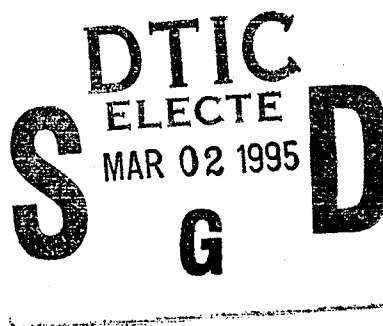


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Hi-Res SAR Data Processing Report

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January 1995



Contract No. N00014-94-C-0137

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13. ABSTRACT (Maximum 200 words) <p>This report summarizes the digital processing activities which have been carried out on the SAR data sets collected during the two ONR/NRL High Resolution field experiments held in September 1991 and June 1993. Features associated with the Gulf Stream boundary are observed in these data sets, with signatures that are dependent on the wind speed, radar frequency and polarization. Estimation of currents using the displacement of features observed on multiple passes appears to be possible.</p> <p>A simplified procedure for large-scale INSAR data processing has been developed and applied to one of the data sets collected in June 1993. Preliminary comparisons with OSCAR measurements indicate that similar features are observed in both data sets. A capability was also developed during this contract to plot image locations on a Transverse Mercator map using the navigation data and radar operating parameters recorded on the P3 engineering data disks.</p>					
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CONTENTS

LIST OF FIGURES iii

1.0 INTRODUCTION 1

2.0 PREVIOUSLY PROCESSED DATA 2

 2.1. 11 SEPTEMBER 1991 2

 2.2. 16 SEPTEMBER 1991 4

 2.3. 20 SEPTEMBER 1991 4

 2.4. 23 JUNE 1993 7

3.0 DATA PROCESSED DURING THIS CONTRACT PERIOD 8

 3.1. 16 SEPTEMBER 1991 8

 3.2. 23 JUNE 1993 11

4.0 CONCLUSIONS AND RECOMMENDATIONS 17

REFERENCES 18

APPENDIX 19

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LIST OF FIGURES

1.	Digitally processed L_{VV} and X_{VV} images for pass 15 collected on 11 September 1991	3
2.	Full-swath L_{VV} image for pass 15 collected on 16 September 1991	5
3.	Partial L_{HH} , C_{VV} , and X_{VV} images for pass 15 collected on 16 September 1991	6
4.	Full-swath L_{VV} image for pass 4 collected on 16 September 1991	9
5.	Full-swath L_{VV} image for pass 3 collected on 16 September 1991	10
6.	Ground track for pass 15 on 23 June 1993 superimposed on OSCAR current map	12
7.	Radial velocities estimated from pass 15 INSAR data and calculated from OSCAR data for 18:20 UTC	14
8.	Comparison of GPS and barometric altitudes for pass 15 on 23 June 1993	15

1.0 INTRODUCTION

A large number of SAR data sets were collected during the two ONR/NRL High Resolution field experiments held in September 1991 and June 1993. All of the L-band (VV polarization) data from the 1991 experiment were optically processed and a few scenes were digitally processed under previous ONR funding. Examination of this data led to the selection of several additional data sets for further processing and analysis. This report summarizes the digital processing activities which have been carried out at ERIM on this data.

In addition to the image processing activities which are described in the remainder of this report, a capability was developed during this contract to plot the image locations based on navigation and radar data recorded on the P3 engineering data disks. This program is described in an appendix to this report.

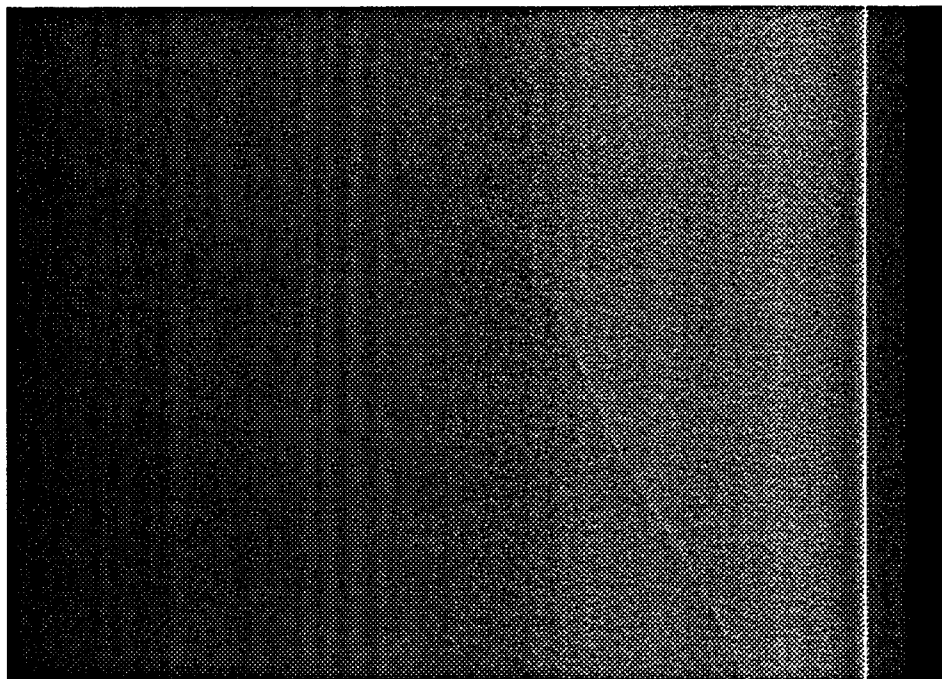
2.0 PREVIOUSLY PROCESSED DATA

Previous digital processing included parts of one pass from 11 September 1991, two passes from 16 September 1991, two passes from 20 September 1991, and one pass from 23 June 1993. These data sets and the reasons for their selection are described briefly in the following paragraphs.

