The two primary components of the IOS Image Processor are an Adage (Ikonas) RDS-3000 Graphics Processor and Raster Display System and its host PDP 11/34 minicomputer. The RDS-3000 is built around a 32-bit 68000 microprocessor and allows image storage in three 512 x 512 planes of 8-bit pixels and in eight 512 x 512 1-bit graphic planes (the latter can also be used as a single 8-bit image plane). Its major subcomponents and external connections, indicated in Figure 2-1, include key links to the minicomputer, a video monitor and a video camera. The video camera was added to the system in the initial phase of the development project. The camera, a MTI model NC-66SLX Instrumentation Camera, was obtained from Dage-MTI Inc., Michigan City, IN, equipped with a selected (for minimal distortion) Newvicon Image Tube and modifications for sync-locking, auto-manual gain selection, black level adjustment and remote power supply (to reduce pickup-induced noise). It was rigidly fixed in a downward-looking configuration to a smoothly adjustable photoenlarger mount (Figure 2-2). A pair of high quality fixed lenses (12.5 mm f/1.9 and 25 mm f/1.4) and front-mounted close-up lenses allowed imaging of different-sized portions of hardcopy imagery mounted on the enlarger stage.

The VI8 video input module digitizes the camera output directly into a 512 x 512 array of 8 bits in an image plane. Disk storage and disposition of these images are controlled from interactive CRT terminals through the minicomputer which, actually performs most of the computational and control functions required by the image processing. Aside from its linkage to the CRT consoles, the minicomputer communicates directly with a line printer and its disk- and tape-data storage peripherals. Output to the video monitor proceeds through the interface module, the Ikonas bus and from the image/graphic plane memories.

Aside from some internal functions associated with the user-specified color look-up tables, or programmable magnification or "zooming" display options, the Adage (Ikonas) unit serves primarily as a digitization and rapid access storage device. The minicomputer carries out almost all of the "image processing", i.e. it makes changes in the contents of the individual or composite displayed image and graphics planes. The various software packages necessary for this processing have been written exclusively for the IOS PDP 11/34 by D. Truax using the OVAAC-8 subroutines for command and data exchanges across the

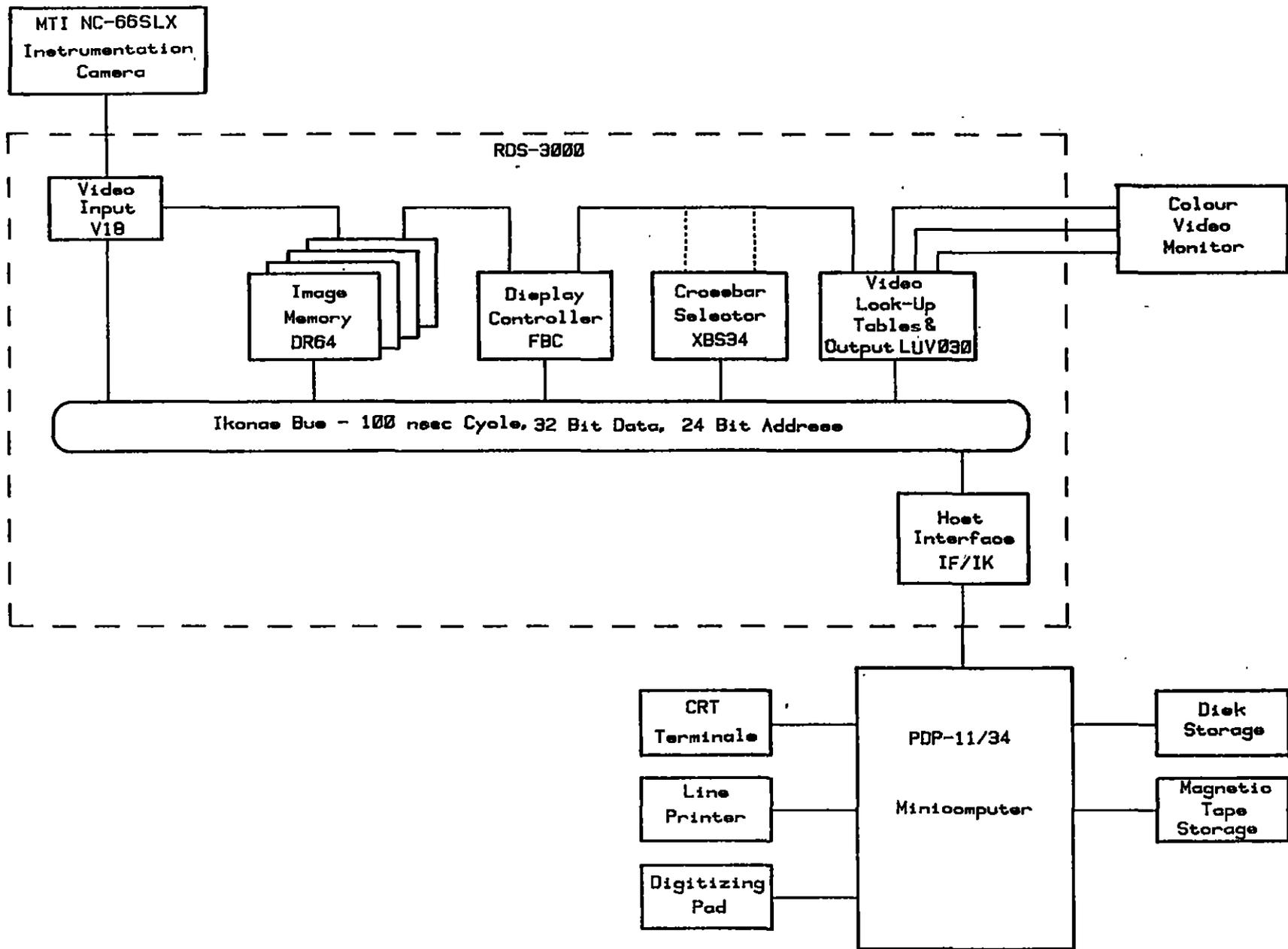


Figure 2-1: Block diagram of the IOS image processor.

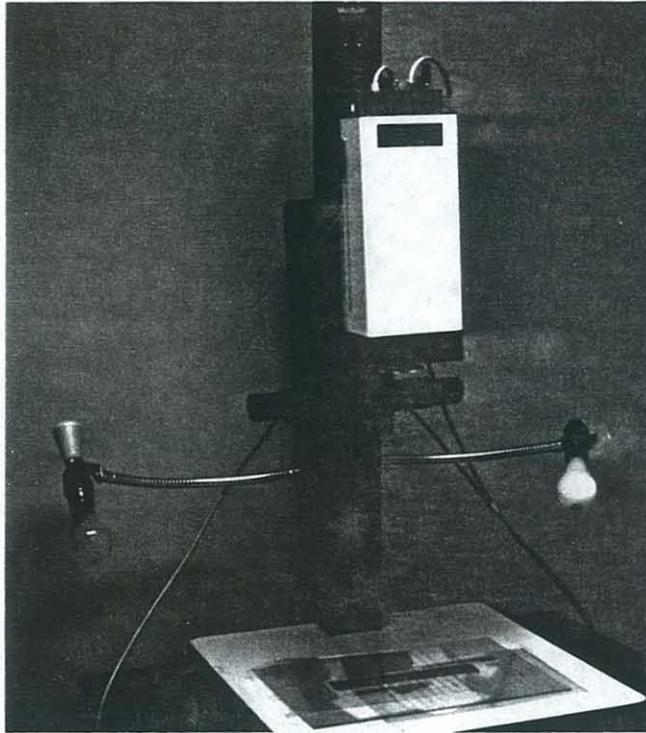


Figure 2-2: The NC-66SLX instrumentation camera and hardcopy mounting stage.

minicomputer-RDS 3000 interface .

2.2 STRATEGY AND CHOICE OF METHOD FOR HARDCOPY PROCESSING

Two different approaches were considered to offer feasible solutions to the hardcopy imagery processing problem.

- 1) The production of new program modules for the PDP 11/34 which utilize and/or are fully compatible with existing IOS processing software. Emphasis would be placed upon the creation of self-contained processing programs which use only the most basic satellite parameters (i.e. nominal altitude and period) and information available on each hardcopy image such as time, date and the positions of recognizable, locatable surface points. As much as possible, the demands on operator time and sophistication would be minimized and data extraction assured for a wide range of image types and qualities.
- 2) The adaptation of the University of Miami Software package (UMS). An earlier version of the widely-acclaimed UMS image-processing software package is stored on disk at the IOS facility. Although not in active use, it could be available for a variety of image processing tasks in conjunction with special OVAAC-8 subroutines specific to the RDS-3000 and PDP 11/34 subcomponents. Moreover, an updated, expanded and perhaps more compact version of this package of programs is available for a relatively nominal cost, \$20,000, but configured to a much larger hardware system. The UMS programs provide a capability for charting and mapping the positions of objects on the ocean surface from sequential satellite images in digital magnetic tape form. The procedures used require the availability of very detailed timing data included within the taped data stream, as well as a number of satellite orbital parameters provided by NORAD facilities. Although no specific UMS programs exist specifically for hardcopy imagery forms, a valid option for our project approach included the writing of suitable conversion programs if a tractable scheme could be devised to obtain timing and orbital data appropriate to images that now only exist in hardcopy form.

Choices between these two alternatives necessarily involved considerations of plans for future expansion of the IOS image processing facility and the more immediate needs of current ice research. To obtain a more realistic appraisal of the advantages

and disadvantages of the UMS alternative, Messrs. R. Chave (Arctic Sciences Ltd.) and D. Truax (project subcontractor) visited the University of Miami Satellite Image Analysis Centre and its Director, Dr. R. Evans, in April, 1984.

It was found that the Centre's original combination of a single Adage (Ikonas) RDS-3000 and a PDP 11/34 minicomputer has now been replaced by a system based on two more powerful computers (VAX Models 750 and 780) and a pair of Adage processors each of which have display memories four times larger (1024 x 1024 pixels) than their predecessor unit. Moreover each of the new Adage processors drives two interactive user stations using several Fujitsu hard disks for on-line image storage. A video-cassette preview system has been incorporated into the facility.

As one might expect, the original UMS software has been considerably modified to reflect the larger operating environment. Individual components of the software system are highly interdependent and structured for the VAX operating system. Many useful programs which run on the University of Miami system could not be configured to a PDP 11/34 minicomputer.

However, as indicated above, the University of Miami Centre is completely oriented toward the input of magnetic tape imagery. Its current imaging library consists of 9000 tapes and online disc storage of imagery is strongly discouraged.

The rectification or navigation of the received tape satellite images (i.e. location onto an earth-centred coordinate system) is achieved using orbital parameters provided by NORAD tracking stations and ancillary information on the magnetic tape. Exact time information is needed for the navigation of each image whence it can be used in conjunction with a time-ordered sequence of similarly processed images of the same surface area to detect changes in surface oceanographic features including, presumably, sea-ice movements. After raw image data have been so navigated and mapped, they are normally written back into magnetic tape form in order to maintain the availability of disc space. In view of the speed of the VAX-based system, users are encouraged to reprocess imagery as opposed to storing intermediate results.

It is apparent that the entry of taped versions of redigitized hardcopy imagery would pose particular problems for the UMS navigation approach because of the unavailability of data on the exact timing of each image scanline (the line of image pixels obtained from a single "scan" of the satellite sensors in a plane perpendicular to the orbital track). Such specification

would have to be established from orbital ephemeris data, the location of known reference points on the image and the often unknown position of the satellite ground track on the redigitized image.

Although the purchase of the existing UMS package would give access to the NORAD orbital data, it was judged that the efforts necessary to convert a hardcopy image into a form compatible with that system's navigation procedure could easily dissipate the advantages offered by the programs. This difficulty combined with the large costs and delays involved in a conversion to a VAX-based system precluded the use of the UMS alternative in the present development. This rejection was extended to half-measure steps such as the rewriting of relevant portions of the UMS programs specifically for PDP 11/34 use, because of the volume and interdependence of the original software.

The capability of the existing IOS software with regard to accurate rectification of digital magnetic tape imagery had already been demonstrated (Truax, 1982). In particular, the IOS constituent AGRID module allowed the mapping of imagery to an accuracy of better than 2 km without the use of any ancillary satellite orbit data. Instead the most probable values of the orbit parameters were estimated from the positions on the image of a small (three or four) number of ground control points. Although other algorithms have been derived to achieve this rectification, Konecny (1977) and MacDonald, Dettwiler and Associates Ltd. (1978), these approaches tend to make large demands on operator time and skill as well as in the required numbers of control points. The latter requirement is often a difficult one to satisfy in Arctic marine imagery because of frequent cloud and ice and snow obstruction and modification of the appearance of coastal and land features. As a result, the general method of the AGRID approach, i.e. specification of orbital geometry and the use of iterative techniques for finding the most probable orbital parameters, was adopted as the basis for at least the initial stage of hardcopy image processing.

Significant additional efforts were anticipated in order to achieve equivalent (to digital tape results) rectification in the absence of subtrack and scan-angle data which is characteristic of hardcopy imagery. The use of additional rectification modules appropriate to special imagery types, and additional error reduction was also visualized as a development component.

2.3 HARDCOPY IMAGERY PROCESSING, OVERALL STRUCTURE

The developed scheme for hardcopy imagery processing is outlined in Figure 2-3 in terms of a newly created set of software modules and their linkages to the IOS Image Processor's pre-existing VCP (Video Control Program) body of image plane manipulation and control commands.

The key elements in the scheme are the OPT, VHR2 and ICE modules which, respectively: 1) redigitize the hardcopy image with minimal additional distortion; 2) rectify or establish the location of each redigitized image pixel in a geocentric coordinate system and/or effect its remapping into a standard map projection; and 3) produce graphical and numerical representations of ice movements from a time-ordered sequence of redigitized, rectified images.

Additional program modules were developed during the study to: eliminate the use of the system image memory planes during the time-consuming remapping process (VHR3); produce further improvements in rectification within a specified, bounded subportion of an image (AFFINE); and facilitate the production of time-lapse film representations of the contained ice movements (MOVIE).

The contents and functions of each of these modules will be described and discussed in detail in the following section.

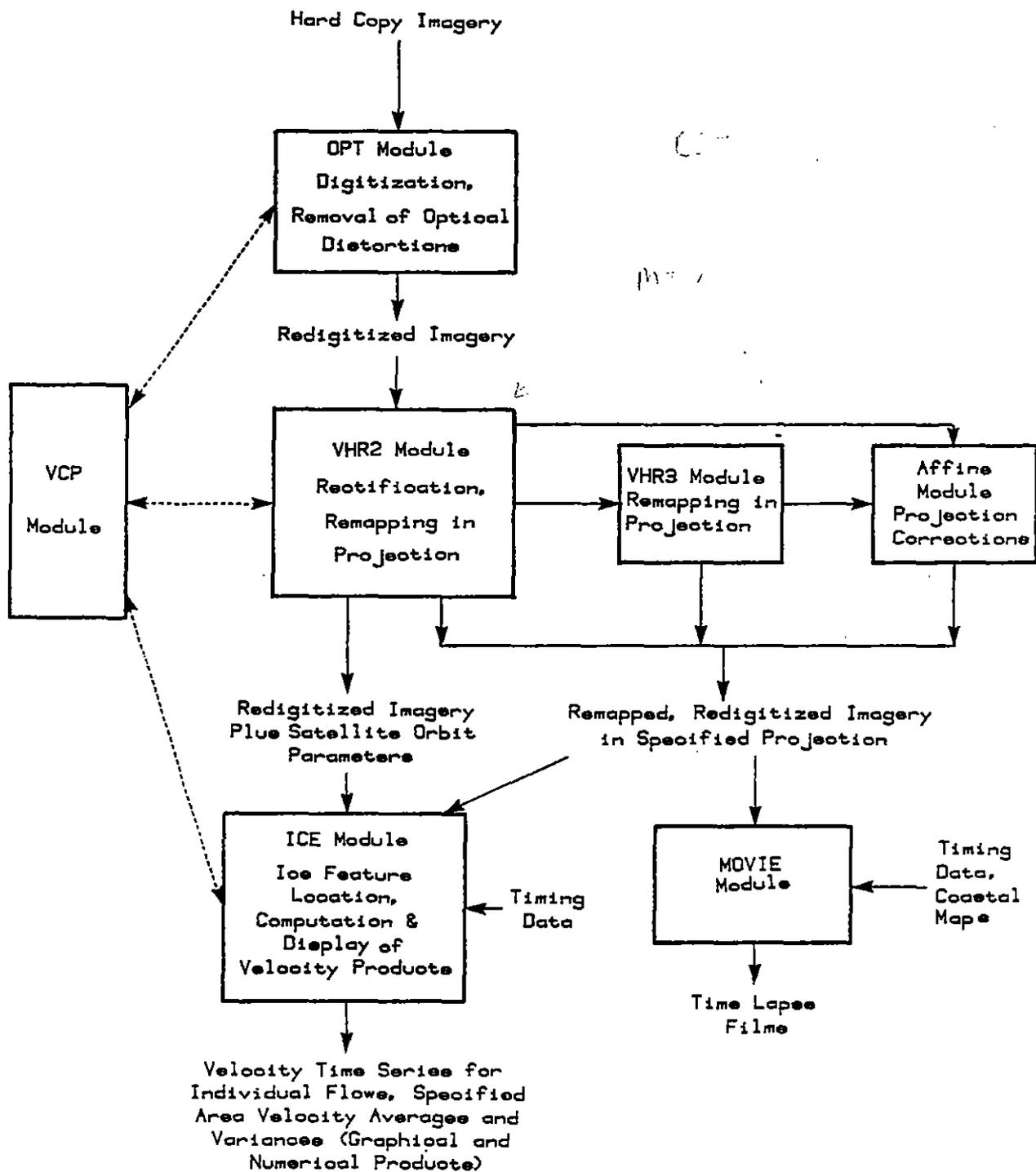


Figure 2-3: Organization of hardcopy processing and linkage of modules.

3. HARDCOPY PROCESSING, APPLICABLE IMAGERY AND SYSTEM MODULES, FUNCTIONS AND DESCRIPTION

3.1 INTRODUCTION, DISCUSSION OF STARTING POINT IMAGERY TYPES

As noted in Section 1, three types of hardcopy imagery were originally visualized for inclusion in the digital processing development. These imagery types were produced by the NOAA VHRR (AVHRR), Landsat MSS and SLAR/SAR imaging systems. It was recognized that, because of its high frequency of repeat coverage, primary emphasis in the ice-motion-related processing development would be given to the NOAA VHRR and AVHRR products. Applications of the developed procedures to Landsat imagery were assumed to be straightforward in view of the common scanning technique used in the formation of both types of images, albeit with widely differing orbital and optical parameters. In practice, most Landsat products already contain nominal and sometimes extensive (precision processed) corrections for earth curvature, rotation and spacecraft altitude changes. As a result, little need was seen for significant further developments specific to this imagery other than assuring the applicability of the digital data extraction and display functions. SLAR/SAR imagery, on the other hand, does need additional processing to allow accurate transferral of high-spatial resolution data to geocentric coordinate frames. An initial investigation of the feasibility of incorporating such products within the basic NOAA-oriented processing scheme was carried out using two tracks of SLAR imagery obtained by the AES instrument in Lancaster Sound (see Appendix B).

The variety of hardcopy imagery types requiring processing, even within the overall category of NOAA VHRR (AVHRR) imagery, is large. Meaningful processing must account for all changes applied to the original satellite imagery (as-received by the ground station). Since, as detailed in Table 1-2, these alterations are associated with the source of the hardcopy imagery, processing modules must allow appropriate selection of the relevant imagery and processing parameters.

Flexibility in this respect and with regard to other variabilities, such as the types of control point data available, was built into the developed modules in the familiar "user-friendly" menu format. The intent in module design was to allow the operator to optimize the processing procedure to the hardcopy image contents in a manner which allows intercomparison and joint use of data from different images.

3.2 OPT (OPTICAL DISTORTION) MODULE

The OPT module uses a standard VCP (Video Control Program) command to allow direct input from the black and white video camera into image plane 1 of the image display system. This first requires conversion of the analog video signal into one of 255 digital levels allowing the input of the video camera output. The free-running video display is used to allow adjustment of illumination levels across the image portions of interest and to align the image scan-lines (usually perpendicular to an image boundary) to parallel the horizontal (x-axis) of the video-screen image. Illumination adjustments usually attempt to achieve uniformity across the imaged portion while minimizing the loss of picture detail through saturation or under-illumination effects.

When a satisfactory image is obtained on the screen, a VCP command is used to freeze or fix the image in the RDS-3000 memory plane as the starting point for the digital processing procedure. An adjustment of the image grey-scale is then effected through VCP, to maximize the visibility of desired image details. This adjustment, in fact, establishes the relationship between the brightness level in each "pixel" of the redigitized image and the grey-levels which can be distinguished on the video screen. A cursor-connected pen and a digitizing pad are used for this task. Pen position along one-axis of the pad establishes the pixel level corresponding to the grey-scale midpoint while the position along the orthogonal axis specifies the net range of pixel levels over which the full width of the grey-scale is applied.

In most instances, it is necessary to correct the redigitized images for distortion introduced by the Newvicon tube and camera lenses. These distortions are equivalent to shifts in position as large as 5 pixels in one particular corner of the video image plane, but are 1 pixel or less over the greater portion of the image. Corrections are applied using two arrays of pixel shift values, one for the x- and one for the y-axis errors. These correction arrays, stored in image buffer disk files and loaded into separate image planes by VCP, are specific to the lens combination and object-lens distance used in the redigitizing. Their derivation is carried out once for a given lens combination and need not enter into the normal image processing procedure. This step involves the use of basic VCP cursor positioning commands to establish the differences between the video screen- and original image-positions of the interstices of a computer-drawn hardcopy grid of 1/8" squares. This procedure is described in the operator's manual (Appendix A).

The OPT program itself allows the operator to apply the pixel correction array, entered into two separate imagery planes, to the raw redigitized image which is stored in a third plane. The corrected product is, by selection of the appropriate program menu choice, generated in the fourth image plane. This image is then stored through VCP in an image buffer file before further processing. Storage includes the corrected pixel entries and the parameters of the selected grey-scale adjustment.

3.3 VHR2 (RECTIFICATION AND MAPPING) MODULE

This module derives the geocentric coordinates of each element of the redigitized image and can remap the latter "pixels" into a standard equi-rectangular map projection.

Like its predecessor AGRID module, VHR2 does not attempt to account for variations in spacecraft attitude or in changes in spacecraft altitude within a single orbital pass. Instead it assumes that the satellite moves at a constant (but possibly varying from orbit to orbit) altitude and constant speed. At the mid-scan or neutral position, the system optics is assumed to look directly downward toward the earth's centre. Deviations of the satellite orbit and the earth surface from circularity and sphericity, respectively, are neglected allowing the orbital subtrack (the intersection of the satellite orbital plane with the earth surface) to be considered as a great circle.

In addition, within this picture (see Figure 3-1), the strip of earth surface covered by a single scan of the imaging system forms an arc on a second great circle oriented perpendicular to the orbital plane. As the satellite advances along the orbital track, the scan line circle (denoted by S in Fig. 3-1) rotates about an axis which is perpendicular to the plane of the orbital circle and passes through its centre. Images are constructed in strip-wise fashion from the radiances recorded at adjoining positions of the system optics in each successive cross-track scan. Actual reproduction of the imagery from the recorded radiance levels require adjustment of the along- and cross-track dimensions of each individual pixel to account for the satellite orbital speed and the scanner aperture- and advance rate-parameters, respectively. In the case of most of the commonly-available NOAA imagery (see Table 1-2), these adjustments include the removal of the foreshortening effect produced by earth curvature. This requires the introduction of a scan-angle dependence into the cross-track pixel dimensions and allows the production of images in which the two pixel dimensions represent equal distances along the corresponding orthogonal great circles.

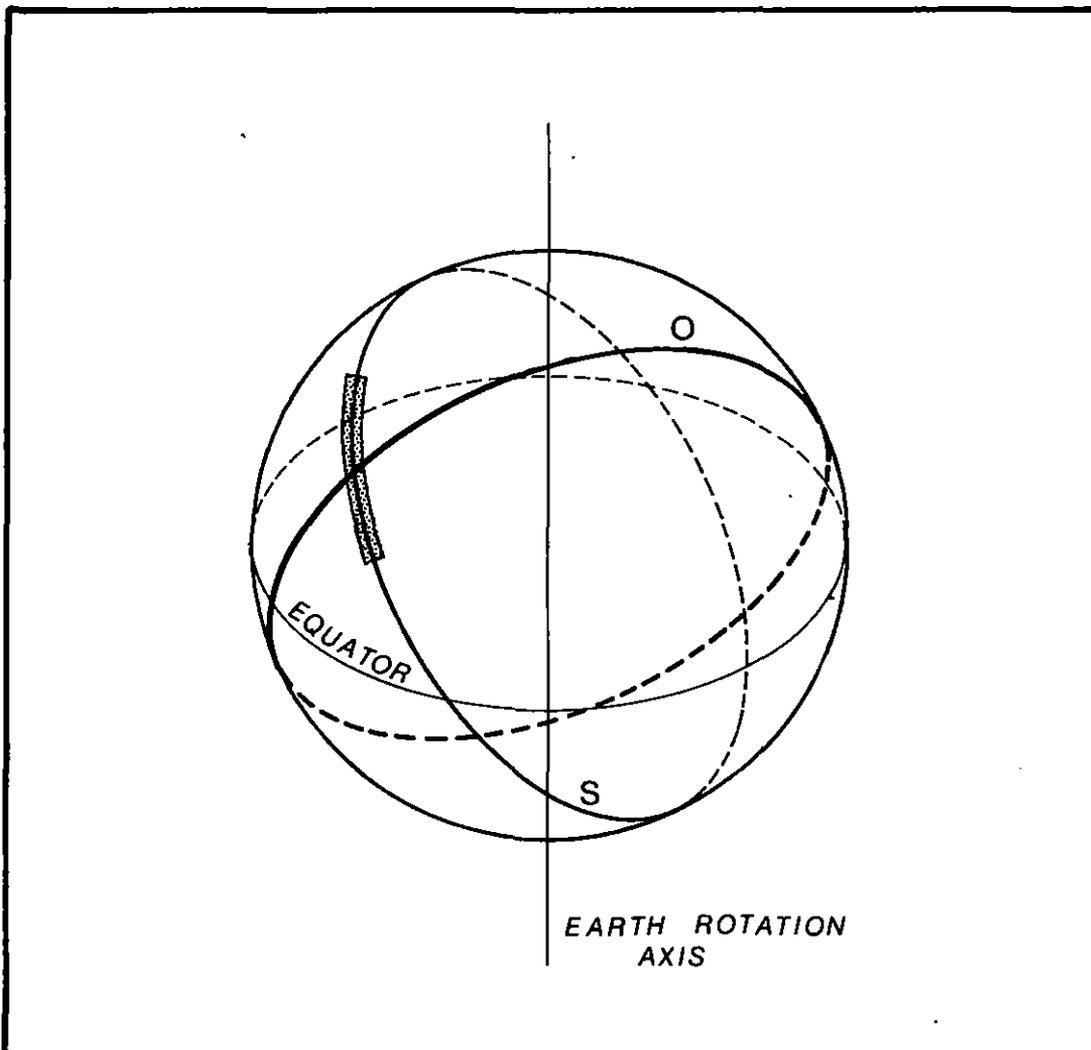


Figure 3-1: The assumed orbital subtrack great circle (O) and an orthogonal great circle (S) containing the scanned surface arc (shaded area).

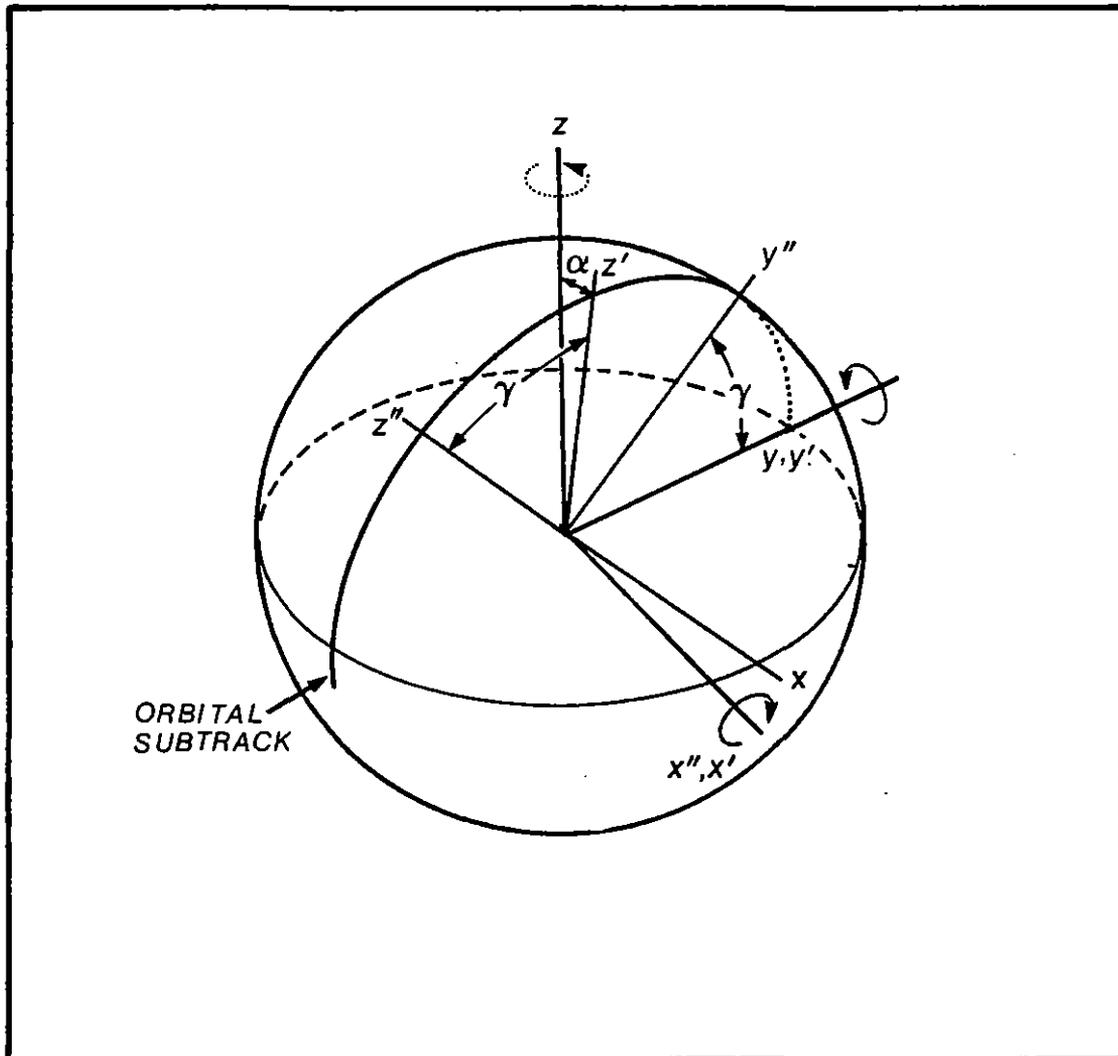


Figure 3-2: The satellite (x'' , y'' , z''), intermediate (x' , y' , z'), and geocentric (x , y , z) coordinate systems and rotation angles.

