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STORM-FORCED CURRENTS ON THE GRAND BANKS FROM A 2-DIMENSIONAL BAROTROPIC MODEL

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ABSTRACT

Petrie, Brian . 1993. Storm-forced currents on the Grand Banks from a 2-dimensional barotropic model. Can. Tech. Rep. Hydrogr. Ocean Sci. 152: vi + 145 pp.

A two-dimensional, barotropic model is used to calculate the currents and sea-level variations caused by 28 severe storms over the Grand Banks of Newfoundland. Current meter observations were available for 7 of the storms. Agreement between these observations and the model's predictions varied from good on the Banks (Storm 25) to poor over the Slope (Storm 26). The observations also indicate that inertial period motions, suppressed in the model because of the neglect of stratification, are important even when vertical density variations are small. The results compiled for all 28 storms show that the peak modelled currents lie in the upper 1% of the histograms of flow rates from data collected over a 5 year period.

RESUME

Petrie, Brian. 1993. Storm-forced currents on the Grand Banks from a 2-dimensional barotropic model. Can. Tech. Rep. Hydrogr. Ocean Sci. 152: vi + 145 pp.

Un modèle barotrope bidimensionnel a été utilisé pour calculer les variations des courants et du niveau de la mer causées par 28 tempêtes violentes sur les Grands-Bancs de Terre-Neuve. La concordance des données de courantomètres dont on disposait pour sept de ces tempêtes avec les prédictions fondées sur le modèle variait de "bonne" sur les bancs (tempêtes 25) à "medicore" sur le talus (tempête 26). Ces données révèlent aussi que les mouvements périodiques inertIELS, supprimés dans le modèle faute de stratification, sont importants, même lorsque les variations de la densité verticale sont faibles. Les résultats compilés pour la totalité des 28 tempêtes indiquent que les courants modélisés les plus forts se trouvent dans la tranche supérieure de 1 % des histogrammes de débit établis d'après des données recueillies sur une période de cinq ans.

1. Introduction

The Hibernia area (approximately $46^{\circ}45'N$, $48^{\circ}45'W$, Fig. 1a) has been the focus of a number of studies that have:

- a) examined available data in order to describe the circulation, property changes and exchanges between the shelf and deep ocean (Petrie and Anderson, 1983; Petrie and Isenor, 1985; Petrie and Warnell, 1988);
- b) developed 1-dimensional models of the wind-forced currents (Petrie, 1982; deYoung and Tang, 1990); and,
- c) presented the results of 2-dimensional tidal (Petrie et al., 1987) and mean, barotropic current models (Greenberg and Petrie, 1988).

These investigations into the observational record and the development of models of a number of processes has been stimulated by the offshore oil exploration that has taken place for more than a decade off Newfoundland. The development of a 2-dimensional wind-forced current model evolved as part of this project, in particular, to focus on the flows and sea-level variations caused by severe storms. The atmospheric forcing has been developed by Mobil Research and Development Corporation (MRDC). The numerical model was formulated at Bedford Institute of Oceanography and programmed in modular units by ASA Consulting Ltd., Dartmouth, Canada.

The meteorological forcing is described in the next section. This is followed by a brief outline of the current model. A comparison is made of the model results and current meter data that were available for 7 of the storms. The current meter records provided insight on how the flows generated by these storms compared to those generated by less severe weather systems; moreover, the observations indicated how important inertial period motions are even when stratification is weak. The format for presentation of the results from all storms and general conclusions about these results follow.

2. Meteorological Forcing

Oceanweather Inc. developed the wind stress fields of 32 severe storms for Mobil Research and Development Corporation (MRDC). The selections were made from the time period 1951-1984 and the criterion was the capacity of the storms to generate high surface waves. The wind stress fields were generated from 6h analysis charts of the North Atlantic using techniques developed by V. Cardone (see Cardone, 1969 for a detailed account or Forristall et al., 1977 for a brief summary).

The calculated wind stress values were provided to Bedford Institute by MRDC on latitude-longitude grids (approximately $1.2^{\circ} \times 2^{\circ}$ for storms 1-20; $.625^{\circ} \times 1.25^{\circ}$ for storms 21-29) that were interpolated to the current model grid. At the time of running of the model, 28 of the 32 storms were readily available and are listed in Table 1. Three versions of the Ocean Ranger Storm (number 21, February, 1982) were used with

numbers 121 and 122 representing intensifications of storm 21.

Severe storms were distributed through the year as follows: 1 in September, 1 in October, 3 in November, 5 in December, 7 in January, 6 in February and 5 in March. Keeley (1981) indicates that the density difference between 0 and 100 m is less than 1 kg m⁻³ from mid-December to early April (Fig. 2). The coincidence of the majority of storms and the time of weakest stratification favours the application of a current model which does not consider density effects.

The x-components of current and wind stress are taken as positive towards the east, the y-components as positive northwards. In the figures to follow time, t=0, starts at the beginning of the storm under discussion.

3. Description of the current model

The current model consists of an 82x47 f-plane with a constant grid spacing of 25 km in the x (positive to the east) and y (positive to the north) directions. An explicit finite difference scheme is used with a Richardson lattice and open boundary radiation conditions as discussed by Greenberg (1989). The equations of motion and continuity are:

$$\begin{aligned} (\partial U / \partial t) - fV &= -gh(\partial \eta / \partial x) + (1/\rho)(\tau_{wind}^x - \tau_{bottom}^x) \\ (\partial V / \partial t) + fU &= -gh(\partial \eta / \partial y) + (1/\rho)(\tau_{wind}^y - \tau_{bottom}^y) \\ (\partial \eta / \partial t) + \partial U / \partial x + \partial V / \partial y &= 0 \end{aligned}$$

where U and V are the depth-integrated currents, positive to the east and north;

f is the Coriolis parameter;

g is the gravitational acceleration;

h is the water depth;

η is the surface elevation;

ρ is the water density;

τ represents the stress due to wind at the surface, and due to quadratic friction ($c_d u |u|$, where c_d is the drag coefficient) at the bottom.

Finite difference forms of the equations were solved using a 144 second time step. The bottom drag coefficient was varied between 1.6×10^{-3} and 2.3×10^{-3} with no appreciable change in the flow fields. The lower value was used in all runs shown in the report.

4. Comparison of observed and modelled currents

Current meter moorings were in place for 7 of the severe storms, numbers 23-29. The locations, total water depth and

instrument depth of the current meter sites in place for these storms are listed in Table 2 and illustrated in Fig. 1b. Current meter records were processed using a 24 h running mean filter in order to reduce the influence of tides and inertial period motions. A comparison of Hibernia currents with observations is made for each individual storm. Adjustment of the model results to the current meter site does not alter the conclusions of the comparison.

Storm 23, 30 January - 4 February, 1982

The time series of wind stress and the currents derived from the model for the Hibernia location are shown in Fig. 3. The wind stress features initial positive and negative pulses of the eastward and northward components, respectively, between 40 and 60 hours. Larger pulses in the same directions follow between 60 and 100 hours. The model response shows an oscillatory current with the v component leading the u component. Speeds of nearly 0.5 m/s are attained.

Current meter data were available from 2 mooring sites, both within 10 km of the nominal Hibernia location (Table 2). The three time series from the first site have current amplitudes that decrease significantly with depth but whose variations occur at the same time as the modelled flows (Fig. 4). Similar depth variation occurs at the second site but the 26 m currents appear to lead those at 75 m on the same mooring, those at the first mooring and the modelled flows by about 8 hours (Fig. 5). We note that the start time of this instrument was given as being 7 hours and 40 minutes earlier than the 75 m instrument on the same mooring. We suspect that the start time may have been improperly recorded.

To summarize, the timing and direction of the modelled currents are correct; in addition, the magnitude of the 26 m flows are comparable with the modelled ones. However, the large depth variation of the observations indicates that the flow is not barotropic as the model requires.

Storm 24, 7-12 December, 1982

This storm featured a very strong eastward wind stress at roughly 80 hours, preceded by a weaker northward pulse and followed by a southward component (Fig. 6). The modelled currents for Hibernia had a southward component of nearly 0.5 m/s and a u component that changed from 0.3 m/s to -0.2 m/s.

Current meter data were available only from a slope mooring near the 200 m isobath about 100 km northeast of Hibernia (Fig. 7). The observations from this site, which may be strongly influenced by the Labrador Current, do not bear any resemblance to the modelled flows even when account is taken of the different position of the mooring.

Storm 25, 5-11 March, 1983

Wind stress variation was dominated by the southward component which reached a maximum amplitude of nearly 3 Pa at 80 hours (Fig. 8). The modelled u component was in phase with the southward wind stress and attained speeds of 0.5 m/s.

Currents were available from only one mooring located within 4 km of the Hibernia site. The flows at all depths were very similar in magnitude and, at 0.35-0.4 m/s, were only slightly weaker than the modelled currents (Fig. 9). However, maximum observed currents occurred 6-8 hours later than the maximum modelled flows perhaps indicating an incorrect start time.

Storm 26 & 27, 25 November - 1 December, 1983

During these storms there was a strong pulse of northward wind stress at 95 hours, followed by a weaker one at 135 hours. Southward stress peaked at 95 hours before reversing direction with a weaker northward pulse at 125 hours (Fig. 10). The modelled current is initially accelerated to the south by the strong wind stress pulse, moves clockwise towards the west and north, and finally finishes as a flow towards the northeast.

The observed currents from the 2 Hibernia sites are somewhat enigmatic. At Site E and Site A, the mid-depth and deeper currents are at least qualitatively similar to the modelled flows - v leads u, there is a transition from negative velocities to positive ones (Fig. 11, 12). The response is not as sharp for the observed currents as it is for the modelled flows. In addition, the u component equals or exceeds the v component unlike the model's results. However, the greatest discrepancy between the observed and modelled currents is from the data at Site E, 20 m, where the v component opposes the deeper observations and the model prediction. The data from the slope area do not resemble the Hibernia observations or the model results (Fig. 13, 14).

Storm 28 & 29, 18-27 December, 1983

Wind stress peaked initially at 90 hours with a strong southeastward component. This was followed by a somewhat weaker event at about 170 hours towards the northeast (Fig. 15). The model indicates a strong current response to the south, rotating in a clockwise sense to the southwest. The second strong wind stress episode produced a variable flow. The current accelerated towards the east-southeast, became more southerly and finally reverted to a roughly southeast flow.

The observed currents at Hibernia, 41 m, indicate a weaker v-component response than the model predicted but are in excellent agreement for the u-component (Fig. 16). The transition to positive v and negative u-components during the second phase of the storm is qualitatively similar for the modelled and observed currents even though the detailed variability differs. The observed currents from the slope do

not agree with the model's predictions very well though there are some superficial similarities , particularly for the 20 m observations (Fig. 17).

Bottom pressure data were collected at Hibernia during these storms (Fig. 18). The variability of the data and the bottom pressure predicted by the model are qualitatively very similar, however the model underpredicts the amplitude of the change that occurs between roughly 90 and 110 hours by a factor of 2. We cannot account for this difference.

5. Summary and Discussion

Overall qualitative agreement was achieved for the model's current results when they were compared to the observations from the shelf. The lack of barotropic response was notable for storm 23, 26 and 27. In particular, for the latter 2 storms, the 20 m v-component data varied in the opposite sense to the model's prediction. Particularly good agreement occurred for storms 25, 28 and 29, perhaps in the latter two cases because only data from 1 instrument on the shelf were available.

Agreement of the modelled currents with observations from the slope was poor, possibly indicating the influence of the Labrador Current which is not accounted for in the model.

Only one bottom pressure record was available for comparison with the model's predictions. Although qualitatively similar, the model underpredicted the bottom pressure variations.

The model has only wind forcing accelerating the flows over the shelf and slope. Other sources of variability associated with the Labrador Current, for example, or from the propagation of motions into the region from outside the model domain are neglected. Moreover, it is evident that the vertical variation of current can still be affected by stratification although it is weak at the time of year that most major storms occur.

The record from Site E at Hibernia illustrates two other points that can be made (Fig. 19). The currents generated by storms 26 and 27 (year days 329-335) and by storms 28 and 29 (year days 352-361) are only marginally stronger than the currents observed about day 339. That is, there may be a large number of storms that can produce flows of similar magnitude as the ones we have discussed so far. It is worthwhile to note again that storm selection was based on the capacity to generate large surface waves not the strongest currents.

The second point that can be made from Fig. 19 is that inertial period motions are an important part of the variability. Significant inertial wave energy cannot be generated by our model due to its neglect of stratification. The variations at the inertial period are more clearly seen in Fig. 20, the time of storm 28 and 29 and a short period following them.

6. Model output for all storms

Plots of the currents, sea-level, and wind stress at 12 hour intervals were created as model output. In addition, printouts of the currents at 1 hour intervals, and wind stress and sea-level every 6 hours at Hibernia were available for each storm. We shall limit our data presentation to 4 plots per storm, namely, the 6 hour time series of the x and y-components of wind stress, the u and v velocities from the model at 1 hour intervals, the sea-level due to wind forcing alone (designated as ASL on the plots), the isostatic adjustment due to atmospheric pressure variations (IA) and sea-level (SL) due to the combined effect of the wind and atmospheric pressure. All of these plots will be for the Hibernia site. In addition, 1 plan view plot of currents at the height of the storm will be shown. This presentation is given in the appendix.

Mean sea-level for each model runs is defined as the mean over the duration of the storm, i. e., longer period variability of sea-level is neglected as are the higher frequency tidal oscillations. At Hibernia, for example, the M_2 constituent has an amplitude of 0.23 m; at St. John's, the annual cycle has an amplitude of about 0.09 m. Thus the model calculations represent a sea-level change due to an individual storm, actual changes will combine the effect of tides and other variability.

7. General results from all storms

Typical maximum current speeds generated by the model were about 0.5 m/s. Several storms (9, 11, 12, and 21 for example) produced flows of 0.6-0.7 m/s. The wind stress associated with storm 122, an enhanced version of 21, led to speeds of about 0.9 m/s. Petrie and Warnell (1988) gave the distribution of current rate in 5 cm/s bins for hourly data that included tides and low frequency variability (Fig. 21). They found that 1.8%, 0.2% and 0.1% of the measurements exceeded 50 cm/s for near-surface, mid- and near-bottom depths at Hibernia. It appears then that the storms that were selected generated currents at the high end of the observed distributions.

Fewer observations of sea-level are available for comparison with the model's predictions. However, some data were collected at Hibernia by Mobil, 19 April-2 June, 1980 and by Mobil and BIO, 18 December, 1983-6 June, 1984. The 1980 observations showed atmospherically forced bottom pressure variations with amplitudes of up to 0.15 m and peak to peak changes over the entire record of nearly 0.3 m. The 1983-84, which have been partially discussed above, had typical amplitudes of 0.16 m and peak to peak changes of 0.8 m. These results are similar to a typical bottom pressure amplitude of just over .33 m with peak to peak changes of up to 1 m (see storm 16, e. g.). We do note again that the one intercomparison that could be made between model and data indicated that the model underpredicted the observed

variability.

8. Acknowledgements

David Szabo (MRDC) provided the meteorological data, advice and encouragement. Charles Tang and David Greenberg made useful comments to clarify and improve the report. I thank them for their efforts. This work was funded through the Federal Panel of Energy, Research and Development.

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TABLE 1
MOBIL SEVERE STORM CLIMATOLOGY

This storm climatology was developed for MRDC by Oceanweather Inc., CT, U.S.A. Storms 121 and 122 represent intensifications of storm 21, the Ocean Ranger Storm. Storms 27 and 28 occurred sequentially as did 28 and 29.

STORM NUMBER	START TIME				END TIME				DURATION DAYS
	YY	MM	DD	HH	YY	MM	DD	HH	
1	73	10	26	03	73	10	29	12	3.4
2	66	02	21	03	66	02	25	12	4.4
3	64	03	14	03	64	03	18	18	4.6
4	66	02	13	03	66	02	17	18	4.6
5	64	01	10	03	64	01	14	12	4.4
6	61	12	15	03	61	12	18	12	3.4
7	67	02	20	03	67	02	24	00	3.9
8	77	01	19	15	77	01	22	12	2.9
9	78	03	01	03	78	03	05	00	3.9
10	80	01	02	03	80	01	06	00	3.9
11	70	01	20	15	70	01	24	00	3.4
12	65	02	17	03	65	02	20	00	2.9
13	61	01	20	03	61	01	23	00	2.9
14	76	03	16	03	76	03	20	00	3.9
15	71	01	16	03	71	01	19	12	3.4
16	74	03	08	15	74	03	13	12	4.9
17	55	09	20	15	55	09	23	13	2.9
18	55	12	09	03	55	12	13	00	3.9
19	54	02	08	15	54	02	11	12	2.9
20	52	11	10	15	52	11	14	12	3.9
21,121,122	82	02	12	06	82	02	16	00	3.8
23	82	01	30	06	82	02	04	00	4.8
24	82	12	07	06	82	12	12	00	4.8
25	83	03	05	06	83	03	11	12	6.3
26,27	83	11	25	06	83	12	01	12	6.3
28,29	83	12	18	18	83	12	27	00	8.3

TABLE 2

Current meter data available during severe storms

Storm	Mooring Lat. N	Location Long. E	Sounding (m)	Instr. Depth (m)
23	46 43.7	48 50.3	77	26
				45
				63
				26
24	46 50.9	48 44.3	82	75
				20
				98
25	47 30.8	48 11.9	196	176
				20
				40
26,27	46 45.5	48 50.2	99	59
				20
				41
				59
26,27	46 43.1	48 47.5	80	41
				61
				20
				74
26,27	46 46.7	48 48.8	81	119
				41
				61
				119
26,27	46 56.3	47 58.1	135	110
				214
				214
				119
28,29	46 43.1	48 47.5	80	41
				20
				74
				119

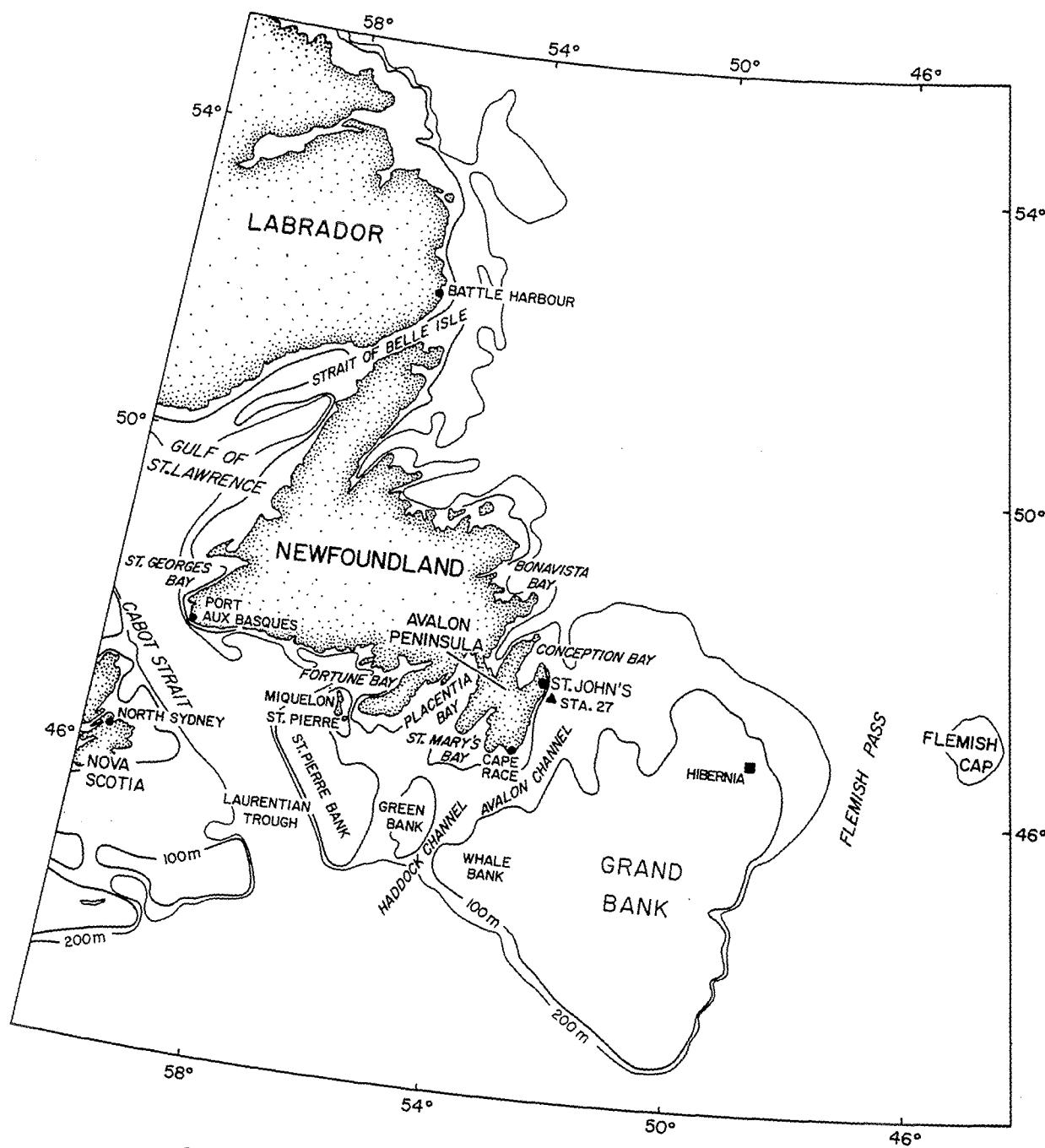


Figure 1a. Map of the study region.

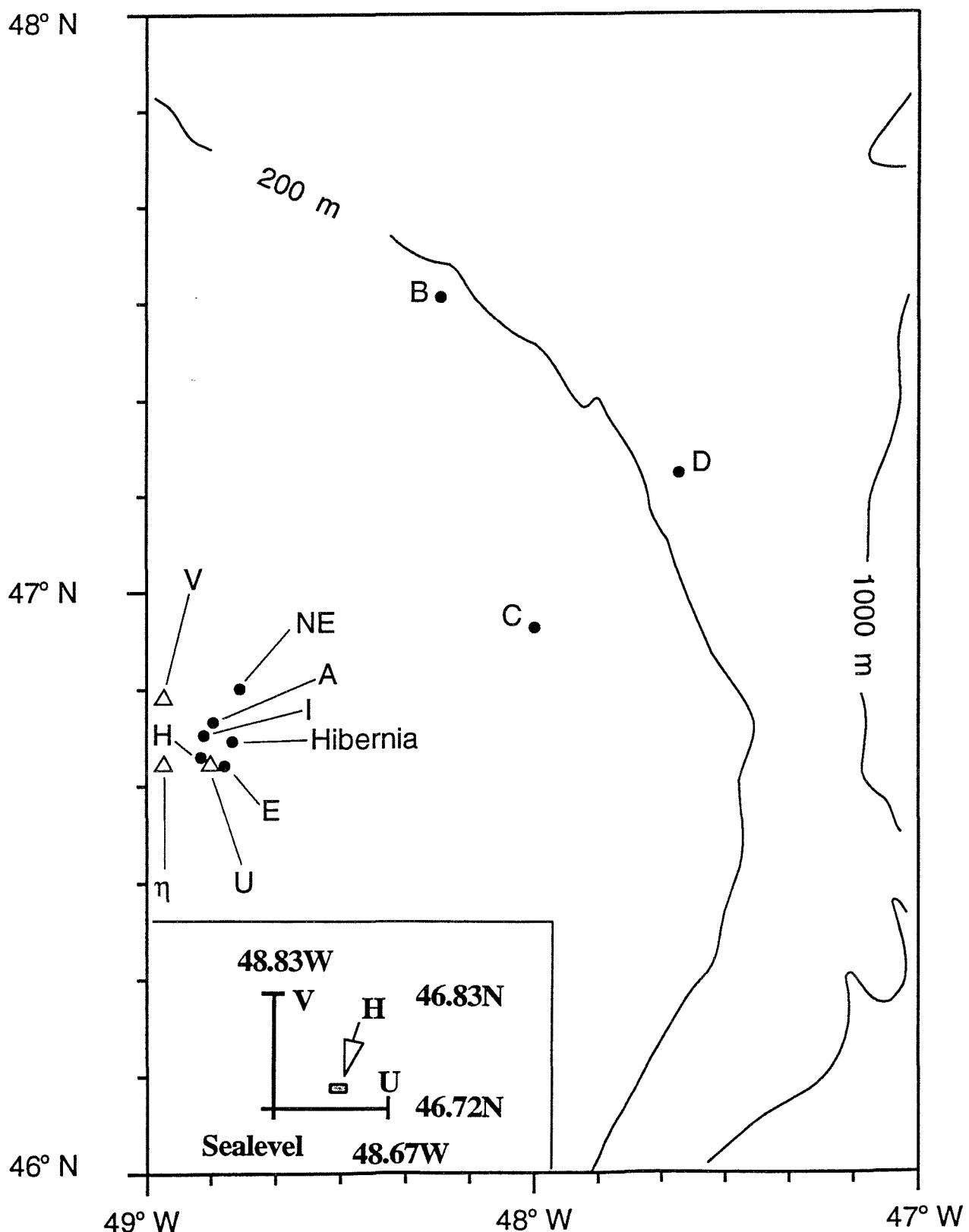


Figure 1b. Hibernia region showing the positions of current meter moorings where data used in the report were collected and a section of the numerical grid (insert, Hibernia = H).

Station 27, Nfld. Shelf Density Difference, 0-100 m

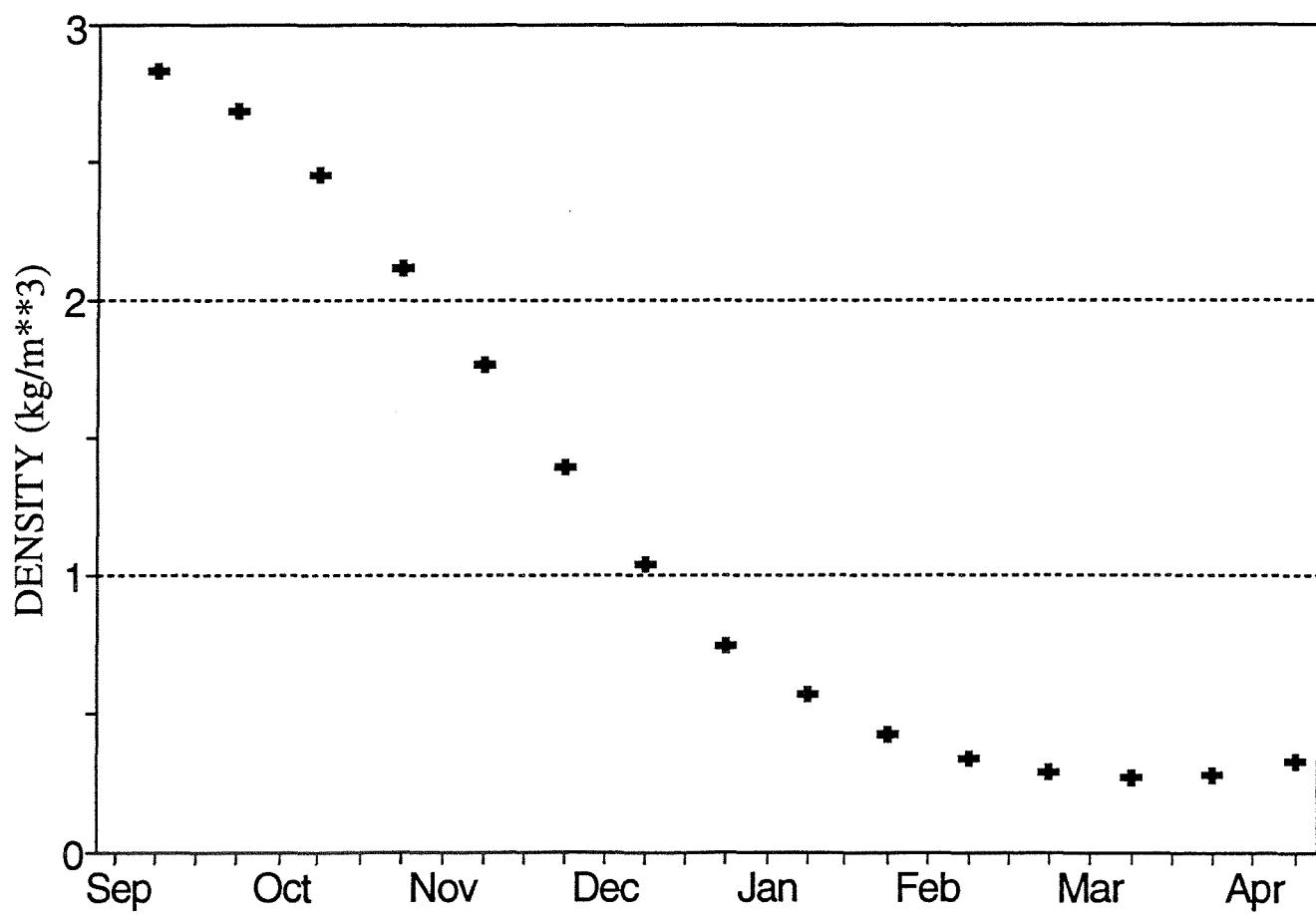


Figure 2. Density difference 0-100m at Station 27, Avalon Channel (Keeley, 1981).

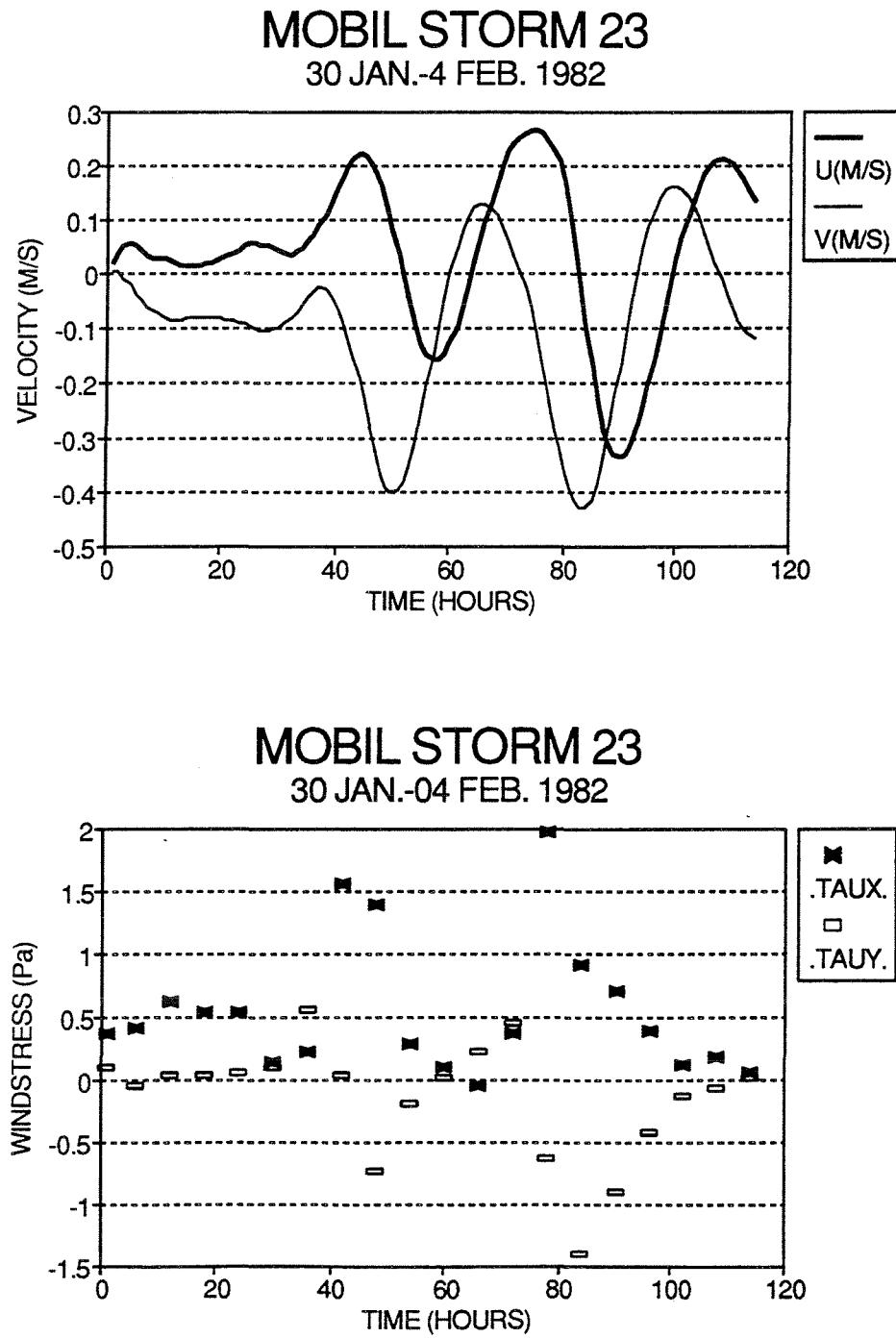
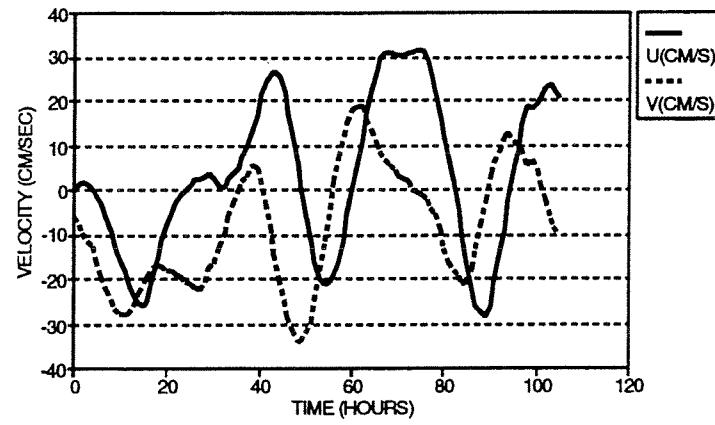
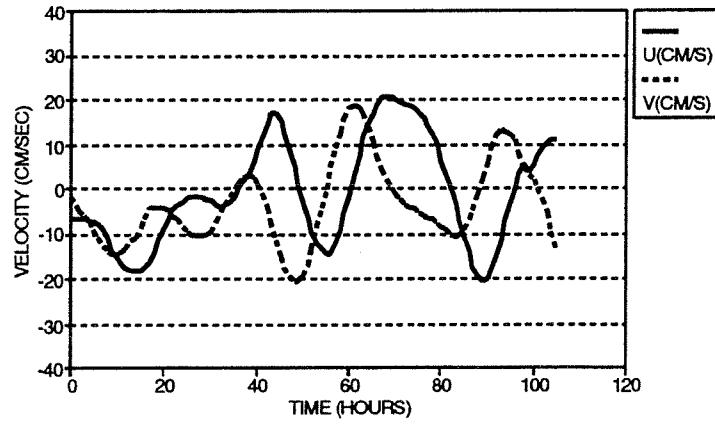


Figure 3. Predicted currents from model for input wind stress.

HIBERNIA, 26m
STORM 23: 30 JAN - 4 FEB 1982



HIBERNIA, 45m
STORM 23: 30 JAN - 4 FEB 1982



HIBERNIA, 63m
STORM 23: 30 JAN - 4 FEB 1982

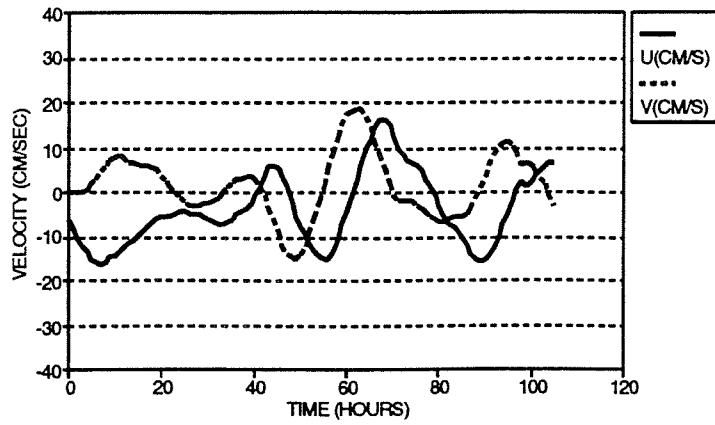
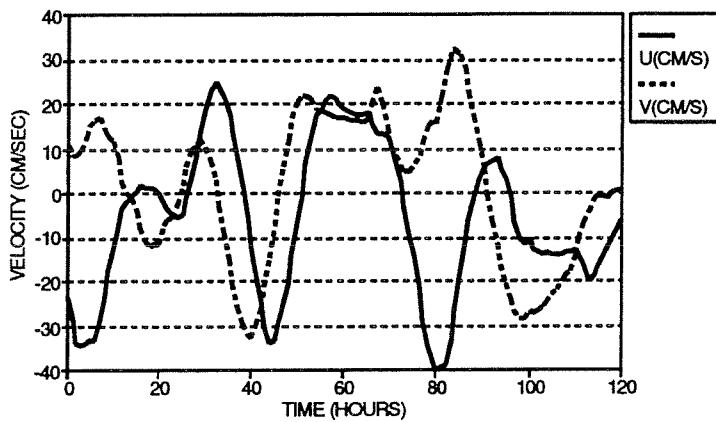


Figure 4. Observed currents at Hibernia (see Table 2 for exact location), bottom depth 77 m.

SITE NE of HIBERNIA, 26m
STORM 23: 30 JAN - 4 FEB 1982



SITE NE of HIBERNIA, 75m
STORM 23: 30 JAN - 4 FEB 1982

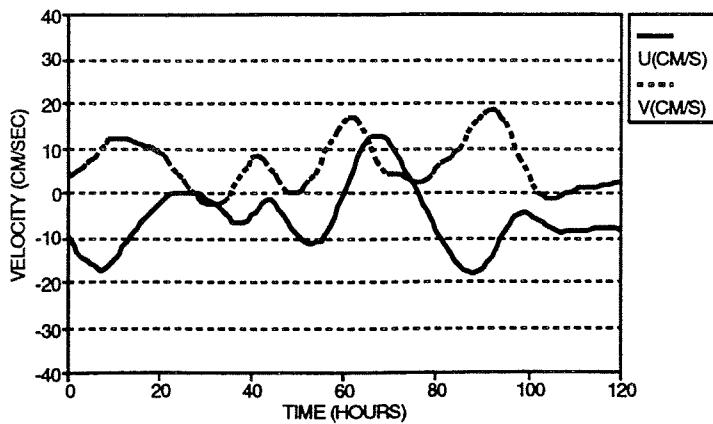


Figure 5. Observed currents at Hibernia (see Table 2 for exact location), bottom depth 82 m.

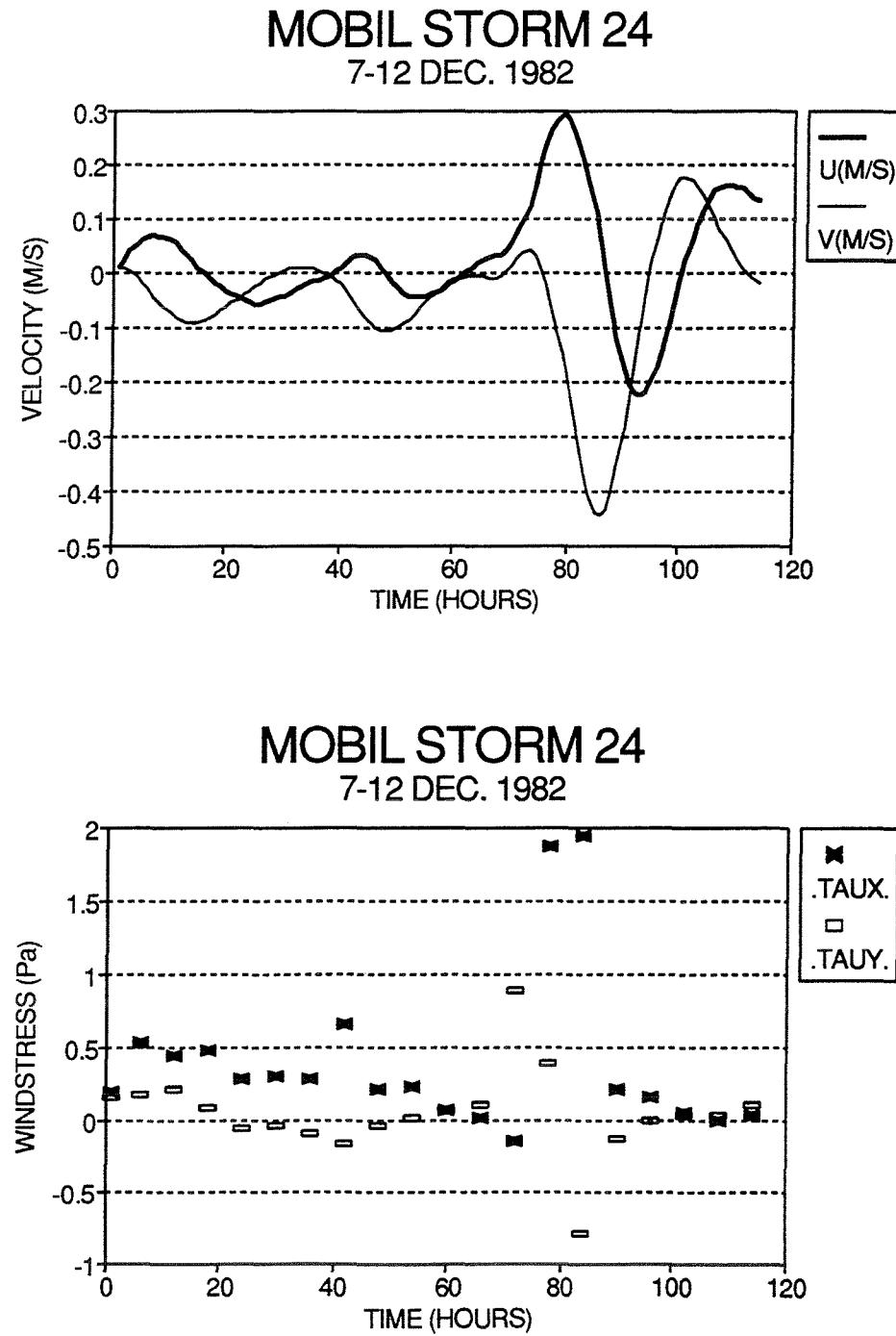
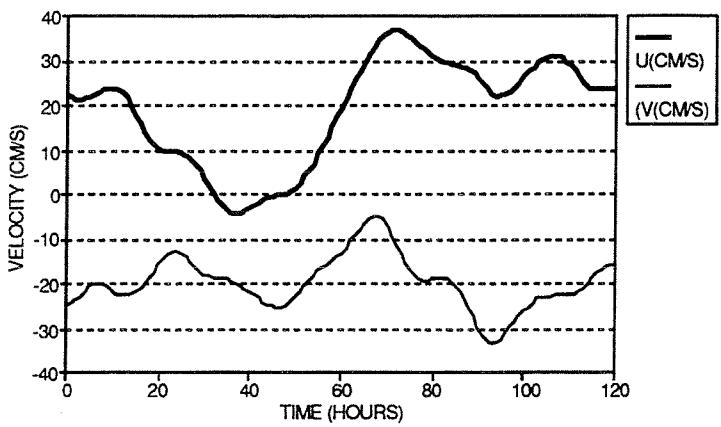
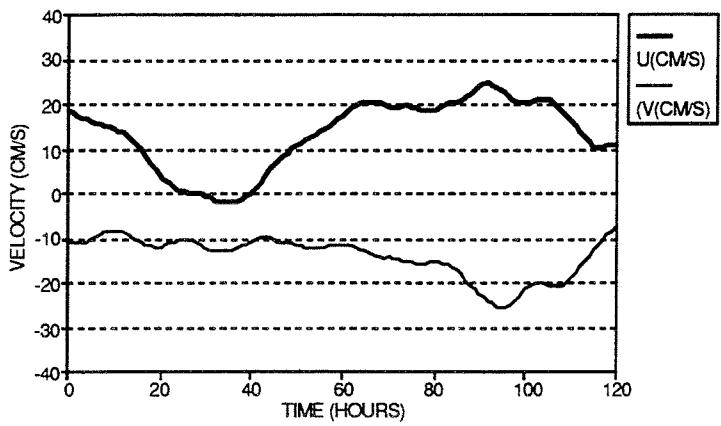


Figure 6. Predicted currents from model for input wind stress.

SITE B NE SLOPE, 20m
STORM 24: 7-12 DEC 1982



SITE B NE SLOPE, 98m
STORM 24: 7-12 DEC 1982



SITE B NE SLOPE, 176m
STORM 24: 7-12 DEC 1982

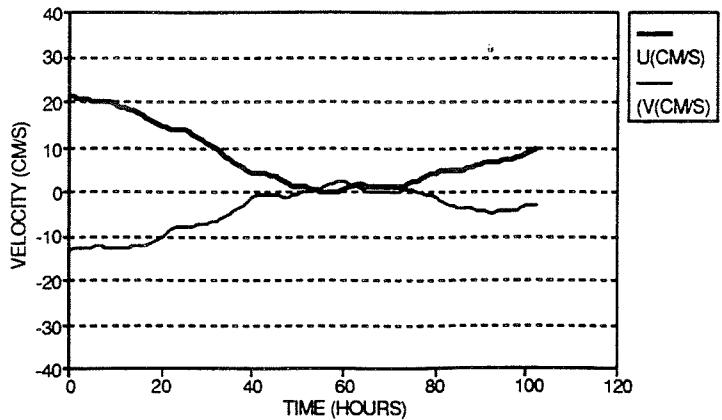


Figure 7. Observed currents from Site B on the northeast slope (see Table 2 for exact location), bottom depth 196 m.

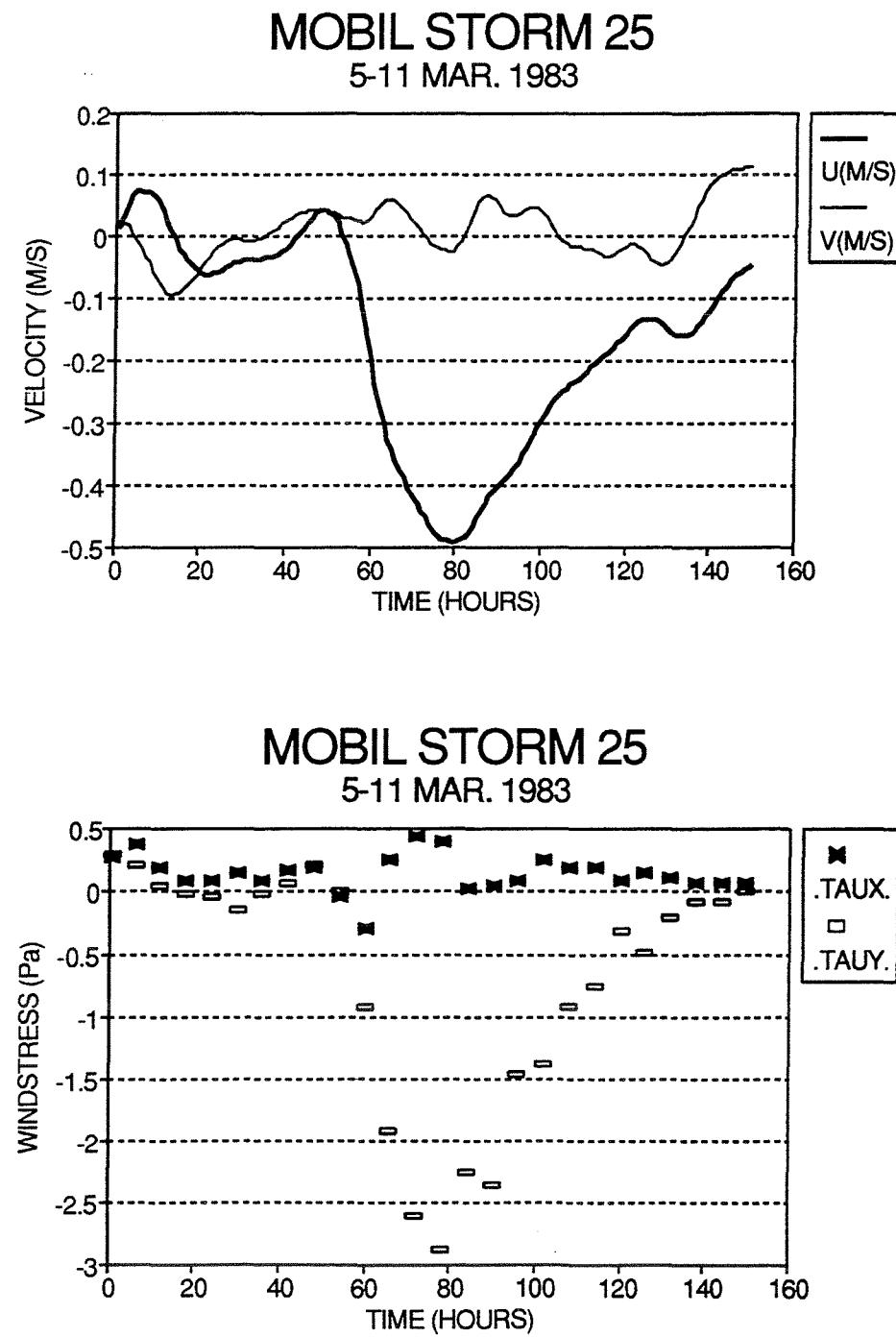


Figure 8. Predicted currents from model for input wind stress.

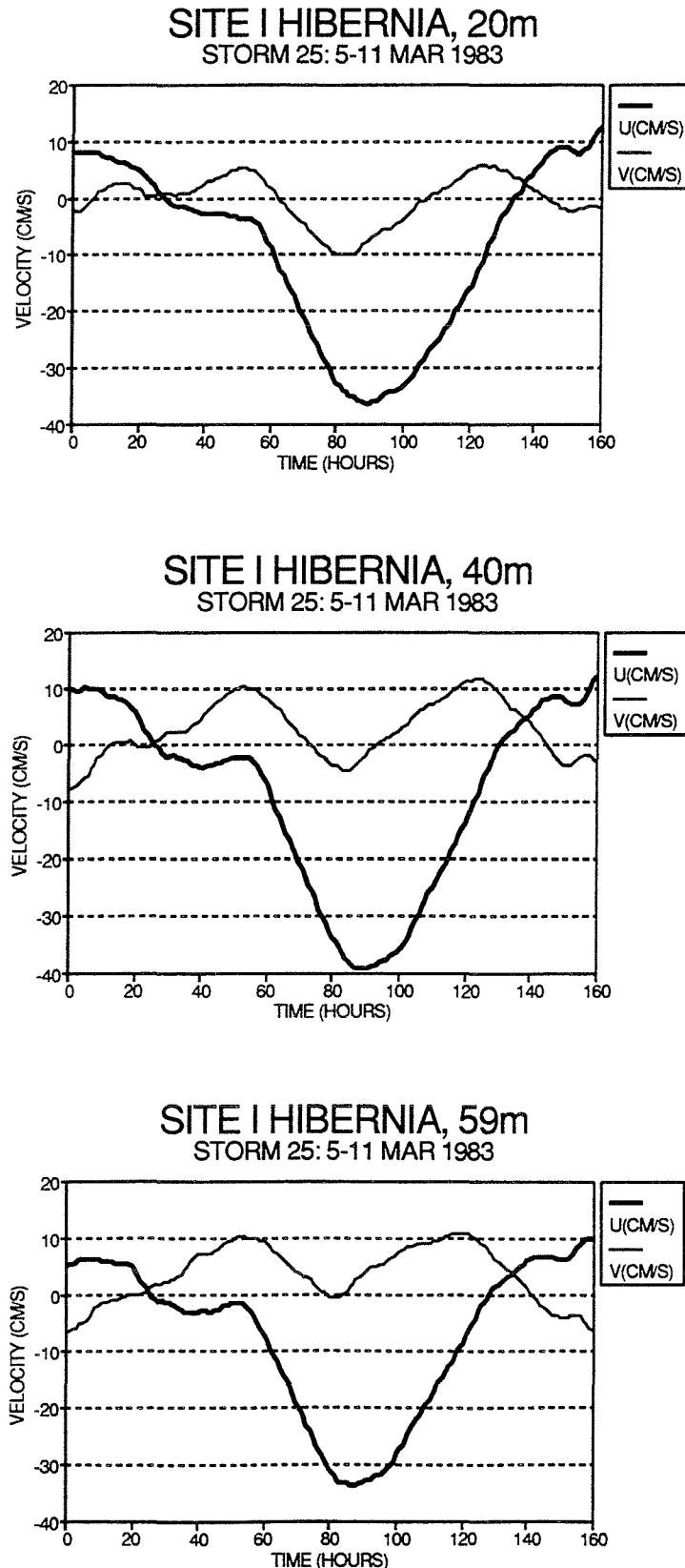
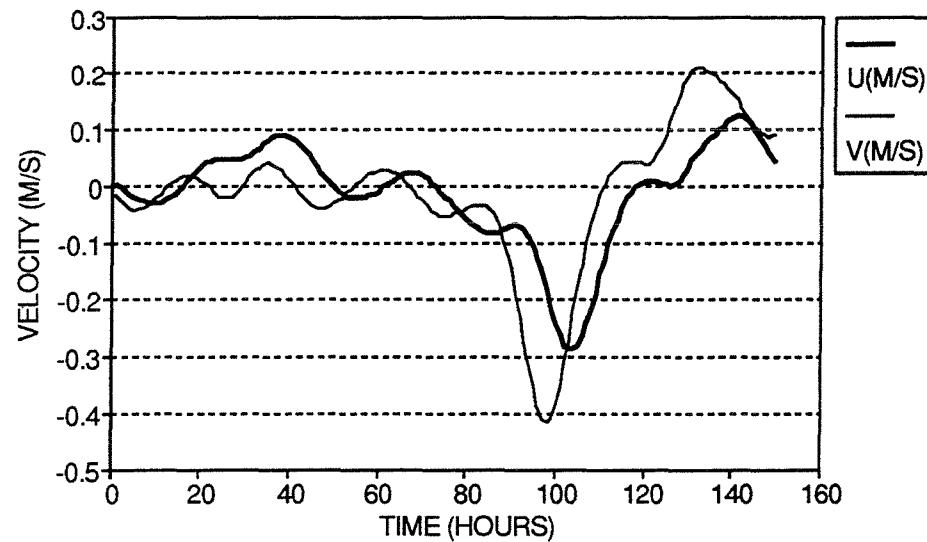


Figure 9. Observed currents from Site I, Hibernia (see Table 2 for exact location), bottom depth 99 m.

MOBIL STORM 26 & 27
25 NOV. -1 DEC. 1983



MOBIL STORM 26 & 27
25 NOV.-1 DEC. 1983

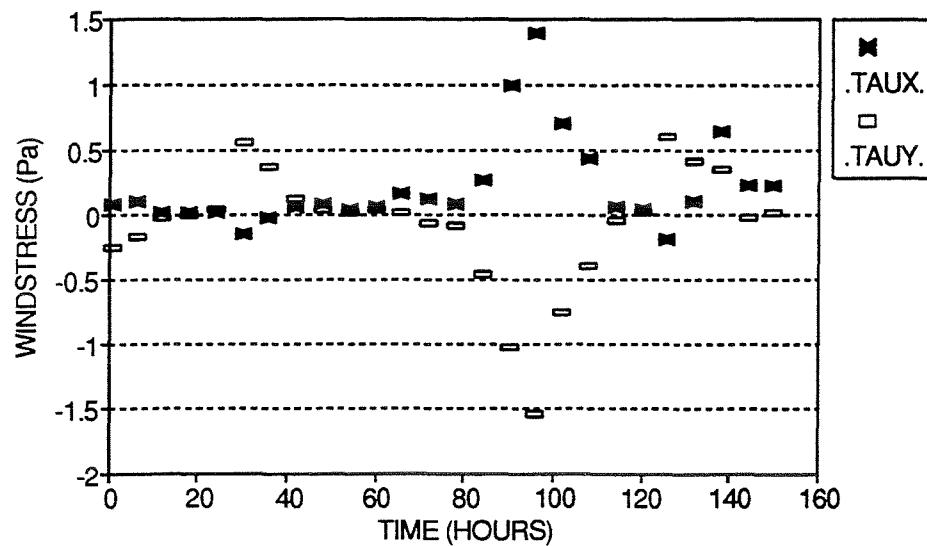
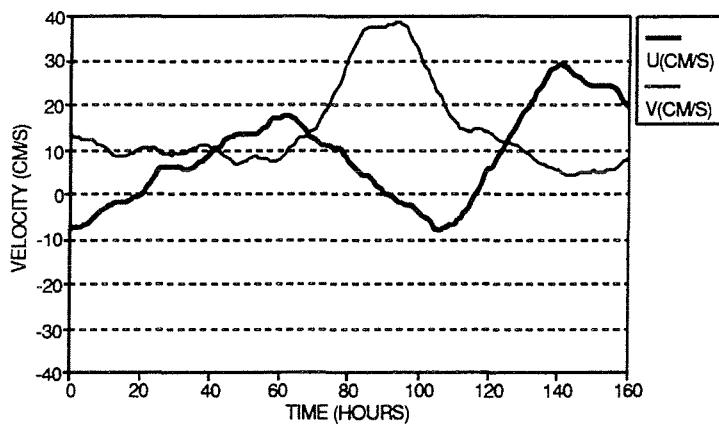
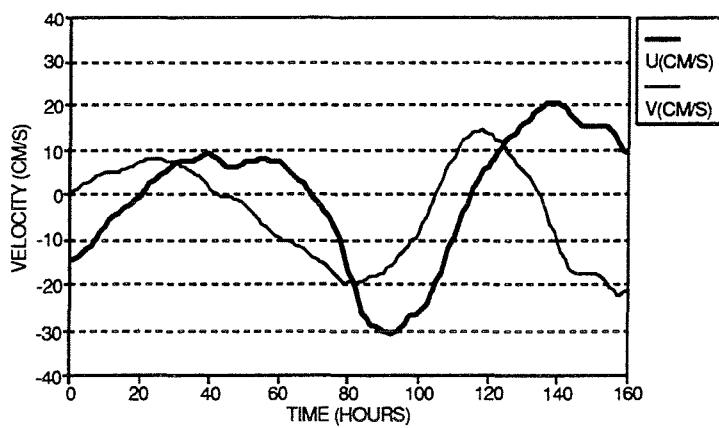


Figure 10. Predicted currents from model for input wind stress.

SITE E, HIBERNIA, 20m
STORM 26,27: 25 NOV - 1 DEC 1983



SITE E, HIBERNIA, 41m
STORM 26,27: 25 NOV - 1 DEC 1983



SITE E, HIBERNIA, 59m
STORM 26,27: 25 NOV - 1 DEC 1983

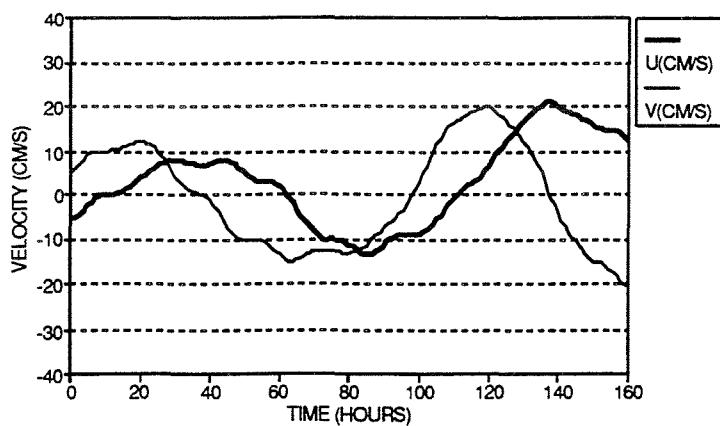
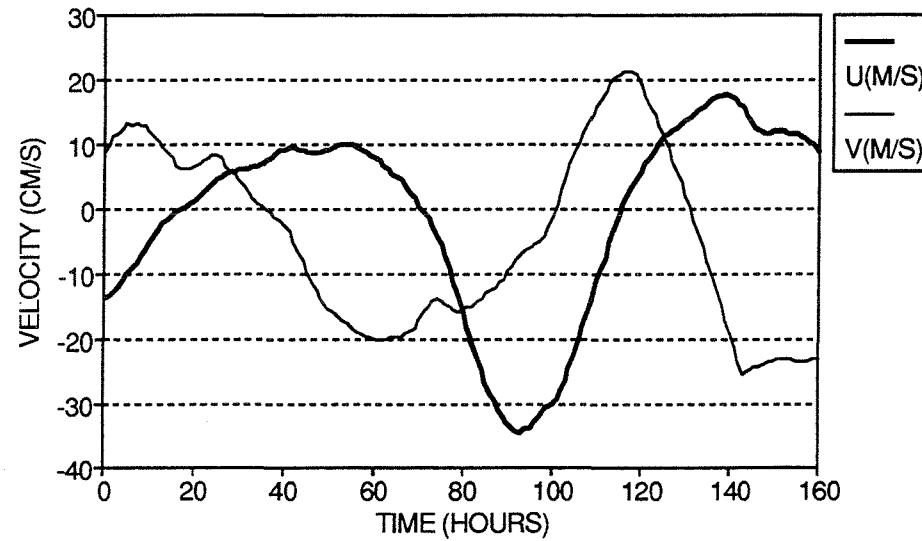


Figure 11. Observed currents from Site E, Hibernia (see Table 2 for exact location), bottom depth 80 m.

SITE A, HIBERNIA, 41m
STORM 26,27: 25 NOV - 1 DEC 1983



SITE A, HIBERNIA, 61m
STORM 26,27: 25 NOV - 1 DEC 1983

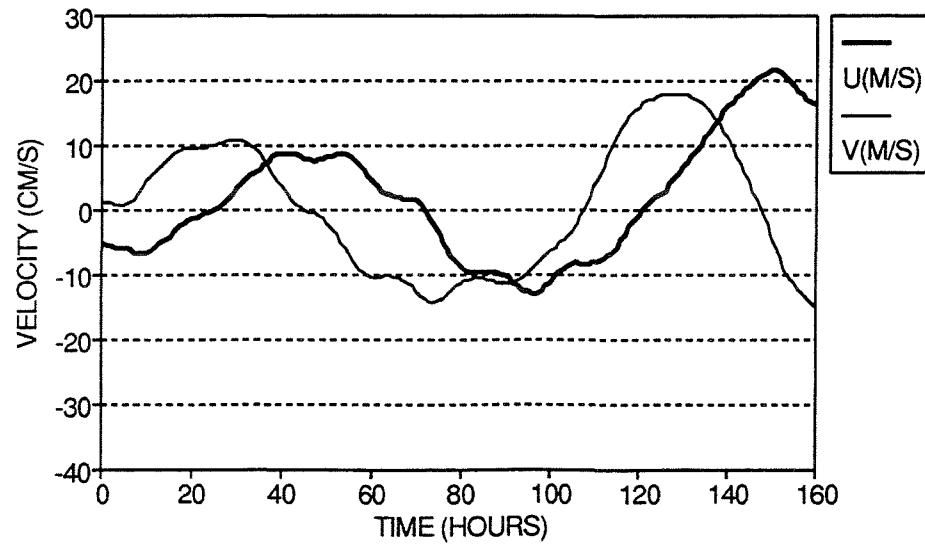
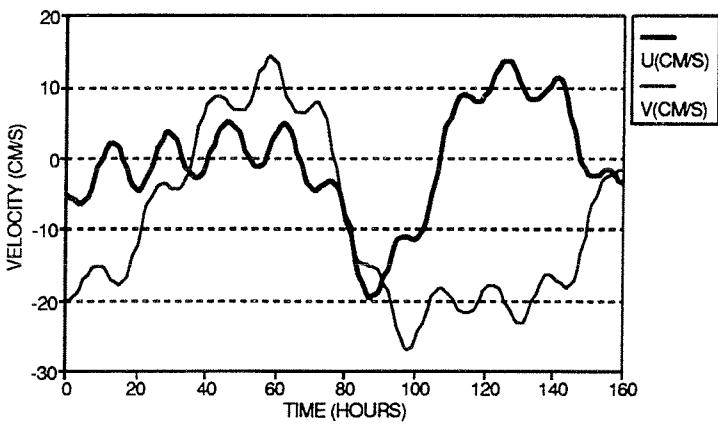
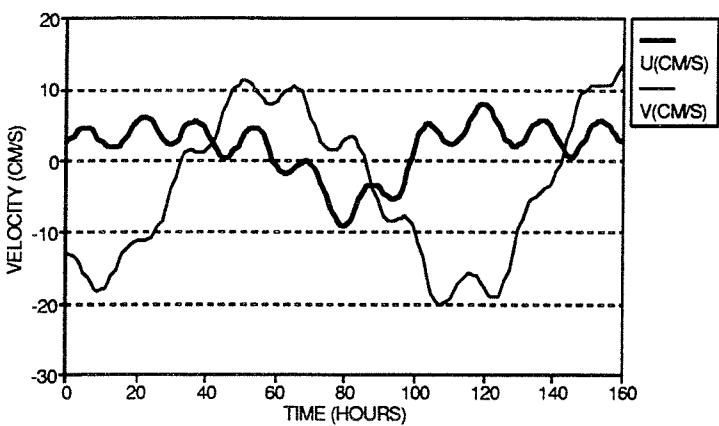


Figure 12. Observed currents from Site A, Hibernia (see Table 2 for exact location), bottom depth 81 m.

