A PRELIMINARY EVALUATION OF AN ACOUSTIC FLOWMETER IN A SHIP CANAL, INCLUDING DATA SUMMARY

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MANAGEMENT PERSPECTIVE

This cooperative study with the Water Survey of Canada has resulted in an understanding of new technology and has provided potentially useful data for assessing the winter water quality of Hamilton Harbour. This first application of the AFFRA to a highly dynamic reversing flow in a ship canal has been evaluated by 40 field experiments using conventional current profiling methods. Significant underestimation of the current and degradation of the data quality over the four-month installation period are potential problems for further investigation by the AFFRA manufacturer.

PERSPECTIVE DE GESTION

Cette étude menée en collaboration avec les Relevés hydrologiques du Canada a permis de comprendre une technologie nouvelle et a fourni des données éventuellement utiles pour l'évaluation de la qualité de l'eau en hiver dans le port de Hamilton. Cette première application de l'AFFRA à un écoulement s'inversant très dynamique dans un canal destiné à la navigation a été évaluée au moyen d'au moins 40 expériences sur le terrain menées par les méthodes classiques d'établissements de profils du courant. Une sous-estimation importante du courant et une dégradation de la qualité des données pendant lea quatre mois qu'a duré l'installation constituent des problèmes éventuels qui nécessiteront une étude plus approfondie de la part du fabricant de l'AFFRA.

ABSTRACT

Measurements of the exchange flow through the Burlington Ship Canal between Lake Ontario and Hamilton Harbour are required to assess the water quality of the harbour and its impact on Lake Ontario. Due to the presence of ship traffic in the canal, long time series measurements of these flows have been difficult to make. Through a joint project with the Water Survey of Canada, an acoustic travel time flowmeter system, called AFFRA, was made available. AFFRA (Acoustic Flowmeter For Remote Areas) offered the possibility of measuring the cross-sectionally averaged flow over long time periods with a minimum disruption from passing ships. The water temperature at the level of the acoustic path can also be determined from the data.

A comparison of the AFFRA results against those obtained with a calibrated conventional current meter shows that the AFFRA underestimated the current by 23%. Temperature was estimated satisfactorily. A progressive degradation of the AFFRA signal return over the four-month experimental period is unexplained. Some evidence was found of possible refraction of the acoustic ray paths by shear, but no dependency of refraction on the relatively weak density stratification in the channel was found. Useful data return from AFFRA was reduced to near zero as the two-layer stratification and bidirectional flow regime was established at the end of May. Passage of ships was not detectable in the data quality.

RÉSUMÉ

Des mesures de l'échange d'eau entre le lac Ontario et le port de Hamilton par le canal pour navires de Burlington sont nécessaires pour l'évaluation de la qualité de l'eau du port et de son incidence sur le lac Ontario. En raison de la circulation des navires dans le canal, de longues successions chronologiques de mesures de ces écoulements ont été difficiles. Dans le cadre d'un projet mené conjointement avec les Relevés hydrologiques du Canada, un système débimétrique basé sur la mesure du temps de parcours acoustique (appelé AFFRA, Acoustic Flowmeter For Remote Areas) a été mis à notre disposition. L'AFFRA offrait la possibilité de mesurer le débit moyen pour une section transversale pendant de longs intervalles avec un minimum de perturbation par le passage des navires. Les données recueillies permettent également de déterminer la température de l'eau au niveau du parcours acoustique.

Une comparaison des résultats obtenus avec l'AFFRA à ceux obtenus au moyen d'un courantomètre étalonné classique montre que l'AFFRA sous-estime de 23 % le courant. Les températures obtenues ont été estimées satisfaisantes. Une dégradation progressive de la qualité des mesures de l'AFFRA pendant les quatre mois qu'a duré l'expérience est inexpliquée. Certaines indications d'une réfraction possible des ondes acoustiques attribuable au cisaillement ont été trouvées, mais aucune dépendance de la réfraction à l'endroit de la stratification de densité relativement faible dans le chenal n'a été observée. Les quantités utiles de données fournies par l'AFFRA étaient réduites à presque rien lorsque la stratification à deux niveaux et le régime d'écoulement dans les deux sens se sont établis à la fin de mai. Le passage des navires n'était pas détectable d'après la qualité des données.

INTRODUCTION

Precise measurements of flow in the Burlington Ship Canal are required to estimate the exchange of material between Hamilton Harbour and Lake Ontario. Individual current measurements and time series of conventional current meters have led to unsatisfactory balances of mass (Klapwijk and Snodgrass, 1985). This is probably due to problems of placement of the meters in representative locations in the cross-section to avoid interference to ship traffic. Flows in the ship canal have been inferred from water level differences between the two ends of the canal by calibrating a mathematical model with a time series of water level differences between the two ends of the canal. However, Hamblin (1989) found that unrealistically high values of the bottom and side wall friction coefficient (Mannings n) had to be invoked to bring the simulations of water level differences into agreement with the observations. The reason for the apparent discrepancy is not known but it could be due to calibration of the water level differences which were taken by an experimental instrument known as the DPDX gauge (Simons and Schertzer, 1983).

The recent development of a differential travel time technique employing acoustic pulses which travel relatively large horizontal distances in the flow, offers a possible solution to the measurement problems of the flow in a ship channel. The acoustic beam averages the flow at a particular level across the entire cross-section and may be placed at the side walls of the channel free of disturbance by passing ships. In an intensive study of the two-layer flow regime found in Burlington Canal, Spigel (1989) developed an accurate current profiling method. A direct reading acoustic current meter was rapidly deployed at four locations evenly spaced across the lift bridge located near the mid point of the canal. A slightly modified version of Spigel's experimental method is used in this study to collect a standard set of current and temperature observations. These data form the basis for evaluating the field performance of a commercially available acoustic time-of-flight flowmeter system called AFFRA (Acoustic Flowmeter For Remote Areas). They were also used to establish the relation between flow at the level of the acoustic path and the cross-sectionally averaged flow that will be required for future studies.

ACOUSTIC FLOWMETER

The AFFRA was kindly made available to the investigators on an evaluation basis by the Water Survey of Canada. The system was developed and is manufactured by Stednitz Maritime Technology Ltd. of Eganville, Ontario. Technical specifications and details of electronic operation and computer interfaces are presented in the Operation Instructions for the equipment (Stednitz Maritime Technology Ltd., 1989). While this device has been evaluated in a laboratory tow carriage (Engel and Fast, 1988), its field performance has not been accurately assessed to date.

In the standard AFFRA installation, two acoustic pulses are simultaneously transmitted in opposite directions across the channel along a known path length diagonal to the flow, and upstream and downstream propagation times are measured. The average travel time of the pulse over the path yields the speed of sound. In turn, this may be related to the temperature of fresh water. The difference in arrival times over the known along channel component of travel results in the flow velocity averaged across the channel. The application in this study was the first to employ an acoustic mirror on the opposite wall so that both acoustic transducers could be located on the same side of the channel. This arrangement simplifies the installation and operation of the instrument. Velocities are sampled every 1.5 s and in our study averaged over a 10-min interval and recorded every 15 min. This sampling time is thought to be well matched to the highly dynamic flow in the channel found by Hamblin (1989). The 5-min window between 10-min measurement intervals allows for interrogation of the microprocessor-based memory of the instrument. It is long enough to examine the present data or to transfer up to one day of previous data to permanent storage without disrupting the measurement process. Finally, the percentage of the approximately 400 individual measurements that meet two criteria for reasonable data is recorded. These criteria are (1) sound velocity between 1380 and 1600 m/s and (2) the speed difference between individual 1.5-s scans less than 0.1 m/s. An additional water level or depth channel is provided but was not evaluated in this study as there was possible interference of the acoustic beam with the walls of the canal.

STUDY AREA AND ANCILLARY MEASUREMENTS

Figure 1 shows the ship canal in relation to Hamilton Harbour and Lake Ontario. Figure 2 gives a schematic layout of the lift bridge from which the current profiles were taken and the locations of the AFFRA transmitter, reflector, and receiver. This site was chosen for the study because of the logistical advantage provided by the lift bridge and the close proximity of our research centre. In addition, this waterway is one of the few installations of the AFFRA instrument where the flow is known to reverse. The two key geometrical factors in the installation of the AFFRA device are the path length, 194 m, and the angle between the acoustic path and channel or flow direction which is 65.96° in this case. The ship canal is 828 m in length and the reflector is located 265 m to the southwest of the bridge. At the end of the experimental period the structure supporting the AFFRA instrument, the geometry and the alignment of the transducers were checked for possible deterioration. This inspection dive showed that the mounting was within the original tolerances.

If channel flow is steady and uniform, then the vertical variation of velocity is logarithmic in distance above the bottom (French, 1985). It is readily shown that the height above the bottom at which the flow is equal to the average flow over the depth, h, is h/e, or 3.3 m in the case of the nominal depth of the canal of 9 m at the time of the study. Although the flow is known to be unsteady and is likely non uniform in such a hydraulically short channel, this height was selected for the installation of the acoustic transducers. A goal of the study was to evaluate the representativeness of measurements taken at a single level in the estimation of the cross-sectionally averaged flow. Hamblin (1989) found that on one occasion the breadth average flow at the e^{-1} depth overestimated the cross-sectional flow by 7%.

Speed of sound measurements were converted to water temperature by means of a quadratic relation based on sound speeds at temperatures between 0 and 10°C given by Stednitz Maritime Technology Ltd. (1989).

Currents at the lift bridge were measured on 40 surveys each consisting of four profiles comprising either eight or nine readings of depth, current speed, flow direction, and water temperature. Under most conditions, the four profiles could be taken during the 15-min sampling interval of the AFFRA instrument.

The more convenient current meter to use in the field was a direct reading type manufactured by Neil Brown Inc. Calibration of this instrument in the Canada Centre for Inland Waters tow tank facility showed that the speed was beyond the manufacturer's error specifications. All speed readings were therefore multiplied by 0.82 to bring them into agreement with the tow tank results. Unfortunately, the direct reading current profiler failed after five field experiments, coincident with the AFFRA operation. Another time-of-travel acoustic current meter, the SACM, also of Neil Brown manufacture, and a time, temperature, and depth logger of Branckner manufacture, were substituted for the direct reading profiler. The SACM instrument was also calibrated during the study and found to be within the manufacturer's specification of ±1 cm/s accuracy. For this reason, no attempt was made to remove the offsets on the two axes of the meter of about 0.5 cm/s evident in the polar response curves shown in Figure 3.

Although both microprocessor-based memories of the substitute instruments were less convenient to use than the direct reading instrument, and required merging of two data files, these data did allow for the computation of the standard errors in the estimated speed and direction at the measurement depths. In general, means and standard deviation were calculated from about 20, 0.5-s readings of current at each dwell and 10, 1.0-s readings of depth and temperature. Although the temperature was recorded by the current meter, the temperature was taken from the Branckner data set on account of the more rapid response of its temperature sensor. The averaged data were then input to a modified version of a computer routine written by Spigel (1989) to calculate the cross-sectionally averaged flow and the averaged temperature and current interpolated from the profile data to the depth of the acoustic ray path connecting transmitter reflector and receiver. The details of the corrections of the flow directions for the disturbance to the earth's magnetic field are given in Spigel (1989). In the subsequent data comparisons, AFFRA measurements are interpolated from the two, 10-min samples adjacent to the mid time of the profile experiment.

The AFFRA device was installed on January 18 but usable data was not recorded until January 28. As a result, a number of early profile experiments do not overlap the AFFRA period, but are included herein for completeness. Collection of profile data in the canal was interrupted in March due to drifting ice floes. The AFFRA data was collected by a telephone link and stored on the mainframe computer at the Canada Centre for Inland Waters. This data file runs nearly continuously from January 28 until May 29, 1989. The AFFRA data quality deteriorated severely with the beginning of the two-layer exchange flow between Hamilton Harbour and Lake Ontario. Hamblin (1989) showed that for typical summer stratification, temperature gradients would be sufficient to severely distort the acoustic ray paths through refraction and that usable data would be unlikely. Measurements of wind speed and direction, water levels at the two ends of the canal, and conductivity at the AFFRA installation, completed the ancilliary data. Archival information on the data storage and retrieval are given in an appendix.

RESULTS

The AFFRA measurements for the 120-day period are displayed in Figure 4. The highly transient and reversible behaviour of the flow is apparent. Towards the end of the measurement period, preliminary plots revealed occasional spikes in the flow and velocity of sound curves which have been replaced by a missing data indicator. It is apparent that the data degrade in quality dramatically over the 120-day period until at the end, when the two-layer summer stratification is established, little usable data is measured.

A typical set of current and temperature observations at the lift bridge are shown in Figure 5. The increase in standard deviation at the near surface level is considered to be due to wind waves propagating along the canal. In general, the means are stable in the statistical sense. These data, as well as the remaining profile experiments provided in Appendix I, reveal a weak cross-channel flow and occasionally uniform temperature, but mainly weak temperature stratification (2°C) during the field experiments.

In a preliminary comparison, the current meter and temperature-depth logger were dwelled from the lift bridge over 7 hr on February 24. Encouraging agreement between the two current time series is seen in Figure 6. The velocity of sound corresponds to the variation in temperatures of the two recording meters, while the depth decreases by 0.4 m at the peak harbour outflow event at 15:00 hr. Since cross-sectional averages are considered to be more reliable than single point dwells, subsequent comparison is based on the 40 profile experiments. The data upon which the subsequent comparisons are made, are summarized in Table 1.

In the scatter diagram of Figure 7, the breadth averaged current, measured by the AFFRA flowmeter, is evidently significantly less than the profile based measurements. The AFFRA current is 77.5 ± 9% of the standard measurements where the error estimate is a 95% confidence interval. The offset of 0.4 ± 1.7 cm/s, is not significantly different from zero. The reason for this unexpectedly large underestimation of the breadth-averaged flow is unknown. Decrease in the flow within a 2-m thick boundary layer on each side of the canal, would likely account for only a 2% difference.

Data from the 40 SACM profile experiments were used for the comparison of the averaged current over the cross-section with that over the breadth of the channel at the AFFRA depth. The results shown in Figure 8 indicate that, on the whole, measurements made at the theoretical e^{-1} depth are representative of the average flow. For the harbour outflow, the averaged flow is 1.0 ± 0.087 of the e^{-1} flow with an offset of -1.3 ± 1.6 cm/s. The cross-sectionally averaged inflow to the harbour is 0.989 ± 0.049 of the e^{-1} flow with an intercept of 1.3 ± 1.0 cm/s. There is no difference in the slopes of the best fit lines in the two flow directions on a 95% confidence basis, contrary to what may be expected if boundary layer thicknesses are different in the two flow directions. The difference in the offsets of the two best-fit lines, while marginally significant, is close to the experimental error of the current measurements of 1 cm/s.

The water temperature deduced from the AFFRA velocity of sound data are compared to temperatures directly measured by the profiler in Figure 9. As in the previous comparison, there is no significant difference between the two methods. AFFRA temperatures are 1.09 ± 0.1 of the profile temperatures. In this case, the intercept of 0.32 ± 0.5°C, while not distinguishable from 0°C on 95% confidence basis, is close to the error of the profile temperatures of ±0.12°C when a temperature offset of 0.1°C is taken in account. This offset arises from a 6 cm underestimation of the path length due to the electronics (W. Stednitz, personal communication).

In the time series plots of Figure 4, there is an indication of lower percentage data return at high speeds, particularly for outflows. This behaviour is supported by the curves of Figure 10, which show a pronounced decrease in the percentage return throughout the experiment but also a tendency for higher return at lower speeds. The reason for the variation of percentage return is not known. It is conjectured that the refraction of the acoustic rays by the current shear is the likely explanation. Since the installation is located much closer to the harbour than the lake, the bottom boundary layer should be thicker for inflows than for outflows. Consequently, the shear would be higher for inflows at the AFFRA depth than for outflows. Since the ultimate disruption of the acoustic signals is clearly associated with the establishment of the sharp two-layer stratification by May 29, an investigation was undertaken of the dependency of the gradient of the velocity of sound over the water column for the 40 field experiments with percentage return. No significant correlation was found. It is noteworthy that the shear is of the same order as the difference in sound velocities. In fact, the degree of stratification in the speed of sound does not show a seasonal progression over the 40 field experiments. As the velocity of sound is less at colder temperatures, the increase in the acoustic path length should be greater at lower temperatures for a given velocity of sound gradient. Therefore, the percentage return should increase over the experimental period if refraction effects are an important factor in the one-layer flow case.

Another factor could be the unsteadiness of the flow. Since transient flow conditions could affect both the profile data and the AFFRA readings, it was decided to correlate the distance from the observation point on Figure 7 to the best fit line with the flow acceleration. Again, no significant correlation was found.

With regard to the influence of ship passage in the canal on the AFFRA system, the percentage returns immediately preceding the ship passage were compared to the those at the time of passage as well as to those one sampling interval after the passage of the ship. No significant difference in returns was found over 240 occasions of large vessels passing through the canal.

CONCLUSIONS

An acoustic pulse techique was found to be a useful means of measuring current, temperature, and, when combined with water depth, discharge in a ship canal under dynamic flow conditions. Clearly, this device is limited to the relatively unstratified one-layer flow found in winter and early spring when distortion of the horizontal ray paths by refraction is limited. A progressive degradation of the acoustic signal quality over the one-layer period, as well as the statistically significant underestimation of the flow by the travel time method, require further investigation. It would be valuable to compare the acoustic travel time technique with other acoustic methods such as the scintillation method (Farmer et al., 1987). In future applications to investigations which require recorded data, a data storage medium of much explanded capacity would be highly desirable along with a faster transfer capability of such data.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance provided by the Water Survey of Canada and, in particular, E. Fast in conducting this study. Messrs. H. Savile and J. Lomas conducted the AFFRA installation. Messrs. J. Carew and Y. Desjardins are thanked for their efforts in making the profile observations; Dr. R. Spigel for providing a copy of his computer program; B. Ventresca for his significant modifications of this routine; and the Department of Transport for providing times of bridge lifts. We are grateful to Dr. Stednitz for his valuable discussions on this project.

Dr. A. El-Shaarawi's advice on the statistical analysis is greatly appreciated.

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LIST OF FIGURE CAPTIONS

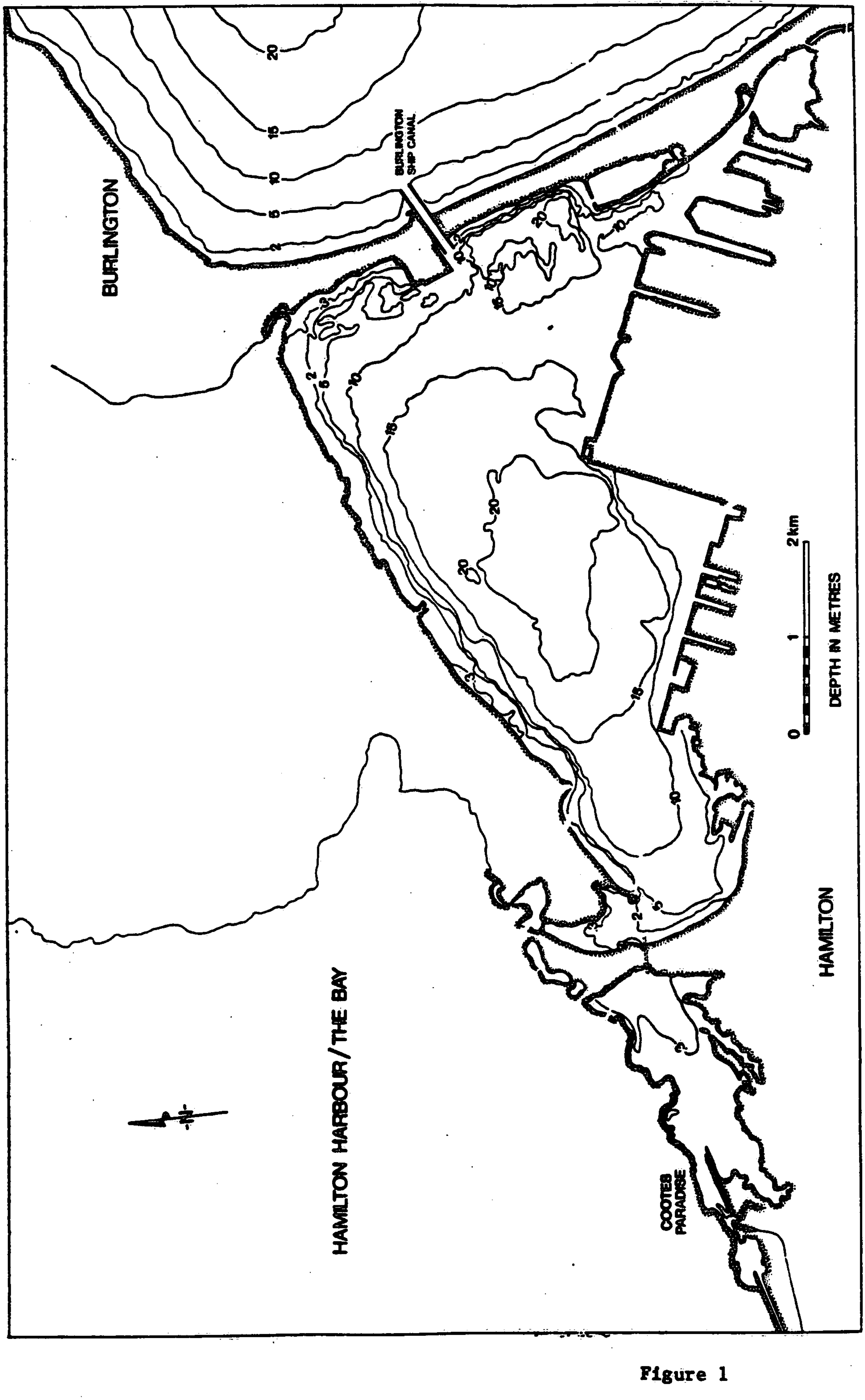
Figure 7. - Interpolated AFFRA flow (cm/s) from measured 15-min samples at the mid profile time versus the breadth-averaged profile data at the AFFRA level. Solid line represents a linear least squares best fit and dashed lines are the standard error of estimate (Parl, 1967). The R value is the correlation coefficient.

Figure 8. Same as Figure 7 but ordinate is the cross-sectionally averaged flow from the profile measurements.

Figure 9. AFFRA water temperature deduced from the speed of sound versus breadth-averaged temperature (°C).

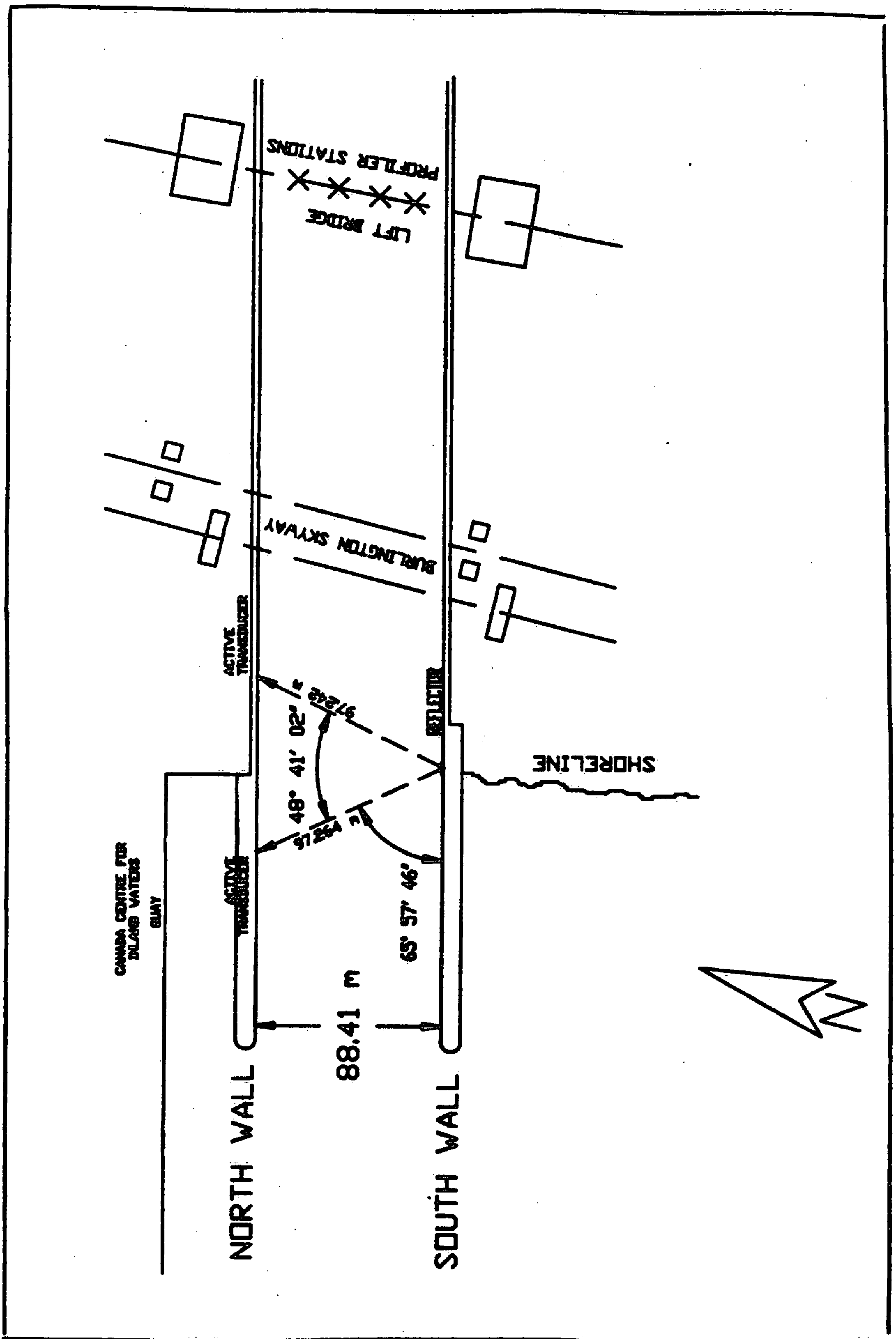
Figure 10. Percentage return versus AFFRA flow for five, 20-day episodes.