In most cases, no additional pair of corrections are applied to account for the rotation of the earth about its own axis.

The object of the rectification process is to transform the redigitized image from its satellite-based recording frame to the more useful earth centred coordinate frame and, if necessary, into a standard map projection. The satellite reference frame can be represented by an earth-centred coordinate system S'' (Figure 3-2) which has its z'' and y'' axes in the orbital plane respectively aligned along the line connecting the satellite and the earth centre and parallel to the line tangent to the orbital subtrack directly below the instantaneous satellite position. Within this frame of reference earth surface points imaged in a given scan line must satisfy the relationship:

$$x''^2 + z''^2 = R^2 \quad (3.3-1a)$$

$$y'' = 0 \quad (3.3-1b)$$

where R is the earth radius.

The transformation of this surface area to a fixed earth centred reference frame takes place in two steps:

- 1) A rotation by an angle γ about the x'' axis producing a new, intermediate coordinate S' , system with z' passing through the orbital maximum (the orbital point with the largest latitude value), y' in the orbital plane and commonality in the x' and x'' axes. The angle γ satisfies

$$\gamma = \eta - \pi/2 \quad (3.3-2)$$

where η equals the orbital angle corresponding to the angle of orbital travel between the last ascending node (the equatorial crossing point) and the subtrack point (see Figure 3-1).

- 2) A rotation by an angle α about the y' axis bringing z' parallel to z the earth rotational axis. The angle α , the orbital inclination angle, is the complement of the latitude of the orbital maximum.

The transformation in each case can be written

$$z' = z'' \cos \gamma - y'' \sin \gamma \quad (3.3-3a)$$

$$y' = z'' \sin \gamma + y'' \cos \gamma \quad (3.3-3b)$$

$$x' = x'' \quad (3.3-3c)$$

and

$$z = z' \cos \alpha - x' \sin \alpha \quad (3.3-4a)$$

$$x = z' \sin \alpha + x' \cos \alpha \quad (3.3-4b)$$

$$y = y' \quad (3.3-4c)$$

Substituting Eqs. 3.3-3 in 3.3-4 we get:

$$z = z'' \cos \gamma \cos \alpha - y'' \sin \gamma \cos \alpha - x'' \sin \alpha \quad (3.3-5a)$$

$$x = z'' \cos \gamma \sin \alpha + y'' \sin \gamma \sin \alpha + x'' \cos \alpha \quad (3.3-5b)$$

$$y = z'' \sin \gamma + y'' \cos \gamma \quad (3.3-5c)$$

As a result, the scanned surface area given by Eq. 3.3-1 is transformed to:

$$z = z'' \cos \gamma \cos \alpha - \sqrt{R^2 - z''^2} \sin \alpha \quad (3.3-6a)$$

$$x = z'' \cos \gamma \sin \alpha + \sqrt{R^2 - z''^2} \cos \alpha \quad (3.3-6b)$$

$$y = z'' \sin \gamma \quad (3.3-6c)$$

If now the scanned surface arc is expressed in terms of the angular deviation β from the orbital track as, of course, measured at the earth centre of the S'' coordinate frame, z'' can be written as:

$$z'' = R \cos \beta \quad (3.3-7)$$

Using the usual convention, the latitude and longitude of a point on this scan line can be written as

$$\theta \text{ (latitude)} = \tan^{-1} \left(\frac{z}{\sqrt{x^2 + y^2}} \right)$$

$$= \tan^{-1} \left[\frac{-(\sin\beta \sin\alpha - \cos\beta \cos\gamma \cos\alpha)}{\sqrt{\cos^2\gamma \cos^2\beta \sin^2\alpha + \sin^2\beta \cos^2\alpha + \frac{1}{2} \sin 2\beta \sin 2\alpha \cos\gamma + \cos^2\beta \sin^2\gamma}} \right] \quad (3.3-8)$$

and

$$\phi \text{ (longitude)} = \phi_0 + \tan^{-1} \left(\frac{\cos\beta \cos\gamma \sin\alpha + \sin\beta \cos\alpha}{\cos\beta \sin\gamma} \right) \quad (3.3-9)$$

In Eq. 3.3-9, ϕ_0 is the ascending node angle, defined as the longitude at which the (assumed ascending) orbit crossed the equator prior to the recording of the image. The use of a specific reference point for the definition of the angle ϕ_0 , in fact, corresponds to a third rotation of the coordinate frames in Figure 3-2. In this case, the S frame is rotated by ϕ_0 in the indicated direction (broken-line, curved arrow) about the z-axis to form a fourth frame, S_0 with a specific reference longitude.

The neglect of earth rotation in the foregoing derivation is easily corrected since the movement of the earth during the orbital pass parallels the lines of constant latitude and hence does not affect the validity of Eq. 3.3-8. The corresponding expression for the longitude (Eq. 3.3-9) is very simply altered by the addition of a term:

$$\phi \text{ (rotation earth)} - \phi \text{ (stationary earth)} = \frac{T_s}{T_e} \frac{(\gamma + \pi)}{2} \quad (3.3-10)$$

where T_s and T_e represent the periods of the satellite orbital- and earth rotation-motions respectively.

The full, rotating earth versions of Eq. 3.3-8 and Eq. 3.3-9 give the geocentric coordinates of a surface point as observed by the satellite in terms of four angular parameters:

- 1) the scanner deviation angle, β , as measured from the centre of the earth with reference to the nadir direction (the line connecting the satellite to the earth centre);
- 2) the orbital rotation angle, γ , between the satellite position and the orbital maximum;
- 3) the inclination angle, α , which is defined in terms of the latitude of the orbital maximum as, θ_m , $\alpha = \pi/2 - \theta_m$; and
- 4) the ascending node angle, ϕ_0 .

Two of these parameters, α and ϕ_0 , are common to all pixels on a given Arctic image, with α having, in addition, a constant, orbit-independent value. As a result, just three angular parameters would be sufficient to specify the geocentric coordinates of a pixel on a digitally-taped satellite image.

In the case of a redigitized hardcopy image, however, an additional piece of information is required, specifying the location of the orbital subtrack on the image. This information is implicitly contained in the digitally-taped image but is lost in conversions to hardcopy which do not reproduce the full 2048 pixel width of the original scanner record. Since perhaps the most useful hardcopy images are "blowup" type products which reproduce only an unspecified subportion of the original imaged area, it can no longer be assumed that the subtrack passes through the image centre. In the general case, subtrack positions not only may be non-central but often may not be located on the image.

As a result, specification of the geocentric coordinates of a given hardcopy image point requires the specification of γ , β , ϕ_0 and p_s (the number of the subtrack pixel, expressed relative to the image pixel range (1 to 512) and the use of orbit-independent fixed values of the satellite orbital-inclination angle (α), -altitude (a) and -period (T_s). Because of the assumed constancy of both the rates of adjustment in the scanning angle and in the speed of the satellite along its track, the coordinates of any pixel (given by a specification of its integral pixel, scan-line values (p , s) satisfying $1 \leq p, s \leq 512$) can be derived by specifying:

- 1) the smallest and largest orbital angles in the image, γ_1 , and γ_{512} ;
- 2) the smallest and largest scanner angles in the image, β_1 , and β_{512} ;
- 3) the subtrack pixel, p_s ; and
- 4) the ascending node angle ϕ_0 .

These six unknown parameters can be derived for each image using an iterative procedure for minimizing the squared errors between the "known" and calculated geocentric positions of three or more ground control points. The latter points can consist of land-fixed permanent surface features such as islands, headlands, lakes etc. and/or more temporary surface features which, for one reason or another, can be assumed to be unchanging and locatable

on the imagery scales of resolution during the time intervals of interest.

Three basic types of control point data input were visualized and incorporated into the program menu selections. These included:

- 1) Direct entry of geocentric coordinate values for routinely used stations. An expandable file of such stations is maintained on the system disk and accessed directly from the program.
- 2) Entry, by cursor selection, of points on a coastal outline map provided on the system in an equi-rectangular projection* derived from U.S. Central Intelligence Agency source material. Appropriate sections of this map are generated in convenient scales and stored in a graphics plane. Selection of control point station numbers in appropriate ranges (2000-2999) automatically initiate simultaneous displays of map and image suitable for choosing control points and establishing their locations on the image.
- 3) Entry from a previously rectified image or images entered into the other image planes. These images can be entered directly from a disk image buffer file with their orbital parameters or in a specific map projection using the image loading and image content selection choices in the program menu. Entry of control point station numbers in the range 3000-3999 immediately triggers the multiple image rectification process requiring specification of the solved and unsolved images and their type.

The zoom capability of the image processor is used to increase the accuracy of the entered type 2 and 3 control points and as well in locating the control points on the redigitized image. It is important to note that since the electronic zoom still utilizes subsets of the original 512 x 512 pixels of the redigitized image, this procedure does not add new information and only allows the greater accuracy in cursor placement. Using a 25 mm camera lens on a full resolution "blowup" NOAA image, each pixel corresponded to a rectangular portion of the earth sur-

*In this "projection" the linear dimensions of the unit latitude and longitude cells are independent of latitude and are scaled to preserve the actual ratio of the corresponding surface distances at the image centre.

face of total area approx. 1.2 km^2 *. The mean 1.1 km linear dimensions of this cell allowed a spatial resolution of approx. 2.2 km or one half of that (1.1 km) nominally obtainable at nadir with the NOAA radiometer. Some improvement in this resolution can be achieved through the attachment of close-up lenses in front of the 25 mm objective. The disadvantage of this procedure is that the reduction in field which accompanies the higher image resolution can, in many applications, significantly reduce the number and spatial spread of the imaged control points. This reduction, in turn, would normally be expected to adversely affect the rectification accuracy of the more detailed image. A two-step rectification process is described in Section 4.4 which allows the simultaneous retention of the close-up image spatial detail and the rectification accuracy of the bare objective image.

The procedure for deriving the image parameters consists of two basic steps:

- a) the calculation of the orbital and scan angles assuming a given value for the subtrack pixel. This calculation involves an iteration in which the angles are adjusted according to the errors obtained between the calculated and known positions of those pixels;

*The deviation from squareness of the image pixels arose from the non-unity aspect ratio of the video camera which effectively produced a 27% compression along the horizontal or x-axis. This circumstance in itself should have given rise to slightly better spatial resolution along the vertical or y-axis of the image. Actual tests of the system spatial resolution against calibrated photographic grids were made late in the project after rectification data gave consistently poor results along image directions which paralleled this same vertical axis (see Section 4). Test data indicated that the minimum spacing of resolvable lines was, in fact, approximately twice as large along the vertical, as opposed to horizontal, axis of the video image. Because of the usual close alignment of the lines of longitude with the vertical video image axis, one would expect this anisotropy to produce the observed poor rectification quality in the latitude coordinate (Section 4). Initial investigations of the resolution anisotropy problem indicate its origins lie in a previously unsuspected requirement for a detailed calibration and adjustment procedure prior to external synchronization of the camera to the image processor unit. Informal documentation has now been acquired on such procedures.

- b) the location of the subtrack where the standard deviation of the calculated/known control point positions reaches its minimum value.

The calculation, described in detail in Appendix C, contains four nested loops which use repeated calculations of the sum of the squared latitude and longitude errors in the computed GCP (Ground Control Points) locations to derive an optimum set of values for β_1 , β_{512} , γ_1 , γ_{512} , ϕ_0 and p_s . The VHR2 program allows this computation to be carried out with negligible preknowledge of the parameters ϕ_0 , p_s , β_1 , β_{512} , γ_1 and γ_{512} . Manual entry of initial values for these parameters is also possible to speed up the computation process in instances where such preknowledge is available.

Actual computation times, of course, depend upon the number of control points used and upon other factors such as the crossing angle between the track-parallel image edges and lines of longitude. For acceptable levels of rectification, e.g. control point error magnitudes < 2.5 km, parameter computations can be as short as 30 seconds and as long as 8 minutes.

At the end of each computation the operator is presented with a display of the derived orbital and image parameters and the specific identifiers and errors of the used ground control points (Figure 3-3). The printed parameters include not only the angles associated with image edges, β_1 , γ_1 , β_{512} , γ_{512} but, for convenience, the net scanner (offset) and orbital travel angles ($\beta_1 - \beta_{512}$) and ($\gamma_1 - \gamma_{512}$).

The entry of a zero satellite altitude in the printed display output was initiated by the operator from the program menu to account for the previous inclusion of an altitude-dependent curvature correction at the source of the hardcopy imagery. Other fixed parameters in the output include the orbital period and maximum latitude derived from a look-up table and the user specified satellite-type identifier.

The control point errors DLAT and DLONG are given in units of minutes of latitude and longitude, respectively. Entries in the "DEV" row represent the standard-derivations or -errors as defined in Appendix C (Eqs. C-13 and C-14) as figures of merit for the achieved fitting to the latitude and longitude, respectively, of all control points.

DIRECTION OF ORBIT ASSUMED TO BE SOUTHWARD

ORBITAL ANGLE 99.47 TO 104.08 ANGLE = 4.6088
 SCAN LINE 1 TO 512
 SCAN OFFSET 1.51 TO -5.45 OFFSET = 6.9607
 PIXEL 1 TO 512
 SUBTRACK PIXEL 112
 ASCENDING NODE 66.65
 ALTITUDE 0.00
 ORBITAL PERIOD 102.03
 ORB MAX LATITUDE 81.10

	REFERENCE STATION	PIXEL	SCAN	LAT	LONG	DLAT	DLONG
3030	COB IS ICE	164	123	75 43	-78 37	0.6161	0.0279
3031	N DEV PT	114	172	75 51	-81 55	-0.4779	-0.6537
3032	KKOD	165	400	73 47	-84 50	0.3630	0.4715
3034	BYLOT E	348	281	72 59	-75 42	-0.7077	-0.6706
3035	E DEV	199	204	74 52	-79 14	0.2307	0.5988
					DEV	0.5687	0.6017

Figure 3-3: A typical line printer output after a 5 control-point rectification.

The choice of northward or southward directions for the imaging orbital pass is made by the user before the start of the orbital parameter calculation. In the absence of other specifications, the program will begin by assuming a southward orbit unless the immediately preceding program application was made in a northward mode. Changes in orbit direction are again made from the menu before initiating the parameter calculation. In most instances orbit directionality is evident from inspection of the hardcopy image. Useful indicators are the sense (clockwise, counterclockwise) of the tilt of land masses relative to the orbital track direction and, in some cases, from consistency in the positioning of image labels relative to the first and last image scanline. Ambiguous images were, however, encountered in which the choice of orbit direction was only apparent after separate calculations of orbital parameters, for the two alternate directions of travel, gave order of magnitude differences in the control point errors (due to the alternatively correct and incorrect incorporation of the earth rotation correction).

It is important to note that the described VHR2 rectification procedure is iterative only in terms of relatively rapid computer-controlled calculations and parameter adjustments. In principle the process needs to be carried out just one time for each image and hence differs from other digital processing approaches (MacDonald, Dettwiler and Associates, 1978) which require alternating cycles of control point selection and parameter calculation until convergence and a satisfactory rectification is achieved.

Nevertheless, in practice, some operational iteration was found to be inevitable particularly with regard to some "High Arctic" imagery in which the relative positionings of the satellite and imaged area are such that the orbital subtracks cross the lines of longitude at angles approaching or exceeding 45° . In these instances, some simplifications made in our angular parameter optimization scheme have lessened validity. More specifically, the difficulty arises in our adjustments of the orbital and scanner angles according to the calculated control point deviations in latitude and longitude respectively (see Appendix C). This approach is consistent with the nearly north-south directionality of orbital tracks at northern hemisphere latitudes south of roughly 72° . At higher latitudes, several successive rectifications were sometimes necessary, with the addition and deletion of control points to optimize rectification quality in terms of either: the average control point latitude and longitude deviations or from a subsequent remapping of the rectified image in a standard projection.

The extent of effort given to the optimization process, is of course determined by the requirements of the imagery application as well as by image quality (in terms of existing grey-scale settings, extent of surface visibility etc.) and latitude. Detailed discussions of the practical requirements on control point-numbers, -areal coverage and optimization are provided in the presentation of pilot project results in Section 4.

Once satisfactory rectification has been achieved, the image can be either: stored in a disk image buffer using the VHR2 menu selections; passed directly on to another processing module, i.e. AFFINE, ICE or VHR3; or remapped within VHR2 into equi-rectangular map projections of specified scale and centre point. Conversion of these images to conic projections is possible by reversion VHR2 to the VCP module.

The storage option allows the retention of the original image with or without the derived orbital parameters. The remapping utilizes the latter parameters to reposition each redigitized pixel at its geocentric coordinate in the selected map projection. A "fill" command option within the VCP module is used to replace any zeroes in the spaces between the remapped pixels with average values of the immediately adjoining non-zero pixels. The remapping process involves the exchange of large amounts of data between image planes and the supplemental disk memory. Typically the procedure requires 5 to 10 minutes of time and occasionally can take as long as 45 minutes. During this period, the video monitor is unavailable for other uses. Avoidance of this bottleneck necessitated the creation of the VHR3 module which carried out the same process without the use of the image planes. The functions of this module are briefly described below. Image projections created from VHR2, like the image and orbital parameter products, can be passed directly on to other modules or stored in the disk buffer files with their listed projection parameters.

3.4 VHR3 BACKGROUND REMOTE MAPPING MODULE

This module carries out the same set of remapping functions by which VHR2 produces, scanline by scanline, rectified images in user-specified projections. The time consuming exchanges of data and computations involved in selecting the original pixels for placement on each line is done by the PDP-11/34 without the use of the RDS-3000 image planes for storage of the original and remapped images.

Provision is made for the multiple insertion or stacking of rectified image buffers (redigitized image plus orbital parameters) and their output and storage in projection form in specified sequential image buffers. The one limitation in this process is that all images in a given stack will be processed onto the same equi-rectangular map projection*.

As noted above, in addition to this stacking and unsupervised processing capability, the principal advantage offered by the VHR3 module lies in the resulting freeing of the RDS-3000 image planes for other uses.

3.5 AFFINE MODULE

In response to difficulties encountered in the rectification of a small number of High Arctic NOAA images early in the pilot project studies, an additional AFFINE rectification program was developed for use in hardcopy processing. Subsequent modifications of the VHR2 iterative routines and the development of more sophisticated techniques for their application eliminated the original difficulties and obviated the immediate need for AFFINE.

Nevertheless, because of its possible utility in other imagery rectification applications, AFFINE was retained as a component of the processing system. The program performs 3 to 11 term AFFINE transformations of an Ikonas image plane into another such plane. The number of terms in the transformation polynomials for each of two coordinates is equal to the number of utilized control points. The agreement between the two images is perfect, i.e. $x'=x$ and $y'=y$ at the control points since the transformation represents the solution for the $2n$ coefficients of 2 n -term polynomials (one for each of two dimensions) obtained by successive equation to the two coordinate values of each of n control points. The general form of the term polynomials are indicated in Table 3-1.

*As in the case of VHR2-remapped images, conversion of these images to a specified conic projection is possible within the image processing system using a VCP subroutine.

Table 3-1: Forms of the AFFINE module polynomials for the (x, y) (x',y') transformation using n control points where $3 \leq n \leq 7$. Extension to n values >7 follows the established pattern for adding new terms.

n	x' Coordinate Polynomial	y' Coordinate Polynomial
3	$x' = a_0 + a_1x + a_2y$	$y' = b_0 + b_1x + b_2y$
4	$x' = a_0 + a_1x + a_2y + a_3xy$	$y' = b_0 + b_1x + b_2y + b_3xy$
5	$x' = a_0 + a_1x + a_2y + a_3xy + a_4x^2$	$y' = b_0 + b_1x + b_2y + b_3xy + b_4x^2$
6	$x' = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2$	$y' = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2$
7	$x' = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2 + a_6x^3$	$y' = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2 + b_6x^3$

It is important to note that in spite of its obvious ability to reduce or eliminate errors close to a given point, enormous distortions can occur in those portions of the transformed region separated by even relatively moderate distances from the control points. This difficulty becomes more apparent with increasing numbers of peripheral control points because of the consequent introduction of higher order (and hence more rapidly spatially varying) terms into the transformation polynomial.

The most likely usage of the AFFINE module would appear to be as a final "touch-up" rectification to images previously rectified by the VHR2 module. Such two level processing could combine the general broad area-wide rectification accuracy of the VHR2 approach with the special point precision characteristic of the AFFINE module.

3.6 ICE MODULE

The extraction of quantitative ice dynamical data from from time-ordered sequences of rectified redigitized imagery required the development of software for:

- 1) the plotting and labelling of trajectories for specific floes or, more correctly, points on specific floes;
- 2) combining floe positions and image timing data to develop velocity time series for individual or area-averaged ice features;

- 3) generating velocity (and acceleration) averages and variances from floe time and position data in specific, defined subunits of the study area and time period;
- 4) generating the sequential display on video-tape or filmstrip of identically registered (with respect to fixed coordinate references) time-ordered images of the marine ice surface.

The latter function was incorporated in a separate MOVIE module described in Section 3.7. The ICE module was designed to meet the first three of these requirements using either the redigitized images as corrected for optical distortions and their orbital parameters (derived by the VHR2 module) or the rectified images in a specific, equi-rectangular map projection. Use of the second type of image requires the additional time and effort required for projection generation (by the VHR2 or VHR3 modules). On the other hand, such expenditures are at least partially recompensed by the greater ease of control point location in a sequence of images having a common projection and scale.

In either case, cursor digitizations of floe point locations are stored in floe-point-specific files labelled using the familiar menu format. The module always allows the user to have at least three differently-timed images in the image planes to facilitate the checking of the consistency of the digitized points and to generally speed up the data extraction process. The menu-type format also allows easy access to the VCP module and its useful functions, such as the flicker command which allows the rapid, repeated alternation of two images on the video screen again as an aid to consistent point selection.

Plotting of successive ice positions and their connection by line segments on a map projection is accomplished from the module using accumulated and stored floe-point specific files.

Other products of common utility, produced from the menu, include average velocity vectors and rectangular variance indicators for all ice floe points within a given, user-specified time and space "window" and equivalent time series of spatial velocity components associated with individual or group-averaged floe points. The variance indicator has been used in previous studies (Marko, 1982; Lemon, Wilson and Cuyper, 1982) to indicate temporal and spatial variance and consists of the construction of a rectangle of dimensions equal to twice the standard deviation of the x- and y-axis velocities centred on the end point of the average velocity vector.

3.7 MOVIE MODULE

The production of film strip representations of ice processes using sequential remotely-sensed imagery was facilitated by the writing of the MOVIE module. The module menu selections and data entry options allow the user to set filming parameters and to carry out the complete filming process from the CRT control console after manual adjustment of camera f-stop and focus. Keystroke selections initiate multiple photographing of each image (to provide the desired film display speed) and enter the next image in the sequence into the video screen. Options are provided for either automatic printing of time and date data at a specified point on each image directly from the corresponding image buffer file title. A mapped labelling option was also provided to allow indications of special features or gaps in the imagery sequence.

4. PILOT PROJECT TESTING

4.1 INTRODUCTION

The use and testing of the ice data extraction system on typical hardcopy imagery products was, from conception, an essential element of the development project. This component not only defined more clearly the scope of potential hardcopy applications, but led directly to several significant additions and modifications to the system software and procedures.

Test imagery were selected to reflect the range of ice and viewing conditions likely to be encountered in Canadian marine applications of the technology. Thus, with one exception*, the imagery were not produced specifically for the project but instead, were borrowed and/or copied from the large hardcopy imagery collections maintained at the AES Ice Forecasting Central in Ottawa and at the AES Arctic Weather Centre in Edmonton.

*Several 1984 images obtained from Mr. A. Aldunate of AES, Toronto and Mr. J. Bullas of the Arctic Weather Centre were used to confirm the correct functioning of the VHR2 module procedure for locating the subtrack pixel. These confirmations used two groups of images centred on western Baffin Bay and Hudson Bay, respectively. In each group, full scene images were produced for both northerly- and southerly-travelling satellite passes. These images covered the full 2048 pixel field of view of the satellite. Two subportions of each of these images, one near the centre and the other near the periphery, were used to produce four(1:2.9·10⁶ scale) blowups of the type now commonly used in AES ice condition assessments (and which return the full resolution of the satellite-received data). All images were rectified by an early version of the VHR2 module using five control points selected from a coastal map. In all cases, subtrack pixels derived from the fractional- and parent-images were in agreement within the full pixel resolution of the larger scale parent images. These results and similar agreements to within 1° in the derived ascending node parameters confirmed at least the general functioning of the module and justified further testing in the pilot studies.

The sites of the selected pilot studies are indicated on the map of Figure 4-1. The readily apparent preference for eastern ice-infested areas is accidental and equivalently significant applications of the tested techniques are to be anticipated in the central and western Arctic Archipelago, the Beaufort Sea and in other marine and freshwater locations. The overall significance of each site and its associated test imagery are briefly described in the following paragraphs.

Lancaster Sound Study

Winter, 1982 imagery of Lancaster Sound and its environs were used to both derive important data on the natural processes of the regional ice cover and to provide a demanding test of the hardcopy processing modules and their associated application techniques.

The ice processes in question involve the establishment and continued stability of a fast ice boundary across the nearly 100 km width of Lancaster Sound. Ice to the west of this boundary remains motionless (on scales of 1 km) until the July period, while the eastern ice moves eastward and eventually enters Baffin Bay. Historical records suggest that the stable edges occur only at five approximate locations (Marko, 1978; 1982) (see Figure 4-2). Year-to-year and intra-annual shifts among these positions can drastically change the winter, spring and early summer marine environments in this region of great Arctic biological productivity. Documentation of ice movements east of these boundaries would give information directly relevant to the understanding of the: operative forcing mechanisms; the mechanical and physical properties of the ice cover; and, hopefully, the reasons for the enormous regional variability. An additional item of interest is the effect of the Lancaster Sound processes on the Baffin Bay ice circulation and vice versa.

Particular rectification difficulties were anticipated in the imagery of this region because of the high latitude (74°), which could retard the convergence in the deduction of orbital parameters (see Section 3.3). Additional problems were posed by the common presence of cloud in many land and marine areas which complicated control point identification. Further difficulties of this kind were introduced by the relative rarity of small islands and distinctive headlands in the area and the tendency for the appearance of many coastal features to be obscured by the region's substantial coastal ice shelves.

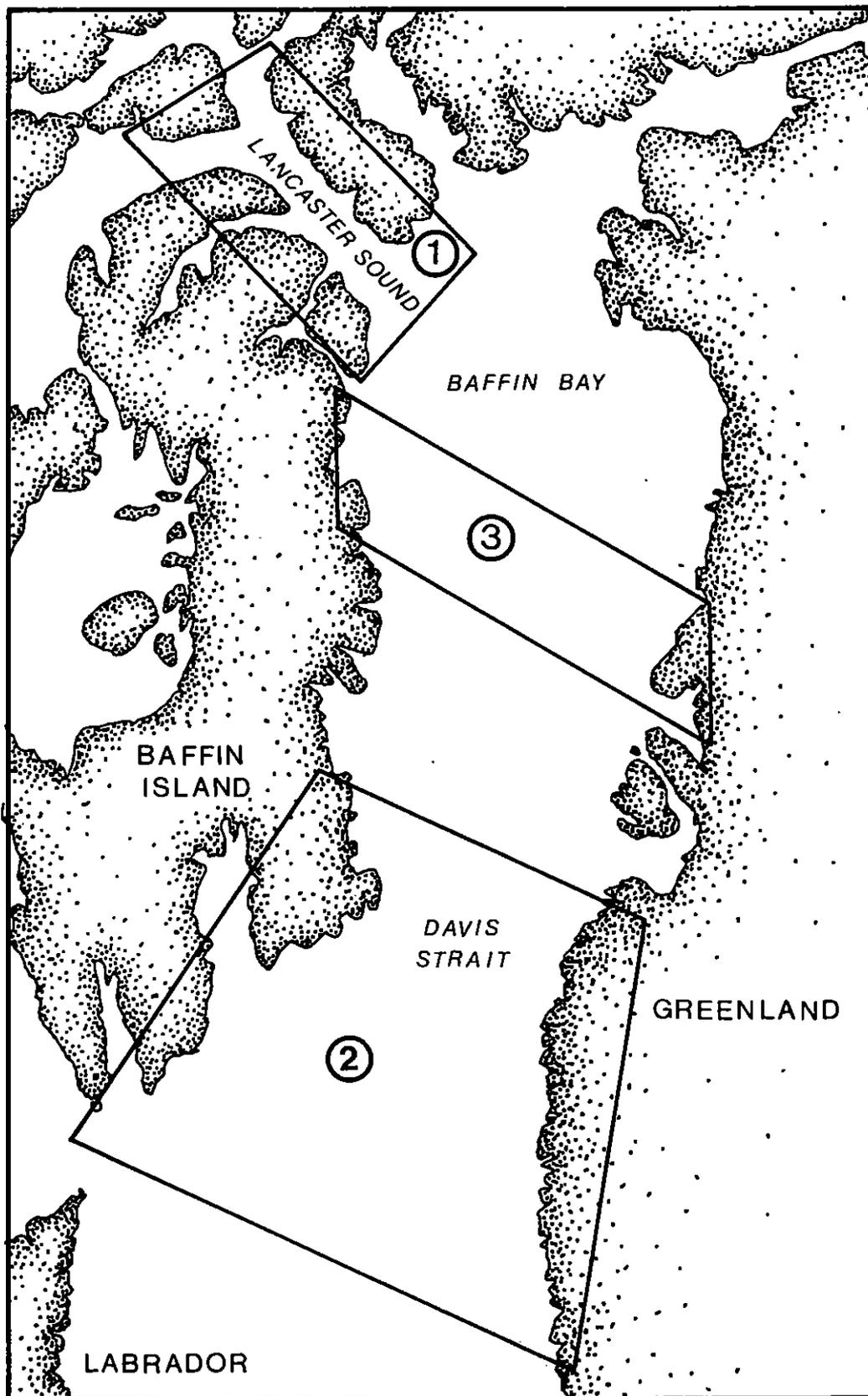


Figure 4-1: Study areas covered in pilot studies 1, 2 and 3.