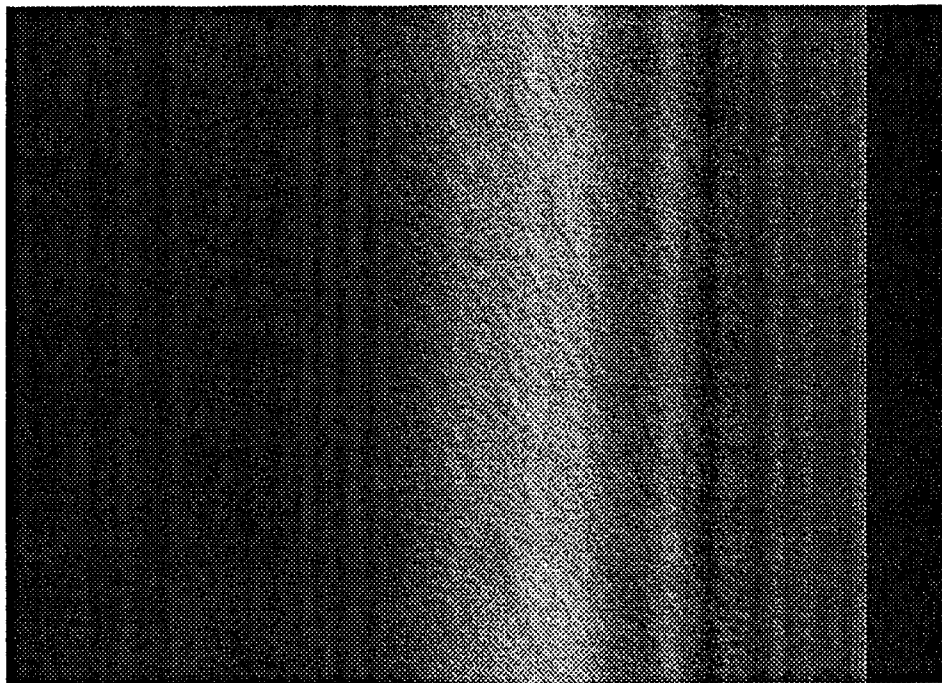
2.1. 11 SEPTEMBER 1991

This data was collected before the research vessels arrived at the test site. However, the Ocean Surface Current Radar (OSCR) operated by the University of Miami during the experiment had begun operations and the first current map collected at 1900 UTC showed a strong current front in the test area. The L-band optically processed image for pass 15, which was collected from 1901 to 1905 UTC, appears to contain a manifestation of this current boundary. The L_{VV} and X_{VV} channels for a section of this pass were digitally processed in anticipation of making a more detailed comparison between these data sets. These two images are shown in Figure 1. The current boundary can be seen clearly in the L-band image but is mostly obscured by other, possibly wind-related features in the X-band image. Further analysis of this data set is recommended, in order to understand this wavelength dependence and its possible relationship to the environmental conditions at the time of the data collection.

9/11/91 Pass 15 1503 EDT



L-band VV-pol



X-band VV-pol

----> Range (North)

Figure 1. Digitally processed L_{VV} and X_{VV} images for pass 15 collected on 11 September 1991.

Image dimensions are 9830 meters in slant range by 6636 meters in azimuth.

2.2. 16 SEPTEMBER 1991

One segment from pass 4 and two segments from pass 15 on 9/16/91 were previously processed. The segment from pass 4 was chosen to include the image of the USNS Bartlett, which was collecting oceanographic measurements at the time of the overpass under the direction of Dr. George Marmorino of the Naval Research Laboratory. The image was sent to Dr. Marmorino, who expressed interest in obtaining a larger section of the image. This was accomplished under the new funding and is described in section 3.1, below.

The two segments from pass 15 included one segment containing the Bartlett and another containing a Y-shaped surface feature which was also imaged by the NRL real-aperture radar. The real-time RAR image was used to direct the Bartlett to the position of the Y-feature, where it made oceanographic measurements about an hour later. The full-swath L_{VV} image is shown in Figure 2, and subsets of the other bands containing the Y-feature are shown in Figure 3. An interesting aspect of this data set is that the contrast of the Y-feature increases with radar frequency, and is also larger for the L_{HH} than the L_{VV} image. Comparisons of these images with *in situ* measurements and with the NRL RAR data are in progress and a joint paper describing these comparisons is in preparation.

2.3. 20 SEPTEMBER 1991

Data was collected on this day in the along-track interferometric (INSAR) mode. Two passes were processed in order to estimate ocean currents and wave spectra. A current map was made using the entire 26 km length of the pass 3 data set. This map indicated the presence of a very sharp current gradient at approximately 35.25°N and 75.10°W. Unfortunately, this location was outside the range of the OSCAR so a direct comparison between the INSAR and OSCAR currents is not possible for this feature. However, the location of the observed current gradient