LIST OF TABLE CAPTIONS



BURLINGTON
BURLINGTON SHIP CANAL
HAMILTON HARBOUR/THE BAY
HAMILTON
COOTES PARADISE
N
0
1
2km
DEPTH IN METRES

Figure 1



NORTH WALL
SOUTH WALL
88.41 m
65° 57' 46"
48° 41' 02"
97.264 m
97.248 m
ACTIVE TRANSDUCER
ACTIVE TRANSDUCER
REFLECTOR
SHORELINE
BURLINGTON SKYWAY
LIFT BRIDGE
PROFILER STATIONS
CANADA CENTRE FOR INLAND WATERS QUAY

Figure 2

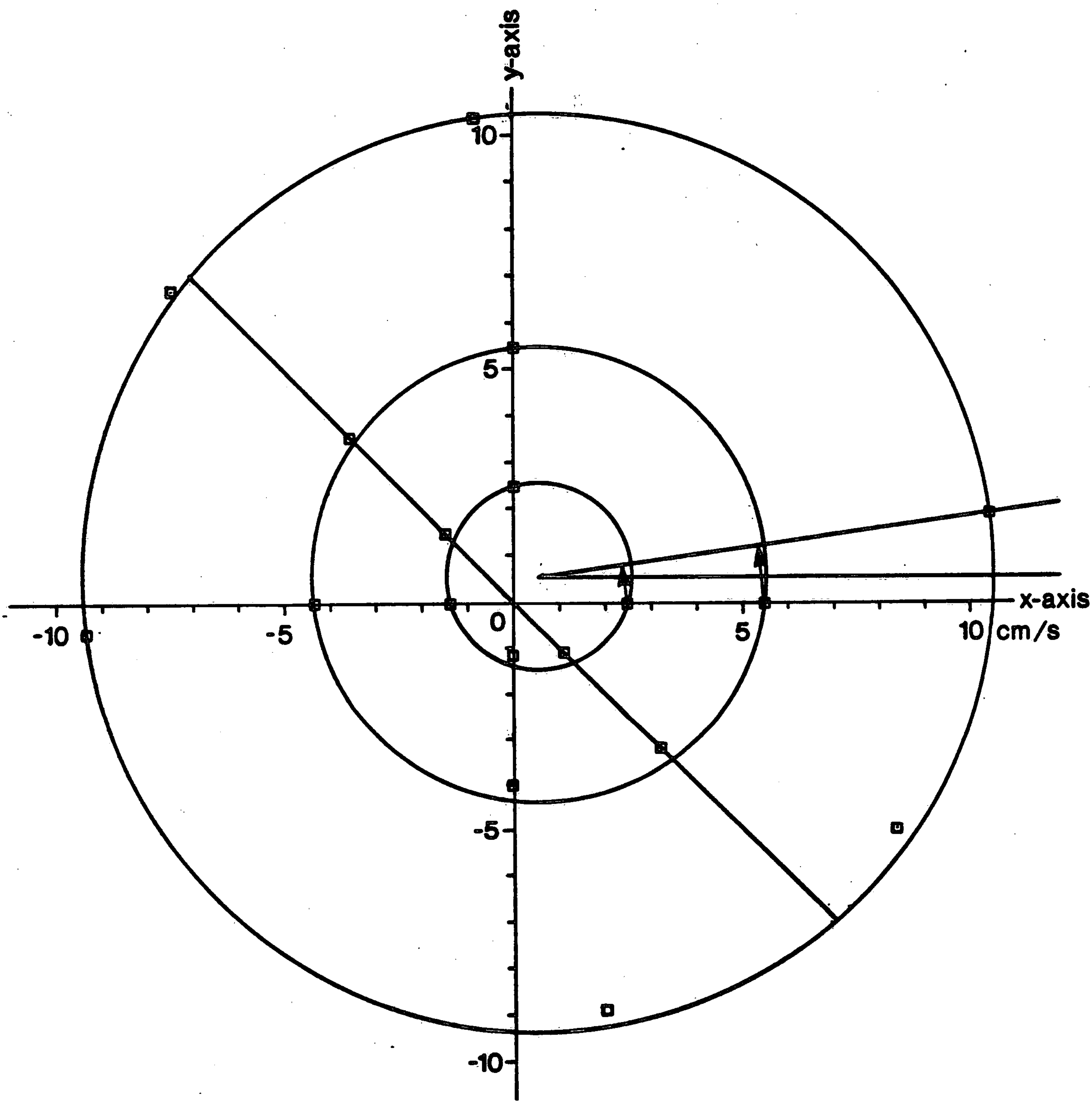


Figure 3

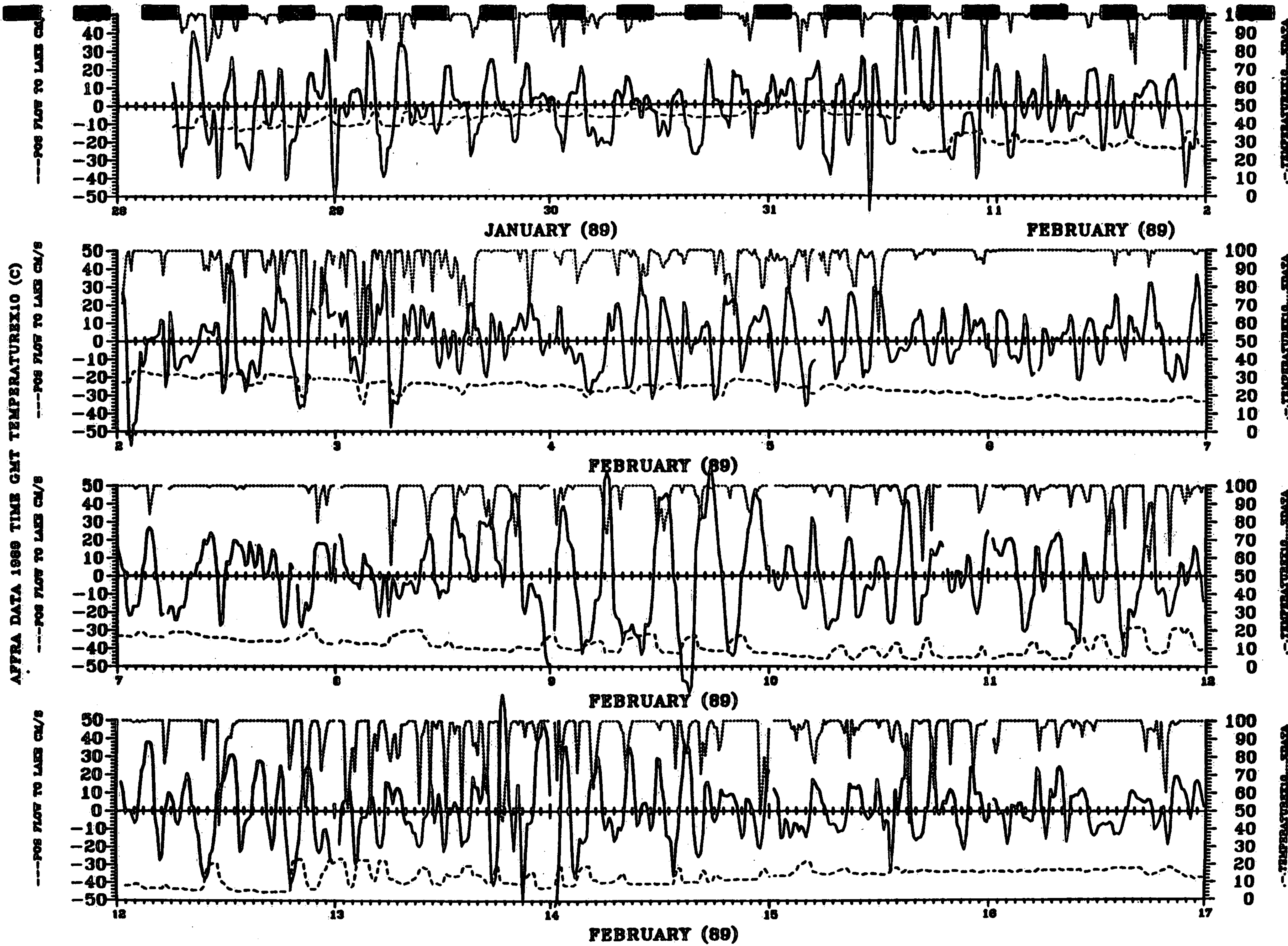
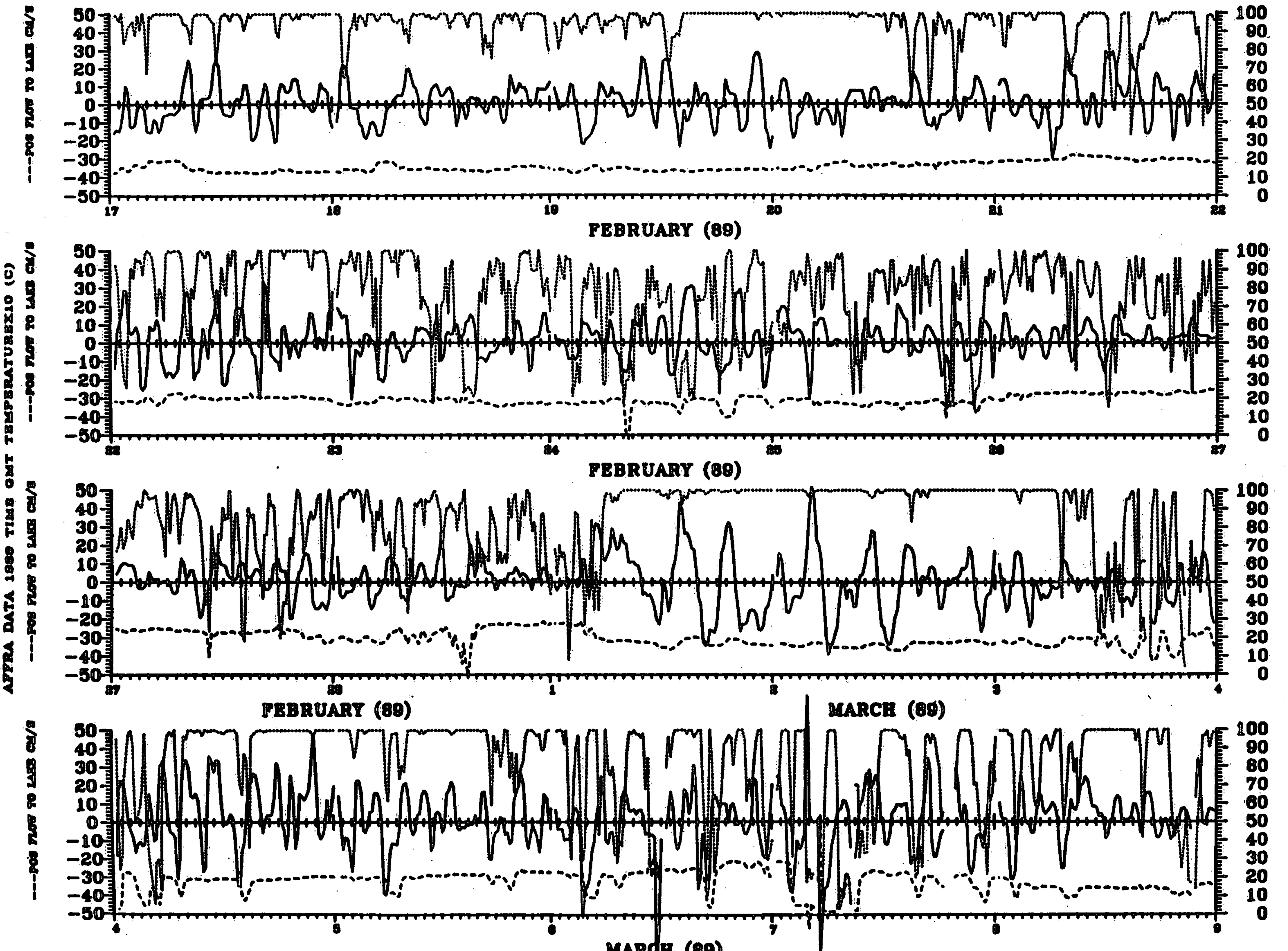
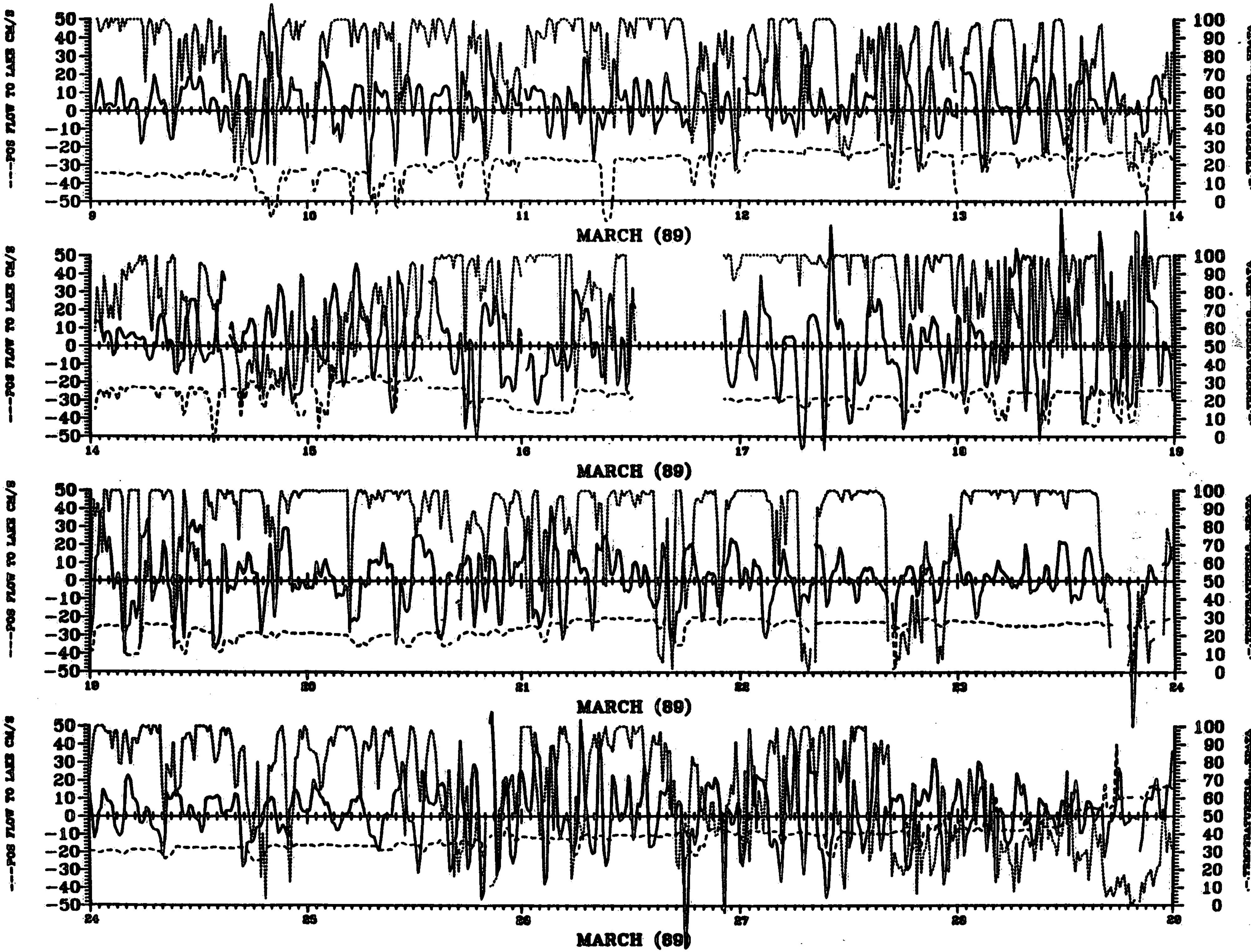
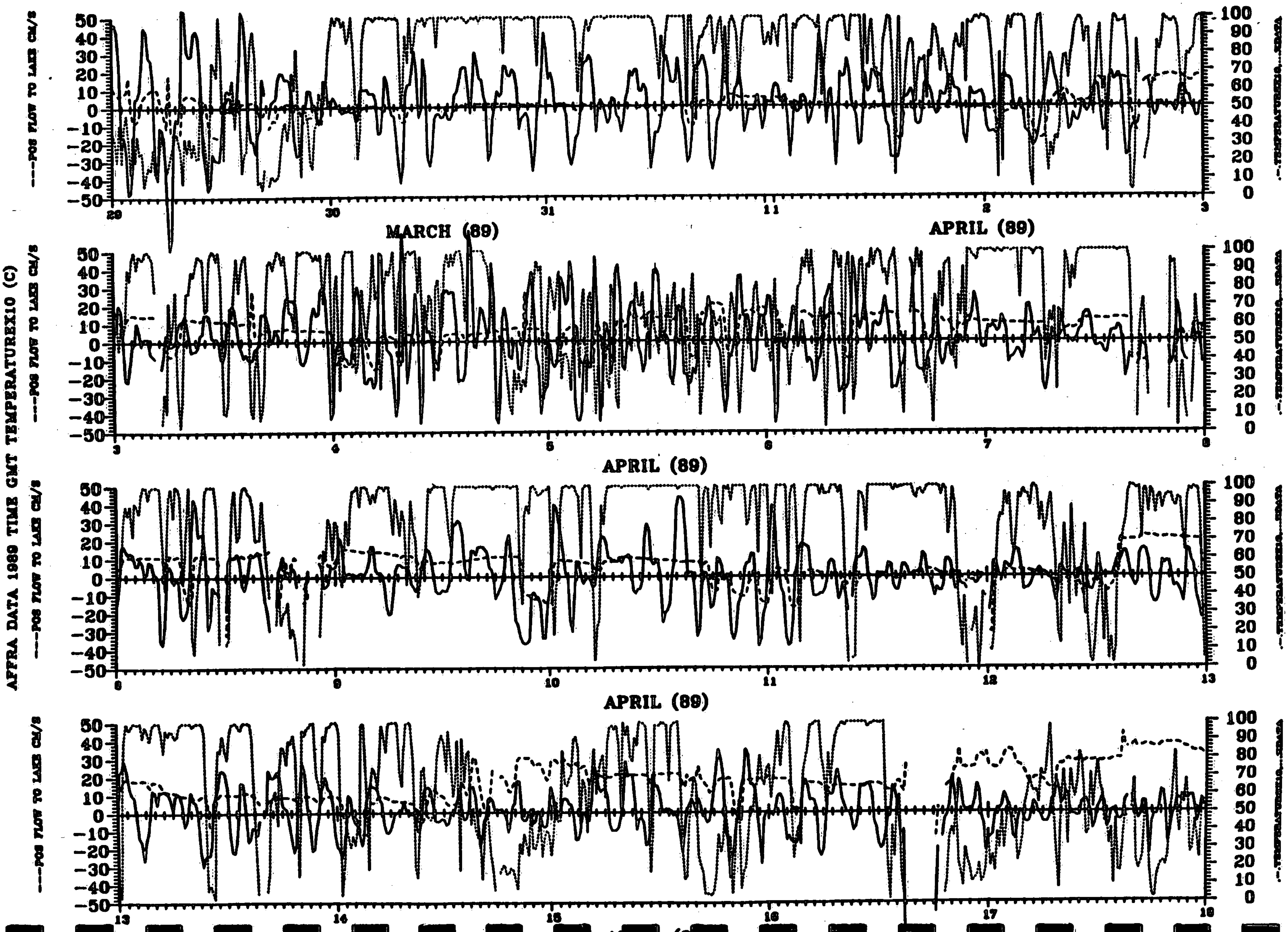

APFRA DATA 1989 TIME GMT TEMPERATUREX10 (C)
---POS FLOW TO LAKE CM/S
-.-TEMPERATUREX10...XDATA
JANUARY (89)
FEBRUARY (89)
FEBRUARY (89)
FEBRUARY (89)
FEBRUARY (89)

Figure 4

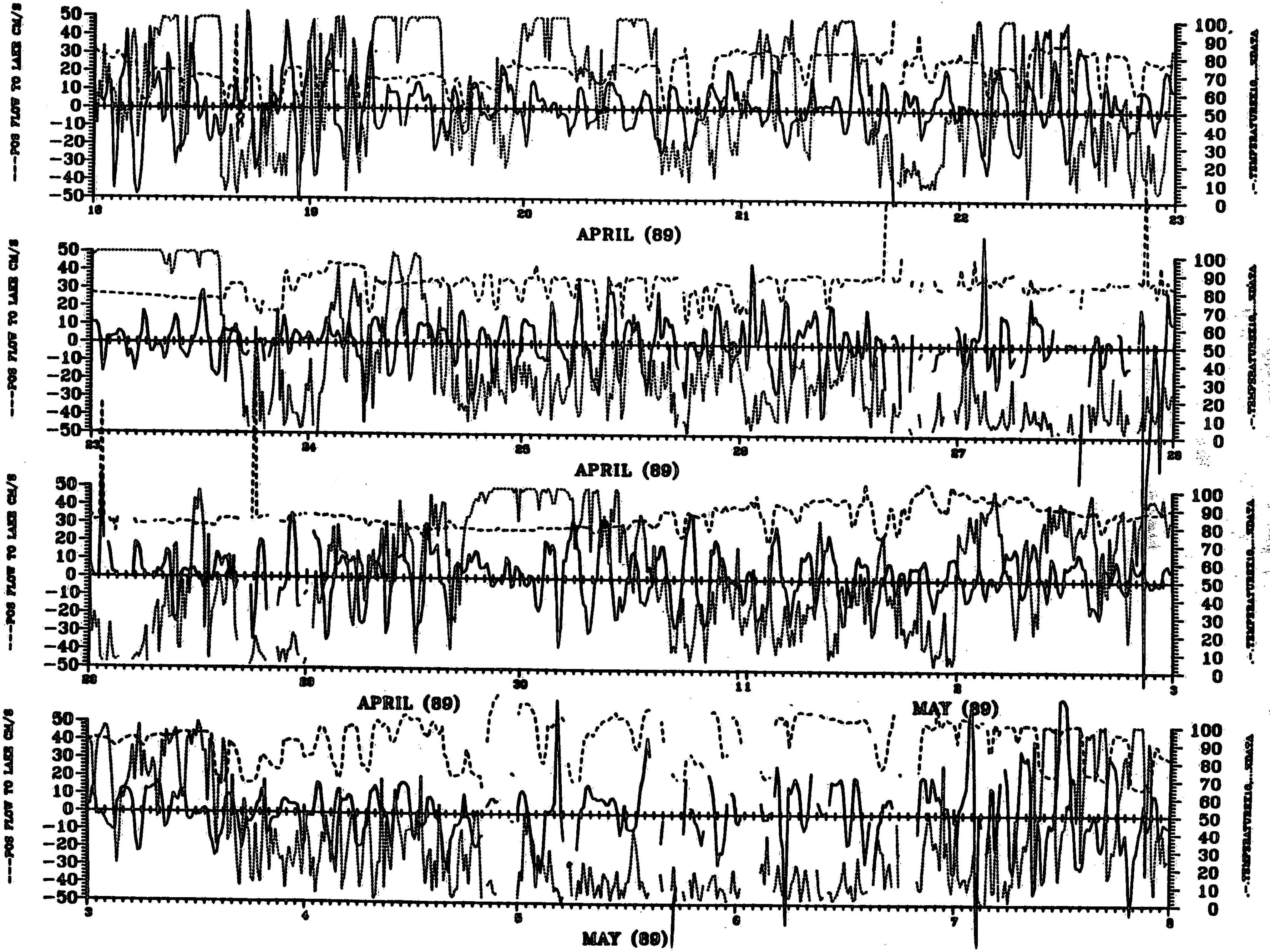

APFRA DATA 1989 TIME GMT TEMPERATUREx10 (C)
---POS FLOW TO LAKE CM/S
-.-TEMPERATUREx10...SRASA
FEBRUARY (89)
FEBRUARY (89)
FEBRUARY (89)
MARCH (89)
MARCH (89)

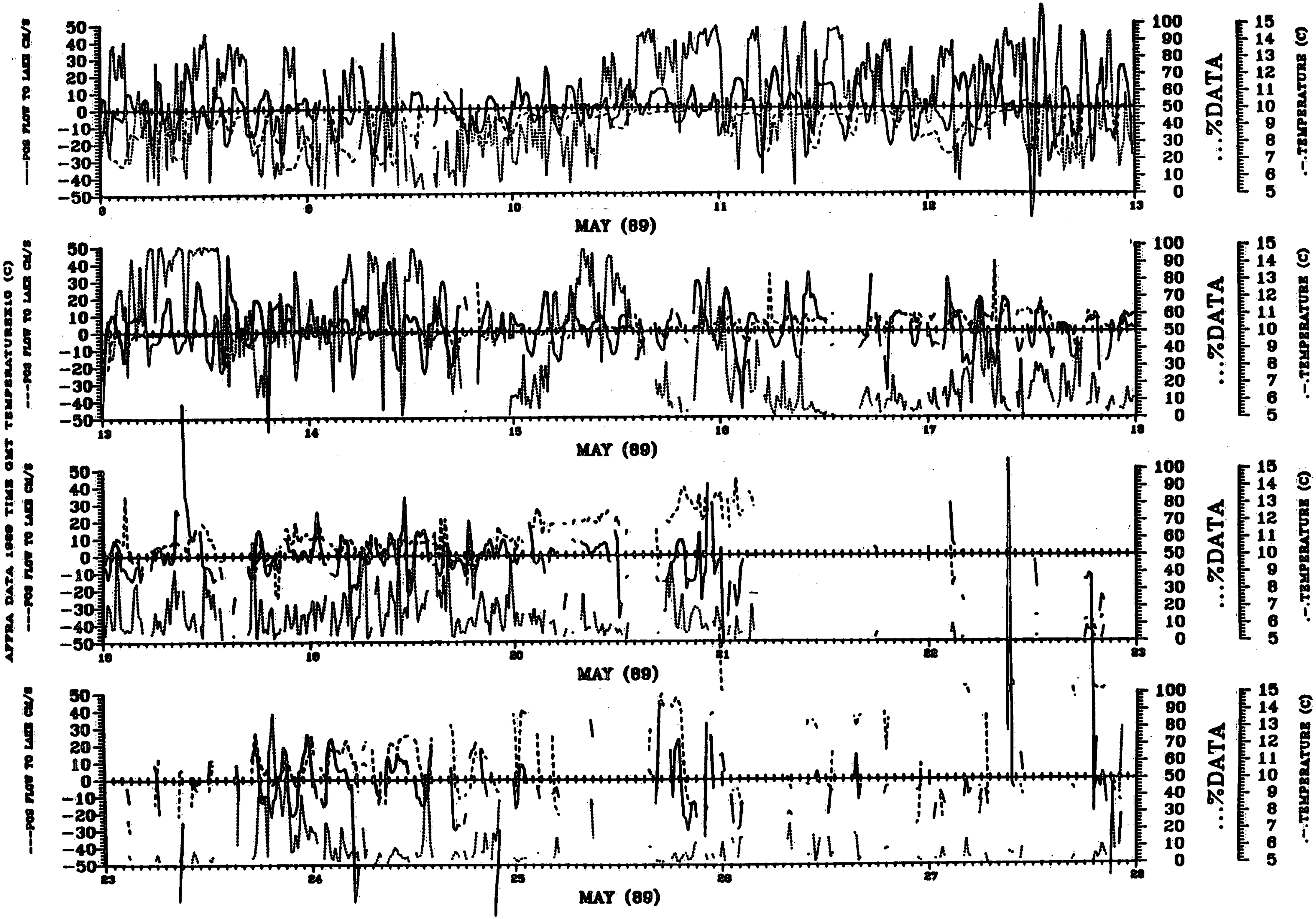
APFRA DATA 1989 TIME GMT TEMPERATUREX10 (C)




AFFRA DATA 1989 TIME GMT TEMPERATUREX10 (C)
---POS FLOW TO LAKE CM/S
MARCH (89)
APRIL (89)
APRIL (89)
APRIL (89)

AFFRA DATA 1989 TIME GMT TEMPERATUREX10 (C)





AFFRA DATA 1989 TIME GMT TEMPERATUREX10 (C)
---POS FLOW TO LAKE CM/S
...%DATA
-.-.TEMPERATURE (C)
MAY (89)