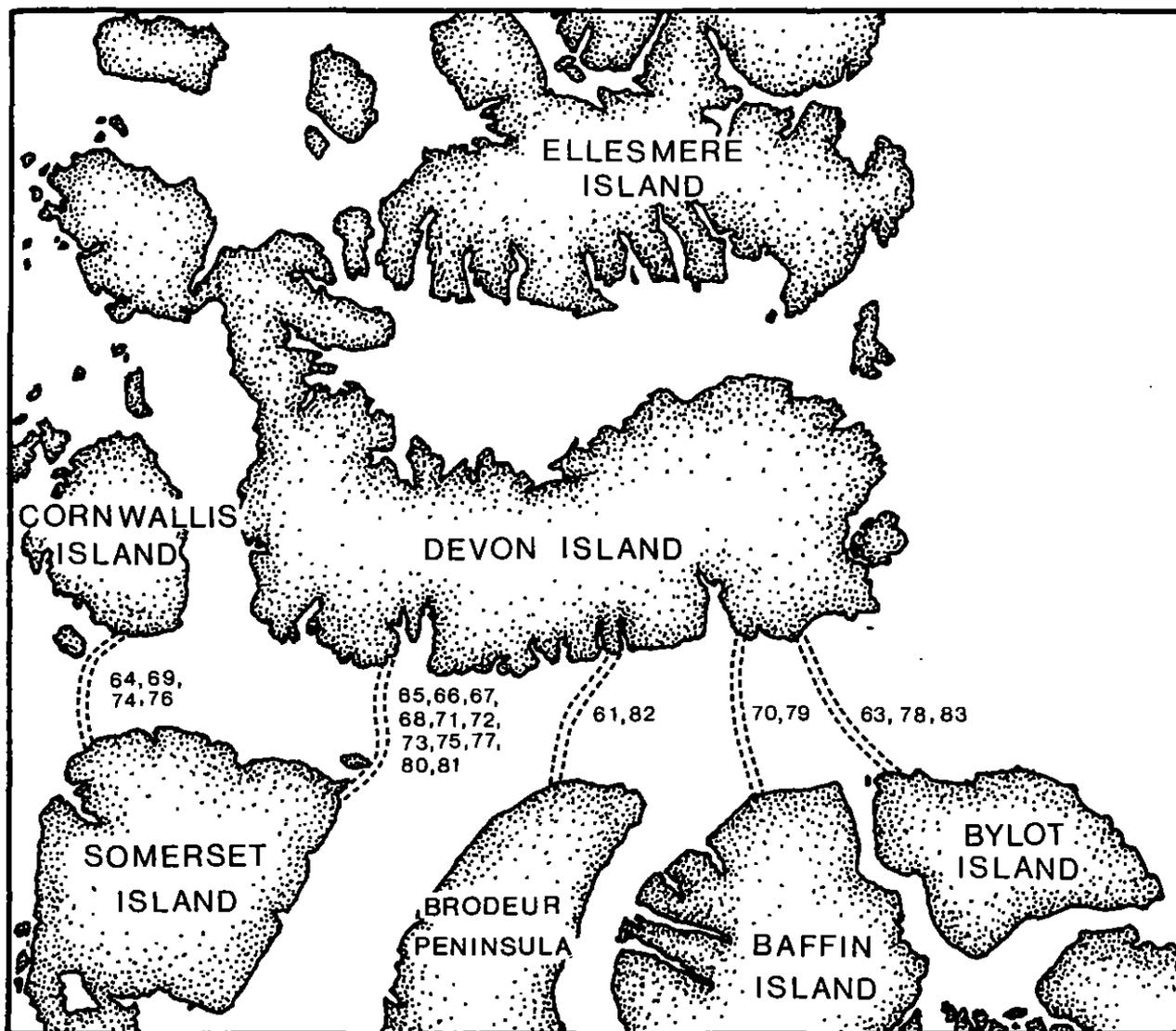


Figure 4-2: Approximate stable positions of the winter ice edge in eastern Parry Channel, 1961-1982.

Under these circumstances, the Lancaster Sound imagery was chosen to be the key venue for the testing program.

Davis Strait Study

NOAA imagery were used to document ice flow-patterns and rates in Davis Strait (Figure 4-1) for a March, 1983 period. The study region is of interest because of its indigenous potential offshore oilfields and its critical role in the process whereby ice and icebergs move into southern, more industrially developed waters. Its oceanographic structure is known to be complex, containing the southern Baffin Current, the northerly West Greenland Current and a vast intermediate area of high current variability. Comparisons of the flow patterns exhibited by its largely first year ice cover against those obtained in Davis Strait would be relevant to characterization of the respective ice rheologies.

The ease of processing Davis Strait imagery is generally enhanced by the presence of numerous small islands along the west Greenland and east Baffin Island coastlines. On the other hand, separations between the latter two islands as large as 500 km provide good tests of hardcopy data extraction in areas well removed from land masses.

Baffin Bay Study

A very small number (3) of images of southern Baffin Bay during March, 1983 were rectified and analyzed with respect to internal ice cover movement in the vicinity of a complicated, slowly changing surface structure formed by the intersections of numerous rectilinear leads. The latter leads are ubiquitous in non-coastal regions of Baffin Bay and in many other Arctic offshore areas (Marko and Thomson, 1975). Their considerable width (up to 10 km), apparently long lifetimes, and convenient northwest-southeast orientation (thus connecting the open water areas of West Greenland with the eastern end of the Northwest Passage), make their detailed properties of potential interest to Arctic marine transport planners.

The locations of the studied leads, as much as 350 km from adjacent land points, were appropriate for the testing of a two-step data extraction process. This process first established the positions of very prominent points in the study area relative to coastal points by the conventional application of the VHR2 module. The second step of the process utilized a close-up lens in the redigitization to retain, as much as possible, the full

spatial details of the hardcopy image. Rectification of this second close-up image was then carried out relative to the internal control points established in the first rectification.

Successful utilization of such techniques would encourage the quantitative use of high resolution imagery in the study of far offshore ice dynamics.

It is important to note that the three study projects were not intended to derive new understandings of the observed dynamical processes. Such understandings clearly would require the examination of auxiliary meteorological- and oceanographic-records as well as considerable increases in the spatial and temporal extent of the satellite imagery coverage, all of which clearly lay beyond the scope of this project. Instead, the study goals were the testing and refinement of the developed data extraction techniques, leading to better definition of the range of applications appropriate to digitally processed hardcopy imagery.

A more detailed description of study results is given in the following sections.

4.2 LANCASTER SOUND STUDY

Approximately fifty 4X "blowup" ($1:2.9 \cdot 10^6$ scale) NOAA 7 and 8 images were borrowed from the AES Arctic Weather Centre and redigitized. One of these images was subjected to multiple redigitizations to test the effect on rectification of incorrect alignment of the hardcopy image edges relative to the orthogonal axes of the camera. Image plane rectifications were carried out using six control points for the aligned image and for three images rotated by $+5^\circ$, $+1^\circ$ and -5° , respectively. A measure of the alignment sensitivity may be gained from the control point deviations obtained with the respective optimum rectifications and setting of orbit parameters (see Table 4-1). The results do not suggest a drastic sensitivity to small misalignments and a consistent trend is apparent only in the longitude results* (at 74° the net displacement associated with 1' longitude is equal to that of 0.280 latitude). Nevertheless, at least, to the extent that the control point errors reflect rectification quality, the results sensibly enough suggest that care be taken in the original alignment of the hardcopy image.

*This last result is probably the result of the finer horizontal resolution noted in the footnote on p. 23

Table 4-1: Control point errors for nominally aligned and rotated hardcopy images.

Stn.		Latitude Errors ('Lat)				Longitude Errors ('Long)			
		Aligned	+5°	+1°	-5°	Aligned	+5°	+1°	-5°
1	73°54', -90°11'	.696	.908	.803	-.209	1.372	1.233	.340	2.359
2	74°29', -85°14'	-.728	-.171	-.317	-.912	1.473	.790	-.128	5.575
3	73°44', -84°50'	1.461	.942	.775	1.139	-2.363	-2.420	-4.872	-2.409
4	74°44', -98°14'	-.463	-1.150	-.880	-.671	.127	1.755	2.223	2.834
5	74°43', -95°11'	-.500	-.845	-.501	.808	-.909	-1.572	-.170	-8.092
6	73°23', -85°46'	-.459	.323	.125	-.144	.169	.104	2.514	-.616
	Dev.	.874	.881	.691	.812	1.450	1.647	2.65	4.86

After such initial tests, redigitization and VHR2 rectification was carried out for 43 images covering the period February 16 to April 1, 1982. This period followed, by one day, the appearance of a north-south lead extending across Lancaster Sound north of the Brodeur Peninsula (the centre lead position in Figure 4-2). Subsequent events demonstrated that the western edge of this lead remained, with small modifications, as the eastern boundary of fast ice in Parry Channel until the following July. During the studied February-April period, the characteristic eastward movement (Marko, 1982) of ice to the east of this edge created an adjacent zone of open water and thin ice. Continued eastward movement of the ice produces (through accretion and further generation of open water) a mobile ice cover of thickness which on average monotonically increases to the east. The details of the movement of this ice cover, and its relationship to the acting current- and wind-drag forces and events in the adjoining sectors of Baffin Bay are directly relevant to several environmental and scientific problems. These problems include the large-scale mechanical properties of ice fields, the still unknown mechanisms of formation of Arctic polynya (the open water region adjacent to the Lancaster Sound fast ice edge and the "North Water" are perhaps the best known examples of such entities) and the winter characteristics of the intrusive flow of the Baffin Current into the eastern end of Lancaster Sound (Fissel, Lemon and Birch, 1981).

The processing of the February-April, 1982 NOAA imagery to quality levels appropriate for the study of the mobile ice field consumed much time and effort. Most of this expenditure was devoted to devising techniques for effective use of the VHR2 rectification module in spite of some difficulties posed by the special characteristics or "idiosyncrasies" of the study region.

Initially the redigitized images, corrected from camera optical distortion, were run through the VHR2 process using 4 or 5 reference points selected from the coastal map projection. As anticipated, difficulties were encountered in obtaining reasonable rectifications for a small number of images having large angles between their edges and the corresponding lines of constant latitude and longitude. Nevertheless, overall control point errors of 1' or less in latitude and less than 2' in longitude were obtained in the rectified versions of the great majority of cases. Improvements were then made in the orbital parameter adjustment routines which brought the control point errors on the troublesome images within the above-cited limits.

Difficulties were encountered when the individual images were put into a map projection and compared against each other and against a corresponding coastal map projection. Large, 5 to 10 nautical mile, day-to-day changes were apparent in the positions of coastal ice edges along eastern and southeastern Devon Island and along northern and eastern Bylôt Island. These changes were artifacts of the rectification process and resulted from the particular difficulties involved in finding good land based control points near these areas. Some certainty in the unchanging positions (on km scales) and shapes of these ice edges was justified because of the distinctively higher brightness of the coastal ice (which tends to be thicker than the adjoining mobile floes). This difference in brightness makes changes in the boundary very apparent either through the gradual growth of darker ice around the periphery or through pieces of freshly detached ice which appear in immediately downstream areas. These results suggested that judgements of rectification quality cannot be simply based on the satisfaction of maximum control point error criteria. Reasonably enough, the positioning of the control points relative to the area of interest is also an important factor. Further testing of individual images demonstrated that the use of 5 or 6 control points arranged to form a roughly regular polygon does insure that errors in the placement of points in the polygon interior do not exceed the largest control point errors.

The impossibility of satisfying this operating criterion on a daily basis in eastern Lancaster Sound forced the use of secondary control points at points in the coastal ice shelves and in interior land areas. The positions of these points were established from those daily images with sufficient conventional coastal control points and other properties to allow excellent all-over rectification. The design of the VHR2 module allowed efficient rectification with secondary control points facilitating the cursor-selection of such control points directly

from previously rectified images stored in the other image planes. In the general case, secondary control points were used in conjunction with the limited number of primary control points selected from coastal maps stored in a graphics plane.

In this way, our collection of 43 daily images was gradually upgraded both in terms of control point errors and by the more demanding tests offered by comparisons with coastal map overlays and sequential or flicker displays of different daily images in a common map projection. Although further improvements are still clearly desirable and possible in many images, ice edge and other discontinuities in the imagery sequence were reduced to levels comparable to the control point deviations calculated for each rectification by the VHR2 module. The mean value of the deviations calculated for the final set of rectified images was 0.89 nautical mile (1.63 km) with a standard deviation of 0.4 nautical mile (0.73 km). The average values of the maximum latitude (north-south) and longitude (east-west) errors recorded in each rectification were 1.3 nautical miles (2.37 km) and 0.55 nautical mile (1 km), respectively.

Assuming a normal distribution, the average error and standard deviation values suggest that points were located to an accuracy of 1.7 nautical miles (3.1 km) with a 95% degree of certainty. Moreover, it is important to take note of the corresponding 0.88 nautical mile (1.61 km) and 0.40 nautical mile (0.73 km) mean error values obtained for the north-south (parallel to lines of longitude) and east-west (parallel to lines of latitude) directions, respectively. The approximate factor of two differences in these mean errors very well reflects the two-fold difference in the video system resolution noted along the two axes of its imaging plane (see Section 3.3).

This second result suggests that the use of the VHR2 module on images redigitized with a comparable video system camera free of the resolution anisotropy would produce characteristic north-south errors having mean values and standard deviations similar to those measured in this study and noted above for the east-west direction. In this case, assuming the errors along orthogonal axes to be uncorrelated, one would expect the overall mean of the control point errors to be reduced to 0.56 nautical mile (1.02 km) with a standard deviation of 0.24 nautical mile (0.44 km). Again for a normal distribution of errors, this result would suggest that without any other improvements in technique, the removal of camera resolution anisotropy would allow point location to a 1.04 nautical mile (1.9 km) accuracy with a 95% confidence level.

The above 3.1 km and 1.9 km accuracy estimates obtainable with and without the present built-in video resolution anisotropy respectively, compare favourably with the 1.1 km (nadir) and 1.96 km (image edge) range of resolutions characteristic of the original digital data versions of the tested NOAA-7 imagery.

Further improvements also now appear to be obtainable with the existing video hardware using the two-step close-up lens technique discussed in Section 4.4.

The rectified sequence contained one image per day except for the intervals 02/18-02/20, 03/09-03/10 and 03/15-03/16 inclusive and the dates 03/02 and 04/08. Cloud obstruction was common during the viewing period. Several images did not include portions of the region of interest and others had characteristically reduced spatial detail due to poor setting of grey-scale levels in the original image production.

Nevertheless, the imagery sequence provided a more than adequate basis for both conventional extraction of position-time data for some 52 different points in the ice pack (326 individual positions were recorded) using the ICE module and the production of film strips depicting:

- a) ice movement in the mobile ice zone of Lancaster Sound and an adjoining sector of Baffin Bay. This area extends from 78° to 86° west longitude and from 73.5° to 76° north longitude;
- b) ice motion for a shorter period (March 17-April 7) in a subportion of the larger area lying just east of Devon Island.

The film strips were produced from daily images remapped in a common 1200 m/pixel vertical scale, 1000 m/pixel horizontal scale equi-rectangular projection centred at 74°N, 87°W. Additional processing was carried out using basic VCP module routines for stretching and shifting image grey-scales to display maximum detail in the ice cover. Possible confusion introduced by changing views of adjacent land areas was eliminated by superimposing a filled overlay of the coastal map. Areas of the mapped region containing no satellite data were filled with the maximum pixel value to give a less-distracting white appearance. After test runs using a VCP movie command on subsets of 16 daily images, the full 43 image sequence was filmed using a camera in conjunction with the MOVIE module.

The filmed results gave by far the most informative representation of the ice cover dynamics. Interruptions by cloud and data gaps were found to be annoying but did not seriously obscure details of the dramatic processes taking place. The main features of these processes were:

- 1) an overall eastward motion of the Lancaster Sound ice cover without significant cross-channel shear except for:
 - a) a period when the Devon Island coastal ice shelf just east of the cross-channel fast ice edge temporarily extended itself in an offshore direction some 15 km beyond its earlier and later boundaries;
 - b) the northeastern quadrant of the Sound where interactions with the currents and ice of the adjoining portion of Baffin Bay altered ice flow properties and appeared to induce large-scale fractures in the ice cover (the width of these fractures increased toward the southern boundary of the channel).
- 2) The existence of an intrusive flow of ice from Baffin Bay into the mouth of Lancaster Sound near the southeast corner of Devon Island. The intruding ice closely skirted the edge of the Devon Island coastal ice, turned westward near Cape Sherard and continued west-southwesterly until near 81°W it encountered the distinctly whiter, thicker portions of the eastwardly moving ice of Lancaster Sound. At this point, the intruding ice reversed its direction and moved eastward and then southeastward with the ice outflow of Lancaster Sound.

Although the easterly trend of the Lancaster Sound winter ice cover has been previously documented (Marko, 1978, 1982), the film provides new information on the time and spatial variability of the flow. Viewing of the film in conjunction with the corresponding graphical display products (see below) could help address important issues such as the correlation between stoppages and starts of motion and the absence of large cross-channel shear. The first of these issues would require calculation of the geostrophic wind record and the review of contemporary oceanographic data. The second issue also involves some assumptions about the spatial and temporal distribution of the external ice forcing. If currents play an important role in this forcing, the small shear magnitude suggests either a strong

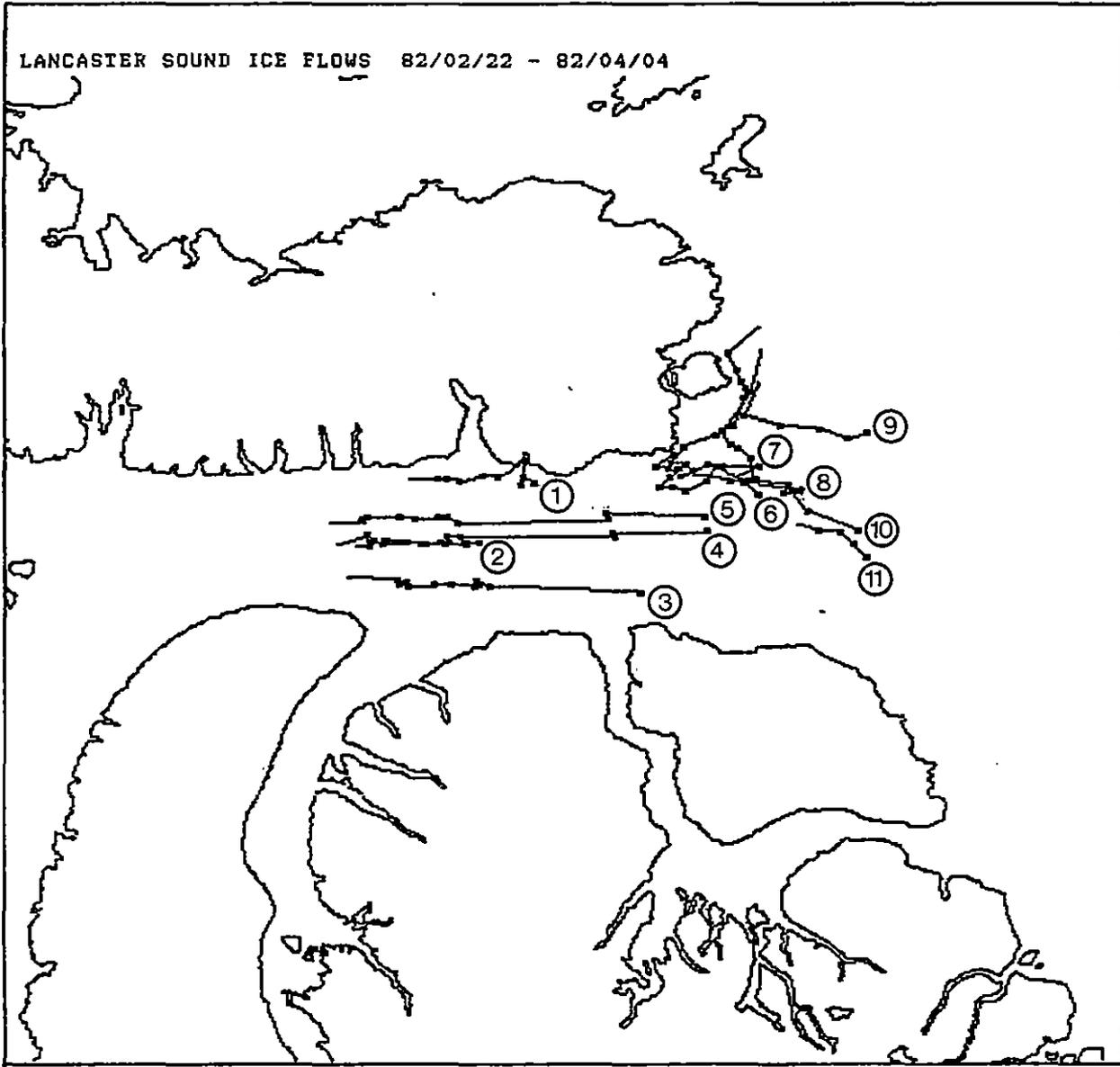
change in the winter current patterns relative to the summer situation (Fissel, Lemon and Birch, 1981) in which strong easterly flow is concentrated in a narrow zone along the southern border of the Sound, or alternatively, a surprising degree of shear strength in an ice cover which (assuming normal rates of growth (Bilello, 1960) and an average easterly drift of 5.3 km/day, see Figure 4-4), should only be, on average, 55 cm thick as it exits the Sound and enters Baffin Bay.

The presence of an intrusive flow of Baffin Bay water, ice and icebergs into eastern Lancaster Sound has been amply documented (Fissel, Lemon and Birch, 1981; Marko, 1982). However, on the basis of current-meter data (Fissel, Lemon and Birch, 1981) and the absence of contradicting ice drift data, the ice intrusion was believed (Marko, 1981) to disappear during the winter period due at least in part to a weakening of the current intrusion. The 1982 ice drift results suggest that this belief is incorrect and that, at least in that single year, large shears were present in the ice flow off southeast Devon Island. The importance of fast ice edge position, winds and currents to this phenomenon remains to be investigated in a fuller study.

Numerical data on the filmed processes were obtained by a technician operator. Displays of typical trajectories, box averaged vectors and time series of the box-averaged daily velocity vectors are presented in Figures 4-3 to 4-5. The latter Figure displays clearly the periods of rapid, negligible and moderate motion along the axes of the respective ice flow patterns.

4.3 DAVIS STRAIT STUDY

Eight NOAA images of Davis Strait were rectified by a relatively inexperienced technician and used for the extraction of ice motion for the March 22-31, 1983 period. The images differed from those used in the Lancaster Sound study in that they were photographically copied from originals in the AES Ice Forecasting Central archives by an Ottawa commercial photographer and printed at slightly larger than original size in Victoria, B.C. Although little loss in resolution was detectable relative to the originals, some images contained obvious defects such as the presence of edge curvature due to insufficiently careful mounting of the originals on the copying stage. While these relatively small blemishes probably introduced errors into the subsequently redigitized and rectified images, they did not seriously affect the operator's ability to obtain good ice position data from the copied products.



ICE FLOW	FROM	TO	ICE FLOW	FROM	TO
1	82/02/22	82/03/06	7	82/02/16	82/03/06
2	82/02/22	82/03/06	8	82/03/12	82/03/14
3	82/02/22	82/03/11	9	82/03/17	82/03/22
4	82/02/22	82/03/14	10	82/02/22	82/03/08
5	82/02/22	82/03/14	11	82/03/20	82/03/24
6	82/03/17	82/04/07			

Figure 4-3: Representative ice trajectories in Lancaster Sound for the indicated time intervals. The squares denote measured floe positions after the initial start of each trajectory.

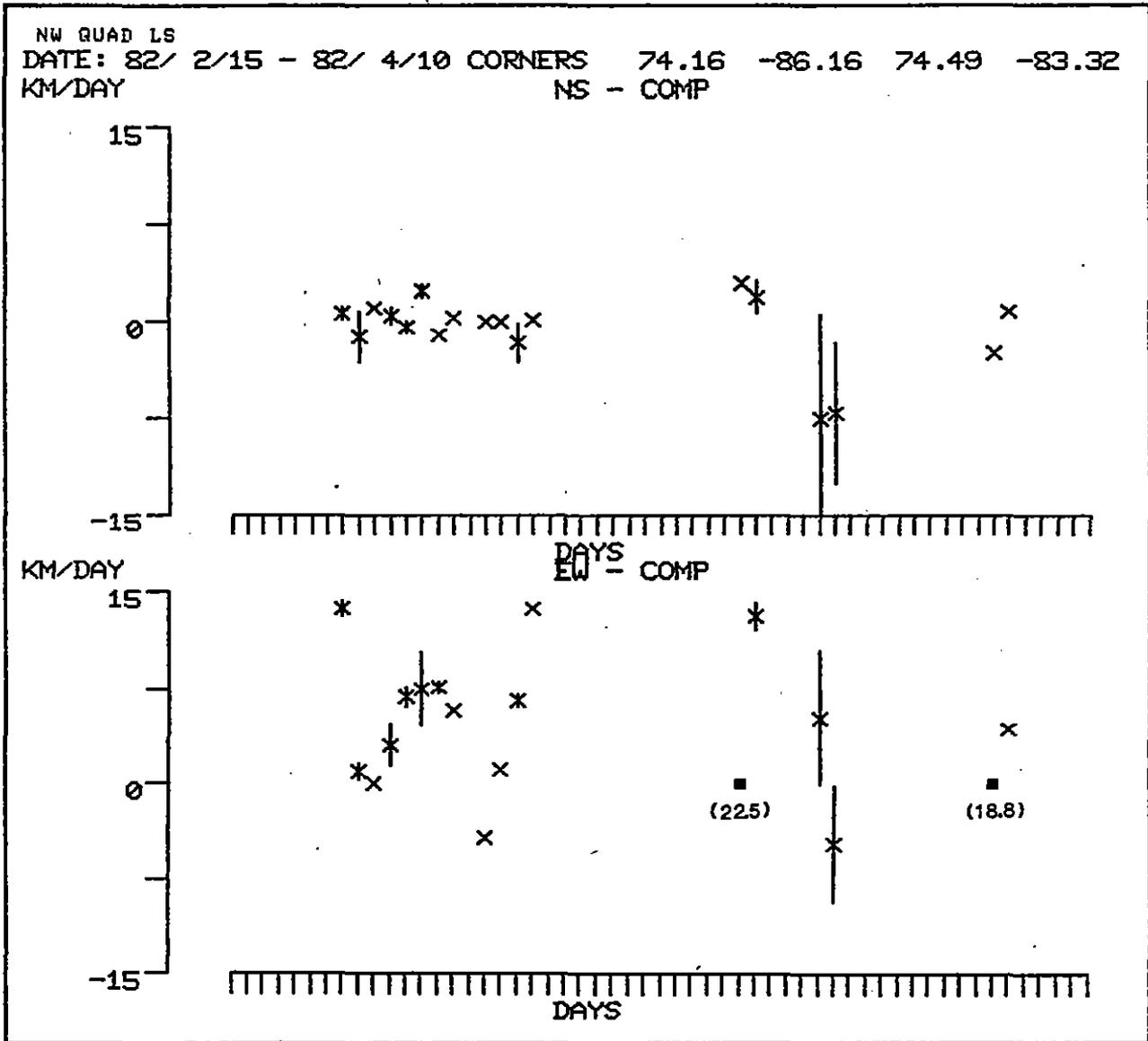


Figure 4-5a: Time series representation of the average daily ice velocities in the NW quadrant of Lancaster Sound.

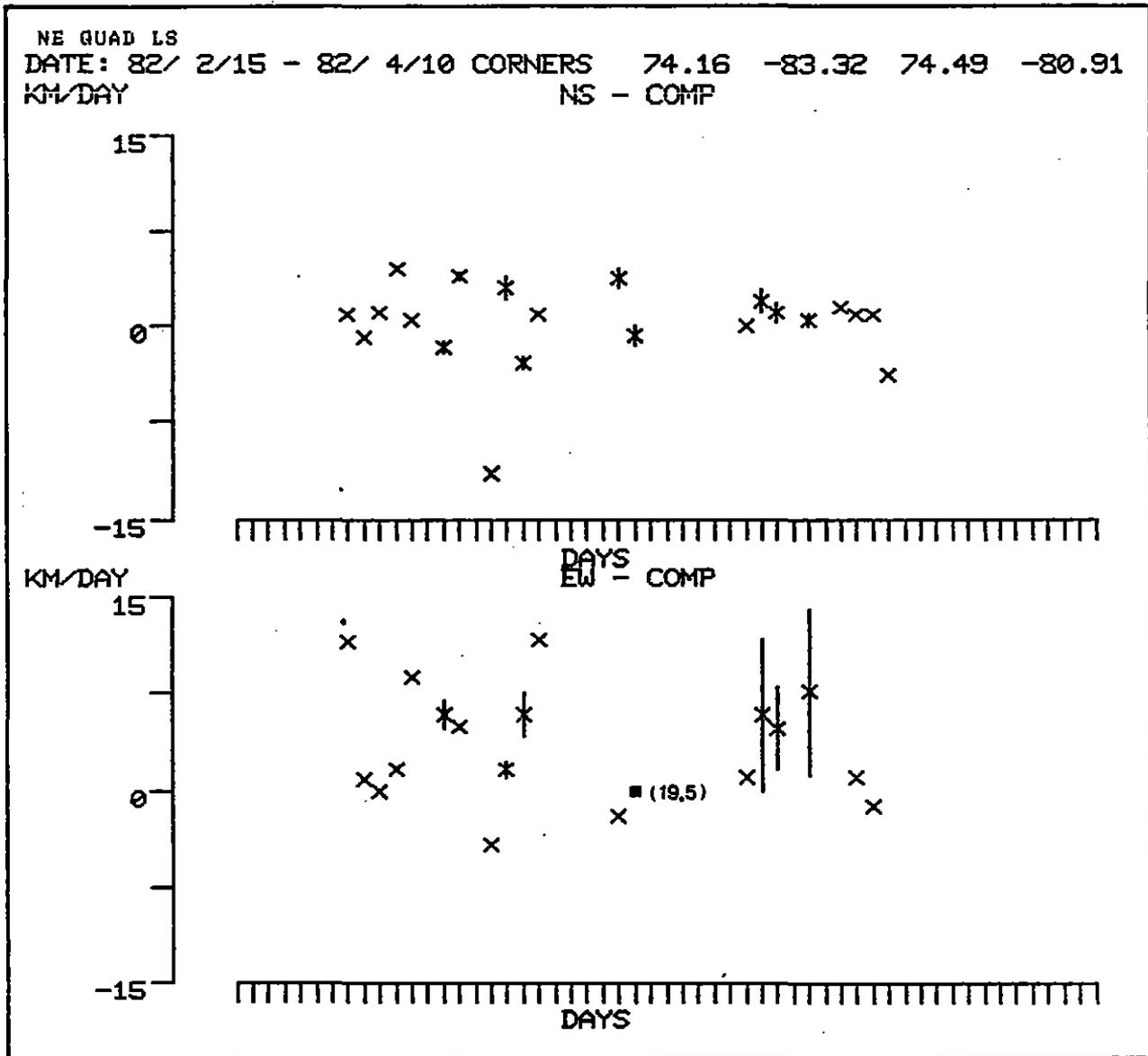


Figure 4-5b: Time series representation of the average daily ice velocities in the NE quadrant of Lancaster Sound.

