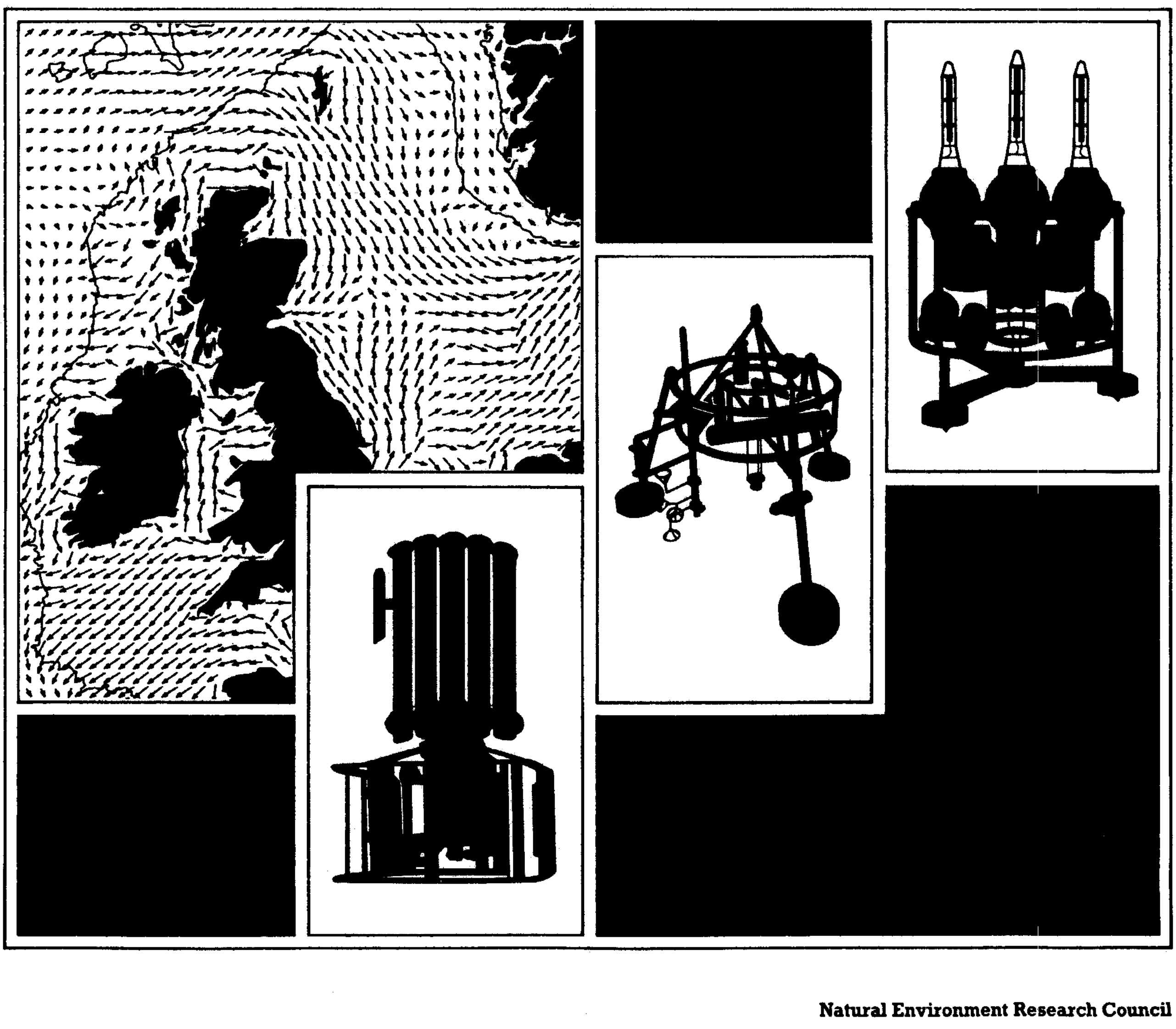
Proudman
Oceanographic
Laboratory

# H.F. radar surface current measurements in the Dover Strait

## June 1990 – September 1991

RJ Player

Report No 25 1992



Natural Environment Research Council

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**Natural Environment Research Council**

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REPORT NO. 25

# H.F. radar surface current measurements in the Dover Strait, June 1990 - September 1991

R.J. Player

1992

# DOCUMENT DATA SHEET

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*ABSTRACT*


A series of H.F. radar deployments were carried out from June 1990 - September 1991, to measure surface currents in the Dover Strait.

This document describes the series of deployments, data collected, analysis and initial results of the deployments.



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|---|---|---|
| *KEYWORDS*<br>HF RADAR<br>SURFACE CURRENTS<br>DOVER STRAIT | OCEAN SURFACE CURRENT RADAR<br>OSCR<br>CURRENT MEASUREMENT<br>ENGLISH CHANNEL | *CONTRACT*<br>*PROJECT* MLS-22-1<br>*PRICE* £26 |


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## Contents

## 1.0 Introduction

A series of HF radar experiments using OSCR II (Ocean Surface Current Radar version 2) was carried out during May 1990 - September 1991 in the Dover Strait, to determine the surface current pattern for this area. The results of the experiment would be used to determine the residual surface flow through the Dover Strait, and ultimately to estimate the total flow (at depth).

Initially one OSCR II system was used, on the French coast, with a range of 22 km, and later 44 km. Subsquently, a second OSCR II system was set up on the English coast, with the two systems running in parallel. For the last three months of the experiment, a single system was used, with the OSCR II 'master' on the French coast, and the 'slave' system on the English coast.

The intention was to use the 44 km range capability with both deployments, to cover almost the entire width of the Dover Strait from either coast, and where the deployments crossed, to compare and later combine results.

This experiment was partly financed by the Department of the Environment. Deployment and maintenance of the radar equipment was sub-contracted to Marex Technology Ltd., Cowes, who also were responsible for the supply of raw data collected. Processing, analysis and interpretation of the results was carried out by POL.

This report describes the series of deployments, data collected, analysis and the initial results, together with the problems encountered. Analysis and interpretation of the tidal components derived from these measurements has been presented in a separate paper (Prandle, Loch and Player. 1992).

## 2.0 Deployment Details

### 2.1 Description of HF radar hardware

Each deployment of OSCR II HF radar equipment consists of:-

1 transmitter antenna
16 receive antennae
1 site computer, used for control and data storage

for each of two sites, known as Master and Slave. At set intervals, currently 20 minutes, each site will collect the component of current speed, either radially towards or away from the geographical position of the transmitter, at up to 700 positions on the sea surface. These are known as radial currents. The slave transmits its data via a radio link or telephone line to the Master computer. The two radial current data sets, together with setup details, cell positions, and times of data form the data sets used for the experiment.

For a technical description of how the OSCR II system works see Prandle, 1991.

### 2.2 Site selection of the Master and Slave sites.

The sites were chosen closest to the narrowest section of the Strait, to cover the areas of strongest current flow. In addition the sites had to comply with the following as near as possible:-

a) Have sufficient flat land to hold the equipment, in particular the 16 receive antennae which had to be spaced 5.625m apart in a straight line (84.4m in total).

b) A secure place with electrical power for the site computer, in a nearby building.

c) Adequate site security to prevent interference/vandalism etc.

d) Clear, unobstructed view of the sea surface.

e) No obvious close radio interference.

f) Offer adequate intersection of master and slave boresights.

Eventually, four sites were chosen, two in France, at Wimereux Research Station, and Cap Gris Nez in northern France, and two in England, at St. Mary's and Dover in Kent. All four sites were used at various times during the deployment.

#### Wimereux

Height above mean sea level approximately 10 metres.
Reasonably secure, flat grassy area in the grounds of the Wimereux Marine Research Institute. Unobstructed view of the sea, but with 1.2 m wire mesh fence between antennae and sea. Mains electricity.

Cap Gris Nez

Height above mean sea level approximately 29 metres.
Secure area in grounds of Coastguard Station. Excellent view of sea, but with antennae orientation restrictions due to presence of two metal radar masts and the coastguard buildings. Mains electricity.

St. Mary's

Height above mean sea level approximately 10 metres.
Open site on grassland behind low sea wall, in private grounds of St. Mary's rugby training ground. Power from adjacent hotel or camp building, mains electricity assumed.

Dover

Height above mean sea level approximately 110 metres, and 0.5 km inland.
Reasonably secure area of grass and scrub covered slope below derelict concrete bunkers and parking area in grounds of Coastguard Station. Mains electricity.

## 2.3 Selection of cell positions

The required latitude and longitude cell positions are set up within the OSCR software, and the cell positions with respect to the boresight (clockwise = +ve) are calculated. The OSCR software then records the signal from that direction, and calculates the corresponding radial speed for the cell area.

## 2.4 Deployments

Each OSCR II deployment consists of a Master and Slave radial collection site, spatially overlapping with each other on the sea surface to produce calculated vector currents. The range, position and control of data collection can all be varied, according to local conditions and required data collection. Over this experiment 7 deployments (known as configurations) were set up.

Table 1 shows the configuration details and Appendix A shows the position of the cells in each configuration.

Figure 1 shows a map of the Dover Strait area with the Master and Slave sites and deployment coverage marked.

## 2.5 Recording interval

Data for each site is recorded at 20 minute intervals, staggered by 5 minutes between each site, in order that the signals from the two sites do not interfere with each other. Data for all cells is recorded every ⅓ second, and averaged over 5 minutes. For a 30 day dataset, 2160 radial speeds and associated quality flags will be recorded for each cell of each site, resulting in large datasets.

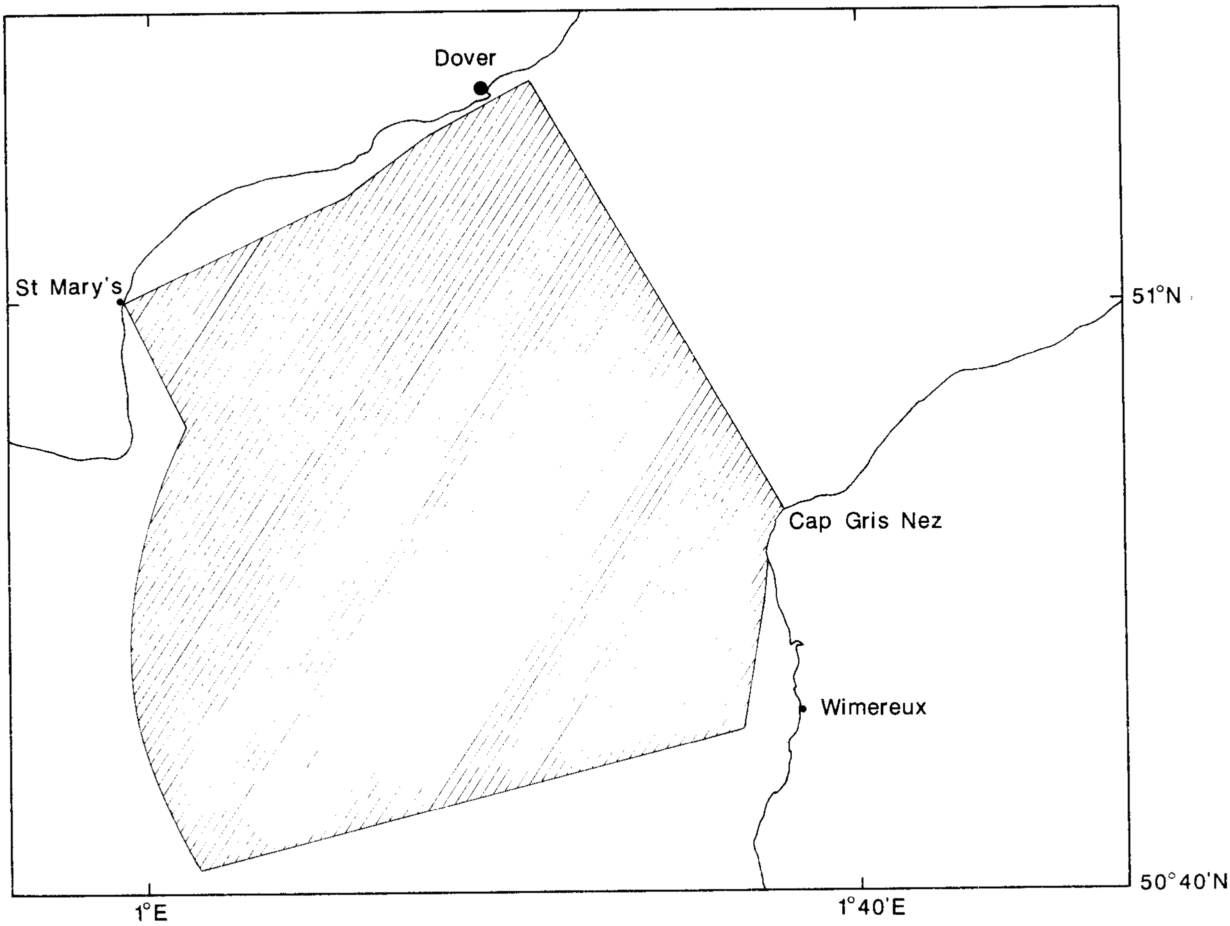



Figure 1. Area covered during Dover Strait deployments.

Table 1

Configuration Details

| Config No. | Dates | Max. Range (km) | No. cells | Master Latitude (N) | Master Longitude (E) | Master Bore# (°T) | Slave Latitude (N) | Slave Longitude (E) | Slave Bore# (°T) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23/05/90 - 26/06/90 | 24 | 700 | 50° 45.7′ | 1° 36.39′ | 301.5 | 50° 52.07′ | 1° 35.11′ | 234.0 |
| 2 | 26/06/90 - 03/08/90 | 24 | 672 | 50° 45.7′ | 1° 36.39′ | 301.5 | 50° 52.06′ | 1° 35.06′ | 253.0 |
| 3 | 03/08/90 - 03/01/91<br>23/03/91 - 21/04/91 (second deployment) | 44 | 700 | 50° 45.76′ | 1° 36.39′ | 301.5 | 50° 52.11′ | 1° 35.06′ | 253.0 |
| 4+ | 07/09/90 - 21/09/90 no data collected, see below | | | | | | | | |
| 5 | 21/09/90 - 25/03/91 | 44 | 700 | 51° 7.86′ | 1° 20.62′ | 196.0 | 51° 0.28′ | 0° 58.75′ | 107.0 |
| 6* | 18/05/91 - 01/09/91 | 44 | 674 | 51° 7.86′ | 1° 20.62′ | 196.0 | | | |
| 7* | 19/05/91 - 01/09/91 | 44 | 674 | 50° 52.11′ | 1° 35.06′ | 273.0 | | | |

+ Configuration 4 was originally set up as per config. 5, but with reversed master/slave. Abandoned due to communications problem.

* Configurations 6 and 7 were set up independantly on either side of the Dover Strait, each as master. Both were combined during processing with configuration 6 as Slave and 7 as Master.

# Boresight is the bearing in degrees (True) perpendicular to the line of receive antennae towards the data capture area, on which the data gathering sector is centred.

## 3.0 Data collected

### 3.1 Datasets

Originally the datasets were received from the contractors as they downloaded data from the site computer at convenient maintenance intervals, usually 7-21 days. For maximum analysis benefit, it was agreed that where possible downloaded datasets would be combined and supplied to POL in 30 day data sets. Table 1.2 gives details of datasets analysed.

Table 2

Datasets retrieved and processed during deployment

| Data Set | Sites | Dataspans | No. Days | Config. No. | Dep. cells | Analys. cells | % return |
|---|---|---|---|---|---|---|---|
| 1 | Wim/C.G.N. | 31/05/90-15/06/90 | 15 | 1 | 700 | 585 | 84 |
| 2 | " | 26/06/90-05/07/90 | 9 | 2 | 672 | 507 | 75 |
| 3 | " | 04/07/90-03/08/90 | 30 | 2 | 672 | 672 | 100 |
| 4 | " | 18/07/90-17/08/90 | 30 | 2 | 672 | 672 | 100 |
| 5 | " | 17/08/90-16/09/90 | 30 | 3 | 700 | 500 | 71 |
| 6 | " | 16/09/90-16/10/90 | 30 | 3 | 700 | 266 | 38 |
| 7 | " | 23/10/90-15/11/90 | 23 | 3 | 700 | 440 | 63 |
| 8 | " | 15/11/90-15/12/90 | 30 | 3 | 700 | 508 | 73 |
| 9 | " | 15/12/90-03/01/91 | 19 | 3 | 700 | 290 | 41 |
| 10 | " | 23/03/91-21/04/91 | 28 | 3 | 700 | 354 | 51 |
| 11 | Dov/St.M | 02/10/90-31/10/90 | 30 | 5 | 700 | 645 | 92 |
| 12 | " | 01/11/90-30/11/90 | 30 | 5 | 700 | 697 | 99 |
| 13 | " | 01/12/90-30/12/90 | 30 | 5 | 700 | 530 | 76 |
| 14 | " | 31/12/90-29/01/91 | 30 | 5 | 700 | 420 | 60 |
| 15 | " | 30/01/91-28/02/91 | 30 | 5 | 700 | 150 | 21 |
| 16 | C.G.N./Dover | 19/05/91-18/06/91 | 30 | 6/7* | 674 | 445 | 66 |
| 17 | " | 18/06/91-18/07/91 | 30 | 6/7 | 674 | 370 | 55 |
| 18 | " | 18/07/91-18/08/91 | 30 | 6/7 | 674 | 393 | 58 |
| 19 | " | 18/08/91-01/09/91 | 13 | 6/7 | 674 | 0 | 0 |

Sites refer to Wimereux and Cap Gris Nez in France, and Dover and St. Mary's in England.
No. days are the maximum number of days available for analysis within that data set.
Config. no. is the configuration setup used for that dataset.
Dep. cells are the number of cells set up in the deployed configuration.
Analys. cells are the number of cells where both master and slave sites have at least 324 values.
% return indicates the percentage of cells analysed. It does not indicate the percentage of data return.

* indicates where OSCR II was deployed as two separate master sites.

Data sets 3-7 and 11-15 only were used in Appendices C,D,E and F, due to space restrictions.

3.2 Variations in OSCR II performance

Throughout the deployments, OSCR II performance was checked regularly via a PC and modem through the public service telephone network (PSTN), generally to the Master site computer. The responsibility for spotting problems at the Master/Slave sites rested with POL, and the repair and maintenance then rested with the contractors. See Appendix B for diagram summary of deployments.

Also, during daily checking, it was observed that the OSCR response varied greatly between adjacent recording times. An initial closer look was taken to see if the data collected varied with the state of the tide, but nothing conclusive was established. At the end of the experiment, a further investigation was undertaken to see if any underlying pattern emerged to explain any variations.

The data were looked at with respect to:-

a) Distance of cell from Master/Slave site
b) Time of day
c) State of tide

Time and computer space allowed only the analyzed cells to be looked at, but it was felt that this would be fairly representative of all the cells, including those that recorded less than 324 values. The results can be seen in Appendix C.

3.3 Quality check during data capture

The internal software on the site computer analyses the measured signal for clarity and the presence of two clearly defined "Bragg peaks" (see Prandle 1991). Each piece of data is then allotted a 'quality code' of 0-9, where 0 is unusable and 9 is the best possible signal. These codes are then used during analysis to select data of a certain quality. Generally in POL analyses all data is used (code = 1).

3.4 Effect of shipping on OSCR performance

A ship passing through the radar 'footprint' will produce an extra peak on the radar return spectrum. In In most cases, the the ship's peak can be distinguished from the two 'natural' bragg peaks, and ignored.

Problems occur when

a) there is only one 'natural' bragg peak and the ships peak is the second one,

b) there is a high background noise and there is only one (ships) peak and where the ships peak = 'natural' bragg peak.

The software deals with these cases as best it can, and flags the data accordingly, with a quality code (see 3.3 above).

In general, ships have little overall effect on the OSCR dataset, as in most cases, the ship signal can be picked out from the known current signal. Also the ship will have no spatial effect on the cell areas outside its current track, and little effect within the complete dataset, since, in most cases, it will move out of the radar area within a relatively short period.

## 4.0 Data processing

The analysis of the datasets was carried out on an IBM PC model 65SX with maths co-processor, 1 Mb memory and 320 Mb hard disc with SCSI controller, running under DOS v. 4.01.

Each dataset was processed using harmonic tidal analysis software. Where each cell had more than 324 values it was analyzed as a single time series, using equilibrium constants as the reference constant set. The program then produced radial tidal constituents for each cell, and also radial residuals. These were then combined to produce vector constituents.

Output data was then loaded onto an IBM mainframe 4381 for pictorial representations of the output constituents. Examples of these for the Z0, M2 and M4 constituents can be seen in Appendix D.

Further details of the PC software analysis package can be seen in a short report by the author.

## 4.1 Wind data

Where available, local hourly wind data, linearly interpolated to 20 minute data, was used in conjunction with the current data, to produce u and v components of wind induced current, and also for the wind residual current (ie. residual current with wind effects removed) for each cell.

Two wind datasets were obtained from the Meteorological Office, Lydd Ranges, Kent (50 deg 7'N, 1 deg 20' E), and Langdon Battery, Kent (50 deg 56' N, 0 deg 54' E). The former was preferred, as the recording site was only 12m above sea level. However large gaps in the data resulted in the latter data set being mainly used, although the recording site was 117m above sea level on the cliffs above Dover.

Pictorial representations of the wind induced current and net tidal drift can be seen in Appendix E.

## 5.0 Operational and Processing Problems

### 5.1 Deployment problems

a) Initially, when any site failure occurred, it was sometimes difficult for POL to know what exactly the problem was, and when it had been repaired, due to communications problems between POL and the contractors. This improved considerably with time.

b) Possible software error sometimes involves recording a zero radial current instead of a null (ie. a current of zero recorded with quality greater than 0 and therefore valid data). This results in circumferential vector currents relative to the 'faulty' site.

c) General poor performance at St. Mary's may have been due to presence of concrete wall between radar and sea surface, obscuring approx. 1/3rd of antennae height, although contractors believe it to be no problem. It was not possible to test this out due to other faults in the equipment.

d) Independent assessor advised small technical modifications to antennae connectors and site software to improve OSCR II performance. See report by J. King May 1991.

### 5.2 POL software and equipment problems

a) Initially there was a problem contacting the sites through the PSTN. The telephone line would suddenly cut out, or the PC would hang. When working correctly, checking each site took about 1 hour per deployment, so this problem resulted in a great deal of time being wasted. The fault was tracked down to a problem with the POL Mercury switchboard, and was solved when a direct line was subsequently used.

b) At the start of the experiment, the software available was that described in POL internal reports 19 and 20. It had previously not been run on the IBM PS/2, or been tested on datasets of more than 15 days. There were inevitable teething problems and some changes were made to the software to overcome these.

c) 1. It was subsequently found that the analysis was taking an excessive amount of time to run. This was a result of the software re-reading the entire dataset for each cell, due to the datasets being in chronological order. As each 30 day input file consisted of 9 million values (2160 * 6 * 700) per site, it was decided to reorganise the input file into cell order.

2. It was also decided to write software to extract radial residuals and also compile vector residuals into separate files.

This resulted in the software having to be developed at the same time as the data was having to be analyzed. Also the size and organisation of the datasets meant that any testing between analyses resulted in huge datasets having to be moved around.

d) The eventual size of each dataset could be 80 Mb, including peripheral files. In practice, only one dataset could be kept on the PC at any one time. This meant downloading one dataset, and uploading the next dataset from quarter inch cartridge (QIC) tape in between analyses.

e) Two large files of 2 Mb and 10 Mb respectively had to be transferred to the mainframe for each dataset. This took a large amount of time under DOS, and in the case of the larger file kept hanging, and tied up the PC for up to a day. Alternatively, the data was transferred to another PC running OS/2, by first dumping to QIC on the first machine, physically moving the QIC reader to the OS/2 machine and connecting up, transferring the data to the OS/2 machine and then loading up to the mainframe using the 3270 emulator. This also took time, and used a second machine, when available.

f) To look at the analysed output files together on the mainframe requires at least 10 Mb * no. of datasets. For the Dover Strait deployment at least 150 Mb was needed, for the input files alone, and more if output files were required. In practice this proved extremely difficult, and so restrictions had to be placed on combinations of datasets, via a sequence of temporary discs and a series of archives/restores (and a fairly organised mind!).

g) Currently the analysis of a complete 30 day data set takes about 3.5 days, which together with ancillary programs and transfers to the mainframe, can take up to 1 working week to process, and the PC is unusable for anything else during this time.

## 6.0 Conclusions

There were inevitable teething problems, and various hardware problems throughout the deployment, with data return trailing off towards the end of the period. Also, as illustrated, the data quality and return varies with site, time of day, and to a certain extent to the state of tide.

However, over the 15 months of the Dover Strait deployments, 8444 cells were analysed, producing tidal current information over approximately 1000 sq. km of sea surface. The results of this experiment can be seen in Prandle, Loch and Player, 1992.

## 7.0 Acknowledgements

Thanks are due to Dr. D. Prandle and S. G. Loch of the Proudman Oceanographic Laboratory for their constant advice and guidance. Also to Rob Palmer, currently of Southampton University Oceanography Department, for initial help during the software development. Finally thanks go to Nigel Bellamy and Mike Osborne of Marex Technologies Ltd. for their response to hardware problems which arose during the Dover Strait deployments. Wind data for the Kent area was supplied by the Meteorological Office, Bracknell.

8.0 References

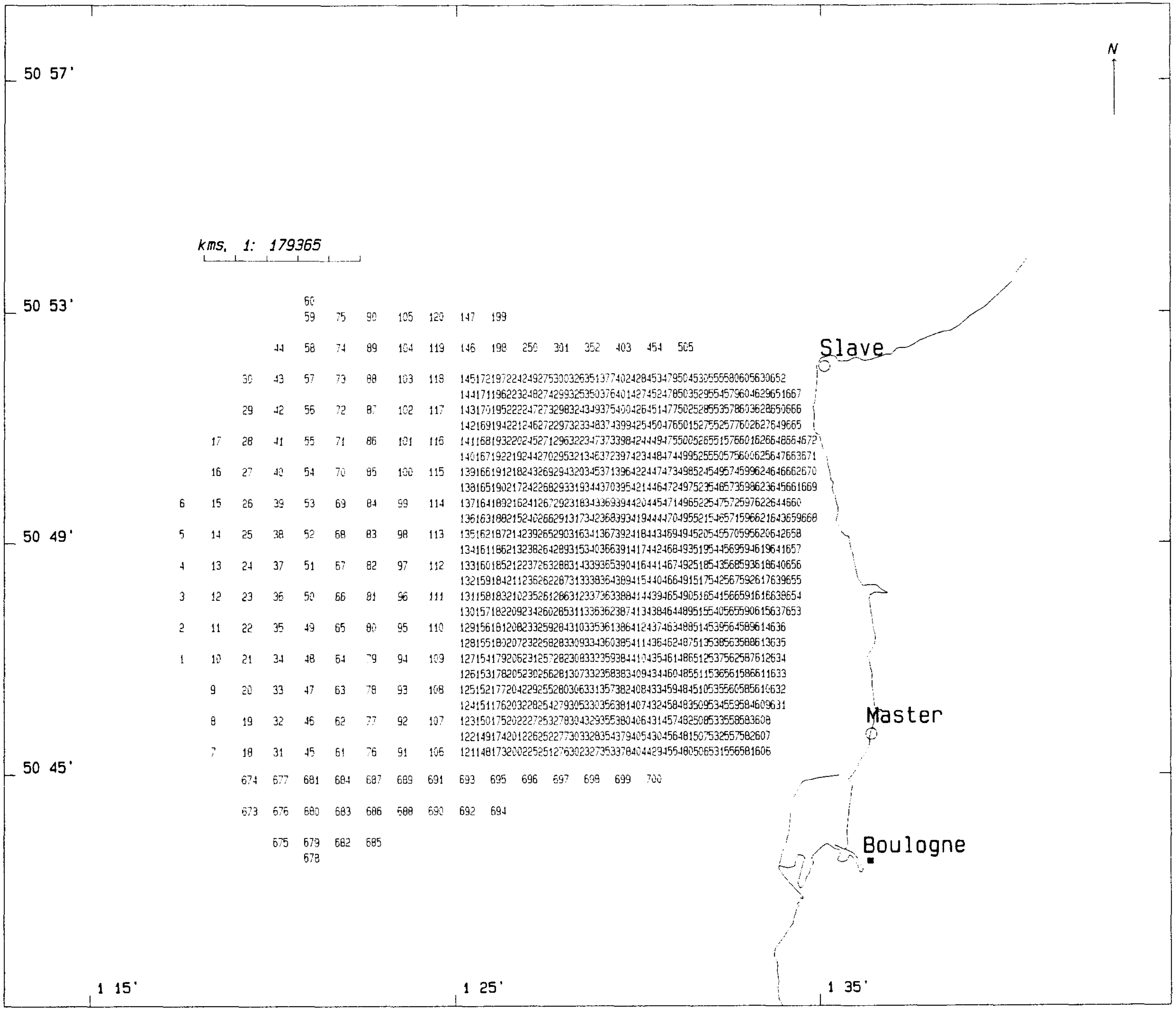
PRANDLE, D. & MATTHEWS, J. 1990 The dynamics of nearshore surface currents generated by tides, wind and horizontal density gradients. Continental Shelf Research, 10, 665-681.

PRANDLE, D. 1991 A new view of near-shore dynamics based on observations from HF radar. Progress in Oceanography, 27, 403-438.

PRANDLE, D., LOCH, S.G. & PLAYER, R.J. Tidal flow through the Straits of Dover. Journal of Physical Oceanography (In press)

Appendix A. Cell positions for each deployment

These were provided by Marex Technology Ltd.