Acoustic cm Measurements, Burlington Ship Canal - May 7, 1989

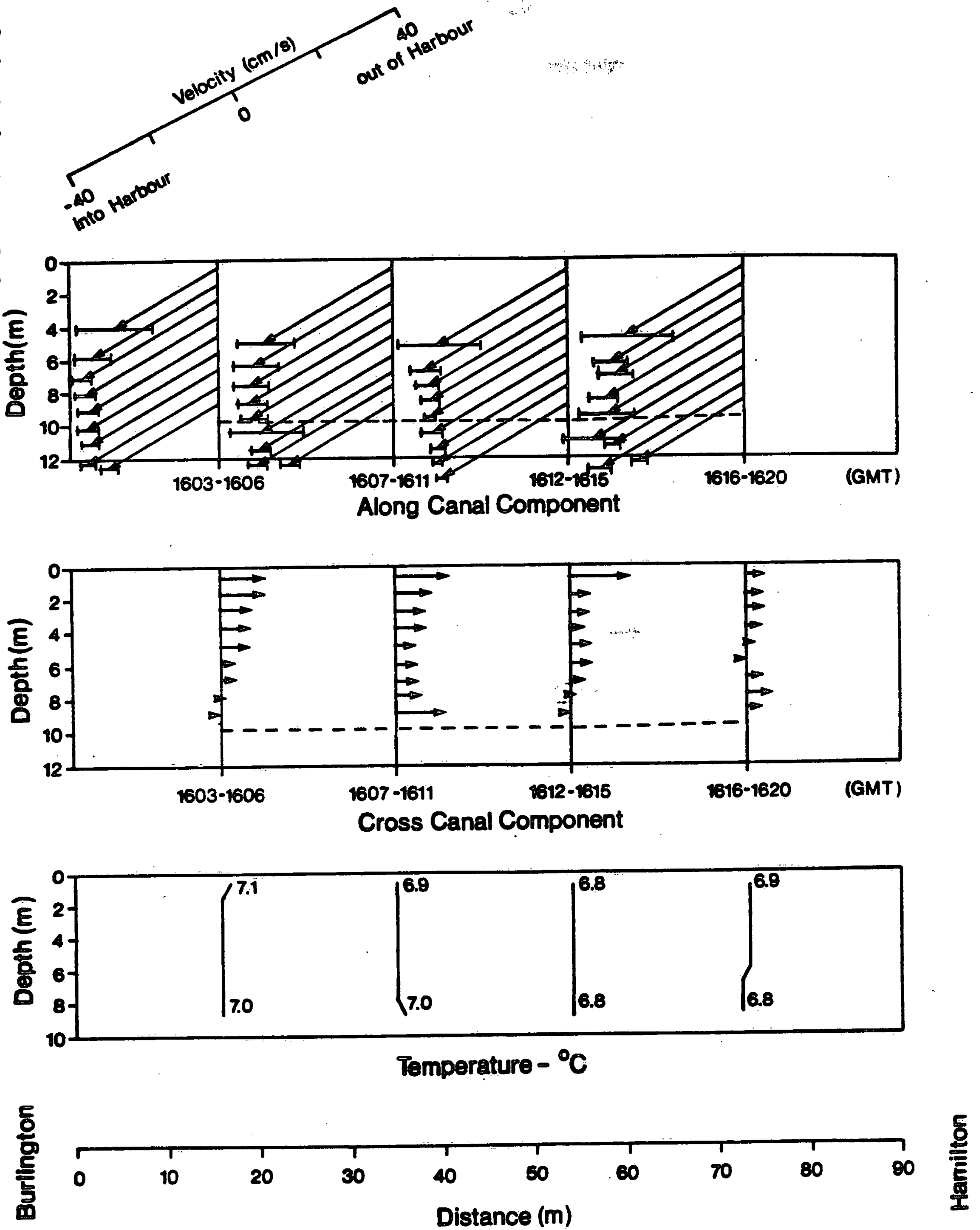
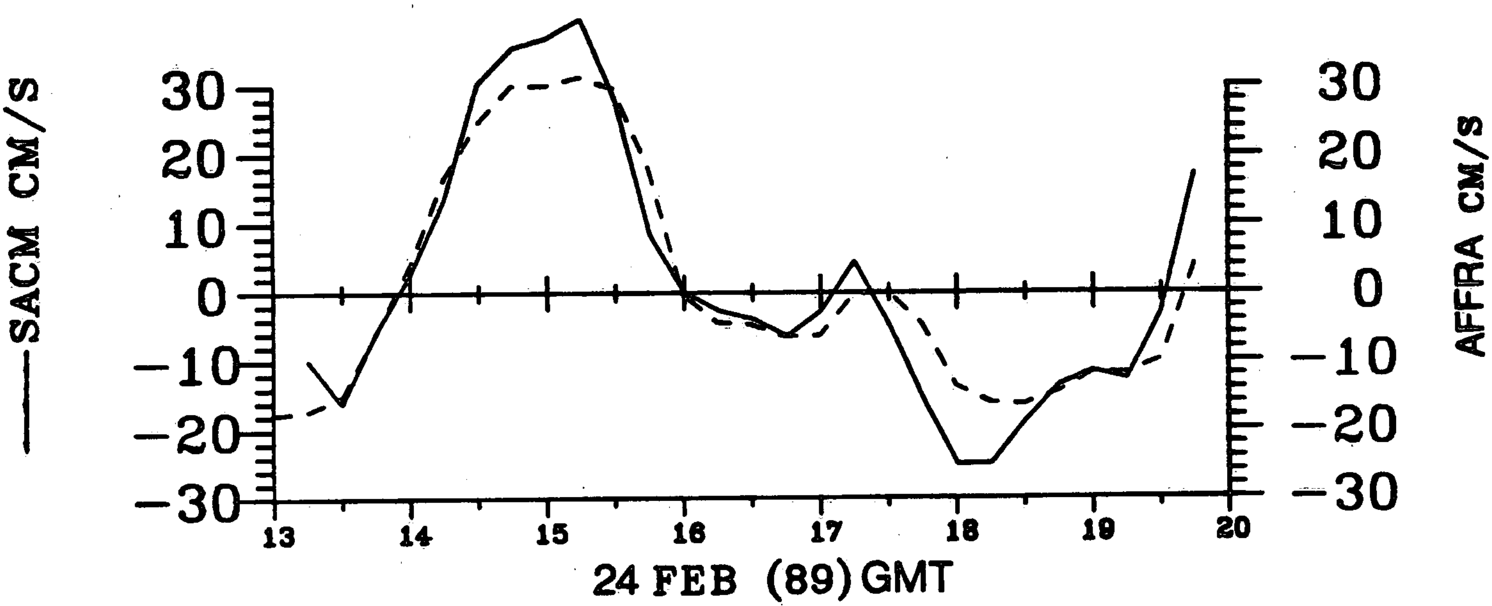
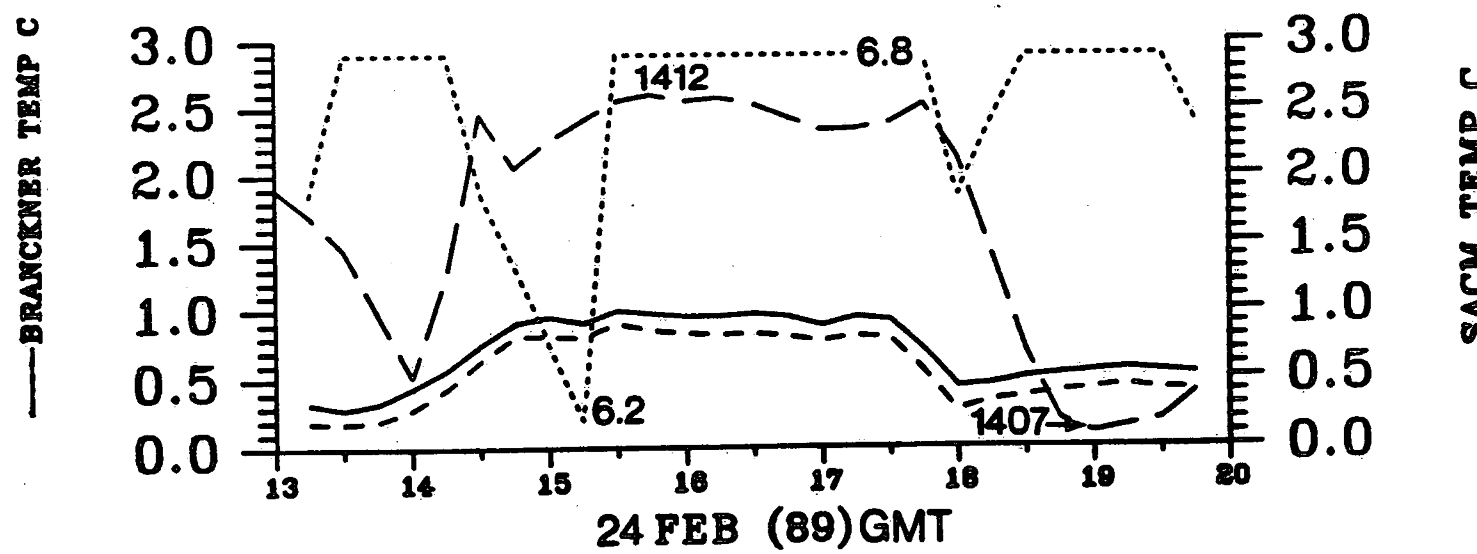


Figure 5



SACM CM/S
AFFRA CM/S
30
20
10
0
−10
−20
−30
13
14
15
16
17
18
19
20
24 FEB (89) GMT



BRANCKNER TEMP C
SACM TEMP C
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1412
6.8
6.2
1407
13
14
15
16
17
18
19
20
24 FEB (89) GMT

Figure 6

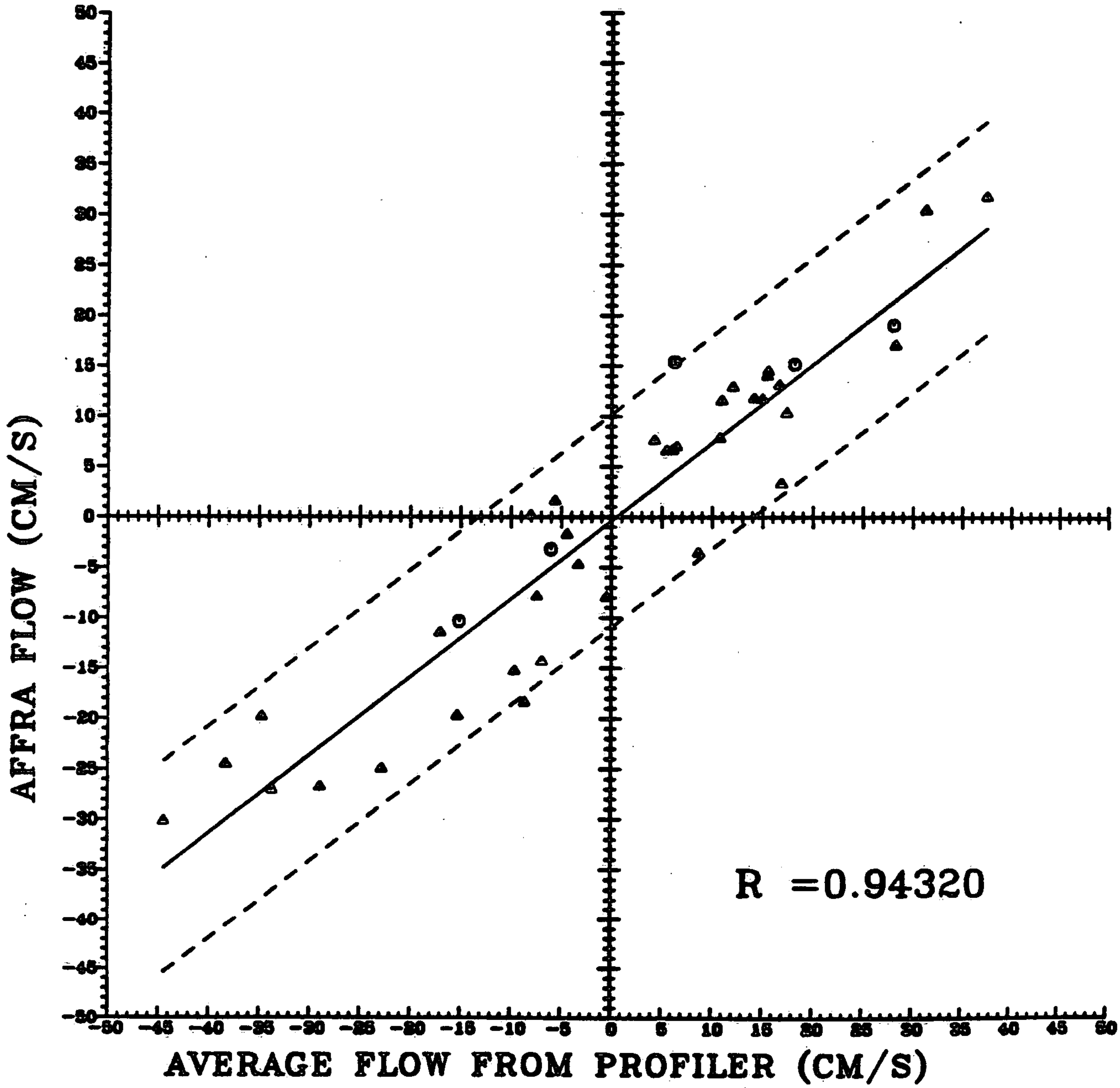


Figure 7

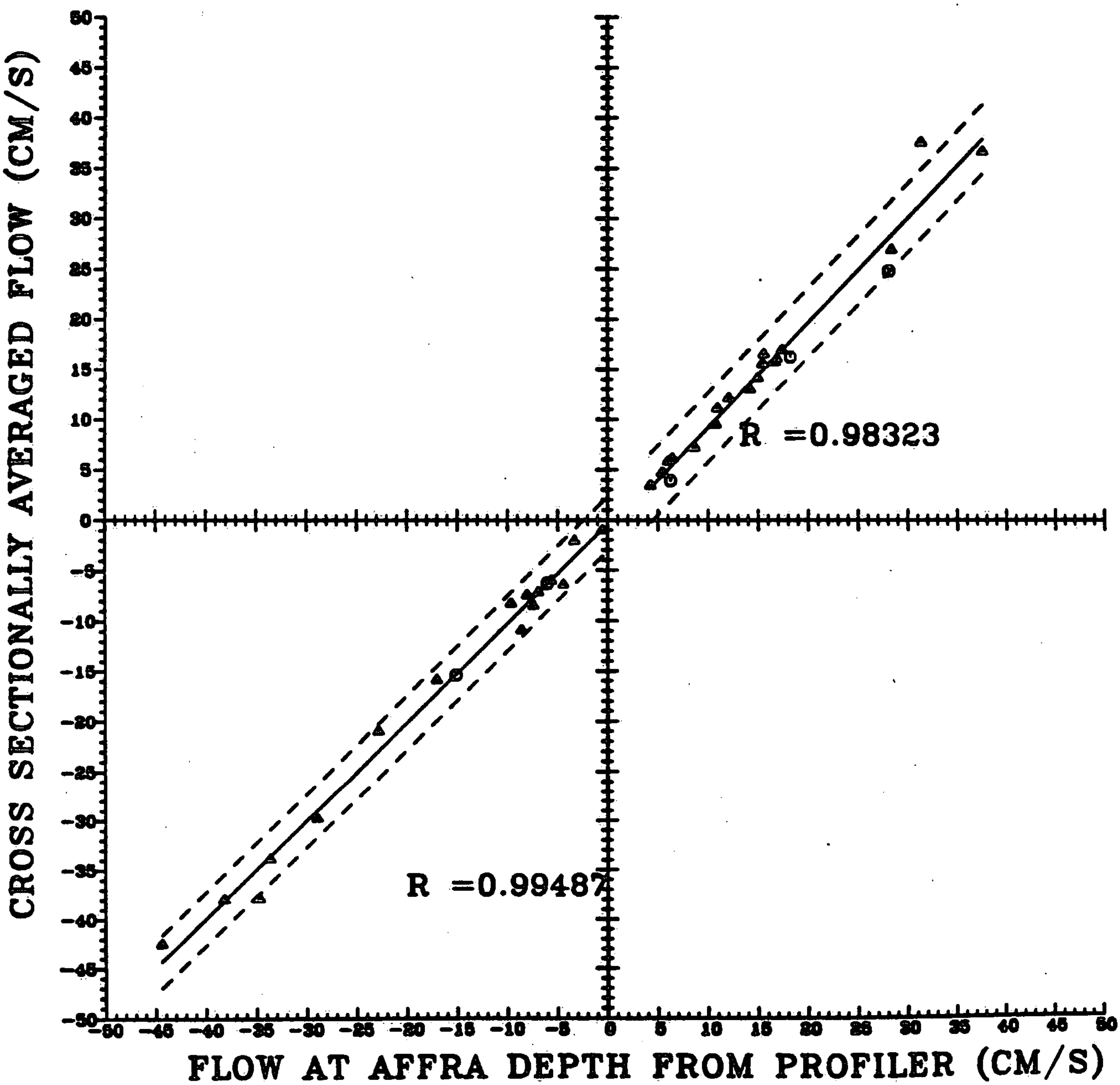
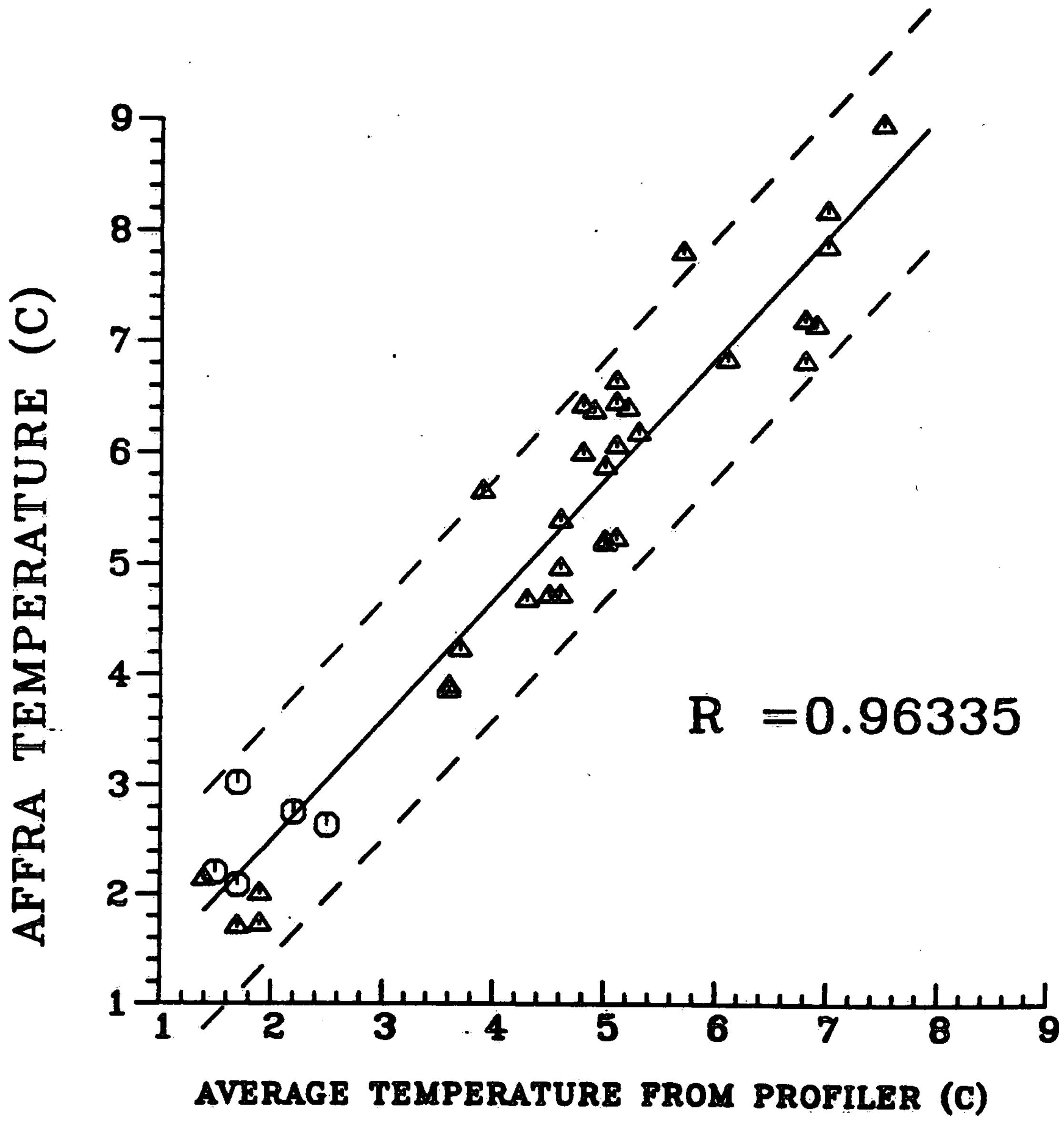

CROSS SECTIONALLY AVERAGED FLOW (CM/S)
FLOW AT AFFRA DEPTH FROM PROFILER (CM/S)
R =0.98323
R =0.99487
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50

Figure 8



AFFRA TEMPERATURE (C)
9
8
7
6
5
4
3
2
1
R =0.96335
1
2
3
4
5
6
7
8
9
AVERAGE TEMPERATURE FROM PROFILER (C)

Figure 9

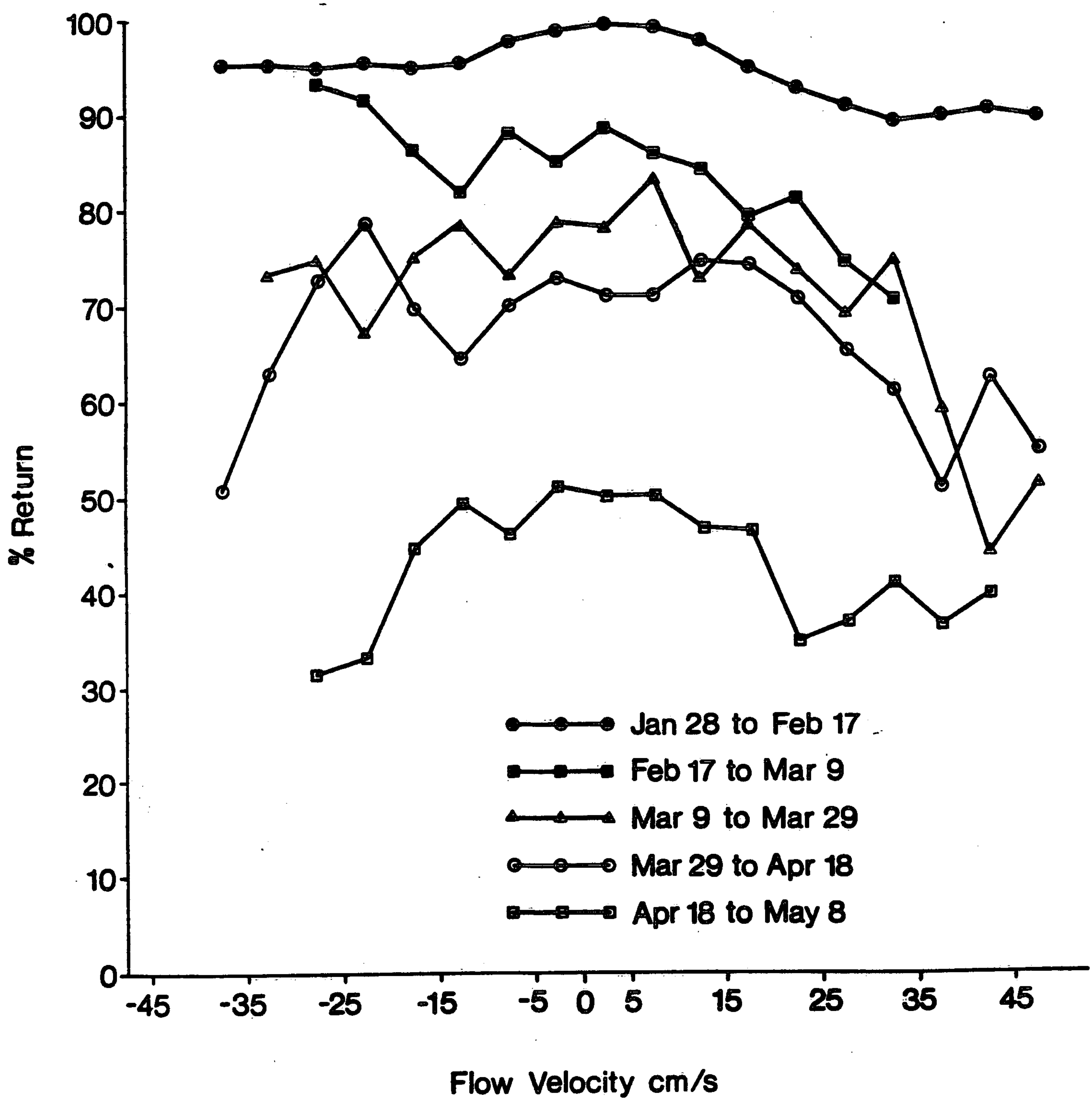

100
90
80
70
60
50
40
30
20
10
0
% Return
-45
-35
-25
-15
-5
0
5
15
25
35
45
Flow Velocity cm/s
Jan 28 to Feb 17
Feb 17 to Mar 9
Mar 9 to Mar 29
Mar 29 to Apr 18
Apr 18 to May 8

Figure 10

TABLE 1: Profile data and AFFRA measurements at profile times.

				Profile Data		AFFRA Data			Cross-Sectionally
Month	Day	Hour	Minute (GMT)	Flow (cm/s)	Temperature (C)	Flow (cm/s)	Temperature (C)	Percent Return	Averaged Flow (cm/s)
2	20	18	53.0	-3.3	1.9	-4.7	1.7	92	-2.10
2	21	19	14.5	-15.3	1.9	-19.7	2.0	99	Missing
3	2	18	33.0	-0.5	1.7	-8.0	1.7	100	-1.00
3	3	18	22.5	-4.4	1.4	-1.8	2.1	82	-6.40
3	15	16	7.5	-6.0	2.5	-3.2	2.6	100	-6.30
3	20	18	33.5	-15.1	1.5	-10.4	2.2	88	-15.40
3	20	19	15.0	6.3	1.7	15.4	2.1	81	3.90
3	21	18	22.0	28.1	2.2	19.0	2.8	48	24.80
3	21	18	53.0	18.2	1.7	15.1	3.0	76	16.20
3	29	19	38.5	11.0	5.0	11.5	5.2	57	11.10
3	29	19	58.0	-6.9	5.1	-14.4	5.2	61	-7.20
3	29	20	18.0	-33.6	5.0	-27.1	5.2	71	-33.90
3	29	20	28.5	-28.9	Missing	-26.8	5.0	36	-29.80
3	31	15	24.5	-38.2	4.3	-24.5	4.7	67	-38.00
3	31	15	37.0	-44.4	3.7	-30.2	4.2	72	-42.50
3	31	15	50.0	-22.8	3.6	-25.0	3.9	100	-21.00
3	31	16	1.0	-9.6	3.6	-15.3	3.9	98	-8.30
4	5	13	53.5	-8.6	5.3	-18.4	6.2	78	-10.90
4	5	14	5.5	8.7	5.2	-3.6	6.4	70	7.20
4	5	14	20.5	28.3	6.1	17.0	6.8	49	26.90

cont'd...