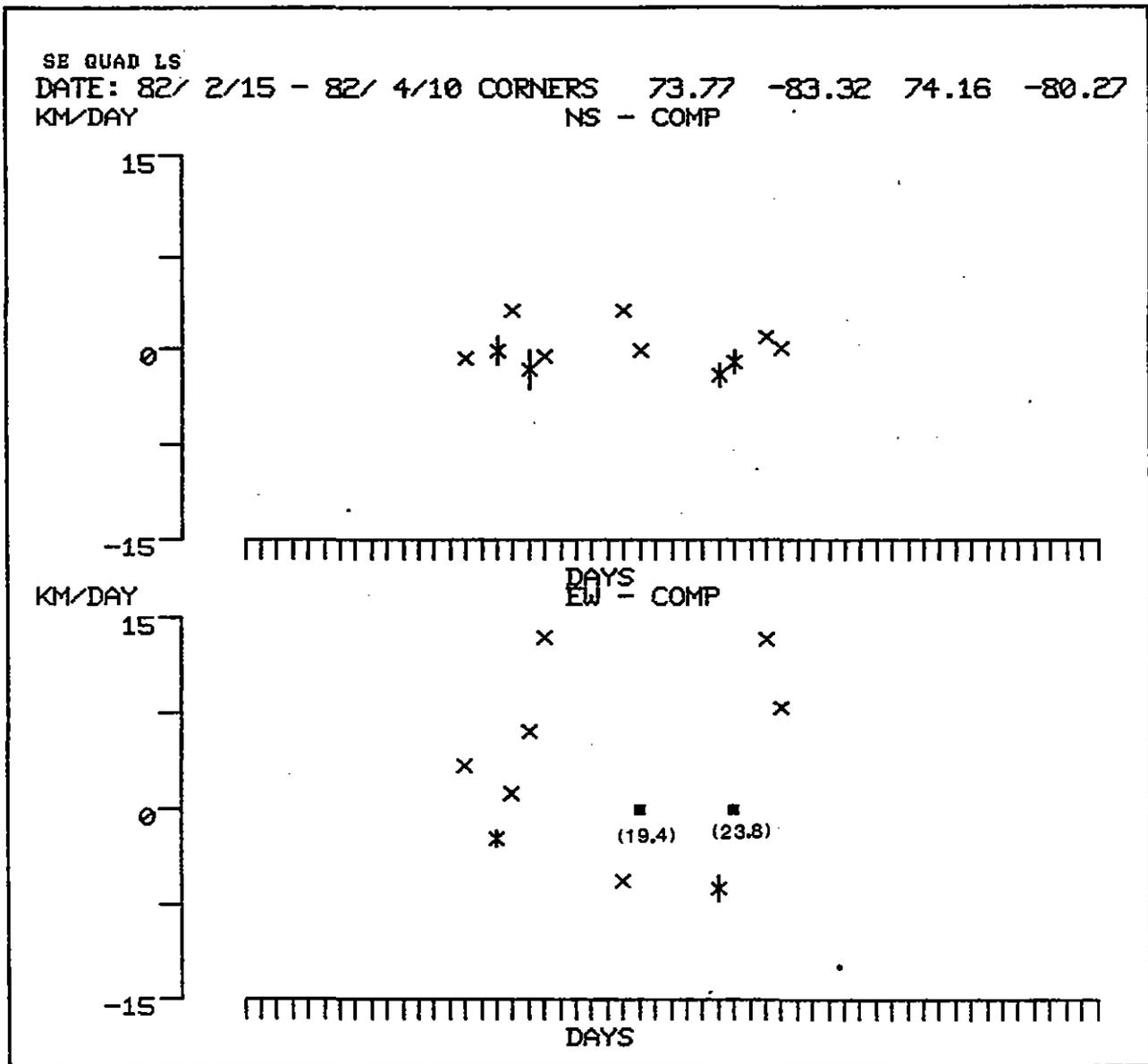


Figure 4-5c: Time series representation of the average daily ice velocities in the SE quadrant of Lancaster Sound.

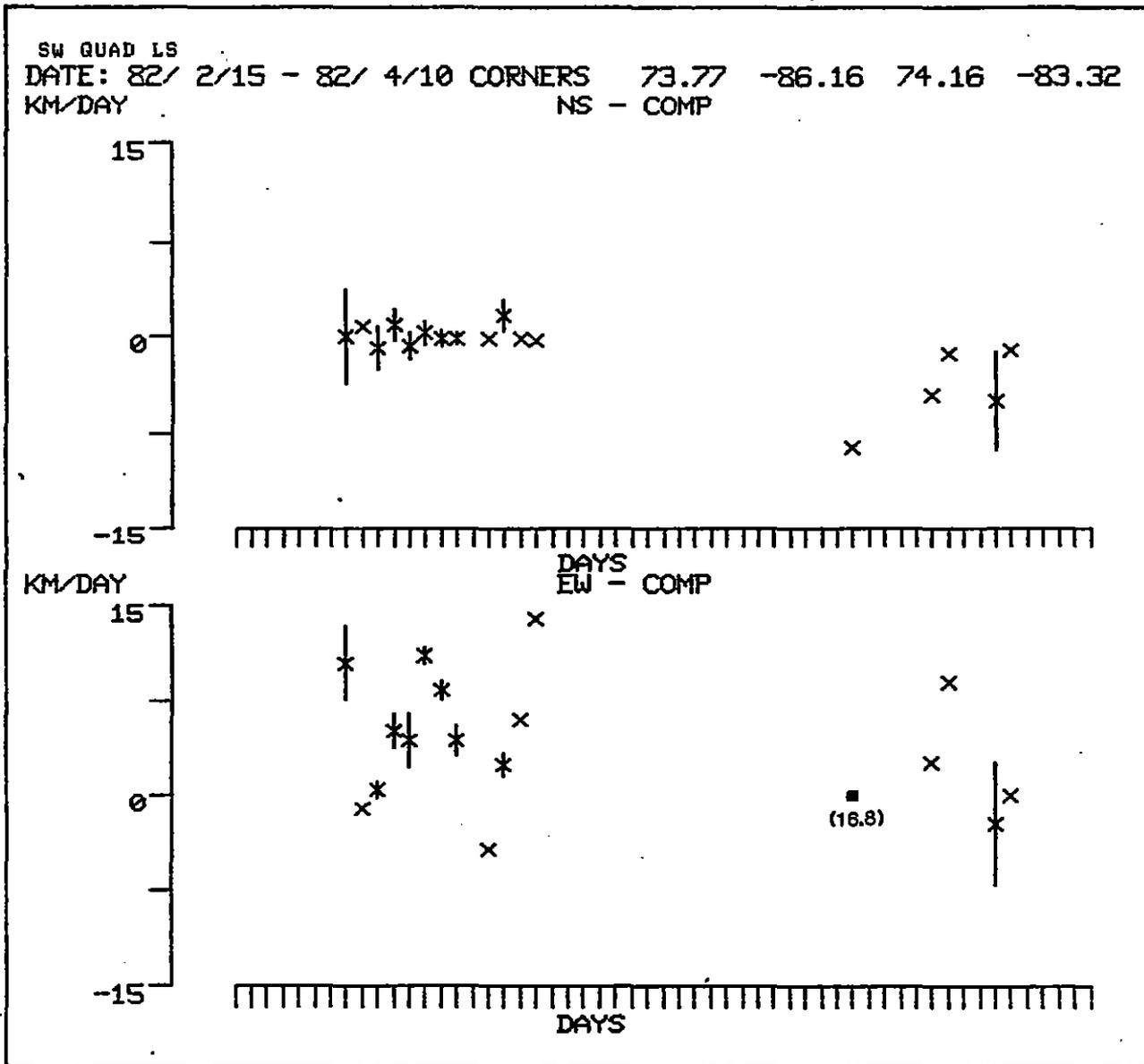


Figure 4-5d: Time series representation of the average daily ice velocities in the SW quadrant of Lancaster Sound.

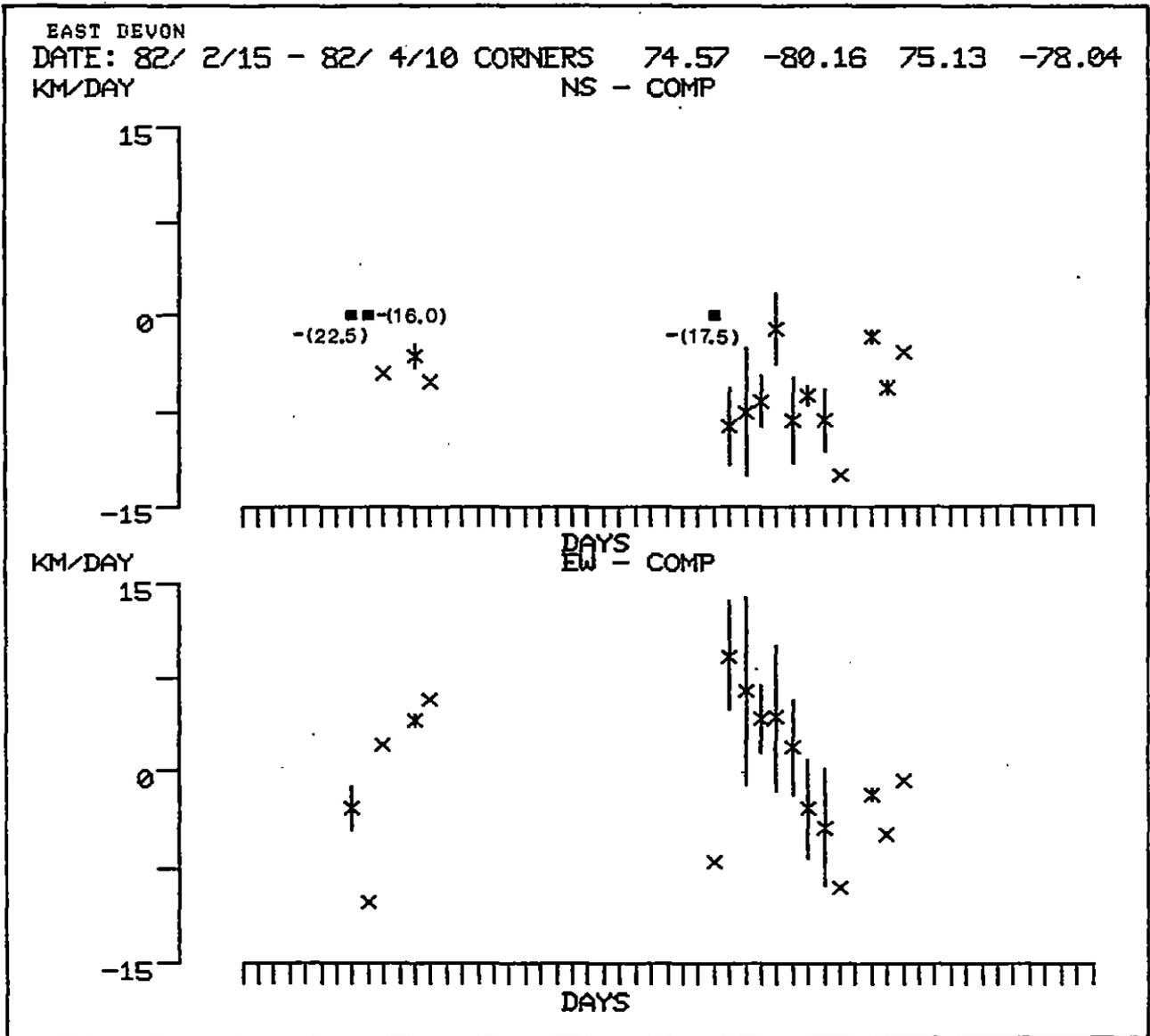


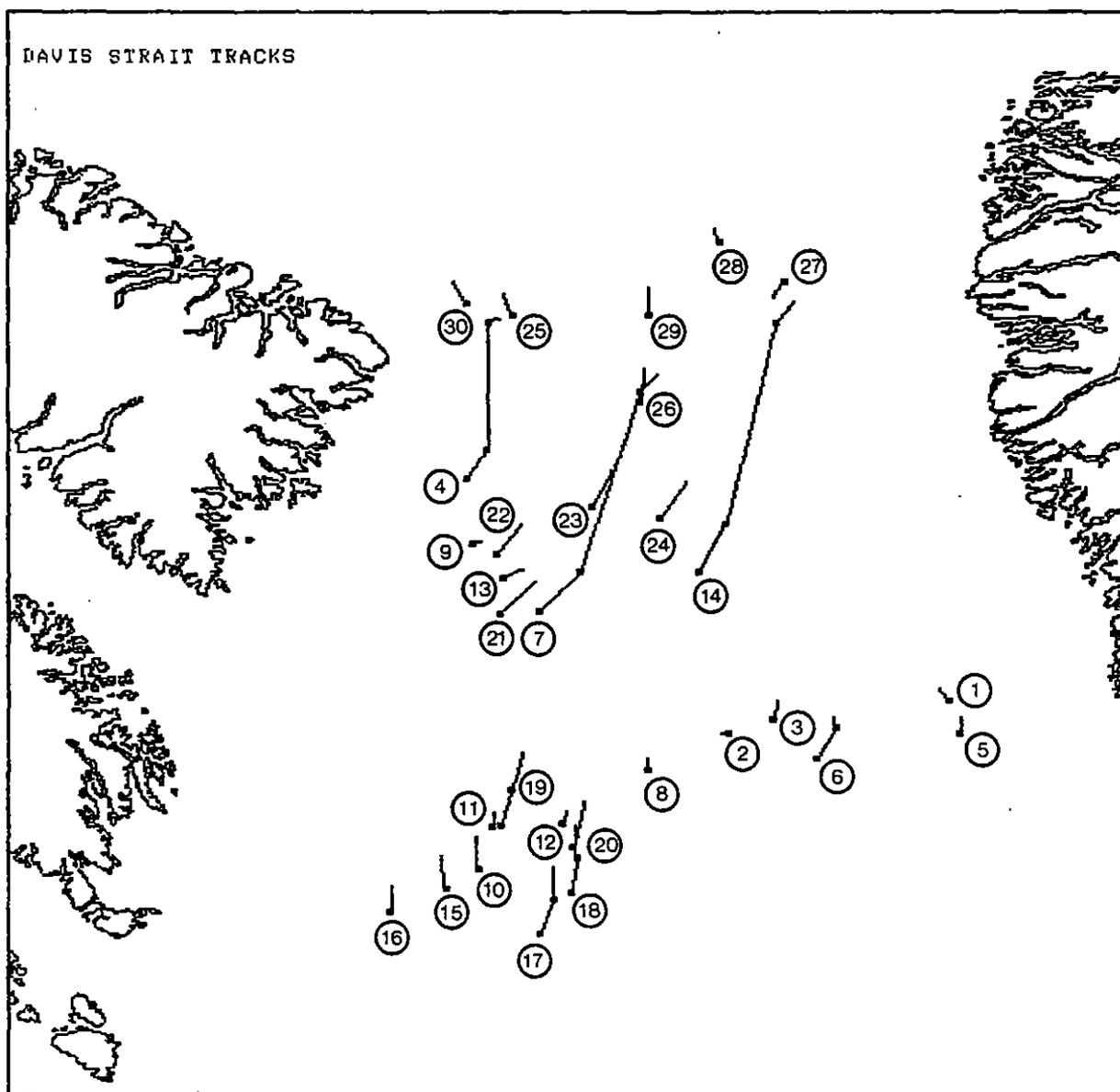
Figure 4-5e: Time series representation of the average daily ice velocities for East Devon Island.

In spite of the large, 300-500 km, separation of the west Greenland and east Baffin Island coastlines, the availability of numerous islands and fiords provided an abundance of control points along two sides of the study area. Good rectifications, as judged both from control point errors and coastal map overlays, were obtained using just four control points per image, as selected from the coastal map.

Seven of the images were used to extract data on the regional velocity field while the eighth (obtained at 22:41Z, 03/29) was used to provide a rough check the accuracy of our position estimates through comparisons with a similar image recorded a little more than five hours previously (18:31Z, 03/29). The recorded differences in points on the two images were within 2 nautical miles of the positions expected assuming the continuance of the velocity calculated from the earlier 03/29 point and the previous position measurement on 03/24. Although obviously, the large uncertainty in the appropriate short-term velocity makes this a somewhat crude estimate, such an error is consistent with expectations on the basis of the mean control point error (1 nautical mile) and standard deviation (0.4 nautical mile) which suggested (again assuming a normal error distribution) that 95% of all errors would be ≤ 1.8 nautical miles (3.3 km). These errors are slightly larger than similar estimates made in the Lancaster Sound study in spite of the much greater ease in lower latitude rectifications. This circumstance is probably a combination of a less experienced operator, the use of a smaller number of control points and the necessarily long sides of the control point polygon imposed by the great width of Davis Strait.

It is important to take note that the same factor of two inequality of north-south and east-west errors observed in the Lancaster Sound study (Section 4.2) was again very evident in the Davis Strait results, thus providing further support for the attainability of near original accuracy with the elimination of camera resolution anisotropy.

The obtained ice drift trajectories indicated a strong south-southwesterly drift through the area (Figure 4-6) with average speeds recorded in each quadrant (Figure 4-7) equal to 14.6 km/d (NW), 22.1 km/d (NE), 11.3 km/d (SE) and 19.1 km/d (SW). Although the analyzed data record is clearly too short to reveal finer details of the flow structure, the accuracy and operational ease of the data extraction suggest such data are now easily obtainable from hardcopy. The minimal problems introduced by the use of photographic image copies also demonstrate that off-site processing can be carried out without accelerating the



ICE FLOW	FROM	TO	ICE FLOW	FROM	TO
1	83/03/22	83/03/23	16	83/03/26	83/03/27
2	83/03/22	83/03/23	17	83/03/26	83/03/29
3	83/03/22	83/03/23	18	83/03/26	83/03/29
4	83/03/23	83/03/29	19	83/03/26	83/03/29
5	83/03/22	83/03/23	20	83/03/27	83/03/29
6	83/03/22	83/03/24	21	83/03/29	83/03/31
7	83/03/23	83/03/31	22	83/03/29	83/03/31
8	83/03/22	83/03/23	23	83/03/29	83/03/31
9	83/03/23	83/03/24	24	83/03/29	83/03/31
10	83/03/26	83/03/27	25	83/03/29	83/03/31
11	83/03/22	83/03/23	26	83/03/29	83/03/31
12	83/03/22	83/03/23	27	83/03/29	83/03/31
13	83/03/23	83/03/24	28	83/03/29	83/03/31
14	83/03/23	83/03/31	29	83/03/29	83/03/31
15	83/03/26	83/03/27	39	83/03/29	83/03/31

Figure 4-6: Representative ice trajectories in Davis Strait for the indicated time intervals.

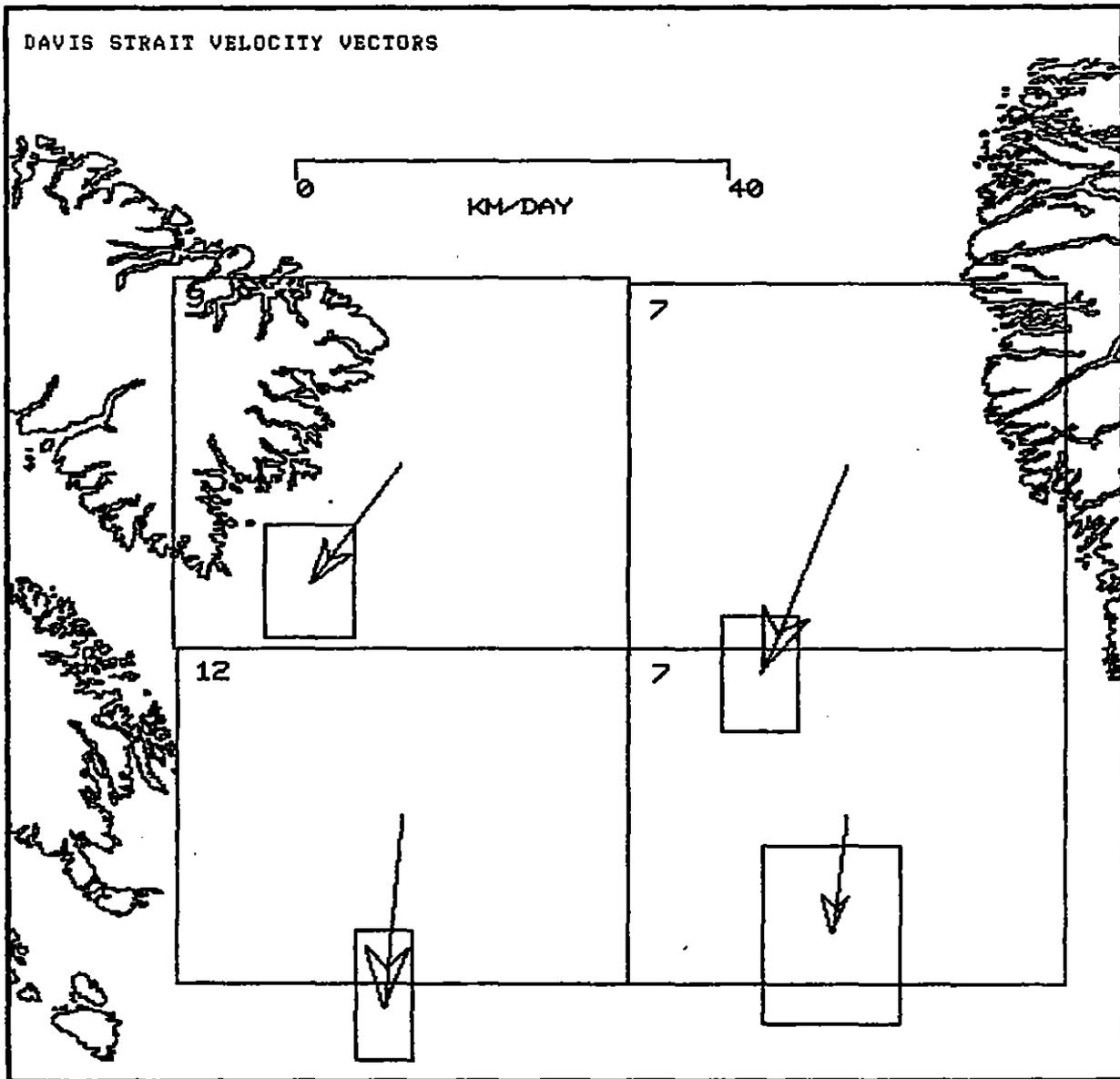


Figure 4-7: Ice velocity vectors averaged over the study period in the indicated zones. Rectangles centred on the heads of the vectors have side lengths equal to twice the corresponding standard deviations of the observed velocity components.

deterioration or loss of archival imagery.

4.4 BAFFIN BAY STUDY

Eight March, 1983 NOAA images of southern Baffin Bay were selected from the AES Ice Forecasting Central archives and copied as described above for the Davis Strait study. These images showed the details of a complex sequence of movements and changes in the observed ice cover. The effects of these movements and changes were most dramatically evident in the creation and disappearance of narrow (usually 1 to 3 km wide) rectilinear leads or openings in the ice cover. These leads are common features of the wintertime ice cover in Baffin Bay, often appearing in grid-like patterns produced by the existence of two or more planes of leads spaced at approximately equal intervals. Their presence has been previously noted in the Beaufort Sea (Marko and Thomson, 1975) and Hudson Bay and attributed to large-scale brittle fractures (Marko and Thomson, 1977). The Beaufort Sea data, obtained from less than 5 consecutive days of Landsat imagery observation indicated the presence of a characteristic pattern of relative motion between the adjoining diamond shaped fields of ice formed by the intersecting leads. The capability to accurately measure absolute and relative ice displacements around these leads over an extended period would enable detailed study of this process through which the relatively rigid ice body makes internal strain adjustments to conform to the overall movement under wind and current forcing and the confinement induced by coastal constrictions. The extracted information would not only be relevant to the overall understanding of the East Coast ice circulation but would also contribute significantly to the increased ice forecasting capabilities which would be required if Arctic marine cargo carriers were to use such structures to achieve time and cost savings.

Although good imagery of the same portion of the ice cover (as indicated by the presence of easily recognizable whiter, thicker, possibly multi-year floes) was obtained over the March 3-25 period, time limitations confined our testing program to the images of March 8, 14 and 21. These images were first rectified by:

- 1) rectifying the intermediate March 14 image using 6 control points selected from a coastal map;
- 2) rectifying the March 8 and 21 images using both coastal map control points and control points selected off the rectified March 14 image;

- 3) The three rectified images were remapped using the VHR3 module into a common projection;
- 4) Five ice points, clearly visible on all 3 processed images, were located in the geocentric coordinate system using a VCP module command in conjunction with the March 14 image.
- 5) A (+2) close-up lens was added to the video camera providing a two-fold magnification. After refocusing and other adjustments, the three original hardcopy images were redigitized and individually rectified using the five ice points located in step 4 as control points.
- 6) The close-up images were remapped into a common projection.

The control point deviations resulting from the second set of rectifications ranged from 60 to 80% of those obtained (Dev (Lat) = 1.07', Dev (Long) = 1.64') in the Step 1 rectification of the March 14 image.

The improvement in the resolution of ice features and structures was readily apparent from comparisons of the close-up and bare objective images. The additional resolving power appeared to bring the resolution of the close-up images reasonably close to the 1.1 km value characteristic (at nadir) of the original digital imagery. On the basis of the good quality of the secondary (Step 5) rectifications, it would seem reasonable to assume that the corresponding offshore positioning accuracy on these images is comparable to, or not greatly inferior to the 1.7 nautical mile (3.1 km) (95% confidence) values which would be expected to be achieved with the large-scale image rectifications (of Steps 1 and 2).

The main intent of the data extraction carried out in this study was to obtain, from the close-up imagery products, measurements of the extents of movements which take place in an apparently internally-stressed portion of the ice cover and secondly to look for correlations between spatial gradients in the displacement (or velocity-) field and the positions of rectilinear leads.

Our limited analysis of the imagery utilized the VCP positioning and labelling commands to locate and mark the same 8 recognizable floe points on each of the three remapped close-up images. These positions were superimposed on the March 21 image and photographed (Figure 4-8). Although much detail has been

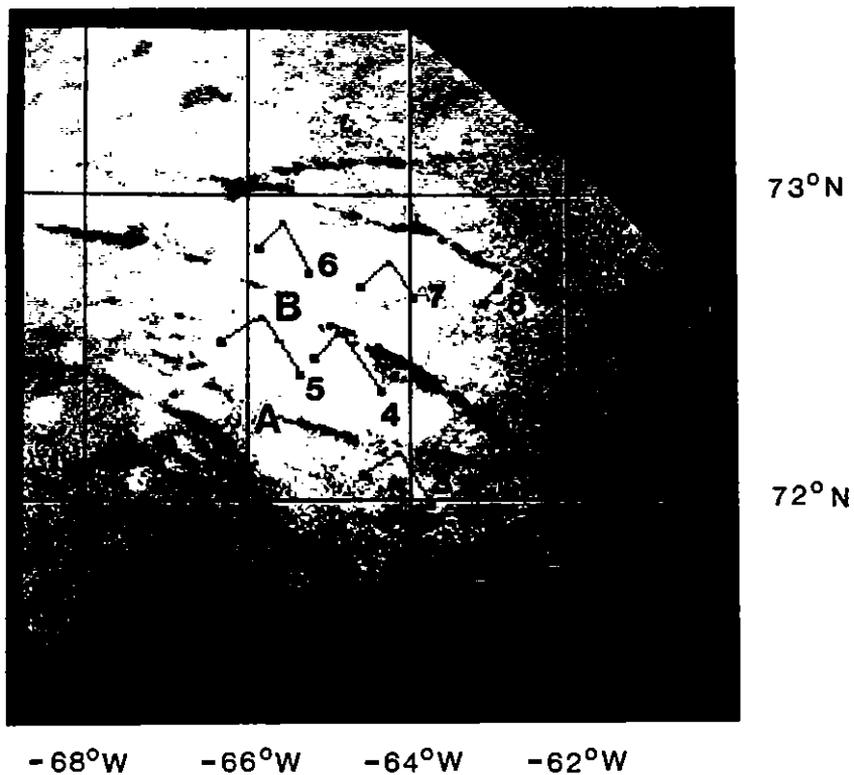


Figure 4-8: Ice point locations on March 8, 1983 (blue square), March 14, 1983 (yellow square) and March 21 (red square), superimposed on March 21 image (video monitor photograph).

lost in the additional photographing step, the Figure adequately displays the floe positions on the three dates relative to the lead patterns as they existed on March 21. Comparison with the superimposed grid indicates that the overall trend of the displacements were approximately 9 nautical miles to the northeast over March 8-14 and 12 nautical miles southeast over March 14-21. The net speeds of 2.3 and 3.1 km/day measured over these intervals were smaller than the corresponding Lancaster Sound and Davis Strait mobile ice values by roughly factors of 2 and 6 respectively. The key lead features of note were the large, long (>400 nautical miles) southeast-northwest lead (A) which was clearly visible on the March 8, and subsequent images. The second lead (B) only became visible on March 14. Examination of the x and y axis displacements (the positive x-axis is defined to be in the direction of decreasing west longitude and the +y axis in the direction of increasing north latitude) of each of the floe points (Table 4-2) indicates a commonality of displacement according to whether the individual floe points lie: south of leads A and B (points 1-3); north of lead A south of lead B (points 4 and 5); or north of both leads (points 6-8). The relatively insignificant differences among the points (1-5) over the March 8-14 period is consistent with the absence of the intervening lead B for much of this initial time interval. The anomalous trajectory of point 8 probably reflects the positioning of this point close to yet another more northern lead.

These results give us a measure of the magnitudes of the ice movements characteristic of those regions of southern Baffin Bay occupied by the internal-stress relieving rectilinear leads. The movements of the ice in the vicinity of these leads, 10 nautical miles, is on the order of 6 times larger than the estimated positioning accuracy attainable with the two-step redigitization and rectification procedure. The apparent relationship between the observed displacement and location relative to lead patterns suggests that the hardcopy processing technique could be a significant tool in the study of lead opening/closing phenomena on time scales of a few days or more.

Table 4-2: Displacements along the x- and y-axes as measured for points 1-8 (Figure 4-8) for the March 8-14, 1983 and March 14-21, 1983 time intervals.

	March 8-14		March 14-21	
	Δy (nautical mile)	Δx nautical mile)	Δy (nautical mile)	Δx (nautical mile)
1	3.8	9.3	-10.2	6.6
2	3.8	7.9	-9.7	7.3
3	4.3	7.3	-10.3	7.3
4	4.8	5.2	-11.3	9.9
5	4.9	9.6	-11.3	8.6
6	5.3	5.95	-10.2	5.3
7	3.9	6.6	-7.0	5.3
8	5.9	5.95	-3.2	-2.6

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

The development and testing program has resulted in a demonstrably economical mechanism for extracting ice position and velocity data from a variety of hardcopy remote-sensing imagery, currently available from archival and real-time new imagery production sources. The developed system used an inexpensive off-the-shelf video camera, a simply-adapted mounting apparatus and a very limited array of output peripherals at the IOS image processing system. The modular software and processing procedures allow the conversion of hardcopy (paper) imagery from the NOAA, Tiros, Nimbus and Landsat series of satellites into remapped digital images in a user-specified equi-rectangular or conic projection prior to the extraction of ice position data and the production of representative products such as time-lapse movies of the ice surface, mappings of trajectories and average velocity vectors and velocity time series.