9/16/91 1515 EDT Pass 15
L-band VV-polarization

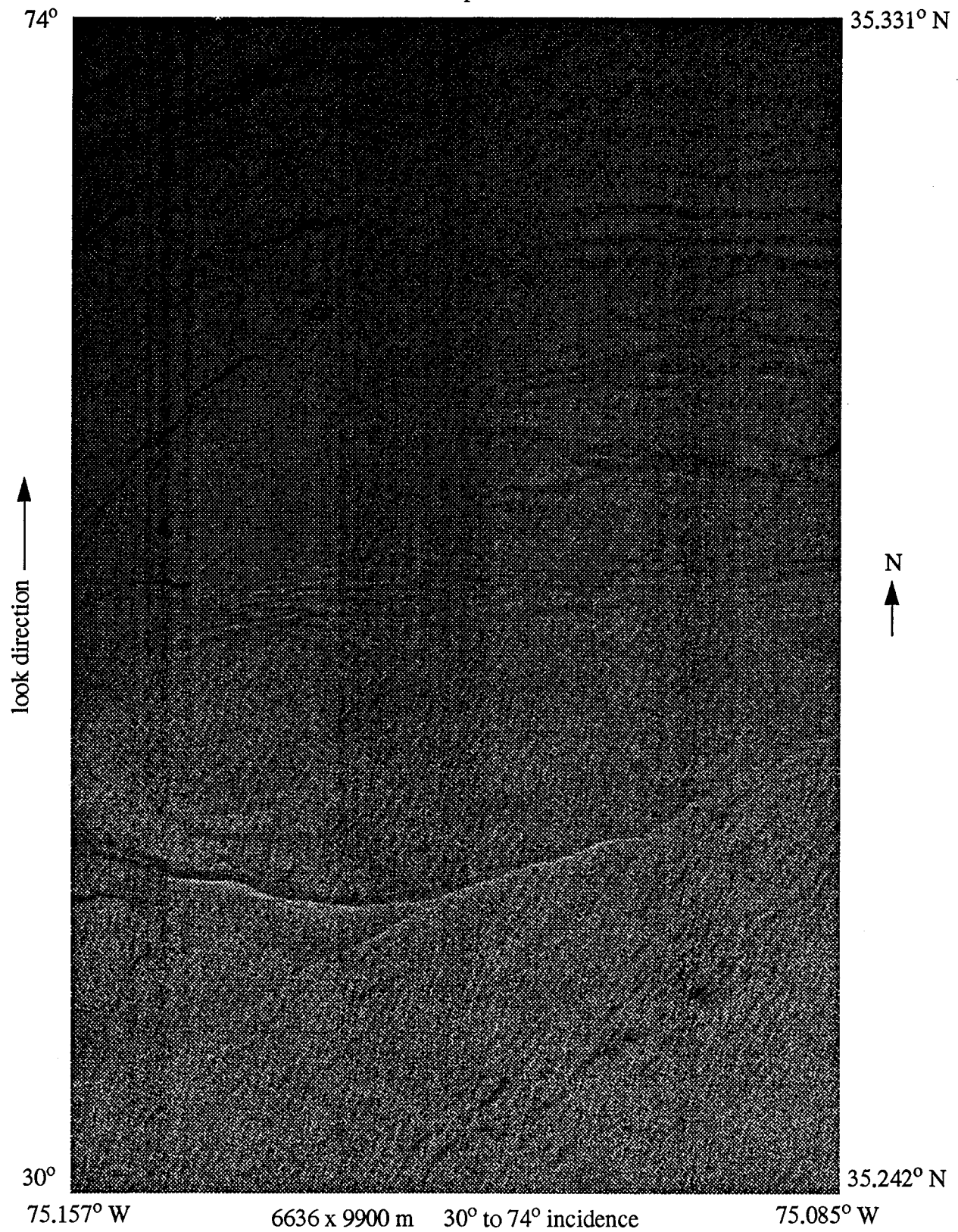
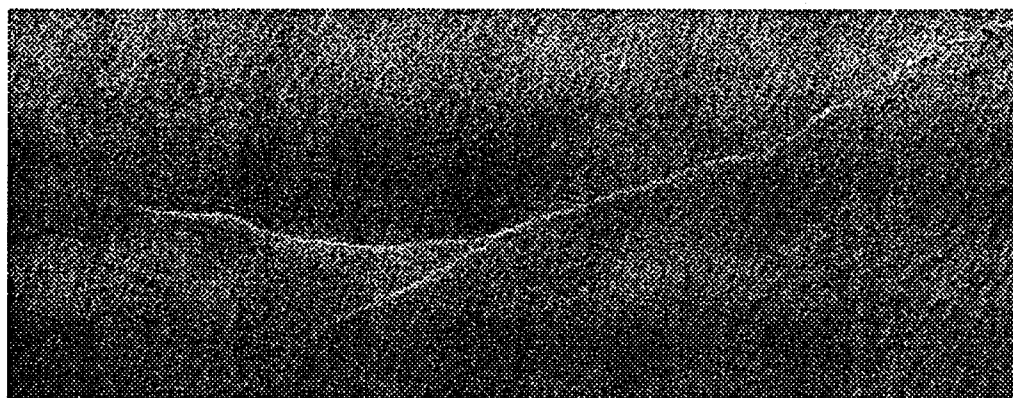
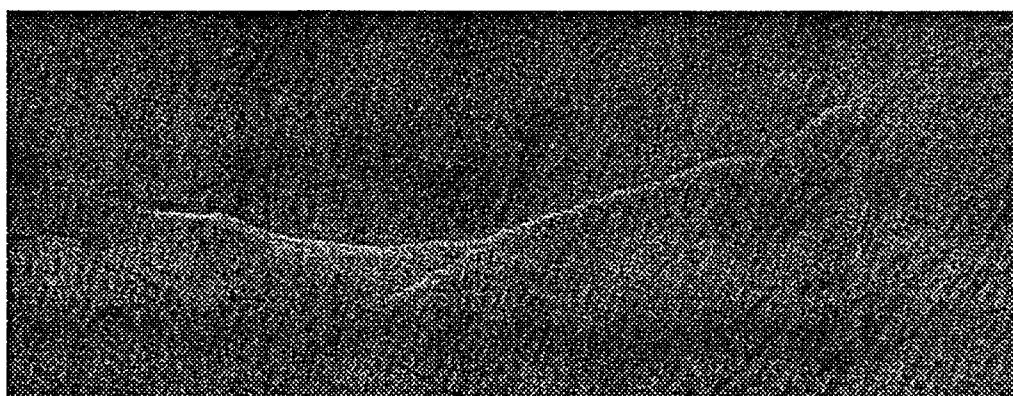


Figure 2. Full-swath L_{VV} image for pass 15 collected on 16 September 1991.

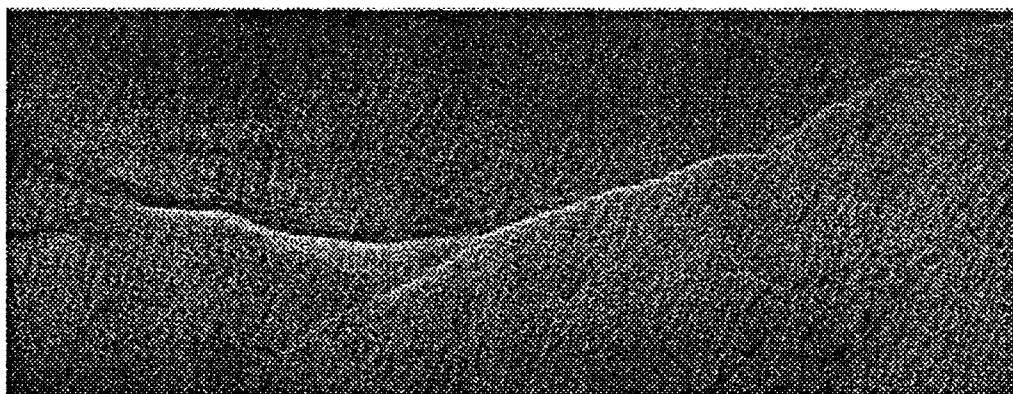
9/16/91 1515 EDT Pass 15



X-band VV-polarization



C-band VV-polarization



L-band HH-polarization



75.157 °W to 75.085 °W, 35.255 °N to 35.278 °N
6636 x 2495 m 45° to 60° incidence

Figure 3. Partial L_{HH} , C_{VV} , and X_{VV} images for pass 15 collected on 16 September 1991.

is consistent with observations of the Gulf Stream boundary made by the Bartlett at the time of the overflight.

A wave system with a dominant wavelength of approximately 80 meters was also observed, propagating in the range direction for pass 3 and the azimuth direction during pass 5. Measurements of the azimuth falloff effect were made for this data set, and these measurements were found to confirm an earlier theoretical prediction regarding the modification of this effect in interferometric SAR systems. More discussion of the data processing and analysis for both of these passes is given in references 1-3.

2.4. 23 JUNE 1993

Preliminary processing of an INSAR data set collected during the 1993 Hi-Res experiment was begun prior to the start of the present contract. This processing was completed, and some initial comparisons of the results with OSCAR measurements were made during the present contract period. Discussion of this data set is presented in section 3.2 below.

3.0 DATA PROCESSED DURING THIS CONTRACT PERIOD

Digital processing activities during the present contract period included two passes from 16 September 1991 and two passes from 23 June 1993. Processing of these data sets is described in the following paragraphs. In addition to this processing, phase histories for four other passes from the 16 September collection were copied onto 8 mm tapes and sent to NRL for processing.