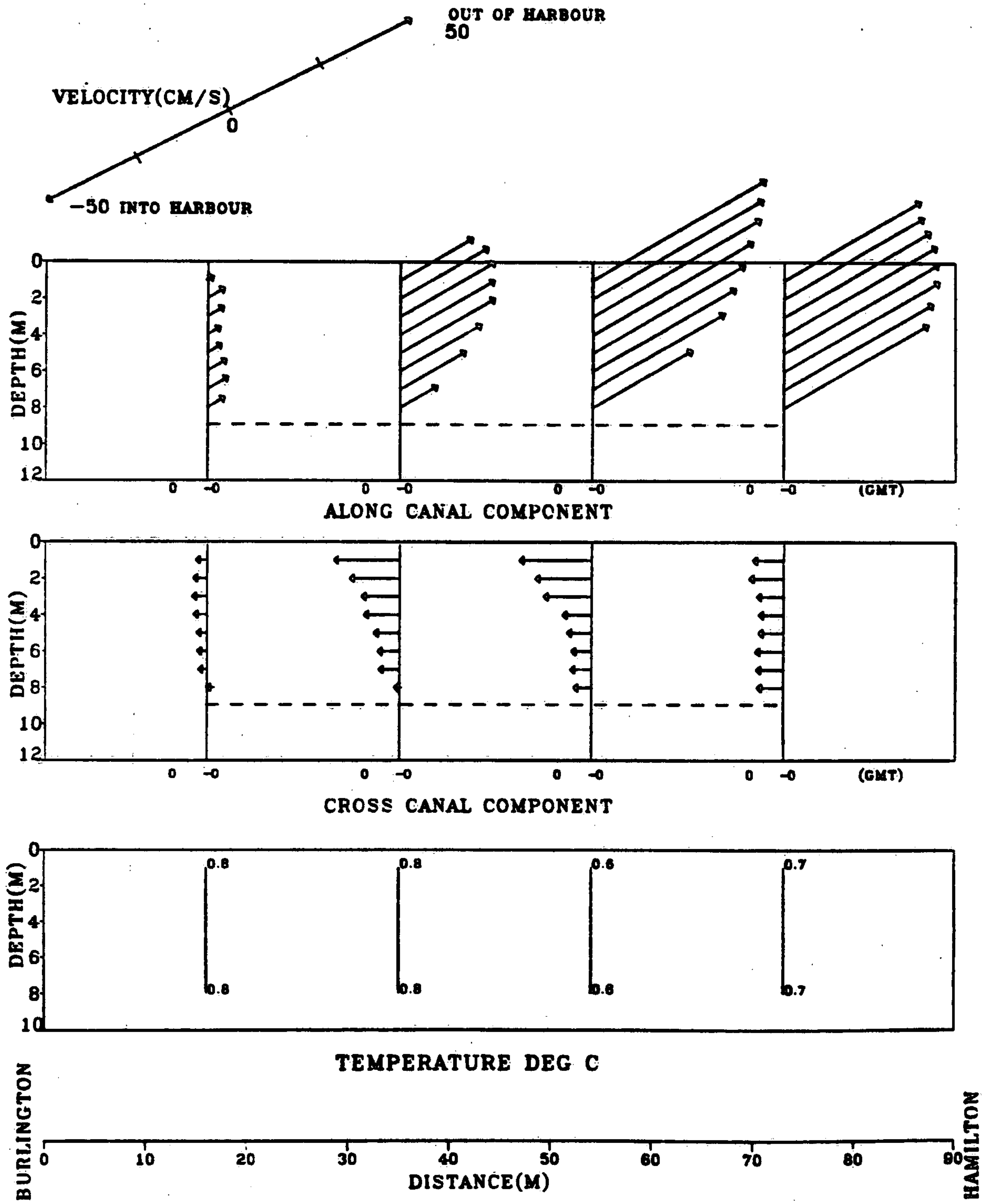
TABLE 1 (cont'd): Profile data and AFFRA measurements at profile times.

				Profile Data		AFFRA Data			Cross-Sectionally
Month	Day	Hour	Minute (GMT)	Flow (cm/s)	Temperature (C)	Flow (cm/s)	Temperature (C)	Percent Return	Averaged Flow (cm/s)
4	5	14	37.0	15.6	5.8	14.4	6.8	55	16.50
4	6	18	21.5	12.1	3.9	12.9	5.7	19	12.10
4	13	13	22.5	10.8	5.1	7.8	6.1	97	9.50
4	18	19	12.5	-17.0	4.5	-11.5	4.7	45	-15.90
4	18	19	26.0	-8.0	4.6	0.2	4.7	67	-7.50
4	18	19	39.5	5.5	4.6	6.6	5.0	37	4.70
4	18	19	56.0	6.5	4.6	7.0	5.4	14	6.10
4	19	16	12.0	17.4	4.9	10.3	6.4	40	16.90
4	19	16	26.0	4.3	5.1	7.6	6.6	49	3.40
4	19	16	38.5	-5.6	5.1	1.6	6.4	37	-6.00
4	19	16	54.0	-7.4	5.0	-7.9	5.9	27	-8.50
4	20	16	39.0	14.2	5.7	11.7	7.8	24	13.00
4	20	16	54.0	6.1	7.0	6.6	7.8	24	5.80
4	20	20	30.5	15.5	4.8	14.0	6.0	20	15.50
4	20	20	44.0	16.7	4.8	13.1	6.4	27	15.70
5	1	13	9.5	15.0	7.5	11.7	8.9	37	14.10
5	7	16	11.5	-34.7	6.9	-19.8	7.1	99	-37.90
5	7	16	45.0	16.9	6.8	3.3	7.2	85	16.00
5	7	17	1.5	31.3	7.0	30.4	8.2	15	37.60
5	7	17	14.0	37.5	7.9	31.8	8.8	16	36.80

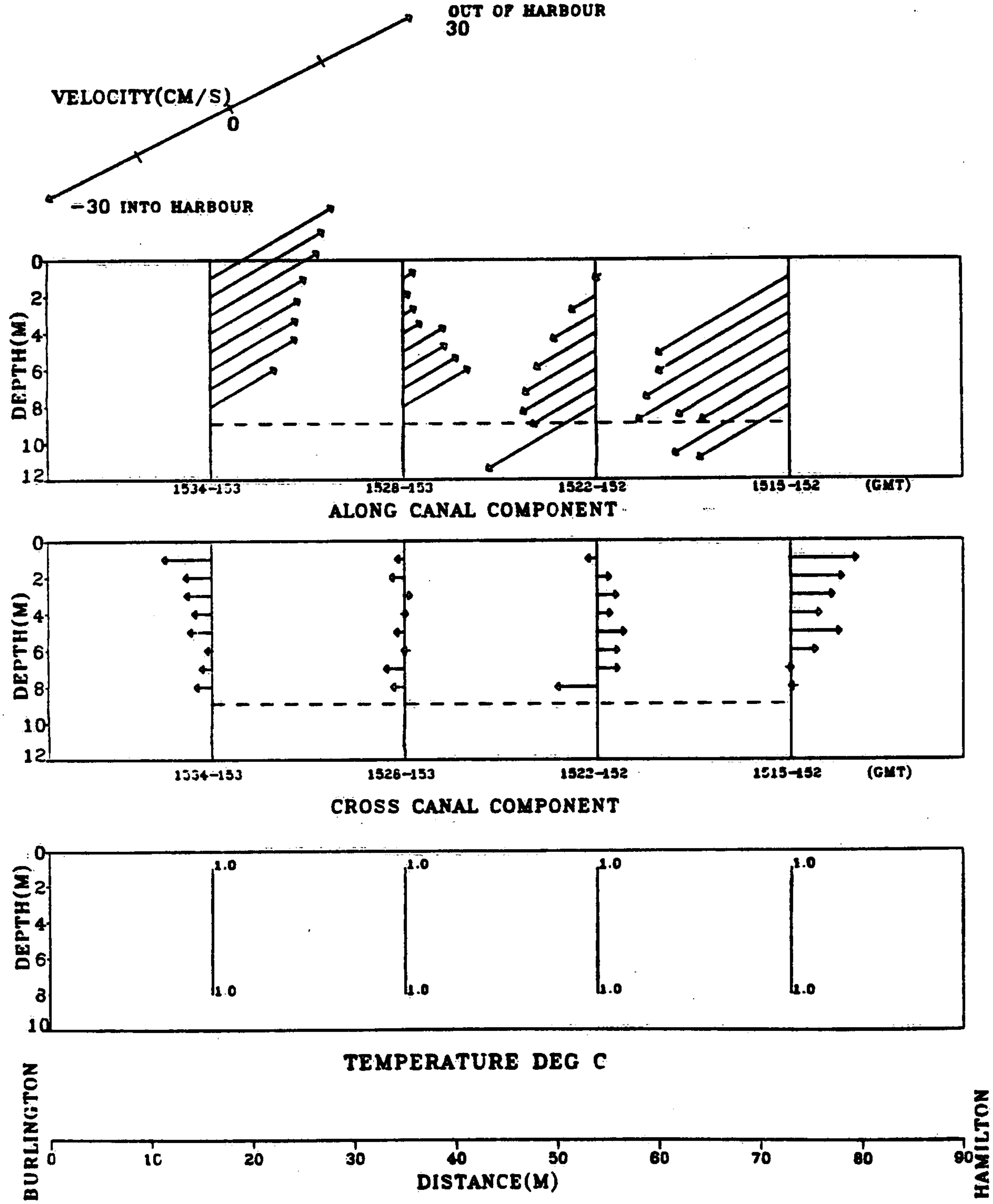
APPENDIX I

Profile Current and Temperatures Observed at
the Lift Bridge of the Burlington Ship Canal
January 10 to May 7, 1989.

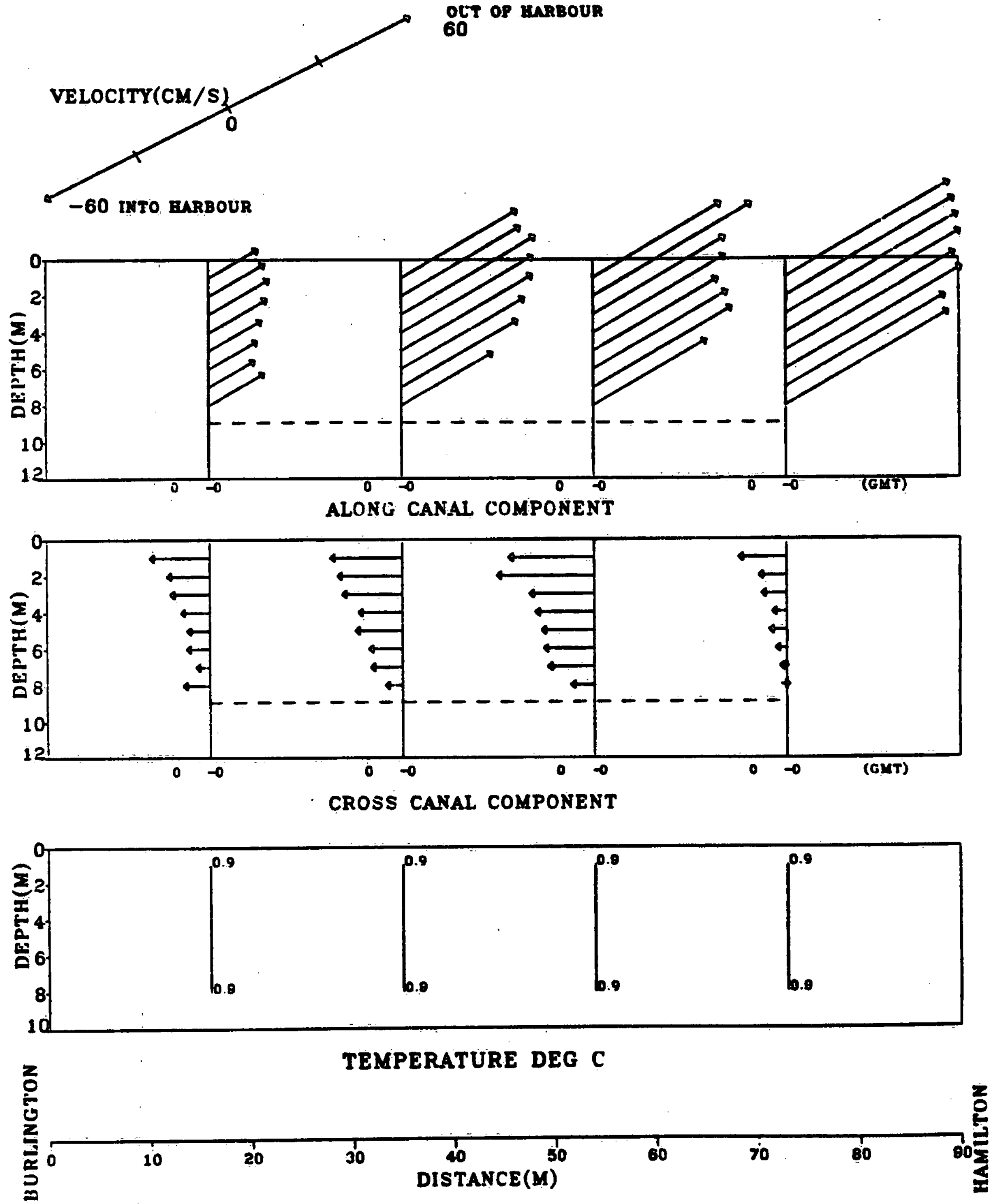
ACOUSTIC CM PROFILE BURLINGTON SHIP CANAL JANUARY 1



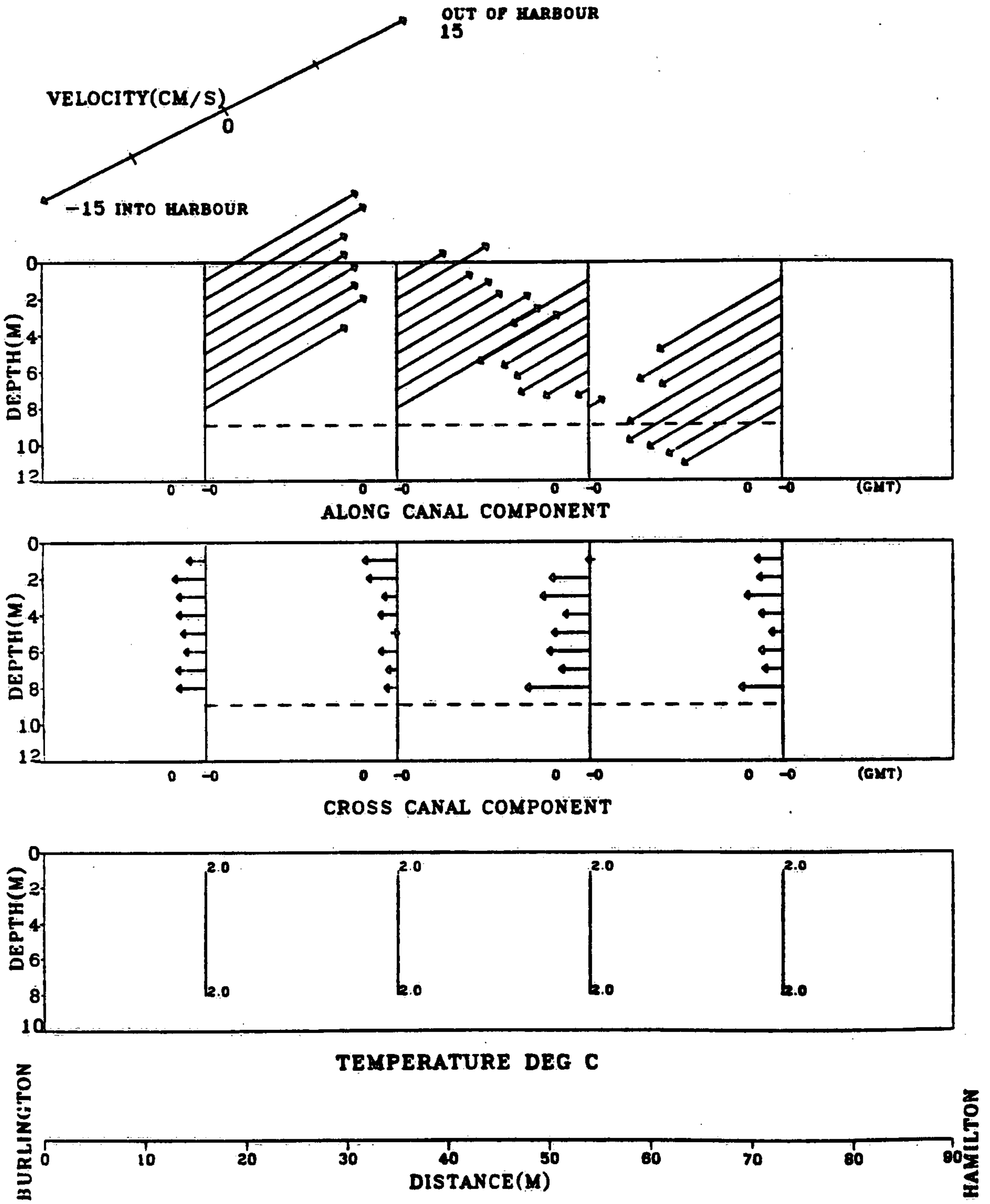
ACOUSTIC CM PROFILE BURLINGTON SHIP CANAL JANUARY 12 1989



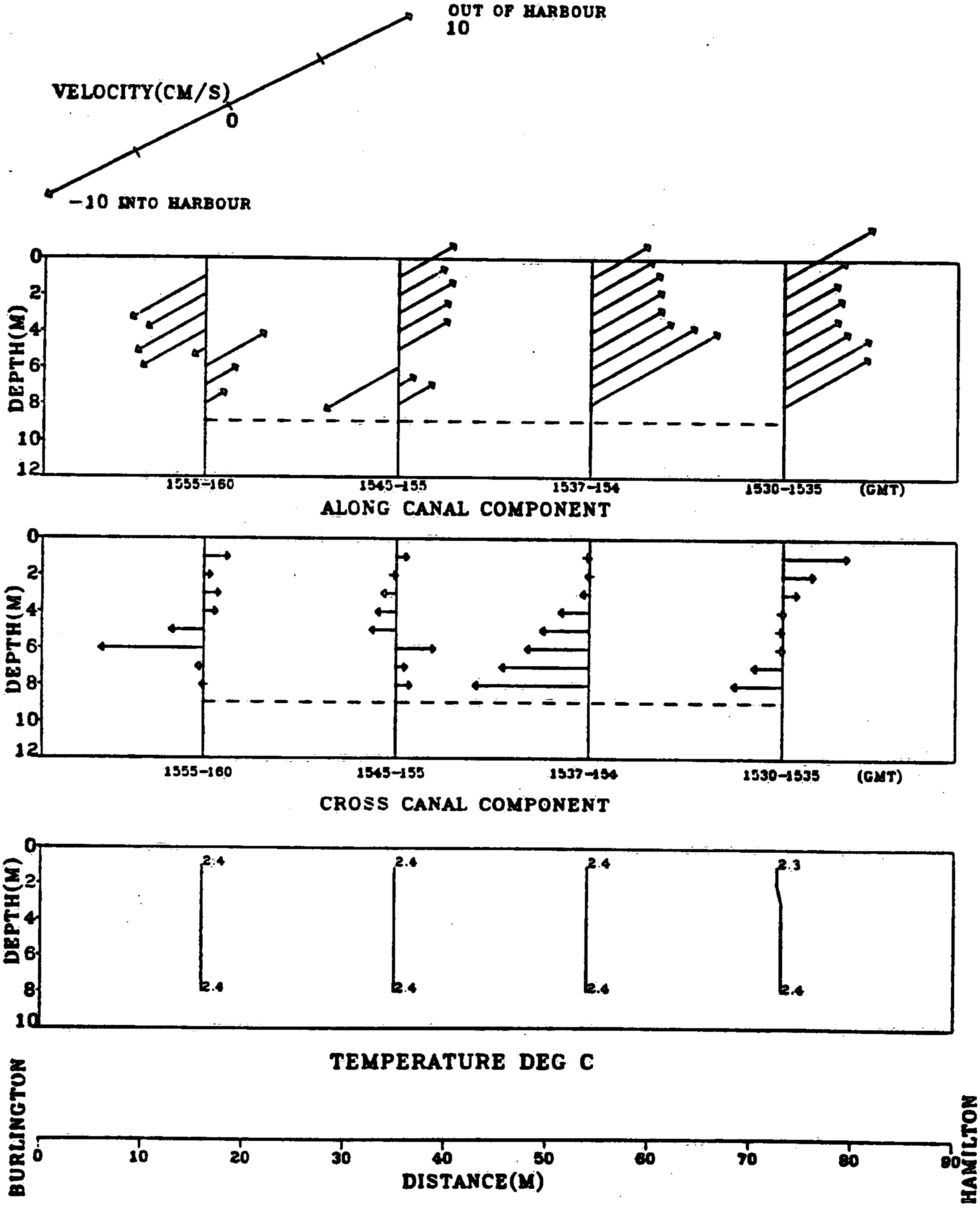
ACOUSTIC CM PROFILE BURLINGTON SHIP CANAL JANUARY 16



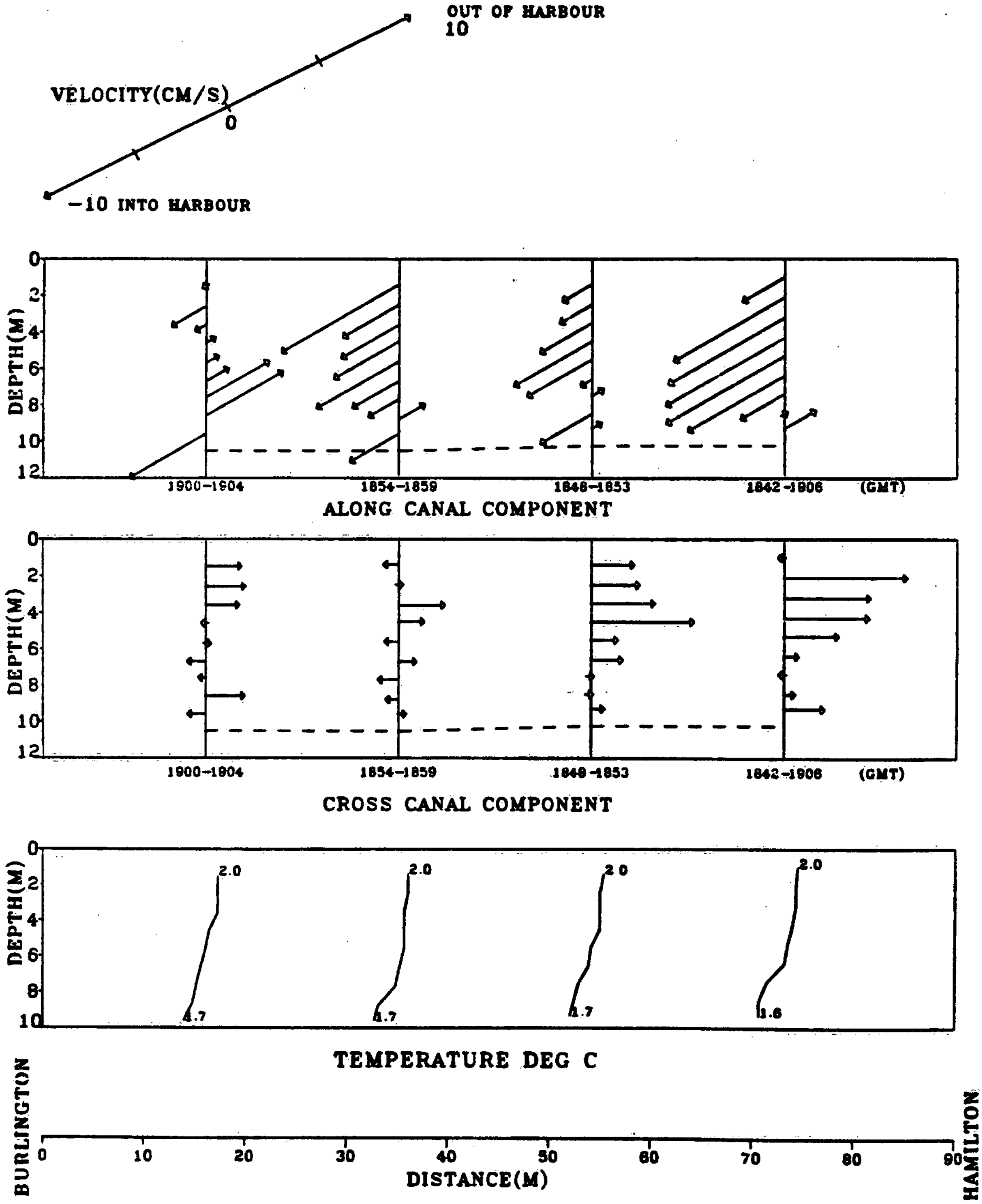
ACOUSTIC CM PROFILE BURLINGTON SHIP CANAL JANUARY 18



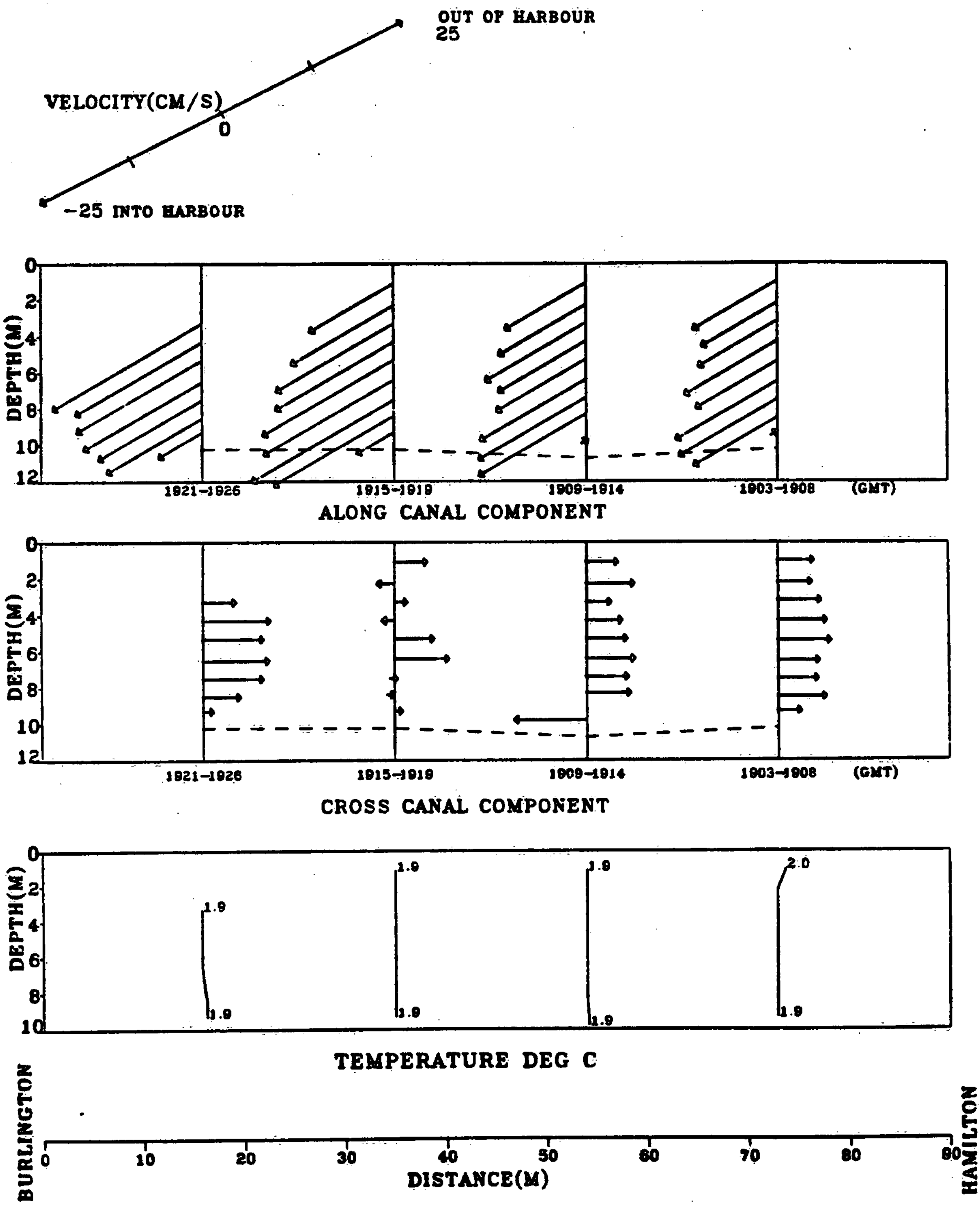
ACOUSTIC CM PROFILE BURLINGTON SHIP CANAL JANUARY 25, 1989