The testing program was concentrated on the use of original and rephotographed versions of the approx. $1:2.9 \cdot 10^6$ (4X "blowup") NOAA images which have been produced by AES Canada operation centres since approximately 1980.

The use of images containing the full observational swath of the satellite was confined to a limited checking of the accuracy with which the VHR2 module locates the subtrack for a given "blowup" or fractional-swath image.

An important feature of the processing development is its independence of all but the most basic of the satellite and orbital parameters, i.e. satellite altitude and orbital inclination. Thus the processing and data extraction can be carried out without the need for access to ephemeris or other data.

Three pilot studies, centred in Lancaster Sound, Davis Strait and Lancaster Sound, were used to guide the development of software, processing procedures and to provide measures of the developed accuracies and image throughput.

The Lancaster Sound study consumed by far the greater part of our effort. The relatively strict tolerances on rectification accuracy required for the production of time lapse films from the studied images provided impetus for software and procedural improvements. Resulting procedural recommendations include: the use of a minimum of 5 control points approximately uniformly

spaced, surrounding the area of interest; the location of one or two control points as close as possible to the latter area; the use of the system zoom commands in all point placements, and, very importantly, the use of secondary control points derived from fast ice- and inland- feature positions on the most easily and accurately rectifiable images in a given sequence. Examinations of control point deviation data and inspection of the time-lapse film indicate that 95% of the placement errors in Lancaster Sound were equal to or less than 3.1 km. Due to a lower spatial resolution along the vertical axis of the video camera image plane, control point errors along lines of constant longitude were found to be, on average, approximately twice as large as those along the perpendicular, constant latitude directions. It was estimated that the removal of this artifact of the system hardware would increase the 95% confidence level accuracy to 1.9 km without further technique refinements.

The results of the data extractions demonstrated an irregular overall eastward movement in the Lancaster Sound mobile ice zones which averaged approximately 6 km/day during the 7-week observation period. Intervals of rapid, moderate and minimal movement can be identified over periods approaching one day. The apparent lack of cross-channel shear in a necessarily thin ice cover was surprising and relevant to the deduction of the wintertime wind and surface current fields and the mechanical strength parameters of the ice cover.

The momentum of the ice flow was found to be sufficient at the northeastern corner of the Sound to reverse the trajectories of thicker floes entering the Sound near Cape Sherard, Devon Island from northwestern Baffin Bay. The latter movements, documented in detail in the film sequence, demonstrate the previously unobserved presence of a wintertime counterpart of the strong intrusive flow of water, ice and icebergs which dominate the surface of eastern Lancaster Sound during the summer period.

Shorter studies of ice movement were carried out to document the much more rapid and much slower movements which are characteristic of, respectively, the southerly drift of large floes in Davis Strait and the readjustments of the internally-stressed ice cover of southern Baffin Bay. In these two studies data were obtained on ice movements in areas as much as 250 to 350 km from land points. Nevertheless a combination of a greater abundance of coastal control points and a greater relative parallelism of the orbital subtracks and lines of longitude, respectively, maintained the positioning accuracy of the approximately 3 km level achieved in Lancaster Sound. Again the presence of a 2 to 1 reduction in north-south resolution,

associated with the video resolution anisotropy, was apparent in these data.

The Baffin Bay imagery were used to test the use of close-up lens attachments to the camera objective lens used in the Lancaster Sound and Davis Strait redigitizations. The close-up image was redigitized and rectified using secondary control points established after a previous redigitization of the same hardcopy image without the close-up lens and a subsequent redigitization. This technique offered a processing alternative which simultaneously retained the accuracy of large-scale image rectification (due to the presence of numerous control points) with the higher resolution provided by close-up image magnification.

Trajectory data and zonally-averaged velocity vectors obtained in Davis Strait indicated that flows were south and southwesterly directed with average magnitudes of 14 to 22 km/day except in the southeasterly quadrant (see Figure 4-7) where smaller speeds of less than 12 km/day were recorded for a short period. In the area, the tested system resolution would allow useful position-measurements on time scales as short as 12 hours.

The ice data in southern Baffin Bay consisted of the geocentric positions of eight points in a far offshore portion of an ice cover composed of an apparently piece-wise continuous first-year ice matrix which contained easily identifiable floes of thicker, possibly multi-year ice. This ice cover was also "criss-crossed" by prominent, roughly rectilinear openings or leads which typically extended for hundreds of kilometres, forming in the process an array of diamond-shaped ice fields. Position data obtained on 3 images from a March, 1983 period indicated that the rates of ice movement in this area averaged approximately 2 to 3 km/day (1.1 to 1.6 nautical mile/day) over roughly one week intervals. Spatial differences in the displacement and velocities correlated with positions relative to the lead structure.

On the basis of the Baffin Bay results, it was concluded that studies of lead properties relevant to both ice forecasting in more southern, downstream areas and to the possible use of leads for marine transport routing could be carried out using the developed processing system and hardcopy images recorded at similar weekly intervals. Still shorter period motions might be expected to be followed in more shoreward locations through the increased positioning accuracy which could be obtained because of the reduced separations from primary, coastal control points.

In common, the results of the pilot studies demonstrated the applicability of the developed processing system to the quantitative study of three areas of interest both as the sites of proposed hydrocarbon extraction or marine transport development and through their respective importance in determining overall ice conditions and energy exchange rates off the east coast of North America. Equivalently significant applications to the Beaufort Sea and other Arctic areas could be devised.

The range of applications of the developed technology would be increased with improvements in positioning accuracy and by reduction in processing times. At present, the estimated accuracies are several times poorer than those (0.5 km) attainable with radio-beacon equipped ice-drifters and the System Argos tracking network. Nevertheless for situations where the larger positioning errors and frequent interruptions of coverage are tolerable, the cost savings of the hardcopy method of data extraction, relative to drifters, are considerable in view of the low per image acquisition costs (approx. \$15/image) and the capacity to obtain data on many ice points in a given image. The other important factor in making cost comparisons is the operator time. This quantity of course depends upon the quality of the image, the data error tolerances and the operator's training and technical level. Experience in the study projects indicated that a previously untrained technician, a draftsman, after a few weeks of practice, required approximately 45 minutes to process an image to the point of entry into the ICE or MOVIE modules for graphic or time lapse data display. This time is comparable to that required for the location and rectification of a digital tape version of the same image suggesting that because of their lower acquisition and handling costs (comparable digital tape image costs can be as high as \$250) hardcopy, in addition to its valuable archival significance, could be the most economical form of imagery for near-real-time ice data extraction. Suggestions for further enhancements of hardcopy utility in terms of decreased processing times and improved positioning accuracy are given in the following concluding section.

5.2 RECOMMENDATIONS

In view of the very apparent usefulness of archival and near-real-time hardcopy remote-sensing imagery for quantitative ice studies, it is perhaps most appropriate to first recommend the procedures to ensure:

- 1) continued recording and storage of full resolution hardcopy NOAA images in all ice-covered marine areas anticipated to be of interest to future researchers/users;
- 2) the subsequent protection against deterioration and loss of all new- and previously archived-hardcopy imagery.

The first step would require considerable input, both in advice and possibly in terms of labour and financial support if operational agency imagery sources (such as the AES Ottawa and Edmonton centres) are to fulfill this function. The second step, inevitably, would appear to require a cataloguing and evaluation of the stored imagery collections and possibly a subsequent redigitization and storage by area and date on magnetic tape or other higher density storage media.

A second set of recommendations is specific to the developed hardcopy processing system and its base, the IOS image processor. Firstly, several hardware upgrades are essential to achieve important increases in: the accuracy of the resulting ice position data; the processing rate or system throughput; and the quality of the output products.

The paramount improvement with respect to data accuracy would be the upgrading and adjustment of the video camera system to eliminate the annoying 4:3 aspect ratio and the vertical/horizontal axes resolution inequality which are characteristic of the present system.

Image throughput would be significantly increased by an enlargement of the PDP 11/34 memory. Available options for memory expansion to 4 megabytes would greatly reduce two of the three major time consuming stages of the rectified image production process namely the calculation of orbital parameters and the remapping of the rectified image in projection.

The final system change worthy of consideration would be in the upgrading and expansion of system output alternatives. Thus for example, the acquisition of an x-y plotter and a dot matrix printer would increase the production rate qualities and ranges of the graphical products offered by the system.

Other recommendations relevant to procedures and further testing are also in order. These include expanded use and testing of close-up lens attachments in the rectification and data extraction steps. Although such procedures were evaluated only in the last portion of the project, they hold promise for

further reduction in position location errors with or without the elimination of the image resolution anisotropy problem.

A comparison of hardcopy and digital tape-image processing should be carried out using hardcopy- and tape-versions of the same images. If possible, surface truth data, such as System Argos ice drifter position points should be available in order to evaluate the relative accuracies of the two approaches. Such a test would help identify those situations in which the inexpensive and less bulky hardcopy products would be most appropriate to a particular measurement application.

Consideration should also be given to the development of techniques for rapid extraction of displacement or velocity data from sequences of rectified images. These techniques could take advantage of recent advances in the fields of pattern recognition and spatial-correlation analysis to produce, with minimum delay, coarse mappings of ice motion patterns which could be used for forecasting purposes or as a guide to the selection of imagery portions worthy of more detailed, manual data extraction.

Finally, we would like to end this report with an overall recommendation for increased use of archived and near real-time hardcopy imagery in extending the spatial and temporal lengths of the records examined in studies of ice processes. The hardcopy imagery is a valuable resource which, in conjunction with the developed techniques for digital processing and graphical- and time-lapse film-data display, could be seminal to the understanding and description of many large-scale ice phenomena. Benefits could quickly be realized from the incorporation of such data, for example, into the types of statistical studies of ice movement and its effects on ocean-atmosphere energy exchange which have been recently carried out in the Arctic Basin and the Greenland Sea (Colony and Thorndike, 1984). While it is extremely unlikely that hardcopy data sources can fully displace either the more expensive radio-beacon tracking technology used in many of these studies or conventional digital satellite imagery, the prospect for a broad range of suitable applications do justify further government and industry support for hardcopy production and quantitative use.

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APPENDIX A

**DIGITIZING HARDCOPY IMAGERY
AND ICE TRACKING:
AN OPERATOR'S MANUAL**

TABLE OF CONTENTS

Page

1.0	INTRODUCTION	
2.0	IMAGE DIGITIZATION	
2.1	INTRODUCTION	
2.2	PROGRAM OPT	
2.3	MAIN MENU	
2.4	VCP	
2.5	CLEARING IKONAS IMAGE PLANES	
2.6	PRODUCE A GRAPHICS GRID	
2.7	CALCULATING OFFSETS	
2.7.1	MENU FOR DIGITIZING OFFSETS	
2.8	COMPUTING THE OFFSET PLANES	
2.9	CORRECTING AN IMAGE FOR DISTORTION	
2.10	HELPFUL HINTS	
3.0	CALCULATION OF ORBITAL PARAMETERS	
3.1	PROGRAM VHR2	
3.2	MAIN MENU	
3.3	VCP	
3.4	SETTING A COASTLINE PROJECTION	
3.5	DRAWING A COASTLINE MAP	
3.6	STATIONS SELECTION	
3.6.1	STATION SELECTION MENU	
3.6.2	SELECTING STATIONS FROM THE DISK FILE	
3.6.2.1	DIGITIZING PIXEL, SCANLINE FOR A STATION	
3.6.3	STATION ENTERED MANUALLY	
3.6.4	SELECTING STATIONS FROM A COASTLINE	
3.6.5	SELECTING STATIONS FROM SOLVED IMAGES	
3.6.6	GETTING A LISTING OF CURRENT STATIONS	
3.6.7	DELETING STATIONS	
3.6.8	REACTIVATING A DELETED STATION	
3.6.9	REPLACING A STATION	
3.6.10	EXITING STATION SELECTION	
3.7	DELETE ALL STATIONS	
3.8	COMPUTATION OF ORBITAL PARAMETERS	
3.9	CORRECTING AN IMAGE TO A PROJECTION	
3.10	SETTING THE IMAGE ORIENTATION	
3.11	LOADING AN IMAGE	
3.12	STORING AN IMAGE	

4.0 CORRECTING AN IMAGE TO A PROJECTION**4.1 PROGRAM VHR3****5.0 ICE TRACKING****5.1 PROGRAM ICE****5.2 MAIN MENU****5.3 VCP****5.4 TRACKING ICE FLOES****5.4.1 TRACK ICE FLOES MENU****5.4.2 SET IMAGE BUFFER RANGE****5.4.3 CHECK IMAGE BUFFER RANGE****5.4.4 TRACK AN ICE FLOE****5.4.4.1 ICE FLOE NAMES****5.4.4.2 ICE PIECE TRACKING MENU****5.4.4.3 ICE POSITION MODIFICATION****5.4.5 UPDATE/EXIT****5.4.6 EXIT NO UPDATE****5.5 PLOT TRACKS AND VELOCITIES****5.5.1 MAIN MENU****5.5.2 VCP****5.5.3 SET COASTLINE PROJECTION****5.5.4 PLOT COASTLINE****5.5.5 PLOT ICE FLOE TRACKS****5.5.6 PLOT VELOCITY VECTORS****5.5.7 PLOT VELOCITY VECTOR GRAPH****5.6 EDITING AN ICE FILE****5.6.1 MAIN MENU****5.6.2 LISTING POSITIONS****5.6.3 USING THE SYSTEM EDITOR TO
EDIT AN ICE FILE****5.6.4 DELETE SPECIFIED RECORDS****5.6.5 DELETE THE ICE FILE****6.0 AFFINE TRANSFORMATION****6.1 PROGRAM AFFINE****7.0 PROGRAM MOVIE**

1.0 INTRODUCTION

The purpose of this manual is to provide the details for running the programs developed for digitizing hard copy imagery and correcting such imager to a known map projection. It is assumed that the reader is familiar with the Institute of Ocean Sciences, Sidney, B.C. (IOS) Image Processing System and, in particular, the Video Control Program (VCP) and its commands.

The procedure for converting hard copy imagery to a corrected version stored on the system consists of four parts:

- a) Digitization of the image and application of corrections to the image for distortions due to the digitization procedure.
- b) Computation of the Orbital Parameters (OP) required to compute the latitude and longitude of each pixel on the image.
- c) Using the OPs computed in b) to rework the image to the standard projection used on the IOS system.
- d) Using an Affine Transformation to touch up small errors in the image.

The programs for tracking ice flows and making time-movies using a time sequence of images is described. Some of the programs are menu driven. The sections of the manual are organized according to individual menu items or functions.

2.0 IMAGE DIGITIZATION

2.1 INTRODUCTION

To digitize an image, the copy is placed under the camera. Entering the VCP command VII causes the video from the camera to be displayed in Ikonas image plane 1. The user adjusts the lighting and makes sure that the image is lined up squarely to the camera. Entering the VCP command VI freezes the image in Ikonas image plane 1. The image will appear to be compressed, this is due to the conversion of a 2 to 3 aspect ratio of the video input to the 1 to 1 aspect ratio of the image plane. This distortion is taken care of in the computation of the OP. However, non-linear distortions due to lens curvature occur in the images. These distortions are most pronounced at the edges of the images, with no distortion in the centre and vary with camera settings (i.e. distance from the image and close-up lenses used).

The method used to correct these distortions calculates the offsets of each pixel between its position in the image and its position in the absence of distortion. These offsets are used to reposition each pixel, thus eliminating the distortions. To compute these offsets, a calibrated hardcopy grid is digitized at the desired camera setting. A graphics dot grid is overlaid on the resulting video image. At each lattice point of the graphics grid, a cursor is used to denote the location of the corresponding lattice point of the digitized grid. The x offset for a given lattice point is stored at the coordinate in image plane 2 and the y offset in image plane 3. When an offset has been derived along each axis, an interpolation is performed to calculate the offsets for each pixel between the lattice coordinates. The resulting fields of x- and y-offsets at each pixel are stored in the Ikonas image planes 2 and 3, respectively. The offsets are stored in image buffers using the appropriate VCP commands. Recall of these buffers allows the repositioning of the pixels in a given redigitized image to account for camera distortion. The calculation of offsets need be carried out only one time for a given camera setting. It should be noted that the accuracy of the resulting offsets increases with the decreasing size of the unit cell in the prepared calibrated hardcopy grid.

2.2 PROGRAM OPT

The program to compute the offsets and apply them is called OPT. To run the program, enter OPT if the program is installed, or RUN [101,2]OPT if it is not installed. The program will respond with the following menu.

2.3 MAIN MENU

*** VIDEO CAMERA OPTICAL DISTORTIONS PROGRAM ***

- | | |
|--|-------|
| 0 - VCP | (2.4) |
| 1 - CLEAR IMAGE PLANES 2 THRU 4 | (2.5) |
| 2 - PRODUCE A GRID | (2.6) |
| 3 - DIGITIZE OFFSETS AT LATTICE POINT OF GRID | (2.7) |
| 4 - INTERPOLATE OFFSETS | (2.8) |
| 5 - APPLY OFFSETS TO AN IMAGE IN IMAGE PLANE 1 | (2.9) |
| 6 - EXIT | |

SELECTION?

The user must enter a number between 0 and 6 followed by a <RETURN>. The following is a description of the separate functions of the menu.

2.4 VCP

The program VCP is entered. This allows the user to perform several functions necessary for running OPT:

- i) Setting up the colours for the graphics used in the digitizing of the offsets;
- ii) Storing the offsets once they have been computed;
- iii) Digitizing images using the VI VCP command;
- iv) Loading existing offsets so they may be used to correct an image in image plane 1 using function (2.9).

Exiting VCP returns the program control to (2.3).

2.5 CLEARING IKONAS IMAGE PLANES

To digitize the offsets for a digitized grid, Ikonas image planes 2 through 3 must first be cleared. This option provides a fast way for the user to clear them instead of using VCP.

CLEAR IMAGE PLANES 2 THRU 4 (Y/N) >

Entering Y <RETURN> clears the image planes and returns the program to (2.3).

Entering N <RETURN> returns the program to (2.3) directly.

2.6 PRODUCE A GRAPHICS GRID

This function allows the user to create a dot grid that overlays the digitized grid.

***** CREATE A DOT GRID IN GRAPHICS PLANE *****

**IMAGE WILL BE ZOOMED AROUND CURSOR
ENTER ZOOM FACTOR (2 - 16) >**

To create this grid, the user is asked to digitize two corners of a grid. To facilitate this, the image is zoomed around the cursor using the above zoom factor.

CENTRE CURSOR ON GRID THEN HIT ANY KEY

The user should choose a grid in the centre of the image where there is no distortion. Centre the cross-hair of the cursor on the desired grid square and press any key. The program zooms in on the grid.

PLACE CURSOR AT A CORNER OF THE GRID THEN HIT A KEY

Place the cross-hair at a lattice, then press any key.

PLACE CURSOR AT A CORNER DIAGONAL FROM LAST THEN HIT A KEY

Place the cross-hair at a lattice diagonal from the last. If the point is the same as the last one, the grid is not produced and the program returns to (2.3).

After the grid is drawn, the program returns to (2.3). The user should enter VCP and with the roam zoom option (RM), check that the grid has been produced properly.

Note that the grid is drawn in graphics plane 2. The user must set the colour of the grid using the GC command in VCP.

2.7 CALCULATING OFFSETS

This function digitizes the offsets at the lattice points produced in function (2.6). To show which lattice point the program is pointing to, it overwrites the dot at the cursor marked lattice point with a dot in graphics plane 3. The user should have set an appropriate colour for graphics plane 3. A zoom factor is chosen by the user when the function is entered. This is the factor with which the program zooms around a lattice point when the user requests a zoom (see below).

***** DIGITIZE OFFSET AT LATICICE POINTS *****

ENTER ZOOM FACTOR (2 - 16) >

Enter the desired zoom factor.

2.7.1 MENU FOR DIGITIZING OFFSETS

***** HELP MENU *****

X - EXIT TO MAIN MENU
 Z - ZOOM AROUND LATICICE POINT
 B - RESET TO ZERO ZOOM FACTOR
 U - UP (A LATICICE POINT)
 D - DOWN
 L - LEFT
 R - RIGHT
 G - TOGGLE GRAPHICS ON/OFF
 A - AUTOMATIC ZOOM TO AROUND LATICICE POINT IF
 U/D/L/R IS USED, THIS IS TOGGLED ON/OFF
 O - DIGITIZE OFFSET AT CROSS HAIR
 O - DIGITIZE OFFSET AS ZERO OFFSET AT LATICICE POINT

X/Z/B/U/D/L/R/G/O/O H - HELP

The full menu above is displayed only once, when this function is entered. To choose one of the functions, the user only needs to depress the keyboard key for the desired function. The last line of the menu is displayed after a function is chosen unless the function is "H".

X EXITING BACK TO (2.3)

Program control returns back to (2.3).

Z ROAM ZOOM

2.7 CALCULATING OFFSETS

This function digitizes the offsets at the lattice points produced in function (2.6). To show which lattice point the program is pointing to, it overwrites the dot at the cursor marked lattice point with a dot in graphics plane 3. The user should have set an appropriate colour for graphics plane 3. A zoom factor is chosen by the user when the function is entered. This is the factor with which the program zooms around a lattice point when the user requests a zoom (see below).

***** DIGITIZE OFFSET AT LATICES POINTS *****

ENTER ZOOM FACTOR (2 - 16) >

Enter the desired zoom factor.

2.7.1 MENU FOR DIGITIZING OFFSETS

***** HELP MENU *****

X - EXIT TO MAIN MENU

Z - ZOOM AROUND LATICES POINT

B - RESET TO ZERO ZOOM FACTOR

U - UP (A LATICES POINT)

D - DOWN

L - LEFT

R - RIGHT

G - TOGGLE GRAPHICS ON/OFF

A - AUTOMATIC ZOOM TO AROUND LATICES POINT IF
U/D/L/R IS USED, THIS IS TOGGLED ON/OFF

O - DIGITIZE OFFSET AT CROSS HAIR

O - DIGITIZE OFFSET AS ZERO OFFSET AT LATICES POINT

X/Z/B/U/D/L/R/G/O/O H - HELP

The full menu above is displayed only once, when this function is entered. To choose one of the functions, the user only needs to depress the keyboard key for the desired function. The last line of the menu is displayed after a function is chosen unless the function is "H".

X EXITING BACK TO (2.3)

Program control returns back to (2.3).

Z ROAM ZOOM

The program zooms around the lattice currently being pointed to.

Note that the cross-hair will not appear at the lattice, it will appear at a position on the screen which corresponds to the position of the lattice of the un-zoomed image (See Figure A-1).

B RESET IKONAS DISPLAY

Resets the image to no zoom.

U UP

Moves the pointer to the lattice above the current position.

D DOWN

Moves the pointer to the lattice below the current position.

L LEFT

Moves the pointer to the lattice left of the current position.

R RIGHT

Move the pointer to the lattice right of the current position.

G GRAPHICS ON/OFF

Toggles the graphics on and off.

A AUTOMATIC ZOOM

When the user presses key Z, the program zooms around the current position. If this function has been turned on by pressing key A, then the program will automatically zoom around the new position when options U, D, L or R are selected. This function is turned off by pressing key A a second time.

O DIGITIZE OFFSET POSITION

When this key is pressed, the program accepts the current position of the cross-hair as the position of the lattice or the digitized grid corresponding to the current lattice being pointed to.

The offset is calculated and written to Ikonas image plane 2 and 3 and a cross drawn at the cursor position in graphics plane 3. A box is drawn around the lattice point (See Figure A-2).

0 NO ERROR AT LATTICE POINT

If there is no error at the grid, then there is no need to line up the cross-hair. Pressing key 0 (zero) causes the cross to be drawn at the graphics lattice for zero offset (See Function 0).

H DISPLAY MENU

Displays the full menu for the user.

2.8 COMPUTING THE OFFSET PLANES

When this function is chosen, the program computes the x and y offsets for the pixels between the lattice points. The result is the x offset for each pixel in Ikonas image plane 2 and the y offset for each pixel in Ikonas image plane 3. The two planes should be stored in image buffers with headers clearly stating the camera settings. The headers should also clearly indicate whether the buffer is an x offset or a y offset for the camera setting.

***** INTERPOLATING OFFSETS IN PLANES 2 AND 3 *****

This function takes several minutes to perform. Pressing any key while this function is being performed causes the program to stop the interpolations and return to (2.3).

2.9 CORRECTING AN IMAGE FOR DISTORTION

This function applies the offsets in image planes 2 and 3 to the image in image plane 1 and stores the result in image plane 4.

***** BUILD INTO IMAGE PLANE 4 A COPY OF IMAGE PLANE 1 *** USING OFFSET VALUES IN IMAGE PLANES 2 AND 3**

**X OFFSETS IN IMAGE PLANE 2
Y OFFSETS IN IMAGE PLANE 3**

OKAY TO PROCEED (Y/N)?

Enter a Y <RETURN> to proceed, any other character to return to (2.3).

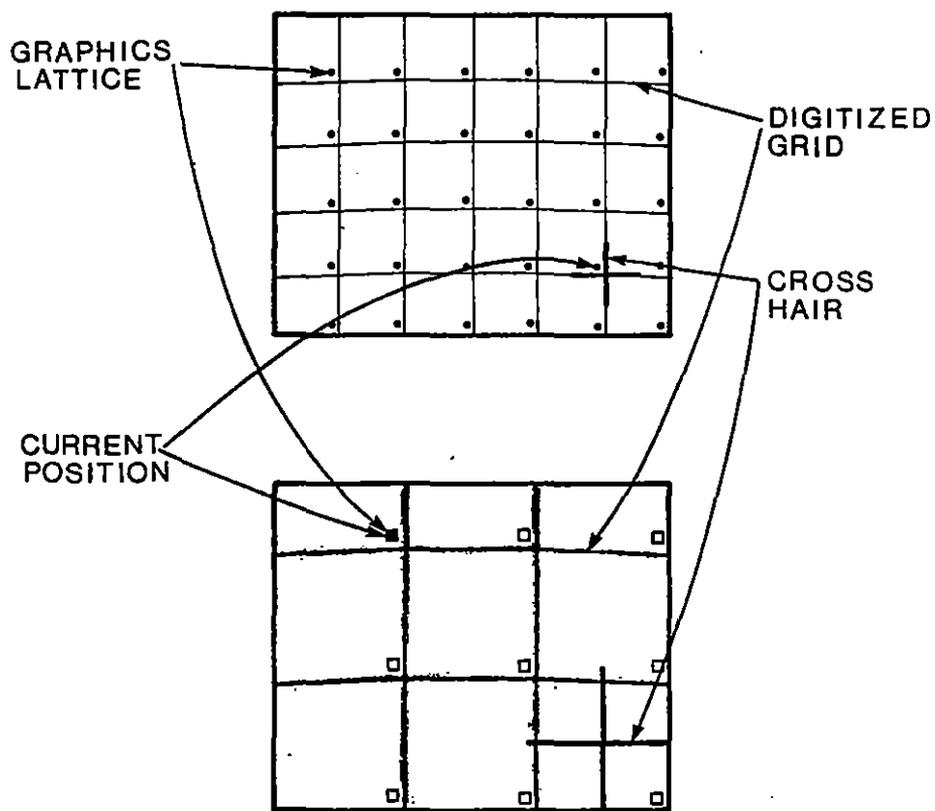


Figure A-1: Test grid and graphics lattice, as represented without (upper) and with (lower) VCP zoom option.

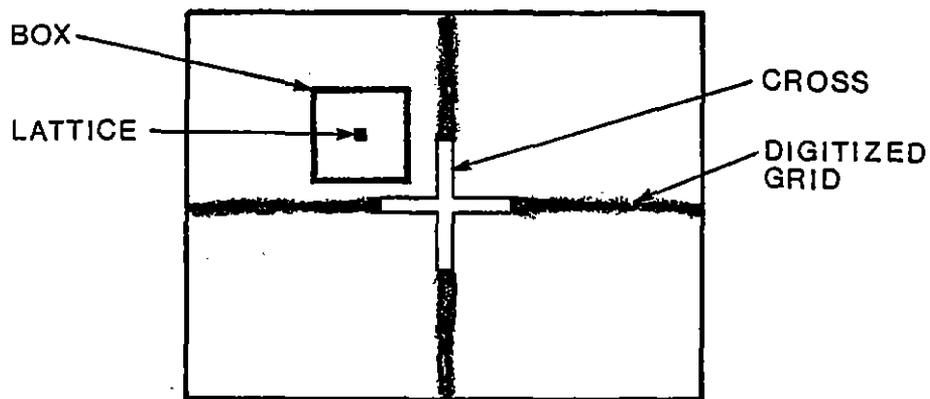


Figure A-2: Cross marks digitized grid lattice position.

2.10 HELPFUL HINTS

When digitizing a grid, in order to ensure that the grid is square to the camera, use the **GV** command in **VCP** to draw a cross across the screen in one of the graphics planes. After the camera is turned on using **V11**, display the cross using the **GA** command. The grid can then be lined up with the cross.

To ensure images are lined up properly, line up a transparent grid using the method described above. When the grid is lined up, tape it to the table. The transparency can be used to line up the satellite images.

3.0 CALCULATION OF ORBITAL PARAMETERS

The next stage is to compute parameters needed to correct an image to the projection used on the IOS system (equi-rectangular). The method involves selecting ground control points or reference stations on the image with known latitudes and longitudes. The selected stations are used to calculate orbital parameters for the image. Note that the images must be oriented such that the first scanline of the image corresponds with the first scanline on the screen. Therefore, north bound images will be oriented with north at the top of the screen. The procedure is explained in detail in the main text of this report entitled "Development and Testing of Techniques for Digital Extraction of Ice Velocities From Hardcopy Remote-Sensing Imagery".

3.1 PROGRAM VHR2

To run the program, enter:

VH2

if the program is installed, or:

RUN [101,2]VHR2

if the program is not installed.

The program then displays the following menu.

3.2 MAIN MENU

*** DIGITIZED DATA CORRECTIONS PROGRAM ***

0 - VCP	(3.3)
1 - SET PROJECTION VALUES FOR COASTLINE	(3.4)
2 - PLOT A COASTLINE	(3.5)
3 - SELECT STATIONS	(3.6)
4 - DELETE ALL SELECTED STATIONS	(3.7)
5 - COMPUTE ORBITAL PARAMETERS USING STATIONS	(3.8)
6 - CORRECT IMAGE TO PROJECTION SELECTED IN OPTION 1	(3.9)
7 - SET IMAGE TO NORTH OR SOUTH BOUND	(3.10)
8 - LOAD AN IMAGE	(3.11)
9 - STORE AND IMAGE	(3.12)
10- EXIT	

SELECTION?

