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HF Radar Measurements of Circulation in the Eastern Strait of Juan De Fuca near Protection Island (July, 1979)

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HF RADAR MEASUREMENTS OF CIRCULATION IN THE EASTERN STRAIT OF JUAN DE FUCA NEAR PROTECTION ISLAND (JULY, 1979)

By

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Completion Report Submitted to
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ENVIRONMENTAL RESEARCH LABORATORIES

by

WAVE PROPAGATION LABORATORY
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This work is the result of research sponsored by the Environmental Protection Agency and administered by the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration.

FOREWORD

An understanding of the surface circulation in a partially- or fully-enclosed marine environment is necessary in order to forecast the effects of an oil spill, pipeline oil leak, or other varieties of floating pollutants. The Wave Propagation Laboratory's program of surface current mapping contributes to this understanding.

In this report we present HF radar observation measurements in the Eastern Strait of Juan de Fuca for a five day period. The hourly measurements give surface currents at 1.2 km intervals. We have estimated the mean surface flow and the semi- and diurnal-components of tidal currents. The current maps demonstrate the extreme complexity of the surface circulation and represent an important advance in understanding the physical oceanography of this complicated, ecologically-sensitive region.

Donald E. Barrick
Chief, Sea State Studies
Wave Propagation Laboratory

ABSTRACT

During July, 1979, the surface currents in the Eastern Strait of Juan de Fuca were mapped with a High Frequency (HF) radar system (CODAR). These currents were measured simultaneously over several hundred square kilometers continuously for five days. The strong tidal currents and estuarine flow dominated the circulation during most of this period of time, while the relatively weak winds seemed to play a minor role. In addition, the effects of the highly variable bathymetry were much more pronounced this year than last year. This may be due to the fact that during August, 1978, the winds were much stronger and, therefore, could have smeared any surface feature introduced by the bathymetry. Whereas, this year, the winds were much less of a factor, so that the horizontal shear zones and areas of convergence and divergence were much more pronounced. Some surface drifters were deployed and tracked by boat in order to study smaller spatial scales (less than a kilometer) in the current field. Although this drifter study was only partially successful, it did demonstrate that large current changes (possibly exceeding a knot) did occur in distances of less than a kilometer. Identical drifters, initially placed within a couple hundred meters of one another, did rapidly spread apart, some to vanish forever.

CONTENTS

Foreword iii

Abstract iv

Acknowledgments vi

1. Introduction 1

2. Conclusions 3

3. Recommendations 4

4. Text 5

Appendix 34

ACKNOWLEDGMENTS

The authors would like to acknowledge the indispensable support of the following people without whom this study would not have been possible. We thank Don Barrick for his leadership and direction before and during the experiment. The operation and maintenance of the radar was largely due to Mike Evans, Dan Law, Alan Carr, Karl Sutterfield, John Forberg, and Bob Weber. These same people designed, built, and operated the radar system that will permit oceanographers to view the sea through new "eyes".

INTRODUCTION

During the summer of 1979, the Sea State Studies group* remotely measured the surface currents in the Eastern Strait of Juan de Fuca using a High Frequency (HF) Doppler radar system (CODAR)**. In the summer of 1978, similar measurements were taken at an adjacent location in a joint oceanographic experiment (Frisch and Holbrook, 1980) that lasted for almost a week. This time, the radar was operated continuously for more than five days in order to study the circulation in the neighborhood of Protection Island (Figure 1), where the proposed oil pipeline would lie. The radar sites at Dungeness Spit and Fort Ebey were selected to provide the optimal coverage area along the proposed pipeline, and they also provided excellent coverage further out in the strait where the measurements were made in the previous year. Comparisons of the data from these two different experiments are of interest, therefore, because the surface winds were much weaker in 1979 than they were in 1978. As a result, the tides and estuarine flow were much more important than the winds in controlling the surface circulation during the latter experiment.

The radar mapped the surface currents simultaneously at several hundred locations across the strait, continuously for more than five days. Thus, both the Eulerian and Lagrangian pictures of the circulation are available at the same time. In this report, we present both Eulerian current vector maps and Lagrangian drift tracks in order to better illustrate the intricate flow in this important region.

During part of the experiment, we also deployed and tracked surface drifters with a boat using mini-Ranger navigation for positioning. The purpose of these drifters studies was twofold. First, we wanted to examine the currents on horizontal scales smaller than the one kilometer resolution of the radar. Second, we attempted to measure the vertical current

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** CODAR is a High Frequency (HF) Doppler radar system developed by NOAA (Barrick et al., 1977).

near the surface due to winds (which turned out to be weak most of the time). We discovered that the currents are so highly variable in both space and time that this form of drifter tracking by boat was impractical, and often impossible. Presently, we are developing drifter transponder systems that will permit us to remotely track drifters from shore in much the same way that we now measure currents with CODAR.

CONCLUSIONS

The results presented here illustrate a circulation pattern around Protection Island and Admiralty Inlet that can change dramatically in as little time as one hour and in as little space as one kilometer. The area studied appeared to split naturally into two regions that exhibited much different current velocities. Over most of the strait, the velocities exceeded 50 cm/s (200 cm/s in Admiralty Inlet) when the tidal currents were strongest, and the estuarine flow itself was almost one knot everywhere. This region we shall identify as the stronger-flow region. A weaker-flow region existed in the area roughly bounded by Dungeness Spit, Protection Island, and Sequim (Figure 1). Here the currents were typically less than 50 cm/s and the estuarine flow was just a few centimeters per second.

Another difference between these two different flow regions was their tendencies to circulate water mass in opposite directions. In the stronger-flow region, the net flow was westerly due to the estuarine influence. However, in the weaker-flow region, the tendency was for an easterly flow. As the tides flooded the strait, strong currents would bring water around Dungeness Spit, sweeping east past Protection Island and into Admiralty Inlet. But, as the tides ebbed, water would be trapped in the pocket north of Sequim as the stronger currents farther out in the strait carried water westward. One might almost guess this behavior based upon the bathymetry alone.

The proposed pipeline would cut across the weaker and stronger flow regions at a place where some of the strongest horizontal current shears can exist. In addition, there appears to be a region of tremendous convergence and divergence just off the point near Fort Ebey. The flow converges at this location from two directions: from the south out of Admiralty Inlet and from the north along the coast of Whidbey Island. Conversely, the flow diverges here when the currents are reversed.

Considering the enormous amount of insight we have gained in both this experiment and that in the previous year, the CODAR system seems ideally suited for studies such as this in an area which is so ecologically and economically important.

RECOMMENDATIONS

This report presents examples of the circulation in the Eastern Strait of Juan de Fuca as remotely measured by CODAR. Comparisons of these measurements with surface-drifter observations show very good agreement. These results indicate that this radar system may be very useful as either an operational tool or a research instrument. It can be used to compute the trajectories that oil may follow in a future tanker spill or pipeline leak. This capability is especially helpful in assessing the hypothetical impact upon the environment and ecology. It could also be of assistance in directing clean-up operations after an oil spill or in designing adequate safeguards in anticipation of future problems. The research potential of CODAR is also far-reaching. CODAR can be used to measure the currents caused by various physical forces such as winds, tides, run-off, etc. Our understanding of the circulation in a particular area is thus improved and our ability to manage the resources in that area are thereby enhanced.

It is recommended that the on-going development of CODAR be directed towards improving its accuracy and reliability (which already meet or exceed those of other instruments such as surface drifters) in order to better accomplish these tasks. This radar system offers remote measurements of current simultaneously over large areas and continuously over many days at relatively low operating costs. Using existing data sets, the projected goals for next year are to obtain: (1) a surface current velocity with standard deviation of 5 cm/s or better, and (2) a surface trajectory position accuracy of 1 km after 24 hours. While CODAR offers many advantages over existing, more conventional instruments, it cannot always be substituted for them. In particular, moored current meters measure the subsurface currents at depths that are not probed by the radar. Both tools provide a powerful combination in cases where the vertical structure of circulation is important and needs to be studied. Surface drifters can be invaluable for examining frontal zones and shear boundaries where fine spatial resolution (hundreds of meters) is important. Several drifters closely spaced may extract features more precisely than the radar. Towards this end we are presently developing a radar transponder package that can be deployed in inexpensive and expendable drifter packages. Thus, a variation of the CODAR system will provide economical drifter tracking capability with improved reliability.

RADAR OPERATION

During July, 1979, two CODAR units were deployed at the Eastern Strait of Juan de Fuca in order to remotely measure surface currents.* One unit operated continuously from Dungeness Spit and the other unit operated continuously from Whidbey Island at Fort Ebey (Figure 1). The data were collected beginning at 0130 Pacific Daylight Time (PDT) on 5 July until 1200 on 10 July. Data were collected at either three-hour intervals or one-hour intervals depending upon the immediate needs of the experiment. The three-hour samples were taken to provide an accurate picture of the strongest tidal components, while the one-hour samples were selected for those times when intense drifter studies and diffusion studies were being conducted. Each data sample represents a 36-minute sea echo record that provides a velocity resolution of better than 1 cm/s, even though the current measurements over a 36-minute period may not be meaningful to better than 5 cm/s. The radar measures the phase velocity of a six-meter ocean wave which is shifted by currents that are present. This phase velocity is also affected by dynamic wave action, limiting the accuracy of the radar-measured currents to a few centimeters per second.

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*All of the data presented in this report are provided on magnetic tape. These are 9-track, ANSI compatible magnetic tapes written at 1600 CPI with phase encoding on a Digital Equipment Corporation PDP-11 computer using RSx11M software. Each map is contained in a separate file with a header that explains the contents of that file.

ESTUARINE CIRCULATION AND TIDES

The mean current and the tidal components at periods of 24.61 hours and 12.3 hours were computed from the entire five and one half days of data using a least-squares method. The mean current (Figure 2) gives a very good picture of the estuarine flow across the strait. The blank area in the middle of the map lies along the baseline drawn between the two radar sites. The total current vectors in this area cannot be measured directly because both radar units measure the same component of velocity. The velocity component perpendicular to this baseline is not measured by the radar, but it can be derived from the data with the appropriate analysis. Further studies with this data will, in the future, include the currents across this baseline area.

In Figure 2, we can clearly see the strong and weak flow regions. At most locations the velocity exceeds 25 cm/s. But, in the pocket southeast of Dungeness Spit and west of Protection Island, the current is barely detectable. This is understandable because there is no large source of fresh water runoff in this region. The currents are also seen to converge off of Fort Ebey, where they combine from the north and south to produce a strong jet going to the northwest. Therefore, it is imperative to study currents in this important area in order to understand the complete circulation pattern blanked by the radar baseline. In future studies, we will examine this area in detail after the baseline problem is removed.

The 12.3-hour tidal ellipses are given in Figure 3 and the 24.61-hour tidal ellipses are given in Figure 4. Again, the region along the baseline is not visible and the ellipses near it are more greatly in error. These figures also show that the weak flow region exhibits relatively weak tides. The strongest tidally-induced currents appear near the convergence zone off Fort Ebey where Admiralty Inlet empties into the strait. The jet-like feature going from Admiralty Inlet to the northwest out into the strait is evident in Figure 4 as in Figure 2. Also, while the 12.3-hour tides are stronger than the 24.61-hour tides in the south (i.e., south of the baseline), both tidal components are about the same strength farther out in the strait. Thus, the shorter-period tides dominate the flow in the vicinity of the proposed oil pipeline, where the longer-period tides and estuarine flow are relatively weak.

SELECTED CURRENT MAPS

A complete set of current maps is supplied at three-hour intervals in the appendix in Figures A1.00 - A1.42. A handful of these are reproduced here simply to illustrate the circulation pattern across the strait. For example, Figure 5 shows the flow at a time when the waters were emptying from the strait with near-maximum velocity. This pattern reproduced itself every morning of the experiment. The strongest currents existed in Admiralty Inlet and just north of Fort Ebey, while the weakest currents were in the area just west of Protection Island. The jet running from Admiralty Inlet to the northwest is evident and the convergence off Whidbey Island is very pronounced.

Figure 6 illustrates the currents sweeping down around Dungeness Spit and east past Protection Island, then on into Admiralty Inlet. The contrast in velocities between the strong-flow and weak-flow regions appeared to be less during flood tide than during ebb tide. This is mainly due to the much larger surface currents that existed in the strong-flow region at ebb tide. The behavior of the currents below the surface could not be measured, but these observations suggest a strong, vertical structure to the circulation.

Other interesting bathymetry-related features were revealed this year that were possibly obscured in 1978 by the high winds. Note, for example, the convergence zone north of the baseline in Figures 7 - 9. Certainly, these maps imply the presence of features on scales smaller than the one kilometer resolution of the radar. These are features that could hardly be discerned in the 1978 data, no doubt due to the smearing influence of winds. These features must be induced by the mountainous bathymetry that exists in the strait. Surface winds would tend to create currents that are not sensitive to bathymetry and thus would be expected to obscure such features.

A very interesting phenomenon is revealed in the sequence of Figures 10 - 12. A very strong convergence zone develops midway between the two radar sites in about three hours. It then dissipates in the next three hours. In looking only at Figure 11, the convergence of water from the north and south would seem to create a very unstable situation. The result (seen in Figure 12) is almost a complete 180 degree reversal in the current at some points. Consider Admiralty Inlet, for example. (It is indeed unfortunate that we were forced to place the radar baseline where it was for logistical reasons. Future studies with this data must include this very significant baseline region.)

We next examine the region around Protection Island in detail. The map sequence in Figures A2.00 - A2.42 in the appendix shows this area enlarged, at three-hour intervals throughout the experiment. In some ways, this is the most difficult region to analyze because of the island and the bathymetry which tends to isolate it from the rest of the strait. In Admiralty Inlet and around Whidbey Island the currents are strong so that mixing readily occurs with the rest of the strait. But in the weaker flow region examined here, the water may be trapped for days. Later, the drifter studies will be used to illustrate this point.

Figure 13 shows the strong easterly flow during flood tide, which usually exceeded the westerly flow at ebb tide by a large margin. This is to be contrasted with the situation in Admiralty Inlet and the rest of the strait where the opposite was normally the case. There the ebbing currents were much larger than those during flooding. Figure 14 shows one rare exception to this rule that occurred near the end of the experiment. Figure 15 gives an example of the flow which is more typical of the ebb tide. The area mapped here is so small that some features may not be resolved by the radar. However, the general circulation near Protection Island should be correctly depicted here.

DRIFTER STUDIES

The drifter studies were conducted in two parts, only one of which is directly pertinent to the present study. On 7 July, several drifters were deployed and tracked west of Protection Island. Four different drogue depths (i.e., 0.0, 0.5, 1.0 and 2.0 meters) were used and three of each drogue were initially spaced very close together. The intent was to detect and measure any horizontal or vertical current shears which could not be measured by the radar. Figures A3.00 - A3.12 in the appendix show the drifter positions and the radar-predicted trajectories for all cases. The agreement is well within the present capabilities of the radar; the radar capability is not yet at its theoretical limit. The strongest effect contributing to the dispersion of the drifters appeared to be the variability in the currents from one place to another spaced perhaps a kilometer apart. Since the winds were not that significant, we conclude that the bathymetry played a key role in establishing those current shears. In Figure 16, for example, we see the currents in this area at about mid-day when the drifters were being tracked. Near the drifter positions, the current changes by about 25 cm/s in 1 kilometer. In one hour, these drifters could double their separation if the currents were constant. Needless to say, when the flow changes rapidly in space and time the picture becomes exceedingly complex.

On that day (7 July), only four of the twelve drifters were recovered due to the rapidly changing currents. The 14-m, twin-engine vessel that was chartered for this work could not keep up with the drifters, even with a cruising speed of 8 m/s. The dispersion rate was so rapid and the tracks so unpredictable that the new positions of the drifters could not be estimated with enough accuracy for recovery. The only way to successfully track the drifters was to stand off at some convenient distance while maintaining constant visual contact. Later in the experiment, reserve drifters were deployed farther out in the strait where we hoped to have less trouble following them. This attempt was doomed even though we tried to maintain closer contact with the drifters. Those tests convinced us of the advantage of tracking drifters using transponders and a shore-based system similar to CODAR. The transponders were successfully tested during the experiment, and the radar system is presently under development to track them.

While we had only limited success in tracking real drifters, we did generate several simulated trajectories to see how some hypothetical floating objects might move. Figure 17 shows a two-day trajectory with an initial position west of Protection Island. In this weak flow region, the drifter appears to be slowly drifting to the east as we predicted earlier. The trajectory looks fairly good, except for a couple of cusps which look suspicious. These might be explained by the fact that the data sampling interval was three hours during the time of the track and the time interval between drifter positions was ten minutes. The trajectory is marked every thirty minutes. Also, the data were not filtered in time. Figure 18 gives the same track for the first of these two days, but using only the mean and tidal currents that were extracted from the data. The general shapes are similar and the cusp is still present. Since the tidal analysis amounts to a very good low-pass filter in time, we conclude that the cusp is a spatial feature and not due to sampling. Because the winds were not very strong, the difference in the tracks in Figures 17 and 18 may be due to our incomplete tidal analysis of the data. On the other hand, the currents here are weak so that perhaps even weak winds could make a difference. The answer to some of these questions must await further analysis.

Figure 19 shows a trajectory starting behind Protection Island and running for 24 hours. Figure 20 gives this same track but extended to 48 hours. The hypothetical drifter very clearly parallels the coast and stops short of land on several occasions. Note that this drifter gets trapped behind the island, and even drifts slowly to the west. Between this trajectory and that shown in Figure 17, we could guess that floating debris or oil might collect behind the island and in Discovery Bay. The next track in Figure 21 actually appears to be entering the bay. Unfortunately, with the present analysis techniques we could not pursue the drifter much further.

The collection of surface-borne objects near Protection Island is made believable when we recall that the westward currents dominate outside of this region but the eastward currents dominate inside the region. Figures 22 and 23 show the trajectories of two hypothetical drifters starting farther and farther to the east of the island. There still is a tendency for the drifter to become trapped, at least temporarily, in the area around Protection Island. The ragged appearance to all of these tracks is again due to the processing, and can be improved with forthcoming analysis techniques.

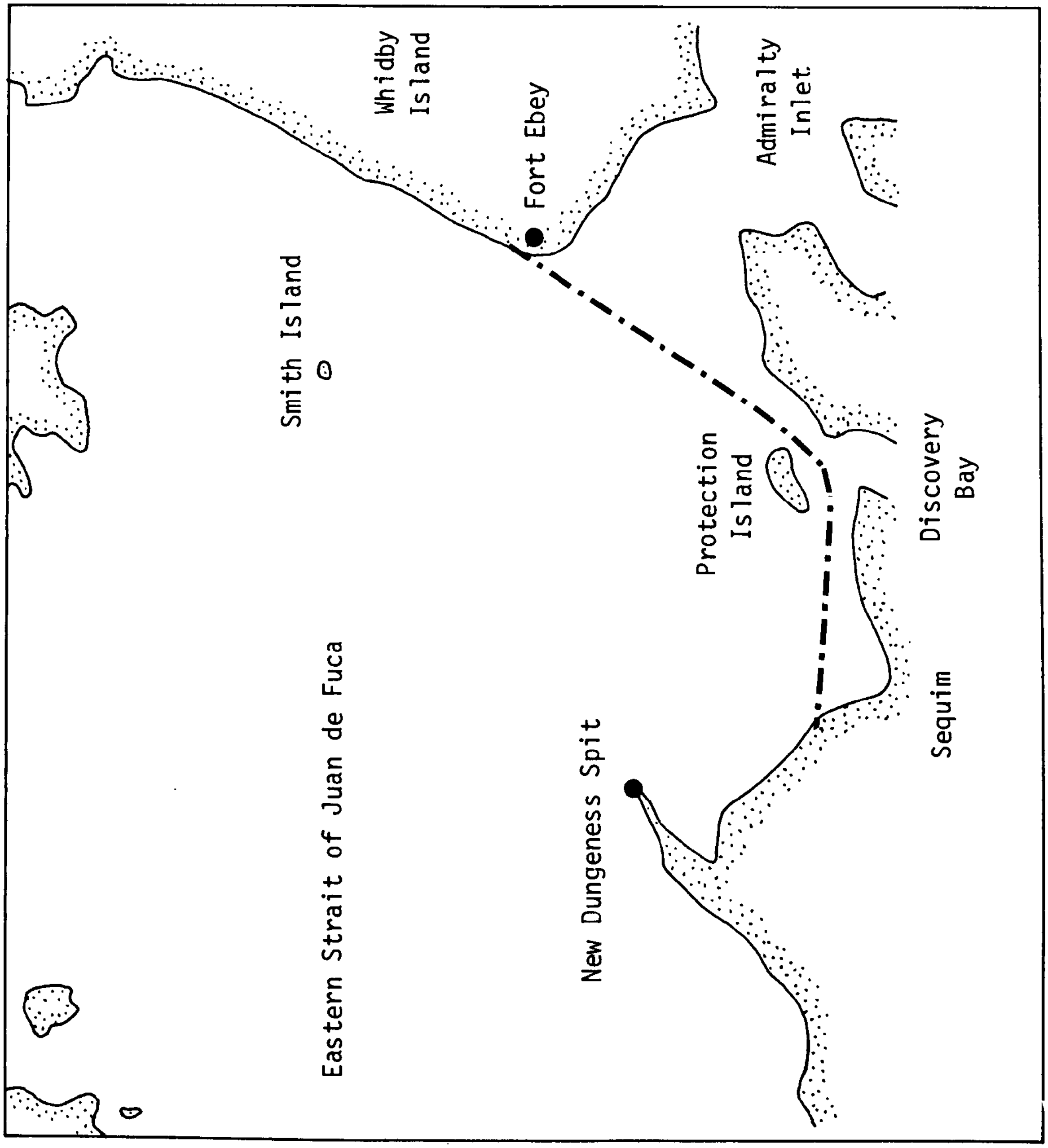


Figure 1. The two units of the CODAR system were located at Dungeness Spit and Fort Ebey on Whidbey Island. These sites were chosen to concentrate upon the area along the proposed pipeline which would run behind Protection Island. At the same time, measurements were made farther out in the strait so that the currents there can be compared with those made in 1978.

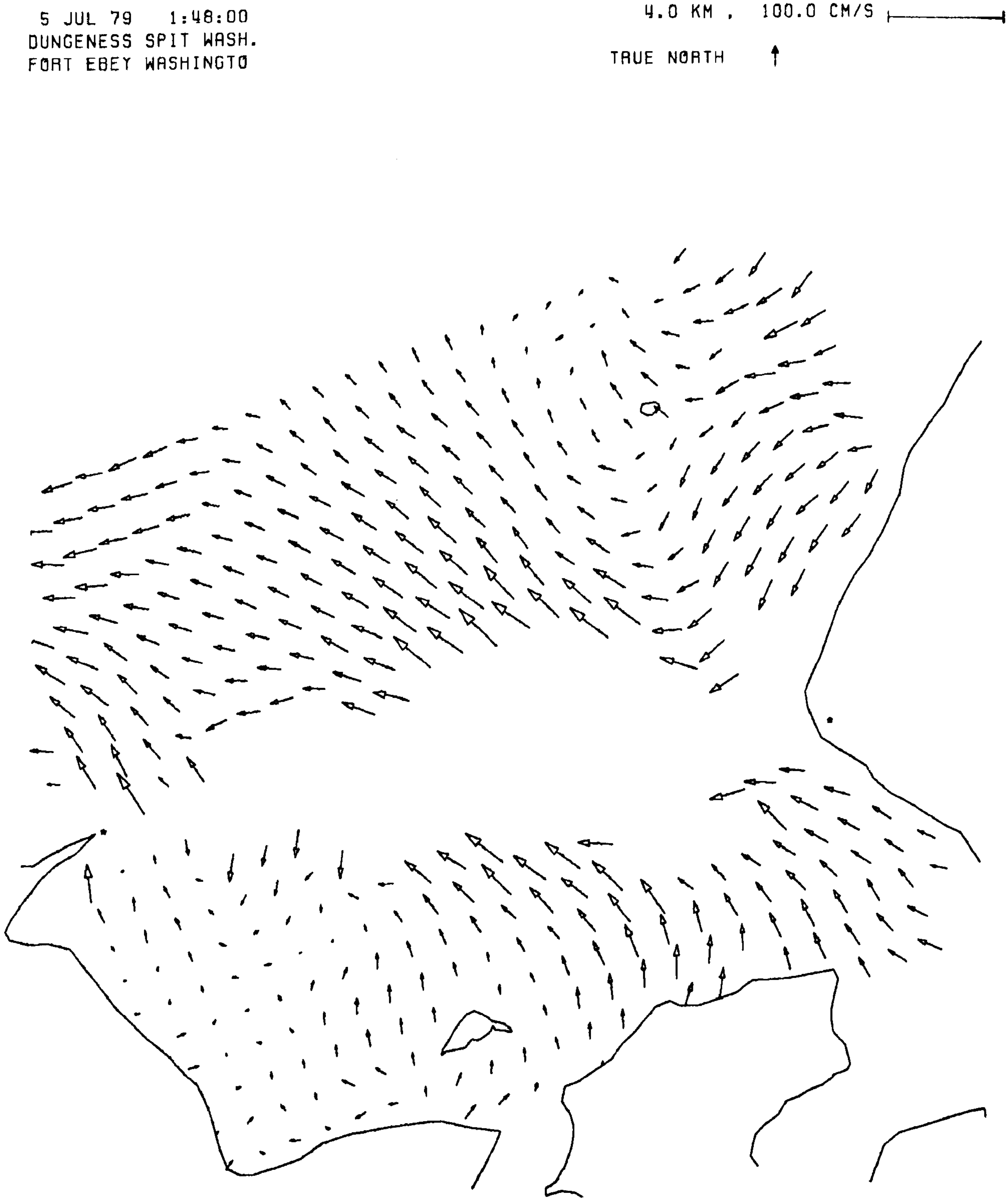


Figure 2. The estuarine flow is shown for the area around the proposed pipeline and for an area farther out in the strait for comparison with last year's data. The current velocities were computed from five and one half days of data by taking the mean value in a least-squares sense.

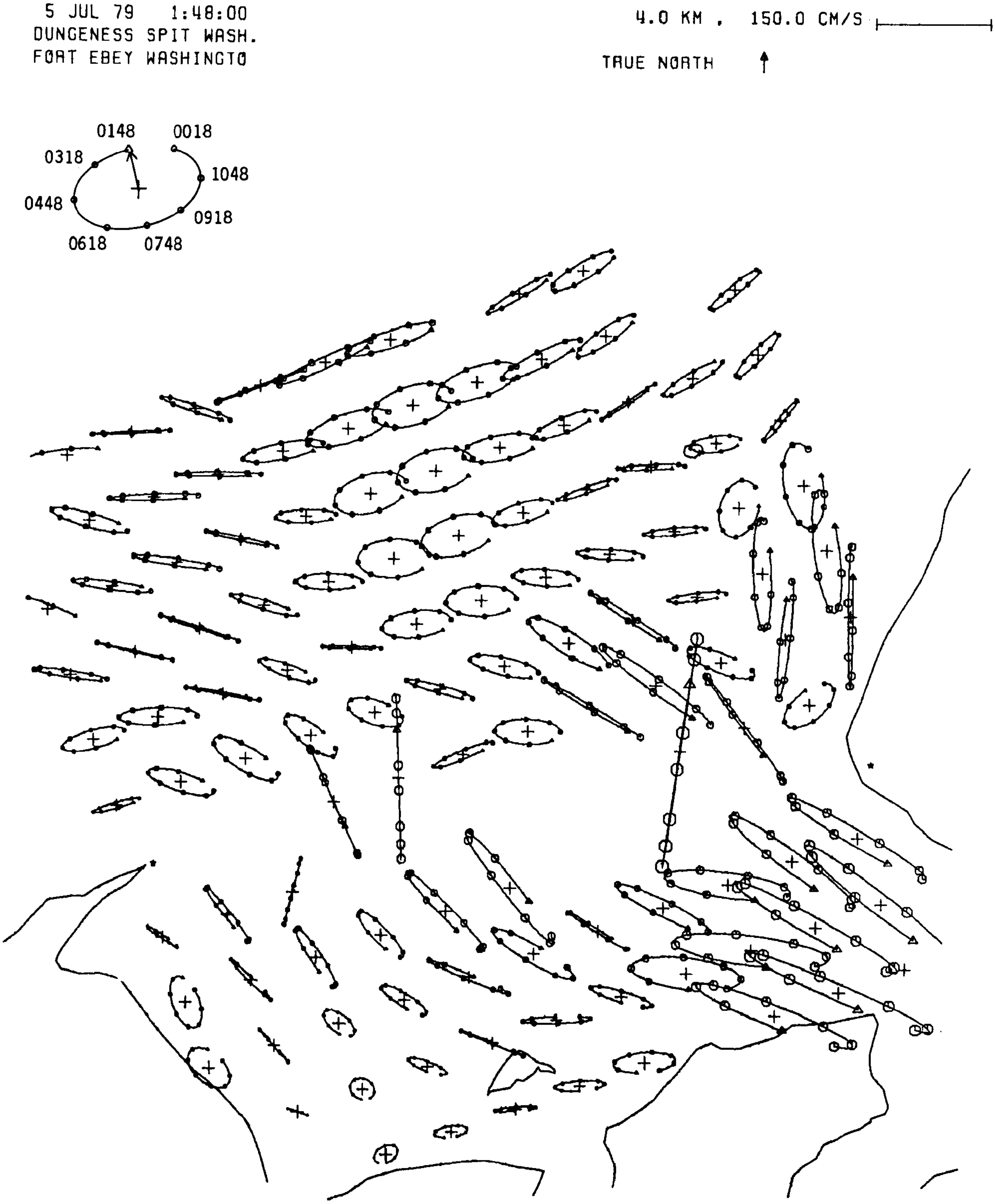


Figure 3. The 12.3-hour period tidal ellipses are shown for the area around the proposed pipeline and for an area farther out in the strait for comparison with last year's data. The tidal coefficients were computed from five and one half days of data by doing a least squares fit to the data.

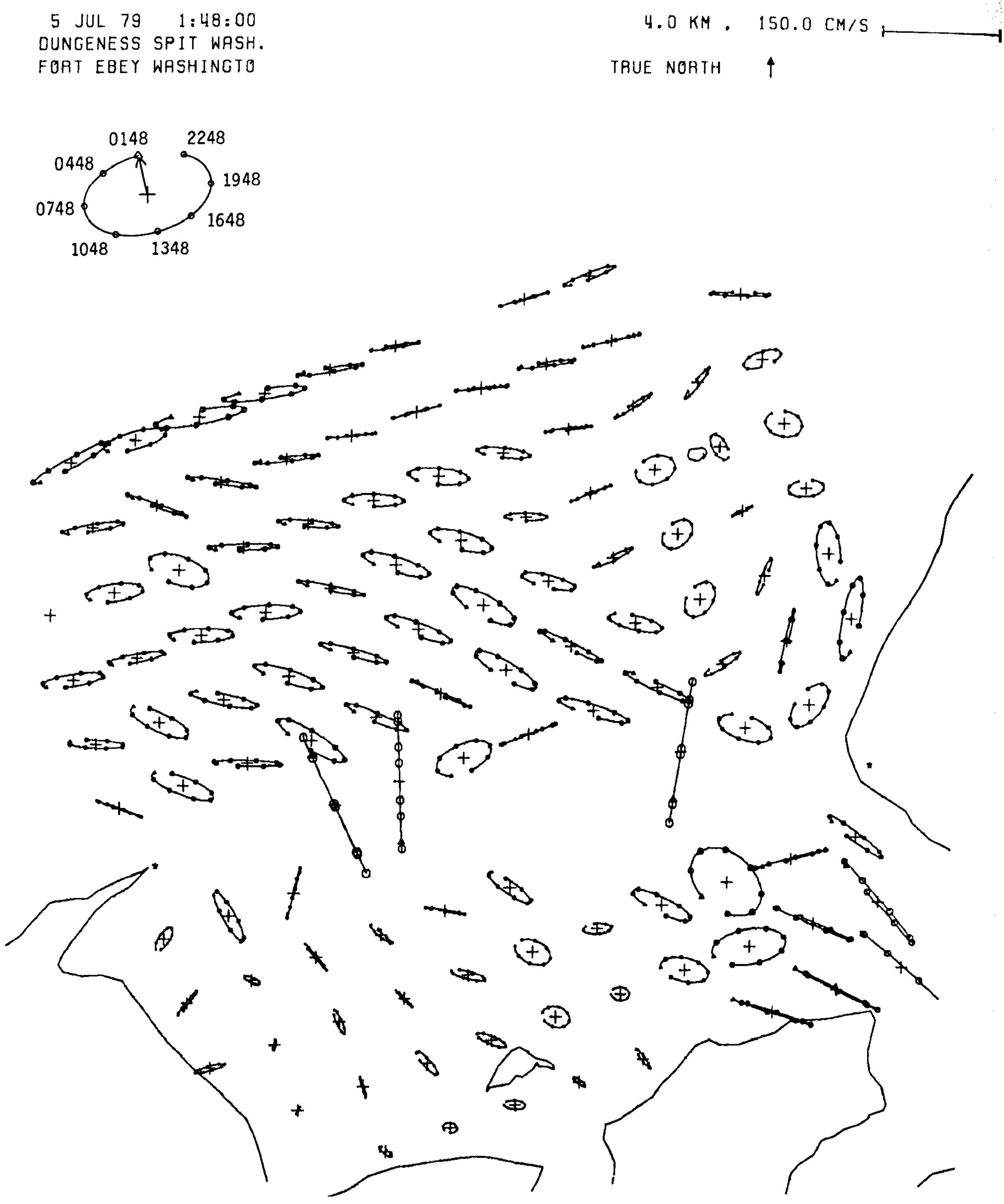


Figure 4. The 24.61-hour period tidal ellipses are shown for the area around the proposed pipeline and for an area farther out in the strait for comparison with last year's data. The tidal coefficients were computed from five and one half days of data by doing a least squares fit to the data.

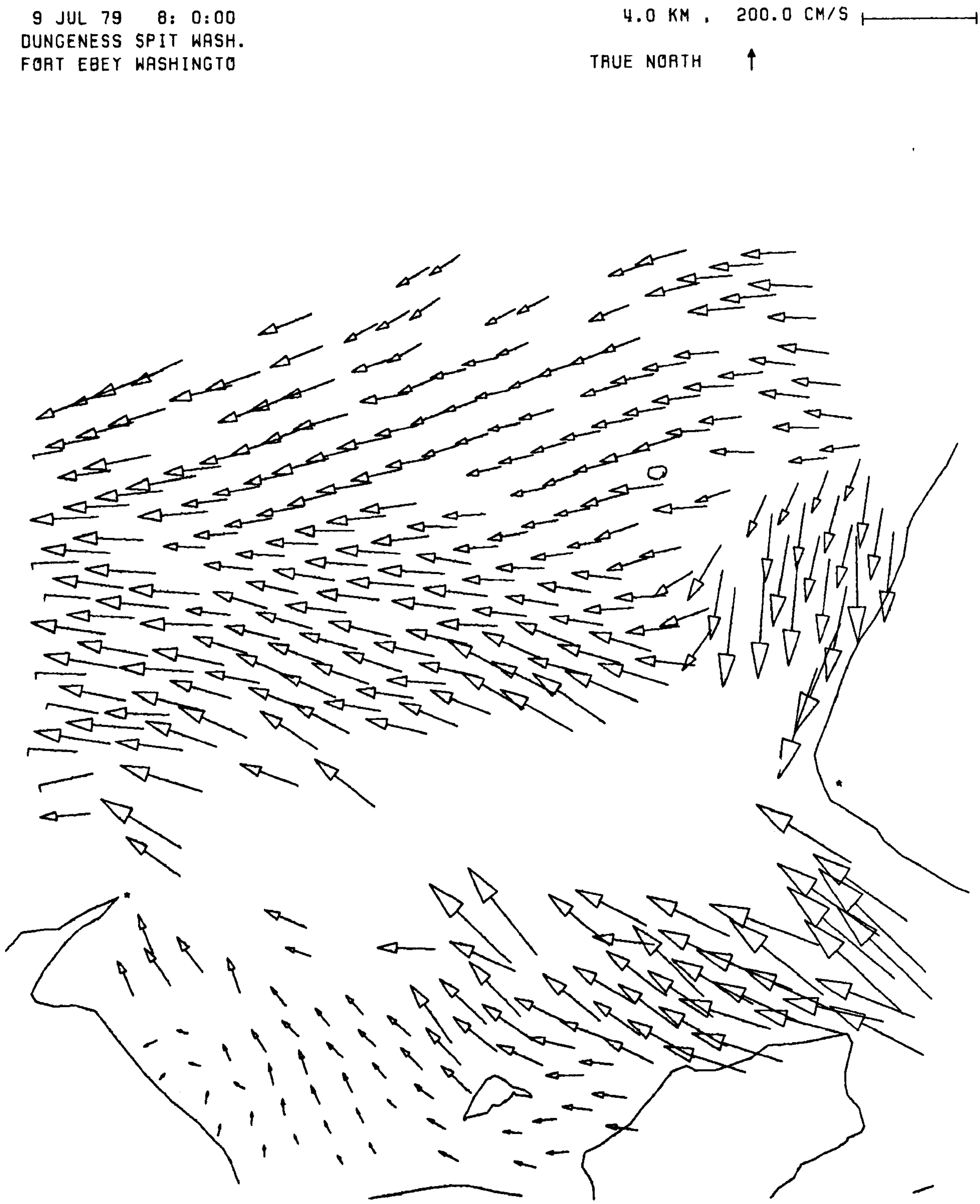


Figure 5. The current field at 0800 (PDT) on 9 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

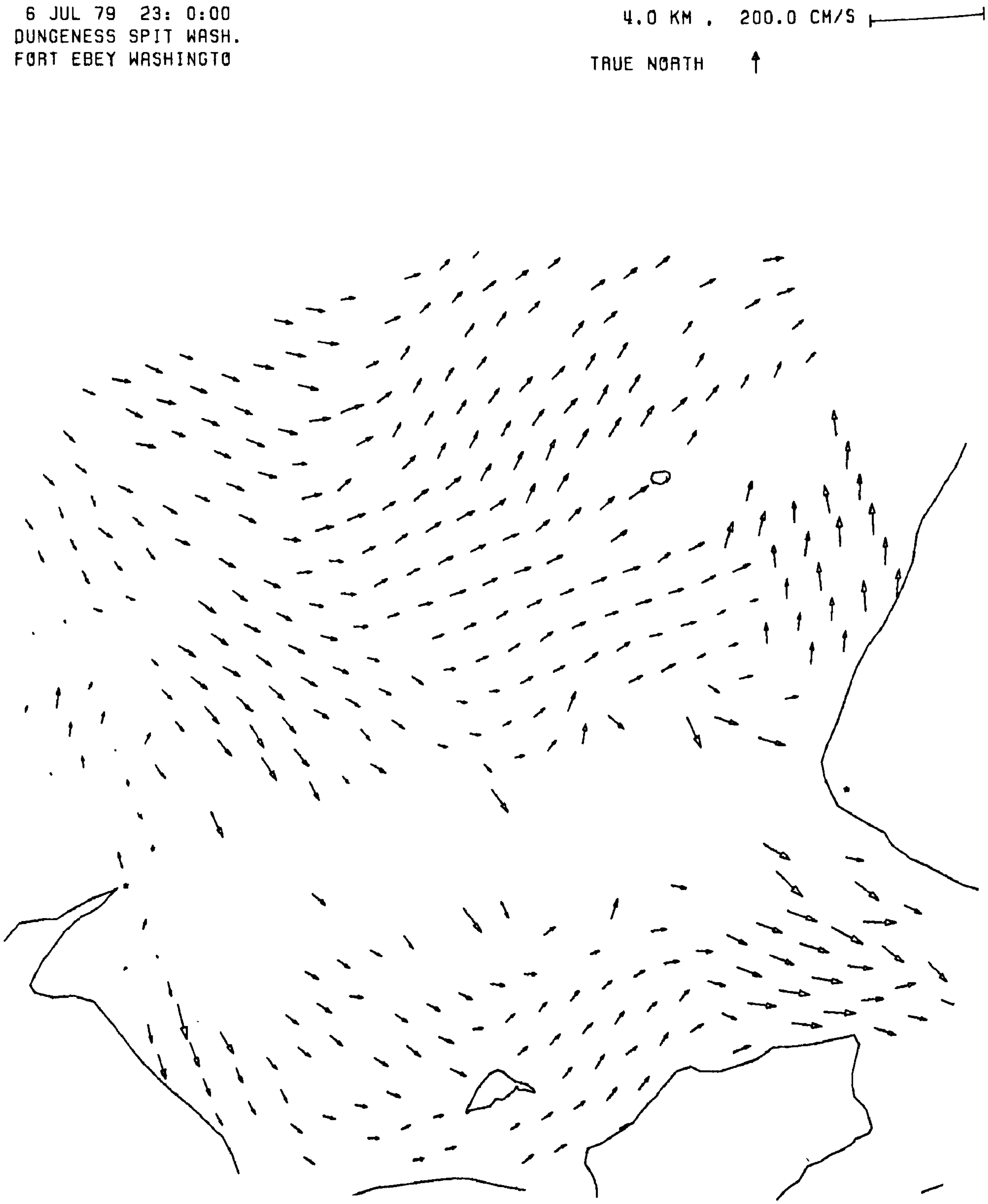


Figure 6. The current field at 2300 (PDT) on 6 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

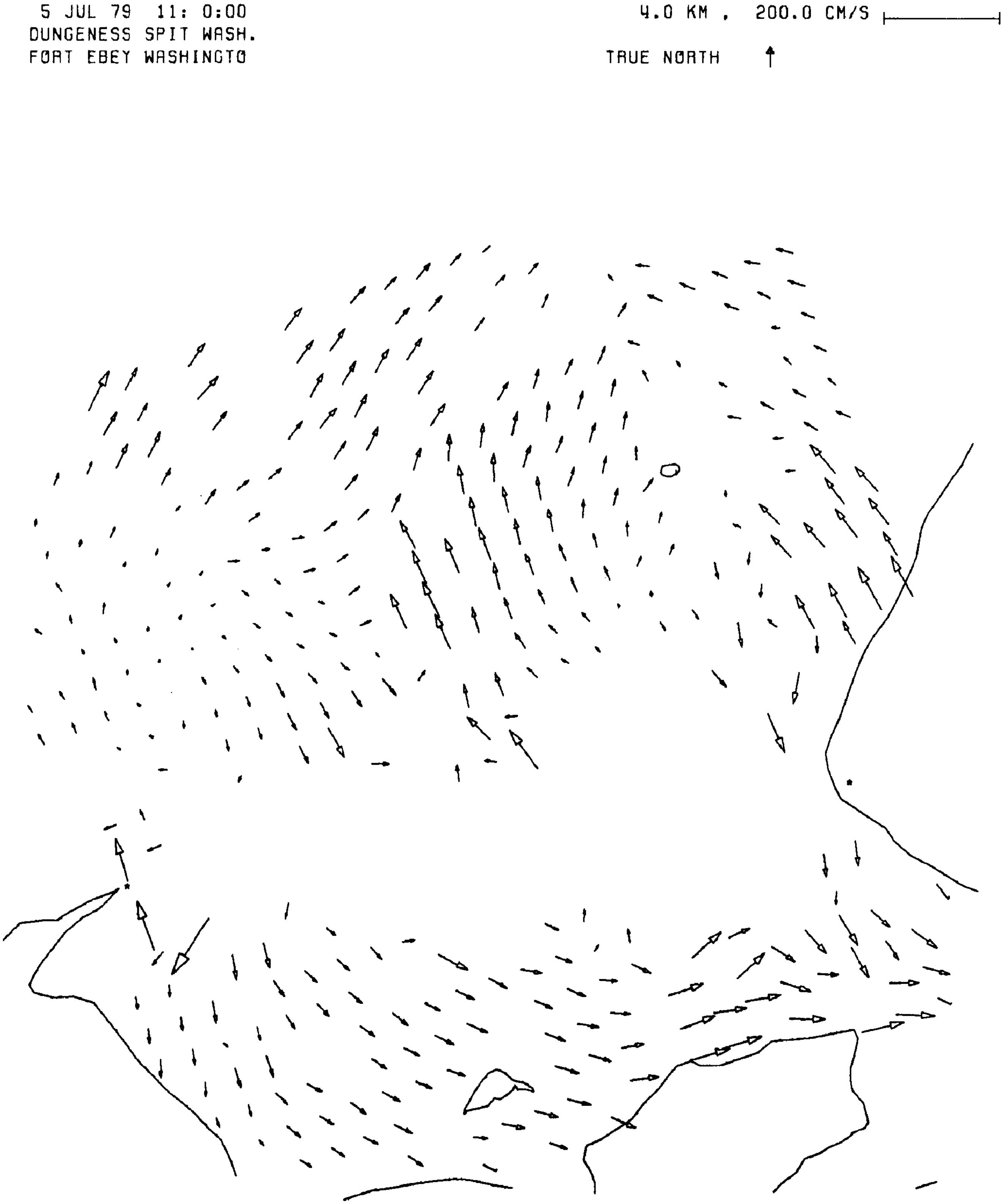


Figure 7. The current field at 1100 (PDT) on 5 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

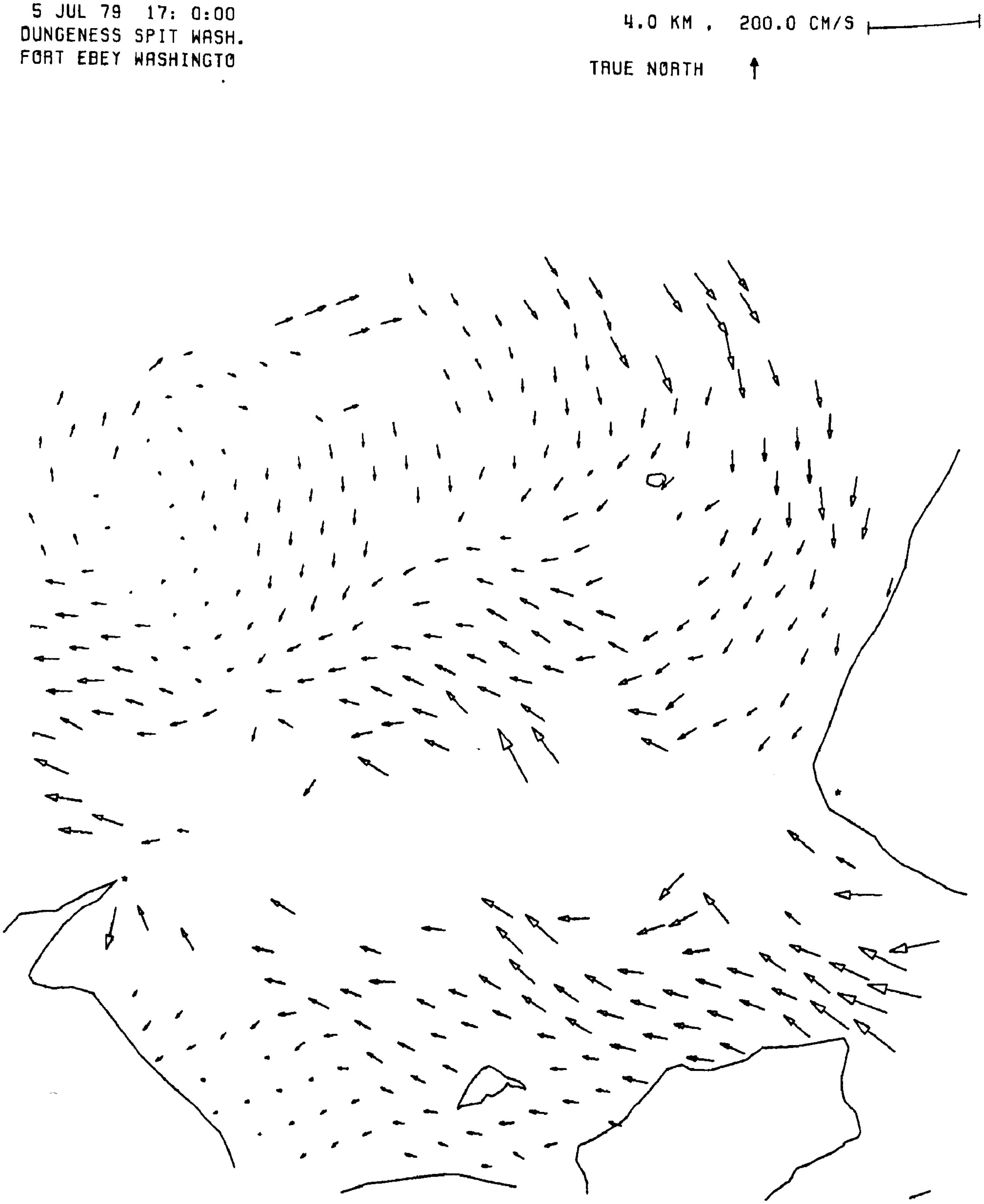


Figure 8. The current field at 1700 (PDT) on 5 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

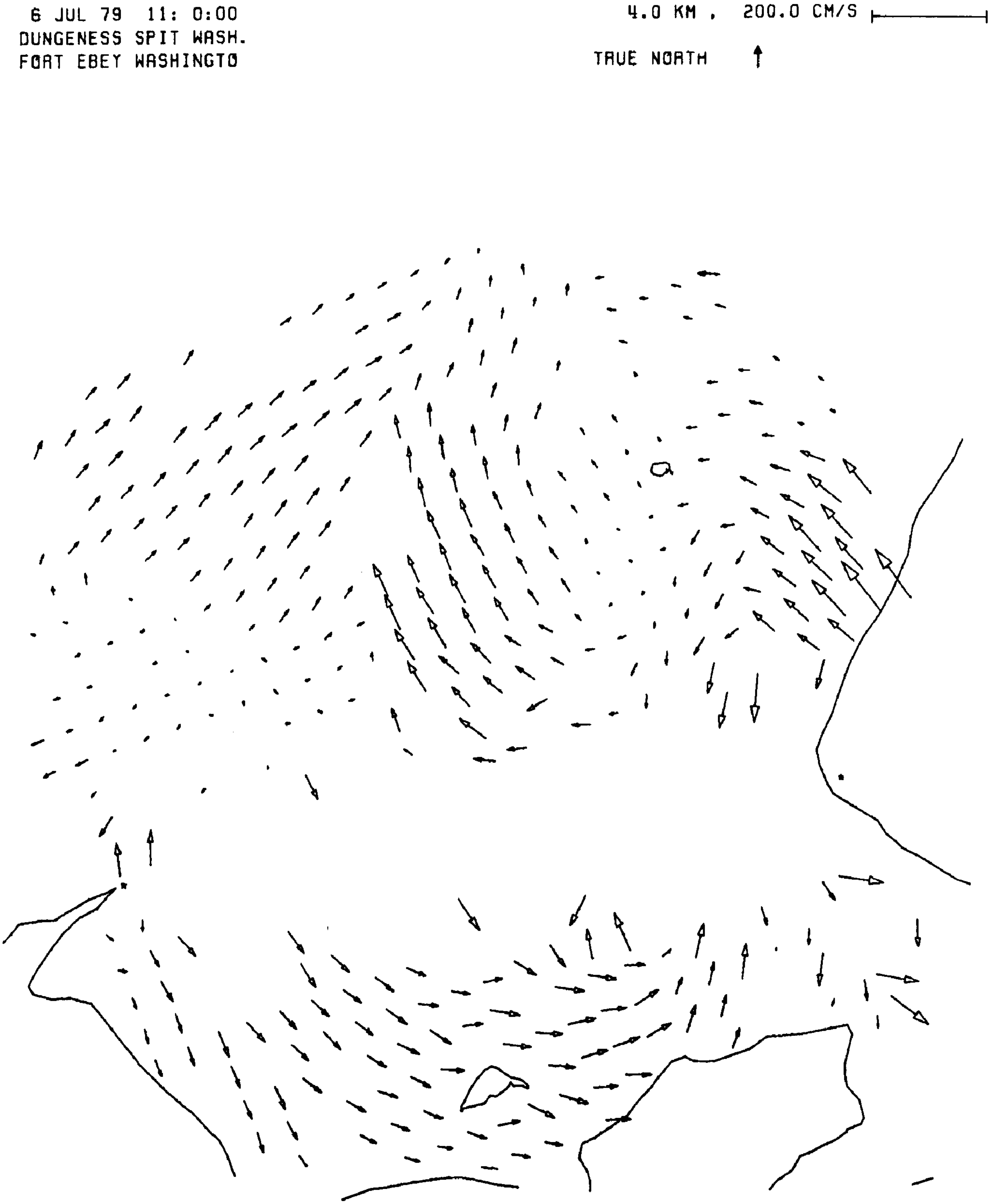


Figure 9. The current field at 1100 (PDT) on 6 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

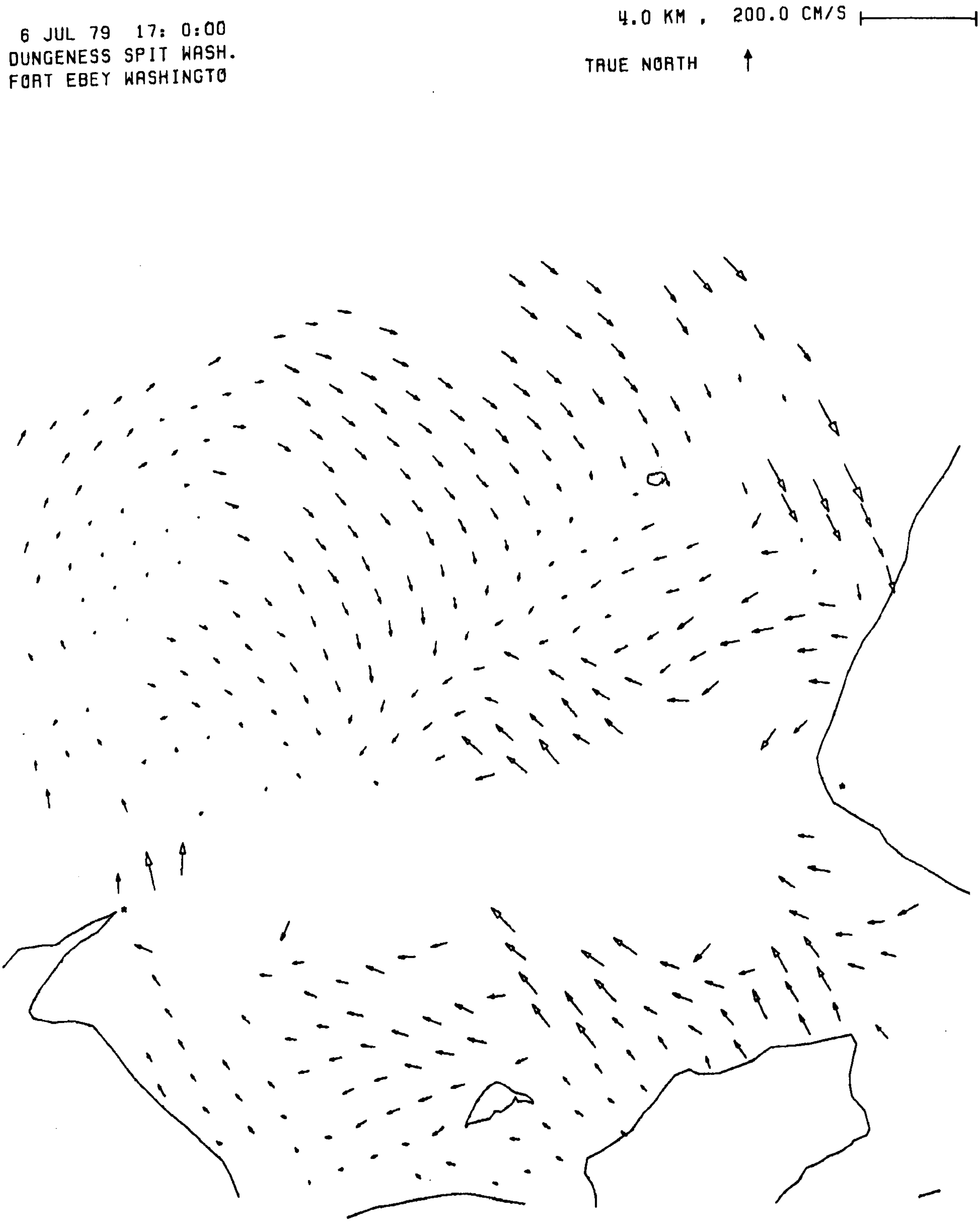


Figure 10. The current field at 1700 (PDT) on 6 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