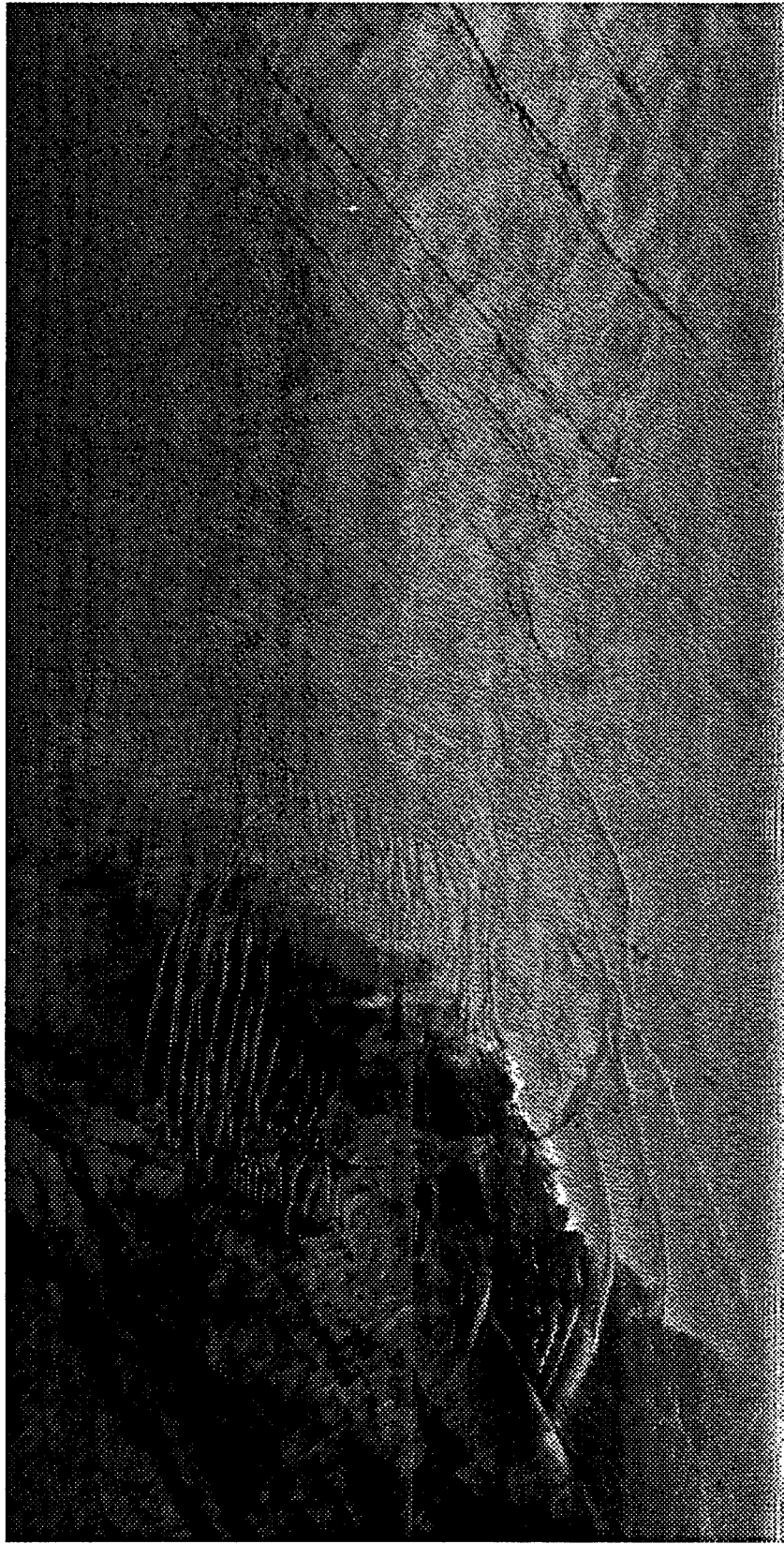
3.1. 16 SEPTEMBER 1991

A 26.5 km segment of the L_{VV} data from pass 4 was processed using the Unix version of the ERIM SAR processor. The first half of this segment was also processed using the other three bands (L_{HH} , C_{VV} , and X_{VV}). The L_{VV} image was downsampled (contracted) and ground-corrected, resulting in a pixel size of 6.48x6.48 meters. A further-reduced version of this image was supplied to George Marmorino, and is shown in Figure 4. Among the interesting features in this image are a wind front that extends diagonally from the lower left corner, a large number of dark streaks running diagonally on the right side, and several bright linear features on the left side of the image. The USNS Bartlett is on the right side of the image at approximately mid-swath. The other ship to the southwest of the Bartlett is the R/V Oceanus, which also was taking part in the experiment.

Many of these features also appear in the pass 3 image, which was collected about 20 minutes earlier on an almost identical ground track. A 19.9 km segment of this image was processed and ground-corrected for comparison with the pass 4 image, and is shown in Figure 5. This segment was selected, using the GPS navigation data, to coincide with the left edge of the pass 4 image. Comparison of these images indicates that (1) the wind front has advanced 1-2 km to the northwest, (2) the dark streaks on the right side of the images have moved by varying amounts to the