The user must select one of the eleven functions, as described below. To enter one of the functions, enter the function number followed by <RETURN>.

3.3 VCP

This function puts the user into the VCP program. When the user exits VCP, control returns to (2.3).

3.4 SETTING A COASTLINE PROJECTION

This allows the user to enter projection values to draw a coastline (See function (3.5)).

If a projection was previously entered, then the values are displayed on the terminal.

*** PROJECTION VALUES ***

```
REF LATITUDE  74 0 0M MIN MAX LATITUDE 7600M 7400M
REF LONGITUDE 87 0 0M MIN MAX LONGITUDE 1050M 7900M
REF PIXEL, SCANLINE 256,256
HOR, VERT SIZE (METERS) 2000 2000
```

ENTER REF LAT DEG, LAT MINUTE (<CR> FOR LAST VALUE) >

Enter the latitude of the reference pixel scanline in degrees latitude and minutes, for example, 74,30 is seventy degrees thirty minutes. Entering a <RETURN> with no value causes the last value entered to be retained.

ENTER REF LONG DEG, LONG MINUTE (<CR> FOR LAST VALUE) >

Enter the longitude of the reference pixel scanline in degrees and minutes, for example, -87,0 is eighty-seven degrees zero minutes. Entering a <RETURN> with no value causes the last value entered to be retained.

ENTER REFERENCE PIXEL, SCANLINE >

Enter the reference pixel, scanline. This is usually 256,256. Enter <RETURN> to retain the last values.

ENTER HORIZONTAL AND VERTICAL SIZES

Enter the horizontal and vertical sizes of the pixels for the projection. Entering <RETURN> retains the last value.

The projection values are displayed again:

***** PROJECTION VALUES *****

REF LATITUDE 74 0 0M MIN MAX LATITUDE 7600M 7400M
 REF LONGITUDE 87 0 0M MIN MAX LONGITUDE 1050M 7900M
 REF PIXEL, SCANLINE 256,256
 HOR, VERT SIZE (METERS) 2000 2000

Program control then returns to (3.2).

3.5 DRAWING A COASTLINE MAP

This function causes the program to draw a coastline using the projection entered in (3.4) into graphics plane 1. All of the graphics planes are deleted before this is done.

If no projection values have been entered:

*****NO PROJECTION VALUES *****

and program control returns to (3.2).

***** DRAWING COASTLINE IN GRAPHICS PLANE 1 *****

***** HIT ANY KEY TO QUIT *****

The coastline is drawn and control returns to (3.2). The drawing of the coastline may be interrupted by pressing any key. Program control returns to (3.2).

3.6 STATIONS SELECTION

This is the station selection function and the user must position a cursor at the pixel, scanline of stations on the image which have known positions. These stations usually are identifiable land marks. There are four methods of obtaining the positions of stations:

- a) The program has access to a file containing station names and their positions. The file is called **IM3:AGRID.STN**. It is up to the user to enter the stations into this file using the system editor. Each station in the file must have the following format:

One station per line.

<u>Character Positions</u>	<u>Description</u>
1-5	Station Number (must be >0 <1000)
6-10	Blanks
11-40	Station Name
41-45	Latitude Degree
46-50	Latitude Minute
51-55	Longitude Degree
56-60	Longitude Minute

The numbers above must be right justified and the station name left justified.

- b) The positions may be entered manually.
- c) The positions may be picked off a coastline drawn using function 1 and 2 or by loading it using function 8.
- d) The positions may be picked off of another image which has had its parameters previously calculated.

When the function is entered:

DO YOU WANT A PRINTOUT OF STATIONS IN DISK FILE? (Y/N) >

Enter Y <RETURN> to get a listing of the stations, enter <RETURN> to ignore the option.

*** REFERENCE STATION SELECTION ***

ZOOM FACTOR? (DEFAULT 8) VALUES (1-16) >

Enter a zoom factor that will be used to help select station positions (see below).

To get the default value, just enter <RETURN>.

3.6.1 STATION SELECTION MENU

*** SELECT STATION ***

1-999	STATION IN FILE	(3.6.2)
1000-1999	USER INPUTS LAT LON	(3.6.3)
2000-2999	PICK STATION LAT,LON FROM COASTLINE	(3.6.4)

3000-3999	PICK STATION FROM SOLVED IMAGE	(3.6.5)
>3999	LIST SELECTED STATIONS	(3.6.6)
-VE VALUE OF STATION TO DELETE (TEMP)		(3.6.7)
ENTER -VE TWICE TO DELETE PERMANENTLY		
+VE VALUE OF STATION TO UN-DELETE		(3.6.8)
+VE VALUE OF STATION TO REPLACE IF NOT DELETED		(3.6.9)
0 OR <RETURN> END OF SELECTION		(3.6.10)

STATION >

3.6.2 SELECTING STATION FROM THE DISK FILE

Entering a station number between 1 and 999 causes the program to read through the station disk file to locate a station with the entered number.

If the station is not found:

***** STATION NOT FOUND *****

and program control returns to 3.6.1.

If the station is found, the program displays the station, for example:

100 CAPE BATHURST 69 30 -130 40

3.6.2.1 DIGITIZING PIXEL, SCANLINE FOR A STATION

CORRESPONDING PIX, SCAN?

PRESS KEY R-RESET DISPLAY, Z-ROAM ZOOM, V-VCP, D-DIGITIZE

A graphics cross cursor appears and the user must select the pixel, scanline on the image which corresponds to the position of the station selected.

Pressing key V puts the user into VCP. Exiting VCP returns the user to (3.6.2.1).

Pressing key Z zooms the image by the factor entered when this function was entered.

***** ROAM ZOOM USING TABLET HIT ANY KEY TO QUIT *****

This function is similar to the RM command in VCP. The cross-hair disappears and by using the tablet pen, the user is able to move the portion of the image that is zoomed until the

portion containing the station comes into view. By pressing any key, the view is frozen at the current position. The cursor reappears and control returns to (3.6.2.1).

Pressing key R resets the image to no zoom factor. Control returns to (3.6.2.1).

The user should zoom in to the proper portion of the image and place the cursor over the corresponding pixel, scanline.

Pressing key D causes the program to read the position of the cursor and use the position for the station:

GOT IX: 100 IY: 150

A graphics cross will mark the position and program control goes to (3.6.1).

3.6.3 STATION ENTERED MANUALLY

Selecting a station number of value 1000 through 1999 causes the program to ask the user to manually enter the latitude and longitude of the station.

ENTER STATION NAME >

Enter a station name.

ENTER STATION LAT DRG, LAT MIN, LONG DRG, LONG MIN >

Enter the position, for example, 74,30,-90,40. Program control goes to (3.6.2.1) for picking the corresponding pixel, scanline.

3.6.4 SELECTING STATIONS FROM A COASTLINE

Entering a station number with a value between 2000 and 2999 causes the program to ask the user to digitize the position of the station off a coastline that has been drawn using function (3.4) and (3.5) or loaded using function (3.11).

If no projection values were entered, then:

*** PROJECTION PARAMETERS HAVE NOT BEEN SET ***

and program control goes to (3.6.1).

If a coastline has been drawn, it is overlaid on the image and the program displays:

**DIGITIZE LAT, LON PAIR FROM COASTLINE, HIT KEY
R-RESET DISPLAY, Z-ROAM ZOOM, V-WCP, D-DIGITIZE**

The description of pressing keys R, Z and V is the same as that described in section (3.6.2.1).

Pressing key D causes the program to translate the position of the cursor to a latitude and longitude position, then:

ENTER STATION NAME >

Enter the station name and mark the position with a graphics mark. The program prints out the station name along with the computed latitude and longitude to the terminal:

2001 TEST ISLAND 69 30 -100 50

and program control goes to (3.6.2.1) to pick the corresponding pixel, scanline.

3.6.5 SELECTING STATIONS FROM SOLVED IMAGES

Entering a station number between 3000 and 3999 signifies that the station is to be picked from a previously solved image (an image with computed OPs). An image with OPs computed must have been loaded using function (3.11) into an image plane. If this is not done, then:

***** NO ORBITAL PARAMETERS *****

and program control returns to (3.6.1).

If an image was loaded, then:

ENTER IMAGE PLANE CONTAINING IMAGE TO BE SOLVED >

Enter the image plan containing the unsolved image.

The above inputs are only requested once, when a station between 3000 and 3999 is selected. For example, if station 3000 is selected, the above inputs are not requested for station 3001 unless function (3.6) was exited between the selection of the two stations.

***** PLACE CURSOR AT STATION ON SOLVED IMAGE *****

**PRESS KEY R-RESET DISPLAY, Z-ROAM ZOOM, V-VCP, D-DIGITIZE
S-SHOW SOLVED IMAGE, U-SHOW UNSOLVED IMAGE**

Pressing keys R, Z, V and D produce the same result as described for selecting stations numbered 2000 through 2999.

Pressing key U causes the image plane with the unsolved image to be displayed.

Pressing key S displays the solved image.

These function of these two keys allows the user to flip between the two images to help in selecting a station. When key D is pressed, the latitude and longitude is computed for the station using the parameters for the solved image. The program asks for a station name and control goes to (3.6.2.1) to pick the corresponding pixel, scanline on the unsolved image.

3.6.6 GETTING A LISTING OF CURRENT STATIONS

Entering a station number greater than 4000 causes a list of the stations to be displayed on the terminal.

The stations with an asterisk (*) are the stations that have been deleted (see section 3.6.7).

DO YOU WANT A PRINTER LISTING (Y/N) >

Enter Y <RETURN> to get a listing of the stations on the printer. Program control returns to (3.6.1).

3.6.7 DELETING STATIONS

To temporarily delete a station, enter the negative value of the station. The station is considered inactive and not used in the computation of OPs should the user exit this function and attempt to compute the OPs (see section 3.8). The station is preceded by an asterisk (*) in station listings as described above.

***** STATION TEMPORARILY DELETED *****

The graphics marks pointing to the station are deleted and program control goes to (3.6.1).

Entering a negative value for a station that has been deleted once, permanently deletes it from the station list. It cannot be reactivated without re-picking it and will not appear when the stations are listed out as described above.

***** STATION PERMANENTLY DELETED *****

Program control goes to (3.6.1).

3.6.8 REACTIVATING A DELETED STATION

Entering the positive value of a station that has been temporarily deleted will reactivate the station.

***** STATION FLAGGED AS ACTIVE *****

Program control goes to (3.6.1).

3.6.9 REPLACING A STATION

The values for a station may be replaced by entering the station number while the station is active. For example, if station 2000 is active:

2000 COASTLINE ISLAND 69 30 -130 30

***** STATION EXISTS <PRESS KEY> *****

R - REPLACE STATION NAME, LAT, LON AND DIGITIZE LOCATION

K - KEEP CURRENT STATION NAME, LAT, LON AND DIGITIZE
LOCATION

? - ANY OTHER KEY TO LEAVE AS IS

R/K/? >

If key R is pressed, program control goes to the appropriate section for the station number. For the example above, the user must re-pick the station off the coastline map.

Pressing key K causes program control to go to (3.6.2.1) where the user redigitizes the corresponding pixel, scanline for the station. The name of the station and the latitude, longitude position remain unchanged.

If any other key is pressed, no action is taken and program control goes to (3.6.1).

3.6.10 EXITING STATION SELECTION

Entering 0 or just <RETURN> causes the program control to go to (3.2).

3.7 DELETE ALL STATIONS

All the reference stations that were picked using option 3 (section (3.6)) are deleted. The graphics markers marking the station locations are also removed. This option saves the user from having to manually delete all the stations using option 3 (section (3.6)) when a new image is loaded.

Program control goes to (3.2).

3.8 COMPUTATION OF ORBITAL PARAMETERS

Selection of this function causes the program to attempt to compute orbital parameters for the image using the selected reference stations. A minimum of three stations must have been selected. If this is not the case:

*****INSUFFICIENT REFERENCE STATIONS ENTERED*****

Program control goes to (3.2). If a sufficient number of stations has been entered:

SUBTRACK BINARY SEARCH SPAN IS 2048

ENTER NEW VALUE (OR <RETURN> FOR SAME) SHOULD BE A POWER OF 2 >

Enter the search span. To keep the current value, just press <RETURN>. If a new value is entered, it will be the current value when the function is entered again. The value should be a power of 2, i.e. 2, 4, 8, 16, 32, 64, etc.

ENTER SUBTRACK START VALUE <RETURN> FOR 0 >

Enter the pixel to start the subtrack search at. Entering <RETURN> sets the start value at 0. The program then displays which direction the orbit is assumed to be. For example:

*****DIRECTION OF ORBIT ASSUMED TO BE SOUTHWARD*****

The direction is set by function 7 (see section 3.10). It is up to the user to determine whether an image is north or south bound.

*****CURRENT SATELLITE 3 ALTITUDE 0.000**

The message above is not displayed the first time the function is entered.

- 1 NOAA-4
- 2 NOAA-5
- 3 NOAA-6
- 4 TIROS-N
- 5 NOAA-7
- 6 LDSAT-1
- 7 LDSAT-2
- 8 LDSAT-3

SATELLITE? (1,2,3,4,5,6,7,8) >

Enter the satellite for the image. If the function was previously entered, pressing <RETURN> without entering a number causes the current satellite to remain in effect.

ENTER ALTITUDE 0.0 IF IMAGE CORRECTED FOR EARTH CURVE

ENTER -1 TO RESET TO 0.0 OR <RETURN> TO KEEP CURRENT VALUE

If the image has been corrected for earth curvature, then an altitude of 0.0 must be used. If the image has not been corrected, the user should enter the average altitude of the satellite.

FIRST ESTIMATE OF ORBITAL ANGLE IS 4.65821
FIRST ESTIMATE OF SCANNER ANGLE IS 32.12345
ENTER YOUR OWN OR PRESS <RETURN> TO TRY THESE
DEFAULT ADJUSTMENT FACTORS FOR ORBITAL AND SCANNER
ANGLE ARE .01 AND .01 ENTER YOUR OWN FOLLOWING THE
ESTIMATES (IE: 1,1,.001,.001) >

The estimates are computed by the program using the selected stations. These are the starting estimates for orbital angle and scanner angle. If the estimates are too far from the true values, the program will not converge on the true subtrack pixel. If the user does not know the approximate values of the true angles, the use of 1,1 usually works.

The program will then display:

*****PLEASE WAIT FOR ITERATION CALCULATION*****

PRESS ANY KEY TO ABORT

```

a) ITERATING FOR SUBTRACK PIXEL 0
b) 0   1.0000   1.0000   0.12345017E+02
    1   2.03451  1.0000   0.11345017E+02
    2   3.03101  1.0000   0.10141023E+02
      .
      .
      .
    25  4.63215  6.12342  0.11234678E-01
c) 0 -57.23452 8.23456 12.12342 3.45678 9.03658 0.11234657E-1
   ITERATING FOR SUBTRACK PIXEL -1024
    26  4.63215  6.12342  0.23456789E+03
   ITERATING FOR SUBTRACK PIXEL -1048
   ITERATING FOR SUBTRACK PIXEL -512
   ITERATING FOR SUBTRACK PIXEL 512
    27  4.63217  6.12342  0.11543214E+01
    28  4.60217  6.12342  0.10543219E+01
      .
      .
      .
    50  4.83214  6.54321  0.12346123E-02
      .
      .
      .
    512 -56.12345 4.32145  9.12321 12.34361 3.42134 0.12346182E-02
   ITERATING FOR SUBTRACK PIXEL 256

```

The labels a), b) and c) shown above do not appear on the terminal.

- a) This line indicates the subtrack pixel the program is going to iterate on.
- b) The program starts iterating on the current orbital angle and scanner angle. Adjust the angles to minimize the deviations of the computed positions of the stations and their actual position. An iteration is defined as the point where the standard deviation is less than the deviation for the last estimate for the angles and the angles are going to be re-adjusted using the errors. When this occurs, the program displays the iteration number, the current orbital angle, the current scanner angle and the sum of the squares of the standard deviations in latitude and longitude of the reference stations.

- c) This line is printed when the program has computed the lowest possible deviation for the current subtrack and the deviation is the lowest deviation yet computed. The orbital angle and scanner angle become the initial estimates for subsequent attempts at locating a better subtrack pixel. The printed values are the subtrack pixel, the ascending node, the start and end orbital angles, the start and end scanner angles and the sum of the squares of the standard deviations in the latitudes and longitudes of the reference stations.

Pressing a key while the program is iterating will cause program control to go to (3.20) without computing the OPs.

When the best OPs have been computed, the program will display:

*****400 ITERATIONS - PRESS RETURN TO CONTINUE*****

Press <RETURN>.

The program then displays the computed parameters and the errors at each reference station:

```

ORBITAL ANGLE      6.12 TO 12.12  ANGLE =  6.0000
SCANLINE           1 TO 512
SCAN OFFSET        4.12 TO 12.12  OFFSET = 8.0000
PIXEL              1 TO 512
SUBTRACK PIXEL     156
ASCENDING NODE     -60.00
ALTITUDE           0.00
ORBITAL PERIOD     114.90
ORB MAX LATITUDE   81.10

```

REFERENCE	STATION	PIXEL	SCAN	LAT	LON	DLAT	DLONG
2000	CAPE COD	215	25	65 30	-130 20	-1.1421	2.4567
2001	CORN ISLAND	315	130	63 20	-131 30	0.0311	-1.0101
2002	PEA ISLAND	100	60	61 40	-132 40	-1.4567	0.0012
2003	SALMON POINT	50	200	62 20	-134 50	0.8010	-1.1121
2004	FIN ISLAND	500	400	59 10	-129 10	3.4124	0.1234

*****WARNING 1 BAD STATIONS*****

DO YOU WANT A PRINTER LISTING OF THIS? (Y/N) >

The program considers stations with errors greater than 3 minutes of latitude or longitude to be a bad station.

To get a printer listing, enter Y <RETURN>.

TITLE?

Enter a title for the listing. The results are printed and program control goes to (3.2).

Entering N <RETURN> or just <RETURN> causes program control to go to (3.2) directly.

If the errors in the stations are satisfactory, the image, along with the OPs, should be stored using function 9 (see section 3.12).

If the results are not satisfactory, the user may wish to add or delete selected stations using function 3 of the menu selection in section (3.2) and return to this function to try and obtain better results.

3.9 CORRECTING AN IMAGE TO A PROJECTION

This function is used to correct an image with OPs that have been computed to a projection. The function maps the images from one image plane to another. The following must be performed prior to entering this function:

- a) A projection must have been set using function 1 (see section 3.4) and optionally, a coastline drawn. Another way of doing the same thing is to use function 8 (see section 3.11) to load an image containing a graphics coastline and having a header containing the projection of the coastline.
- b) An Ikonas image plane (1, 2 or 3) must contain an image with OPs that are the OPs currently known by the program. This can be done in two ways:
 - i) Compute the OPs for the image using function 5 (see section 3.8). The resulting OPs are the current values known by the program.
 - ii) Load an image using function 8 (see section 3.11) with OPs contained in the header.

If there are no current OPs:

*****NO ORBITAL PARAMETERS HAVE BEEN COMPUTED*****

and program control goes to (3.2).

If there are no projection values:

*****NO PROJECTION HAS BEEN SELECTED*****

and program control goes to (3.2).

*****APPLY ORBITAL PARAMETERS TO CORRECT IMAGE
TO A PROJECTION*****

ENTER SOURCE IMAGE PLANE <CR TO QUIT> >

Enter the number of the Ikonas image plane containing the uncorrected image. If just <RETURN> or an invalid image plane number is entered, program control goes to (3.2). The image plane is displayed.

REPLACE ZERO VALUES IN SOURCE PLANE WITH ONES (Y/N)?

Entering a Y <RETURN> causes the program to replace each pixel in the source image plane with a value that is zero with a value that is now one. This is helpful later if the user wishes to change the zero valued pixels of the destination plane to a different value. The zero valued pixels in the destination plane correspond to pixels with positions that did not correspond to any position on the source image.

ENTER DESTINATION PLANE (NOT EQUAL TO SOURCE)<CR> TO QUIT >

Enter the image plane to map the source plane into. An invalid value causes program control to go to (3.2).

CLEAR IMAGE PLANE 2 (Y/N) >

Assuming destination plane 2 was chosen, the above message is displayed. Entering Y <RETURN> causes the program to replace the value of each pixel in the destination plane with zero.

**POSITION CURSOR AT TOP LEFT CORNER OF AREA TO CORRECT
THEN PRESS KEY**

D - DIGITIZE

Q - QUIT

? - ANY OTHER KEY DEFAULT CORNER (1,1)

A graphics cross cursor will appear on the screen. The user has the option of only correcting a portion of the image. Pressing key Q causes program control to go to (3.2). Pressing key D causes the cursor position to be the top left corner of the area to be corrected. Any other key tells the program to start the correction at pixel, scanline (1,1).

**POSITION CURSOR AT BOTTOM RIGHT CORNER OF AREA TO CORRECT
THEN PRESS KEY**

D - DIGITIZE

Q - QUIT

? - ANY OTHER KEY DEFAULT CORNER (512,512)

Pressing key Q causes program control to go to (3.2). Pressing key D causes the cursor position to be the bottom right corner of the area to be corrected. Any other key defaults the bottom corner of the area to (512,512).

The program will display the destination plane along with graphics plane 1 (it assumes a coastline for the projection is drawn). The corrected image will start to be built in the destination plane.

*****MAPPING FROM PLANE 1 (1,1), (512,512) TO PLANE 2*****

*****PRESS ANY KEY TO QUIT*****

When the mapping is complete, or a key is pressed:

FILL DESTINATION PLANE (Y/N)?

Entering Y <RETURN> causes the program to fill holes in the destination plane. This is similar to the VCP function IL.

When the filling is complete, the program will ask again if the destination plane needs to be filled. Entering N <RETURN> causes the program control to go to (3.2).

3.10 SETTING THE IMAGE ORIENTATION

When the program is first entered, the default setting assumes images to be south bound images. This function allows the user to set the orientation. When this function is entered, it displays the current orientation.

*****ORBIT ASSUMED TO BE SOUTHWARD*****

ENTER S - SOUTH BOUND, N - NORTH BOUND >

Enter the desired orientation, for example, N <RETURN>.

*****ORBIT ASSUMED TO BE NORTHWARD*****

Program control goes to (3.2).

3.11 LOADING AN IMAGE

This function is similar to the VCP LD command. It was written because of the fact that there is no communication between the two programs to pass parameters and VCP does not know about OPs. The OPs are local to this series of programs.

When the function is entered, it displays whether or not projection values or OPs have been computed or loaded.

*****ORBITAL PARAMETERS HAVE BEEN COMPUTED OR LOADED*****

*****PROJECTION VALUES HAVE BEEN ENTERED*****

*****LOAD IMAGE BUFFER INTO AN IMAGE*****

ENTER IMAGE PLANE TO LOAD <CR> TO QUIT >

Enter the Ikonas image plane to load. Entering a <RETURN> by itself causes the program control to go to (3.2).

ENTER BUFFER NUMBER TO LOAD FROM <CR> TO QUIT >

Entering <RETURN> by itself causes the program control to go to (3.2). If the image buffer is valid and the Ikonas image plane to load is four (4), the program assumes the image buffer contains a coastline map with its projection values stored in the header. The image is loaded into image plane 4 and its projection values become the current projection values (see section 3.4). The pseudo colour table for the image is not loaded. (Note that unlike VCP, the program does not store or load graphics buffers.) The purpose of treating images loaded into image plane 4 as a special case allows the loading of different, previously drawn coastlines. This avoids manually setting projections and drawing the coastline (section 3.3 and 3.4) of frequently used areas. Note that if the coastlines are drawn and stored using VCP, the coastline must be drawn in graphics plane 1.

If any of the other image planes are to be loaded:

*****ENTER TYPE OF HEADER (CHOOSING 1 OR 2 OVERWRITES
CURRENT VALUES*****

- 0 - QUIT
- 1 - LOAD HEADER WITH PROJECTION VALUES
- 2 - LOAD HEADER WITH ORBITAL VALUES
- 3 - NEITHER

SELECTION?

Enter the desired selection followed by a <RETURN>. If 0 is selected, program control goes to (3.2). If 1 is selected, the selected buffer number must contain projection values. If it does not, the image is not loaded and program control goes to (3.2). If it does, the image along with its pseudo colour table is loaded and its projection values become the current projection values. Program control goes to (3.2). If 2 is selected, the image buffer must contain orbital values. If it does not, the buffer is not loaded and program control goes to (3.2). If it does contain the values, they are loaded and become the current OPs, overwriting values that may have previously been loaded or calculated. They are also the parameters that will be used to pick stations of a solved image (see section 3.5). If 3 is selected, the program loads the image without affecting the current projection or OP values.

3.12 STORING AN IMAGE

This function is similar to the VCP function ST, except it allows the storage of the current OP in the buffer. When the function is entered, it displays whether or not projection values have:

*****NO ORBITAL PARAMETERS HAVE BEEN COMPUTED OR LOADED*****

*****PROJECTION VALUES HAVE BEEN ENTERED*****

ENTER IMAGE PLANE TO STORE <CR> TO QUIT >

Enter the Ikonas image plane to store. Entering <RETURN> by itself causes program control to go to (3.2). Otherwise, the image plane is displayed.

ENTER IMAGE BUFFER TO STORE IMAGE IN <CR> TO QUIT >

Enter the image buffer to store the image into.

*****ENTER TYPE OF HEADER TO STORE*****

- 0 - QUIT
- 1 - STORE HEADER WITH PROJECTION VALUES
- 2 - STORE HEADER WITH ORBITAL PARAMETERS
- 3 - NEITHER

SELECTION?

Entering 0 causes program control to go to (3.2). If 1 is entered, then the image is stored into the buffer with the current projection values stored in the header. If 2 is selected, the image is stored with the current OP stored in the header. If 3 is entered, the image is stored without projections or OPs.

If the buffer already exists, its header is displayed and the program asks if it should be deleted.

DELETE [Y/N] >

Entering N <RETURN> causes the program control to go to (3.2).

TITLE >

Enter the title for the image. The title is stored in the buffer header.

4.0 CORRECTING AN IMAGE TO A PROJECTION

Using function 6 (see section 3.2) of the program VHR2 corrects an image to a map projection. However, this method ties up the Ikonas image display. A program was developed to read image buffers with headers containing OPs and to produce image buffers containing the image corrected to a desired projection.

4.1 PROGRAM VHR3

To run the program, enter:

VH3

if the program is installed, or:

RUN [101,2]VHR3

if it is not.

VHR3 IMAGE DATA CORRECTIONS PROGRAM

INPUT VCP BUFFERS MUST CONTAIN ORBITAL PARAMETERS
COMPUTED BY VHR2

Up to 100 image buffers may be corrected in one run of the program.

ENTER INPUT VCP BUFFER NUMBER 1 <RETURN> TO QUIT >

Enter a buffer number. If the buffer is invalid or does not exist, the user is asked to re-enter buffer number 1. If it contains OPs, the OP values are printed:

IB: 100: 82/03/04 10:51 LANCASTER SOUND

ORBITAL ANGLE	6.82 TO 12.82
SCANLINE	1 TO 512
SCAN OFFSET	-5.43 TO -13.24
PIXEL	1 TO 512
SUBTRACK PIXEL	260
ASCENDING NODE	-57.21
ALTITUDE	800.00
ORBITAL PERIOD	114.02
ORB MAX LATITUDE	81.01

The program then asks the user to enter buffer number 2 and so on.

Enter <RETURN> by itself to stop input buffer input.

ENTER FIRST OUTPUT BUFFER >

Enter the first buffer number to store the corrected images in. The output buffer number will be incremented by one for each input buffer as it is processed. If the value of the output buffer corresponds to an existing buffer, the value is incremented until a number is found for a non-existent buffer.

The projection values must then be entered.

ENTER REF LAT DEG, LAT MINUTE >

Enter the reference latitude degree and minute.

ENTER REF LONG DEG, LONG MINUTE >

Enter the reference longitude degree and minute.

ENTER REFERENCE PIXEL, SCANLINE >

Enter the reference pixel and scanline.

ENTER HORIZONTAL AND VERTICAL SIZES >

Enter the horizontal and vertical sizes in meters.

The values that have been entered are displayed.

*****PROJECTION VALUES*****

REF LATITUDE	74 D 0 M
MIN MAX LATITUDE	76 D 30 M : 71 D 30 M
REF LONGITUDE	-87 D 0 M
MIN MAX LONGITUDE	-91 D 0 M : -83 D 0 M
REF PIXEL, SCANLINE	256 256
HOR, VERT SIZE (METERS)	1200 1200

ARE THE VALUES ABOVE OKAY (Y/N) >

If N <RETURN> is entered, the values must be re-entered.

If Y <RETURN> is entered, the input buffers are processed one at a time.

*****PROCESSING BUFFER 201*****

IB: 201: 82/03/01 10:51 LANCASTER SOUND

INPUT SCAN 1 MINPX 312 MAXPX 512 MINSL 1 MAXSL 300

The line above is repeated at the bottom of the terminal display for each input scanline. It shows the minimum and maximum pixel and scanline the input scanline is mapped into.

*****FILLING WORK BUFFER*****

CREATING OUTPUT BUFFER 300

*****PROCESSING BUFFER 202*****

IB: 202: 82/03/01 12:05 LANCASTER SOUND

.
.
.

This is repeated for each input buffer. Pressing any key as the images are being processed causes the program to terminate.

5.0 ICE TRACKING

This section deals with the tracking of ice pieces over a time series of images. A program was developed to perform the following functions:

- a) Track ice pieces over a time series of images, storing the latitude, longitude positions of the ice pieces in a disk file.
- b) Allow editing of the ice positions.
- c) Produce output products, such as listings, plots of the ice tracks and velocity vector plots using the positions collected in a).

5.1 PROGRAM ICE

The program uses a time series of images as its input. The following is a list of requirements of the images:

- a) The first 14 characters of the header title of each image must contain the date and time of the image in the following format:

YY/DD/MM/HH:MM

For example: 82/04/12 01:15.

- b) The images must occur in a sequence of increasing buffer numbers of increasing dates. The buffer sequence does not necessarily have to increment by 1. For example, a sequence of buffer 100,101,104,105 is valid as long as the dates in 100, 101, 104 and 105 increase.
- c) The header in each image buffer in the sequence must contain the projection of the image if it has been corrected or the OP if it is an uncorrected digitized image.

The files used to store the ice positions are named in a similar fashion to the VCP buffers. The program allows the user to create ice files 1 through 999. It is up to the user to decide when to create a new file when tracking ice pieces. For example, the user may wish to use different files for different areas of ice being tracked or use separate files for different periods of time.

The program stores the following information in the ice files:

- a) A TITLE for the file.
- b) The number of positions and the number of distinct ice pieces contained in the file.
- c) Each record of the file corresponds to a picked position for an ice piece and contains the following information:
 - i) The THREE character name of the ice piece.
 - ii) The latitude and longitude of the position.
 - iii) The pixel and scanline of the position.
 - iv) The date, time and buffer number of the image the position was picked from.