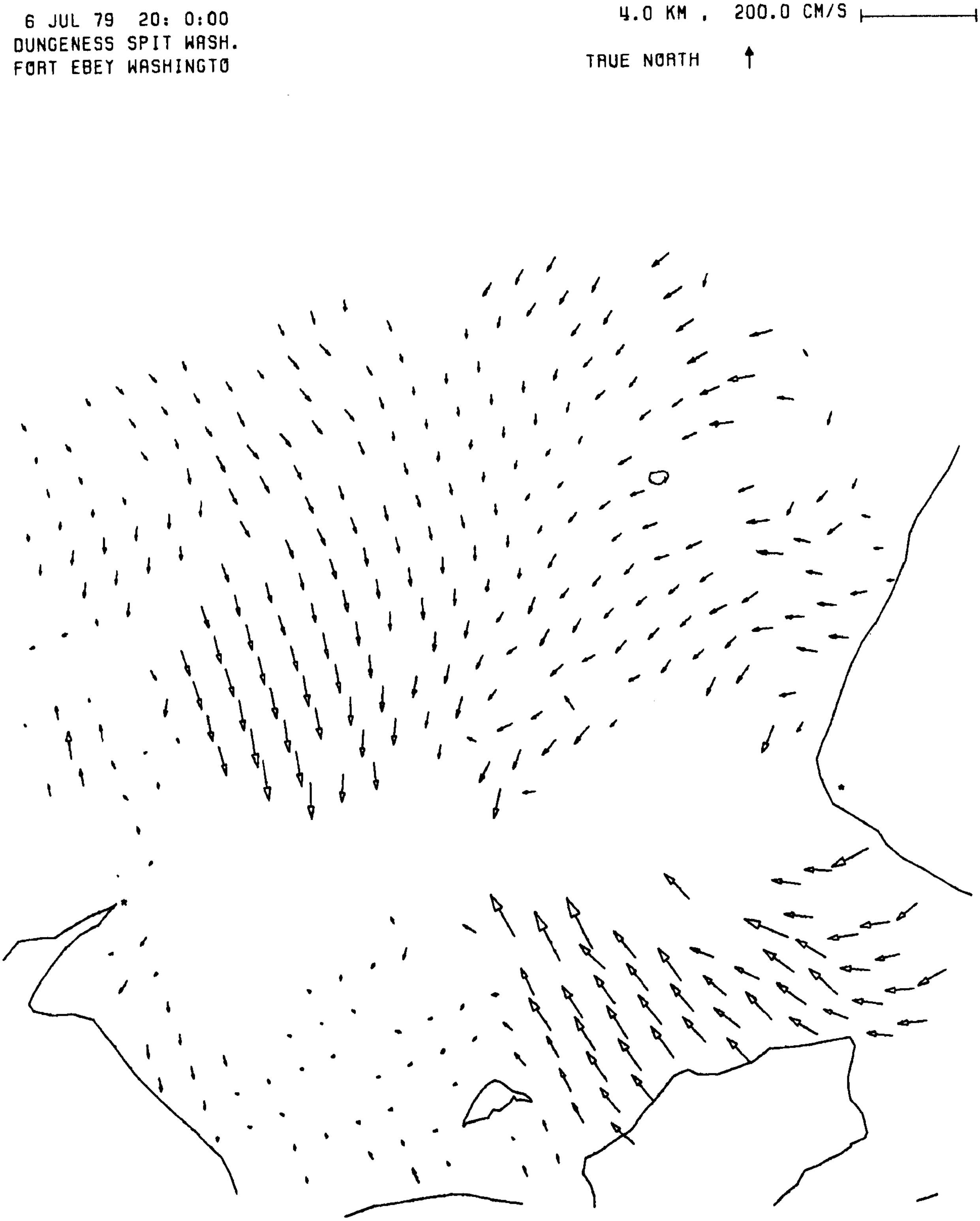


Figure 11. The current field at 2000 (PDT) on 6 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

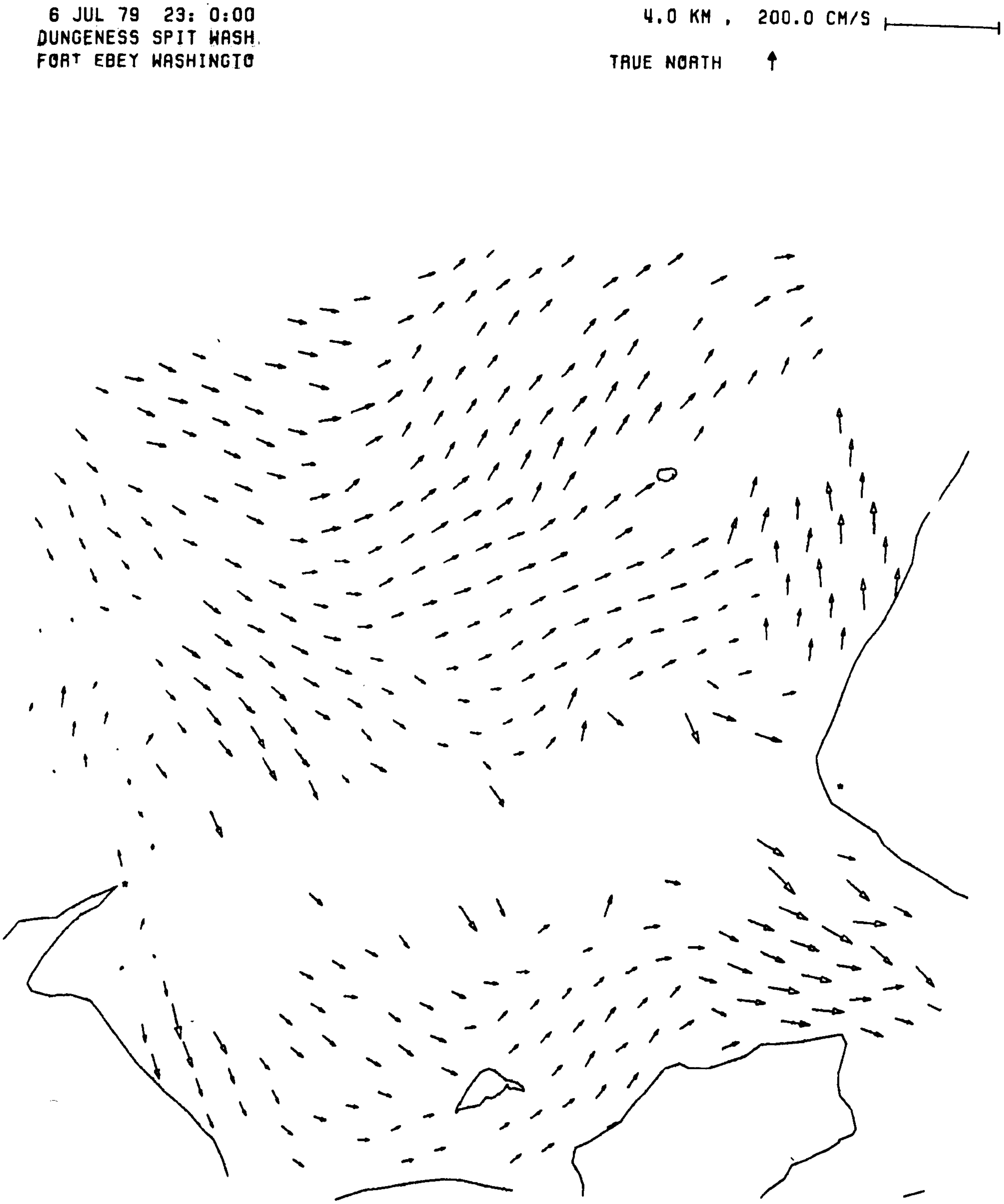


Figure 12. The current field at 2300 (PDT) on 6 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

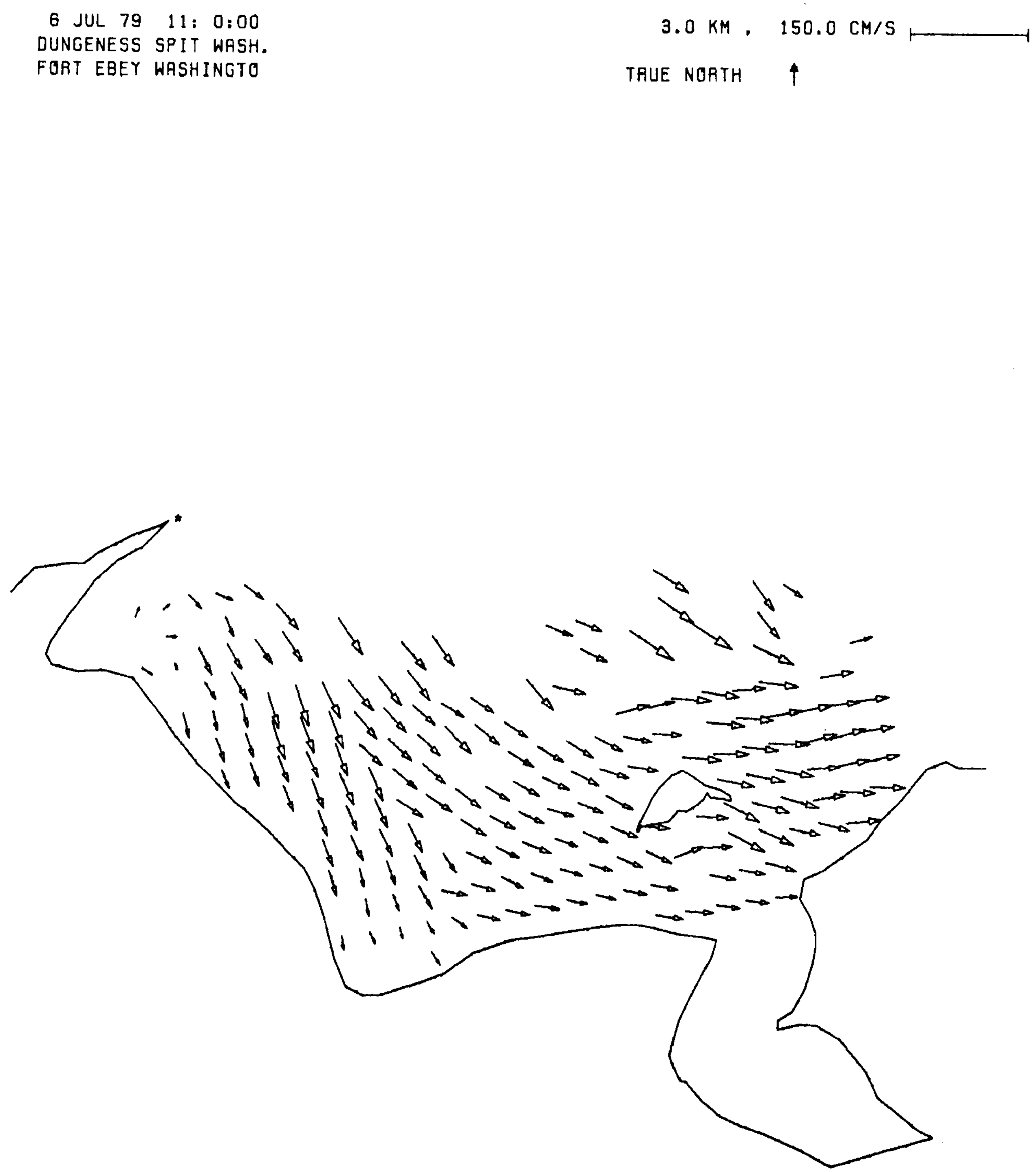


Figure 13. The current field at 1100 (PDT) on 6 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

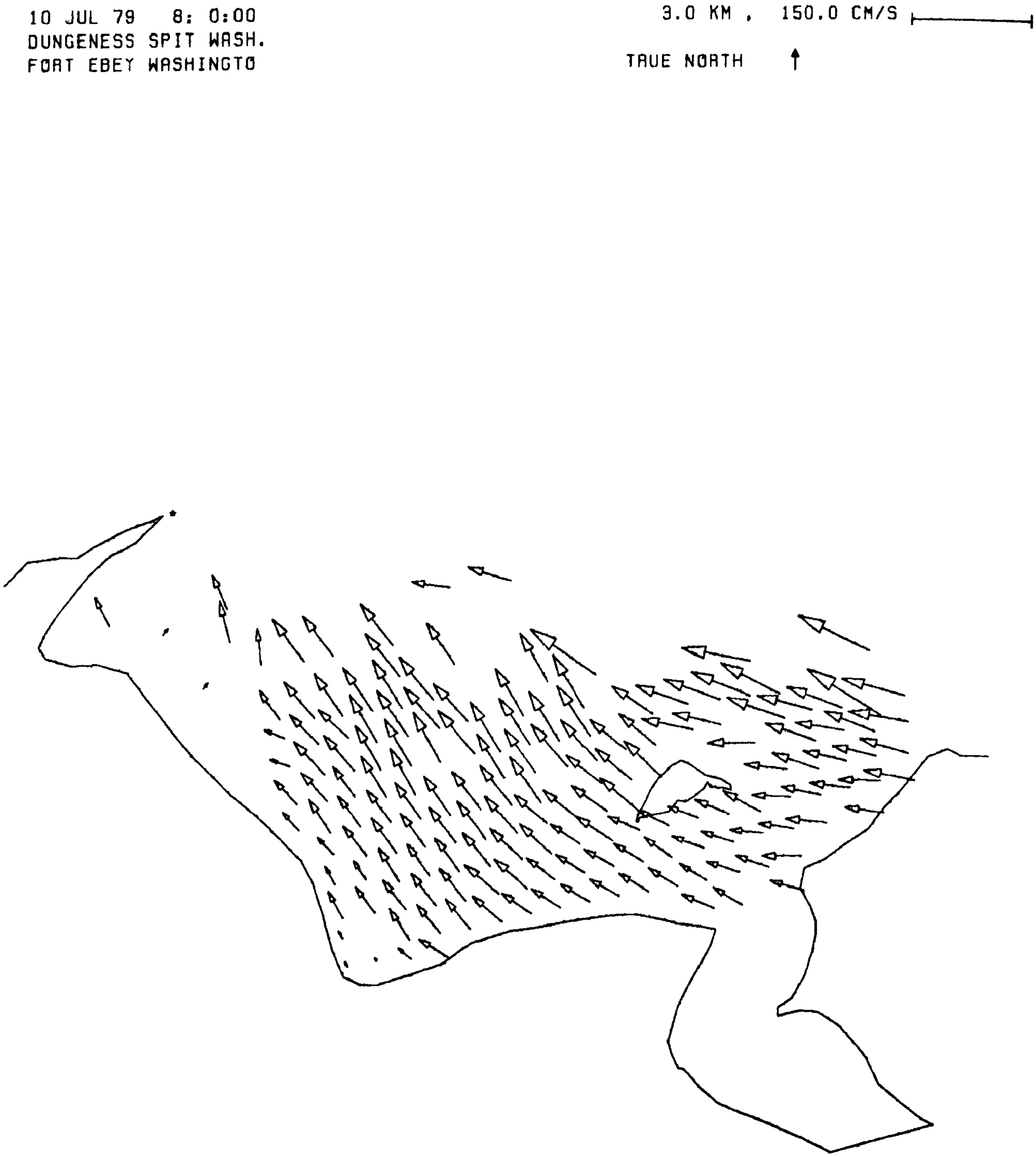


Figure 14. The current field at 0800 (PDT) on 10 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

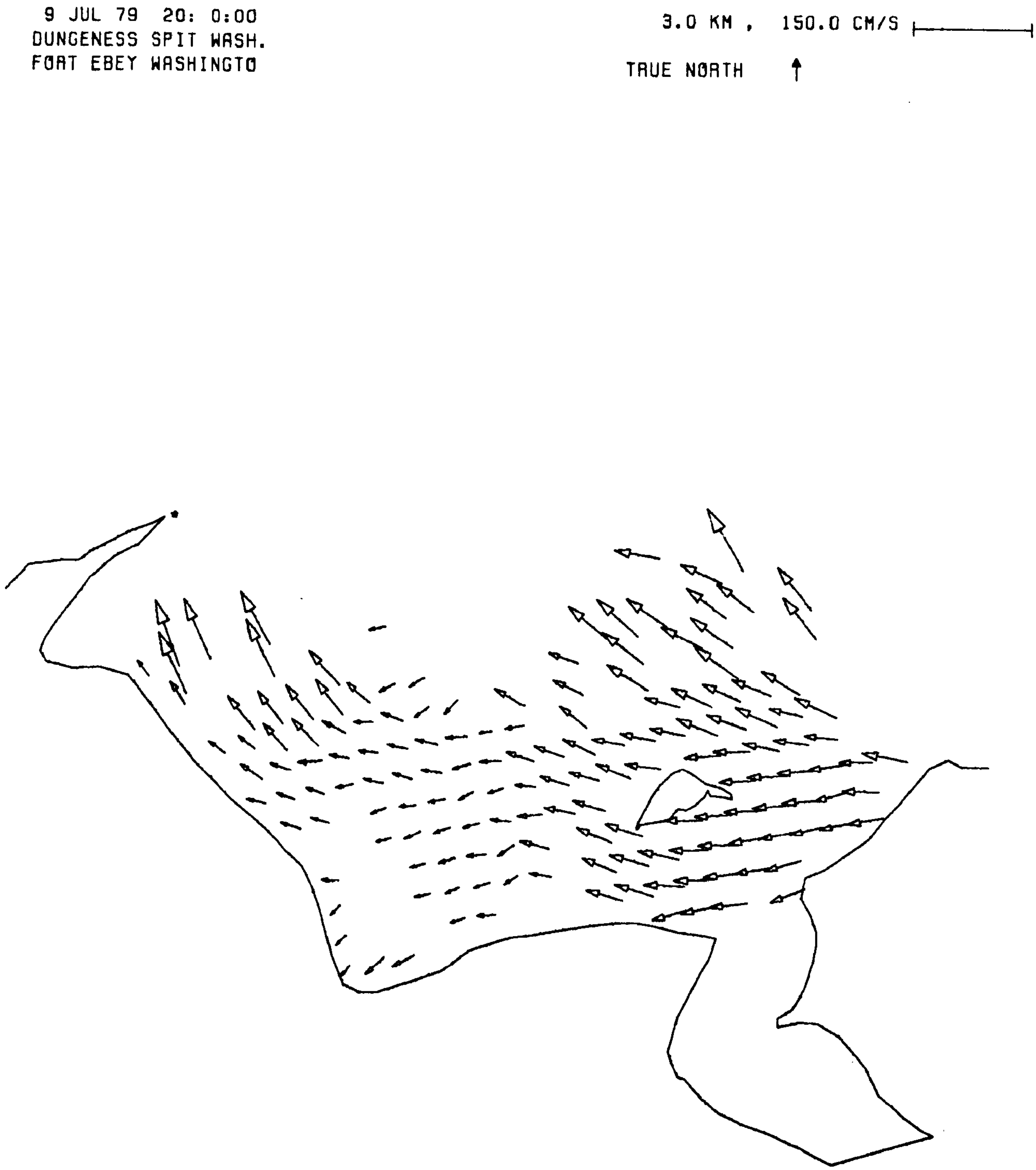


Figure 15. The current field at 2000 (PDT) on 9 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

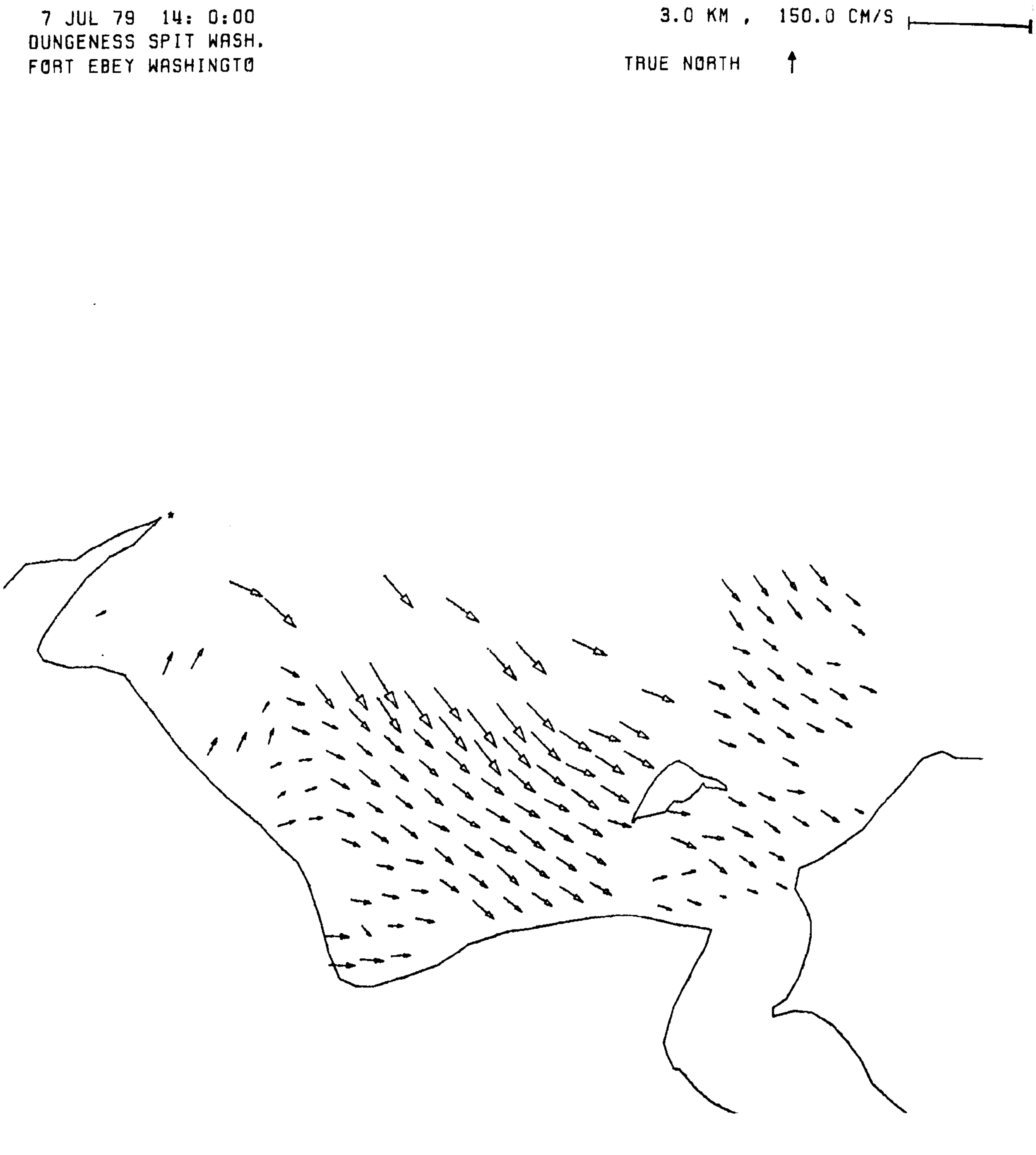


Figure 16. The current field at 1400 (PDT) on 7 July 1979 is shown for the Strait of Juan de Fuca. The radar sites were located at Dungeness Spit and Whidbey Island where the star is positioned.

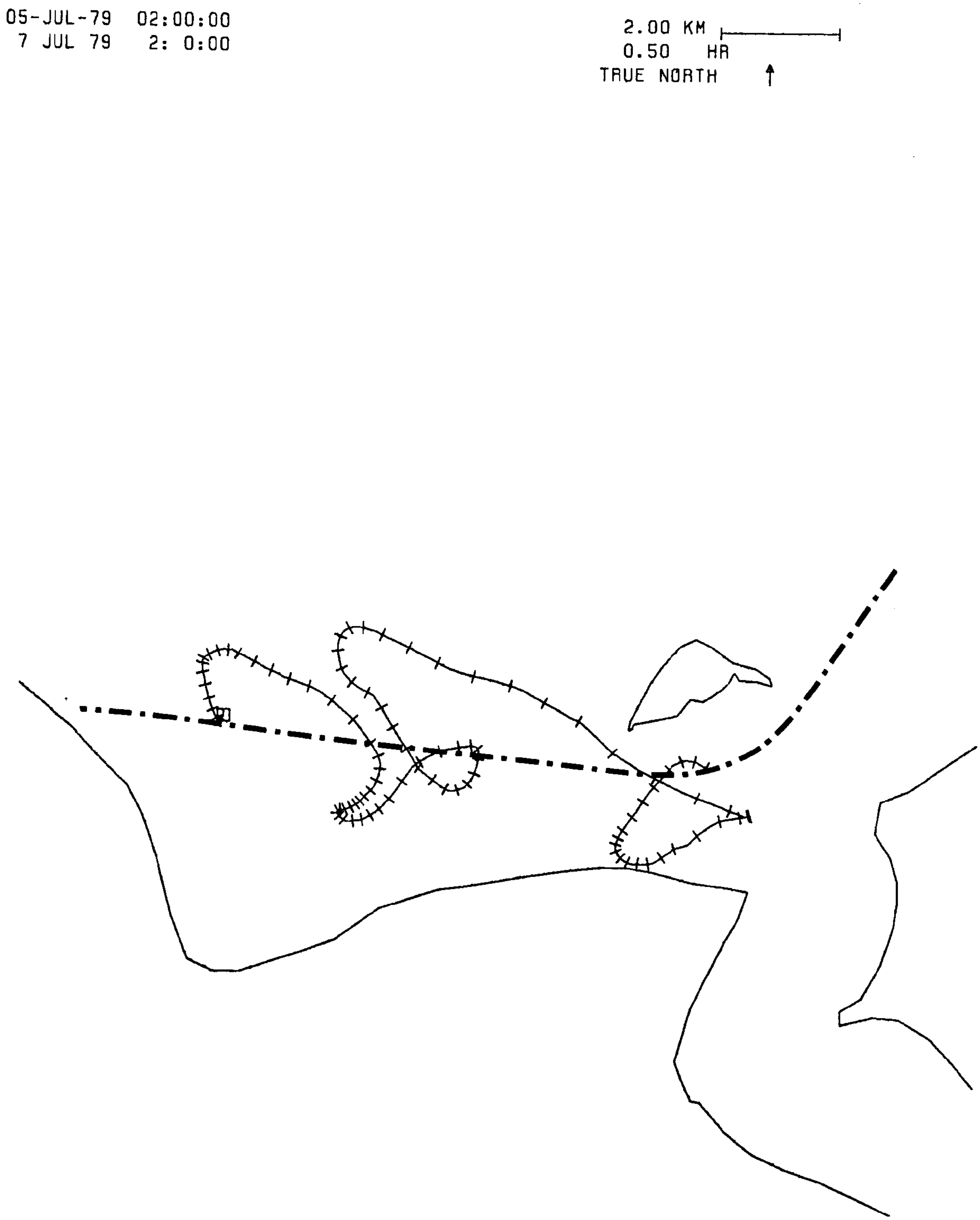


Figure 17. A two-day trajectory is shown for a hypothetical drifter initially placed west of Protection Island. The start time is 0200 (PDT) on 5 July 1979. The track is marked every half hour and the initial location is marked with a box.

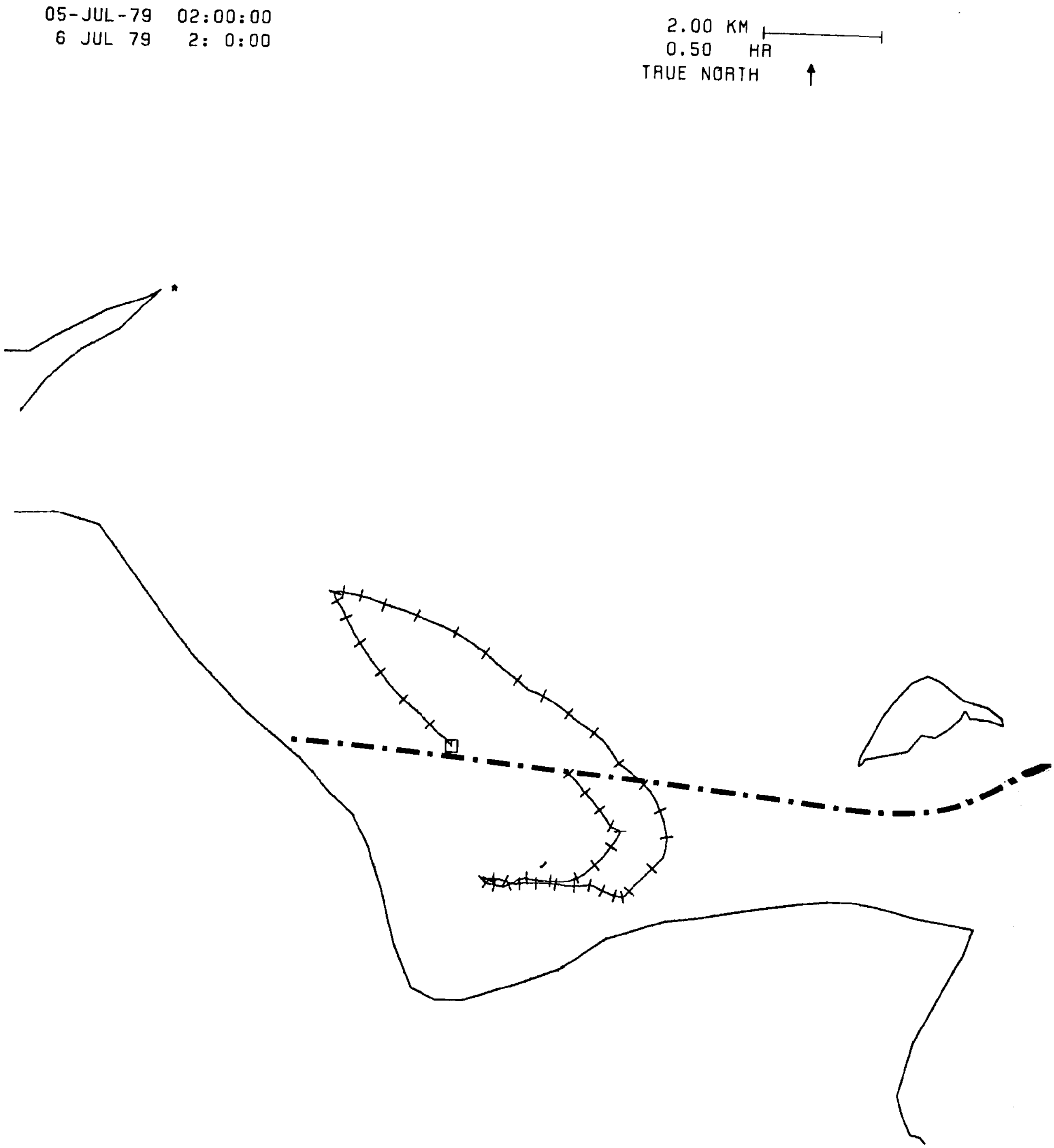


Figure 18. The first day of the two-day trajectory in Figure 17 is reproduced here but only the estuarine flow and tides are included.

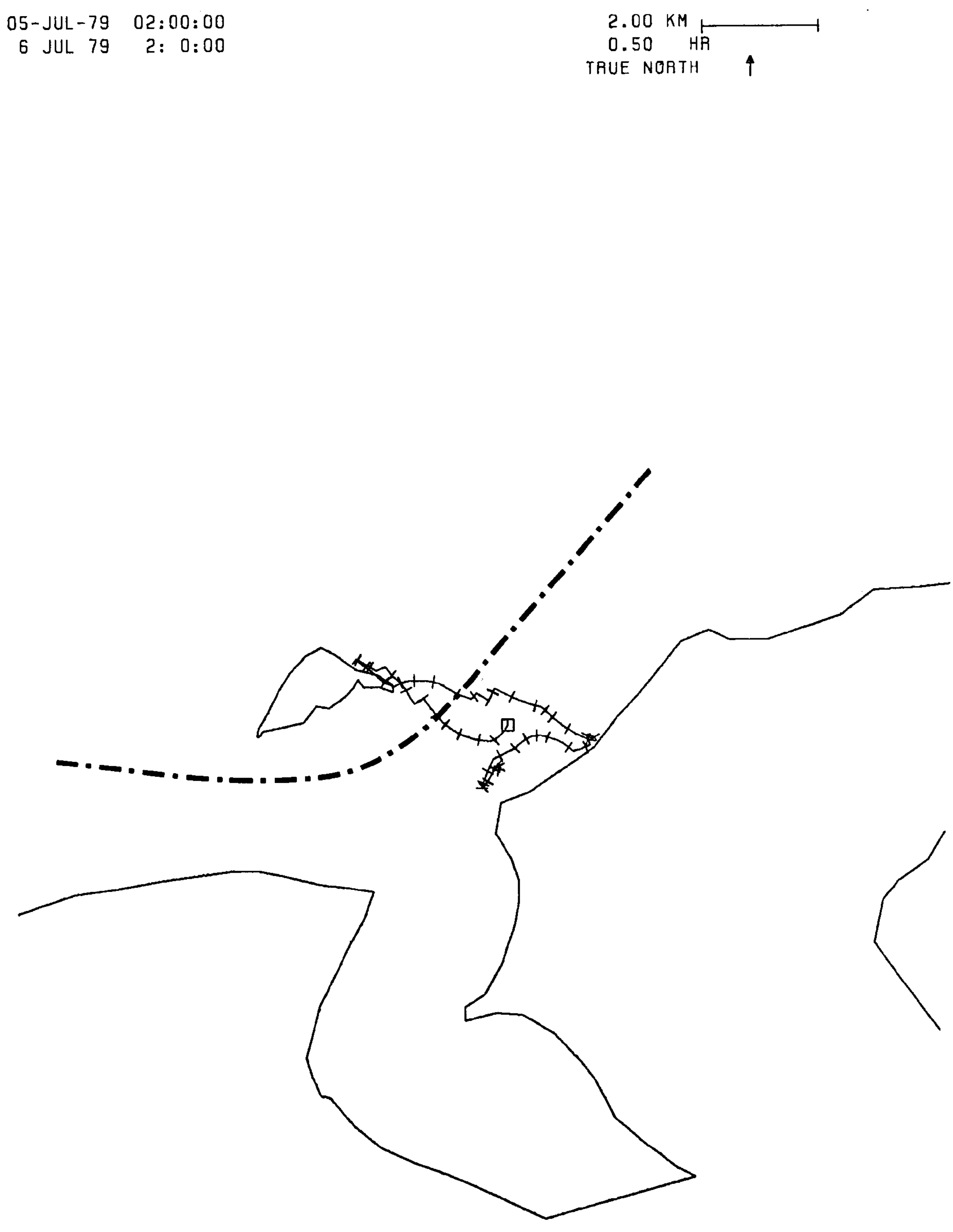


Figure 19. A one-day trajectory is shown for a hypothetical drifter initially placed just east of Protection Island. The start time is 0200 (PDT) on 5 July 1979. The track is marked every half hour and the initial location is marked with a box.

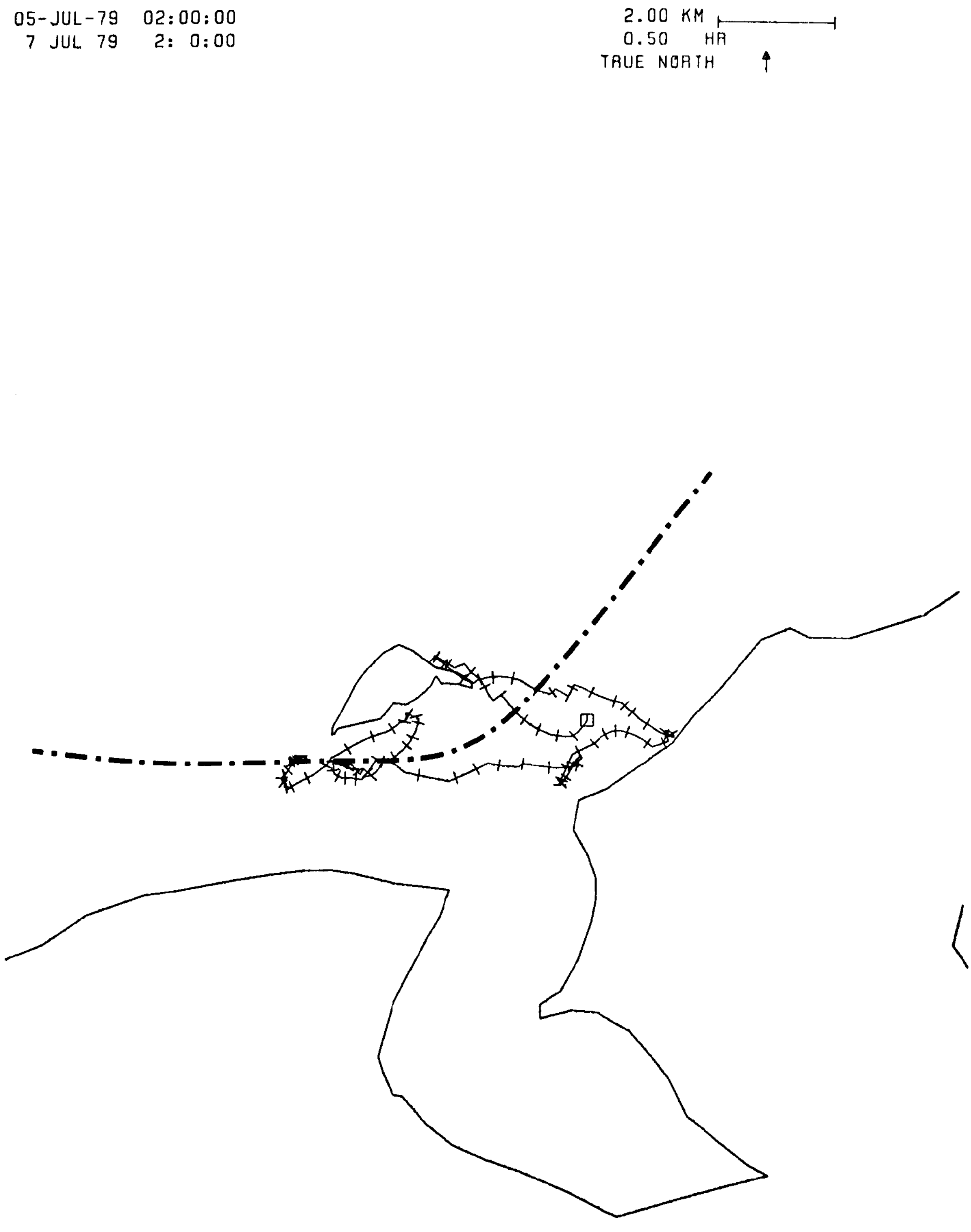


Figure 20. The trajectory in Figure 19 is extended to two days.

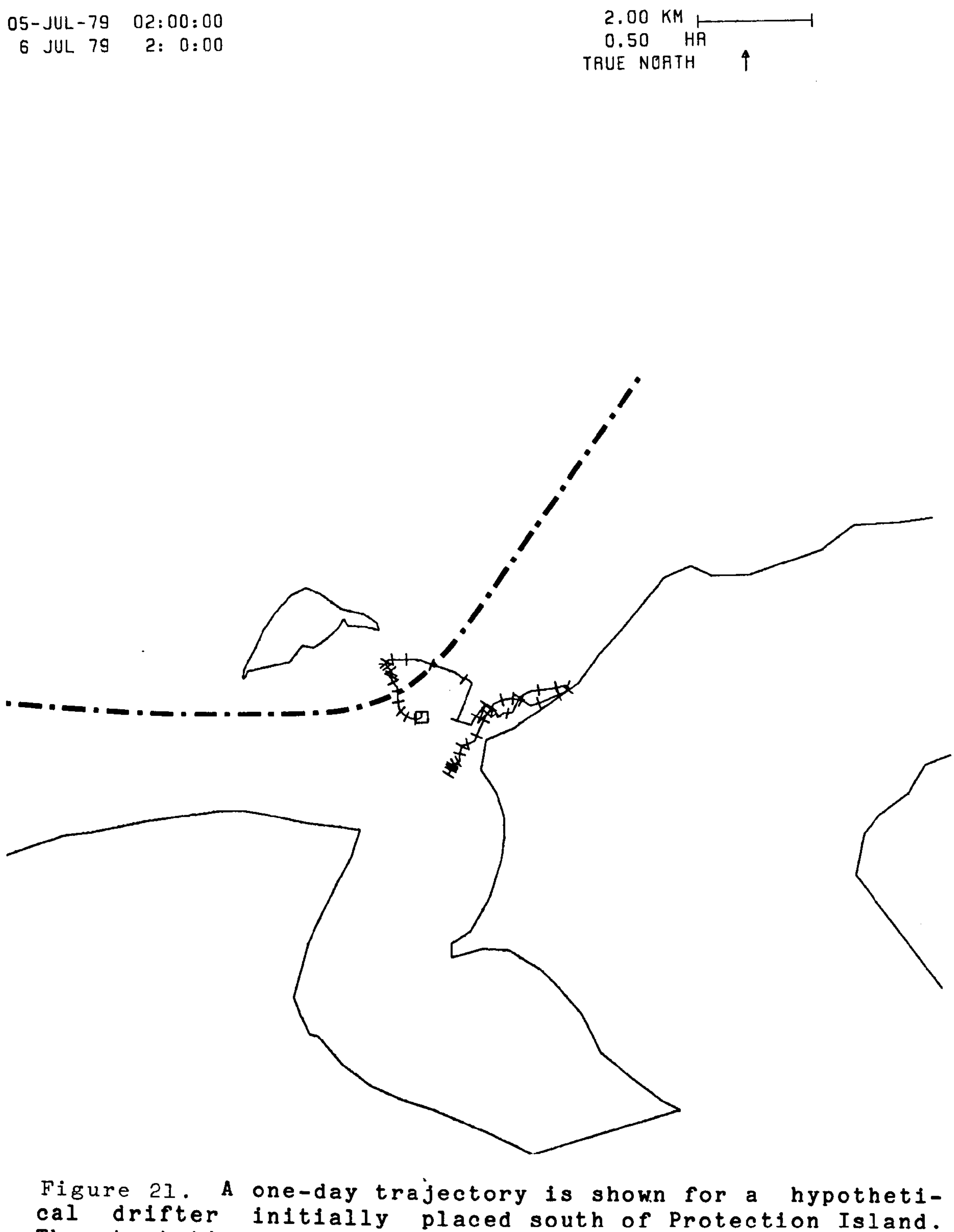


Figure 21. A one-day trajectory is shown for a hypothetical drifter initially placed south of Protection Island. The start time is 0200 (PDT) on 5 July 1979. The track is marked every half hour and the initial location is marked with a box.

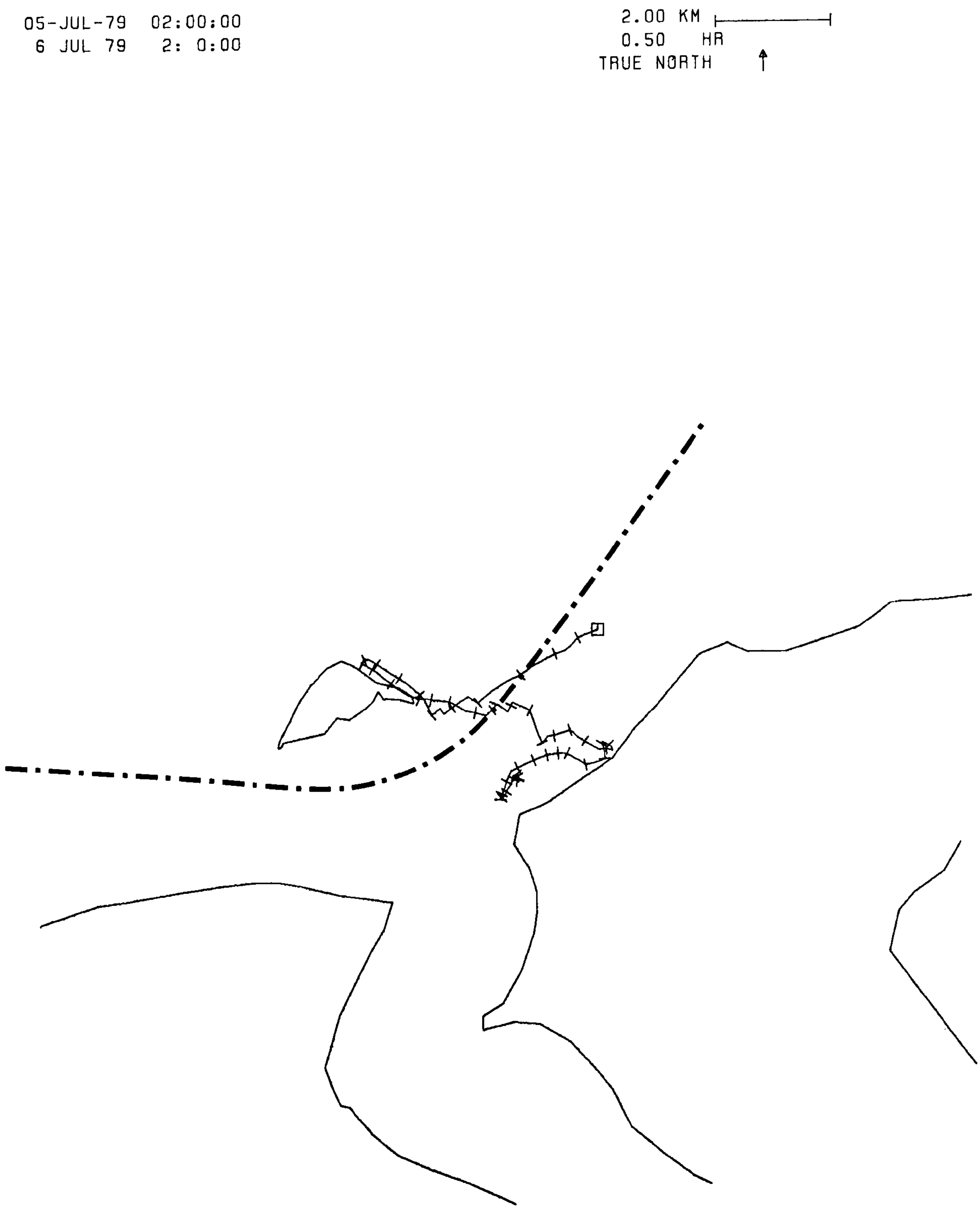


Figure 22. A one-day trajectory is shown for a hypothetical drifter initially placed east of Protection Island. The start time is 0200 (PDT) on 5 July 1979. The track is marked every half hour and the initial location is marked with a box.

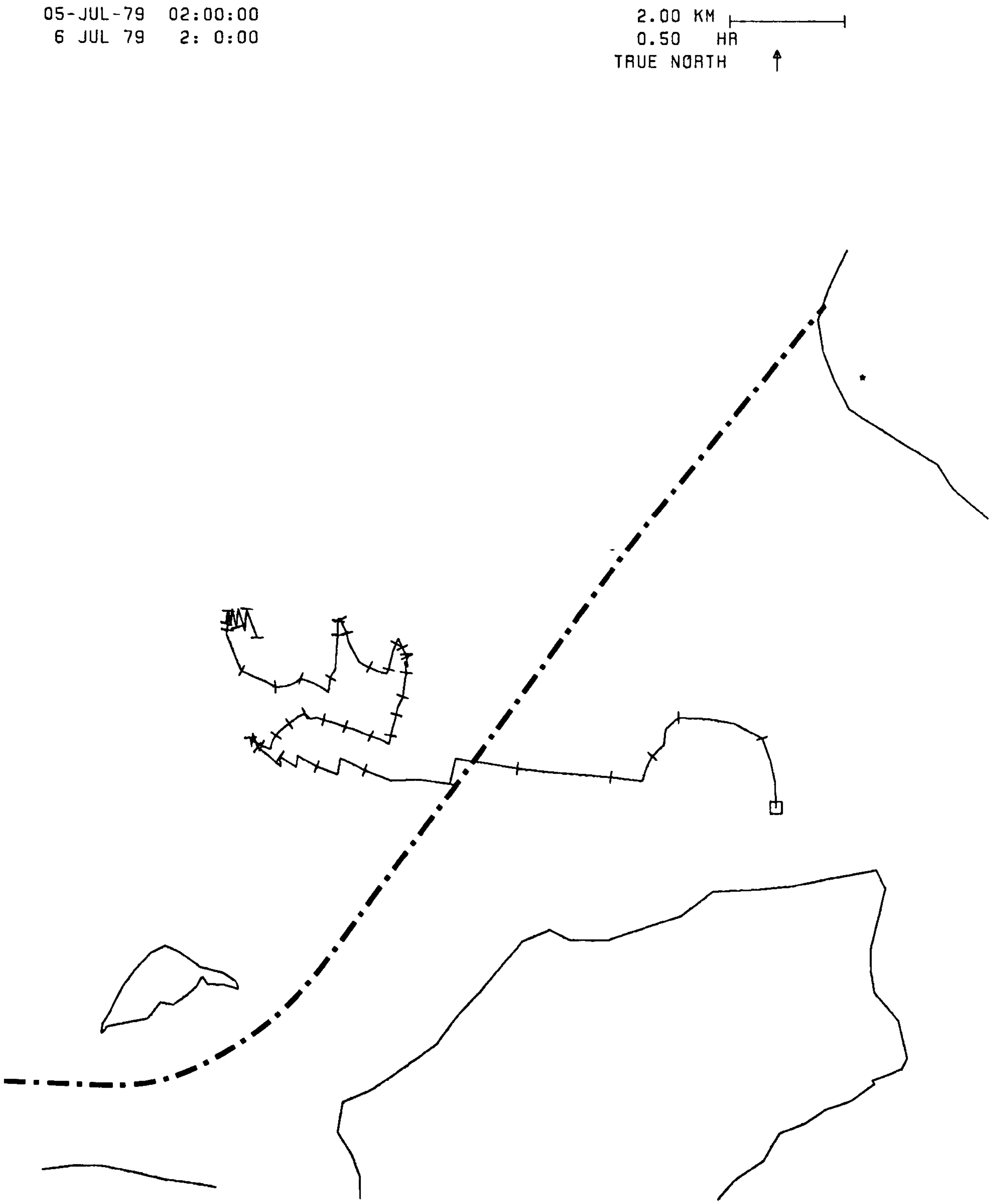


Figure 23. A one-day trajectory is shown for a hypothetical drifter initially placed just west of Admiralty Inlet. The start time is 0200 (PDT) on 5 July 1979. The track is marked every half hour and the initial locoation is marked with a box.

APPENDIX

Figures A1.00 - A1.42 (pgs. 35 - 77) give the surface currents at three-hour intervals from 0200 (PDT) on 5 July to 0800 on 10 July. The radar sites are indicated with a small star and are located at Dungeness Spit in the west and Fort Ebey in the east. The blank area in the middle of the maps is along the baseline between the two sites where both vector components of the current velocity are not directly available. Future analysis of this data will include the currents in this area.

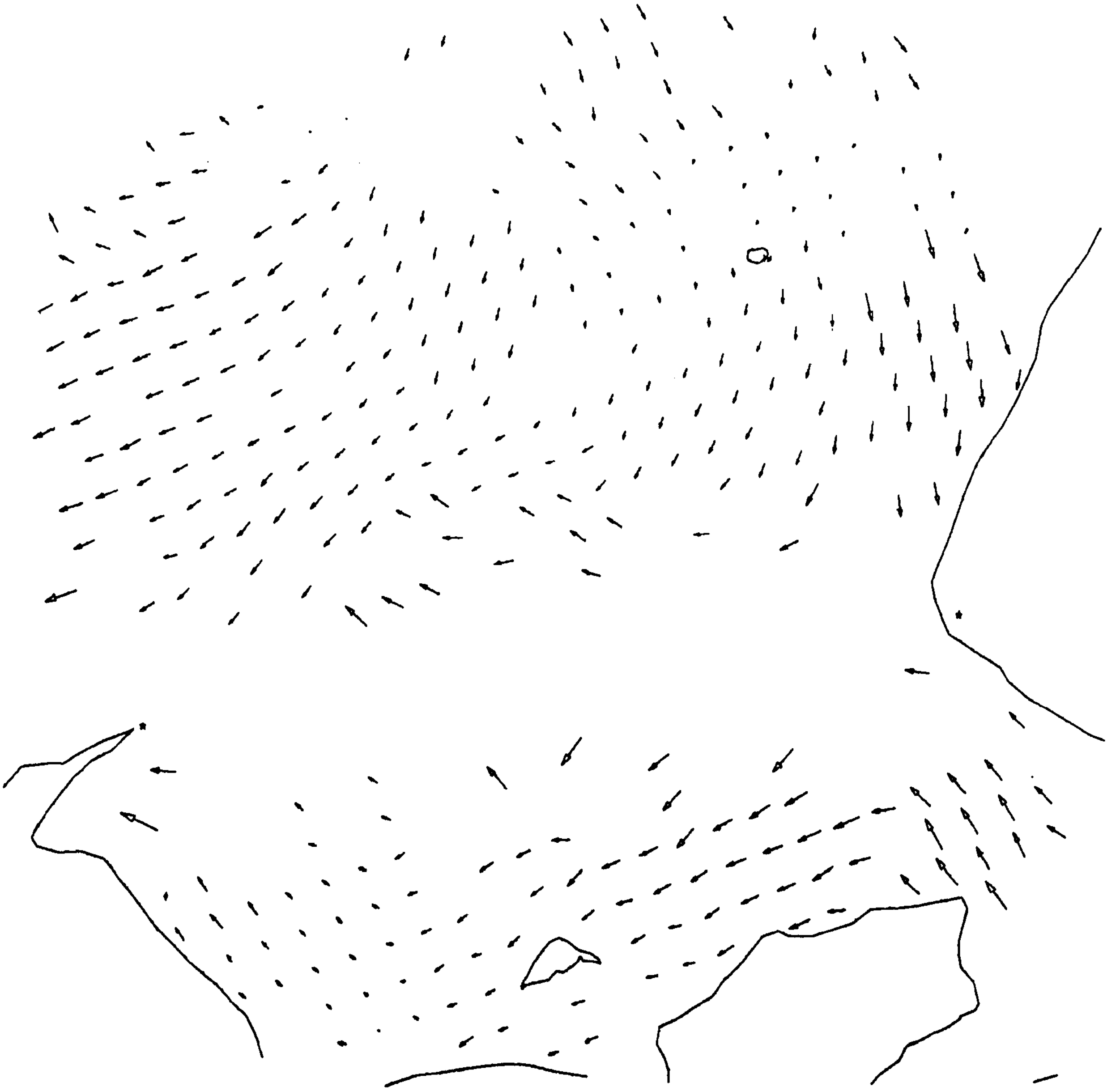
Figures A2.00 - A2.42 (pgs. 78 - 120) give the currents in the area of interest bounded by Dungeness Spit, Protection Island, and Sequim. This area is included in the previous set of maps, but here it is shown with greater resolution. This region of weaker flow does not show very well in these earlier maps where the scale was chosen to better display the stronger currents in Admiralty Inlet and farther out in the strait.

Figures A3.00 - A3.50 (pgs. 121 - 172) show the actual drifter positions and the radar predicted trajectories starting at the initial position for those drifters. The drifter positions are marked with a circle while the radar track is marked with ticks every half hour. The drogue depth is indicated as follows: A0 is drifter "A" with zero drogue, A1 is with 0.5 meter drogue, A2 is with 1.0 meter drogue, A3 is with 2.0 meter drogue. The letters "A", "B", "C", etc. were used to distinguish identical drifters with the same drogue.