# Wimereux M.R.S
# Cap Gris Nez C.G

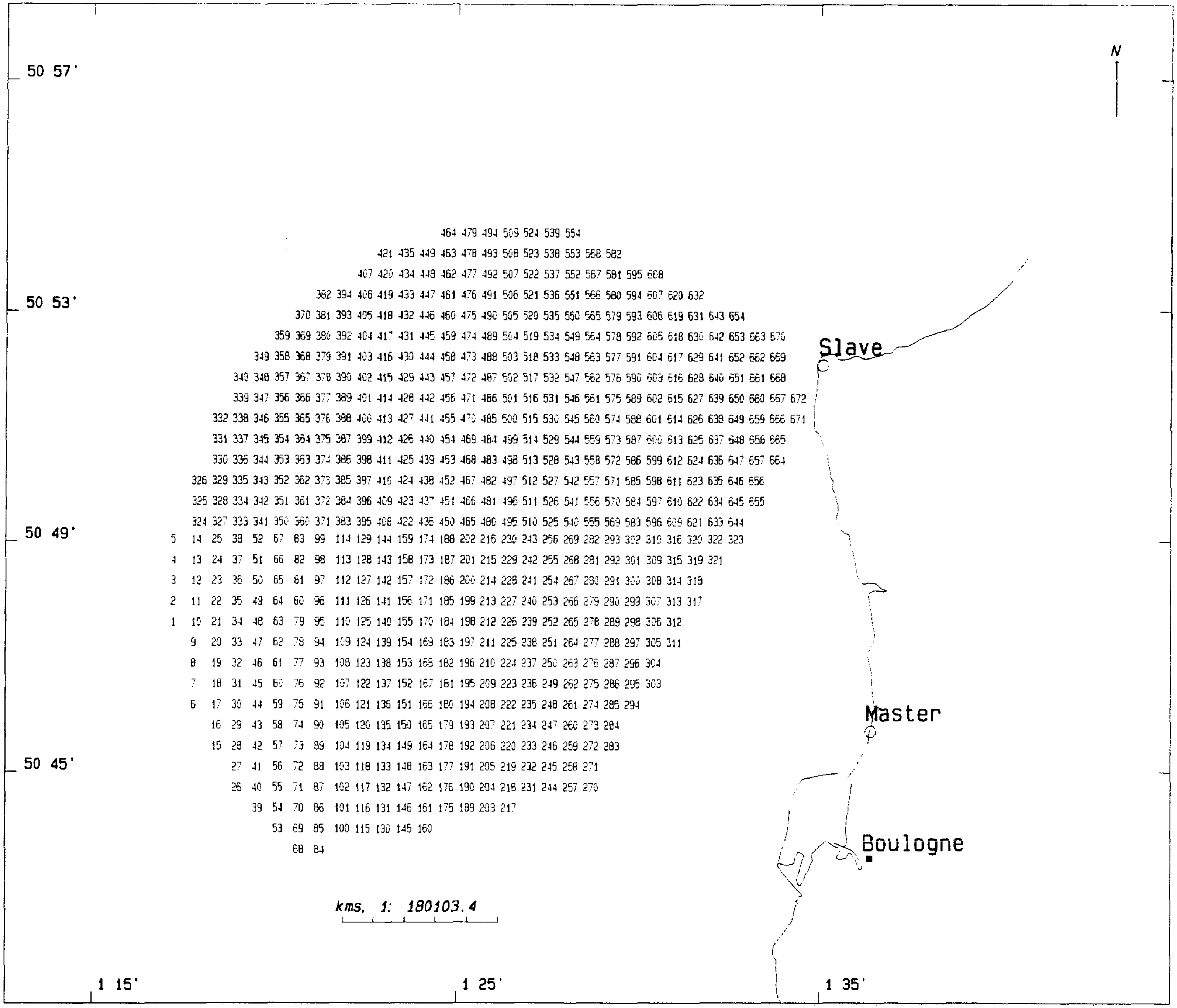
## Cell Locations

## Config. No.1

Printed:
22-10-91 16:29

marex OSCRII

# Wimereux M.R.S
# Cap Gris Nez C.G

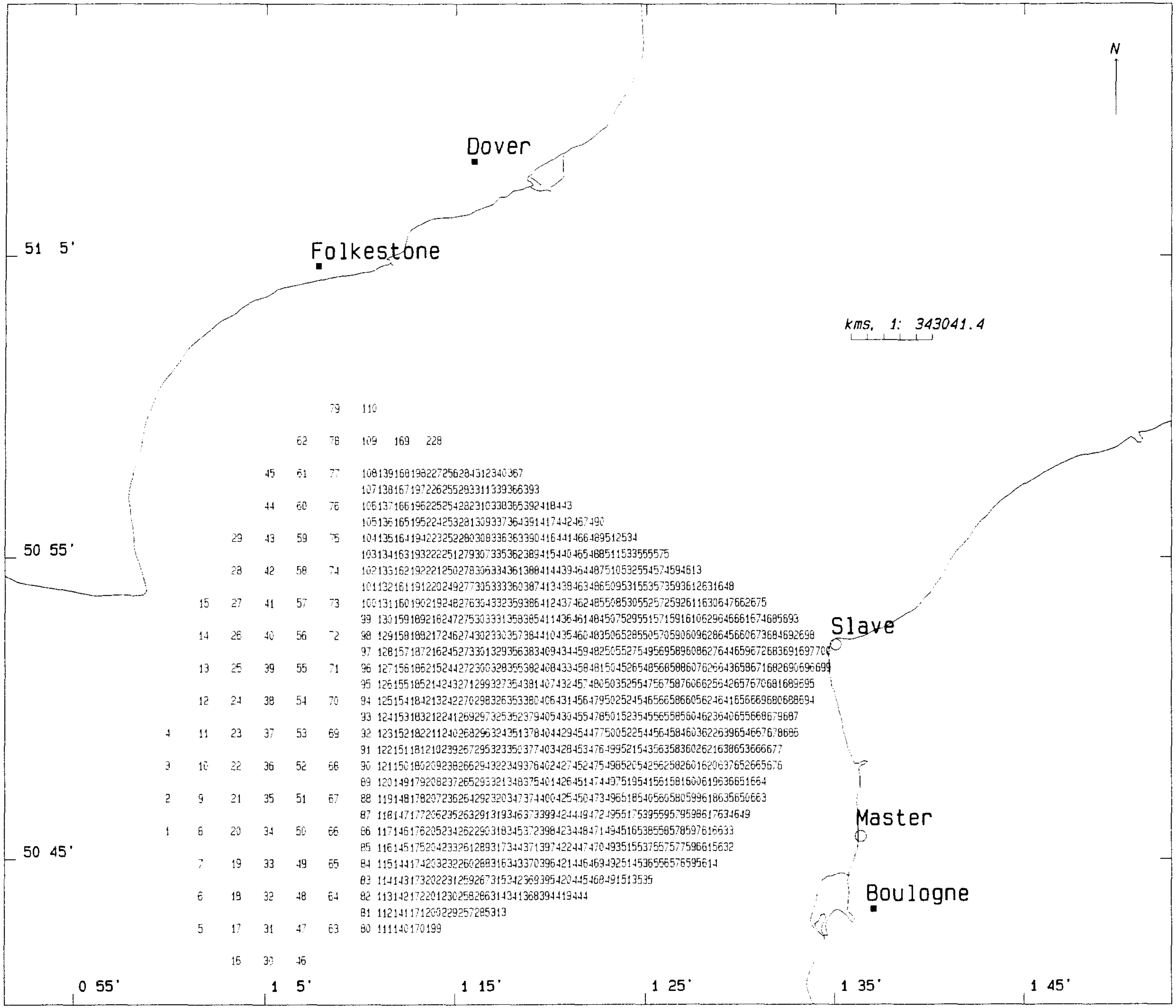



Cell Locations

## Config. No.2

Printed:
28-10-91 16:25

marex OSCRII

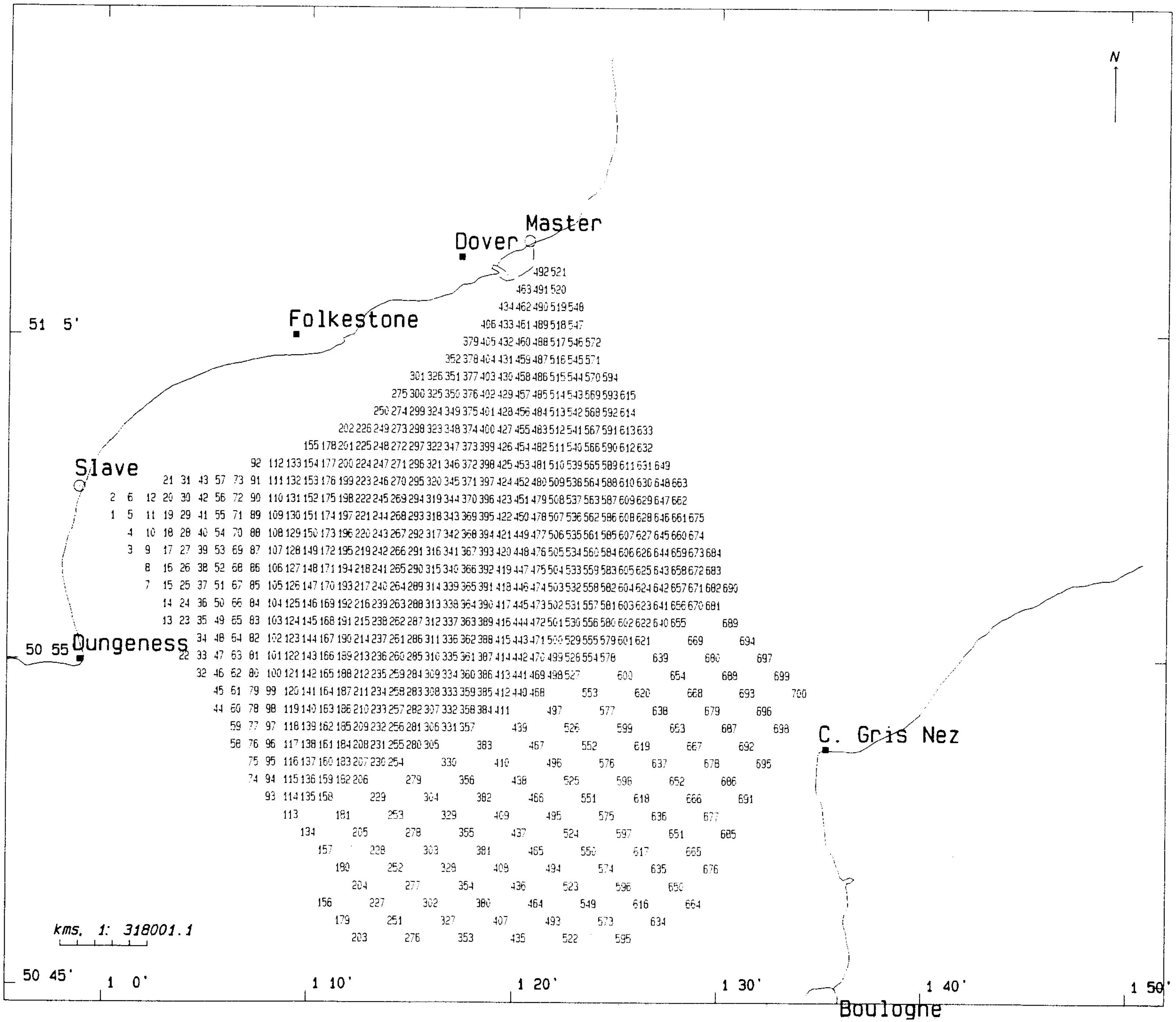



# Dover Strait
# Config. No. 3

## Cell Locations

Printed:
22-10-91 11:44

marex OSCRII

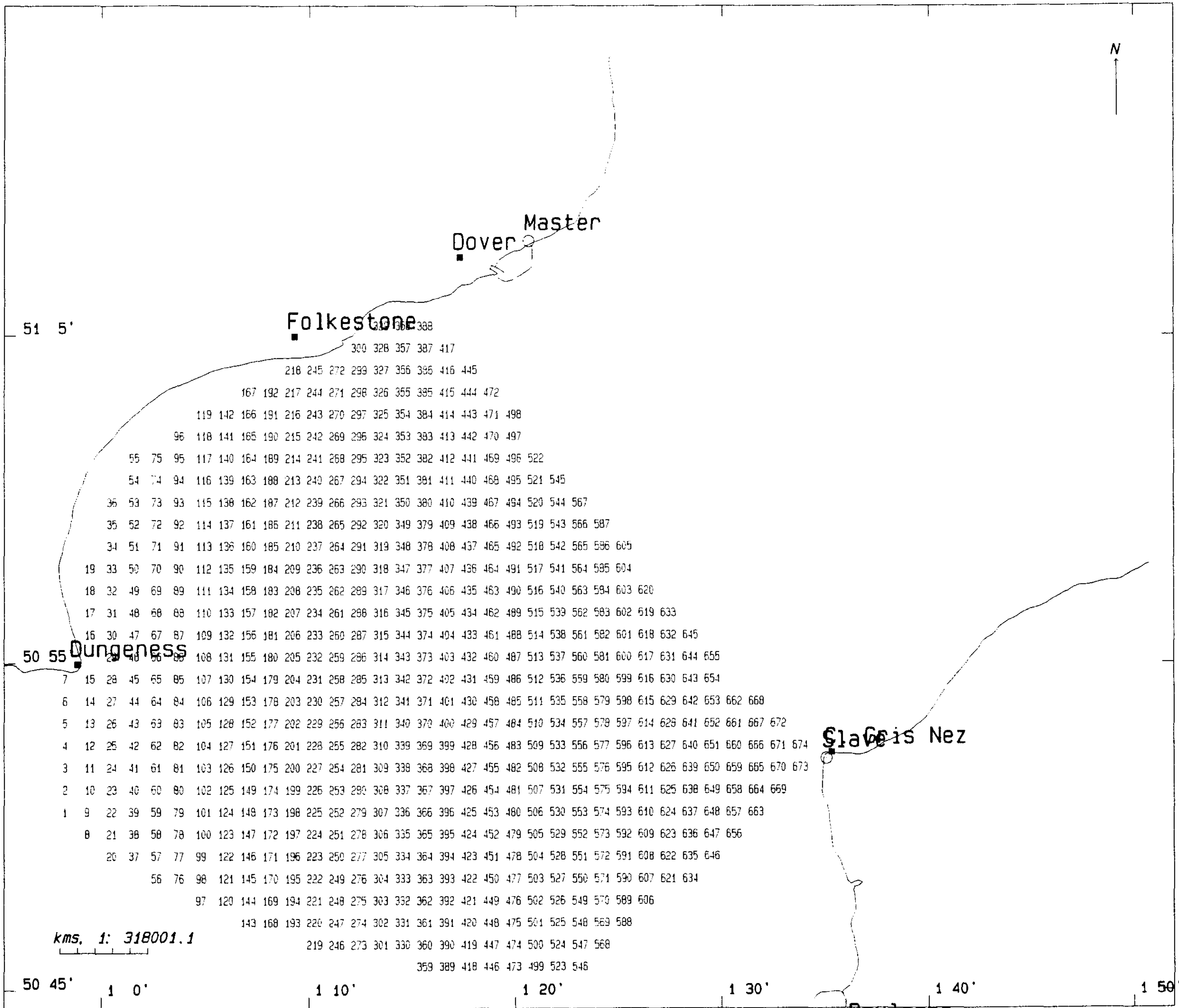



# Dover Strait
# Config. No. 5

Cell Locations

Printed:
18-11-91 15:54

marex OSCRII




# Dover Strait
# Config. No. 6

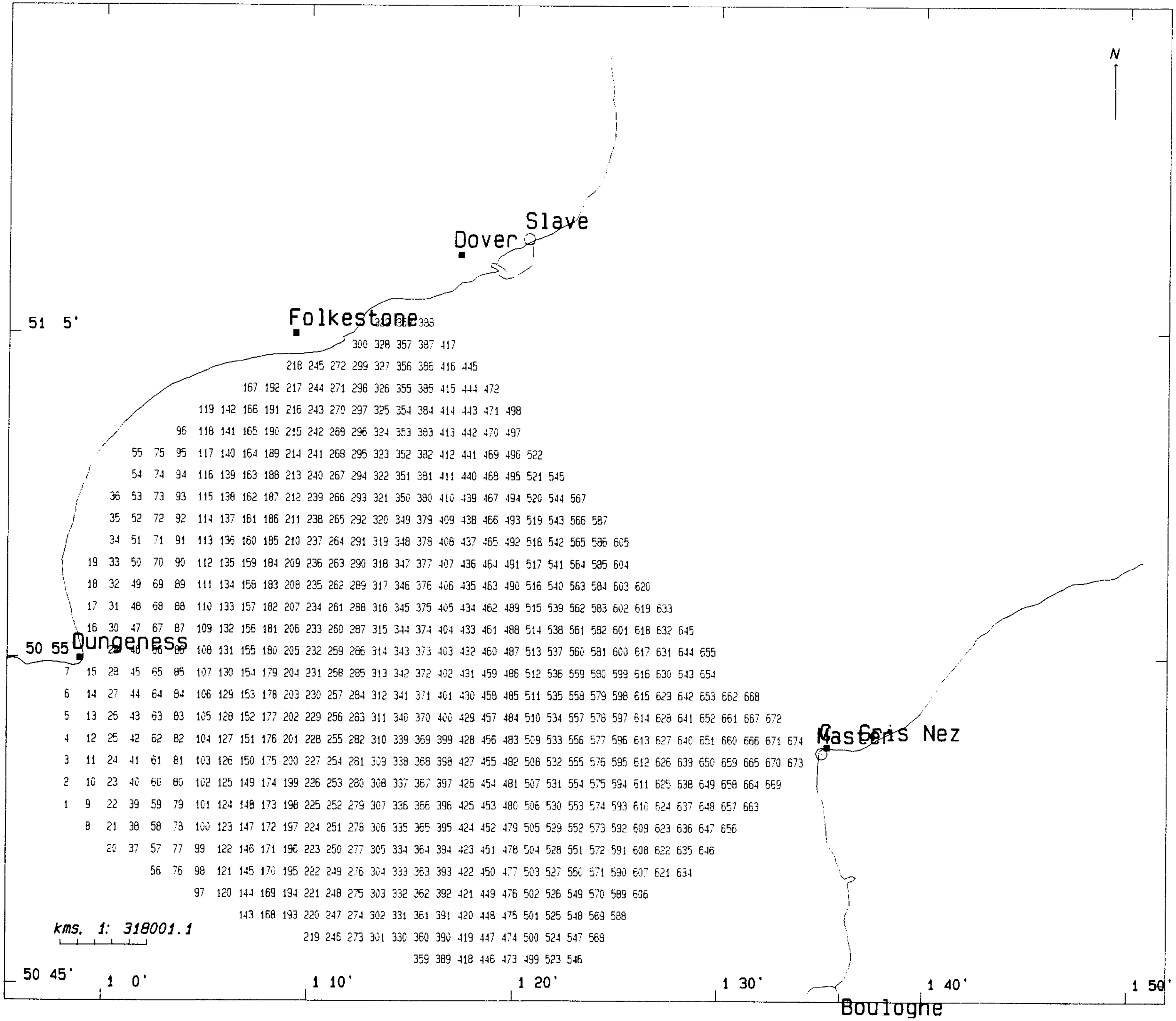
## Cell Locations

Printed:
8-11-91 14:54

OSCRII

# DOVER STRAIT
# Config. 7

Cell Locations




Printed:
13-11-91 11: 11

OSCRII

Appendix B. Deployment and data collection summary

Gaps, problems and changes during deployments, together with reasons where known.

Configuration 2 and 3

| | |
|---|---|
| 18/06/90 - 22/06/90 | Wimereux/Cap Gris Nez |
| 13/07/90 - 17/07/90 | Wimereux/Cap Gris Nez |
| 03/08/90 | Wimereux/Cap Gris Nez, 30 degree cutoff angle removed |
| 10/08/90 - 16/08/90 | Cap Gris Nez, disc failure |
| 17/08/90 - 23/08/90 | Wimereux/Cap Gris Nez, setup 1 day in error, to be corrected on merging datasets |
| 17/09/90 - 26/09/90 | Wimereux/Cap Gris Nez |
| 28/09/90 - 03/10/90 | Cap Gris Nez ) Unknown reason for failure, |
| 04/10/90 - 09/10/90 | " ) equipment removed for repair. |
| 11/10/90 - 23/10/90 | Wimereux ) Field tests were carried out |
| 12/10/90 - 23/10/90 | Cap Gris Nez ) after re-instatement 25/10/90. |
| 23/03/91 - 04/04/91 | Wimereux, no power amplifier. |
| 25/03/91 - 11/04/91 | Wimereux, power board fault |

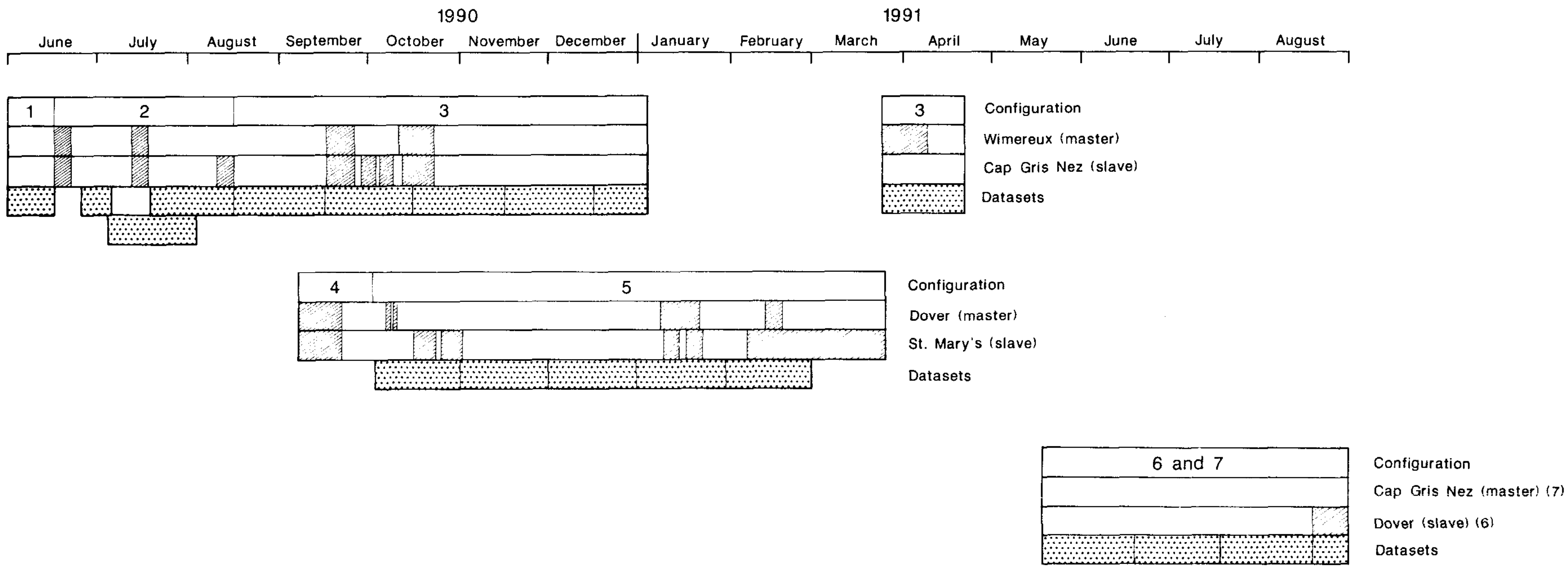
Configurations 4 and 5

| | |
|---|---|
| 07/09/90 - 21/09/90 | Dover/St. Mary's, configuration 4 failure |
| 06/10/90 - 07/10/90 | Dover |
| 09/10/90 | Dover |
| 16/10/90 - 22/10/90 | St. Marys |
| 25/10/90 - 01/11/90 | St. Marys |
| 09/01/91 - 21/01/91 | Dover, circuit board failure |
| 10/01/91 - 14/01/91 | St. Marys |
| 18/01/91 - 22/01/91 | St. Marys, multiplexor failure |
| 07/02/91 - 25/03/91 | St. Mary's, balun failure, poor performance later. |
| 14/02/91 - 18/02/91 | Dover |

Configurations 6 and 7

| | |
|---|---|
| 19/06/91 - 29/06/91 | Dover, partly disconnected antennae cable. |

Appendix B. Diagram summary of Dover Straits deployments.



Appendix C. Variation in data collection

The following plots indicate the amount of data return for all analysed cells. Due to practical considerations only datasets 4/7/90-15/11/90 and 2/10/90-28/2/91 have been used, representing Configurations 2,3 and 5 (see Table 2). It should be noted that these results have been extracted only from cells that recorded enough data to be analysed, ie. more than 324 radial values over the complete dataset.

Data return with respect to time of day

As can be seen from the results, all sites show a variation with the time of day, with more data being collected overnight, and less during the daytime. This was more marked at the Dover and St. Mary's sites, and is attributed to local interference from industry, CB radios etc during 'working' hours.

Data return with respect to state of tide

Only Wimereux shows a marked variation with the state of tide, with return peaking around high water, and falling to a minimum just after low water. It is suspected that this may be caused by the long shallow sloping beach drying out at low water, and affecting the antennae receive signals.

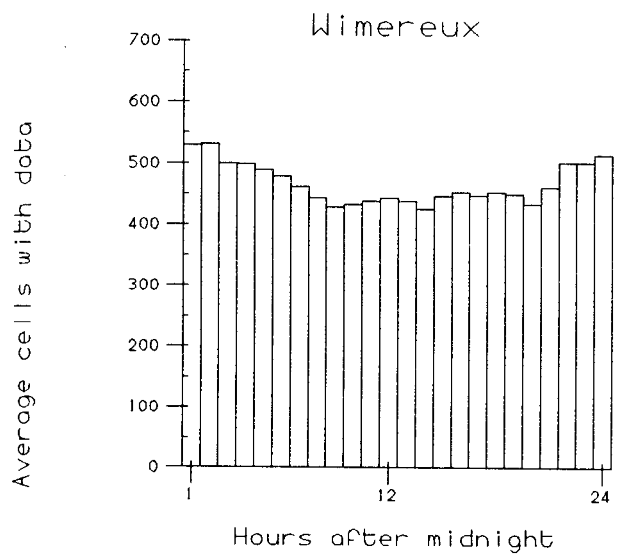
Data return with respect to distance of cell from OSCR site

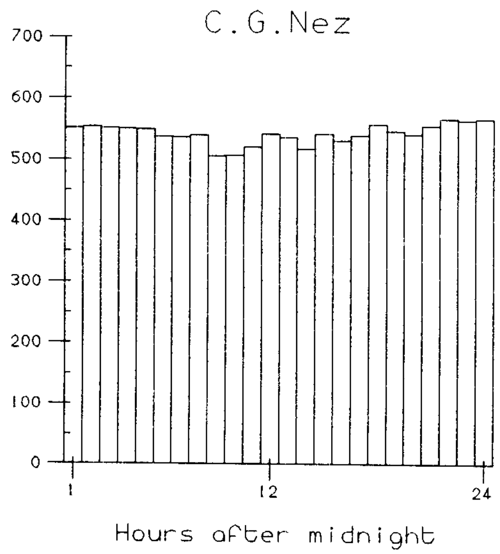
Wimereux data return tends to trail off intermittently after a distance of about 11 km, whereas Cap Gris Nez records consistently up to a distance of about 18 km and then trails off consistently with distance. The data return became less by October 1990, when Wimereux trailed off almost from the nearest cell, and Cap Gris Nez from about 11 km onwards.

Dover return was generally consistent up to about 8 km, and then deteriated gradually with distance. St. Mary's showed a similar pattern but was more consistant up to about 13 km.