9/16/91 16:49:23 - 16:52:00 UTC Pass 4

L-band VV-pol



35.2330 °N
75.1765 °W

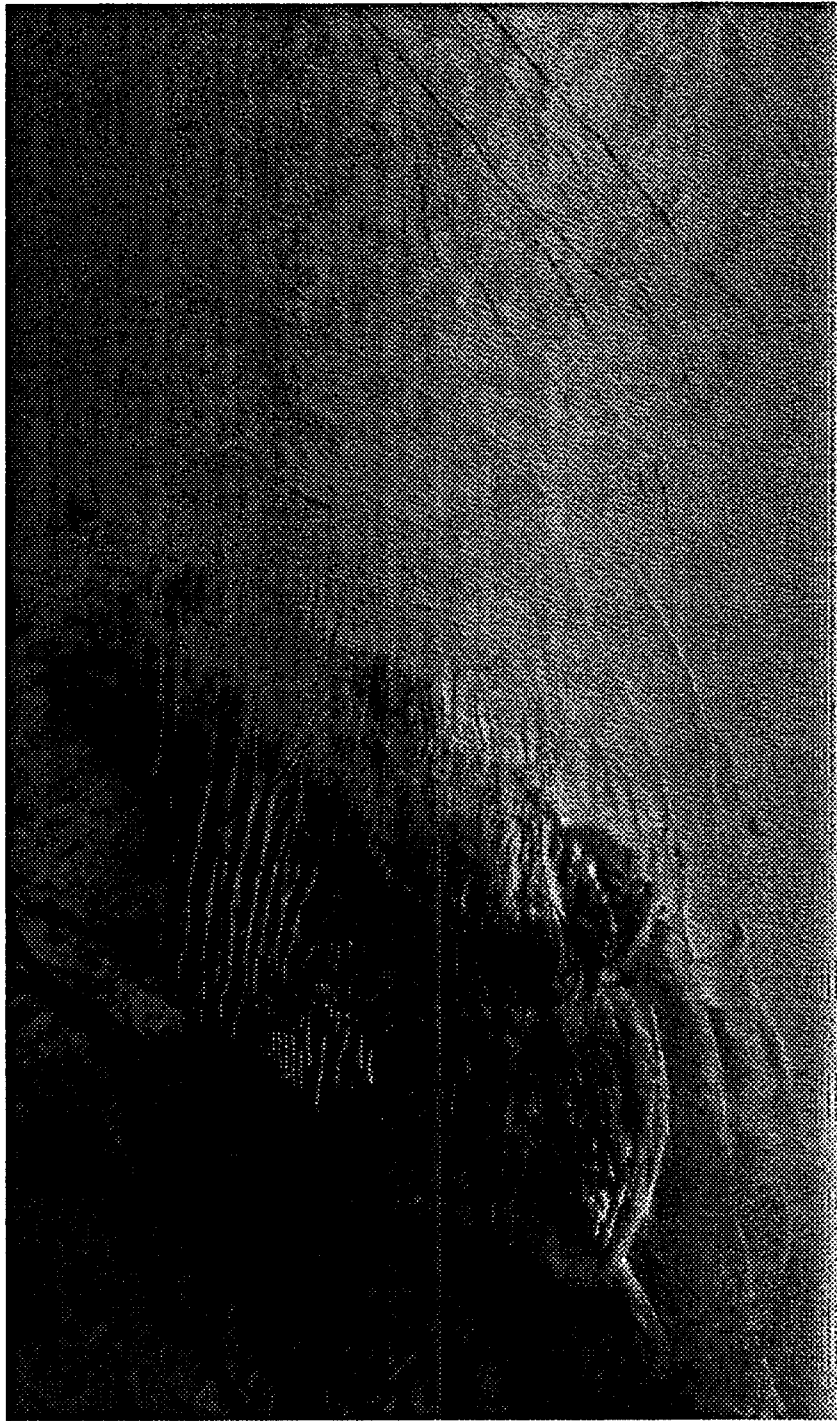
35.2338 °N
74.9335 °W

5 km

Figure 4. Full-swath L_{VV} image for pass 4 collected on 16 September 1991.

9/16/91 16:27:46 - 16:30:05 UTC Pass 3

L-band VV-pol



35.2338 °N
75.1765 °W

35.2338 °N
74.9665 °W



Figure 5. Full-swath L_{VV} image for pass 3 collected on 16 September 1991.

northeast, and (3) the bright linear features on the left side of the images are nearly unchanged.

The motion of the dark streaks is clearly observable because of their distinctive shapes, which can be recognized on both images. A rough calculation based on the displacement of features near the Bartlett yields a velocity of about 1.6 m/s, which is consistent with ADCP measurements aboard the Bartlett. A more careful and systematic analysis of these motions is recommended, using a cross correlation of the images.

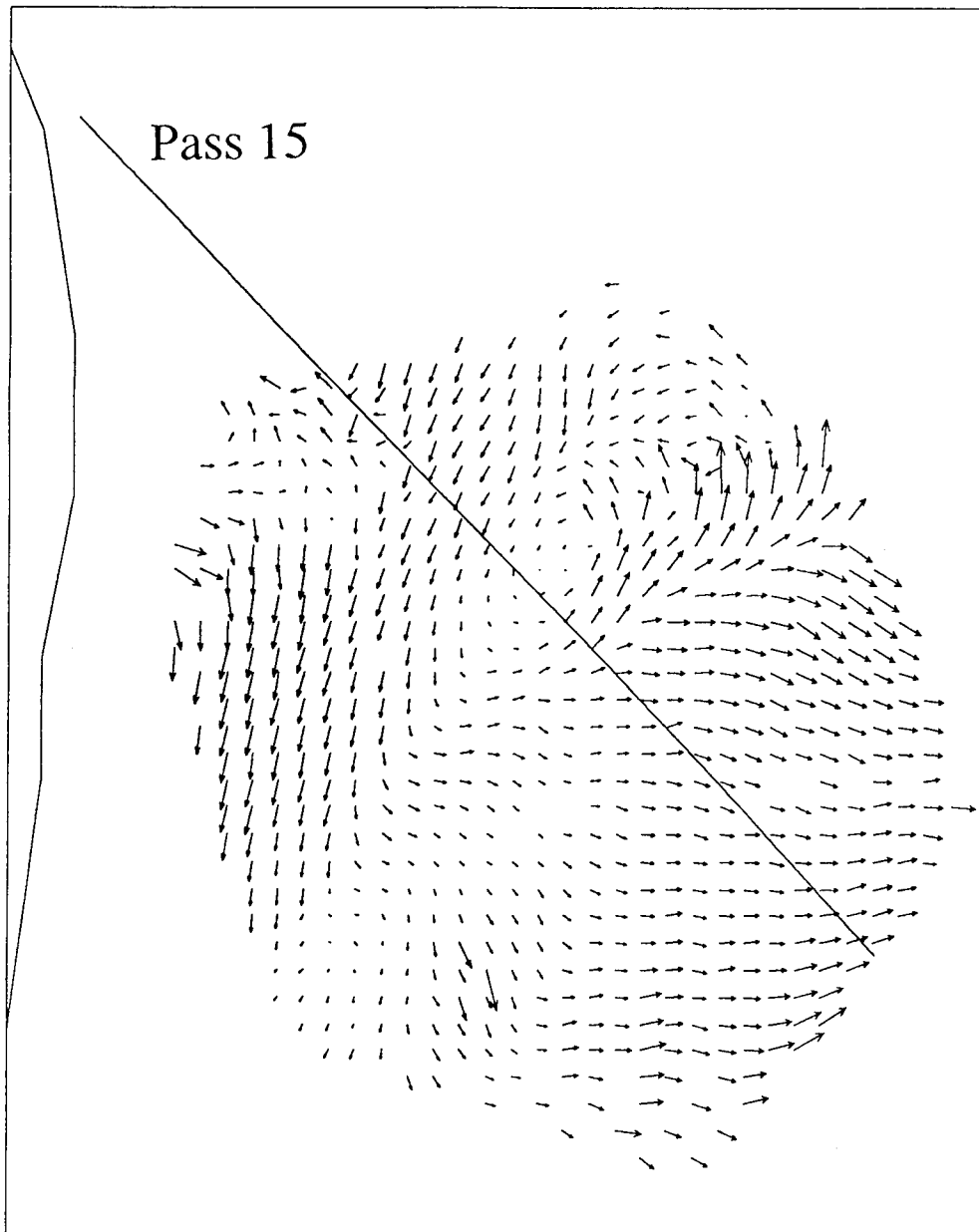
The fact that the bright linear features on the left side of the images are nearly stationary suggests that these may be related to the bottom topography in this area. Some of the features may be southward propagating internal waves whose phase velocity is equal to the current speed. There is also at least one internal wave packet propagating to the northeast, near the center of both images.