05-JUL-79 02:00:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH



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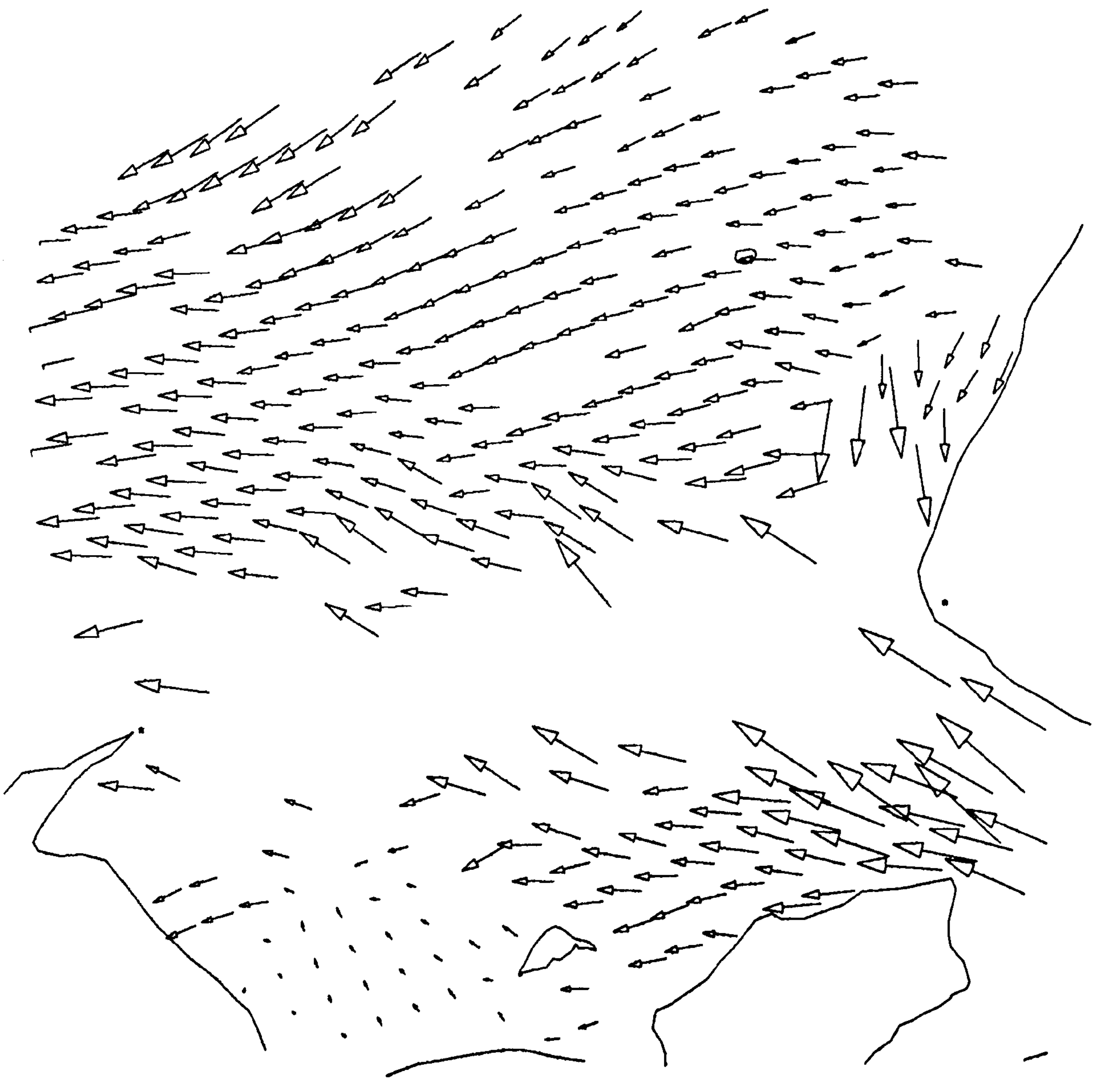
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH ↑



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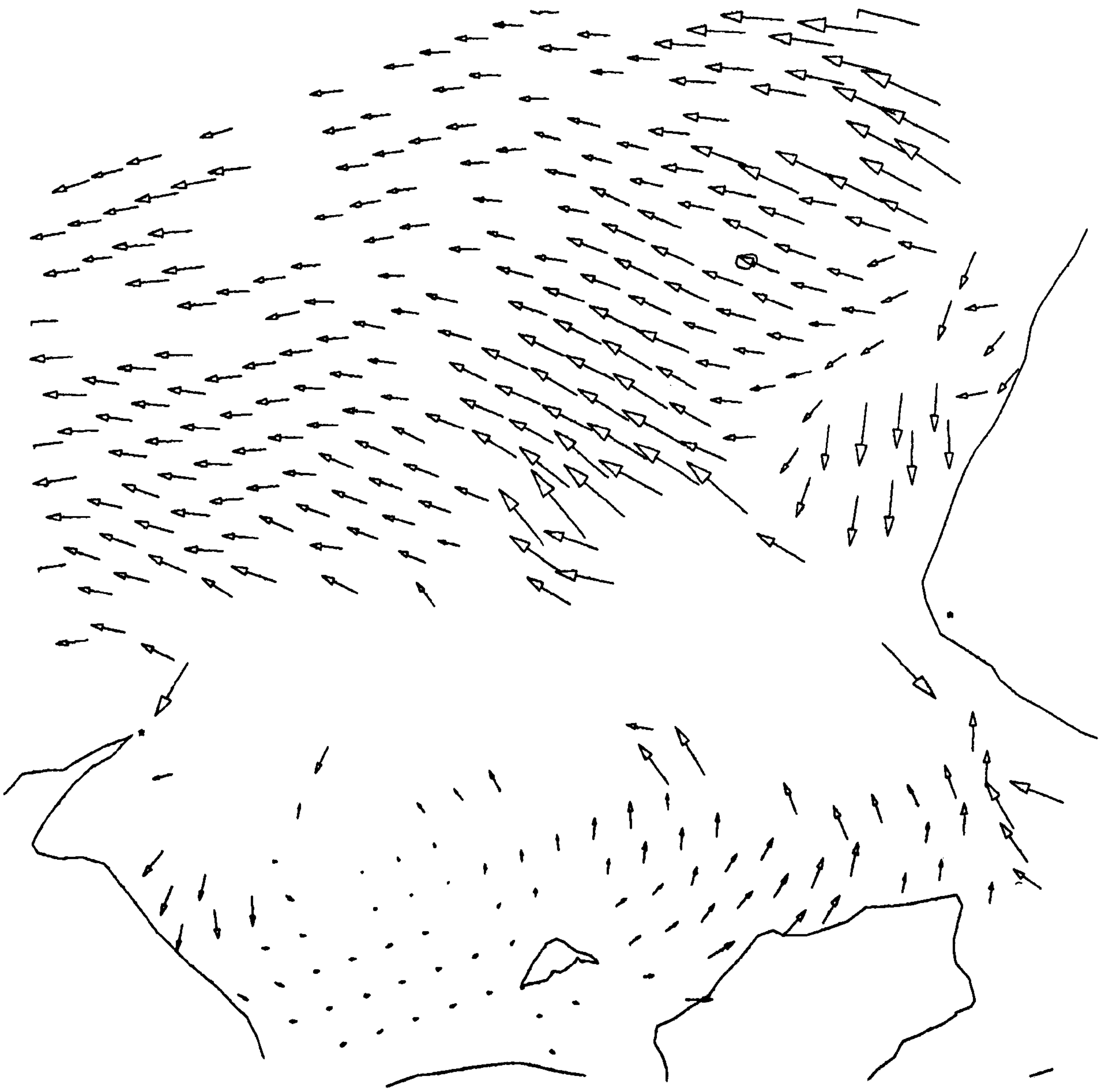
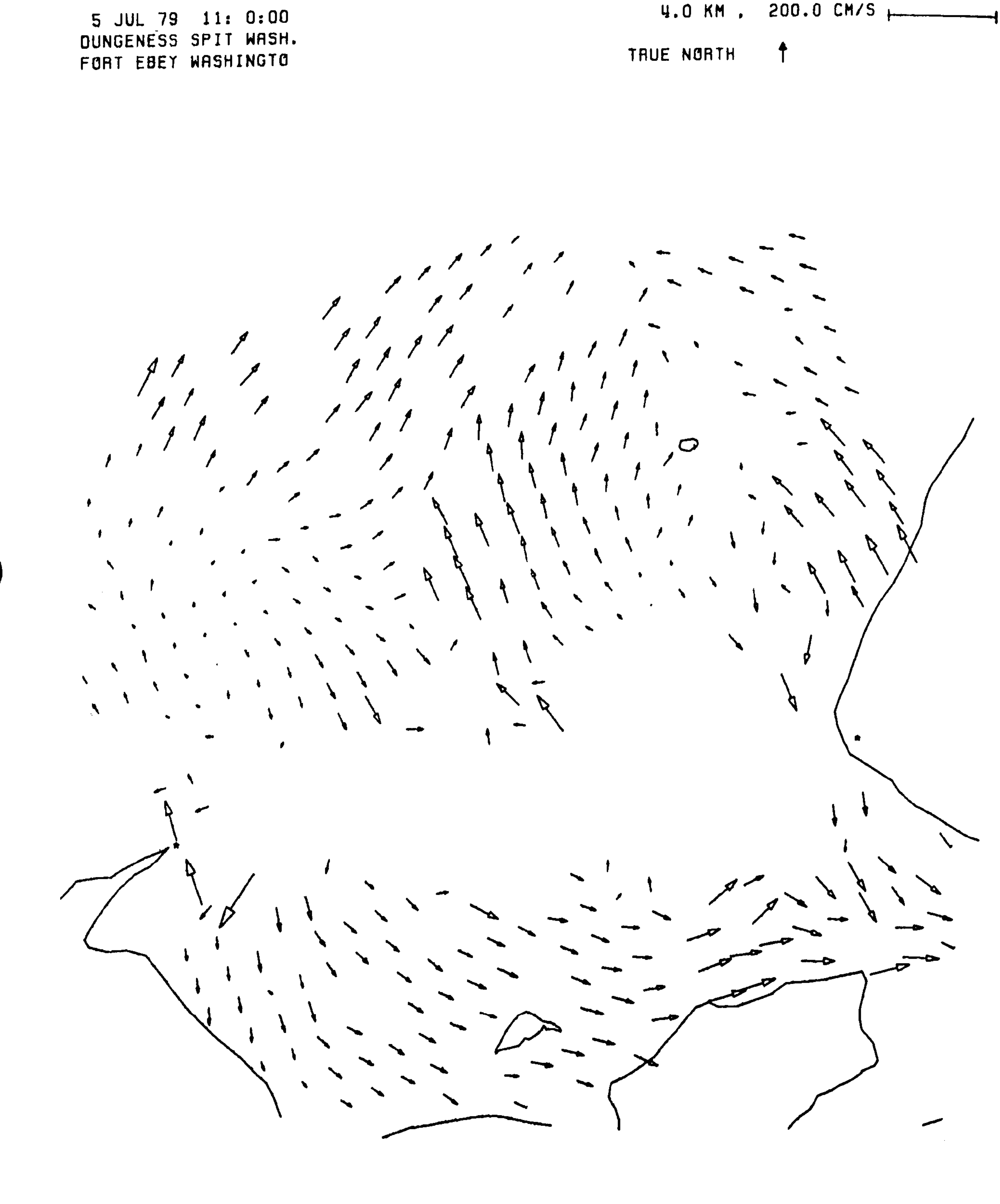
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH

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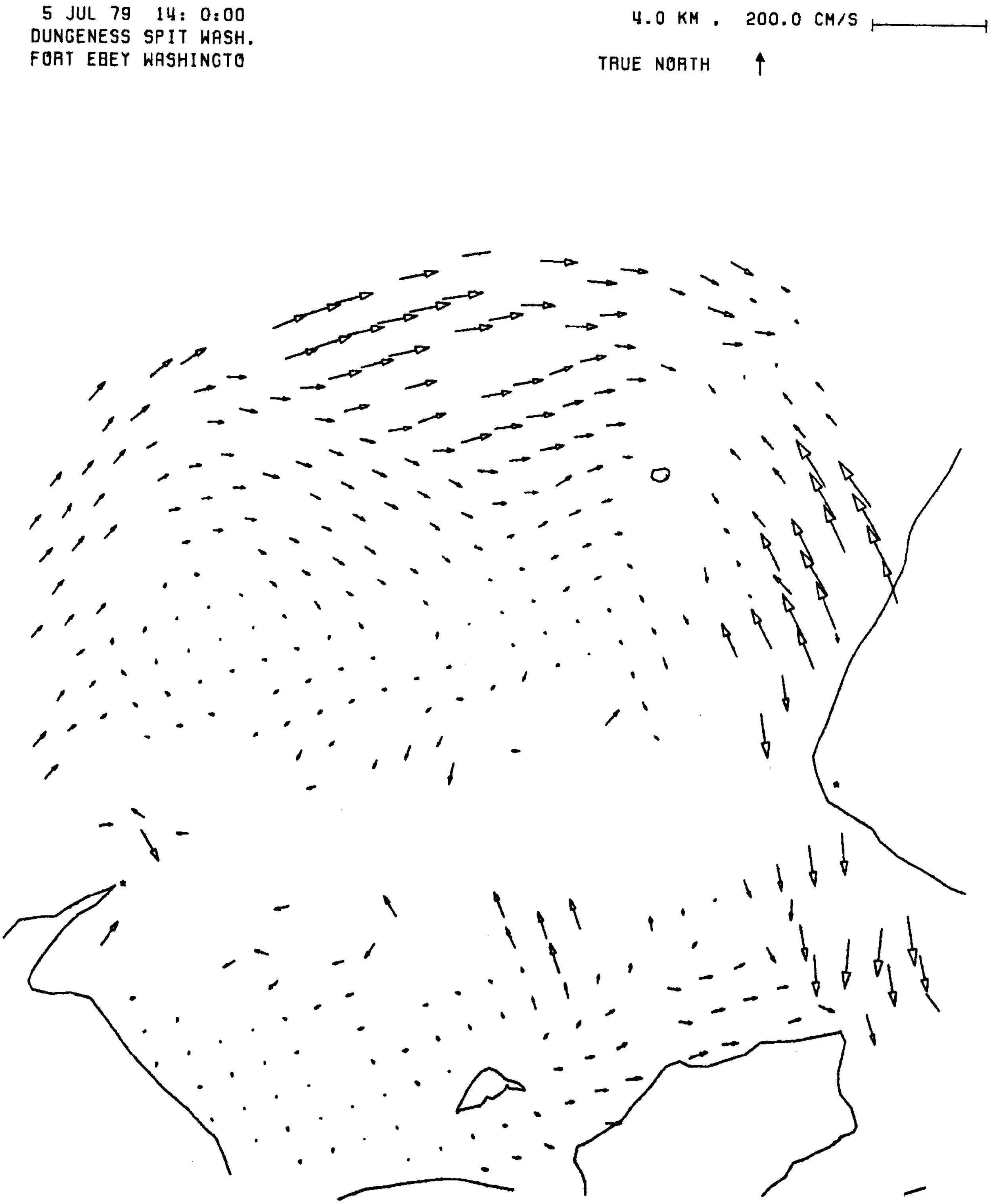
FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH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FORT EBEY WASHINGTO
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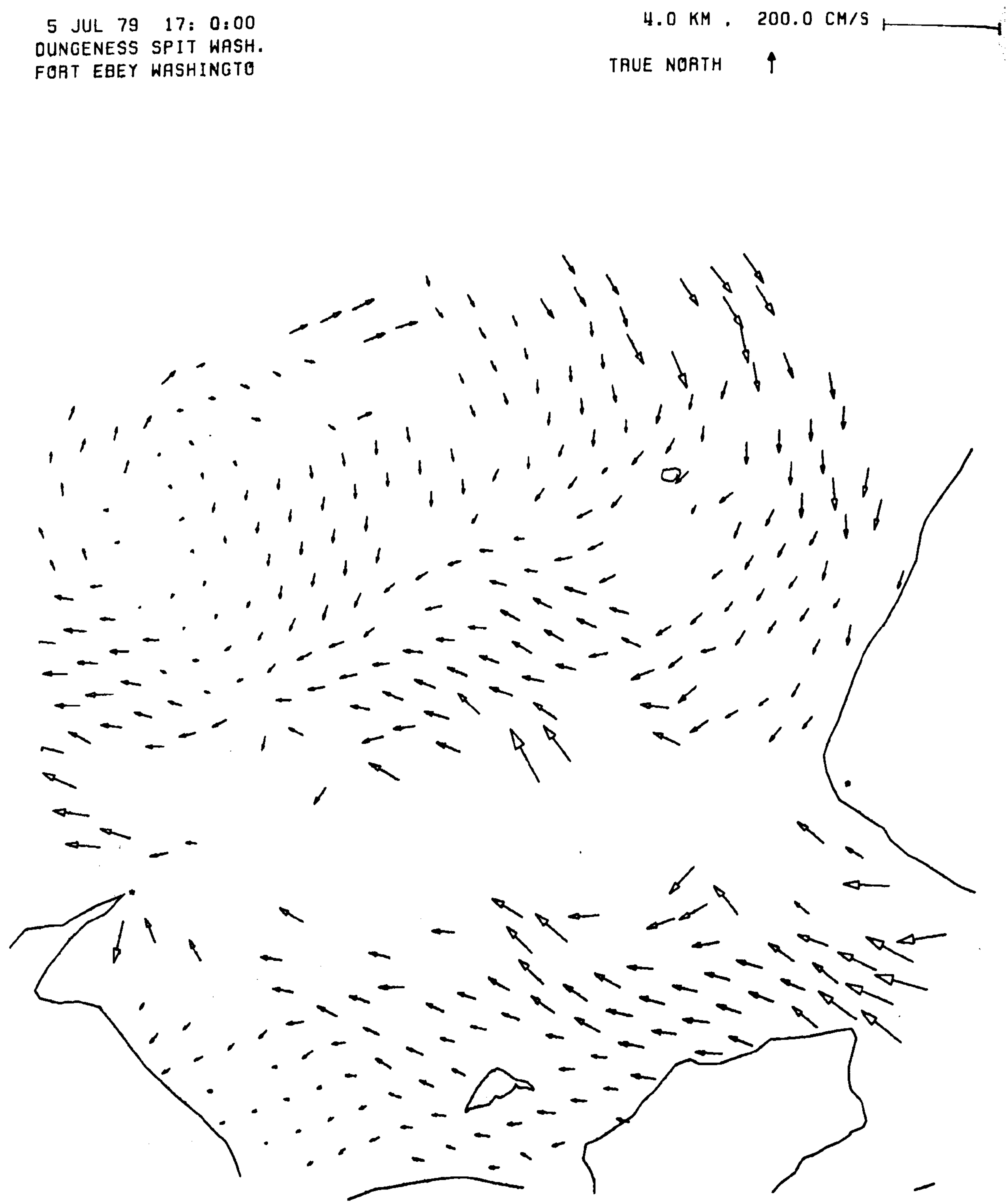
TRUE NORTH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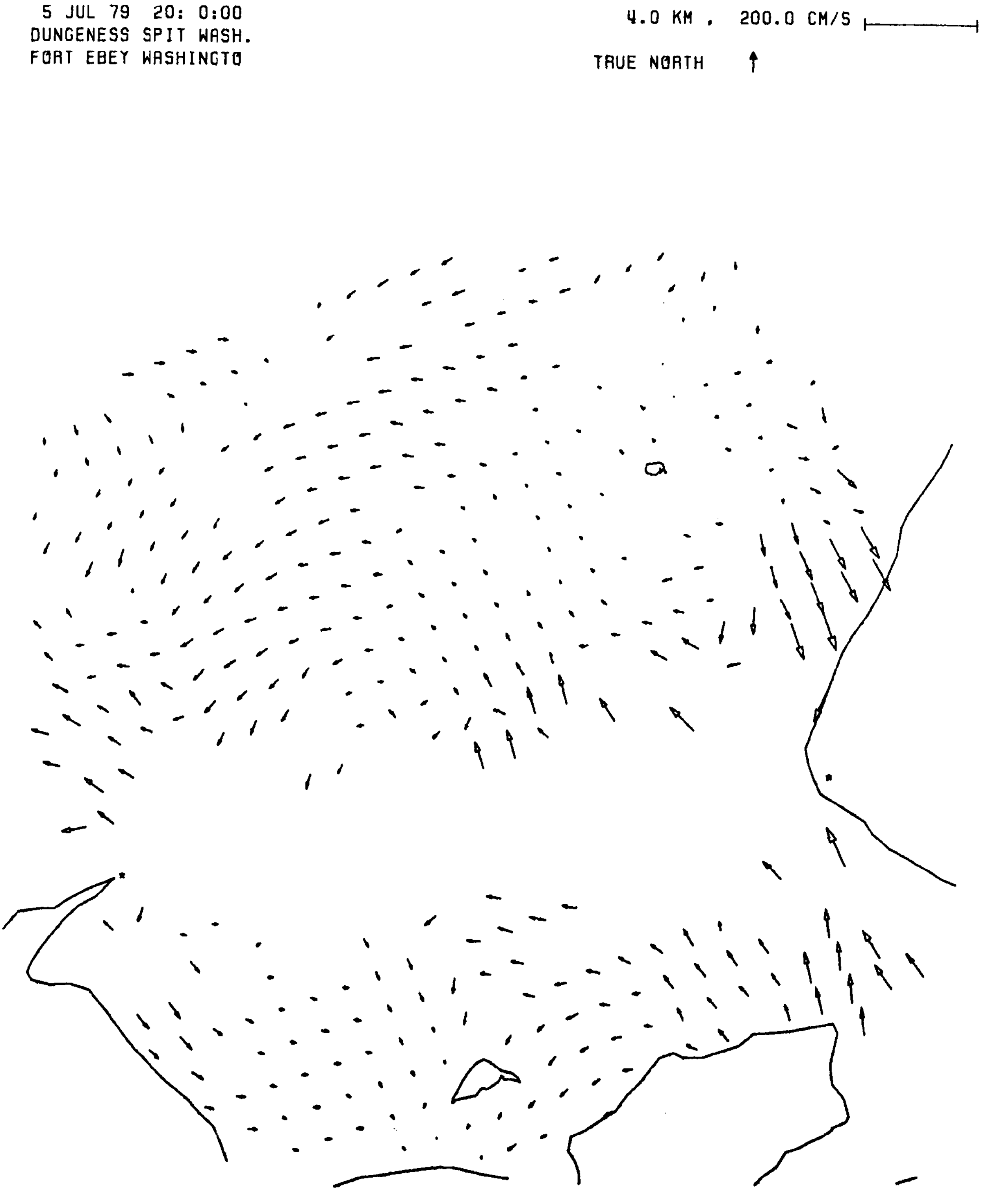
FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH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FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH

5 JUL 79 23: 0:00
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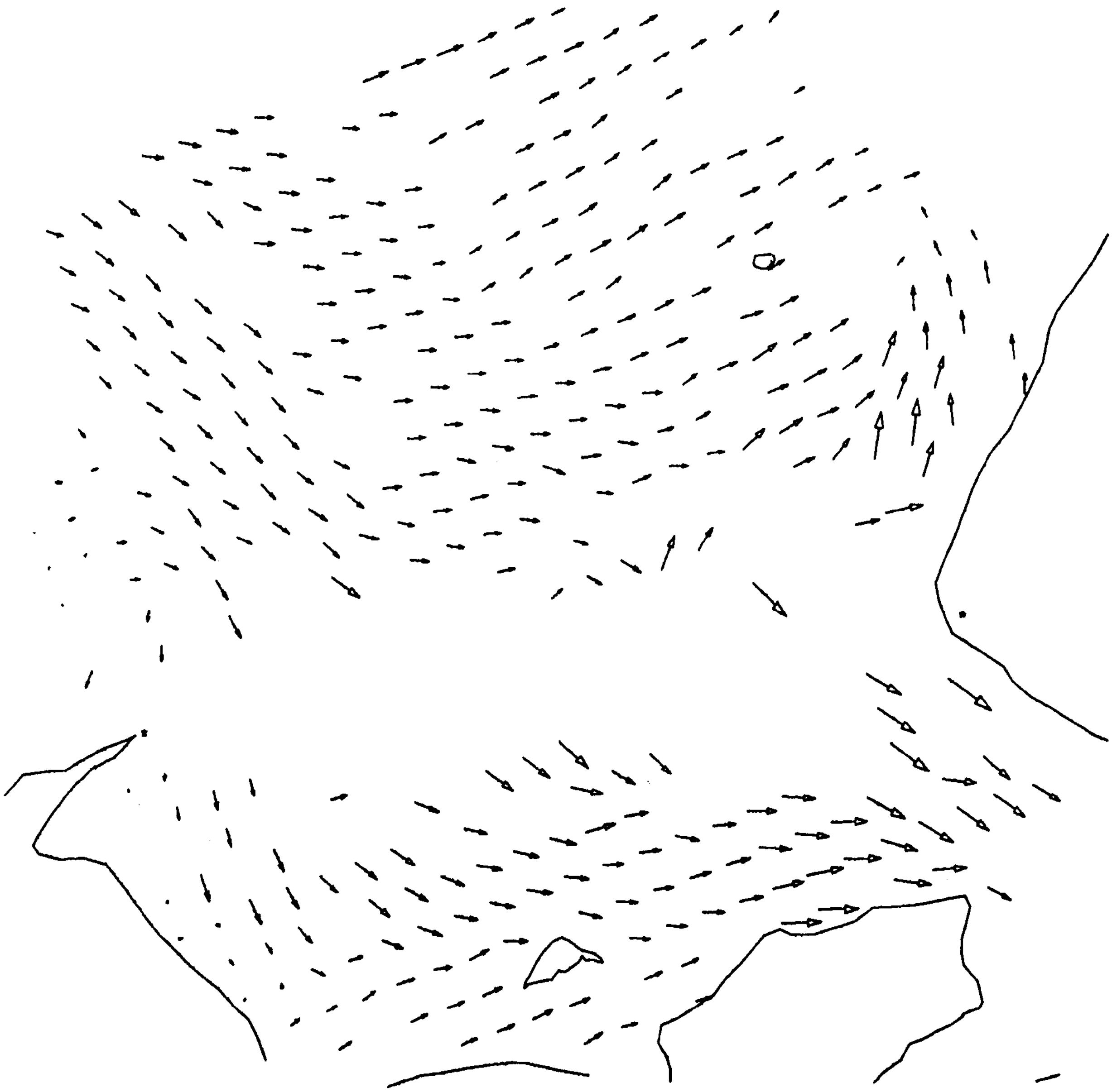
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH



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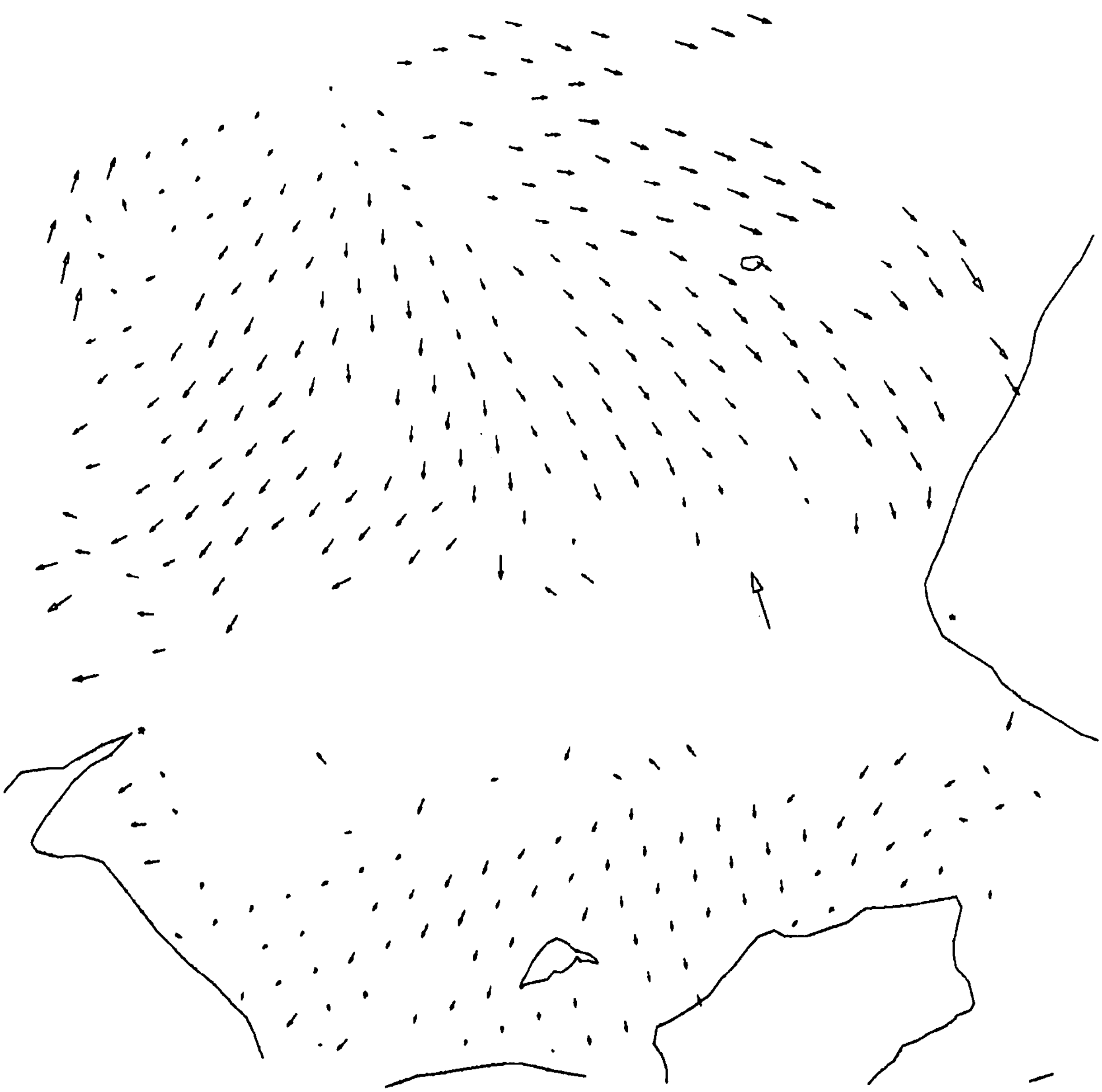
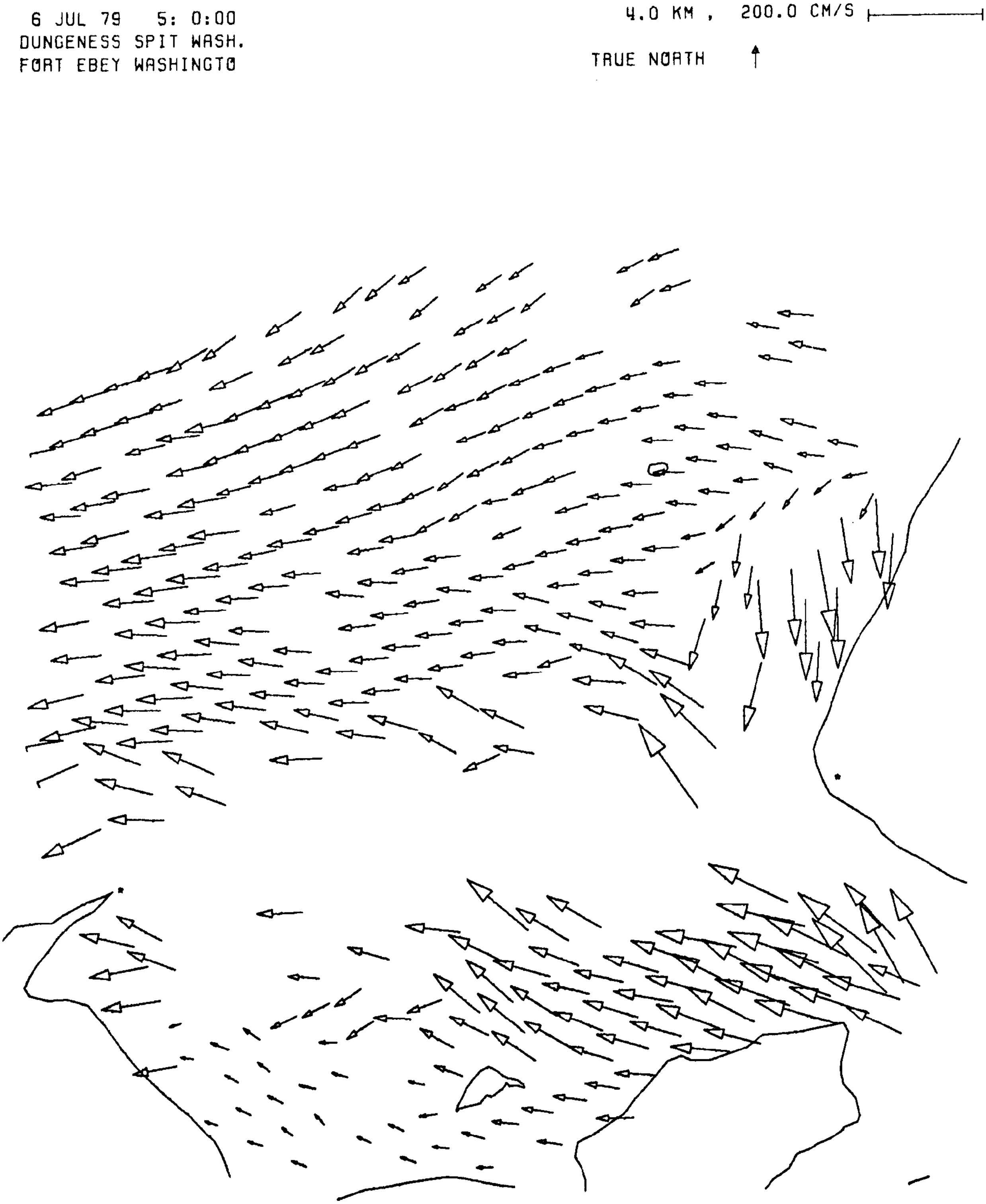
FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH

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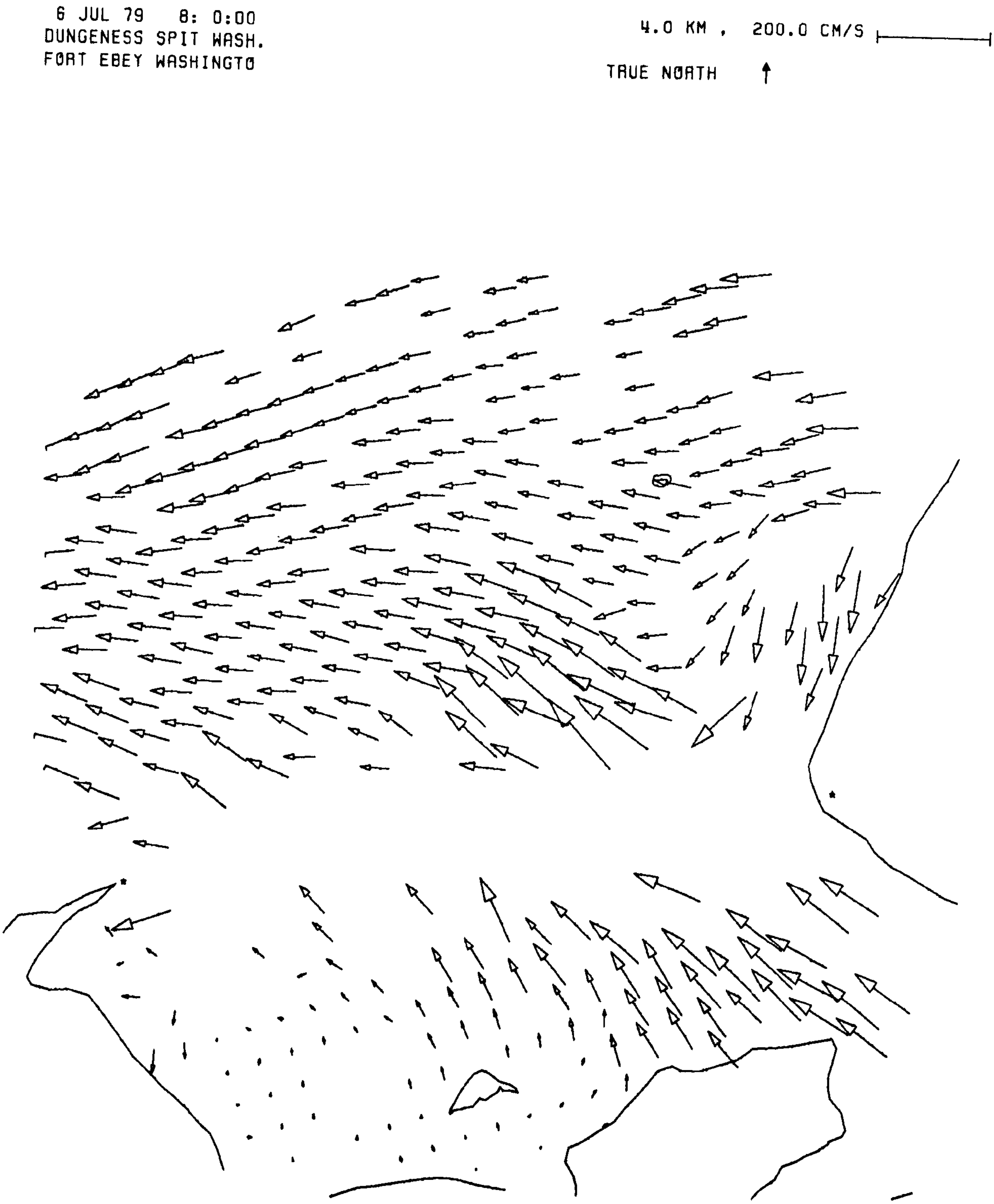
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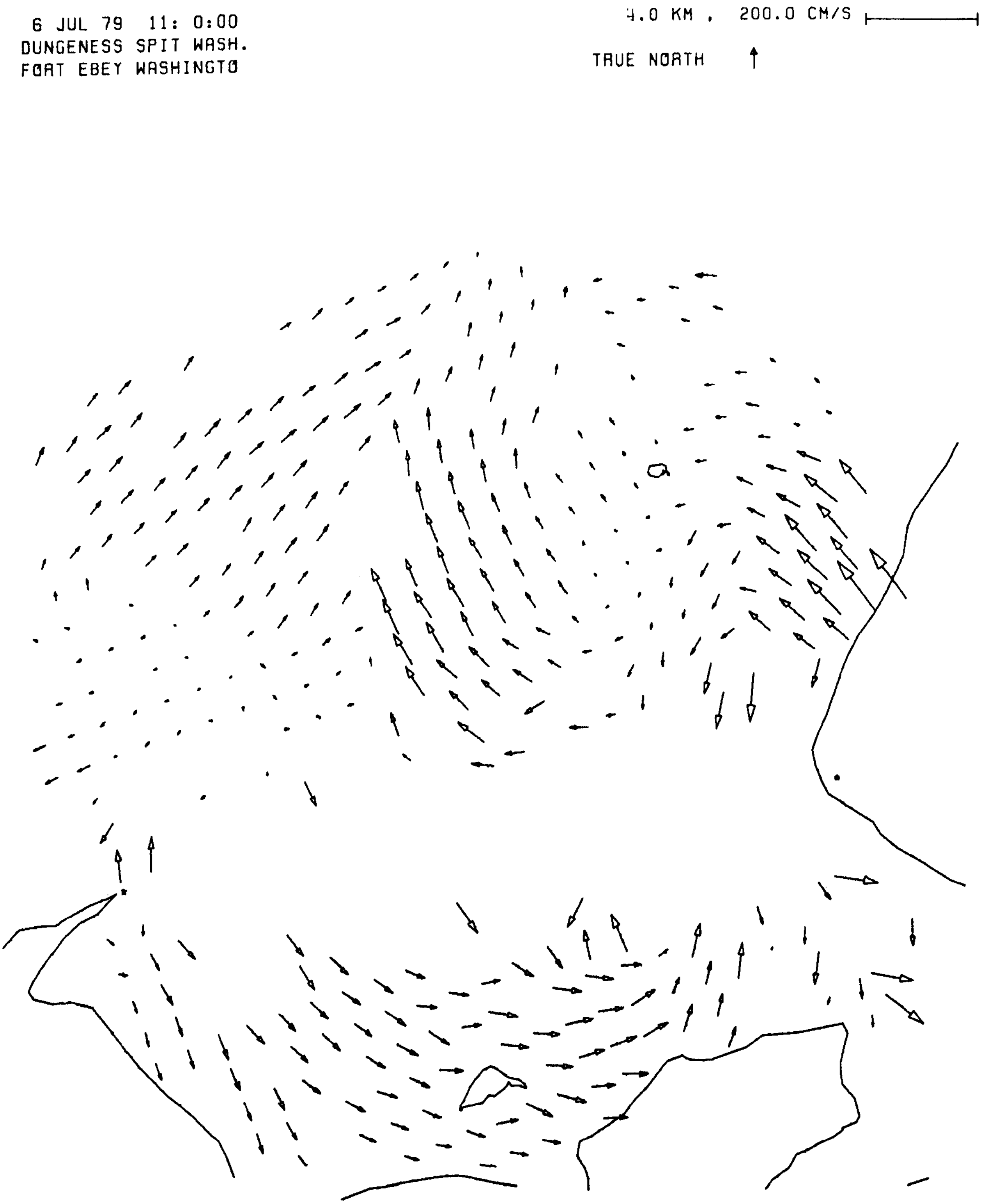
FØRT EBEY WASHINGTØ
4.0 KM , 200.0 CM/S
TRUE NØRTH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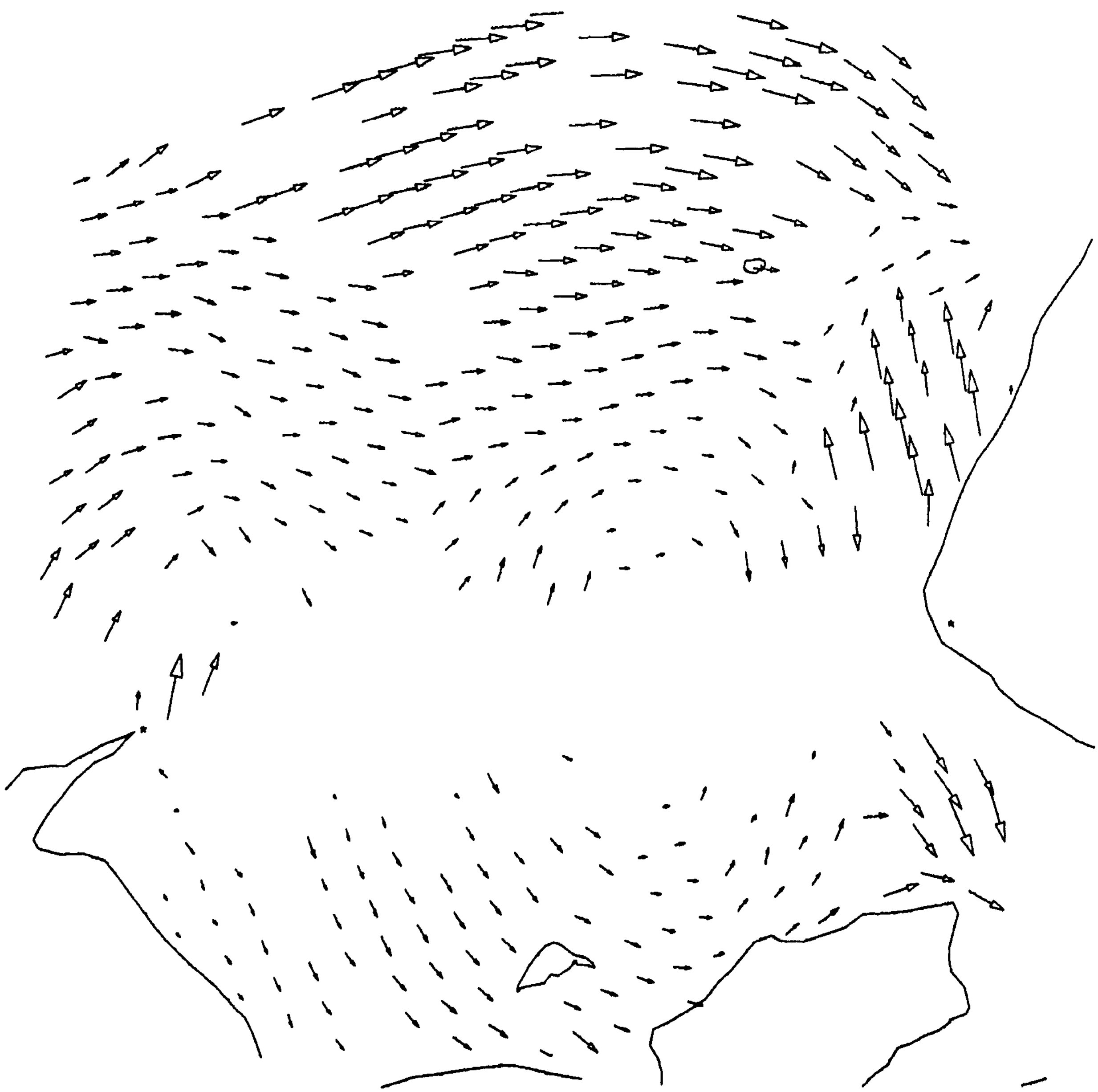
FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH

6 JUL 79 14: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH ↑



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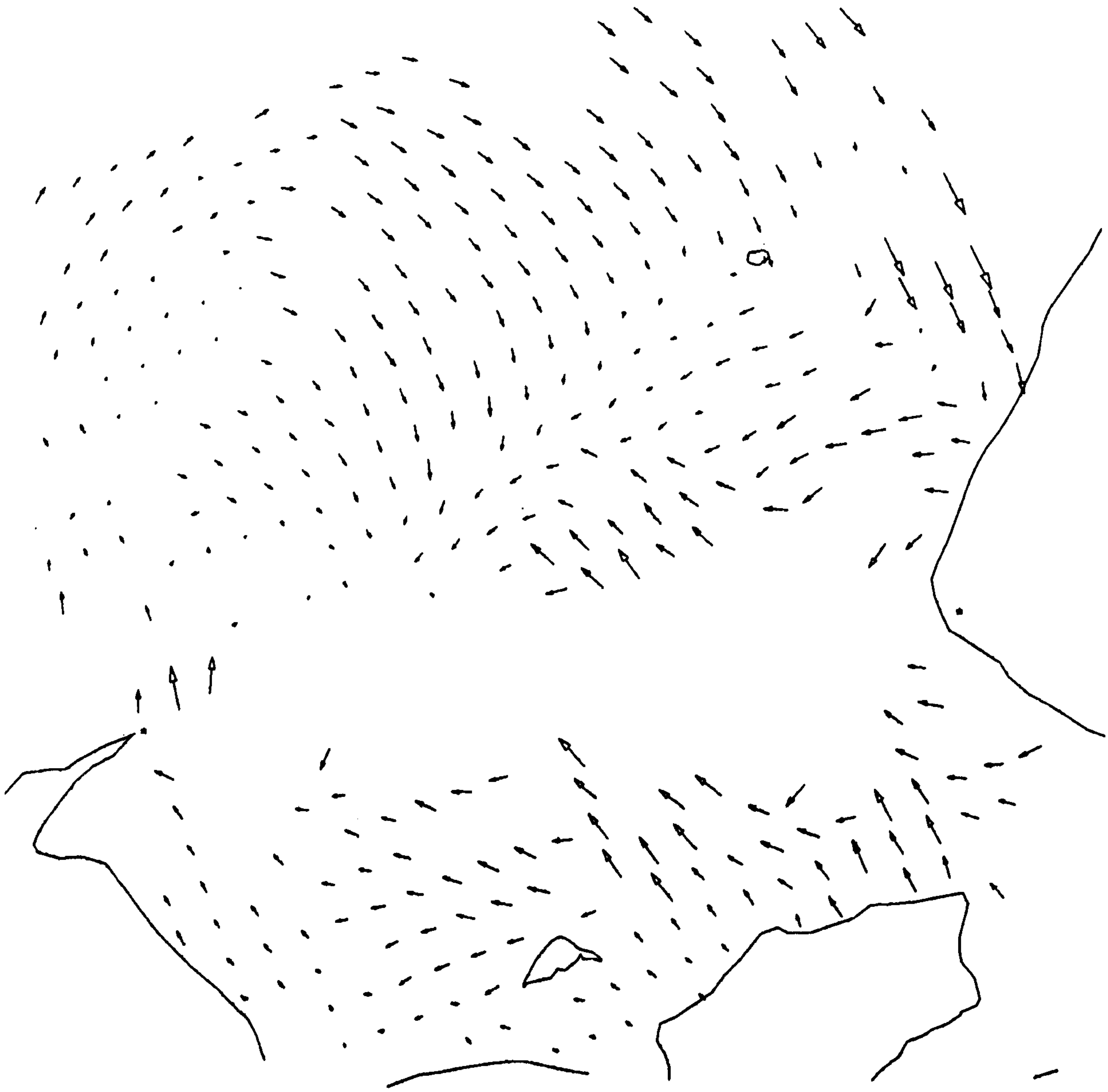

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4.0 KM , 200.0 CM/S

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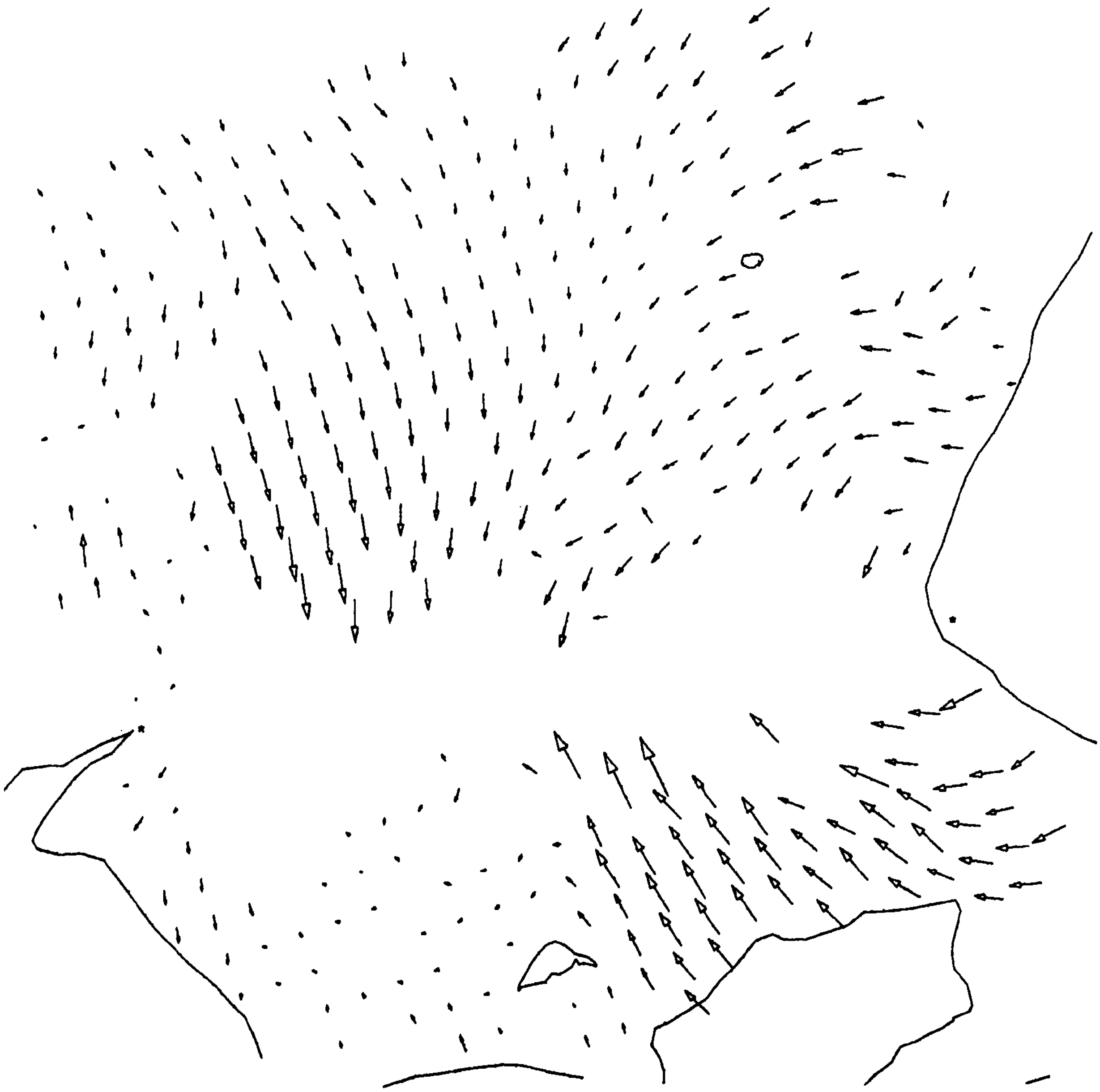

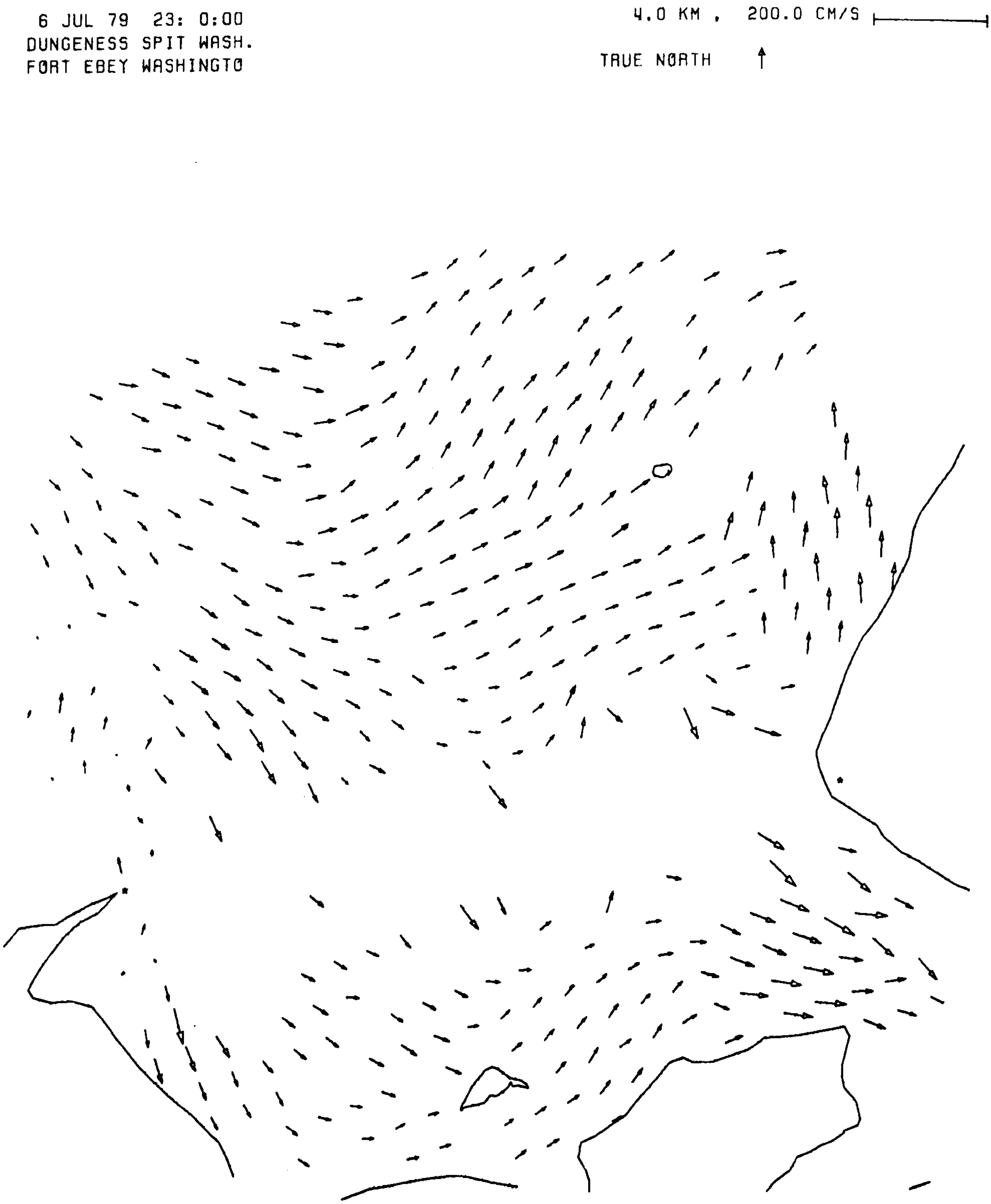
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FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
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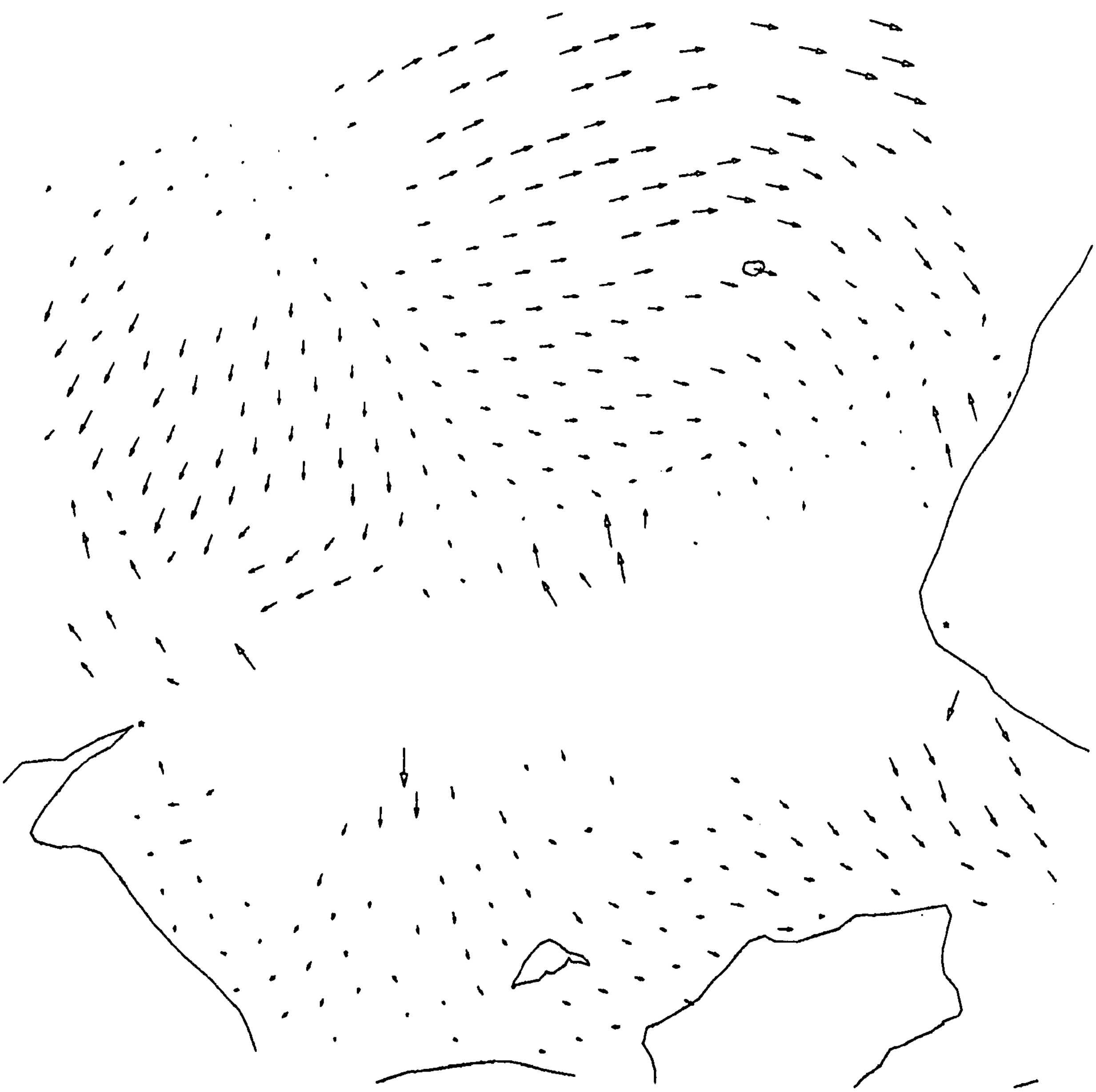