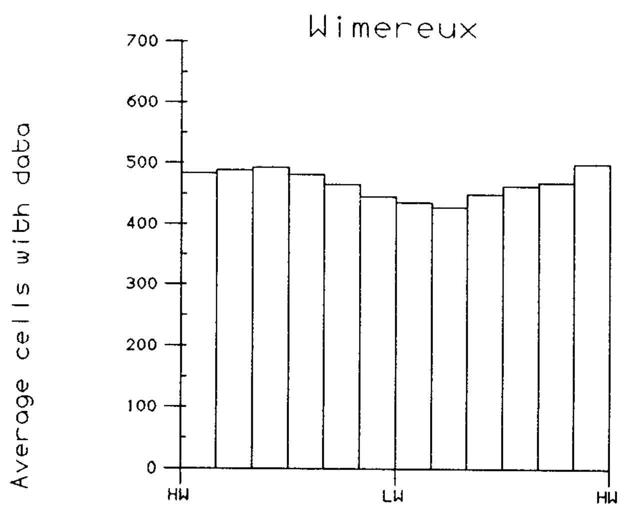
# OSCR II Jul 4 - Aug 3 1990

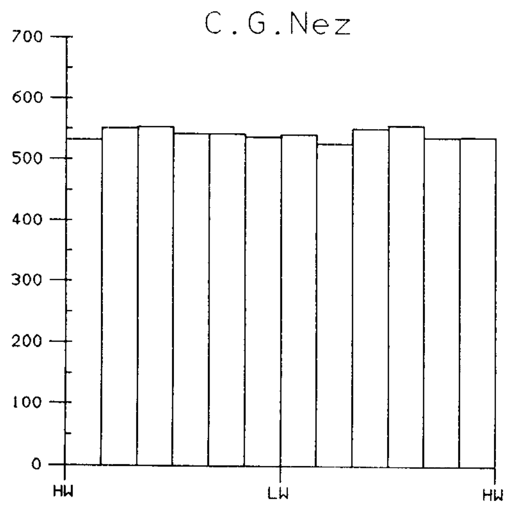
## Data variation with time of day



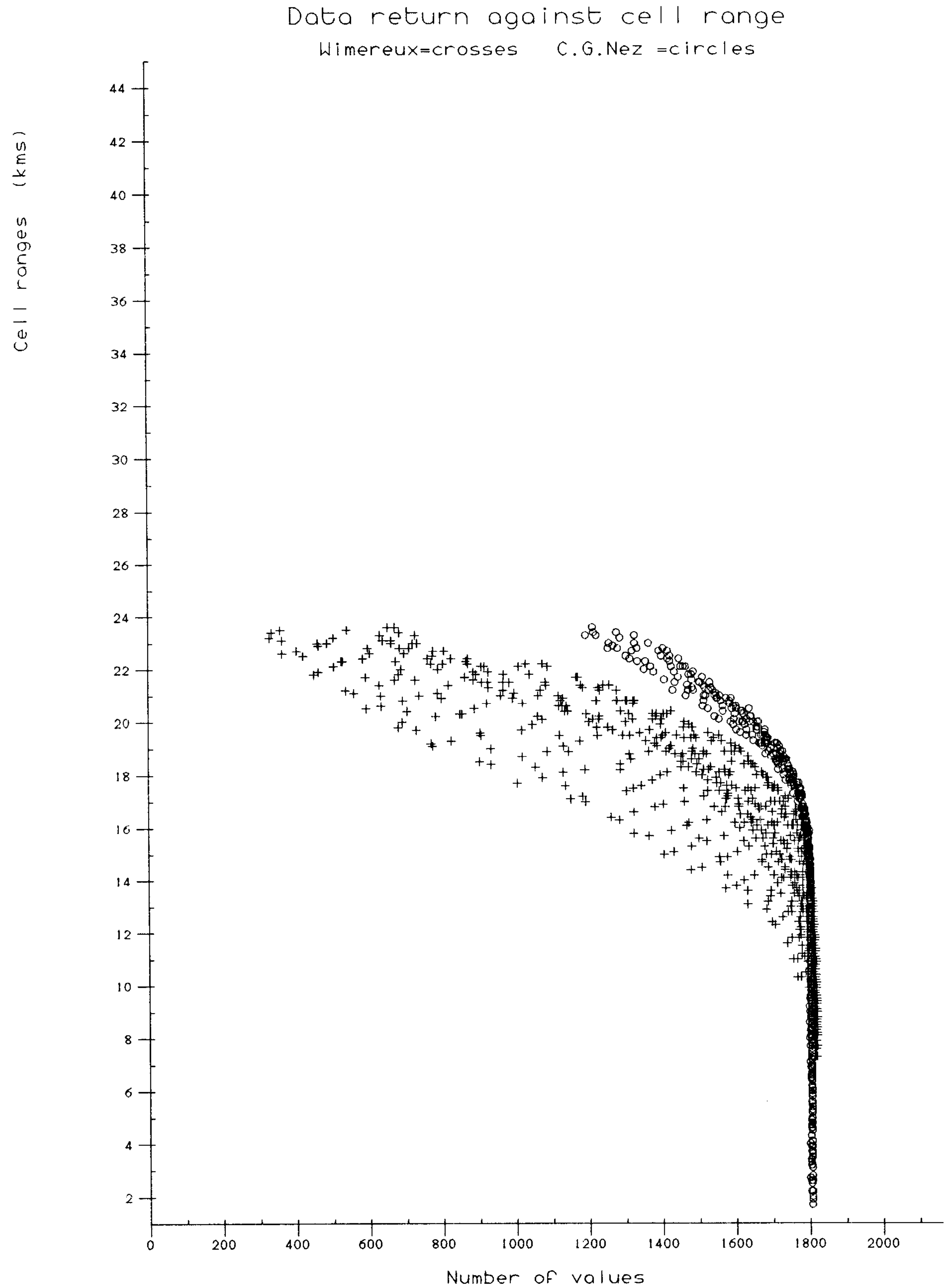




## Data variation with state of tide



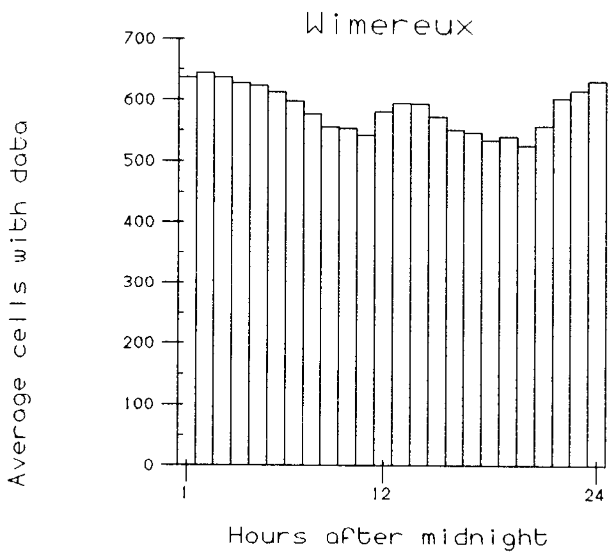



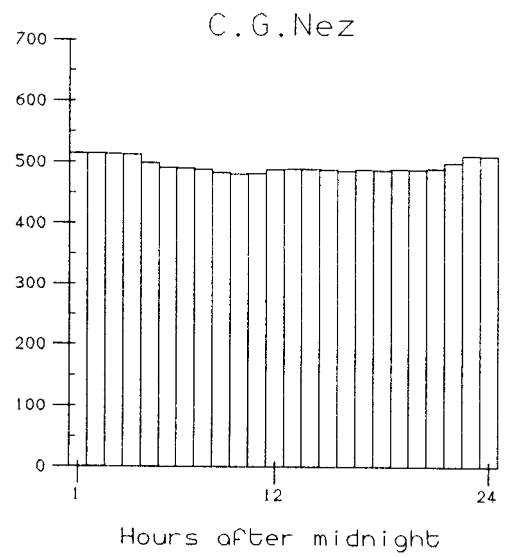
# OSCR II Jul 4 - Aug 3 1990



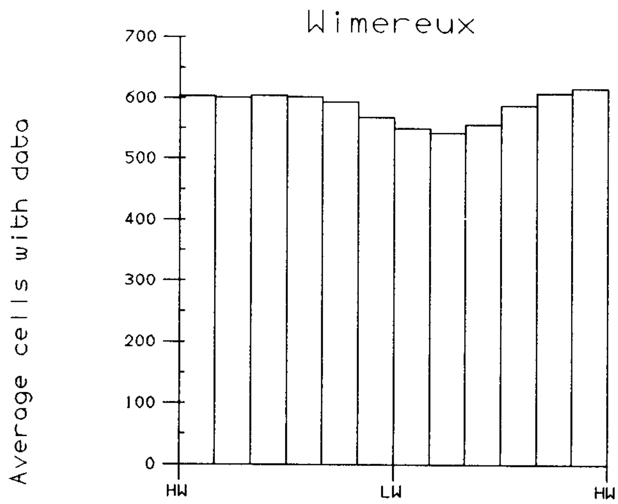
# OSCR II Jul 18 - Aug 17 1990

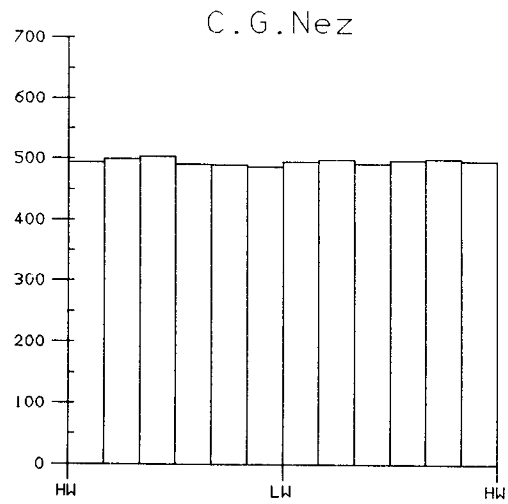
## Data variation with time of day



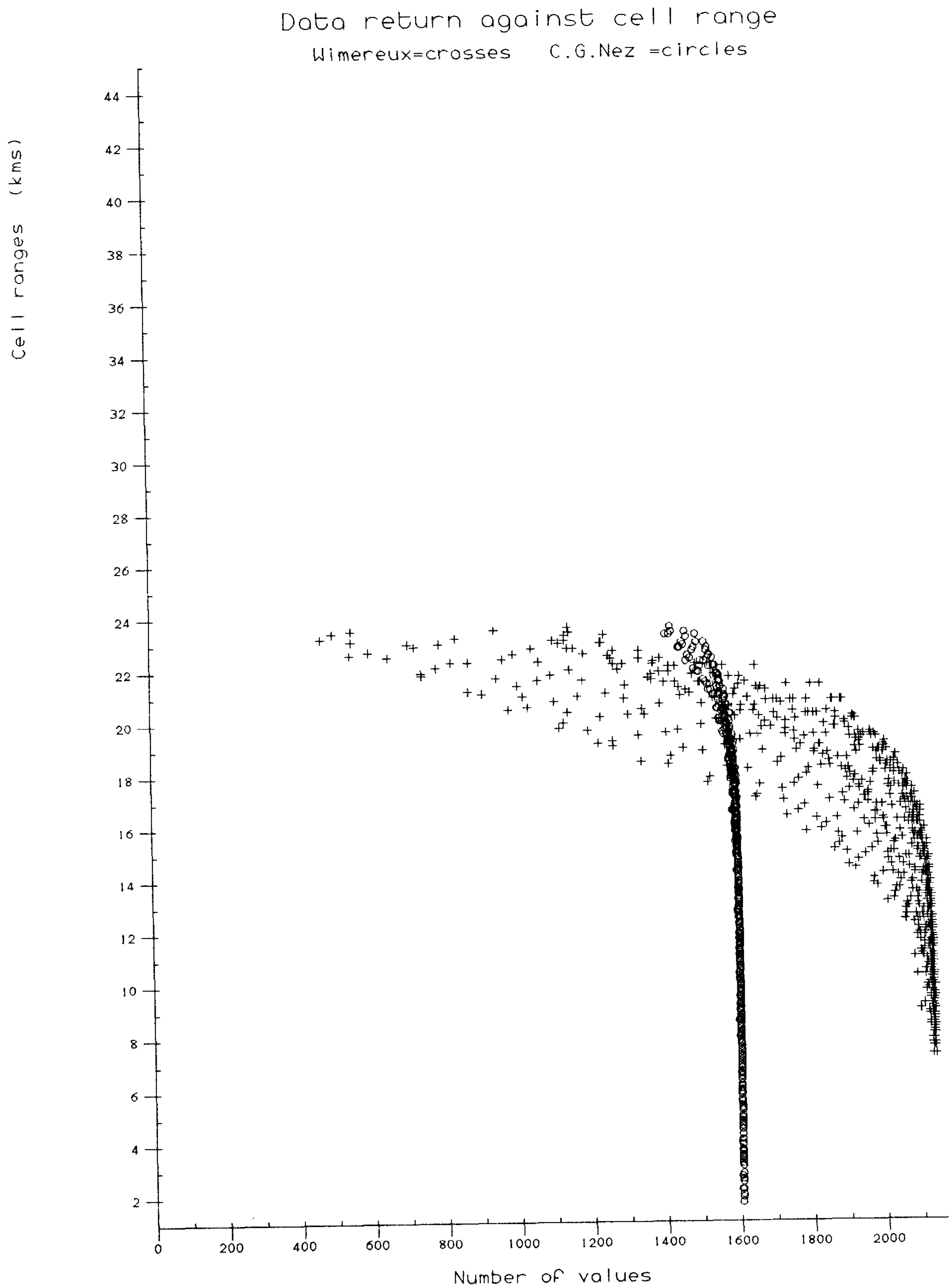




## Data variation with state of tide



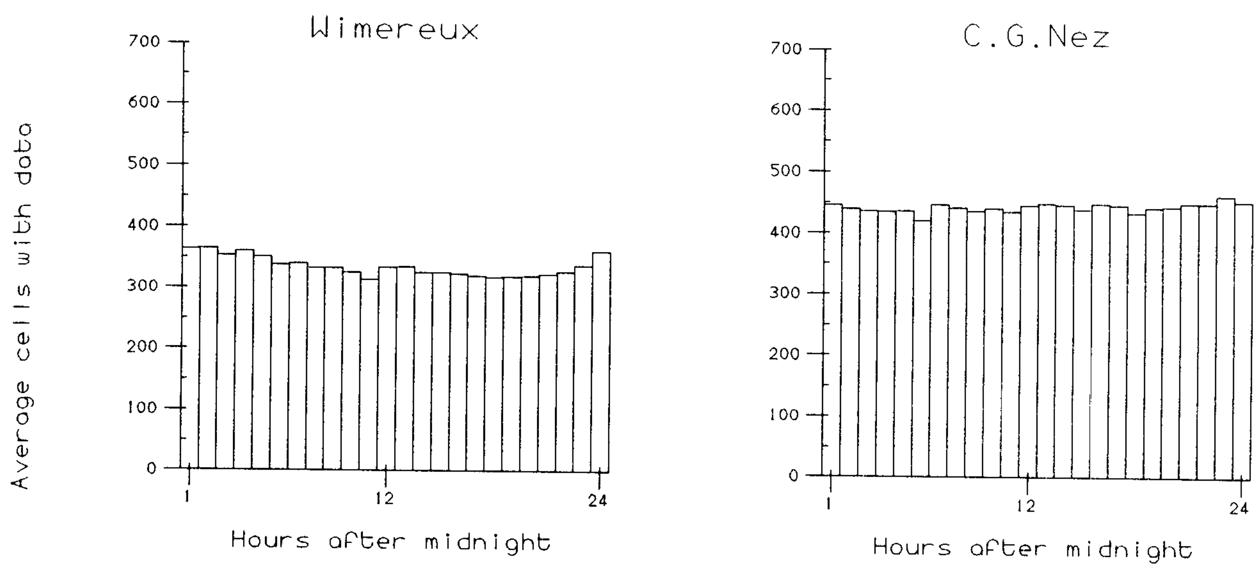



OSCR II Jul 18 - Aug 17 1990

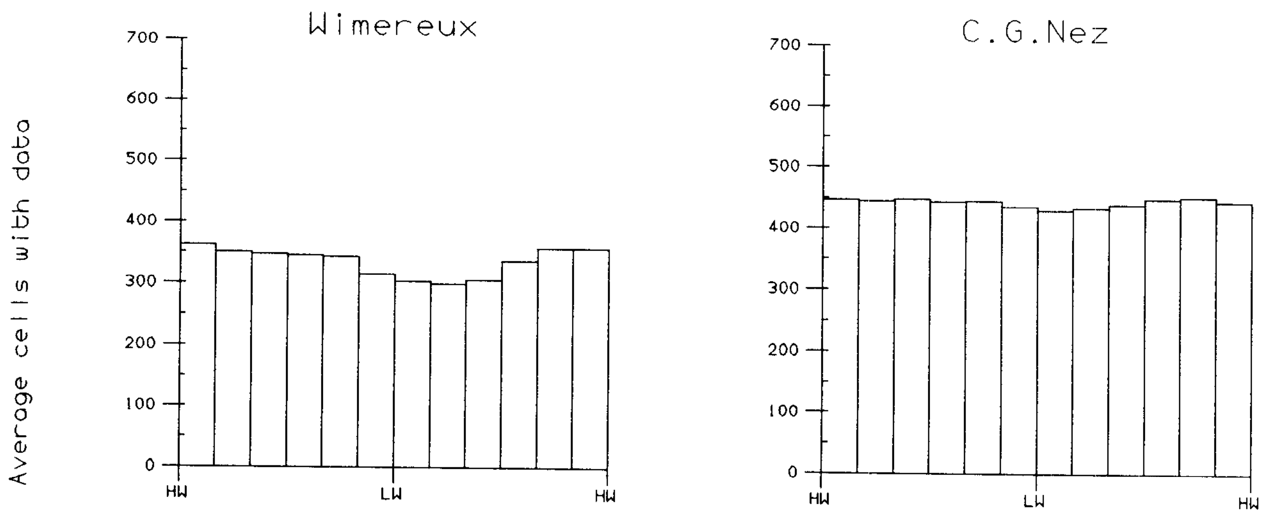


# OSCR II Aug 17 - Sep 16 1990

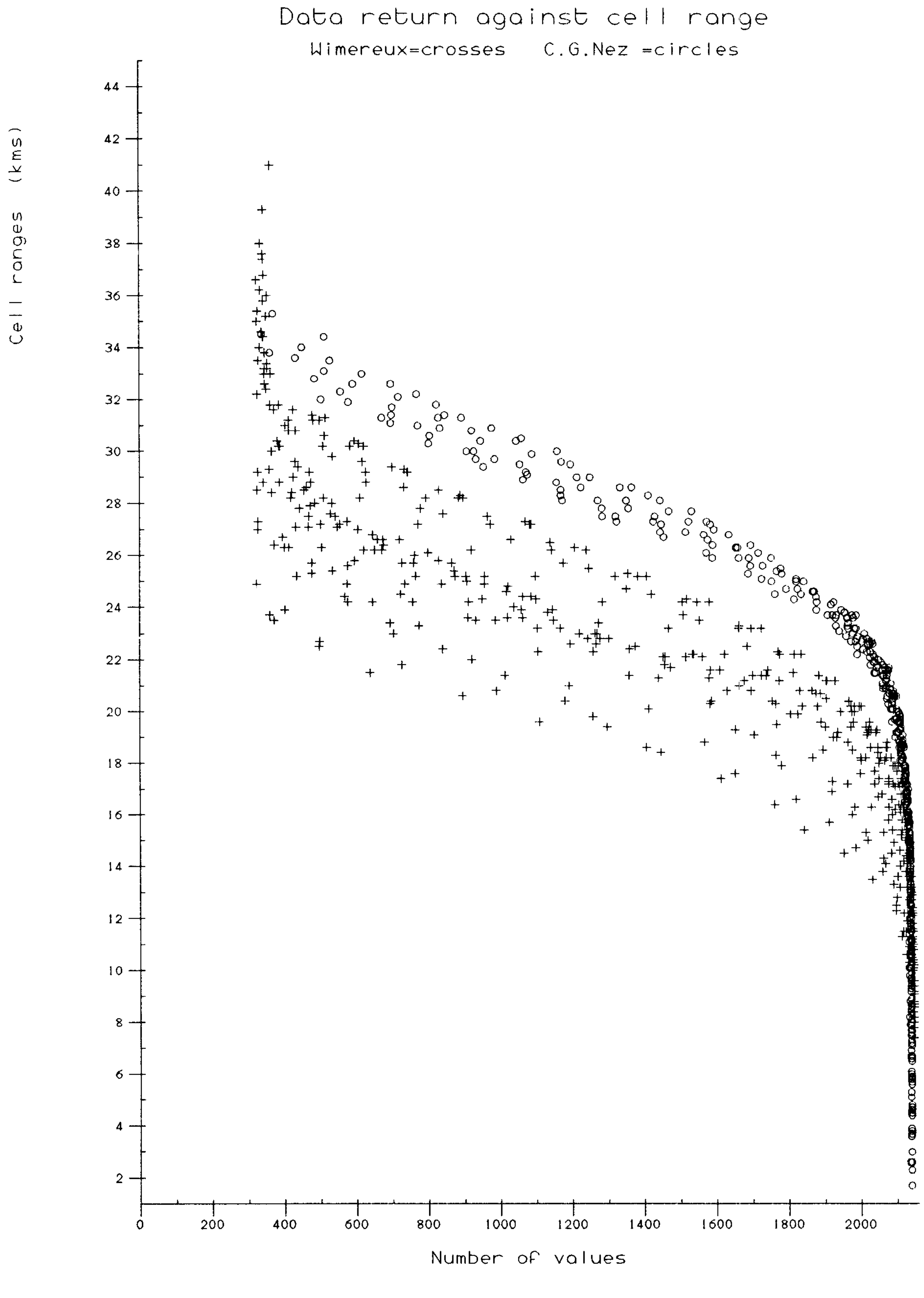
## Data variation with time of day




## Data variation with state of tide

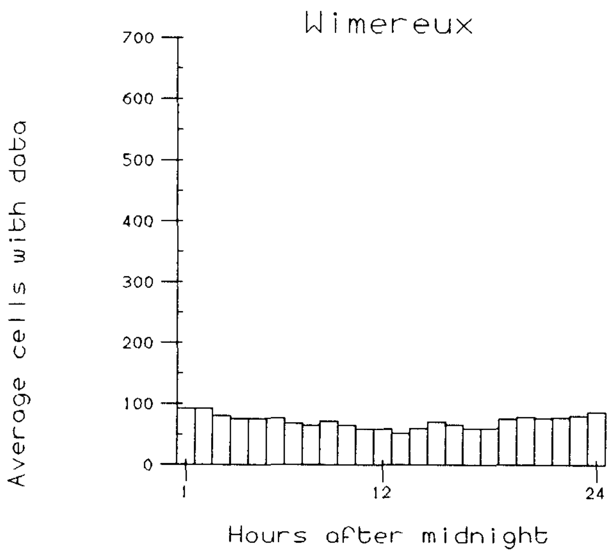


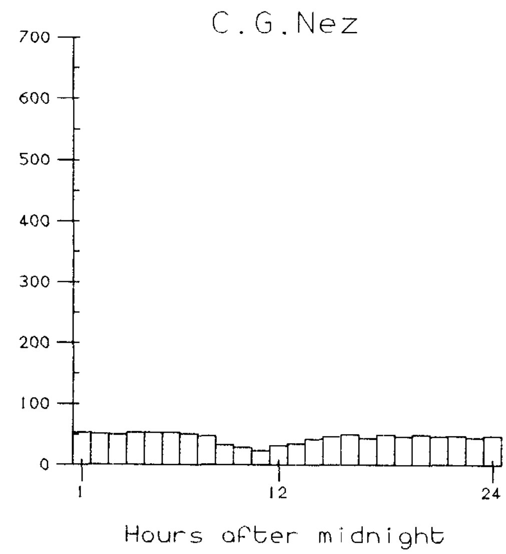
OSCR II Aug 17 - Sep 16 1990



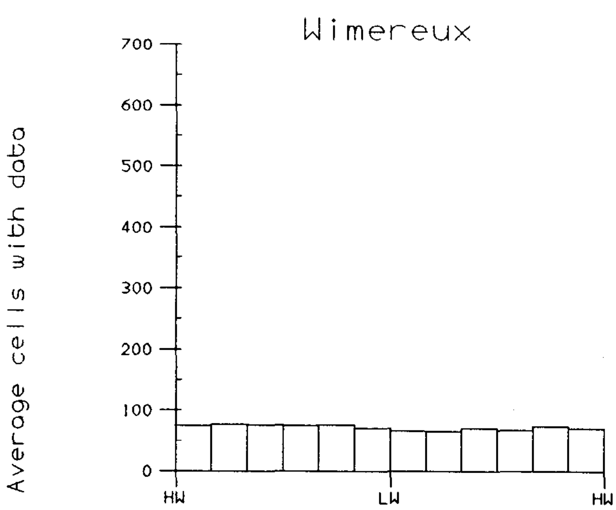
# OSCR II  Sep 16 - Oct 16  1990

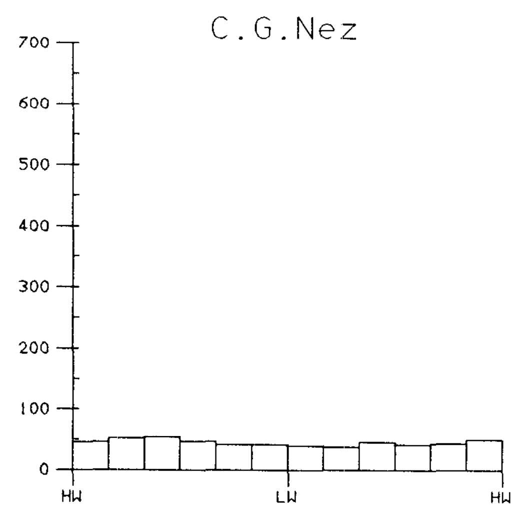
## Data variation with time of day



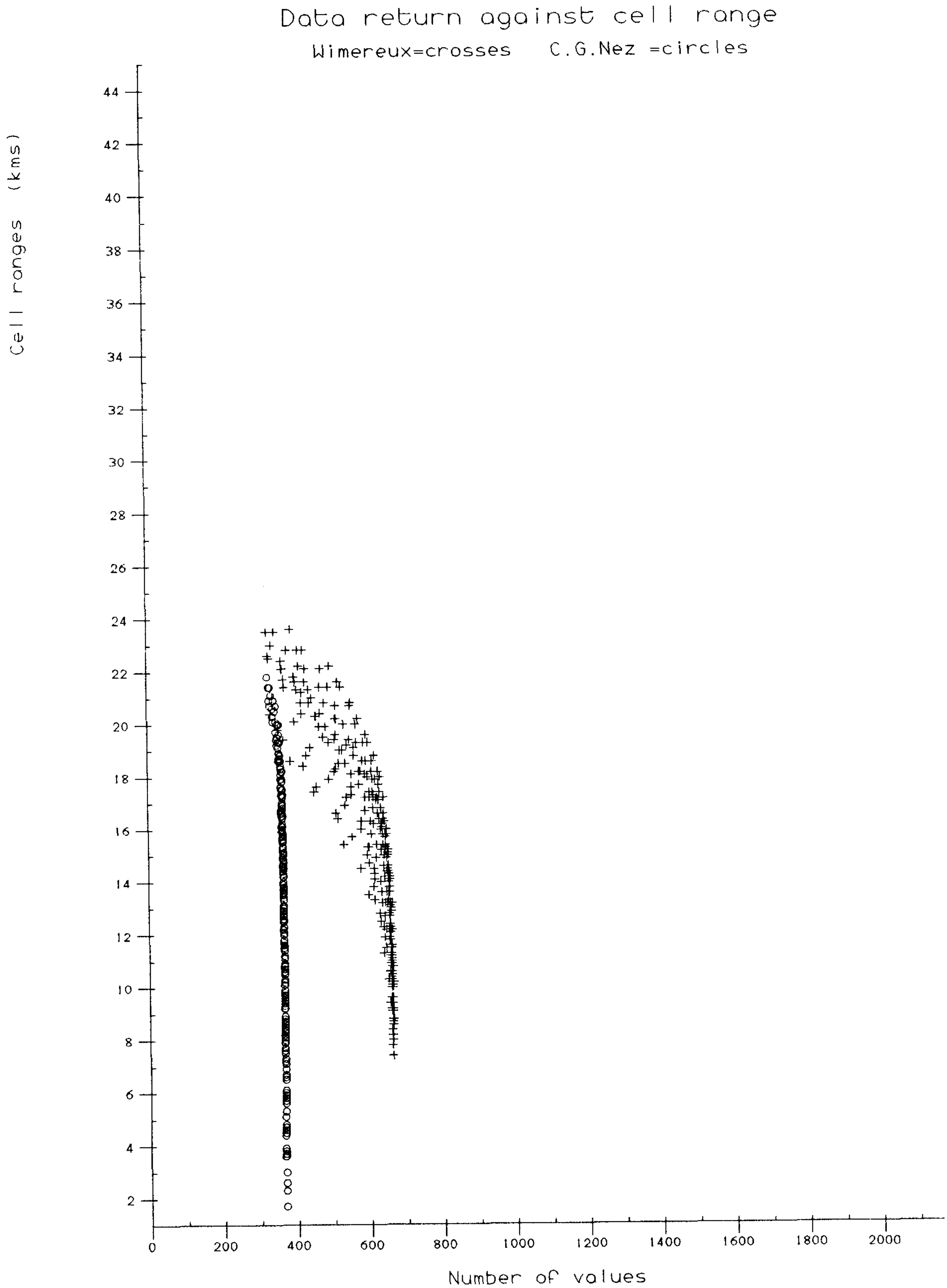




## Data variation with state of tide



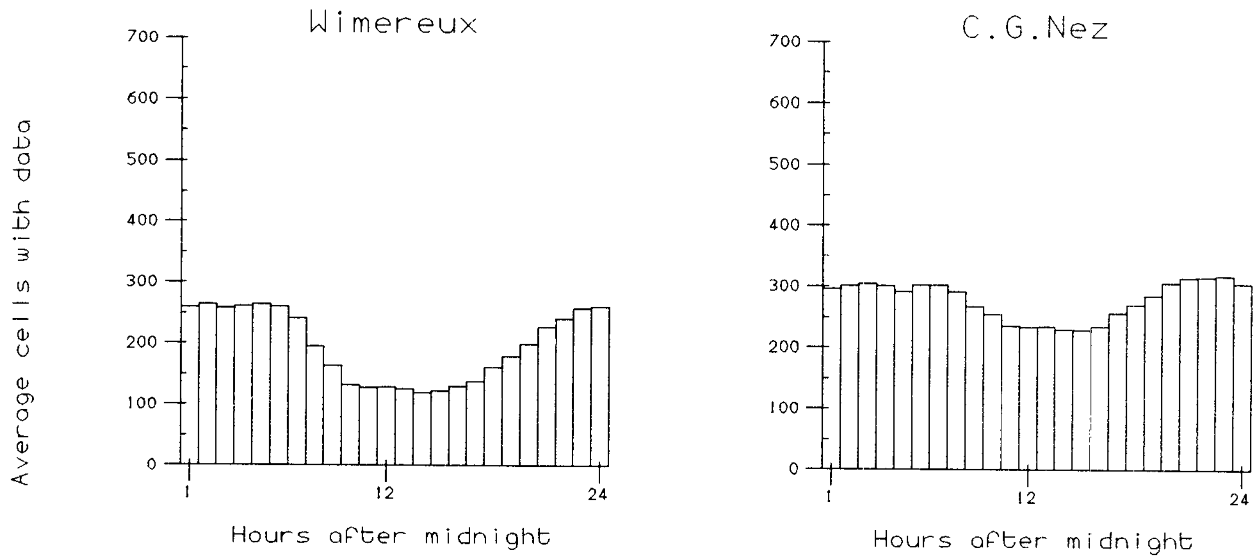



OSCR II Sep 16 - Oct 16 1990

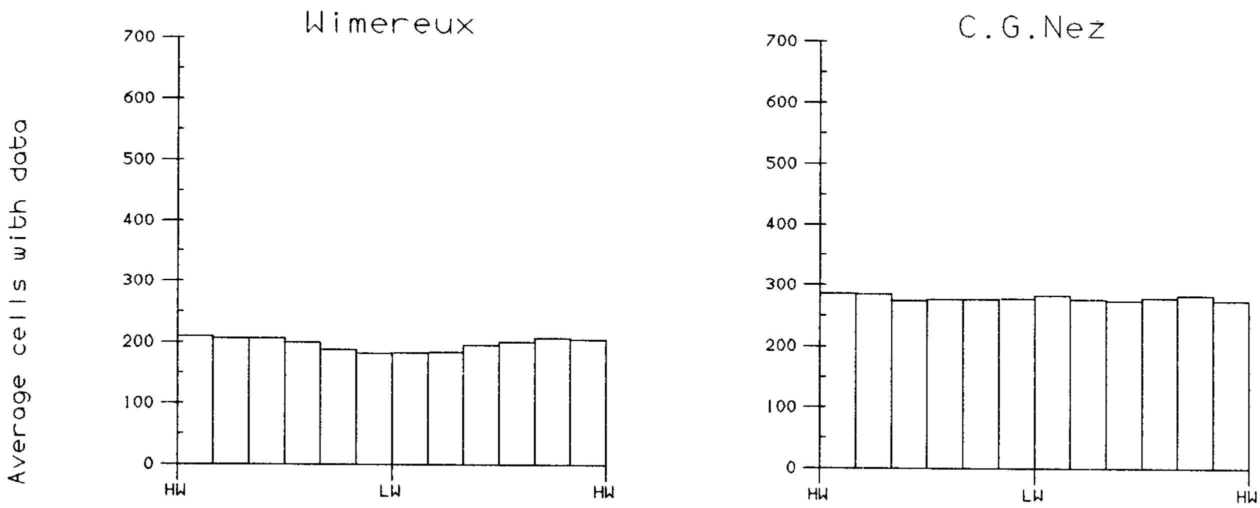


# OSCR II Oct 23 - Nov 15 1990

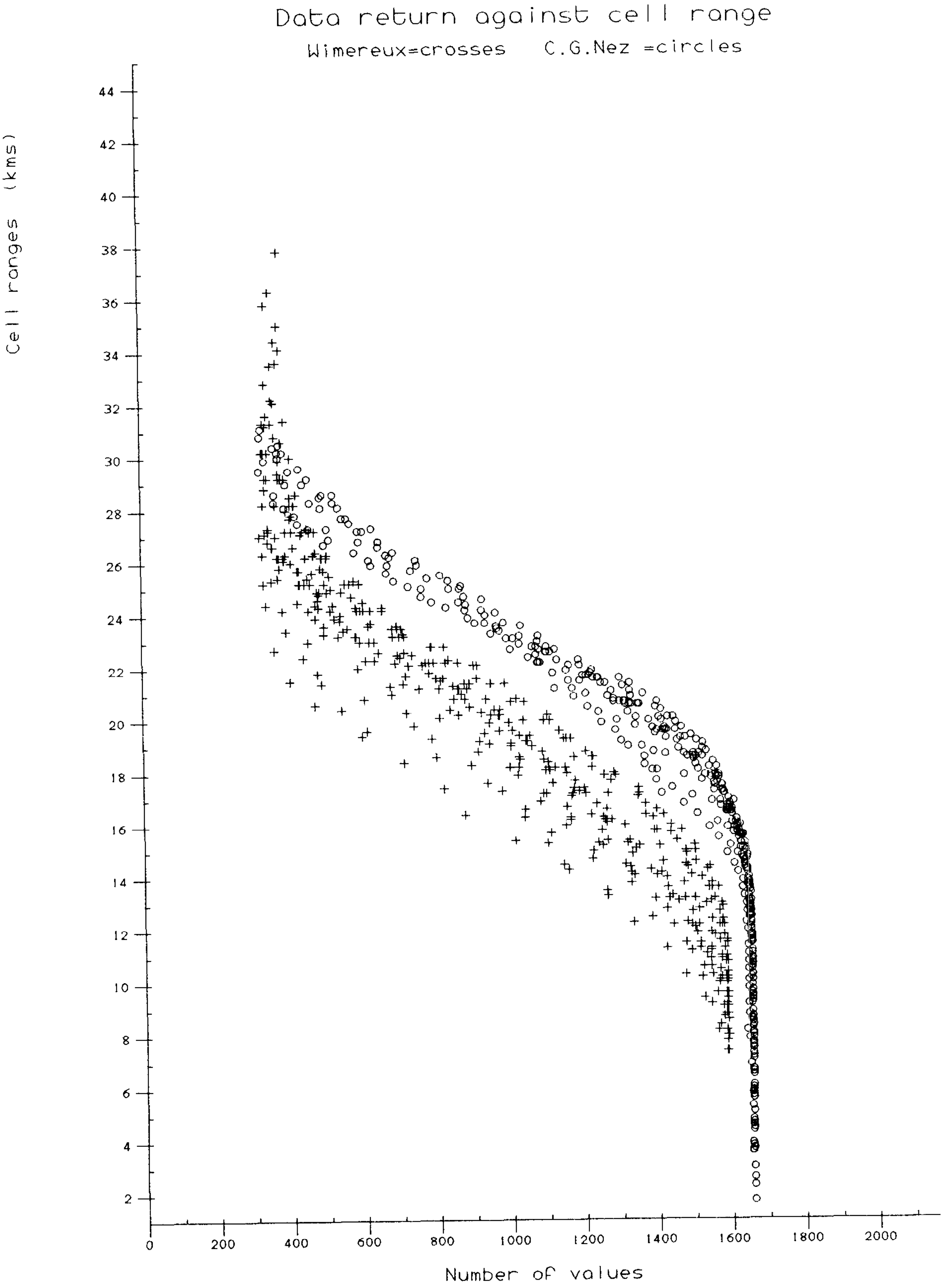
## Data variation with time of day




## Data variation with state of tide

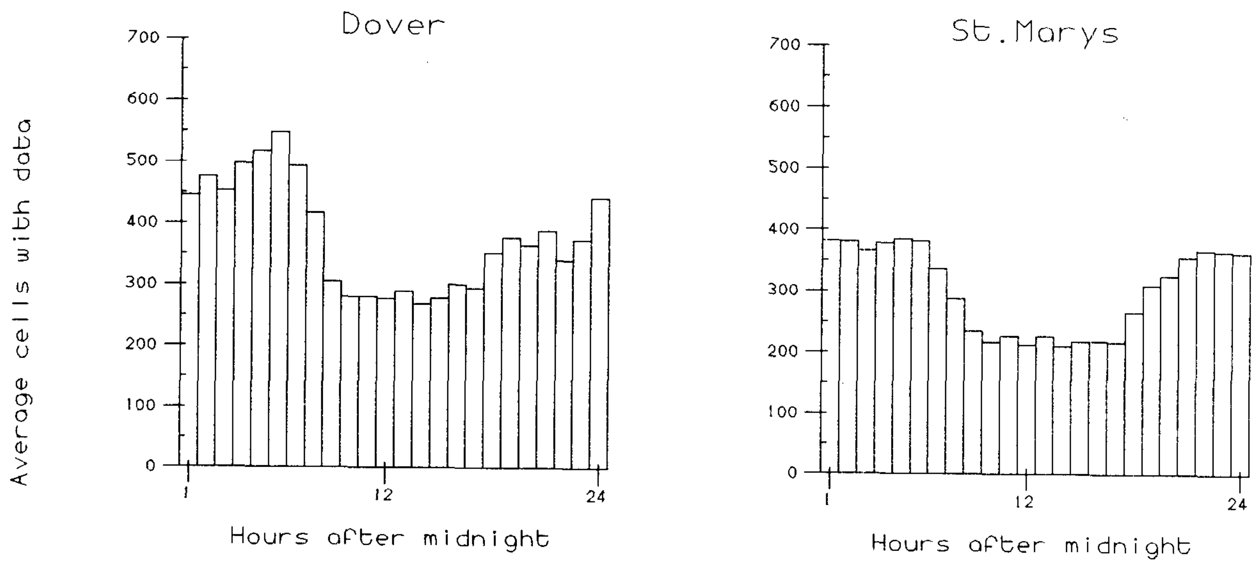


# OSCR II Oct 23 - Nov 15 1990

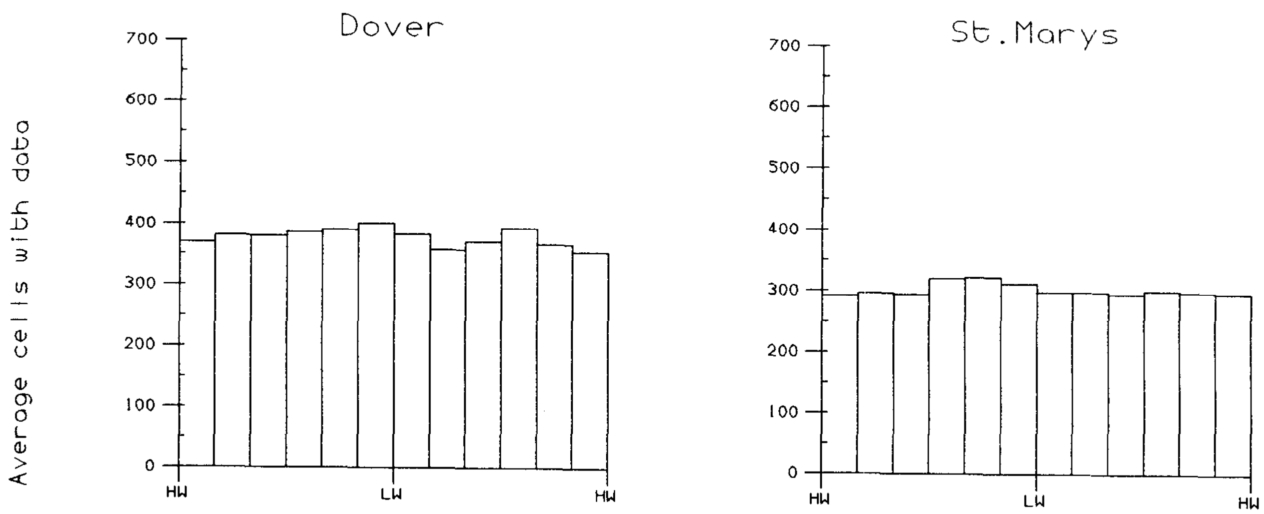


# OSCR II Oct 2 - 31 1990

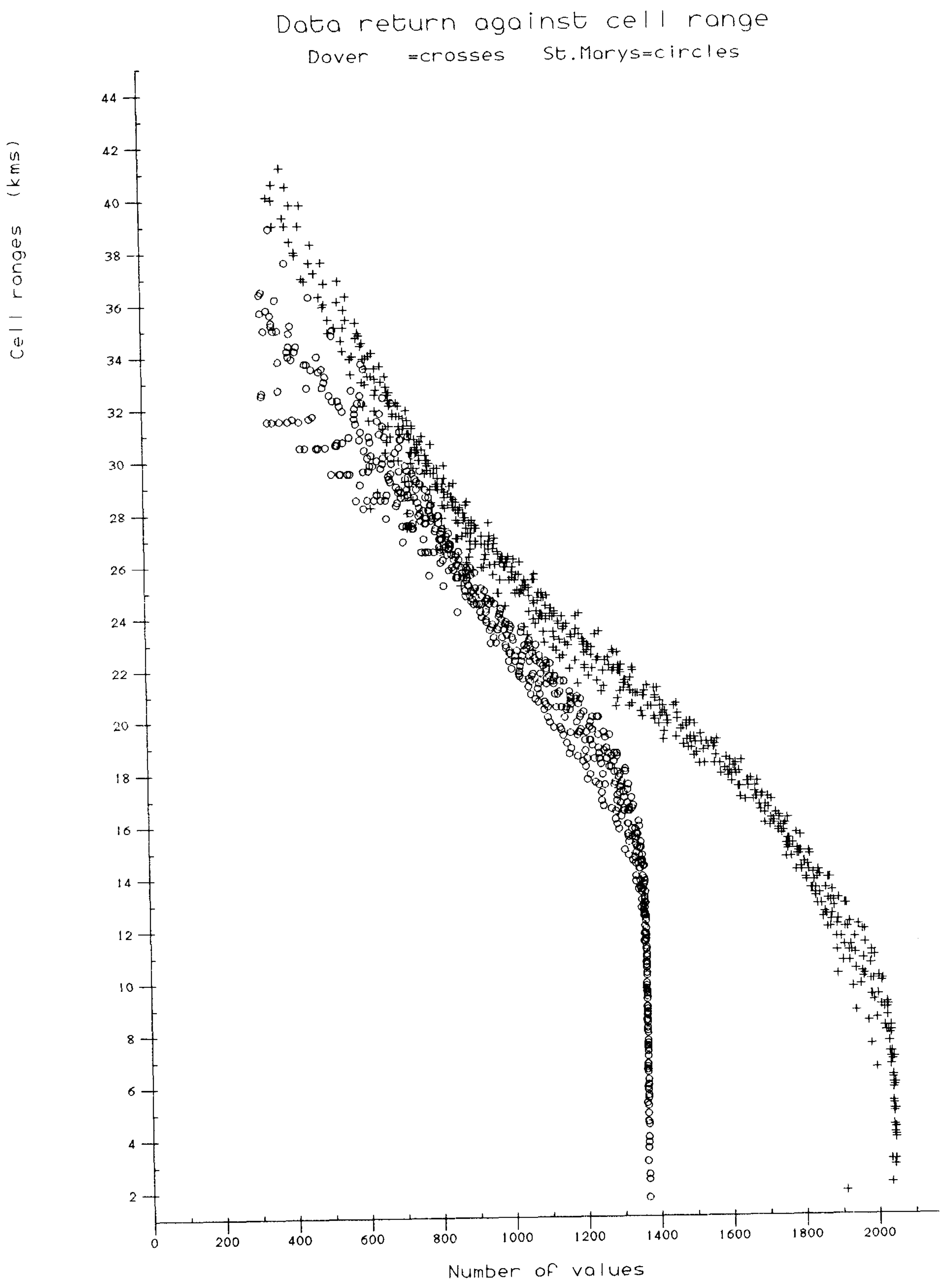
## Data variation with time of day




## Data variation with state of tide

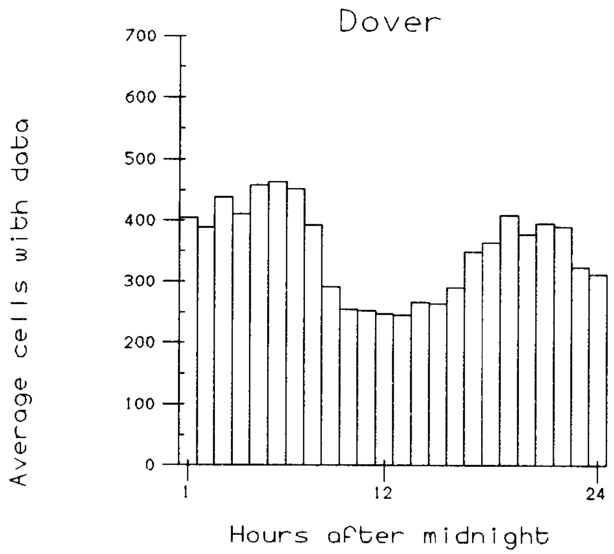


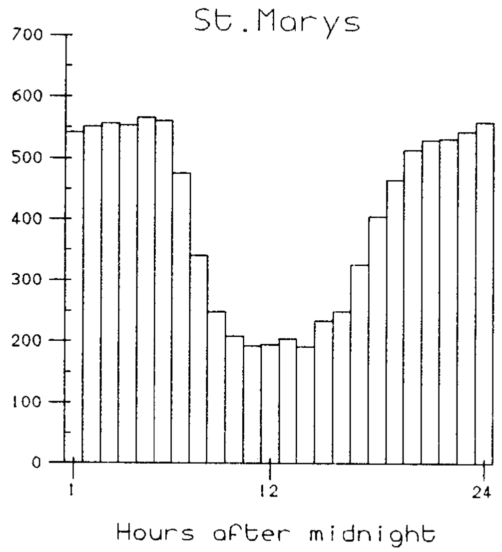
# OSCR II Oct 2 - 31 1990



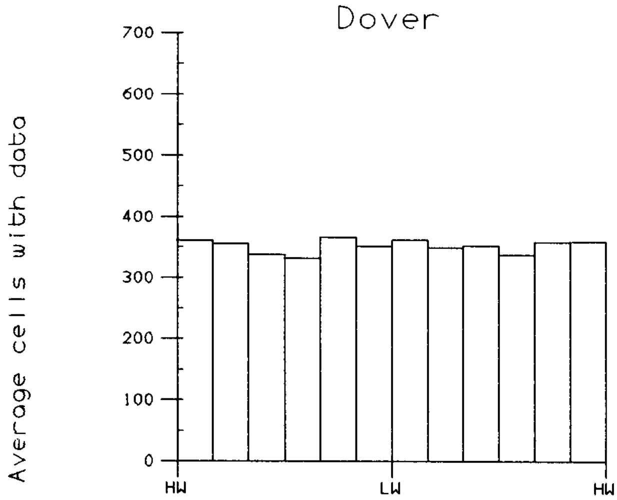
# OSCR II Nov 1 - 30 1990

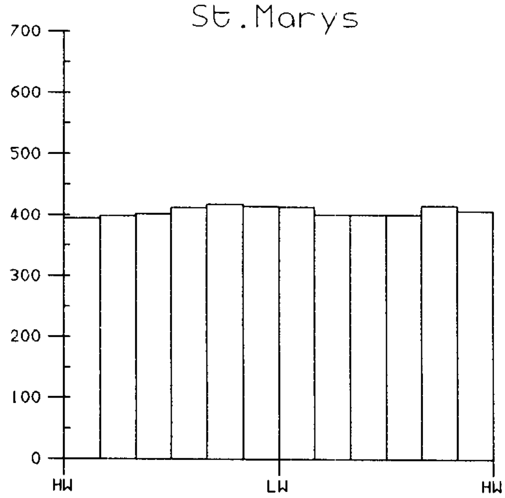
## Data variation with time of day



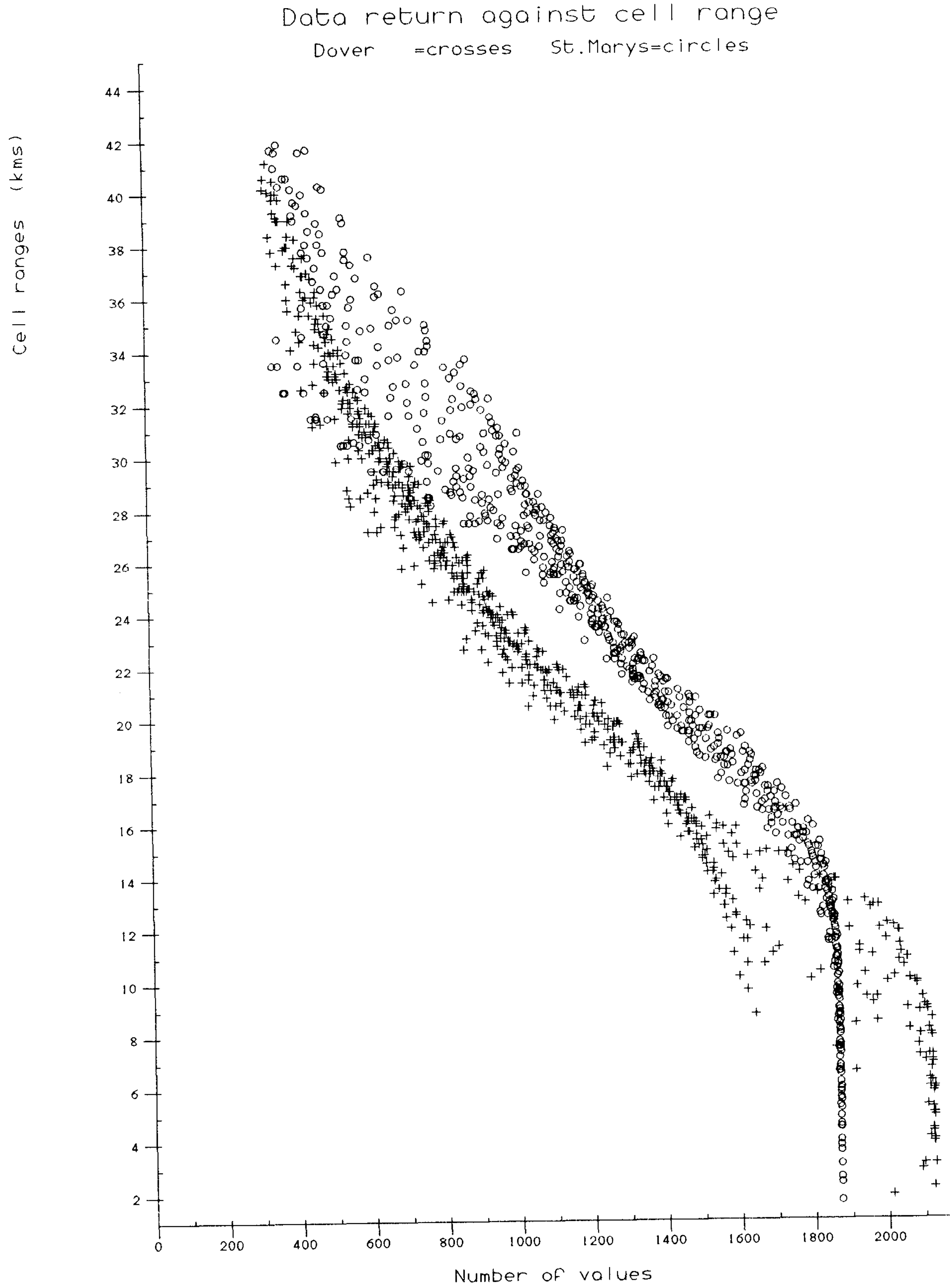




## Data variation with state of tide



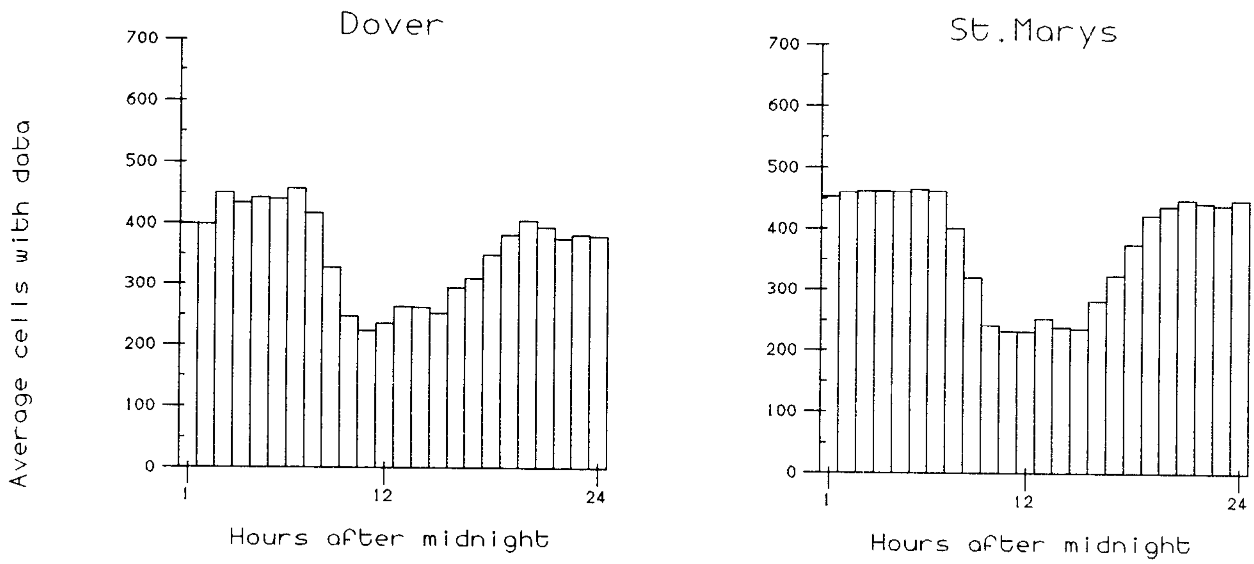



OSCR II Nov 1 - 30 1990

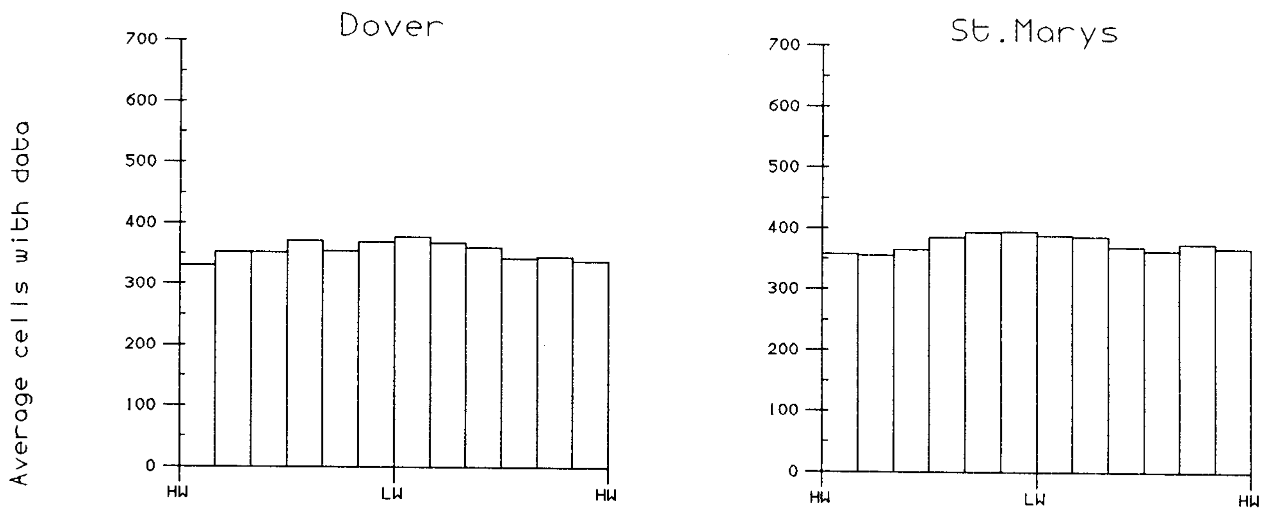