SITE C on SLOPE, 20m
STORM 26,27: 25 NOV - 1 DEC 1983



SITE C on SLOPE, 74m
STORM 26,27: 25 NOV - 1 DEC 1983



SITE C on SLOPE, 119m
STORM 26,27: 25 NOV - 1 DEC 1983

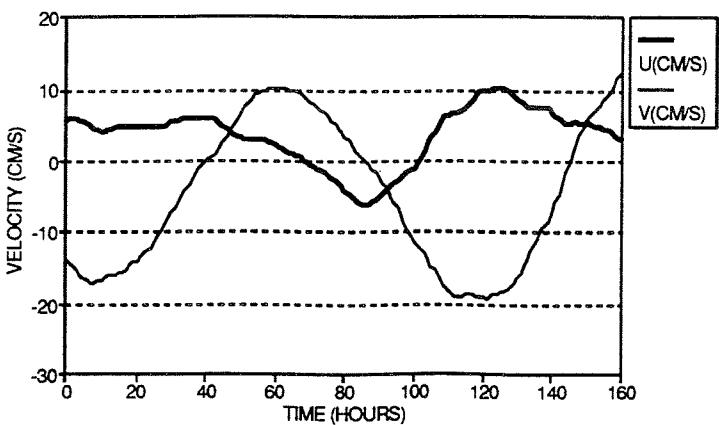
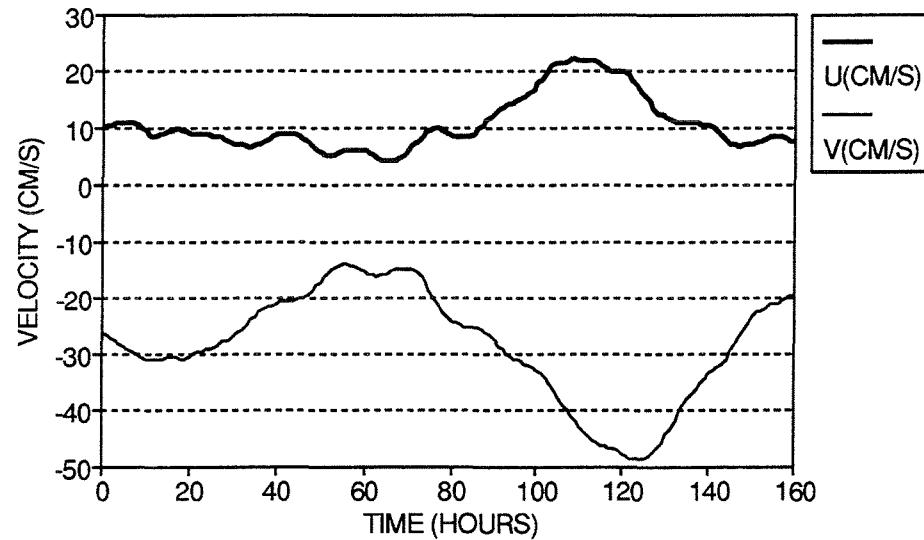


Figure 13. Observed currents from the slope to the east-northeast of Hibernia (see Table 2 for exact location), bottom depth 135 m.

SITE D on SLOPE, 110m
STORM 26,27: 25 NOV - 1 DEC 1983



SITE D on SLOPE, 214m
STORM 26,27: 25 NOV - 1 DEC 1983

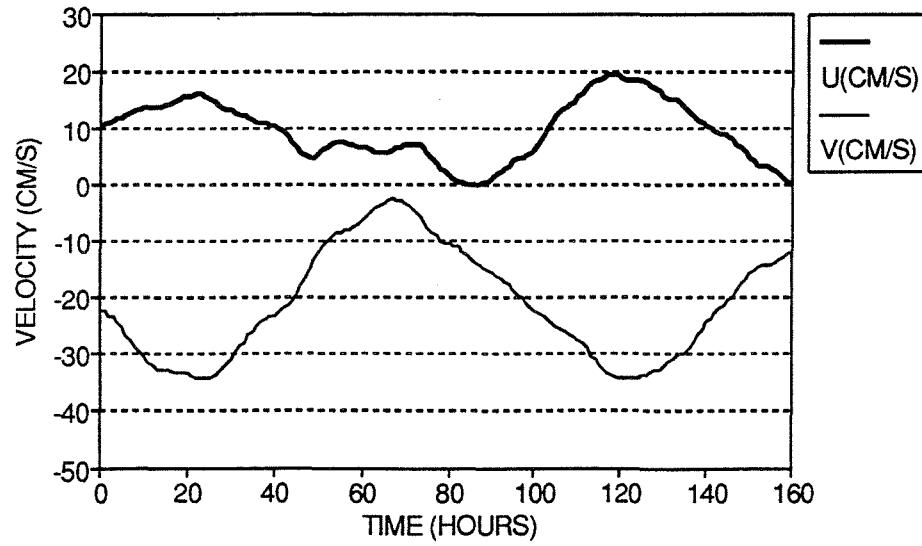
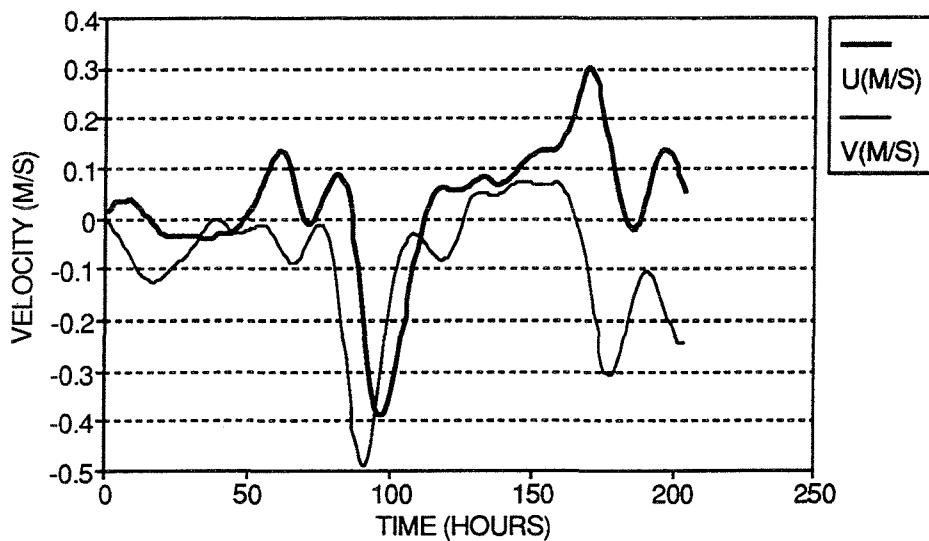


Figure 14. Observed currents from the slope to the southeast of Hibernia (see Table 2 for exact location), bottom depth 215 m.

MOBIL STORM 28 & 29

18-27 DEC. 1983



MOBIL STORM 28 & 29

18-27 DEC. 1983

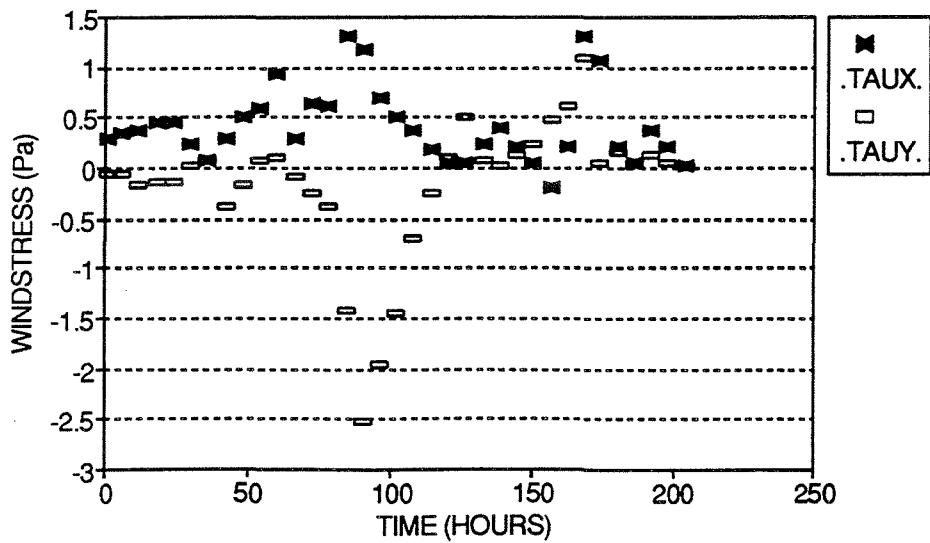


Figure 15. Predicted currents from model for input wind stress.

SITE E, HIBERNIA, 41m
STORM 28,29: 18-27 DEC 1983

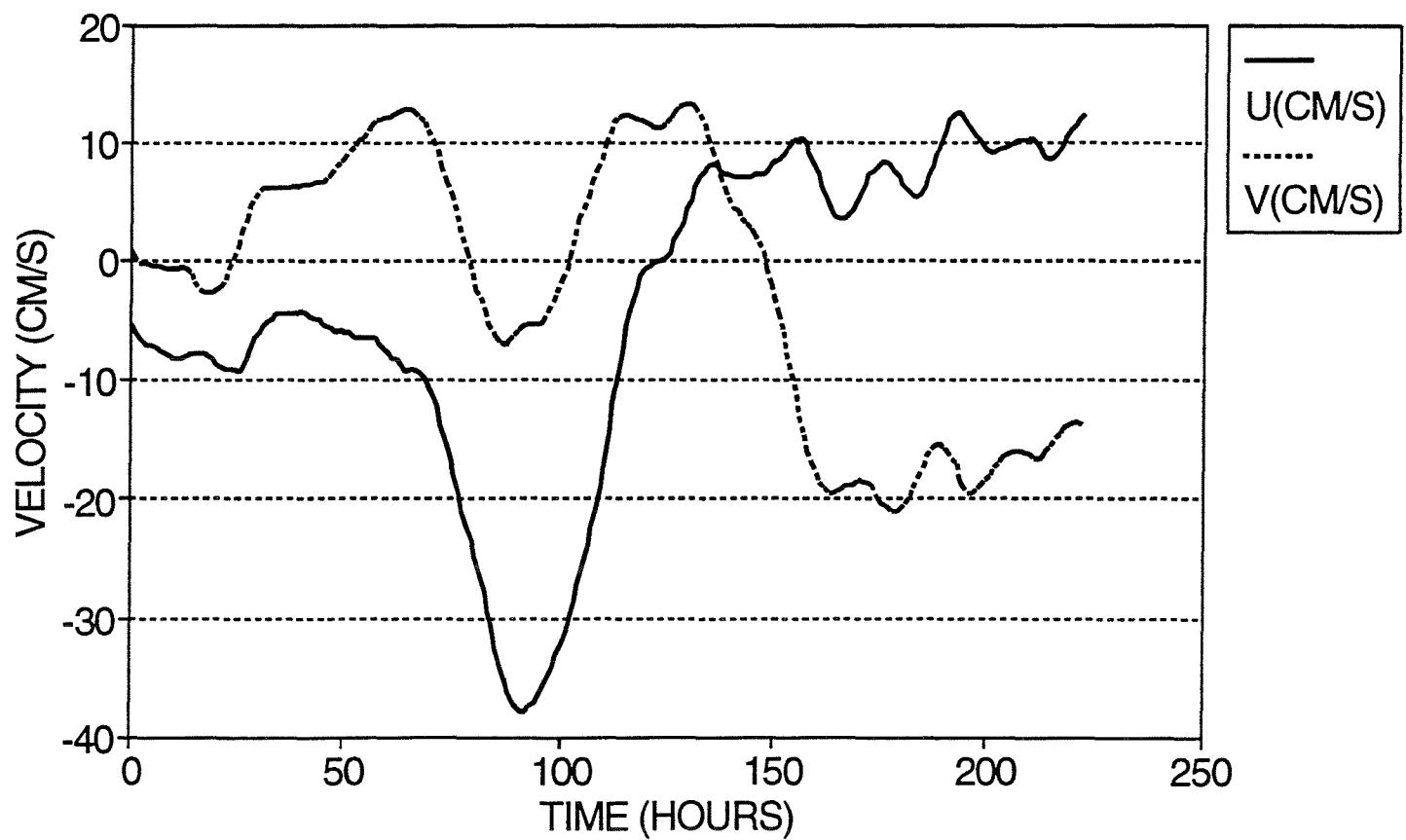
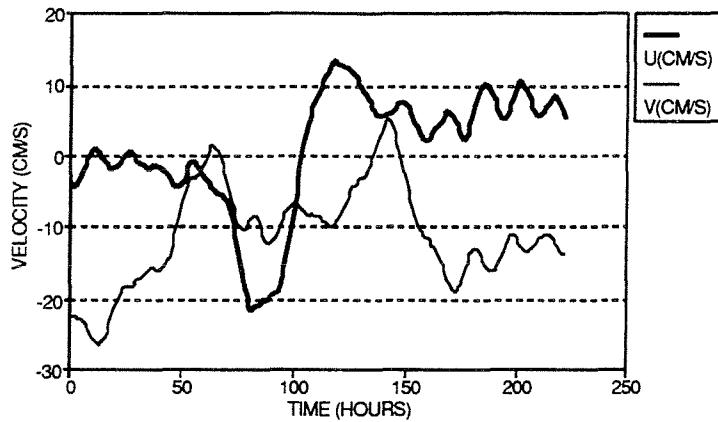
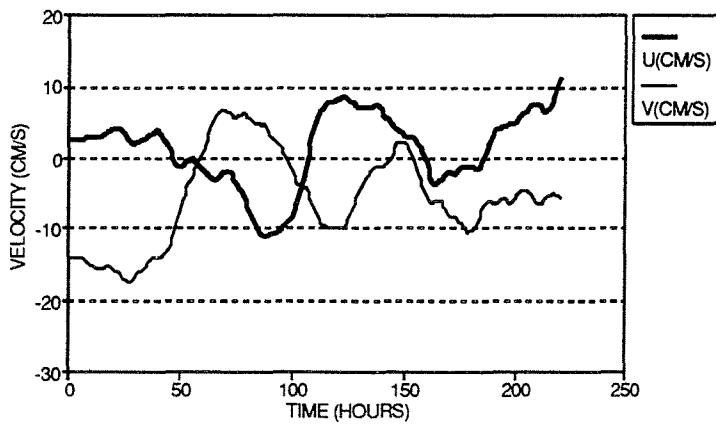


Figure 16. Observed currents from Site E, Hibernia (see Table 2 for exact location), bottom depth 80 m.

SITE C on SLOPE, 20m
STORM 28,29: 18-27 DEC 1983



SITE C on SLOPE, 74m
STORM 28,29: 18-27 DEC 1983



SITE C on SLOPE, 119m
STORM 28,29: 18-27 DEC 1983

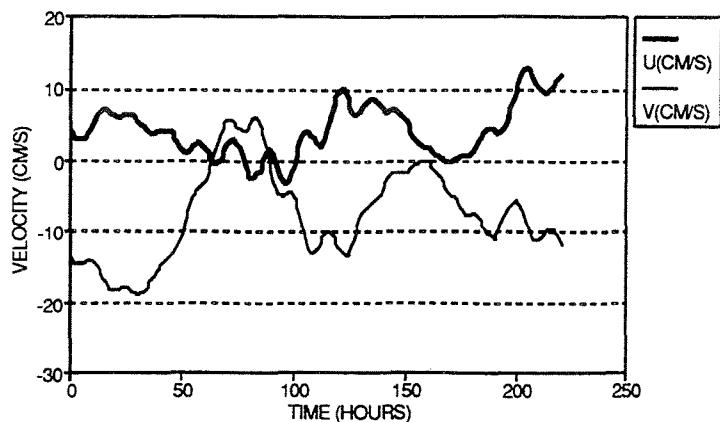


Figure 17. Observed currents from the slope to the east-northeast of Hibernia (see Table 2 for exact location), bottom depth 135 m.

MOBIL STORM 28 & 29

18-27 DEC. 1983

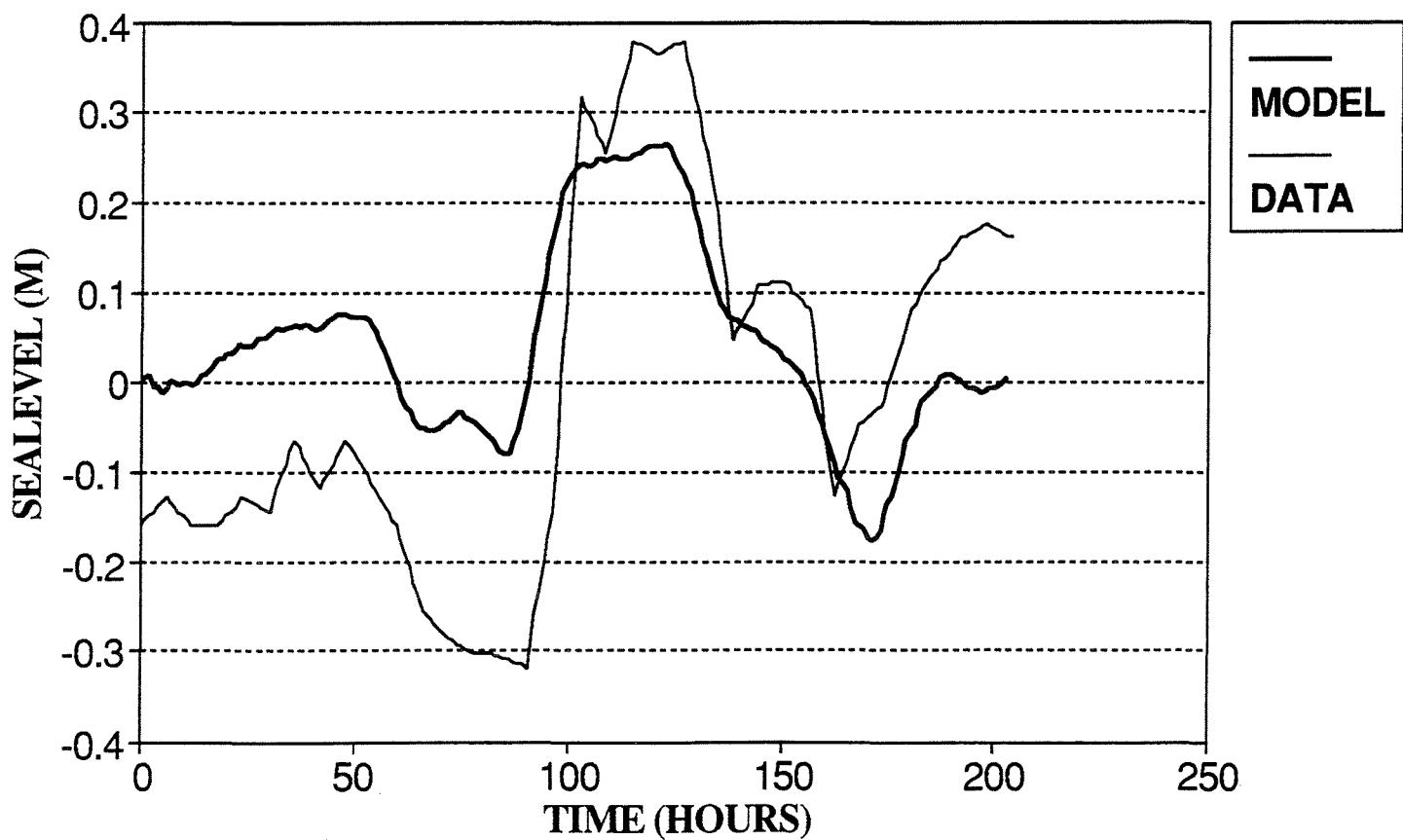
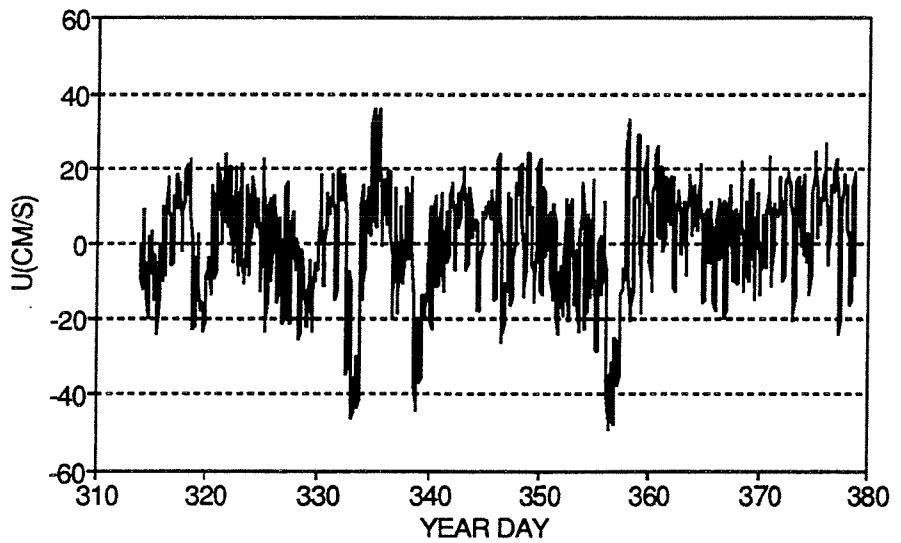


Figure 18. Comparison of bottom pressure observations from Hibernia with model predictions.

SITE E AT HIBERNIA
INSTR. DEPTH, 41m; SOUNDING, 80m



SITE E AT HIBERNIA
INSTR. DEPTH, 41m; SOUNDING, 80m

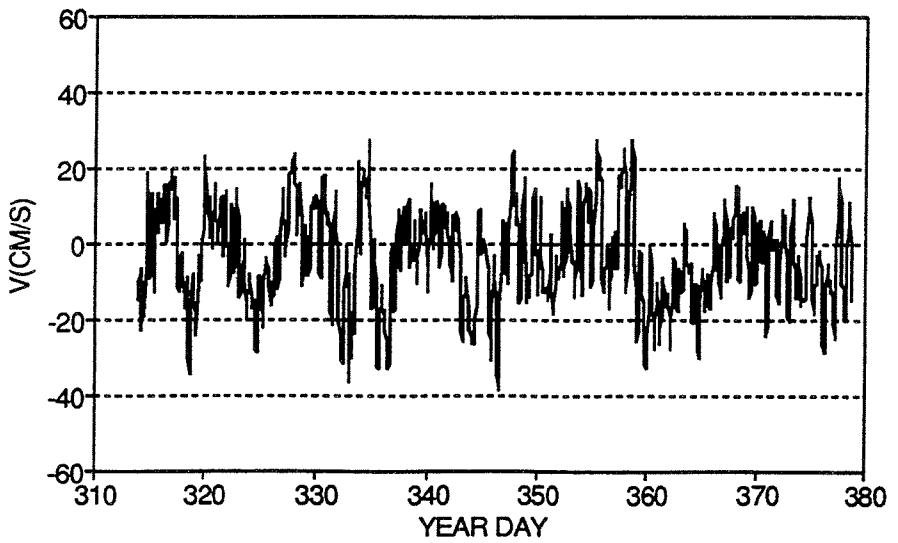


Figure 19. Current meter record from Site E, Hibernia,
starting on 9 Nov., 1983 and ending 13 Jan., 1984.

SITE E AT HIBERNIA

INSTR. DEPTH, 41m; SOUNDING, 80m

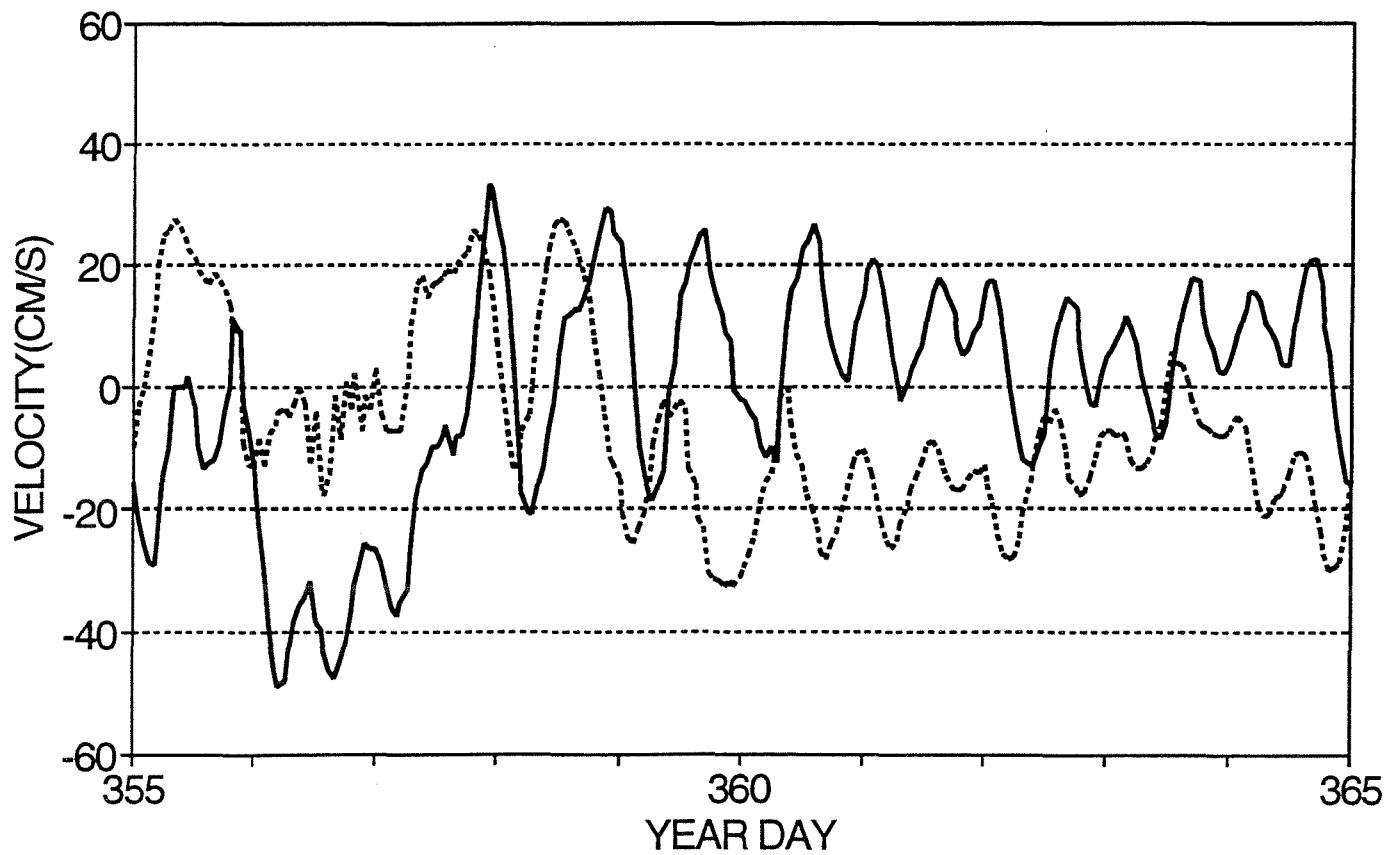
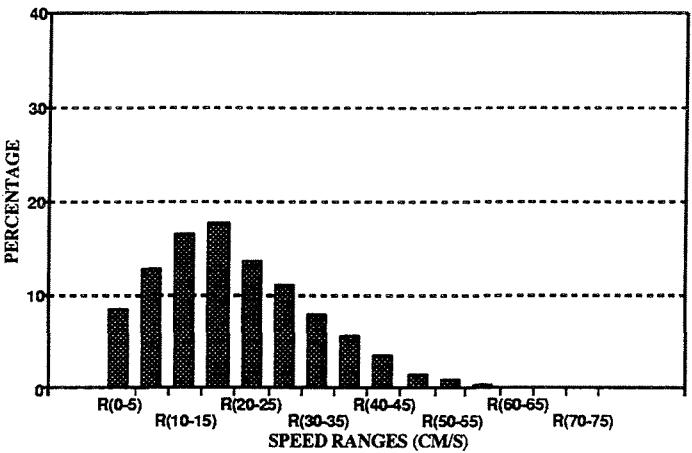
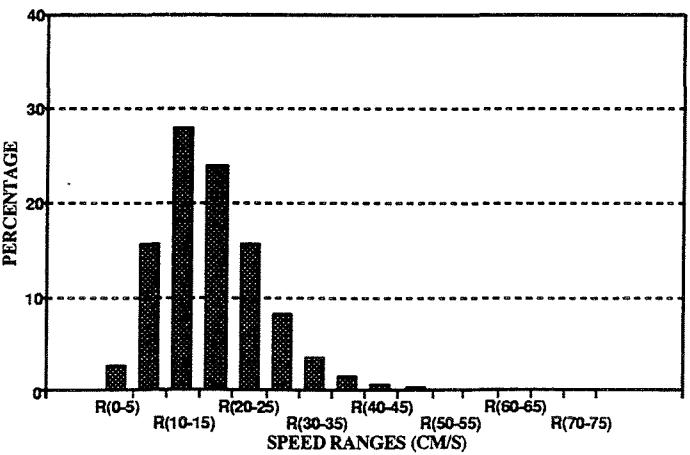


Figure 20. Portion of the current meter record from Site E, Hibernia, starting on 21 Dec. 1983 and illustrating the inertial period motions.

CURRENT RATE DISTRIBUTION HIBERNIA, NEAR-SURFACE



CURRENT RATE DISTRIBUTION HIBERNIA, MID-DEPTH



CURRENT RATE DISTRIBUTION HIBERNIA, NEAR-BOTTOM

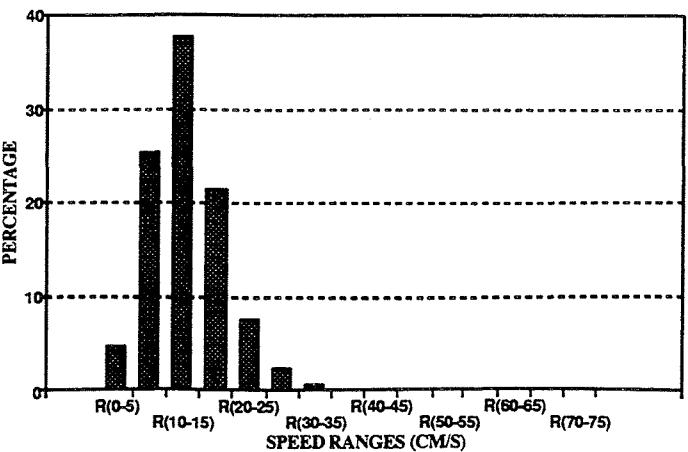


Figure 21. Histograms of current rate at Hibernia from Petrie and Warnell (1988).

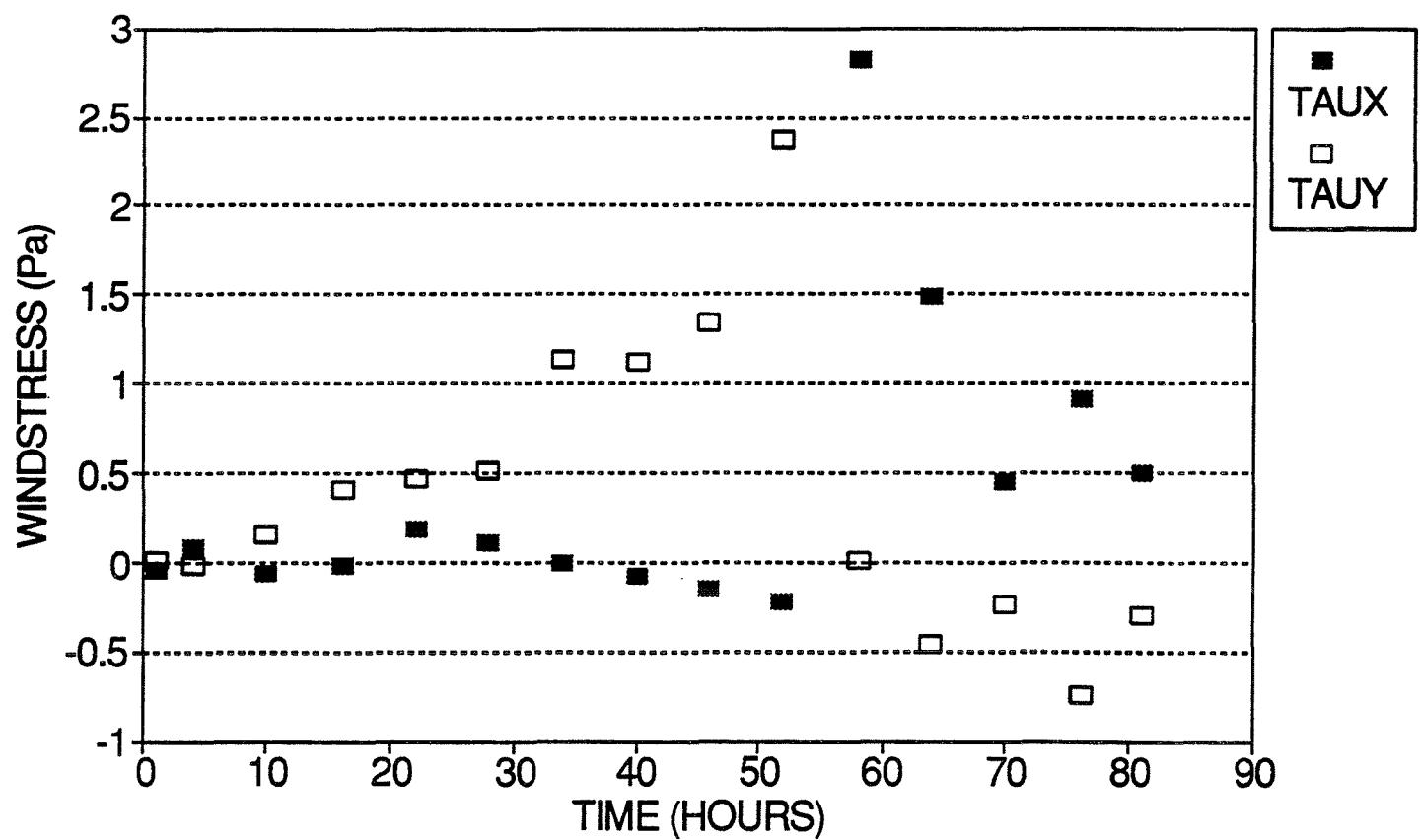
APPENDIX

Plots of wind stress and barotropic model results for each storm are presented in the following order:

- 1) TAUX and TAUY, the x and y components of wind stress at Hibernia;
- 2) U and V, the x and y components of current at Hibernia;
- 3) The sea-level variation due to wind forcing alone (ASL), the isostatic adjustment due to barometric pressure (IA), the sea-level variation due to the combined effects of wind and atmospheric pressure at Hibernia;
- 4) Plan view of predicted currents in model domain at height of storm.