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4.0 KM ,   200.0 CM/S

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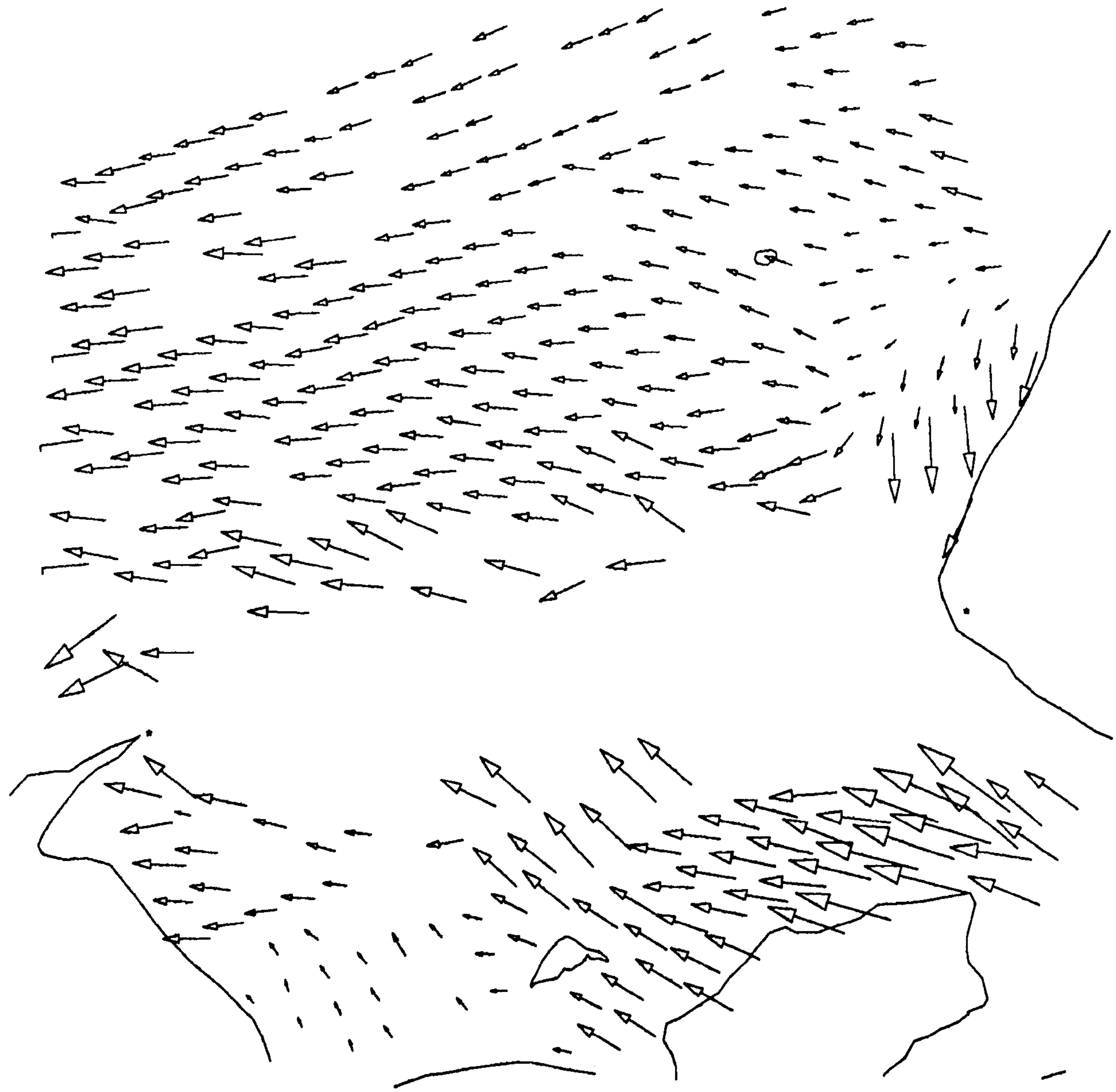

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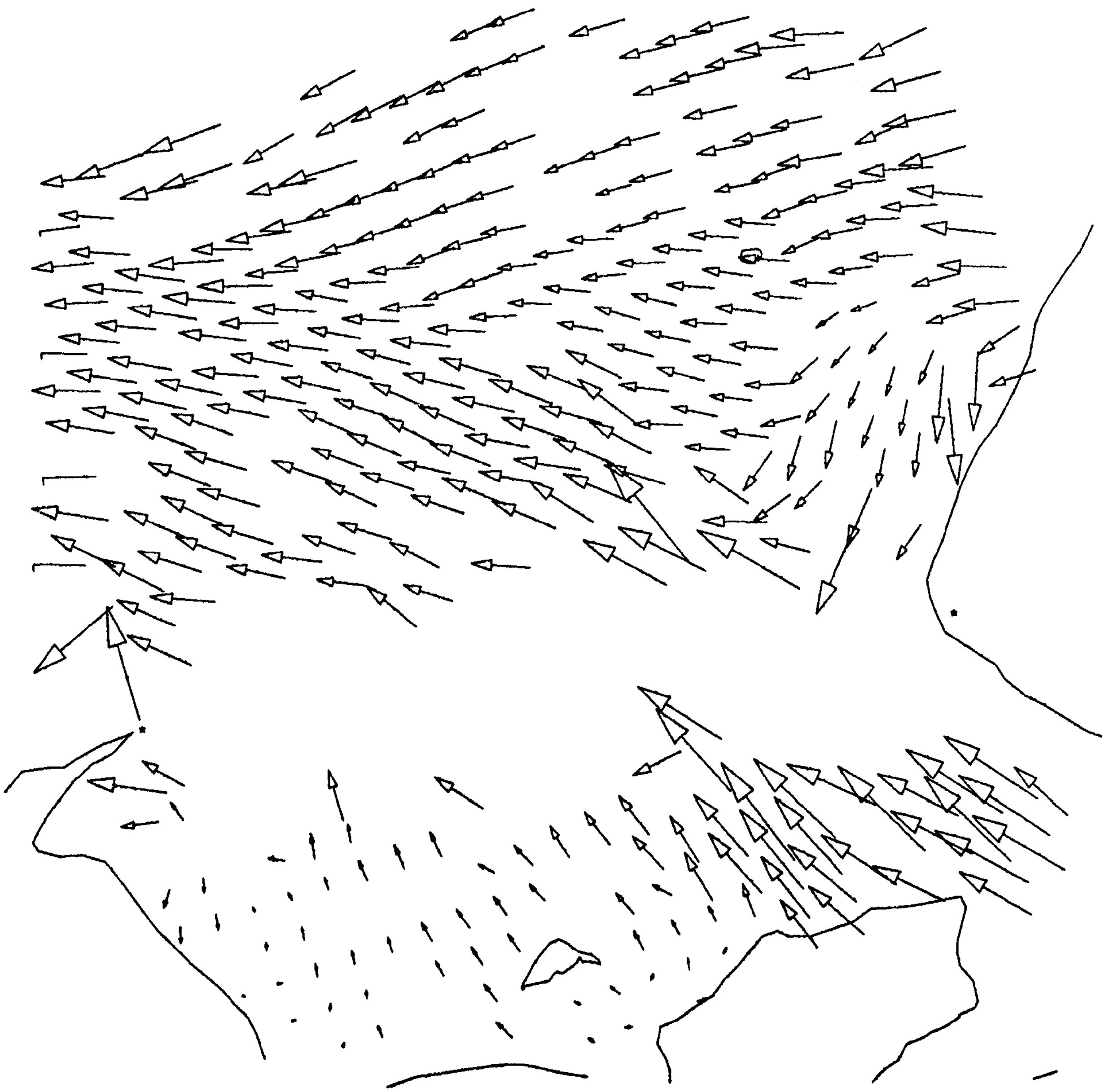

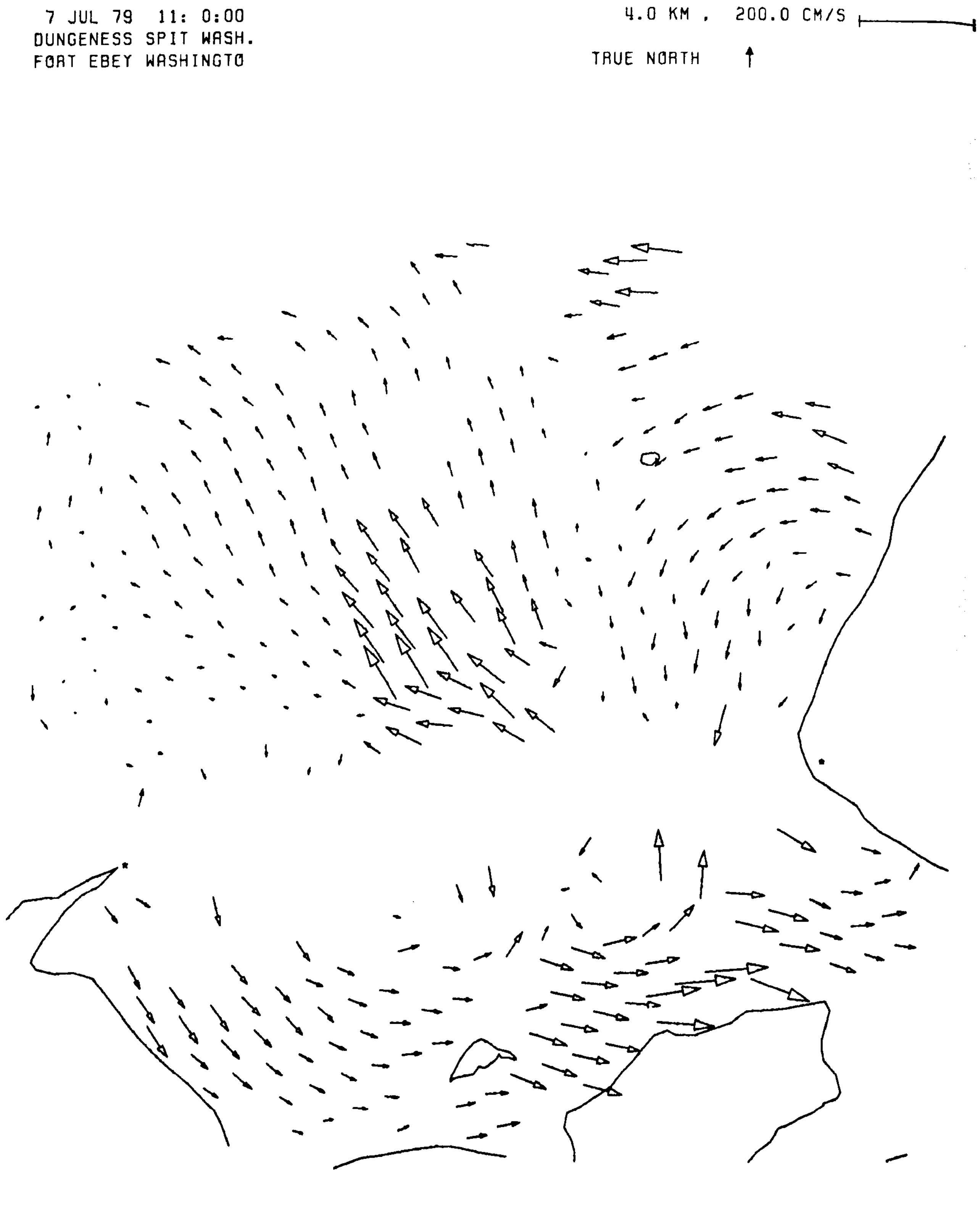
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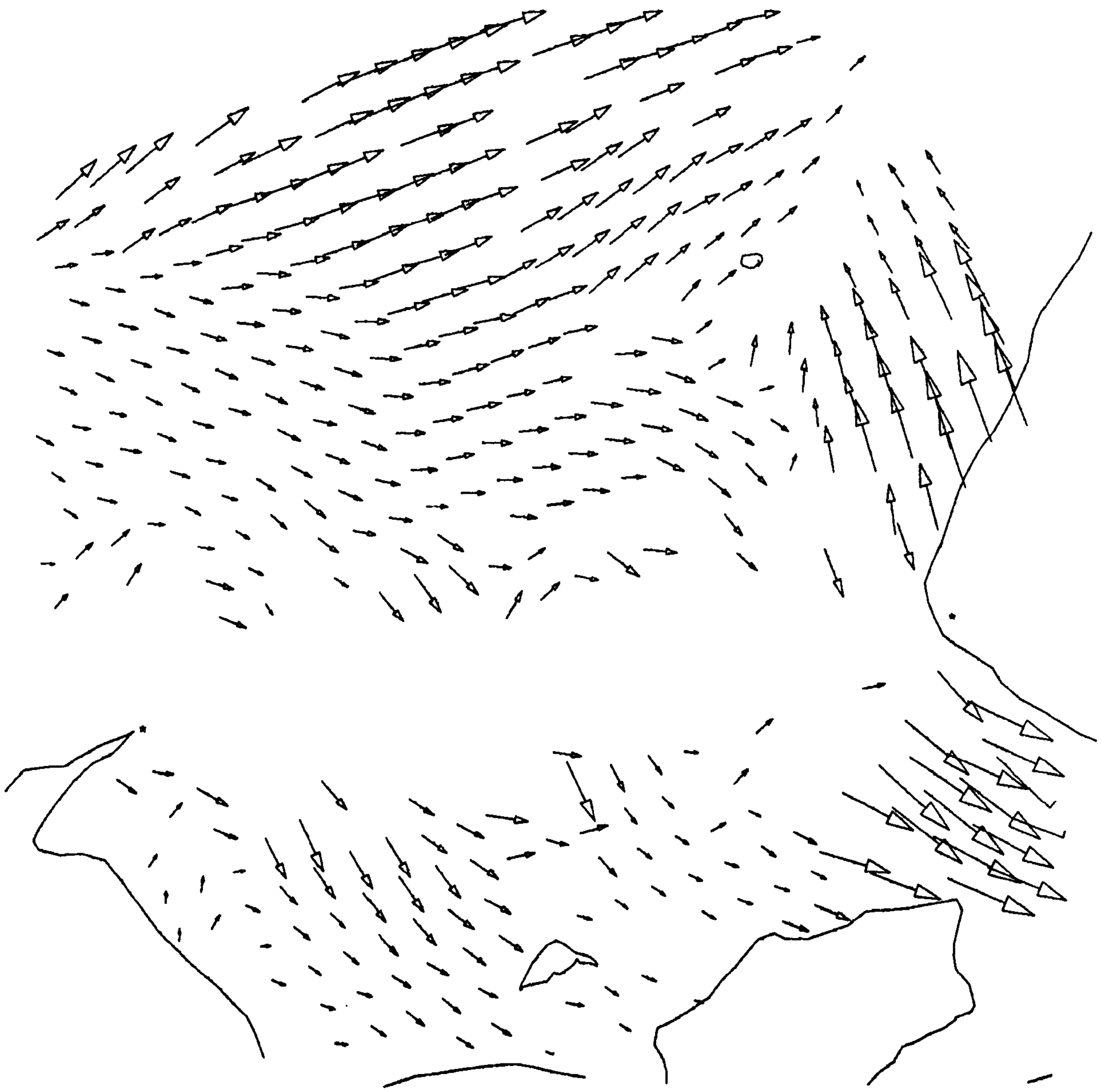

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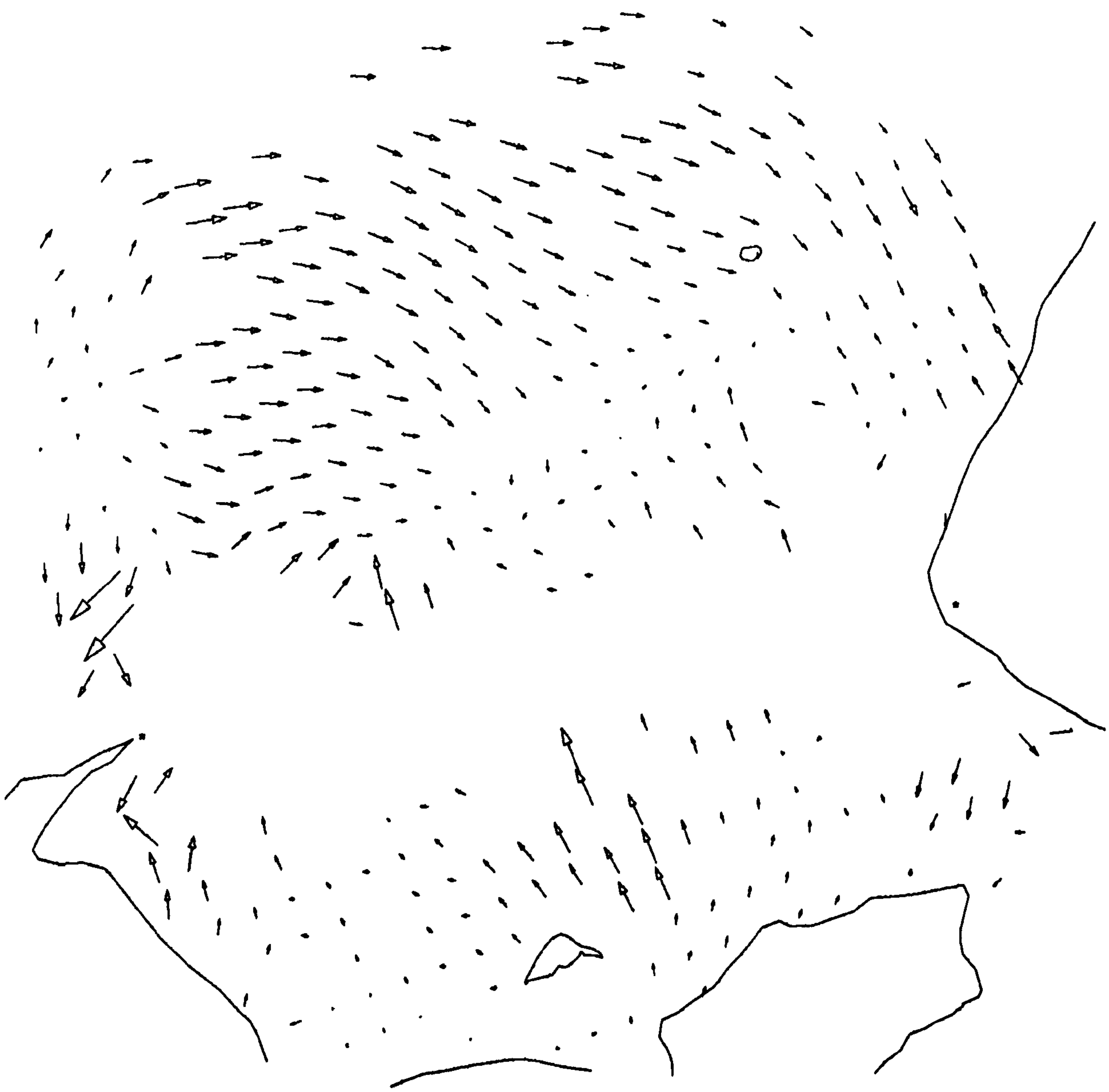

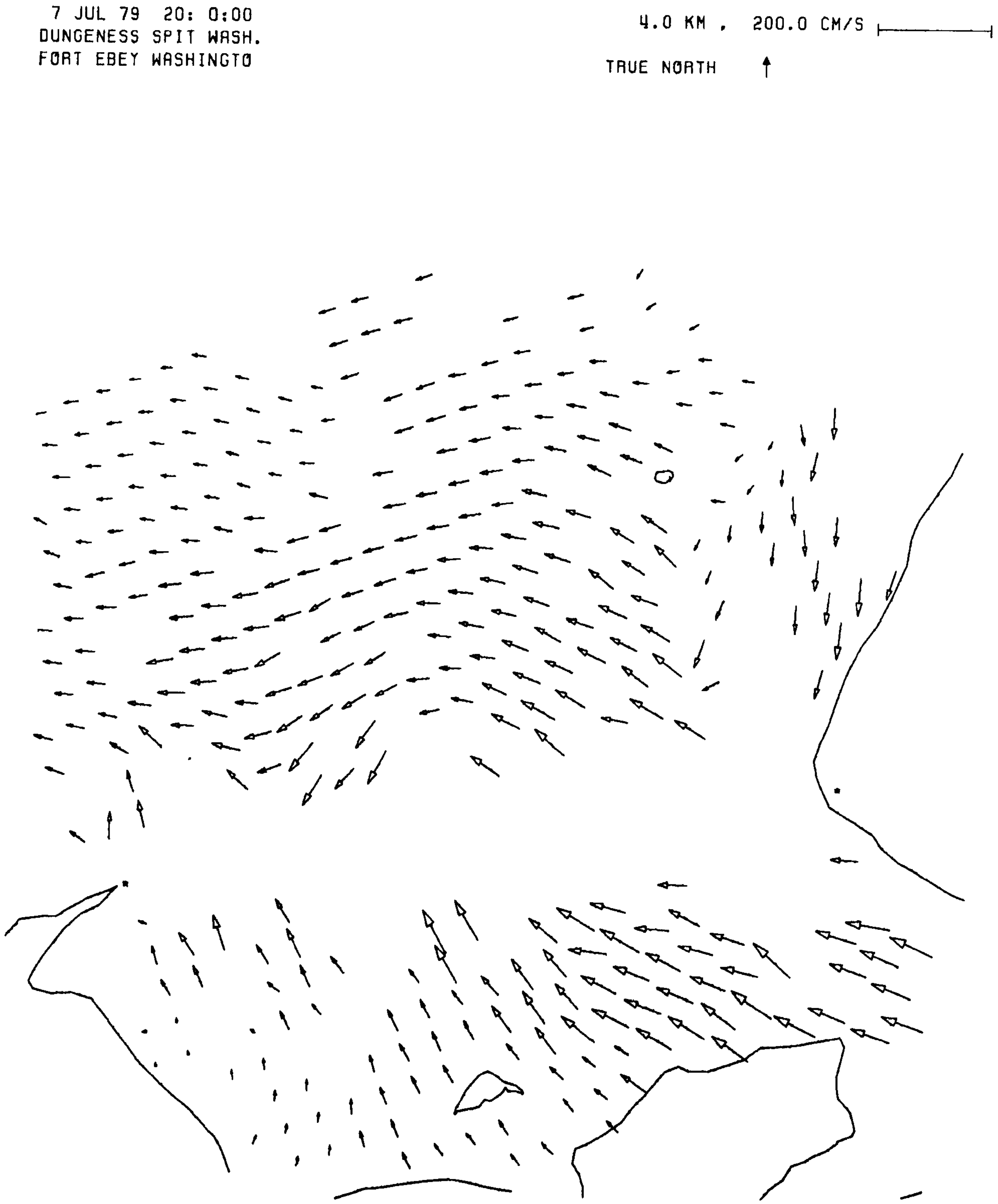
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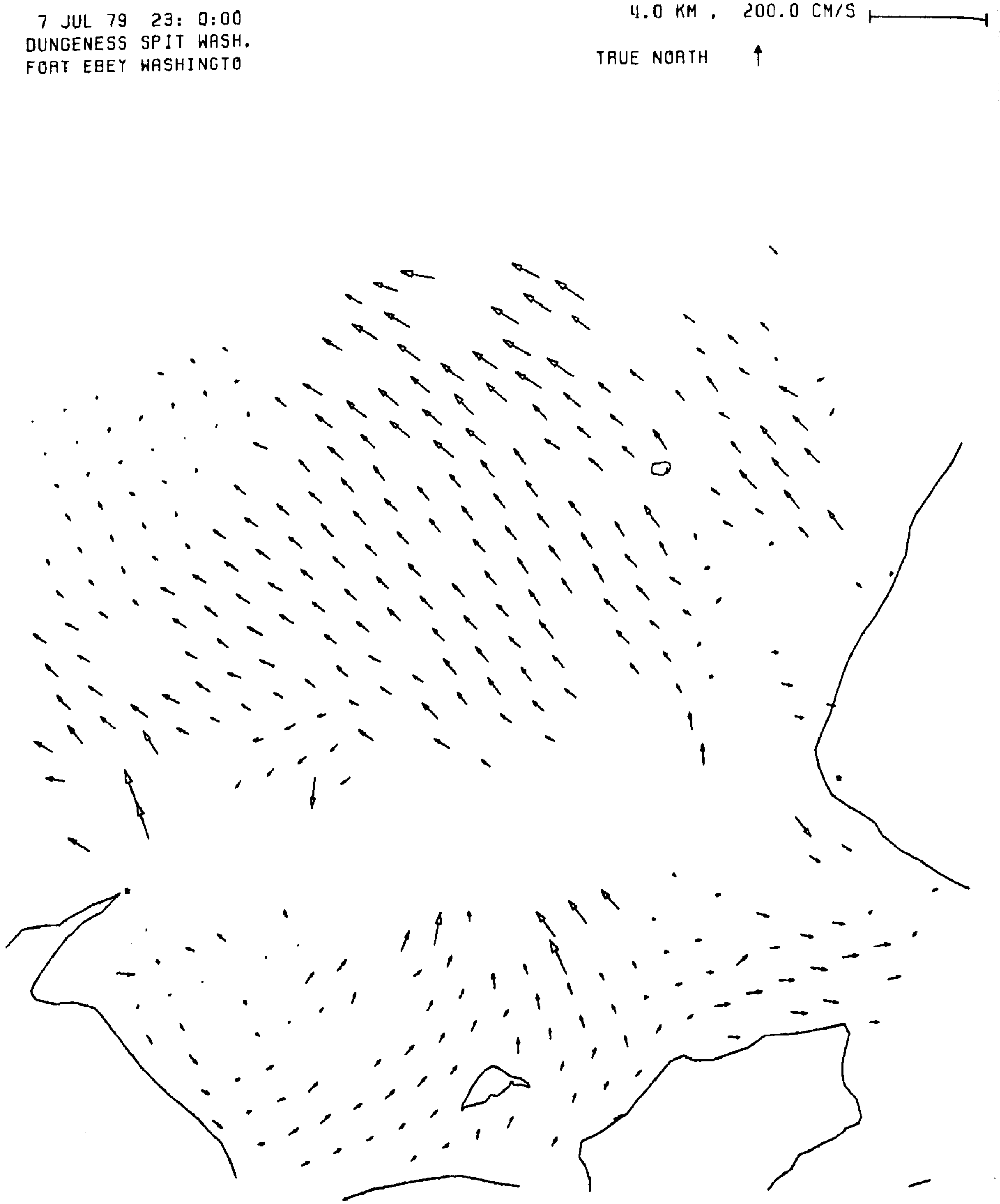

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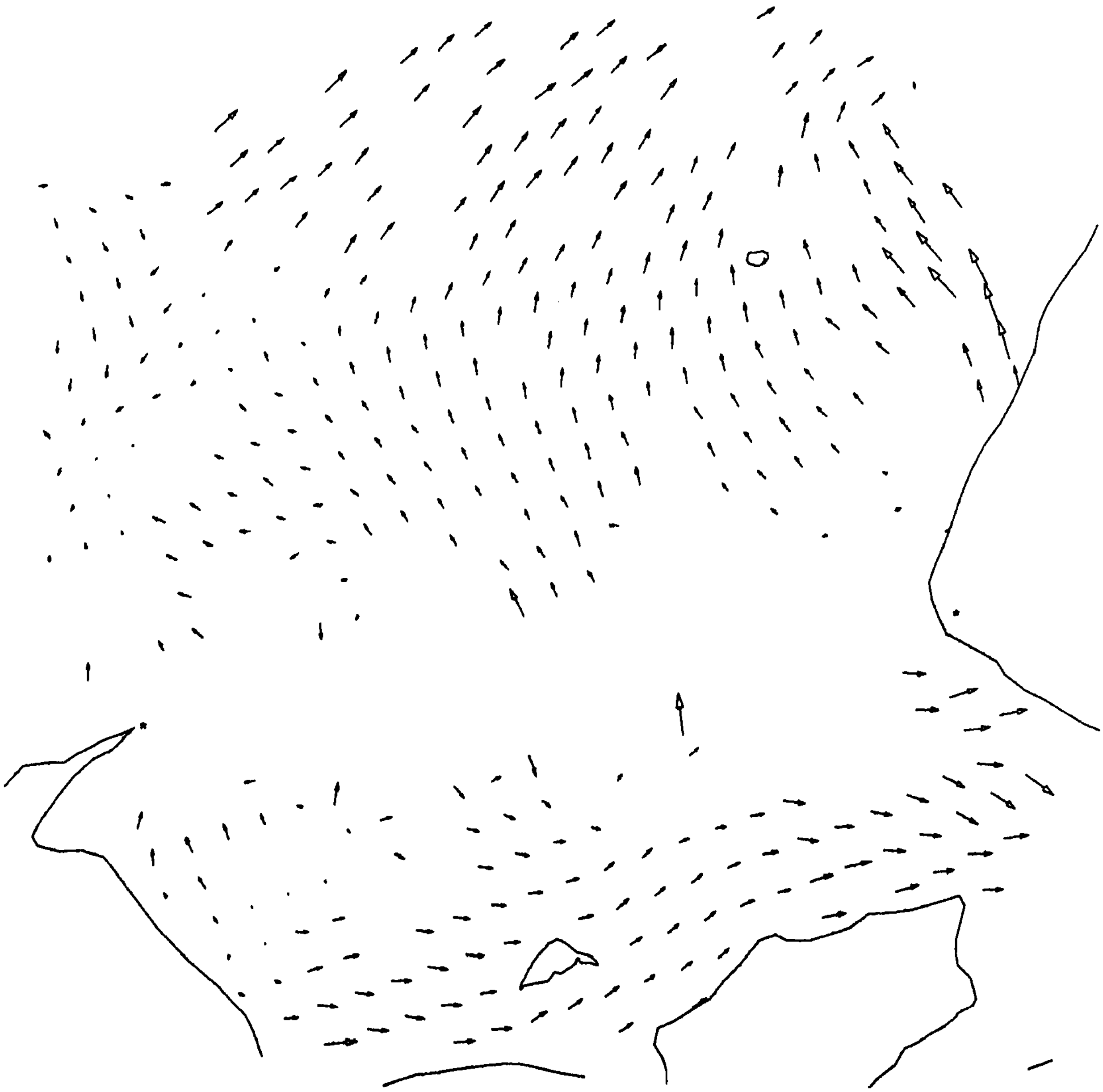

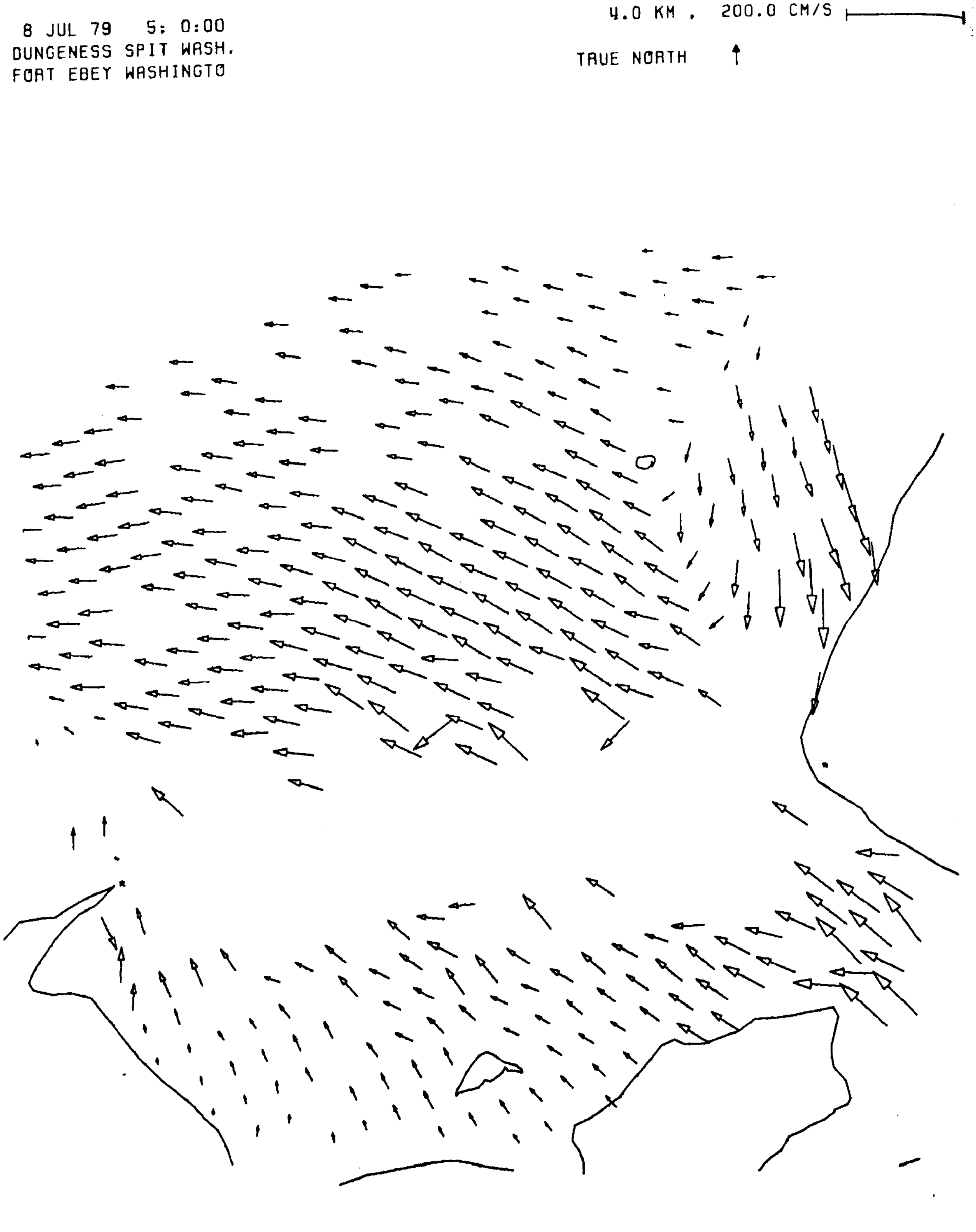
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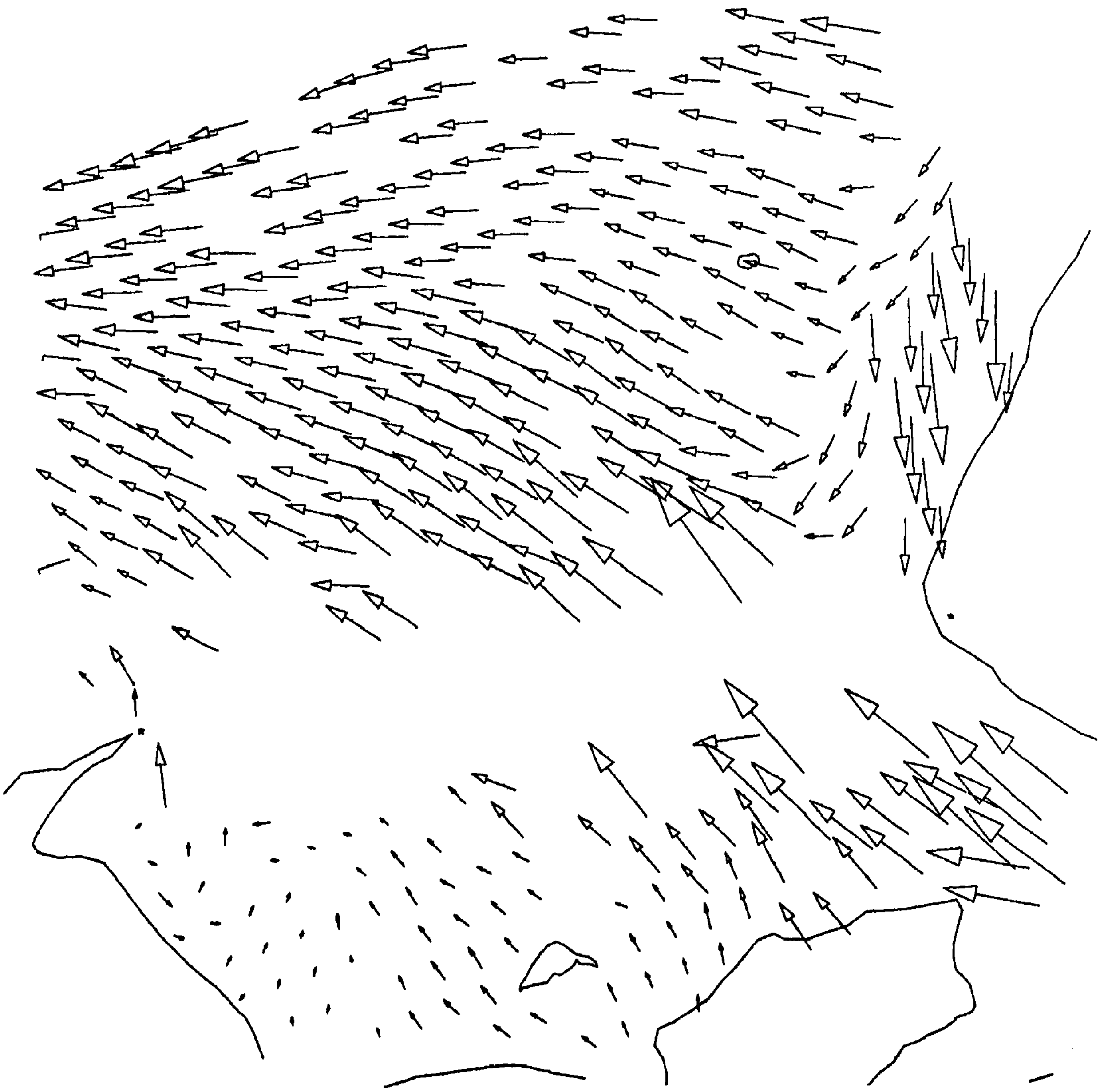
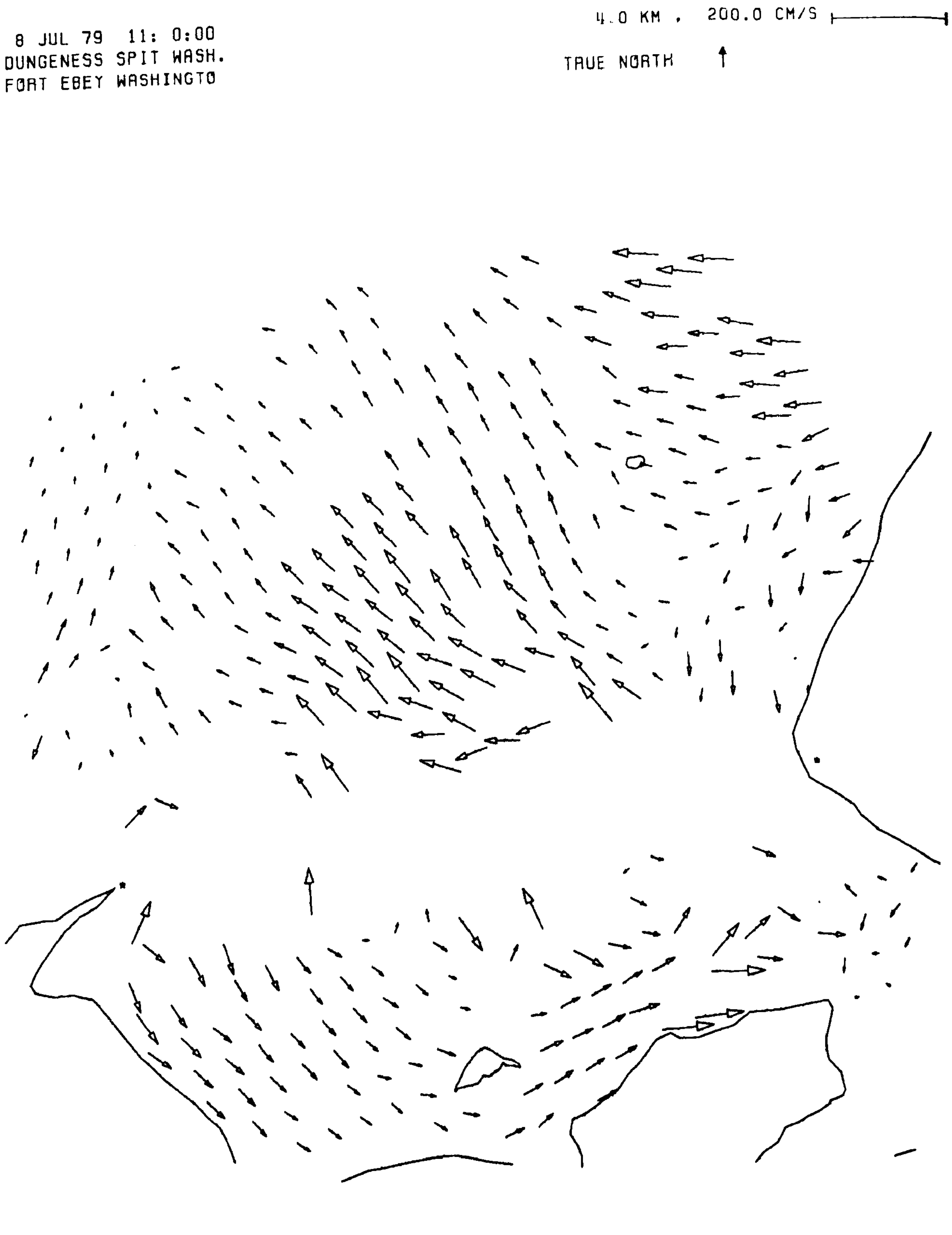
4.0 KM , 200.0 CM/S

TRUE NORTH





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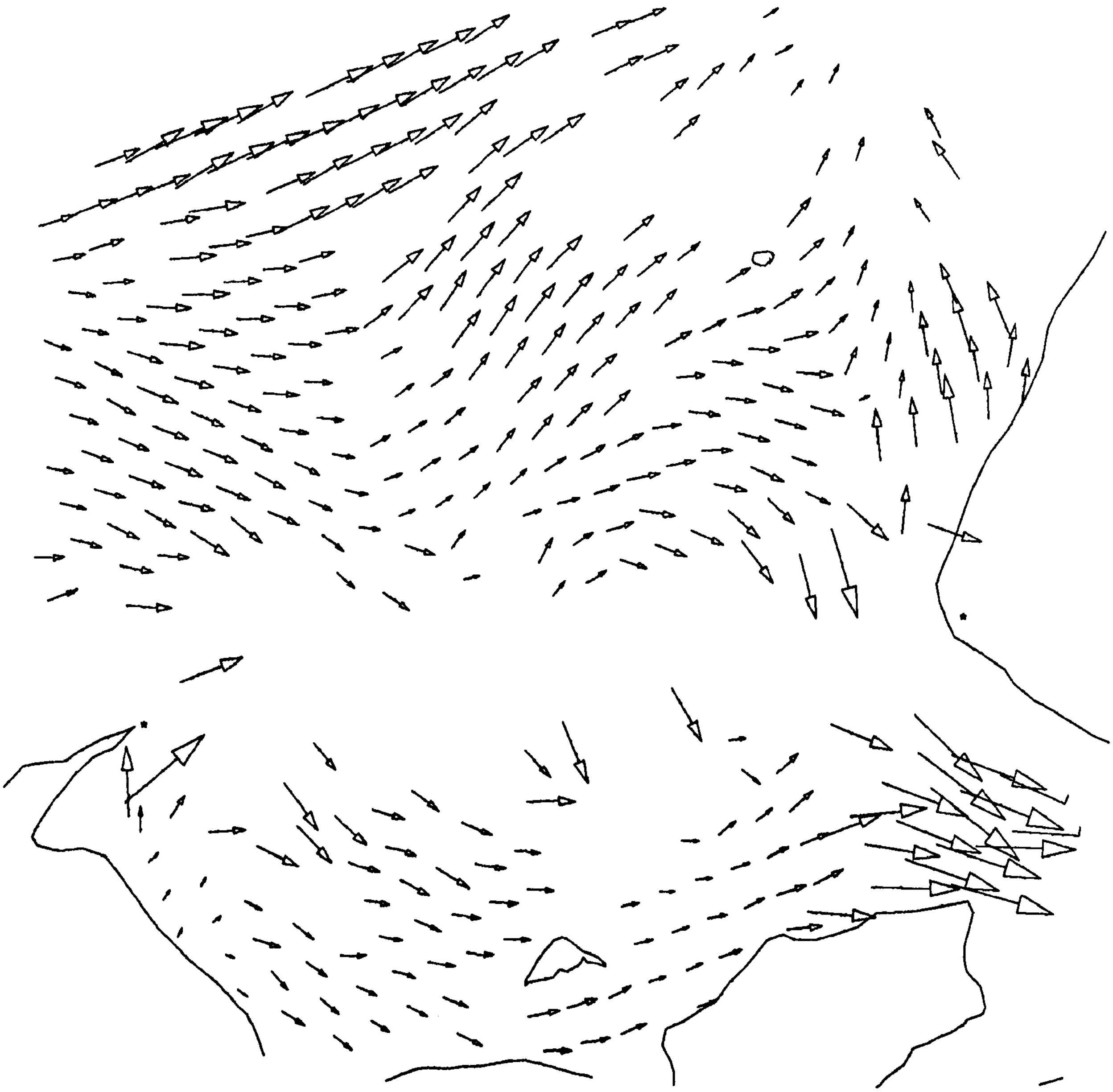
4.0 KM , 200.0 CM/S

TRUE NORTH ↑



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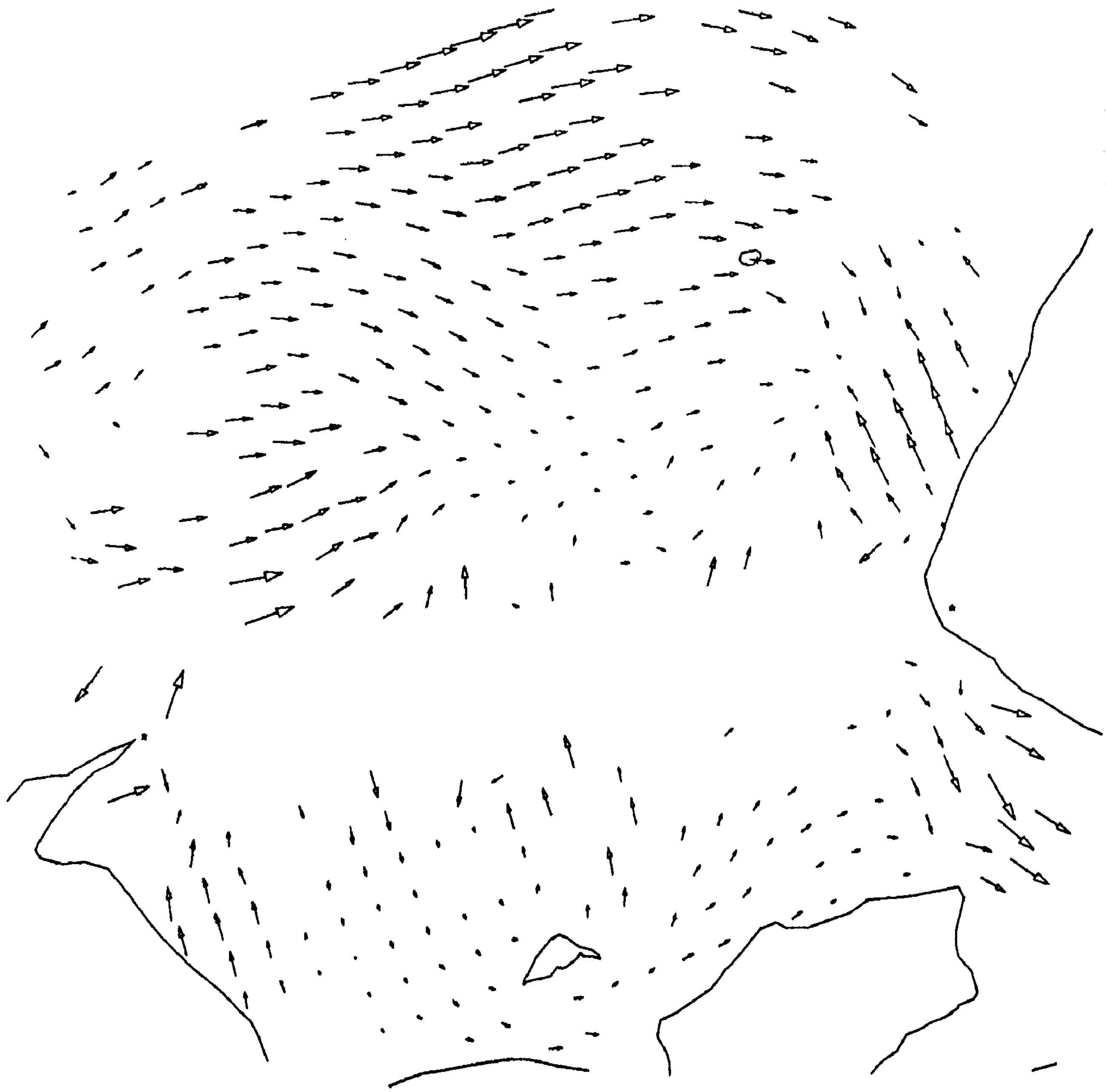

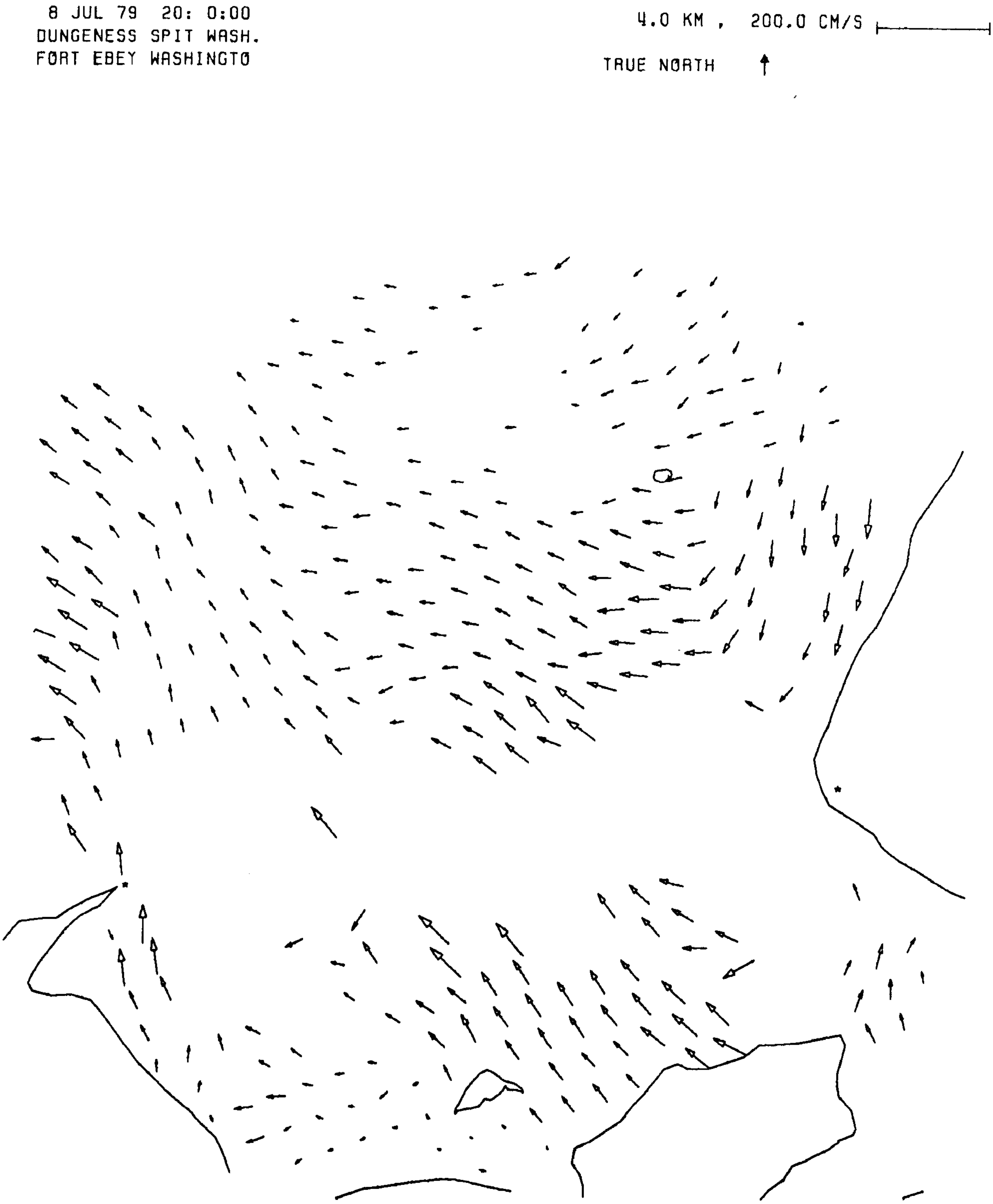
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FORT EBEY WASHINGTO
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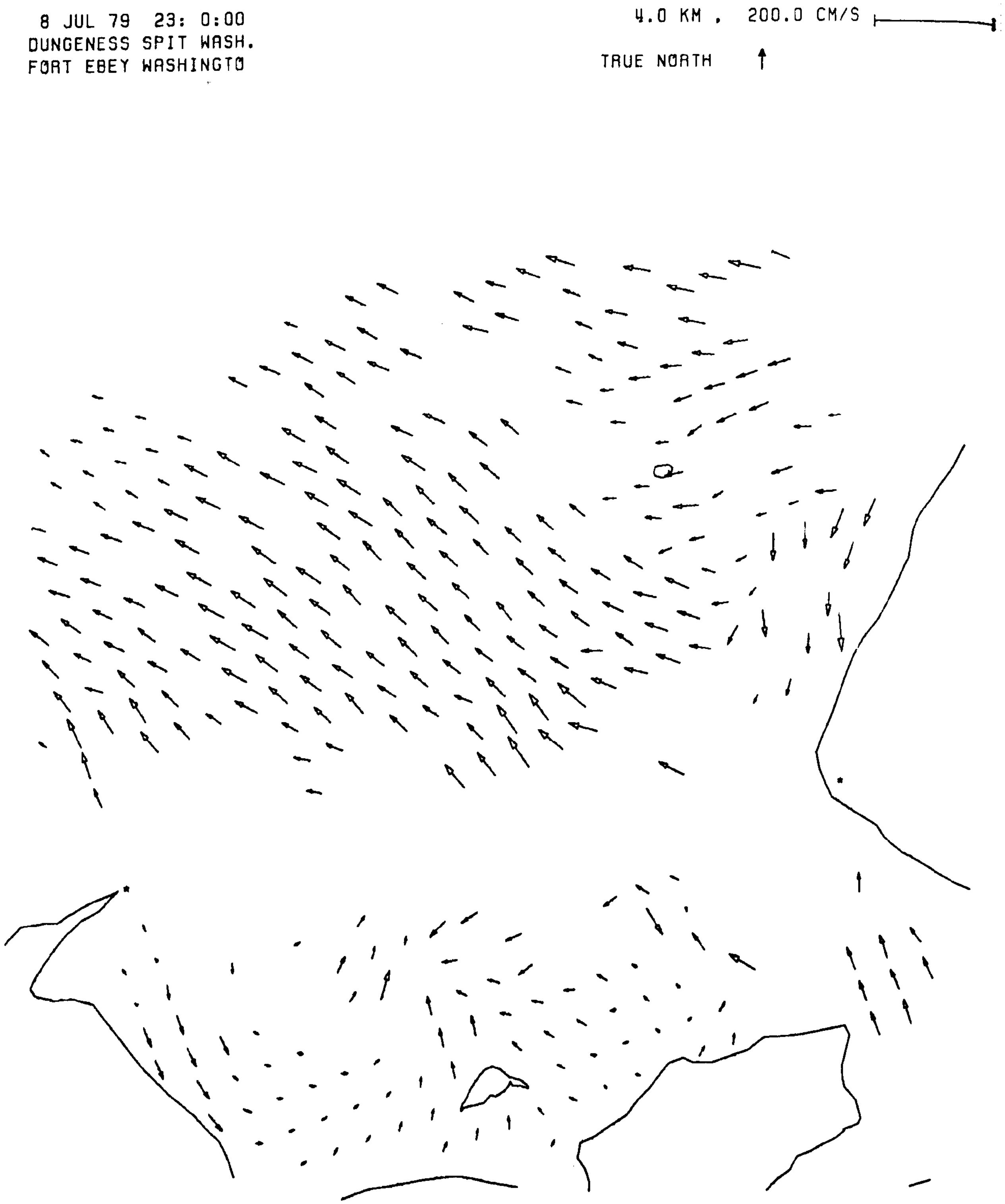
TRUE NORTH