# OSCR II Dec 1 - 30 1990

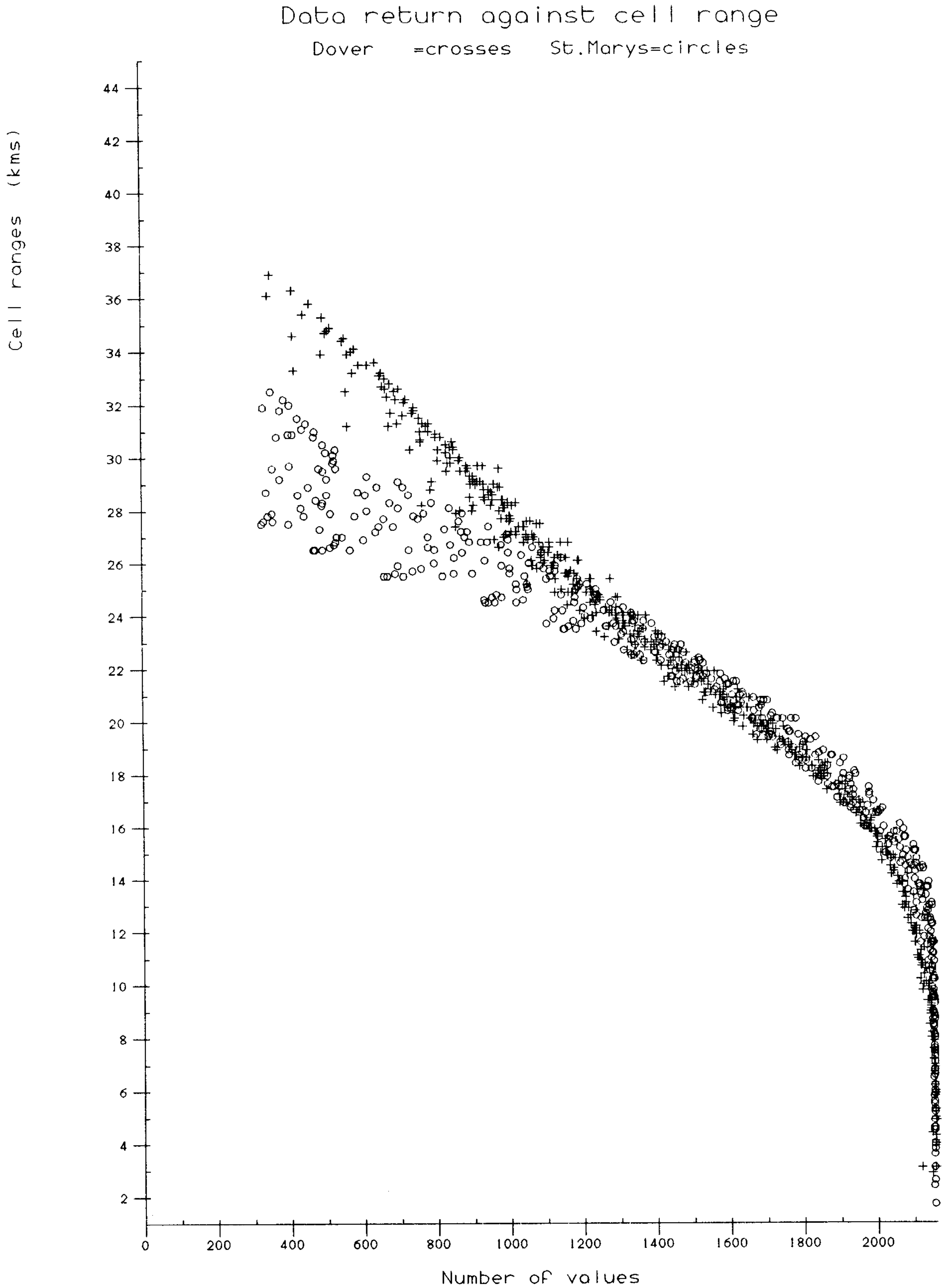
## Data variation with time of day




## Data variation with state of tide

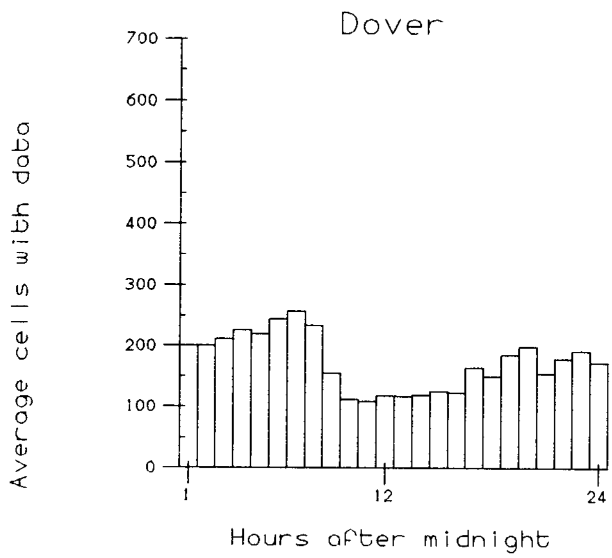


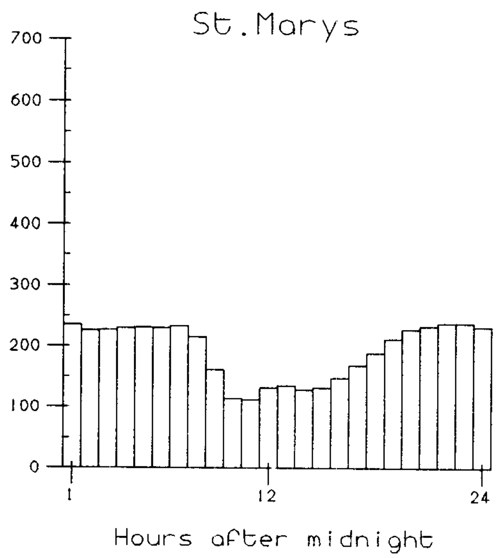
# OSCR II Dec 1 - 30 1990



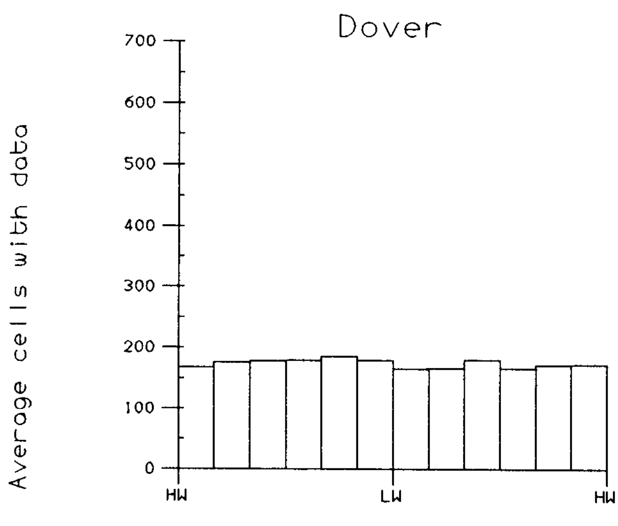
# OSCR II Dec 31 - Jan 29 1991

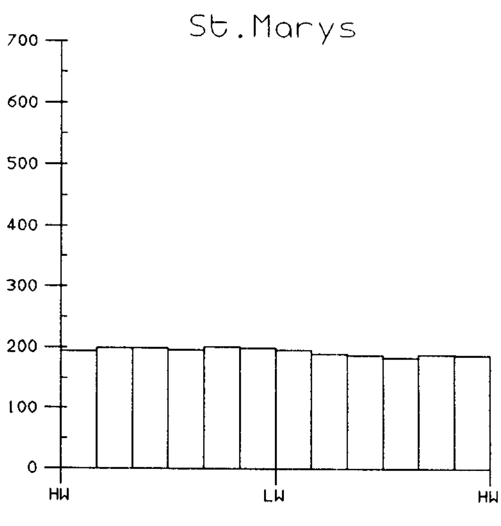
## Data variation with time of day



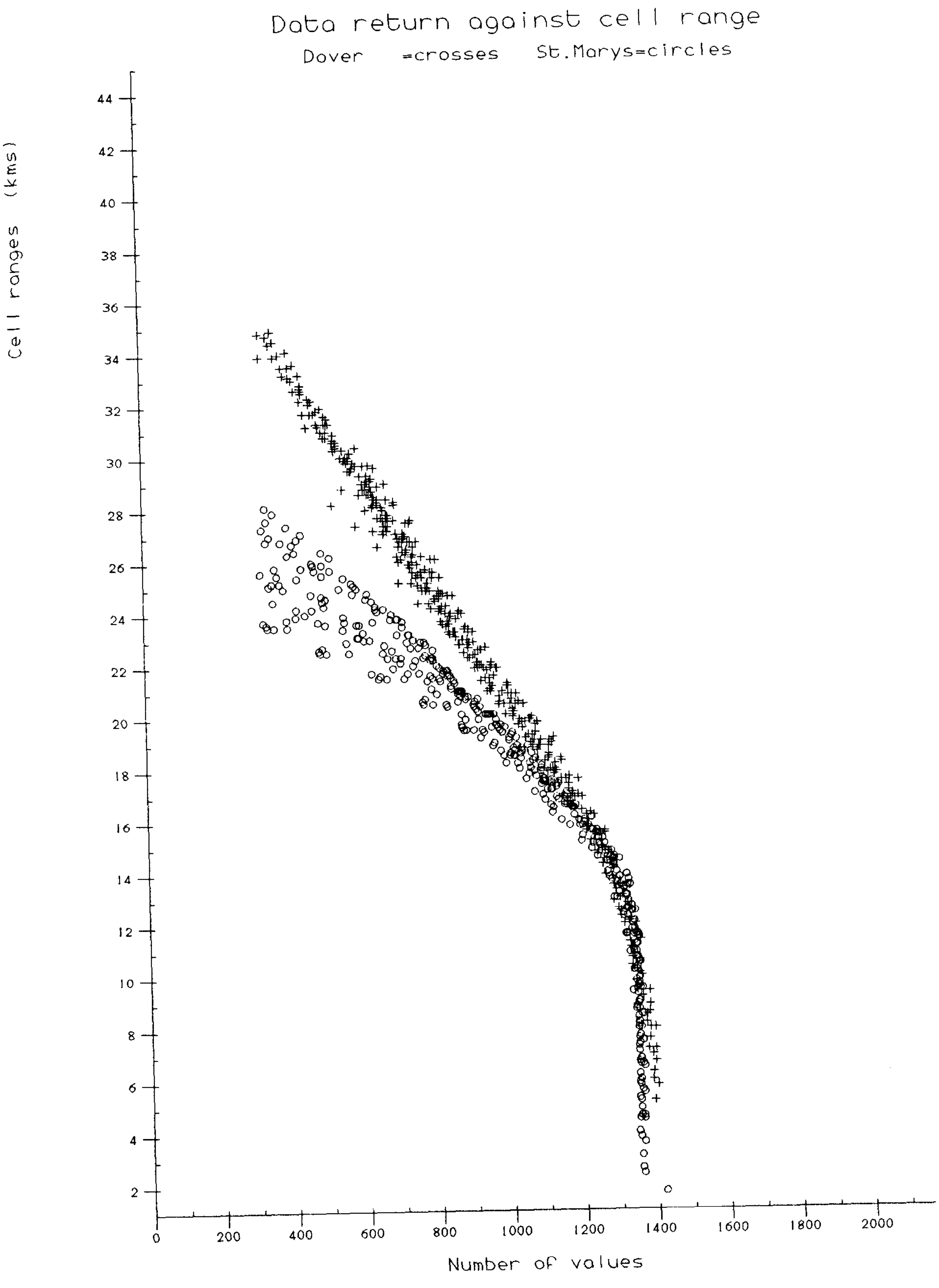




## Data variation with state of tide



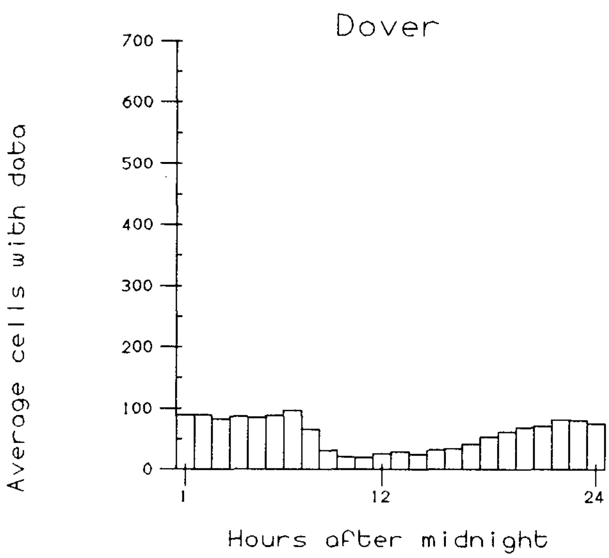



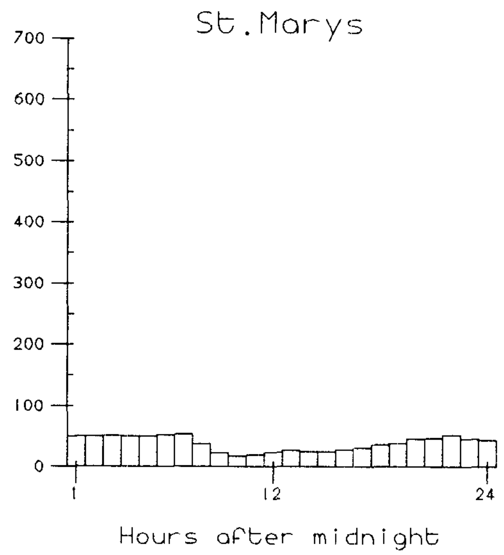
OSCR II Dec 31 - Jan 29 1991



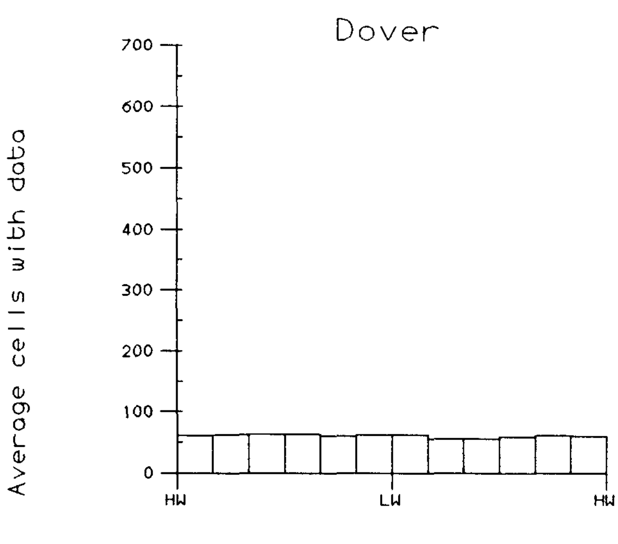
# OSCR II Jan 30 - Feb 28 1991

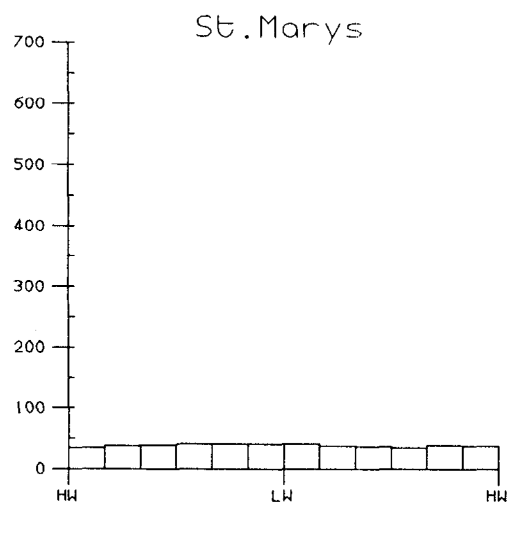
## Data variation with time of day



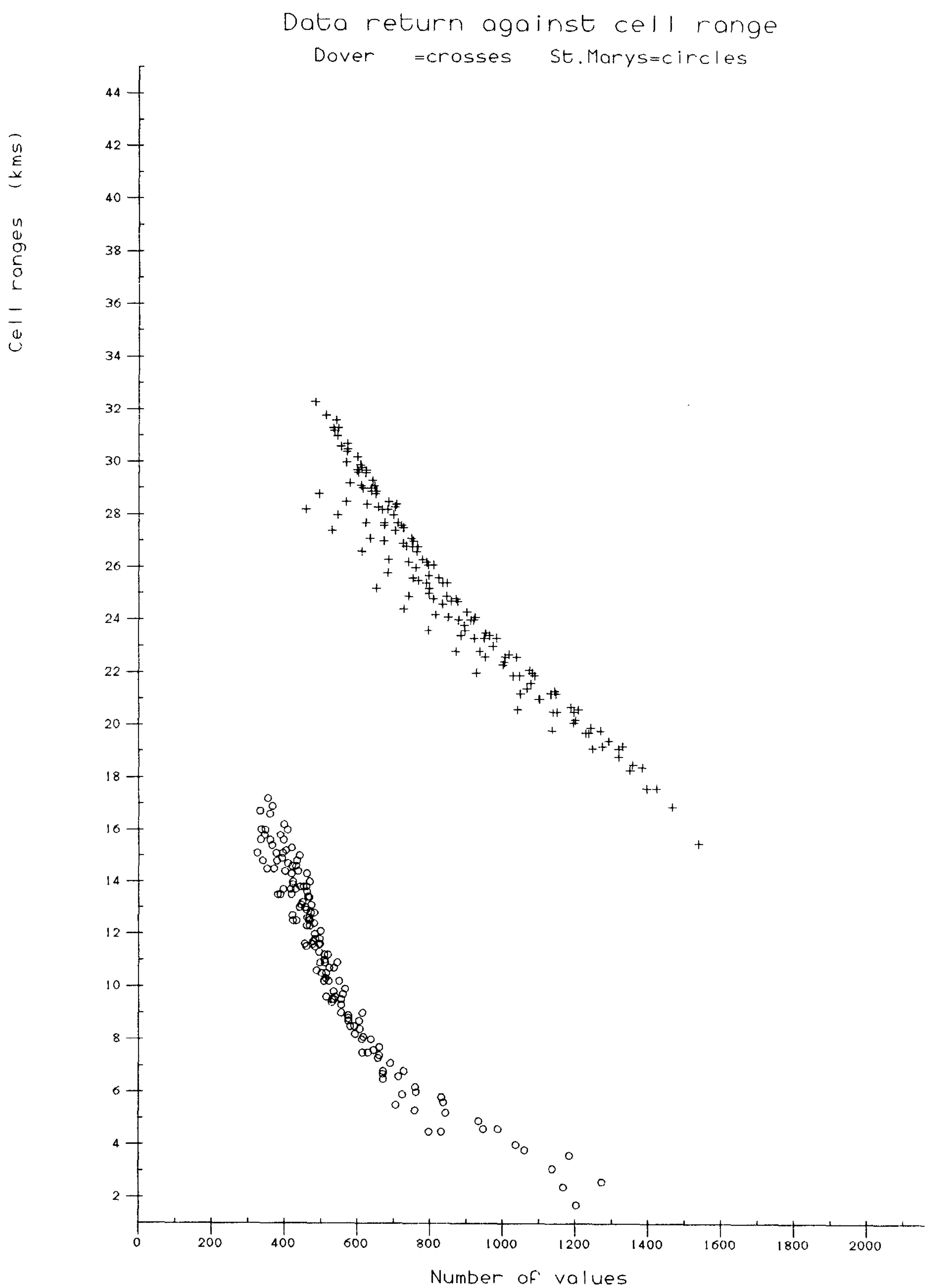




## Data variation with state of tide



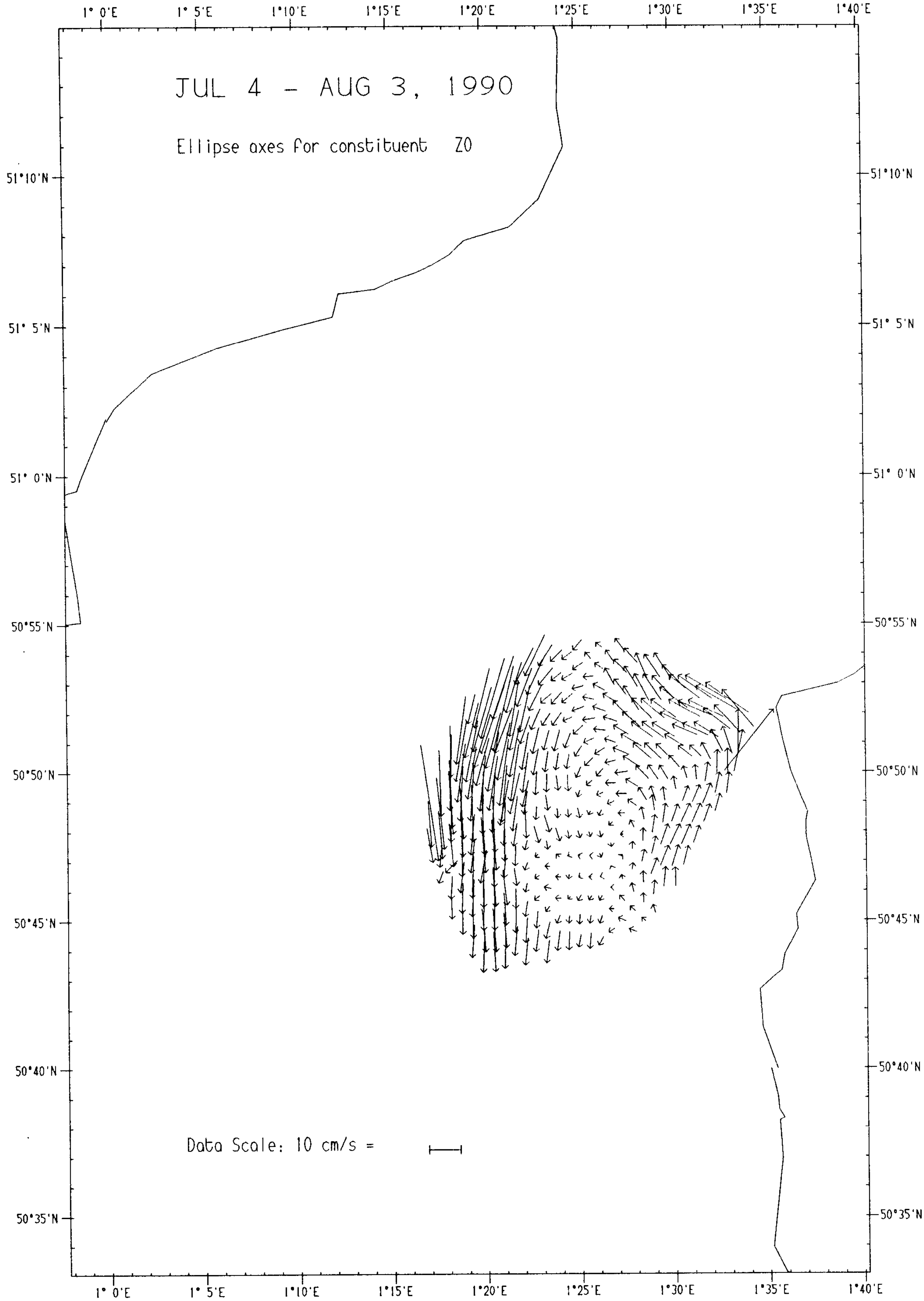



OSCR II Jan 30 - Feb 28 1991

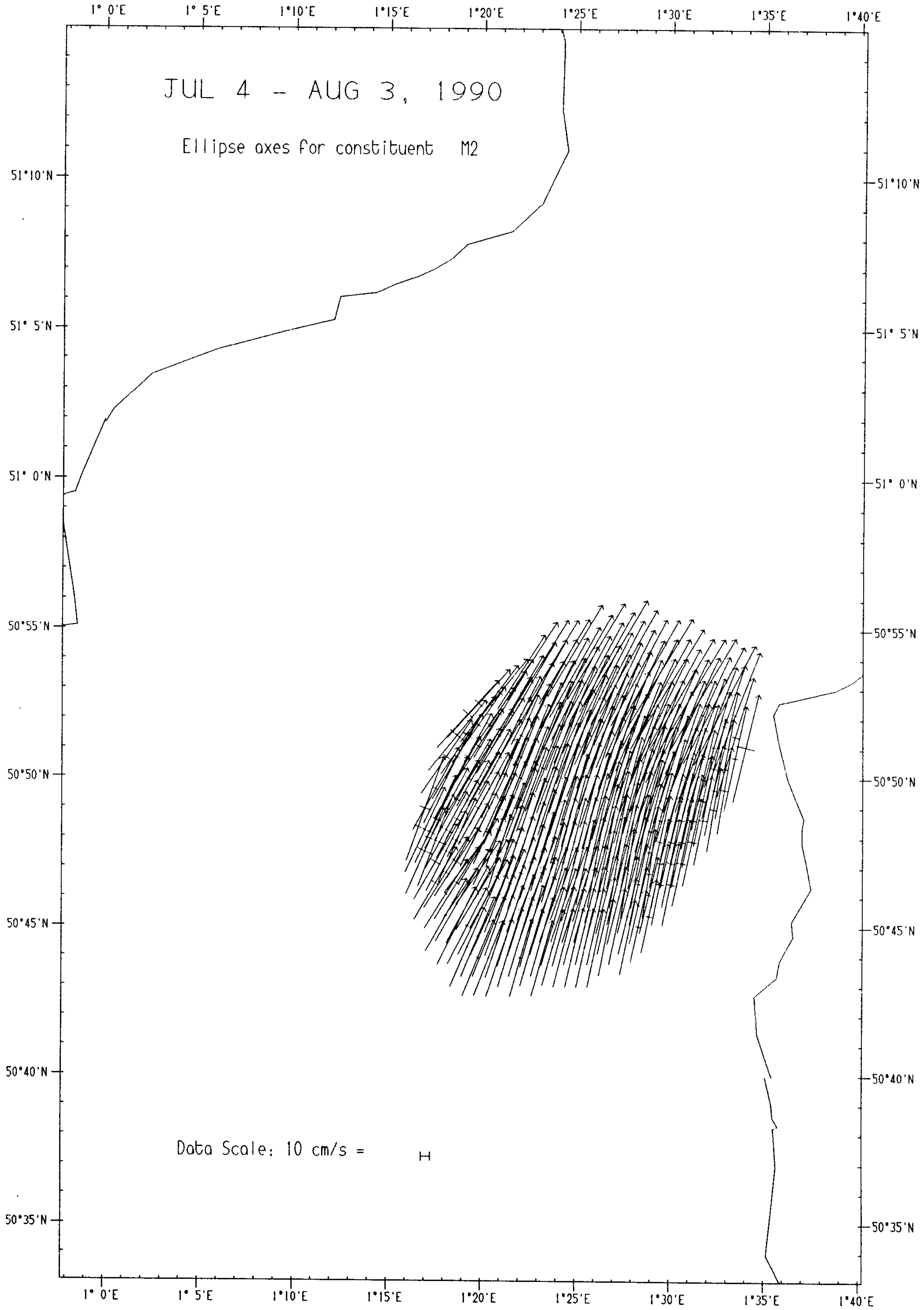


Appendix D. Output constituent plots for ZO, M2 and M4

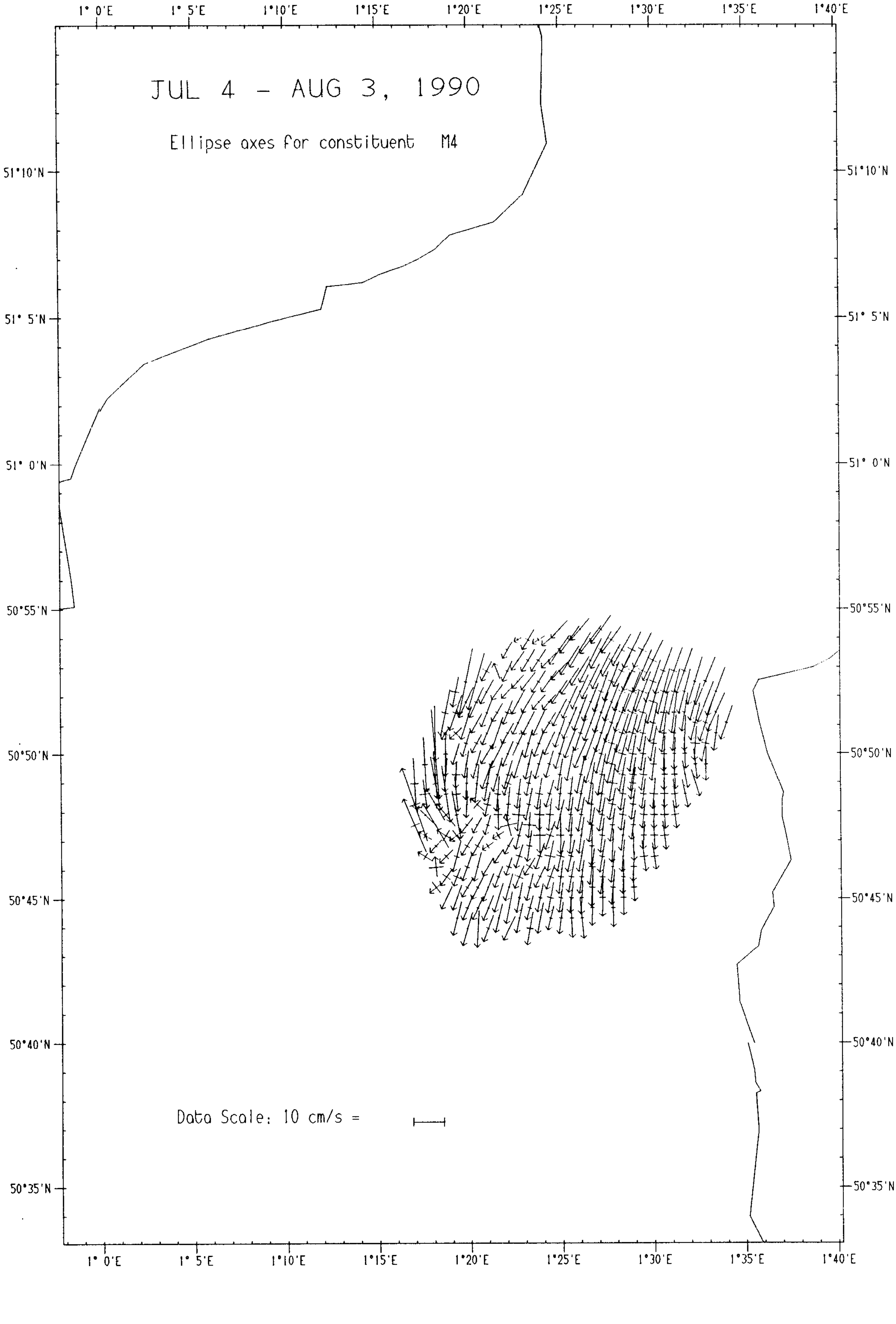
The entire length of the vector arrows indicate the amplitude of the constituent, for both major and minor axes. The major axis direction is indicated by the arrowhead.

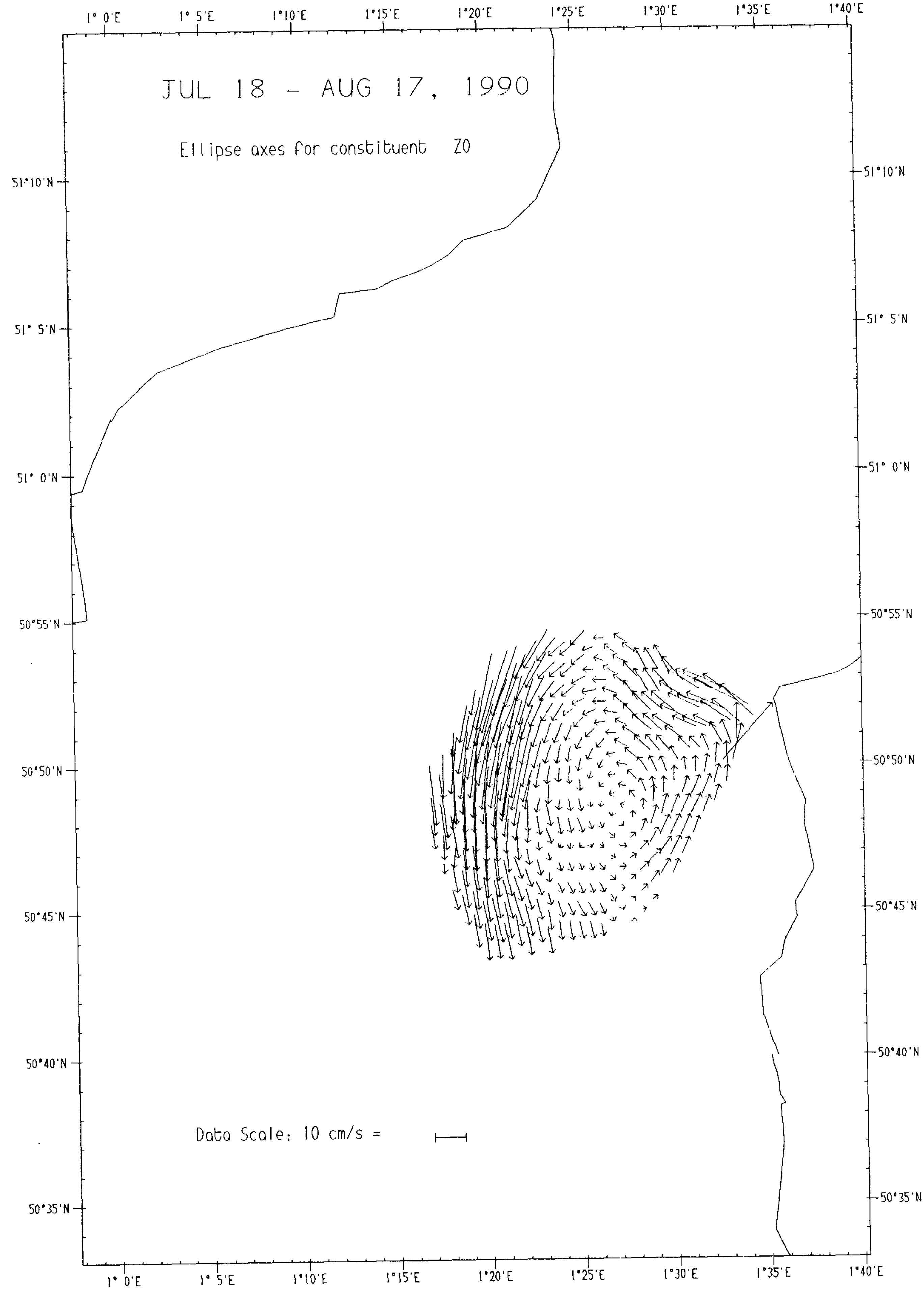


JUL 4 - AUG 3, 1990
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N

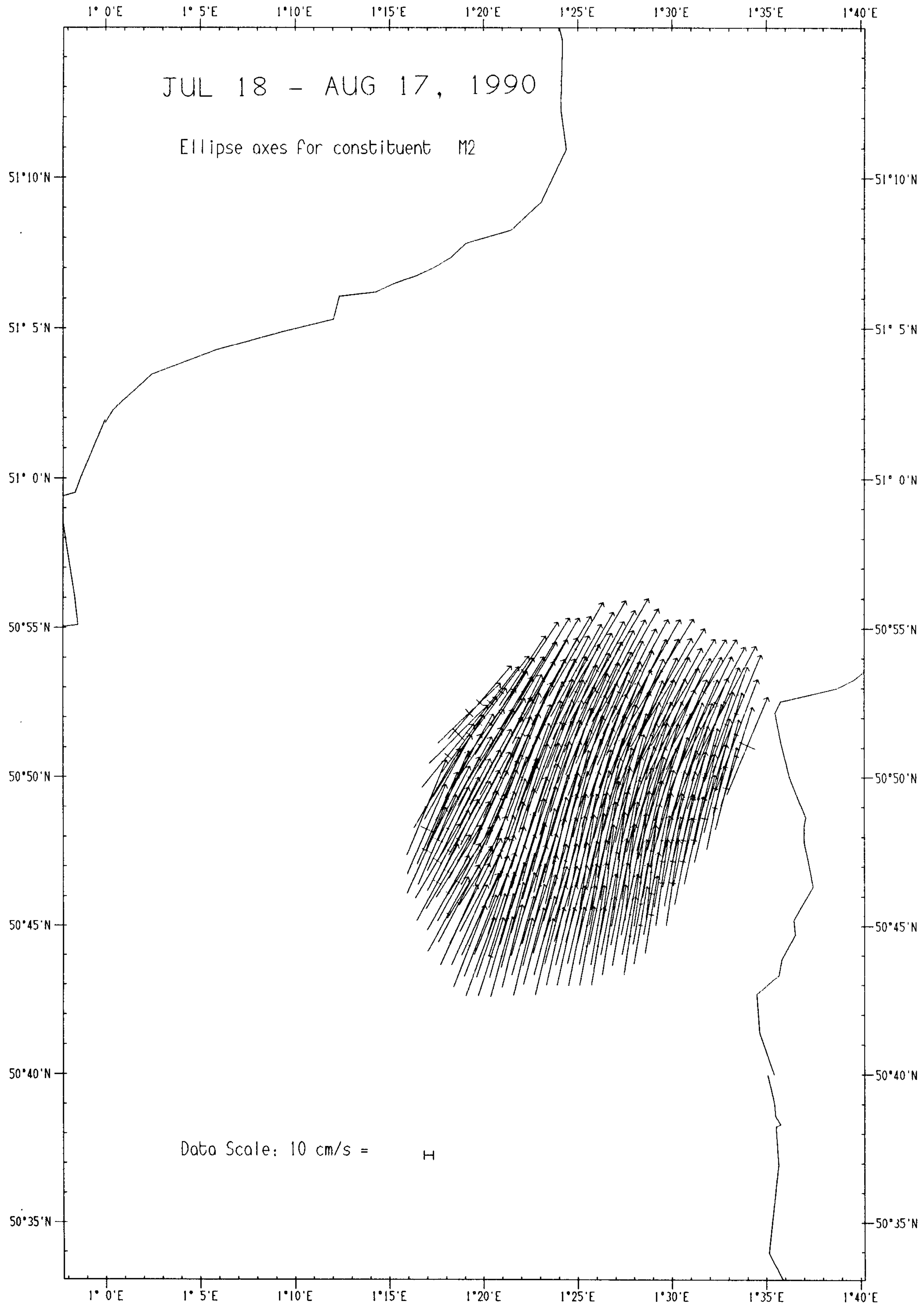


JUL 4 - AUG 3, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


JUL 4 - AUG 3, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



JUL 18 - AUG 17, 1990
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



JUL 18 - AUG 17, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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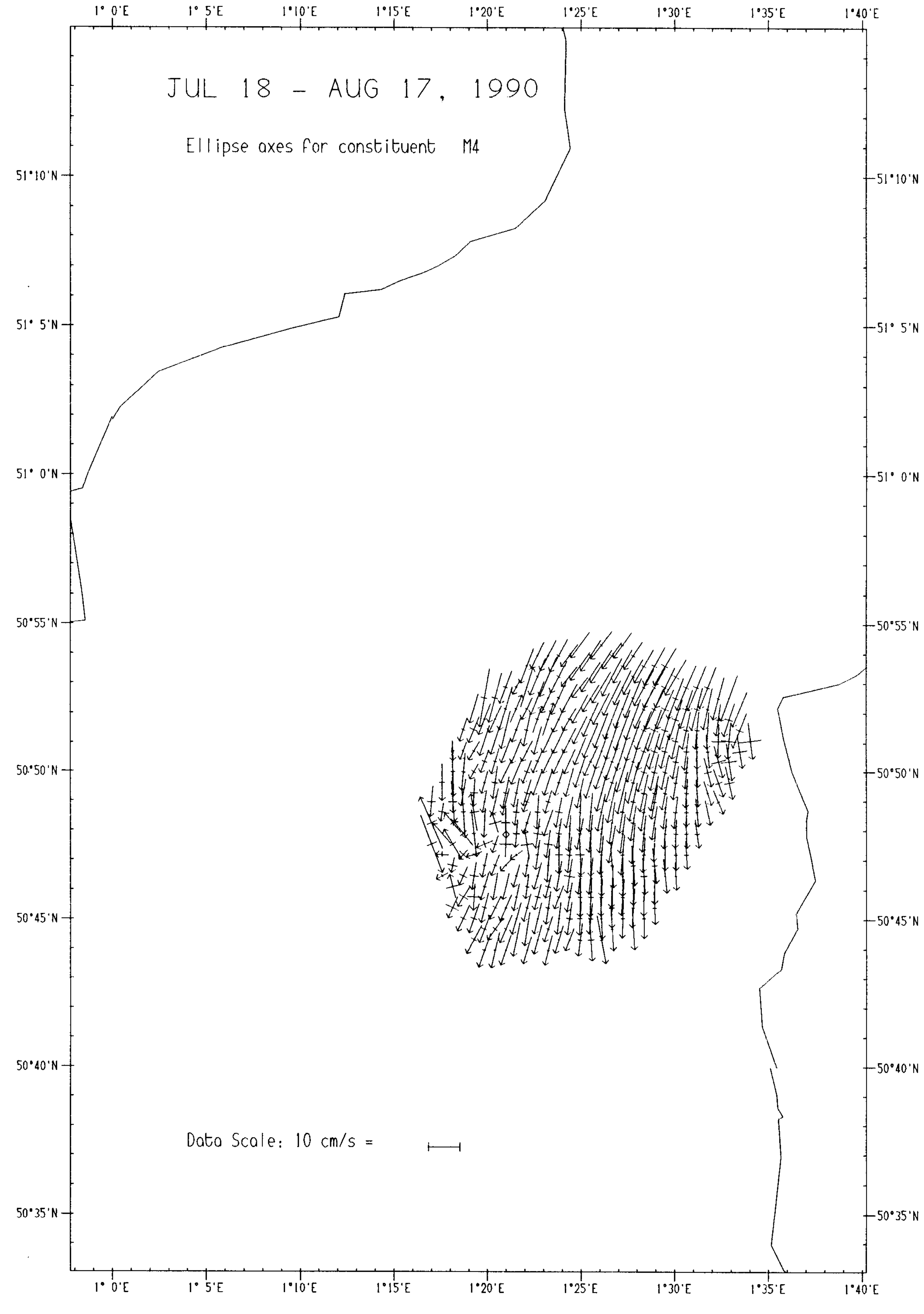
50°45'N
50°40'N
50°35'N


JUL 18 - AUG 17, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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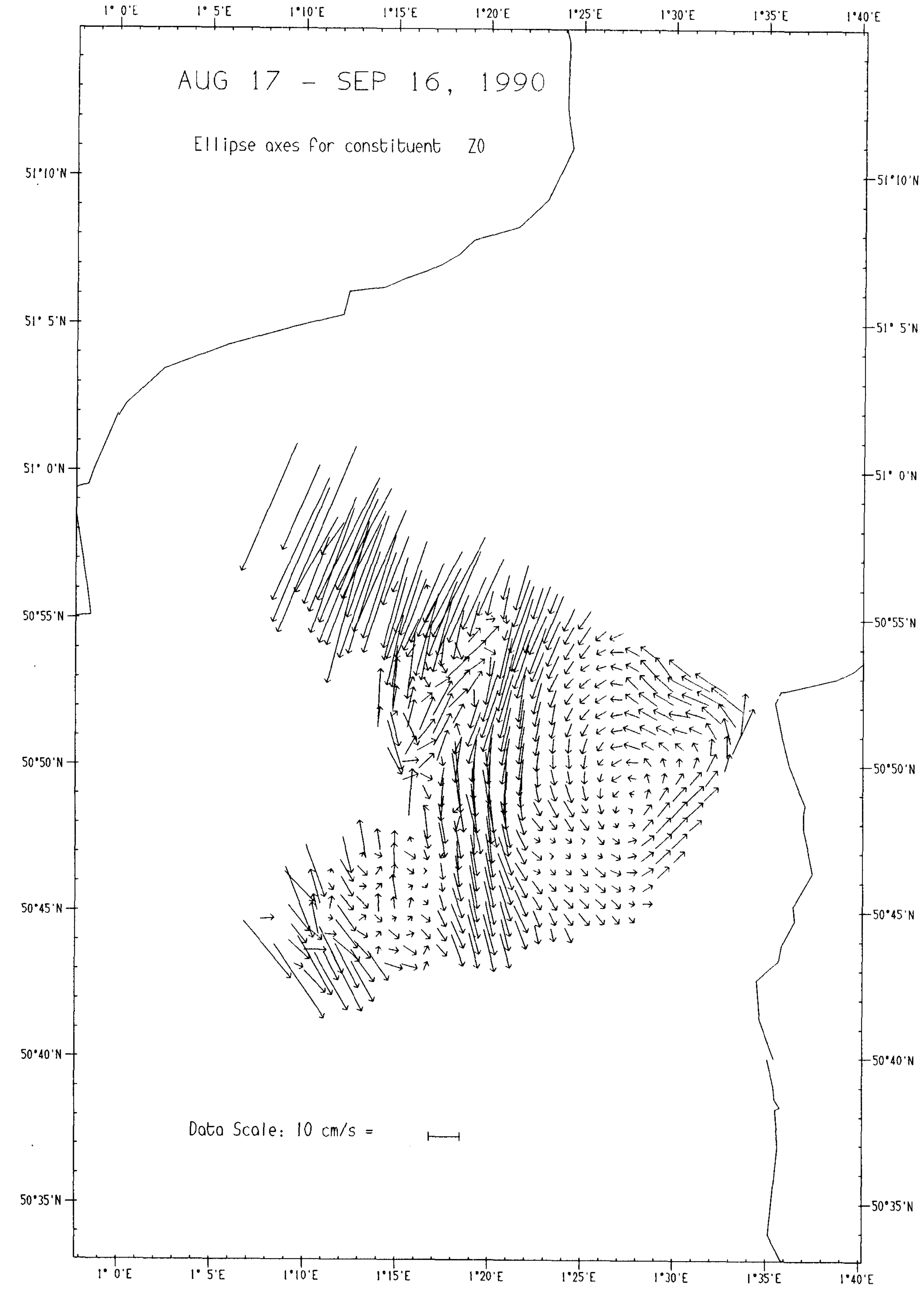
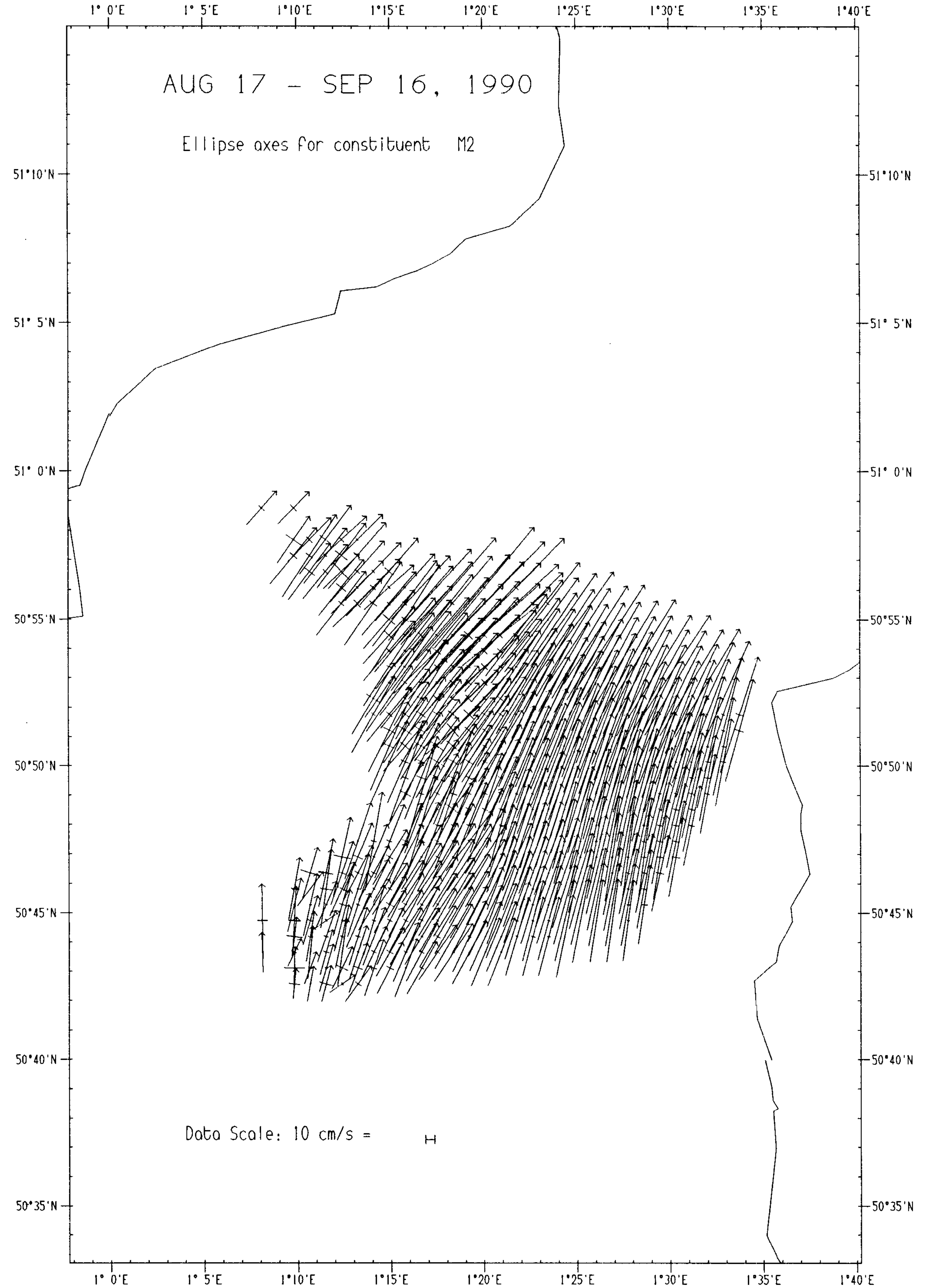
50°45'N
50°40'N
50°35'N



AUG 17 - SEP 16, 1990
Ellipse axes for constituent Z0
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N
Data Scale: 10 cm/s =