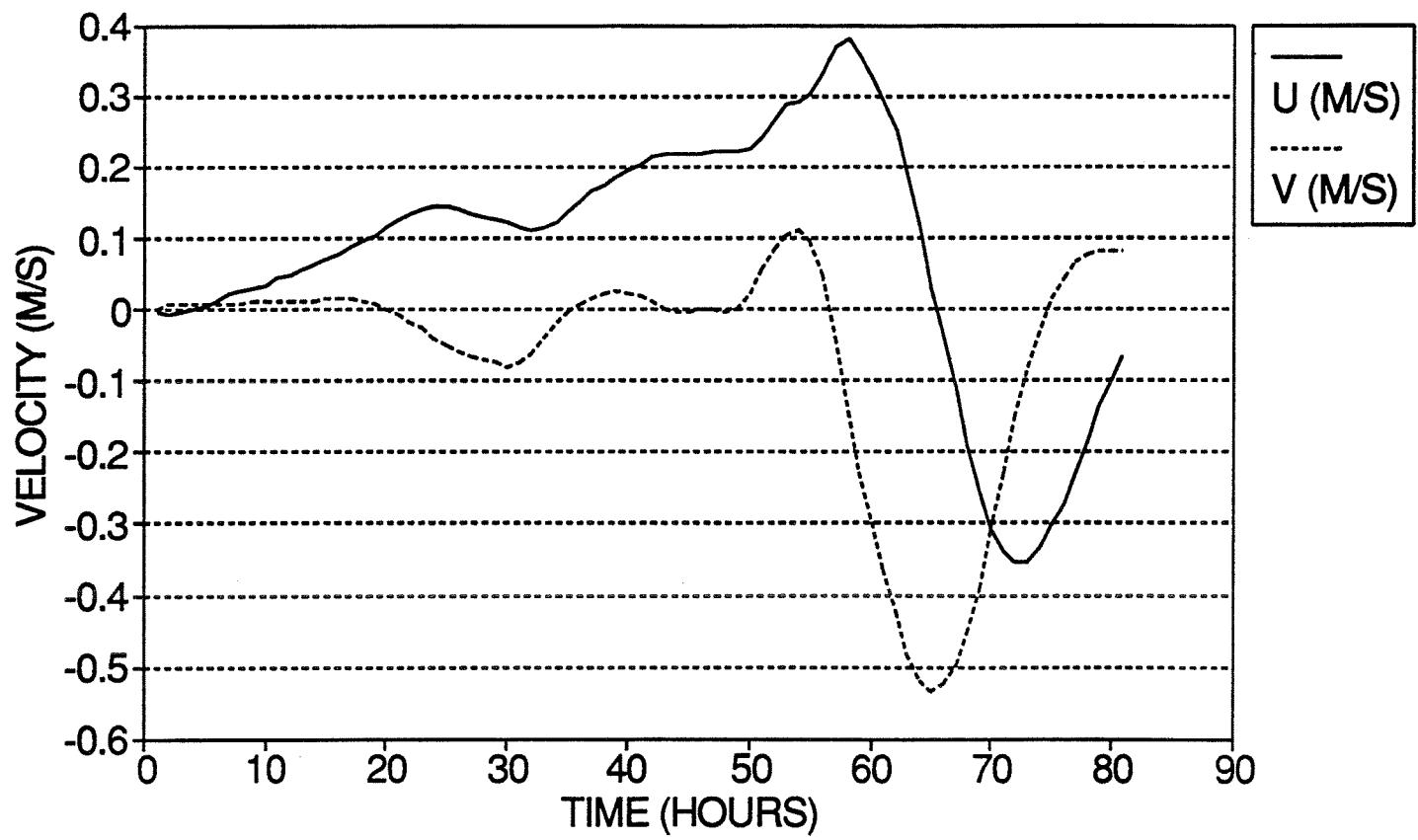
MOBIL STORM 1

26-29 OCT. 1973



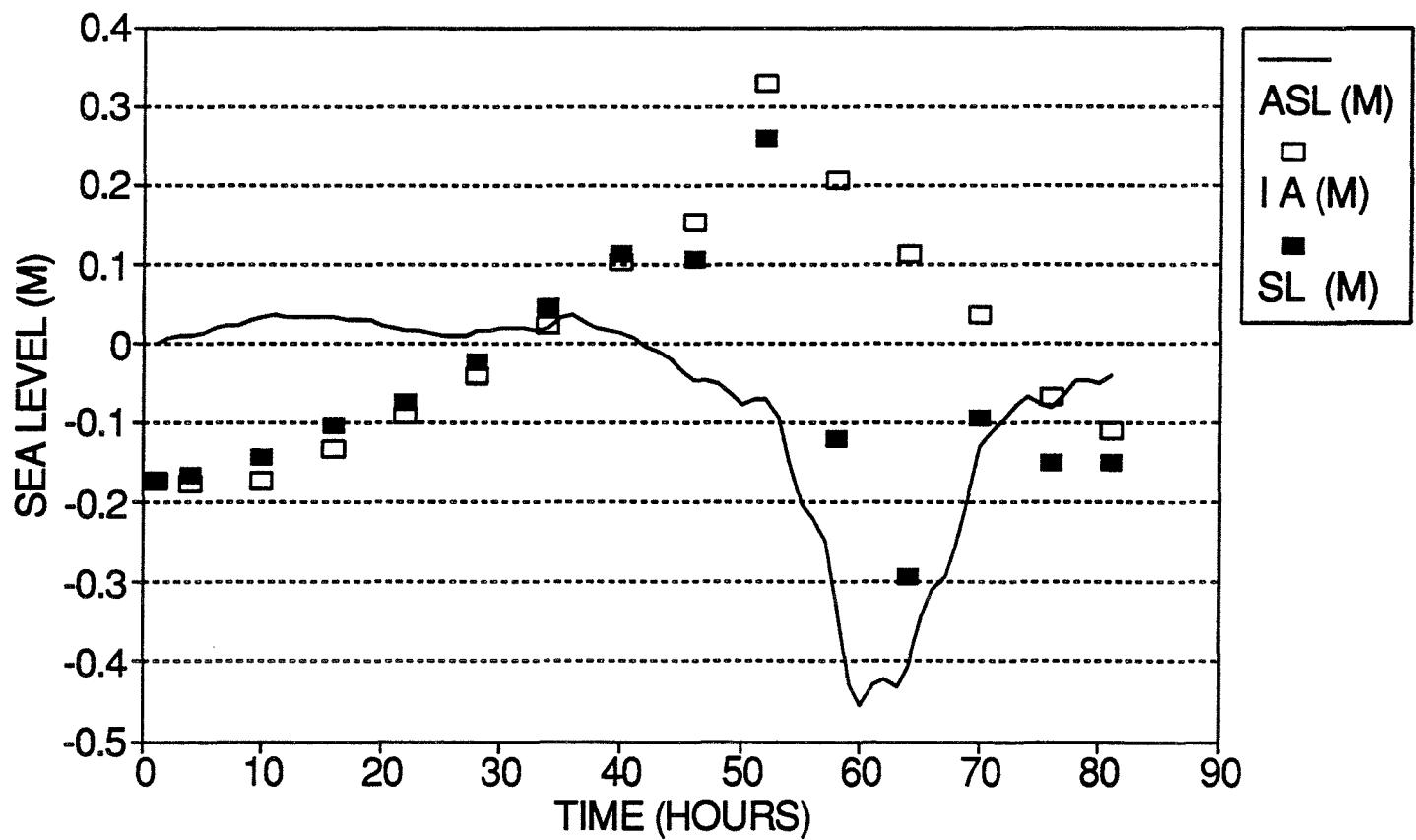
MOBIL STORM 1

26-29 OCT. 1973

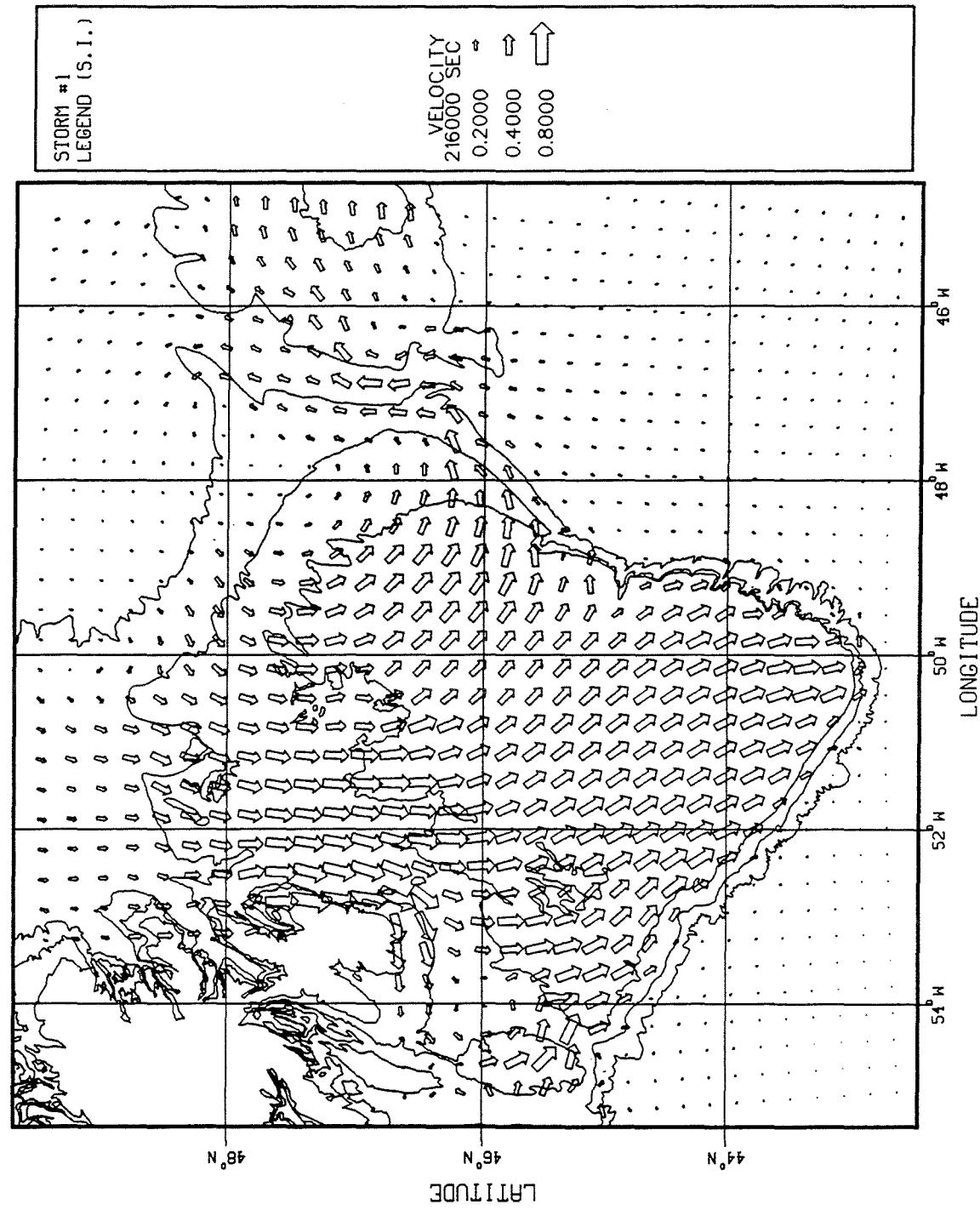


MOBIL STORM 1

26-29 OCT. 1973

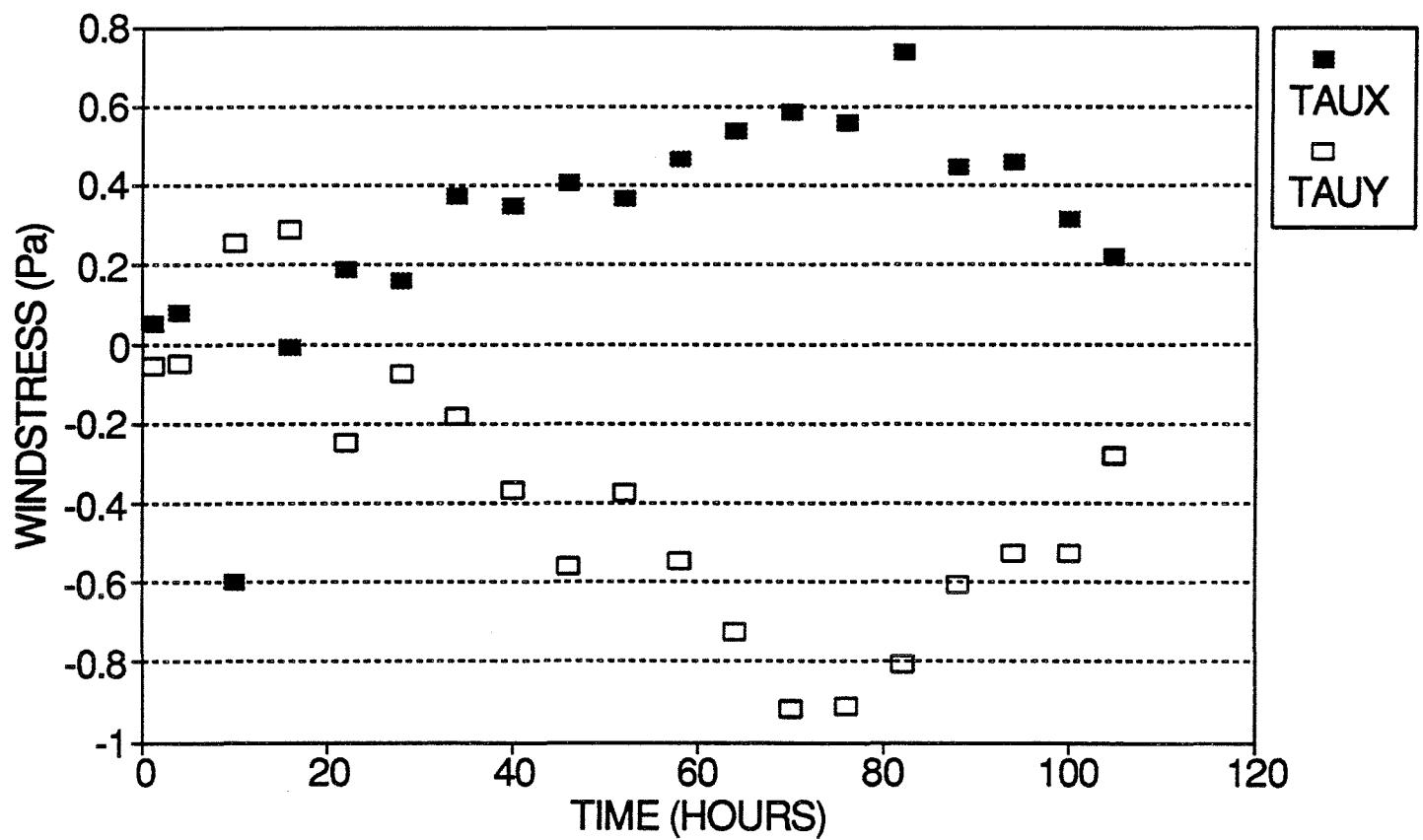


GRAND BANKS STORM MODEL



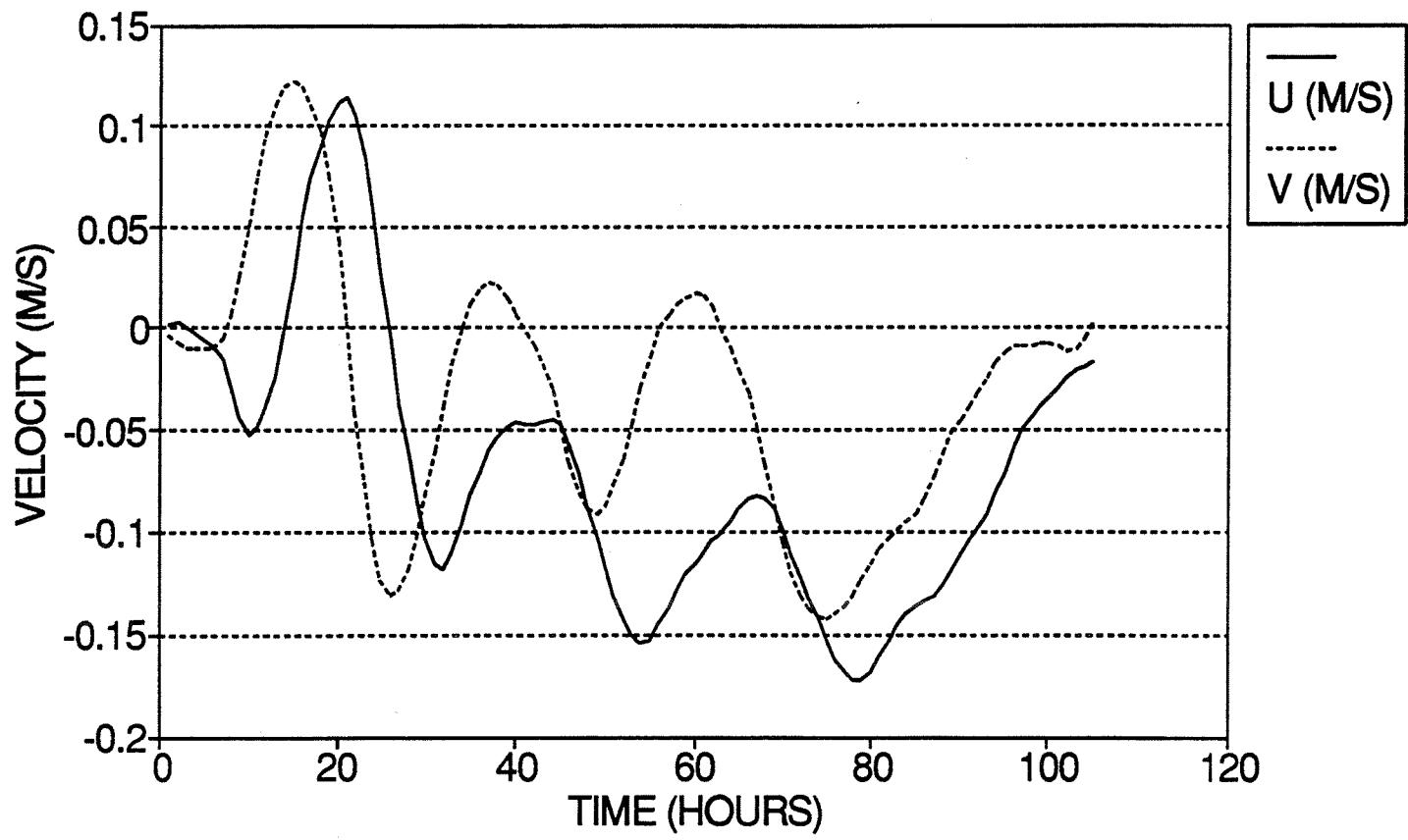
MOBIL STORM 2

21-25 FEB. 1966



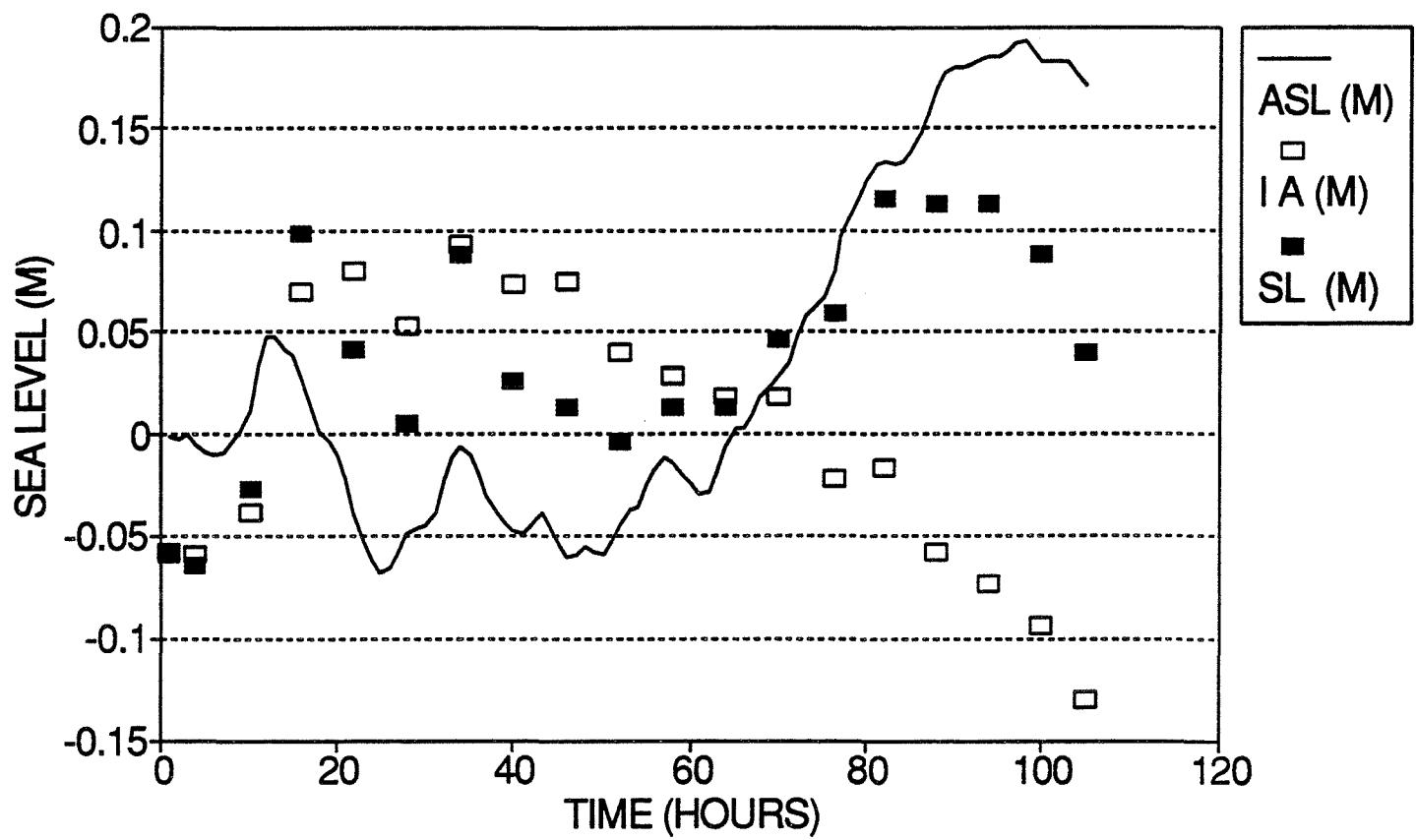
MOBIL STORM 2

21-25 FEB. 1966

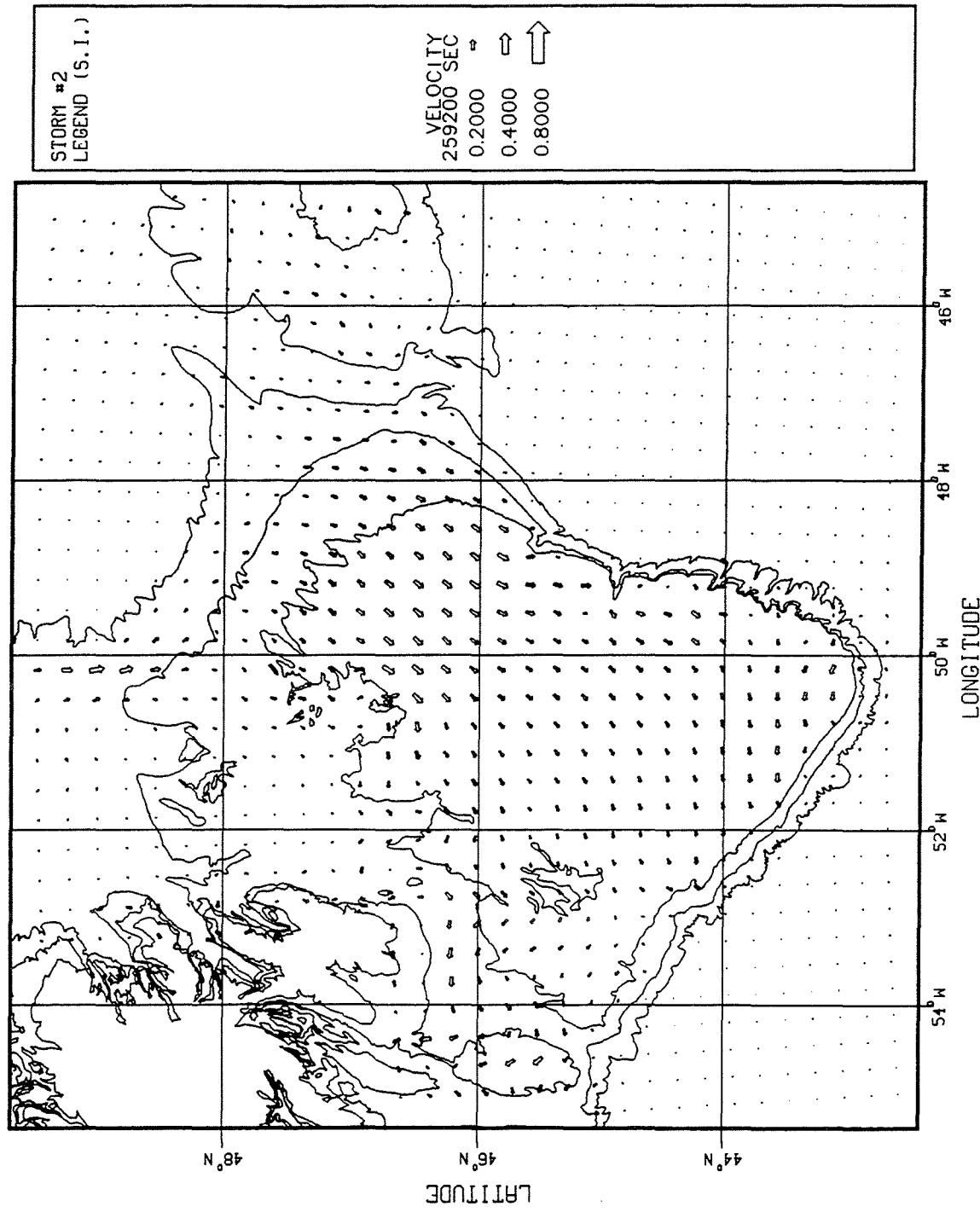


MOBIL STORM 2

21-25 FEB. 1966

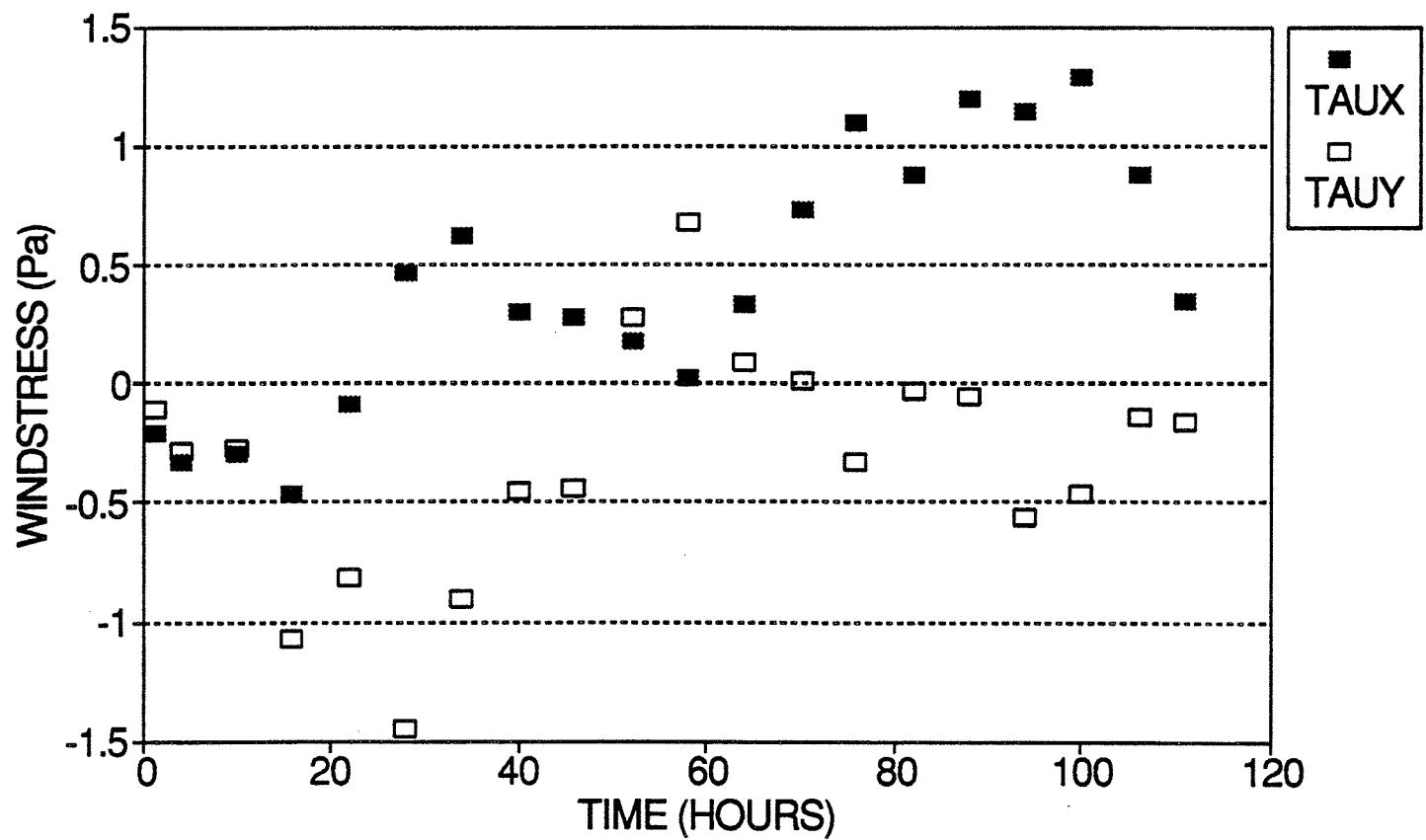


GRAND BANKS STORM MODEL



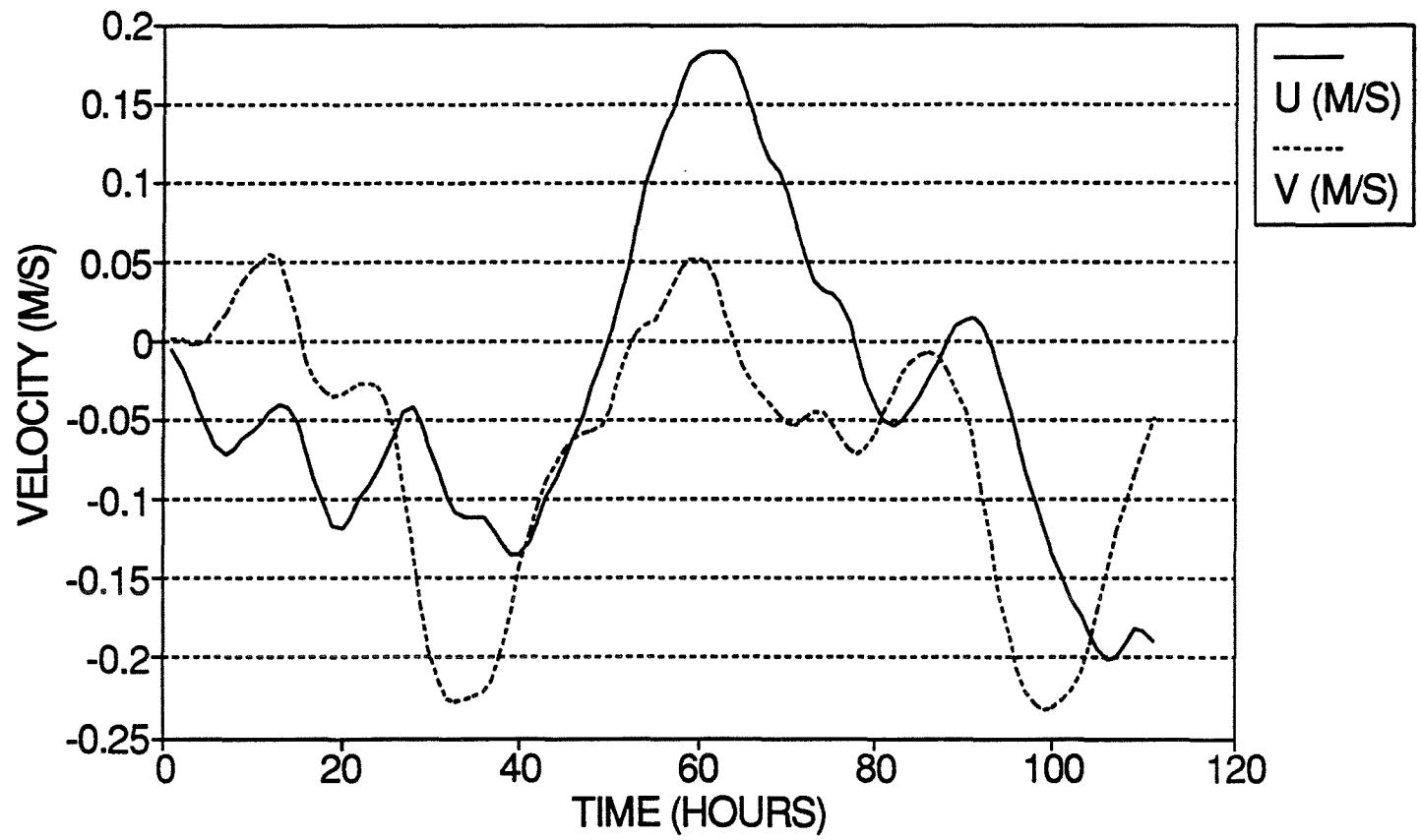
MOBIL STORM 3

14-18 MAR. 1964



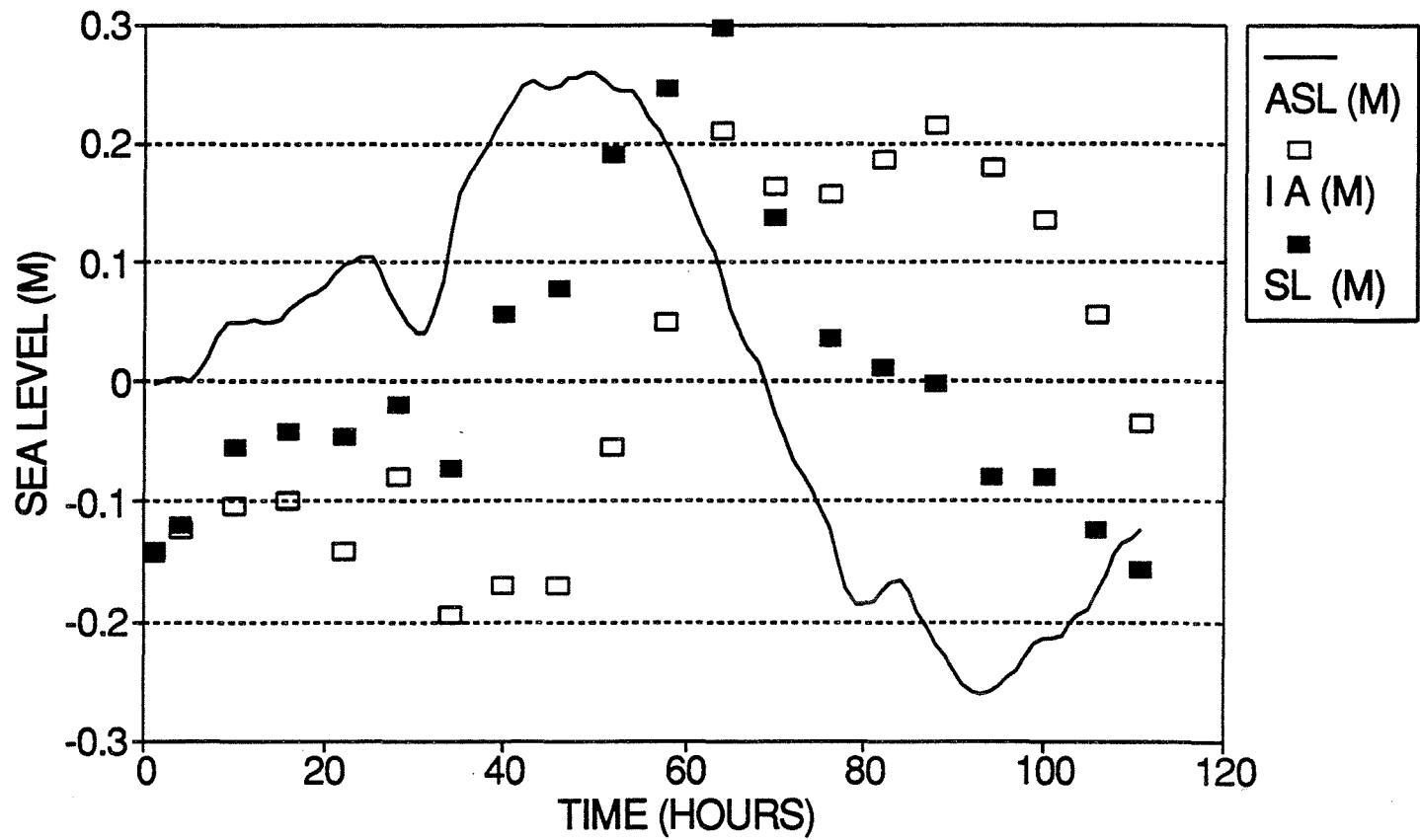
MOBIL STORM 3

14-18 MAR. 1964



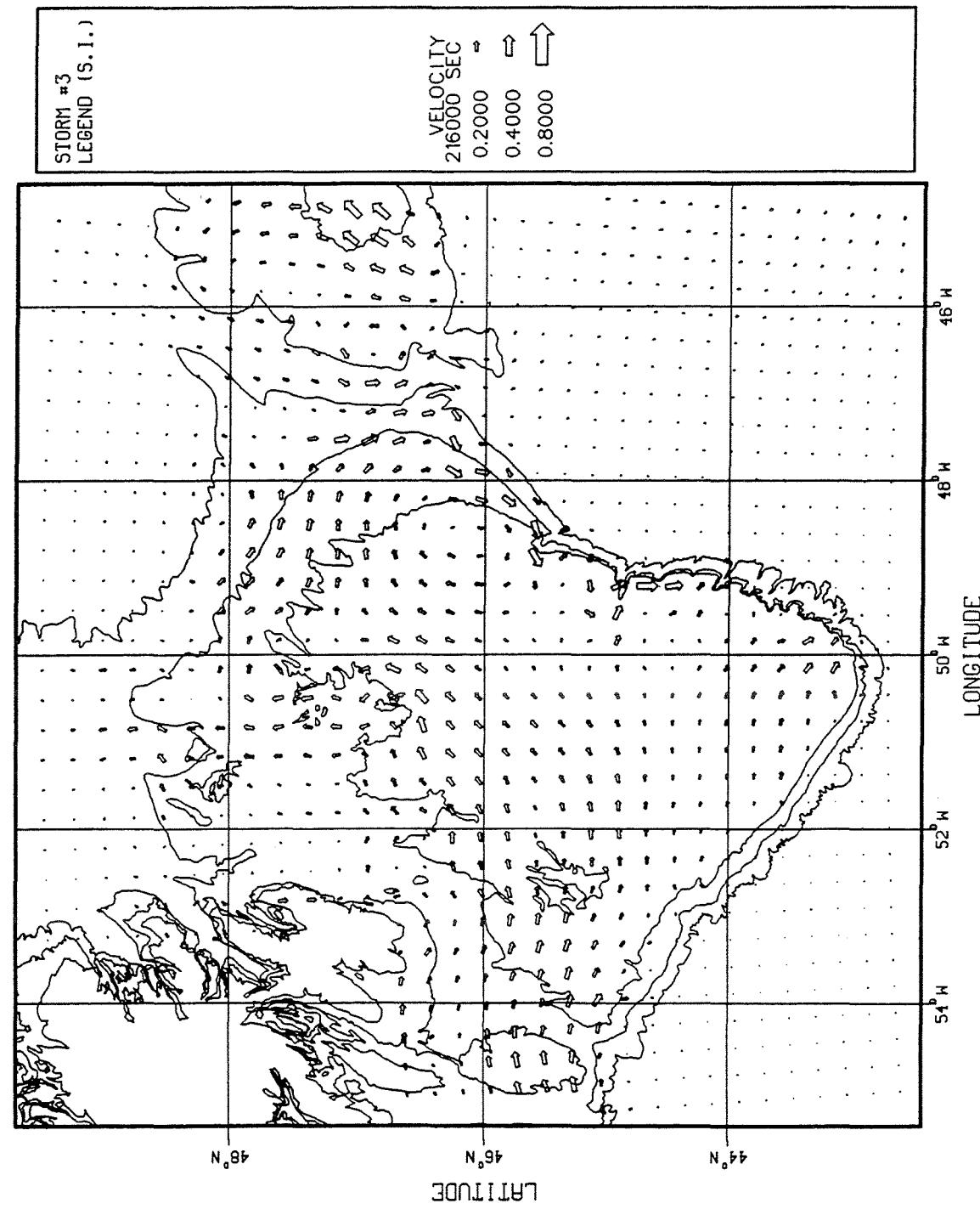
MOBIL STORM 3

14-18 MAR. 1964



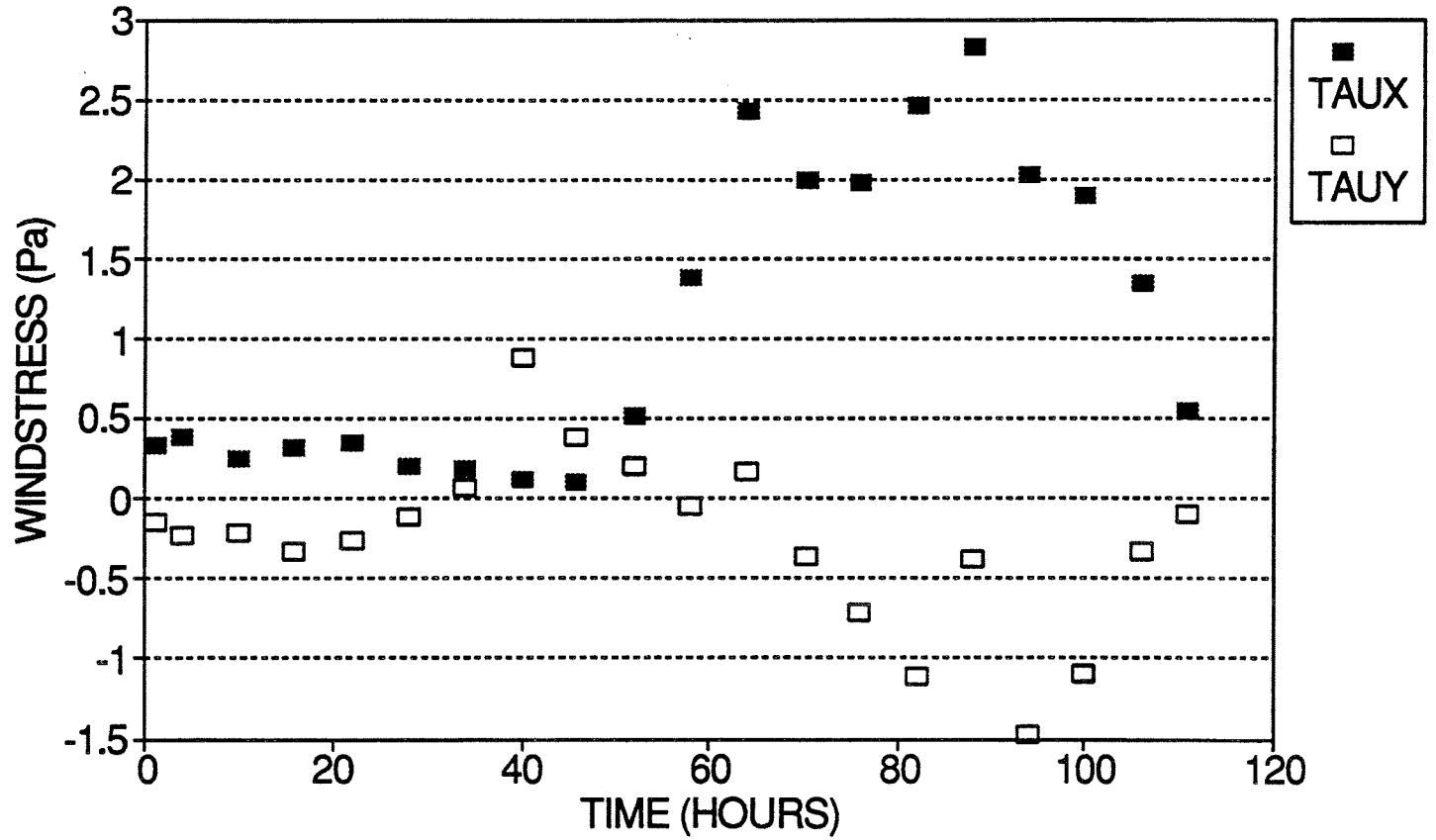
GRAND BANKS STORM MODEL

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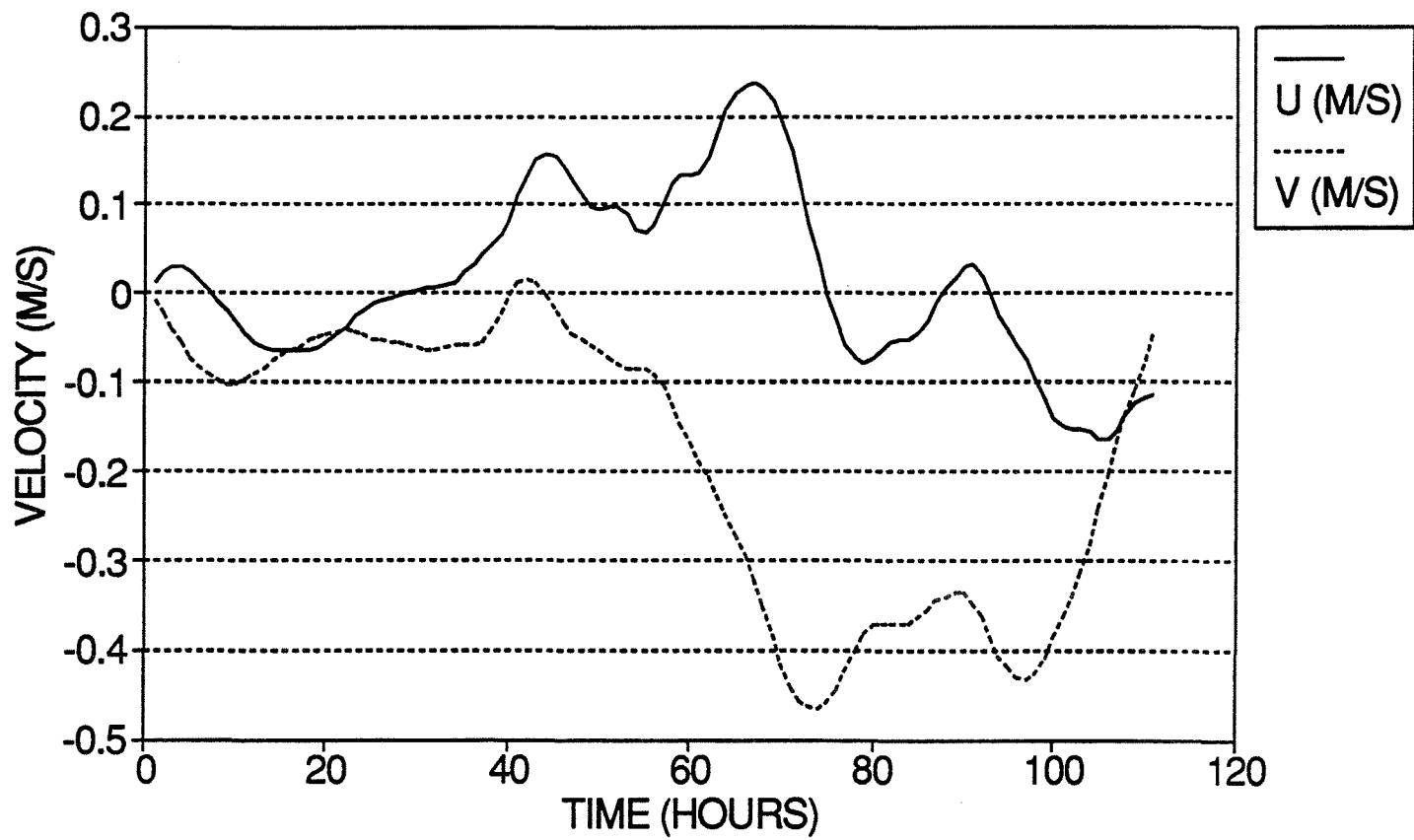
MOBIL STORM 4