3.2. 23 JUNE 1993

Because of the extremely large volume of INSAR data required for comparison with the OSCAR measurements, a simplified processing method was implemented and tested using this data set. First, the phase history data for roughly the last half of pass 15 (covering the time interval from 18:15:51 to 18:24:27 UTC) was copied onto 8 mm tapes. This 516-second segment, consisting of approximately 8.5 Gbytes of phase history data, was chosen to overlap with the OSCAR region. The ground track for this segment is shown superimposed upon the OSCAR current map for 18:20 UTC in Figure 6.

The first step in processing this data was to compress the phase history signals from both antennas by a factor of 50 in azimuth using a simple pre-summing operation. This results in an unfocused resolution and sample spacing both equal to about 6 meters in the along-track direction. The interferogram was then computed by

June 23, 1993
18:20 OSCR Currents



pass 15 18:16 - 18:24 UTC

Figure 6. Ground Track for Pass 15 on 23 June 1993 Superimposed on OSCR

forming the conjugate product of the two images, and this interferogram was further averaged by a factor of 50 in azimuth and 256 in range, resulting in a sample spacing of approximately 300 meters in both dimensions. This averaging also makes the normal range compression operation unnecessary, as was confirmed by comparing results with and without range compression.

The phase of the interferogram was then extracted and converted into an estimate of the radial velocity for each sample using the equation

$$V_z = \frac{\lambda V}{4\pi D} \phi$$

where $\lambda = 0.032$ m, $V = 118$ m/s, and $D = 0.71$ m. These velocities are plotted in Figure 7 versus latitude (obtained from the GPS navigation data) along with the corresponding values obtained by linear interpolation of the OSCAR measurements.

The dominant feature in the current field appears to be a narrow jet which is observed in both the OSCAR and INSAR data, although at slightly different locations. There is an overall difference on the order of 50 cm/s between the two data sets which is not considered to be meaningful since no attempt was made to obtain the absolute phase of the interferogram. However there is also some evidence of a slight drift in the INSAR estimate. This may be related to a difference between the GPS and barometric measurements of the platform altitude, as shown in Figure 8. Further examination of the navigation data and more detailed comparisons with OSCAR measurements are recommended, in collaboration with the University of Miami investigators responsible for the collection of the OSCAR data.

The pass 15 data was collected at X-band with VV-polarization. The same track was repeated (pass 17) about 80 minutes later with HH-polarization. The phase history data for this pass was copied onto 8 mm tapes in anticipation of processing to compare with the VV-polarization data. However, we were not able to complete the

INSAR vs OSCR currents

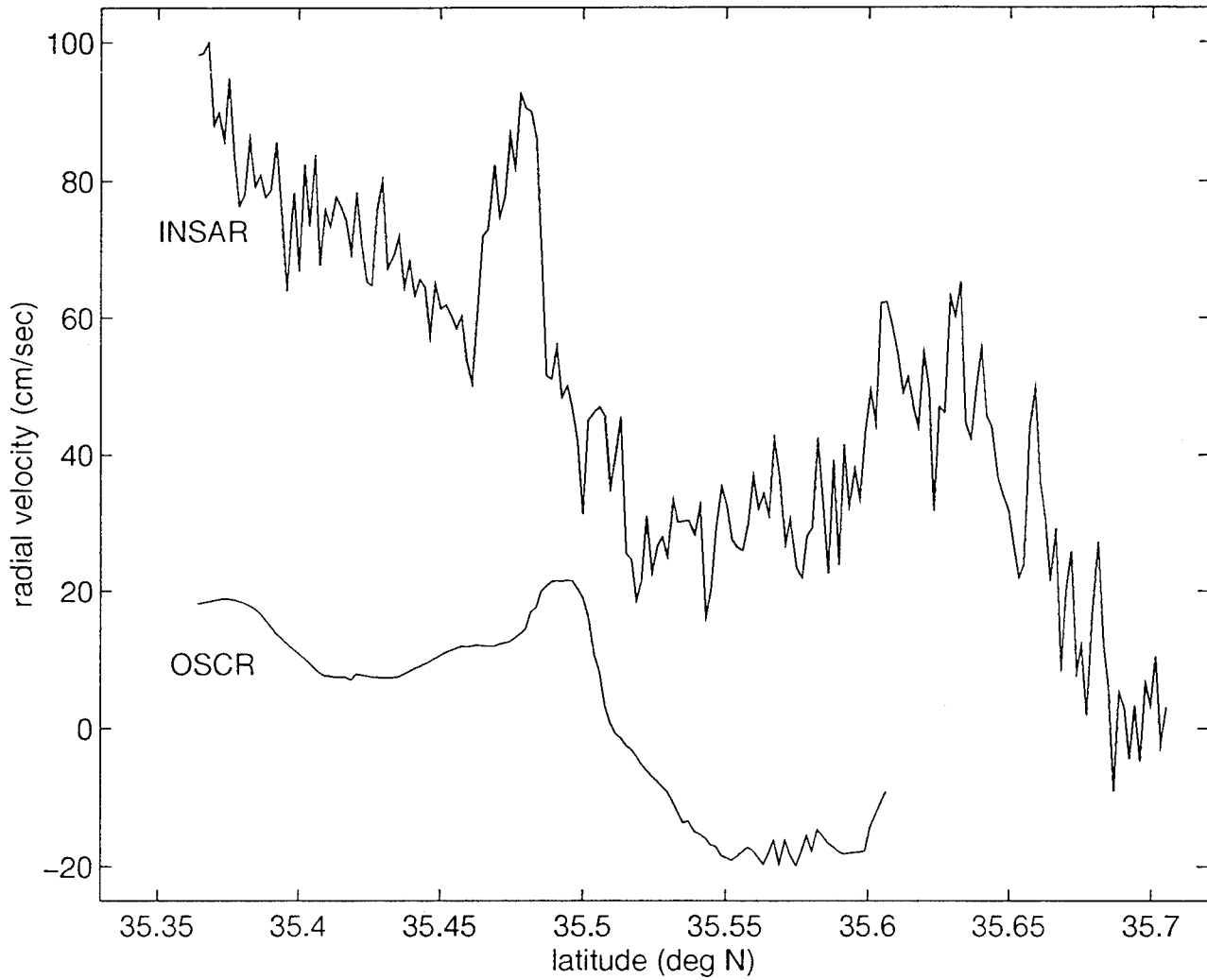


Figure 7. Radial Velocities Estimated From Pass 15 INSAR Data and Calculated From OSCR Data for 18:20 UTC.