AUG 17 - SEP 16, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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51° 5'N
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50°55'N
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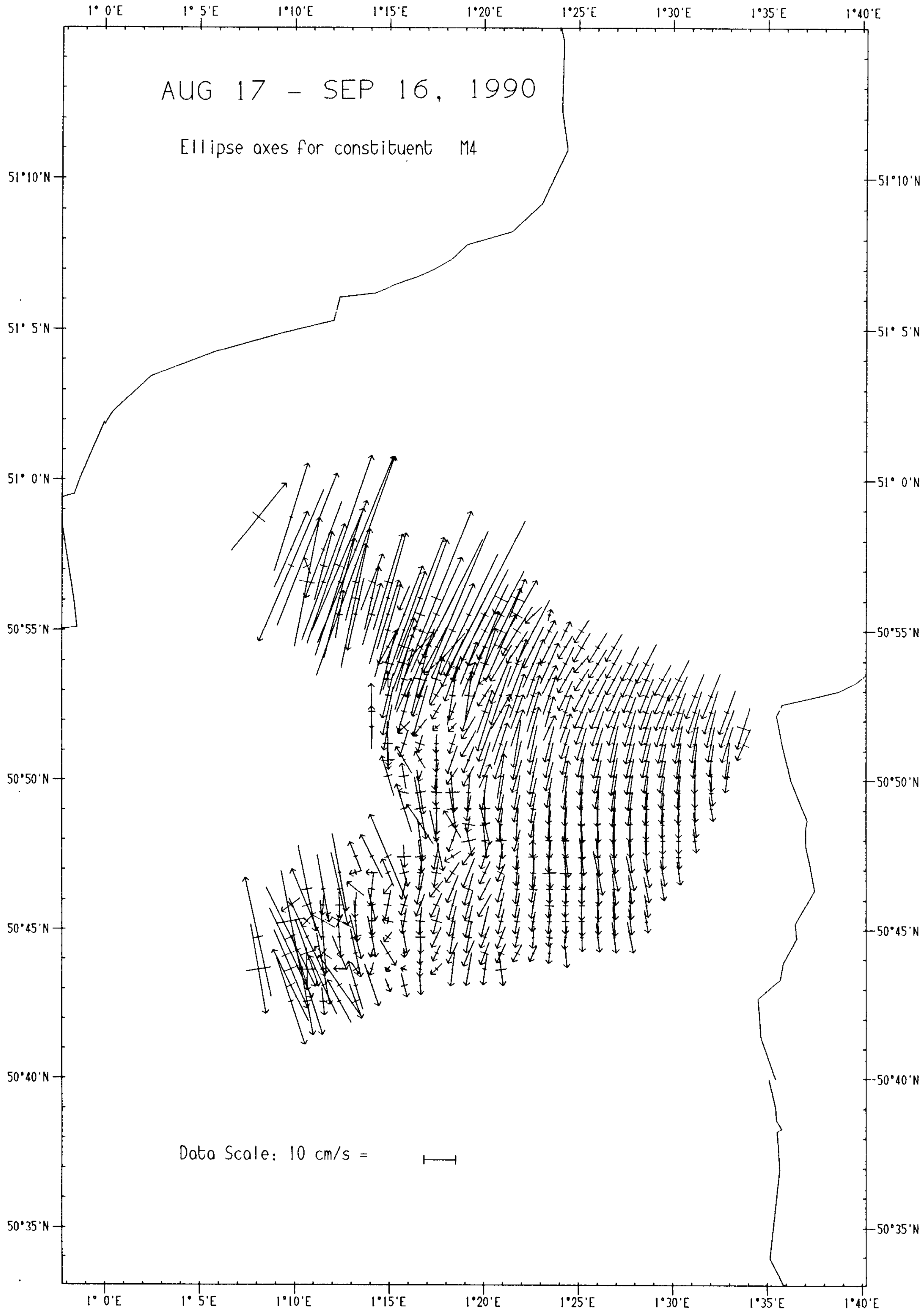
50°45'N
50°40'N
50°35'N



AUG 17 - SEP 16, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
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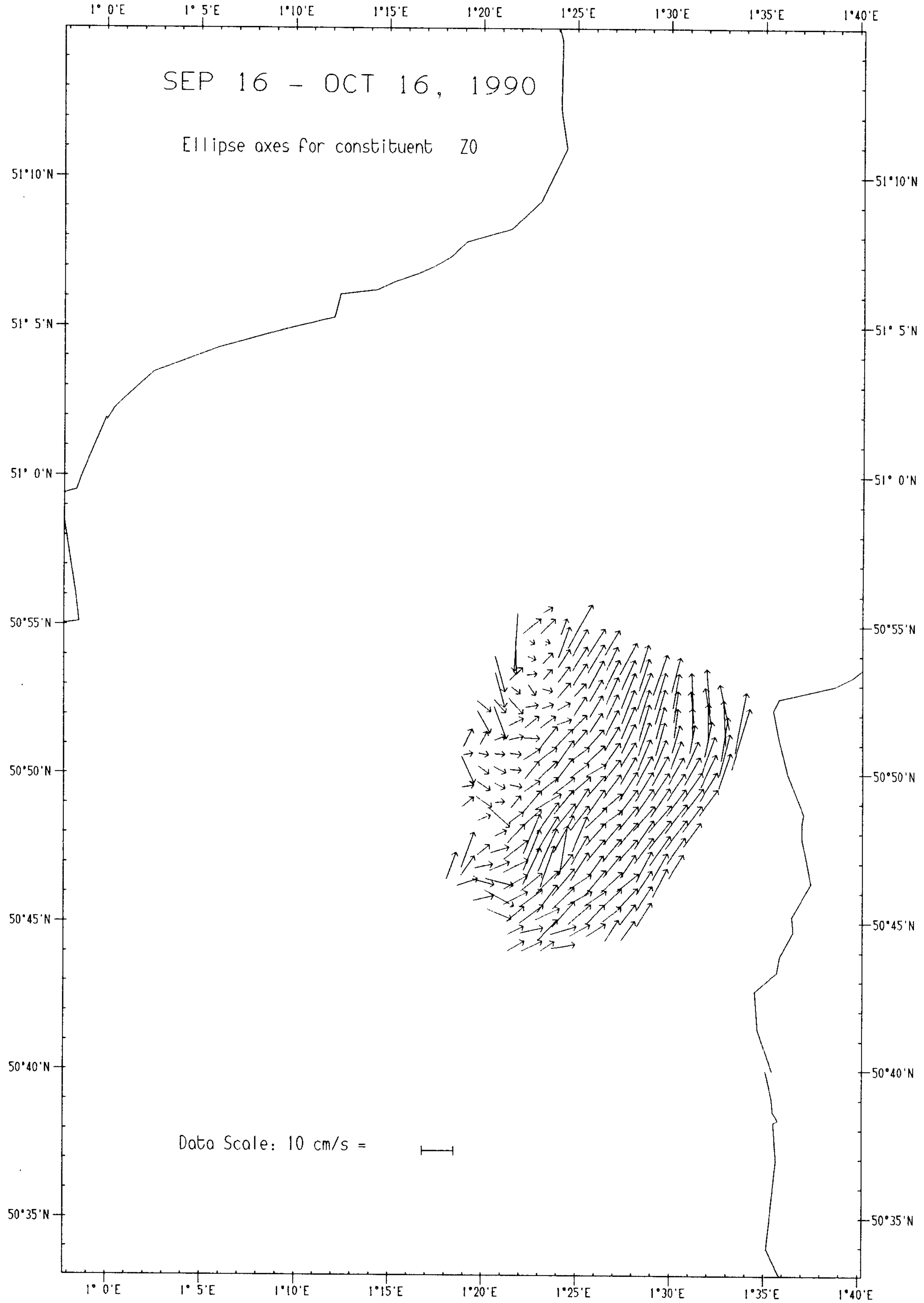
50°45'N
50°40'N
50°35'N


SEP 16 - OCT 16, 1990
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
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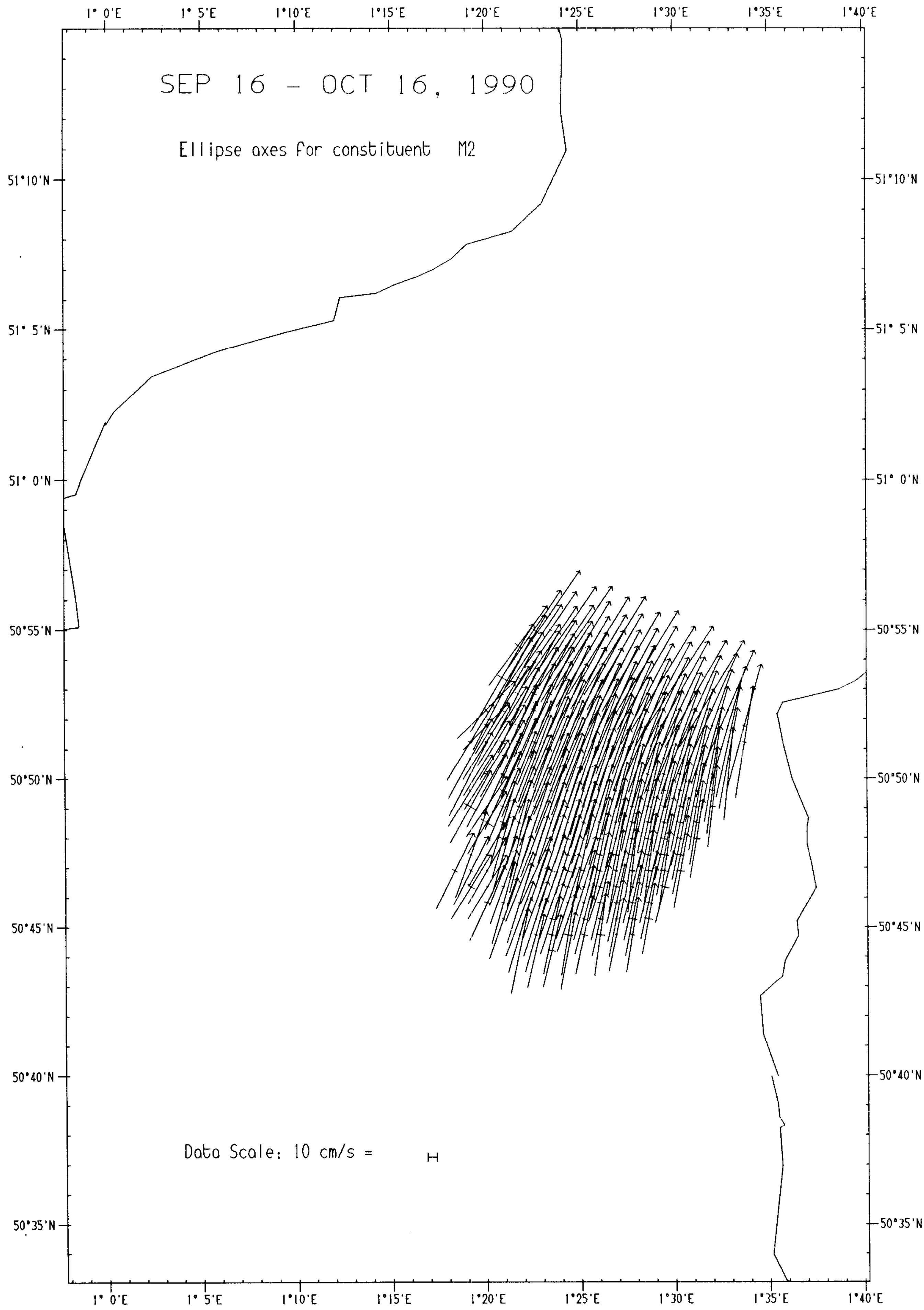
50°45'N
50°40'N
50°35'N


SEP 16 - OCT 16, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
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50°55'N
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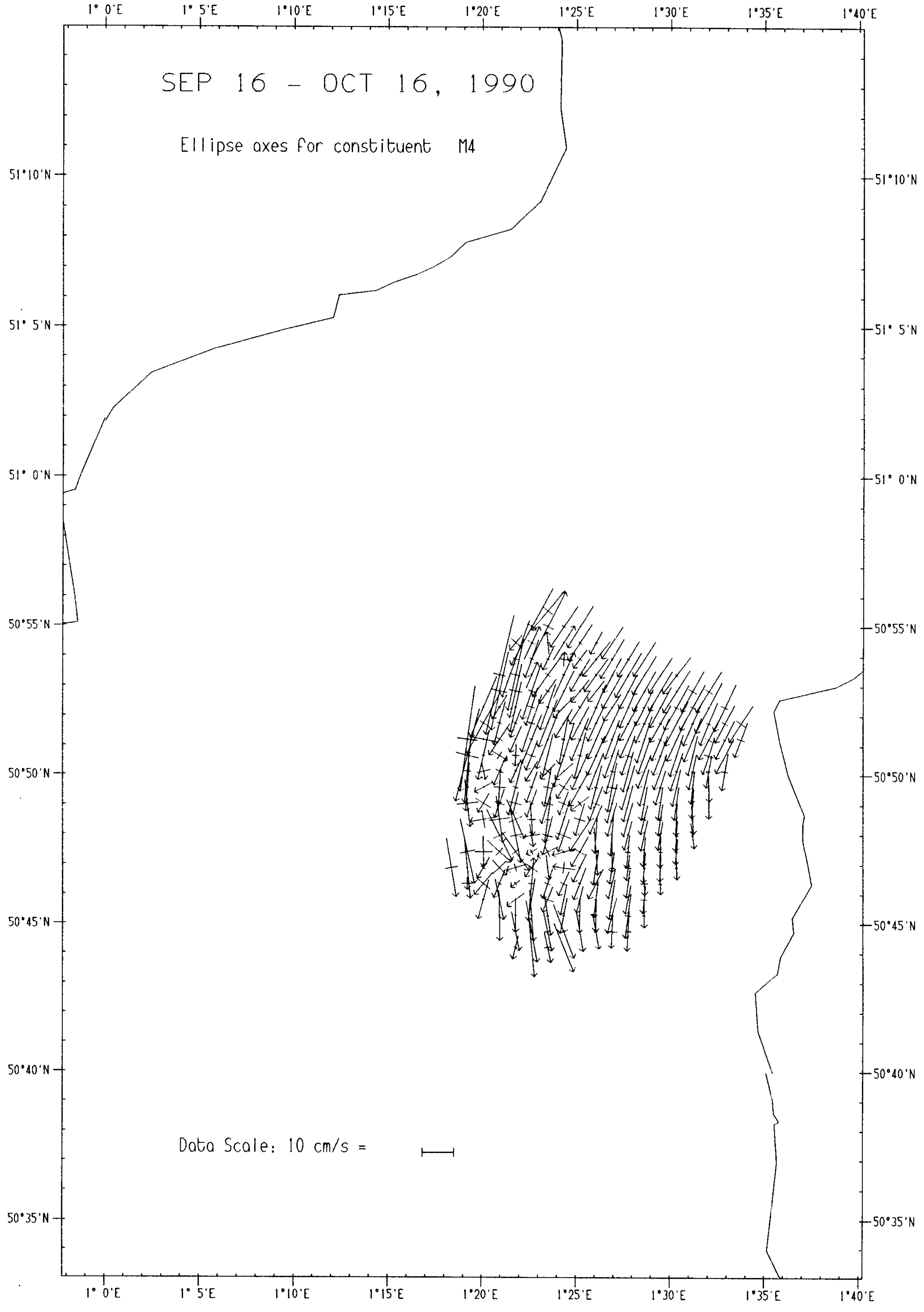
50°45'N
50°40'N
50°35'N


SEP 16 - OCT 16, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
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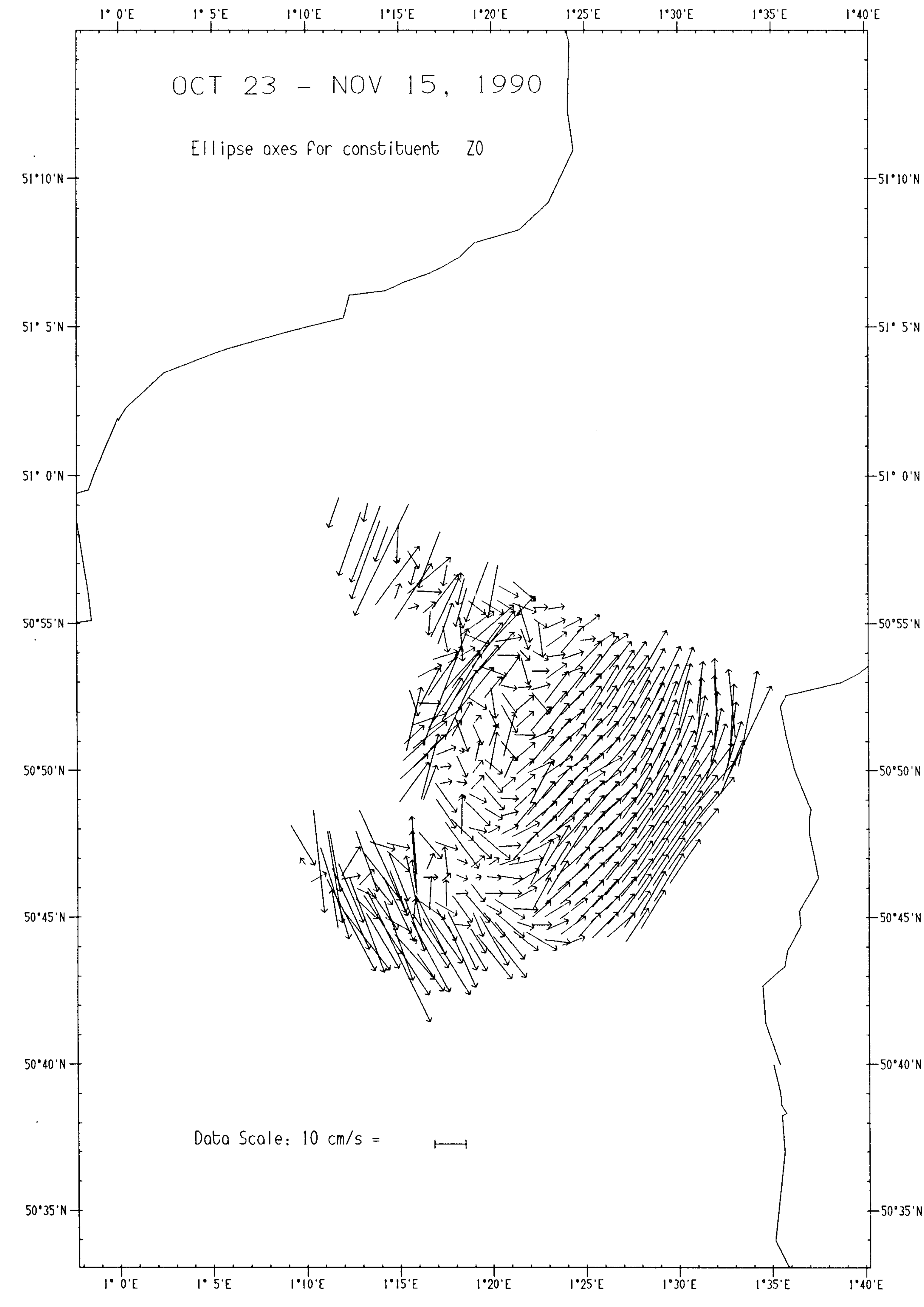
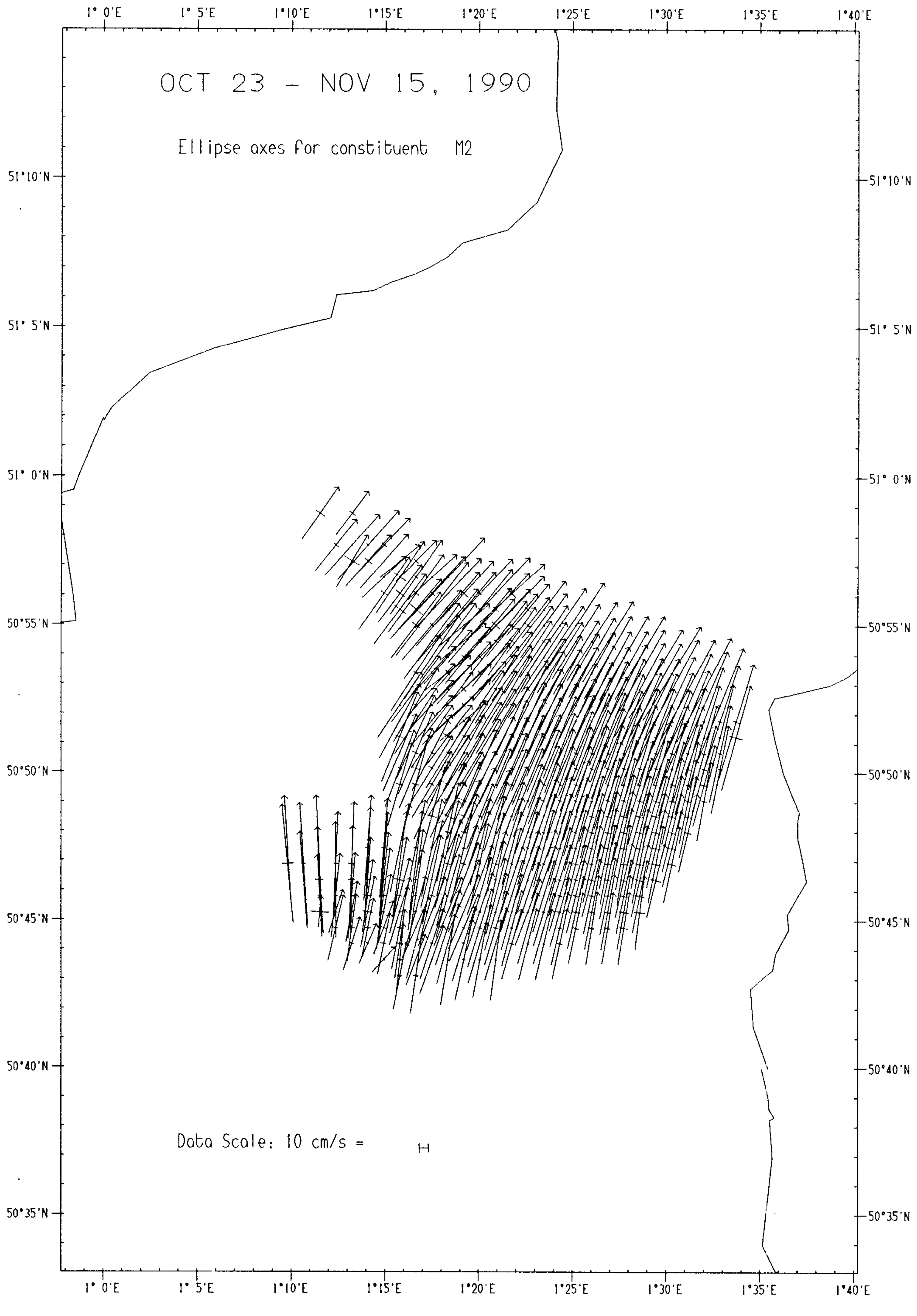
50°50'N
50°45'N
50°40'N
50°35'N



OCT 23 - NOV 15, 1990
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



OCT 23 - NOV 15, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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51° 0'N
50°55'N
50°50'N
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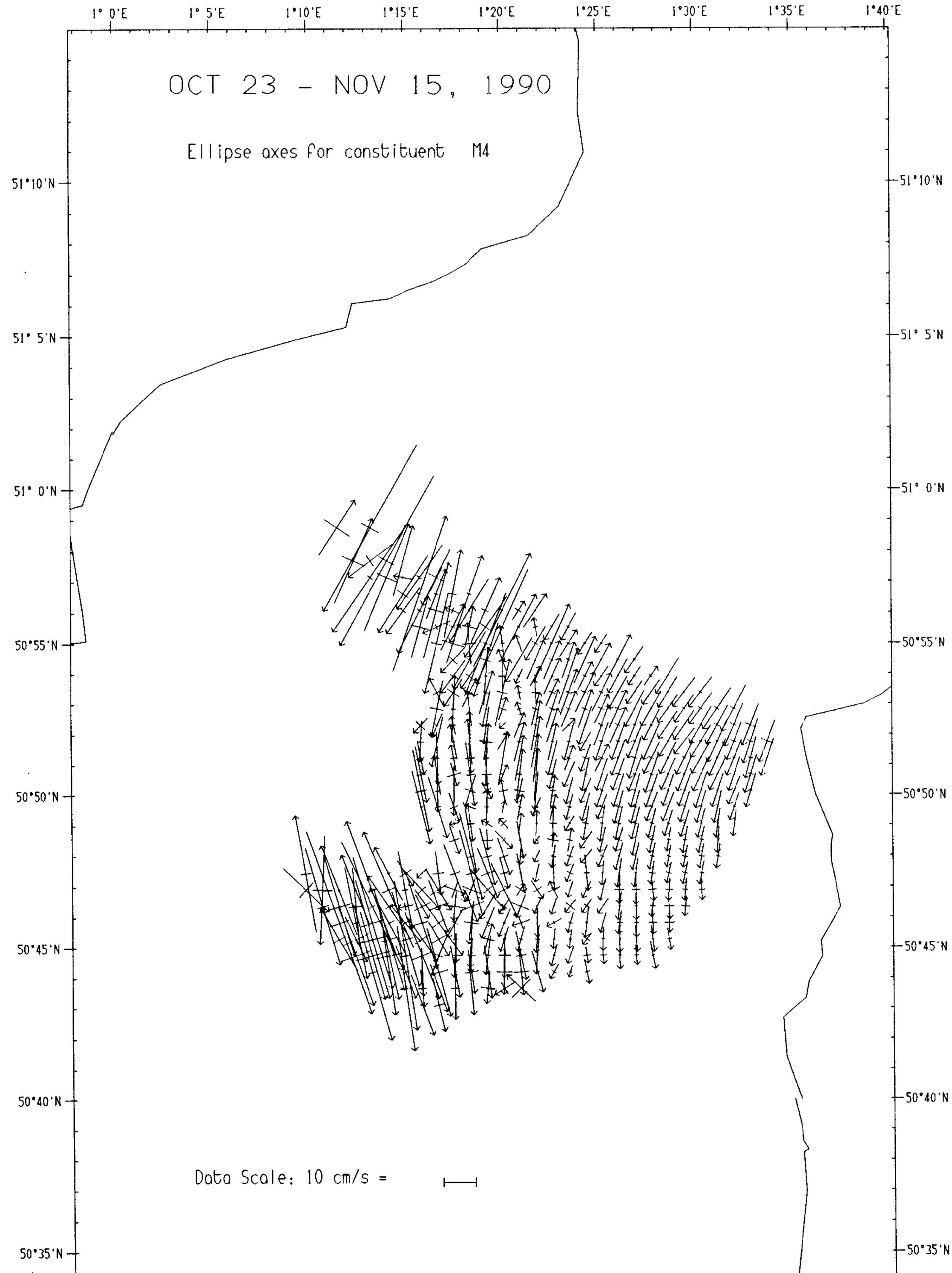
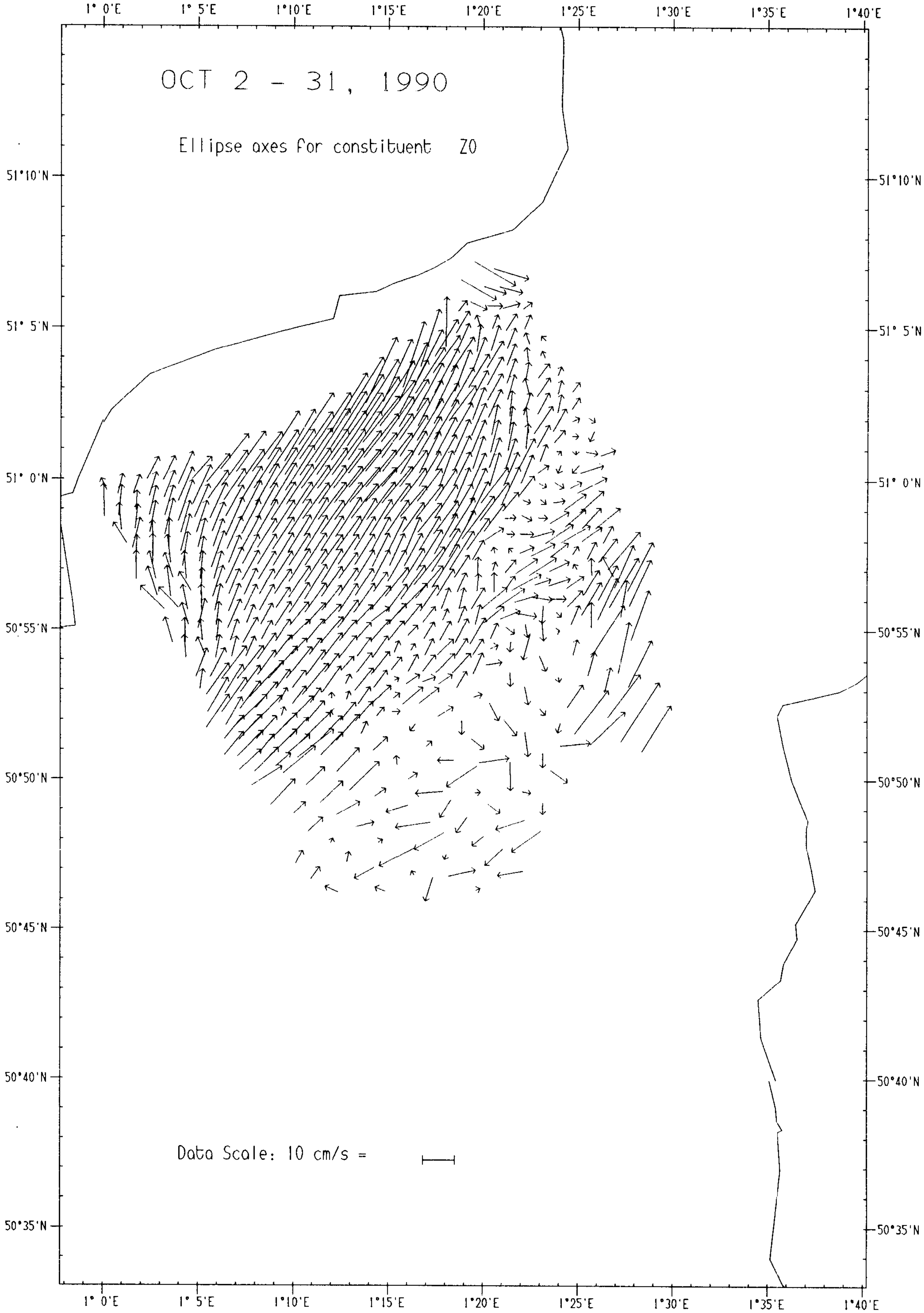
50°40'N
50°35'N



OCT 23 - NOV 15, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


OCT 2 - 31, 1990
Ellipse axes for constituent Z0
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
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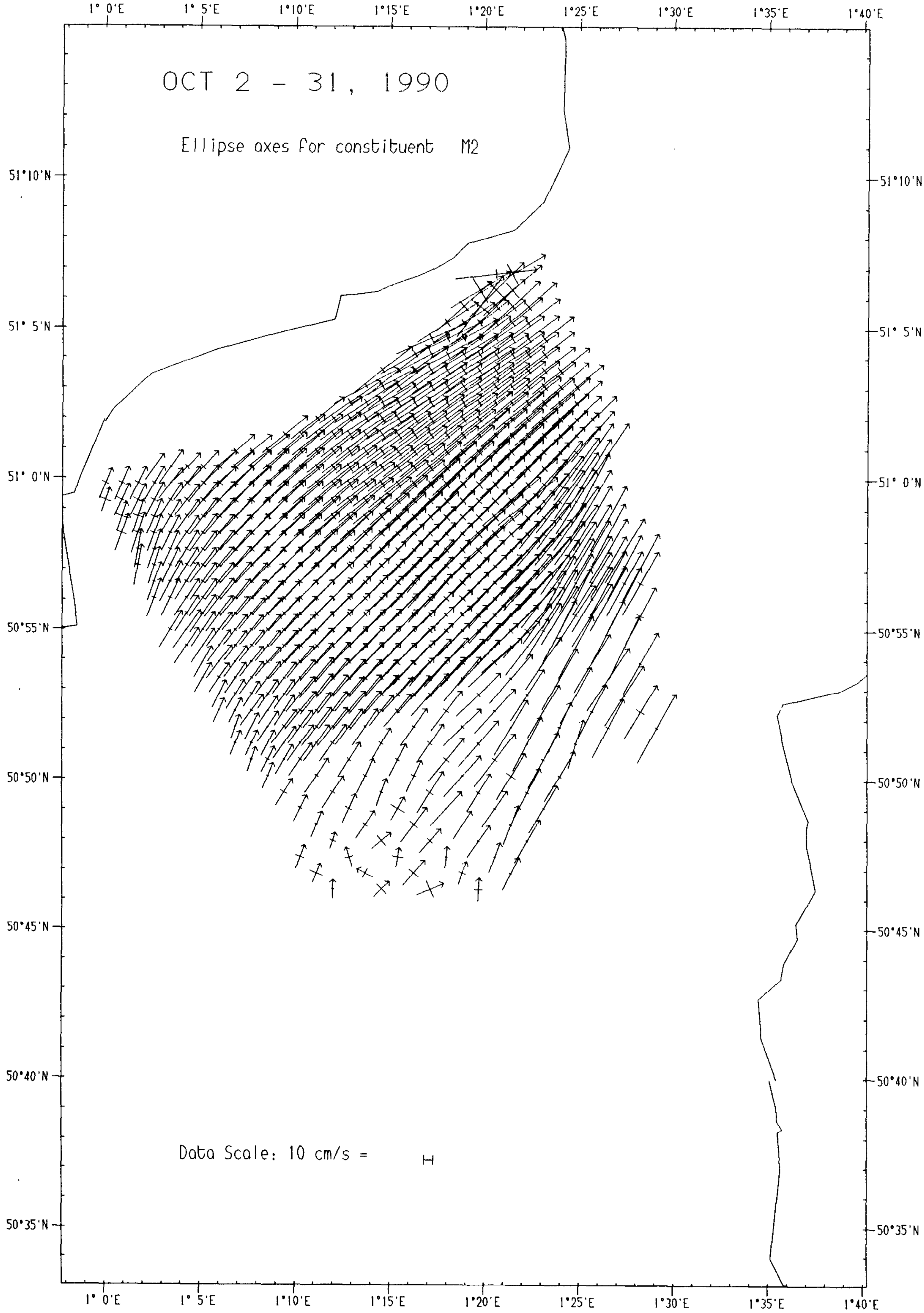
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N
Data Scale: 10 cm/s =


OCT 2 - 31, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
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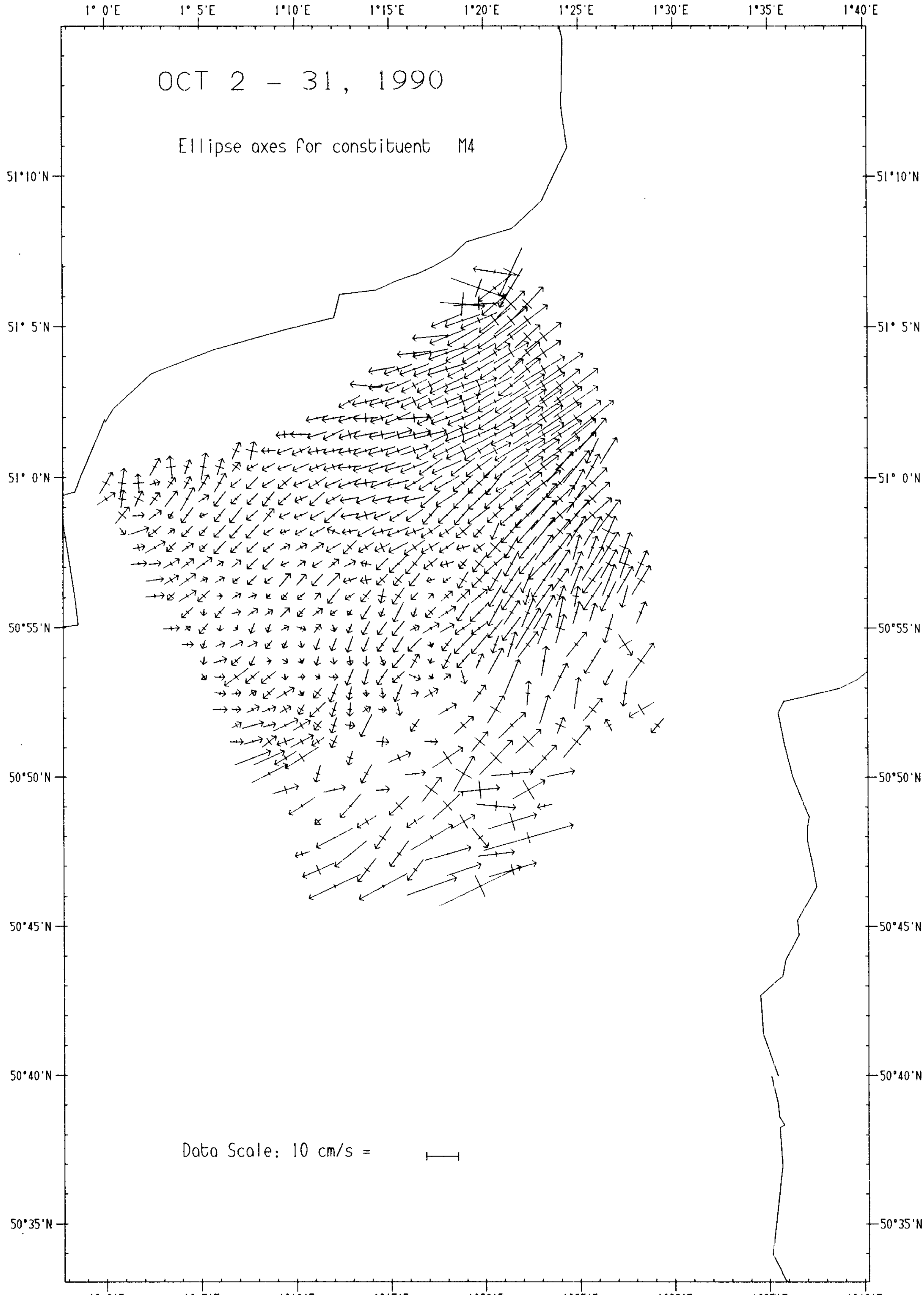
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N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Ellipse axes for constituent M4
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
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1°25'E
1°30'E
1°35'E
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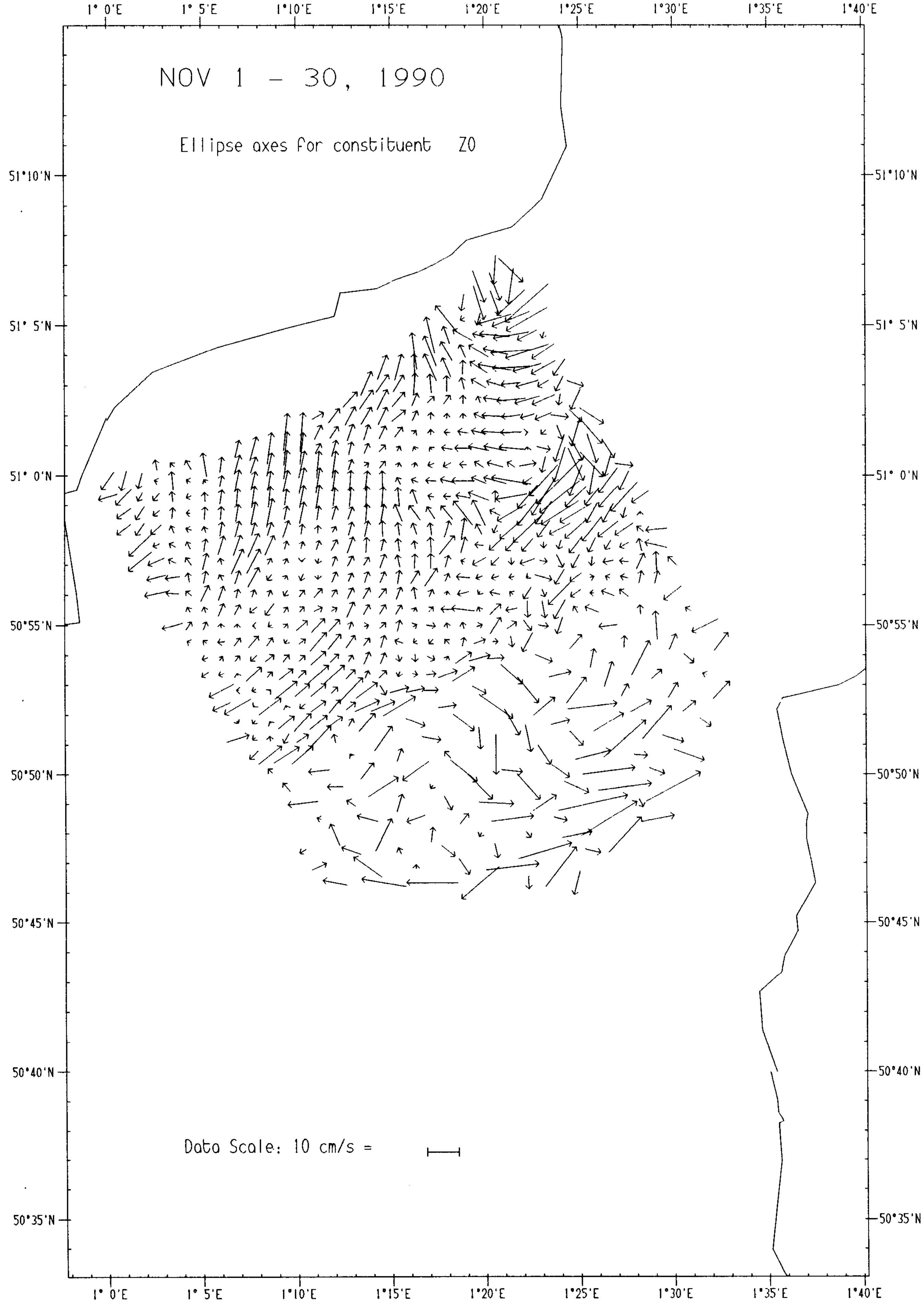
50°40'N
50°35'N