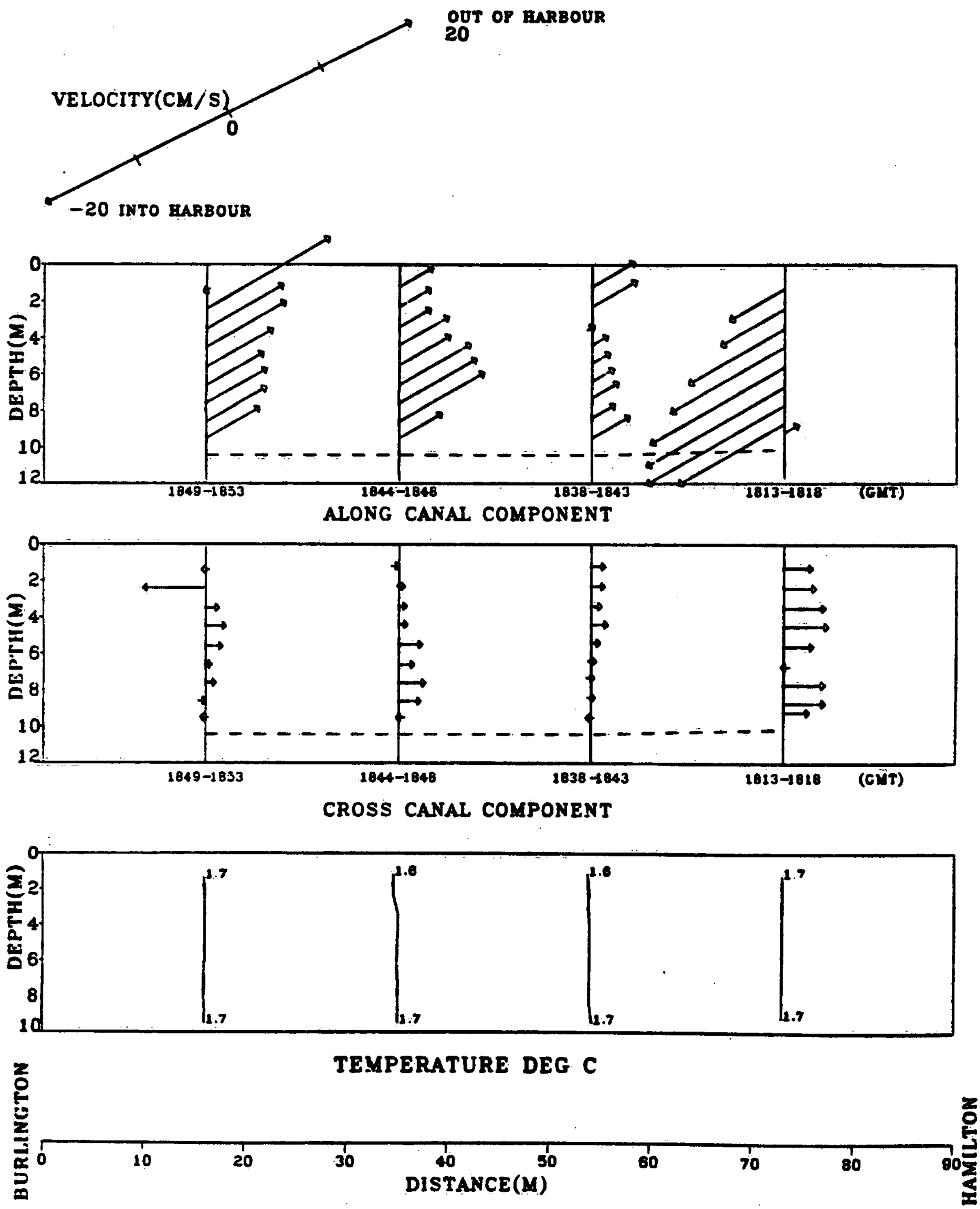
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL FEB 20 1989



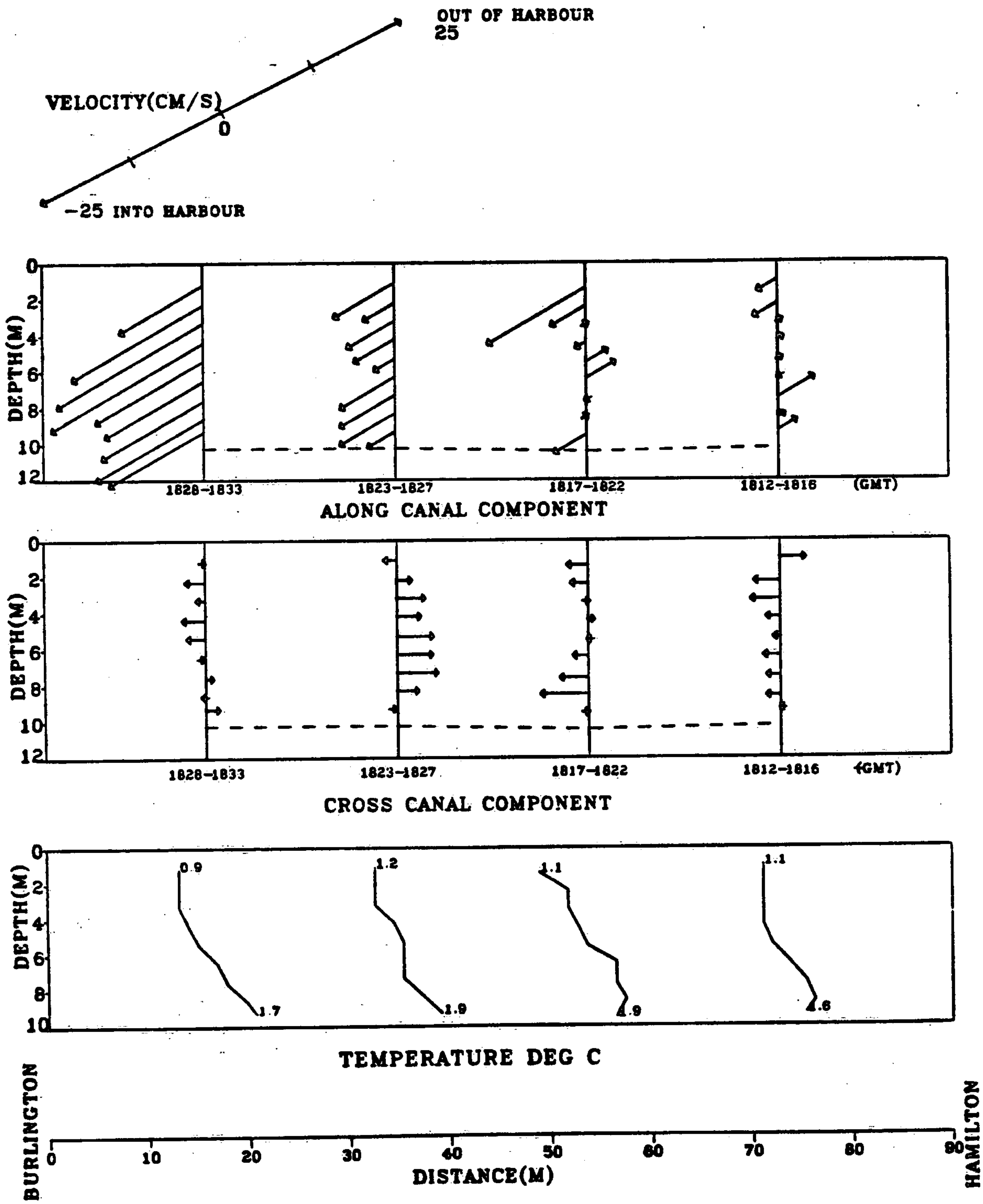
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL FEB 21 198



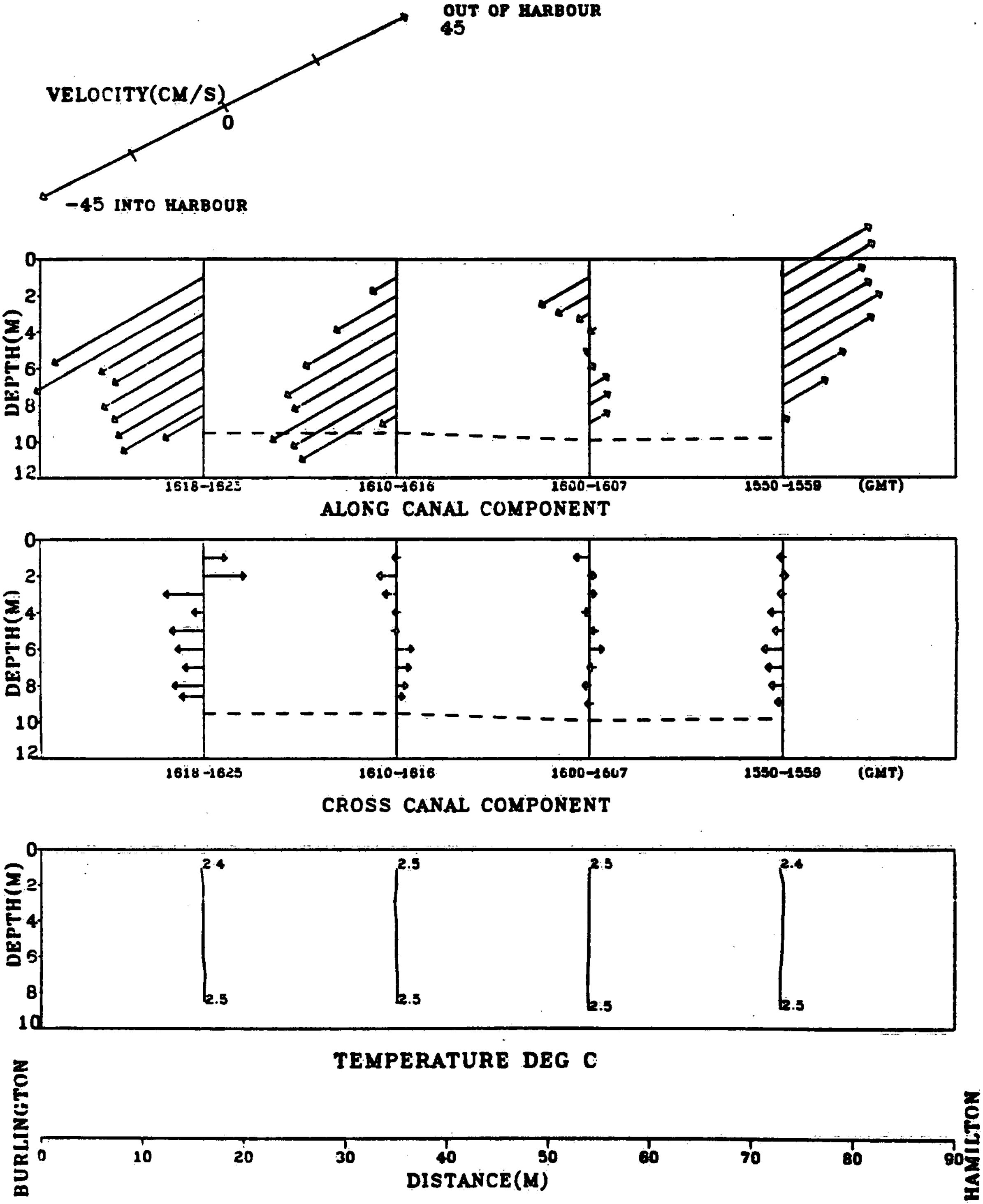
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 02 1989



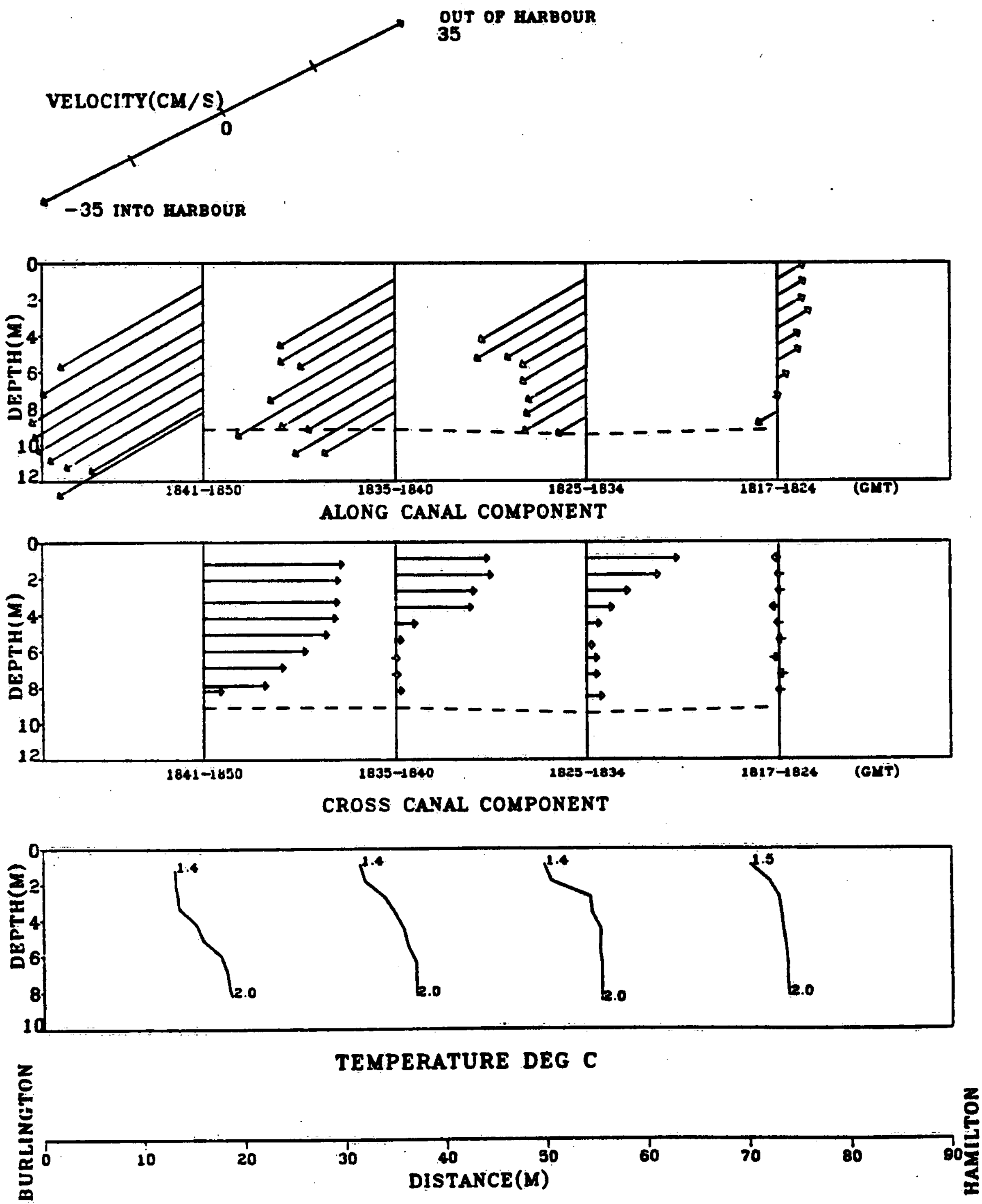
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 3 1989



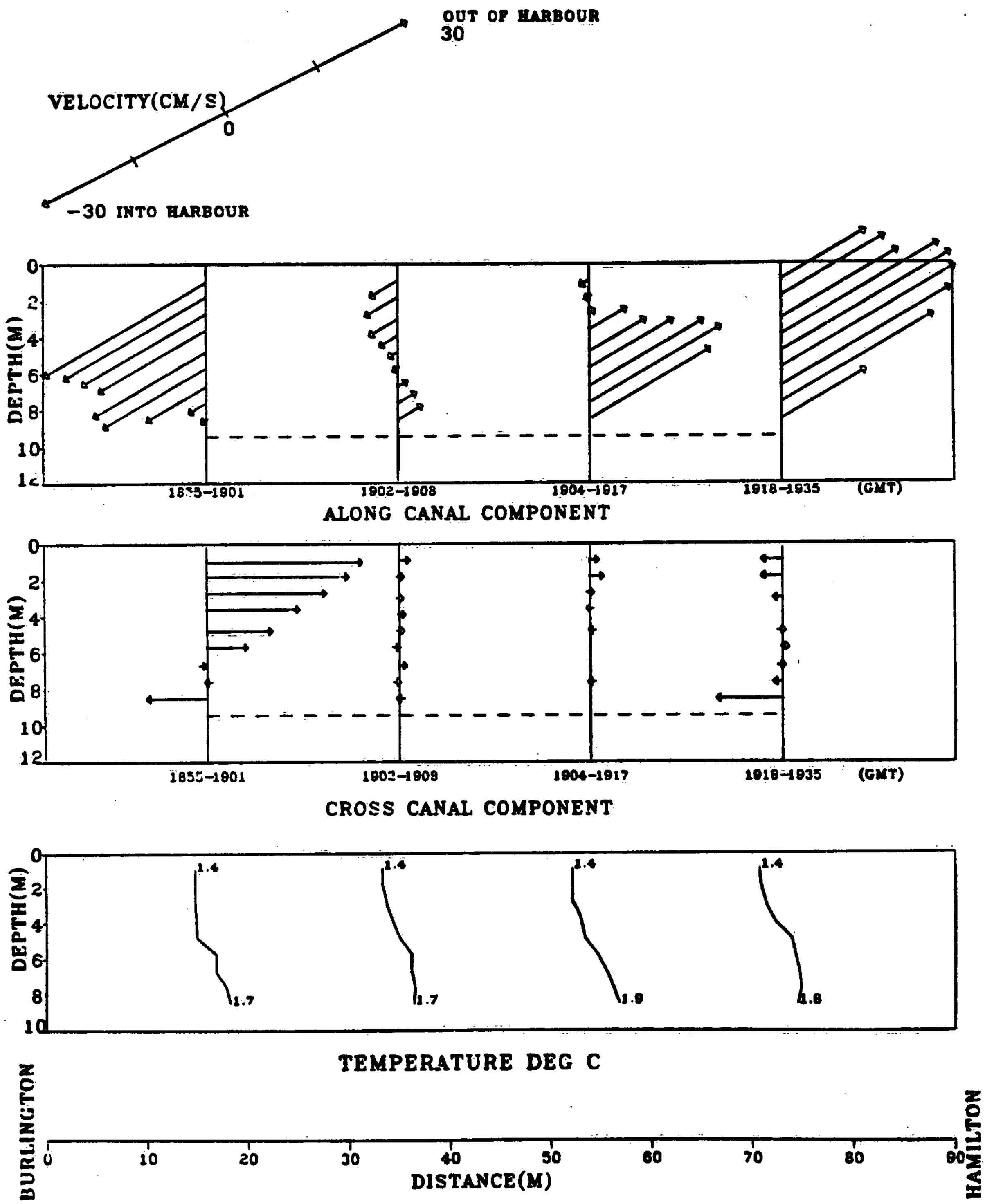
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 15 1989



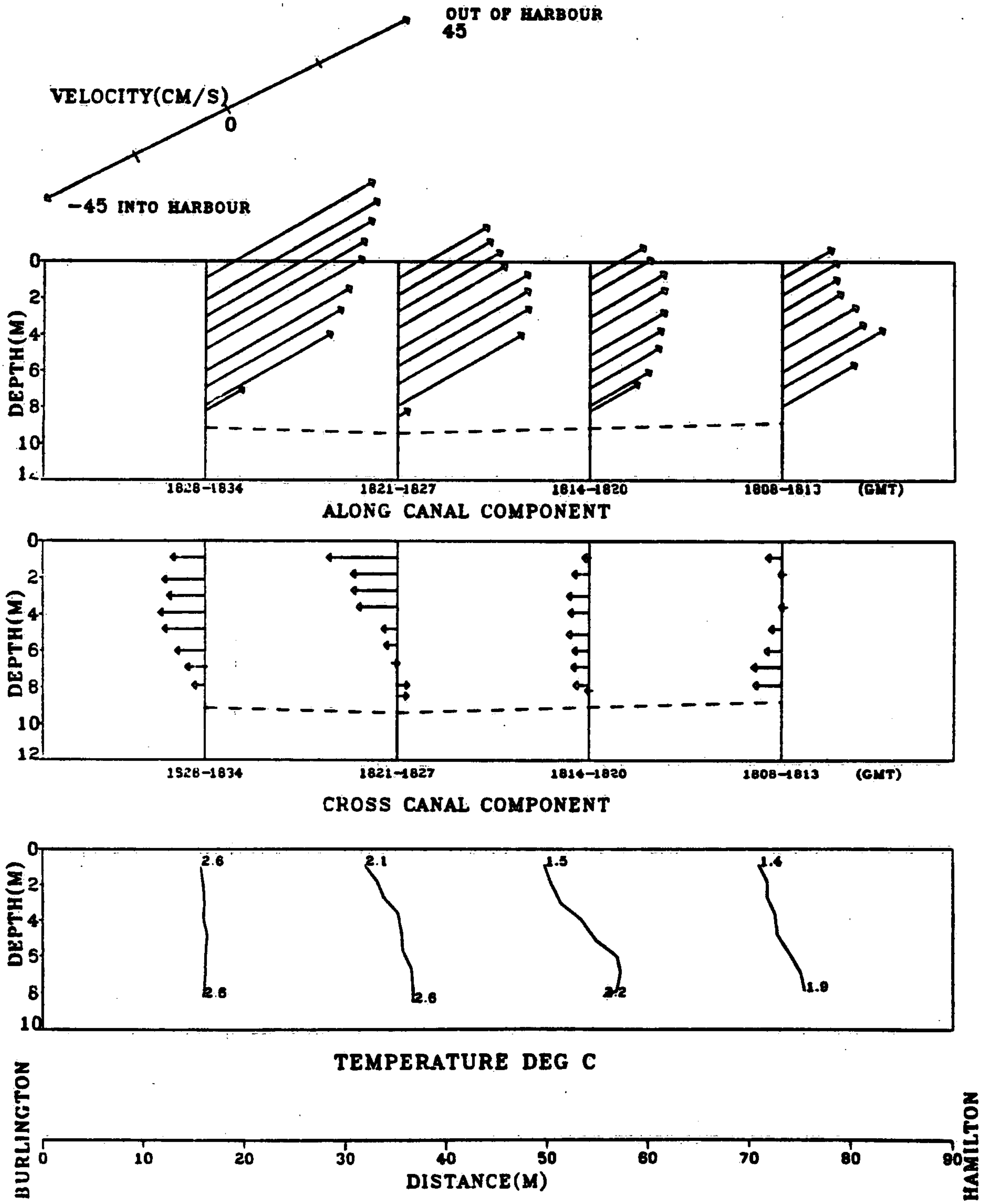
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 20 198



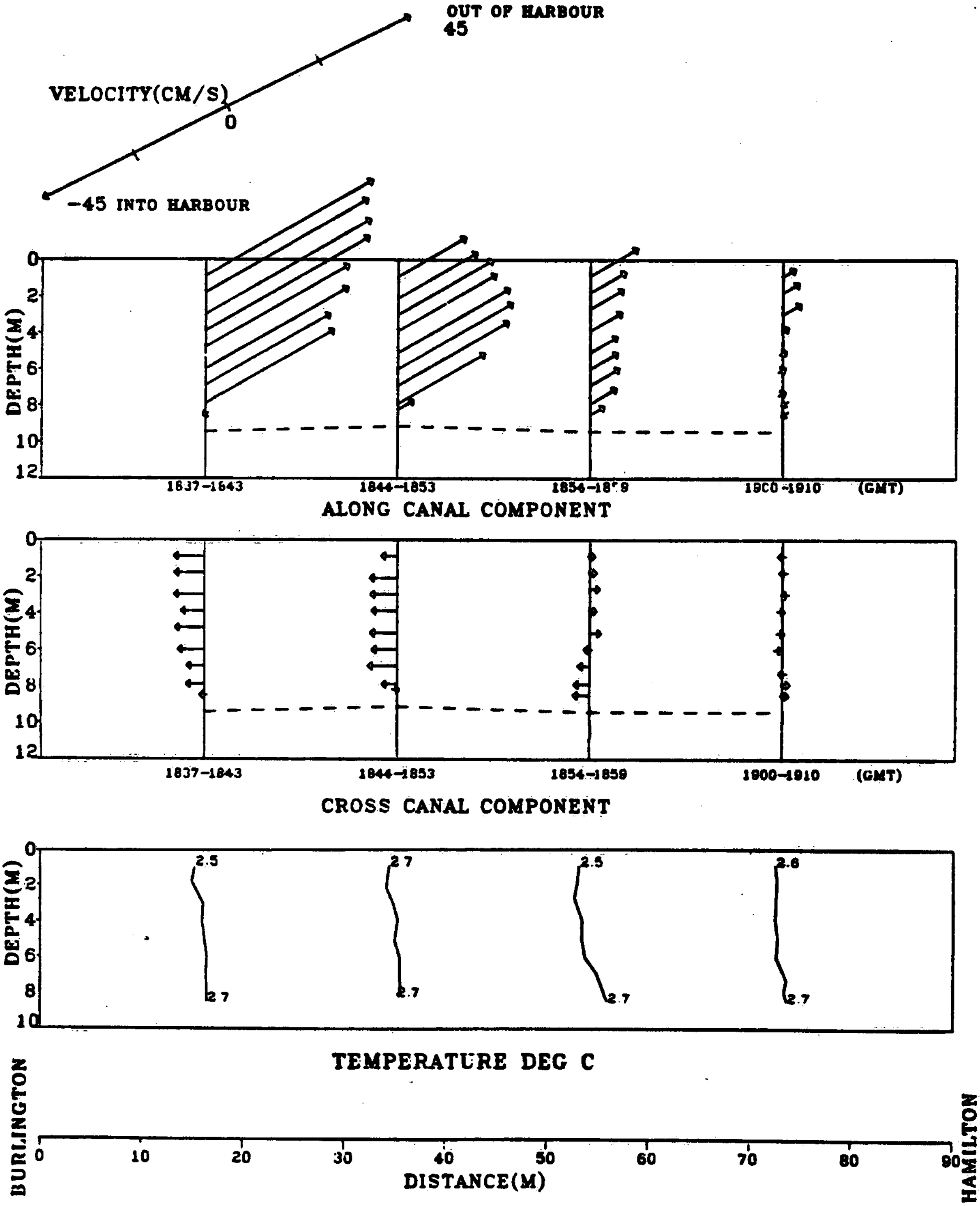
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 20 1989