The program is menu driven and the user needs only to press the appropriate key board keys to execute menu functions. Many of the menus allow the user to enter the VCP program. However, there should be little need to do so.

To execute the program, enter:

ICE

If it is not an installed task, enter:

RUN [101,2]ICE

*** ICE TRACKING PROGRAM**

PROCEED? [Y/N]

Enter Y to proceed, N to exit. If the user proceeds, the program does some initialization of the screen, such as deleting the graphics planes.

5.2 MAIN MENU

*** ICE TRACKING FUNCTIONS ***

V - VCP	(5.3)
T - TRACK FLOES	(5.4)
P - PLOT TRACKS OR VELOCITY	(5.5)
E - EDIT POSITIONS FILE	(5.6)
X - EXIT	(5.7)

PRESS KEY: [V/T/P/E/X]:

Pressing key X terminates the program.

5.3 VCP

Pressing key V puts the user into the VCP program. Exiting VCP returns the program to (5.2).

5.4 TRACKING ICE FLOES

Pressing key T puts the user into the ice tracking section.

ENTER ICE FILE NUMBER (1-999) >

Enter a number, press <RETURN>. If it exists, it is opened, otherwise, the program asks for a title and creates the file. An invalid file number causes the program control to go to (5.2).

5.4.1 TRACK ICE FLOES MENU

**** TRACK ICE FLOES ****

R - SET IMAGE BUFFER LOADING RANGE CURRENT RANGE [0,0]	(5.4.2)
C - CHECK EACH BUFFER FOR A VALID DATE, PROJECTION OR ORBITAL PARAMETER IN THE HEADER	(5.4.3)
T - TRACK AN ICE FLOE	(5.4.4)
U - UPDATE/EXIT	(5.4.5)
X - EXIT (NO UPDATE OF PICKED POSITION)	(5.4.6)

PRESS KEY [R/C/T/U/X]

5.4.2 SET IMAGE BUFFER RANGE

Pressing key R allows the user to input the range of images that are to be loaded in sequence for tracking ice pieces.

ENTER FIRST, LAST BUFFER (IE: 100,150) >

The user enters two numbers separated by a comma and followed by pressing the <RETURN> key.

If the range entered is valid, the range shown in the menu in section 5.4.1 is changed to the entered values.

The program does not accept an invalid range. For example, values less than 1 or greater than 999, or ranges where the first value is greater than the second. If the range entered is invalid, the range is set to [0,0]. Program control returns to (5.4.1).

5.4.3 CHECK IMAGE BUFFER RANGE

Pressing key C causes the program to check the image buffers for valid dates, increasing dates and that the header contains projection values or OPs.

When an error is detected, the type of error is printed out. The user may stop the checking at any time by pressing any key.

*** CHECKING BUFFERS 100 THRU 150 ***

*** PRESS ANY KEY TO ABORT ***

```
100 82/02/01  10:53 LANCASTER SOUND
101 82/02/02  11:00 LANCASTER SOUND
102 82/02/03  05:12 LANCASTER SOUND
105 82/02/04  10:15 LANCASTER SOUND
106 82/02/03  12:15 LANCASTER SOUND
*** DATE NOT INCREASING ***
110 82/02/07  01:10 LANCASTER SOUND
111 82/13/08           LANCASTER SOUND
*** INVALID DATE ***
```

.
.
.

When the range has been checked, or a key pressed to abort:

NUMBER OF VCP BUFFERS IN RANGE 100 TO 150 IS 40
WITH 5 ERRORS DETECTED

DO YOU WANT A PRINTER LISTING OF THE RESULTS

PRESS KEY: [Y/N]:

Press key Y to get the results printed. Program control returns to (5.4.1).

The user should correct the errors detected in the image buffer range before it is used to track ice floes.

5.4.4 TRACK AN ICE FLOE

Pressing key T lets the user track a specific ice floe over the range of images selected in (5.4.1).

5.4.4.1 ICE FLOE NAMES

ENTER A 3 CHARACTER ICE PIECE IDENTIFIER
ENTER XXX TO REPOSITION EXISTING PIECES >

Enter a three character ice piece identifier. If a valid identifier is entered, the program checks that the ID has not been previously used. If it has, the user is asked to try again.

A valid ID causes the program control to go to (5.4.4.2).

Entering XXX causes the program control to go to (5.4.4.3).

5.4.4.2 ICE PIECE TRACKING MENU

The program loads the first image in the image range and displays the following menu. The date of the image is displayed in the top left corner of the screen.

*** TRACKING ICE PIECE AB1 ***

V - VCP (VIDEO CONTROL PROGRAM)
N - LOAD NEXT IMAGE (OVERWRITE OLDEST IMAGE)
M - LOAD NEXT IMAGE (OVERWRITE LAST IMAGE LOADED)
1 - DISPLAY MOST RECENT IMAGE
2 - DISPLAY SECOND OLDEST IMAGE
3 - DISPLAY OLDEST IMAGE
D - DIGITIZE POSITION OF ICE PIECE ON CURRENT IMAGE
E - DELETE POSITION OF ICE PIECE ON CURRENT IMAGE
S - DISPLAY ALL POSITIONS PICKED ON THIS IMAGE

K - REMOVE FROM DISPLAY POSITIONS PICKED ON IMAGE
W - NAME ICE PIECES
Z - ROAM ZOOM FUNCTION
F - SET ZOOM FACTOR DEFAULT IS 3
R - RESET IMAGE TO NO ZOOM
H - DISPLAY THIS MENU
X - EXIT

KEY? [V/N/M/1/2/3/D/E/S/K/W/Z/F/R/H/X] [V/X]:

The menu is only displayed once. After a key is pressed, only the last line of the menu is displayed. To display the full menu, press key H.

A graphics cross cursor is displayed to help pick ice floe positions.

The following is a description of the functions in the menu.

- V VCP is entered.
- N The next image in the sequence is loaded. It overwrites the oldest image. If there are no more images to load, program control goes to (5.4.1).
- M The next image in the sequence is loaded as in N. However, the image that was last loaded is overwritten. If there are no more images to load, program control goes to (5.4.1).
- 1 The last image to be loaded is displayed.
- 2 The second last image loaded is displayed.
- 3 The image loaded before the last two is displayed.
- D The position of the cross hair is used as the position of the ice piece. An X-shaped cross will appear at the position. If a position was already picked, the old X disappears. Note that the position applies to the current image being displayed.
- E Removes the X-shaped cross of the current image being displayed if one was picked.

S A mark shaped like a plus (+) will appear at all the locations on the current image where other ice piece locations have been picked.

K The marks produced by **S** are removed.

W A mark shaped like a plus (+) appears at all the locations on the current image where ice piece locations have been picked.

*****POSITION CURSOR NEAR POSITION YOU WANT NAMED*****

*****THEN PRESS ANY KEY*****

The user should position the cursor at the mark to be named, then press any key. A square will surround the named position.

*****MARK WITH BOX POINTS TO ICE FLOE AAI*****

PRESS C TO CONTINUE

When key **C** is pressed, the square disappears.

Z The image is zoomed by a factor of 3 as the default, or a factor determined by the user using **f**.

*****ROAM ZOOM USING TABLET PRESS ANY KEY TO QUIT*****

Use the tablet pen to position the zoomed portion of the image. Press any key to freeze the zoomed portion.

f Set the zoom factor.

*****CURRENT ZOOM FACTOR 3
ENTER NEW VALUE (1-16) >**

Enter the desired value <RETURN>.

R Reset the image to no zoom factor.

H Display the full menu.

X Program control goes to (5.4.1).

5.4.4.3 ICE POSITION MODIFICATION

The program loads the first image in and the image range and displays the following menu:

TRACKING ICE PIECE

V - VCP
 N - LOAD NEXT IMAGE (OVERWRITE OLDEST IMAGE)
 M - LOAD NEXT IMAGE (OVERWRITE LAST IMAGE LOADED)
 1 - DISPLAY MOST RECENT IMAGE
 2 - DISPLAY SECOND OLDEST IMAGE
 3 - DISPLAY OLDEST IMAGE
 C - LOCATE AND MODIFY AN EXISTING ICE POSITION
 S - DISPLAY ALL POSITIONS PICKED ON THIS IMAGE
 K - REMOVE FROM DISPLAY POSITIONS PICKED ON IMAGE
 W - NAME ICE PIECES
 Z - ROAM ZOOM FUNCTION
 f - SETT ZOOM FACTOR DEFAULT IS 3
 R - RESET IMAGE TO NO ZOOM
 H - DISPLAY THIS MENU
 X - EXIT

KEY? [V/N/M/1/2/3/C/S/K/W/Z/f/R/H/X]

The difference between this menu and the one in 5.4.4.2 is that D and E are replaced with a function C. The rest of the functions are the same as in 5.4.4.2. All previously picked positions on the image are displayed (see function W, section 5.4.4.2).

If C is pressed:

POSITION CURSOR NEAR POSITION YOU WANT TO MODIFY

THEN PRESS ANY KEY

A square is drawn around the picked position:

ID AAZ

D - REDIGITIZE LOCATION
 X - RETURN TO MENU

PRESS KEY [D/X]:

Pressing X causes the last line of the menu above to be displayed.

Pressing D causes the position of the ice piece to be repositioned at the cursor position.

5.4.5 UPDATE/EXIT

The positions that have been picked and/or modified are added to the ice file. The file is updated and closed. Program control goes to (5.2).

5.4.6 EXIT NO UPDATE

None of the additions or modifications are added to the ice file. If positions have been picked or positions modified, then:

EXIT WITH NO UPDATE? [Y/N]

If Y <RETURN> is pressed, no update is performed. Program control goes to (5.2). If N <RETURN> is pressed, program control goes to (5.4.1).

5.5 PLOT TRACKS AND VELOCITIES

This section deals with output products using the ice position files created in the tracking section.

The following menu is displayed.

5.5.1 MAIN MENU

*****PLOT POSITIONS*****

V - VCP	(5.5.2)
P - SET COASTLINE PROJECTION	(5.5.3)
C - PLOT COASTLINE	(5.5.4)
T - PLOT ICE FLOE TRACKS	(5.5.5)
S - PLOT VELOCITY VECTORS	(5.5.6)
G - PLOT VELOCITY GRAPH	(5.5.7)
X - EXIT	

PRESS KEY: [V/P/C/T/S/G/X]:

5.5.2 VCP

The user enters VCP. When VCP is exited, program control goes to (5.5.1).

5.5.3 SET COASTLINE PROJECTION

Before functions T, S or G can be entered, projection values must be set. The inputs are the same as described in section (3.4).

Program control goes to (5.5.1).

5.5.4 PLOT COASTLINE

The coastline corresponding to the projection entered in (5.5.3) is drawn in graphics plane 1. The rest of the graphics planes are deleted.

*****DRAWING MAP ON GRAPHICS PLANE 1*****

*****PRESS ANY KEY TO QUIT*****

Program control goes to (5.5.1) when the coastline is drawn or a key is pressed.

5.5.5 PLOT ICE FLOE TRACKS

The positions of ice pieces are linked by a line drawn in graphics planes 2 through 7 (see Figure A-3).

**ENTER NUMBER OF FILES TO PROCESS
MAXIMUM IS 20 (PRESS RETURN TO QUIT) >**

Enter the number of files for which track plots are desired. Pressing <RETURN> by itself causes program control to go to (5.5.1).

ENTER FILE # 1 (1-999) (ANY OTHER VALUE TO QUIT)

Enter an ice file number that will be processed. The program continues to ask until the specified number of files have been entered.

The user must then specify the date span that the positions must occur in to be plotted.

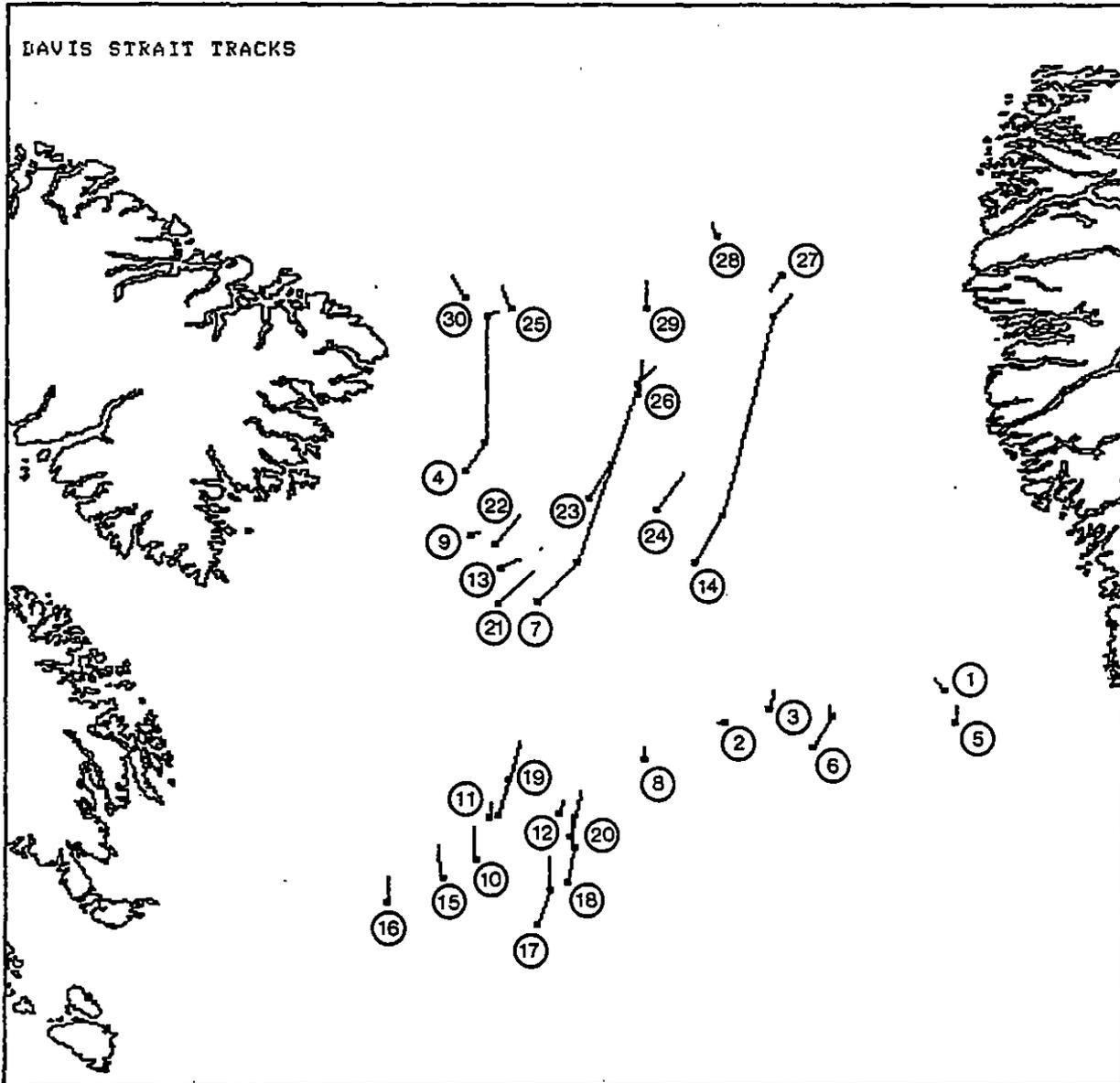


Figure A-3: Ice tracks.

ENTER FIRST DATE TO PLOT POSITIONS (YY,MM,DD,HR,MIN)
 (PRESS RETURN FOR FIRST DATE IN FILES) >

Enter a valid date.

ENTER LAST DATE TO PLOT POSITIONS (YY,MM,DD,HR,MIN)
 (PRESS RETURN FOR LAST DATE IN FILES) >

Enter a valid date or <RETURN> by itself.

5.5.5.1 MAIN MENU

PLOT TRACK FUNCTION

V - VCP
 R - RESET START, STOP DATE
 D - DISPLAY ICE FLOE IDS BEFORE PLOTTING
 A - PLOT ALL ICE FLOES
 X - EXIT

PRESS KEY? [V/R/D/A/X]

- V Puts the user into VCP. Exiting VCP causes program control to go to (5.5.5.1).
- R The user can reset the start and stop dates.
- D The program displays the ice piece identifier before the track is plotted, allowing selected ice floes to be plotted.

ICE ID AAl

P - PLOT ID
 S - SKIP ID
 L - PLOT AND LABEL
 V - VCP
 N - NEXT FILE
 Q - QUIT

PRESS KEY: [P/S/L/V/N/Q]

If P is pressed, the track for the ice piece is plotted.

If S is pressed, it is not plotted.

If V is pressed, VCP is entered.

If L is pressed, then the track is plotted and the user is asked to position the cursor at the position on the Ikonas screen to plot the ice piece identifier.

If N is pressed, the program starts plotting the position in the next ice file.

If Q is pressed, program control goes to (5.5.5.1).

A The program plots all the ice floe tracks.

X Program control goes to (5.5.1).

Note that the tracks are alternately plotted in graphics planes 2 through 7.

5.5.6 PLOT VELOCITY VECTORS

The average velocity is computed for specified areas chosen by the user and a velocity vector is plotted showing the speed and direction of the average velocity of the area (see Figure A-4).

The user is asked to enter the ice files to process and the date span as in section (5.5.5).

ENTER KM/DAY PER PIXEL >

Enter the number of km/day each pixel will represent in the vectors.

5.5.6.1 MAIN MENU

COMPUTE VELOCITY VECTORS FUNCTIONS

V - VCP
 D - RESET START, STOP DATES
 S - RESET KM/DAY SCALE
 C - CALCULATE AND PLOT A VECTOR
 P - PLOT THE VECTOR SCALE
 A - SET ARROW TYPE
 X - EXIT

PRESS KEY: [V/D/S/C/P/A/X]

V VCP is entered. Program control goes to (5.5.6.1) when it is exited.

VELOCITY VECTORS OF LANCASTER SOUND

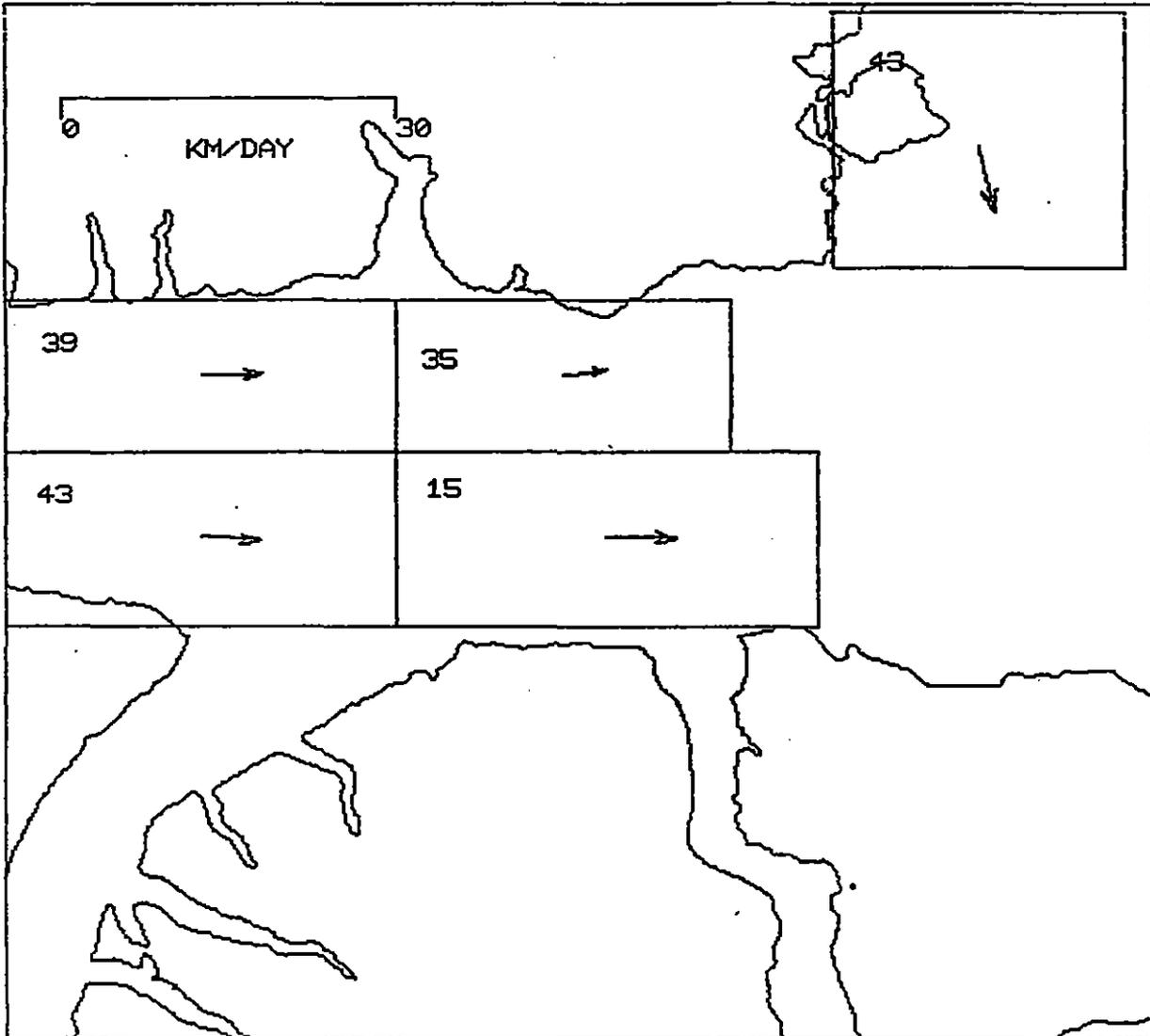


Figure A-4: Velocity vectors.

- D The user can reset the start and stop dates.
- S The user can reset the km/day scale.
- C The coastline is displayed. The user is asked to digitize two corners of an area to compute the velocity vector for. A square is drawn showing the borders of the area. The velocity vector is calculated and the vector plotted in the centre of the area.

PLOT STANDARD DEVIATION? [Y/N]

If Y <RETURN> is pressed:

WAITCALCULATING STANDARD DEVIATION

The deviation is plotted.

10 VECTORS WERE USED TO COMPUTE THE AVERAGE, PLACE CURSOR WHERE YOU WISH THIS NUMBER PLOTTED THEN PRESS ANY KEY OR X TO NOT PLOT THE NUMBER

Program control goes to (5.5.5.1).

- A Set arrow type.

PRESS KEY FOR ARROW TYPE: [1/2/3/4/5/6/7/8]

The default arrow type is 1.

5.5.7 PLOT VELOCITY VECTOR GRAPH

The average velocity for every day over a period of time for specified areas are plotted as a graph of velocity components versus day (see Figure A-5).

ENTER NUMBER OF ICE FILES TO PROCESS
MAXIMUM 10 (PRESS RETURN TO QUIT) >

ENTER FILE #1 (1-999) (ANY OTHER VALUE TO QUIT) >

.
.
.

ENTER START DATE (YY,MM,DD) >

ENTER STOP DATE (YY,MM,DD) >

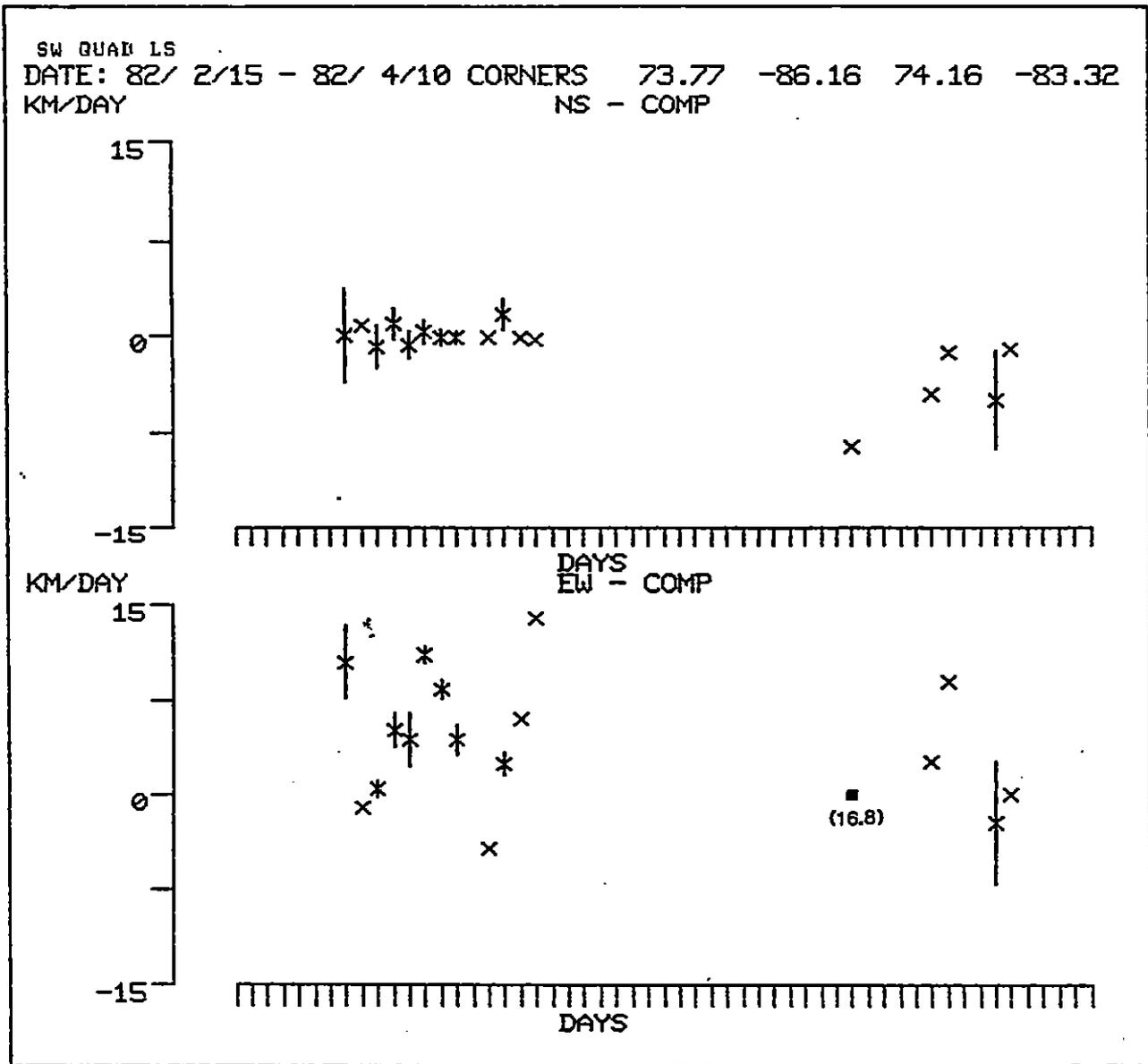


Figure A-5: Vector components vs days graph.

ENTER MAXIMUM KM/DAY (INT) >

Enter the dates and maximum km/day.

5.5.7.1 MAIN MENU

*****COMPUTE VELOCITY VECTORS FUNCTIONS*****

V - VCP
 D - RESET START STOP DATES, KM SCALE
 C - PLOT A GRAPH FOR AN AREA
 X - EXIT

PRESS KEY: [V/D/C/X]:

- V VCP is entered. When VCP is exited, program control goes to (5.5.7.1).
- D The user can reset the start and stop dates. This causes graphics planes 2 through 8 to be erased.
- C The coastline is displayed and a graphics cross cursor appears.

POSITION CURSOR AT THE BOTTOM LEFT CORNER OF A DESIRED AREA TO COMPUTE GRAPH FOR THEN PRESS ANY KEY

POSITION CURSOR AT THE TOP RIGHT CORNER OF DESIRED AREA THEN PRESS ANY KEY

A border is drawn around the area (graphics plane 2).

OKAY? PRESS KEY [Y/N]

If N <RETURN> is pressed, the border is erased and program control goes to (5.5.7.1).

If Y <RETURN> is pressed, the program computes the average velocities for each day and plots the results in the graphics planes 3 and 4. A printer listing of the velocities is also produced.

Program control goes to (5.5.7.1).

5.6 EDITING AN ICE FILE

This section deals with editing ice files.

ENTER ICE FILE (1-999) >

5.6.1 MAIN MENU

ICE FILE EDIT FUNCTIONS [FILE: 3]

L - LIST POSITIONS	(5.6.2)
E - EDIT FILE USING EDITOR	(5.6.3)
D - DELETE SPECIFIED RECORDS	(5.6.4)
R - DELETE ICE FILE	(5.6.5)
X - EXIT	

PRESS KEY: [L/E/D/R/X]:

Pressing key X causes program control to go to (5.2).

5.6.2 LISTING POSITIONS

This function allows the user to list out the positions and velocities in the ice file.

LIST METHOD

D - LIST BY DATE
N - LIST BY RECORD NUMBER

PRESS KEY: [D/N]:

If key D is pressed:

ENTER START DATE YY,MM,DD,HR,MIN >

Enter the start date.

ENTER STOP DATE YY,MM,DD,HR,MIN >

Enter the stop date.

If key N is pressed:

ENTER START, STOP RECORDS TO PRINT (IE: 1,100)
ENTER <RETURN> TO PRINT ALL OR -1 TO QUIT >

Enter the records to print or just <RETURN> to print them all.

PRESS T-TERMINAL, P-PRINTER OUTPUT

If T is pressed, the listing goes to the terminal. If P is pressed, the listing goes to the printer. For example:

ICE FILE: 111

DATE	TIME	ID	LATITUDE	LONGITUDE	SPEED	KM/DAY	DIRECTION
1:82/ 2/22	14:25	AA1	74.1258	85.0055			
2:82/ 2/24	20:25	AA1	74.1527	84.5754	5.9595		77.0896
3:82/ 2/25	18:34	AA1	74.1527	84.5363	1.2862		90.0000
4:82/ 2/26	10: 9	AA1	74.1437	84.4189	5.7031		105.6814
5:82/ 2/16	16:44	AB1	74.5120	80.1954			
6:82/ 2/17	14:41	AB1	74.5569	80.1954	5.4617		0.0026
7:82/ 2/22	14:25	AB1	74.5030	80.4691	2.0225		233.5694
8:82/ 2/23	14:25	AB1	74.4941	80.2736	5.8945		99.7010
9:82/ 2/24	20:25	AB1	74.4581	80.0781	5.6489		124.5319
10:82/ 2/22	14:25	AC1	75.0420	78.8658			
11:82/ 2/23	14:25	AC1	74.8444	79.0222	22.4287		191.6222
12:82/ 2/24	20:25	AC1	74.6647	79.4524	18.8857		212.1915
13:82/ 2/26	10: 9	AC1	74.6018	79.3350	4.9625		153.6842
14:82/ 2/22	14:25	AD1	74.2336	85.3966			
15:82/ 2/23	14:25	AD1	74.2425	84.9273	14.2084		85.9845
16:82/ 2/24	20:25	AD1	74.2425	84.8882	0.9444		90.0000
17:82/ 2/25	18:34	AD1	74.2515	84.8882	1.0845		0.0000
18:82/ 2/26	10: 9	AD1	74.2605	84.8491	2.3817		49.7079

Program control goes to (5.6.1).