NOV 1 - 30, 1990
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
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1°35'E
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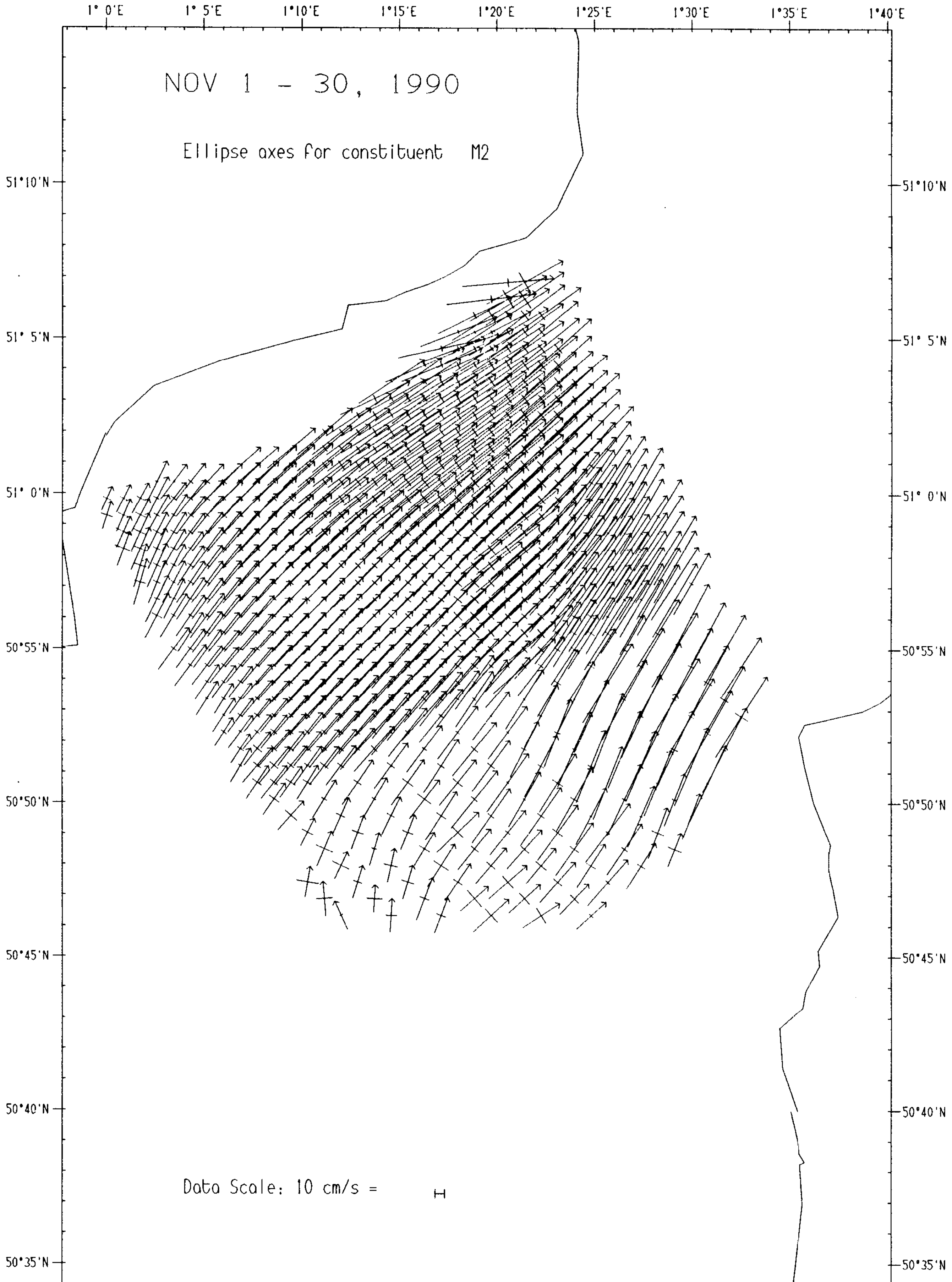
50°40'N
50°35'N



NOV 1 - 30, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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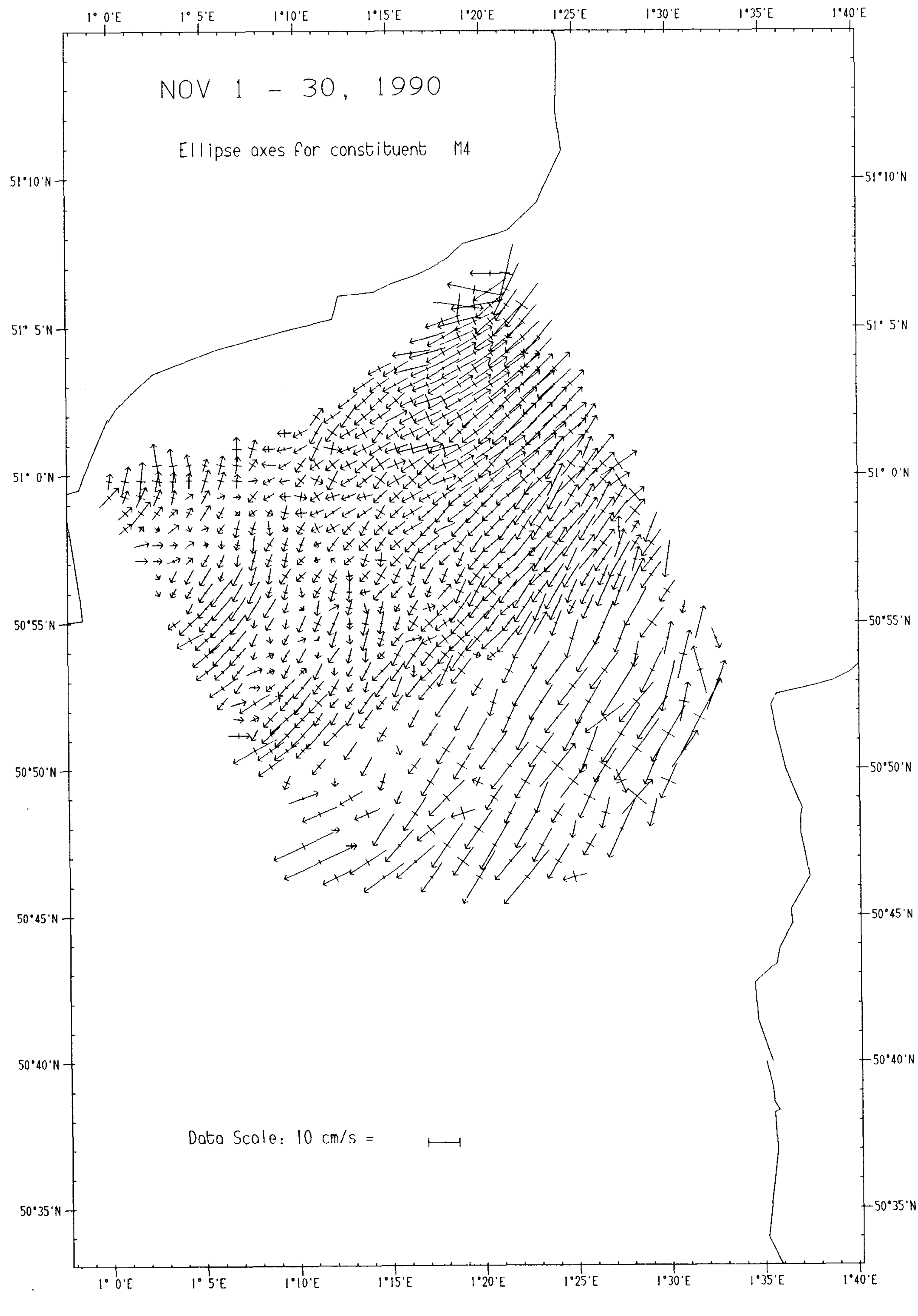
50°40'N
50°35'N



NOV 1 - 30, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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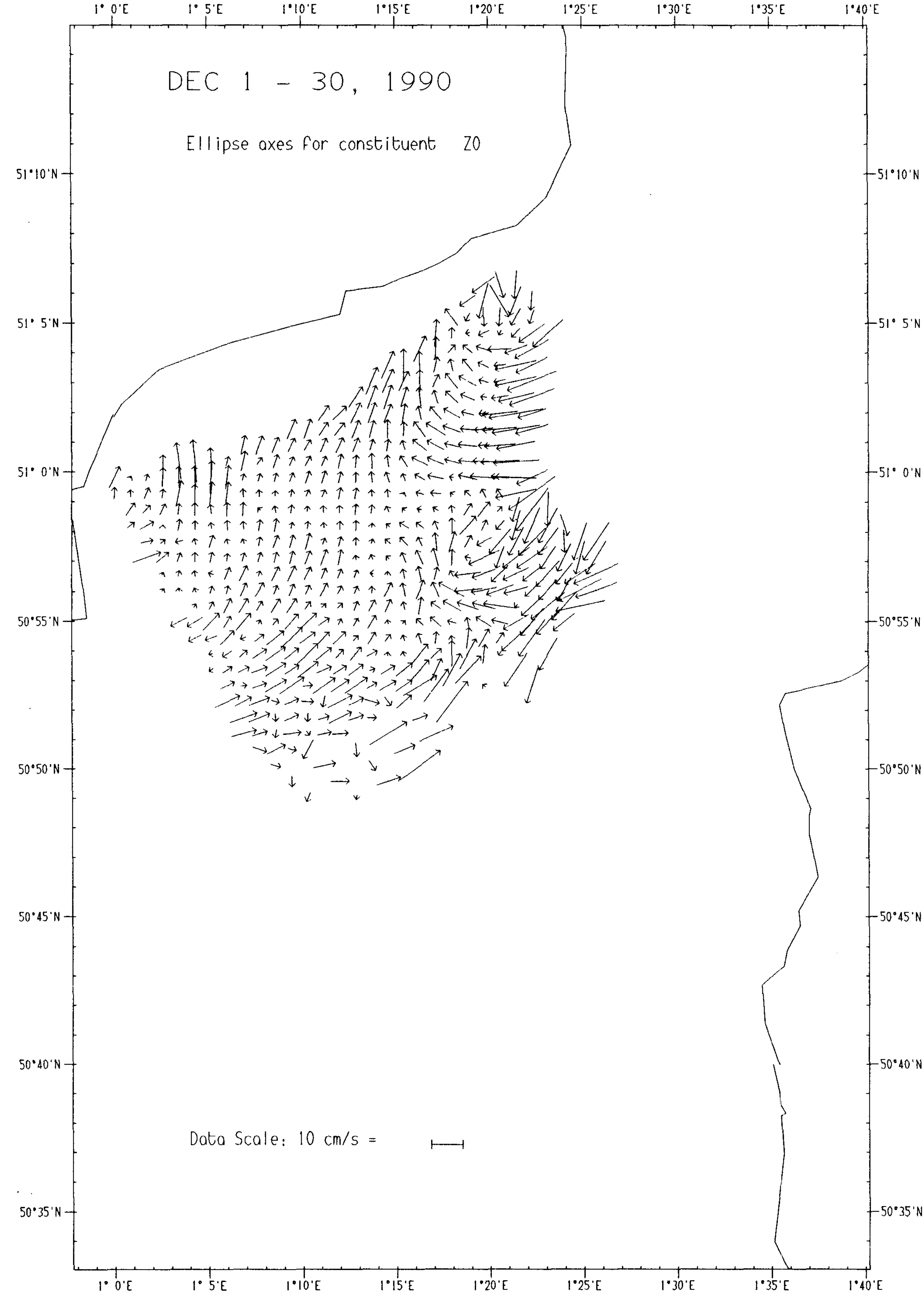
50°40'N
50°35'N



DEC 1 - 30, 1990
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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51° 5'N
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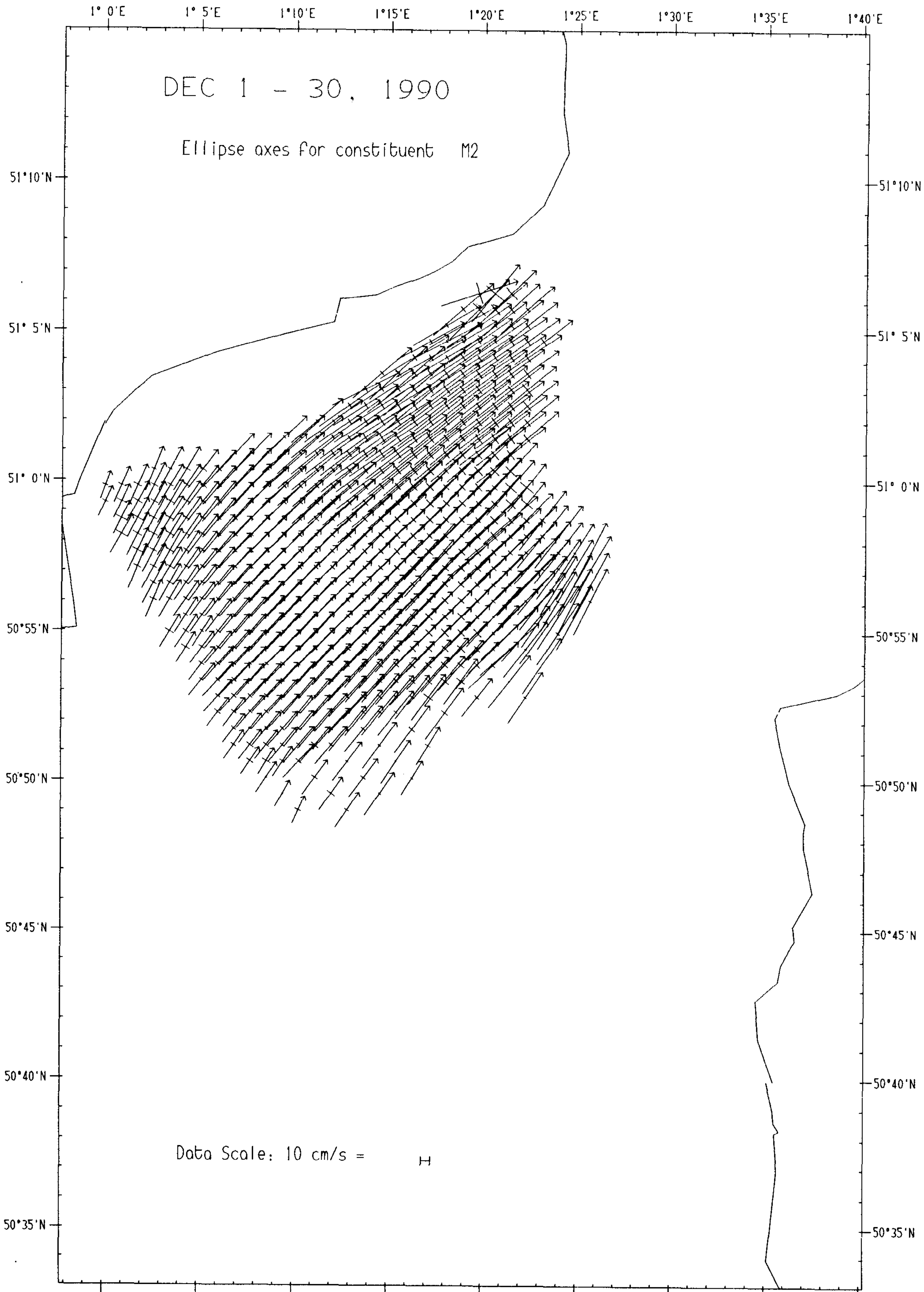
50°40'N
50°35'N


DEC 1 - 30, 1990
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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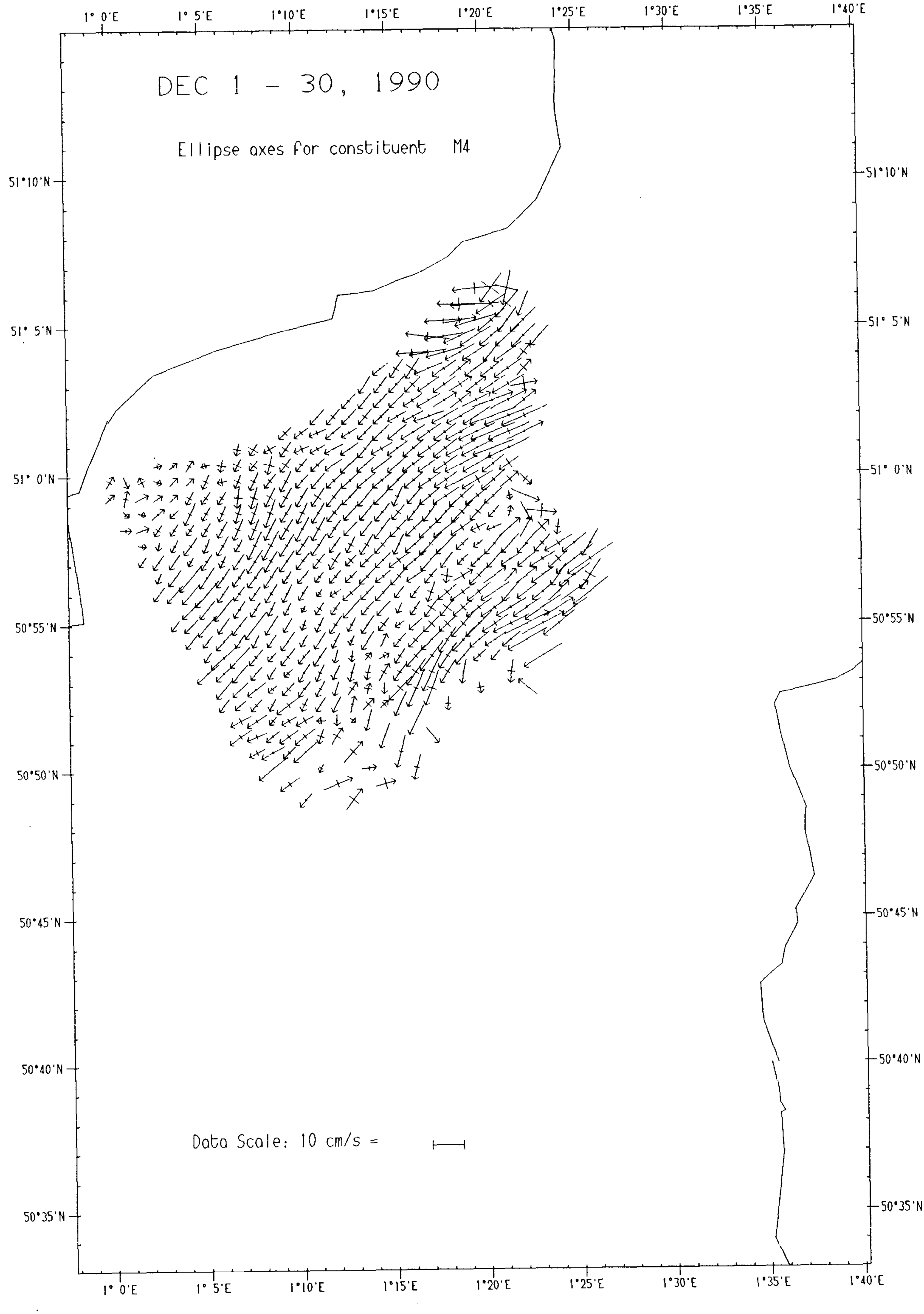
50°40'N
50°35'N


DEC 1 - 30, 1990
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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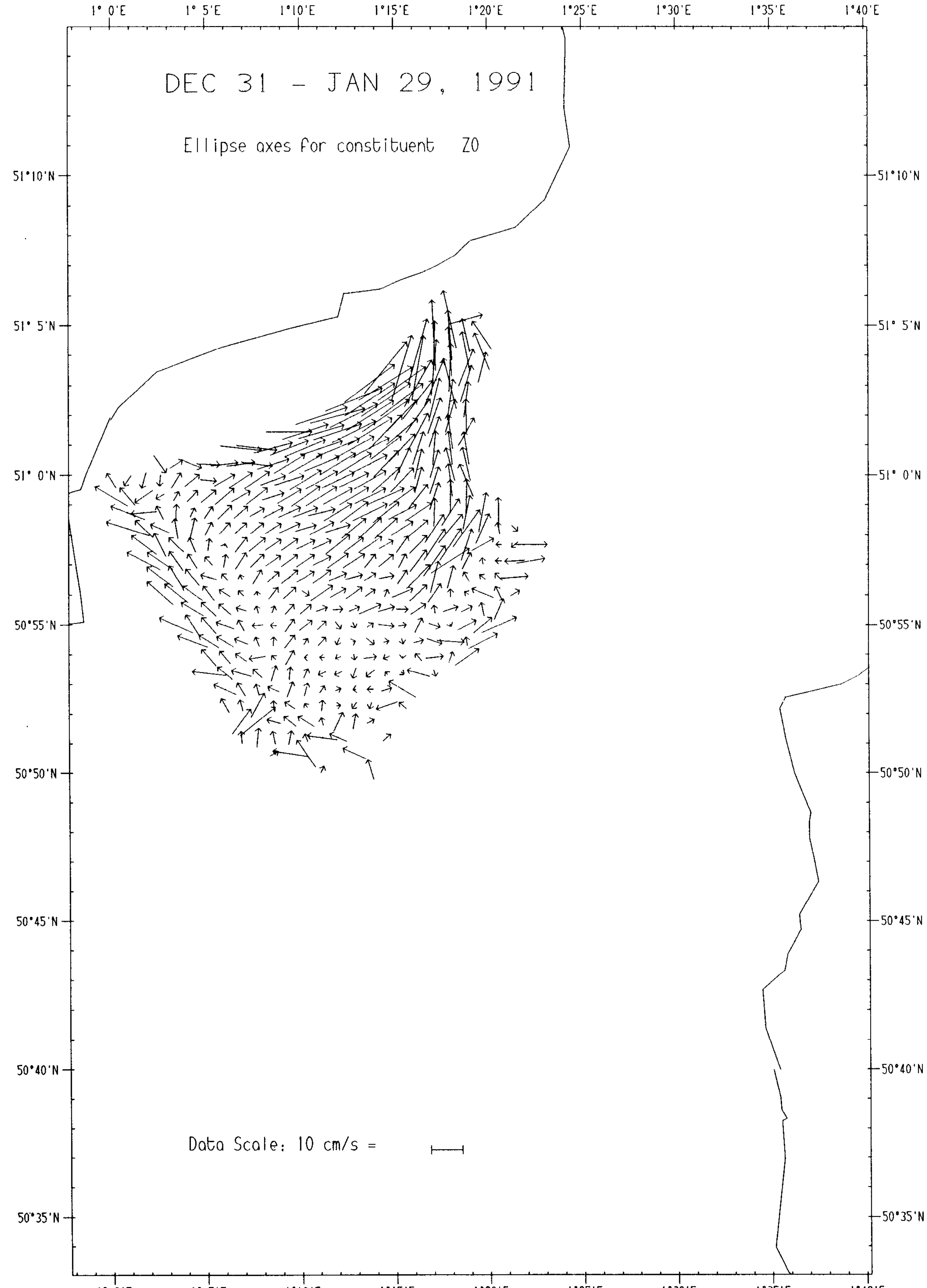
50°45'N
50°40'N
50°35'N


DEC 31 - JAN 29, 1991
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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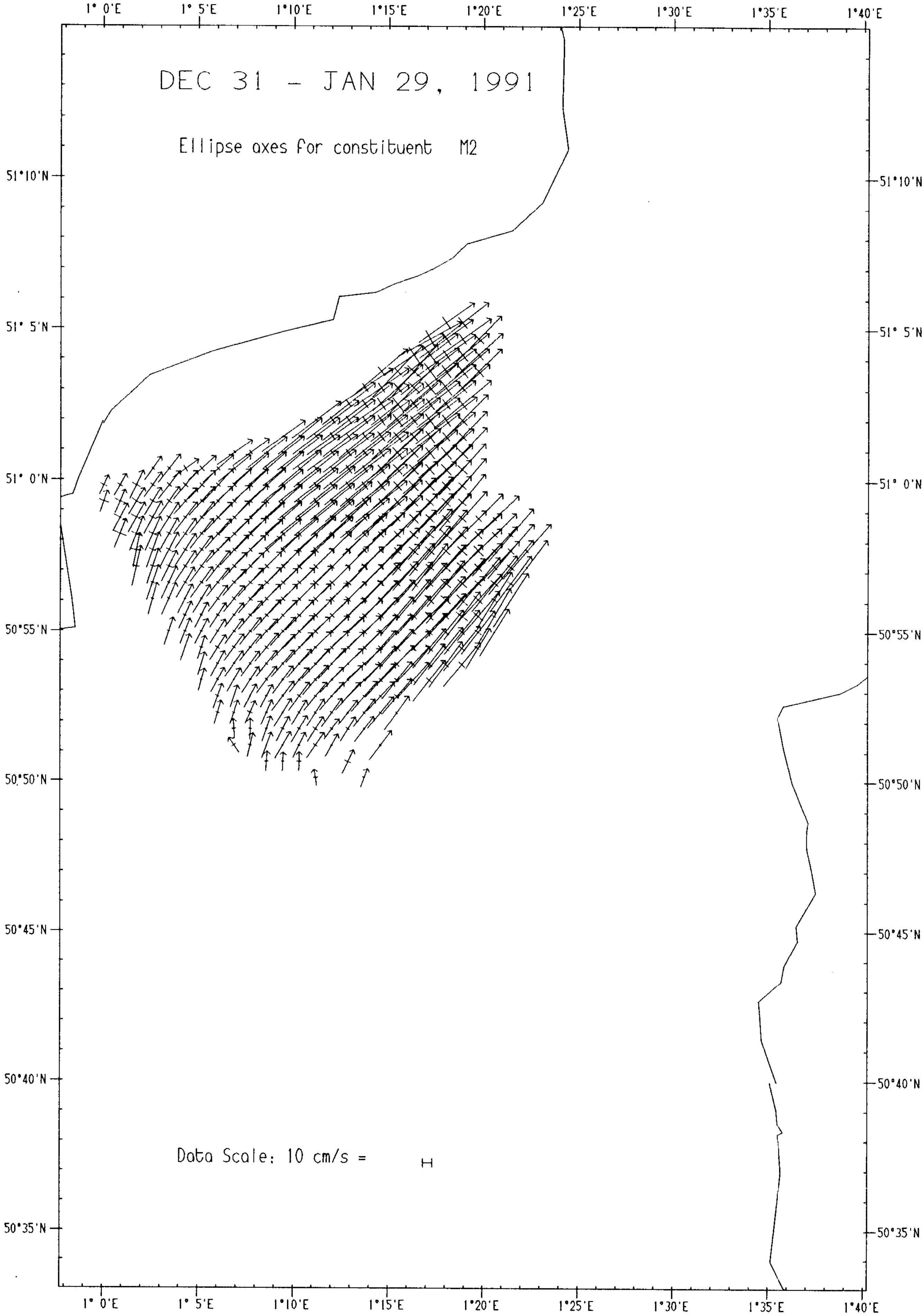
50°40'N
50°35'N



DEC 31 - JAN 29, 1991
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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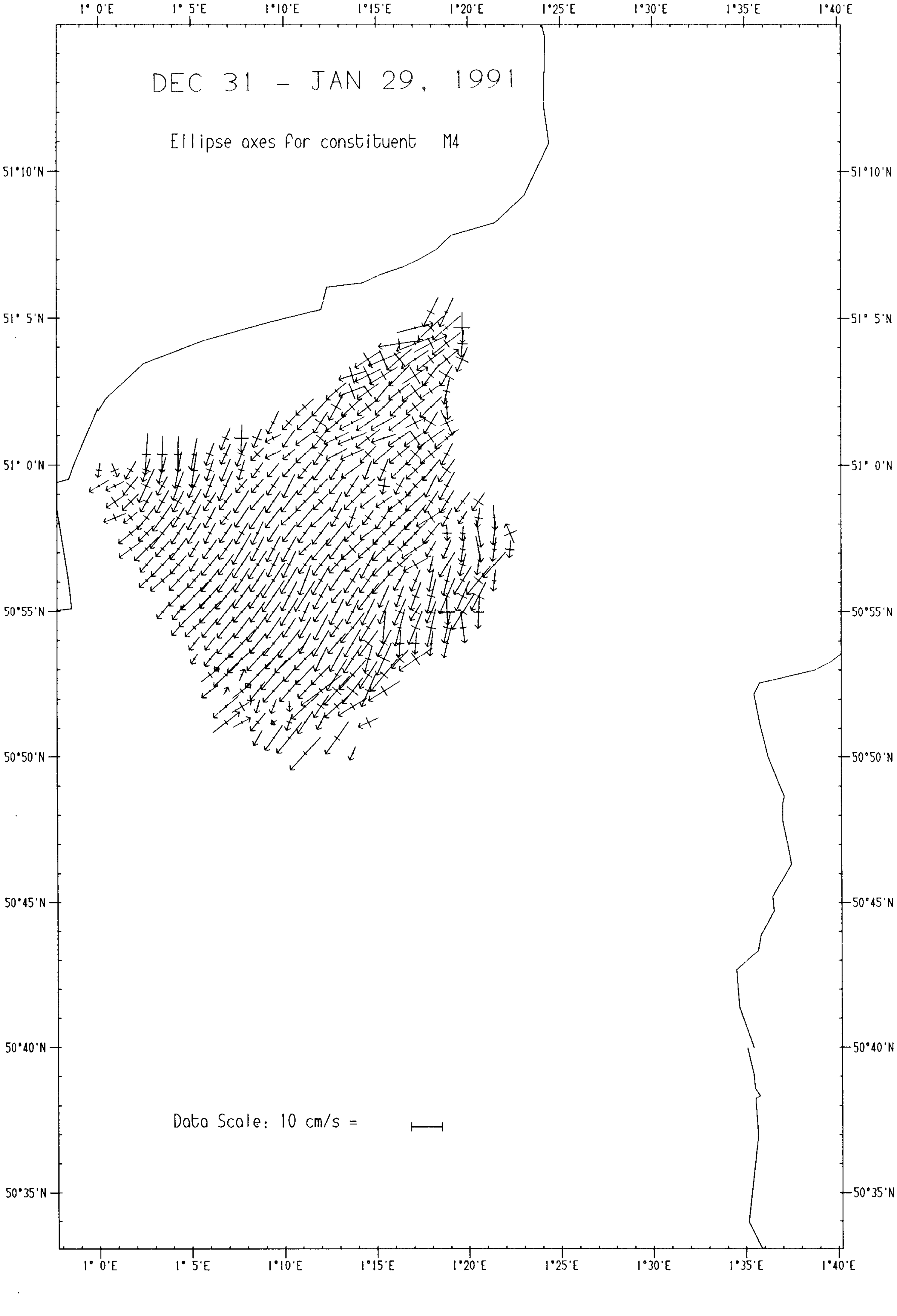
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



DEC 31 - JAN 29, 1991
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
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1°25'E
1°30'E
1°35'E
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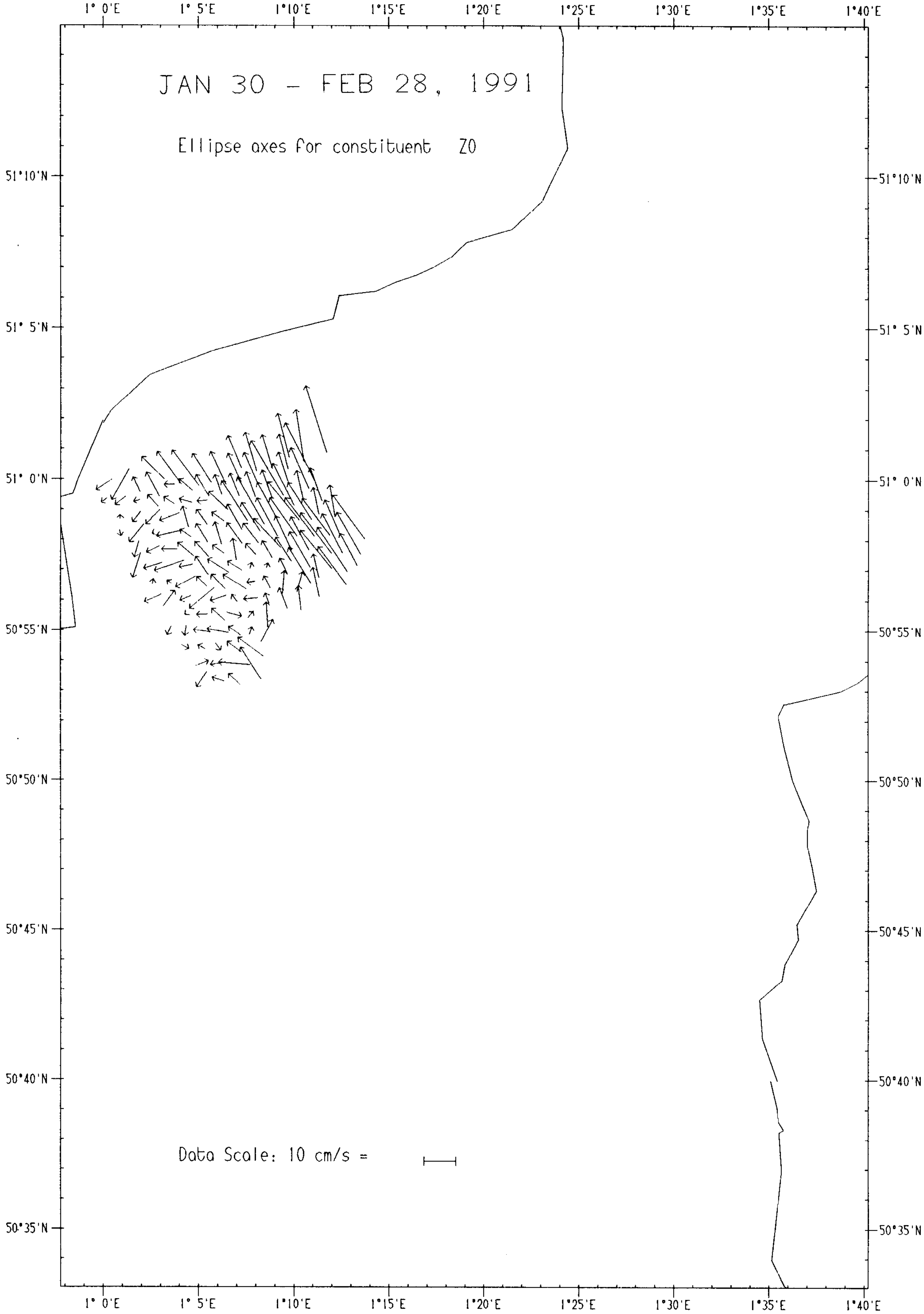
50°40'N
50°35'N



JAN 30 - FEB 28, 1991
Ellipse axes for constituent Z0
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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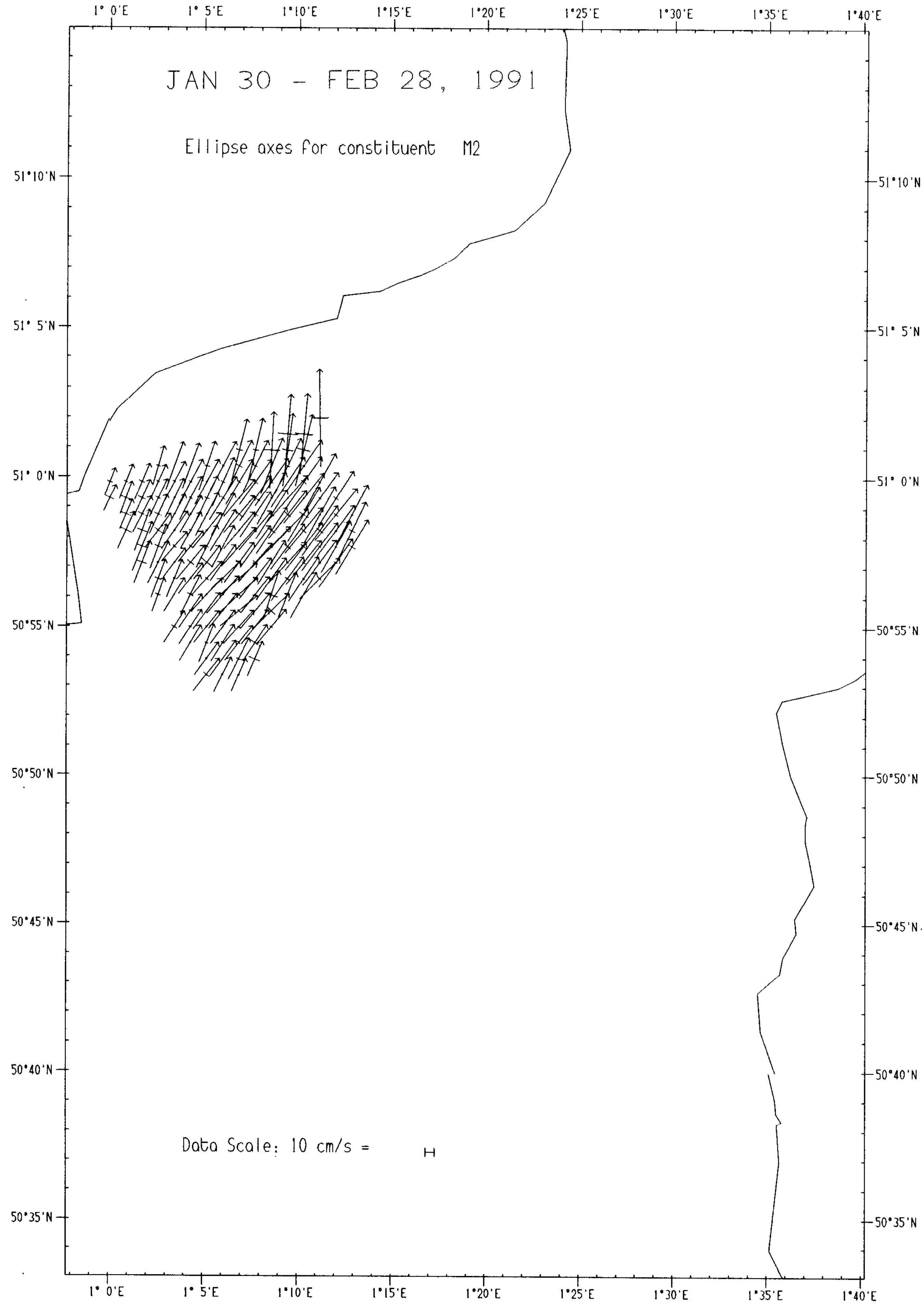
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


JAN 30 - FEB 28, 1991
Ellipse axes for constituent M2
Data Scale: 10 cm/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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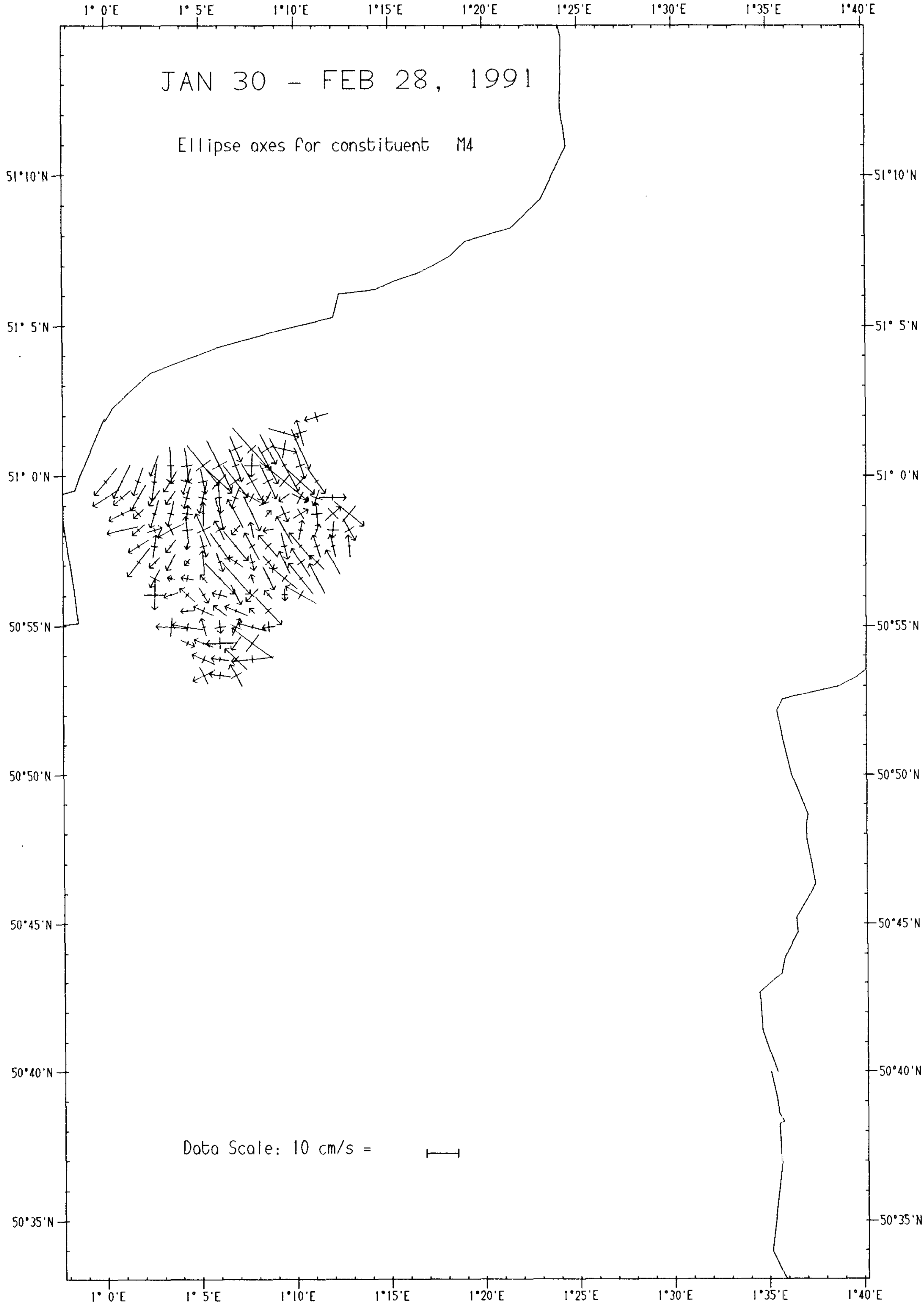
50°40'N
50°35'N



JAN 30 - FEB 28, 1991
Ellipse axes for constituent M4
Data Scale: 10 cm/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N

Appendix E. Wind analysis results

Where correlation between wind and residual currents was less than 5% the cell has not been plotted.