13-17 FEB. 1966



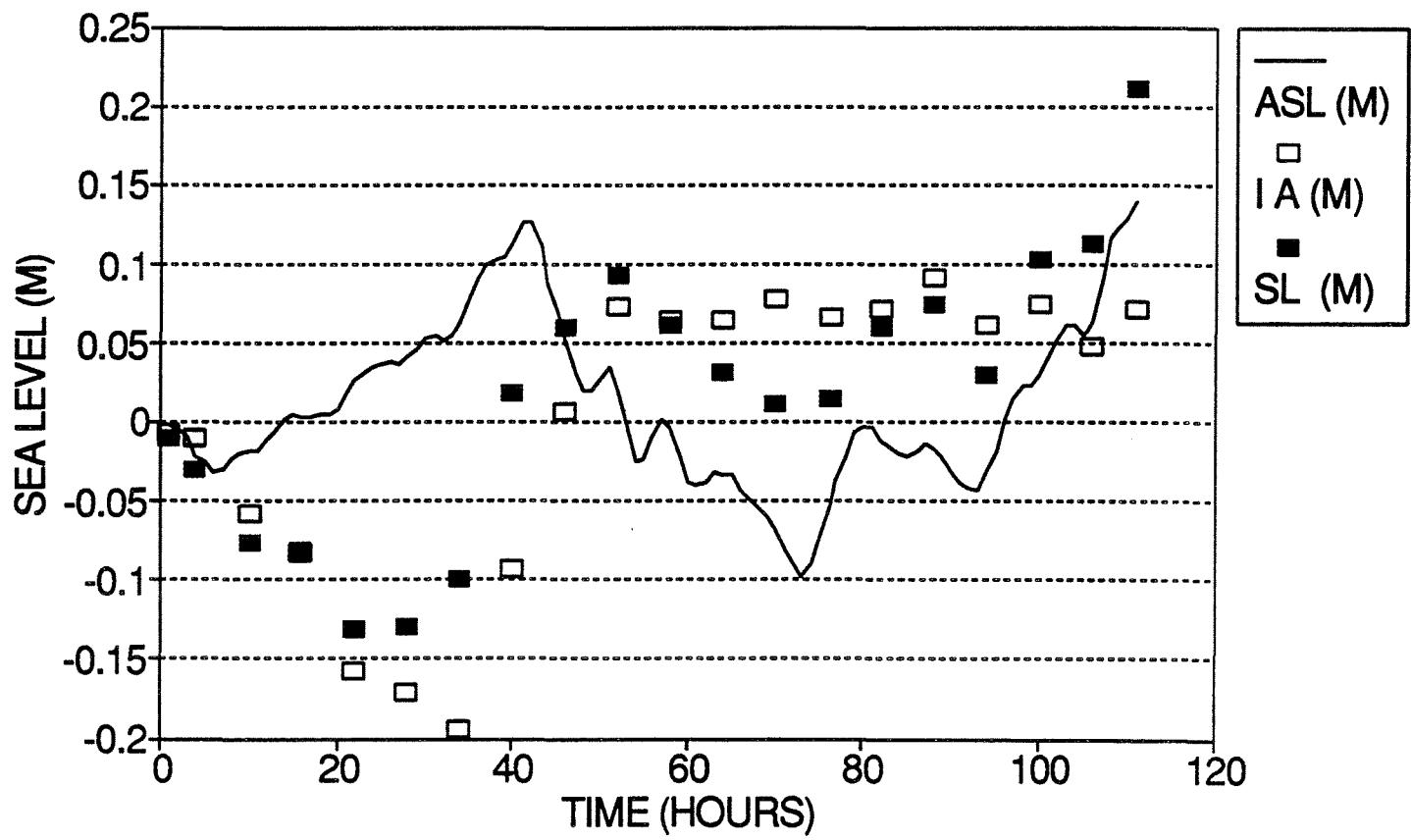
MOBIL STORM 4

13-17 FEB. 1966



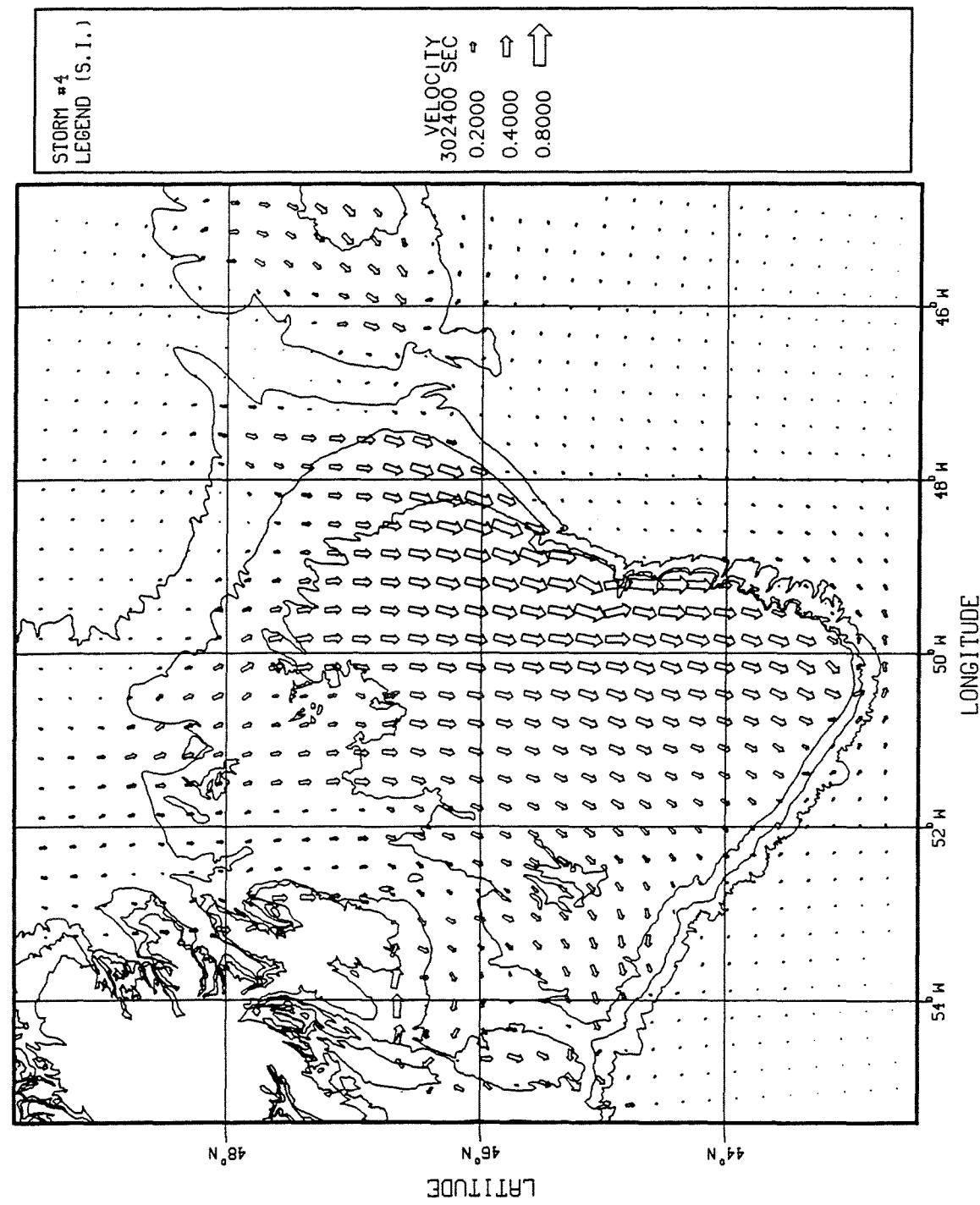
MOBIL STORM 4

13-17 FEB. 1966



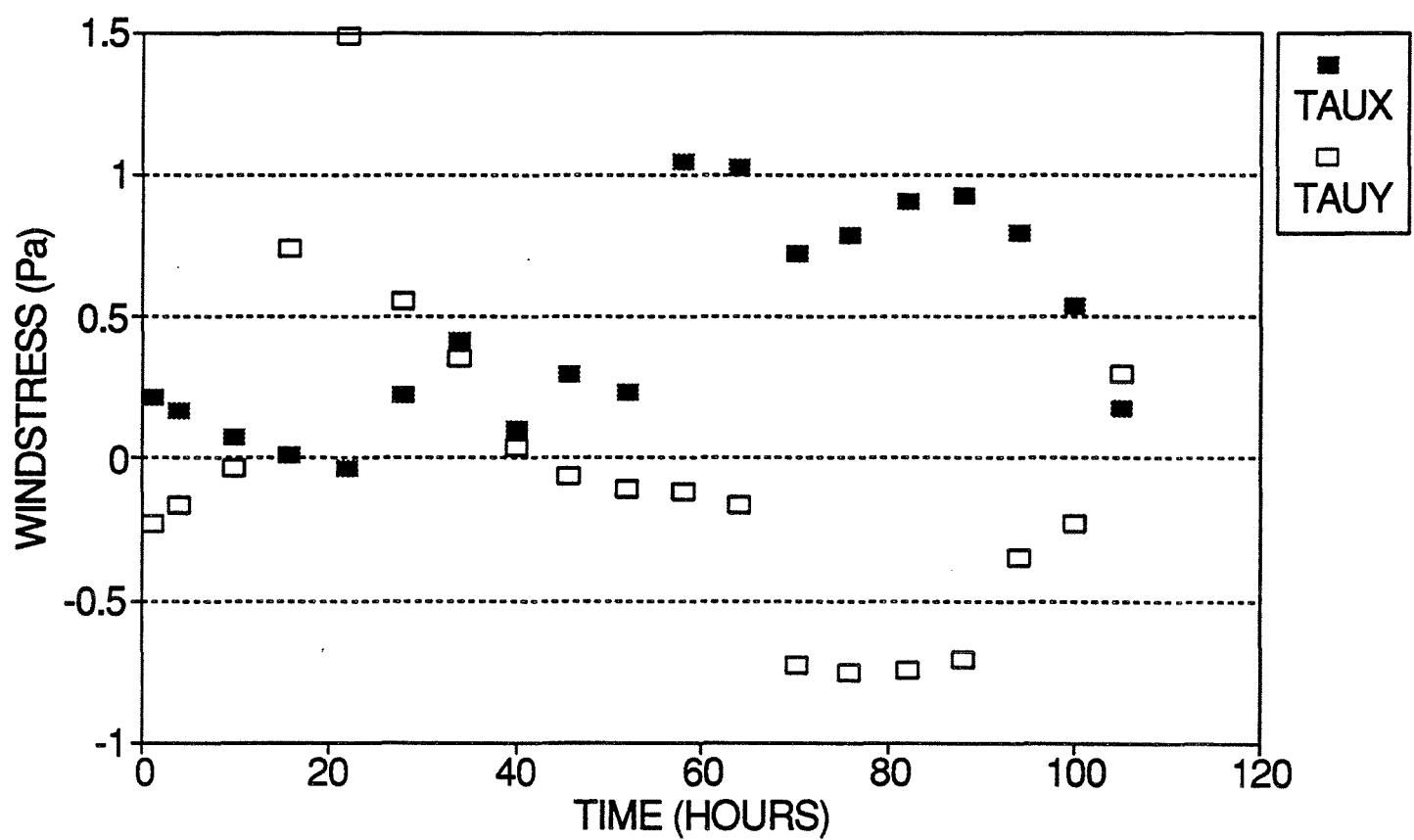
GRAND BANKS STORM MODEL

49



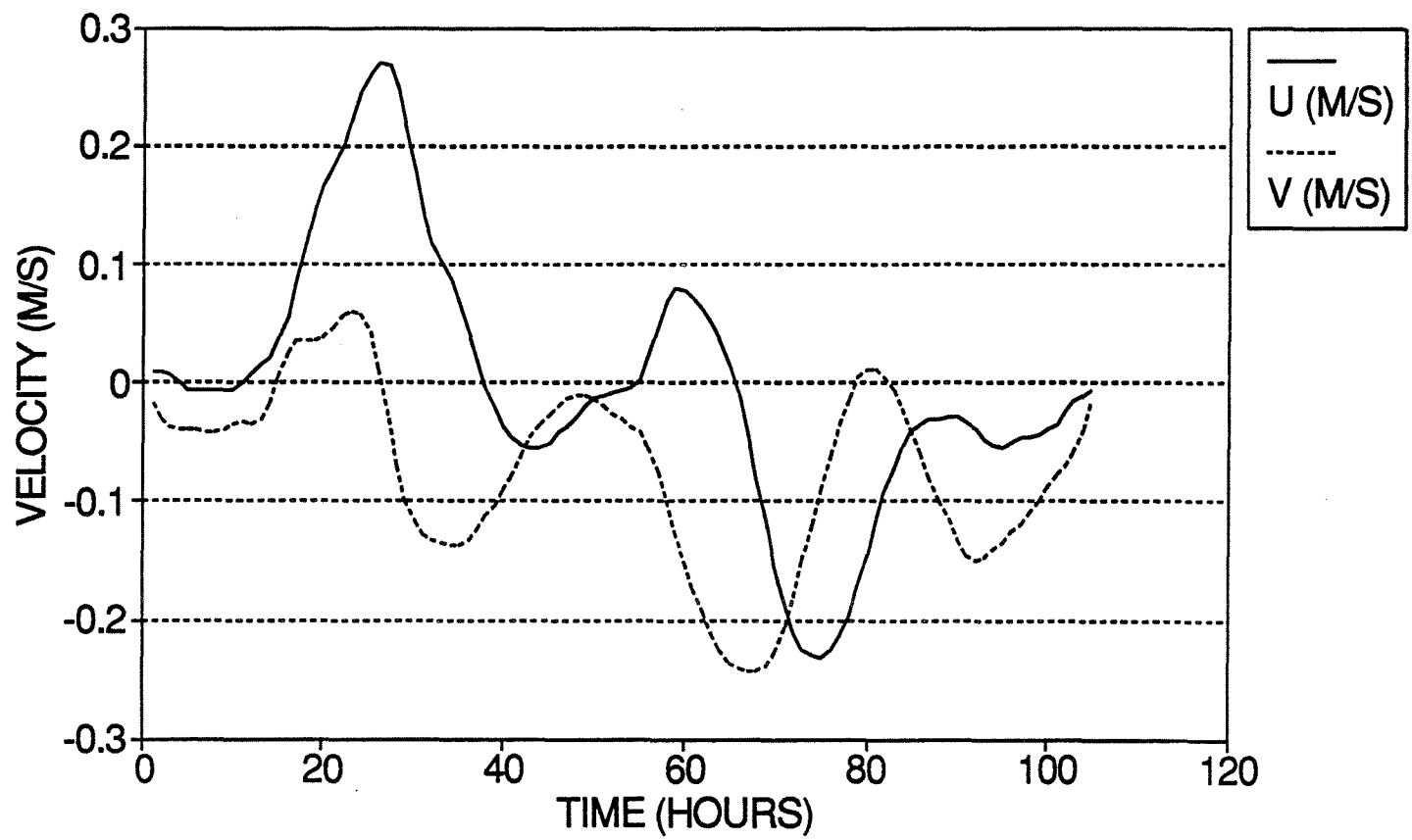
MOBIL STORM 5

10-14 JAN. 1964



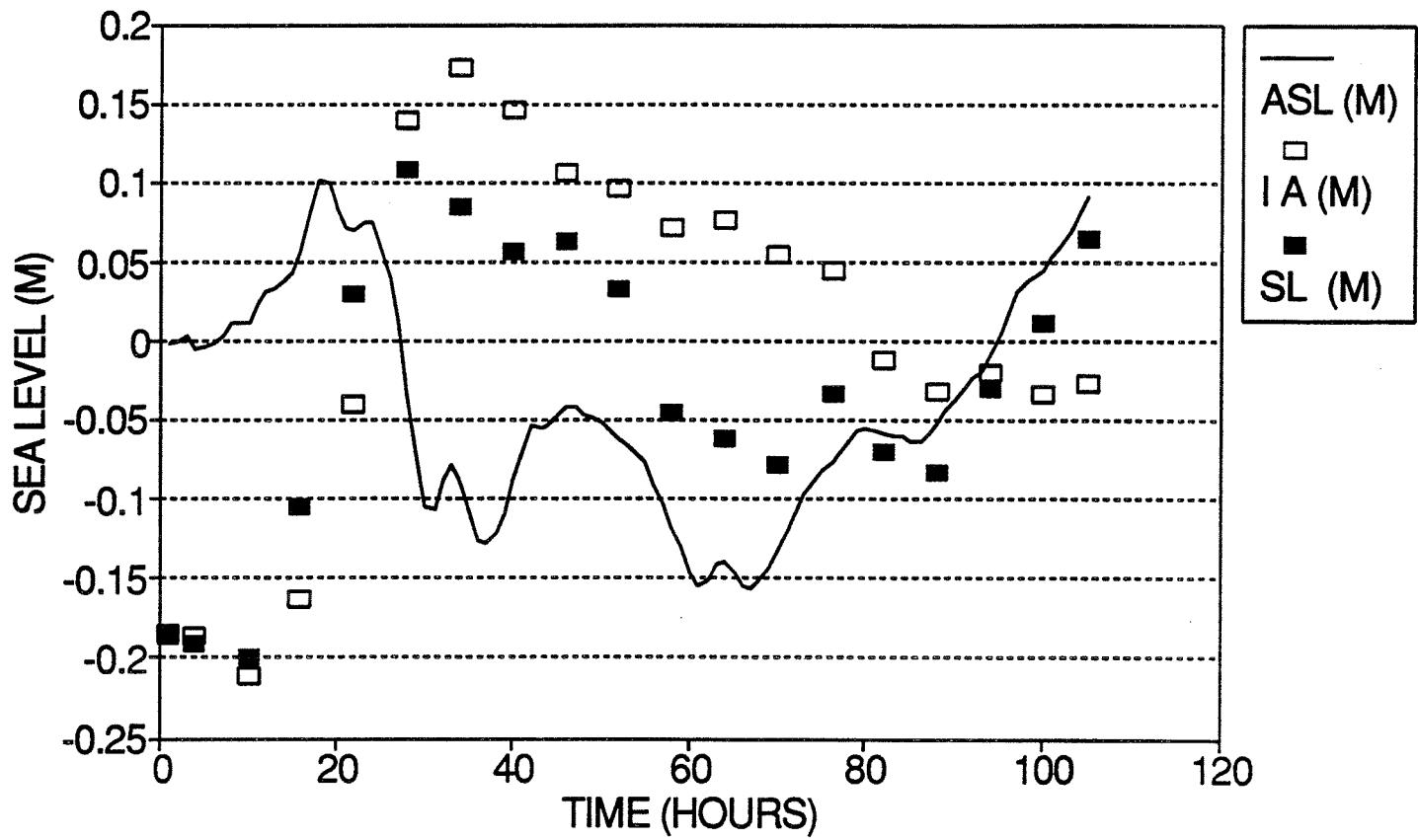
MOBIL STORM 5

10-14 JAN. 1964

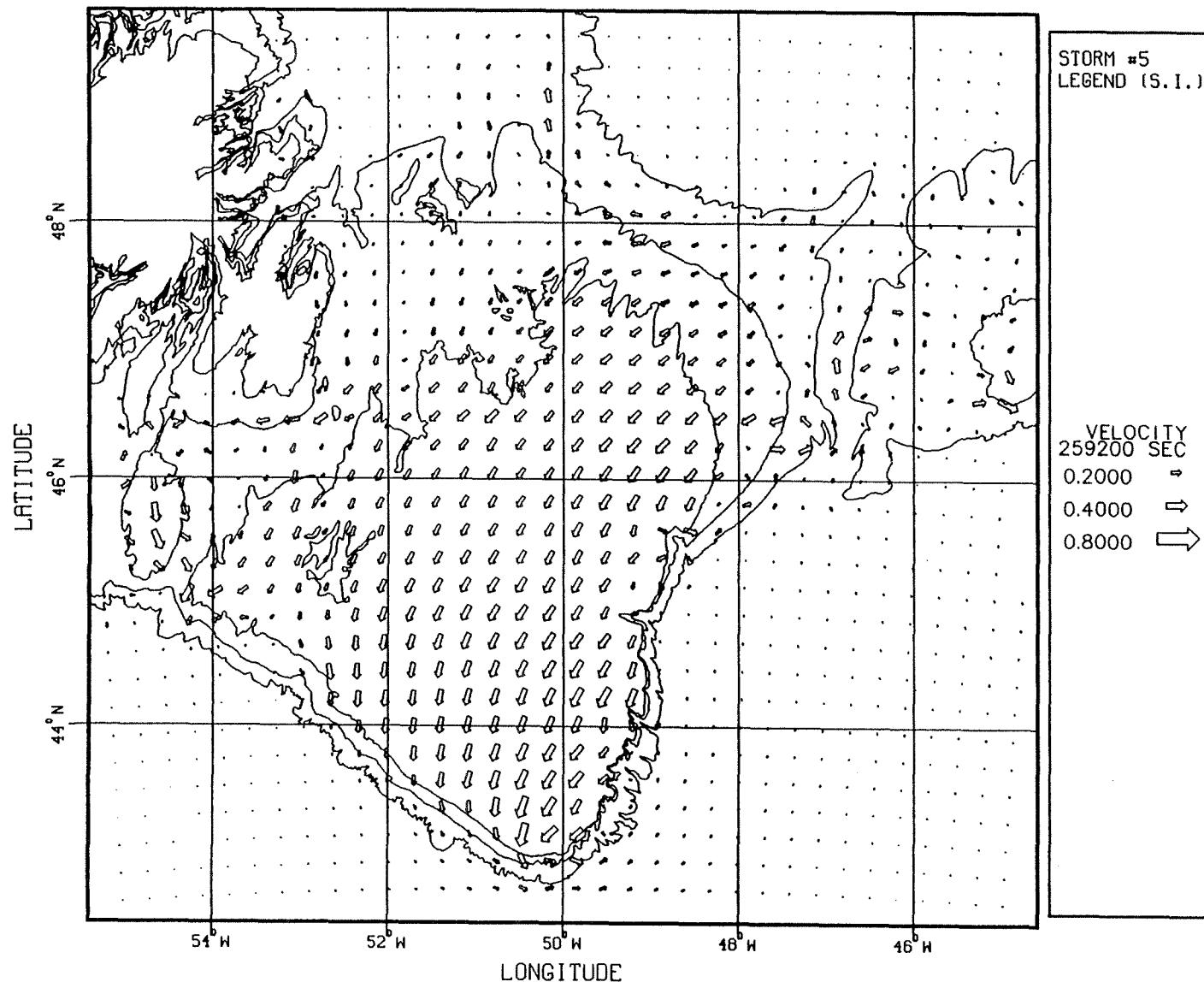


MOBIL STORM 5

10-14 JAN. 1964

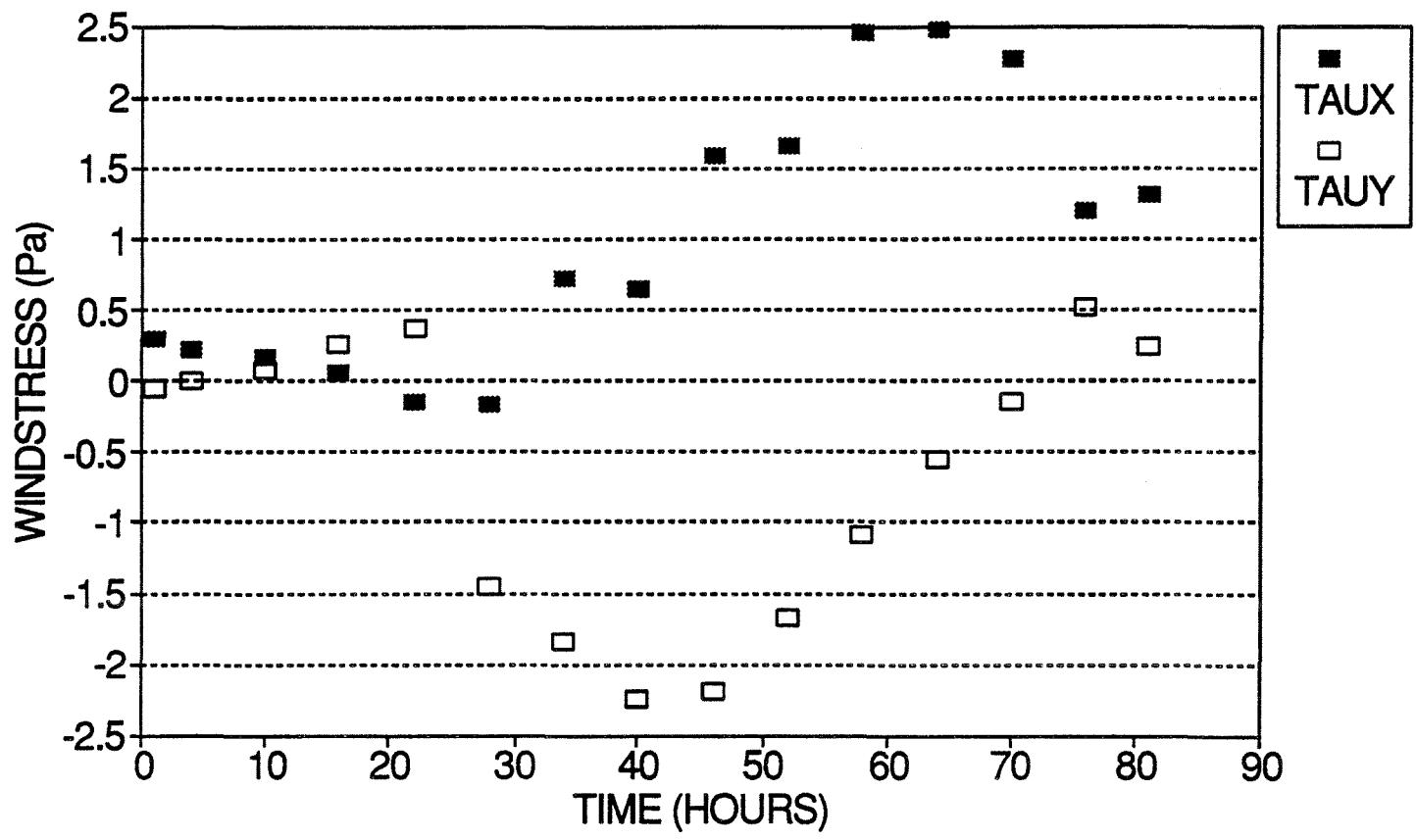


GRAND BANKS STORM MODEL



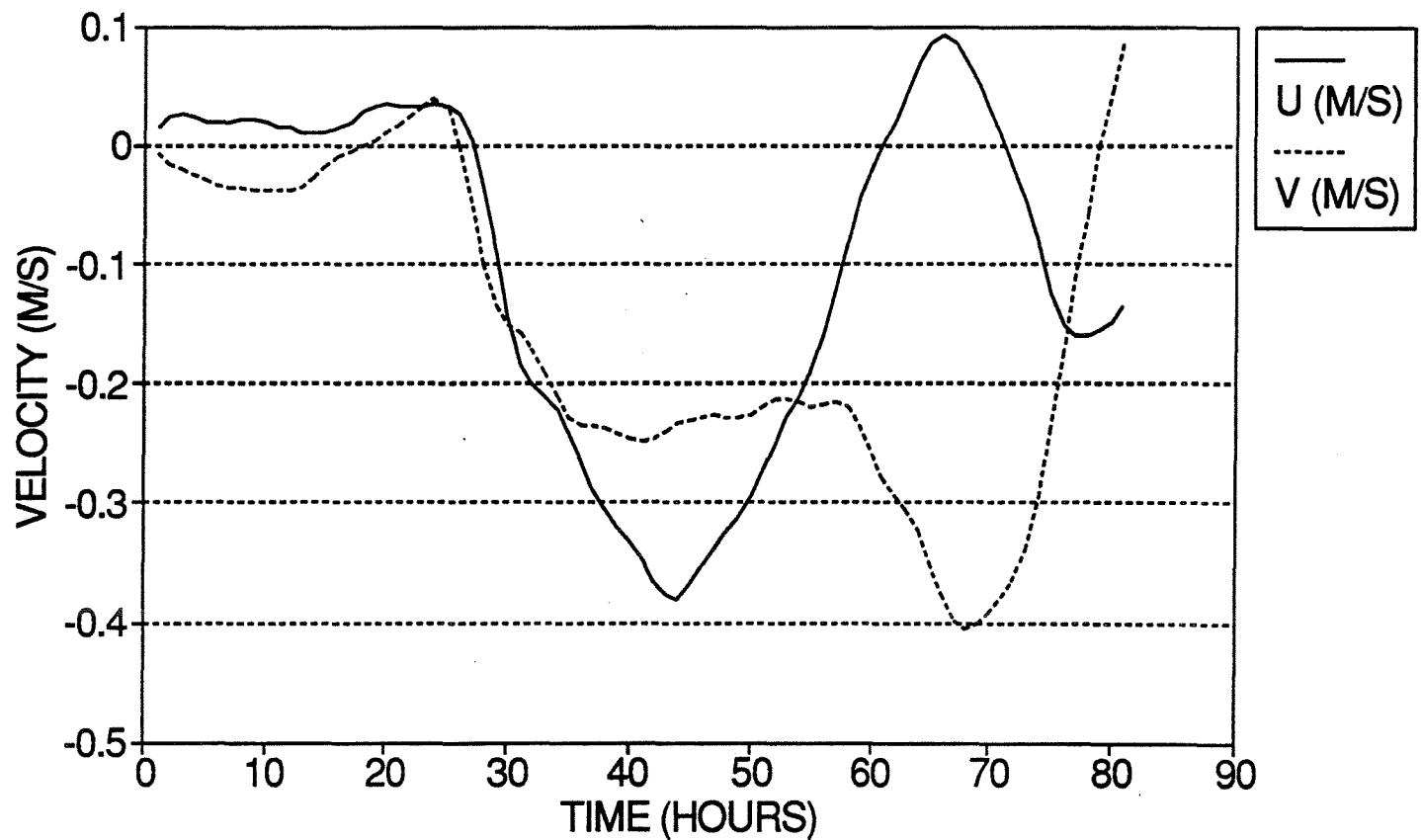
MOBIL STORM 6

15-18 DEC. 1961



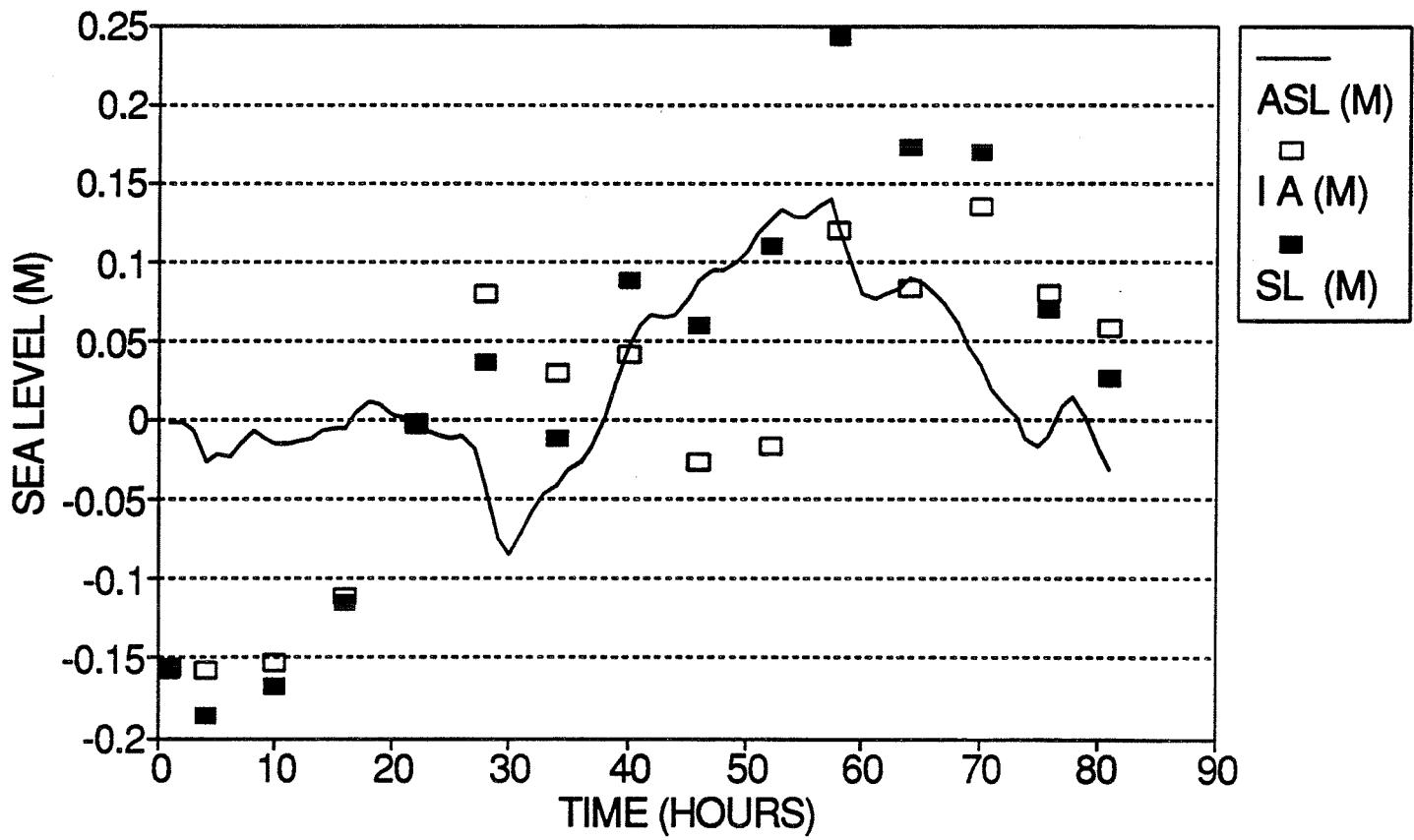
MOBIL STORM 6

15-18 DEC. 1961

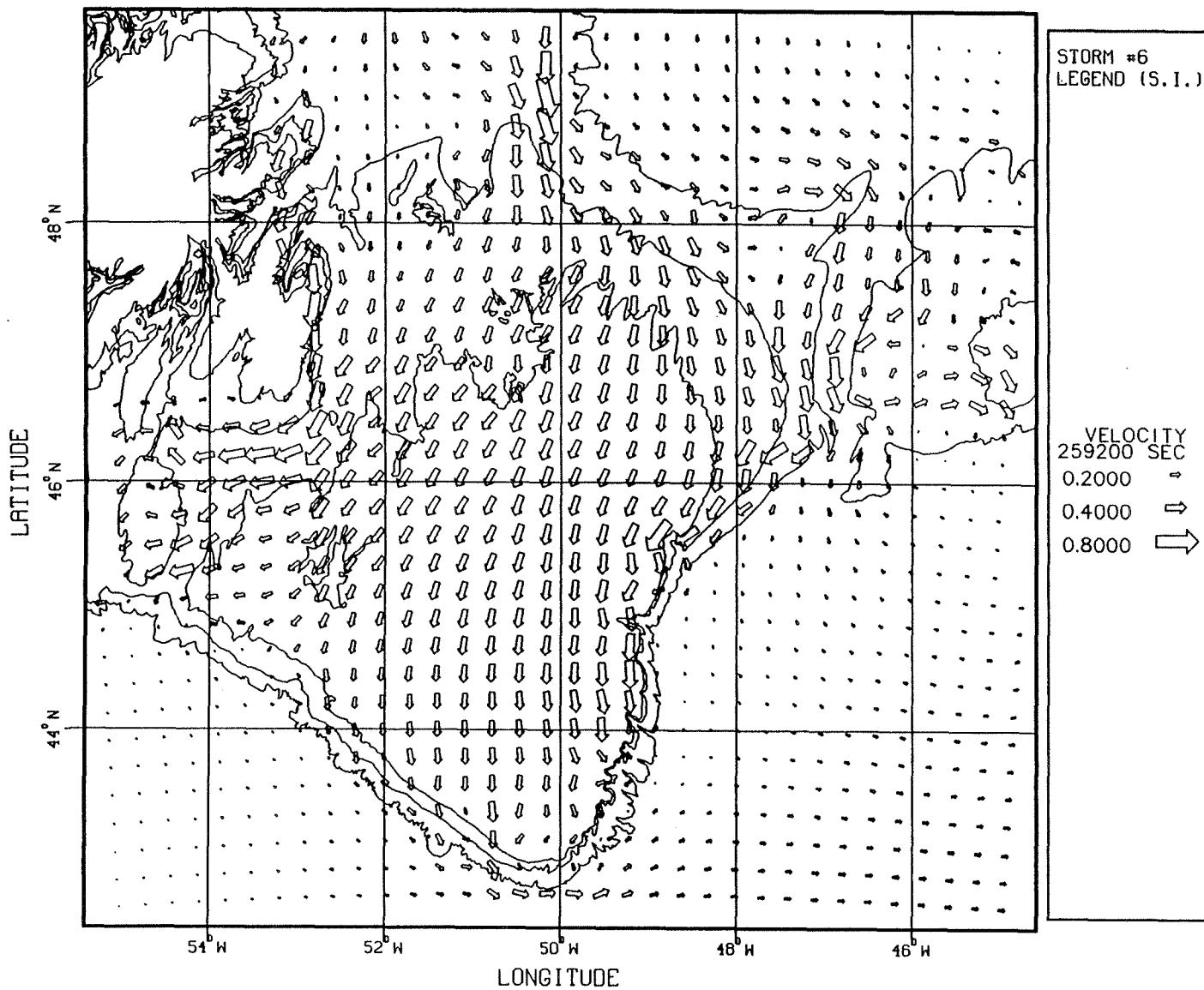


MOBIL STORM 6

15-18 DEC. 1961

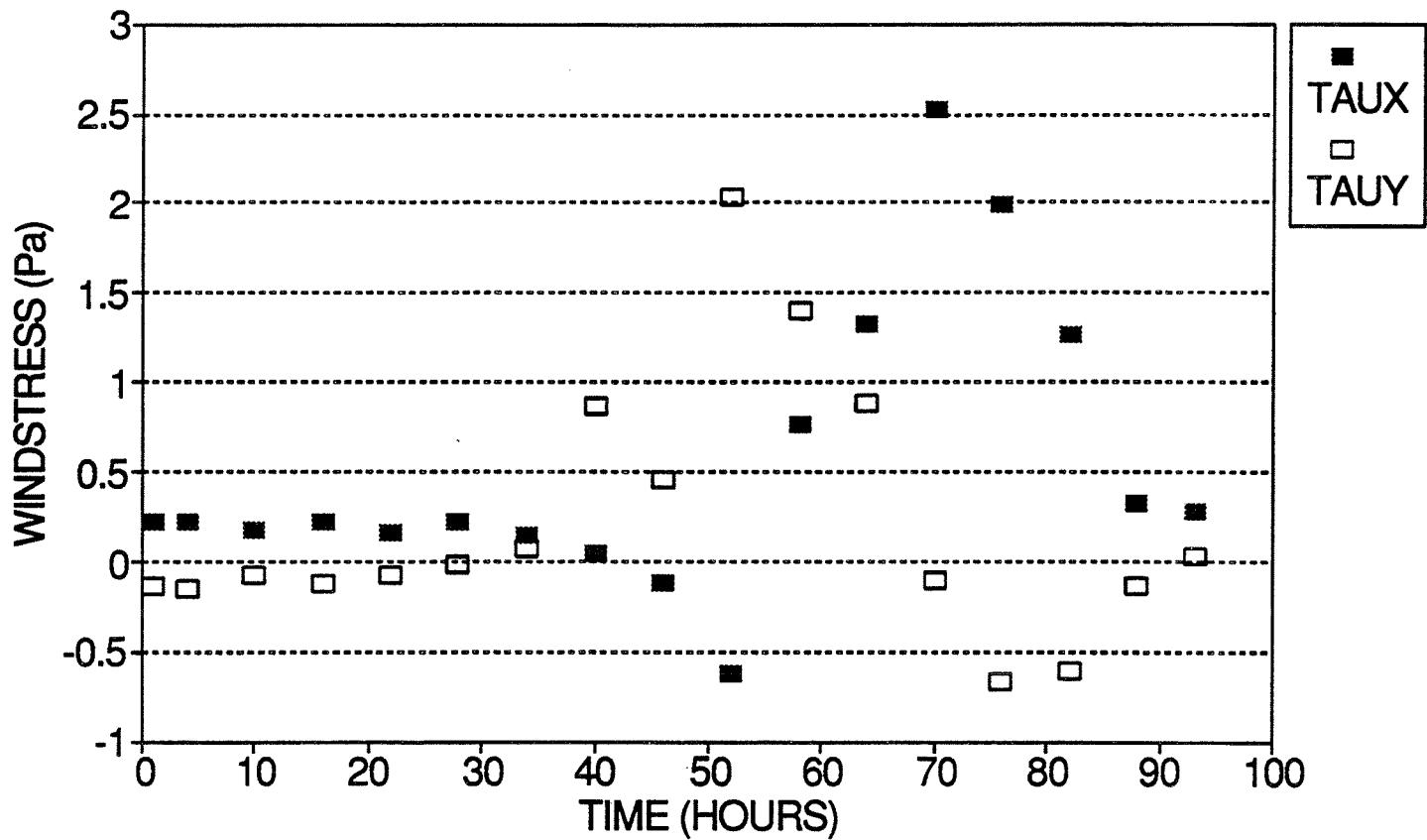


GRAND BANKS STORM MODEL



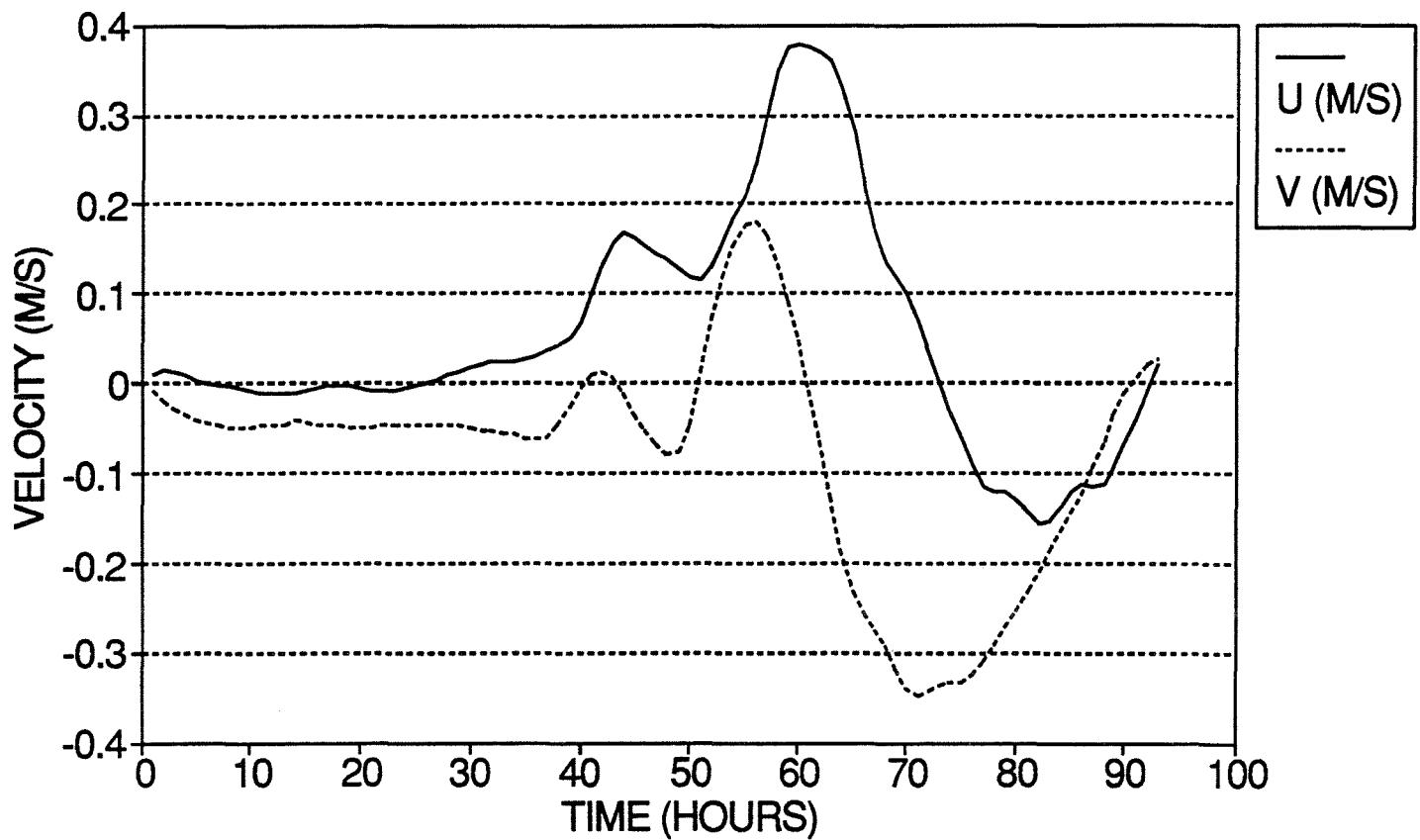
MOBIL STORM 7

20-24 FEB. 1967



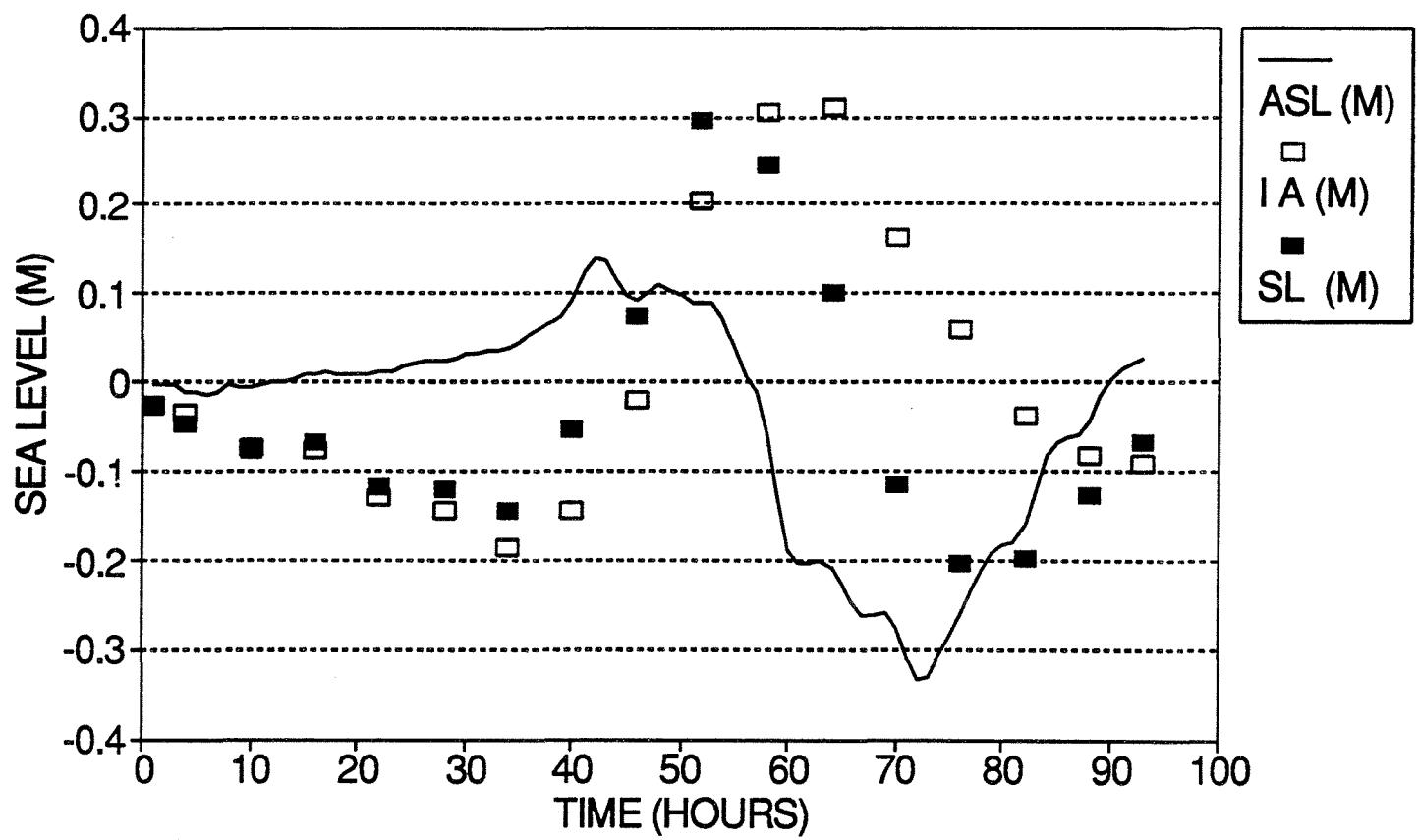
MOBIL STORM 7

20-24 FEB. 1967

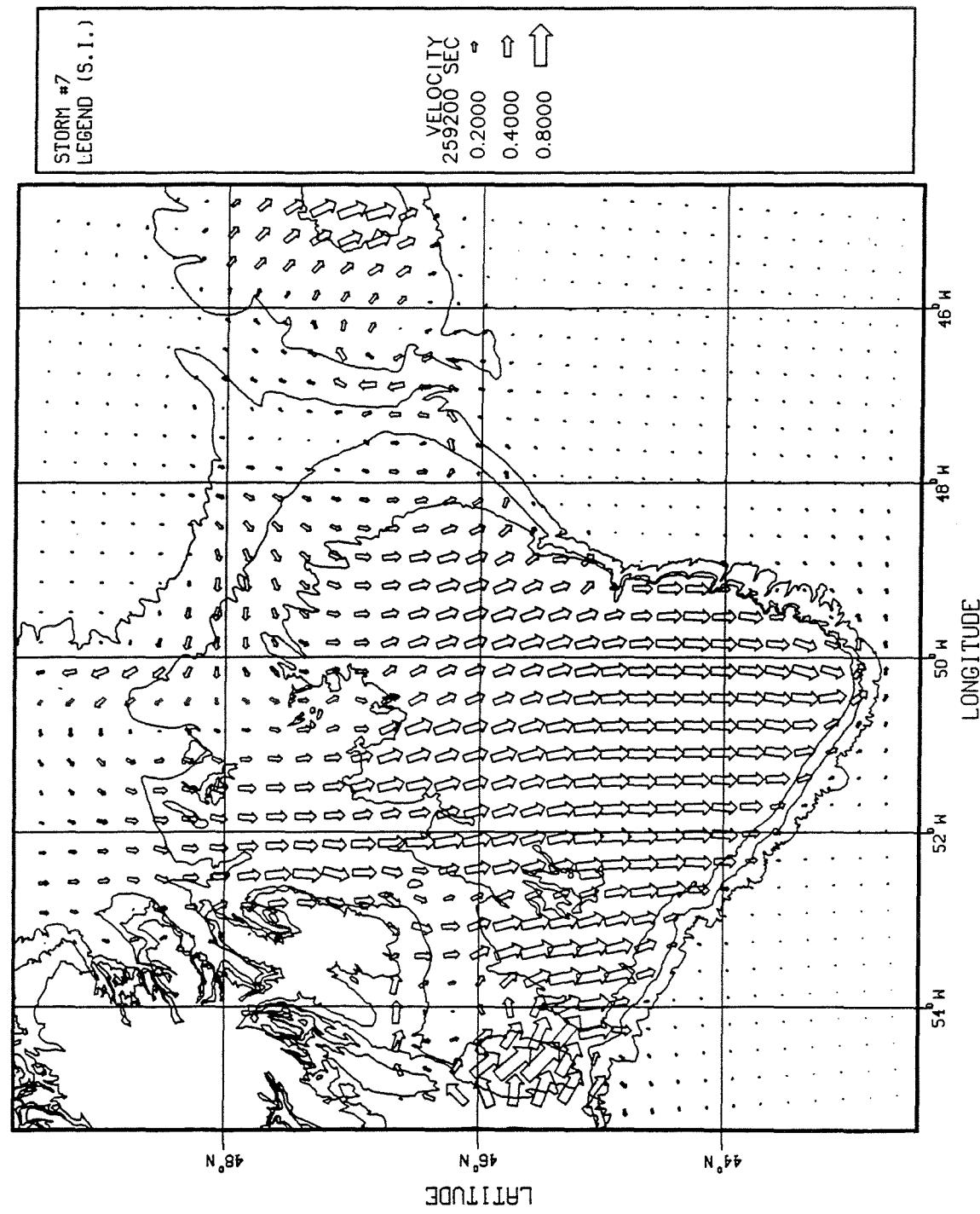


MOBIL STORM 7

20-24 FEB. 1967

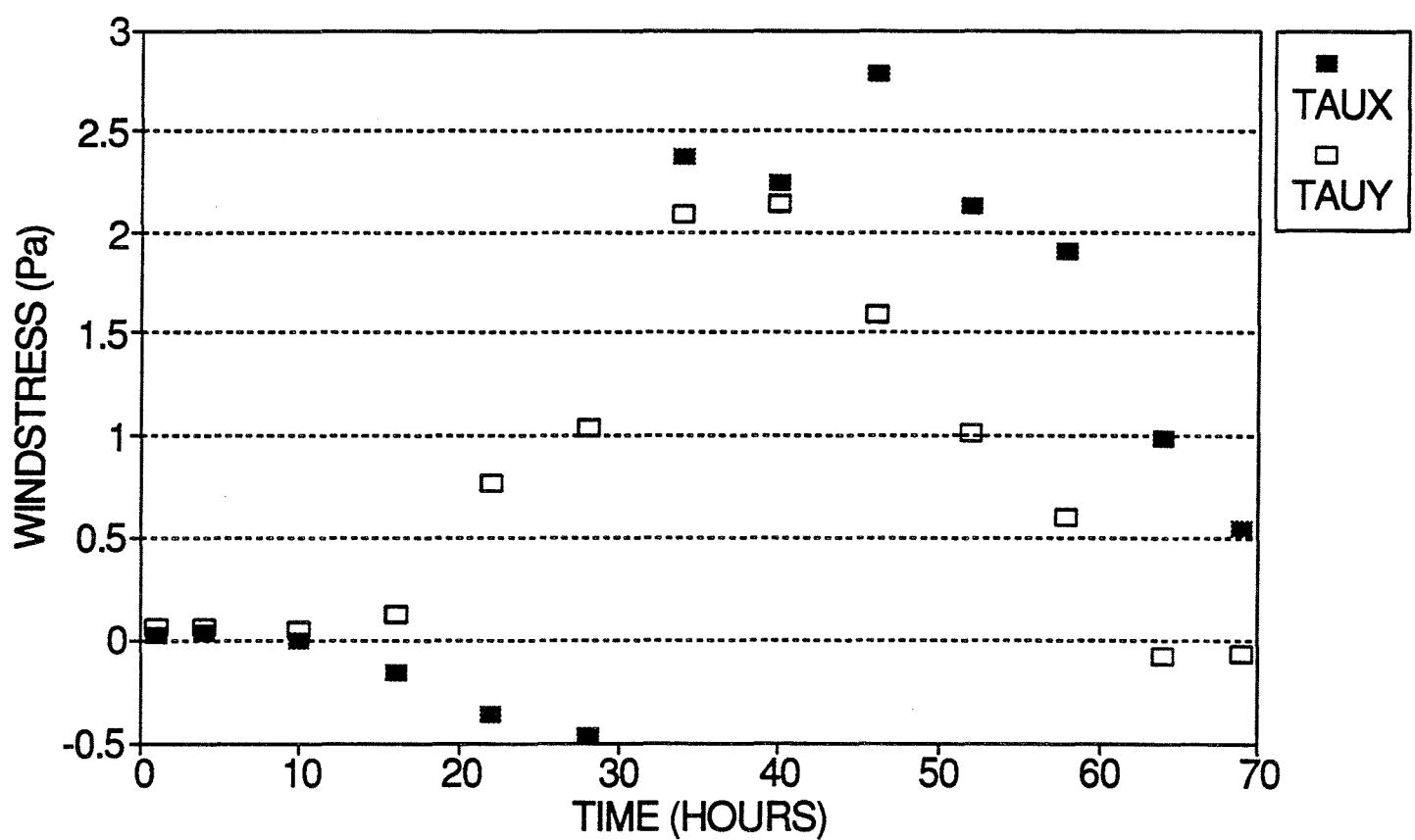


GRAND BANKS STORM MODEL



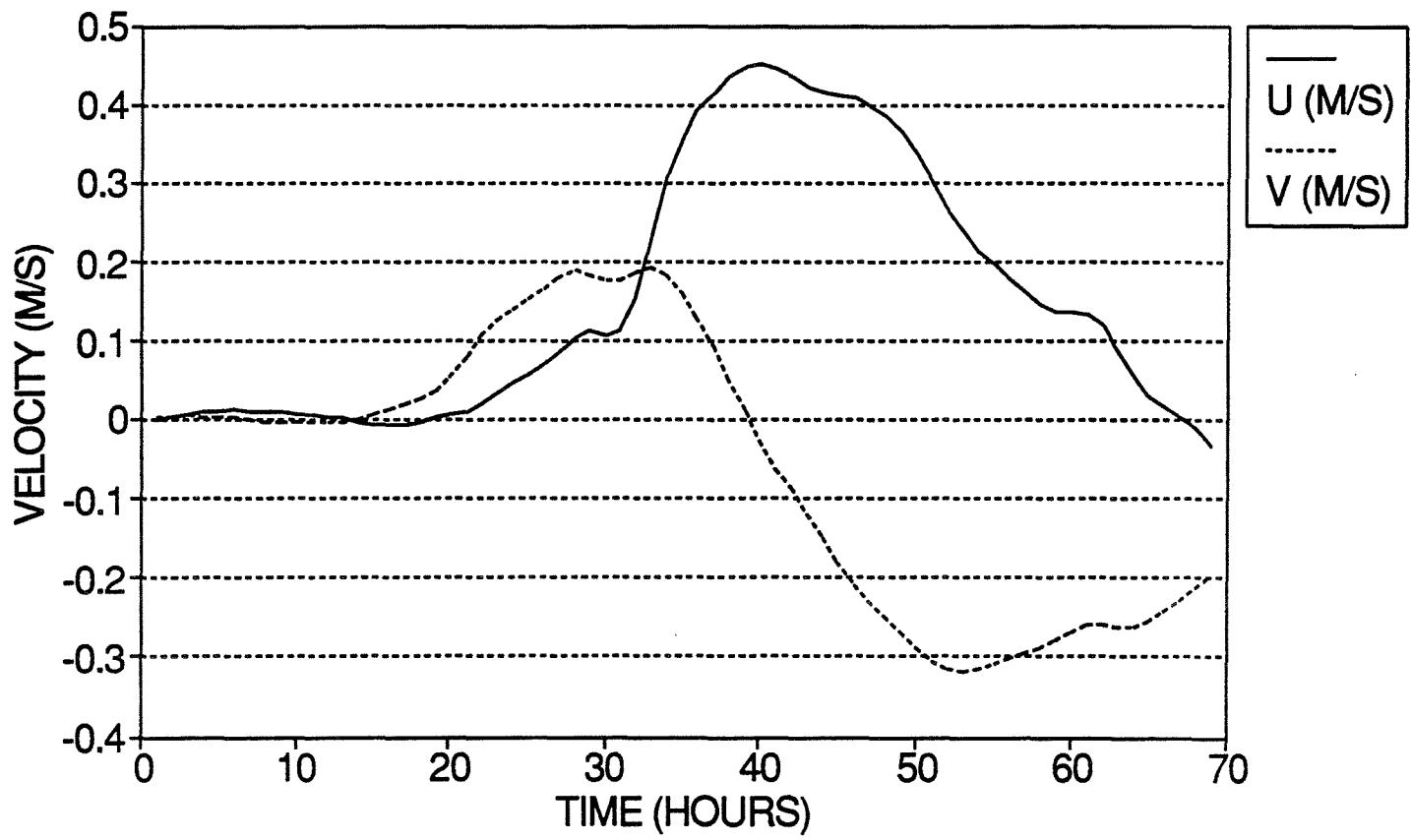
MOBIL STORM 8

19-22 JAN. 1977



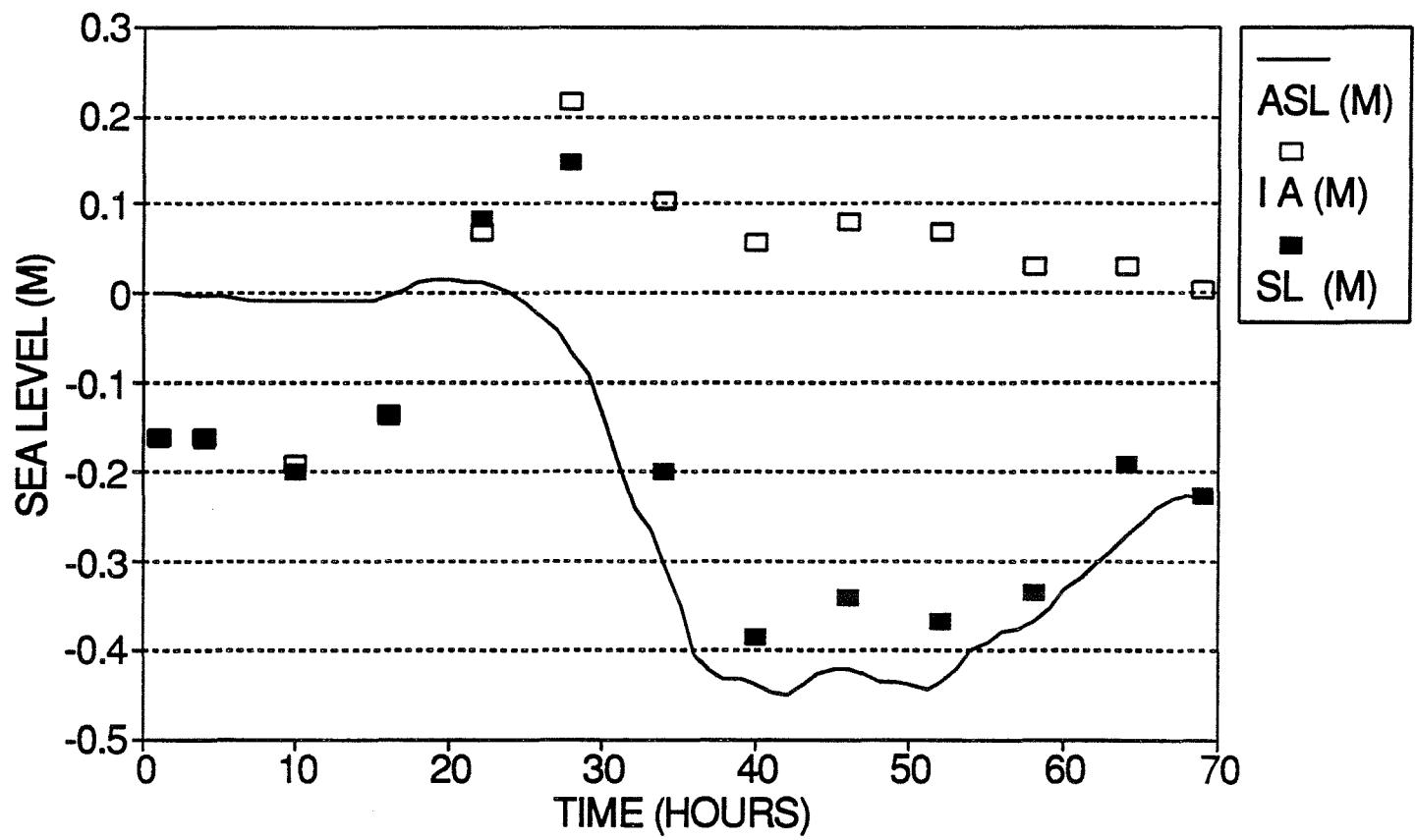
MOBIL STORM 8

19-22 JAN. 1977

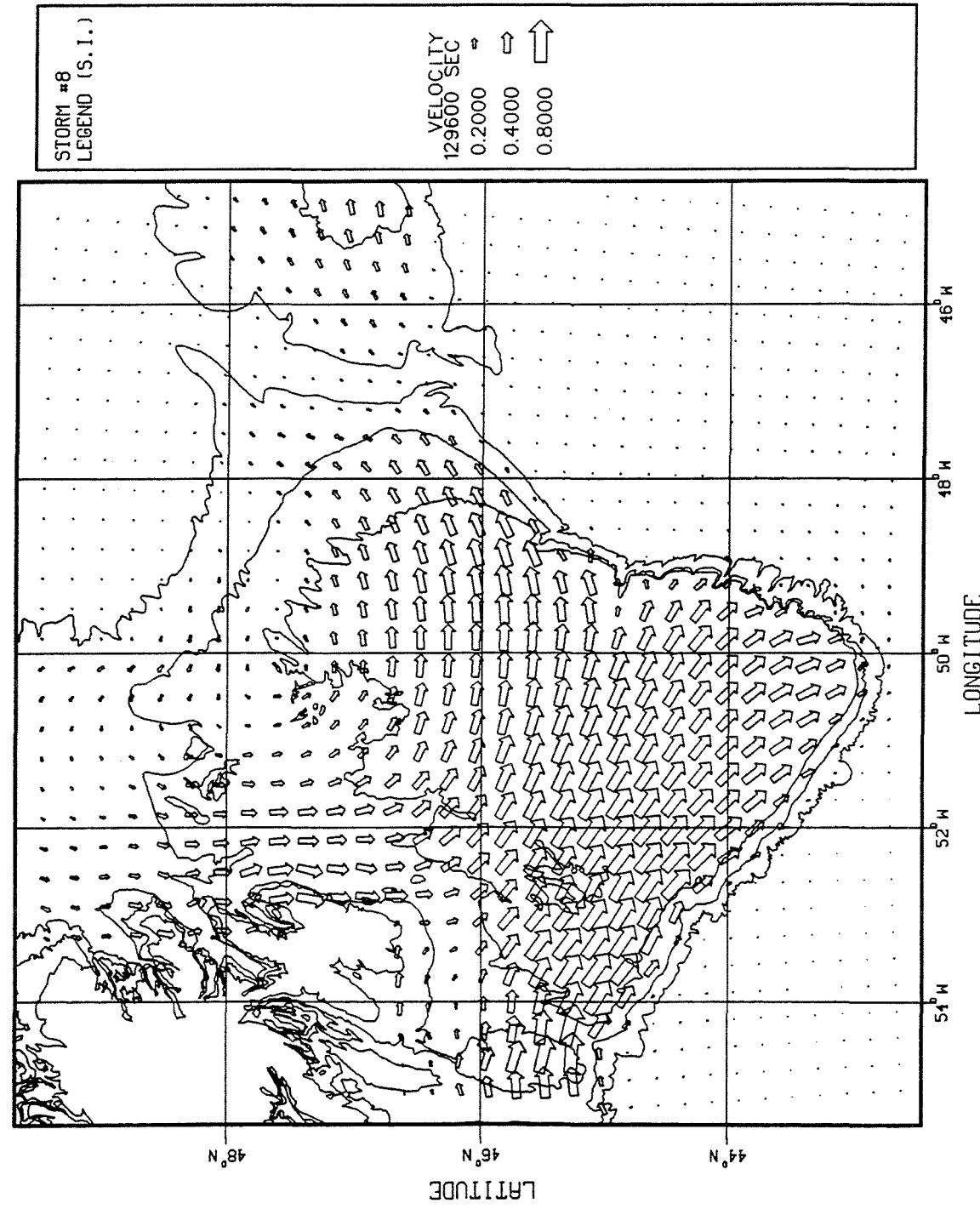


MOBIL STORM 8

19-22 JAN. 1977

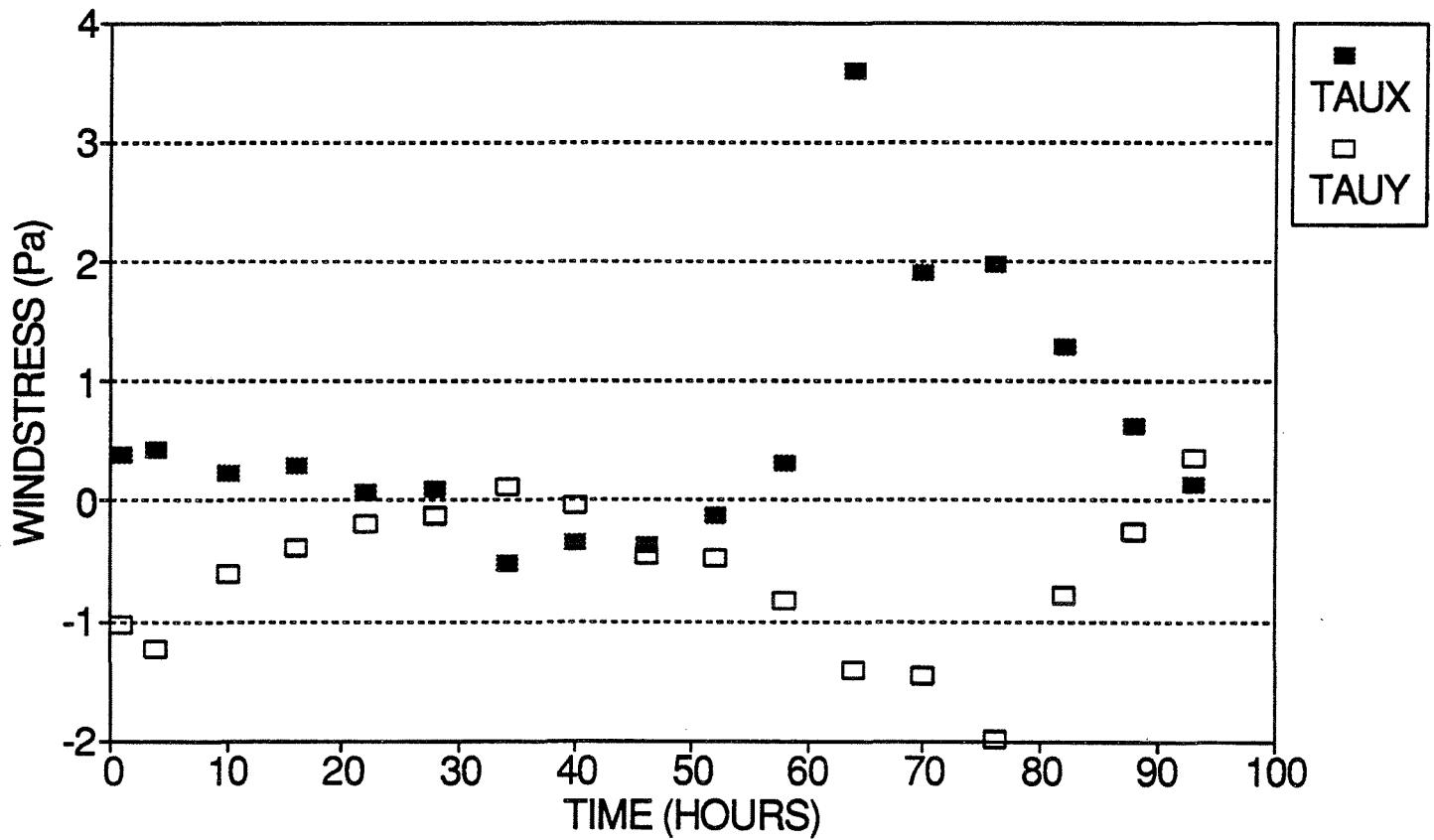


GRAND BANKS STORM MODEL



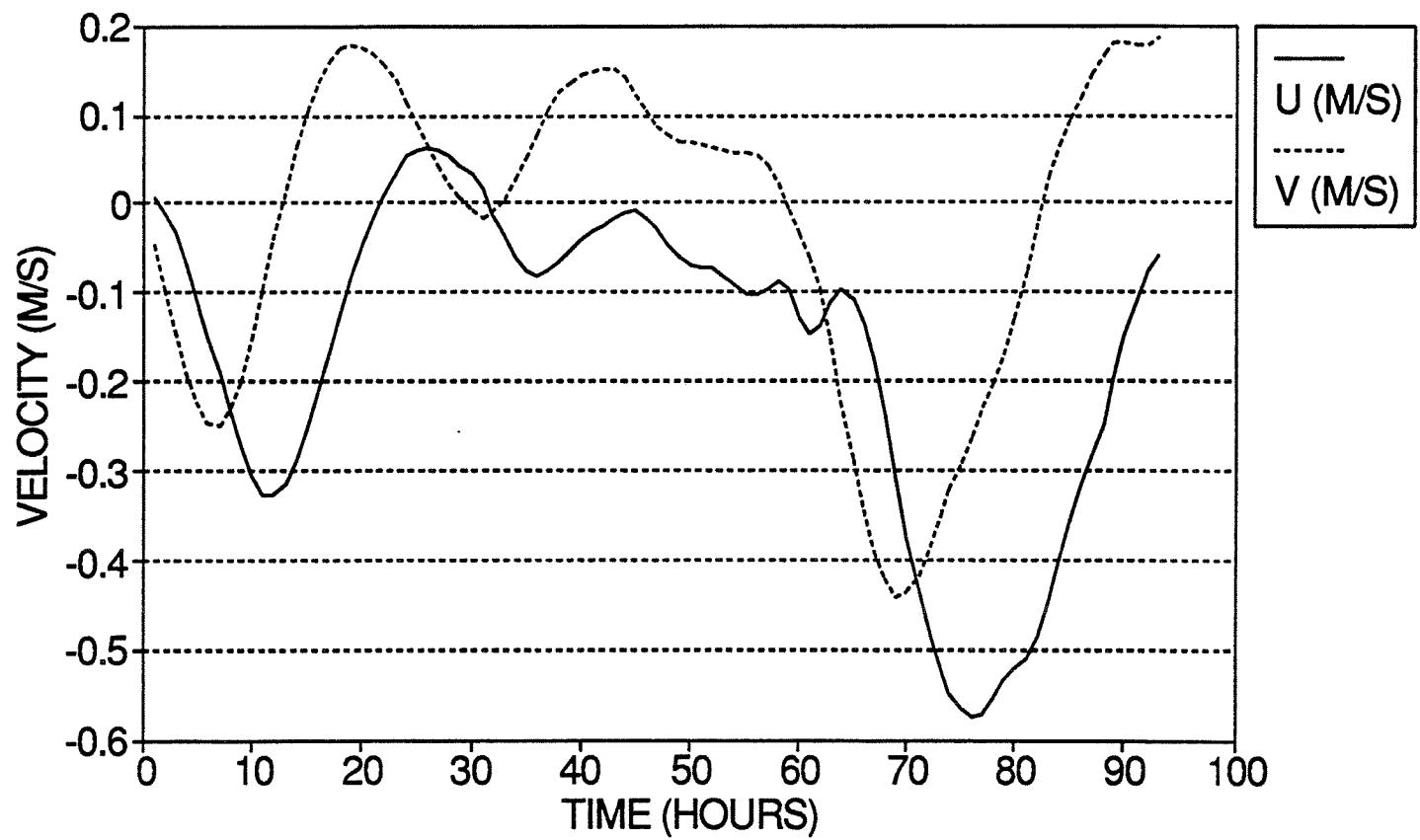
MOBIL STORM 9

1-5 MAR. 1978



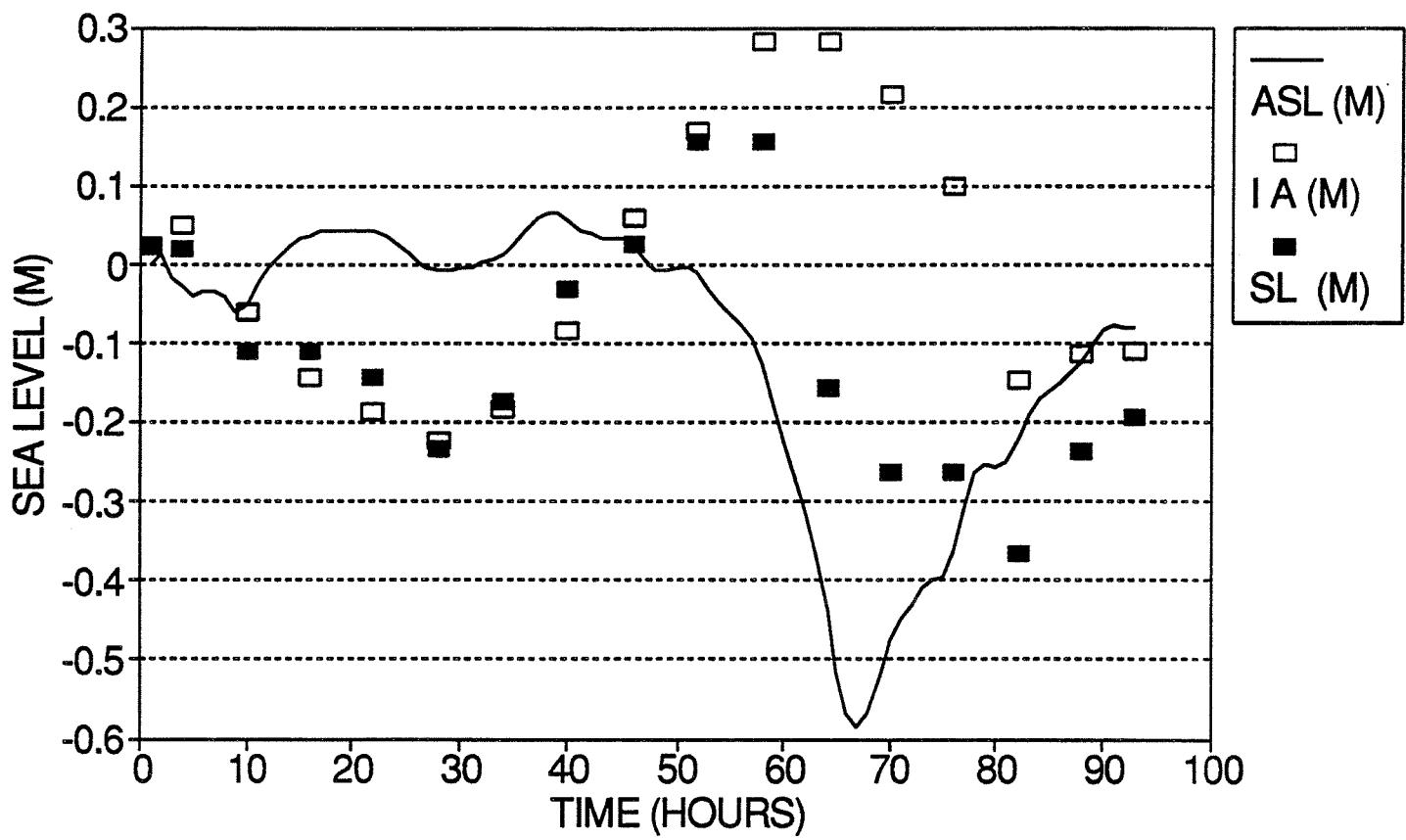
MOBIL STORM 9

1-5 MAR. 1978

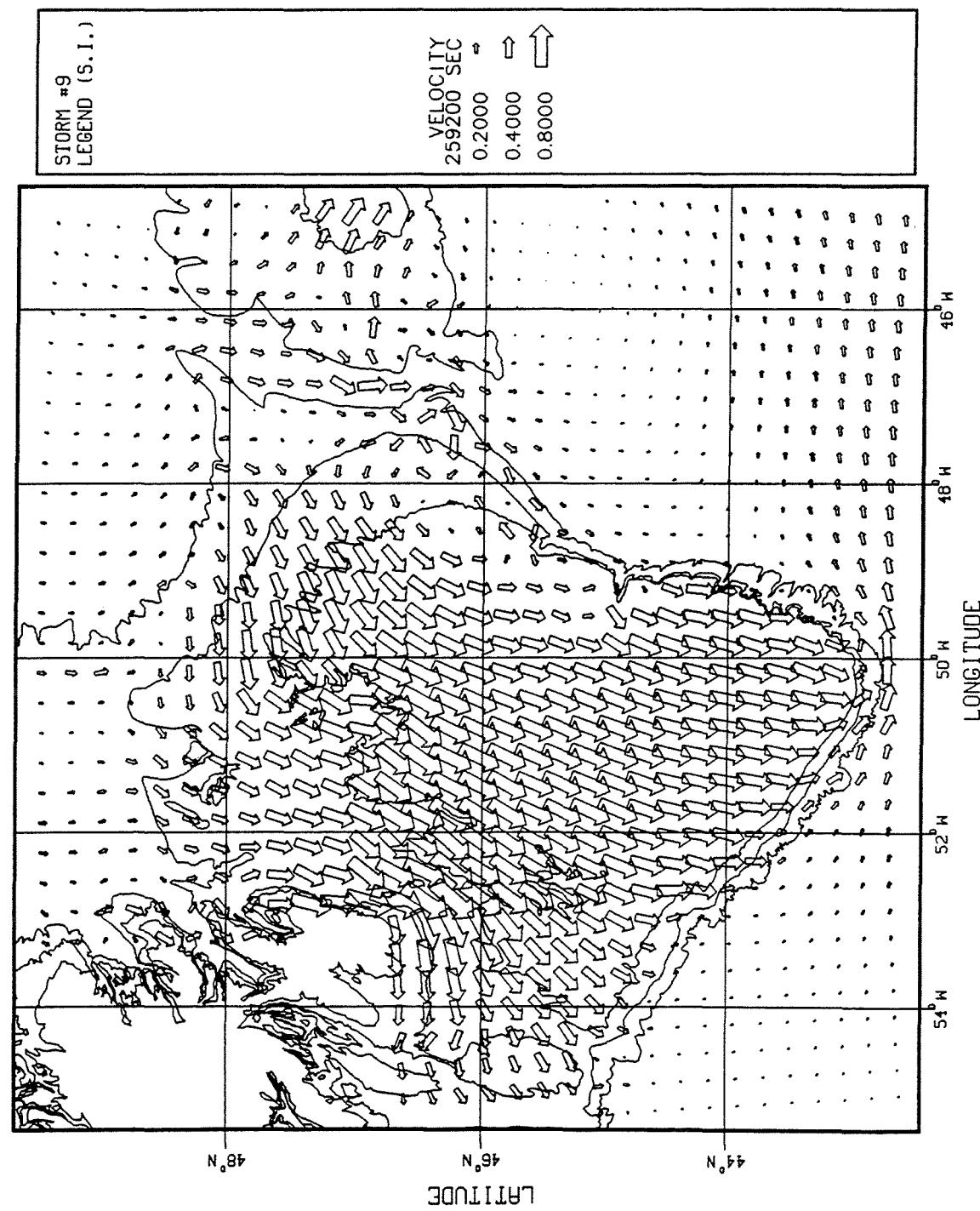


MOBIL STORM 9

1-5 MAR. 1978

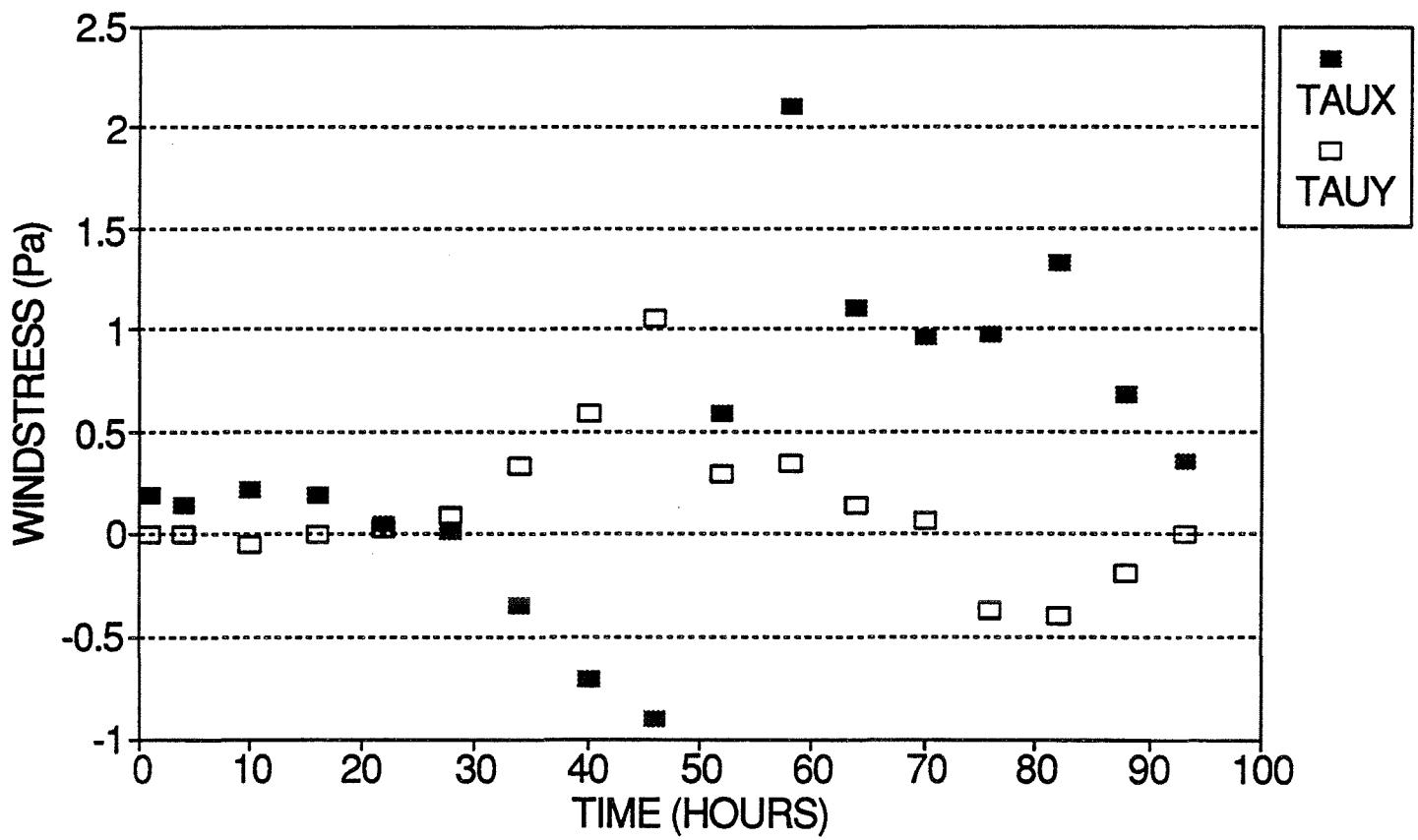


GRAND BANKS STORM MODEL



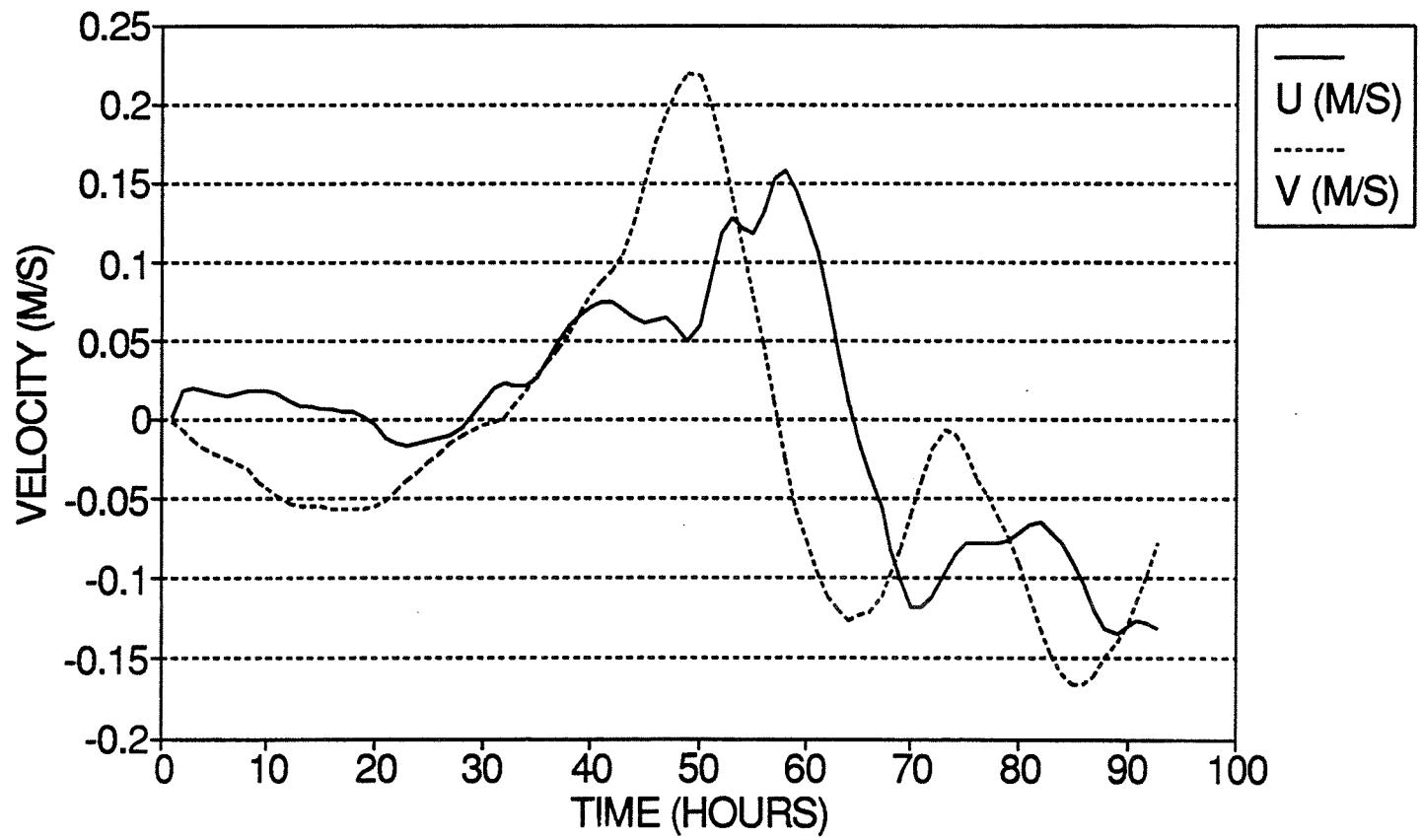
MOBIL STORM 10

2-6 JAN. 1980



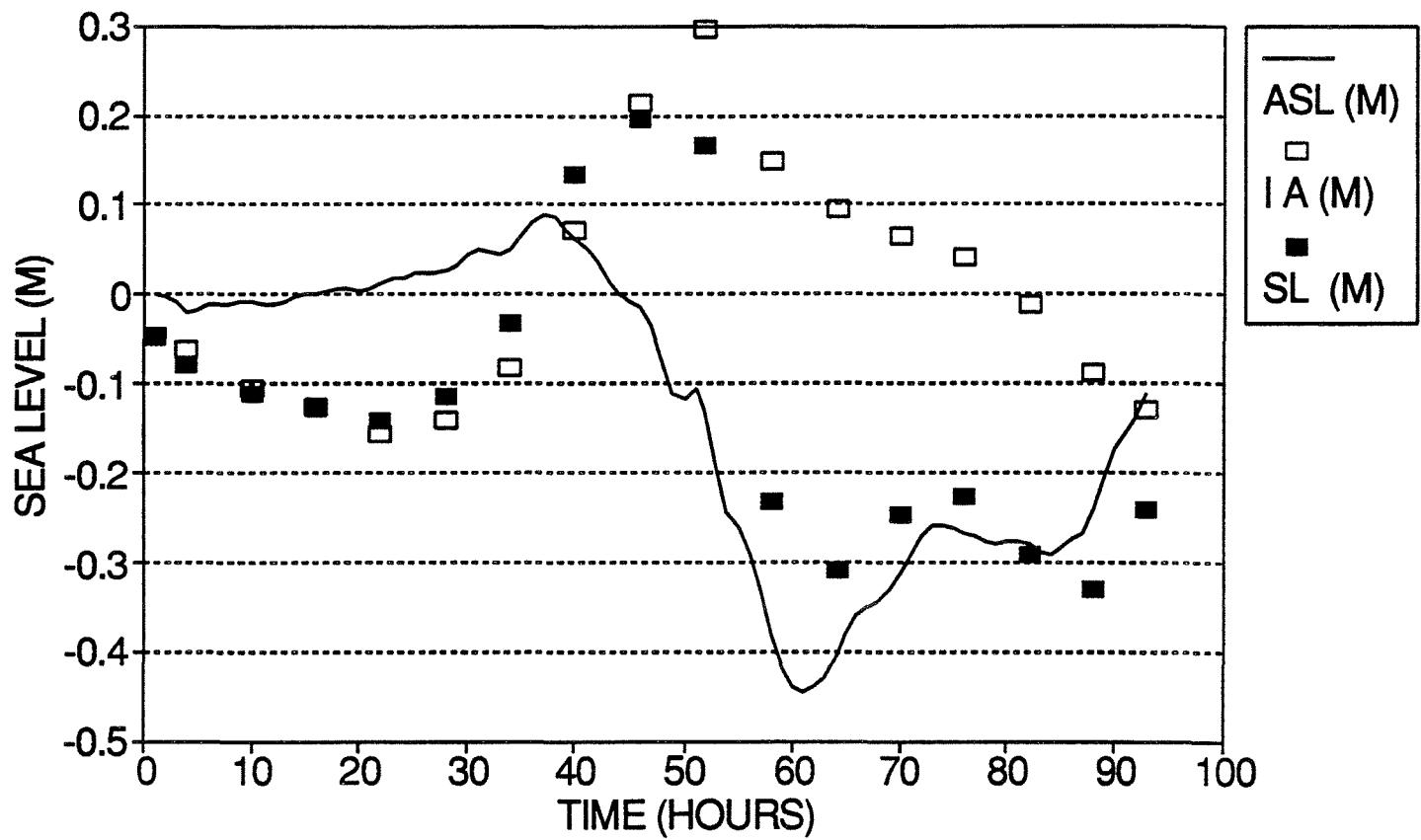