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4.0 KM , 200.0 CM/S
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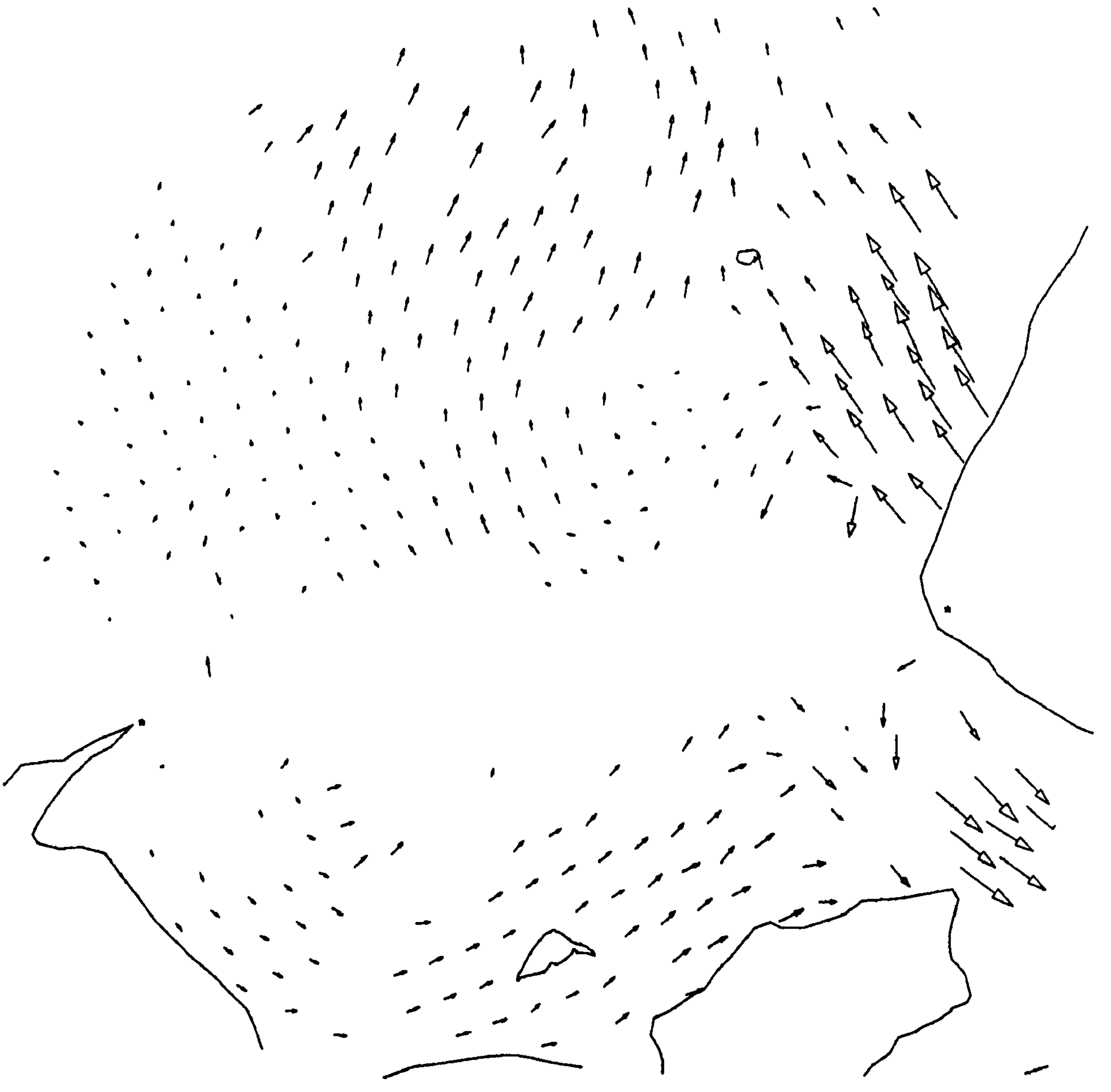
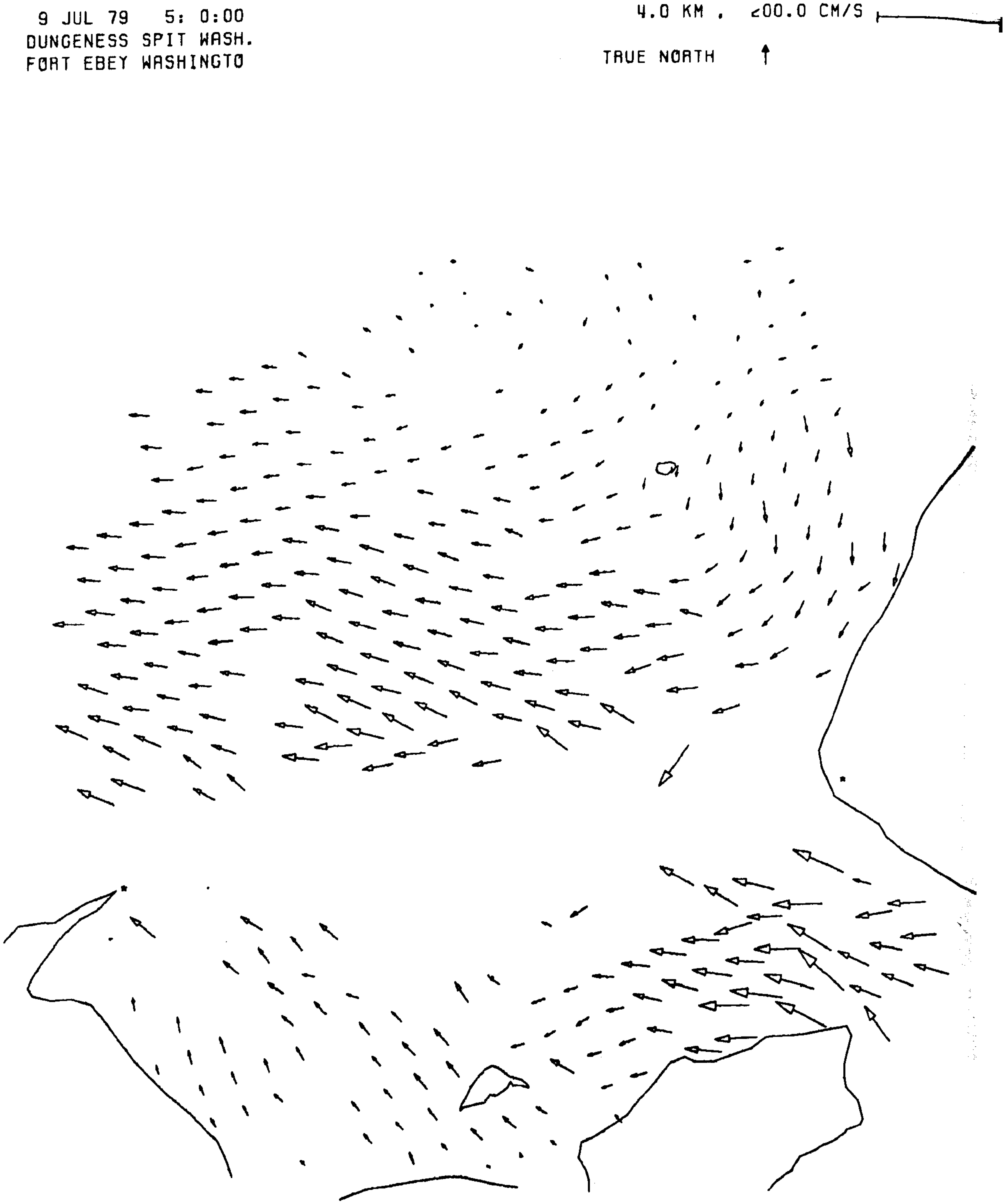
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH

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FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
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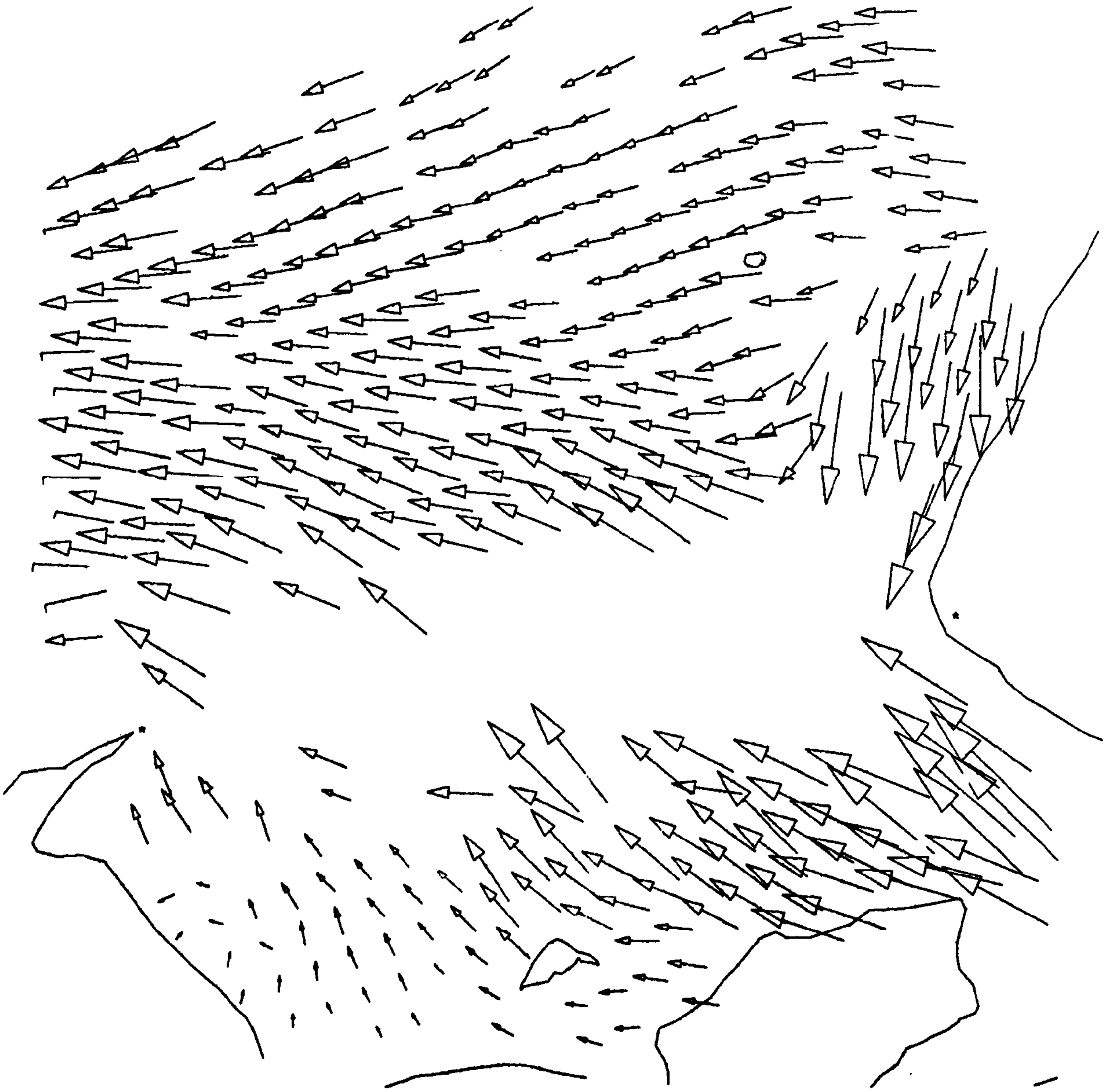
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH ↑



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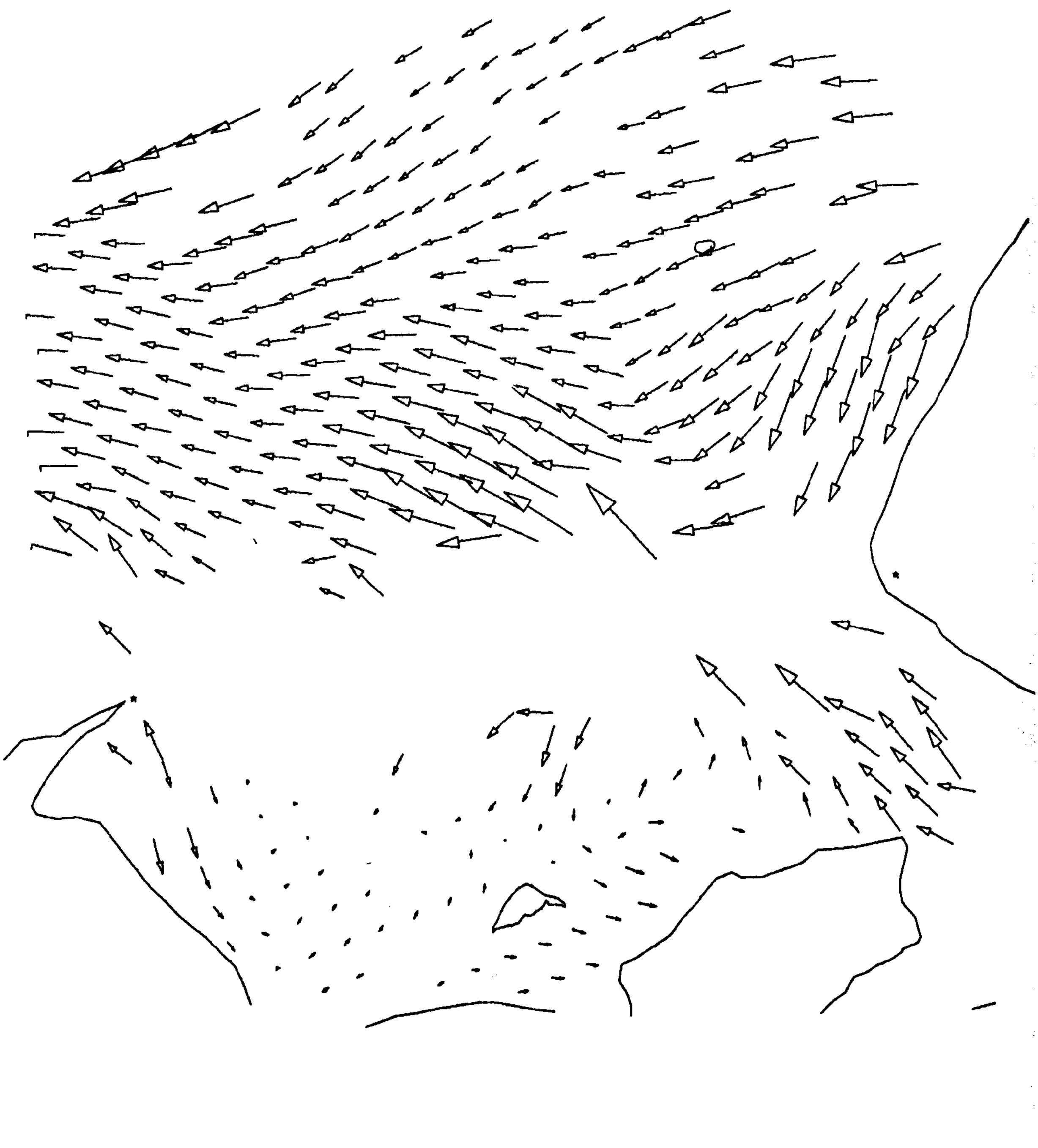
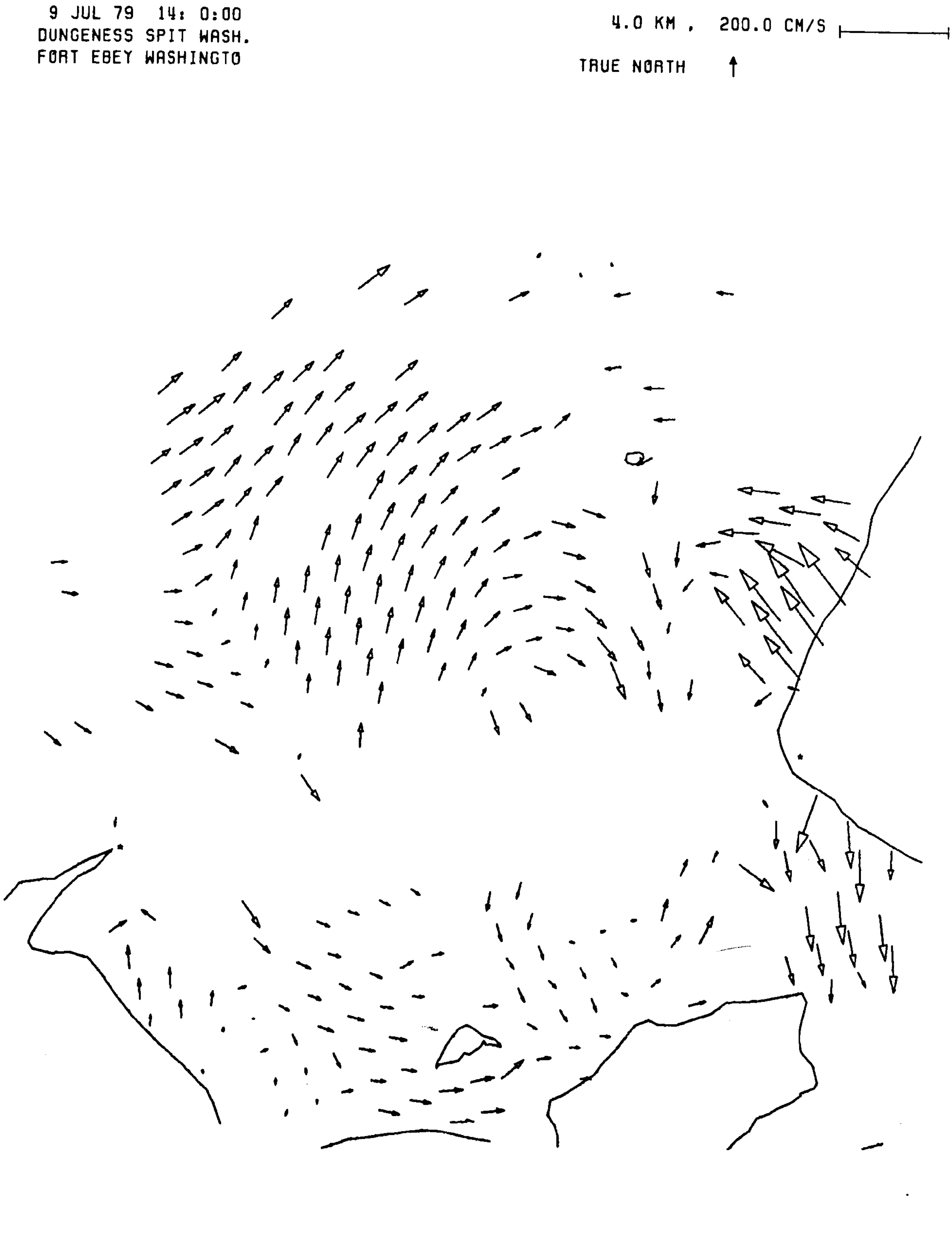
FØRT EBEY WASHINGTØ

4.0 KM , 200.0 CM/S

TRUE NORTH ↑

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FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH

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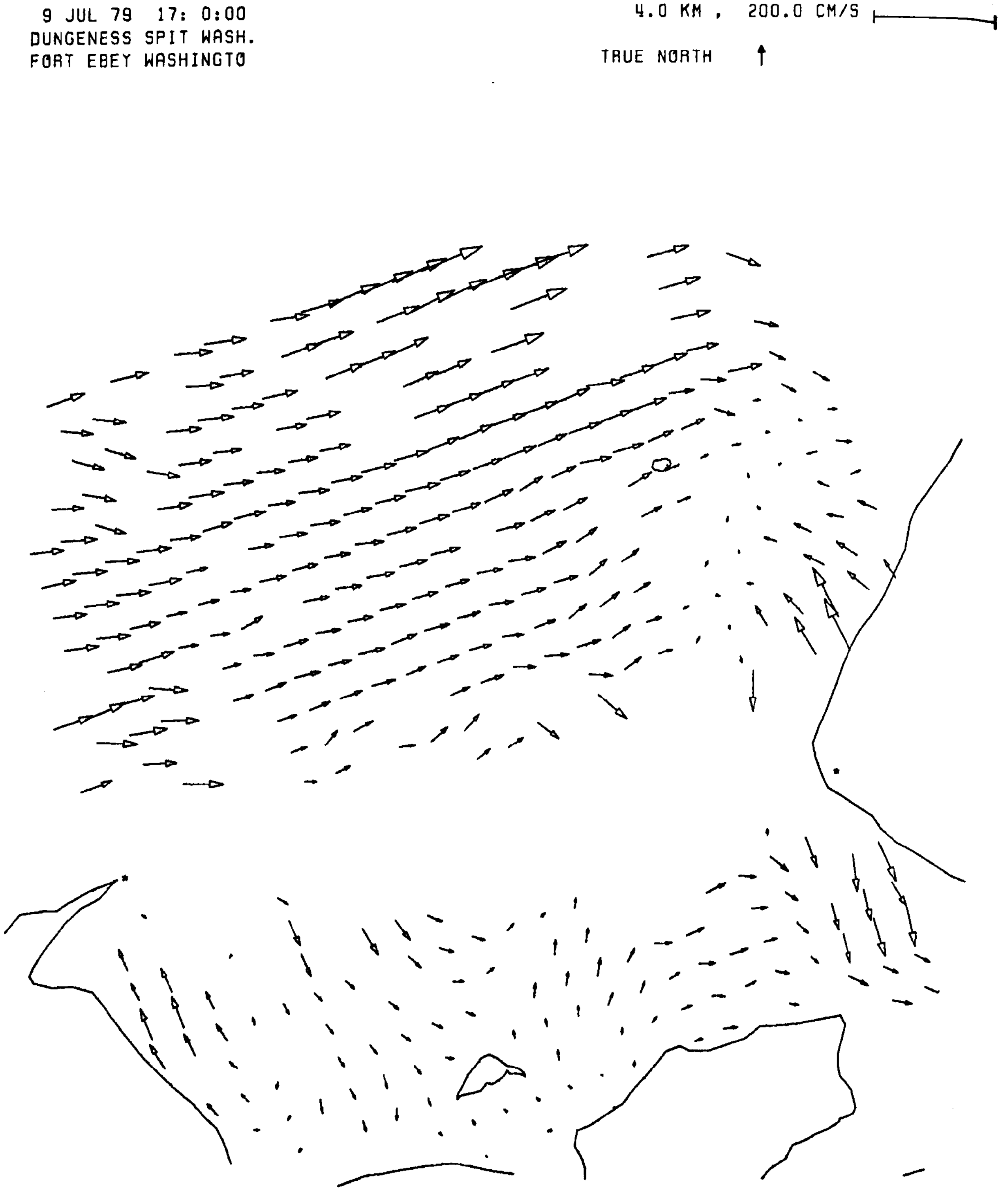
4.0 KM , 200.0 CM/S

TRUE NORTH



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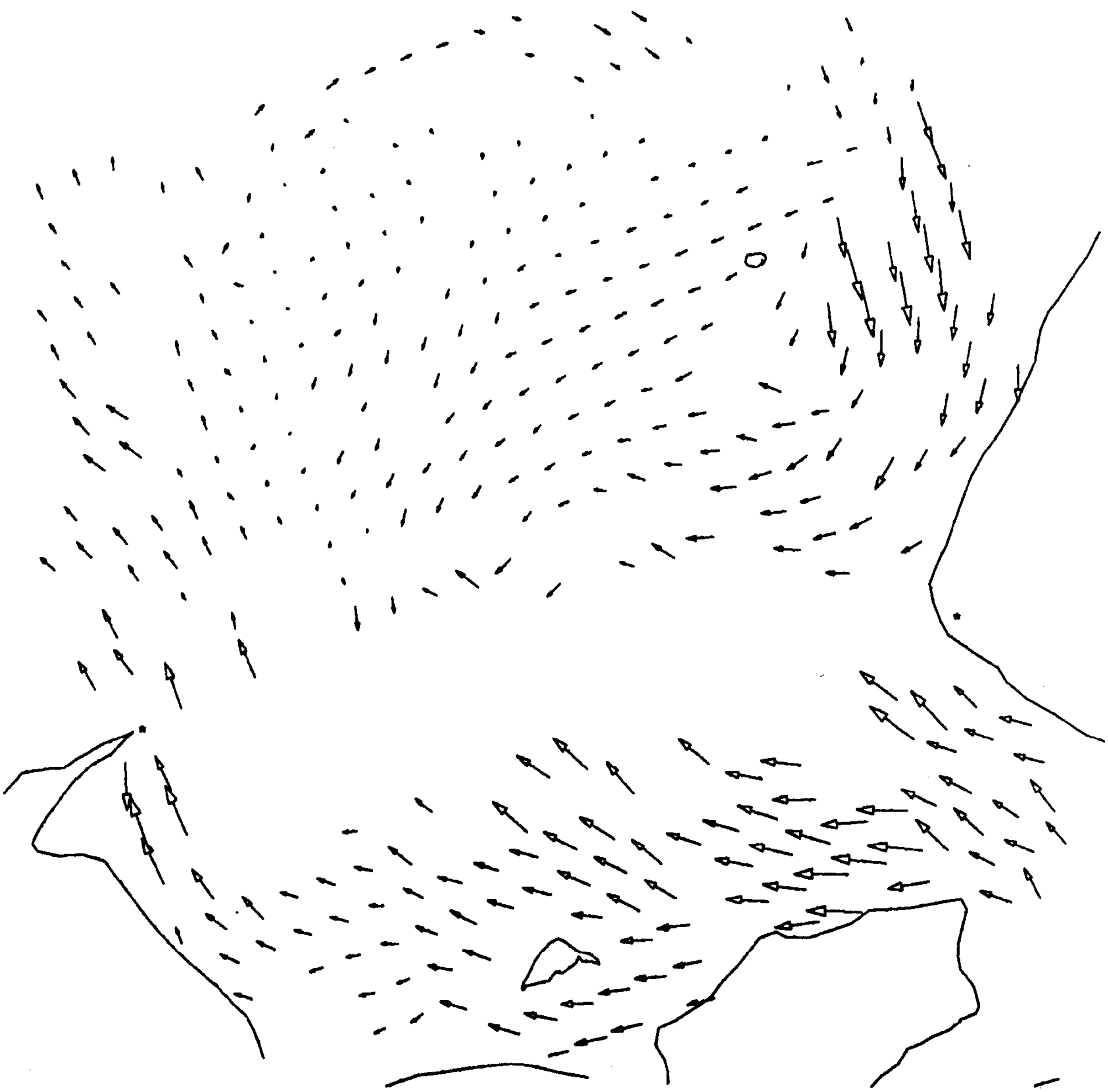

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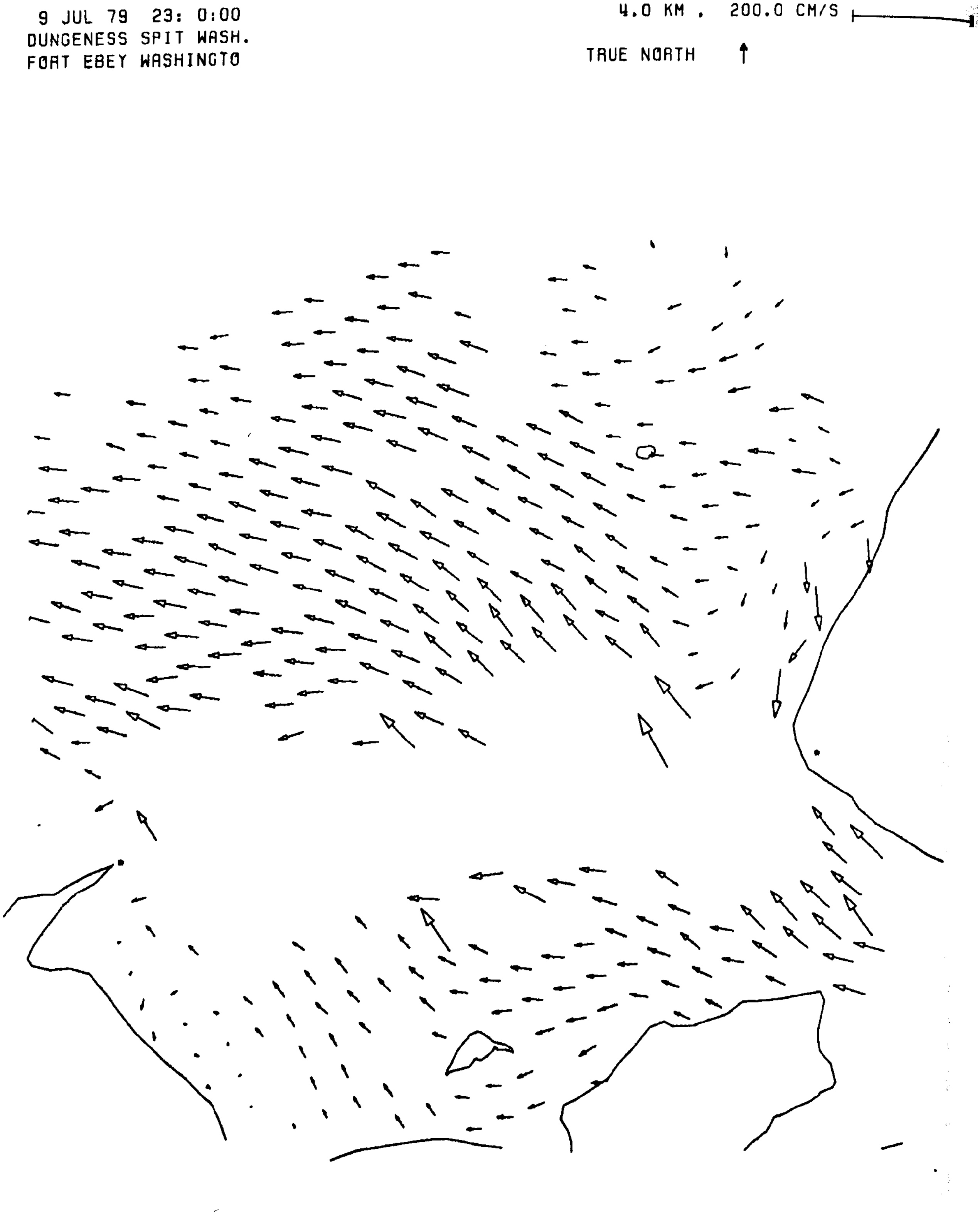

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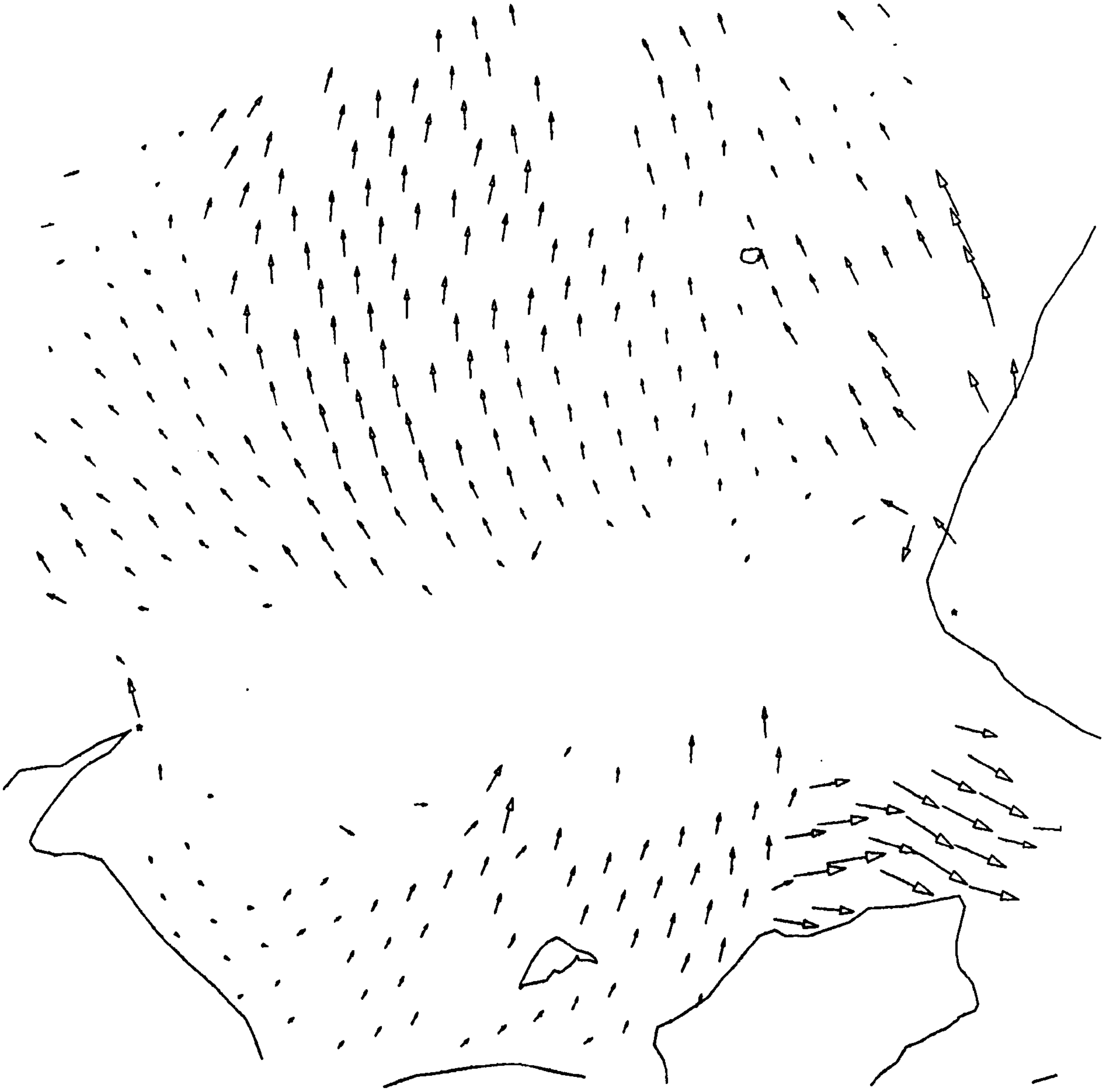
FORT EBEY WASHINGTO

4.0 KM ,   200.0 CM/S

TRUE NORTH



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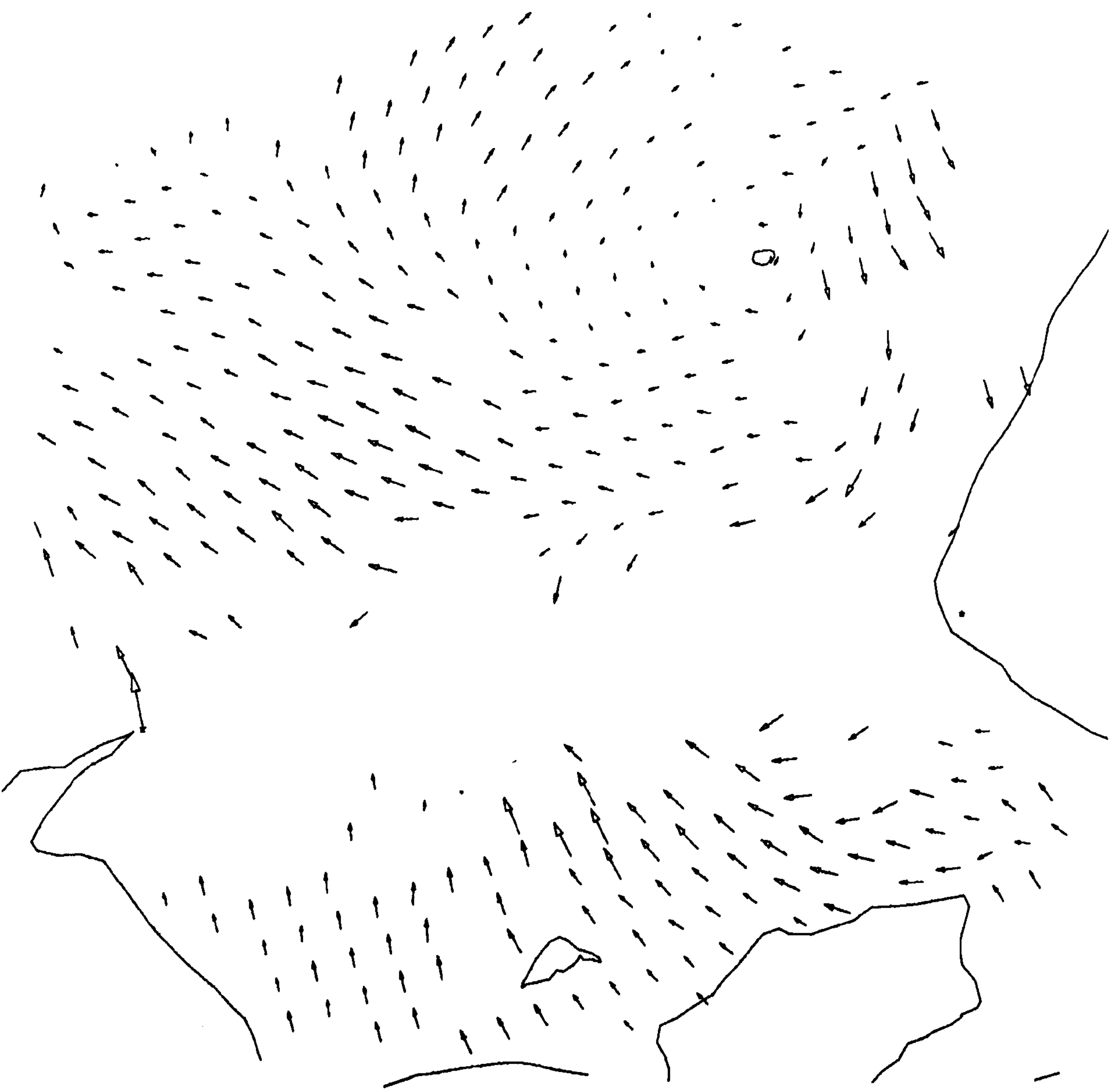
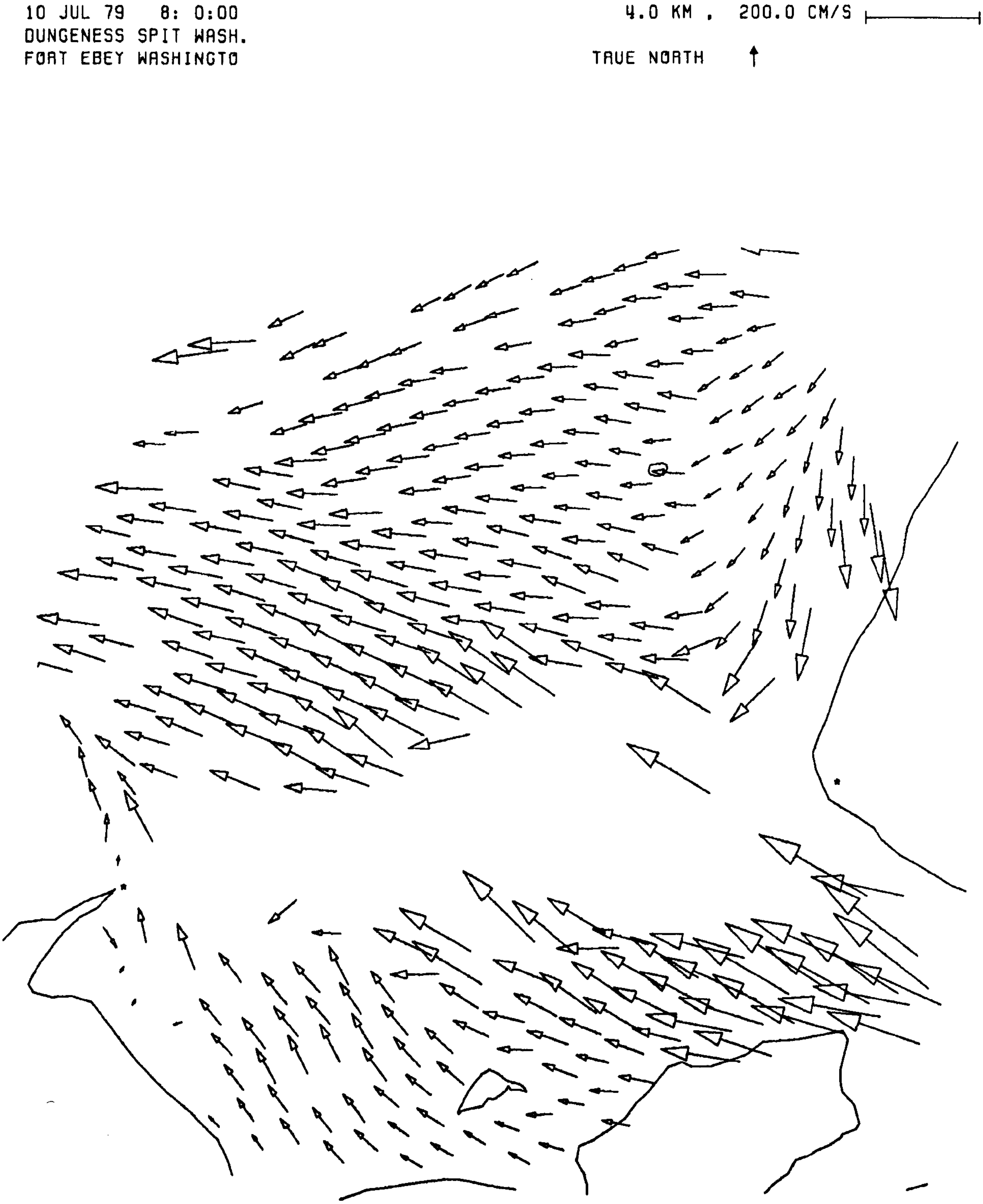
FORT EBEY WASHINGTO

4.0 KM , 200.0 CM/S

TRUE NORTH

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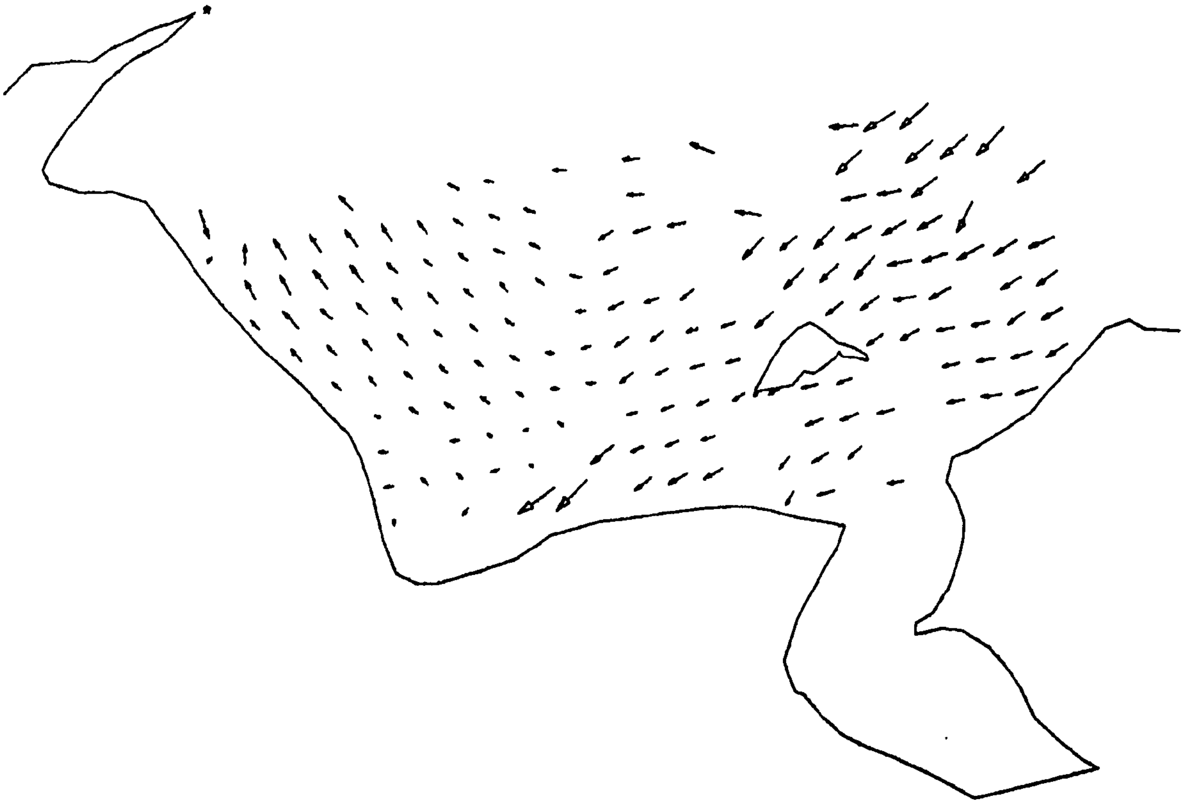
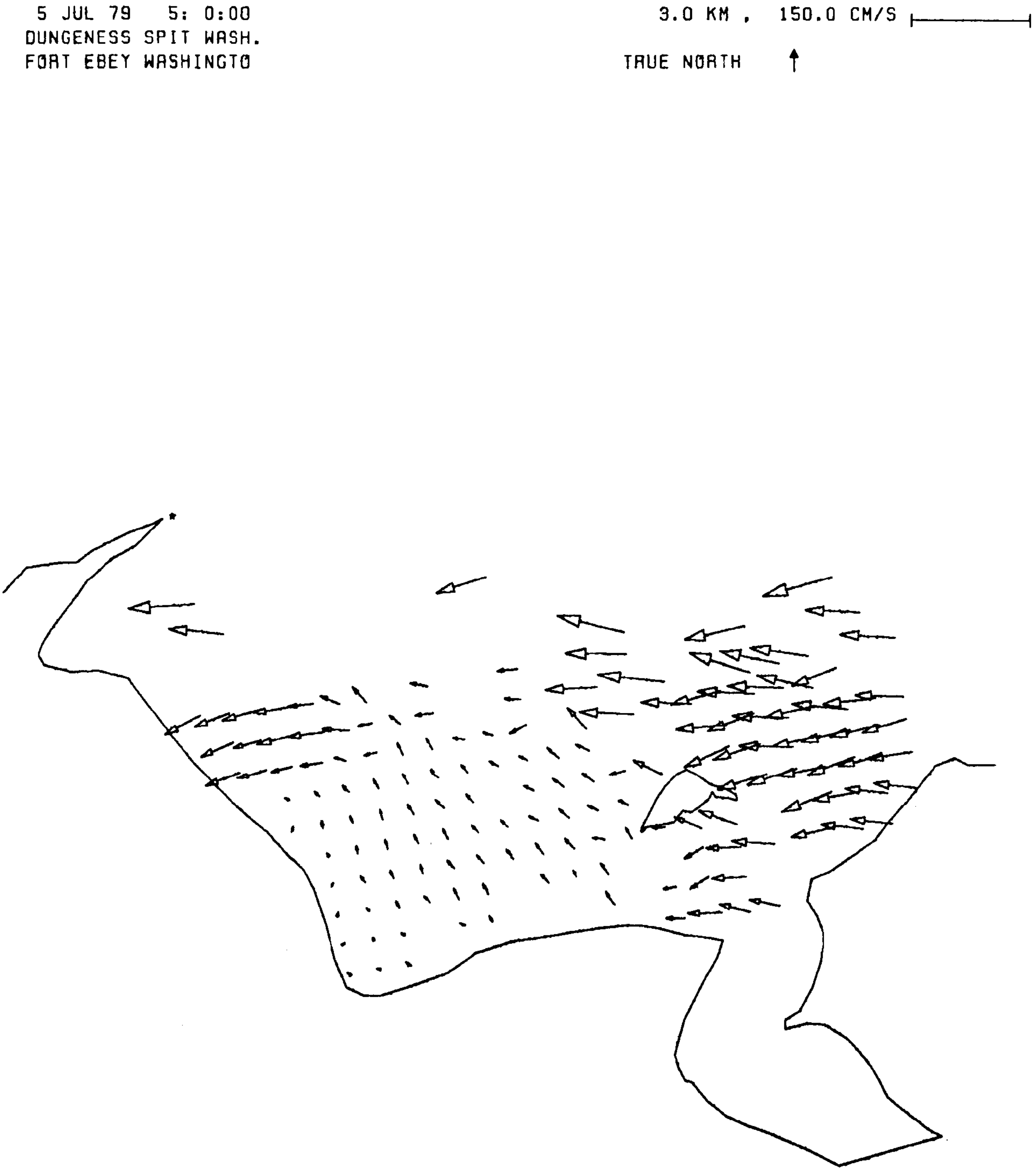
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
4.0 KM , 200.0 CM/S
TRUE NORTH