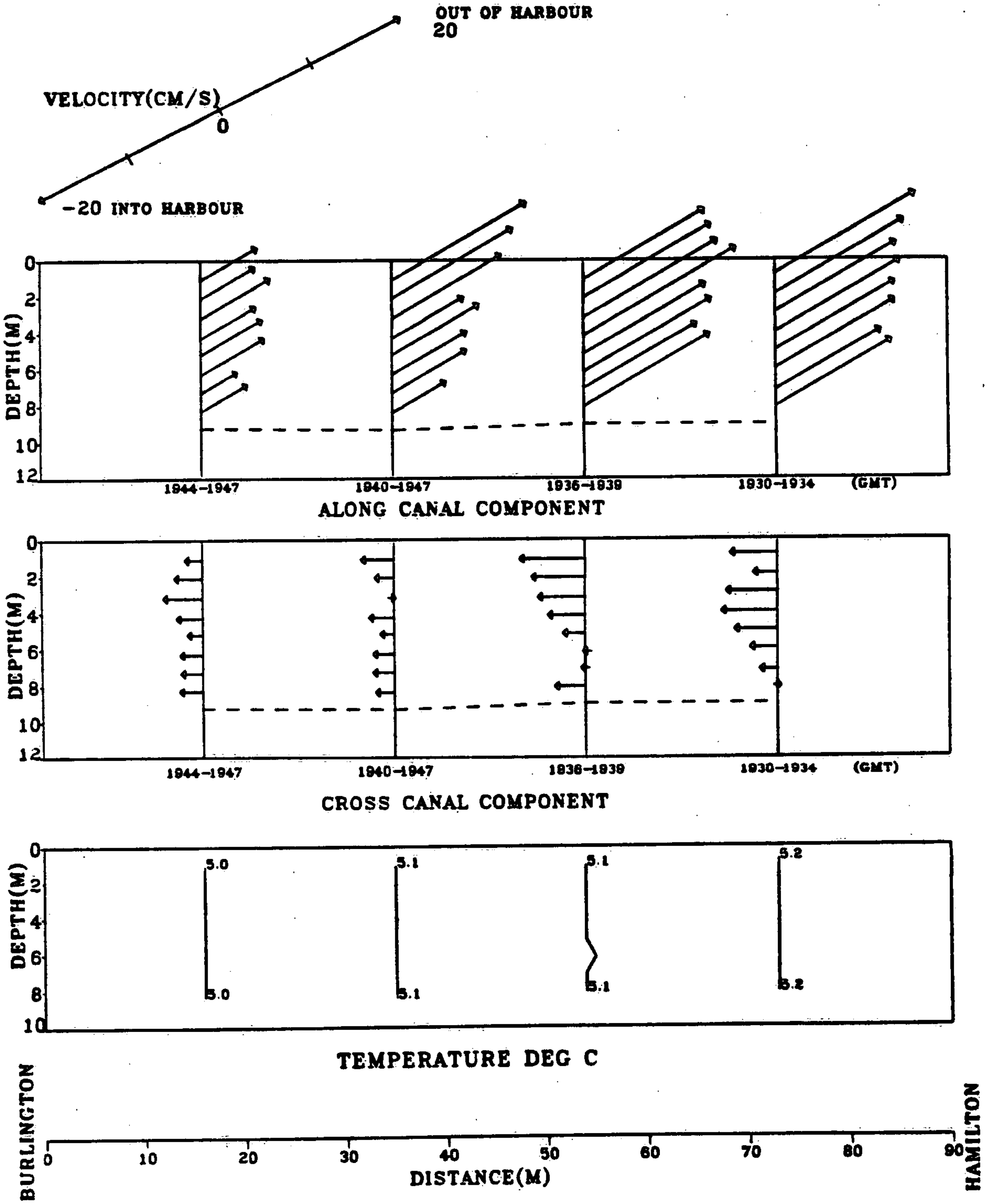
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 21 1989



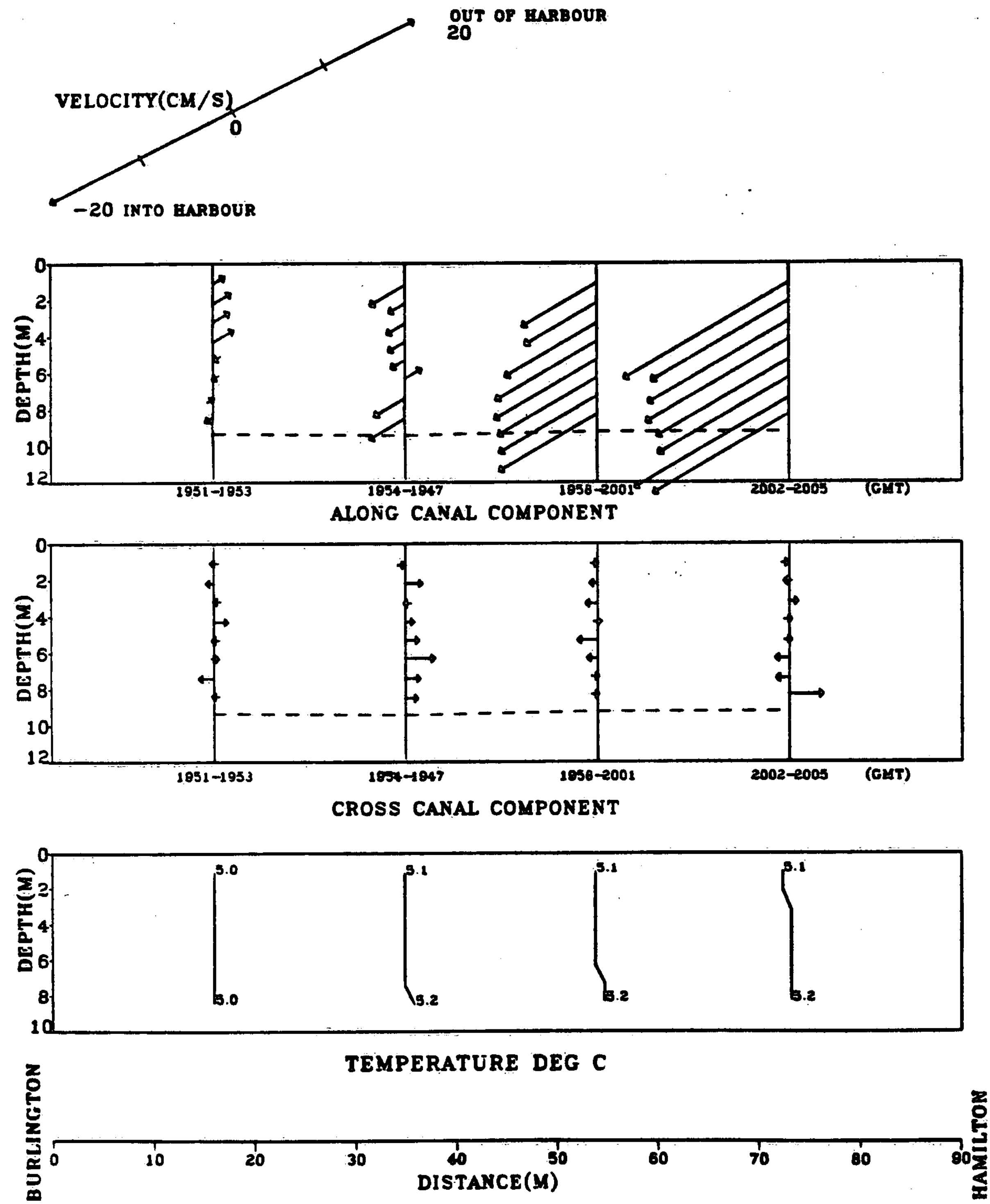
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 21 1989



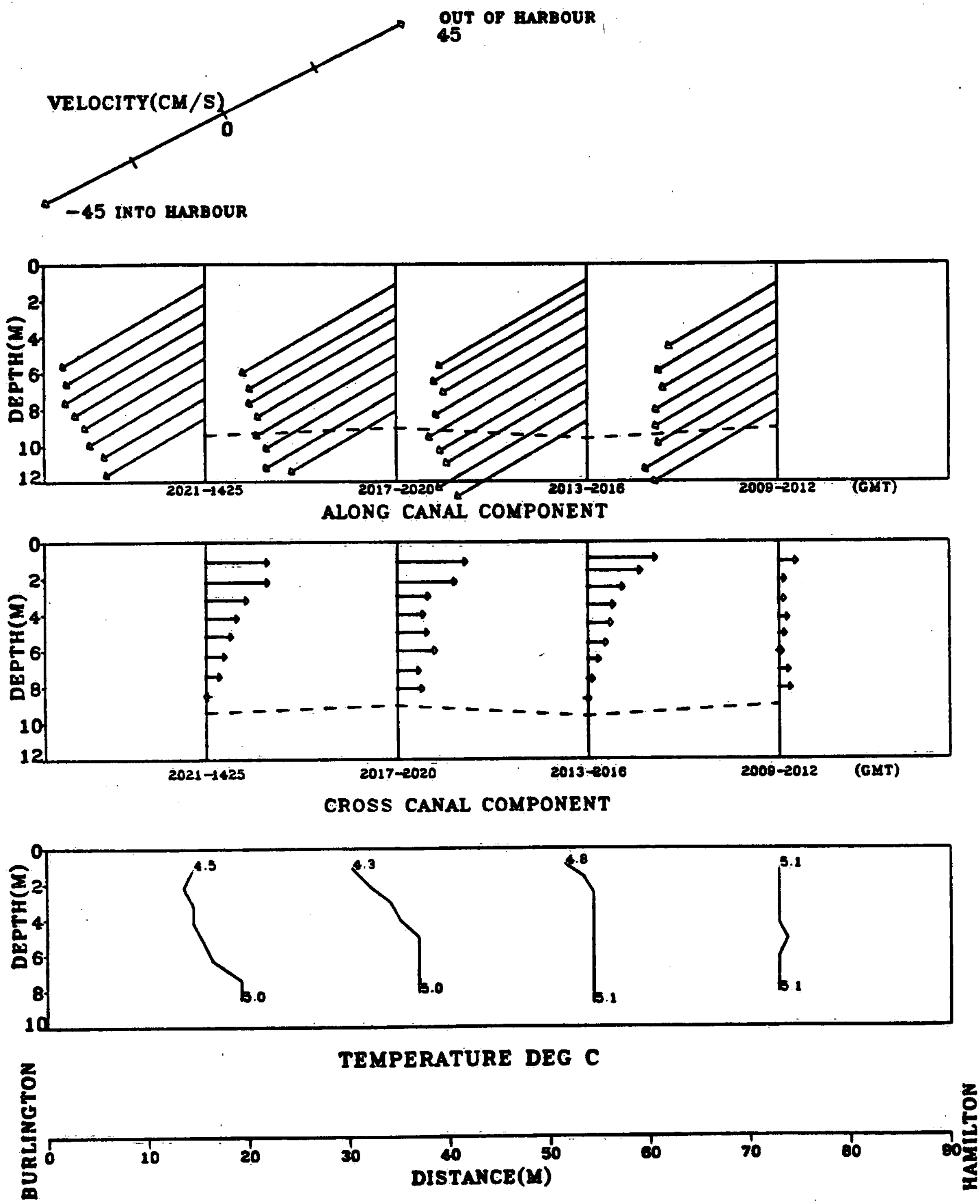
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 29 1989



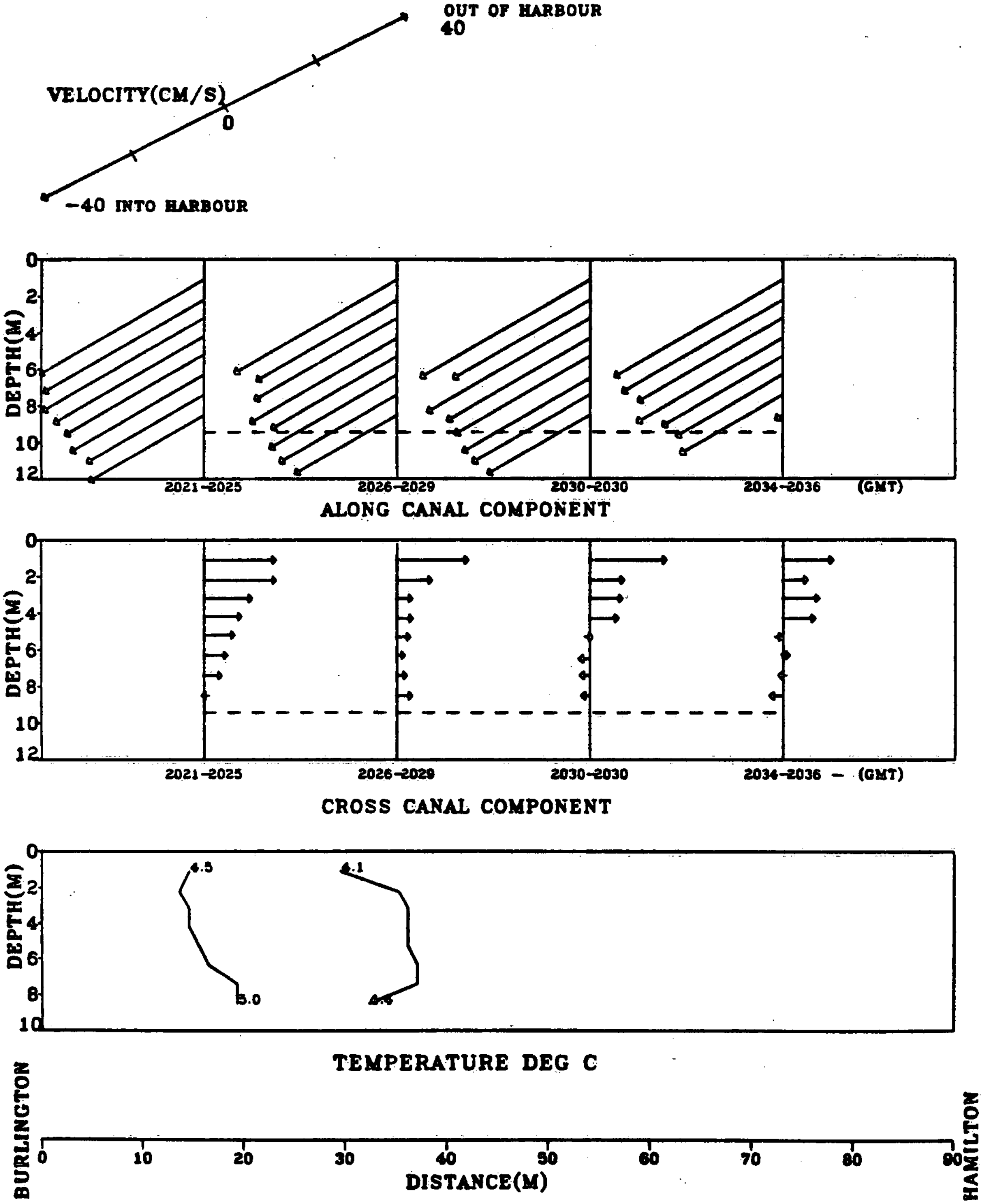
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 29 1989



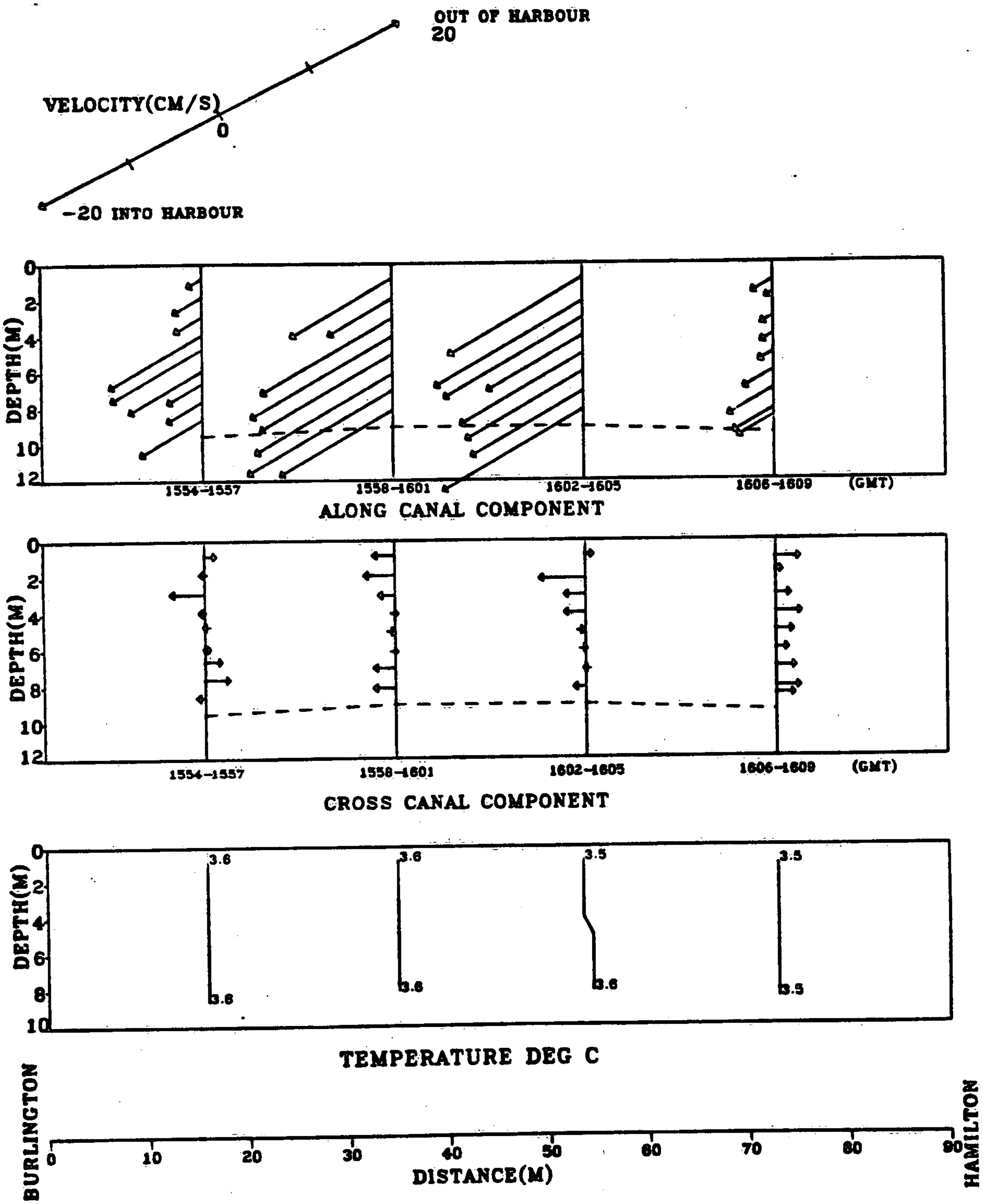
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 29 1989



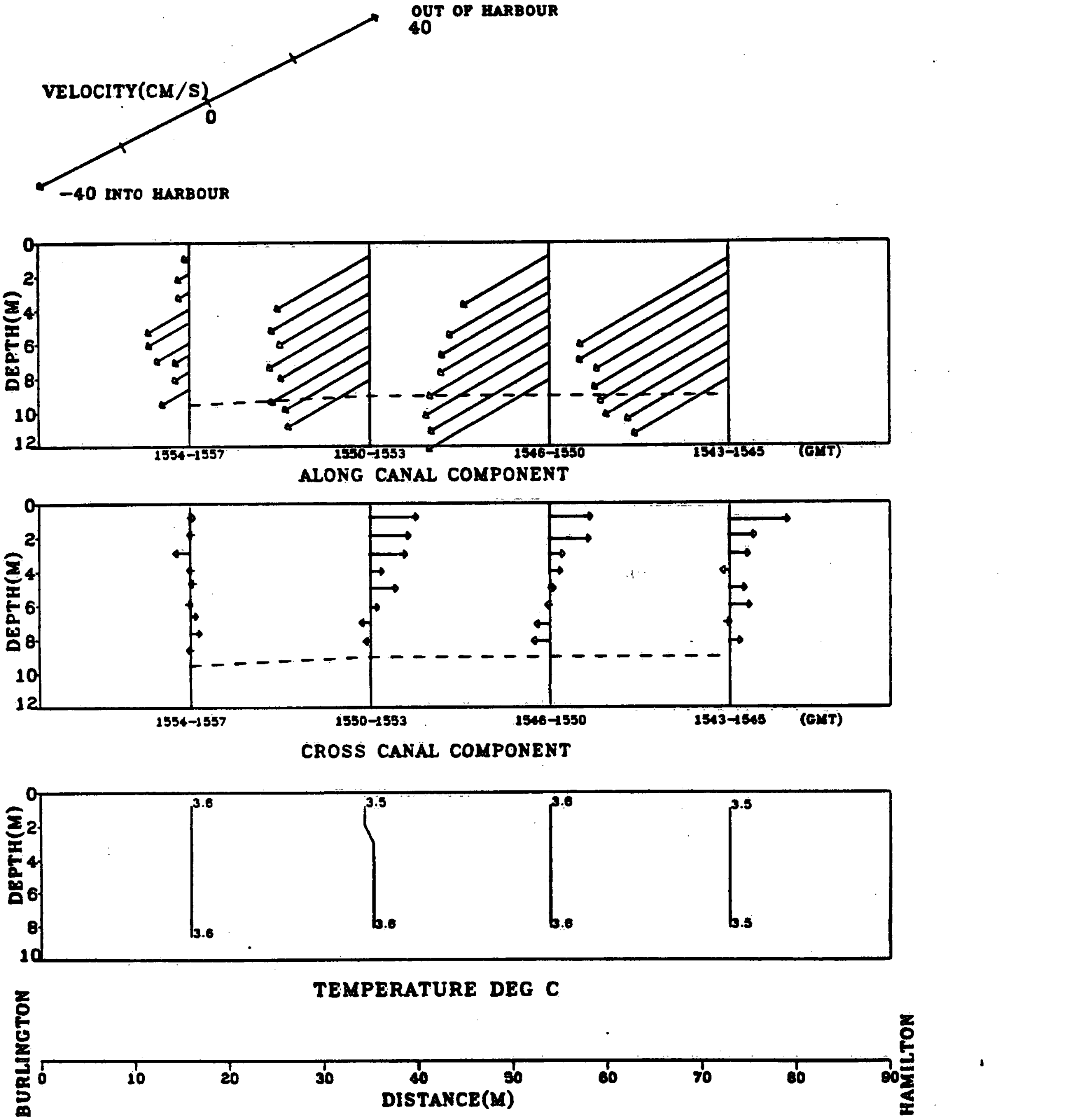
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 29 1989



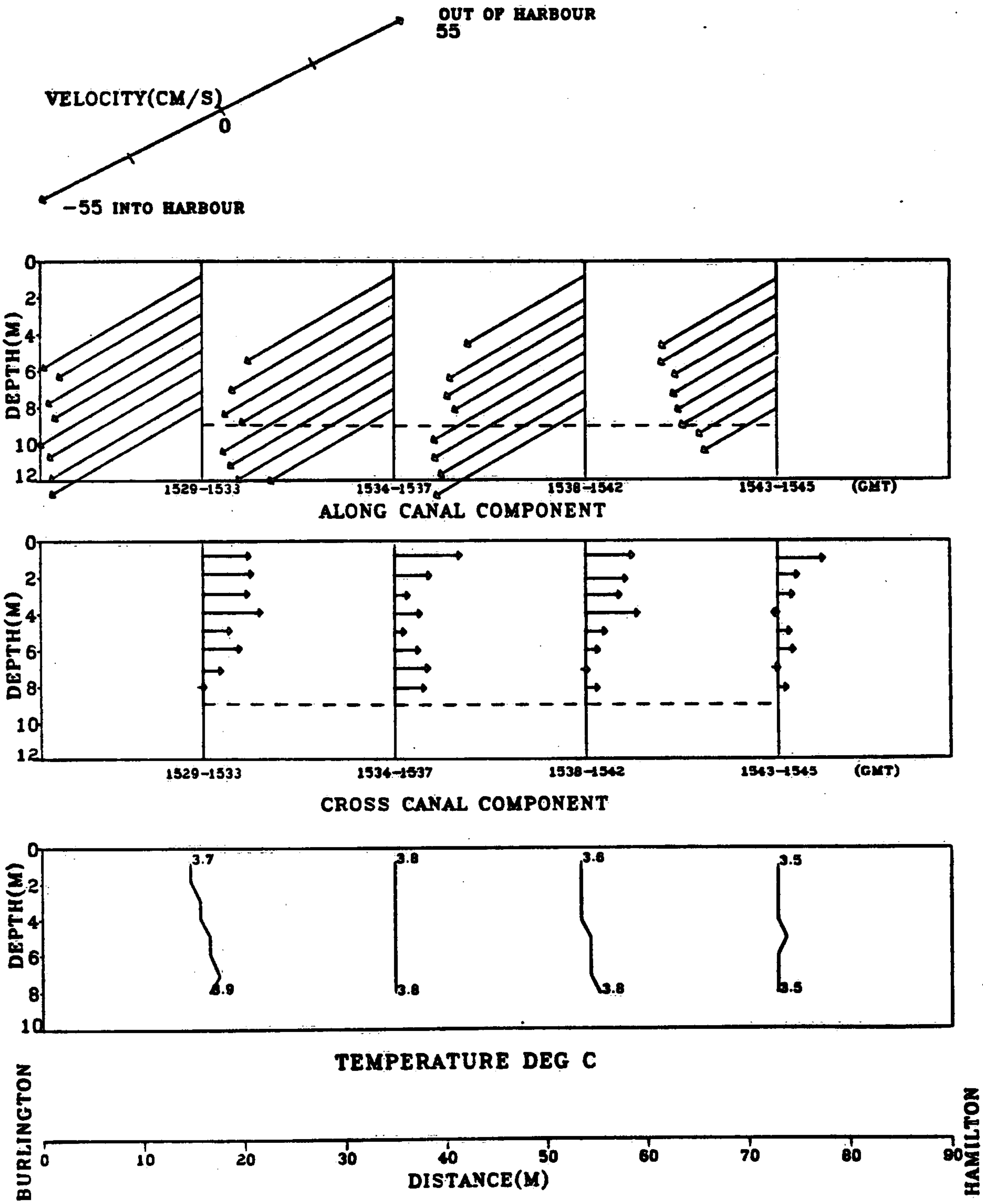
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 31 1989



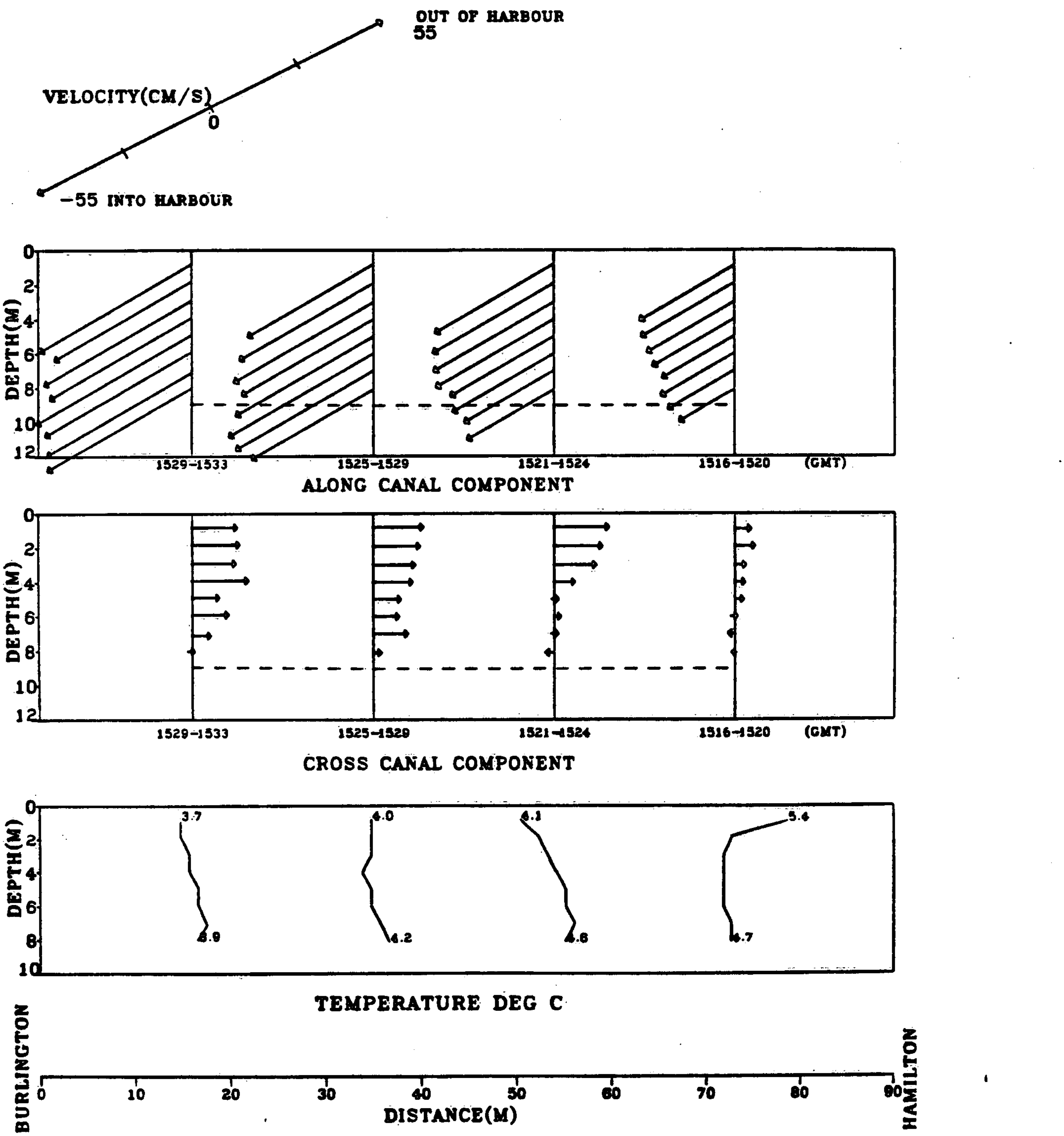
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 31 1989