MOBIL STORM 10

2-6 JAN. 1980

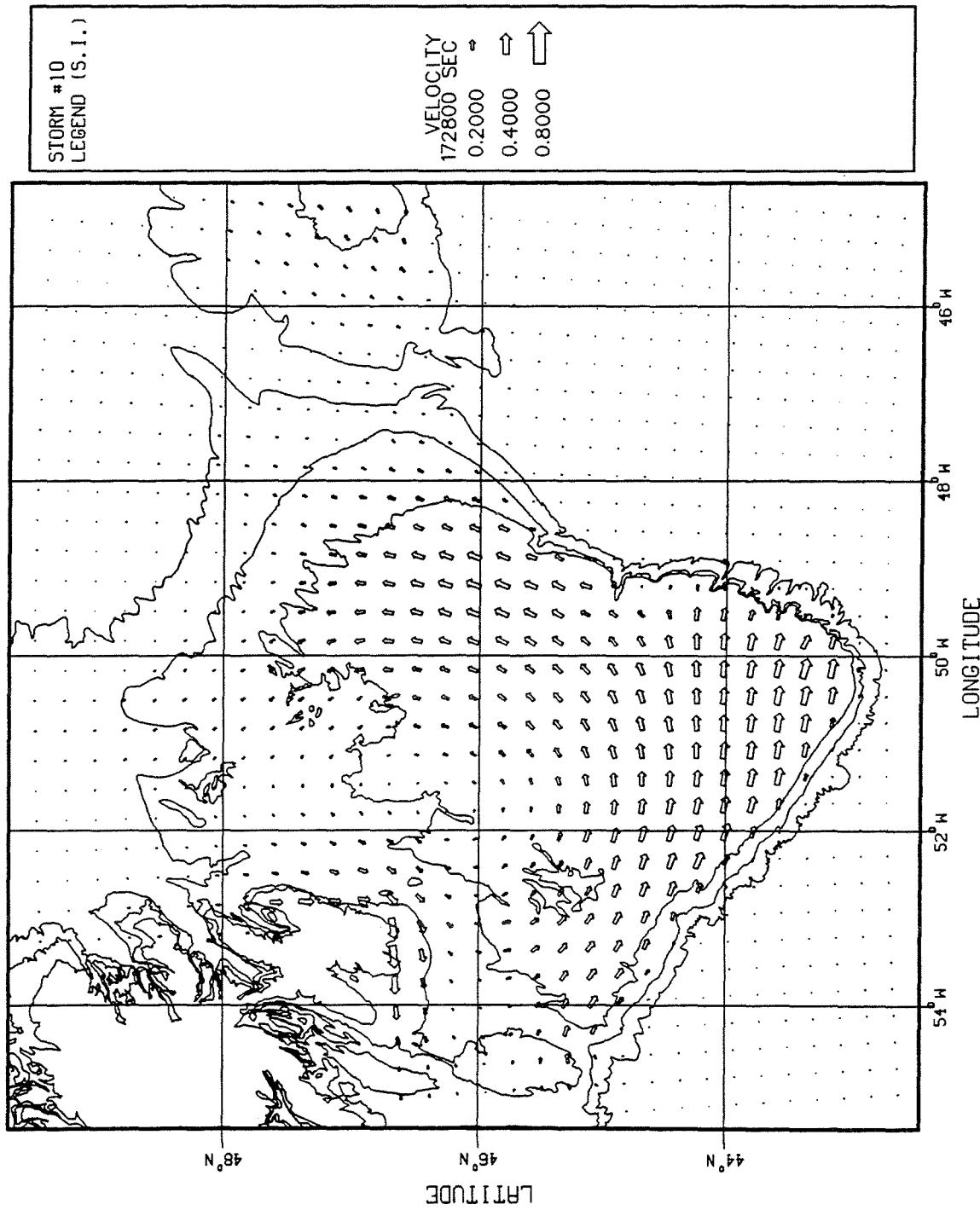


MOBIL STORM 10

2-6 JAN. 1980

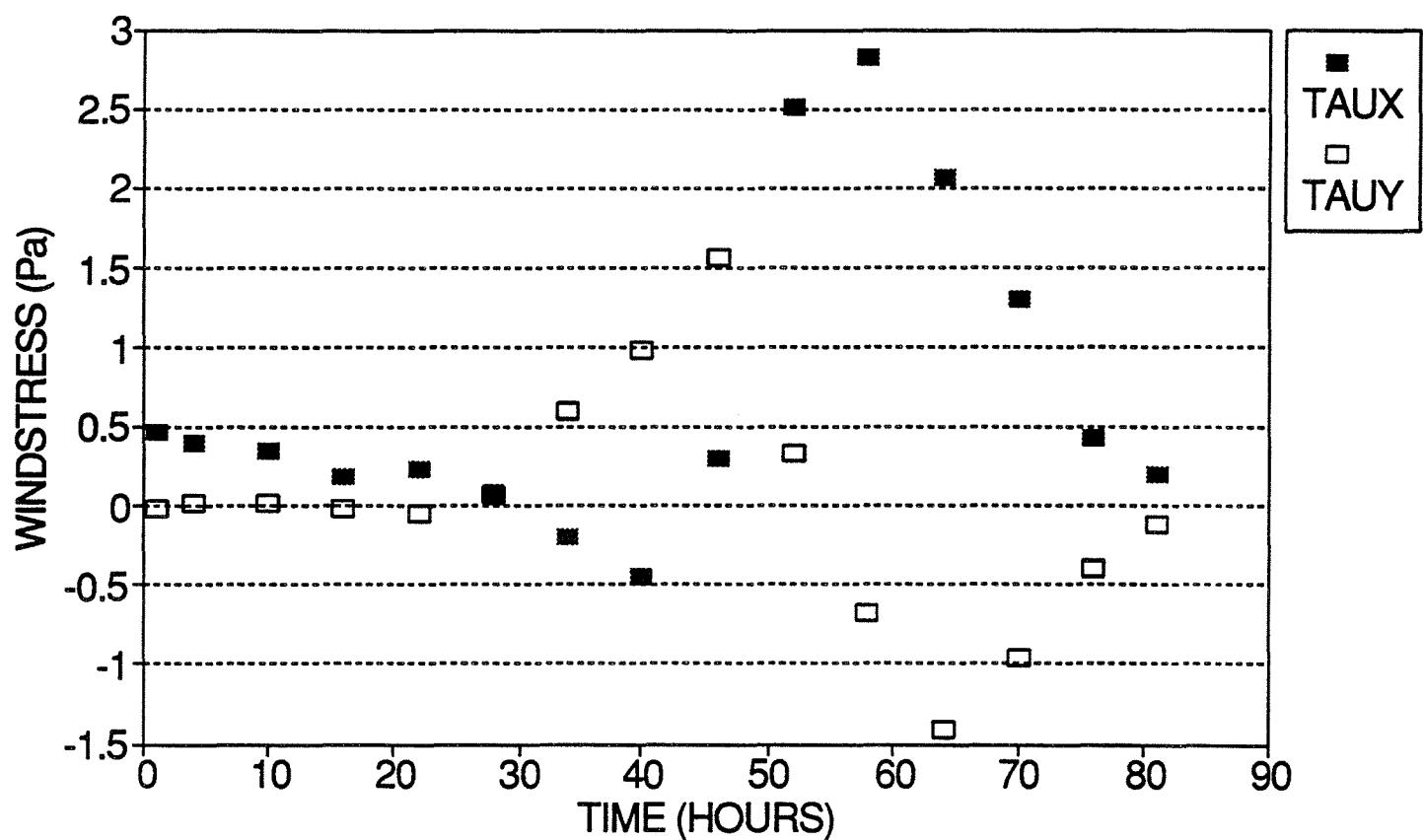


GRAND BANKS STORM MODEL



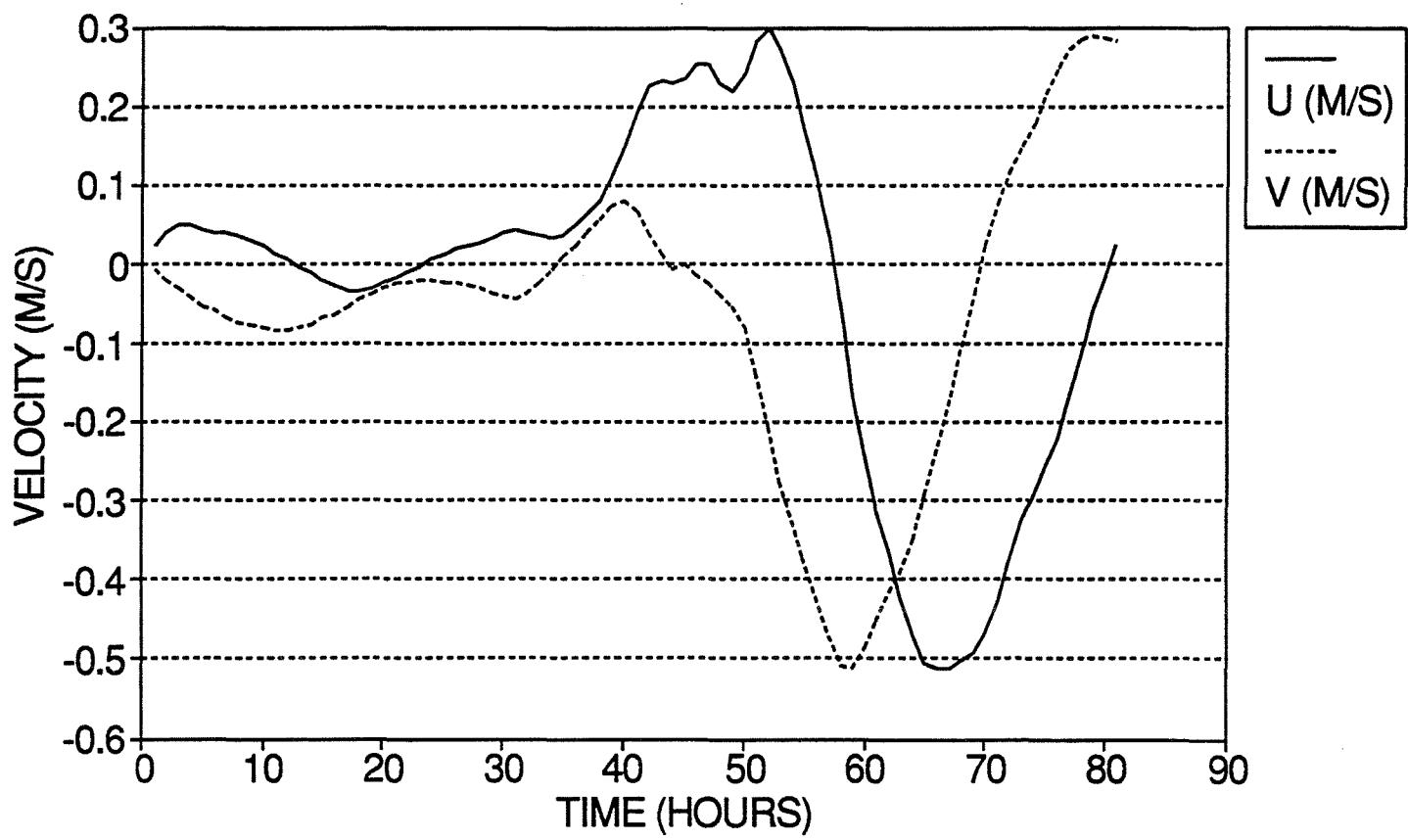
MOBIL STORM 11

20-24 JAN. 1970



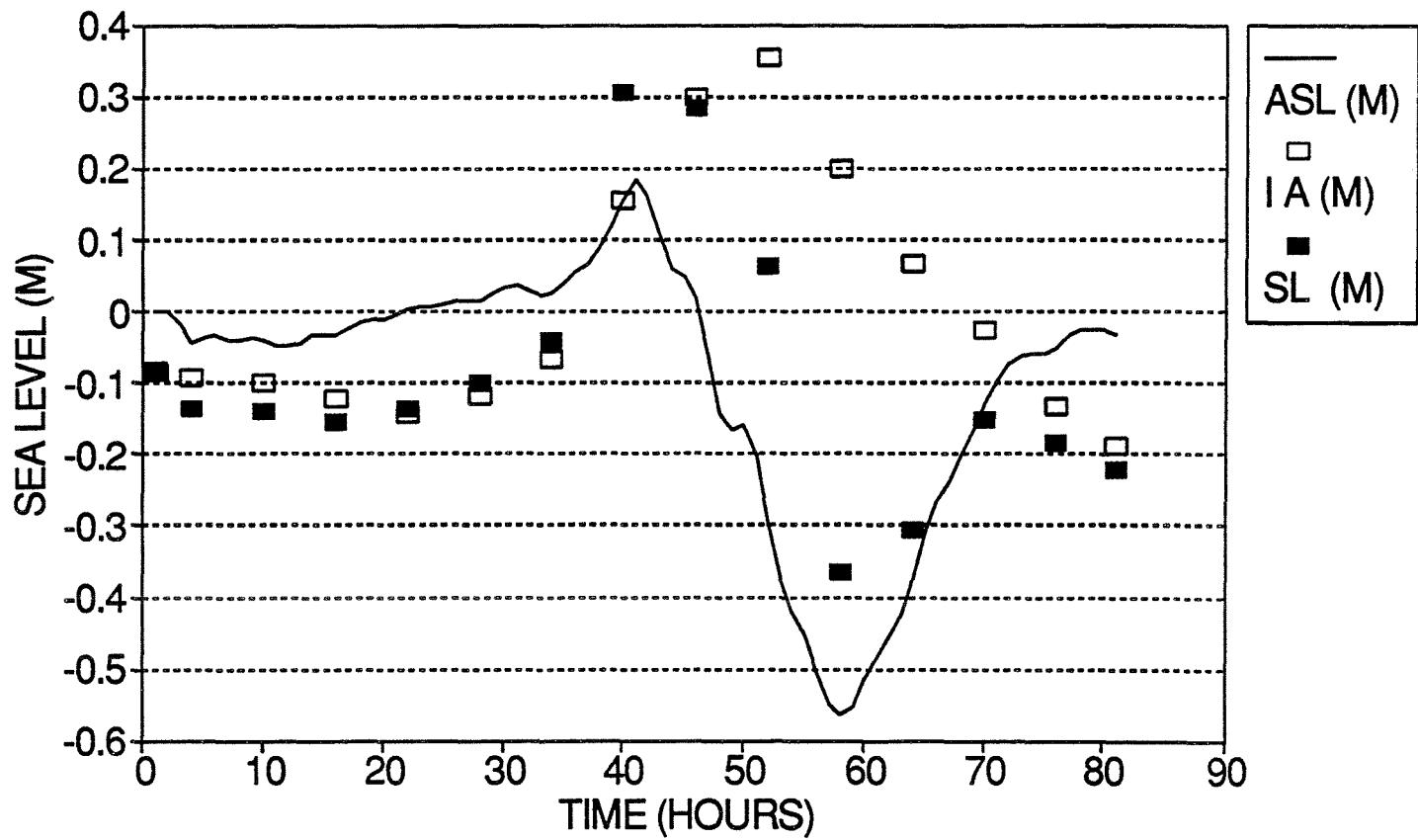
MOBIL STORM 11

20-24 JAN. 1970



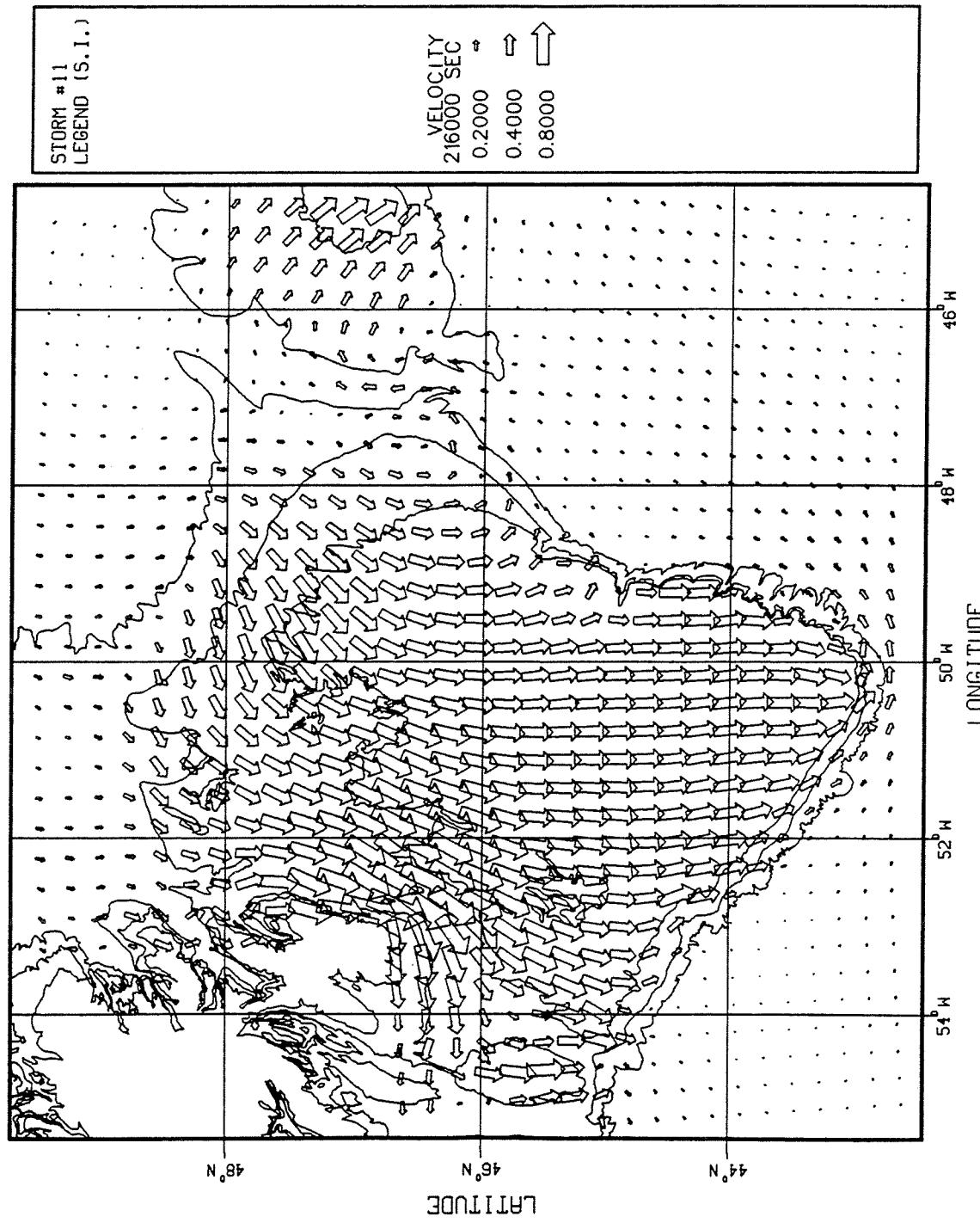
MOBIL STORM 11

20-24 JAN. 1970



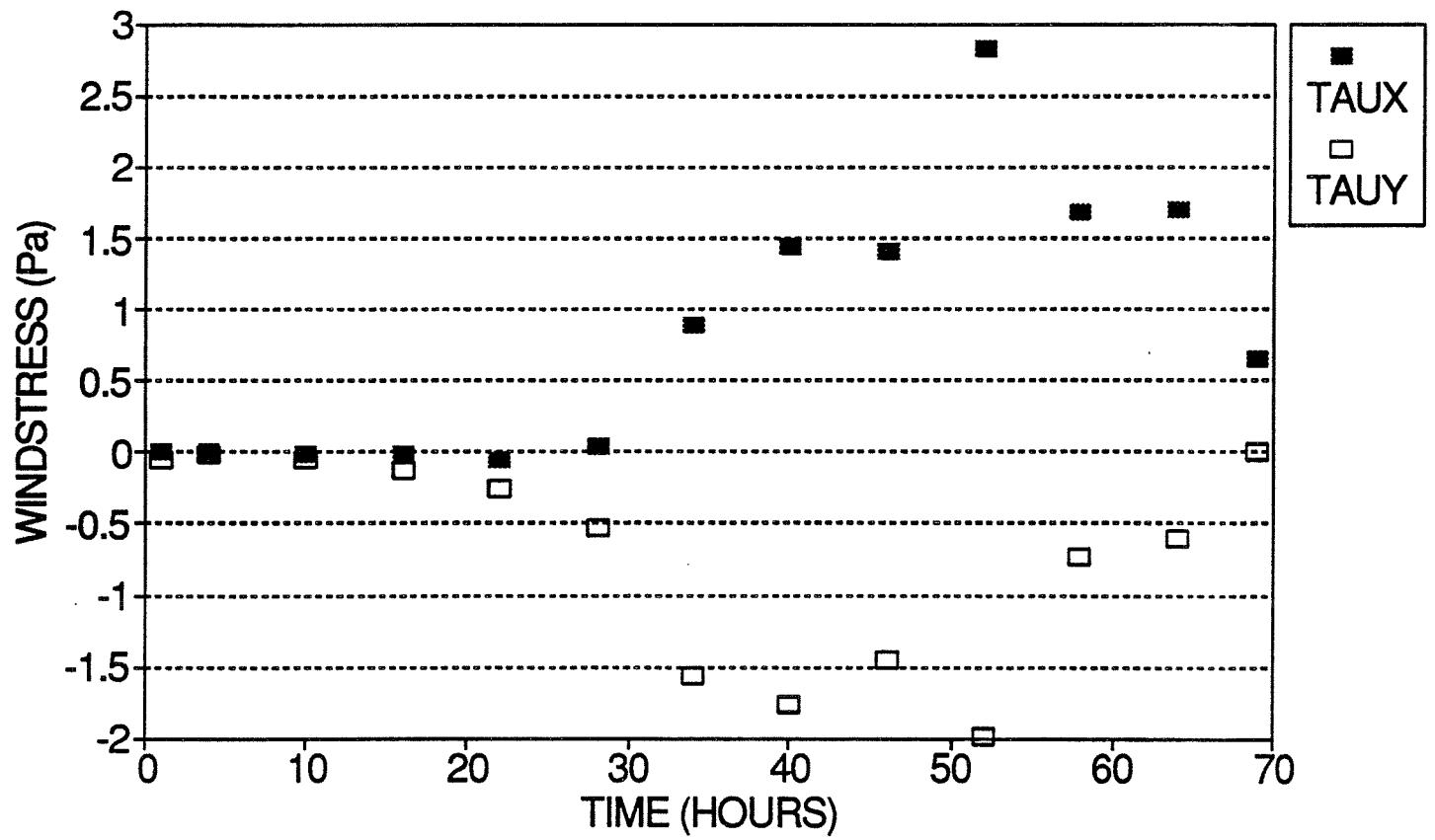
GRAND BANKS STORM MODEL

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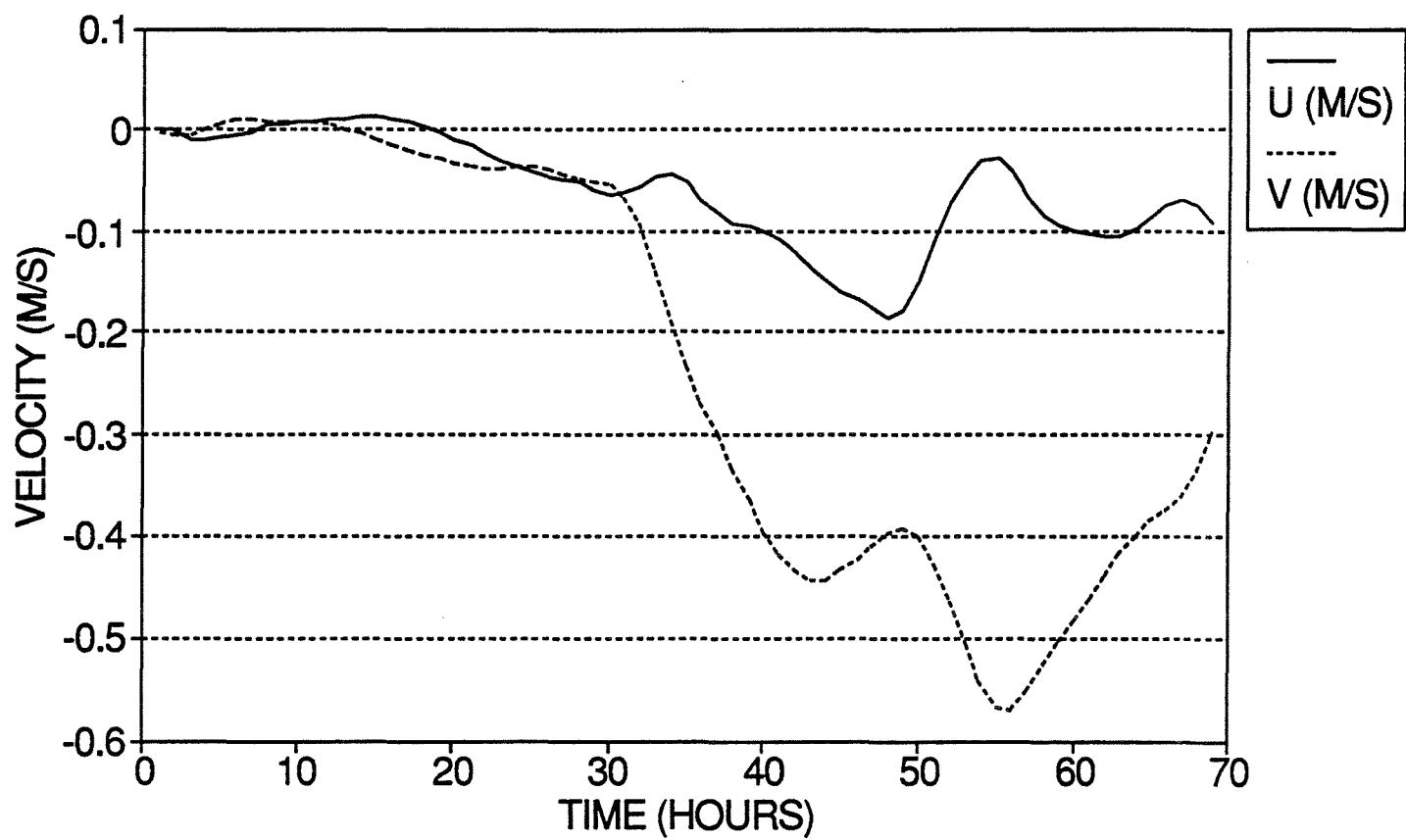
MOBIL STORM 12

17-20 FEB. 1965



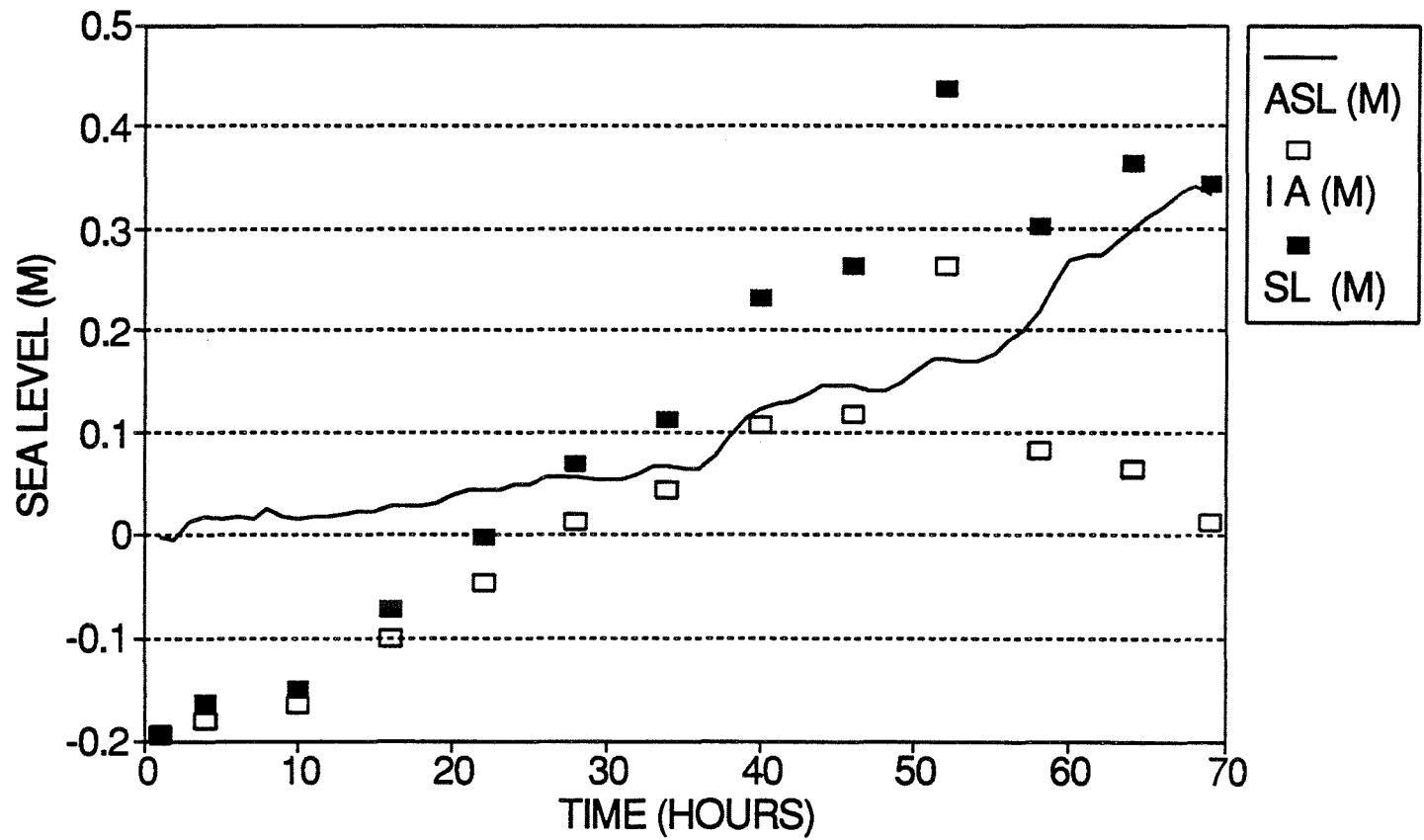
MOBIL STORM 12

17-20 FEB. 1965

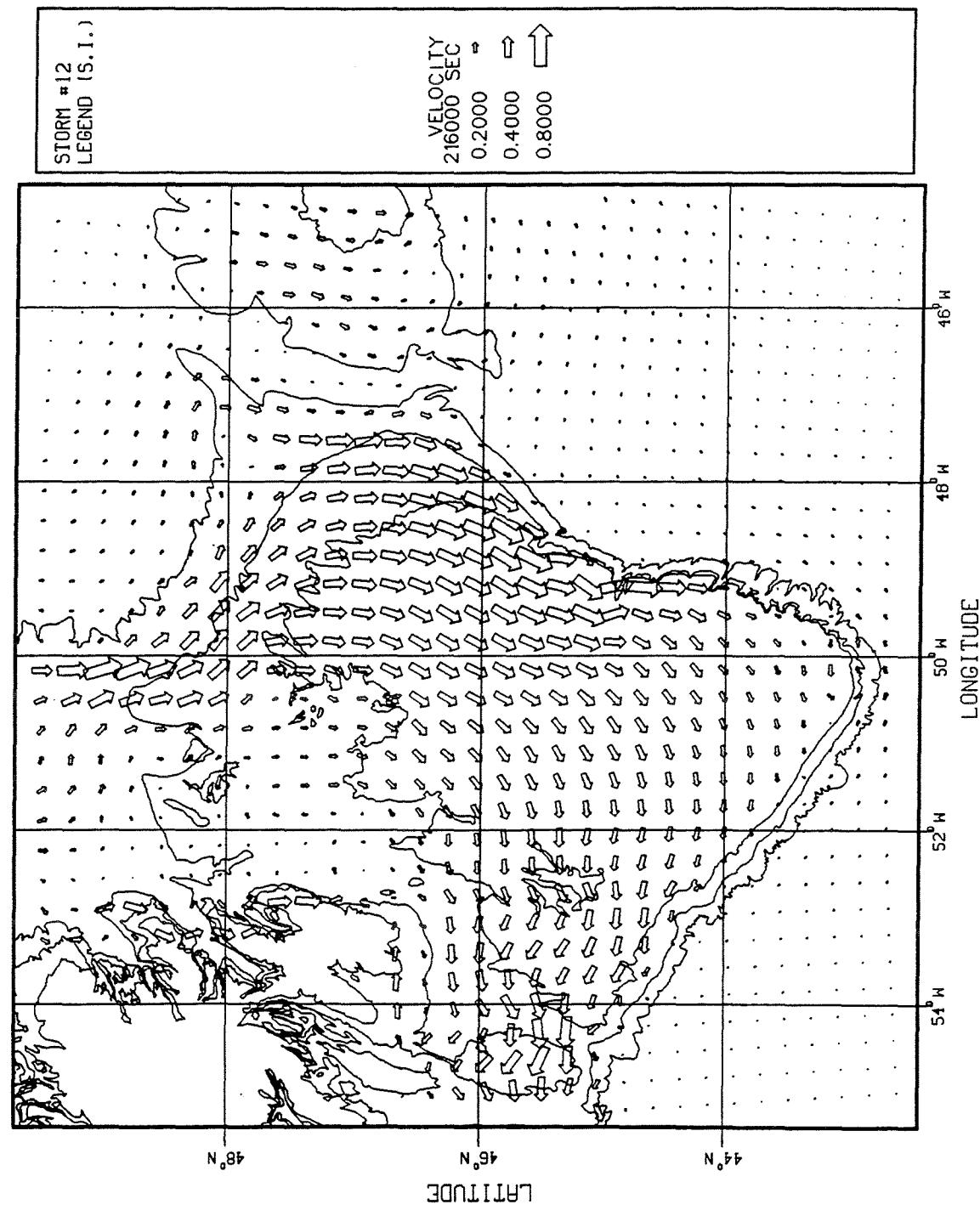


MOBIL STORM 12

17-20 FEB. 1965

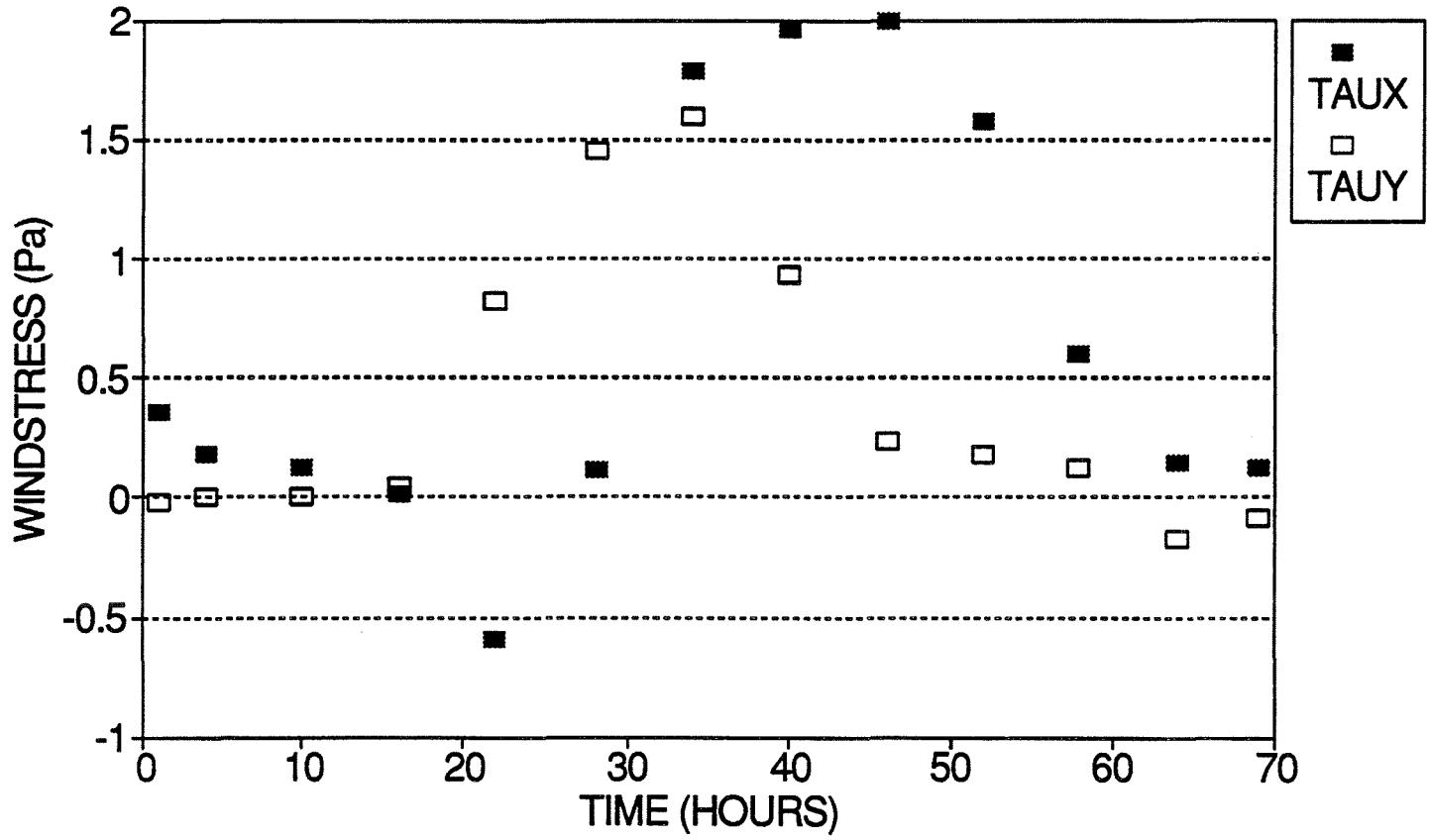


GRAND BANKS STORM MODEL



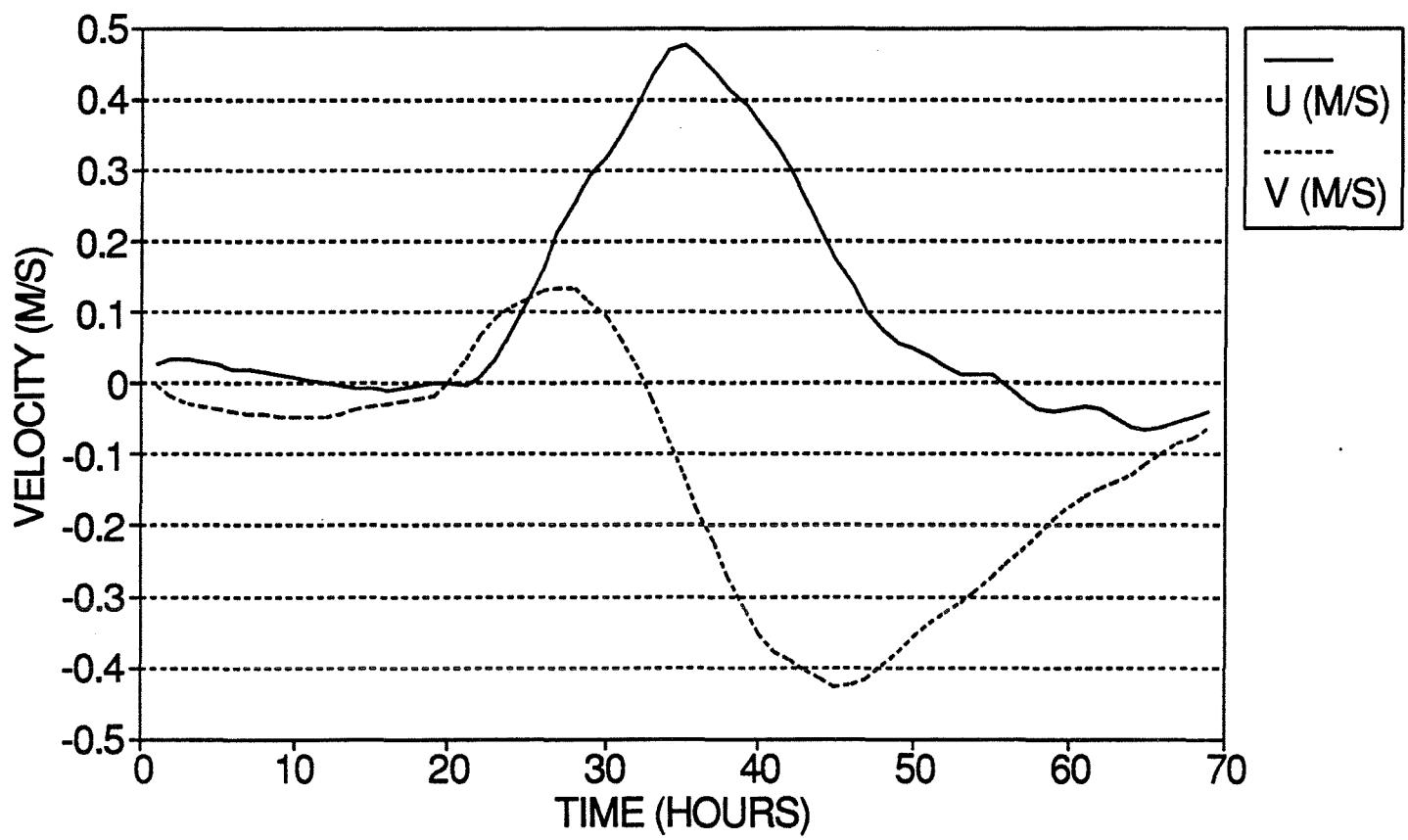
MOBIL STORM 13

20-23 JAN. 1961



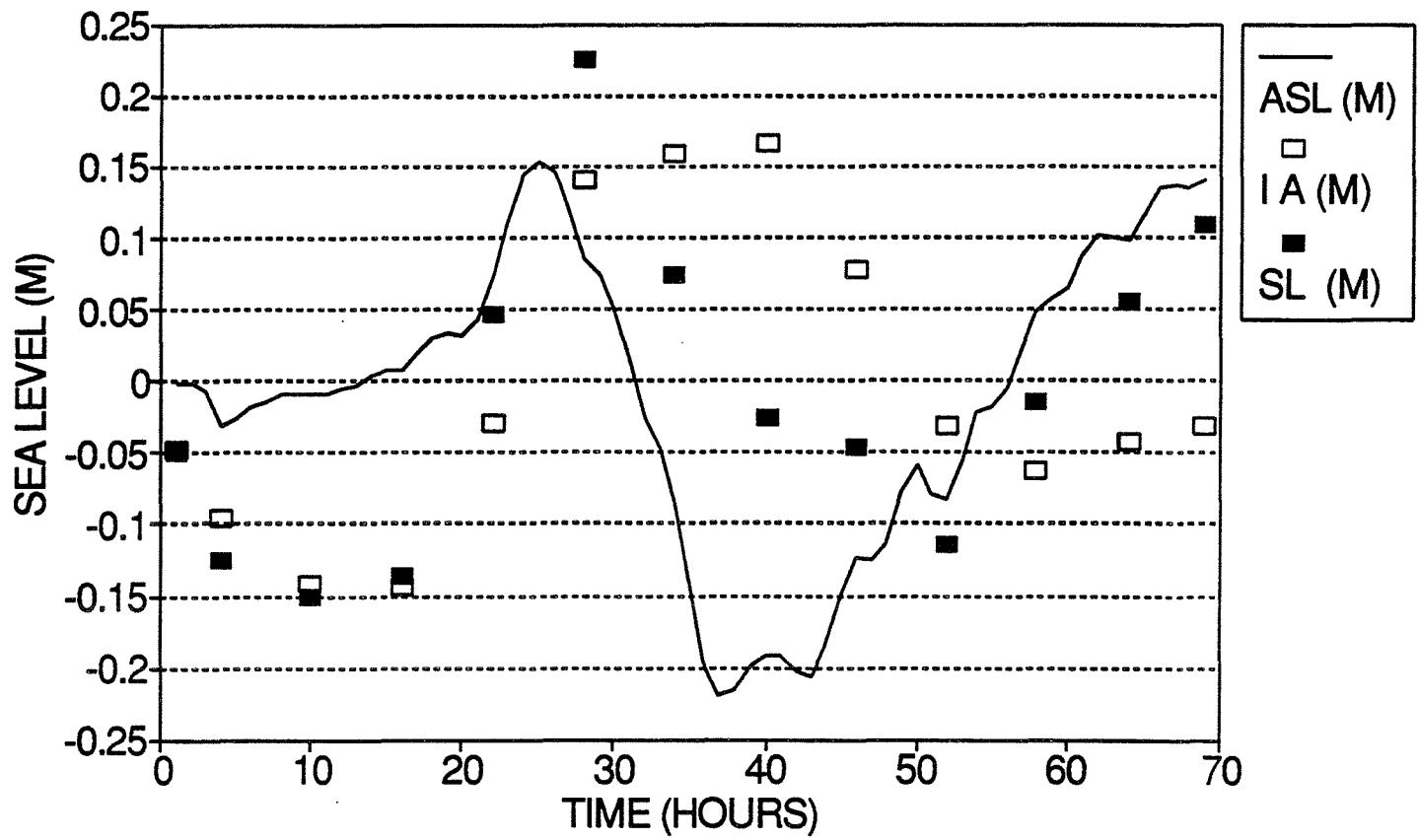
MOBIL STORM 13

20-23 JAN. 1961

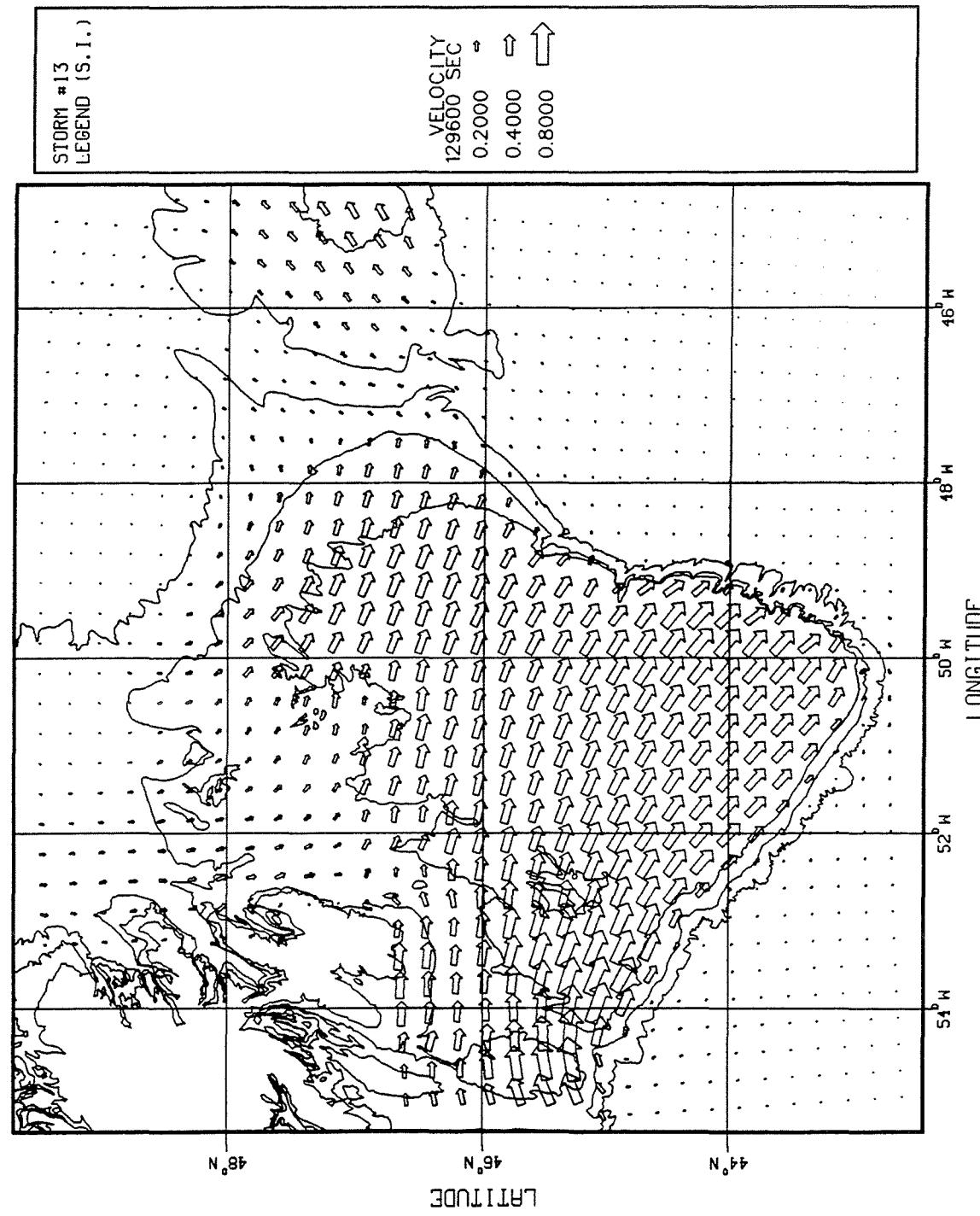


MOBIL STORM 13

20-23 JAN. 1961

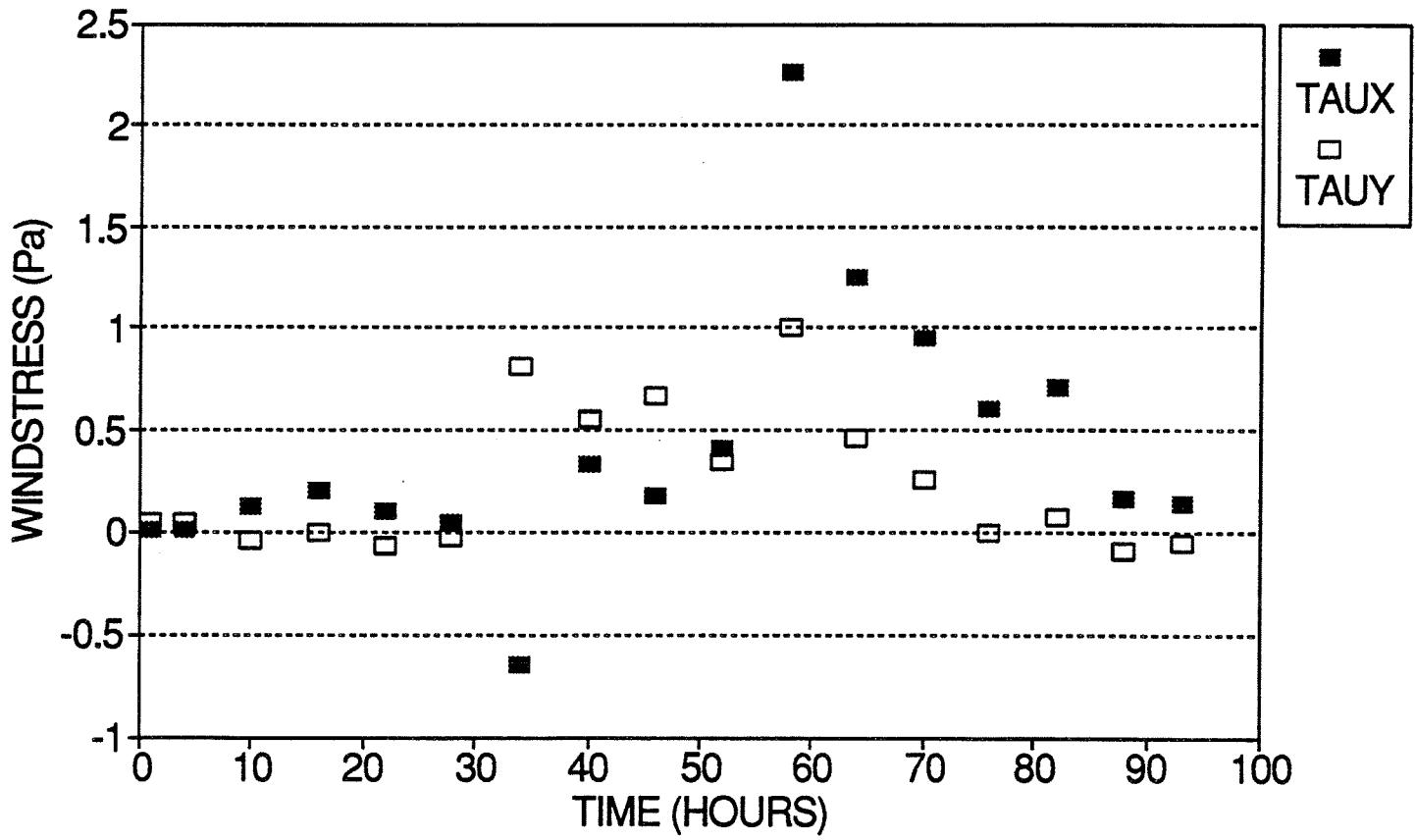


GRAND BANKS STORM MODEL



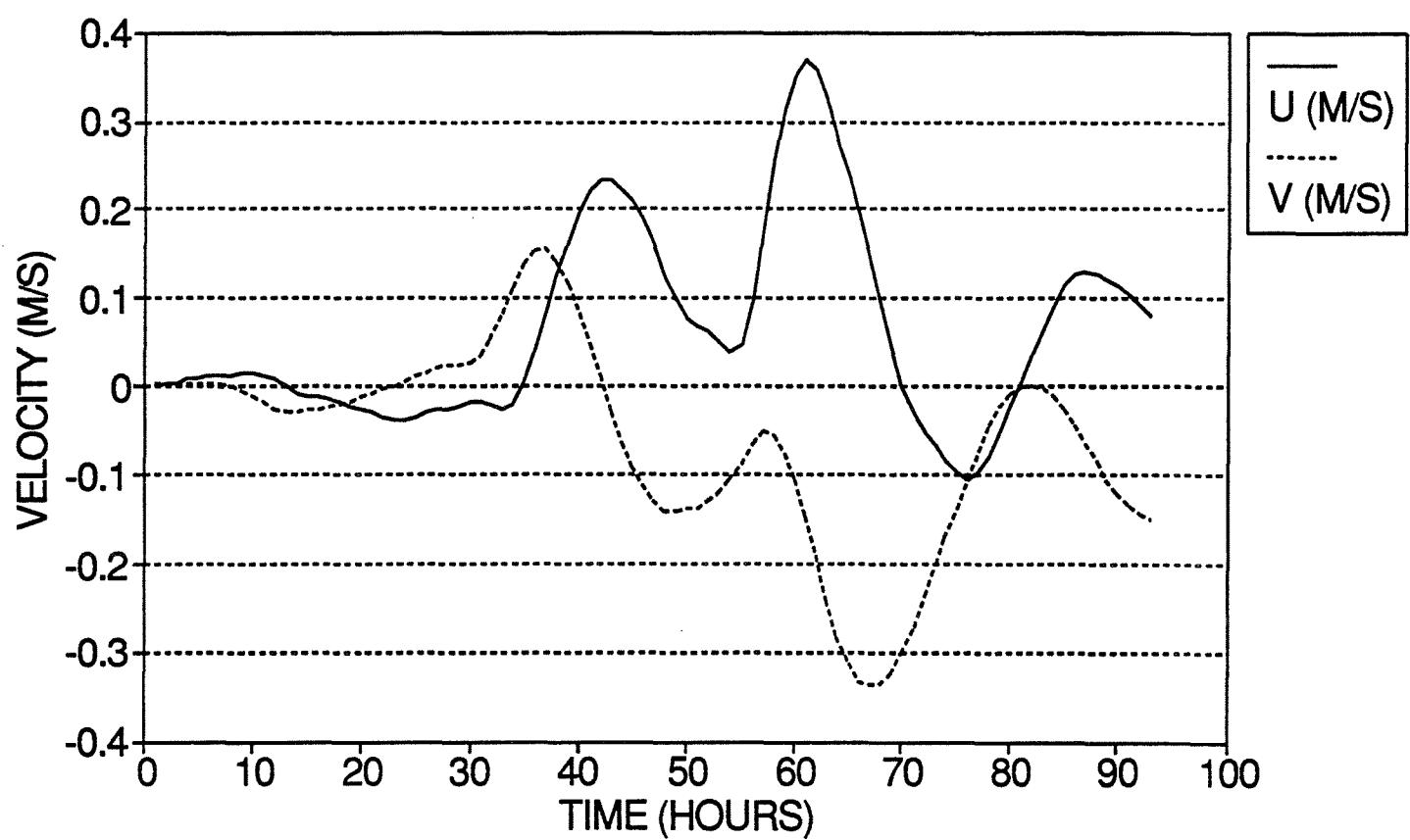
MOBIL STORM 14

16-20 MAR. 1976



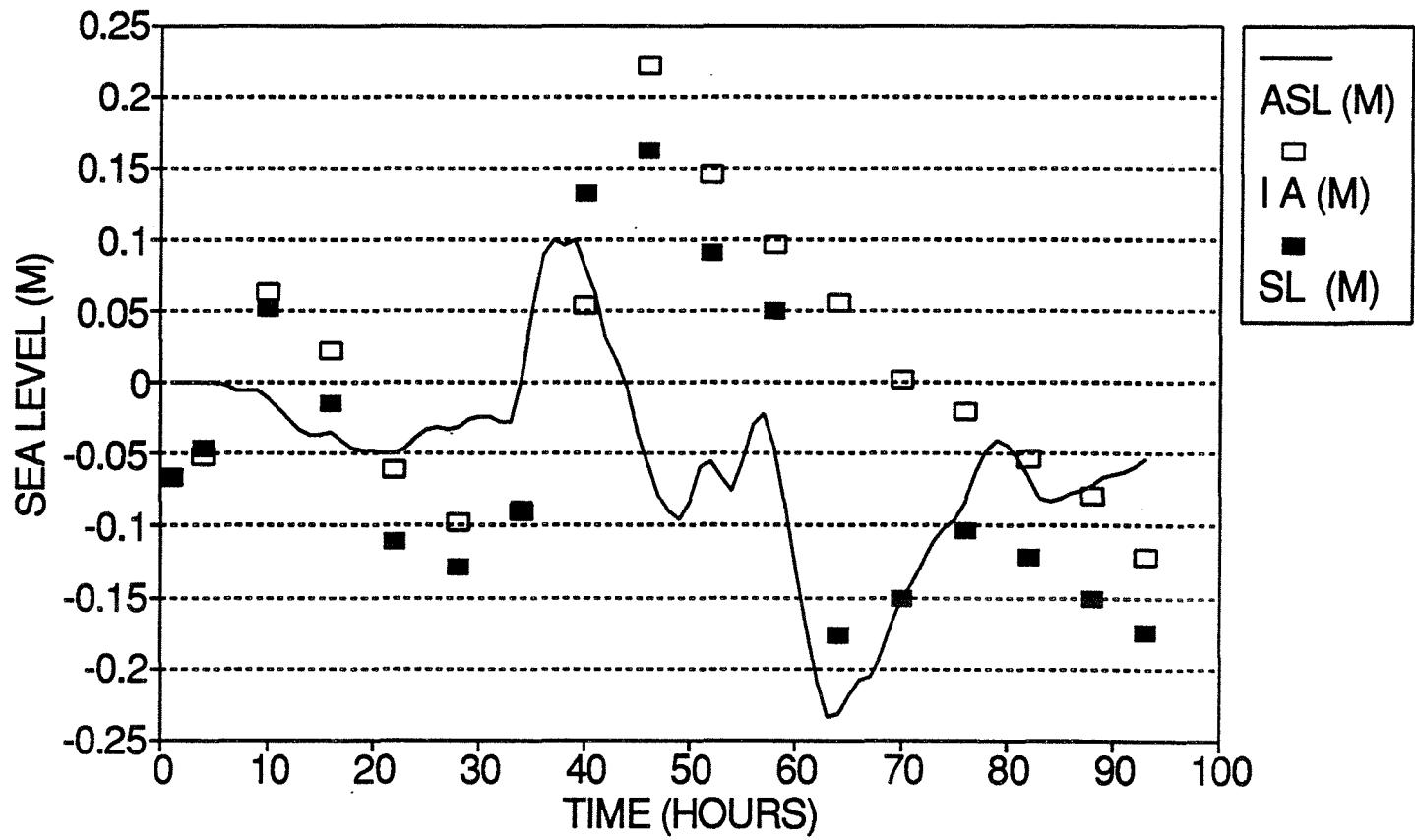
MOBIL STORM 14

16-20 MAR. 1976

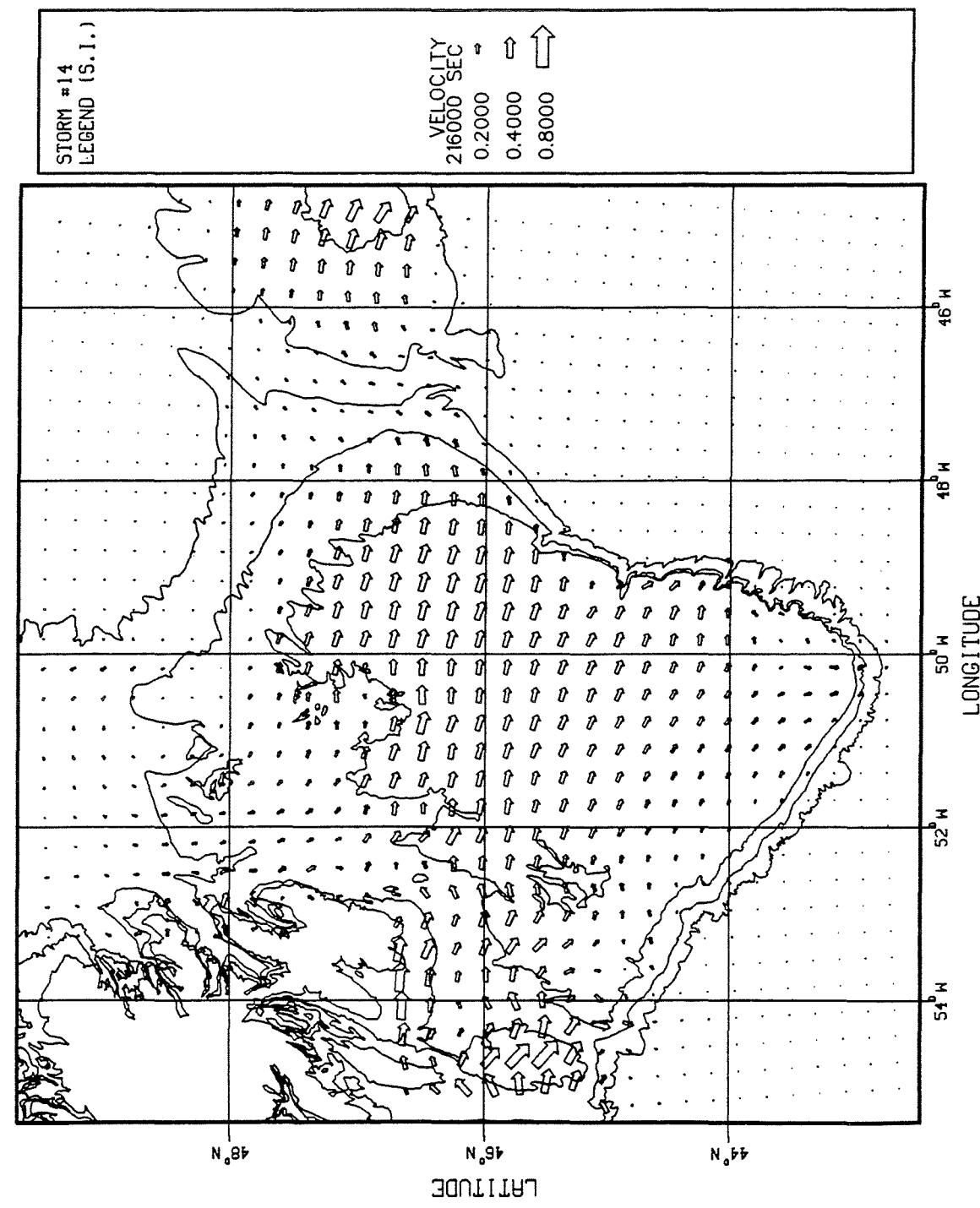


MOBIL STORM 14

16-20 MAR. 1976

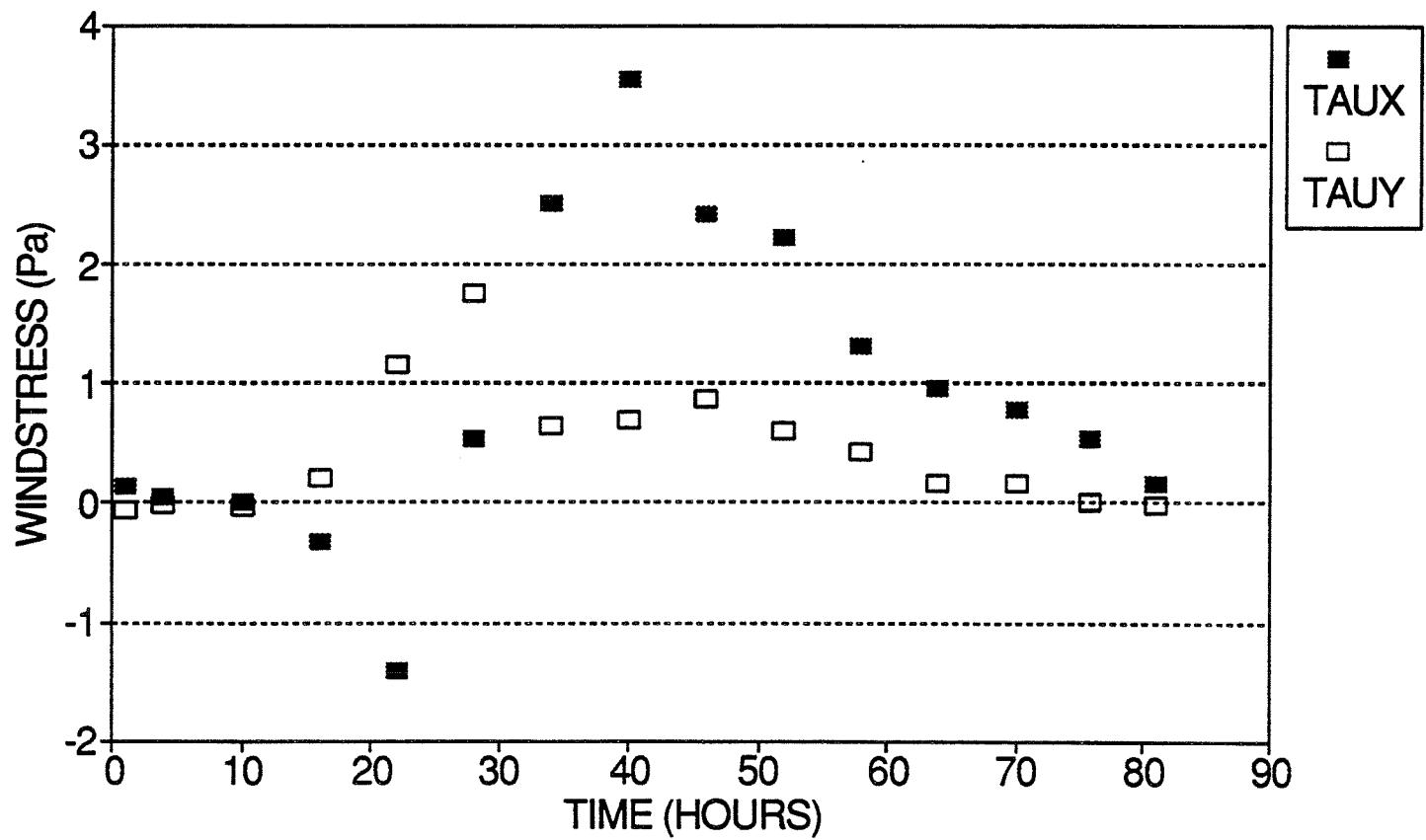


GRAND BANKS STORM MODEL



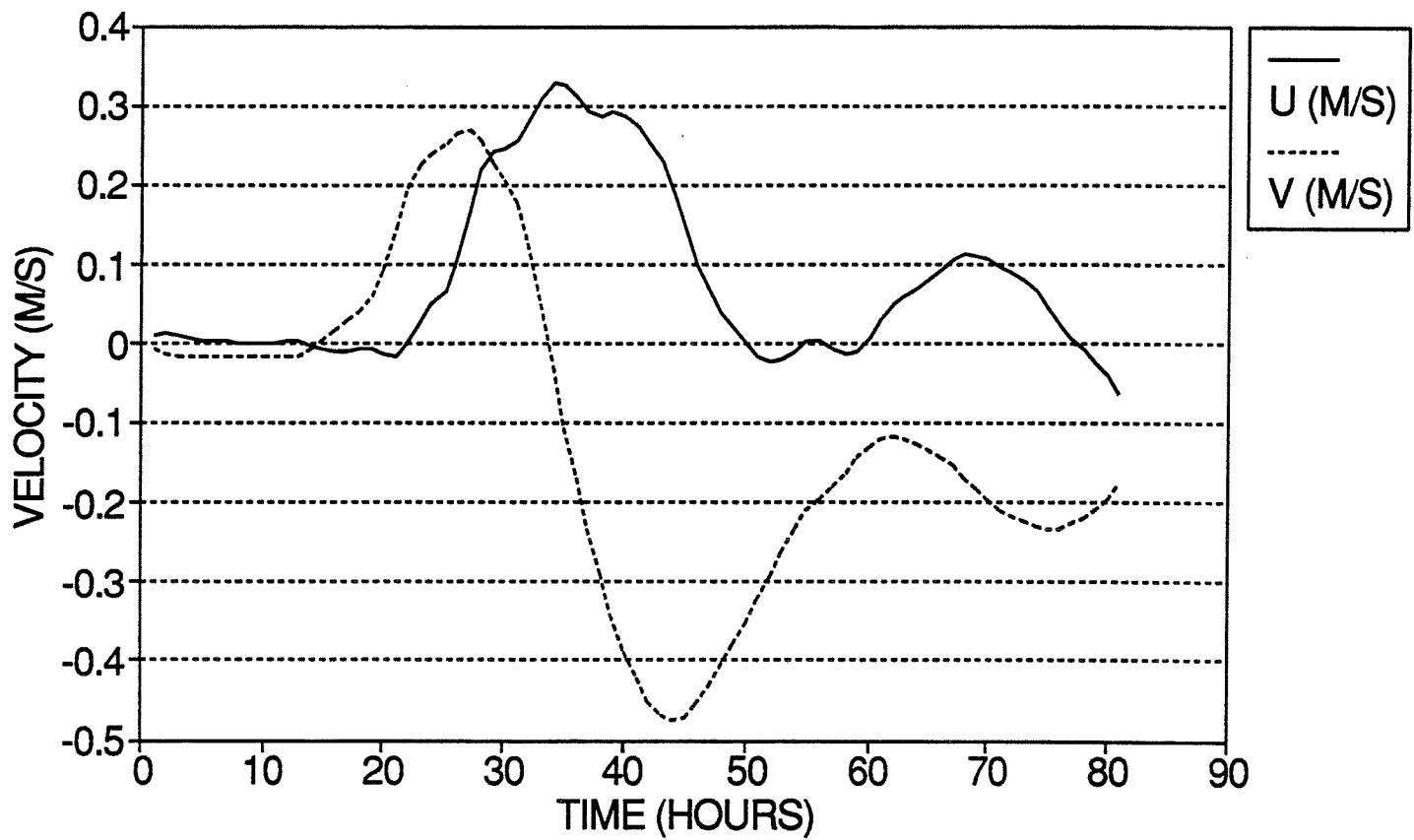
MOBIL STORM 15

16-19 JAN. 1971



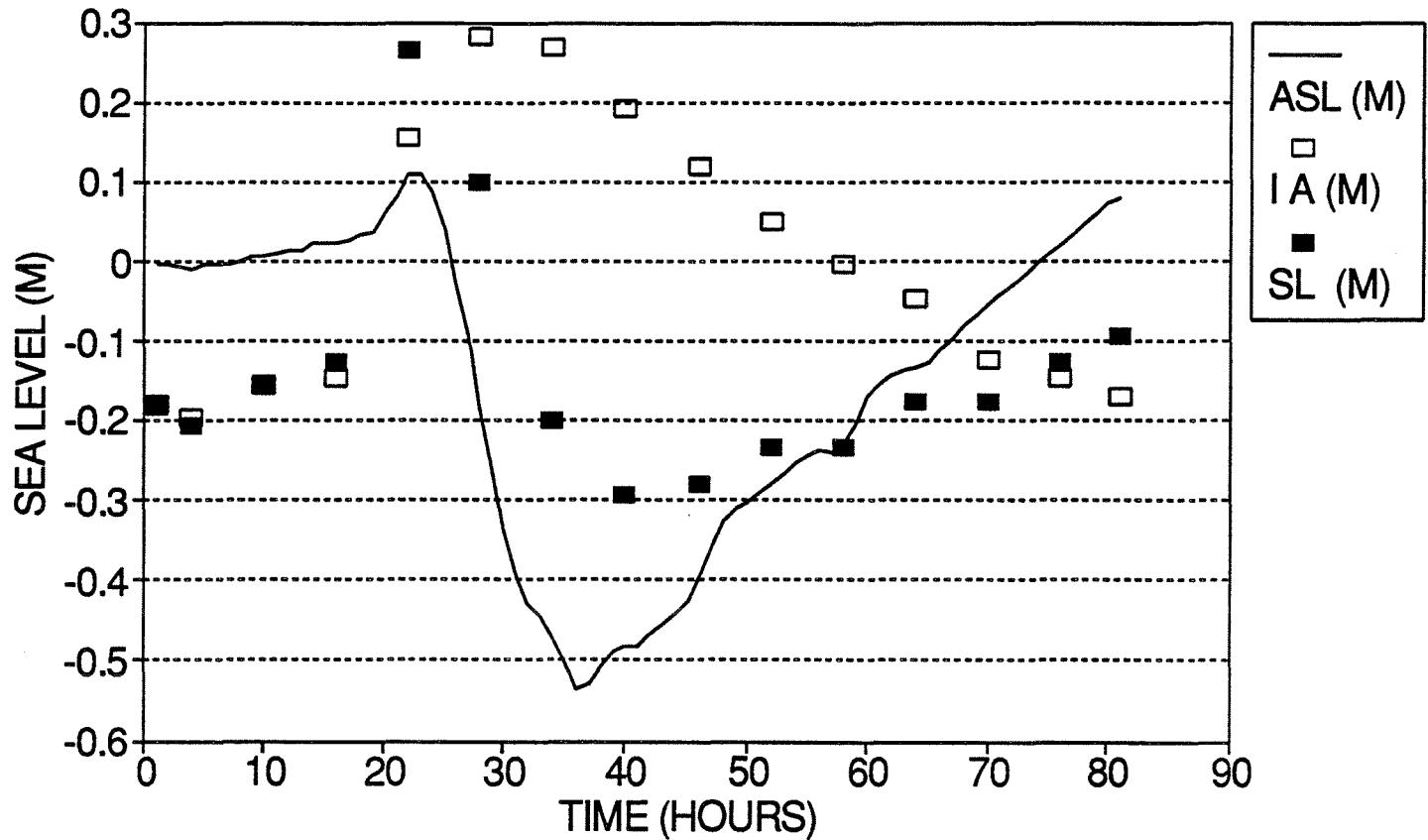
MOBIL STORM 15

16-19 JAN. 1971



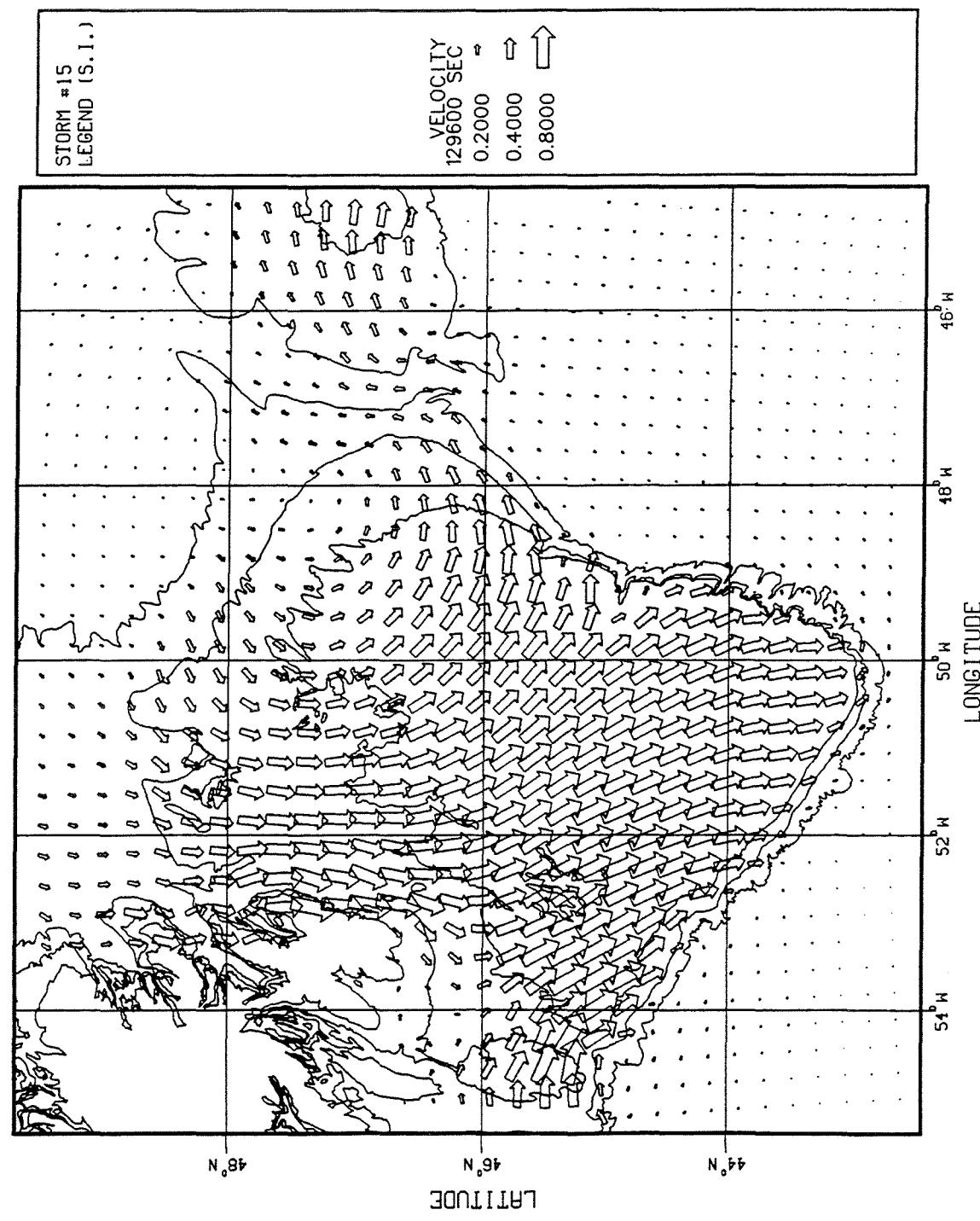
MOBIL STORM 15

16-19 JAN. 1971



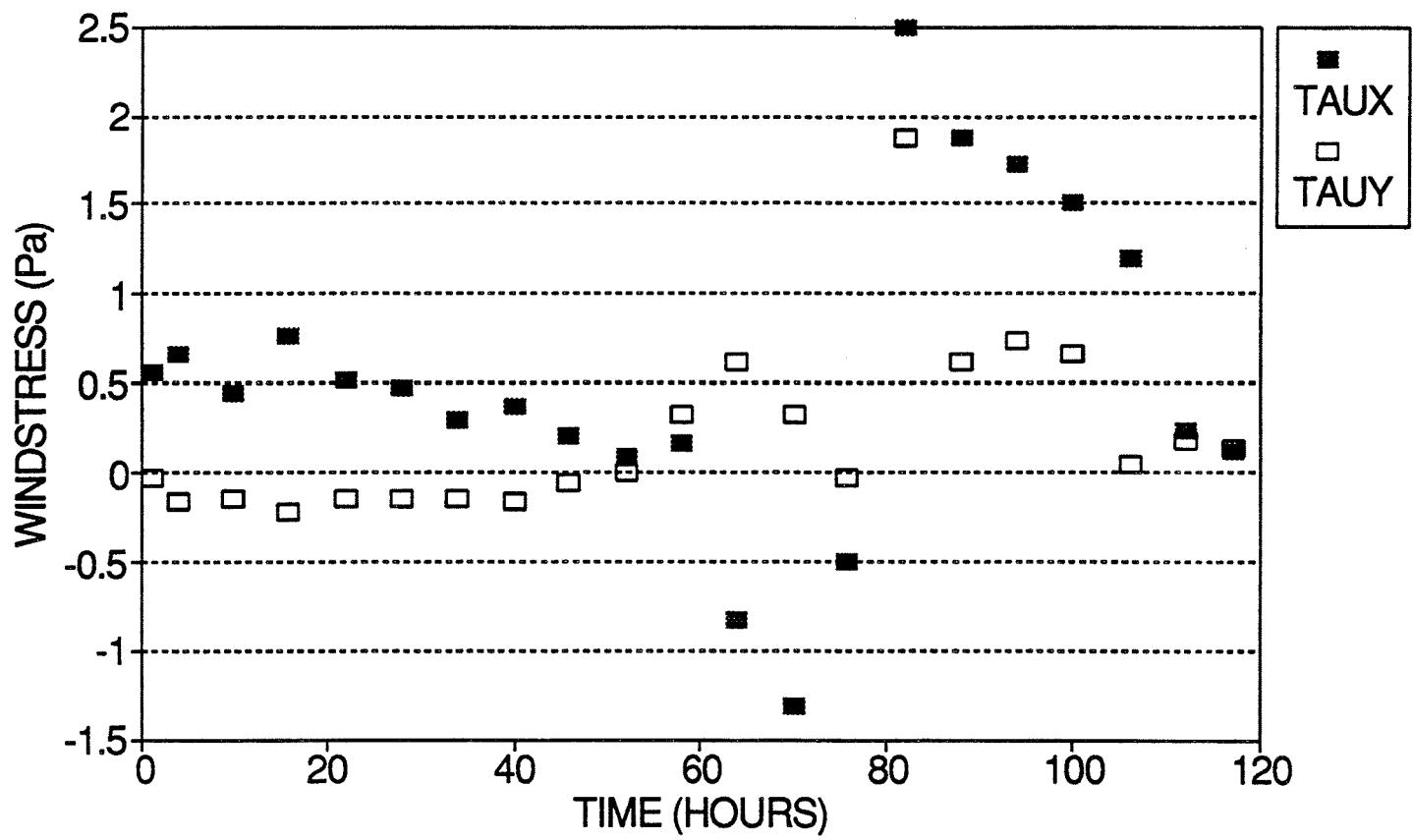
GRAND BANKS STORM MODEL

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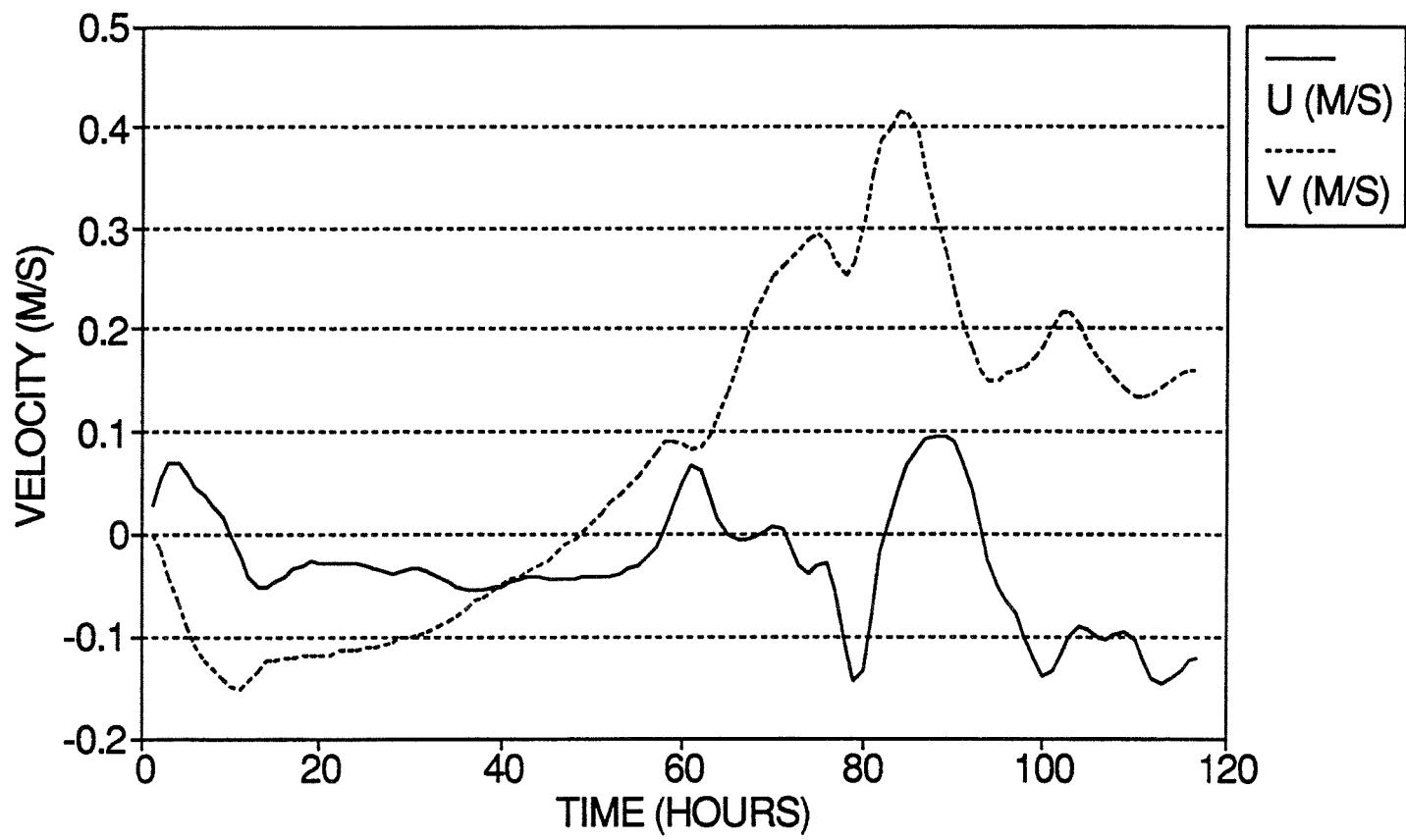
MOBIL STORM 16