05-JUL-79 02:00:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH

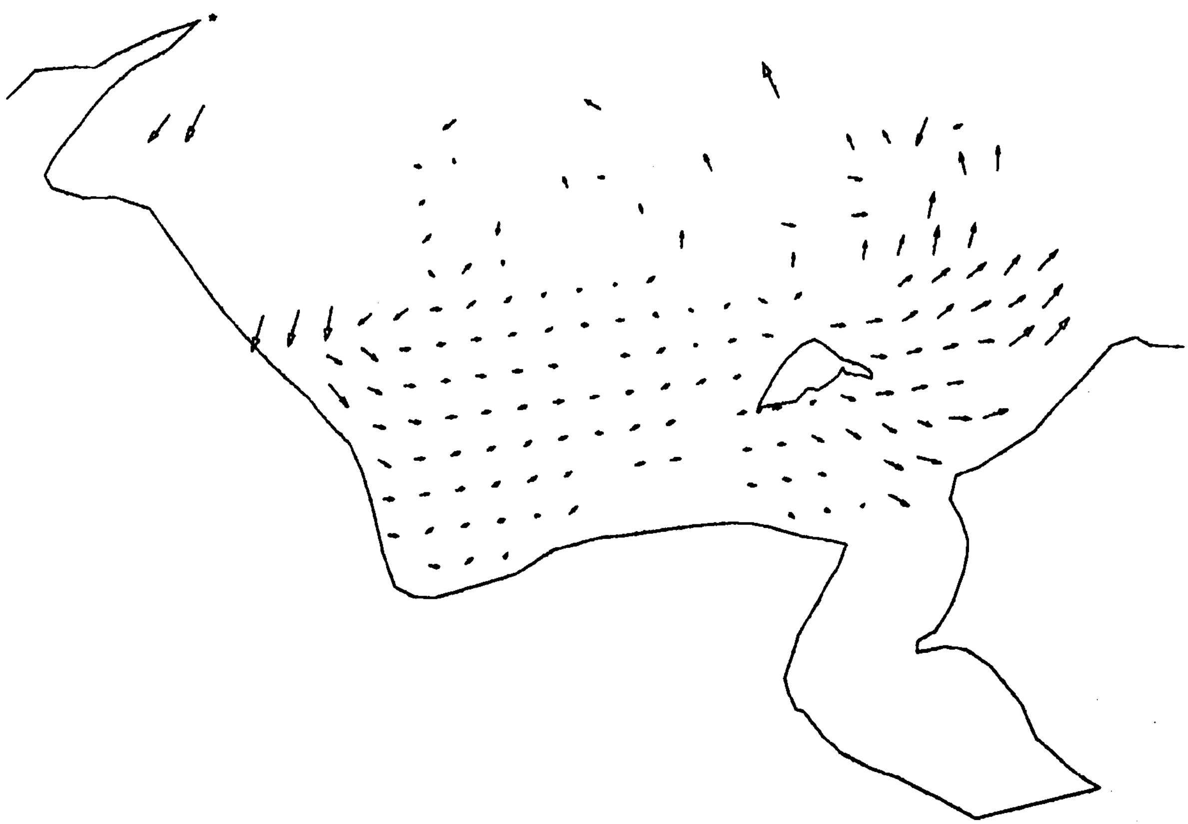



5 JUL 79 5: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

5 JUL 79 8: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

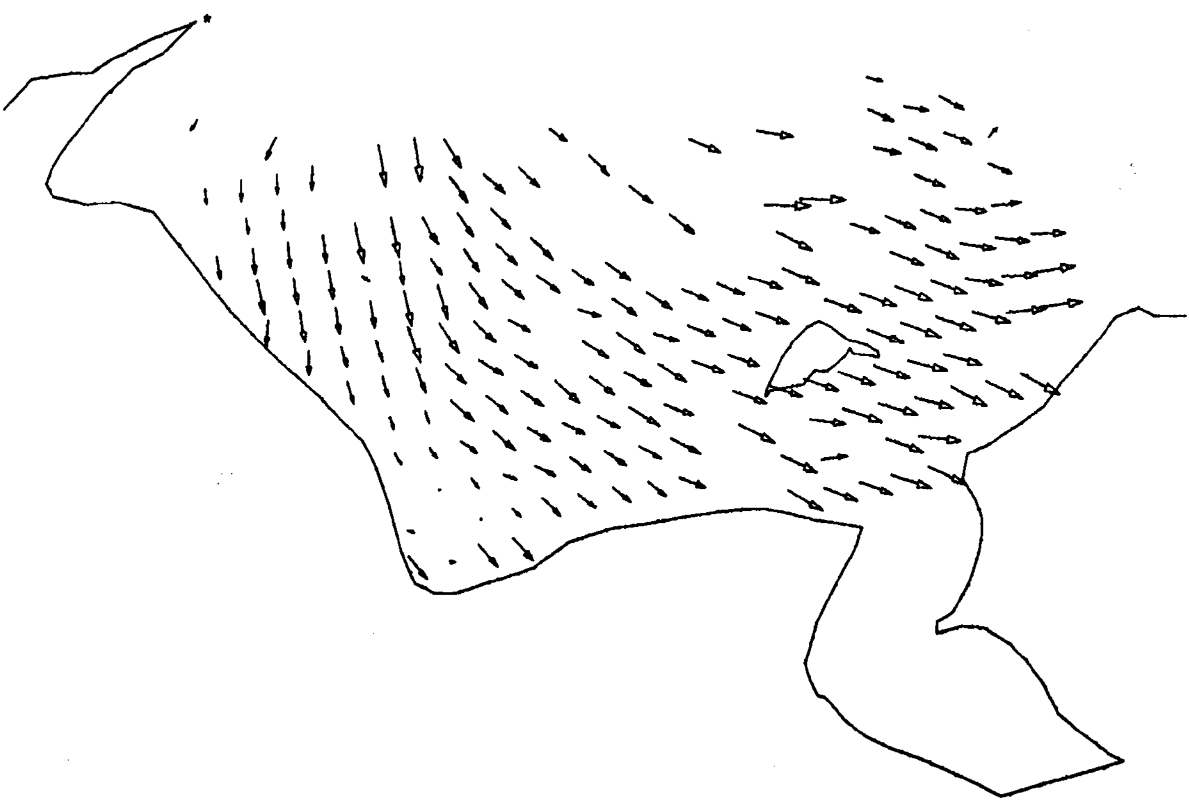
TRUE NORTH

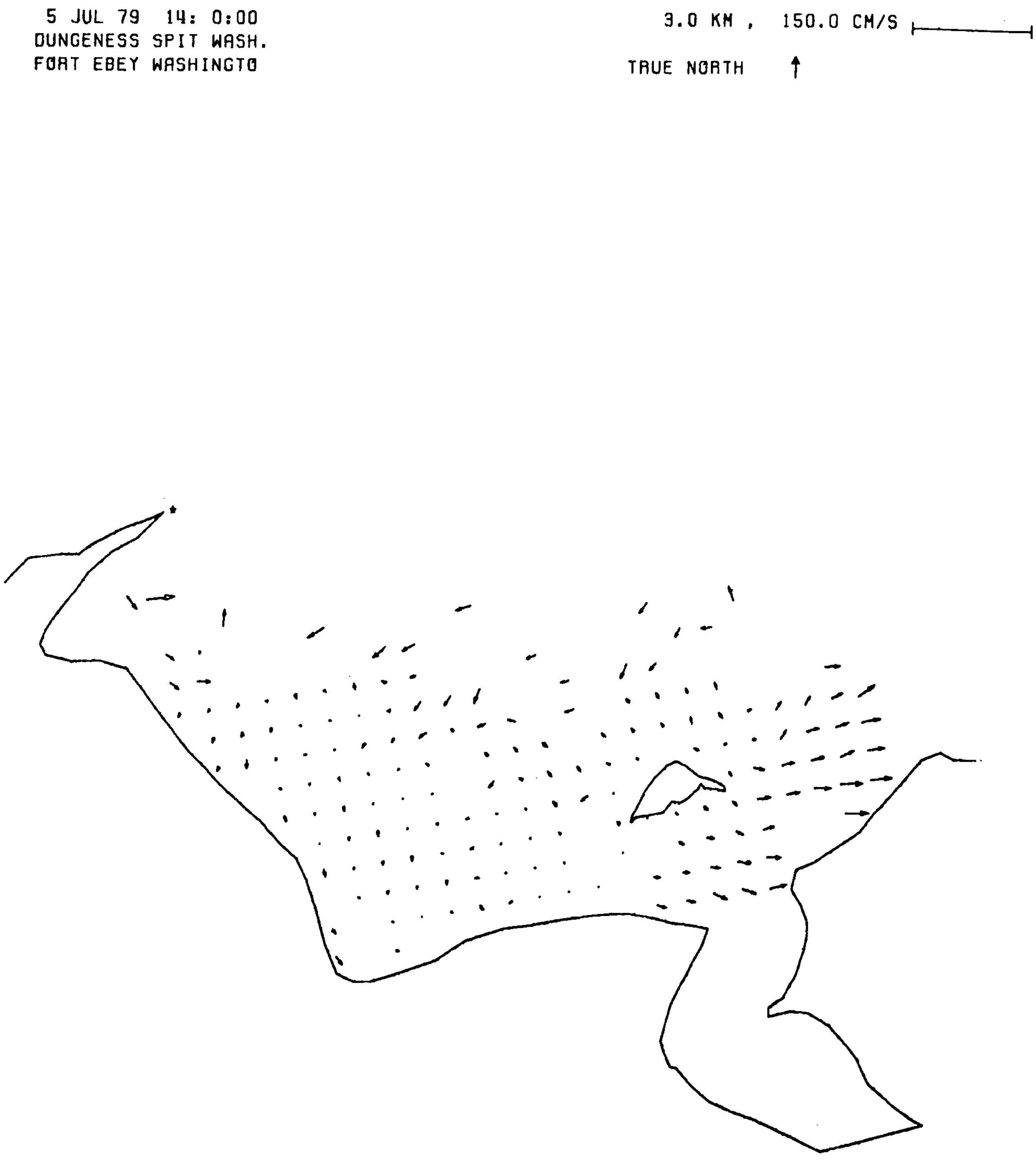


5 JUL 79 11: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH ↑

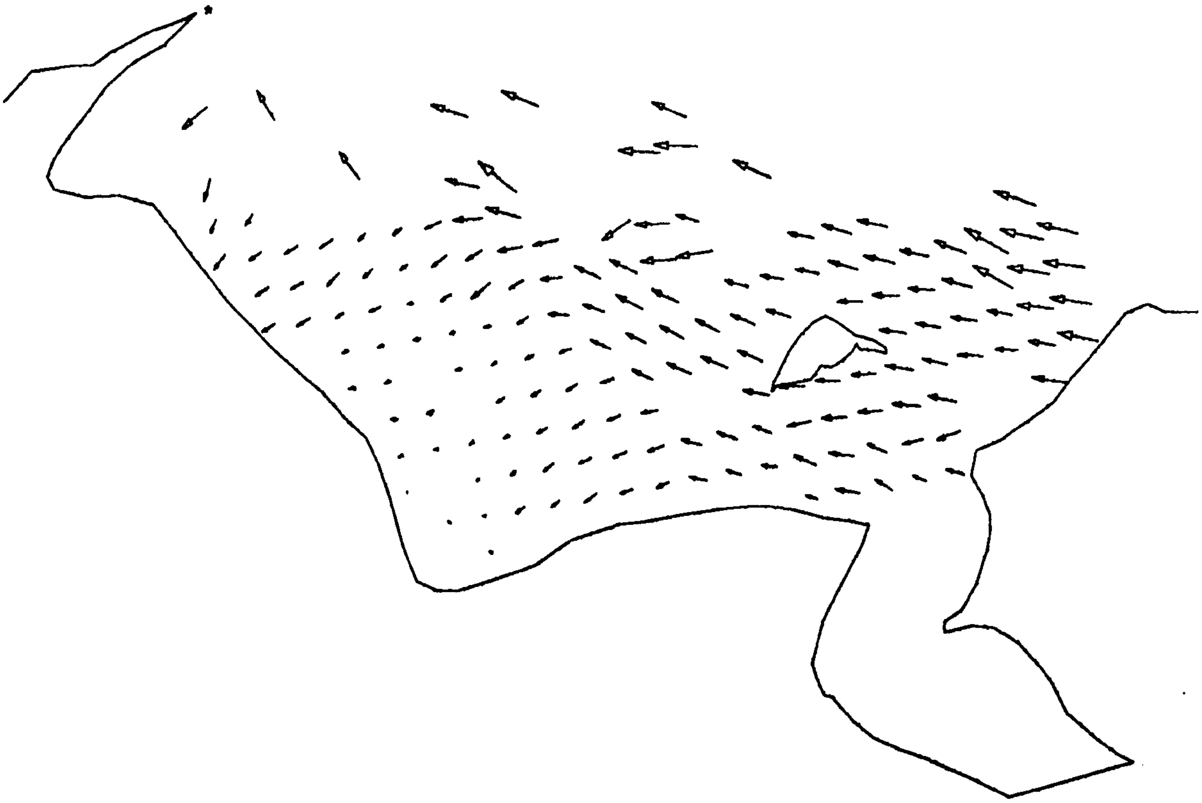


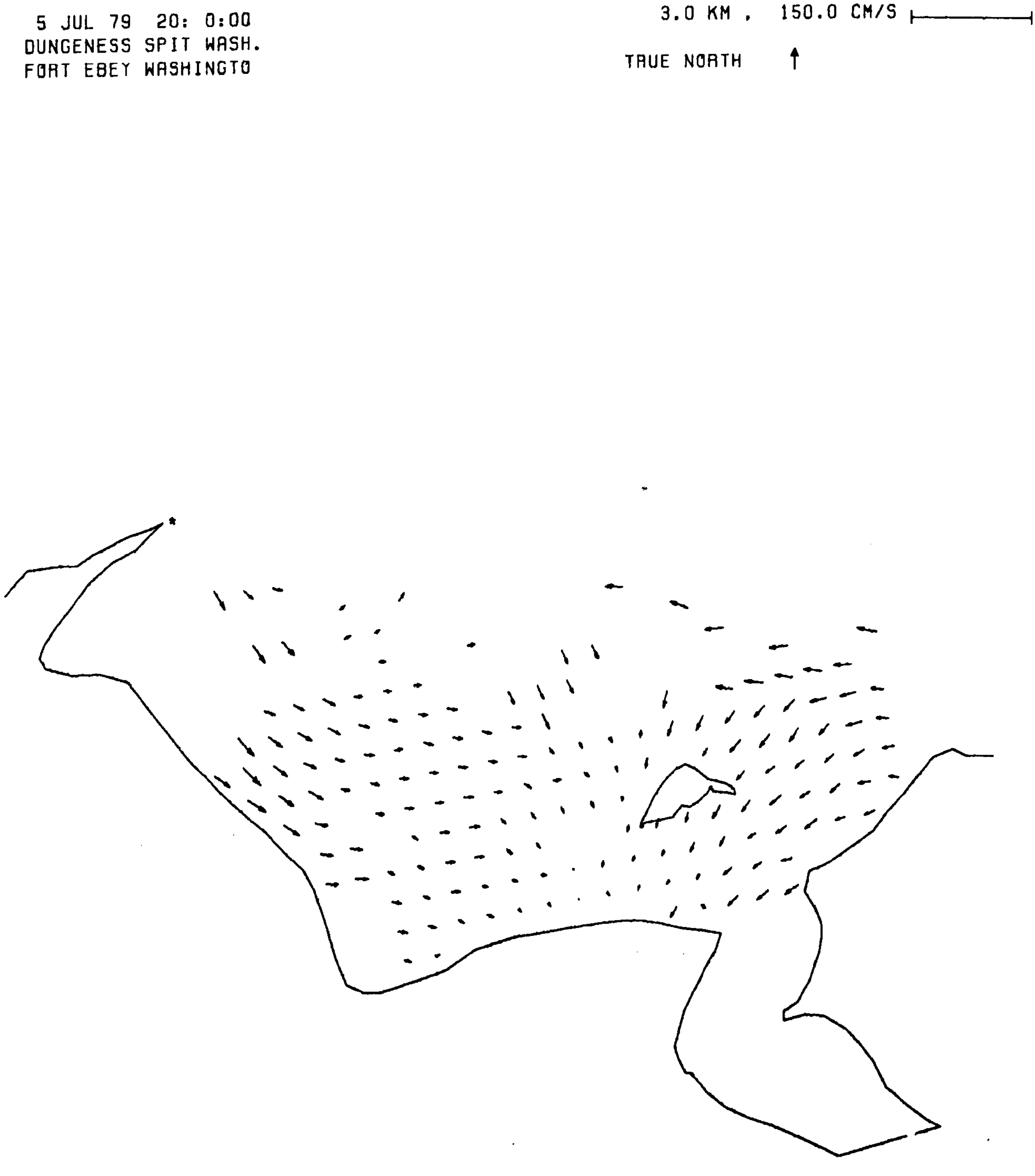

5 JUL 79 14: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

5 JUL 79 17: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH

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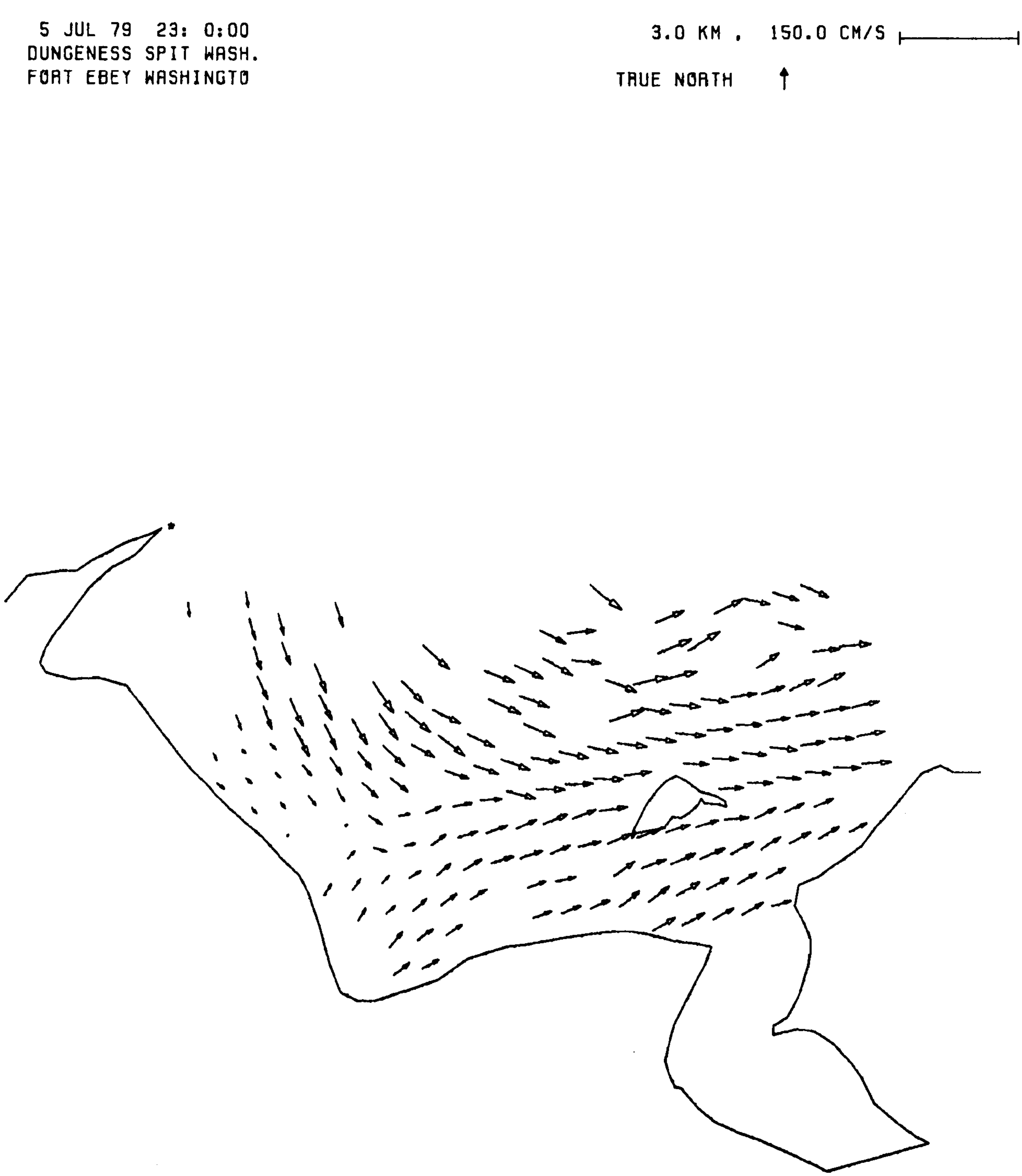
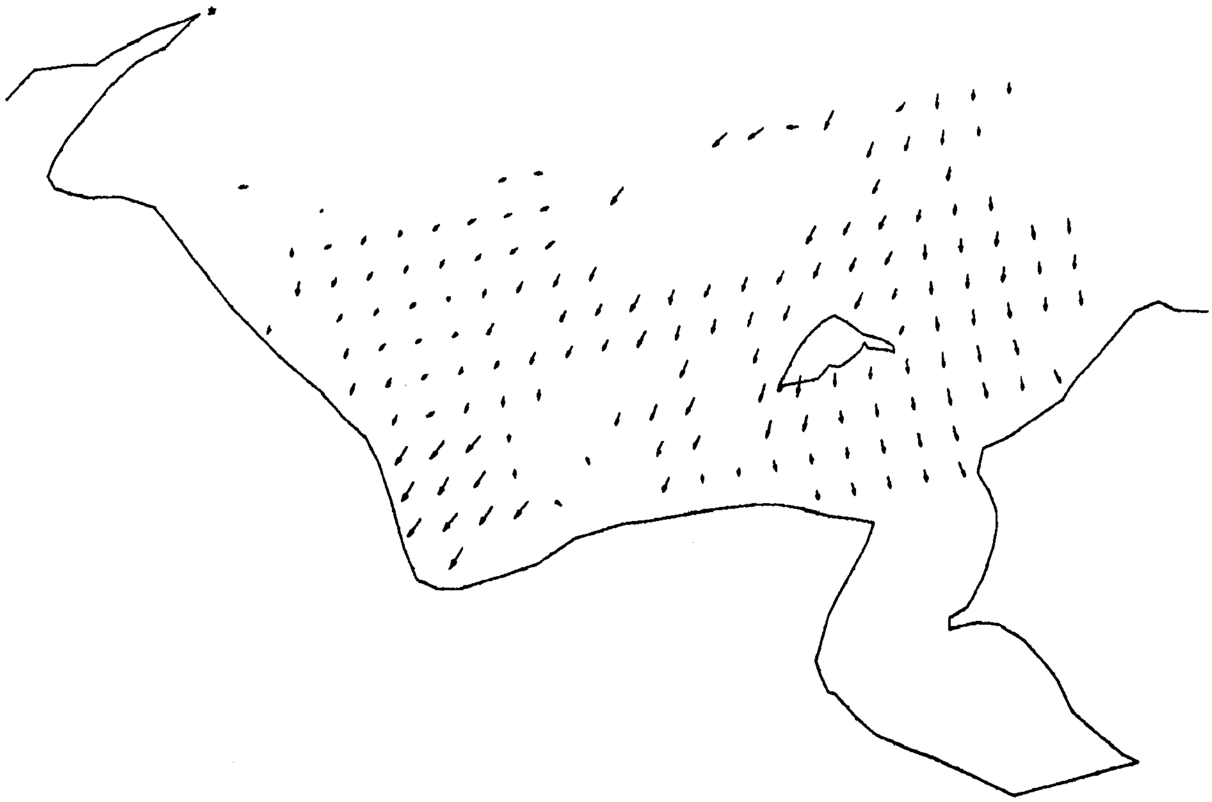
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

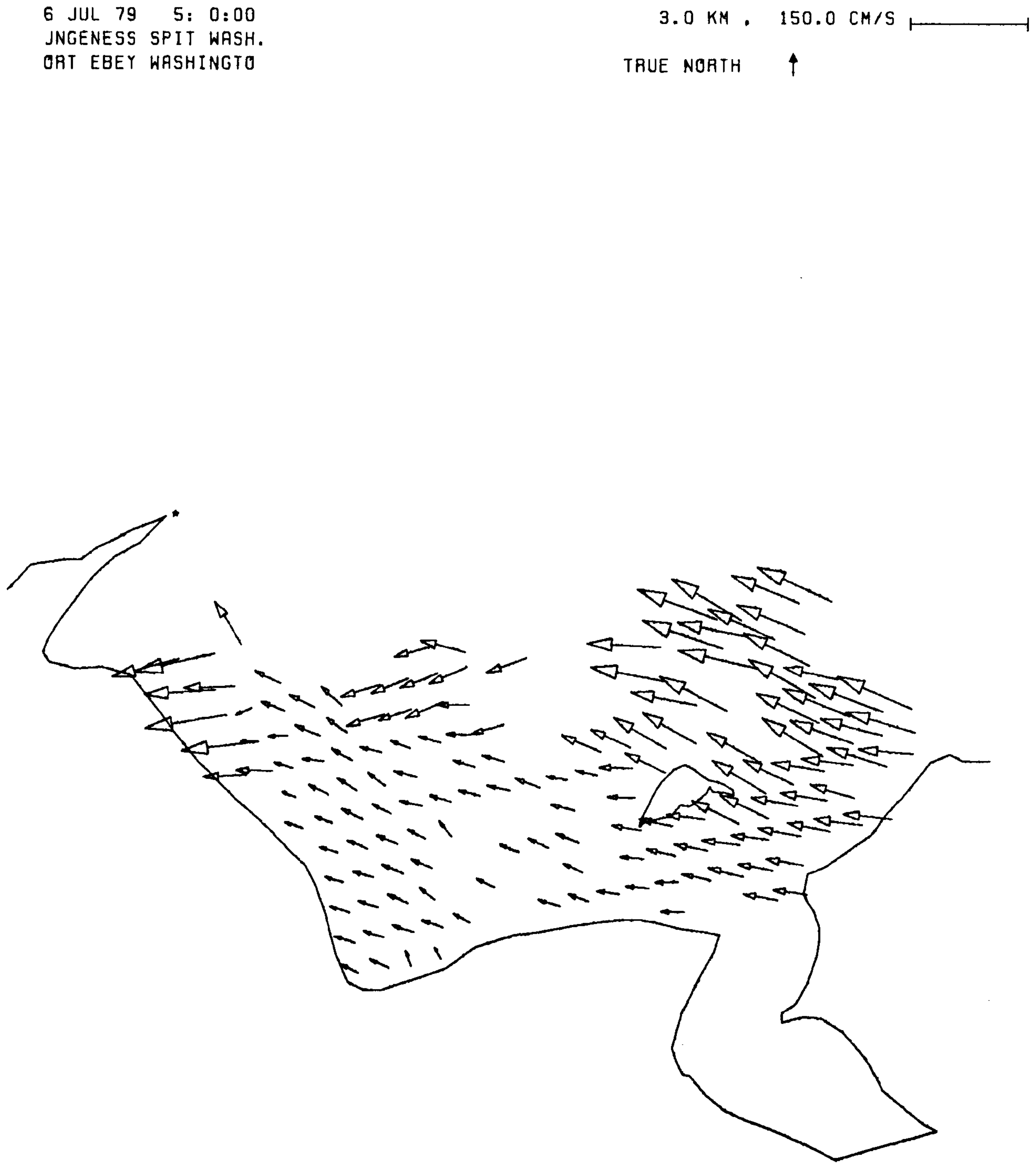

5 JUL 79 23: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

6 JUL 79 2: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH ↑

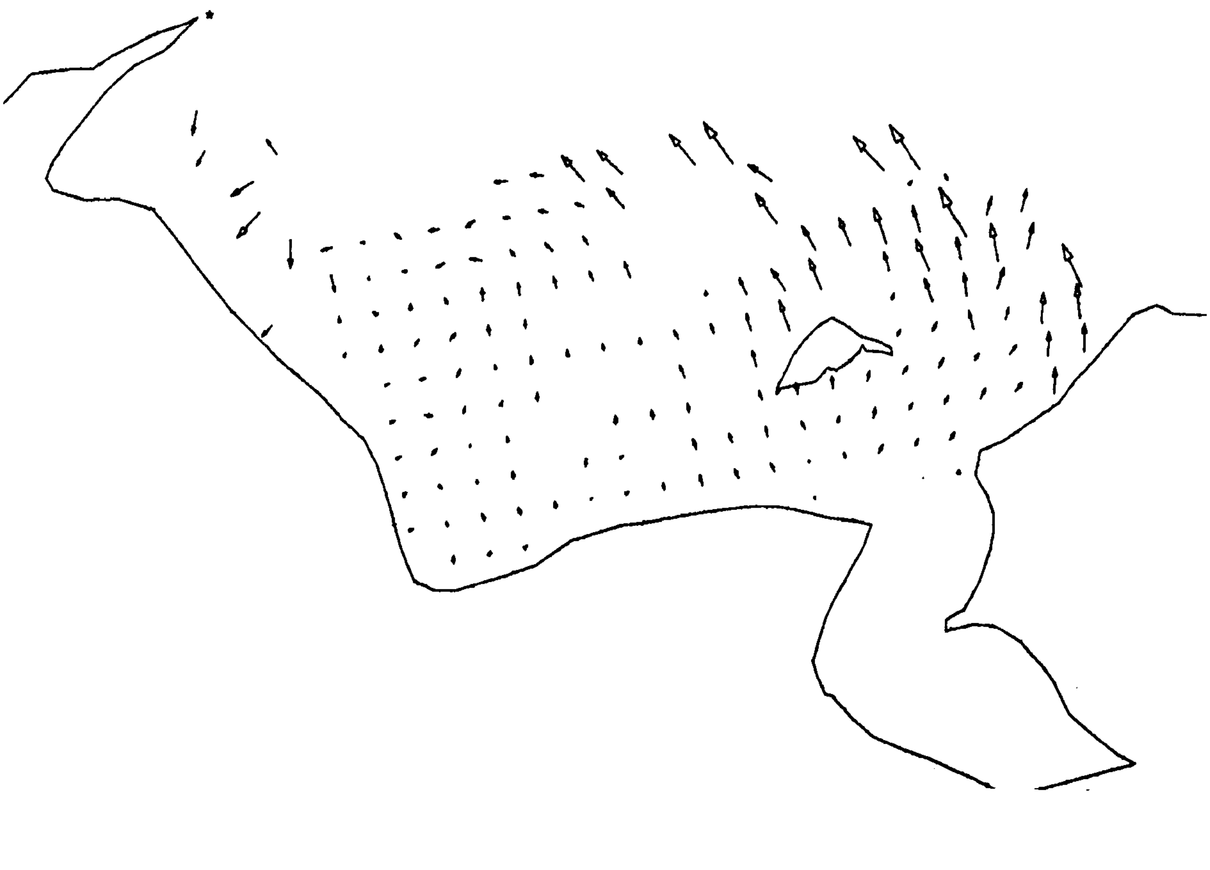



6 JUL 79 5: 0:00
JNGENESS SPIT WASH.
ORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

6 JUL 79 8: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH



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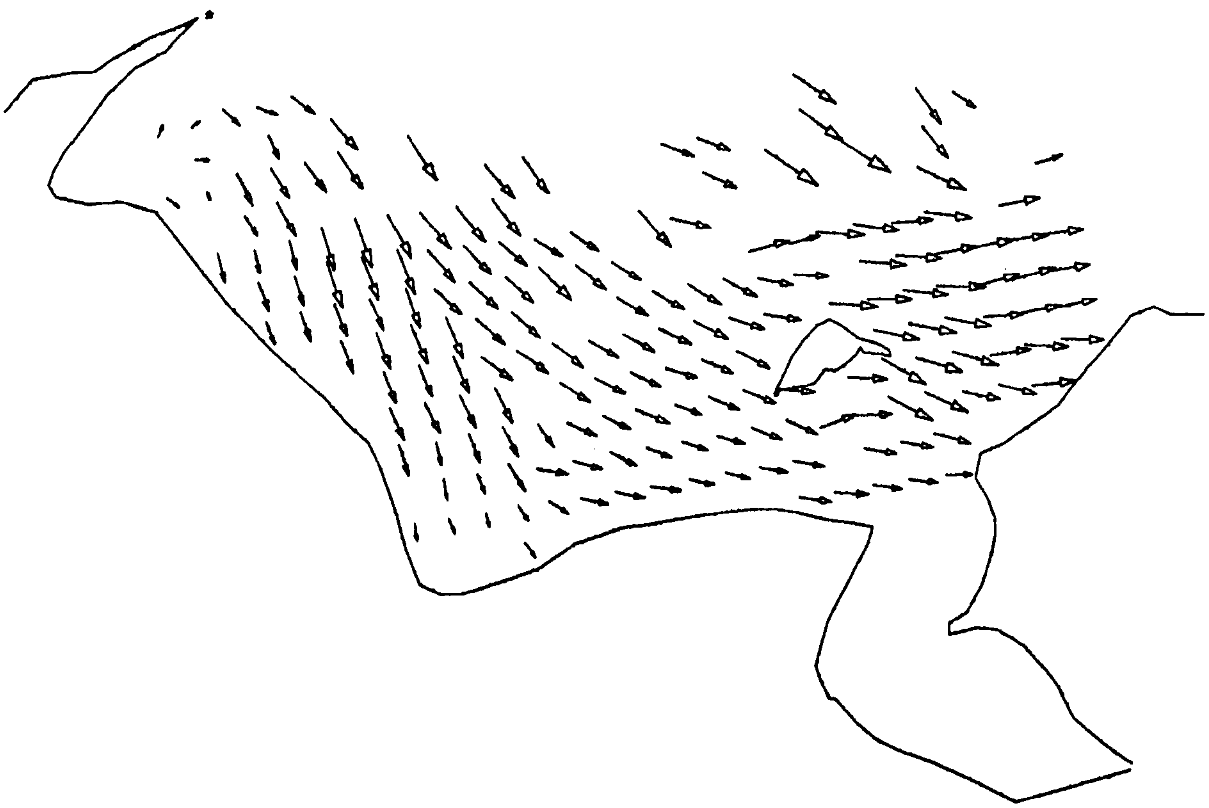
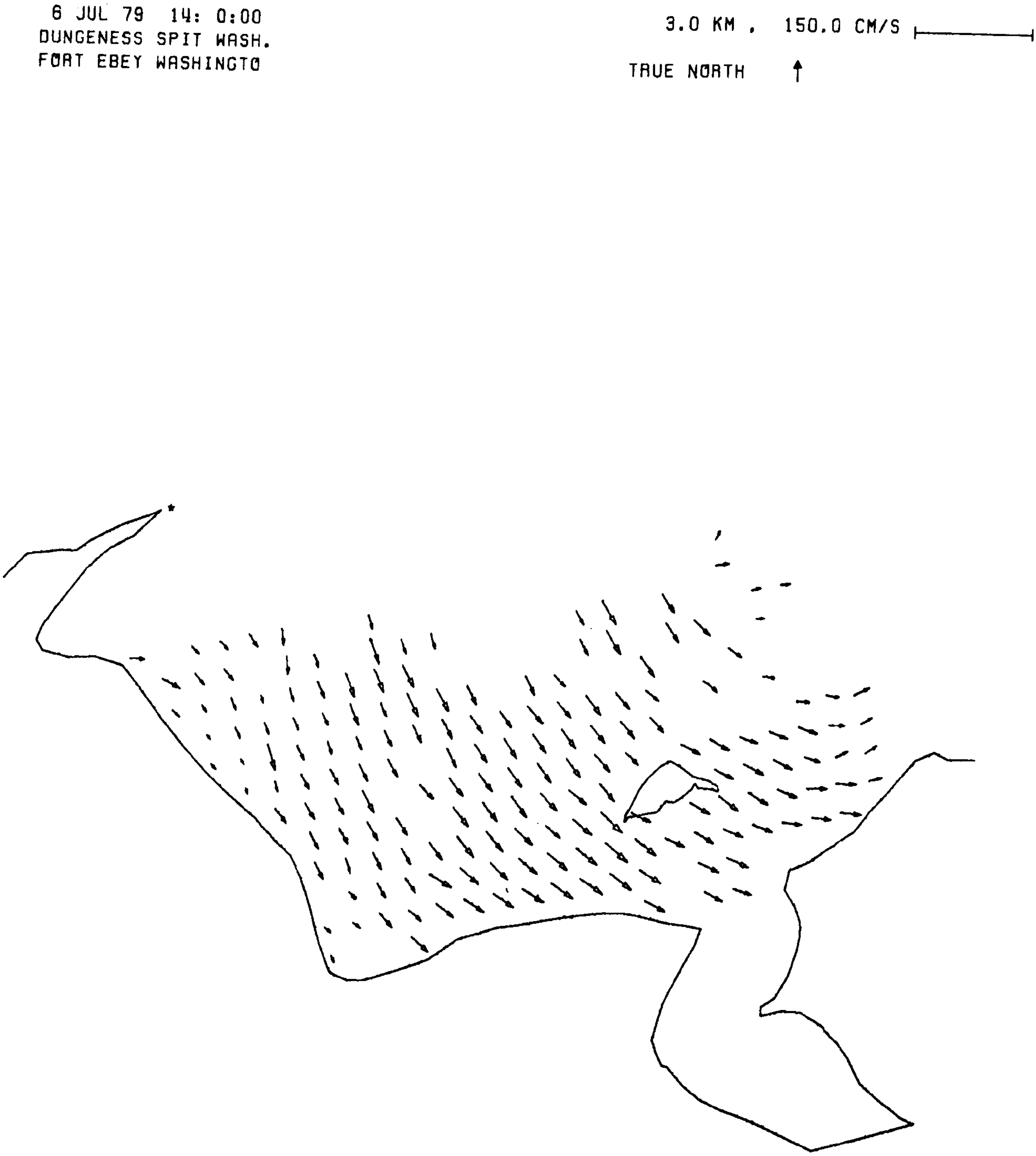
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH

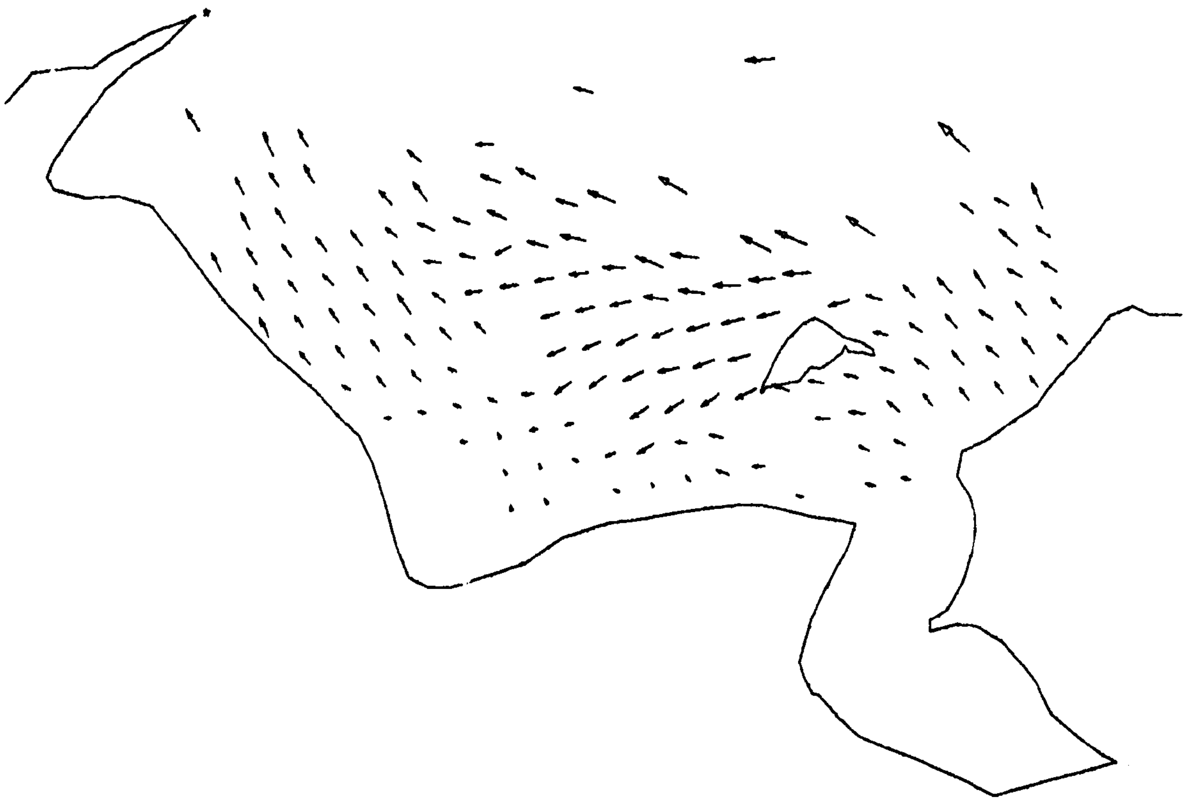



6 JUL 79 14: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

6 JUL 79 17: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH



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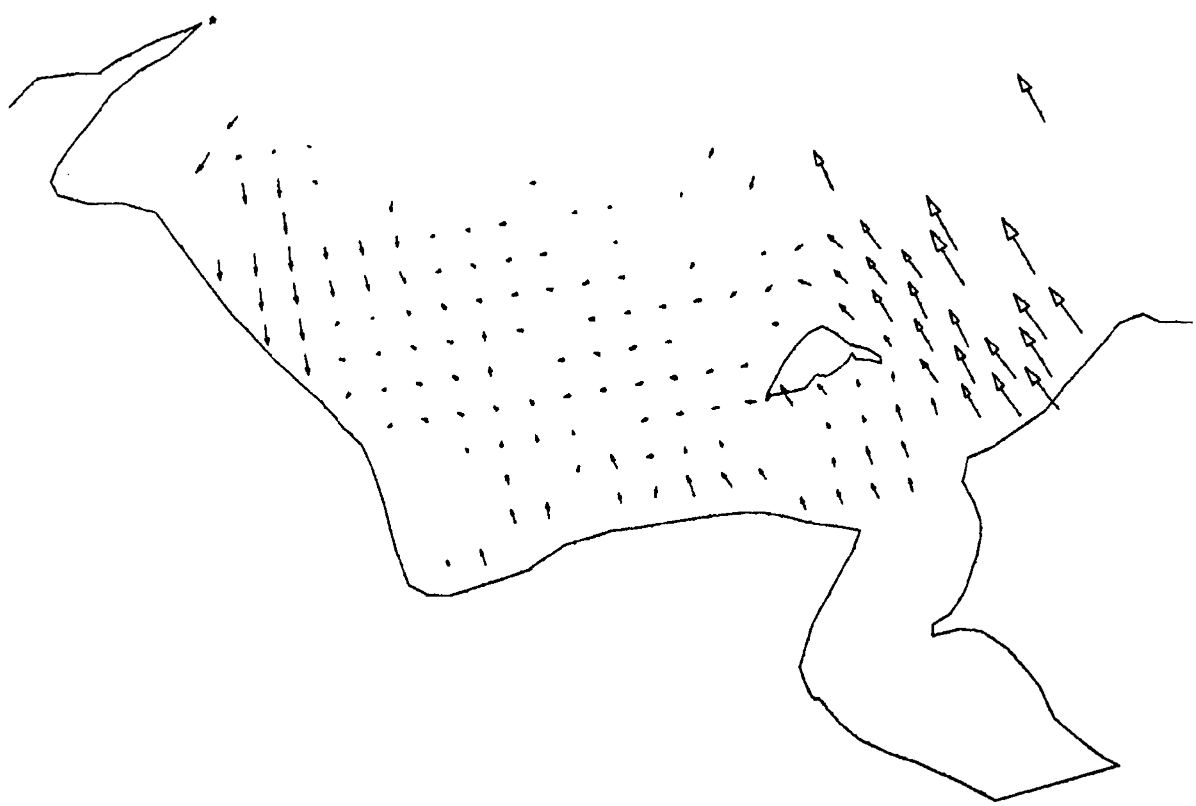
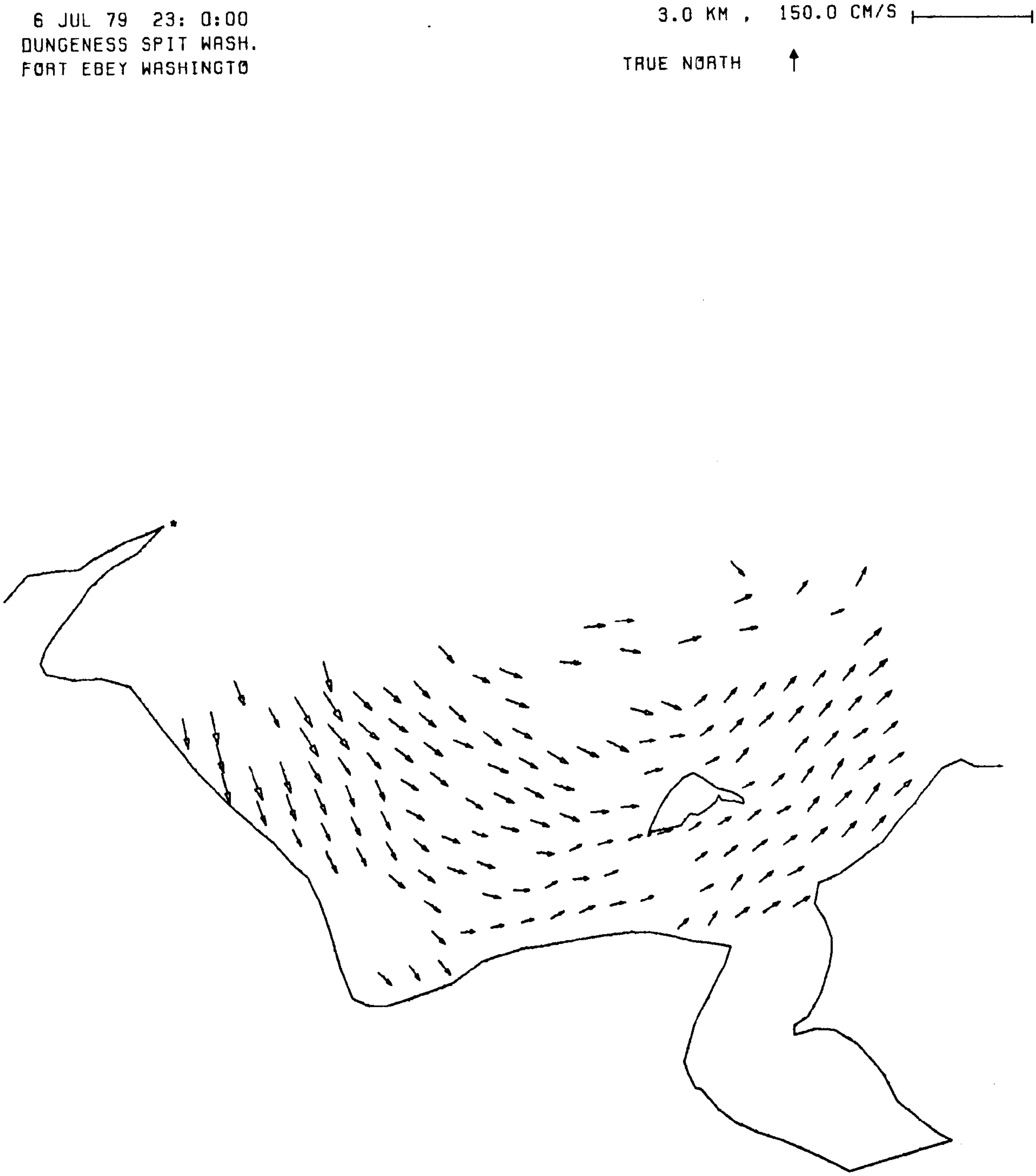
DUNGENESS SPIT WASH.
FØRT EBEY WASHINGTØ

3.0 KM , 150.0 CM/S

TRUE NØRTH

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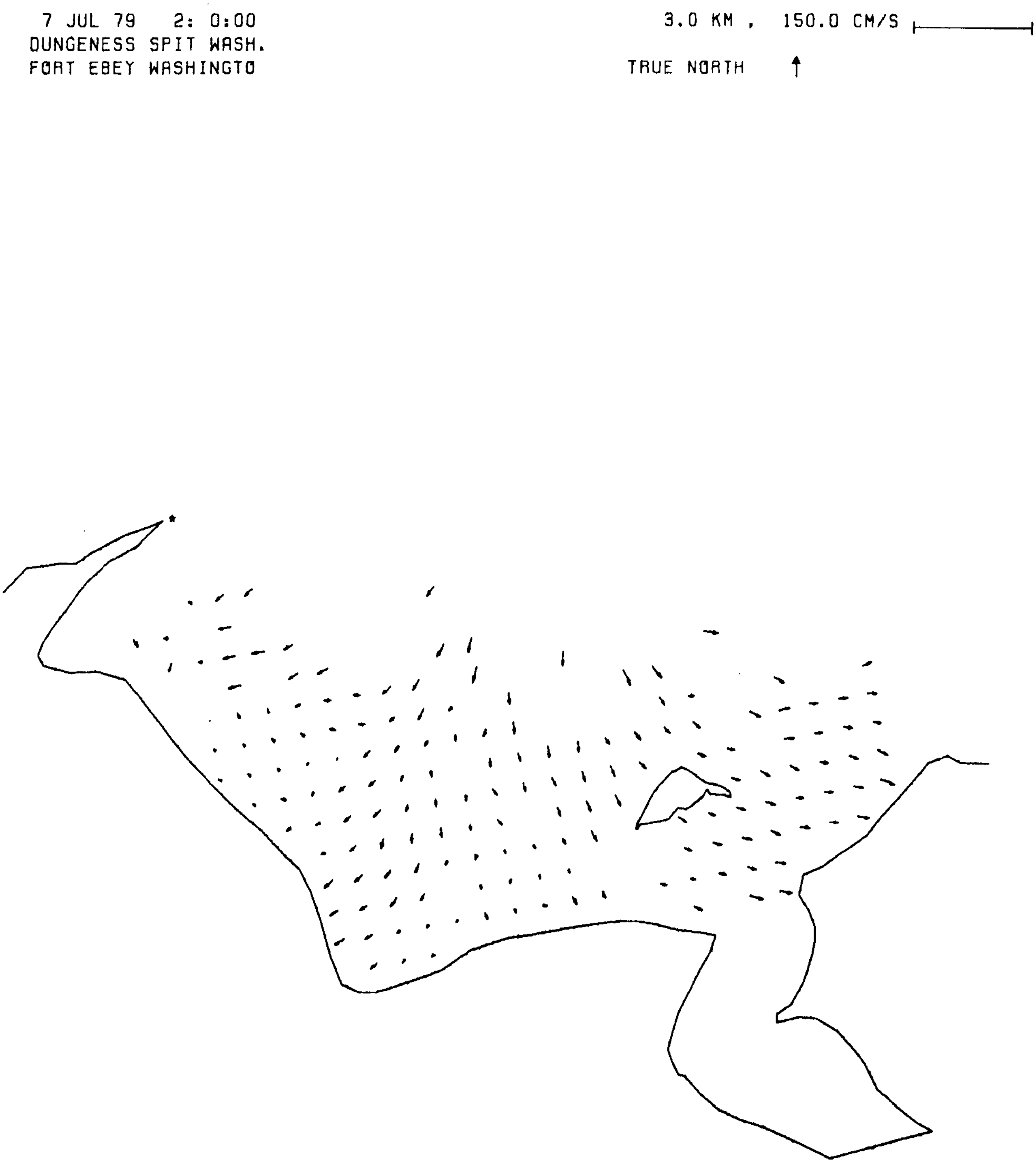
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH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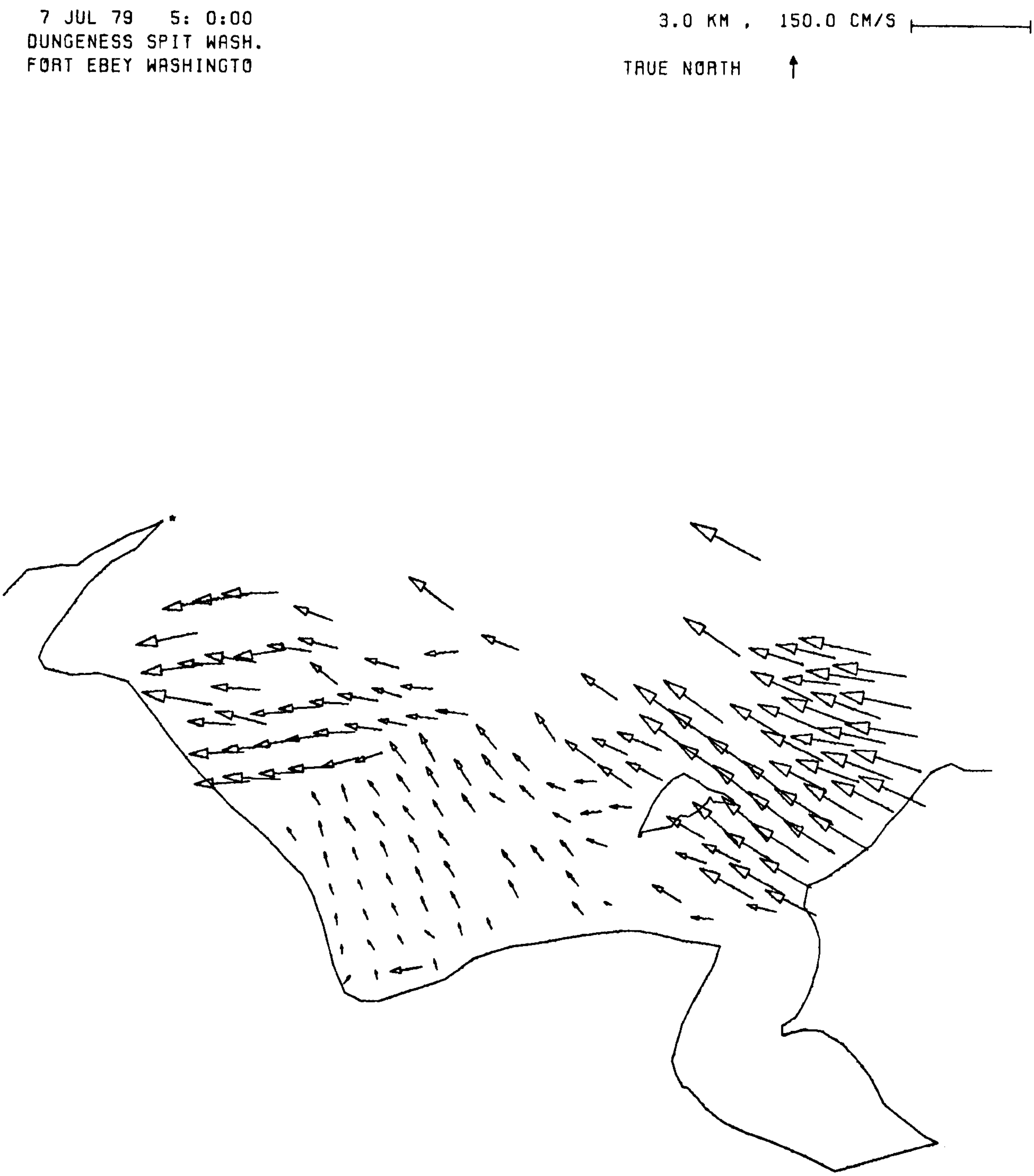
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

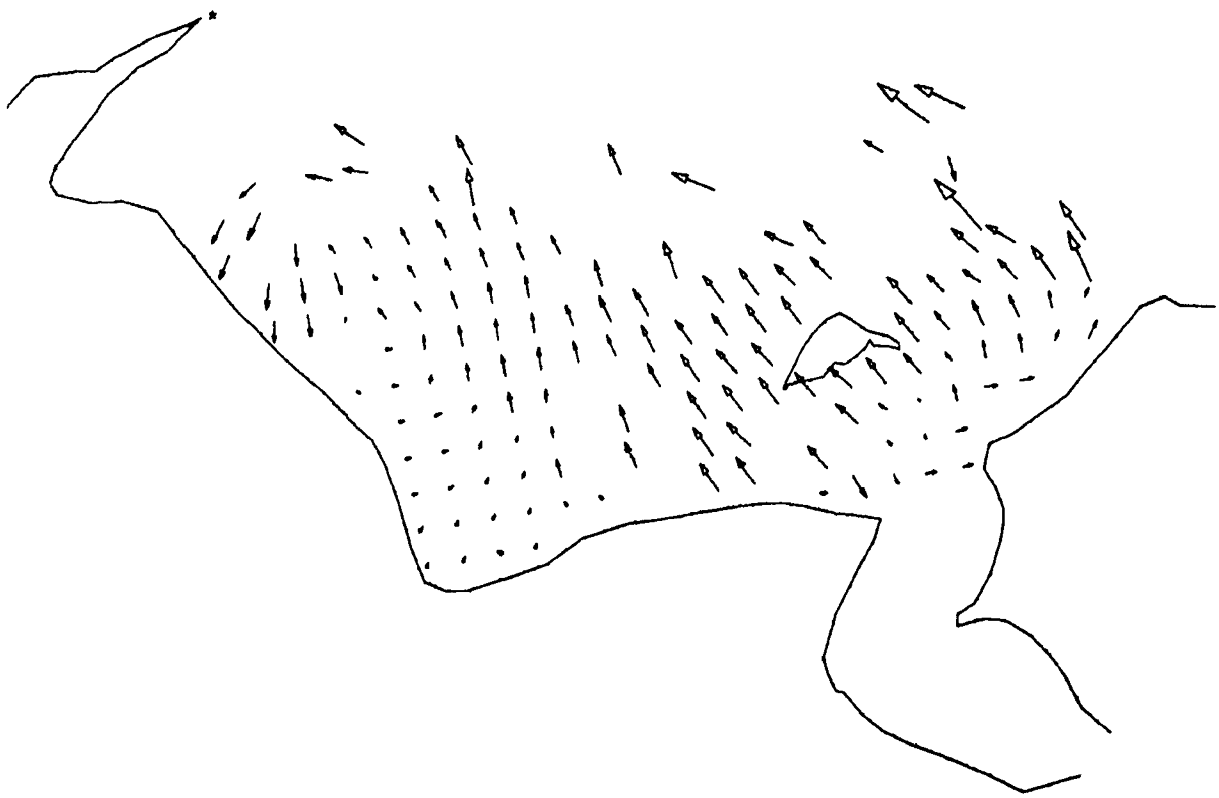


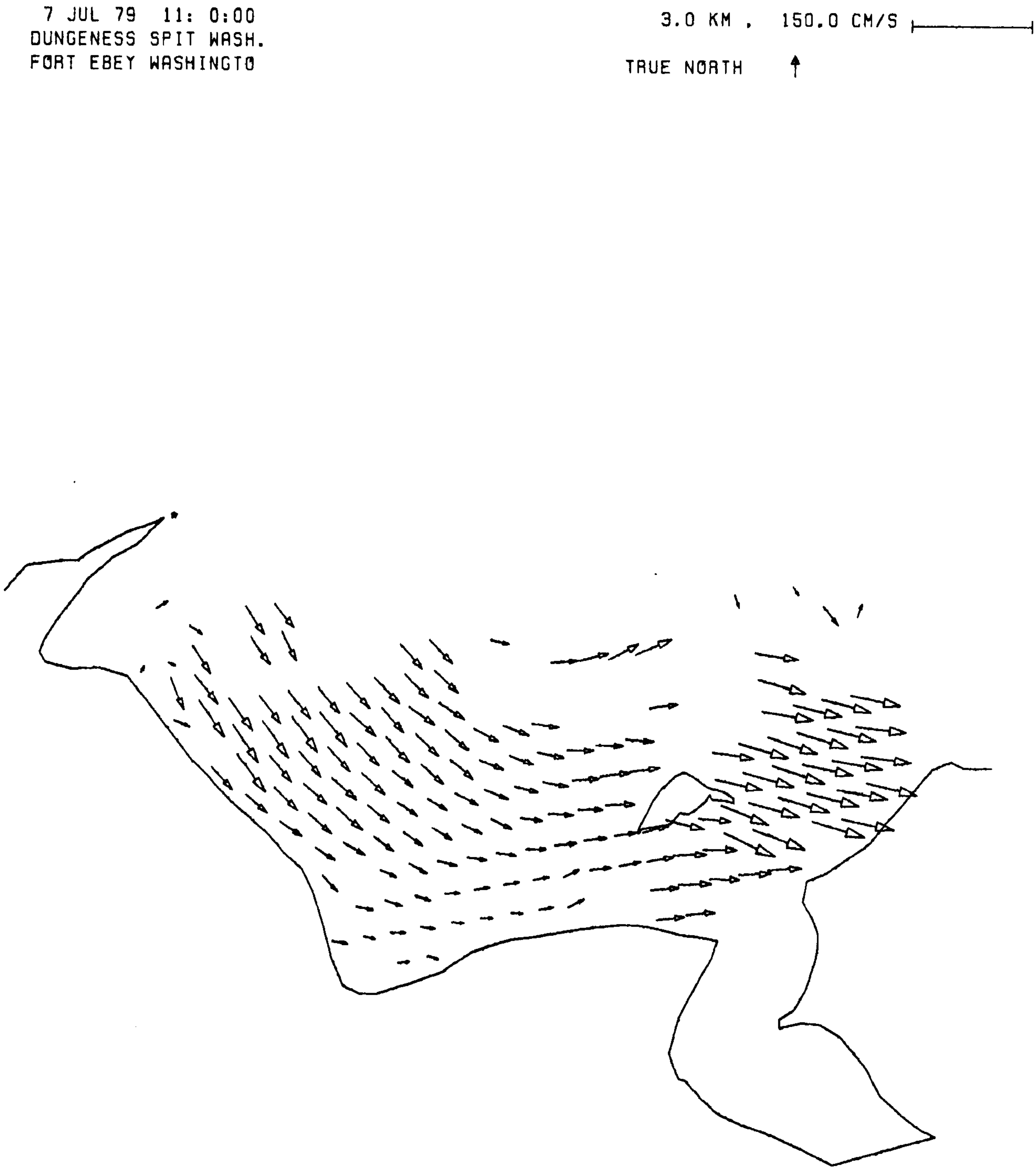
7 JUL 79 5: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