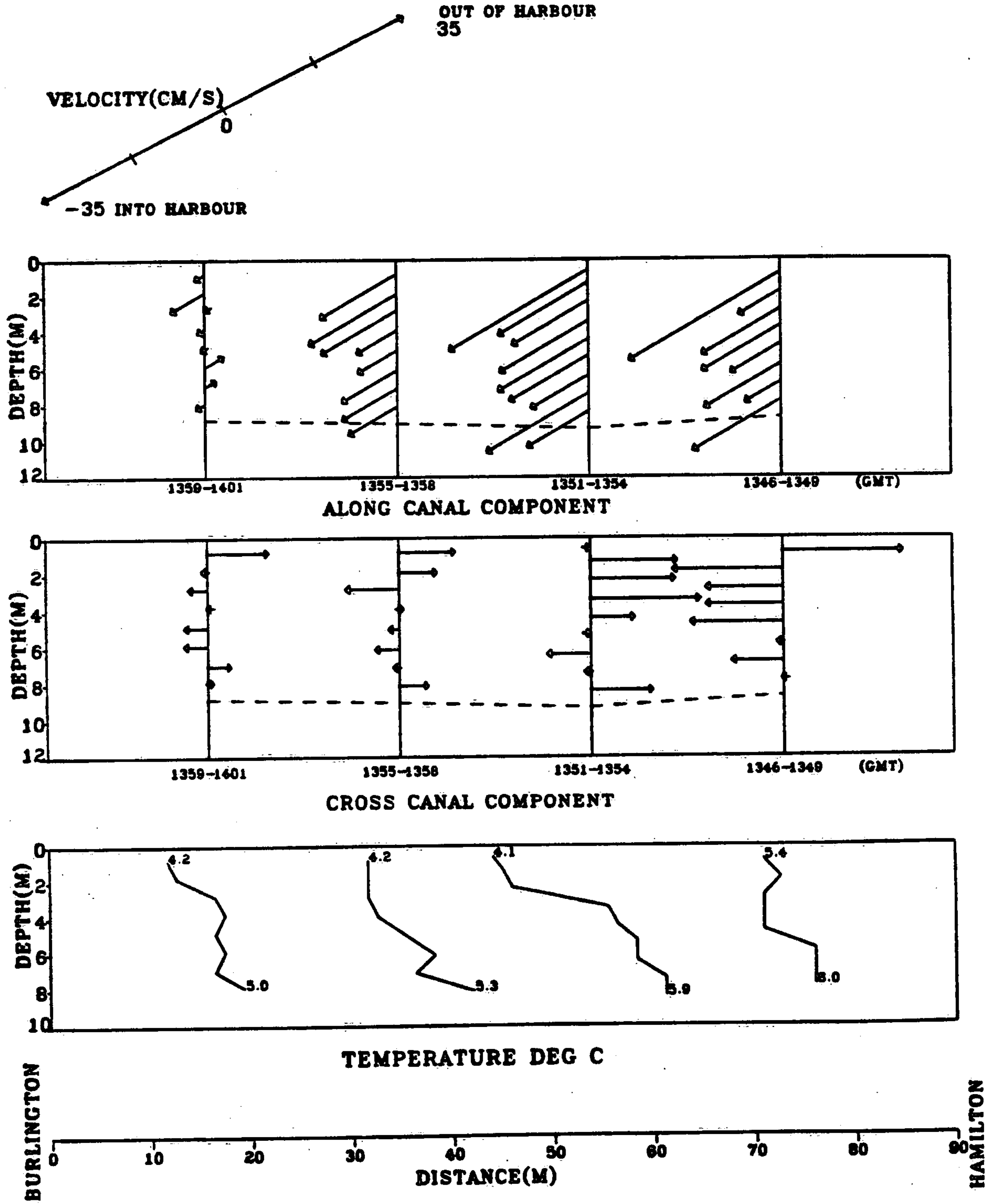
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 31 1989

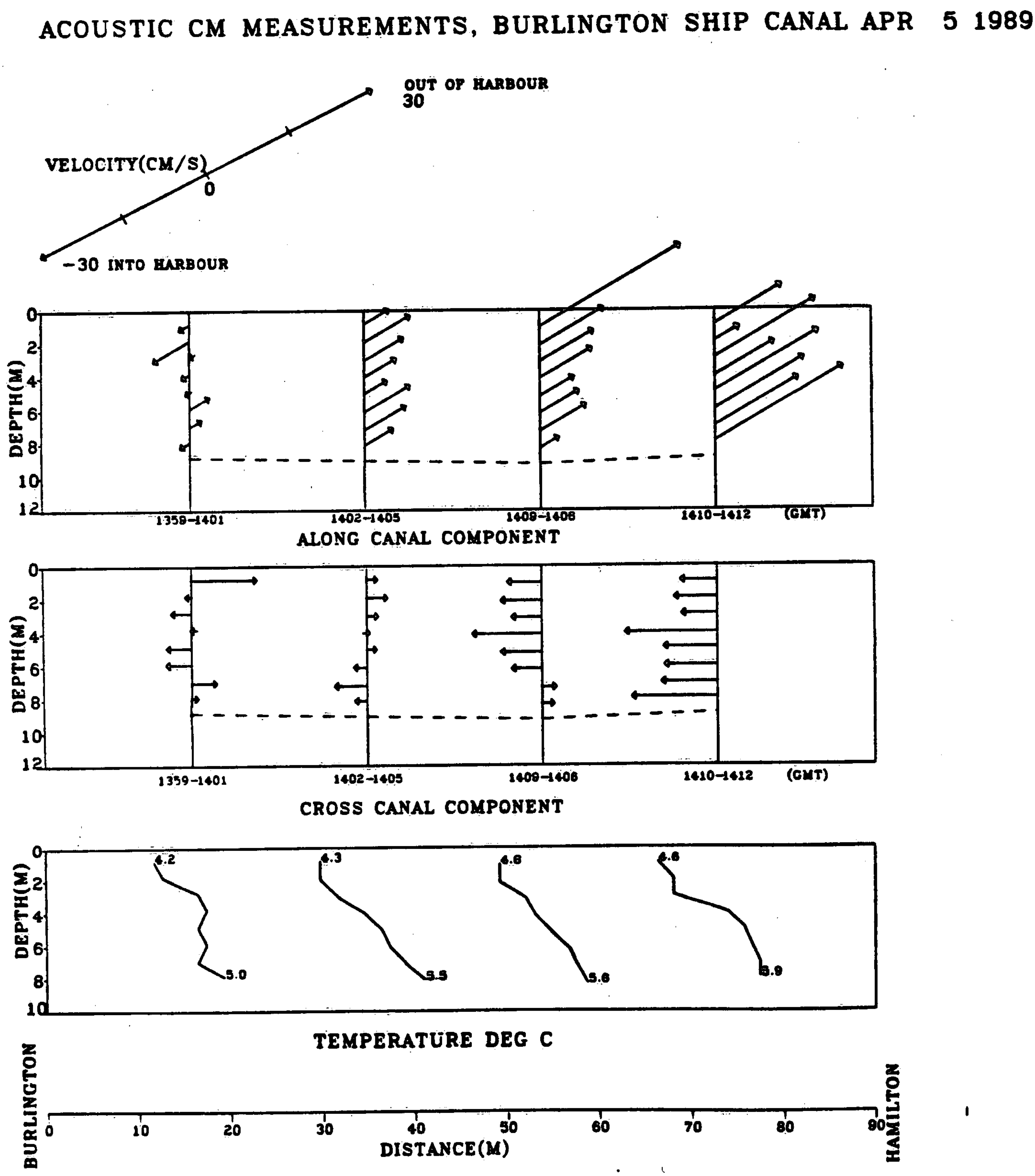


ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAR 31 1989

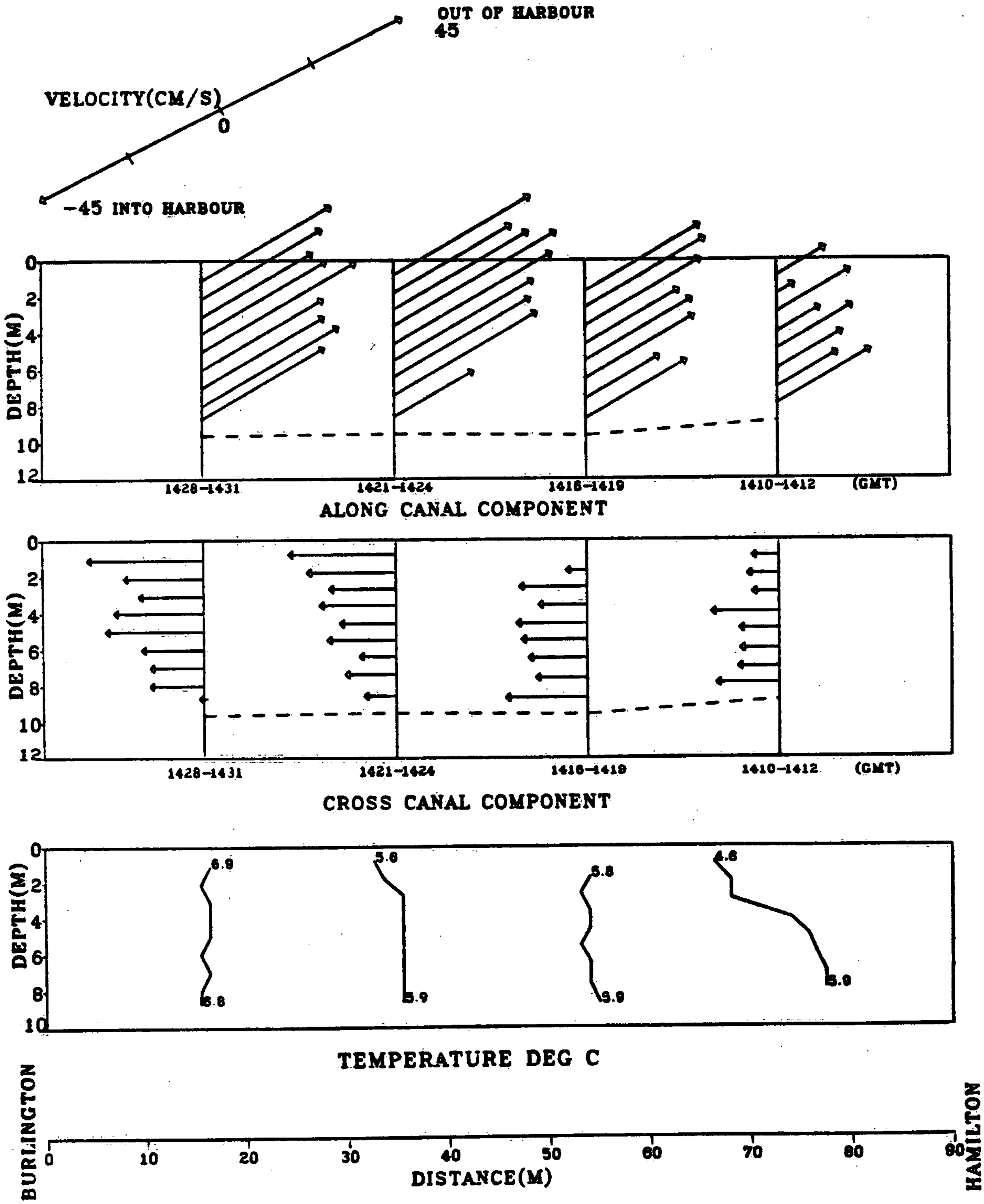


ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 5 1989

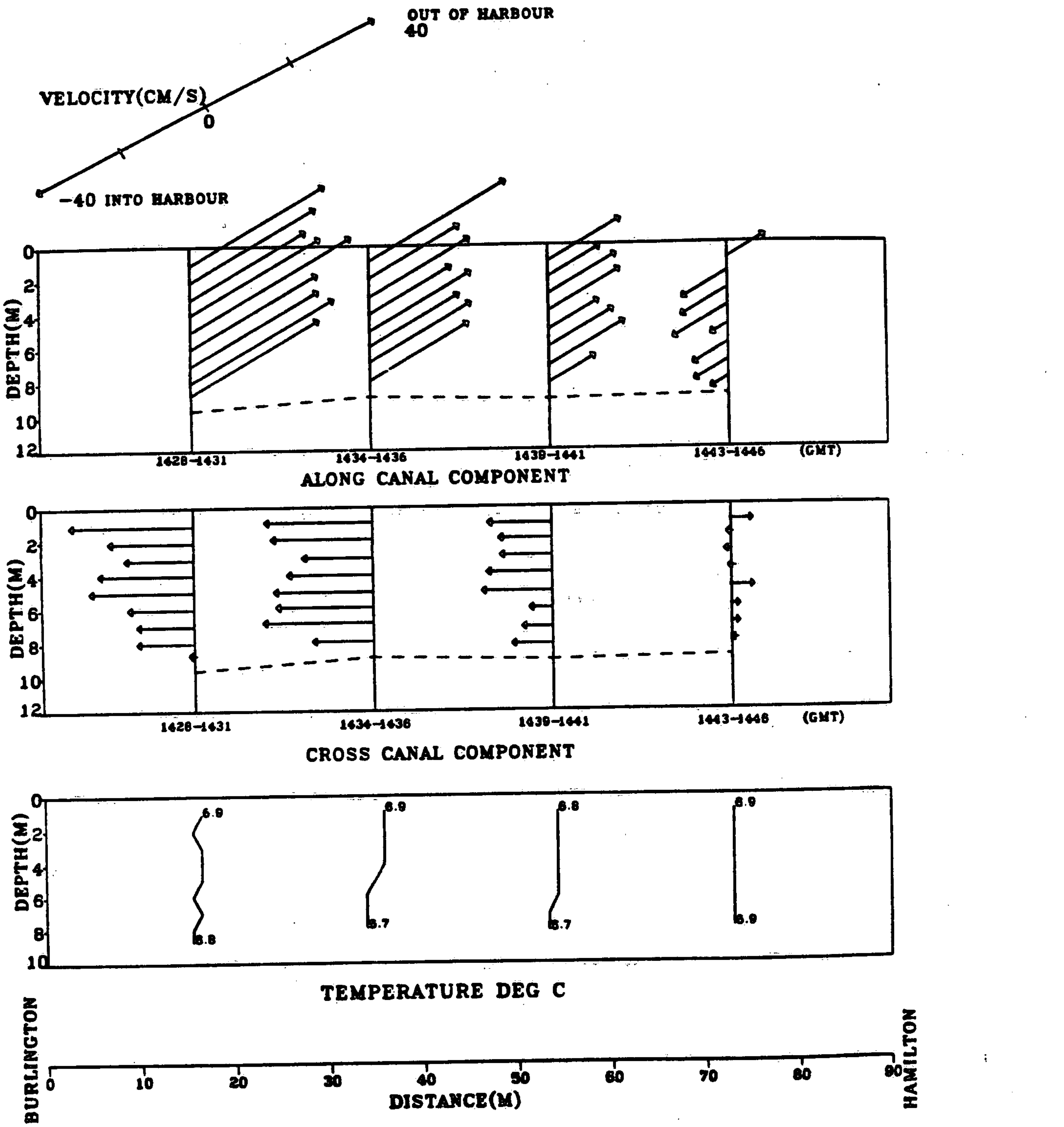



ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 5 1989
OUT OF HARBOUR
30
VELOCITY(CM/S)
0
-30 INTO HARBOUR
DEPTH(M)
1359-1401
1402-1405
1409-1406
1410-1412
(GMT)
ALONG CANAL COMPONENT
CROSS CANAL COMPONENT
4.2
5.0
4.3
5.5
4.6
5.6
5.9
TEMPERATURE DEG C
BURLINGTON
HAMILTON
DISTANCE(M)

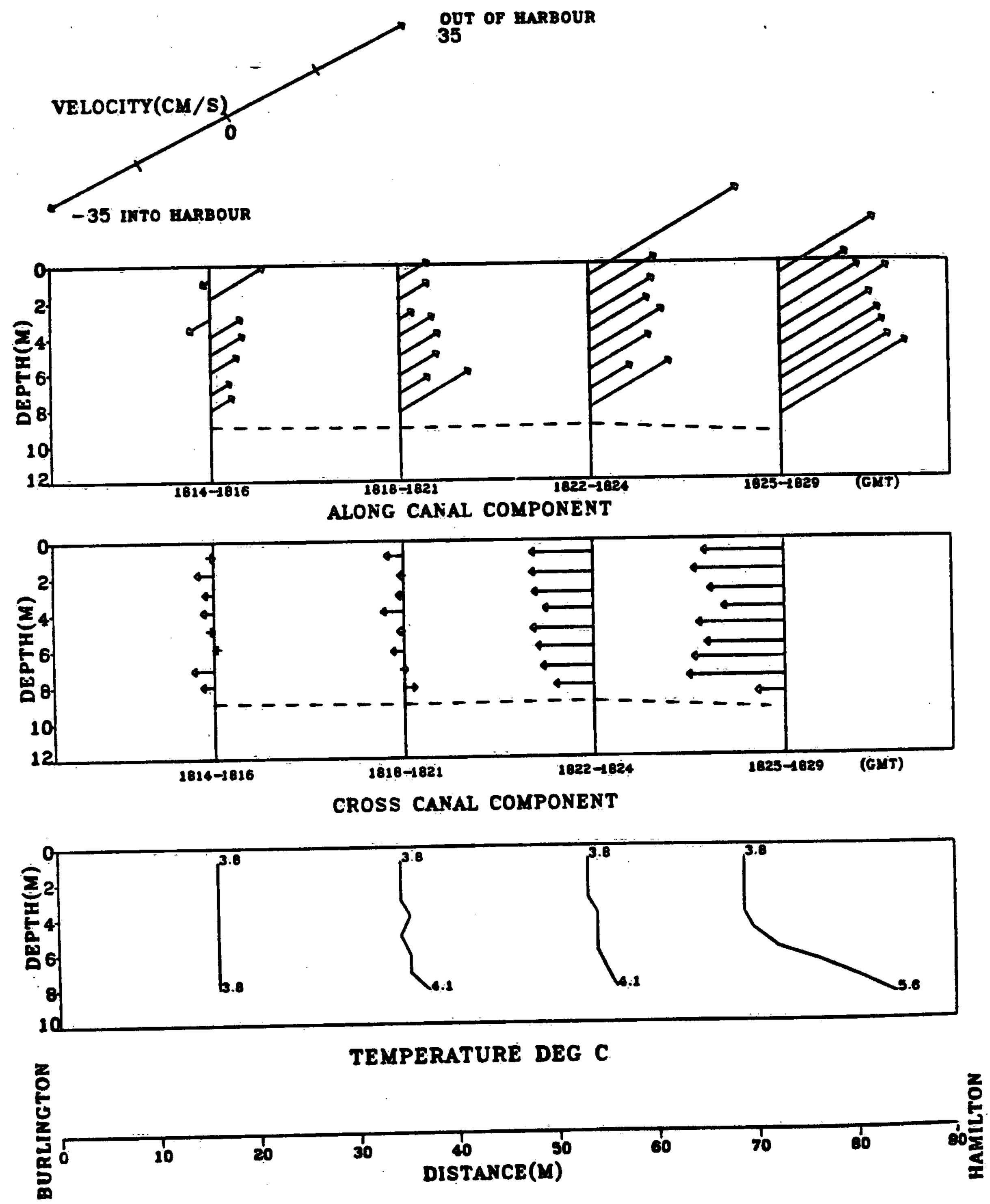
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 5 1989



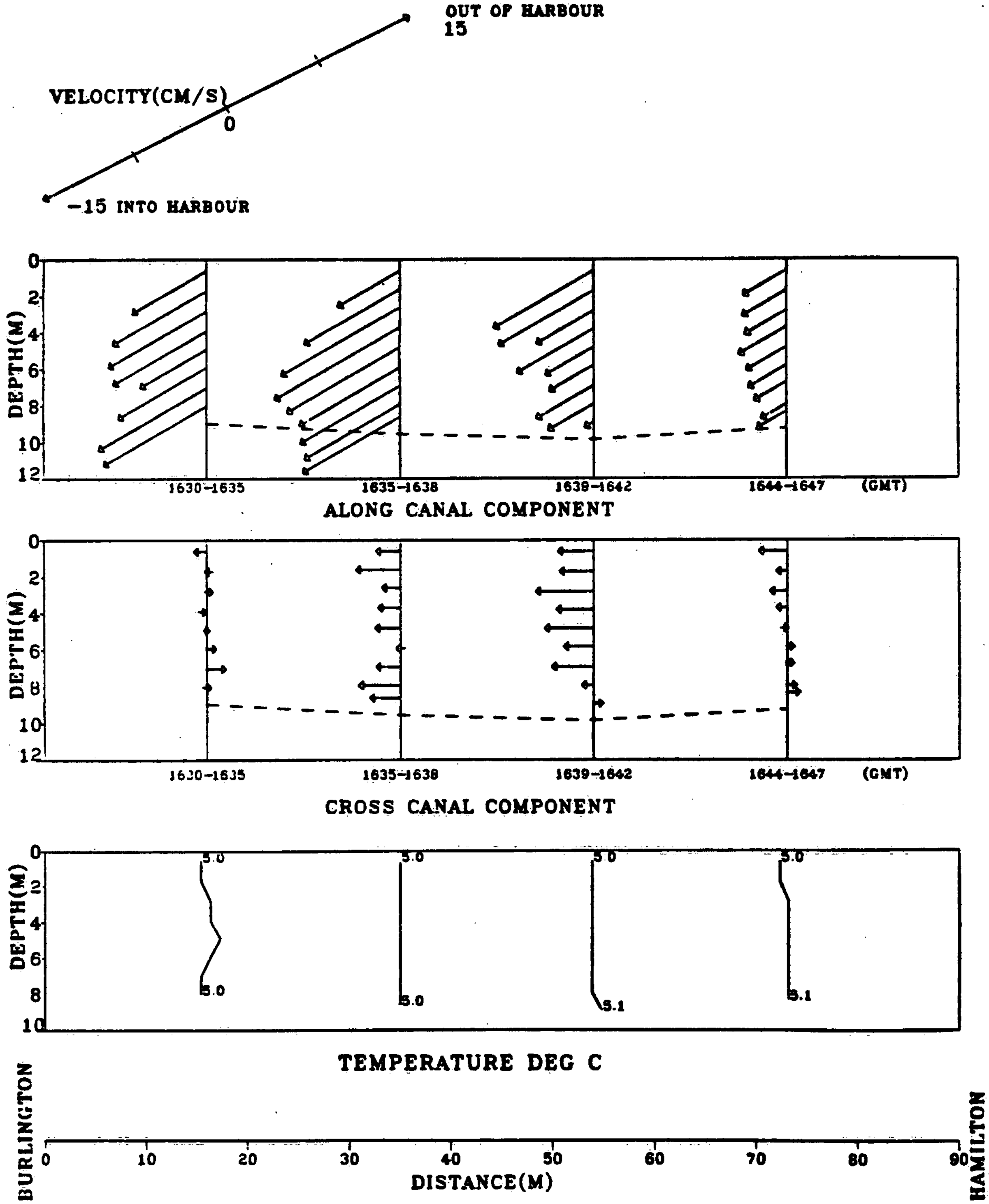
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 5 1989



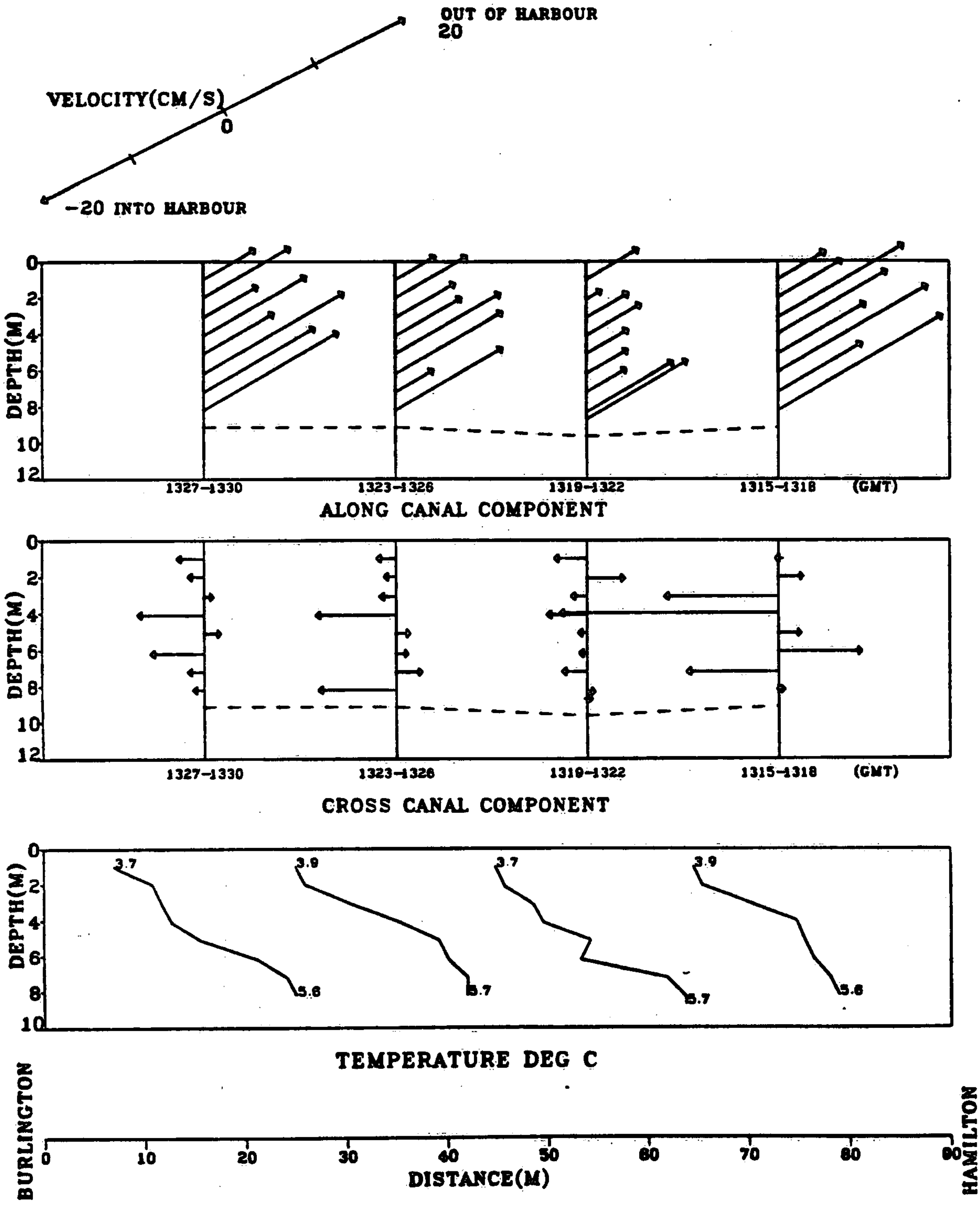
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 6 1989