8-13 MAR. 1974



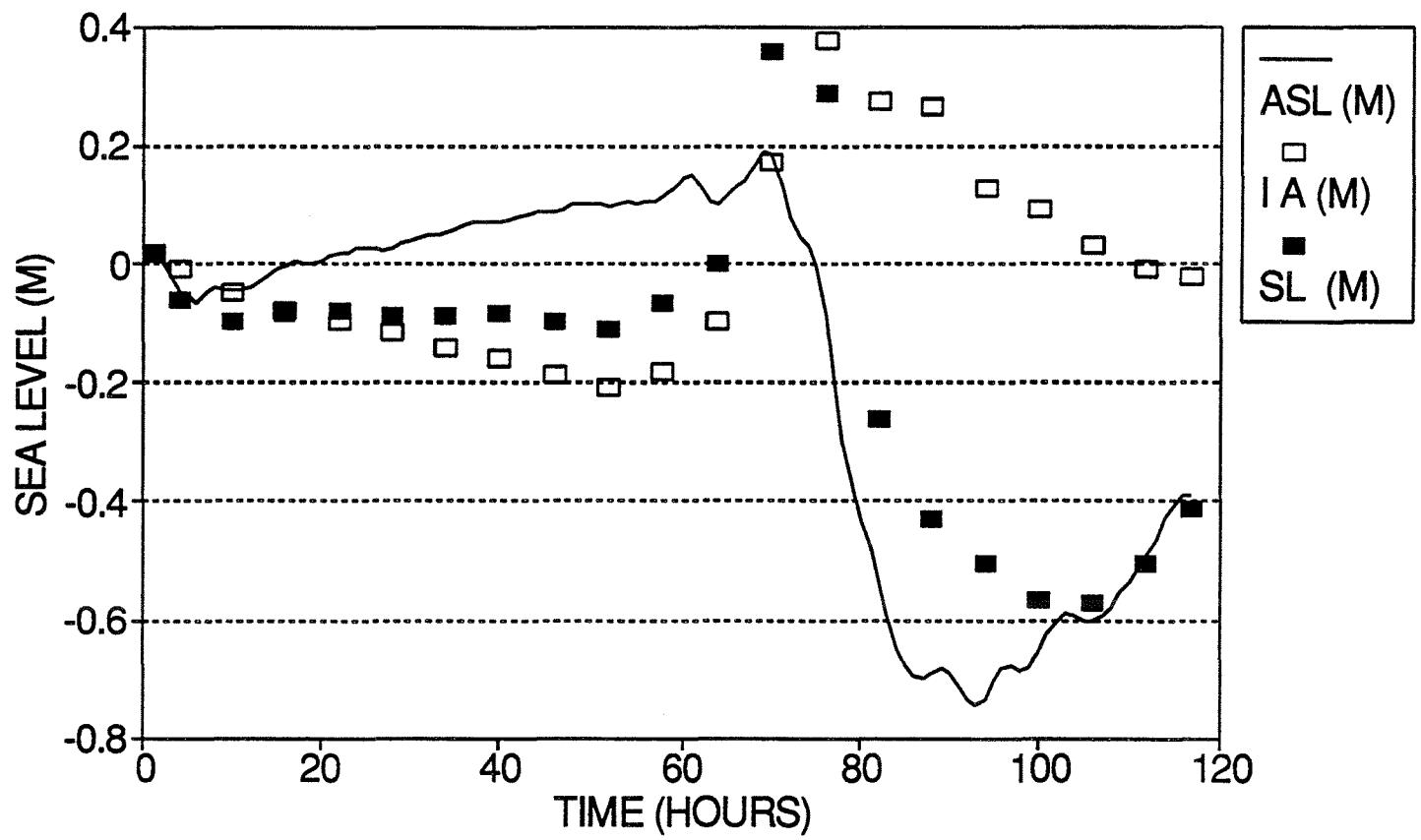
MOBIL STORM 16

8-13 MAR. 1974

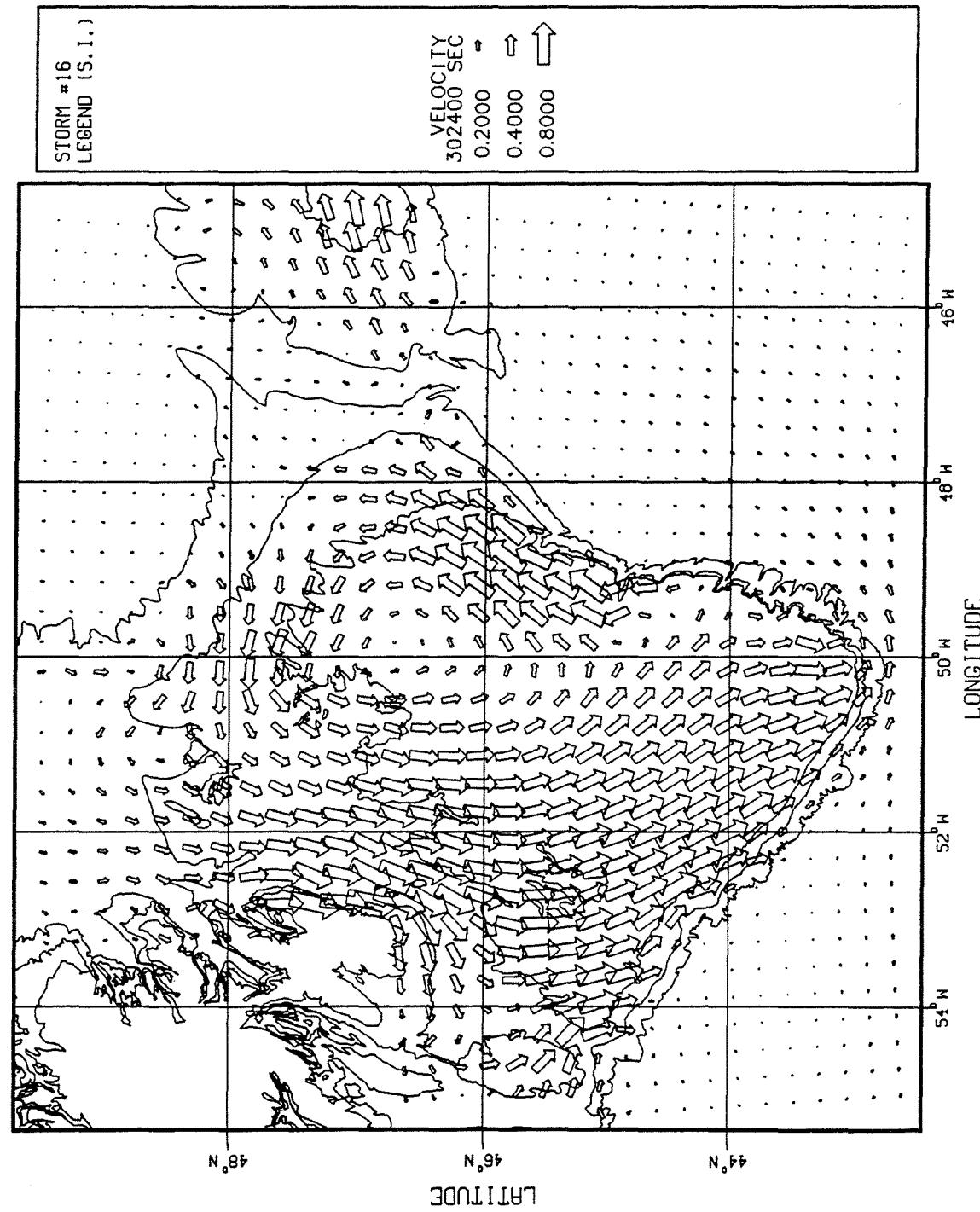


MOBIL STORM 16

8-13 MAR. 1974

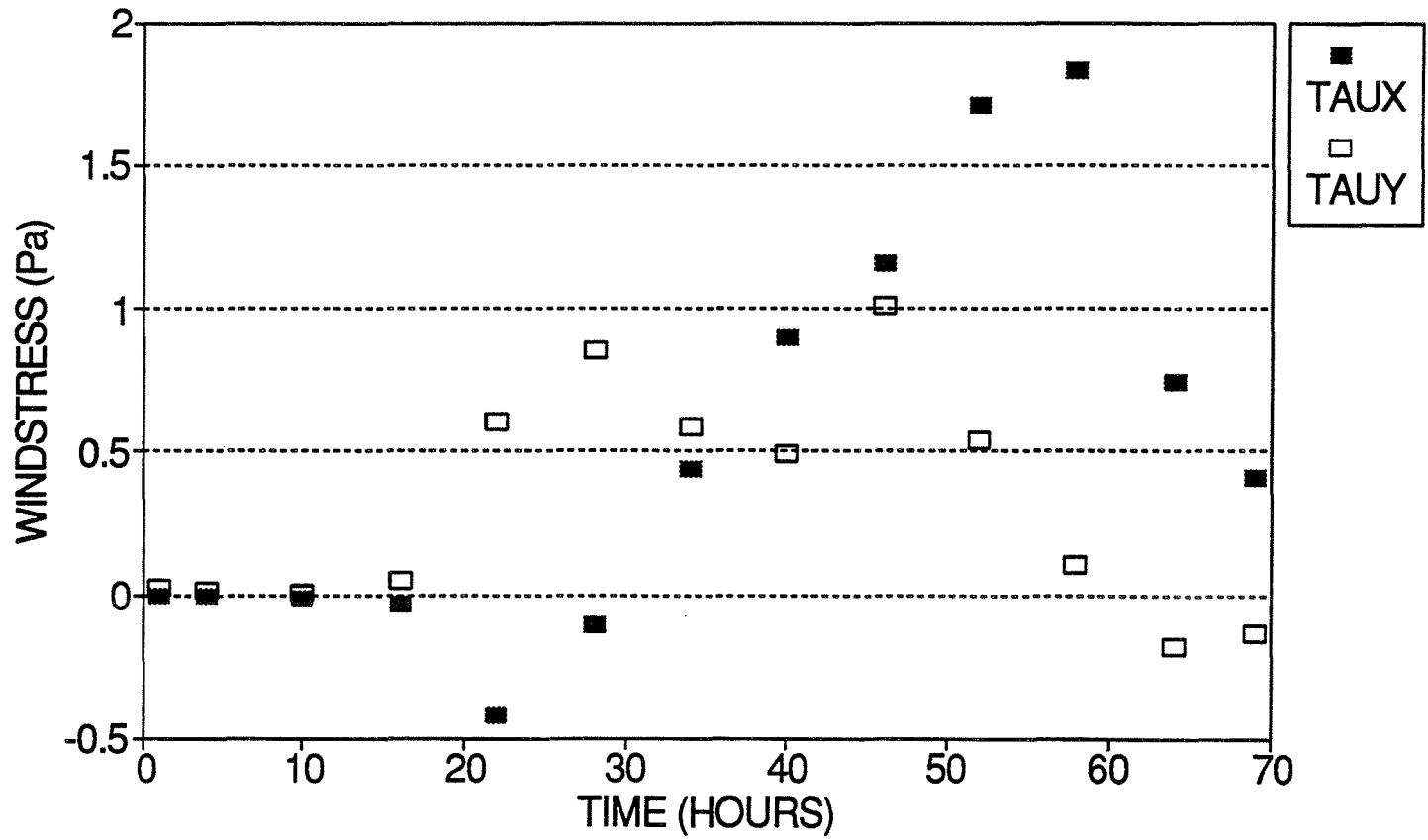


GRAND BANKS STORM MODEL



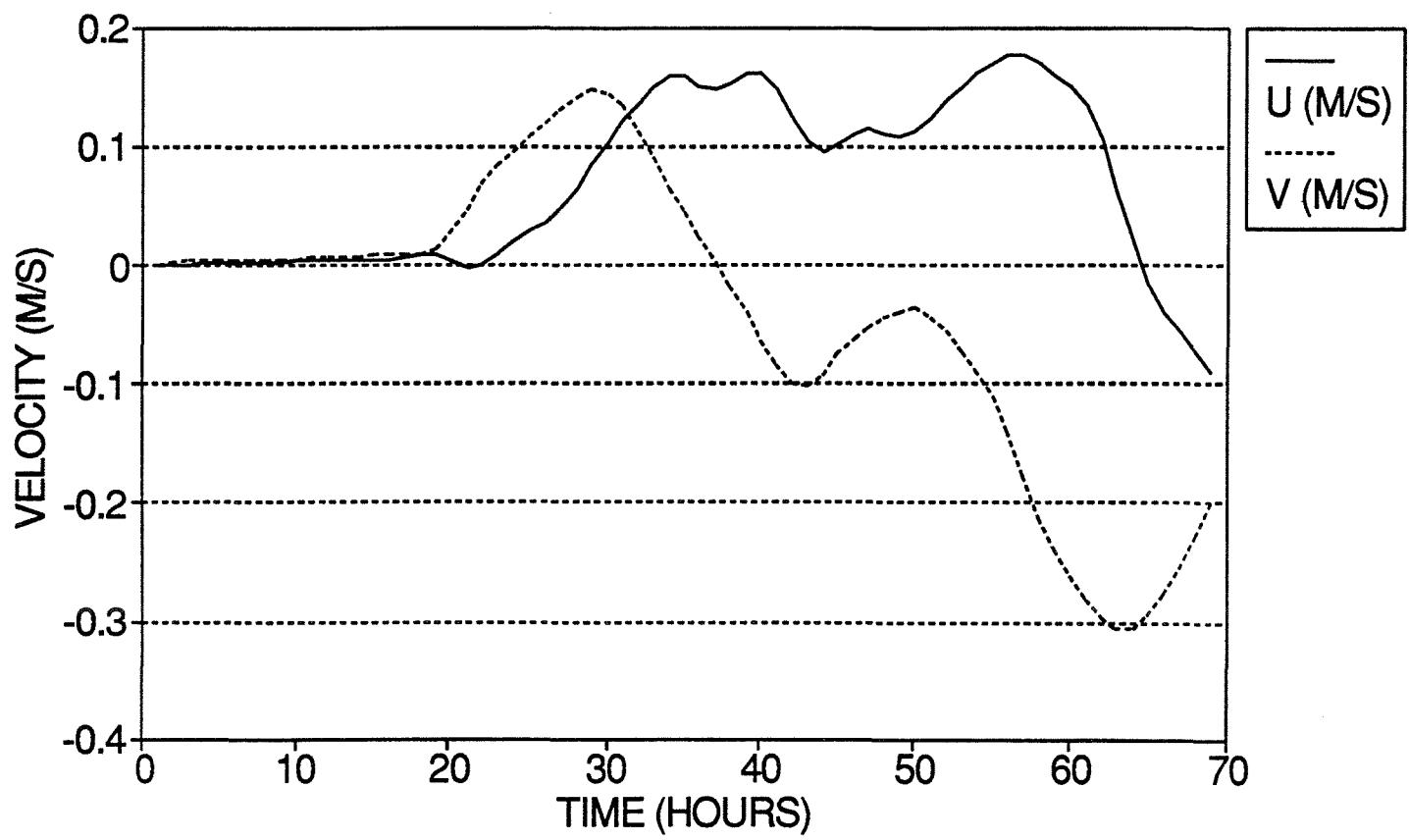
MOBIL STORM 17

20-23 SEPT. 1955



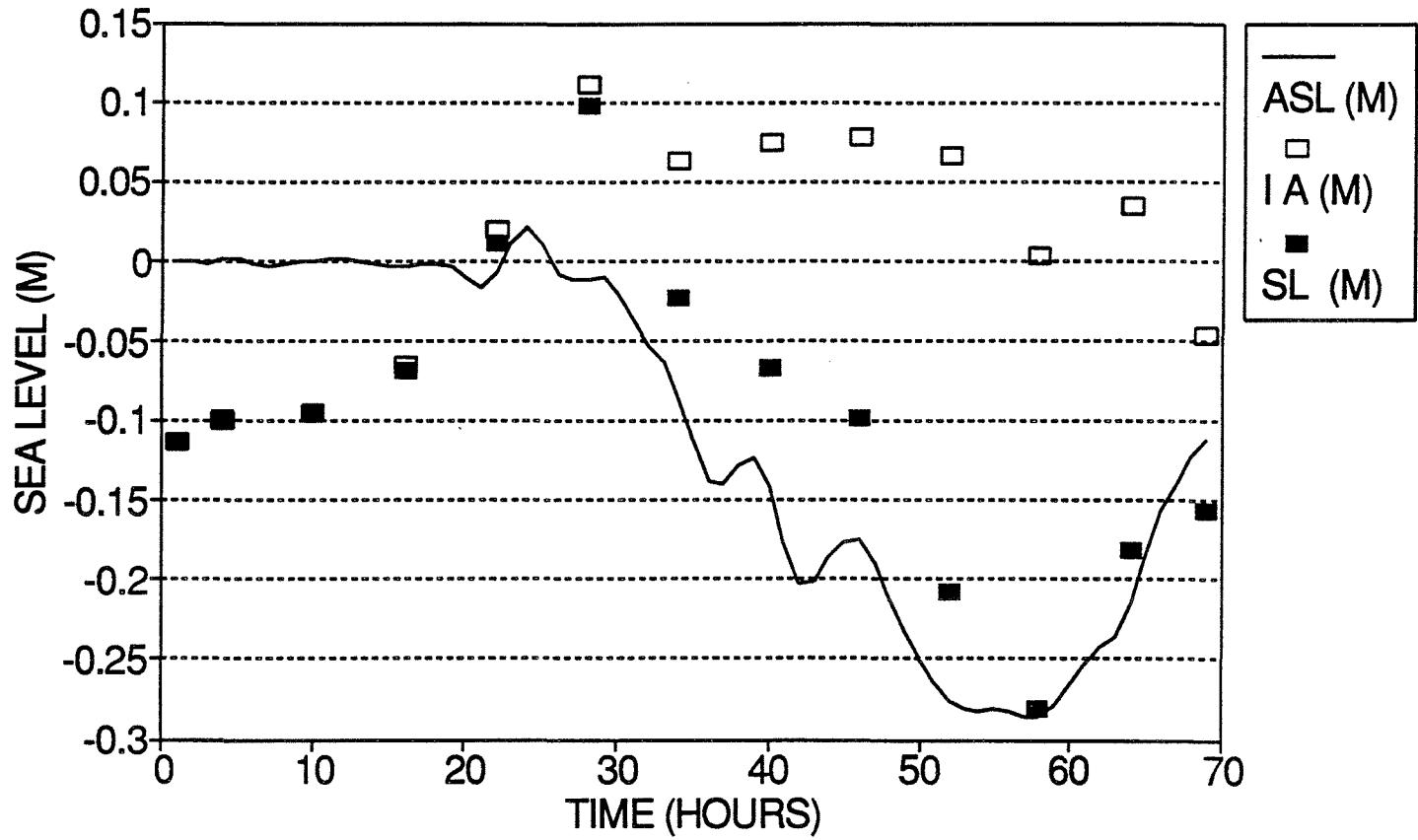
MOBIL STORM 17

20-23 SEPT. 1955

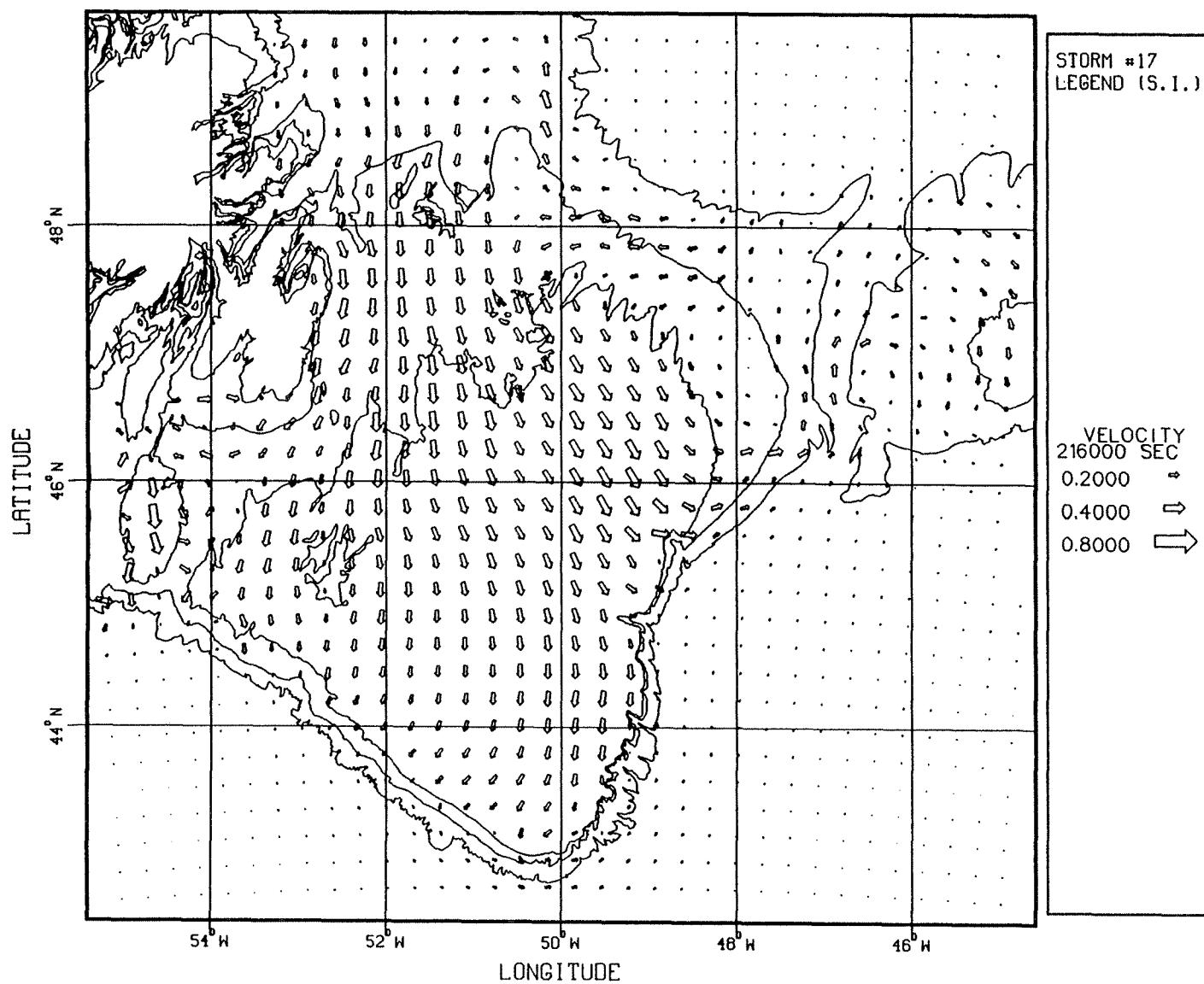


MOBIL STORM 17

20-23 SEPT. 1955

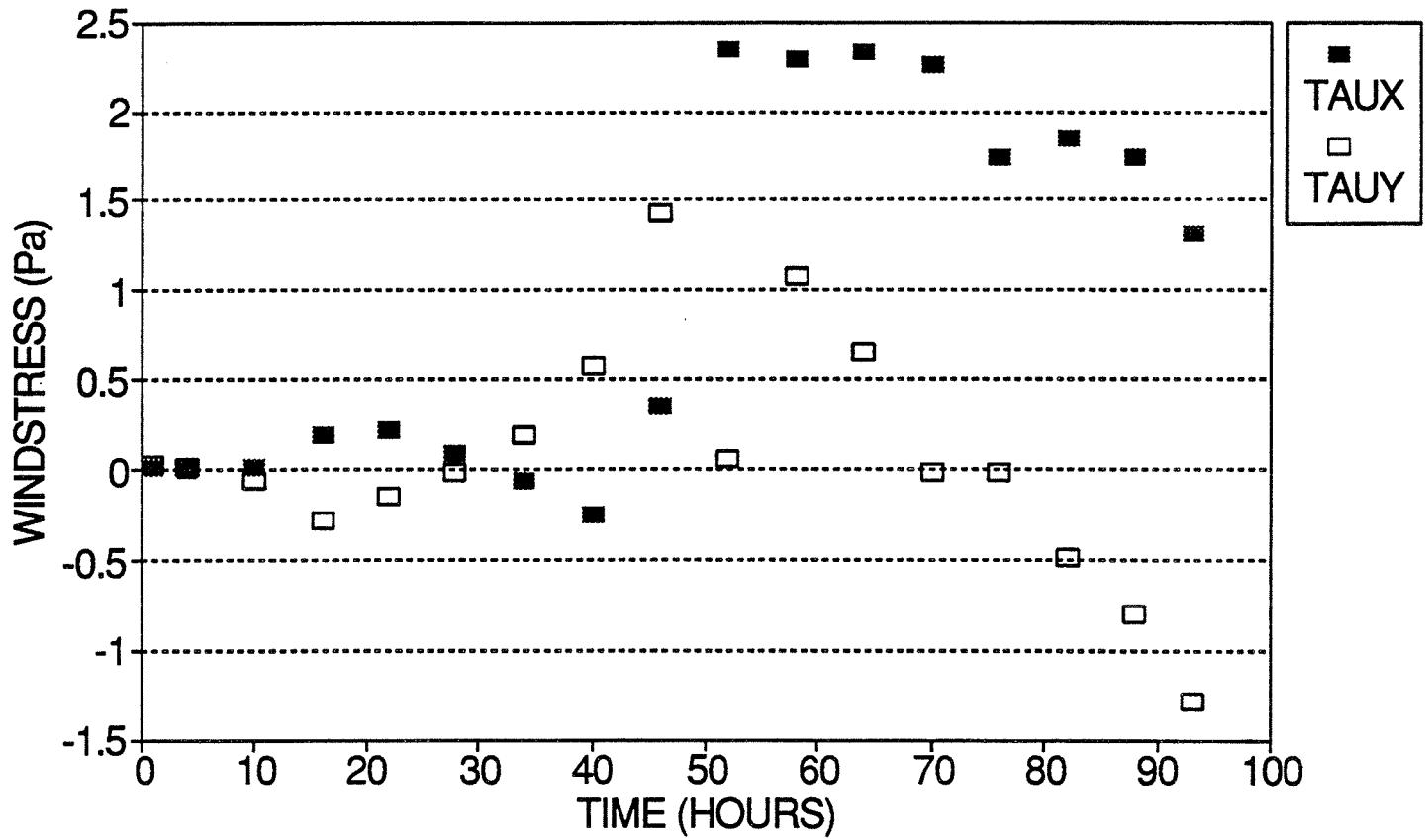


GRAND BANKS STORM MODEL



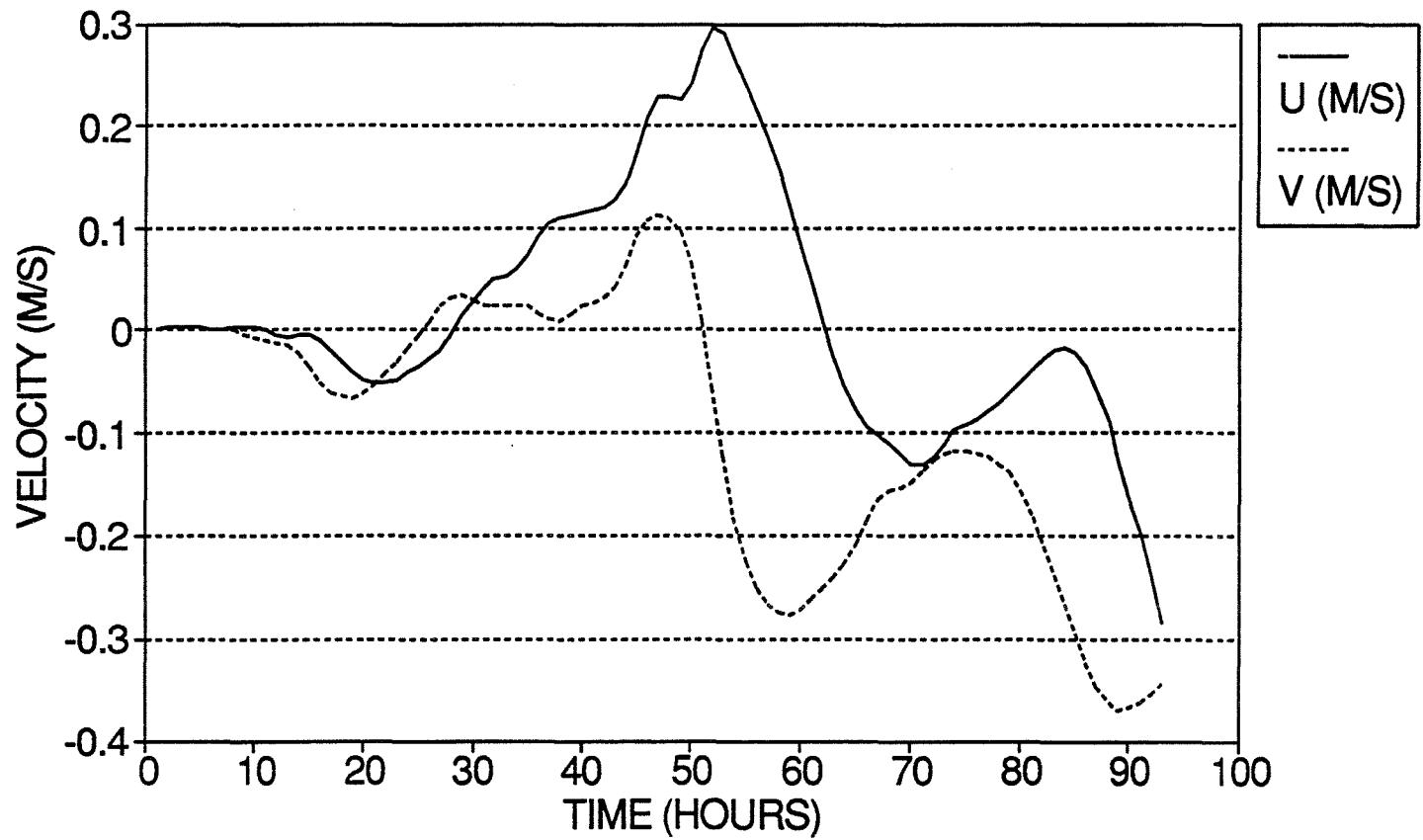
MOBIL STORM 18

9-13 DEC. 1955



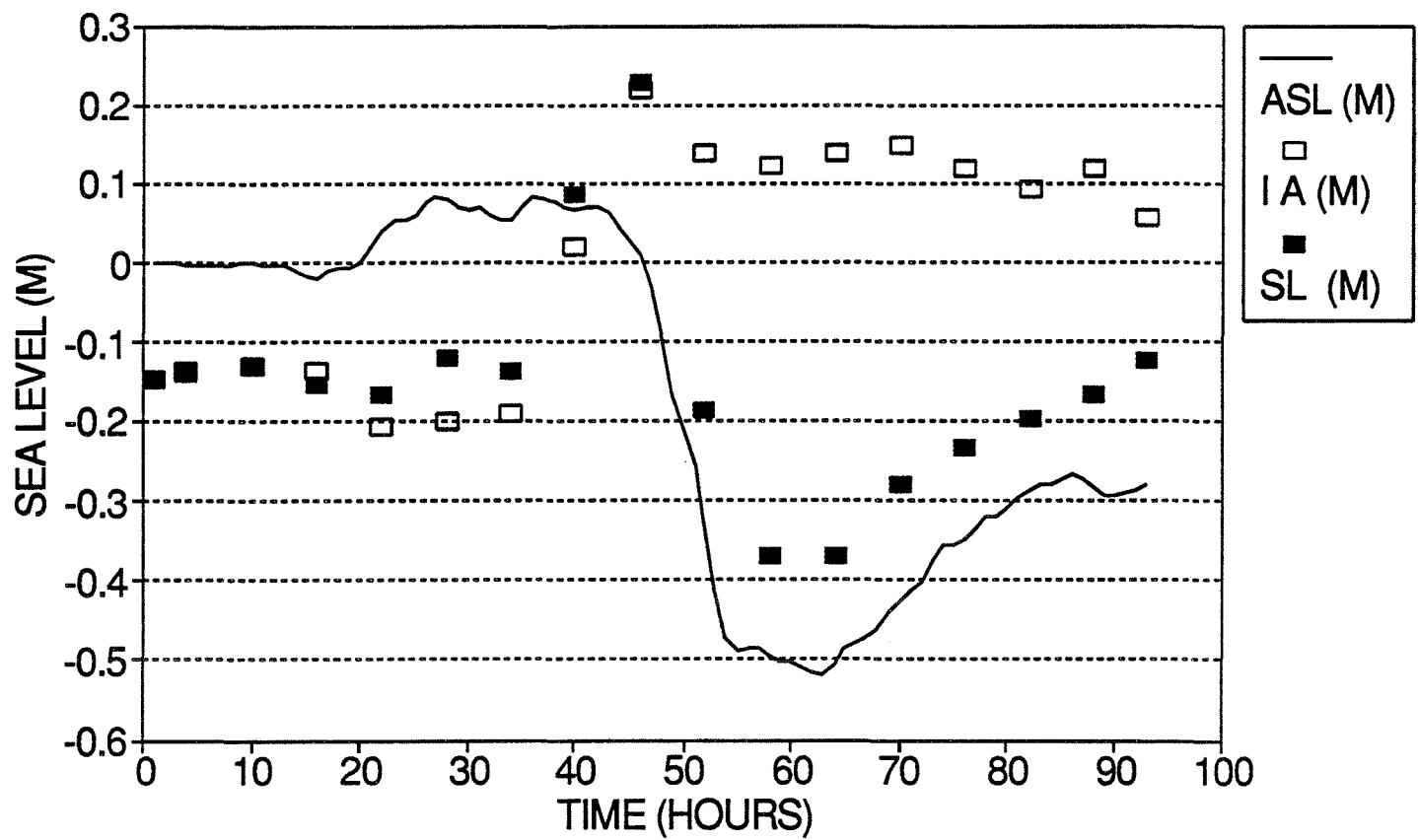
MOBIL STORM 18

9-13 DEC. 1955

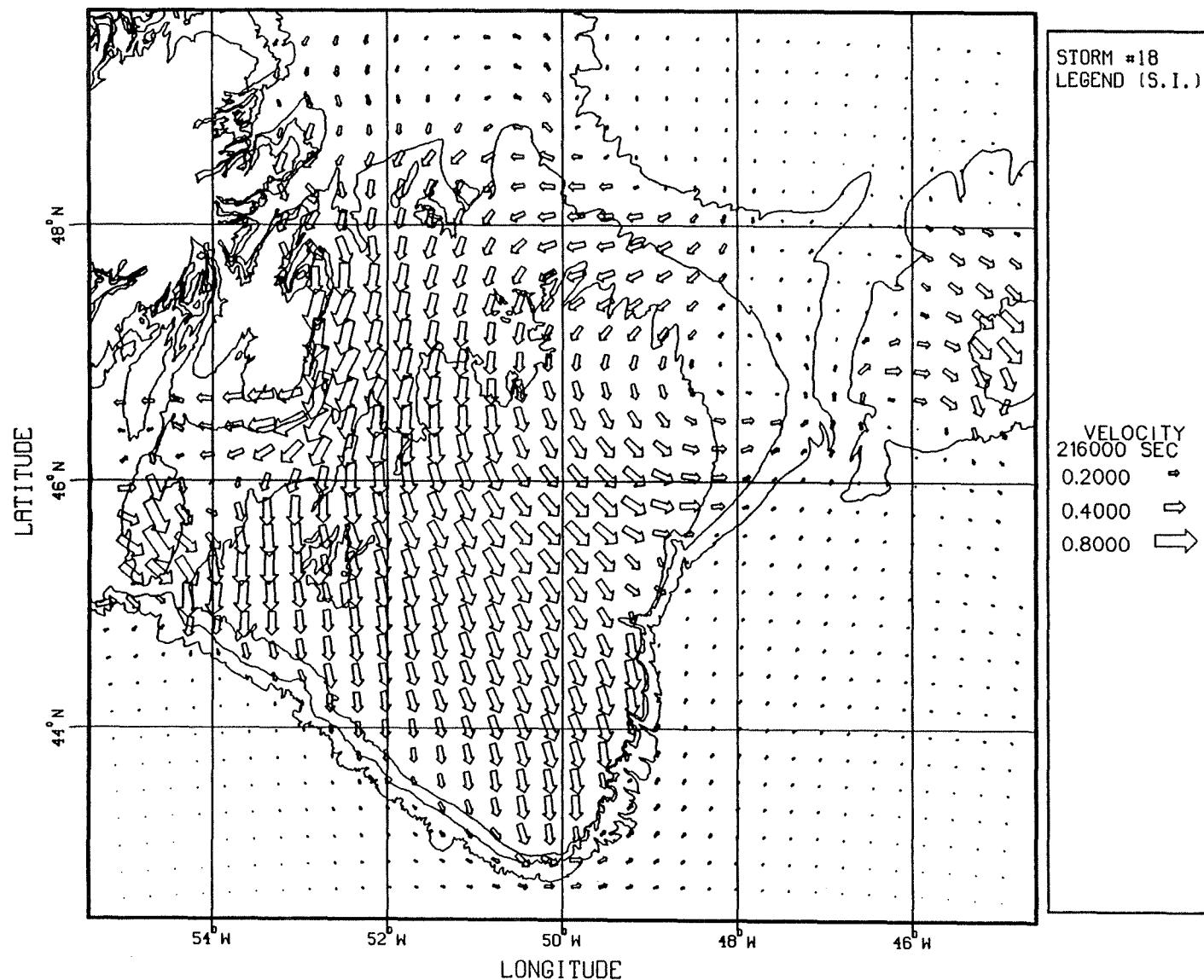


MOBIL STORM 18

9-13 DEC. 1955

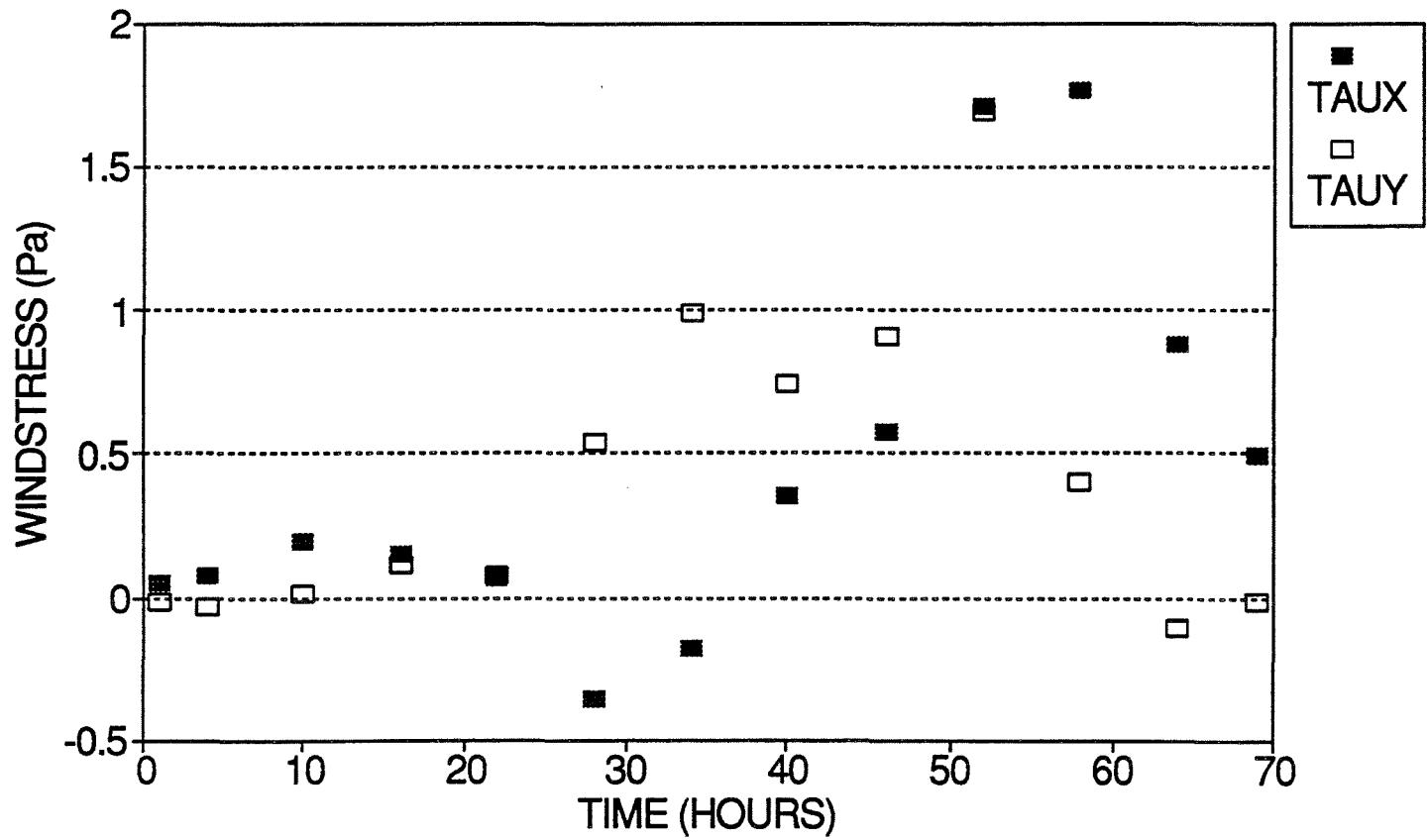


GRAND BANKS STORM MODEL



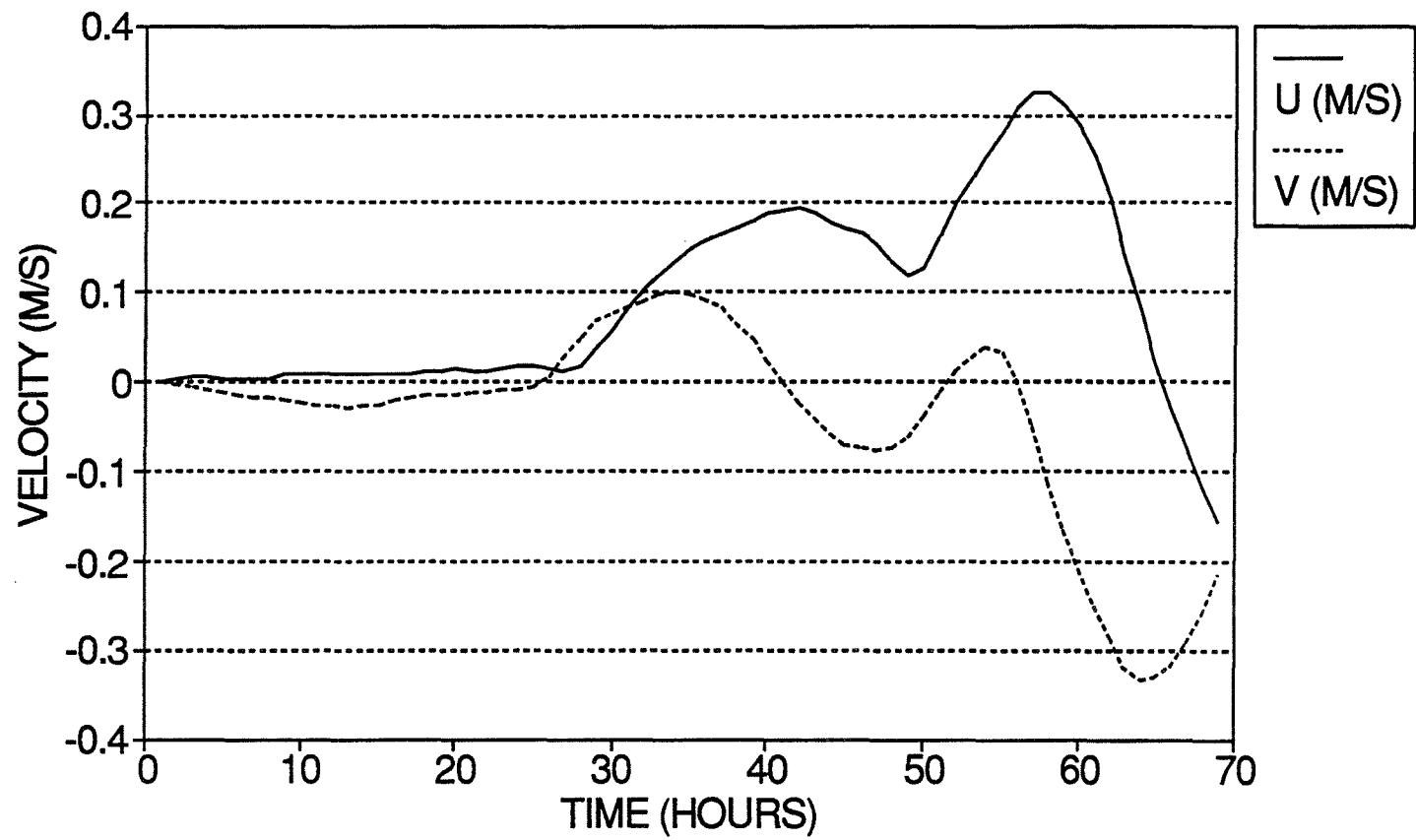
MOBIL STORM 19

8-11 FEB. 1954



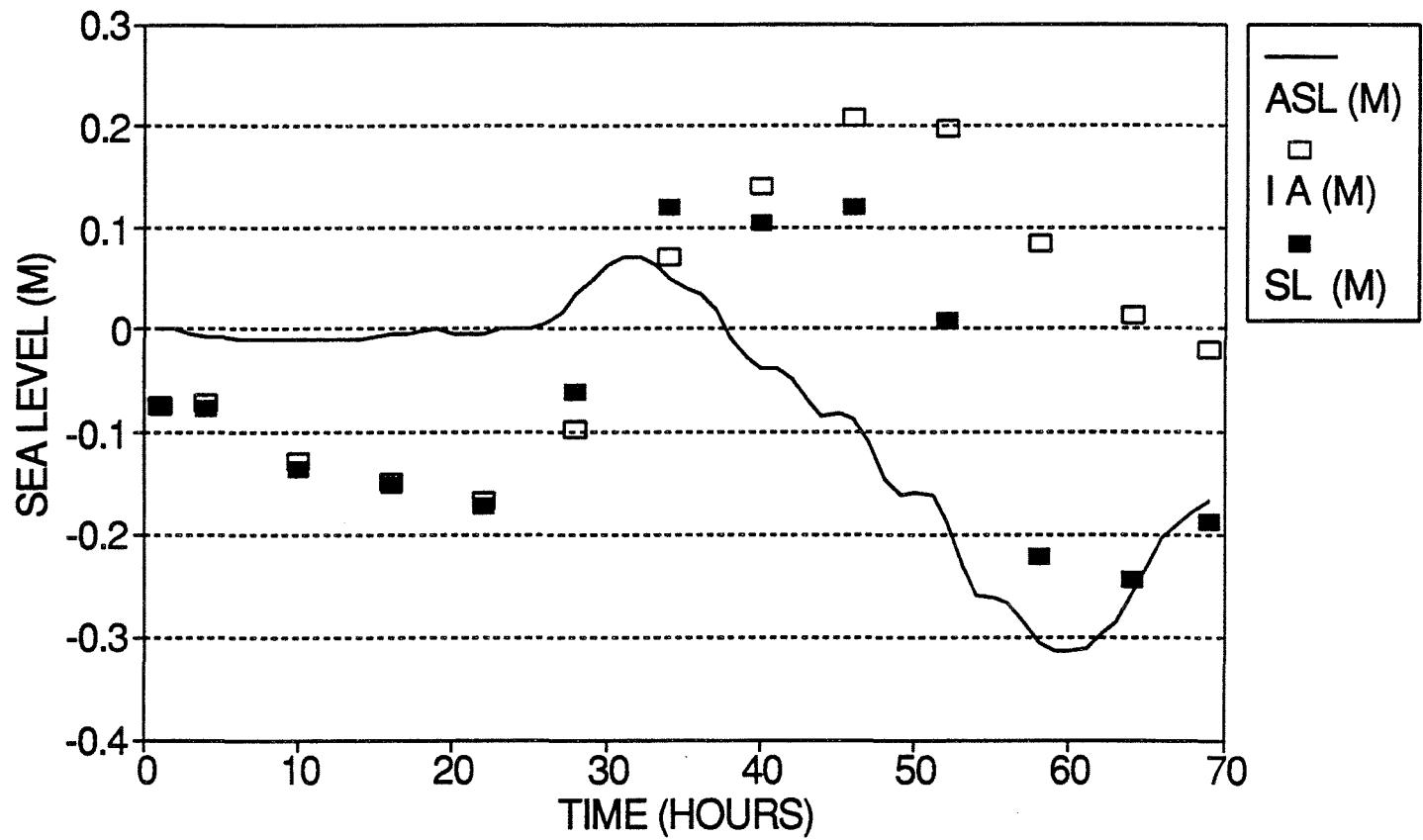
MOBIL STORM 19

8-11 FEB. 1954

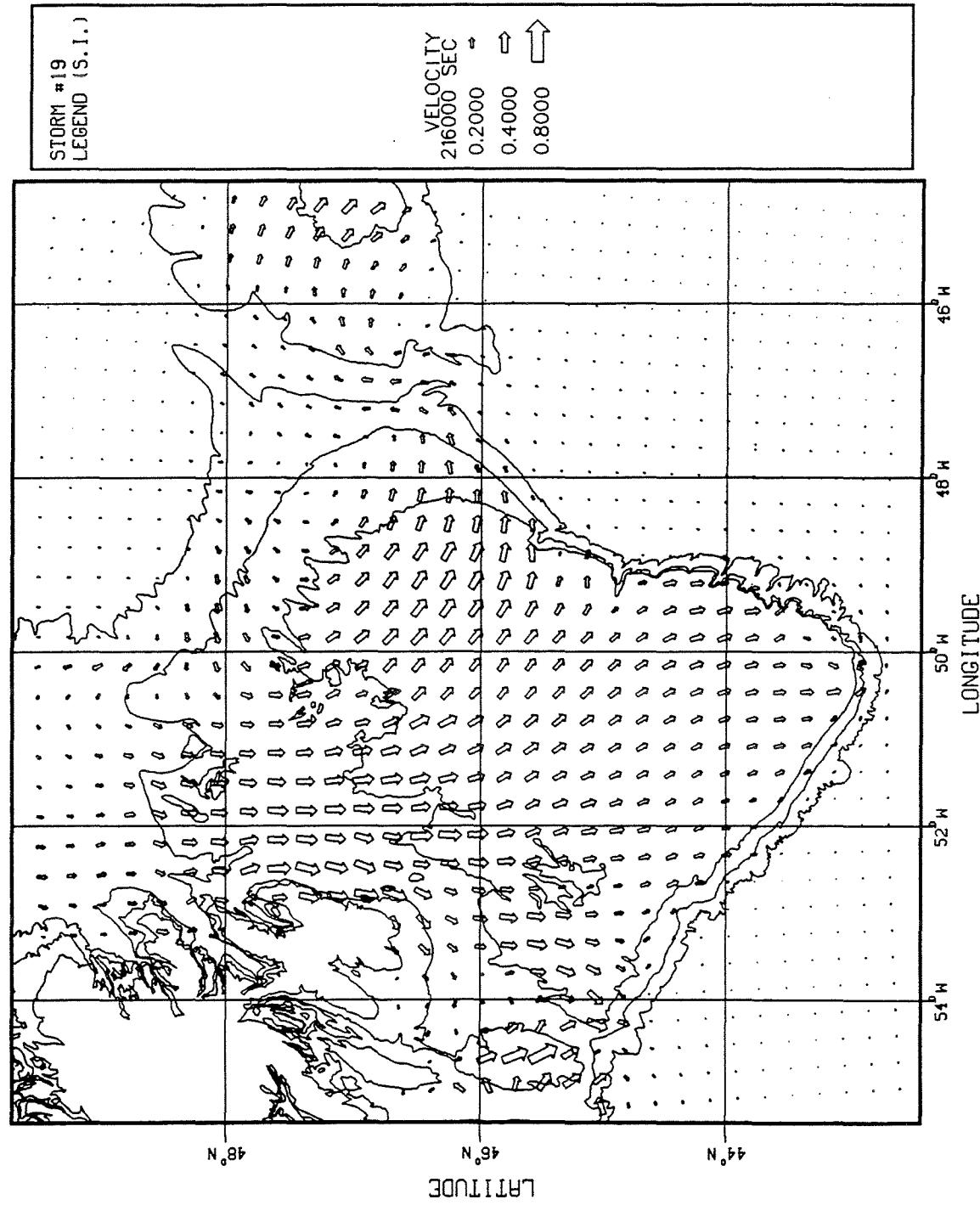


MOBIL STORM 19

8-11 FEB. 1954

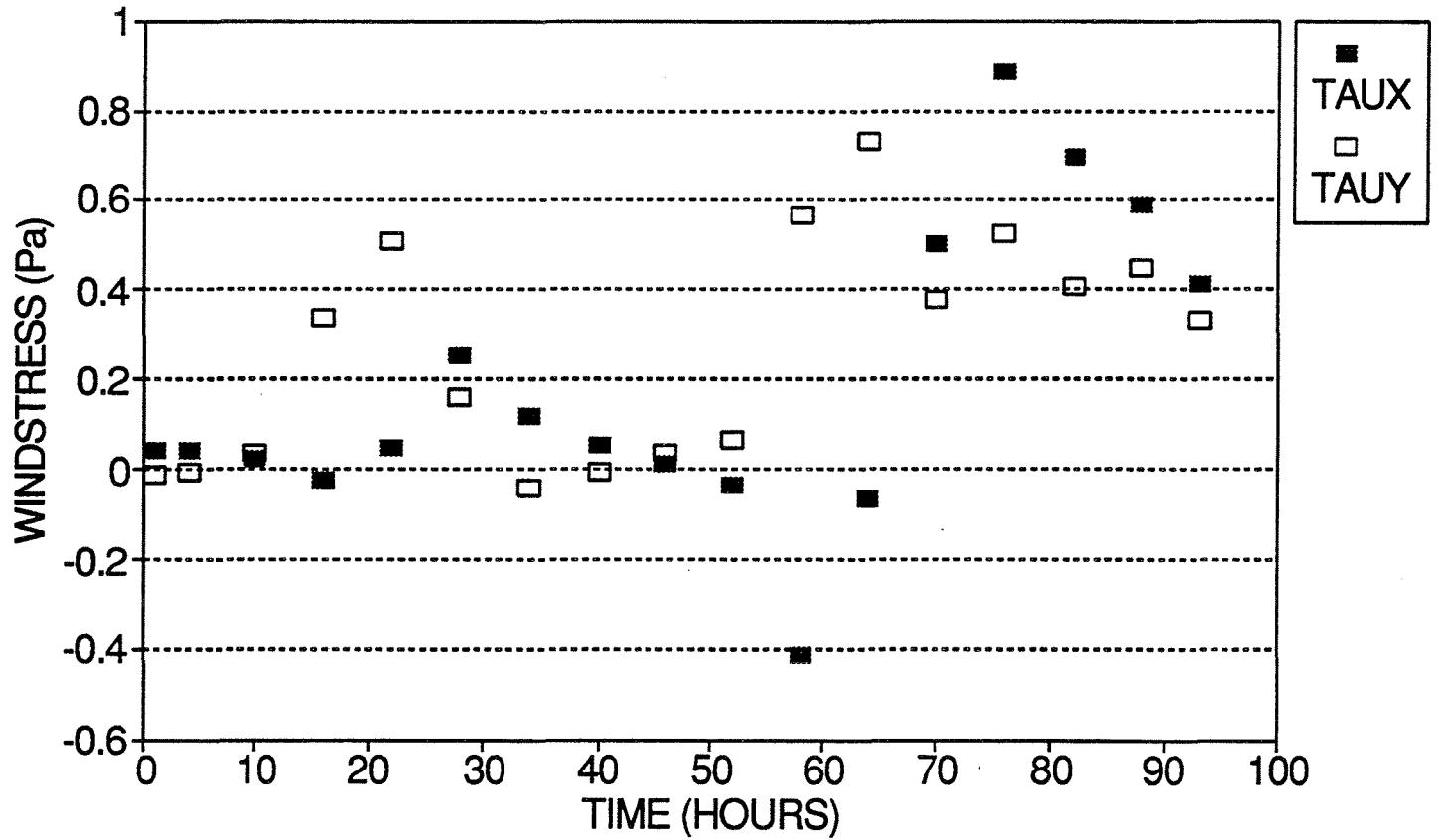


GRAND BANKS STORM MODEL



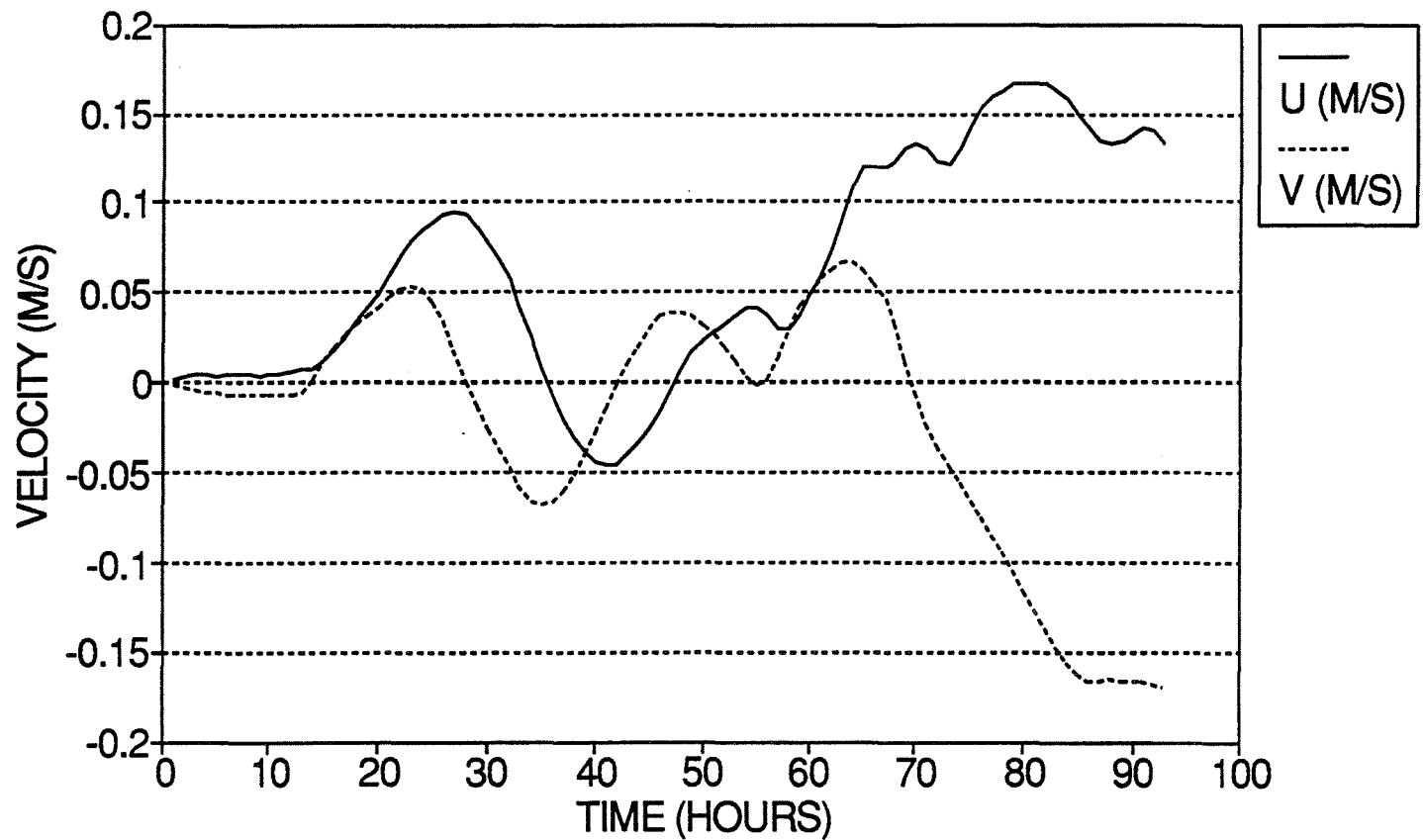
MOBIL STORM 20

10-14 NOV. 1952



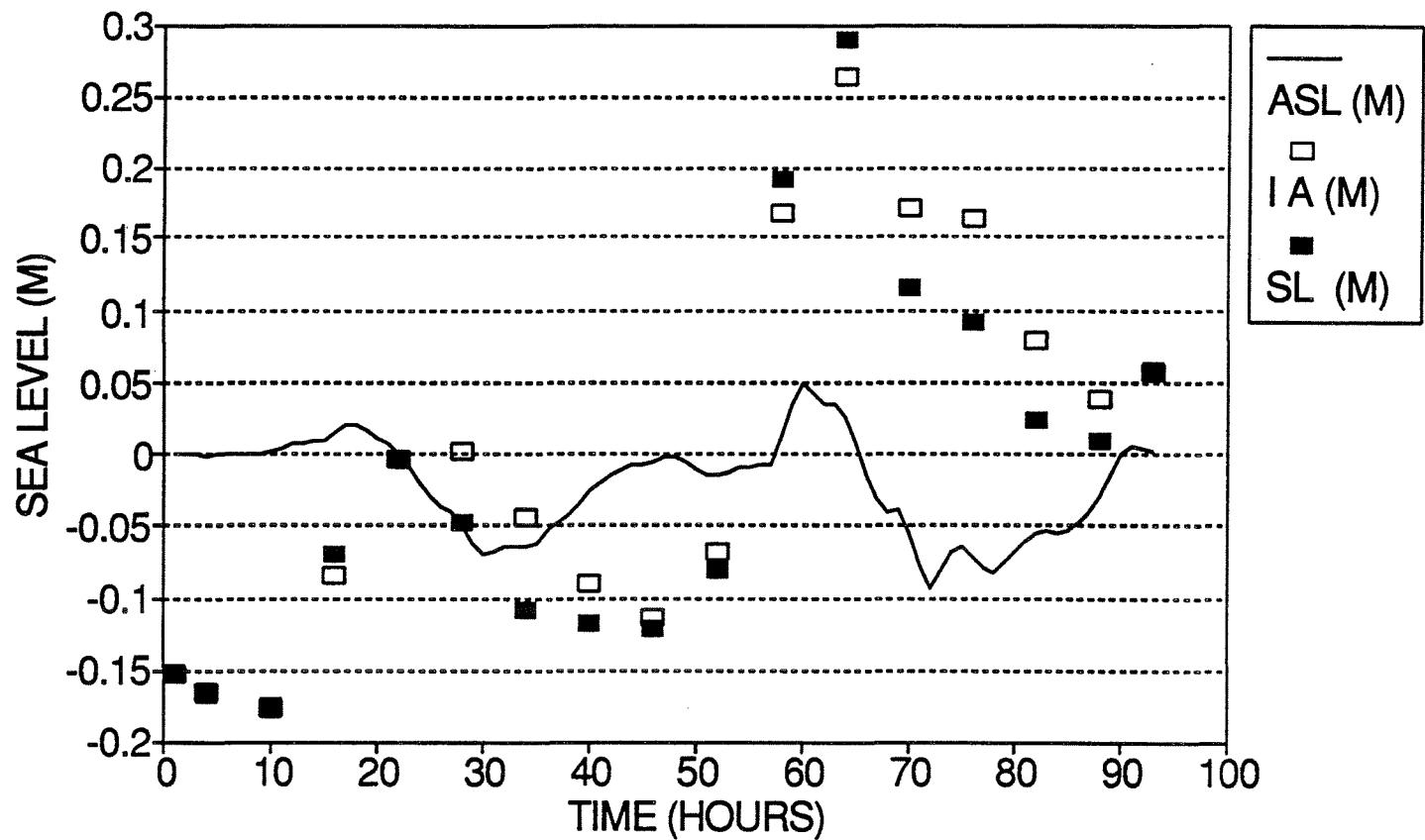
MOBIL STORM 20