7 JUL 79   8: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM ,   150.0 CM/S

TRUE NORTH

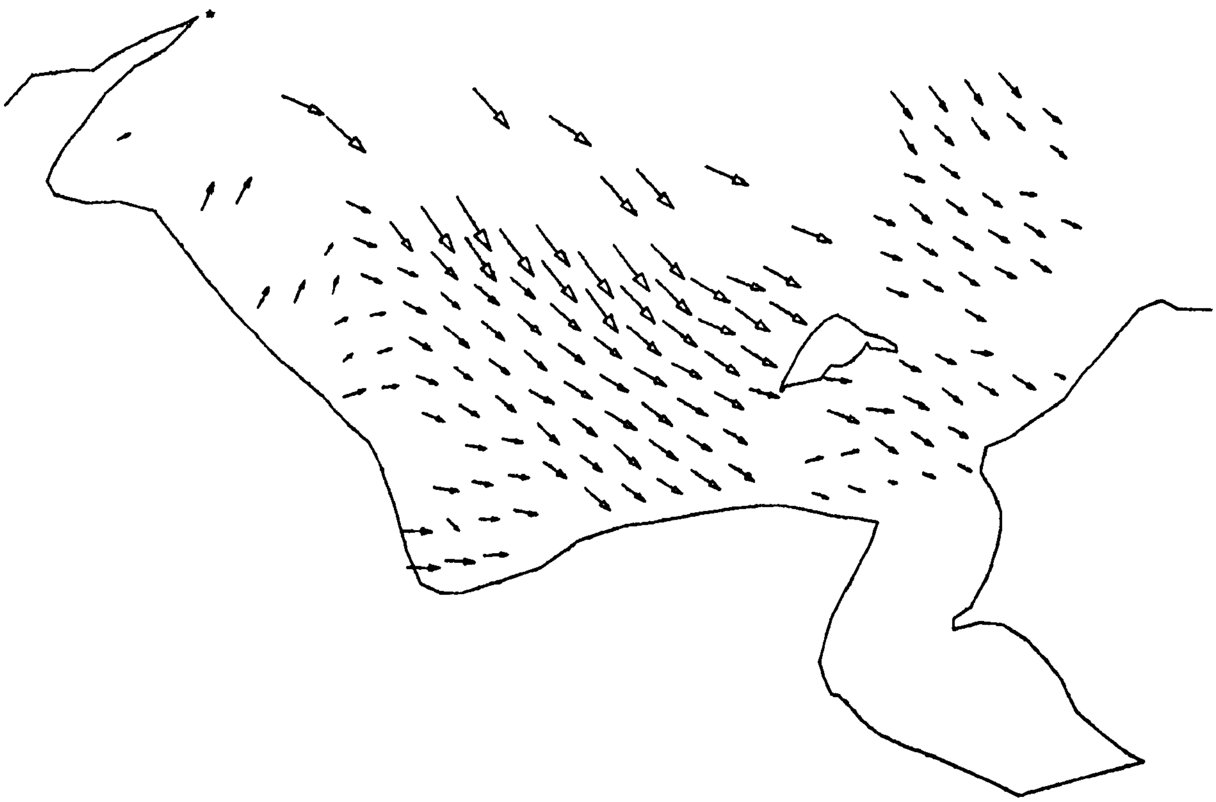


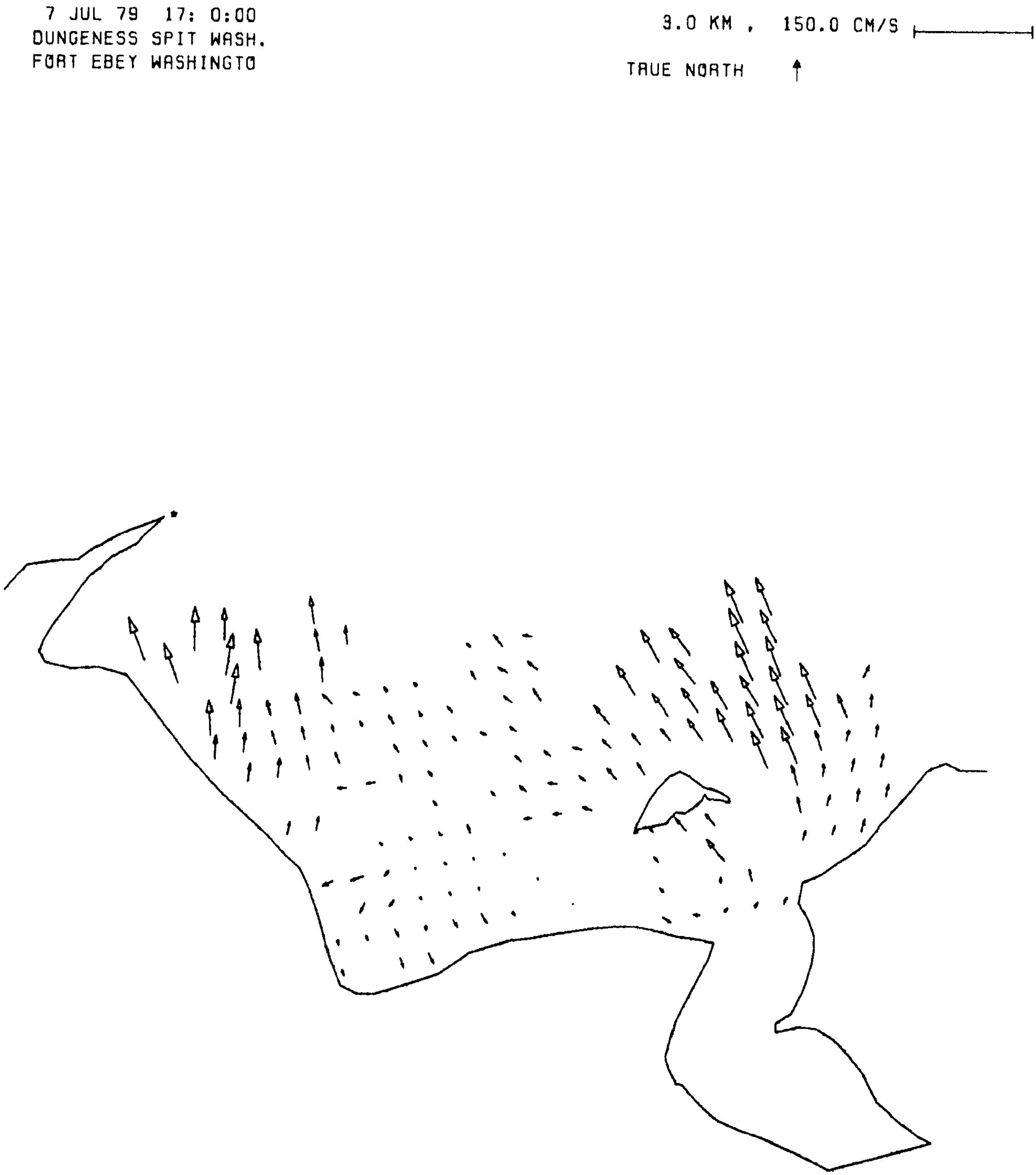

7 JUL 79 11: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

7 JUL 79 14: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH ↑

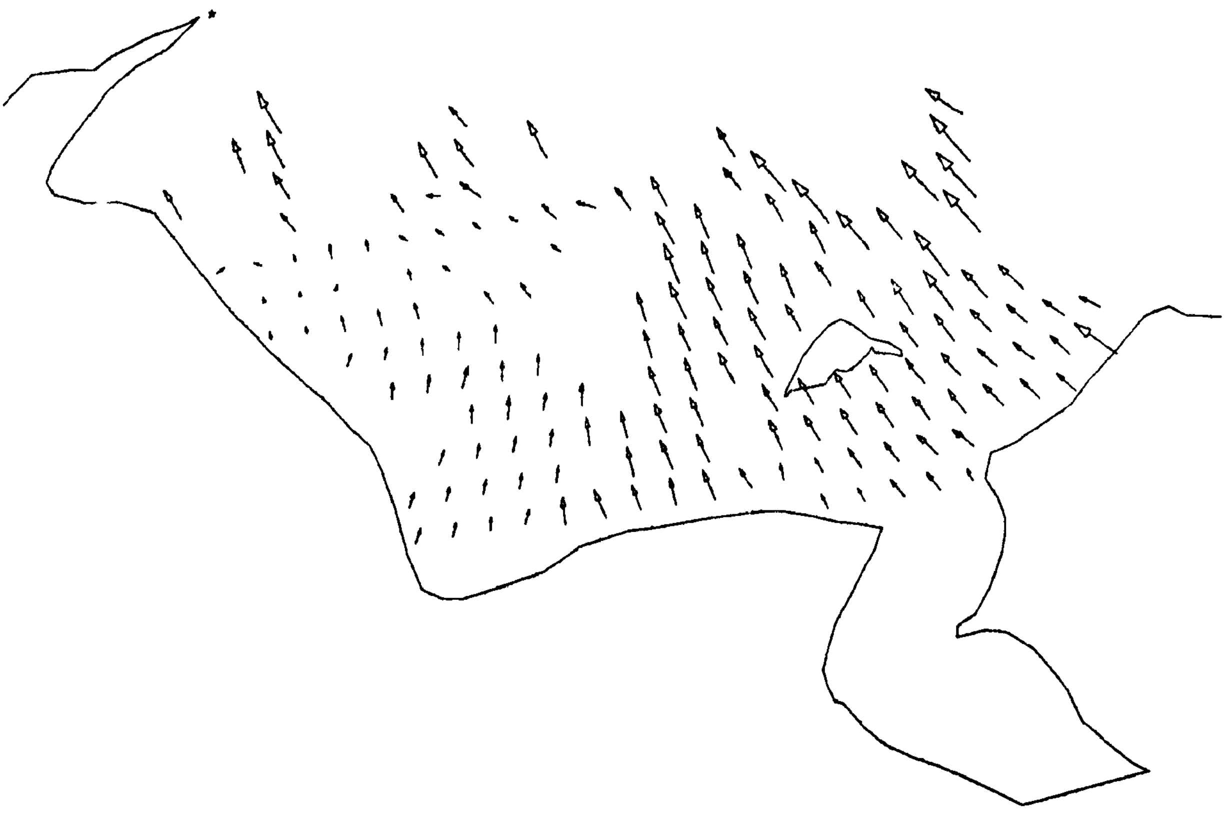


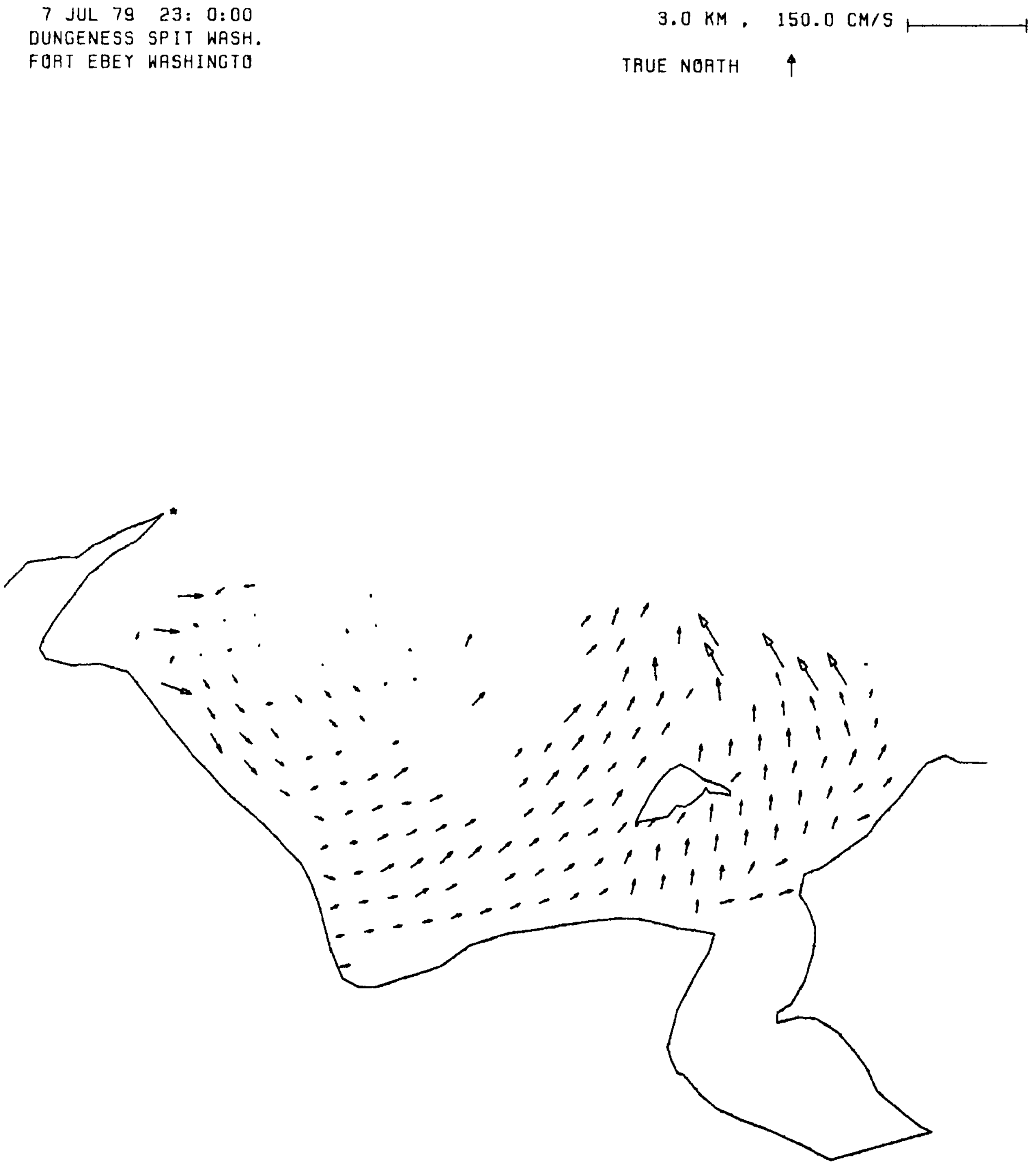

7 JUL 79 17: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

7 JUL 79 20: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH





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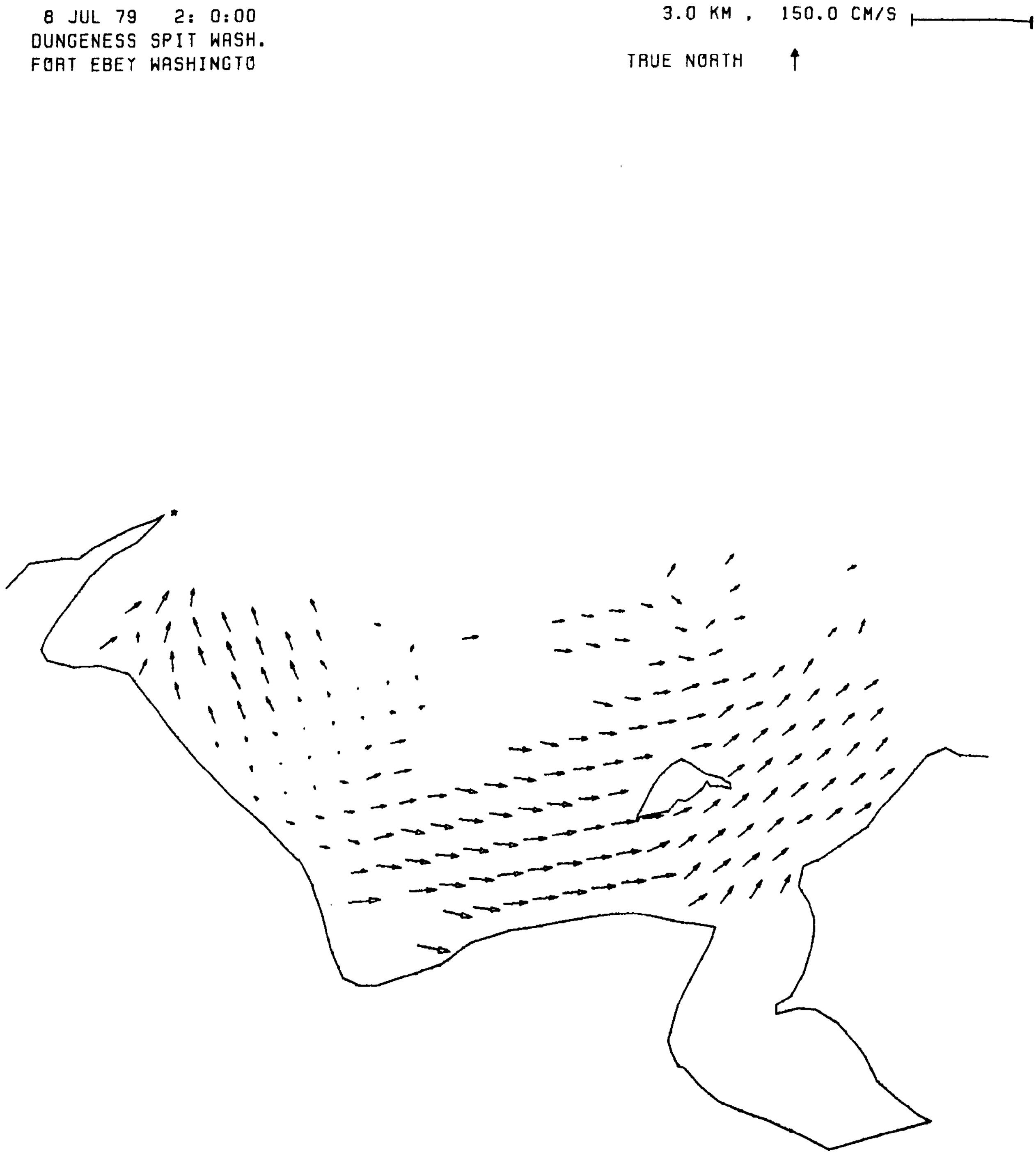
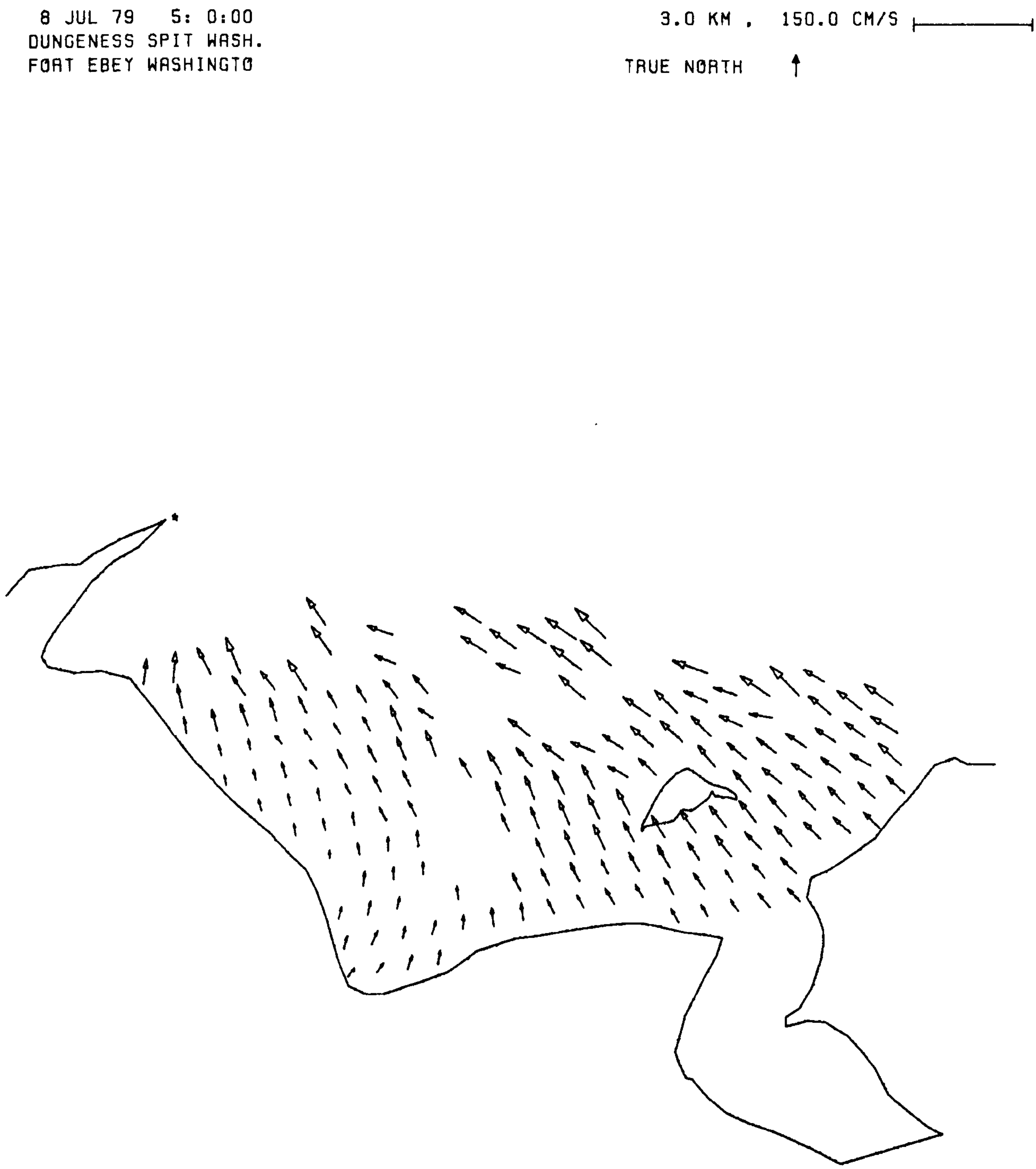
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

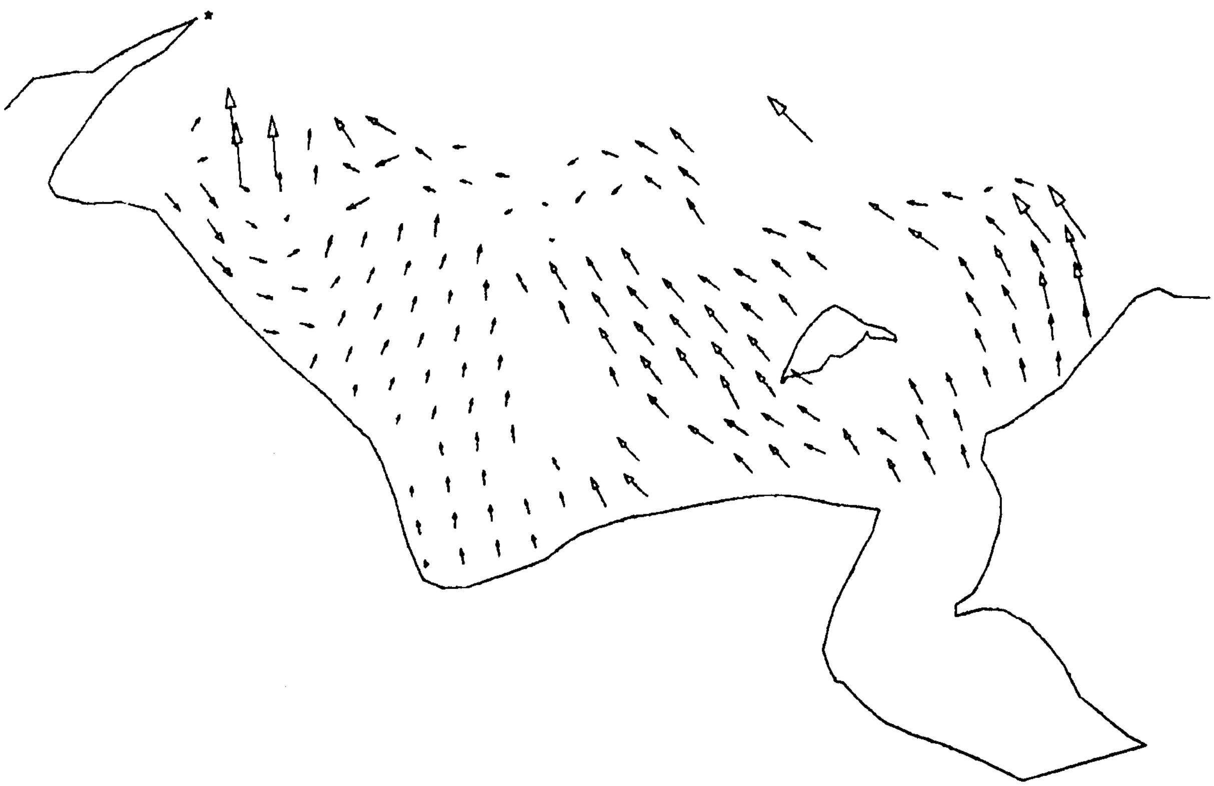

8 JUL 79 2: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

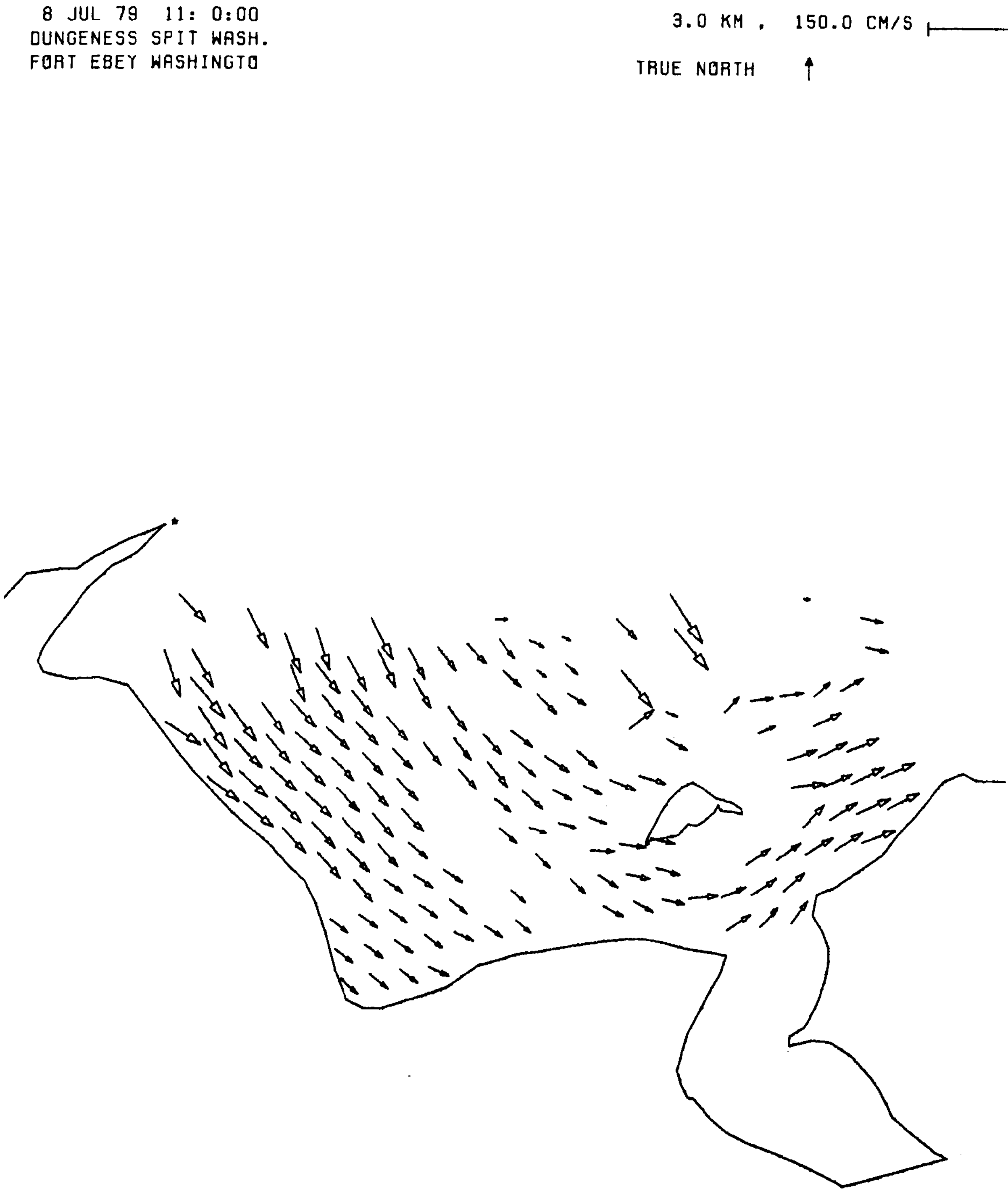

8 JUL 79 5: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

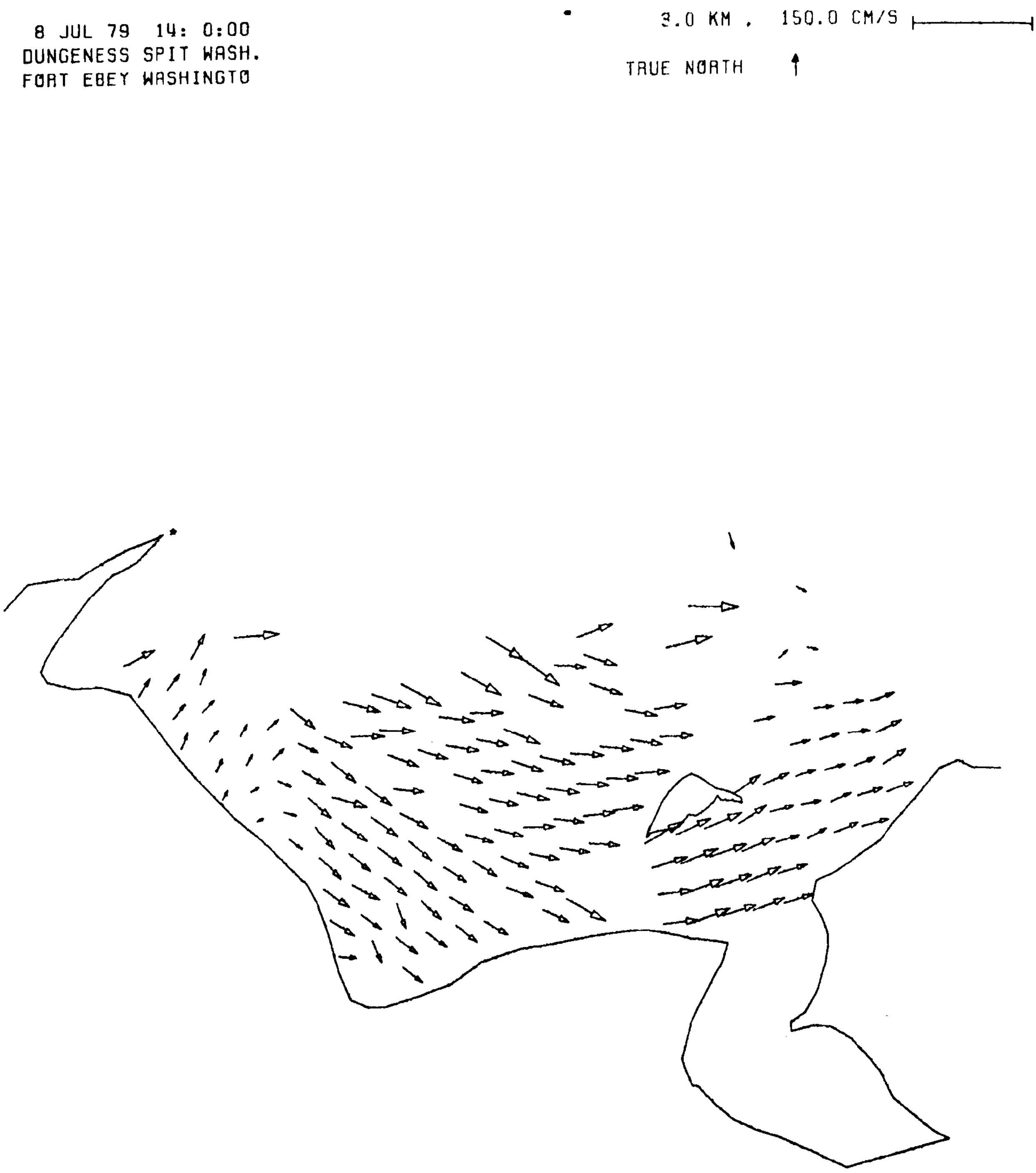
8 JUL 79 8: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

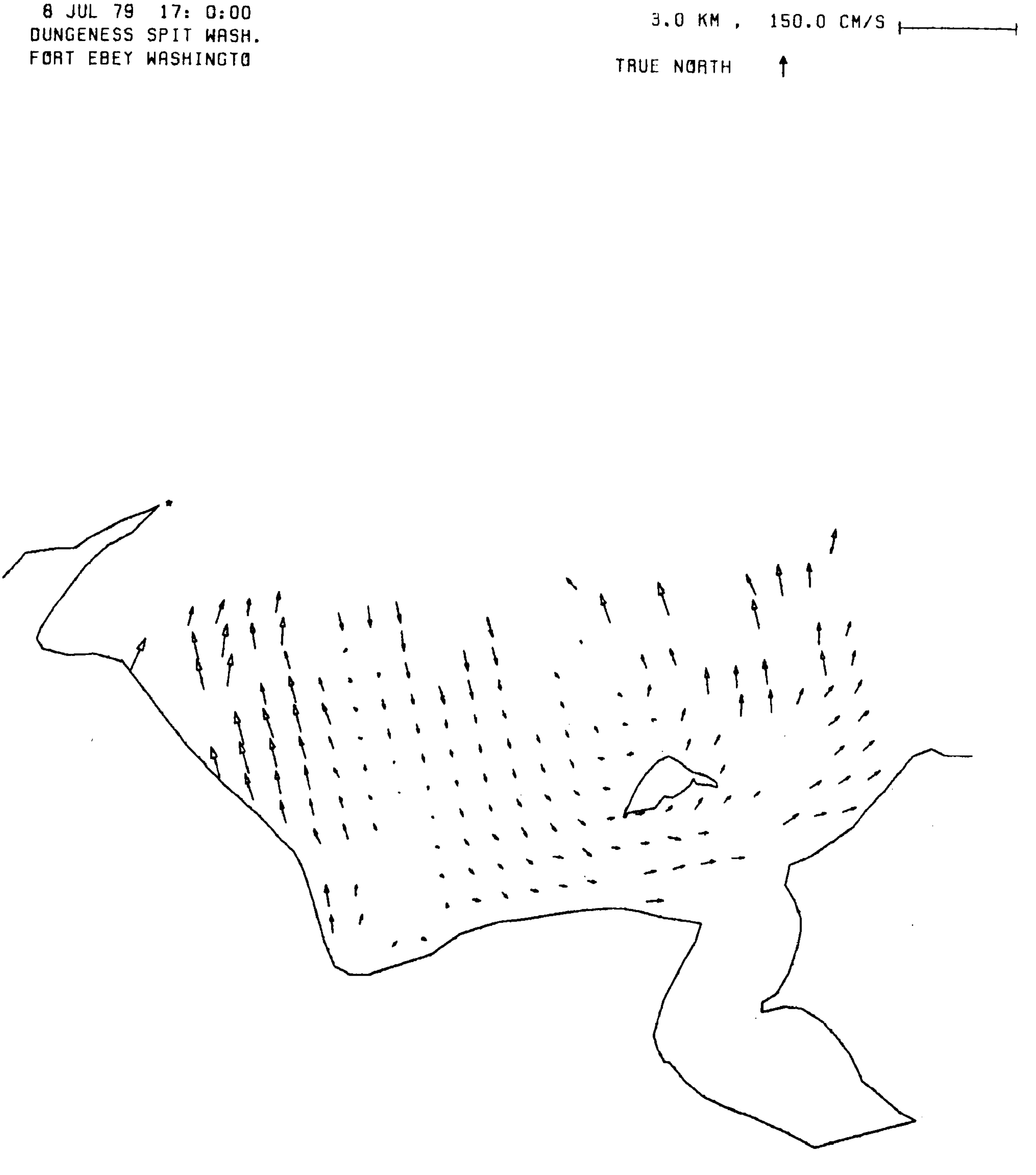
3.0 KM . 150.0 CM/S

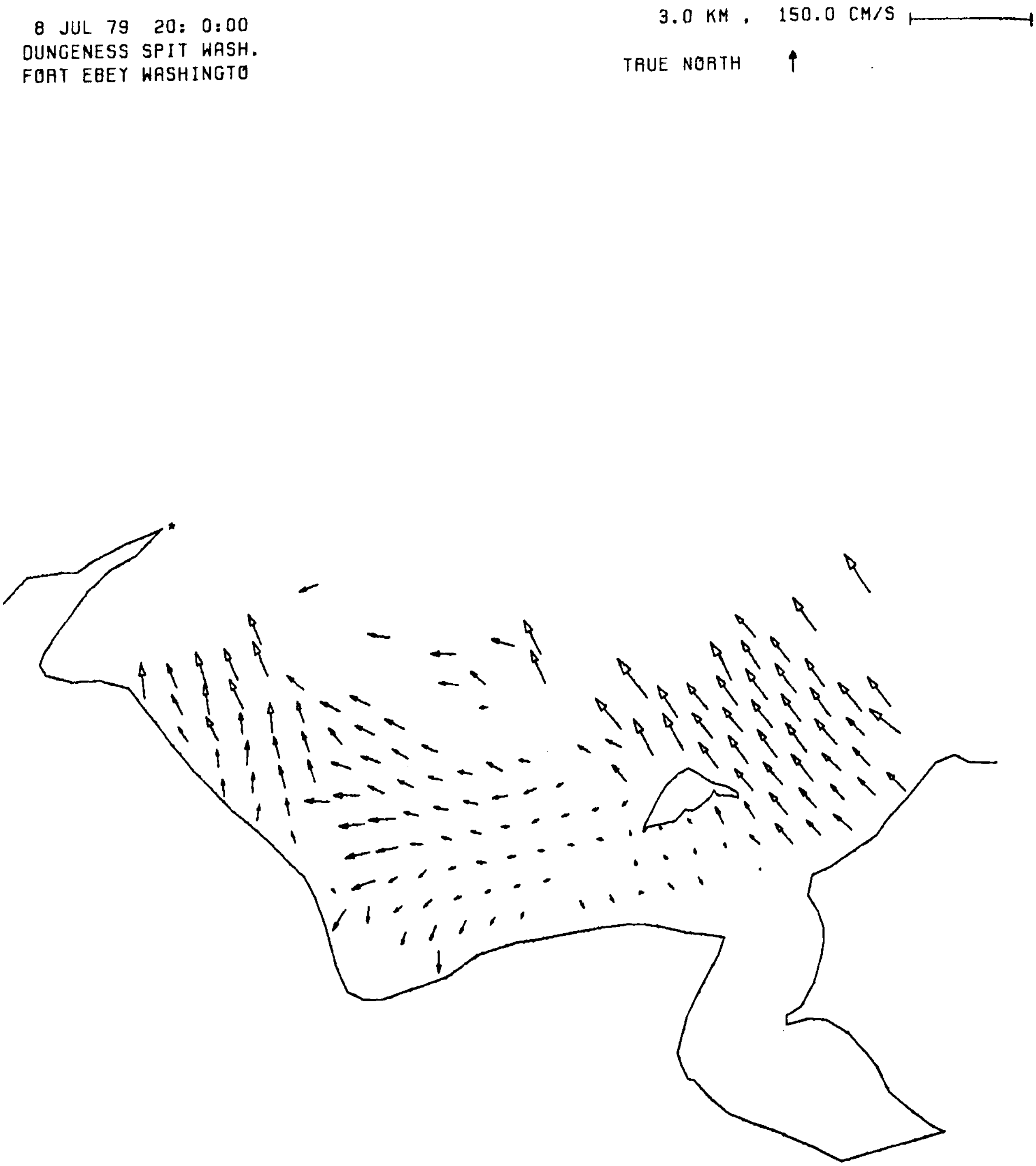
TRUE NORTH




8 JUL 79 11: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH


8 JUL 79 14: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

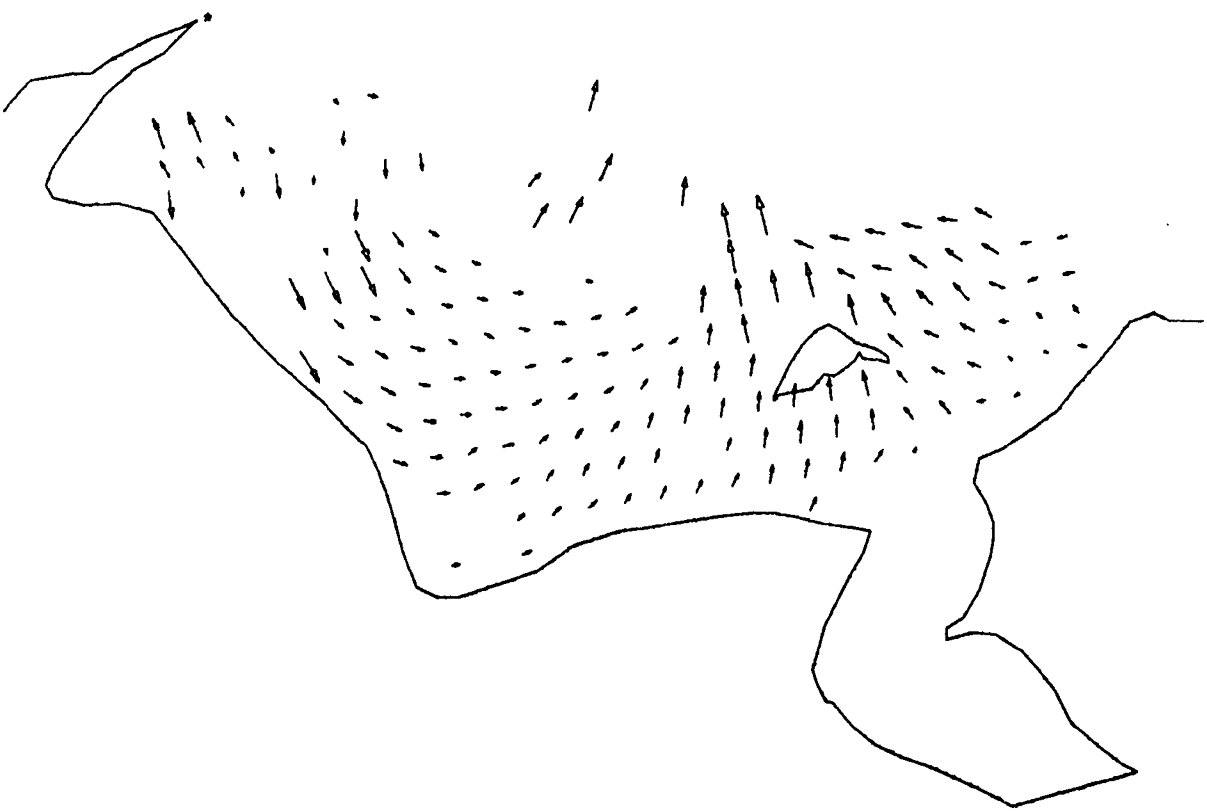

8 JUL 79 17: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

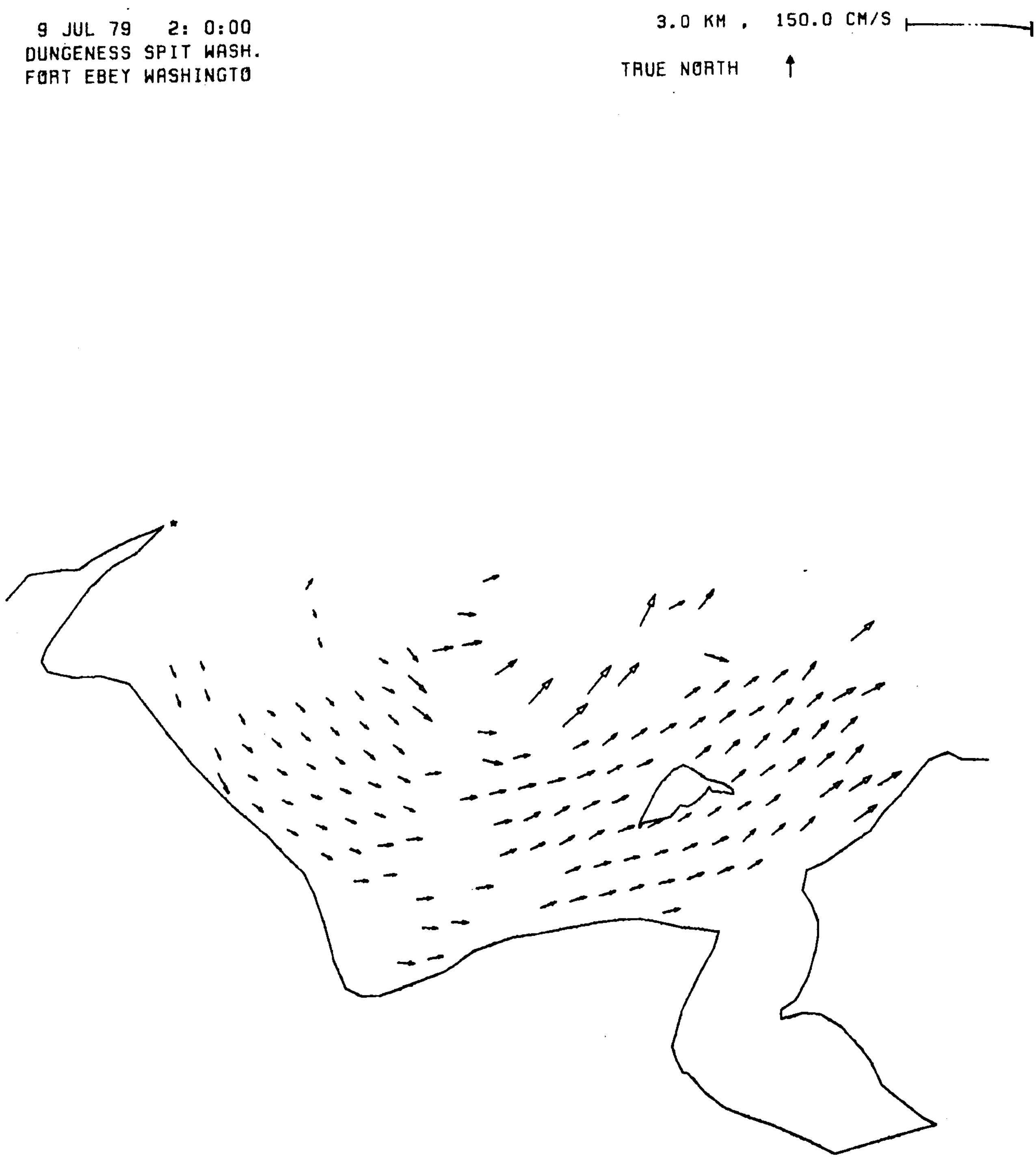

8 JUL 79 20: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

8 JUL 79 23: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH

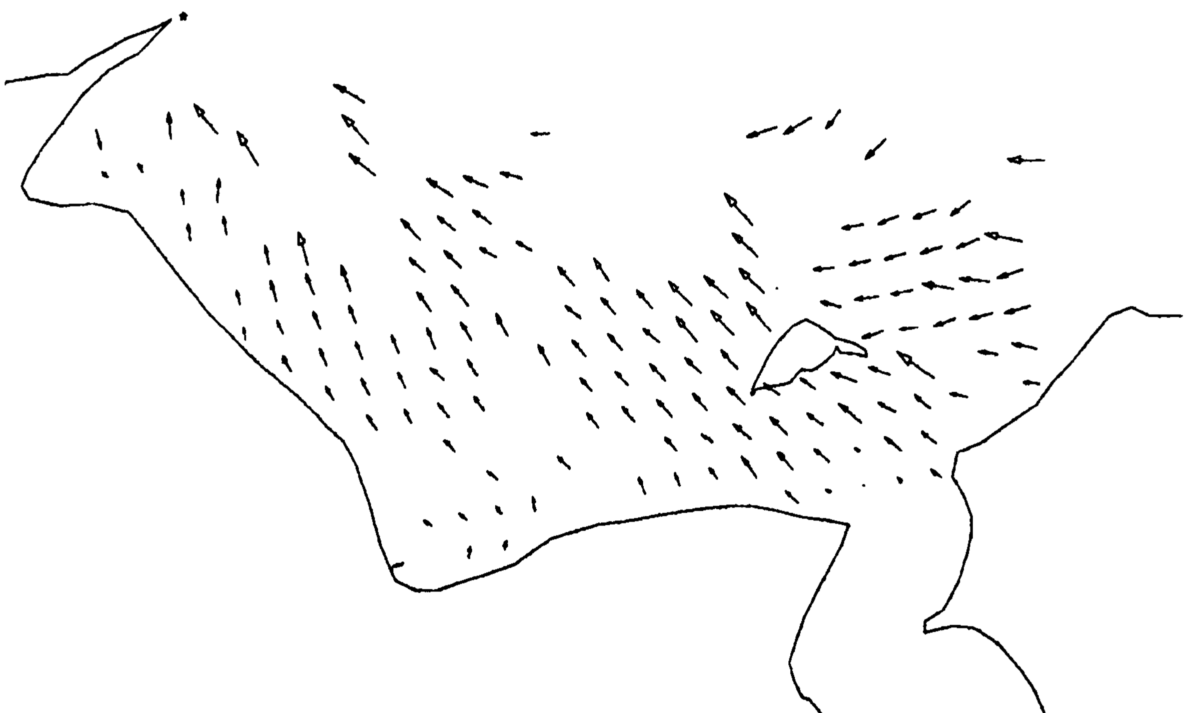


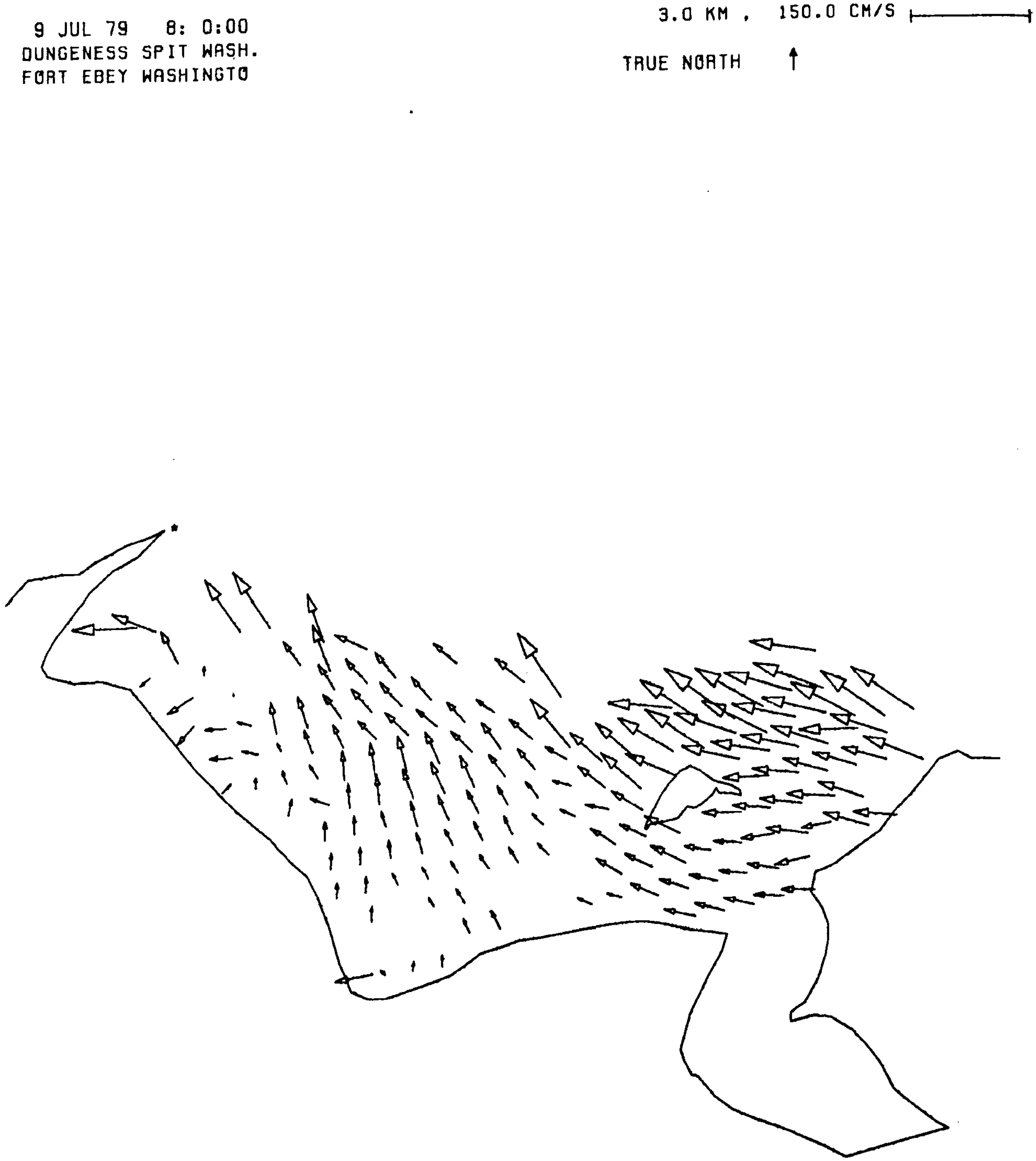

9 JUL 79 2: 0:00
DUNGENESS SPIT WASH.
FØRT EBEY WASHINGTØ
3.0 KM , 150.0 CM/S
TRUE NØRTH

9 JUL 79 5: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH ↑

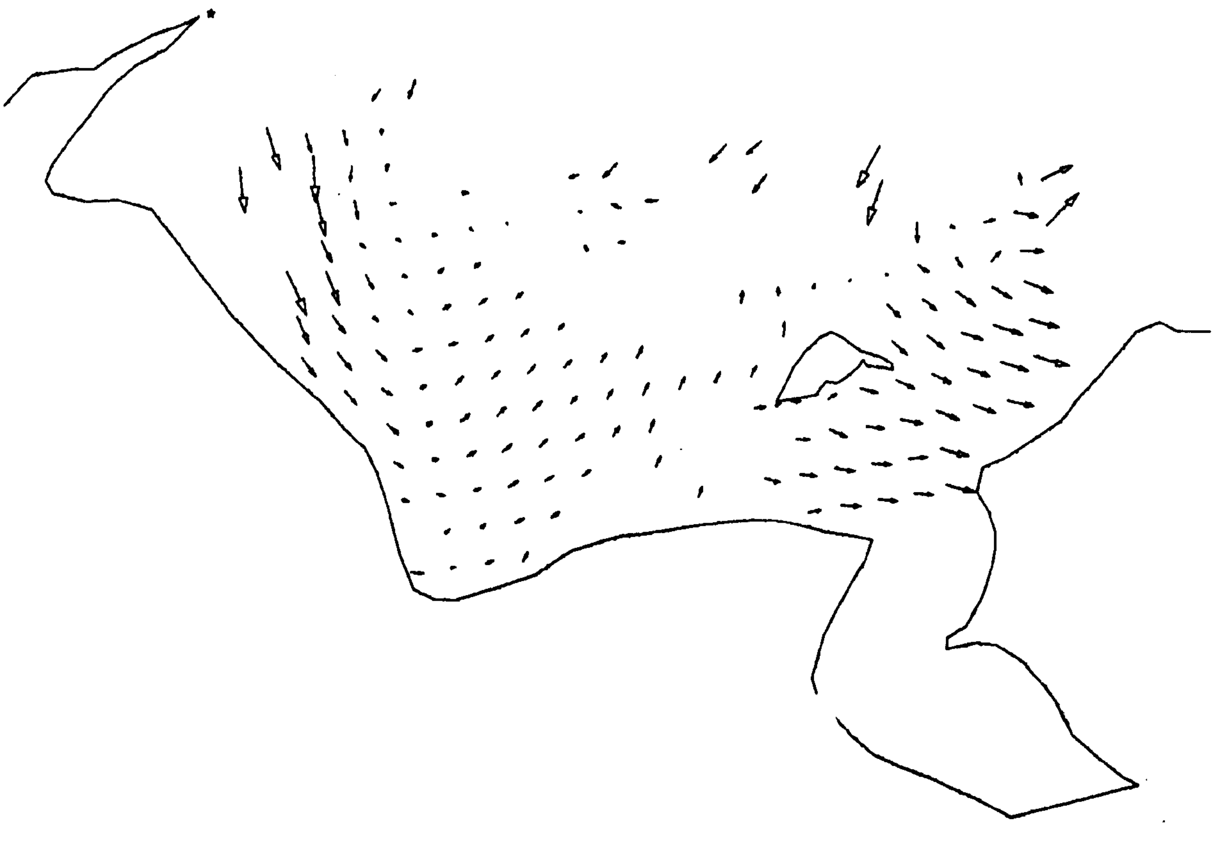



9 JUL 79 8: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

9 JUL 79 11: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

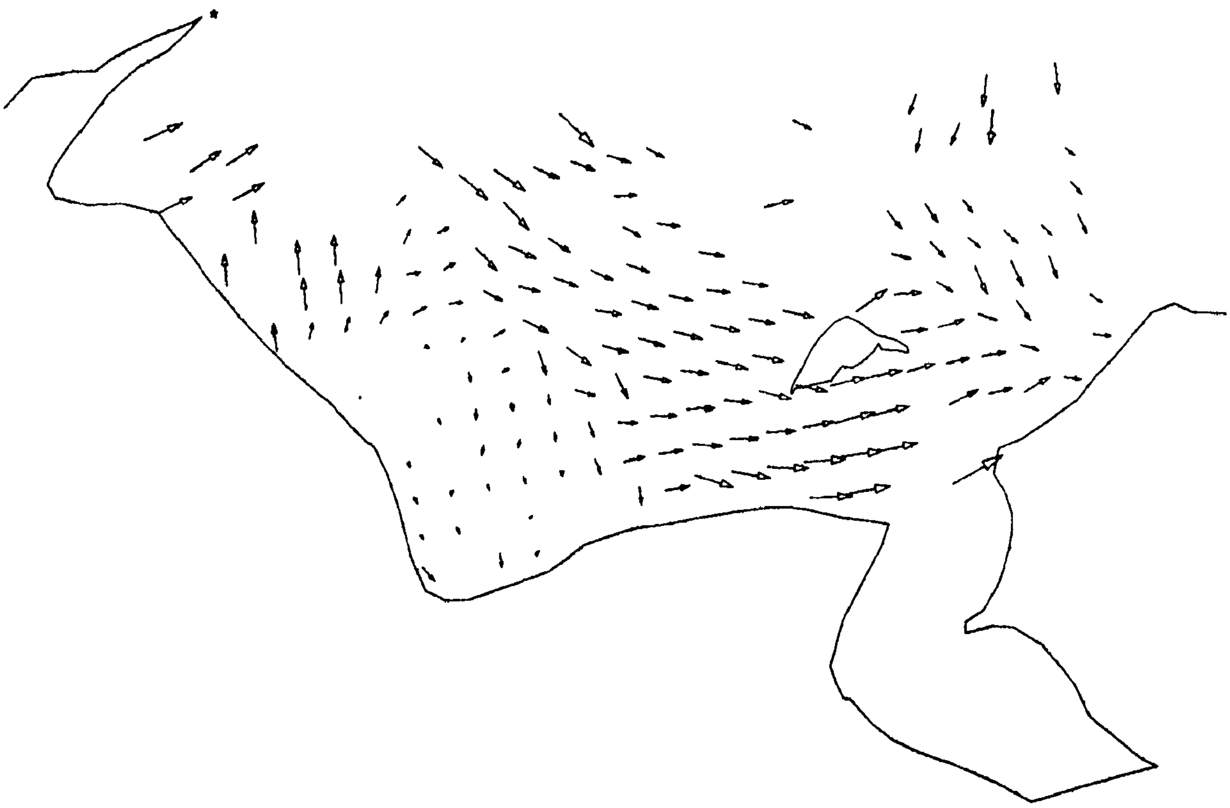
TRUE NORTH



9 JUL 79 14: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

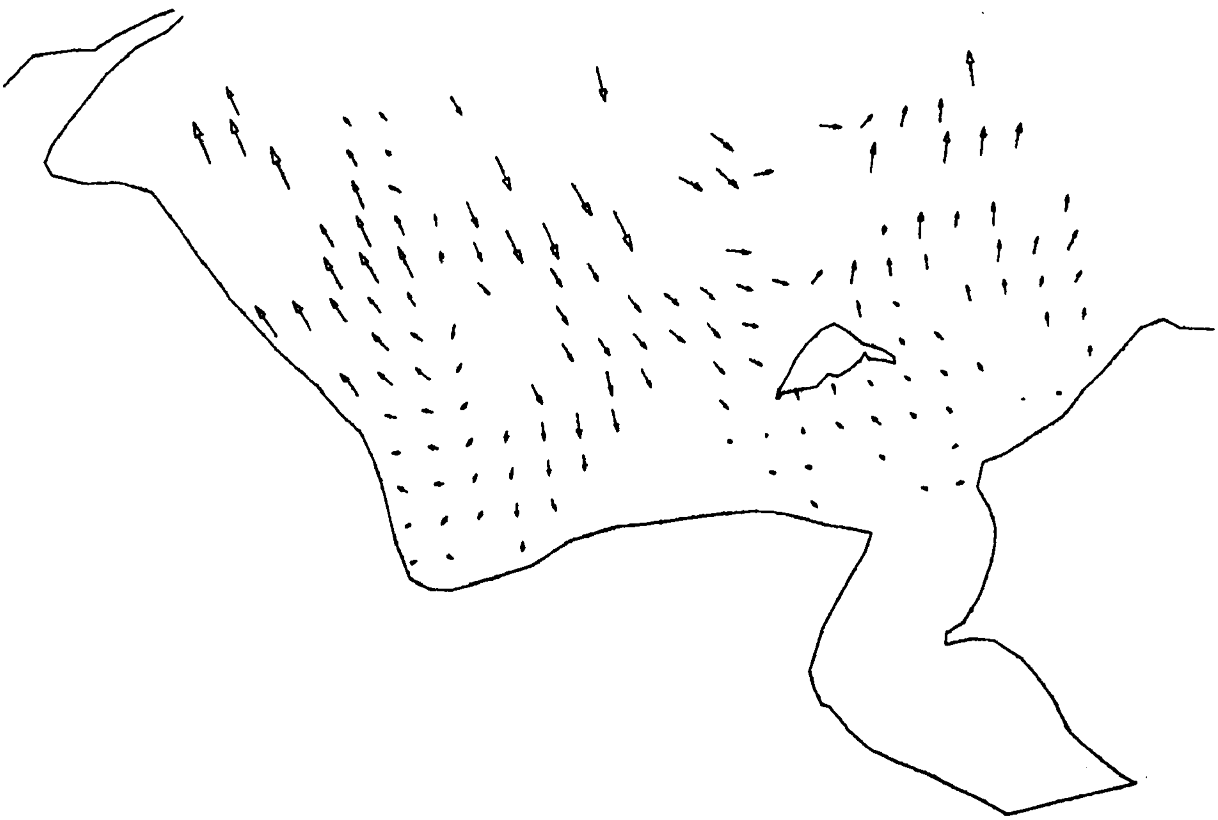
TRUE NORTH ↑

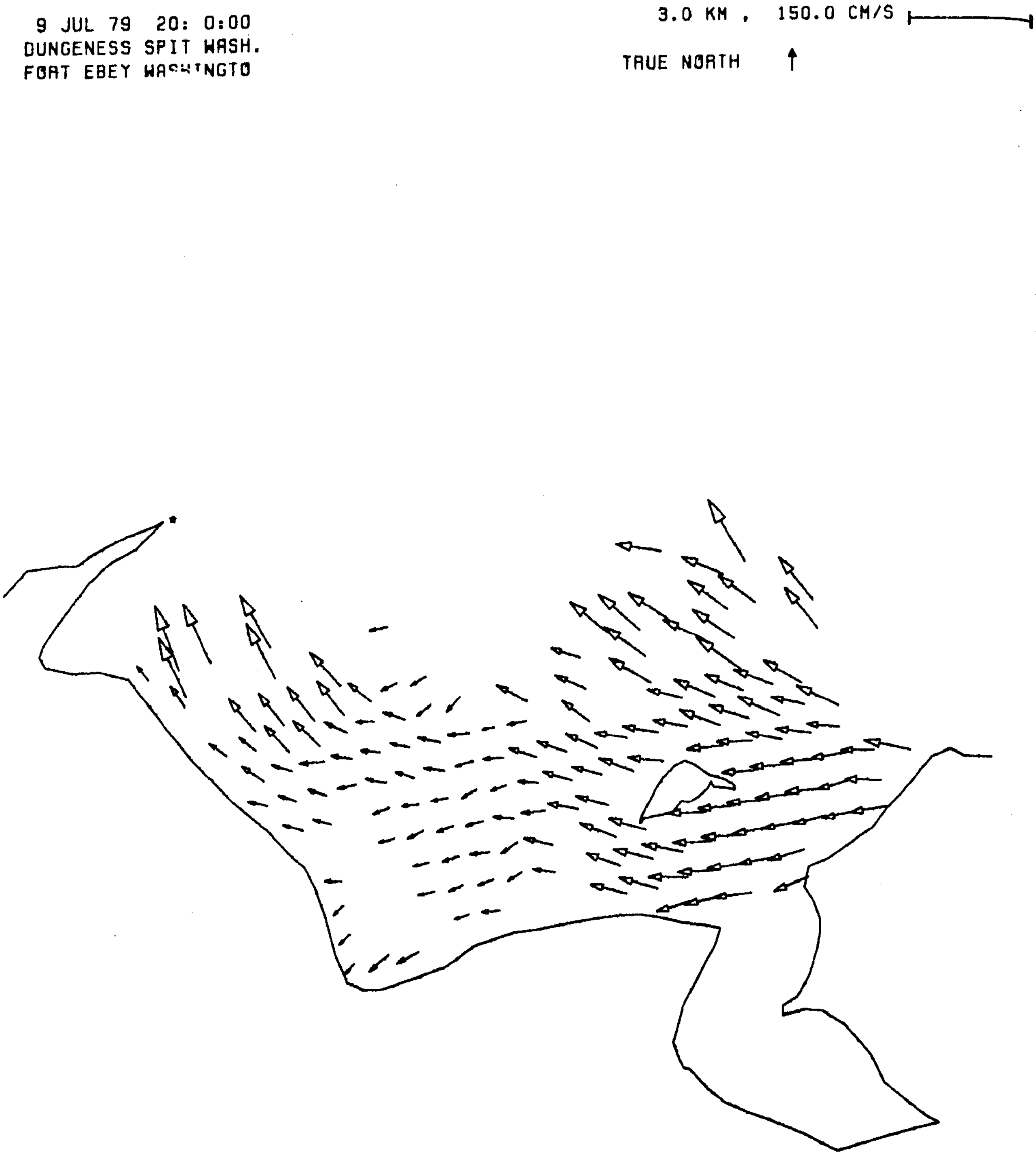


09-JUL-79 17:00:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM . 150.0 CM/S