6/23/93 pass 15

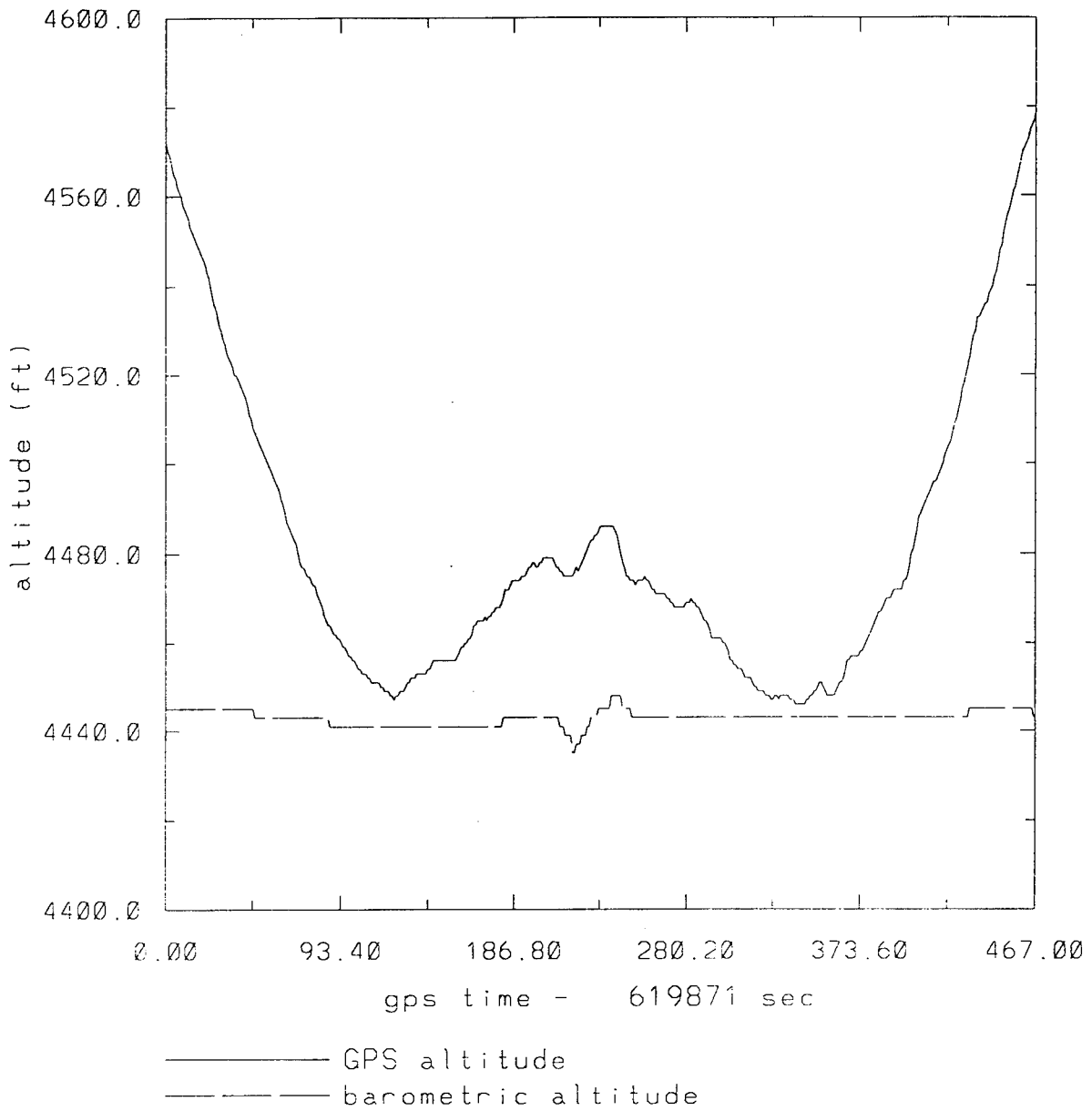


Figure 8. Comparison on GPS and Barometric Altitudes for Pass 15 on 23 June 1993.

processing of this data under the present funds. An INSAR data set was also collected simultaneously with an ERS-1 overpass on June 17, 1993. Further processing of both of these data sets is recommended.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Features associated with the Gulf Stream boundary have been observed in several digitally processed SAR data sets, including pass 15 collected on 9/11/91 and passes 3, 4 and 15 collected on 9/16/91. Further analysis of these data sets is recommended, with respect to the wind speed, radar frequency and polarization dependence of the signatures. Estimation of currents using the displacement of features observed on the pass 3 and pass 4 images would also be of interest.

A simplified procedure for large-scale INSAR data processing has been developed and applied to one of the data sets collected in June 1993. Preliminary comparisons with OSCAR measurements indicate that similar features are observed in both data sets, but a more detailed evaluation is called for. Processing of two other data sets and further comparisons with *in situ* measurements and ERS-1 images are also recommended.

REFERENCES

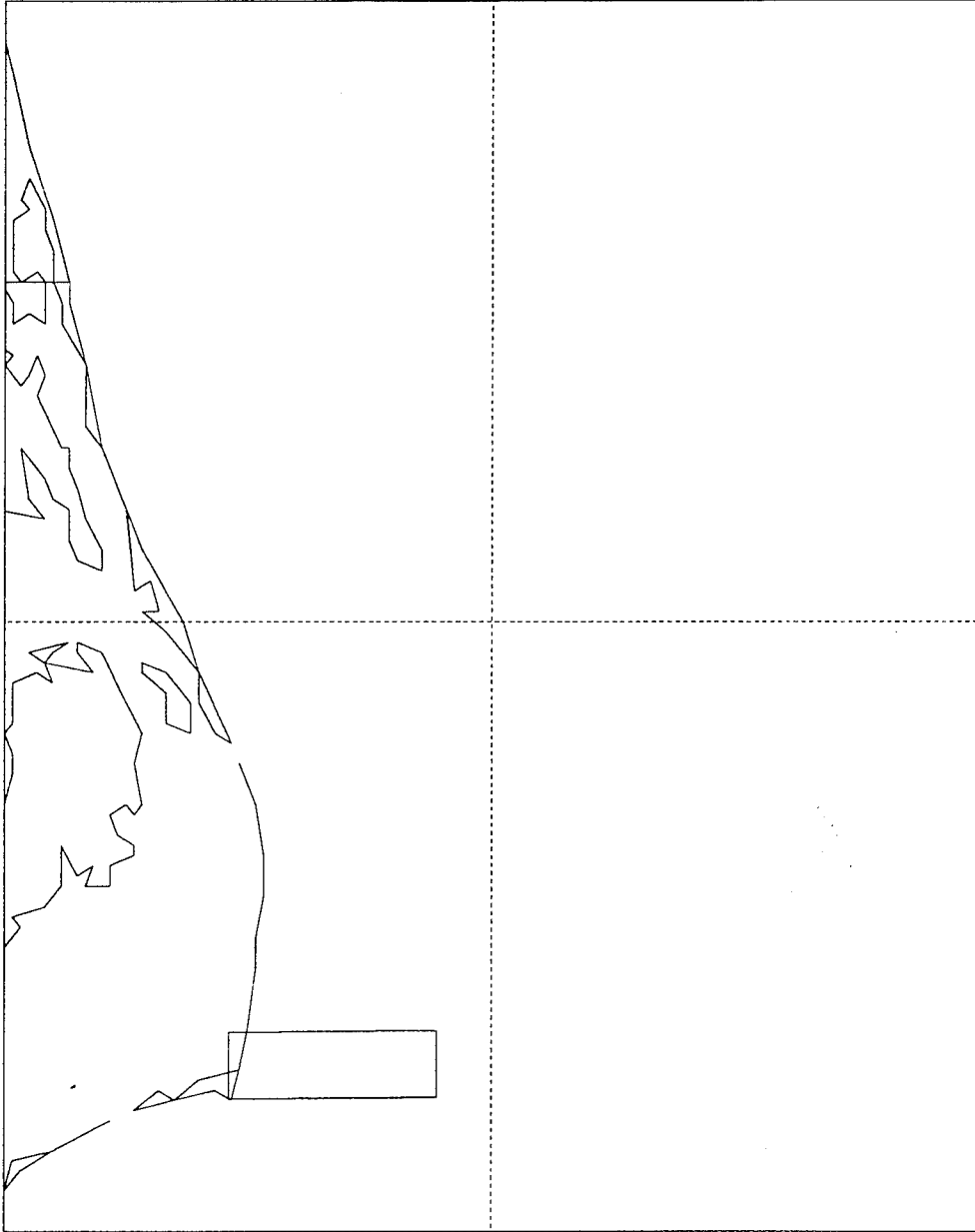
1. R. Shuchman, A. O Chadlick, P. Cho, W. Dunlevy, J. Lyden, D. Lyzenga, and C. Wackerman, "Interferometric SAR Measurements Collected During the High Resolution Ocean Experiment," *Proceedings of the IGARSS '92 Conference*, Arlington, Texas, May 1992, pp. 458-459.
2. D. Lyzenga and N. Malinas, "Airborne Radar Measurements of Coastal Ocean Currents and Waves," *Second Thematic Conference on Remote Sensing for Marine and Coastal Environments*, New Orleans, LA, February 1994, vol. I, pp. 379-388.
3. D. Lyzenga and N. Malinas, "Azimuth Falloff Effects in Two-Antenna SAR Measurements of Ocean Wave Spectra," submitted to *IEEE Trans. Geoscience and Remote Sensing*, December 1994.