10-14 NOV. 1952

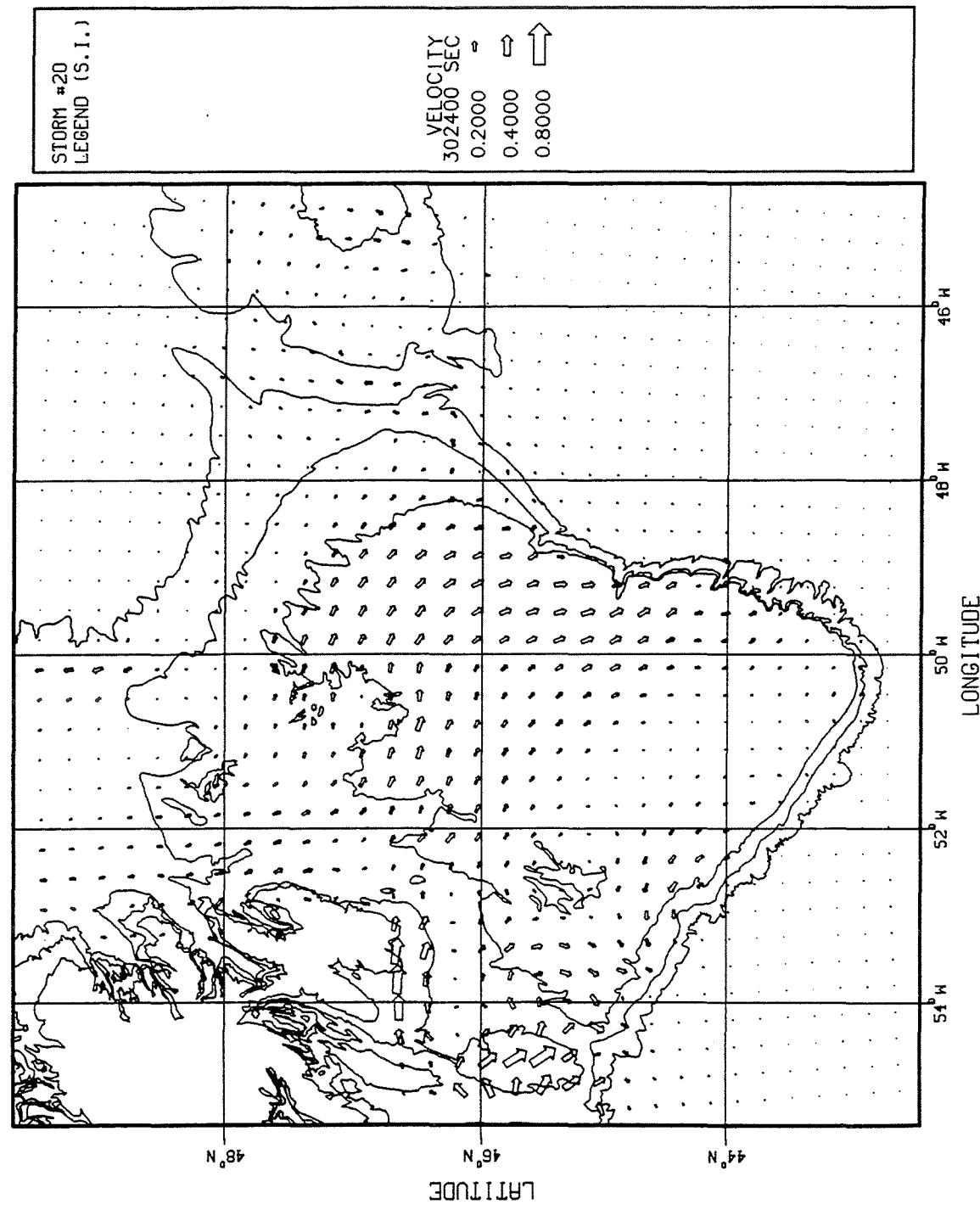


MOBIL STORM 20

10-14 NOV. 1952

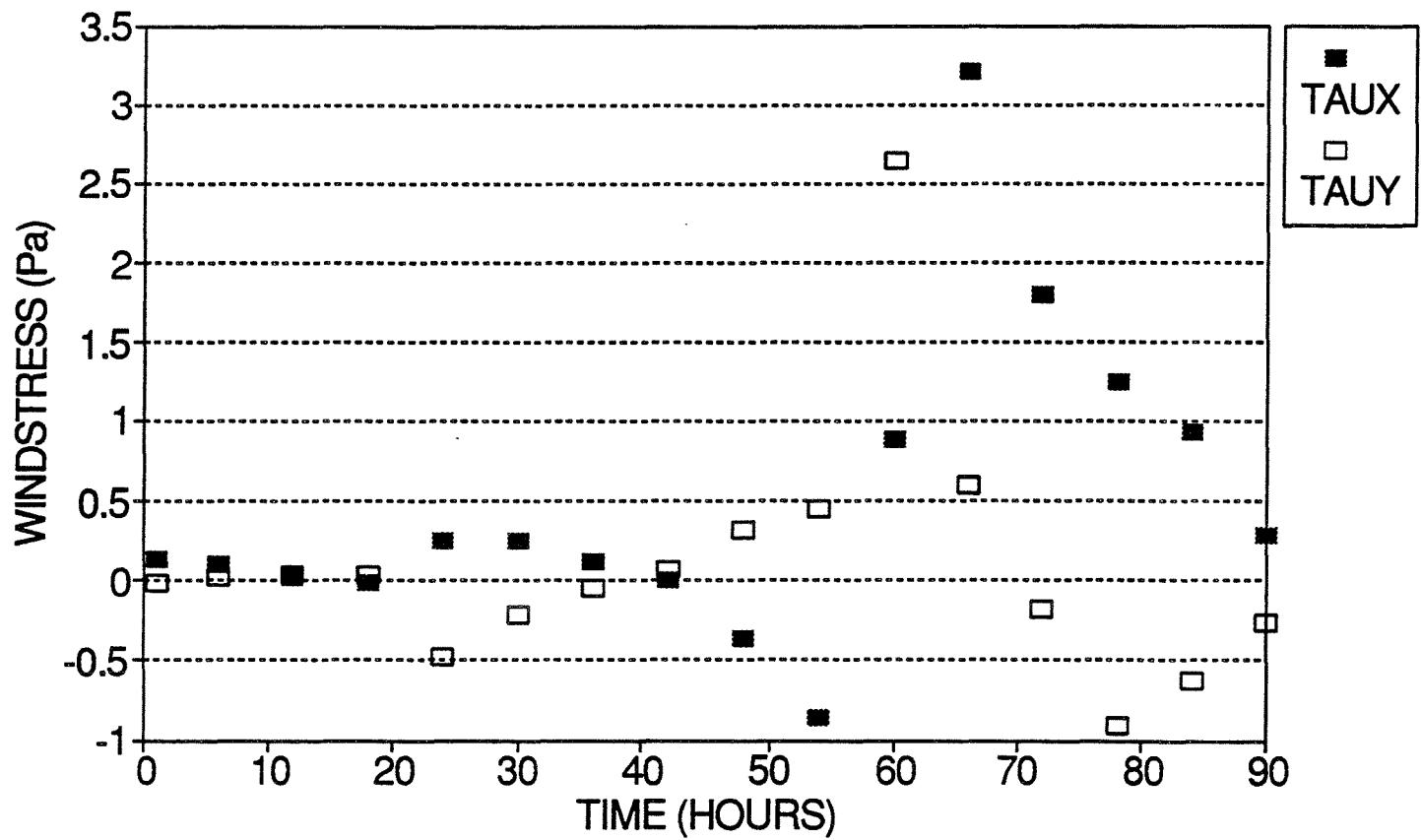


GRAND BANKS STORM MODEL



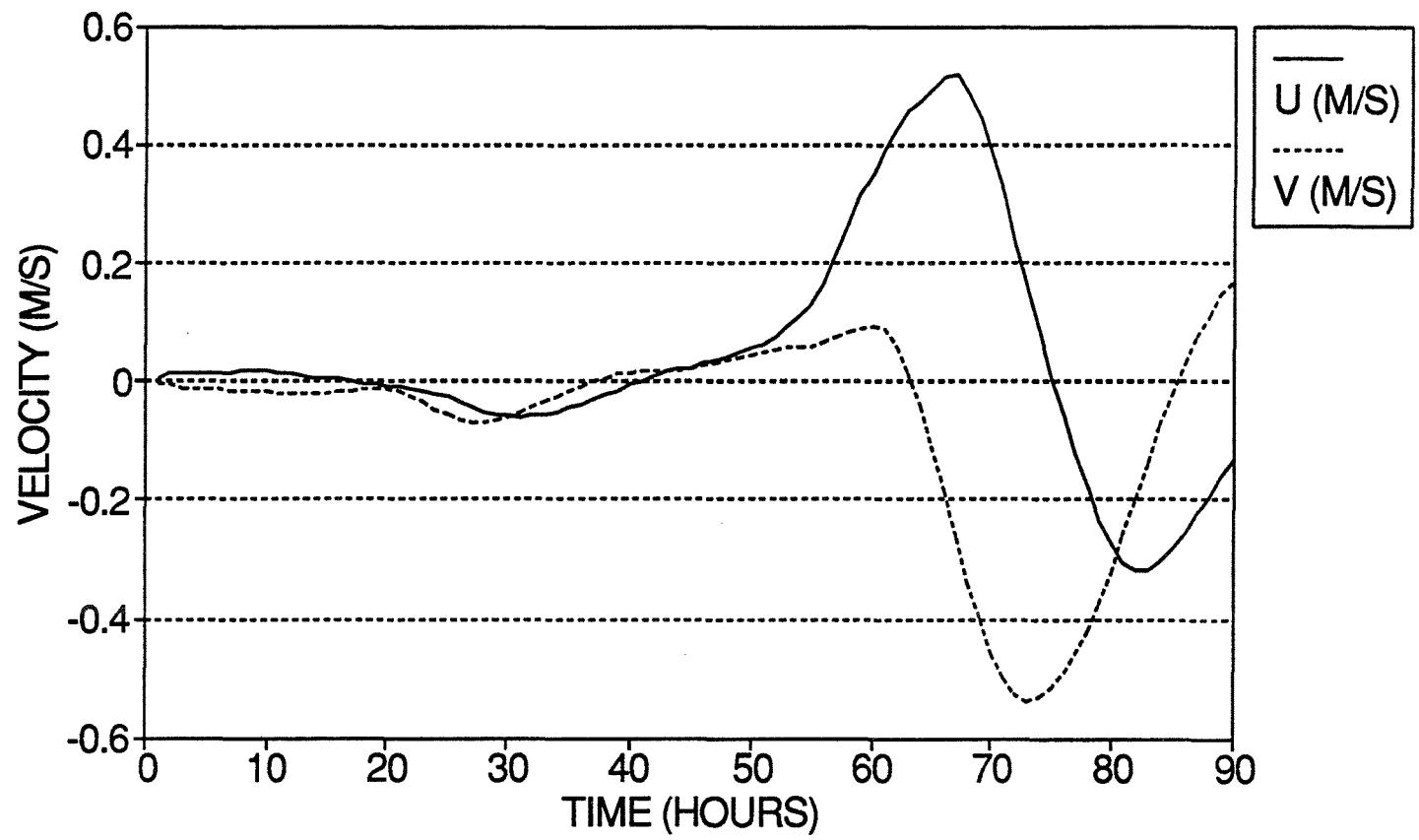
MOBIL STORM 21

12-16 FEB. 1982



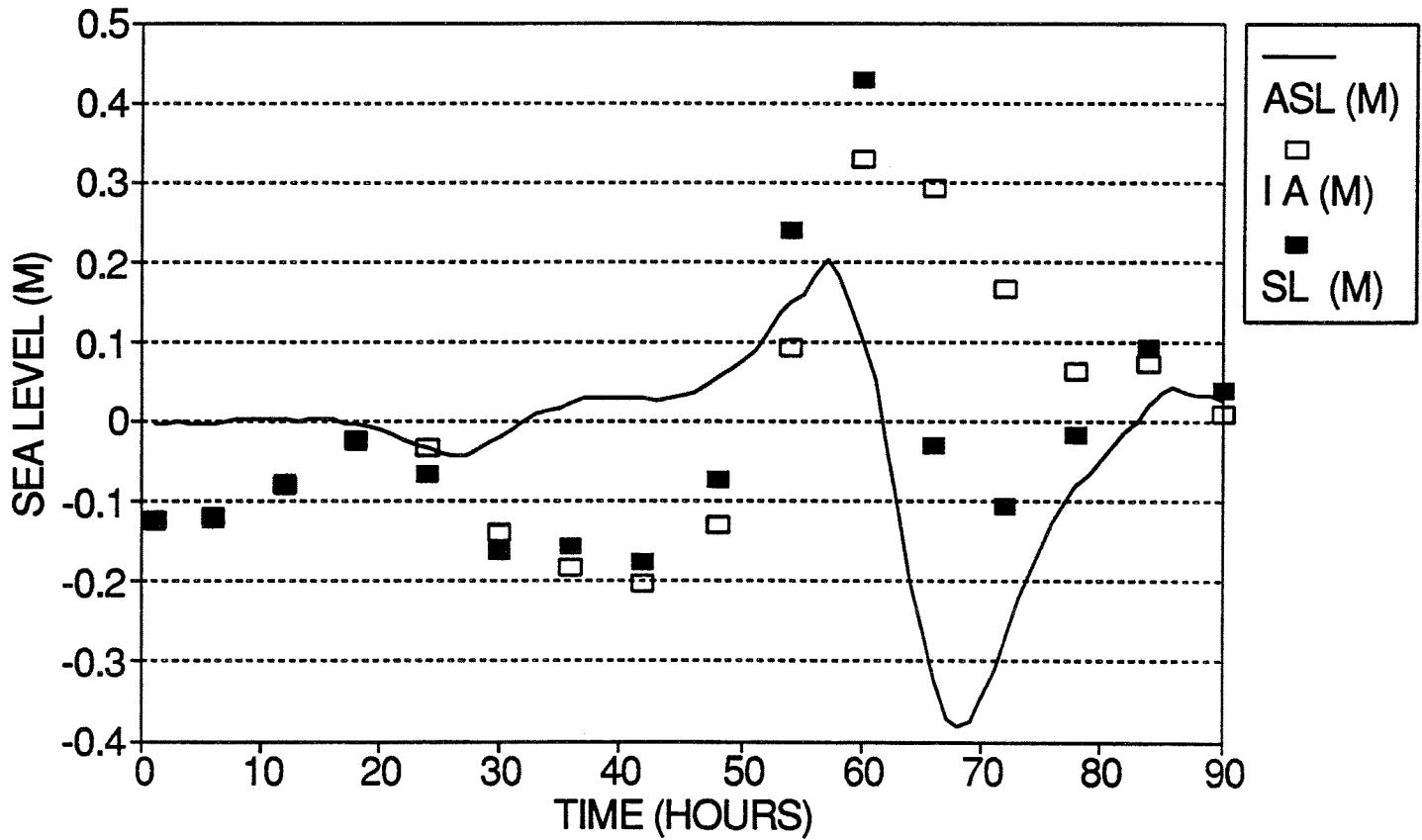
MOBIL STORM 21

12-16 FEB. 1982

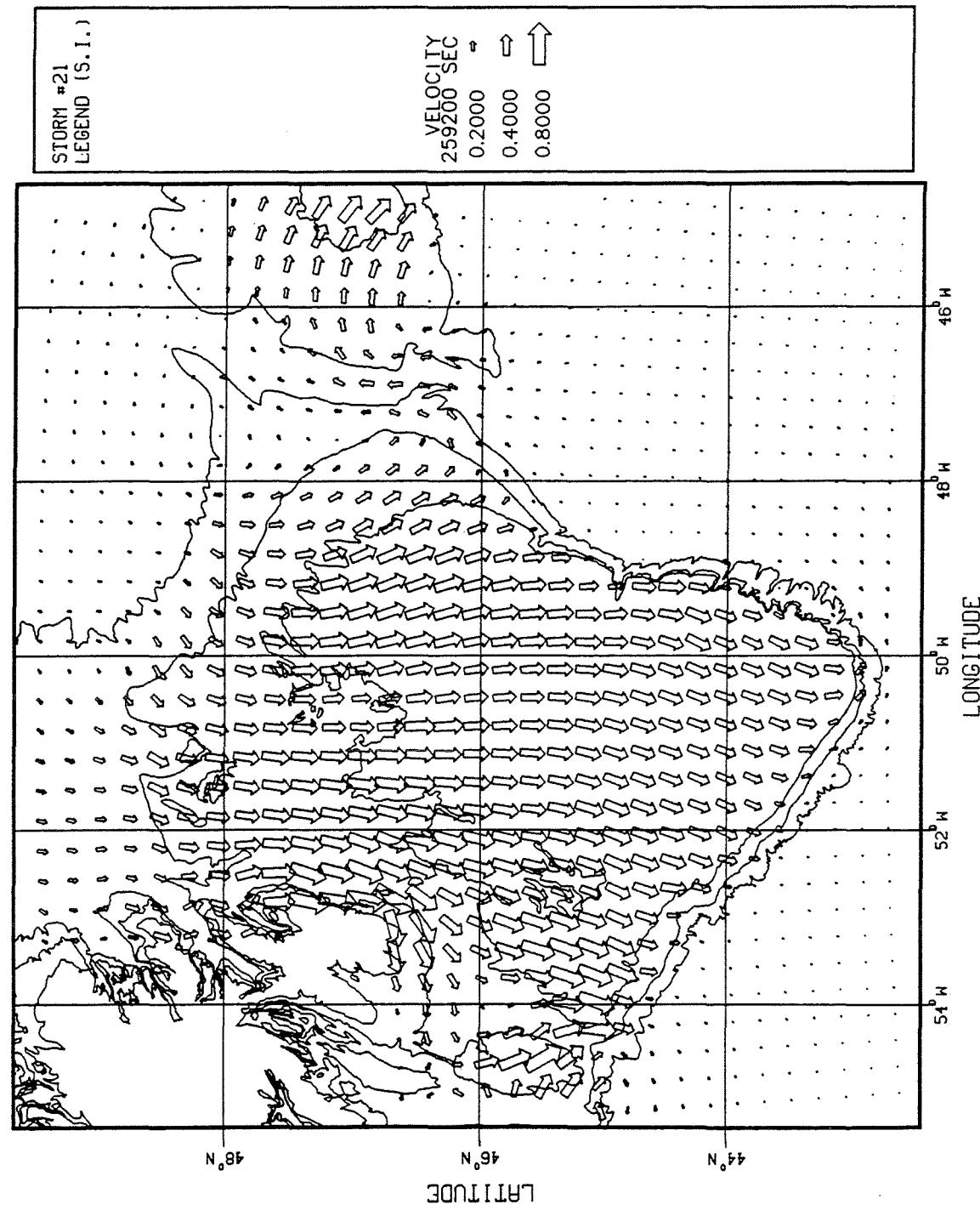


MOBIL STORM 21

12-16 FEB. 1982

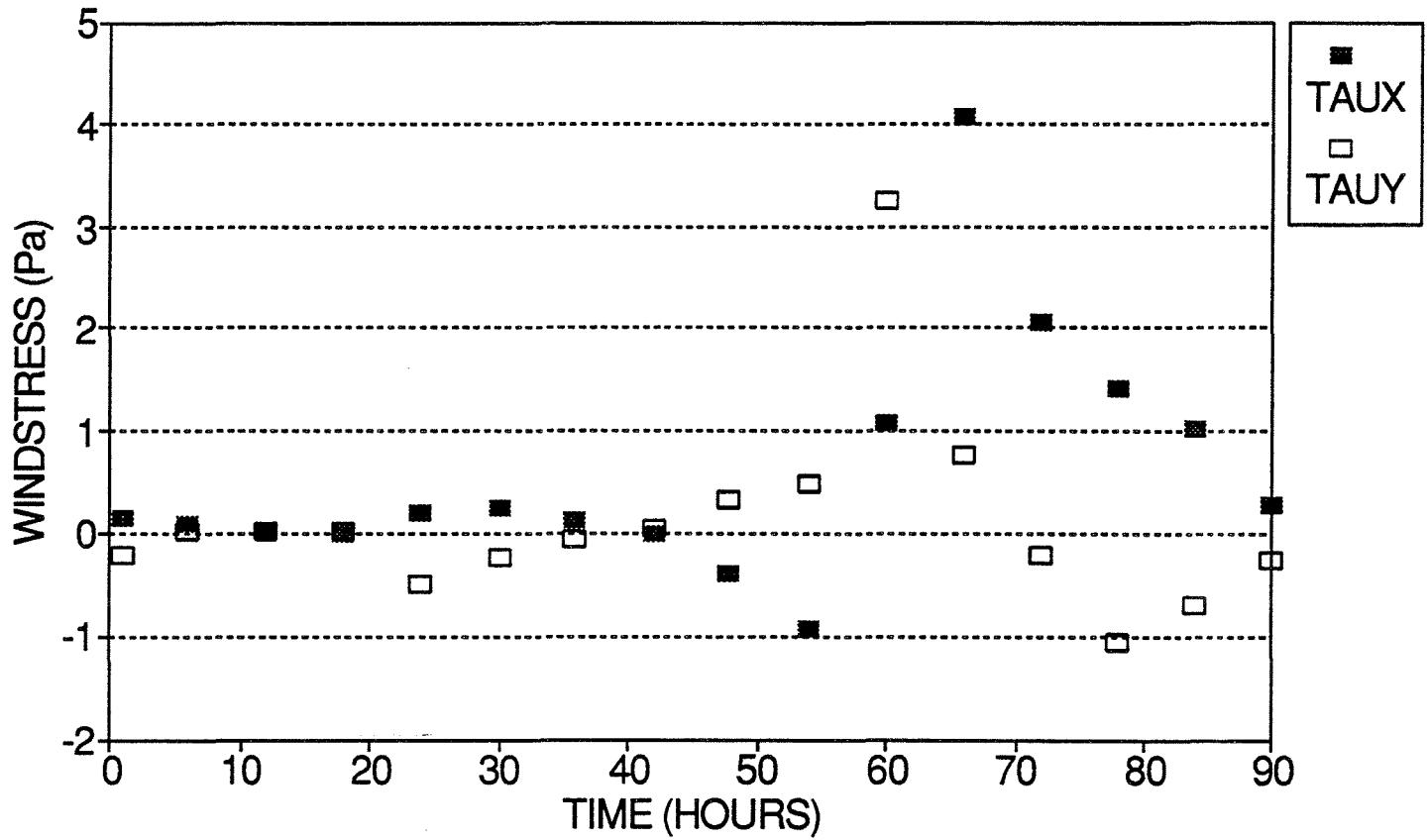


GRAND BANKS STORM MODEL



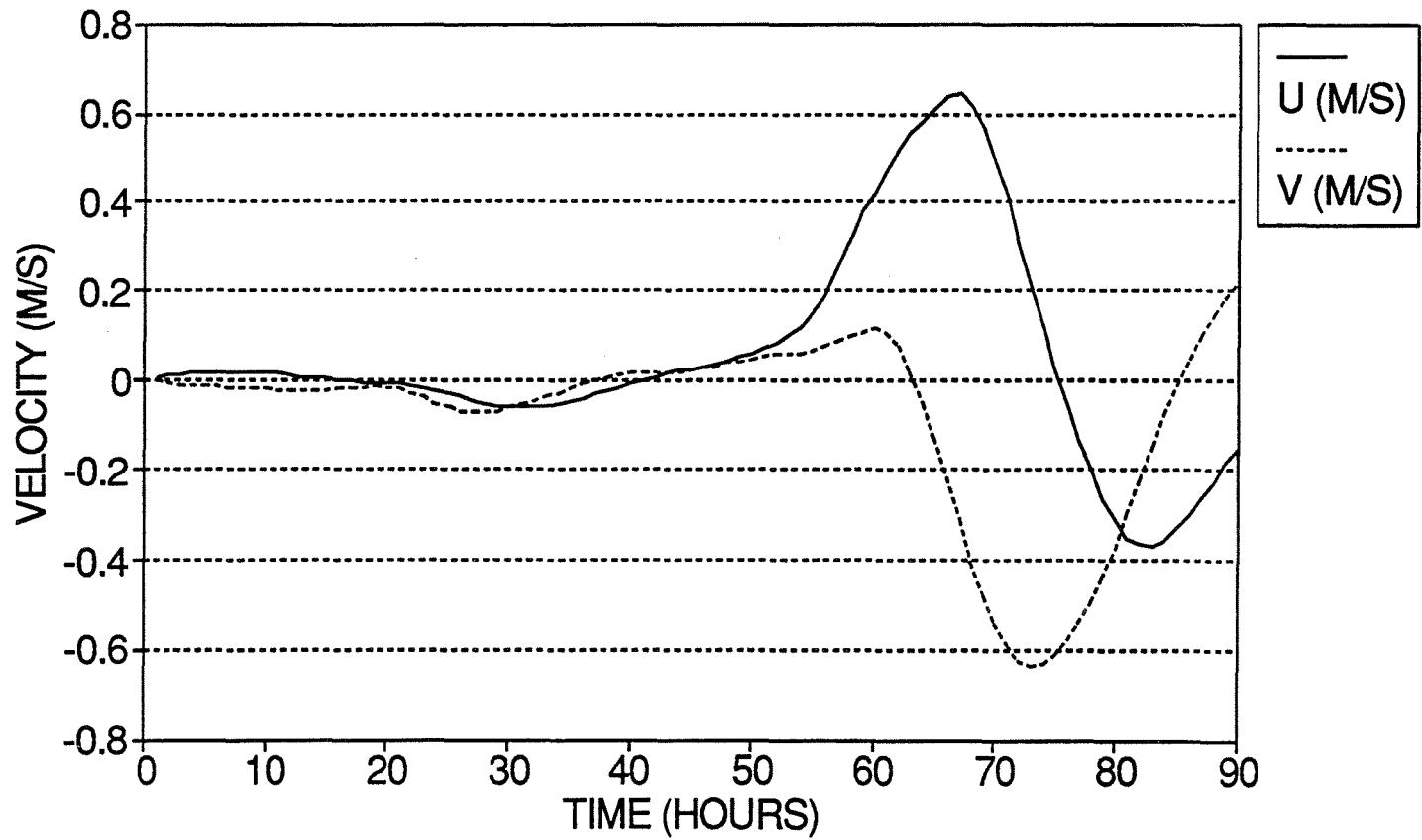
MOBIL STORM 121

12-16 FEB. 1982



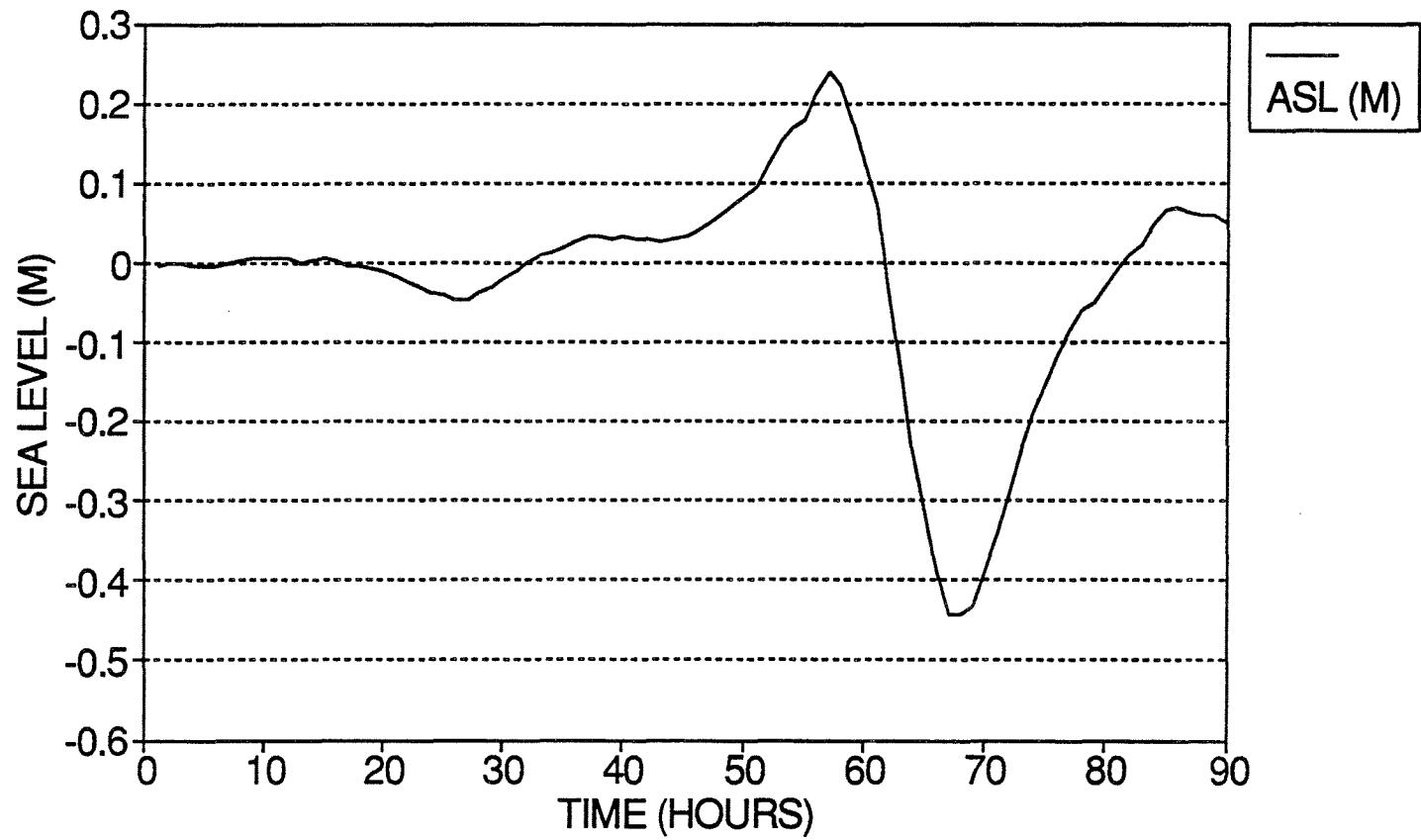
MOBIL STORM 121

12-16 FEB. 1982

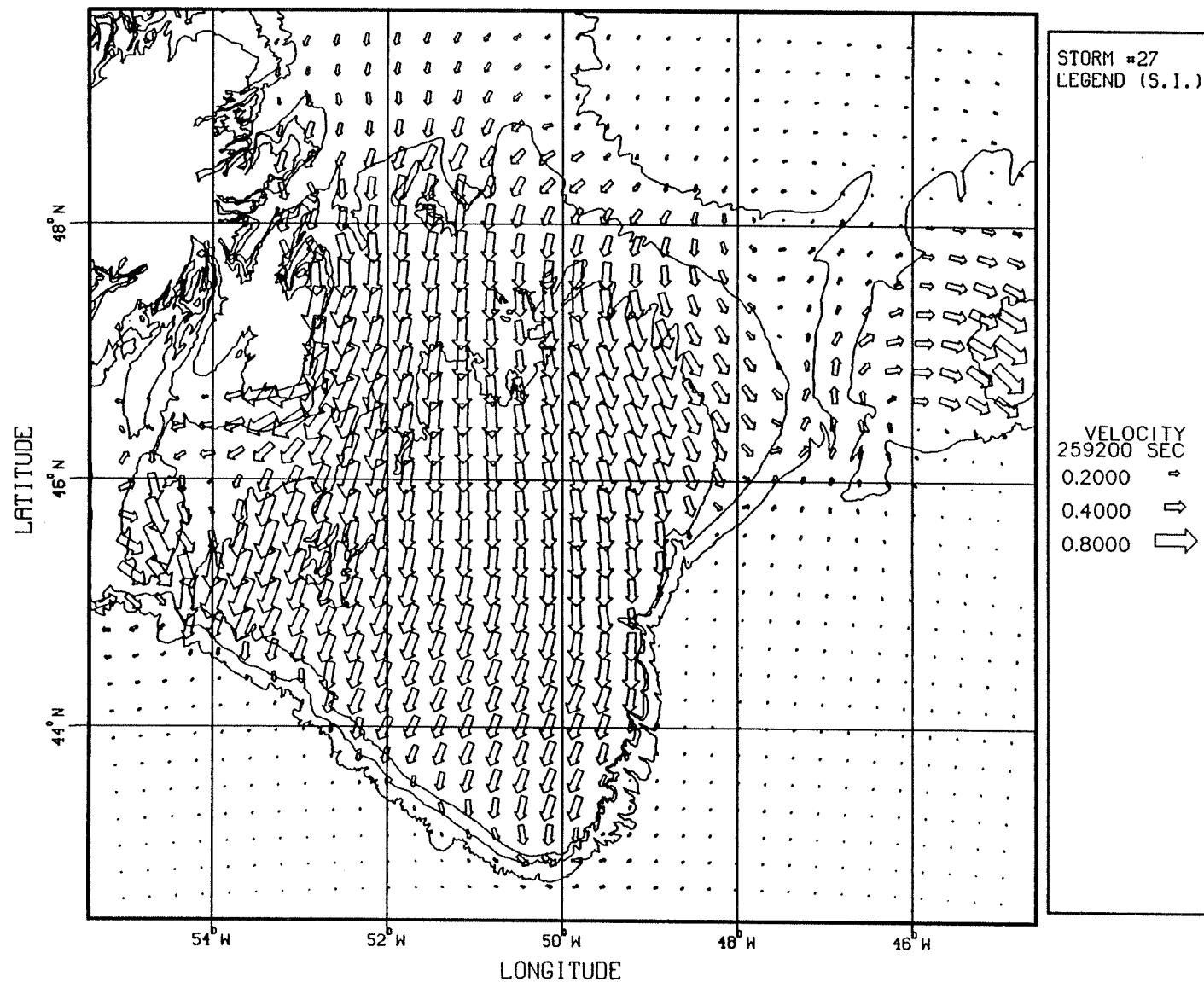


MOBIL STORM 121

12-16 FEB. 1982

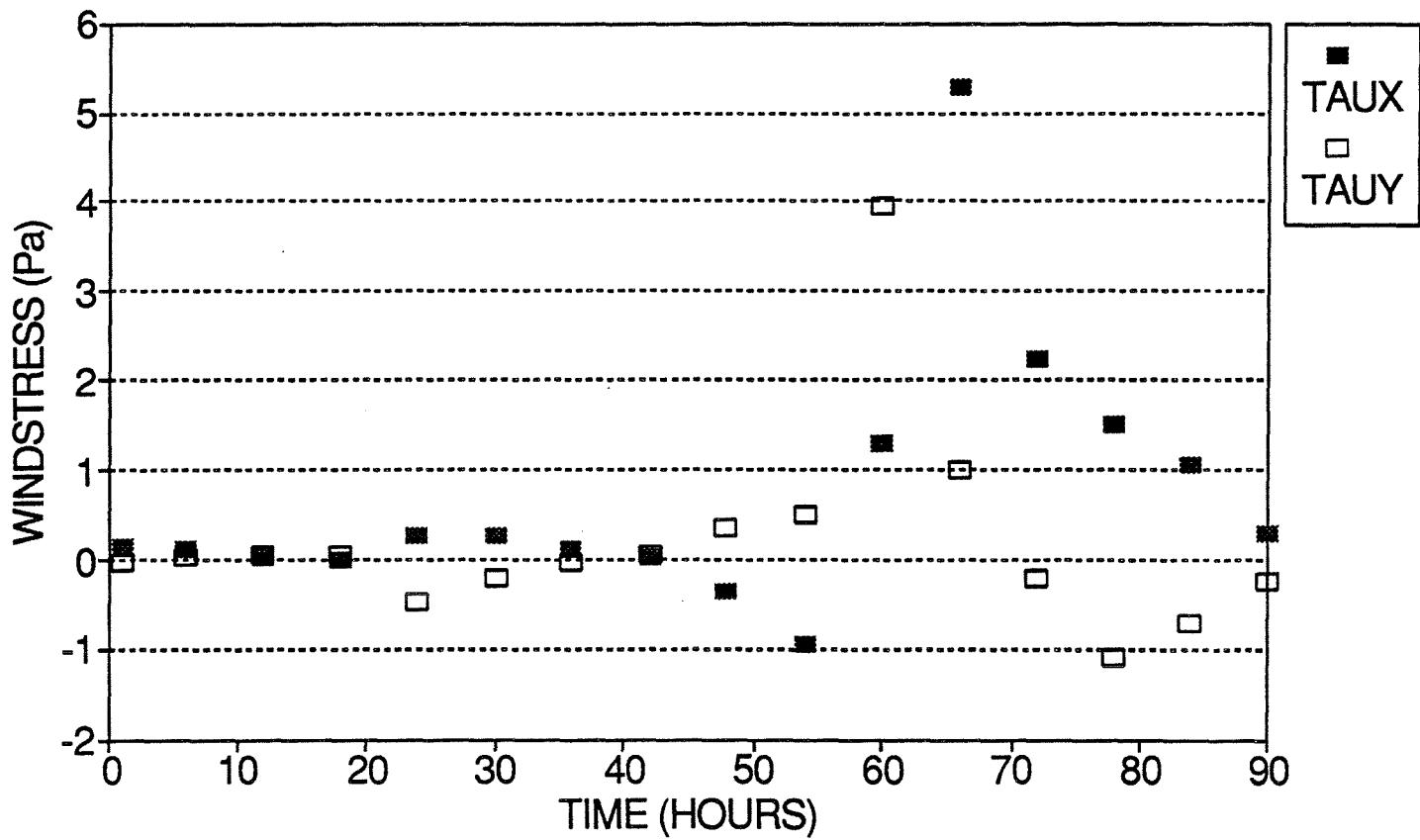


GRAND BANKS STORM MODEL



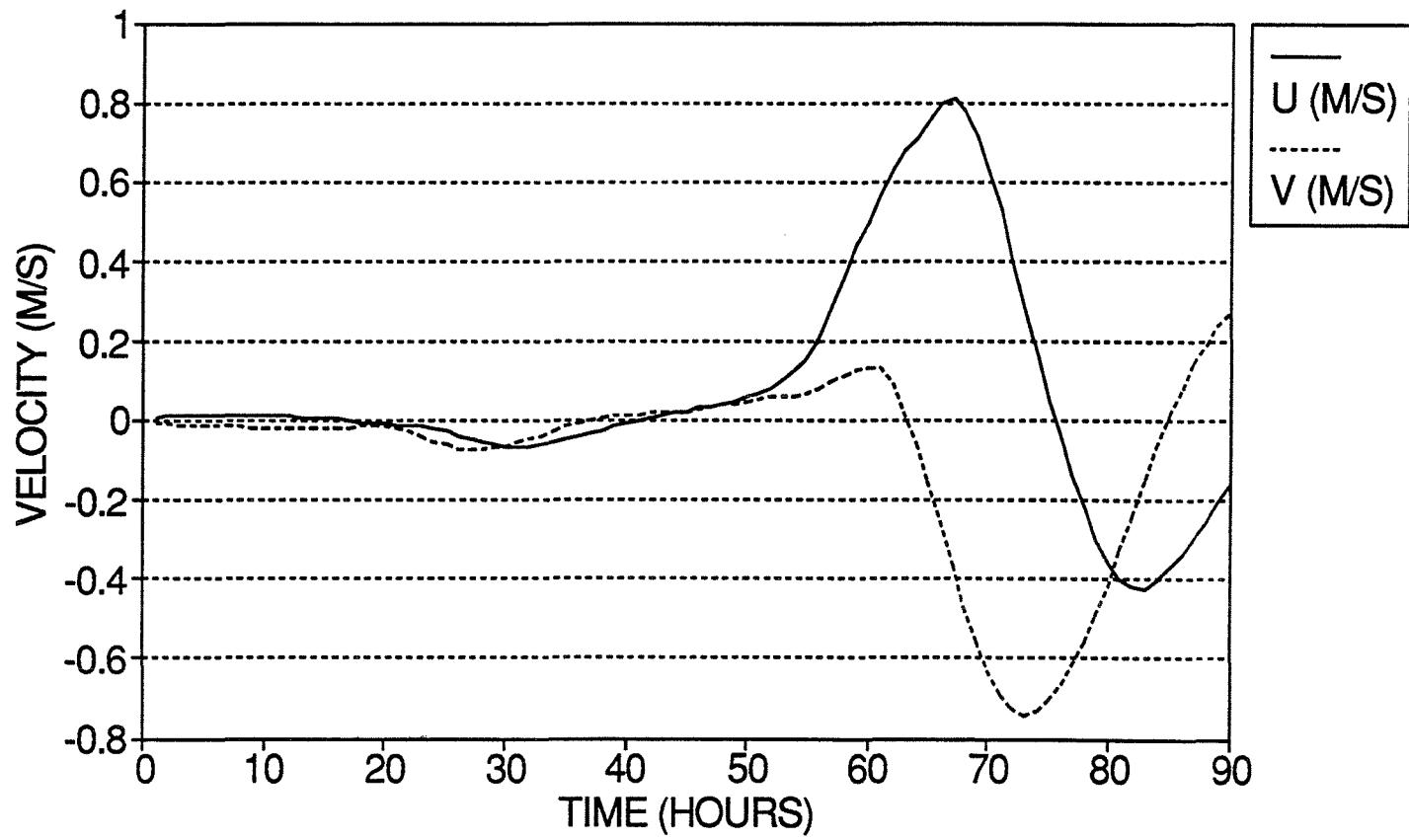
MOBIL STORM 122

12-16 FEB. 1982



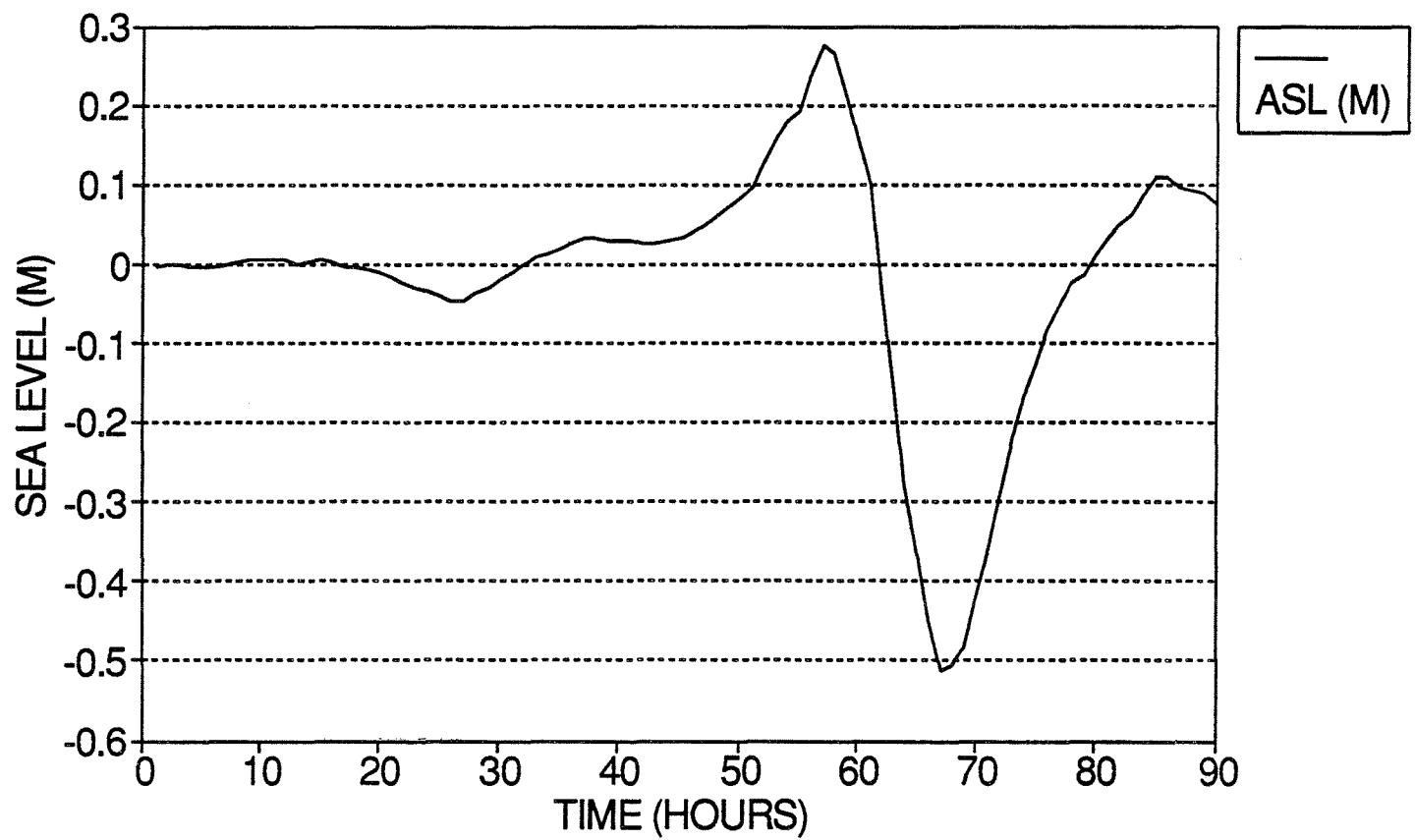
MOBIL STORM 122

12-16 FEB. 1982

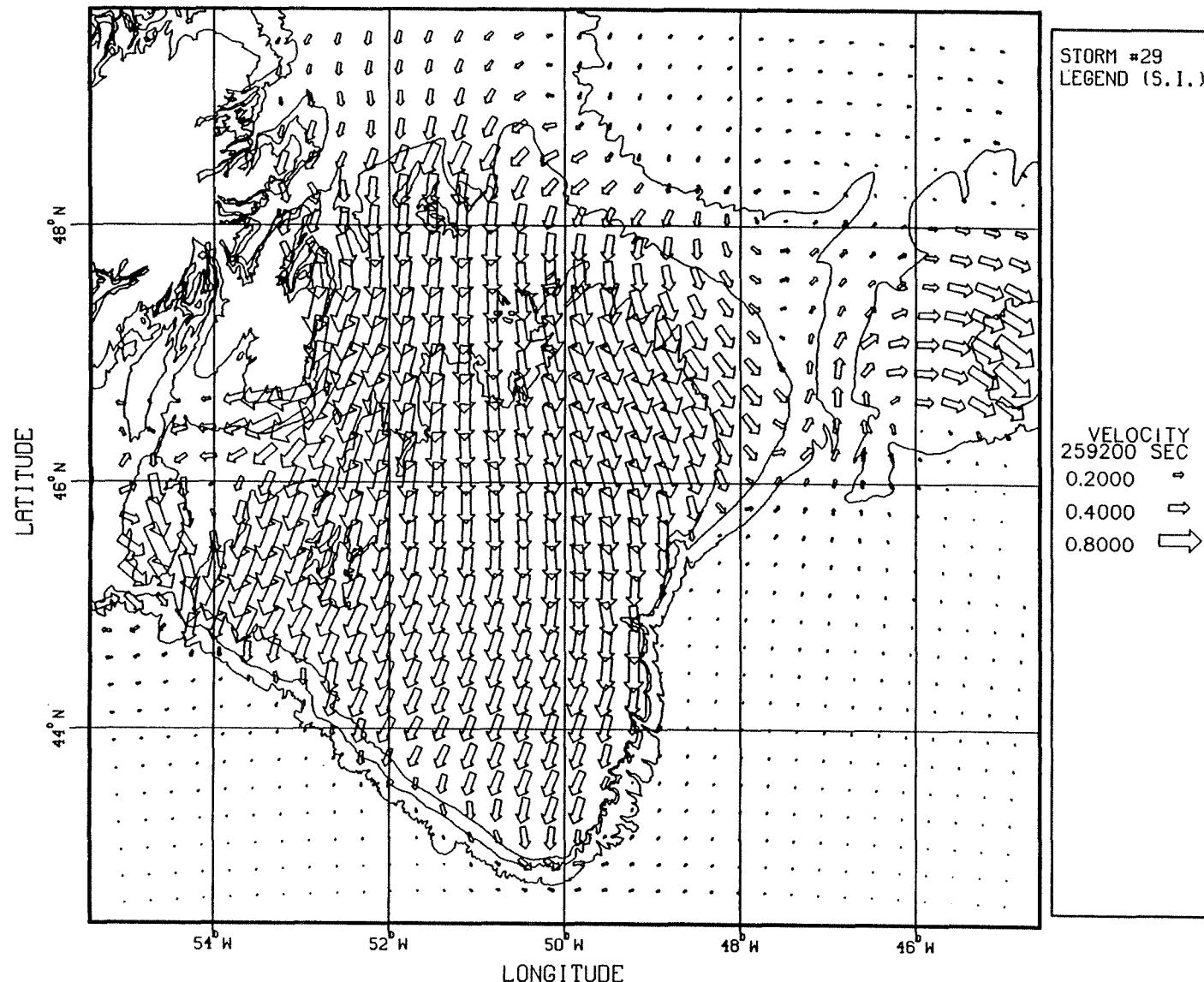


MOBIL STORM 122

12-16 FEB. 1982

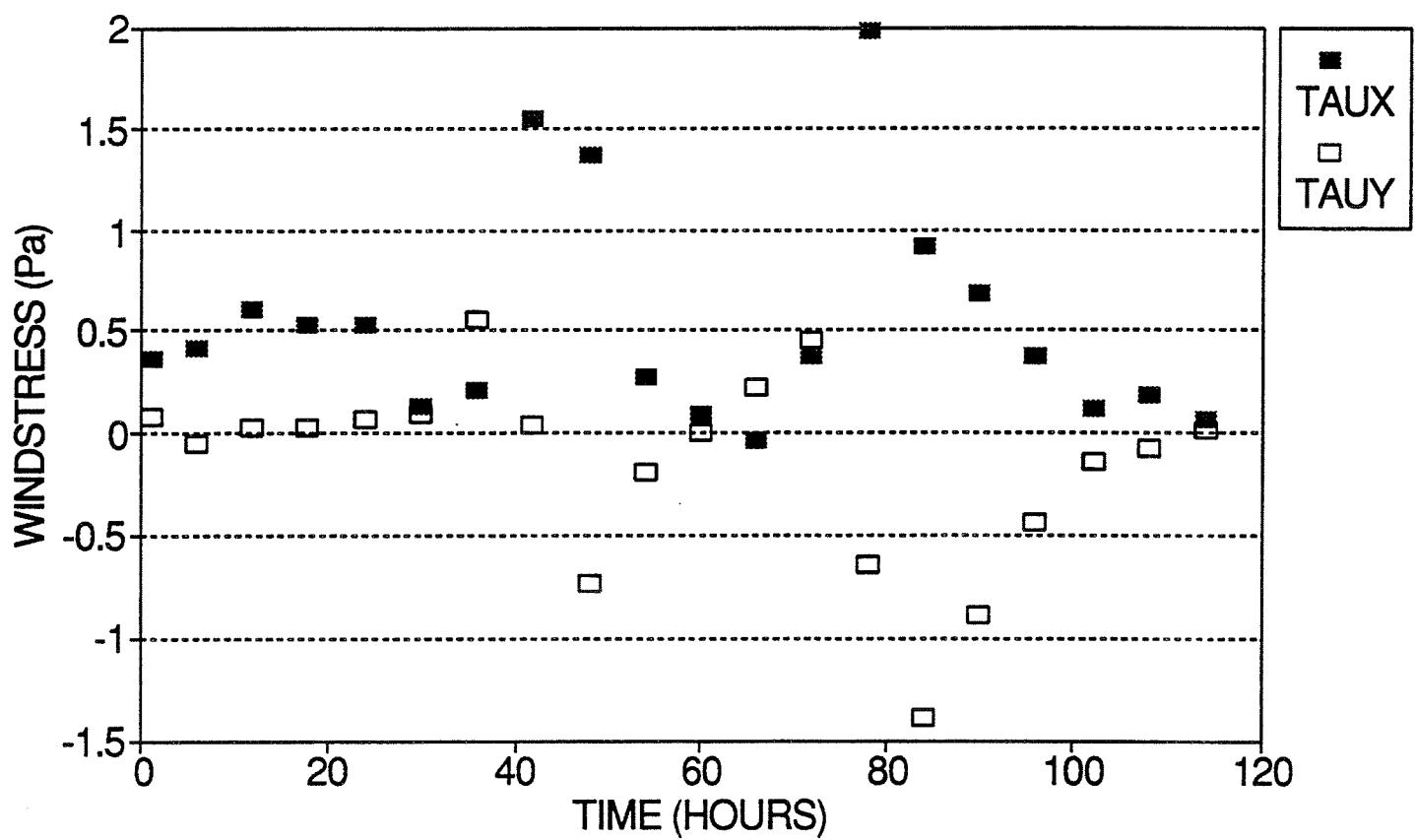


GRAND BANKS STORM MODEL



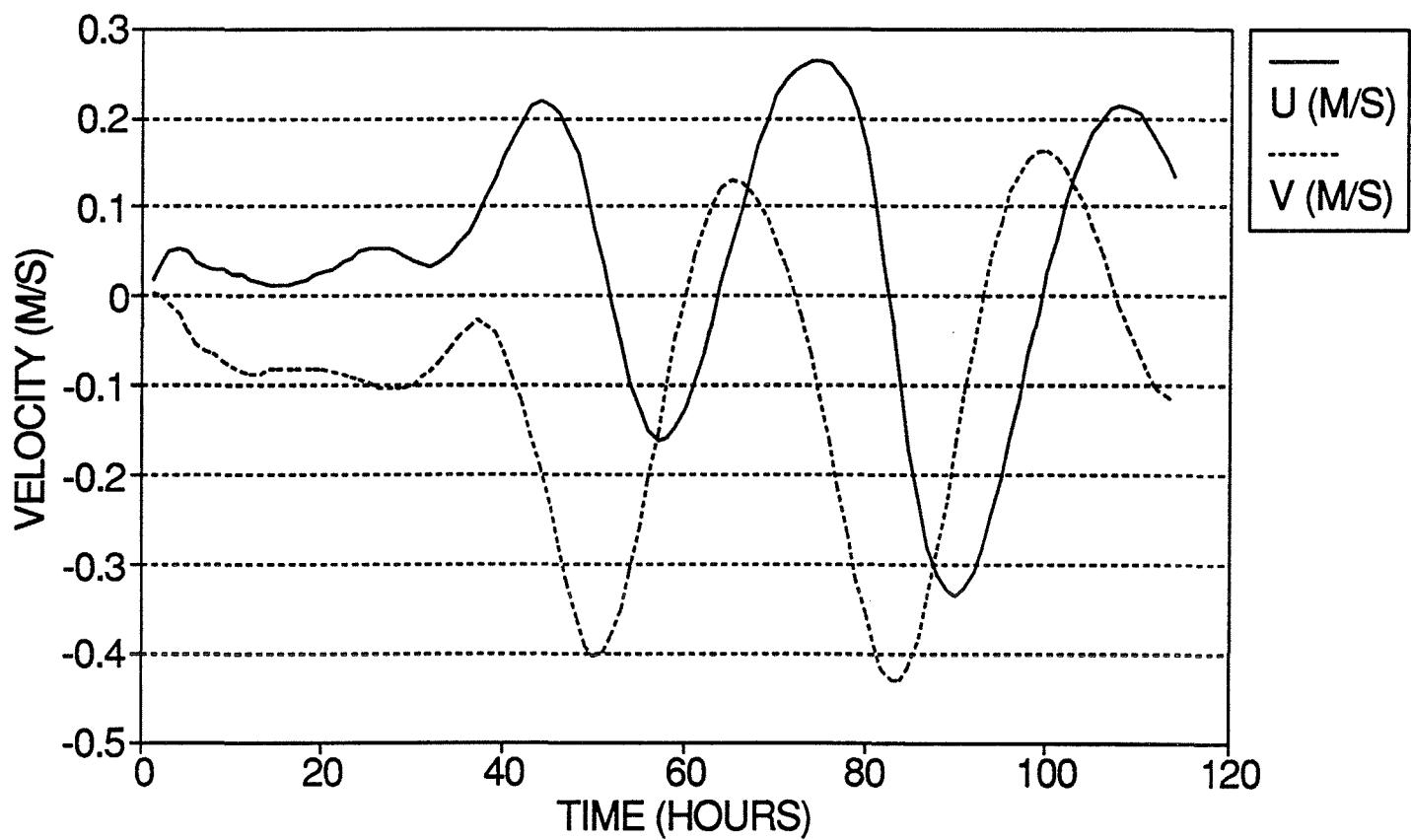
MOBIL STORM 23

30 JAN.-04 FEB. 1982



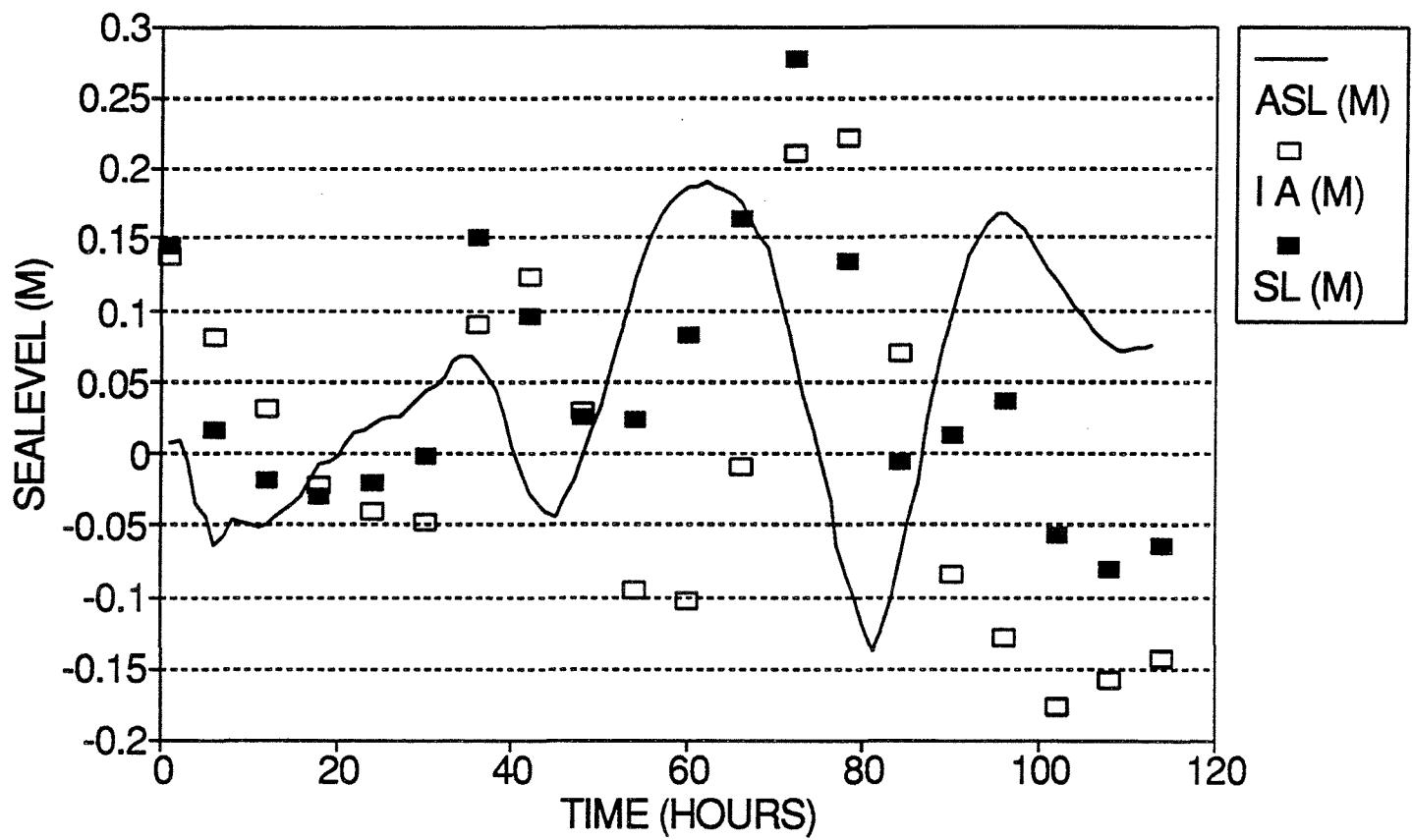
MOBIL STORM 23

30 JAN.-04 FEB. 1982

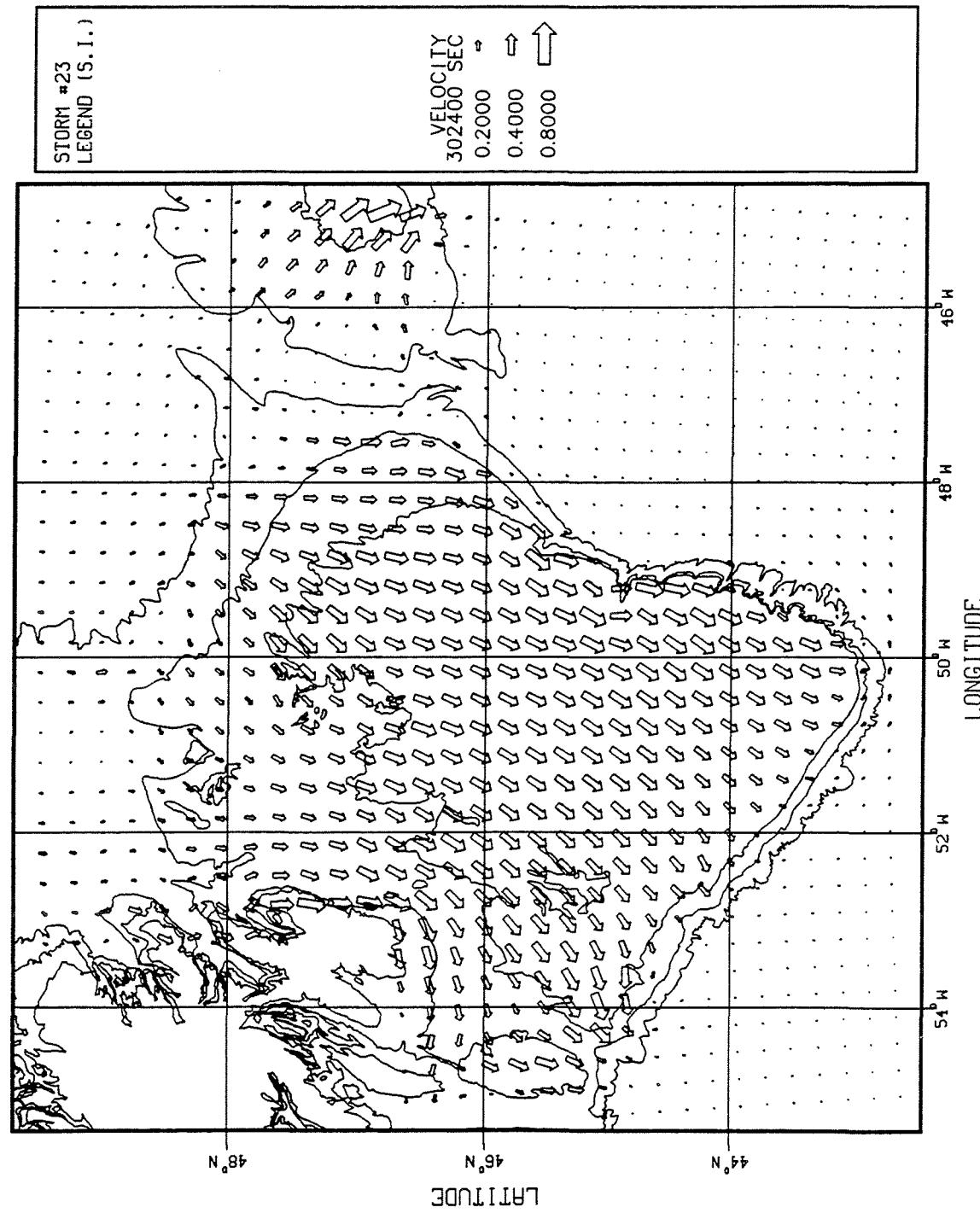