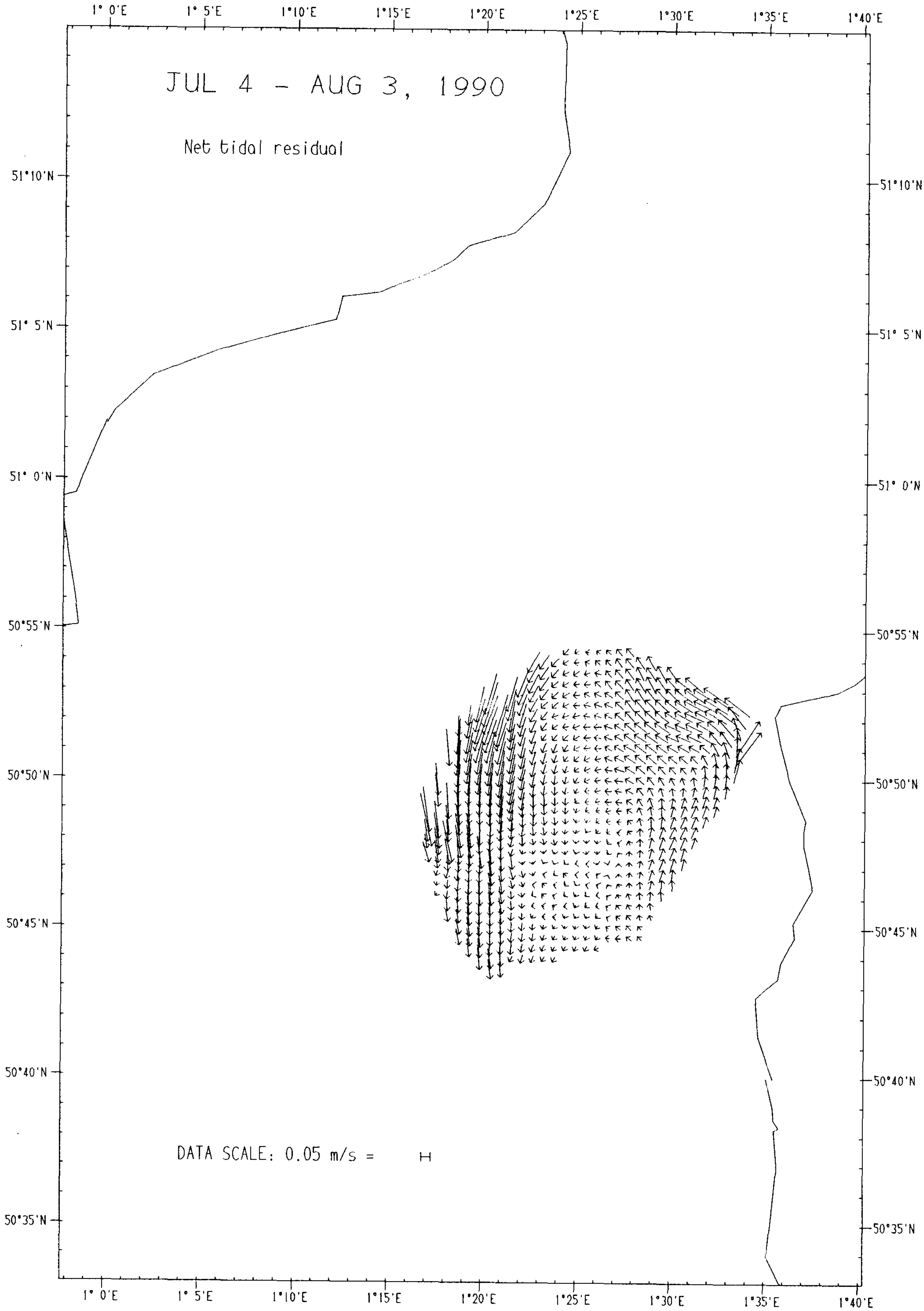
Net tidal residual is the remaining residual current after the wind effect has been removed.

Wind current is that part of the residual current due to the effects of the wind during the same period. The amplitude response and veer between the wind and the tidal residual current is illustrated for a 1 m/s wind from the west, for each deployment.

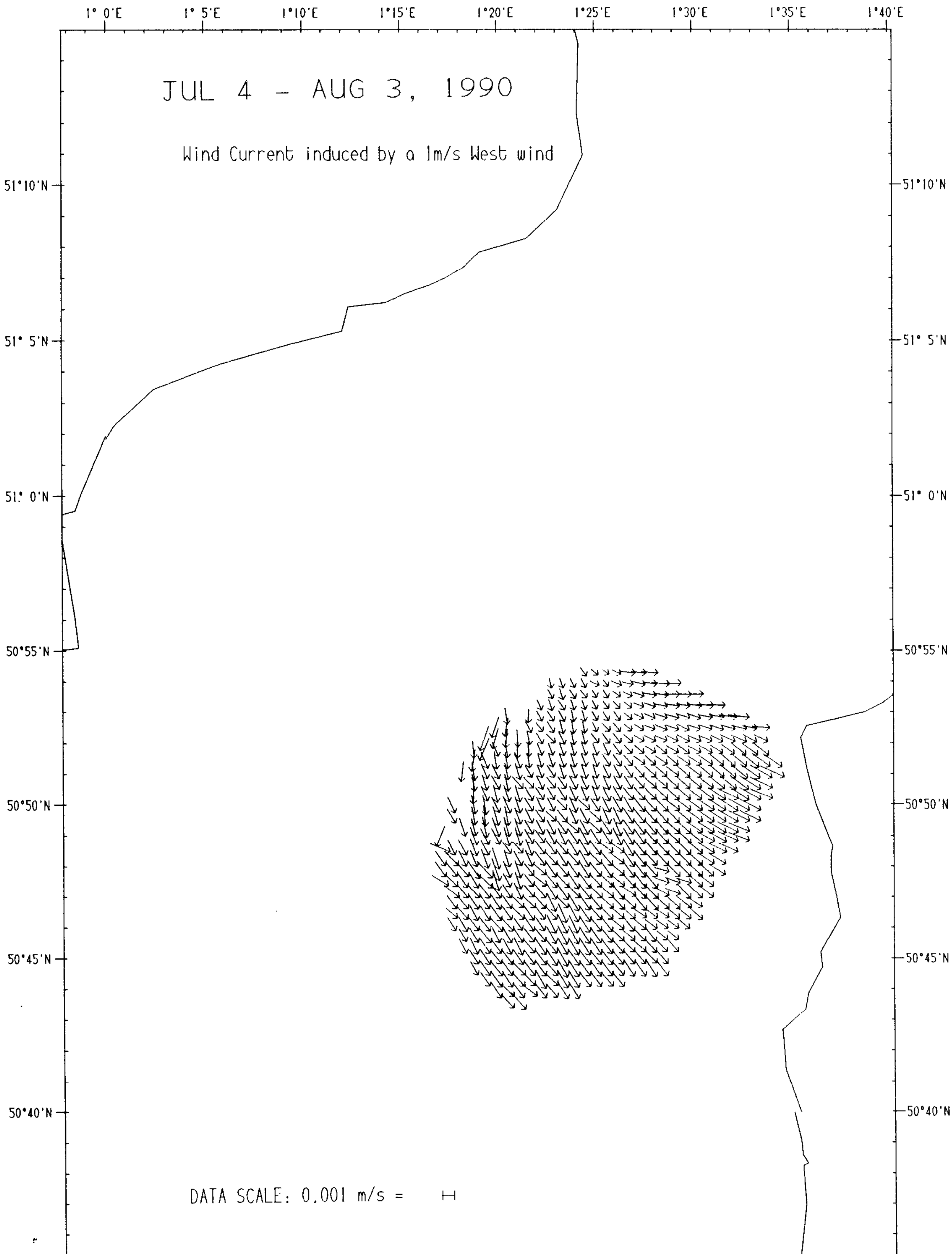
The response was calculated by least squares fitting

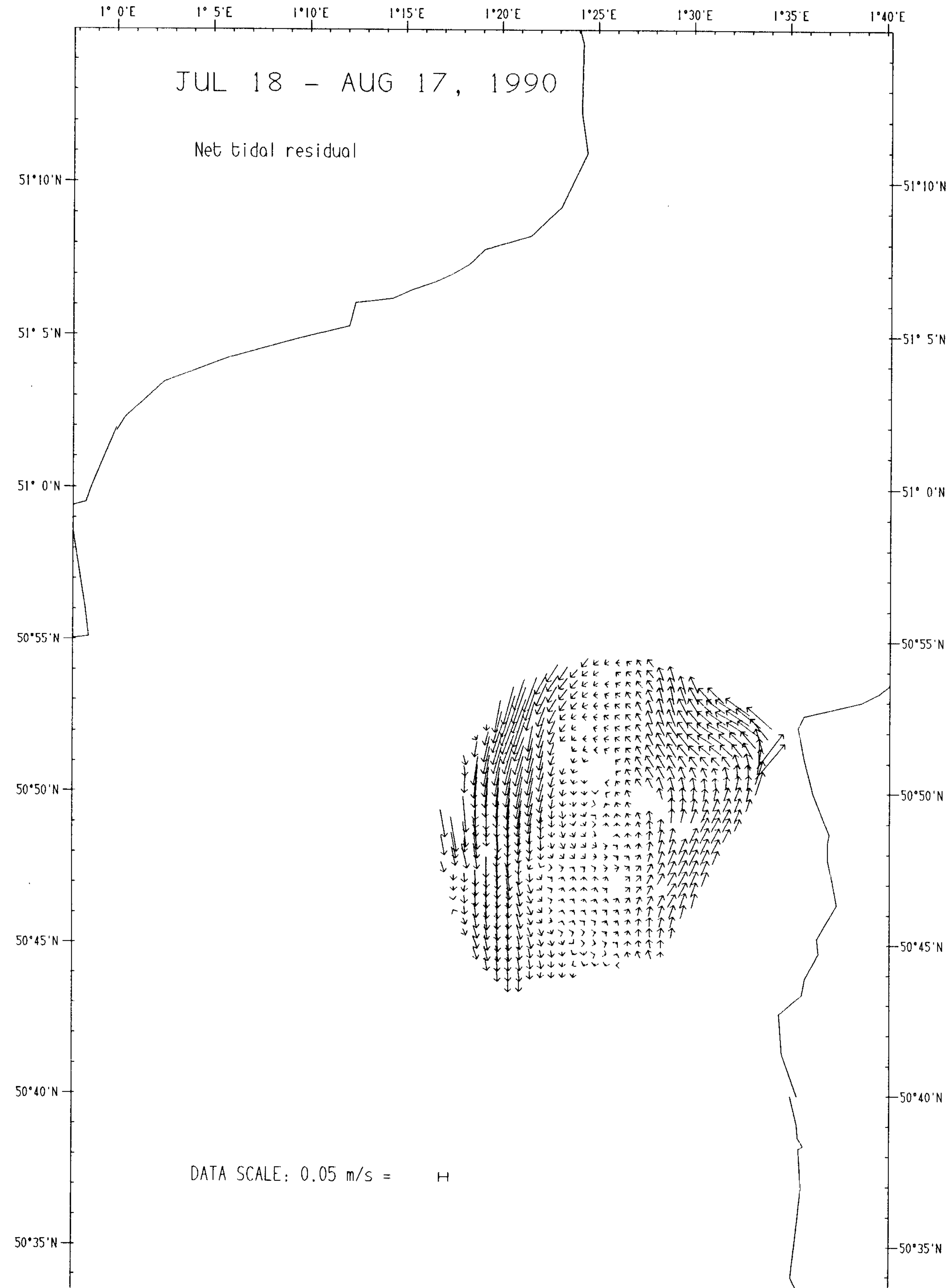
$$R(t) = \overline{R} + \alpha W(t-\Delta t)$$

where R is the tidal residual current, W is the wind and $\alpha$ the response. R, $\overline{R}$, $\alpha$ and W are complex. The lag $\Delta t$ which gave the best correlation varied between 0 and 100 minutes (in multiples of 20 minutes). The net tidal residual, $\overline{R}$ is driven by non-linear tidal and density forcing (Prandle,D. & Mathews,J. 1990).



JUL 4 - AUG 3, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


JUL 4 - AUG 3, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



JUL 18 - AUG 17, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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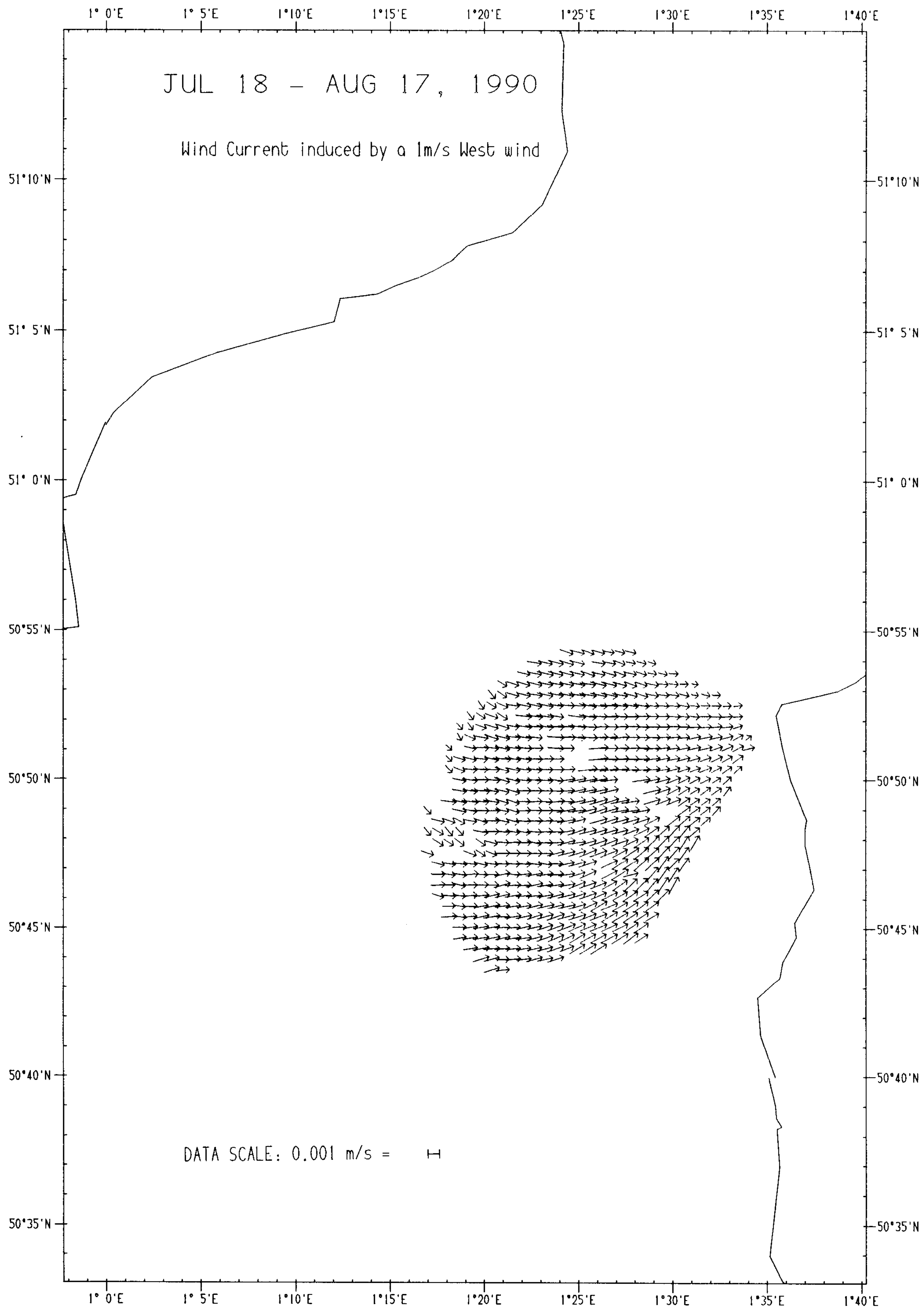
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


JUL 18 - AUG 17, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
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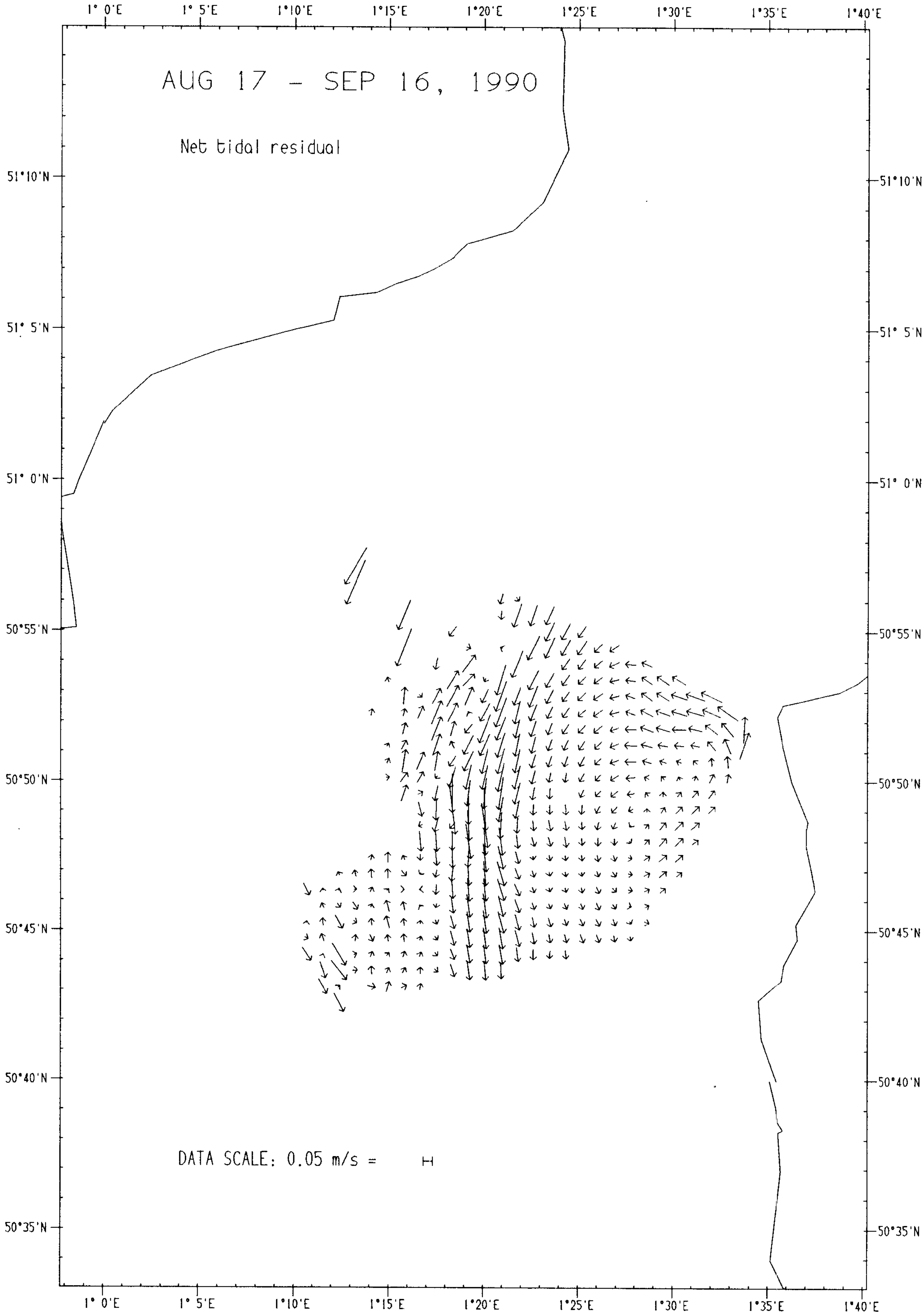
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



AUG 17 - SEP 16, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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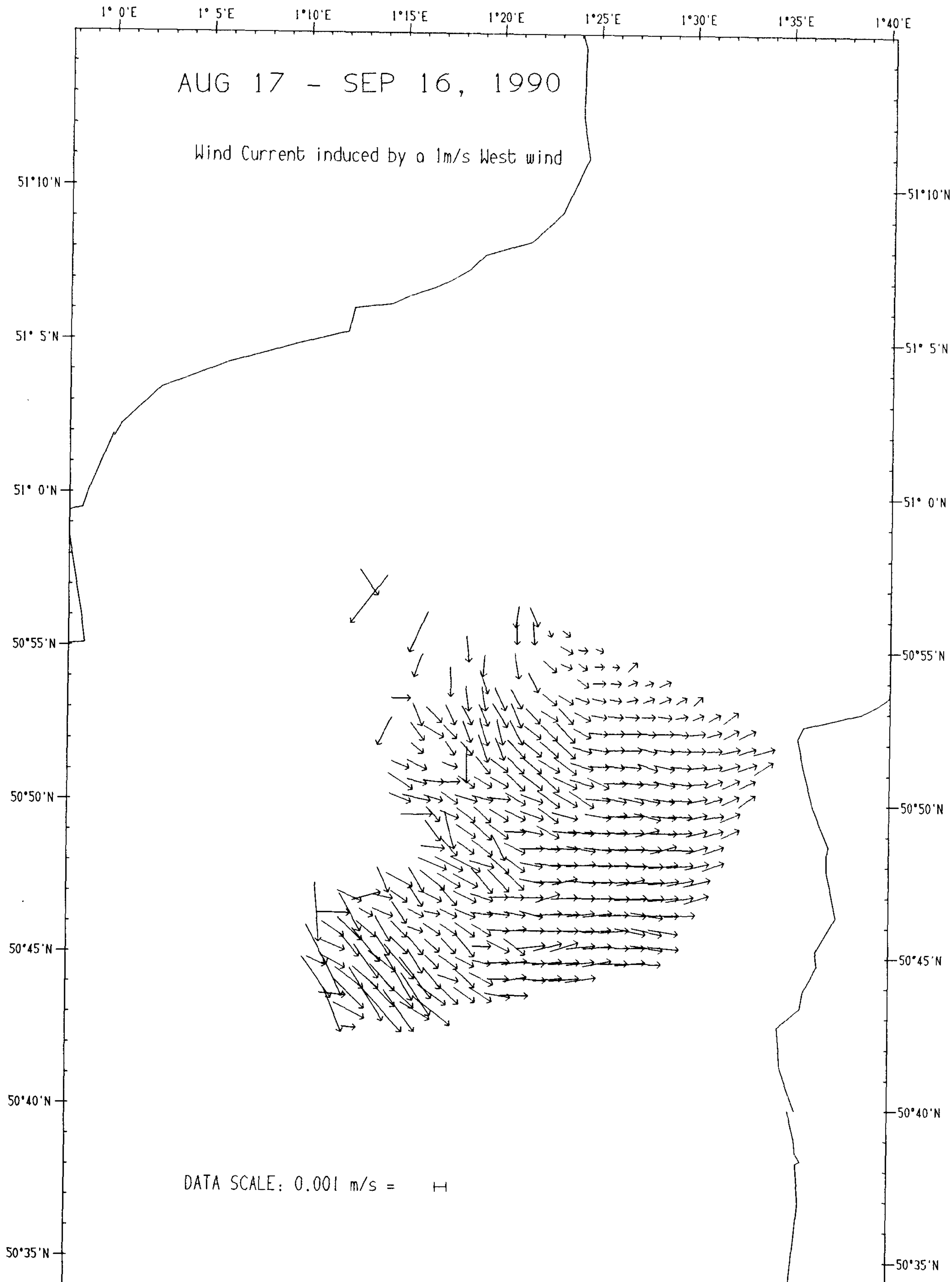
50°40'N
50°35'N



AUG 17 - SEP 16, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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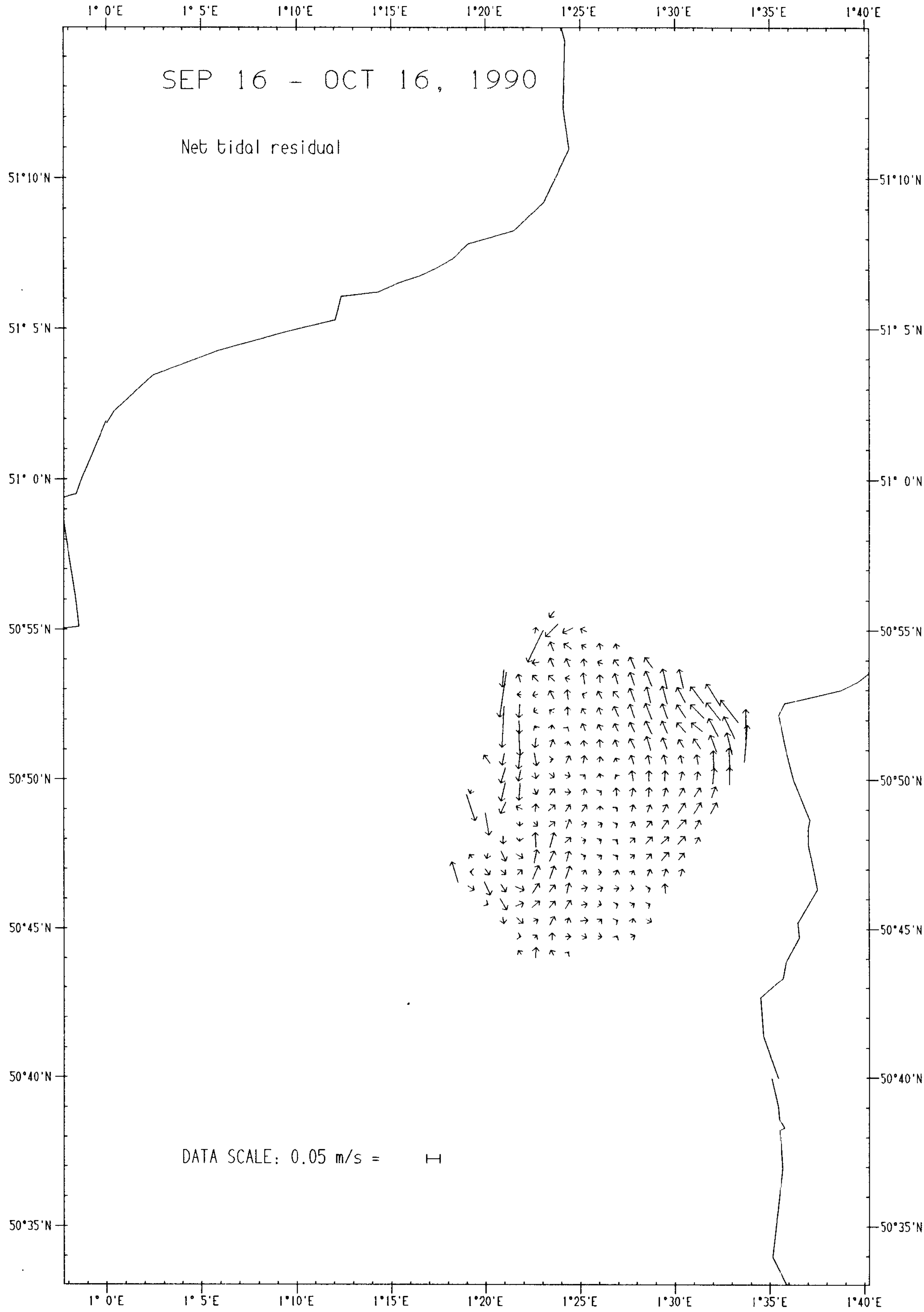
50°40'N
50°35'N


SEP 16 - OCT 16, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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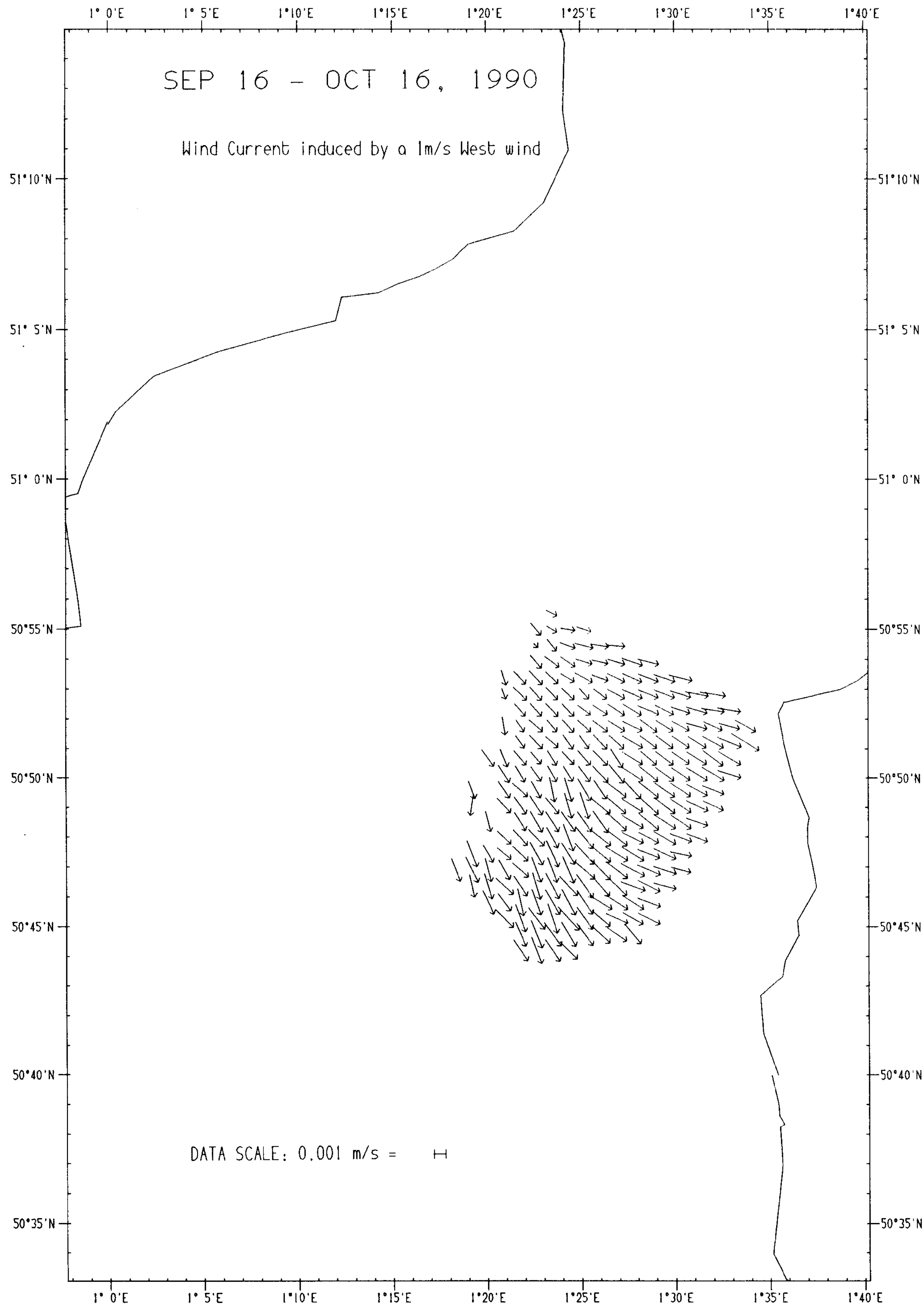
50°40'N
50°35'N



SEP 16 - OCT 16, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
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1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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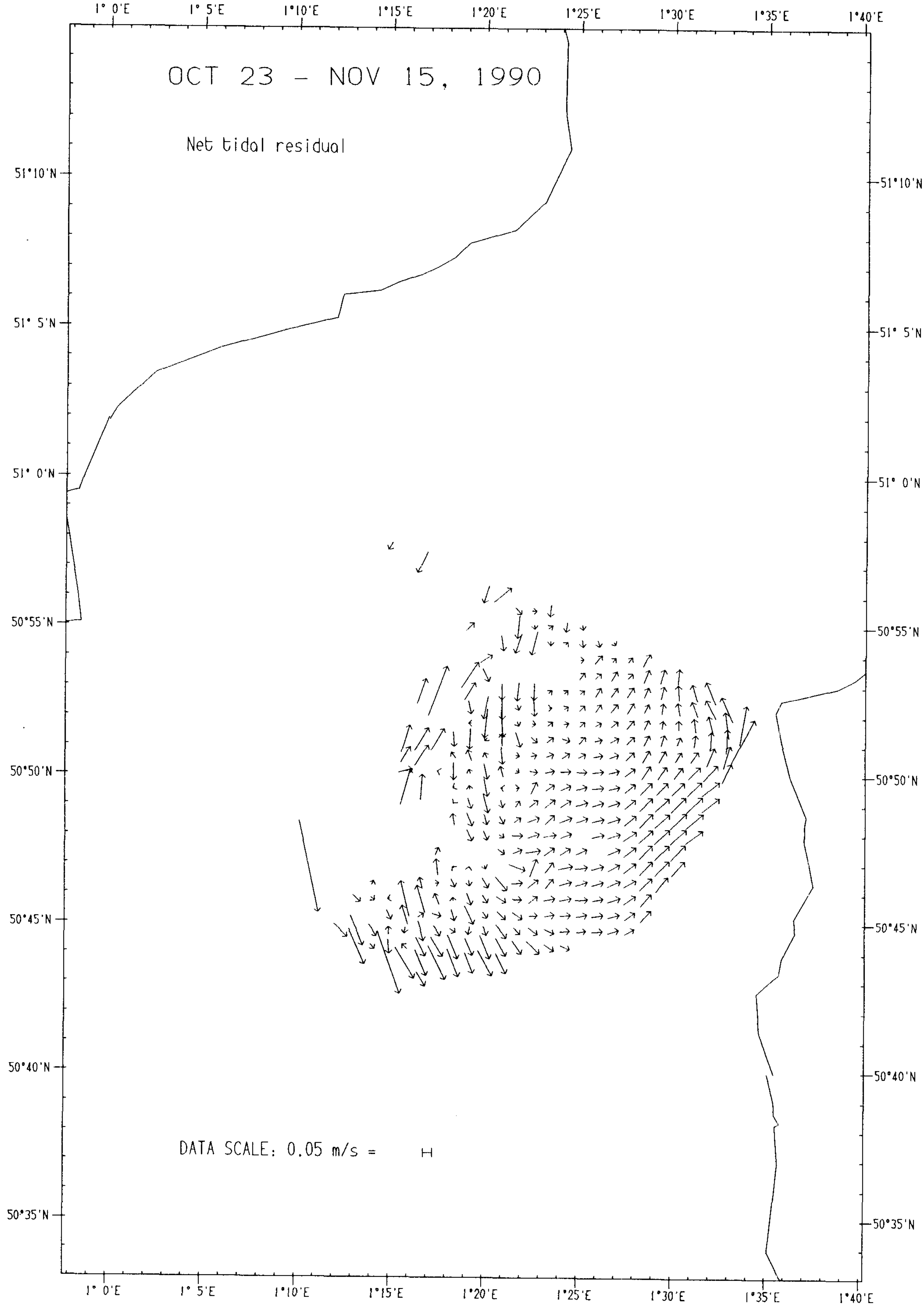
50°35'N


OCT 23 - NOV 15, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
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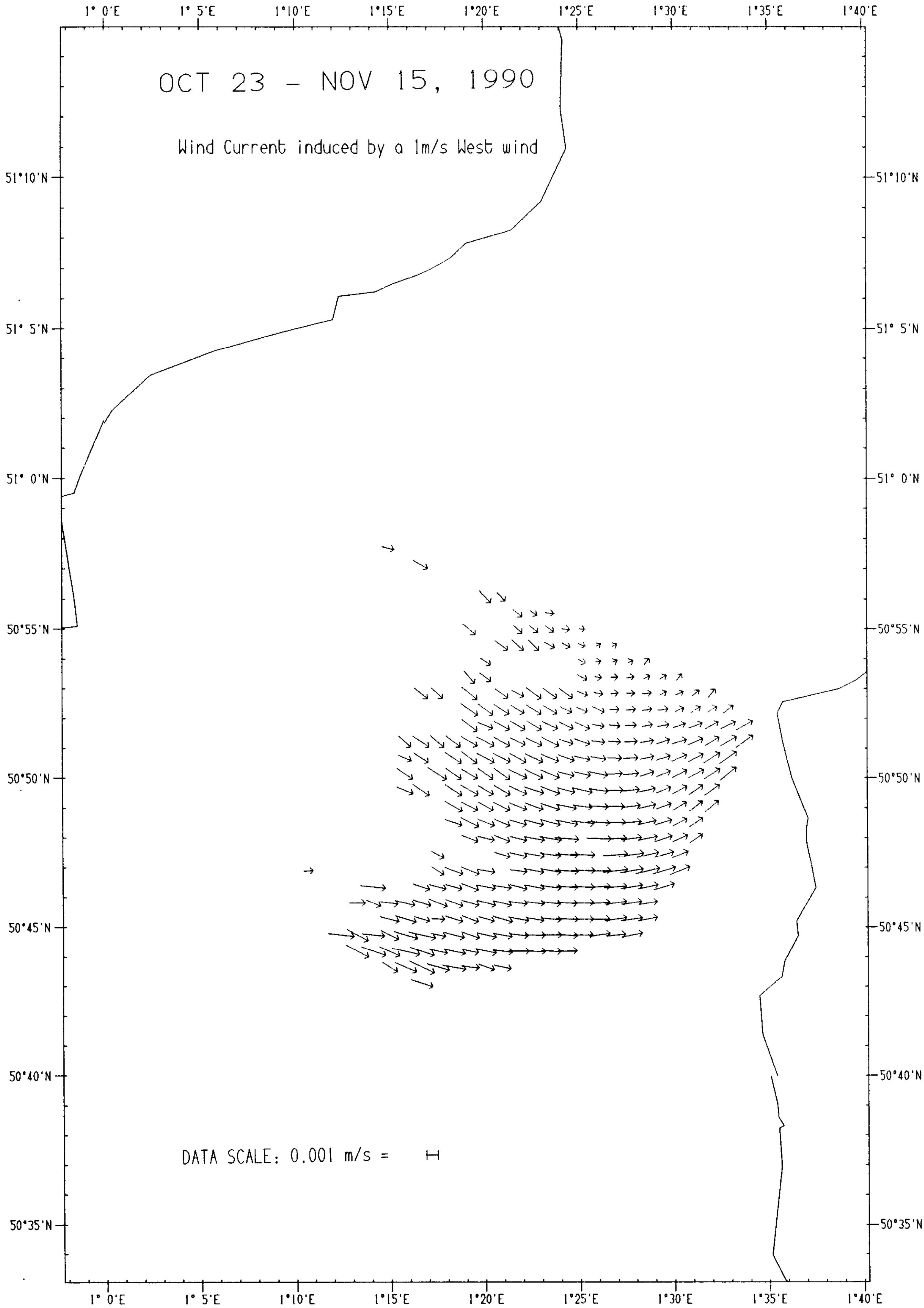
50°40'N
50°35'N