APPENDIX

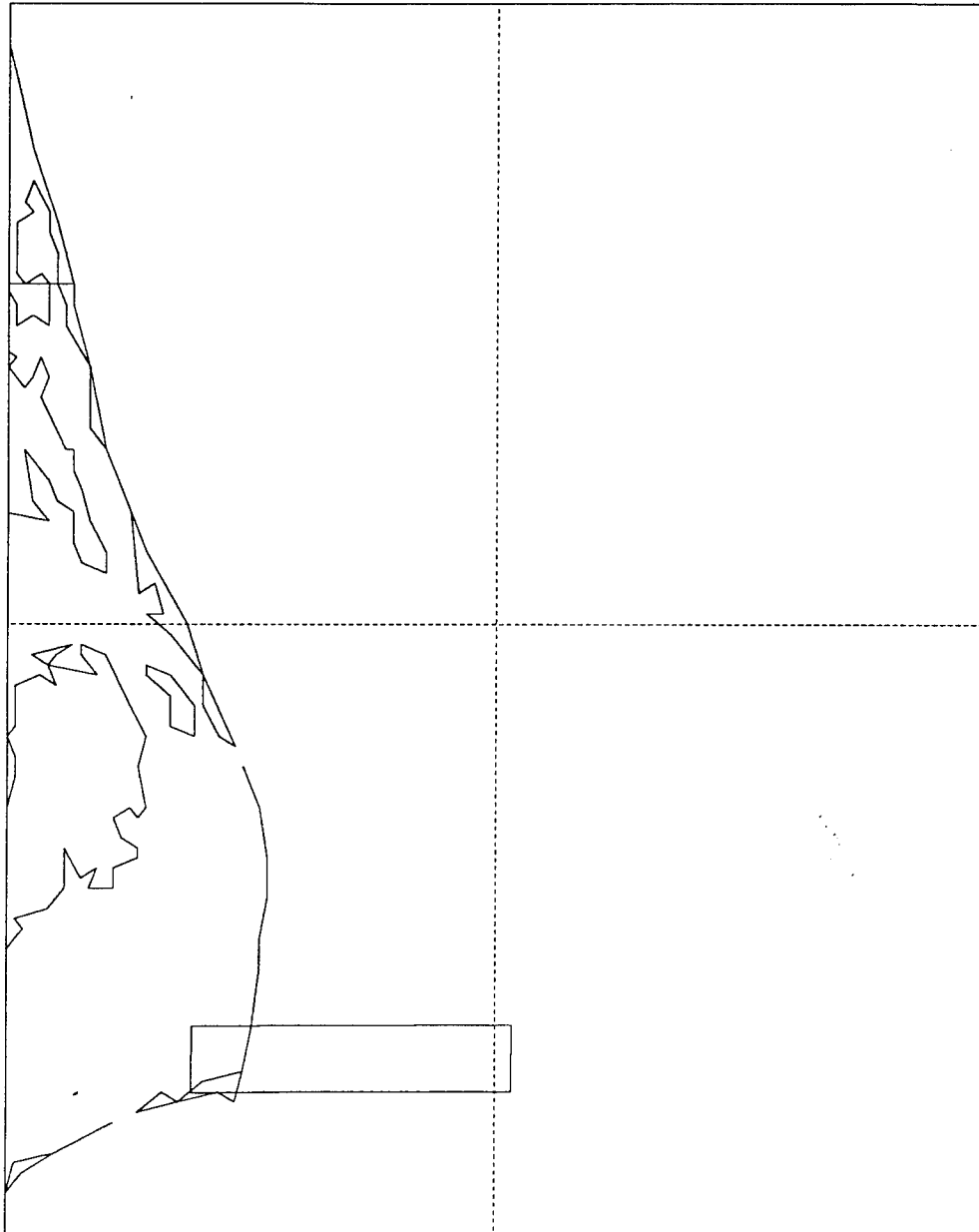
IMAGE LOCATION PLOTTING PROGRAM

Engineering data is recorded on 3.5 inch diskettes during each P3 SAR pass and is normally printed out in the form of post-line data sheets after each mission. Included in these files are the radar operating parameters and aircraft navigation data. A program was written to read this data and plot the approximate locations of the images on a Mercator projection map. The program uses the continental outline data base within the NCAR Graphics package to plot nearby shorelines. The GPS latitudes and longitudes are first plotted to indicate the ground track of the SAR platform. Then, using the altitude, minimum range, swath width, and look direction parameters at the endpoints of the pass, the locations of the four corner points of the image are computed relative to the ground track. These distances are converted into latitudes and longitudes assuming a spherical earth with a radius of 6378.16 km and plotted on the map. Example plots are shown below for pass 15 on 9/11/91 and passes 3, 4, and 15 on 9/16/91.

9/11/91 - pass 15



9/16/91 - pass 3



9/16/91 - pass 4



9/16/91 - pass 15