5.6.3 USING THE SYSTEM EDITOR TO EDIT AN ICE FILE

The program creates an ASCII version of the ice file and puts the user into the system editor EDT to edit the file. It is assumed that the user knows how to use the editor. The following is an example of the file created.

EDITING ICE FILE 111

THE DATA RECORDS OF THE FILE START AFTER THE LINE FILLED WITH ASTERISKS (*). THIS LINE MUST NOT BE DELETED FROM THE FILE. THE USER MAY MODIFY ANY OF THE RECORDS BUT MUST RETAIN THE RECORD FORMATS. A CHANGE MADE THAT DOES NOT CONFORM TO THE FORMAT WILL RESULT IN A DETECTED OR UNDETECTED ERROR WHEN THE FILE IS UPDATED WHEN THE USER EXITS THE EDITOR. IF AN ERROR IS DETECTED THE PROGRAM ASKS THE USER IF HE/SHE WISHES TO RETURN TO THE EDITOR OR ABANDON ALL CHANGES. SOME ERRORS MAY NOT BE DETECTED AND WILL RESULT IN INVALID INFORMATION IN THE FILE.

THE FIRST LINE FOLLOWING THE ASTERISK LINE IS THE FILE HEADER. FOLLOWED BY THE POSITIONS WHERE:

<u>COLUMNS</u>	<u>TYPE</u>	<u>VALUE</u>
1 - 2	INT	YEAR
4 - 5	INT	MONTH
7 - 8	INT	DAY
10 - 11	INT	HOUR
13 - 14	INT	MINUTE
16 - 23	REAL	LATITUDE
24 - 31	REAL	LONGITUDE
33 - 35	CHAR	IDENTIFIER
37 - 39	INT	VCP BUFFER POSITION PICKED FROM
41 - 43	INT	PIXEL ON IMAGE OF POSITION
45 - 47	INT	SCANLINE ON IMAGE OF POSITION

LANCASTER SOUND ICE FLOES

82/ 2/22 14:25 74.1258 85.0055 AAl 355 307 242
82/ 2/24 20:25 74.1527 84.5754 AAl 357 318 239
82/ 2/25 18:34 74.1527 84.5363 AAl 358 319 239
82/ 2/26 10: 9 74.1437 84.4189 AAl 359 322 240
82/ 2/27 9:57 74.1437 84.3016 AAl 363 325 240
82/ 2/28 9:46 74.1347 83.9497 AAl 364 334 241
82/ 3/ 1 9:34 74.1347 83.6759 AAl 365 341 241
82/ 3/ 3 19: 6 74.1617 83.2066 AAl 366 353 241
82/ 3/ 4 15:33 74.1437 83.3631 AAl 367 349 240
82/ 3/ 5 15:10 74.1347 83.2066 AAl 368 353 241
82/ 3/ 6 14:47 74.1437 83.1284 AAl 369 355 240
82/ 2/16 16:44 74.5120 80.1954 AB1 353 430 199
82/ 2/17 14:41 74.5569 80.1954 AB1 354 430 194
82/ 2/22 14:25 74.5030 80.4691 AB1 355 423 200
82/ 2/23 14:25 74.4941 80.2736 AB1 356 428 201
82/ 2/24 20:25 74.4581 80.0781 AB1 357 433 205
82/ 2/26 10: 9 74.4851 79.9216 AB1 359 437 202
82/ 2/28 9:46 74.5120 79.6870 AB1 364 443 199
82/ 3/ 1 9:34 74.5120 79.5306 AB1 365 447 199
82/ 3/ 3 19: 6 74.5174 78.8658 AB1 366 464 208
82/ 3/ 4 15:33 74.4312 79.3350 AB1 367 452 208
82/ 3/ 5 15:10 74.4402 79.1786 AB1 368 456 207

The user may delete or modify the records.

When the editor is exited:

U - PROCEED WITH UPDATES MADE IN EDT
 X - IGNORE ANY UPDATES MADE IN EDT

PRESS KEY: [U/X]:

Pressing key X causes program control to go to (5.2).

If key U is pressed, the program checks the file for errors caused by the editing. If an error is found, the line number in the file it occurred at is displayed on the terminal.

*****FORMAT ERROR LINE 50*****

**E - RE-EDIT FILE WITH SYSTEM EDITOR
X - EXIT DO NOT UPDATE ICE FILE**

PRESS KEY: [E/X]:

If key X is pressed, program control goes to (5.2).

If key E is pressed, the system editor is re-entered.

If no errors were detected, then:

**FILE 111 WILL HAVE 400 RECORDS FOR 50
ICE PIECES IF UPDATED**

**U - UPDATE FILE WITH CHANGES
X - EXIT (NO UPDATE)**

PRESS KEY: [U/X]:

If key X is pressed, program control goes to (5.2).

If key U is pressed, the ice positions file is updated and program control goes to (5.2).

5.6.4 DELETE SPECIFIED RECORDS

*****DELETE FUNCTIONS EDITING FILE [111]*****

**D - DELETE BY DATE
N - DELETE BY RECORD NUMBERS
I - DELETE BY ID
S - EXIT (UPDATE FILE WITH DELETIONS)
X - EXIT (IGNORE ANY DELETIONS)**

PRESS KEY: [D/N/I/S/X]:

D Delete records within a date span. The user is asked to enter two dates. The program marks all records with the date span for deletion. Program control goes to (5.6.4).

- N Delete specified records by record numbers. The user is asked for a start and stop record number to delete. The specified records are marked for deletion. Program control goes to (5.6.4).
- I The user is asked to enter a specified ice floe identifier. All the positions for the ice identifier are marked for deletion. Program control goes to (5.6.4).
- S Update the ice file with the deletions. Program control goes to (5.2).
- X Do not update the deletions file. Program control goes to (5.2).

5.6.5 DELETE THE ICE FILE

DELETE FILE? [Y/N]

If Y <RETURN> is pressed, the file is deleted and program control goes to (5.2).

If N <RETURN> is pressed, program control goes to (5.6.1).

6.0 AFFINE TRANSFORMATION

Generalized Video Display AFFINE Transformation Program

Program AFFINE performs a three to eleven term Affine Transformation from one Ikonas image plane into another Ikonas image plane. The number of terms of the transformation function is dependent on the number of reference points entered by the user which is also three to eleven. The transformation is exact, that is, there is no error at the reference points. However, enormous distortions can occur at other points on the output image if the reference points are chosen incorrectly.

The following is a table of the transformation functions used for each number of reference points entered.

<u>Stns</u>	<u>Transformation Function</u>
3	$T = C + X + Y$
4	$T = C + X + Y + XY$
5	$T = C + X + Y + XY + X^2$
6	$T = C + X + Y + XY + X^2 + Y^2$
7	$T = C + X + Y + XY + X^2 + Y^2 + X^2Y$
8	$T = C + X + Y + XY + X^2 + Y^2 + X^2Y + XY^2$
9	$T = C + X + Y + XY + X^2 + Y^2 + X^2Y + XY^2 + X^2Y^2$
10	$T = C + X + Y + XY + X^2 + Y^2 + X^2Y + XY^2 + X^2Y^2 + X^3$
11	$T = C + X + Y + XY + X^2 + Y^2 + X^2Y + XY^2 + X^2Y^2 + X^3 + Y^3$

As can be seen, the number of higher order terms and cross terms increases with the number of reference points.

6.1 PROGRAM AFFINE

To run the Affine Transformation Program, enter **AFF**.

The terminal will respond with:

GENERALIZED AFFINE TRANSFORMATION ROUTINE

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MODE 0    STATIONS FROM DISPLAY
MODE 1    STATIONS FROM TERMINAL
MODE 2    COEFFICIENTS FROM TERMINAL

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ENTER MODE [0] >

Enter the desired data entry mode as requested. The default mode 0 is the usual method of entering reference points where the user interactively selects stations from a reference image and

the input image. Mode 1 is used if the input and output pixel and scanline coordinates are known, and mode 2 is used to rerun a previous transformation with exactly the same or with slightly altered transformation coefficients.

If mode is 0 or 1, the terminal will next respond with:

ENTER REFERENCE IMAGE PLANE >

Optionally enter the Ikonas image plane from which the reference stations are to be selected. If no reference image plane number is entered, then the program assumes the user is selecting reference stations from a reference coastline graphics plane only.

Note that reference stations may be selected from either a reference image plane or a reference coastline graphics plane or from the two combined.

The terminal will next respond with:

ENTER INPUT IMAGE PLANE TO BE RECTIFIED >

Enter the Ikonas image plane containing the image to be rectified.

The terminal will next respond with:

ENTER INPUT IMAGE COASTLINE GRAPHICS PLANE >

Optionally enter the Ikonas graphics plane containing the coastline map. If selected, the coastline map will be displayed along with the image to be rectified.

If the mode is 1, the terminal will next respond with:

ENTER GRAPHICS PLANE FOR CURSOR >

Enter an Ikonas graphics plane in which the special cursor used to select reference stations is displayed.

The terminal will next respond with:

DO YOU WANT TO CLEAR GRAPHIC PLANE N? [Y/N] >

Answer Y to clear the cursor graphics plane.

The terminal will next respond with:

ENTER GRAPHICS PLANE FOR REFERENCE STATIONS >

Optionally enter the Ikonas graphics plane in which the symbols representing reference station positions are displayed.

The terminal will next repond with:

DO YOU WANT TO CLEAR GRAPHIC PLANE N? [Y/N] >

Answer Y to clear the reference station graphics plane.

The terminal will next respond with:

ENTER GRAPHICS PLANE FOR INPUT STATIONS >

Optionally enter the Ikonas graphics plane in which the symbols representing input station positions are displayed.

The terminal will next respond with:

DO YOU WANT TO CLEAR GRAPHIC PLANE N? [Y/N] >

Answer Y to clear the input station graphics plane.

The Ikonas display is now set up for interactive station selection (mode 0) or non-interactive station selection (mode 1). The display will switch between the reference image and/or graphics display and the input image and/or graphics display as the stations are selected.

The following line will next appear on the terminal:

***** REFERENCE STATION SELECTION *****

The Ikonas will display the reference image and/or coastline along with the cursor and the reference station graphics plane.

If mode is 1, the terminal will next respond with:

ENTER REFER PIXEL, SCANLINE FOR STATION N >

Enter the reference pixel and scanline for the nth station.

If the mode is 0, the terminal will next respond with:

**DIGITIZE REFERENCE FEATURE FOR STATION N, HIT KEY
R-RESET DISPLAY, Z-ROAM ZOOM, V-VCP, D-DIGITIZE, E-EXIT**

To digitize a reference station, move the cursor using the digitizing tablet and pen to the reference station position and press D on the terminal. If no more stations are to be selected, press E and the program will exit from the station selection routine.

The other keys listed above allow the user to enhance the display to better select a reference station.

Pressing Z causes the following line to appear on the terminal:

ENTER ZOOM FACTOR (DEFAULT 3) VALUES (1-16) >

Enter a digit in the range 1 to 16 to invoke a roamed zoom of the reference display.

Pressing R resets the roamed zoom and pressing V invokes the video control program VCP, which allows for a large number of display options, especially the PS and PT commands for enhancing the display pseudocolour lookup table.

Whenever a key other than D is pressed, the program will branch back to the reference station selection prompt. Once D is pressed, the station is selected and its position is marked if a reference station graphics plane has been selected.

The Ikonas will display the input image and/or coastline along with the cursor and input station graphics plane.

If mode is 1, the terminal will next respond with:

ENTER INPUT PIXEL, SCANLINE FOR STATION N >

Enter the input pixel and scanline for the nth station.

If mode is 0, the terminal will next respond with:

**DIGITIZE INPUT FEATURE FOR STATION N, HIT KEY
R-RESET DISPLAY, Z-ROAM ZOOM, V-VCP, D-DIGITIZE, E-EXIT**

Similarly select the reference station position on the input image which corresponds to the reference station position on the reference image.

If mode is 0 or 1, the terminal will next respond with:

***** STATION N SELECTED *****

DO YOU WISH TO RESELECT STATION N? [Y/N] >

This is your last chance. If you are not happy with the station you have just selected, enter Y and the program will allow you to reselect the station, otherwise the station is considered selected and the program will prompt you to select another station.

The program will now perform a matrix inversion on the reference stations selected. If the matrix inversion fails, the following message will be printed and the program will terminate.

AFFINE TRANSFORMATION MATRIX INVERSION FAILED

A matrix inversion failure usually occurs when reference stations describing an impossible Affine Transformation have been entered. Failure can also occur for some symmetrical transformations.

The program next prints out a table of Affine Transformation coefficients. These coefficients can be re-entered at a later date if mode equals 2, in which case the program will prompt as follows:

ENTER X-COEFFICIENT, Y-COEFFICIENT N FOR M >

Where N is the coefficient and M indicates the term.

The program next prints a summary of the input and output pixel and scanline indices for each station, followed by the prompt:

DO YOU WANT A PRINTER LISTING OF THIS? [Y/N] >

Answer Y to print out the Affine Transformation coefficients and if mode is 0 or 1, the station summary.

The program next prints out a table of pixel shifts followed by a table of scanline shifts for every 32nd pixel and scanline, starting at pixel 17 and scanline 17. These tables allow you to tell at a glance whether the Affine Transformation is going to work. Pixel and scanline shifts greater than can be printed are indicated by 999. Large pixel and/or scanline shifts indicate that the Affine Transformation did not work.

The terminal will next respond with:

ENTER OUTPUT IMAGE PLANE >

Enter the image plane into which the transformed image is to be placed. You can get out of applying the transformation by defaulting this prompt.

If an output image plane was selected, the terminal will next respond with:

DO YOU WANT TO CLEAR IMAGE PLANE N? [Y/N] >

Answer Y to clear the output image plane.

The terminal will next respond with:

PERFORMING AFFINE TRANSFORMATION...

When the Affine Transformation is complete, the terminal will respond with:

DO YOU WISH TO APPLY AFFINE AGAIN? [Y/N] >

If you answer Y, the terminal will respond with:

**USE VCP TO STORE OUTPUT IMAGE PLANE N
AND TO LOAD INPUT IMAGE PLANE M**

The program will now invoke VCP to allow you to write your transformed image to disk and load another image to the Ikonas Display. In this way, several images which require exactly the same Affine Transformation can be processed without re-entering the station positions or the Affine Transformation coefficients.

If you did not answer Y, the terminal will respond with:

DO YOU WISH TO SELECT MORE STATIONS? [Y/N] >

If you answer Y, the program will branch back to the station selection routine, otherwise the program will terminate with the message:

AFFINE TERMINATED

7.0 PROGRAM MOVIE

This program assists in producing a movie of a time series of corrected images.

Plug the movie camera into the terminal keyboard provided with a special connector for running the camera.

To run the program enter:

MOV

if the program is installed, otherwise enter:

RUN [101,2] MOVIE

The following menu is displayed on the terminal:

*** MOVIE FUNCTIONS ***

<u>FUNCTION</u>	<u>DESCRIPTION</u>	<u>CURRENT</u>	<u>VALUE</u>
B	SET AND LOAD A CURRENT BUFFER		0
N	LOAD NEXT BUFFER		
E	SET EXPOSURE PER FRAME		1
T	SET MILLISECONDS PER EXPOSURE	2000	
L	SET LABEL POSITION, IF 0,0 NO LABEL IS PLOTTED	0	0
R	ROLL CAMERA		
P	PLOT A NEW LABEL AT LABEL POSITION		
X	EXIT PROGRAM		

PRESS KEY: [U/N/E/T/L/R/P/X]

B The user is asked for a buffer to load into Ikonas image plane 1.

ENTER BUFFER TO LOAD >

If the buffer exists it is loaded. The buffer number becomes the current buffer known to the program.

N The current buffer number is incremented by one and the next buffer loaded.

E The default value for the number of exposure per image is 1. This function allows the user to set it to a different value.

ENTER EXPOSURES PER FRAME >

- T The default value for the number of milliseconds between exposures is 2000 milliseconds or two seconds. This is enough time for the camera to position itself between each exposure. However, the user may modify the value.

ENTER EXPOSURE TIME >

- L Whenever a new image buffer is loaded, the first 14 characters of the image title is drawn in graphics plane 1 at the current x,y label position unless it is 0,0 which is the default.

ENTER X,Y POSITION OF LABEL >

- R The specified number of exposure with the specified delay are taken. A bell character is sent to the terminal to activate the camera for each exposure.
- P The user may substitute the label of the current image with his own.

ENTER NEW LABEL FOR CURRENT POSITION 50,50 MAX 14 CHAR >

Enter the desired label.

- X The program is terminated.

After a function is executed the full menu is redrawn.

APPENDIX B

APPLICATIONS TO RADAR HARDCOPY IMAGING

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APPLICATIONS TO RADAR HARDCOPY IMAGERY

Two positive transparency strips were obtained from AES Ice Forecasting Central representing the output of the AES SLAR (Side Looking Aperature Radar) on two December 1982 flights along sections of Barrow Strait and Lancaster Sound. Original project plans were to test the feasibility of using the basic VHR2 algorithm to rectify, in a piecewise fashion, individual segments of the image strip as recorded between the successive marked pairs of inertial navigation points. In this scheme, the individual aircraft subtrack segments and the two strips of the surface image (one on each side of the aircraft separated by an unobserved shadow zone) were assumed to be representable, as in the satellite case, as arcs of orthogonal great circles. An initial simple calculation was carried out for a portion of the track characterized by negligible yaw or angular differences between aircraft heading and direction of progress. Using standard values for the minimum and maximum instrument downward look angles, the positions of points along the adjacent shorelines of Devon Island were calculated to within a few kilometres of their actual positions. In the general case, the difficulties in this approach became apparent due to: the obvious violation of the orthogonal great circle assumption in the case of non-zero aircraft yaw; and our inability, because of the weak signal returns, to unambiguously establish image points corresponding the minimum downward look angle direction. Other complications of consequence were our lack of adequate data on the imaging system's built-in yaw compensation and the apparent presence (according to an AES source) of evidence for substantial errors in the aircraft position values as derived from the inertial navigation instrument. These complexities raised the required degree of effort well beyond planned levels and work on the hardcopy radar imagery problem was terminated.

APPENDIX C

**CALCULATION OF ORBITAL
AND IMAGE PARAMETERS**

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CALCULATION OF ORBITAL AND IMAGE PARAMETERS

The first step in the VHR2 calculation process outlined in Section 3.3 consists of the calculation of the orbital parameters β_1 , β_{512} , γ_1 , γ_{512} and ϕ_0 for a fixed value of the subtrack pixel. The procedures involved in this step are summarized in Figure C-1. The parameters which appear in Figure C-1 are defined in Tables C-1 and C-2.

The calculation for a fixed value of p_s contains 3 nested loops which derive the optimum values of the give parameters. The individual steps of this are described below with reference to Figure C-1 and Tables C-1 and C-2.

Step 1: Initialization

The entered values of the parameters listed in Table C-1 are used to derive values of the image and control point specific quantities listed in Table C-2. The latter, the orbital and scanner offset angles, are, in turn used to establish the starting values of γ and β for the iteration process.

$$\gamma = (Lt_{\max} - Lt_{\min}) \times \frac{512}{s_{\max} - s_{\min}} \quad (C-1)$$

$$= (Ln_{\max} - Ln_{\min}) \times \frac{512}{p_{\min} - p_{\min}} \quad (C-2)$$

Alternatively, γ and β may be manually entered by the operation at the start of the calculation.

The latitude and longitude standard deviations of the calculated and known control point locations are set to an arbitrarily large number, i.e. 10^{18} to provide a starting point for the iteration process which acts to reduce these deviations to less than a given set level. Finally average values for the control point latitudes are computed:

$$\overline{Lt} = \sum_{i=1}^N Lt_i / N \quad (C-3)$$

$$\overline{Ln} = \sum_{i=1}^N Ln_i / N \quad (C-4)$$

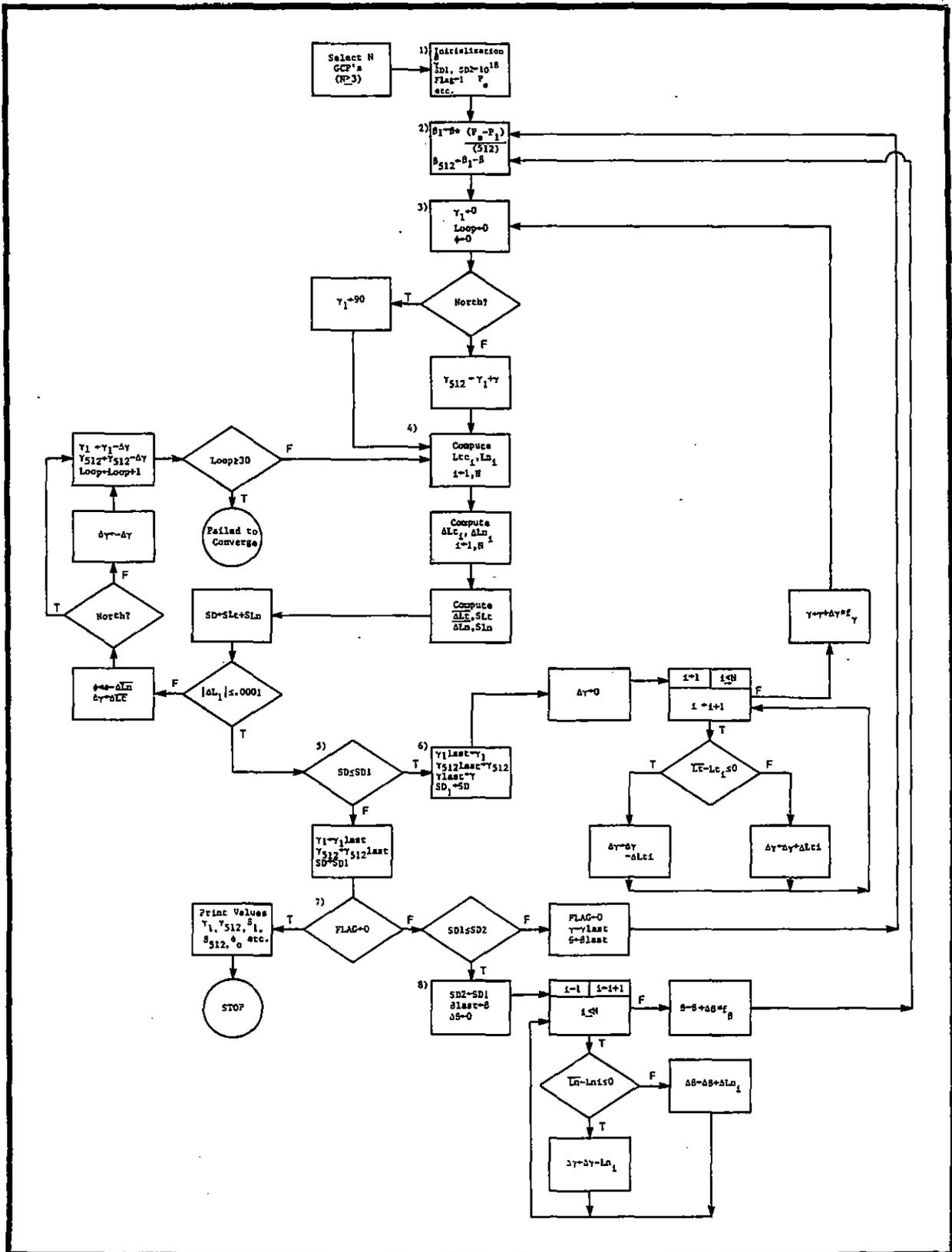


Figure C-1: Flow chart representation of the processing steps involved in the rectification or derivation of orbit parameters for a redigitized image. Numbers (1-8) appended to parts of the diagram indicate the appropriate calculation stage as described in the test.

The remaining steps are discussed for the first iteration.

Step 2: Computation of Scanner Angles at Image Boundaries

$$\beta_1 = \beta \times \frac{(Ps-1)}{(512)}$$

$$\beta_{512} = \beta_1 - \beta$$

Step 3: Computation of Orbital Angles at Image Boundaries

γ_1 is set = 0 (=90 if image is north bound)

$$\gamma_{512} = \gamma_1 + \gamma$$

$$\text{and } \phi_0 = 0$$

Step 4: Computation of Control Point Deviations

For each GCP, latitude and longitude, Ltc_i and Lnc_i ($i=1,N$), are computed using current values of β_1 , β_{512} , γ_1 , γ_{512} , ϕ_0 and p_s and the geocentric coordinate relationships derived in Section 3.

The deviations are computed at each GCP:

$$\Delta Lt_i = Ltc_i - Lt_i \quad i=1, \dots, N \quad (C-8)$$

$$\Delta Ln_i = Lnc_i - Ln_i \quad i=1, \dots, N \quad (C-9)$$

and used to compute the average deviation:

$$\overline{\Delta Lt} = \left(\sum_{i=1}^N Lt_i \right) / N \quad (C-10)$$

$$\overline{\Delta Ln} = \left(\sum_{i=1}^N Ln_i \right) / N \quad (C-11)$$

The standard deviation is set as:

$$SD = SL_t = SL_n \quad (C-12)$$

where

$$SL_t = \sqrt{\left(\sum_{i=1}^N \Delta L t_i^2 - \left(\sum_{i=1}^N \Delta L t_i \right)^2 / N \right) / (N-1)} \quad (C-10)$$

$$SL_n = \sqrt{\left(\sum_{i=1}^N \Delta L n_i^2 - \left(\sum_{i=1}^N \Delta L n_i \right)^2 / N \right) / (N-1)} \quad (C-11)$$

If $|\overline{\Delta L t}| < .0001$ convergence is achieved and the calculation advances to step 5. If the inequality is not satisfied, ϕ_0 is adjusted using the longitude error as

$$\phi_0 = \phi_0 - \overline{\Delta L n} \quad (C-15)$$

Adjustments in γ_1 and γ_{512} follow the form

$$\gamma_1 = \gamma_1 - \Delta \gamma \quad (C-16)$$

$$\gamma_{512} = \gamma_{512} - \Delta \gamma \quad (C-17)$$

where $\Delta \gamma = \overline{\Delta L t}$ (for north bound satellite tracks $\Delta \gamma = -\overline{\Delta L t}$).

The calculation returns to the beginning of this step with the loop cycle continuing until the above $|\overline{\Delta L t}|$ inequality is satisfied.

Step 5:

If the current standard deviation SD satisfies $SD < SD1$, γ is adjusted according to step 6. Otherwise, γ_1 and γ_{512} are reset to the values which gave a standard deviation equal to SD1, i.e.

$$\gamma_1 = \gamma_1(\text{last})$$

$$\gamma_{512} = \gamma_{512}(\text{last})$$

$$SD = SD1$$

and the calculation advances to step 7.

Step 6:

Adjustments in γ are made using $\Delta L t_i$ according to:

$$\gamma_1(\text{last}) = \gamma_1$$

$$\gamma_{512}(\text{last}) = \gamma_{512}$$

$$\gamma(\text{last}) = \gamma$$

$$SD_1 = SD$$

$$\Delta\gamma = 0 \text{ for } i = 1 \text{ to } N.$$

The program includes an option for altering the strength of the successive adjustments in γ through selection of one of four fixed values for the factor f_γ in the substitution:

$$\gamma = \gamma + \Delta\gamma \times f_\gamma \quad (\text{C-20})$$

In the absence of a selection (default), a value $f_\gamma = .01$ is used. The output of this step is entered back into step and rerun through the step 4 loop.

Step 7: Exit Testing

Depending upon the presence or absence of a zero flag state, the $\Delta L n_i$ values are used, respectively, to recalculate or to reset both β and γ to their last values and to calculate final values of the 5 orbital parameters. Failure of the zero flag test is followed by a testing of the SD_1, SD_2 inequality before either setting the flag to zero and running the last parameter values through the upper circuit one last time or going on to step 8.

Step 8: Scanner Angle Adjustment

Starting with a resetting of SD_2 to the current SD_1 value, the last value of β and an initial zero value of $\Delta\beta$ are used with the current values of the other parameters to find an optimal value of β . The adjustment

$$\overline{L_n} - L n_i$$

utilizes the signs of the individual station longitude deviations from an overall group average

$$\overline{L_n} - \overline{L n_i}$$

to determine whether the corresponding calculated longitudinal errors $\Delta L n_i$ increase or decrease a correction quantity $\Delta\beta$. After running through an $i = 1, N$ loop, the resulting value of β is used with an operator selectable reduction factor f (Default value $f_\beta = .01$) to reset β according to:

$$\beta = \beta + \Delta\beta \times f_\beta \quad (\text{C-21})$$

and the calculation returns to step 2 with the new set of parameters.

The second part of the optimal parameter selection process utilizes the rough correspondence between the separation of a p_s value from the true subtrack pixel and the standard deviation or error in the calculated positions of the ground control points. A simple binary search routine based on this correspondence operated by testing the i th pixel number as a candidate for the subtrack pixel. The standard deviation for the GCP's ($\cong S(i)$) was calculated using the orbital parameters computed (by the procedure of Figure C-1) for $p_s = i$. To test the subtrack assumption, pixel values at $i + n$ and $i - n$ were also tested by calculations of $S(i \pm n)$. On the basis of the above correspondence, the next stage of the iterative testing procedure would be centered on the tested pixel value i , $i + n$, or $i - n$, characterized by the lowest deviation. In each successive step in the selection process, n is divided by 2. When n reaches the value = 1, the subtrack pixel is selected as the pixel with the lowest value of the deviation.

To ensure the inclusion of the subtrack in the pixel search span, the starting value n is normally, in the case of NOAA imagery, set equal to 2048, the number of pixels in the full scanned image frame.

Table C-1: Definition of general image and correction routine parameters.

N :	Number of ground control points
Lt_i :	Latitude of i th ground control point (GCP)
Ln_i :	Longitude of i th ground control point (GCP)
Lt_{ci} :	Calculated latitude of i th GCP for the current set of angular and orbital parameters
Ln_{ci} :	Calculated longitude of i th GCP for the current set of angular and orbital parameters
P_i :	Pixel of i th GCP
S_i :	Scanline of i th GCP
γ :	$\gamma_{512} - \gamma_1$ orbital angle
β :	$\beta_1 - \beta_{512}$ scanner angle
f_γ :	Adjustment factor for orbital angle (set to .01)
f_β :	Adjustment factor for scanner angle (set to .01)

Table C-2: Definition of parameters used to initiate calculations for individual images.

$L_{t_{max}}$:	Maximum GCP latitude on image
S_{max} :	Scanline of GCP associated with $L_{t_{max}}$
$L_{t_{min}}$:	Minimum GCP latitude on image
S_{min} :	Scanline GCP of GCP associated with $L_{t_{min}}$
$L_{n_{max}}$:	Maximum GCP longitude on image
P_{max} :	Pixel associated with $L_{n_{max}}$
$L_{n_{min}}$:	Minimum GCP longitude on image
P_{min} :	Pixel of GCP associated with $L_{n_{min}}$