MOBIL STORM 23

30 JAN.-04 FEB. 1982

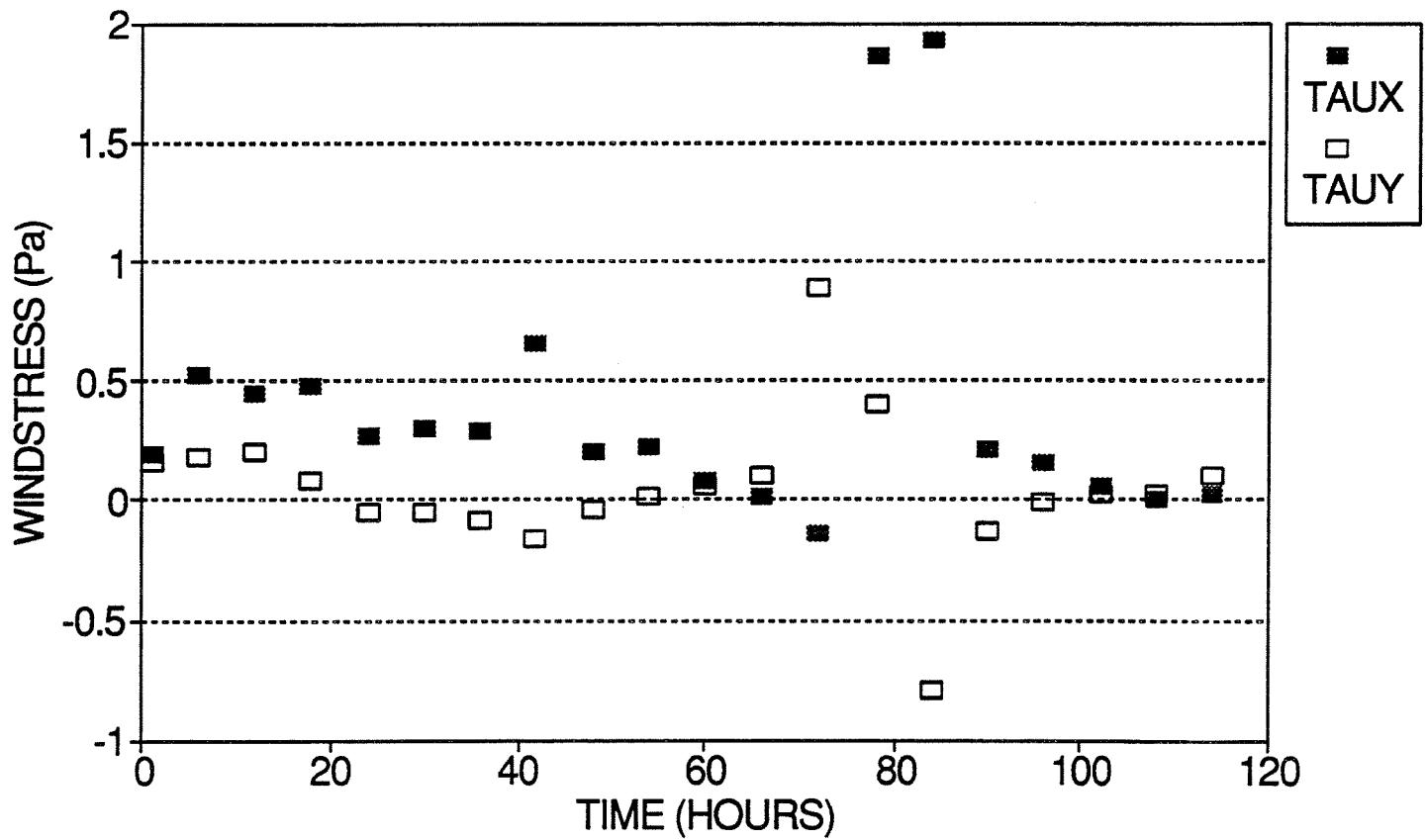


GRAND BANKS STORM MODEL



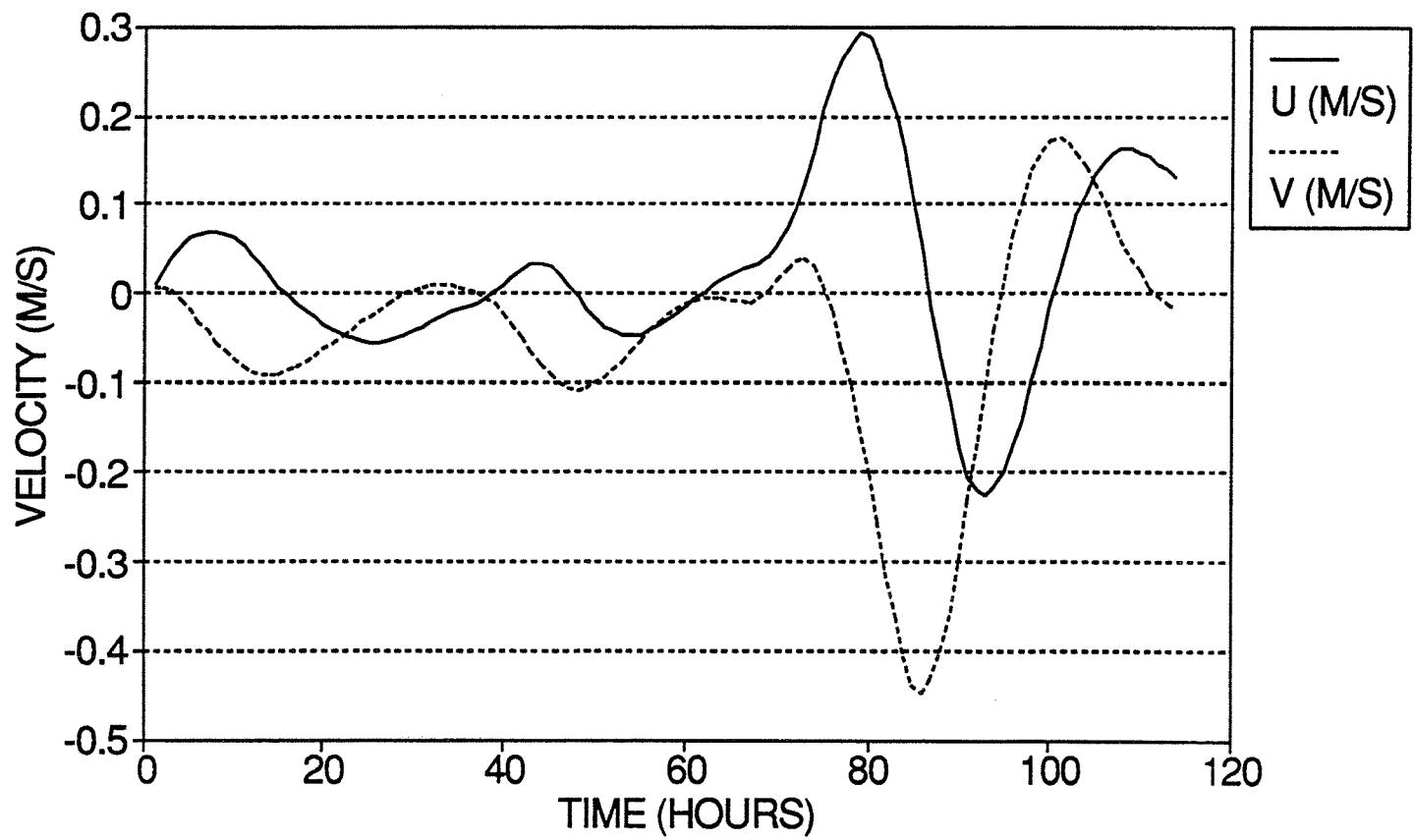
MOBIL STORM 24

7-12 DEC. 1982



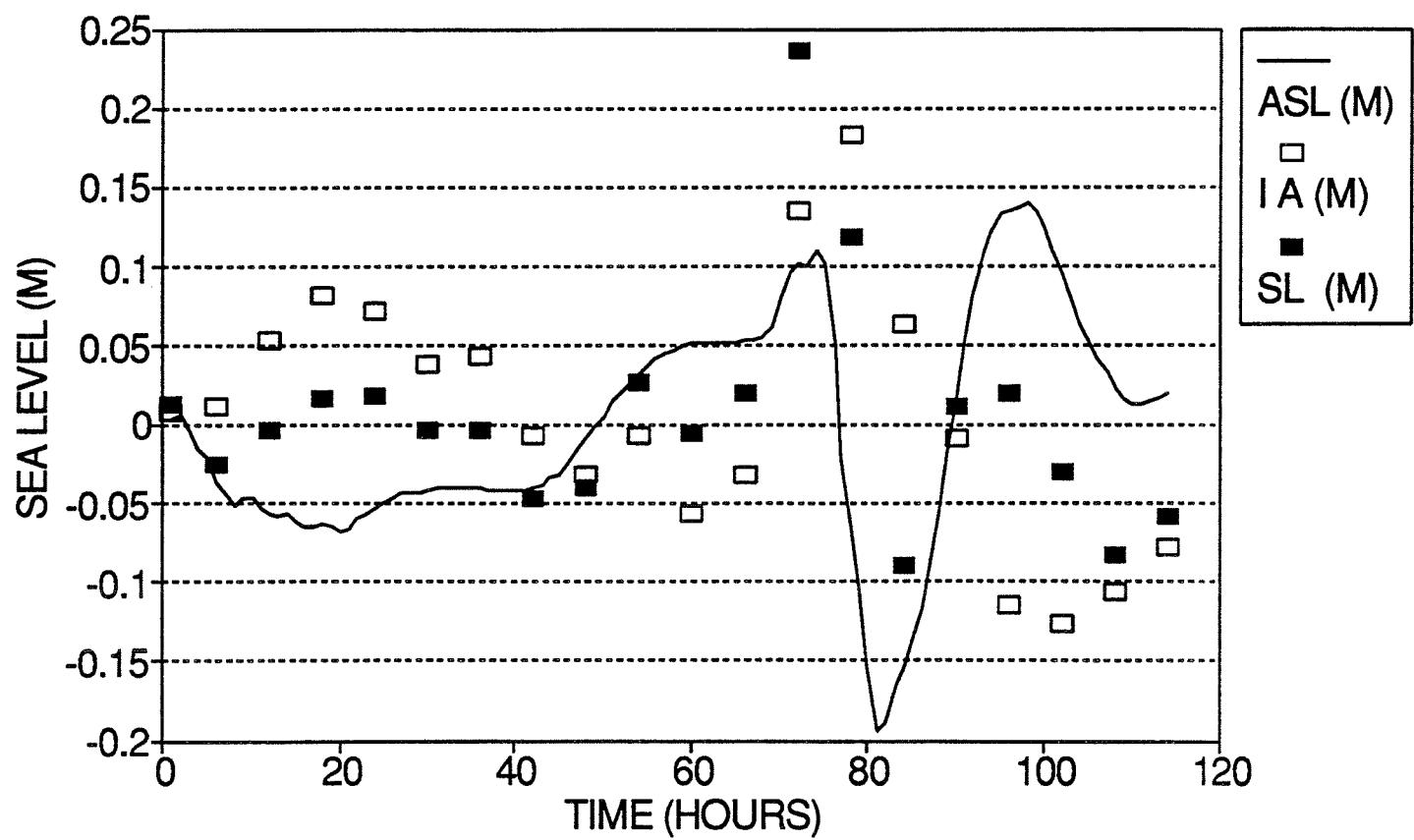
MOBIL STORM 24

7-12 DEC. 1982

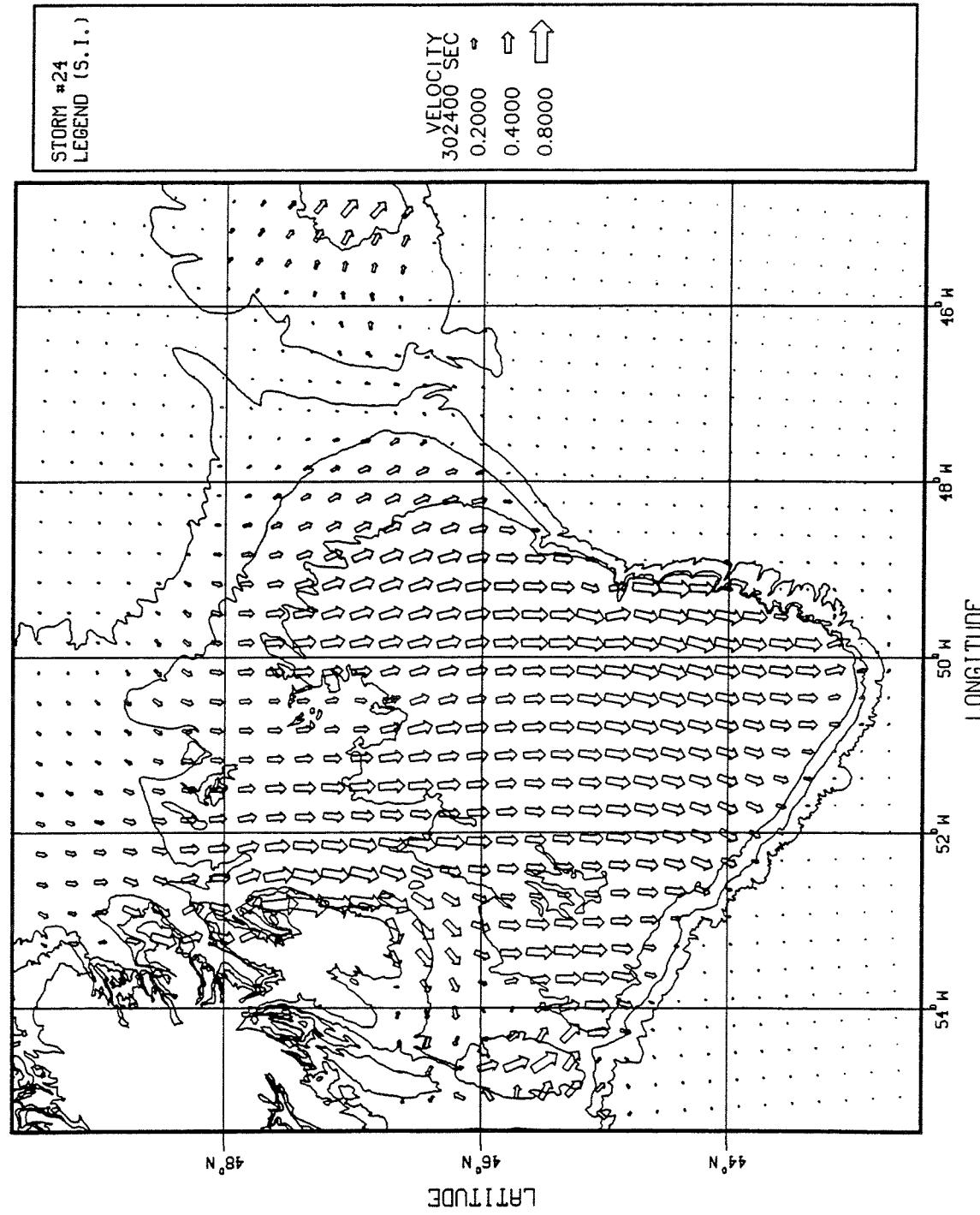


MOBIL STORM 24

7-12 DEC. 1982

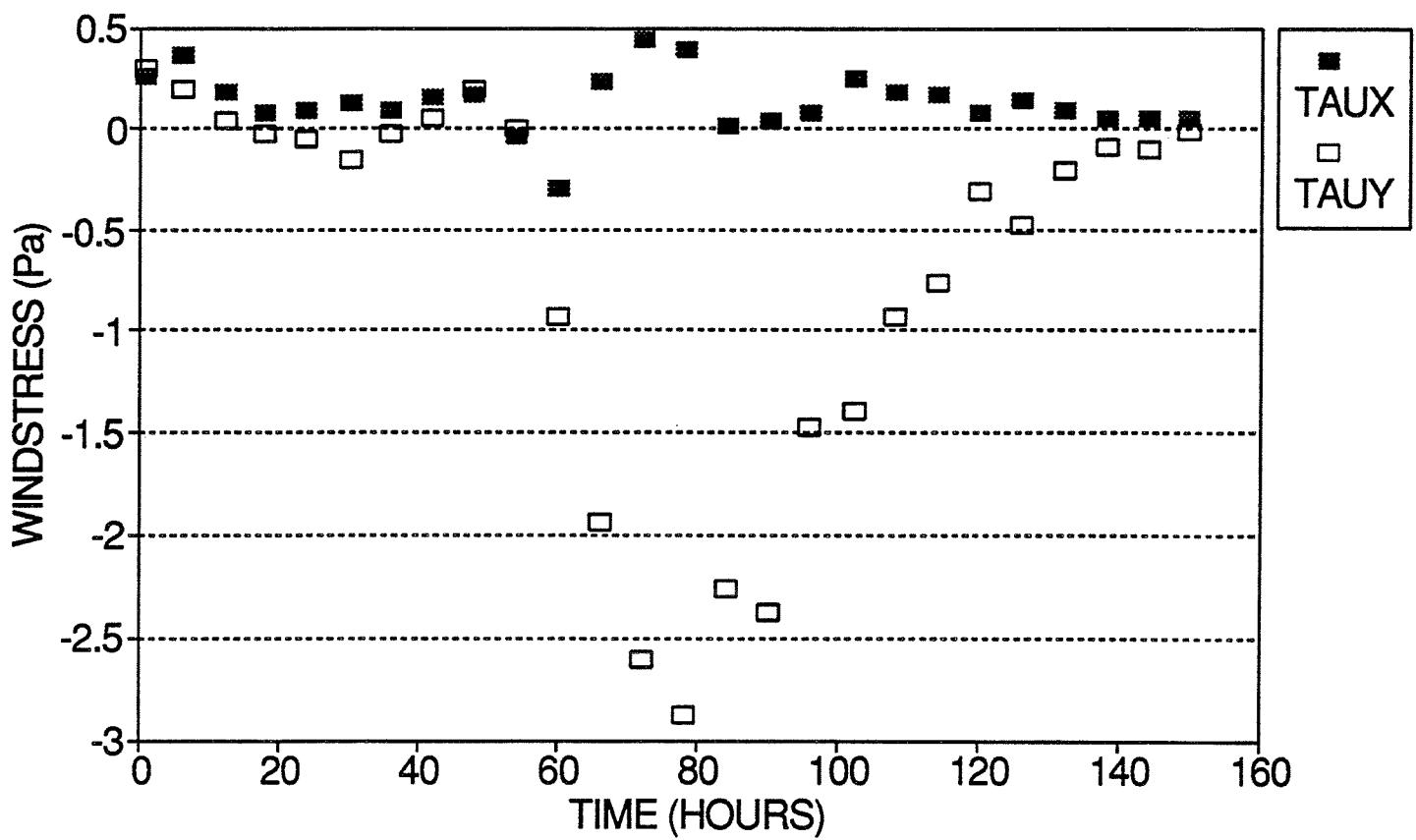


GRAND BANKS STORM MODEL



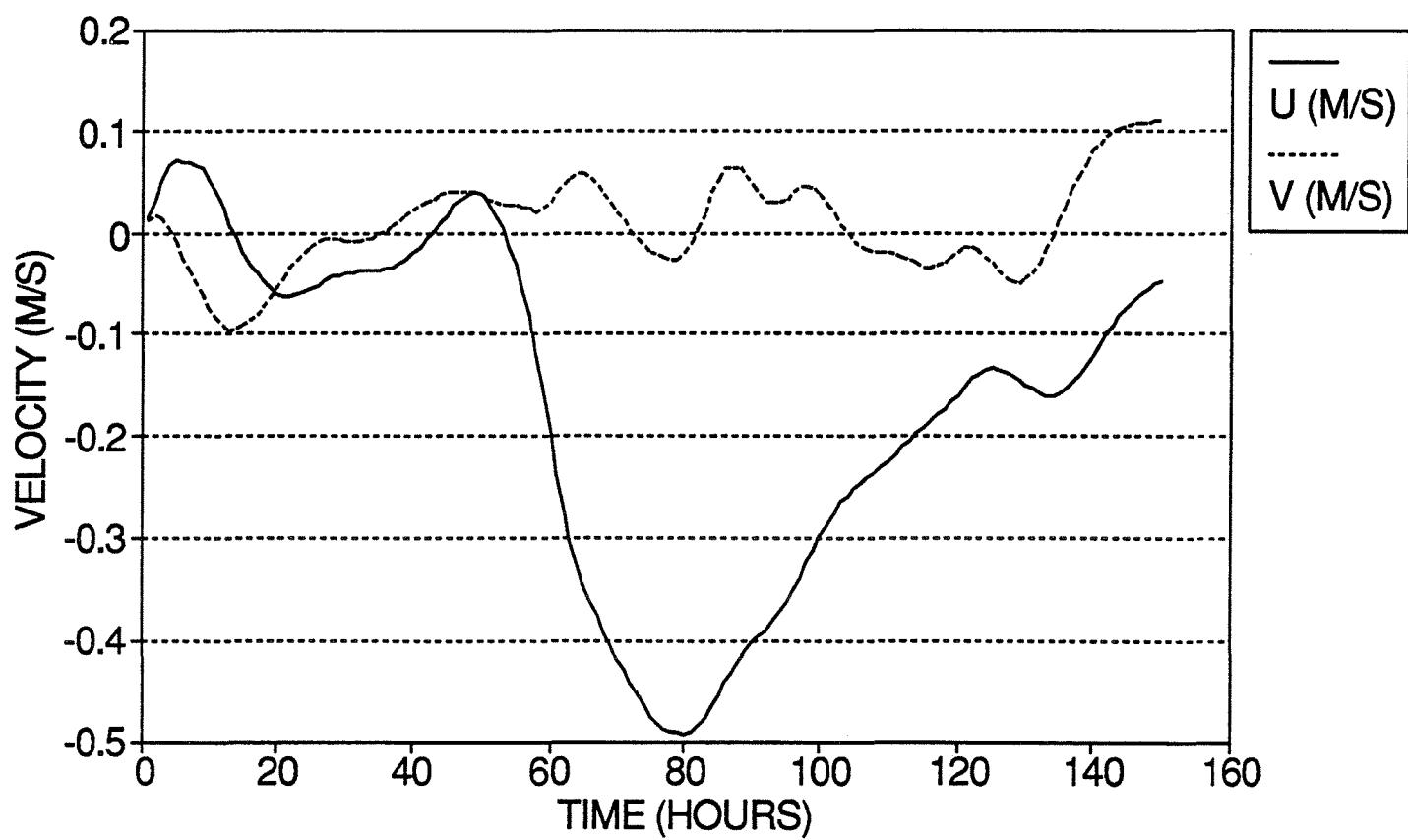
MOBIL STORM 25

5-11 MAR. 1983



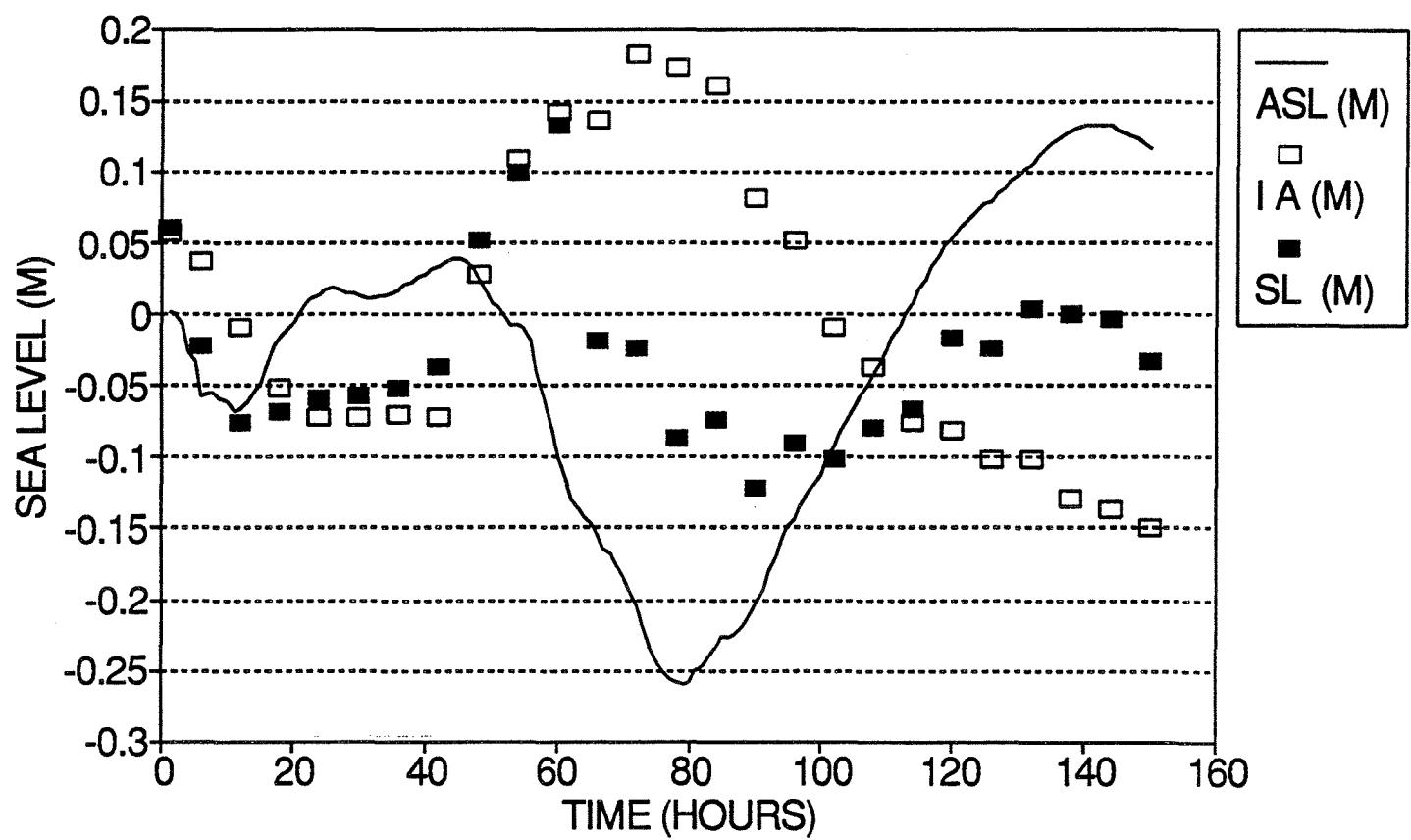
MOBIL STORM 25

5-11 MAR. 1983

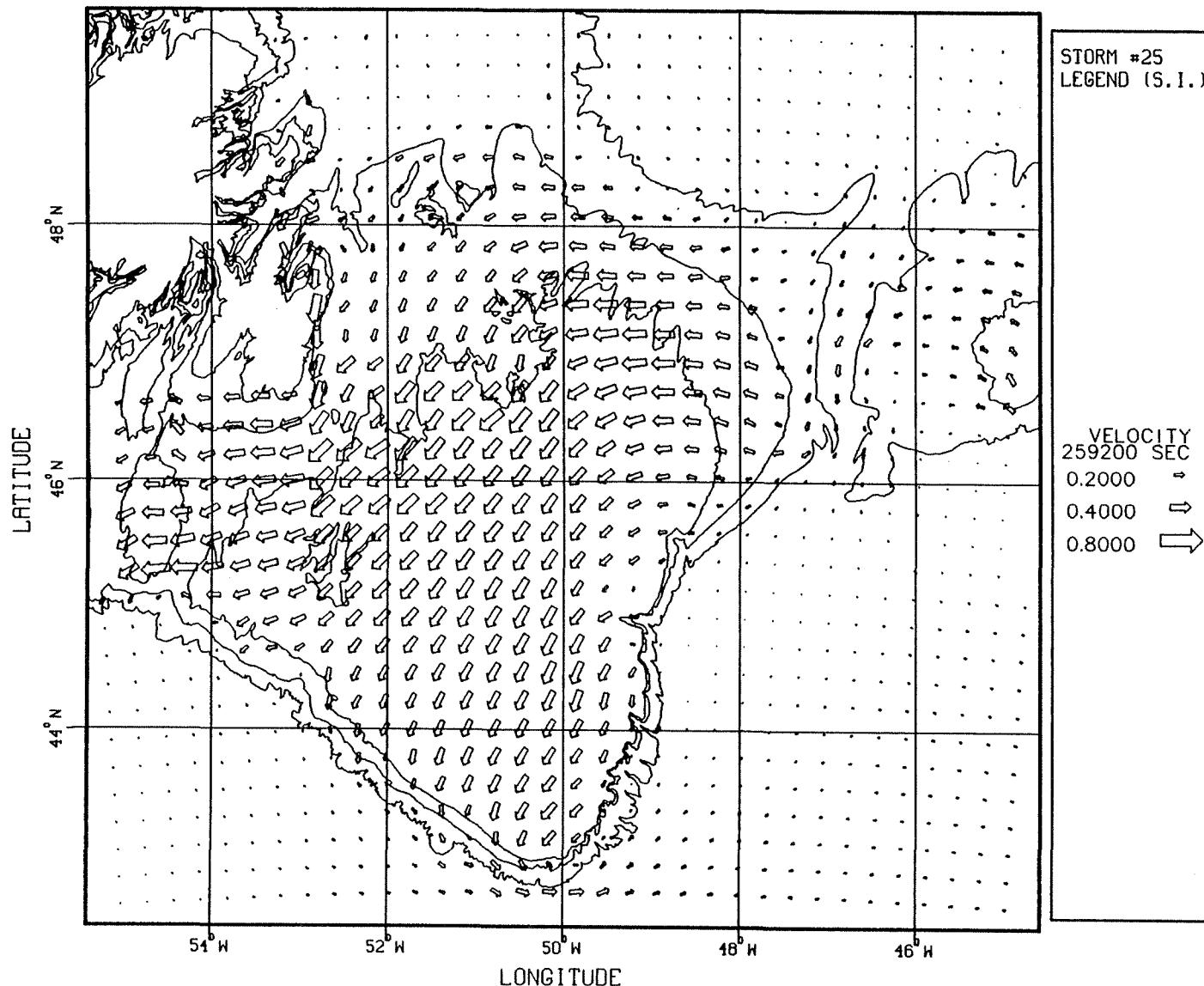


MOBIL STORM 25

5-11 MAR. 1983

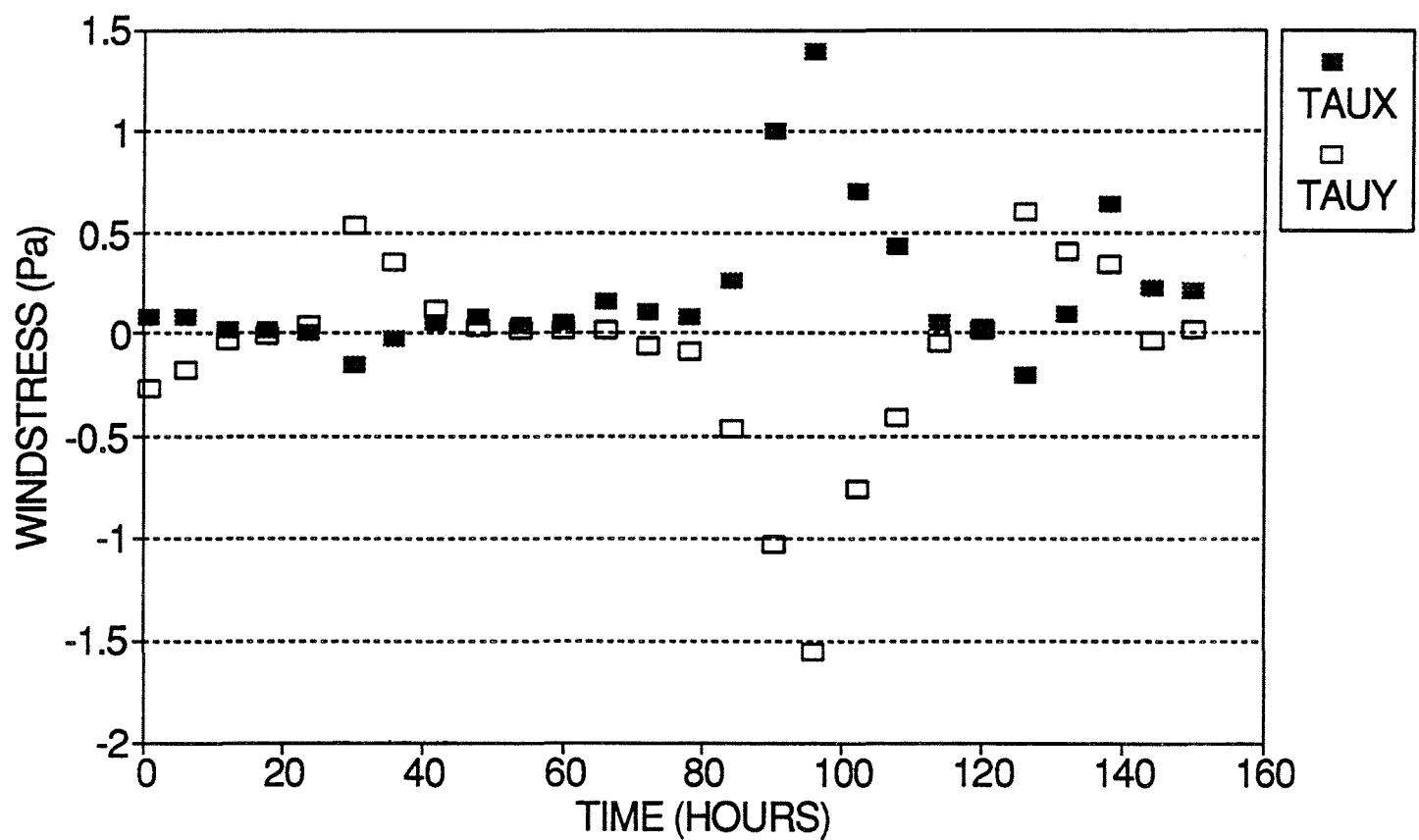


GRAND BANKS STORM MODEL



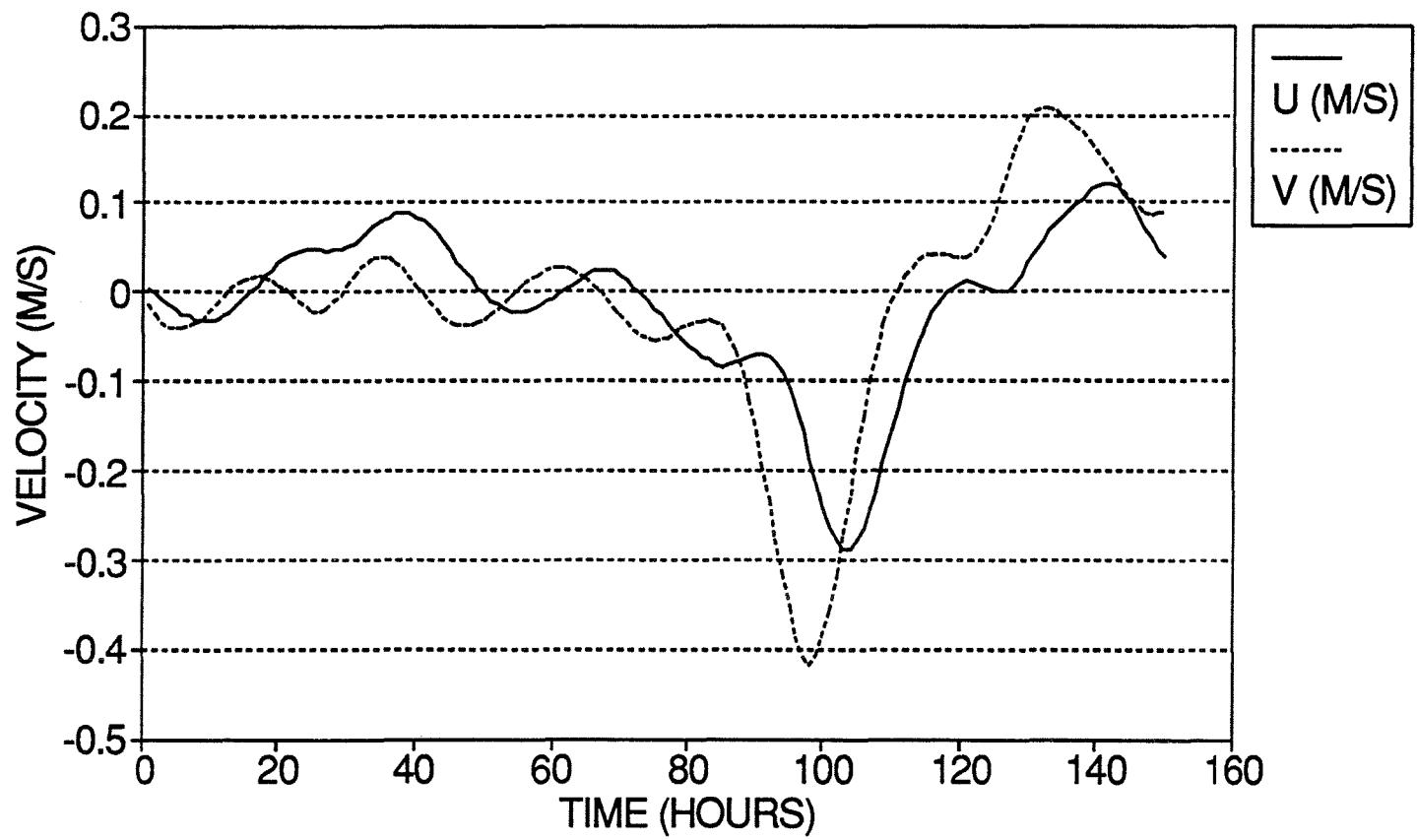
MOBIL STORM 26 & 27

25 NOV.-1 DEC. 1983



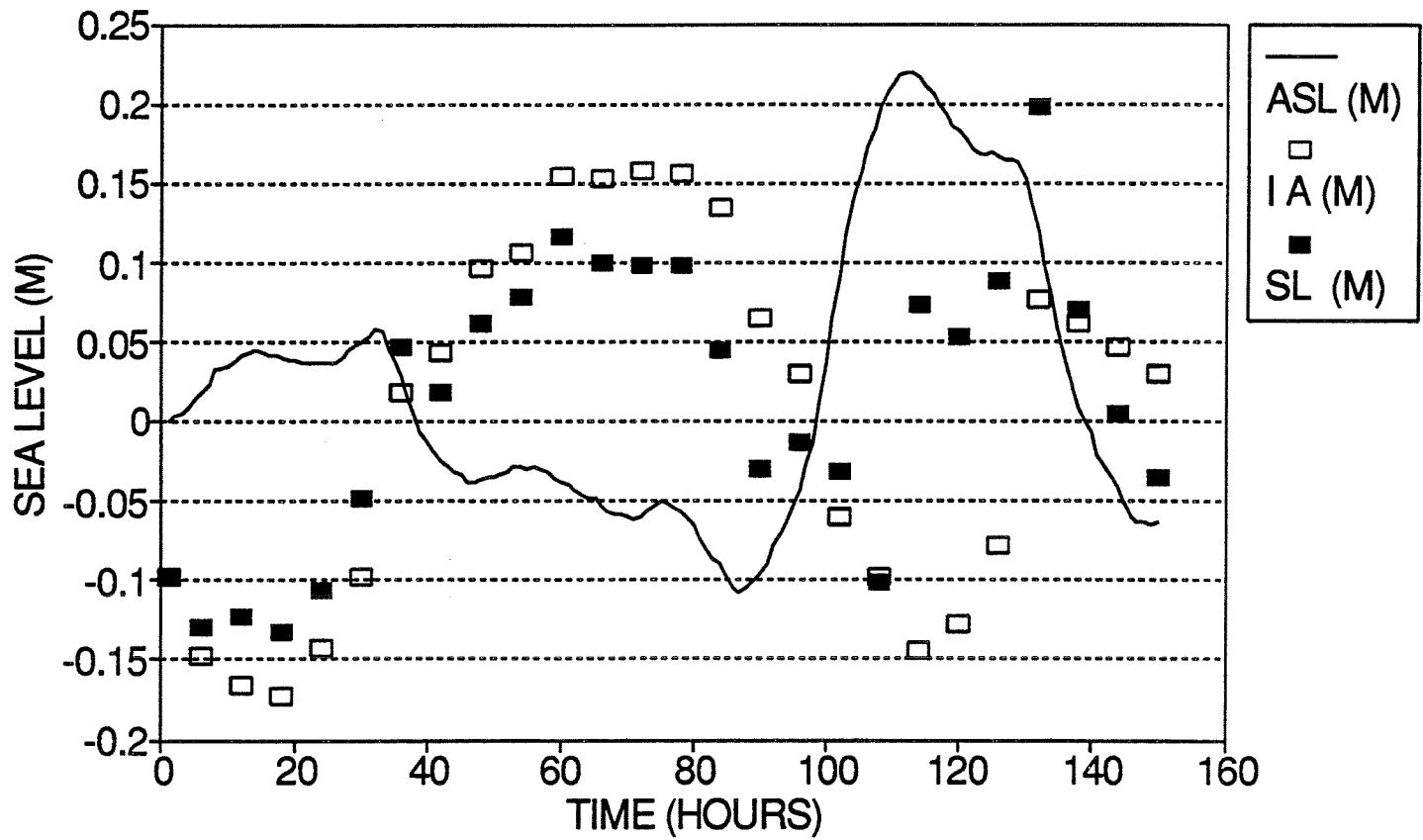
MOBIL STORM 26 & 27

25 NOV. -1 DEC. 1983

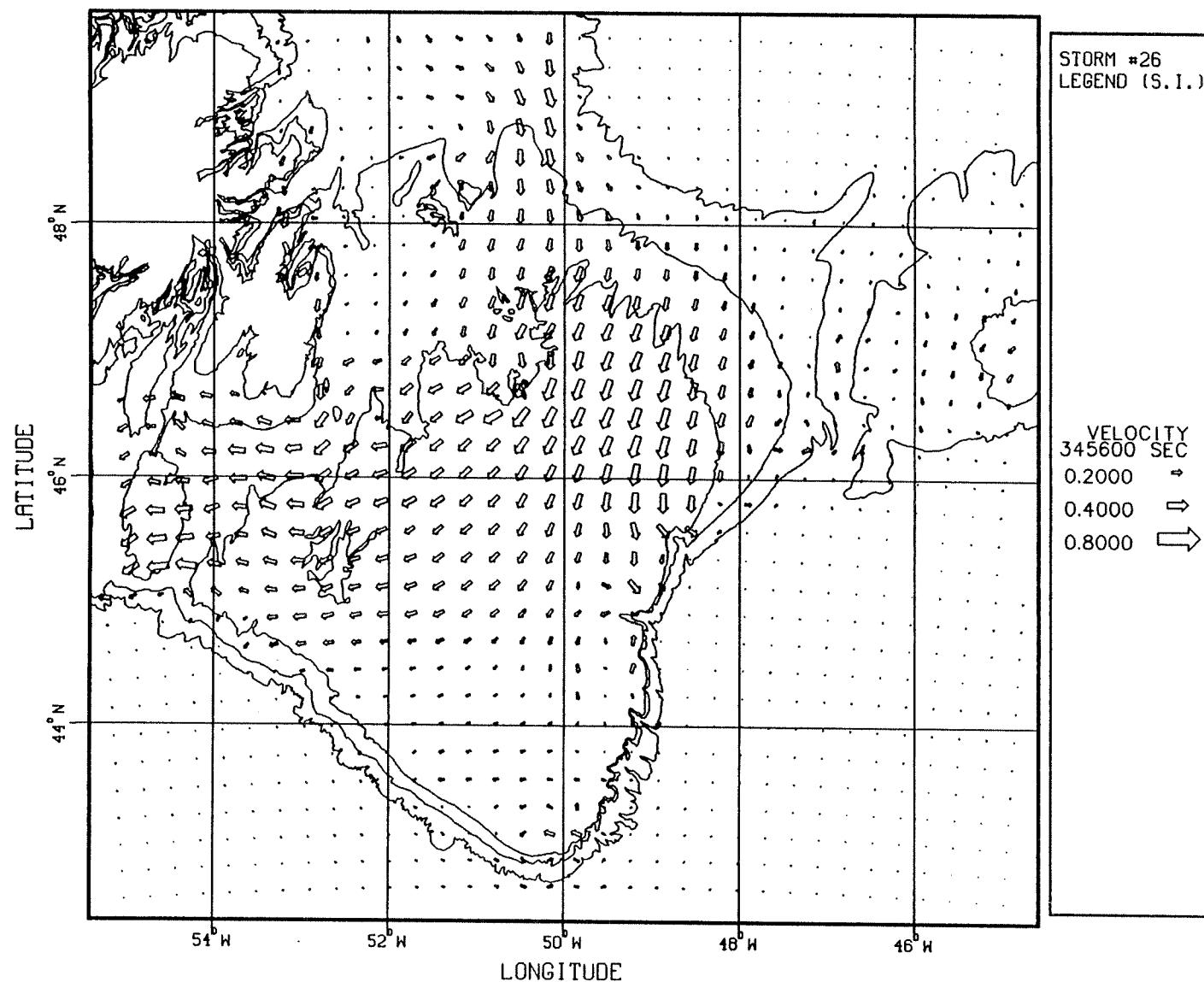


MOBIL STORM 26 & 27

25 NOV.-1 DEC. 1983

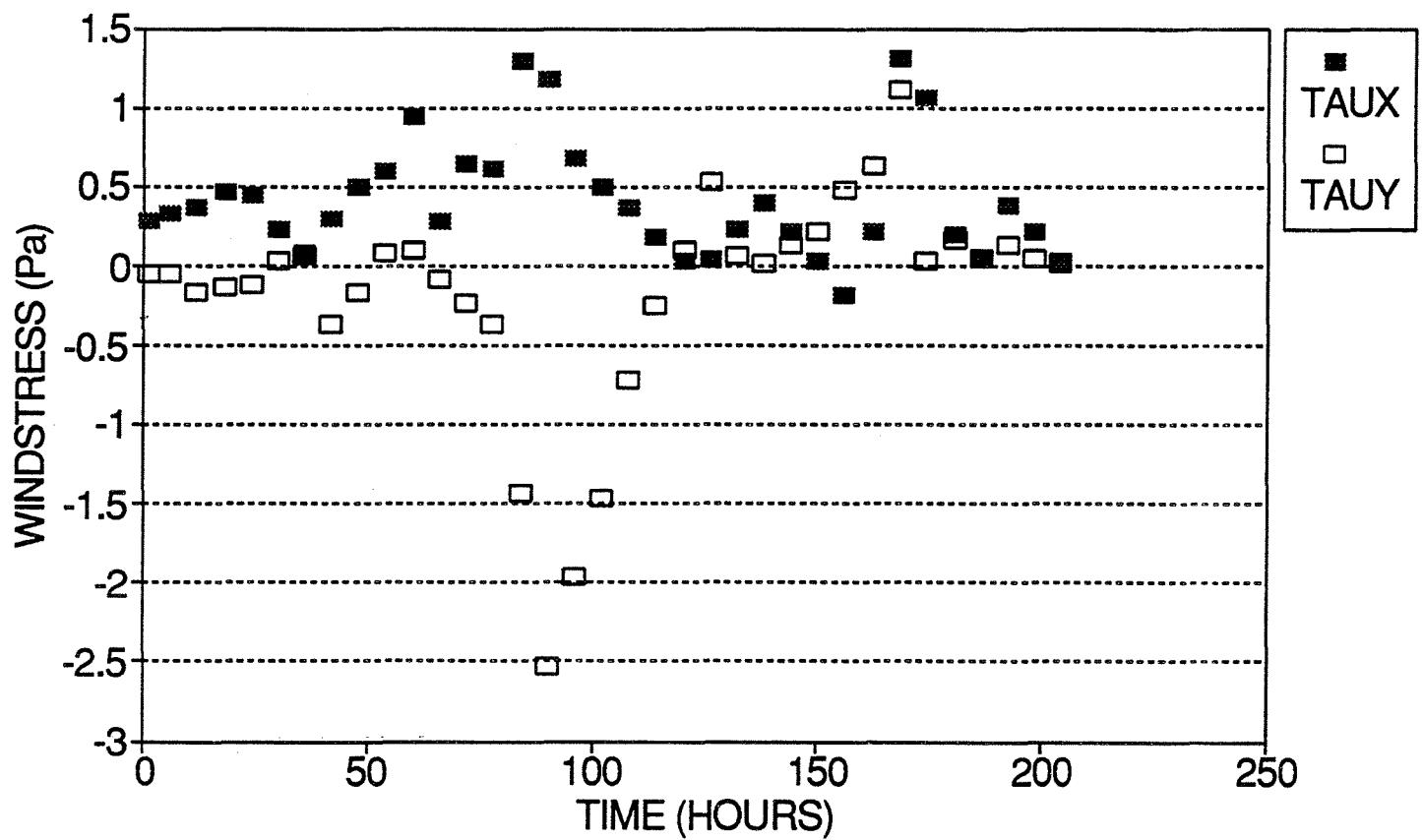


GRAND BANKS STORM MODEL



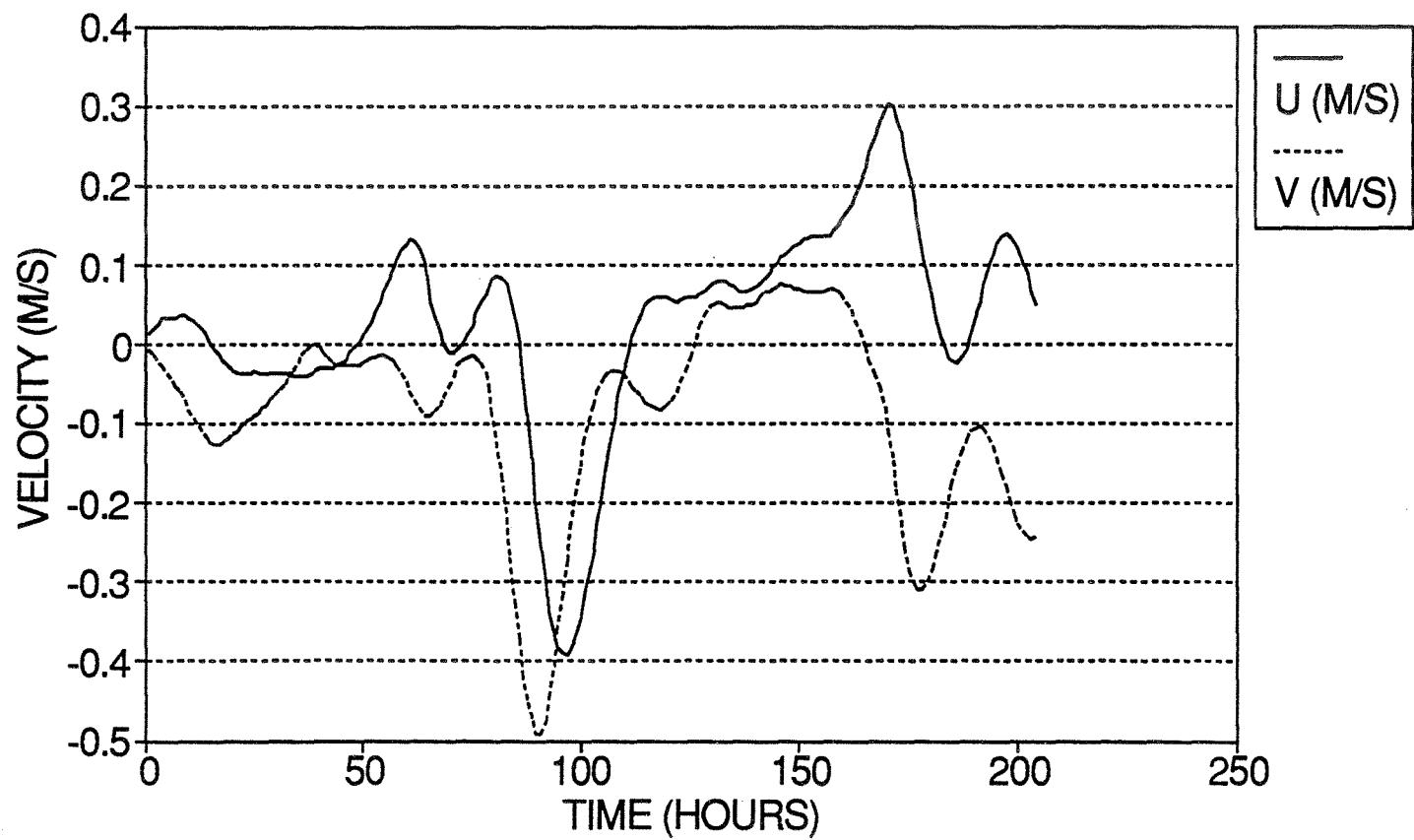
MOBIL STORM 28 & 29

18-27 DEC. 1983



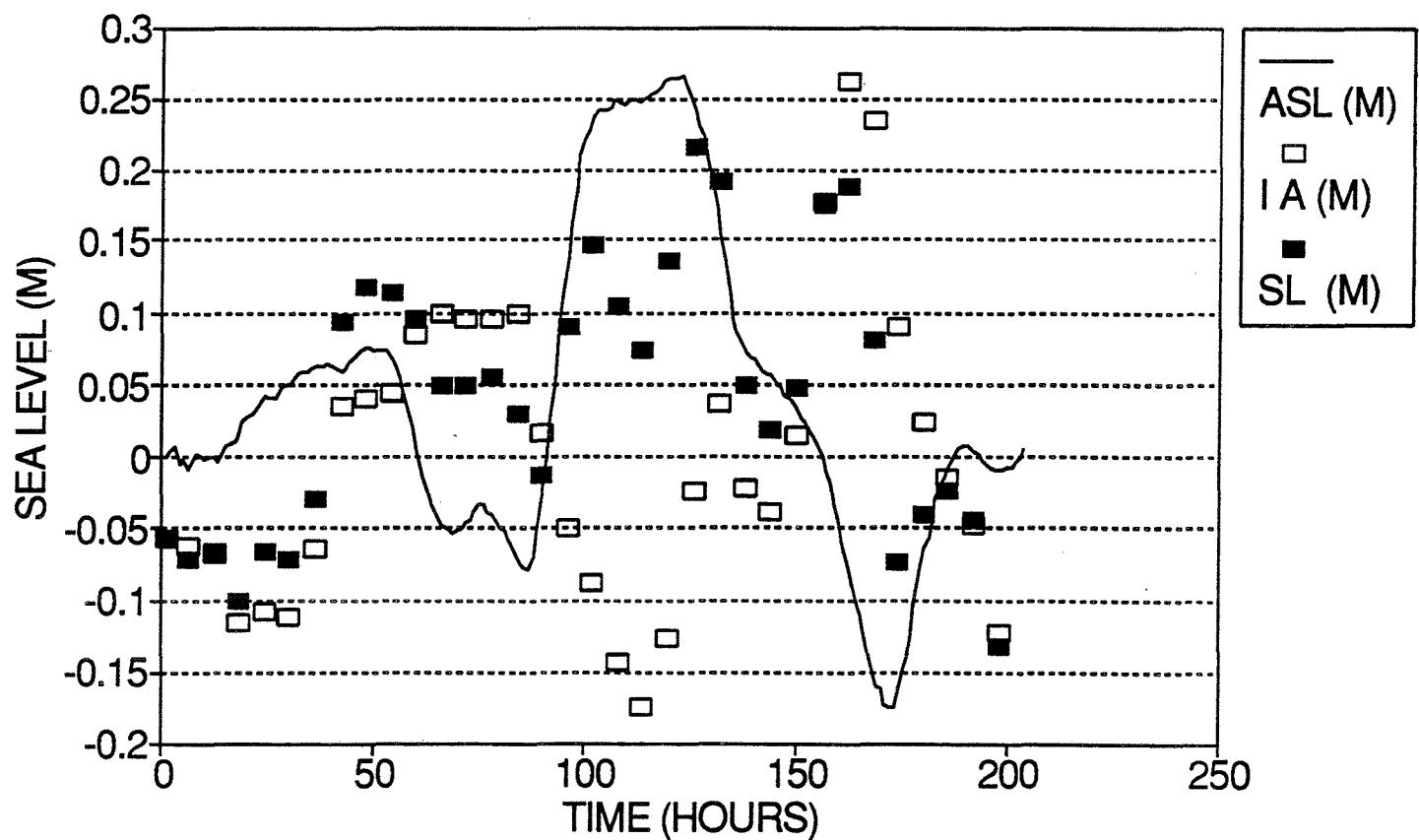
MOBIL STORM 28 & 29

18-27 DEC. 1983



MOBIL STORM 28 & 29

18-27 DEC. 1983



GRAND BANKS STORM MODEL