TRUE NORTH



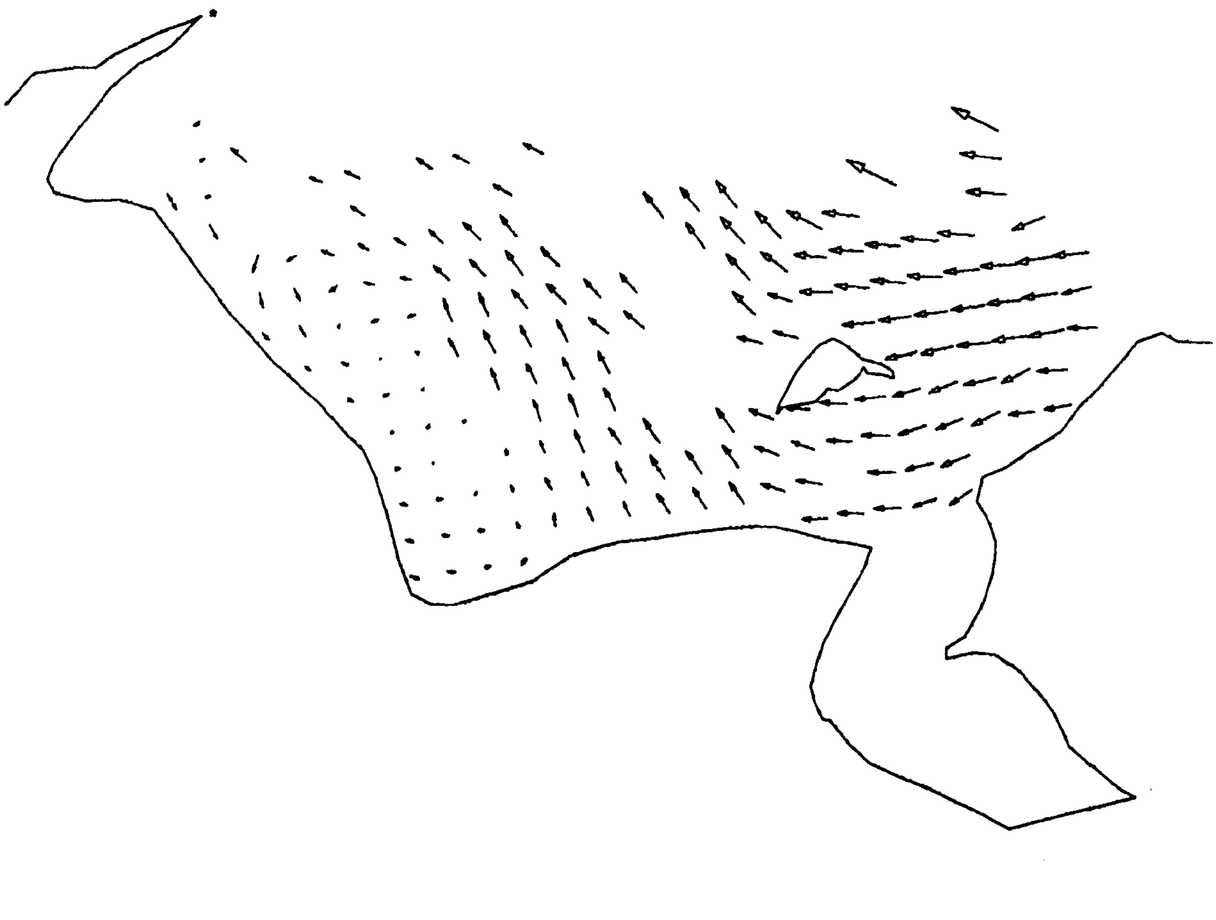


9 JUL 79 20: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WA^^^INGTO
3.0 KM , 150.0 CM/S
TRUE NORTH

9 JUL 79 23: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

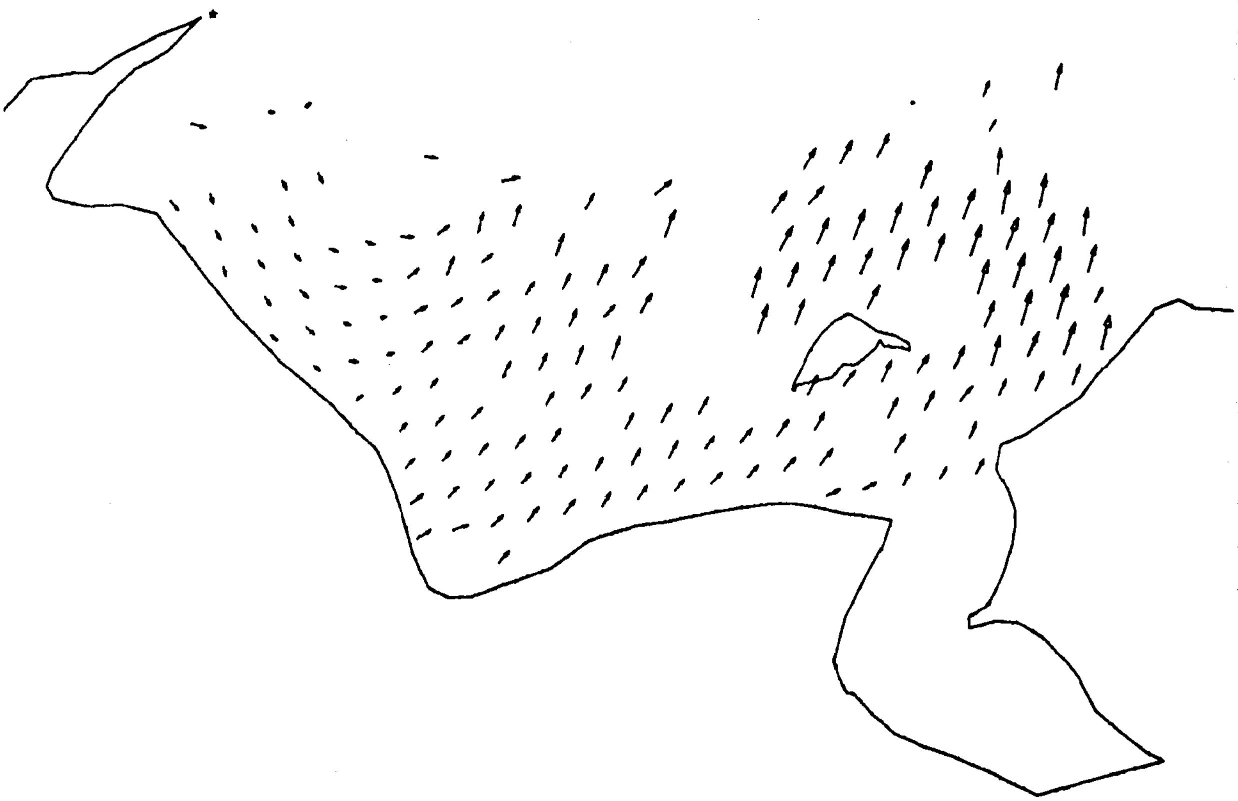
TRUE NORTH



10 JUL 79   2: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

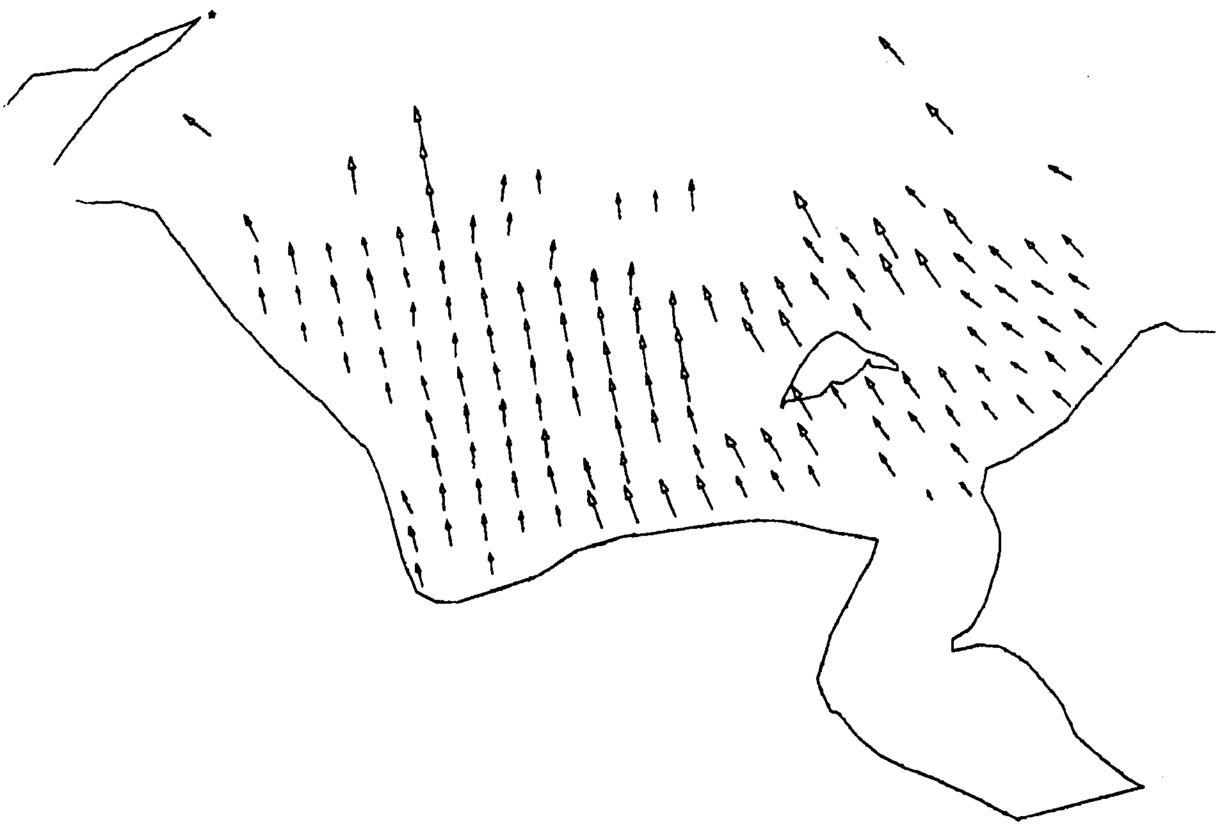
TRUE NORTH ↑

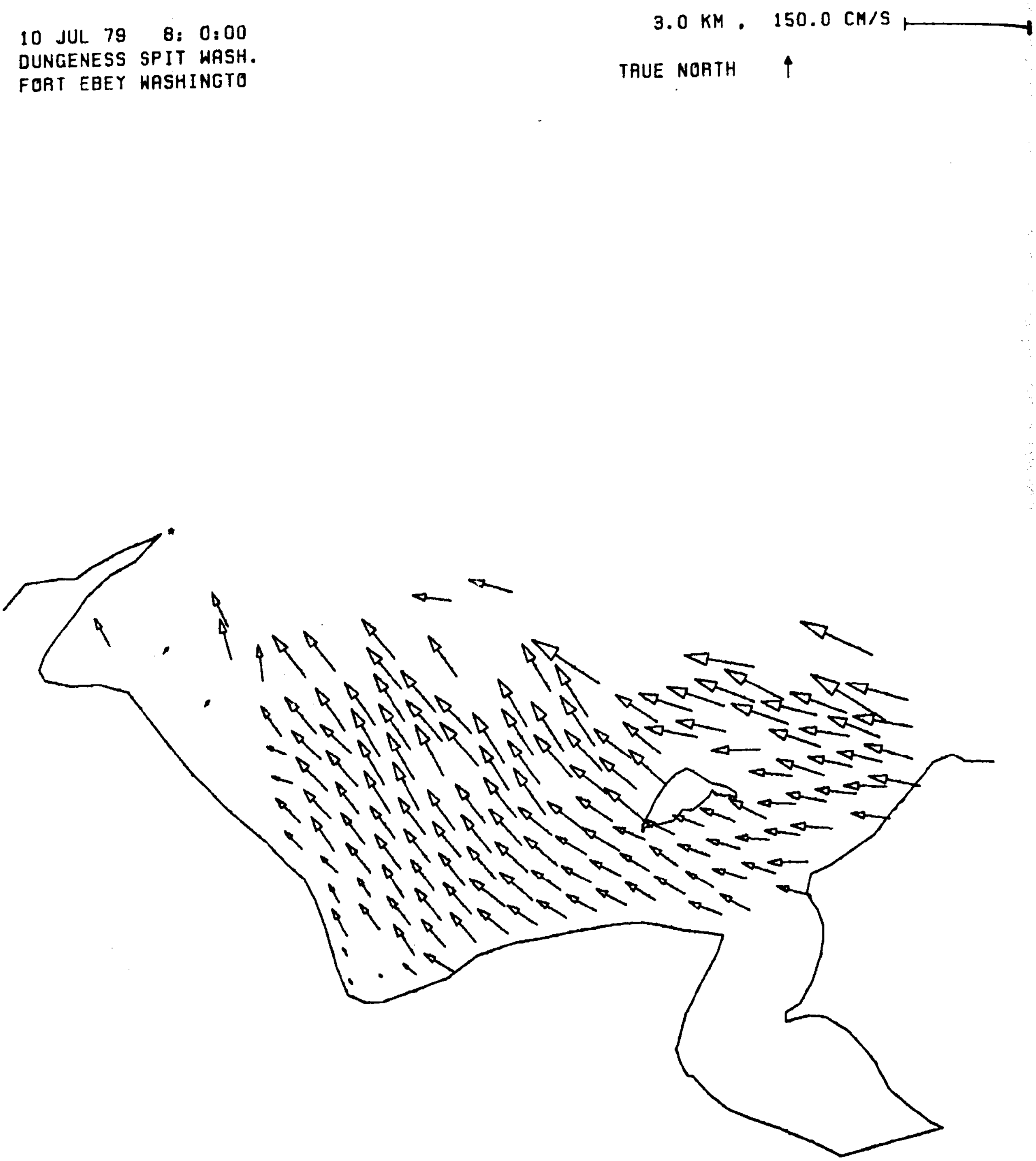


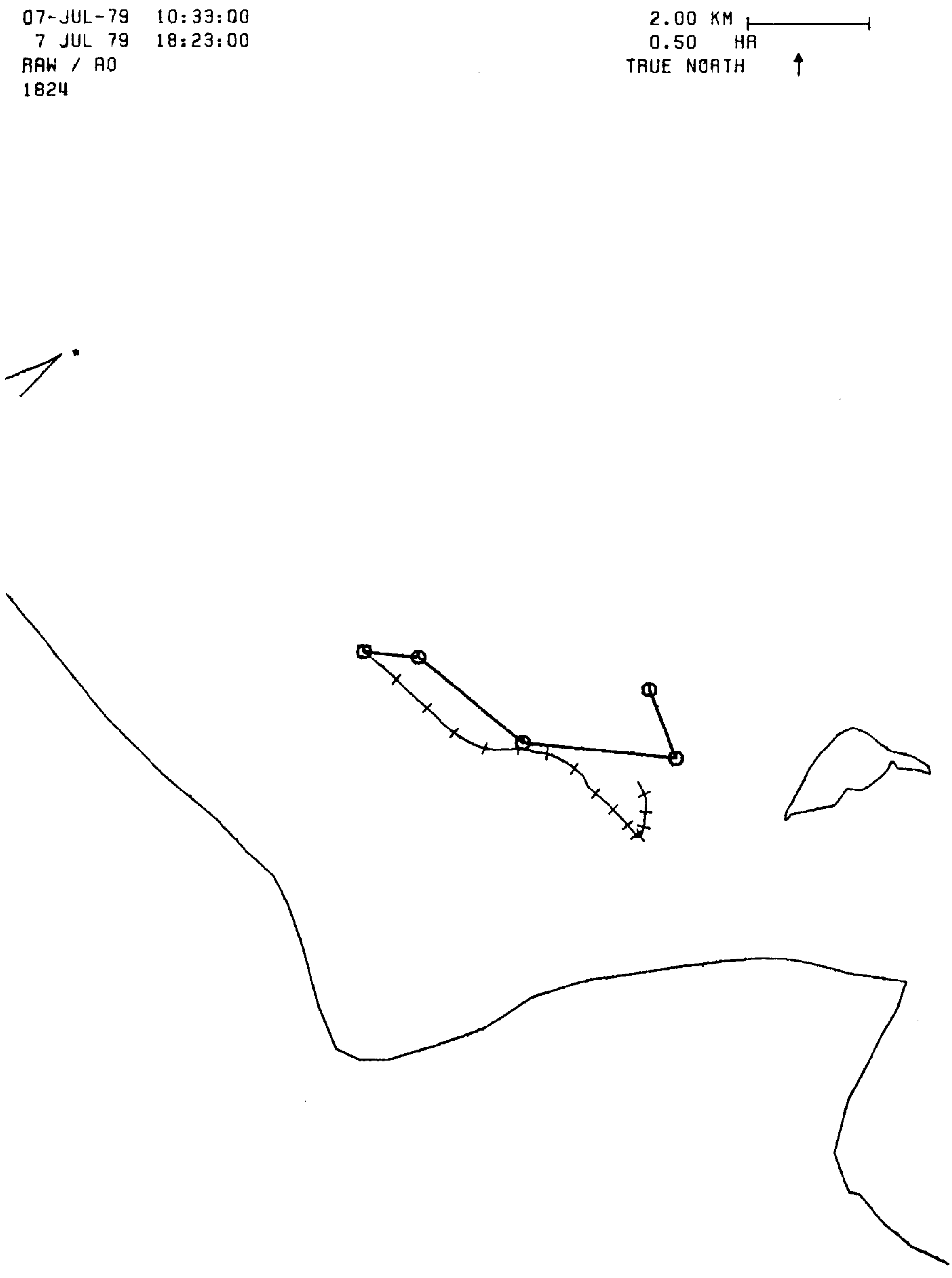
10 JUL 79 5: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO

3.0 KM , 150.0 CM/S

TRUE NORTH

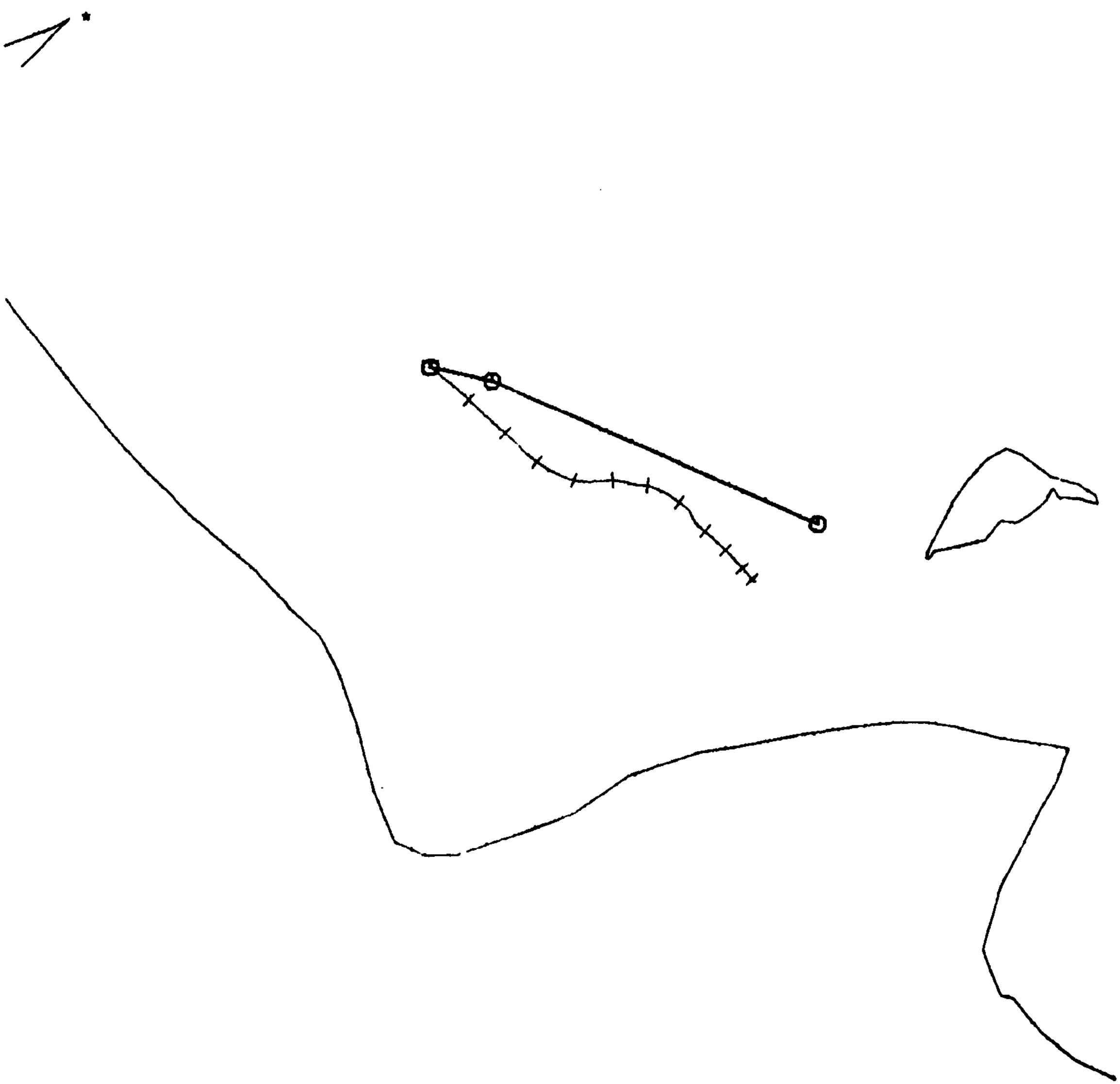



10 JUL 79 8: 0:00
DUNGENESS SPIT WASH.
FORT EBEY WASHINGTO
3.0 KM , 150.0 CM/S
TRUE NORTH


07-JUL-79 10:33:00
7 JUL 79 18:23:00
RAW / AO
1824
2.00 KM
0.50 HR
TRUE NORTH

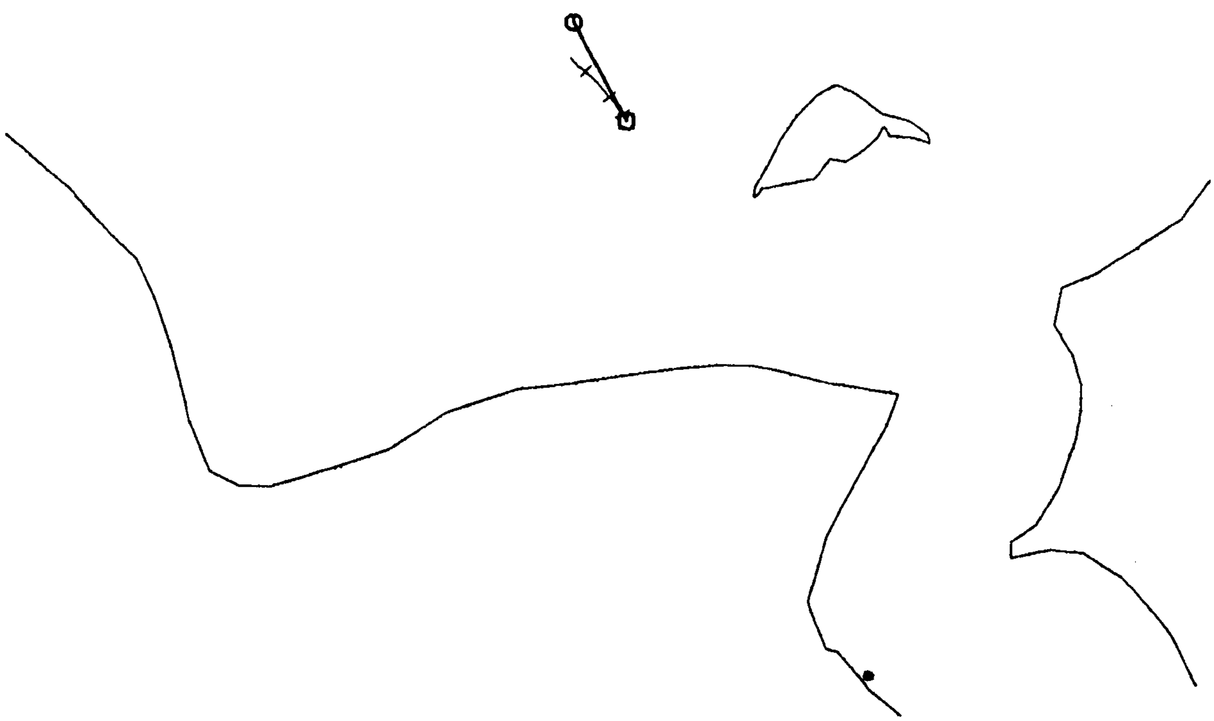
07-JUL-79 10:33:00
7 JUL 79 16:23:00
RAW / A1
1623

2.00 KM
0.50 HR
TRUE NORTH

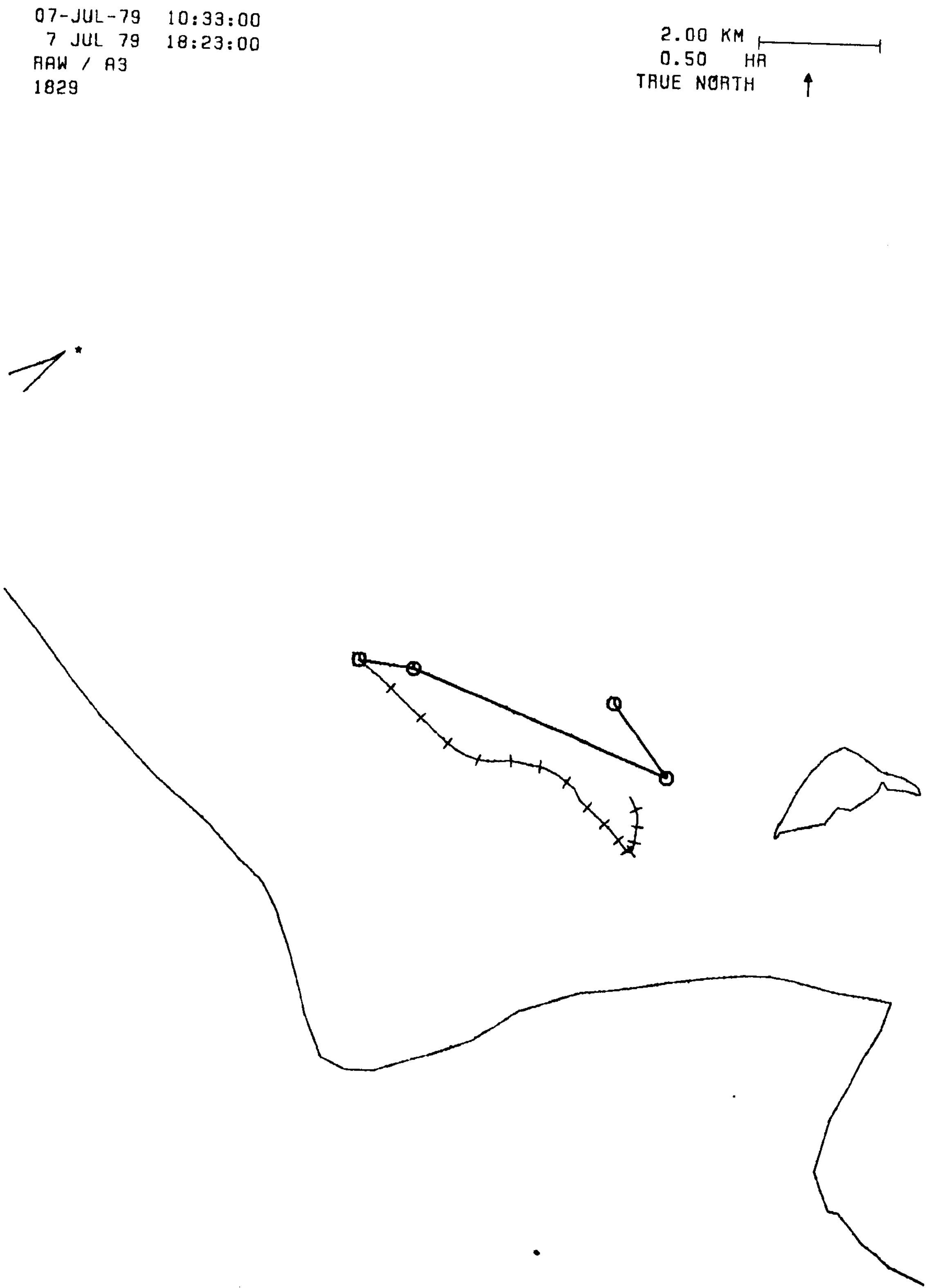


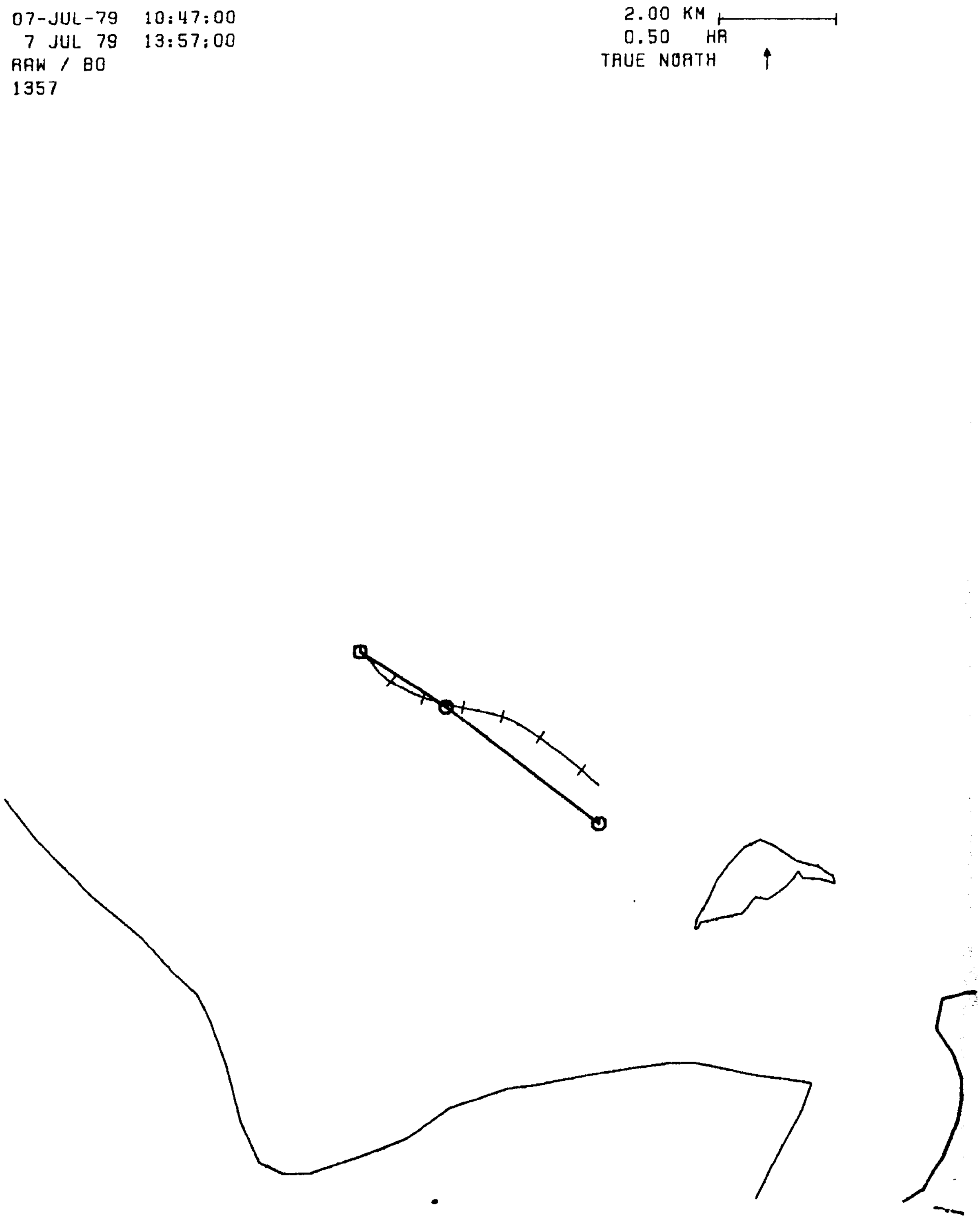
07-JUL-79 16:27:00
7 JUL 79 18:17:00
RAW / A1
1826

2.00 KM
0.50 HR
TRUE NORTH




07-JUL-79 10:33:00
7 JUL 79 18:23:00
RAW / A2
1830
2.00 KM
0.50 HR
TRUE NORTH

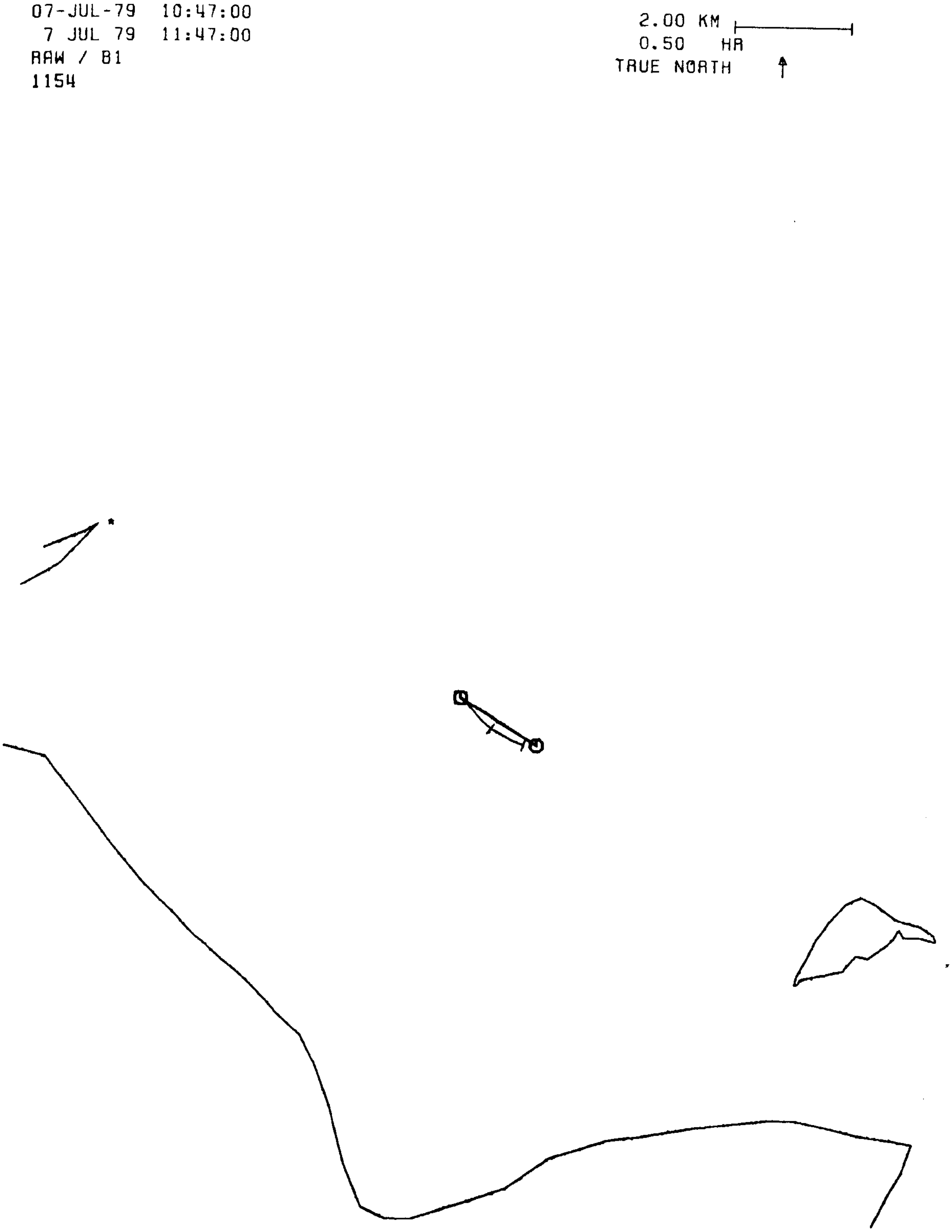

07-JUL-79 10:33:00
7 JUL 79 18:23:00
RAW / A3
1829
2.00 KM
0.50 HR
TRUE NØRTH



07-JUL-79 10:47:00
7 JUL 79 13:57;00
RAW / BO
1357
2.00 KM
0.50 HR
TRUE NORTH

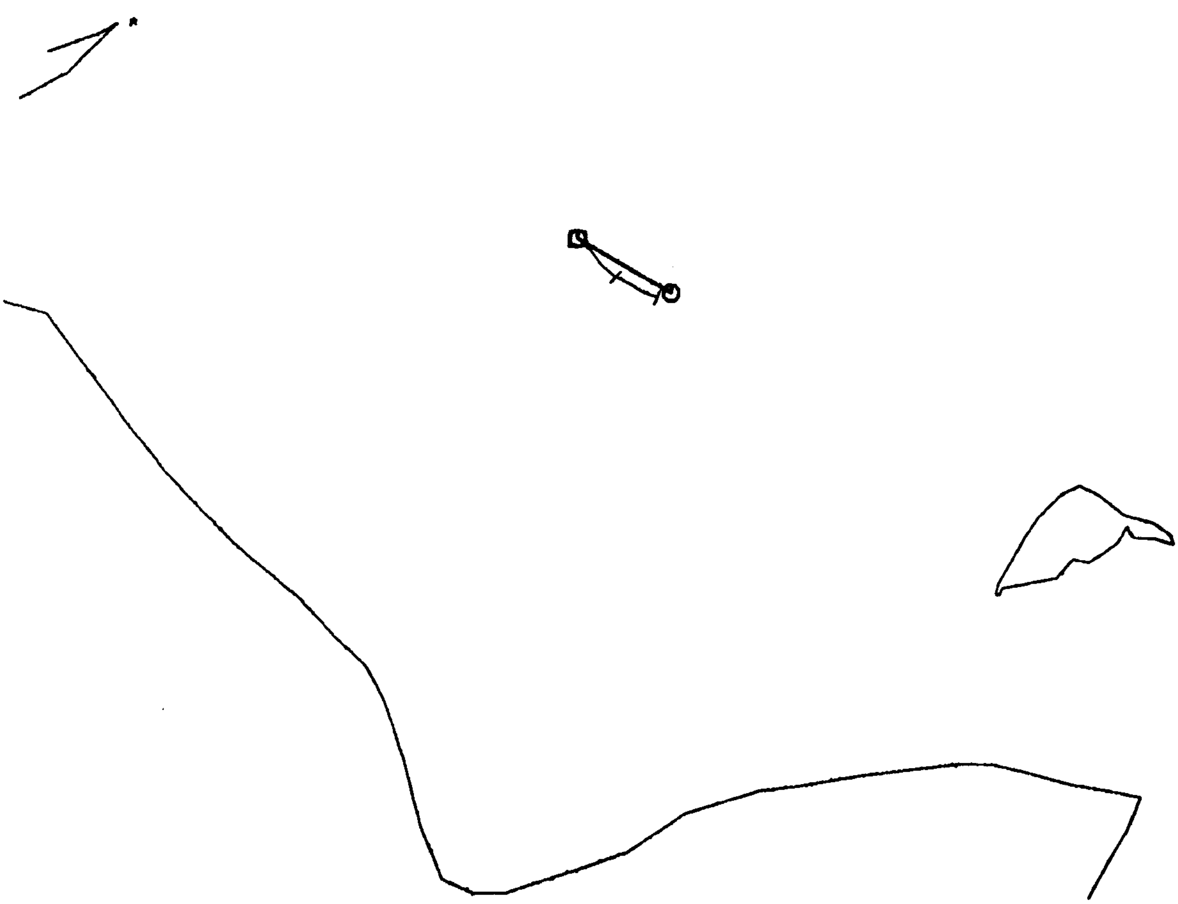
07-JUL-79 10:47:00
7 JUL 79 11:47:00
RAW / B1
1154

2.00 KM
0.50 HR
TRUE NORTH



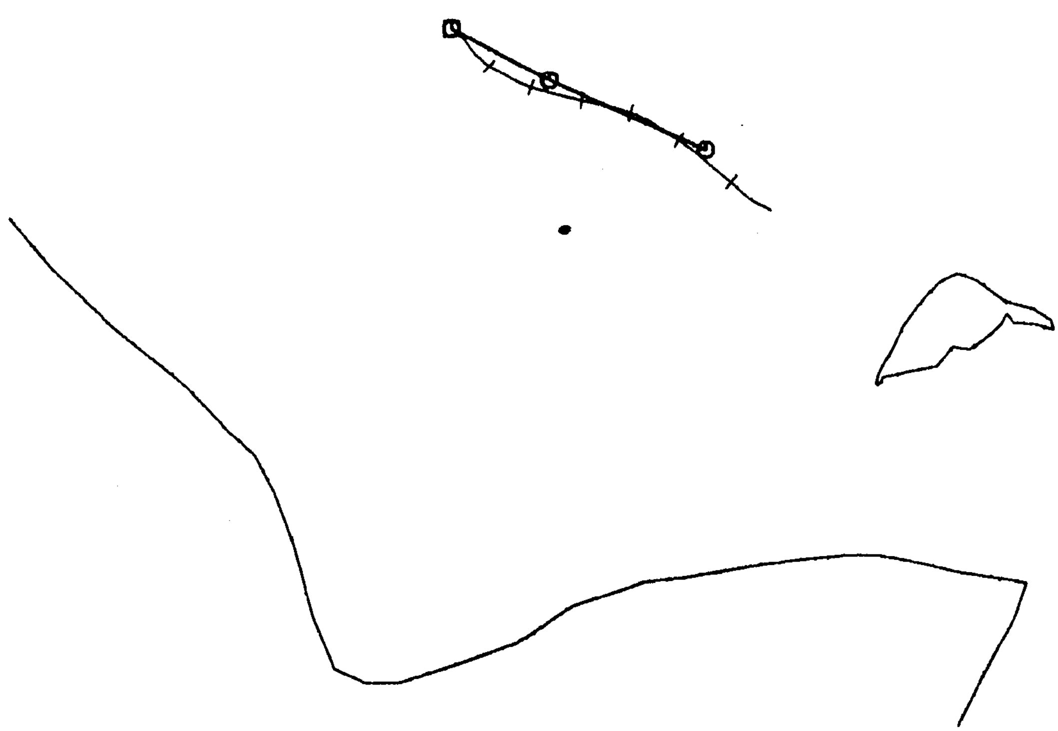
07-JUL-79 10:47:00
7 JUL 79 11:47:00
RAW / 82
1162

2.00 KM
0.50 HR
TRUE NORTH



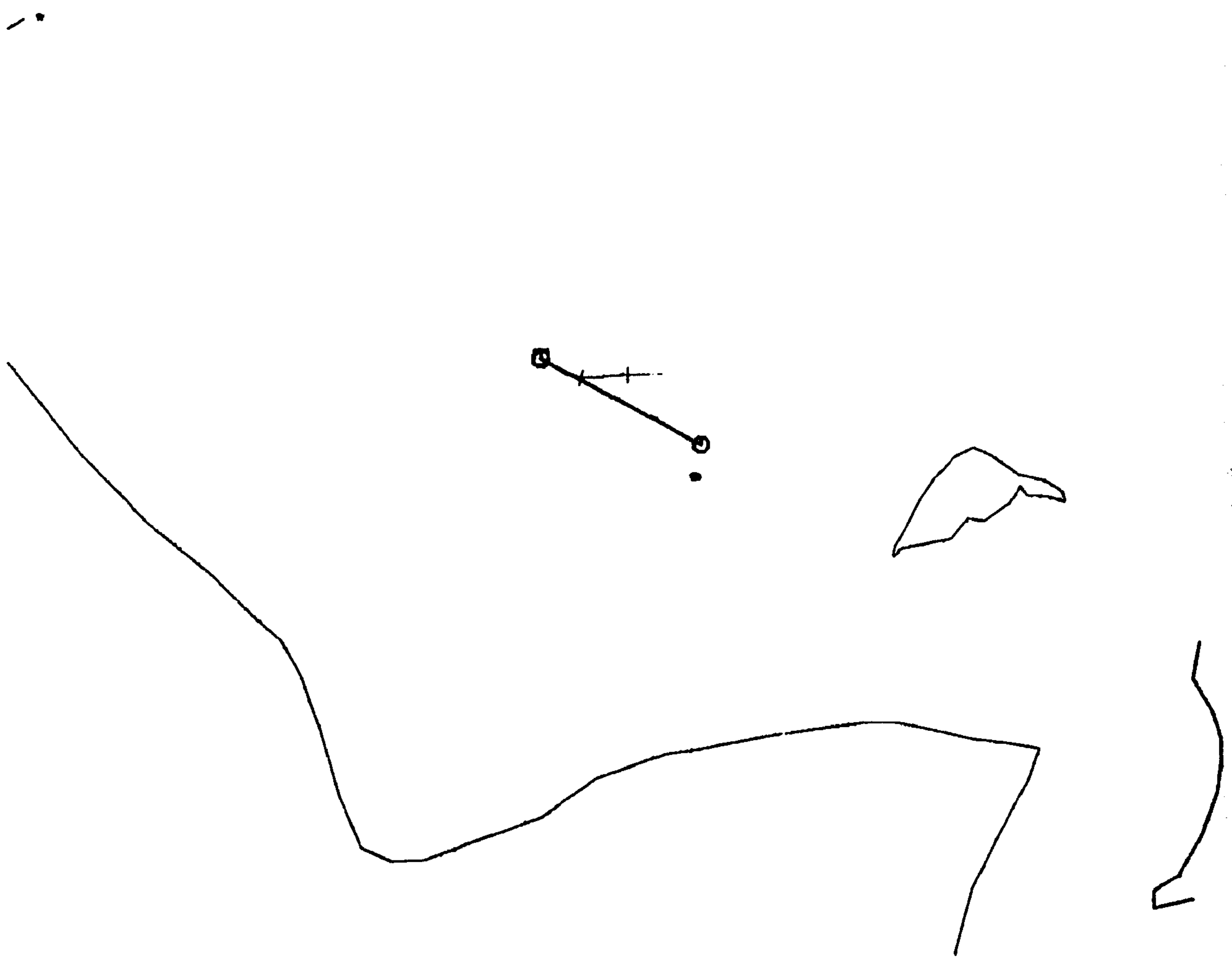
07-JUL-79 10:47:00
 7 JUL 79 14: 7:00
RAW / B3
1411

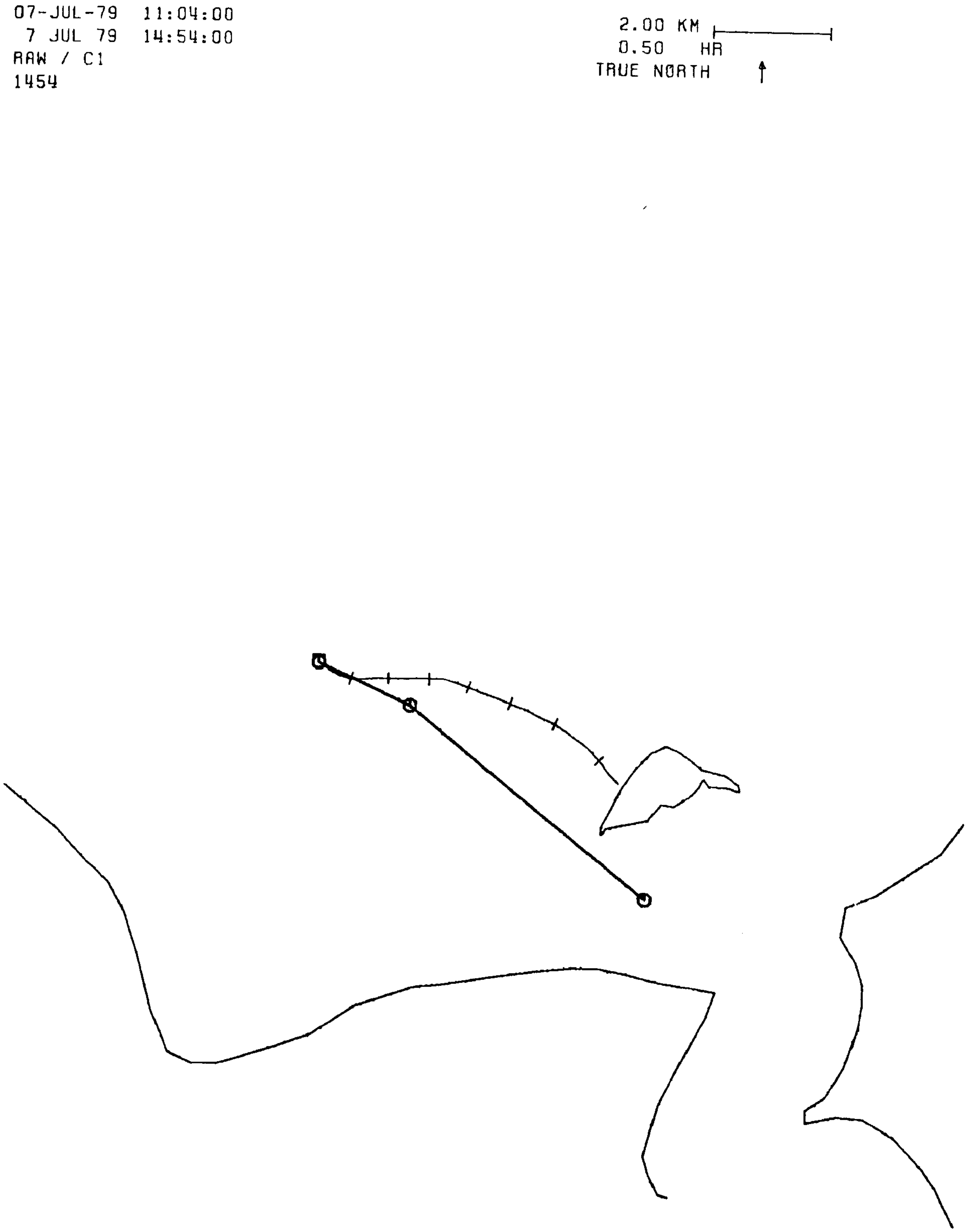
2.00 KM
0.50 HR
TRUE NORTH



07-JUL-79 11:04:00
7 JUL 79 12:24:00
RAW / CO
1230

2.00 KM
0.50 HR
TRUE NORTH

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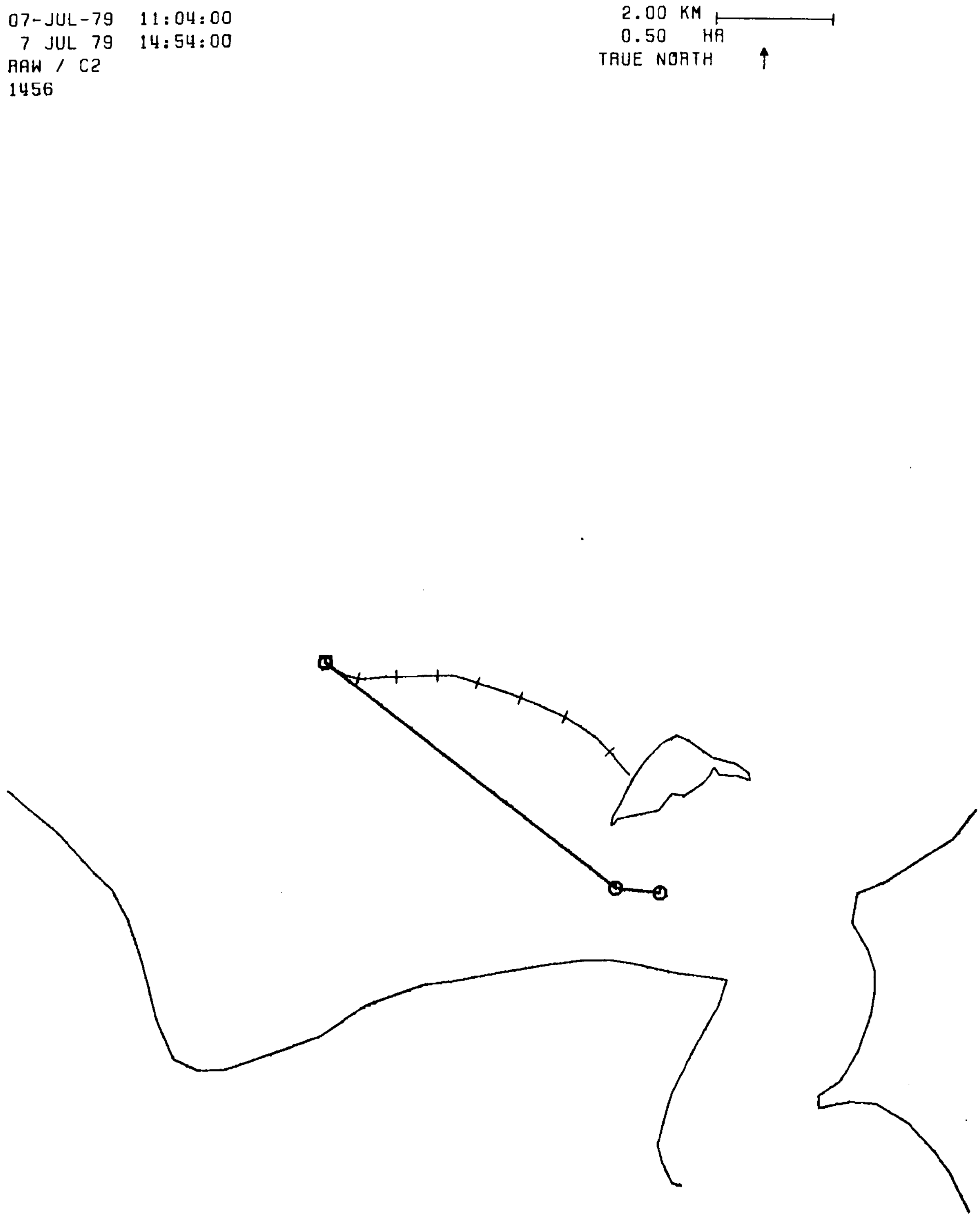
7 JUL 79 14:54:00
RAW / C1
1454
2.00 KM
0.50 HR
TRUE NORTH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RAW / C2
1456
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RAW / C3
1502

2.00 KM
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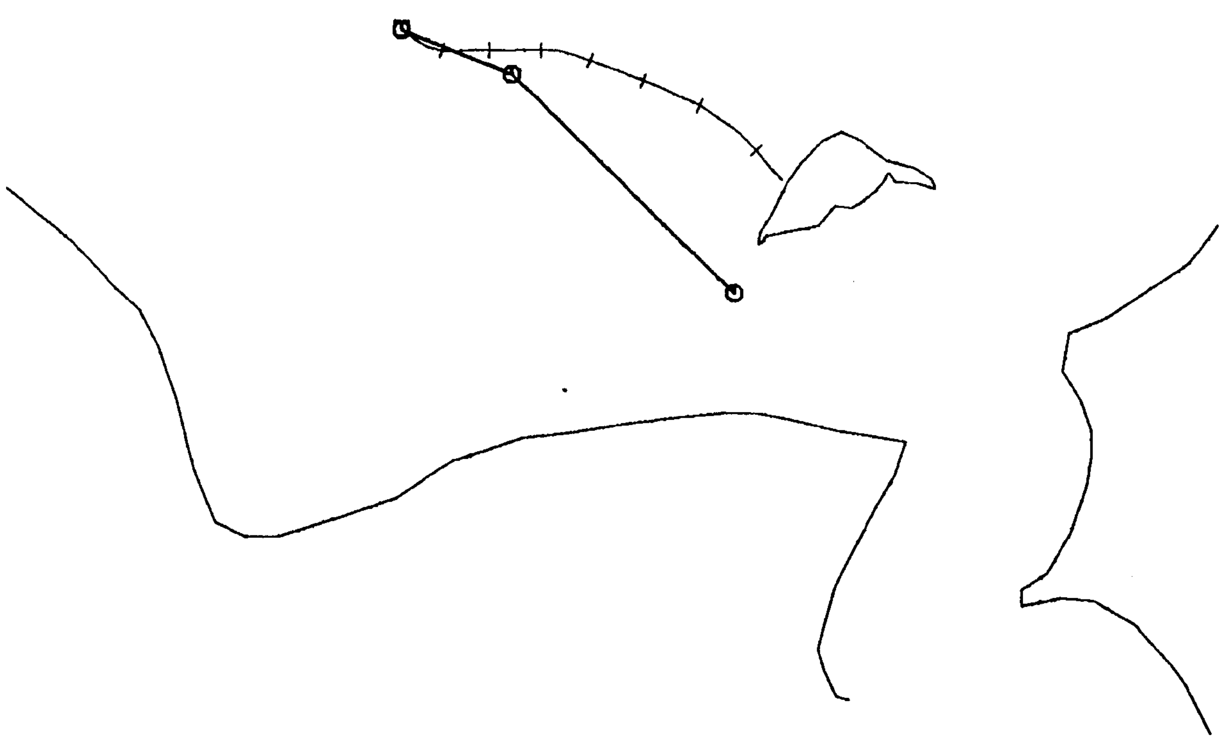

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