OCT 23 - NOV 15, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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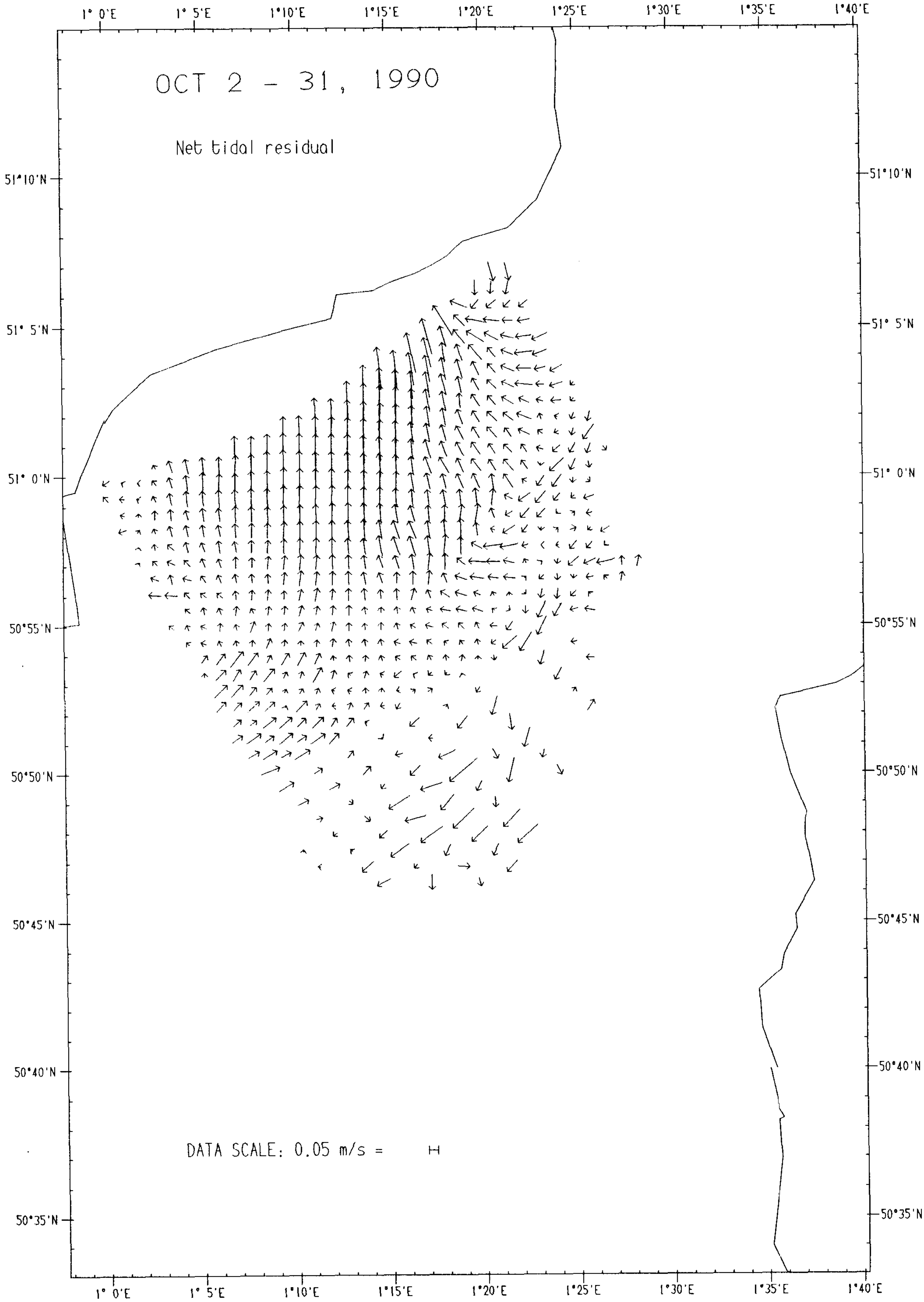
50°40'N
50°35'N



OCT 2 - 31, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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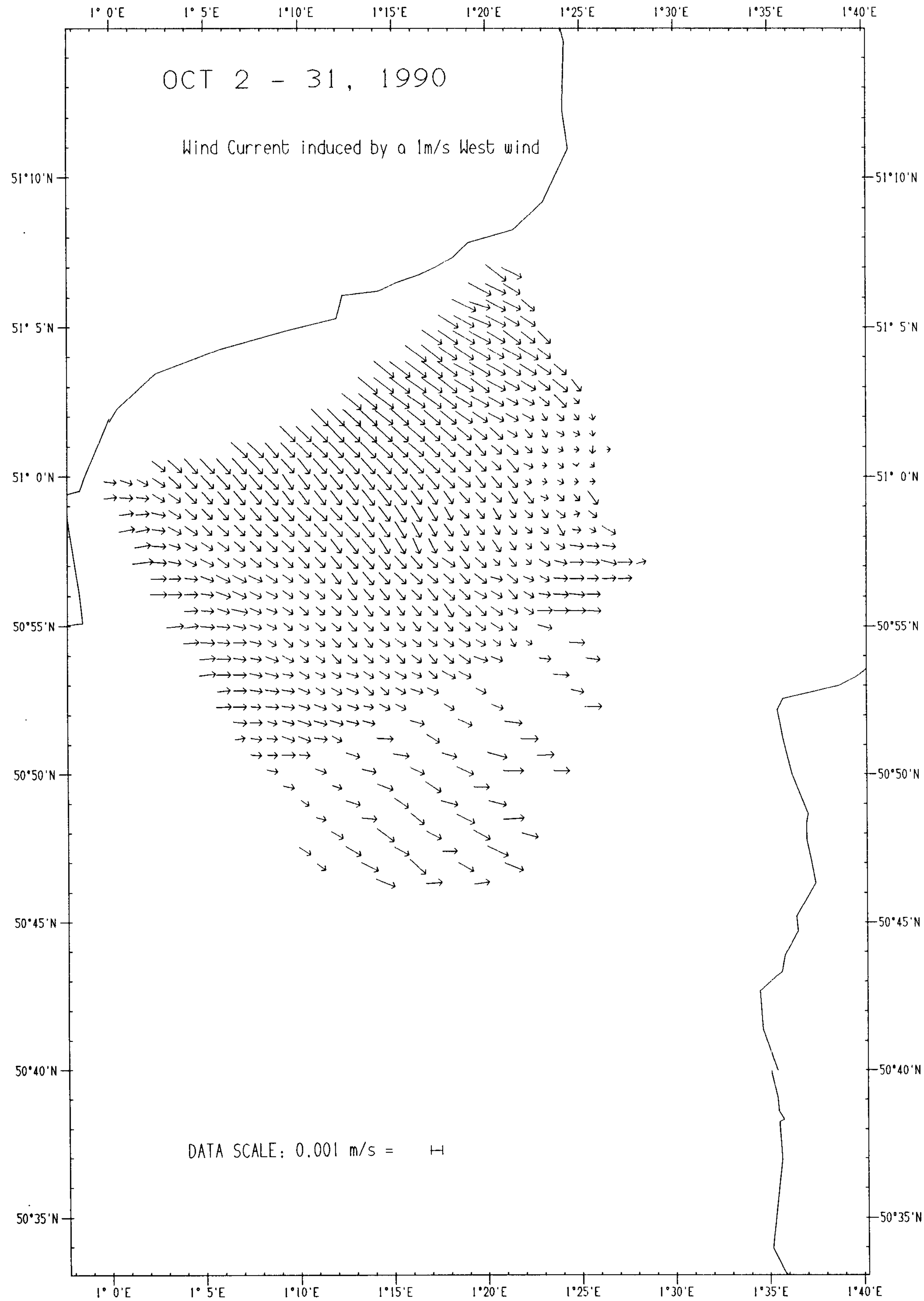
OCT 2 - 31, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
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1°30'E
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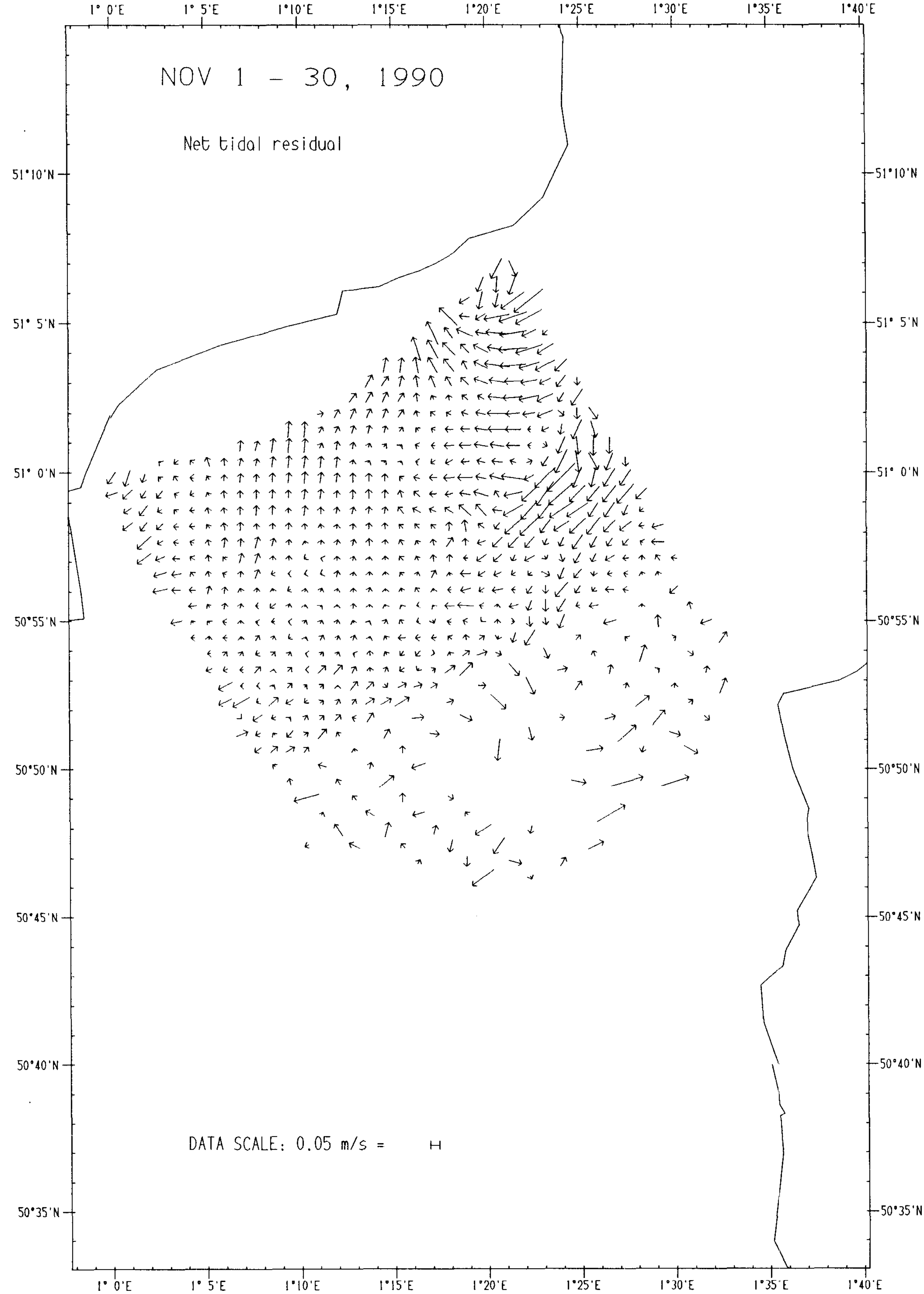
NOV 1 - 30, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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1° 5'E
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1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
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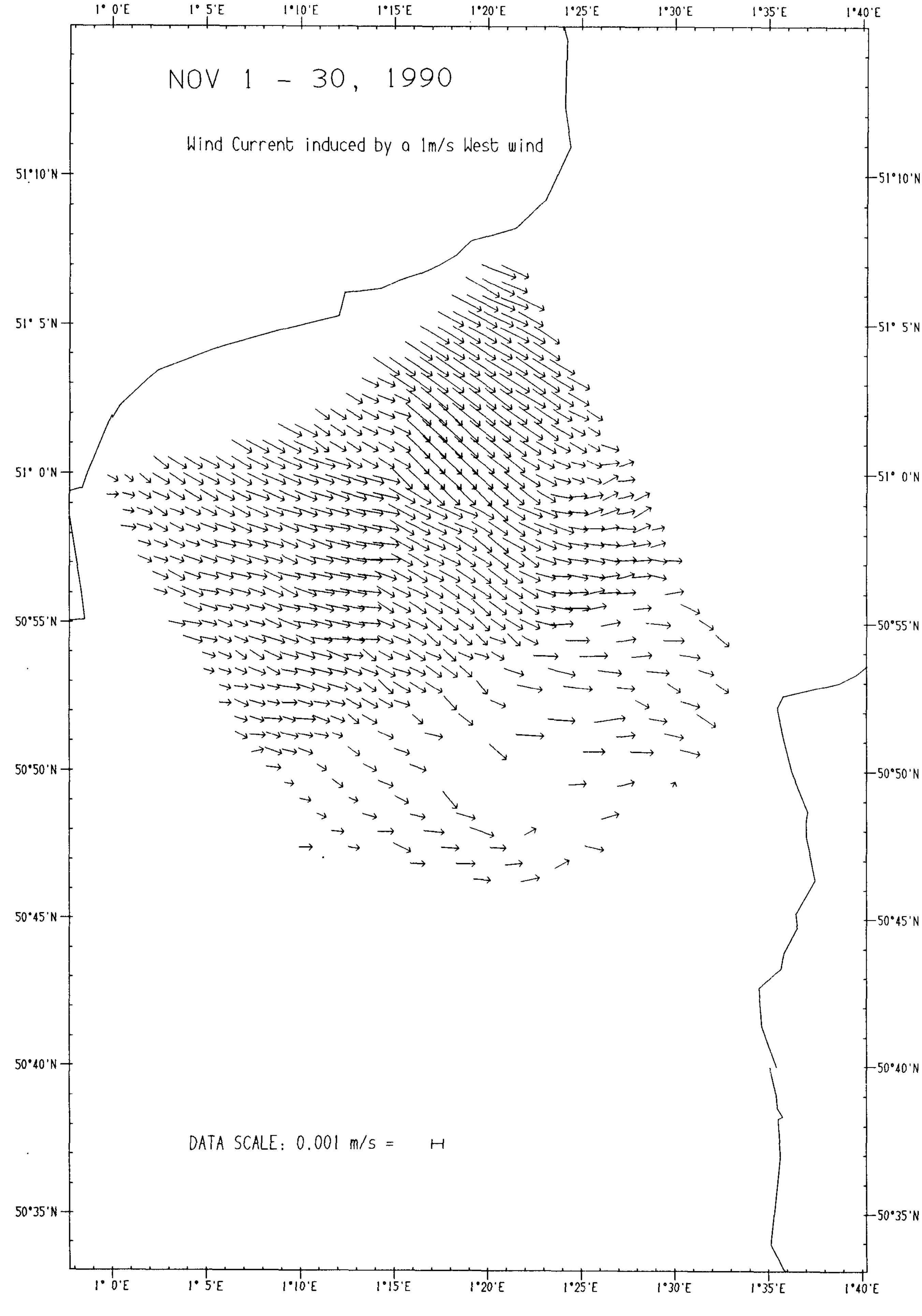

NOV 1 - 30, 1990
Wind Current induced by a 1m/s West wind
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1°40'E
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51° 5'N
51° 0'N
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50°50'N
50°45'N
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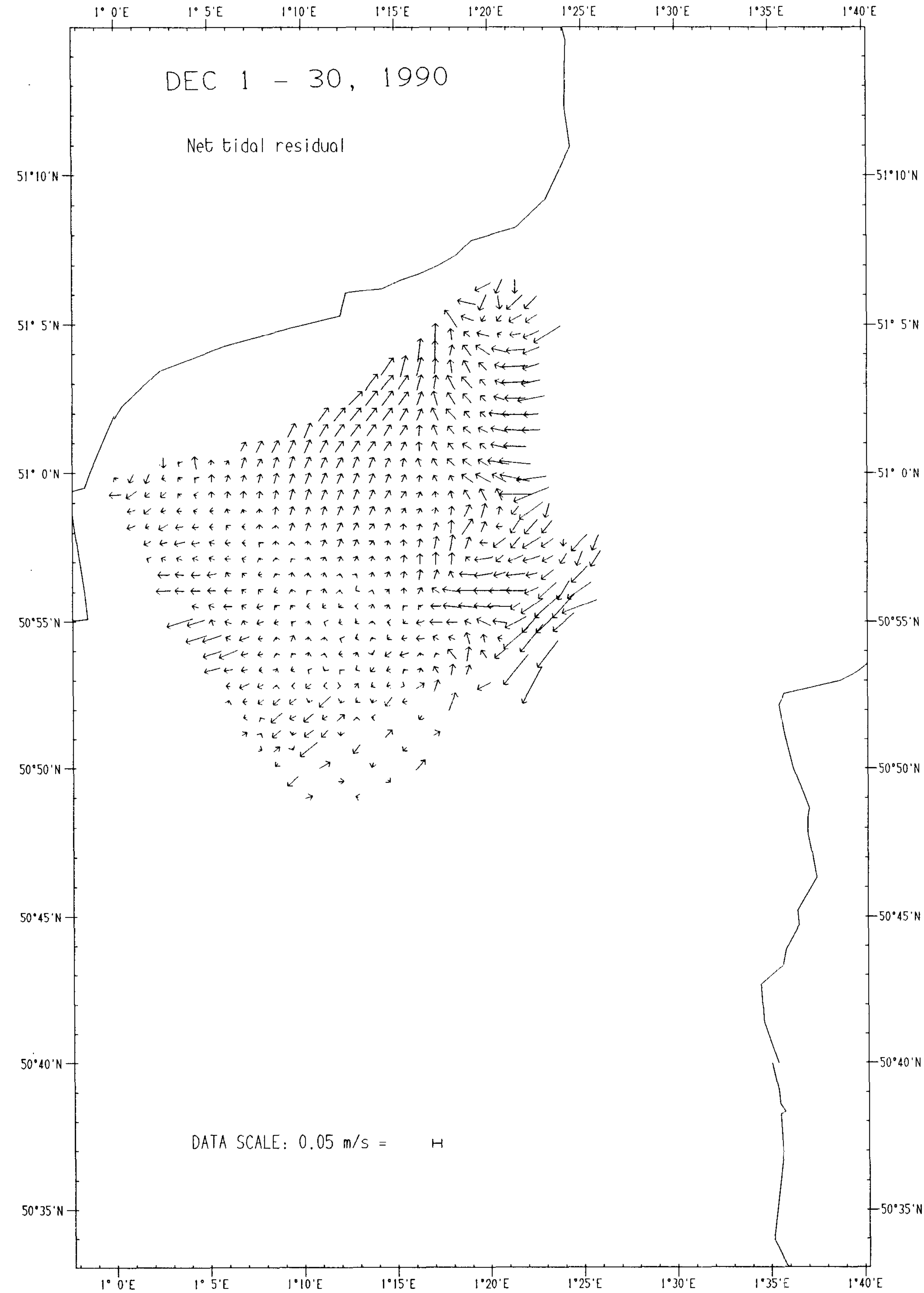

DEC 1 - 30, 1990
Net tidal residual
DATA SCALE: 0.05 m/s =
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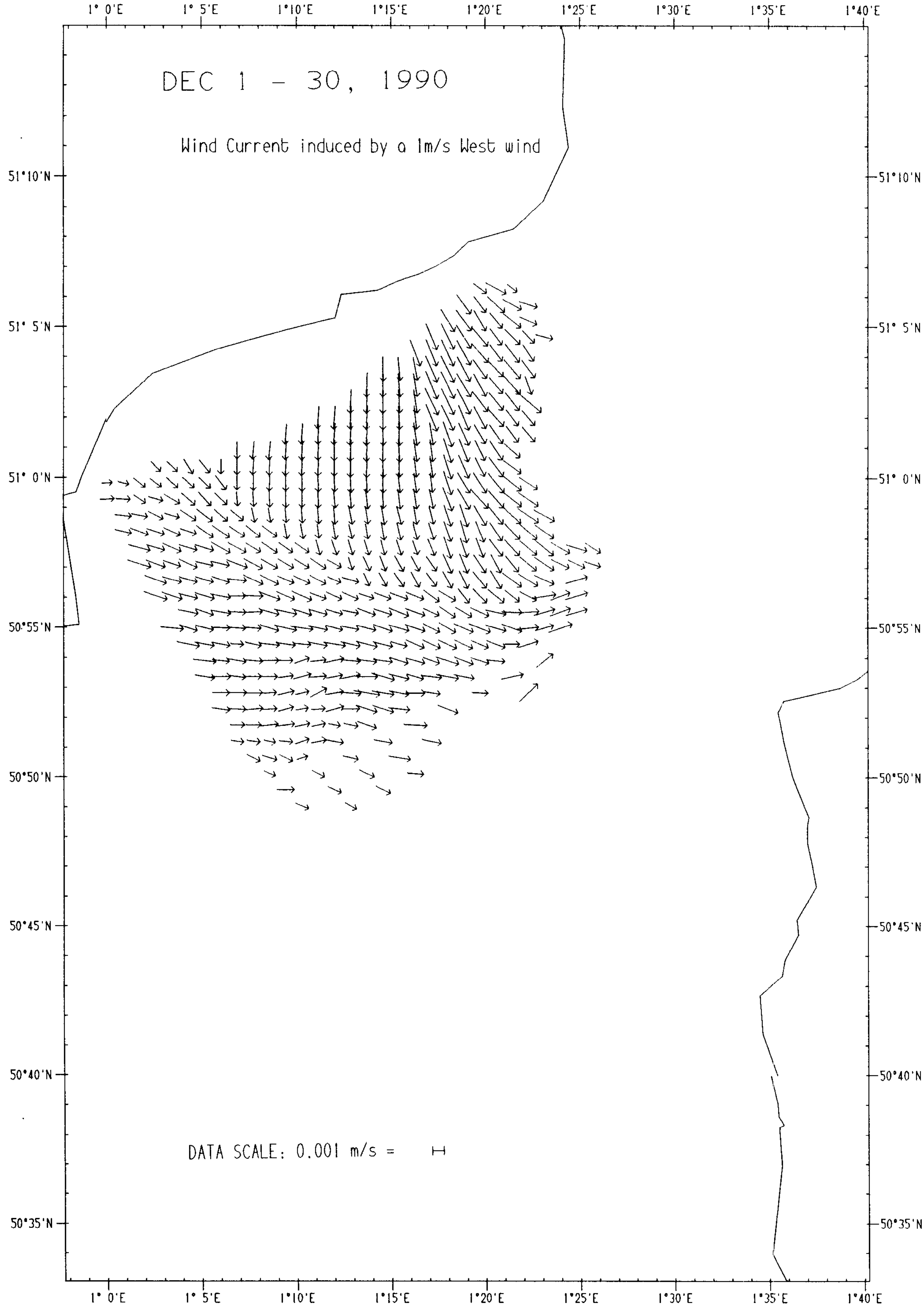
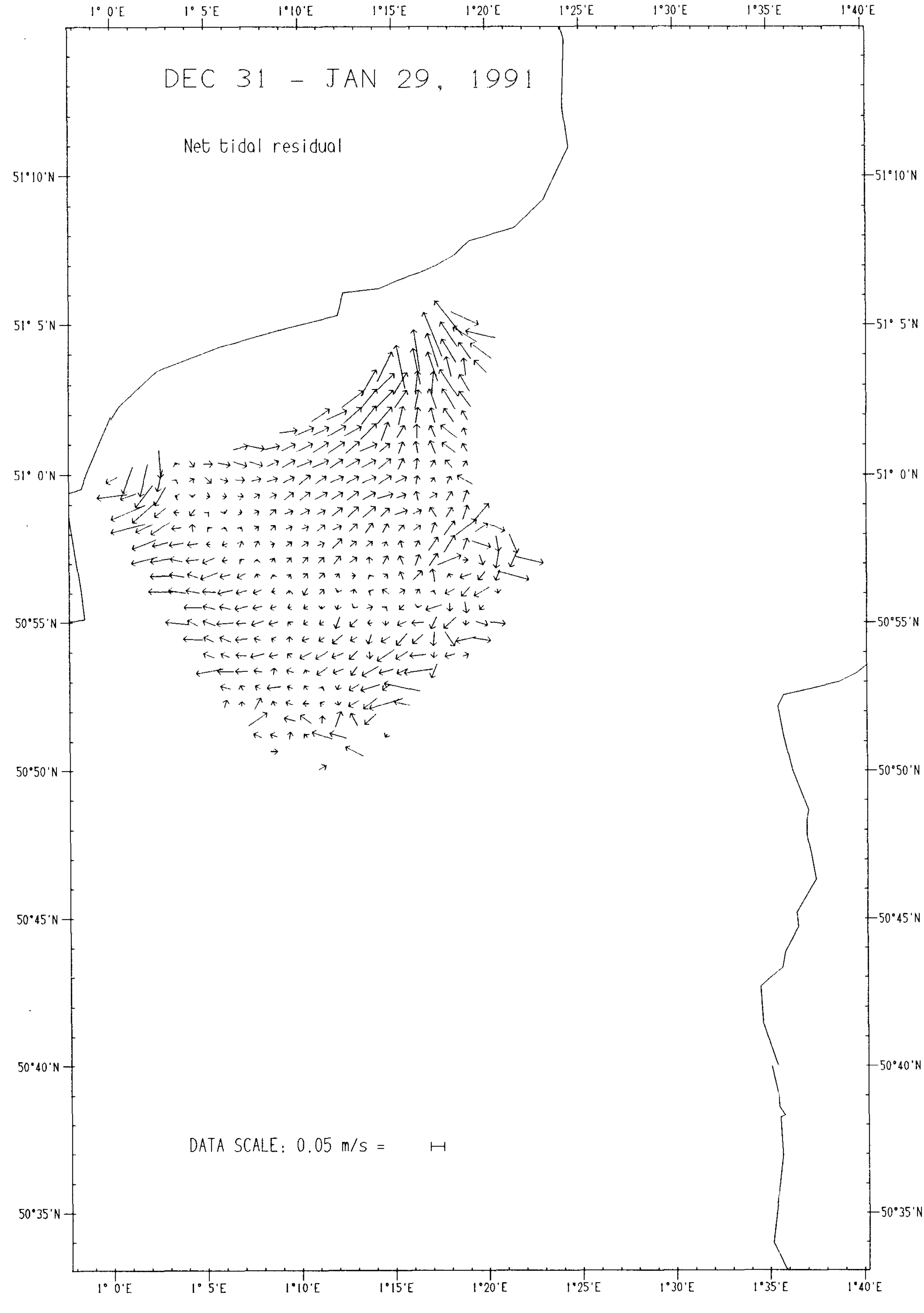
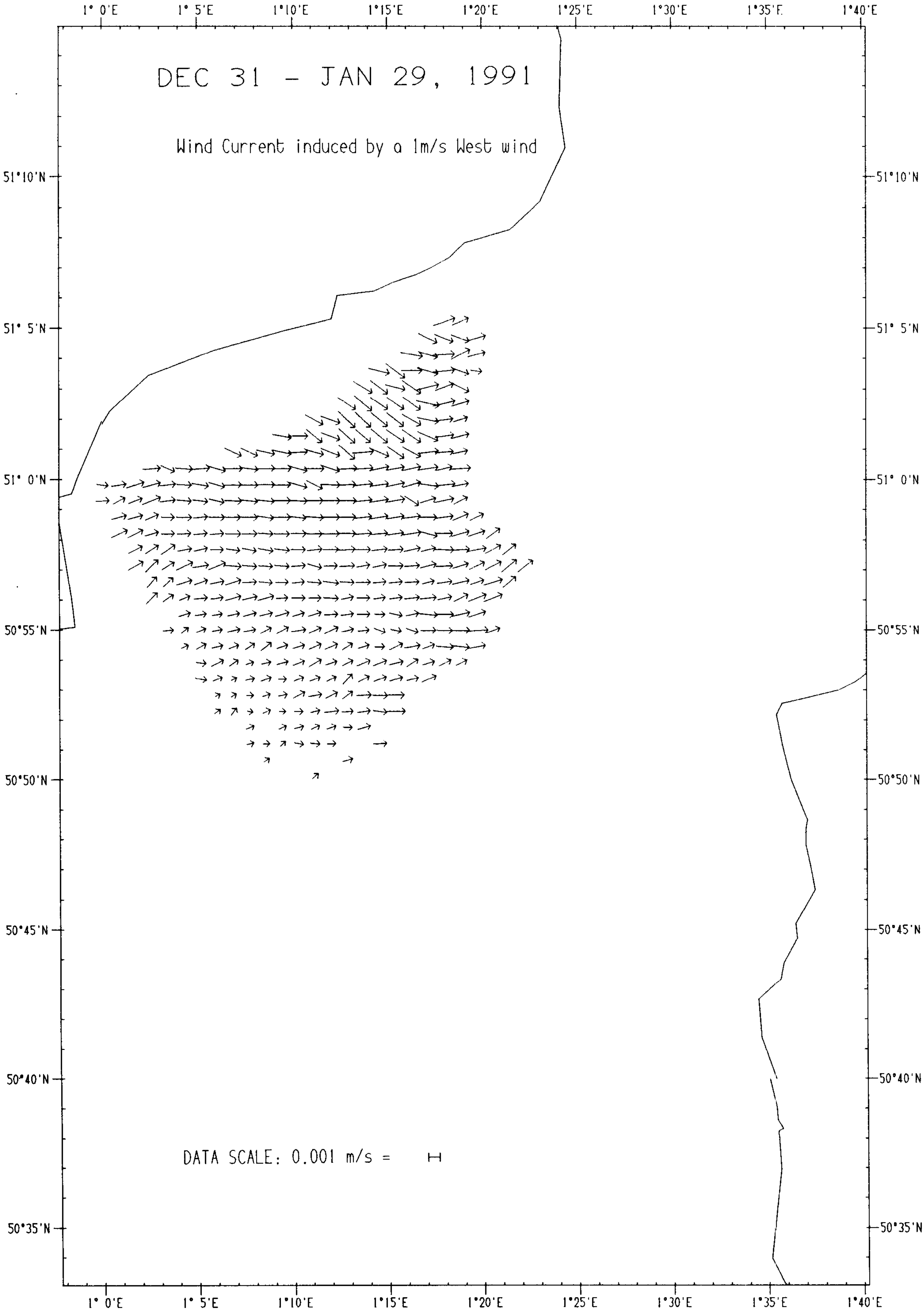
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N

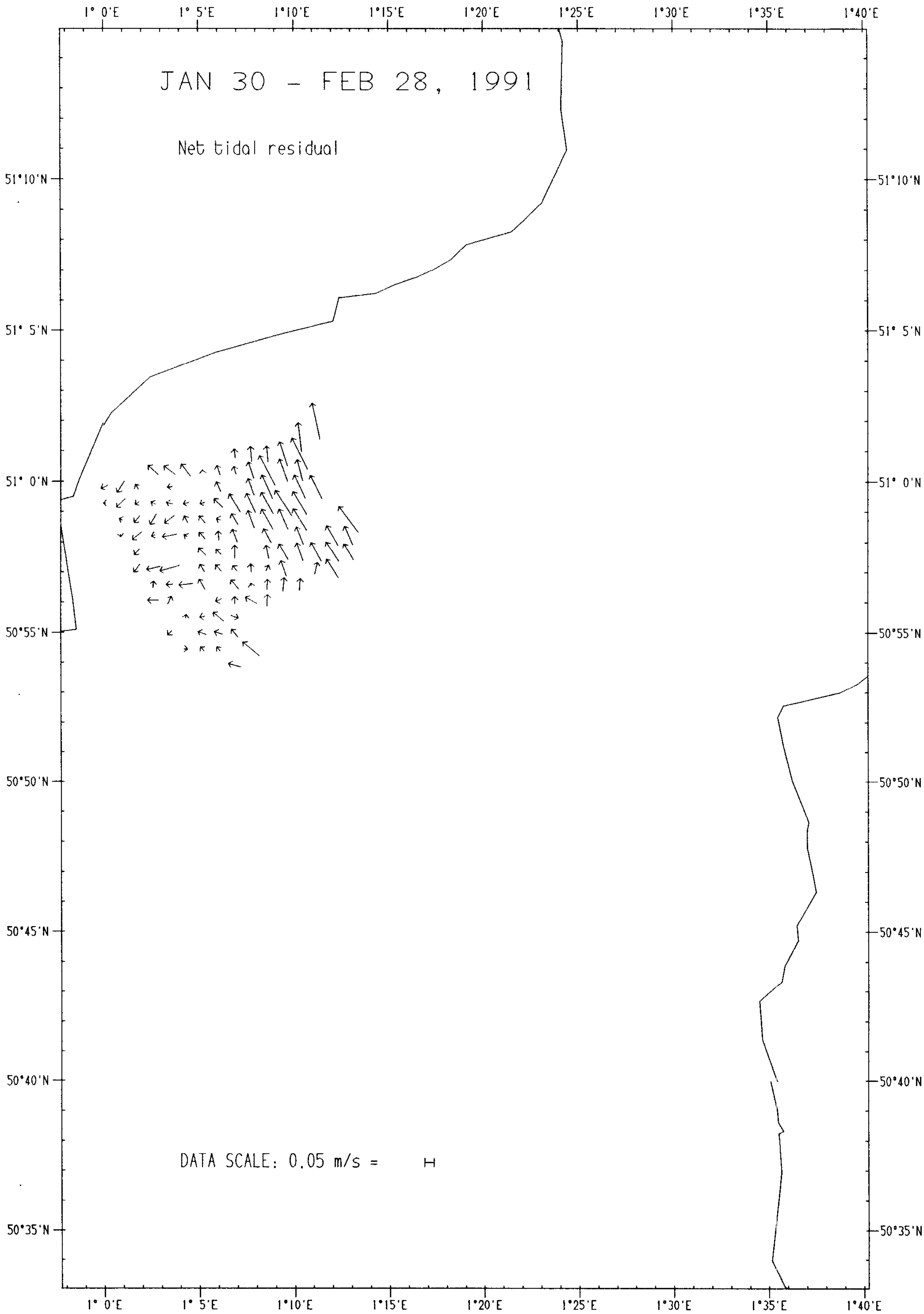


DEC 1 - 30, 1990
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N

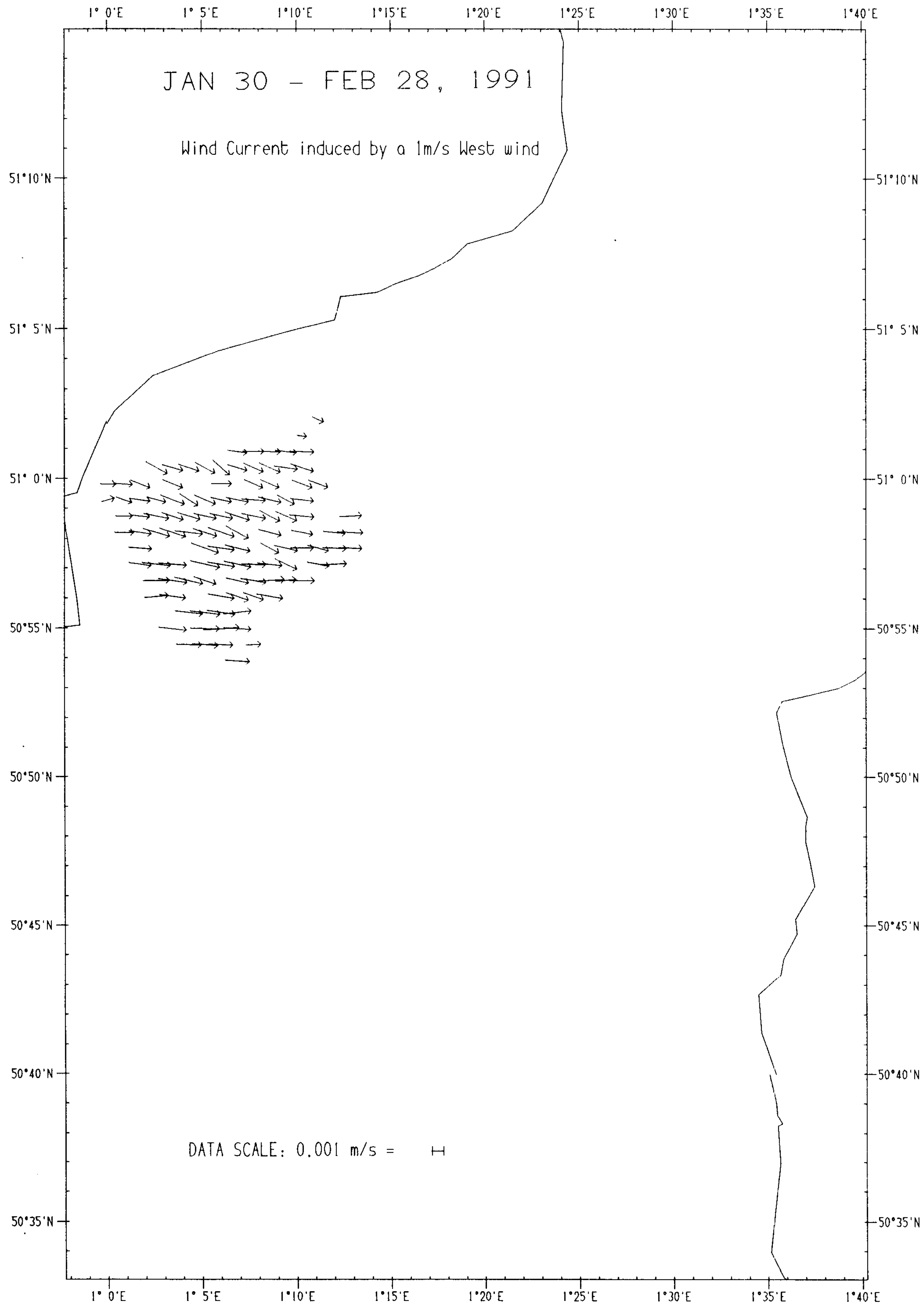


DEC 31 - JAN 29, 1991
Net tidal residual
DATA SCALE: 0.05 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


DEC 31 - JAN 29, 1991
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N



JAN 30 - FEB 28, 1991
Net tidal residual
DATA SCALE: 0.05 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N


JAN 30 - FEB 28, 1991
Wind Current induced by a 1m/s West wind
DATA SCALE: 0.001 m/s =
1° 0'E
1° 5'E
1°10'E
1°15'E
1°20'E
1°25'E
1°30'E
1°35'E
1°40'E
51°10'N
51° 5'N
51° 0'N
50°55'N
50°50'N
50°45'N
50°40'N
50°35'N

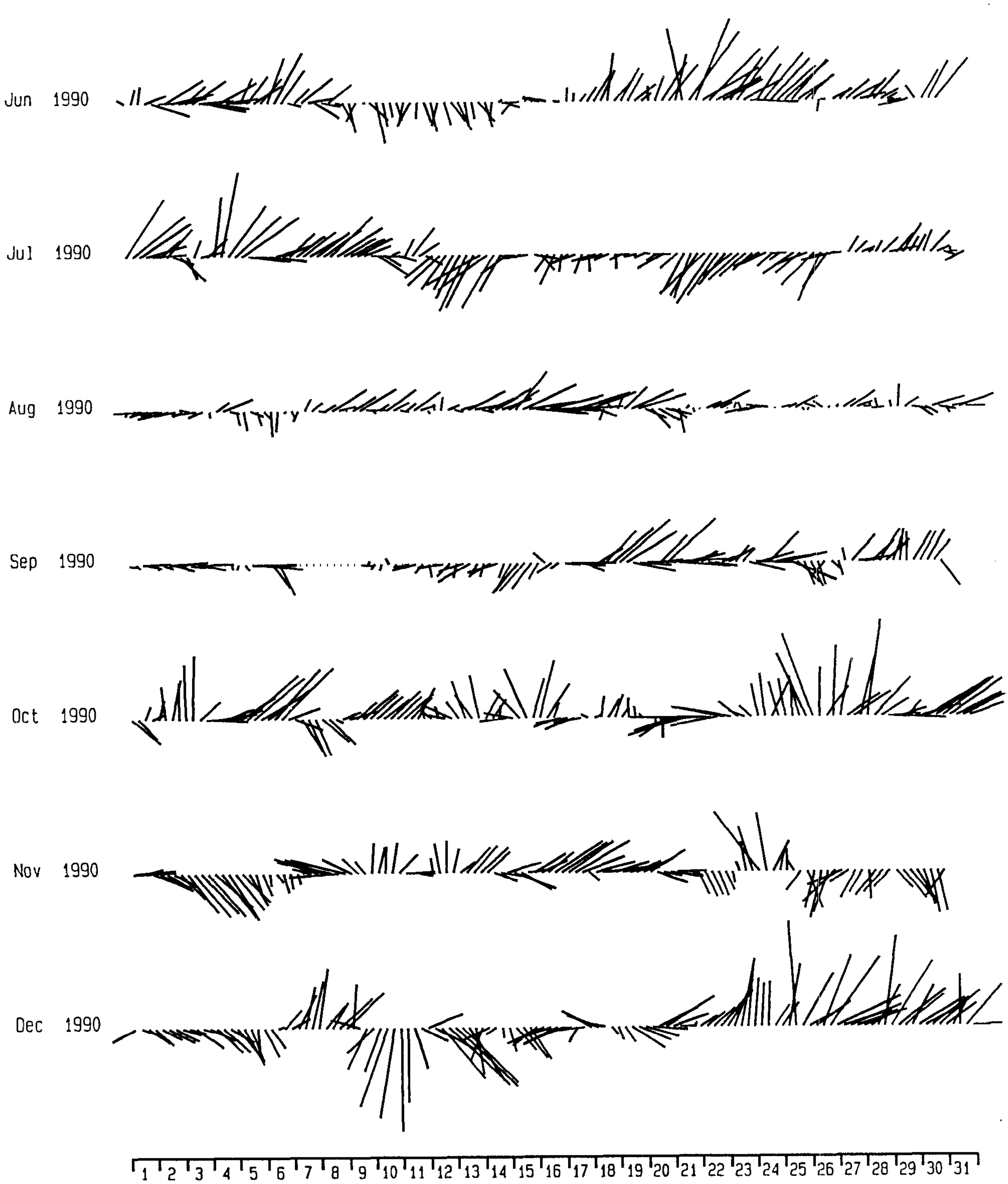
Appendix F. Wind recorded during experiment.

Wind data presented is 6 hourly data filtered from hourly values.

The length of the line indicates the speed, and the line direction away from the axis indicates the direction which the wind is blowing to.

# Wind Speed for Lydd Ranges/Langdon Battery

Scale 10 m/s



# Wind Speed for Lydd Ranges/Langdon Battery