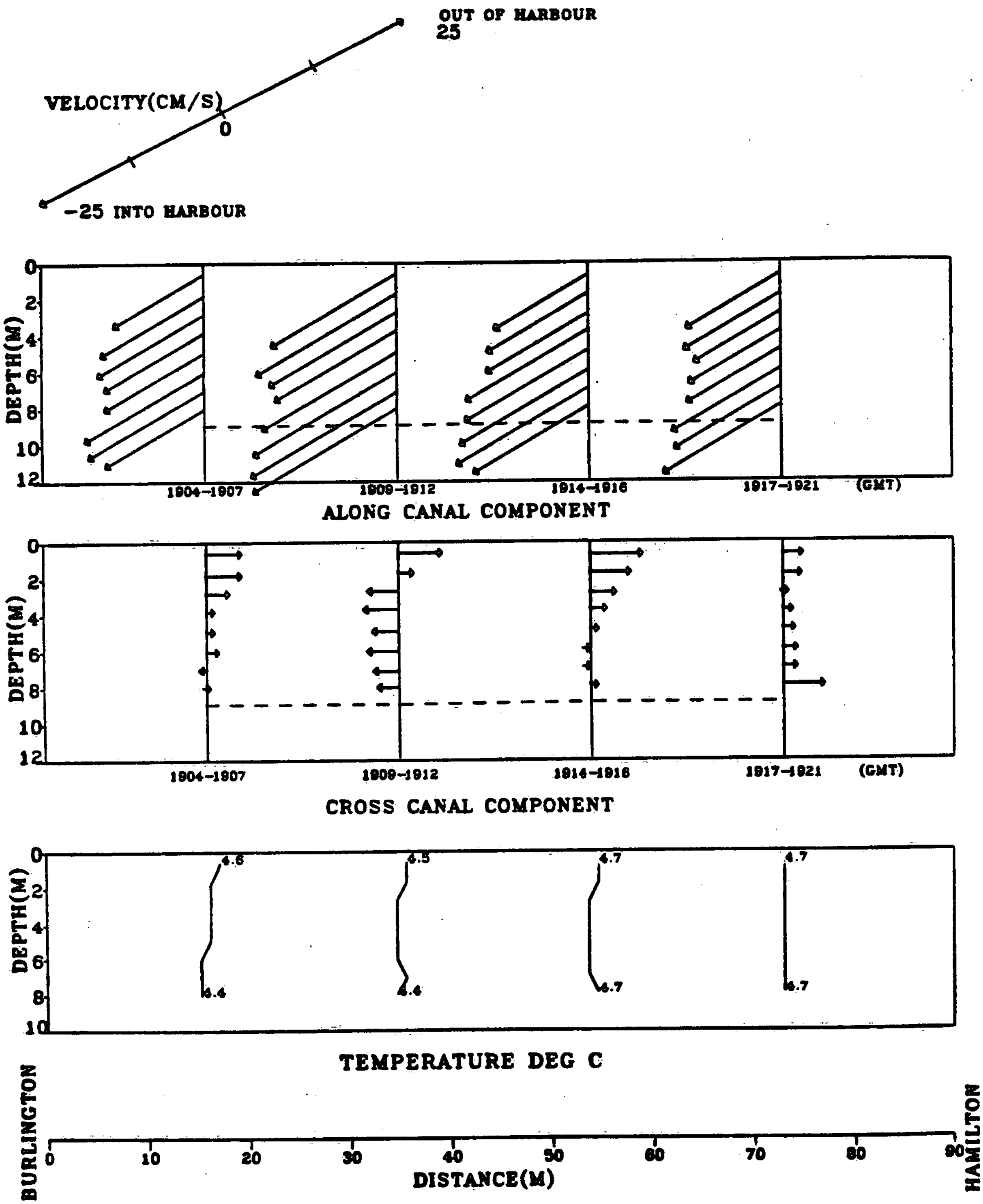
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 19 1989



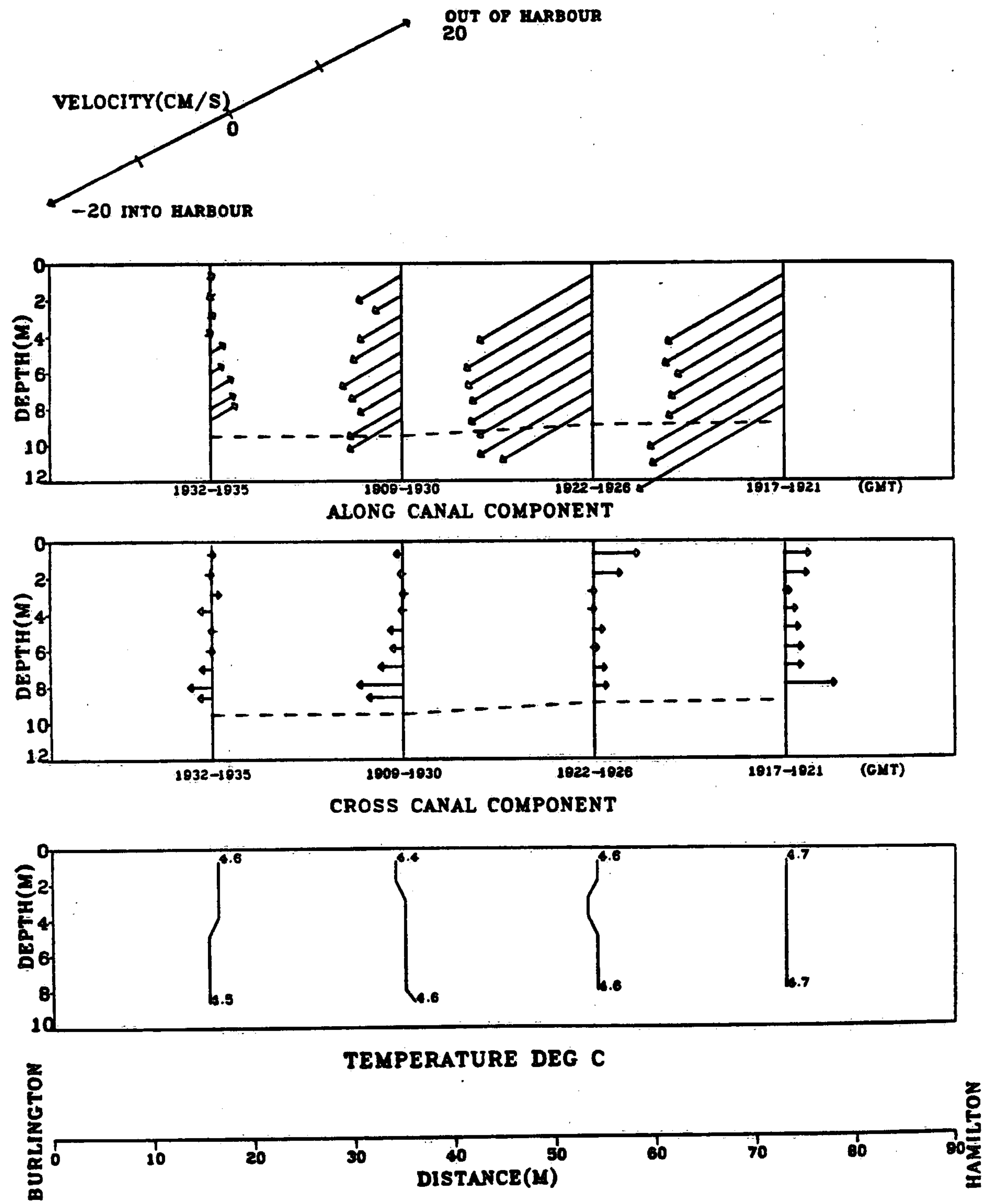
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 13 1989



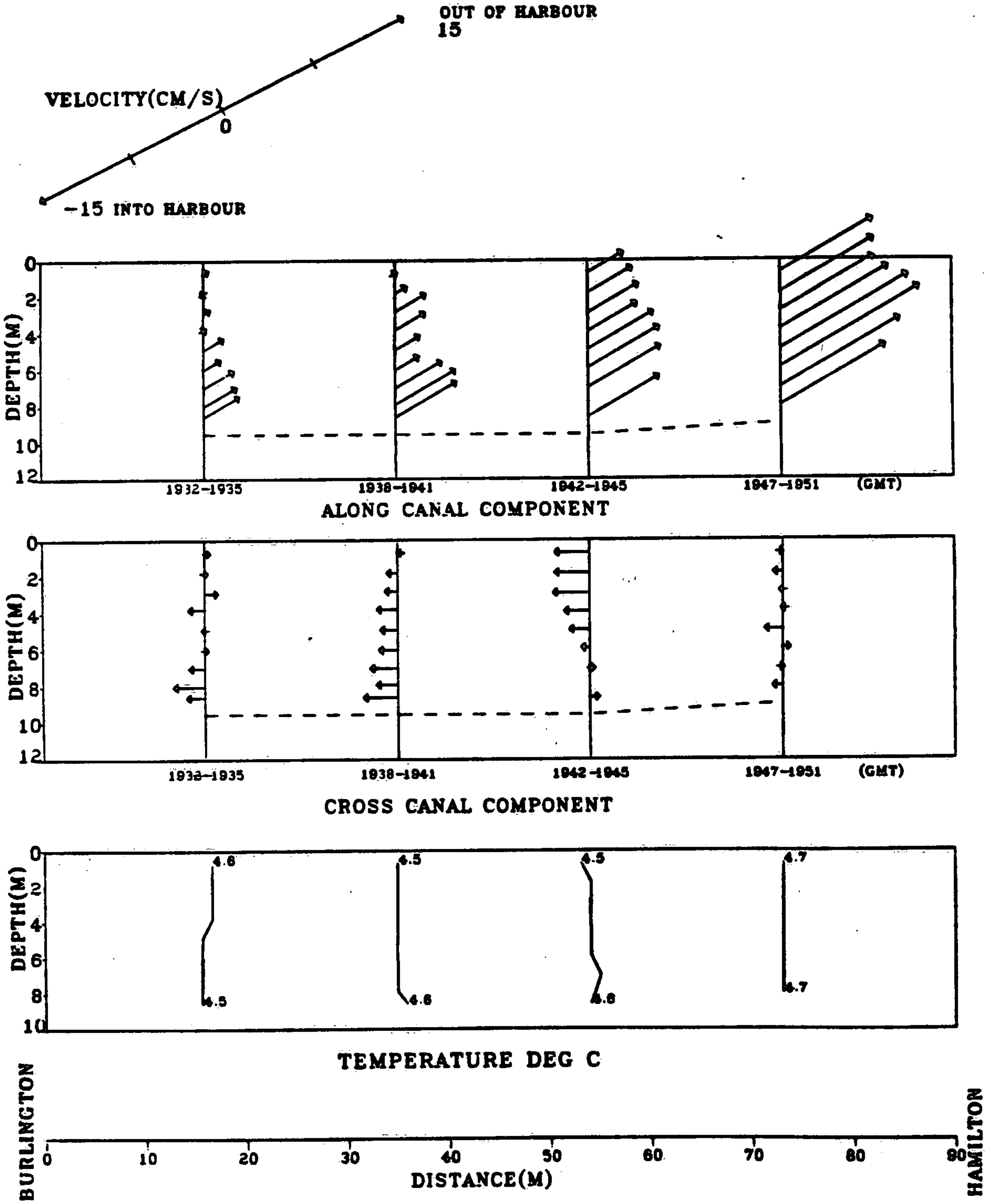
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 18 1989



ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 18 1989



ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 18 1989



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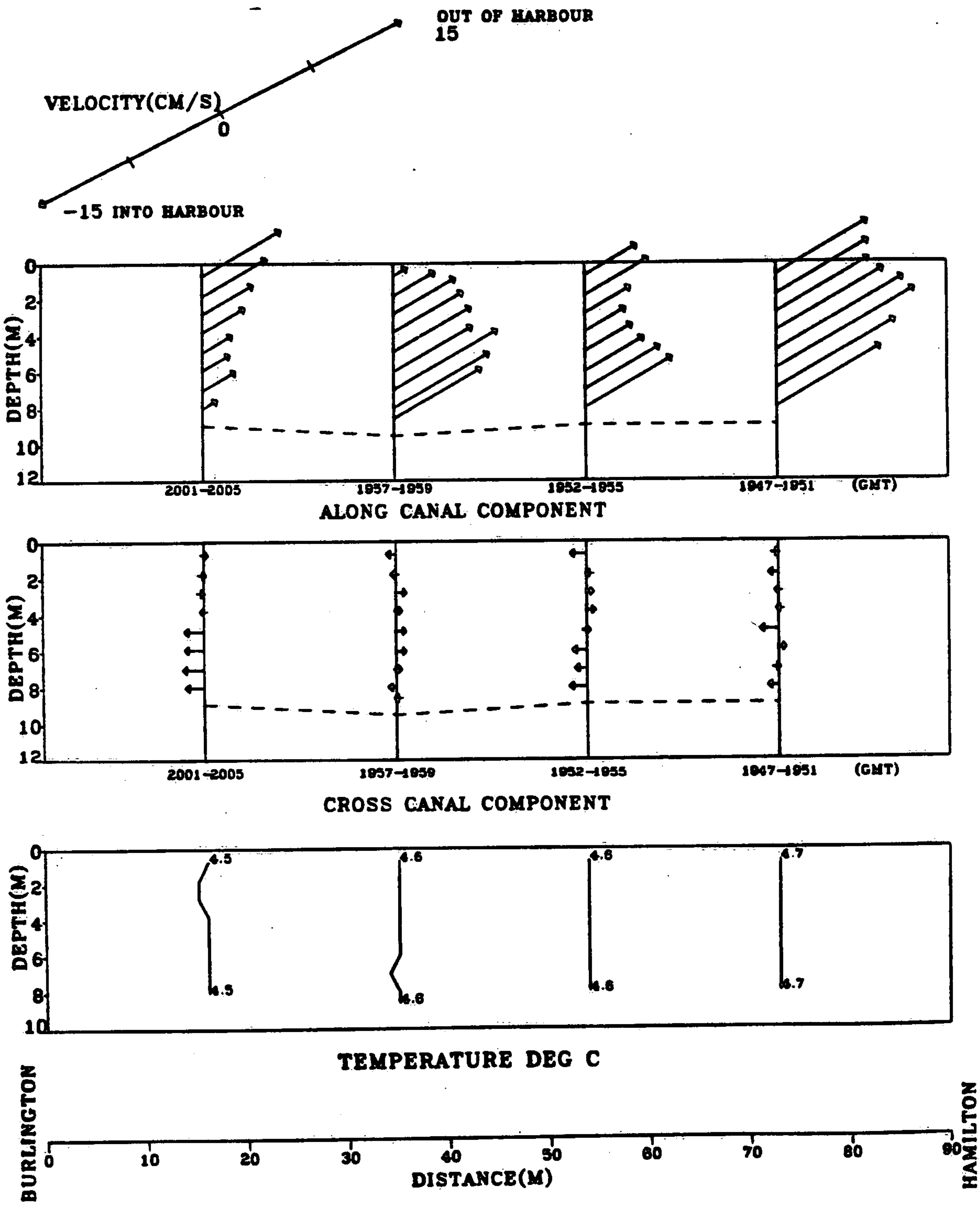
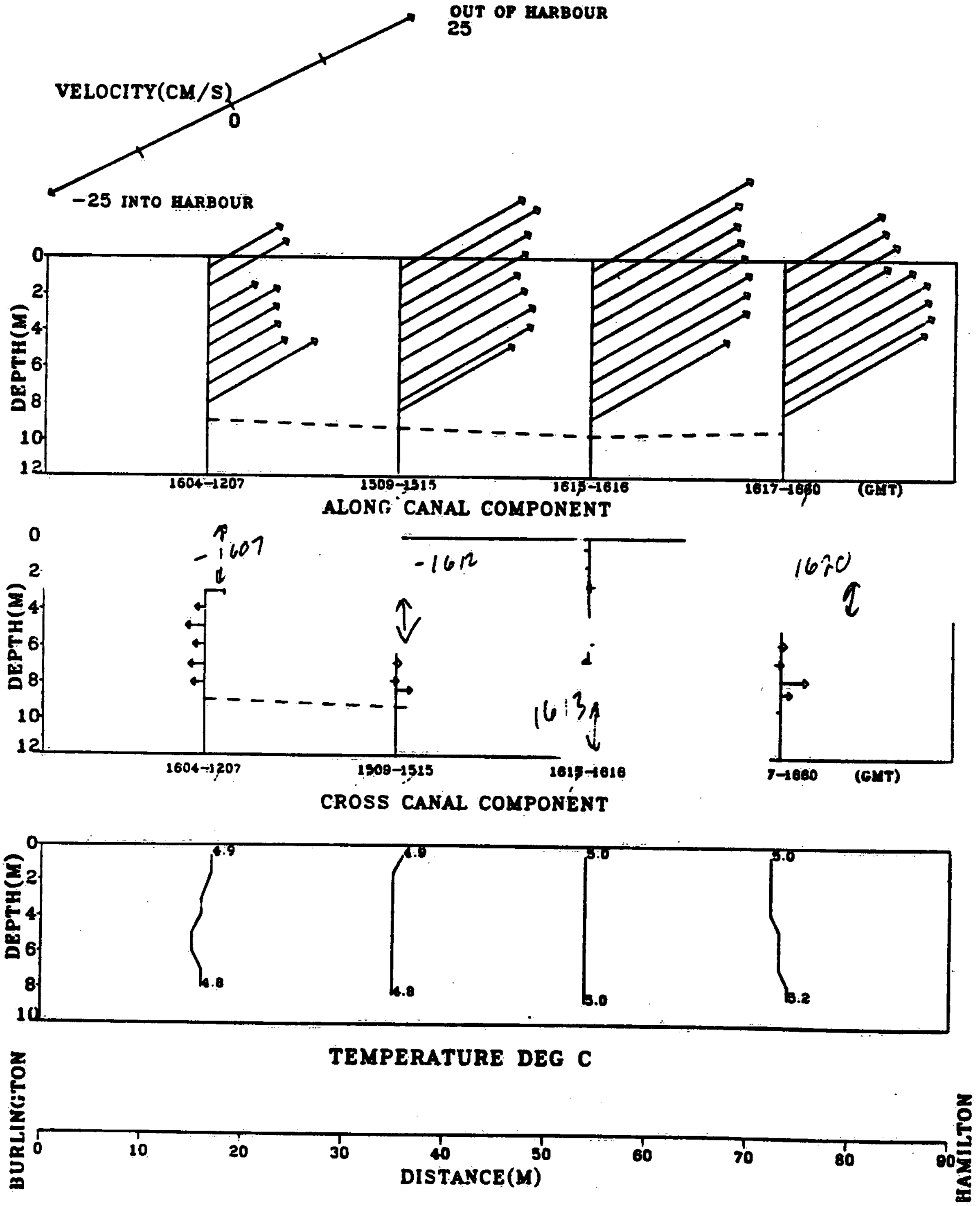
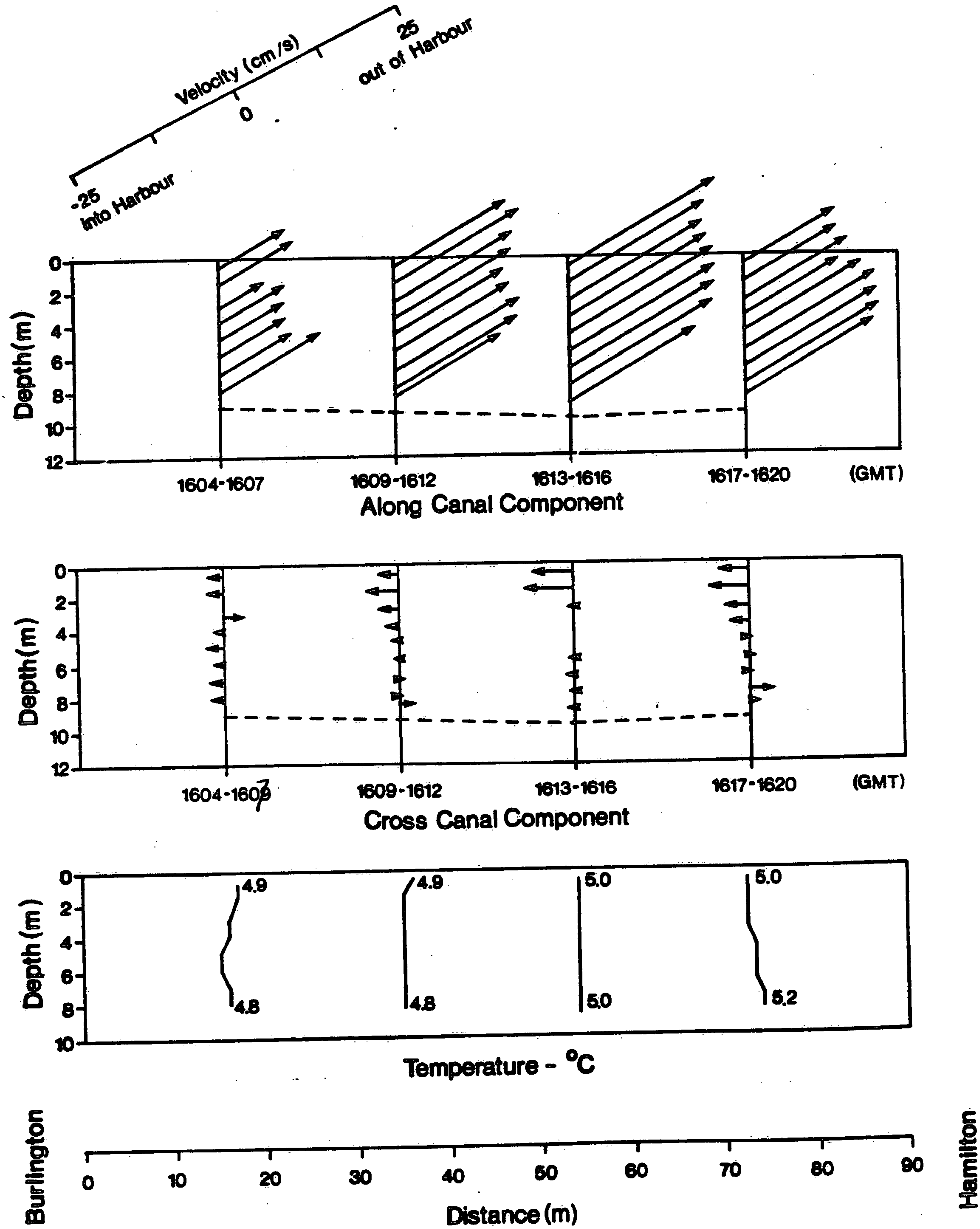


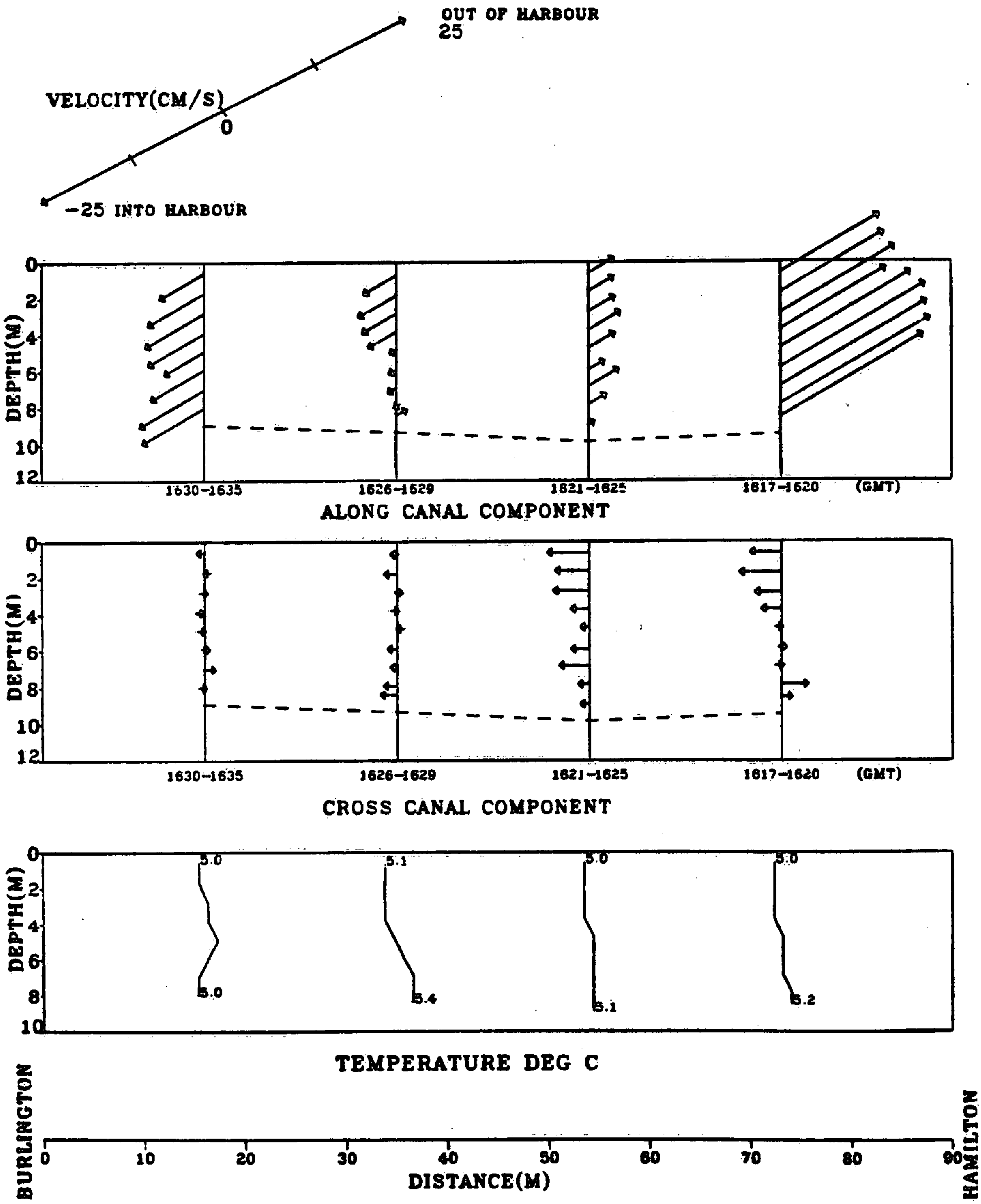
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 19 1989



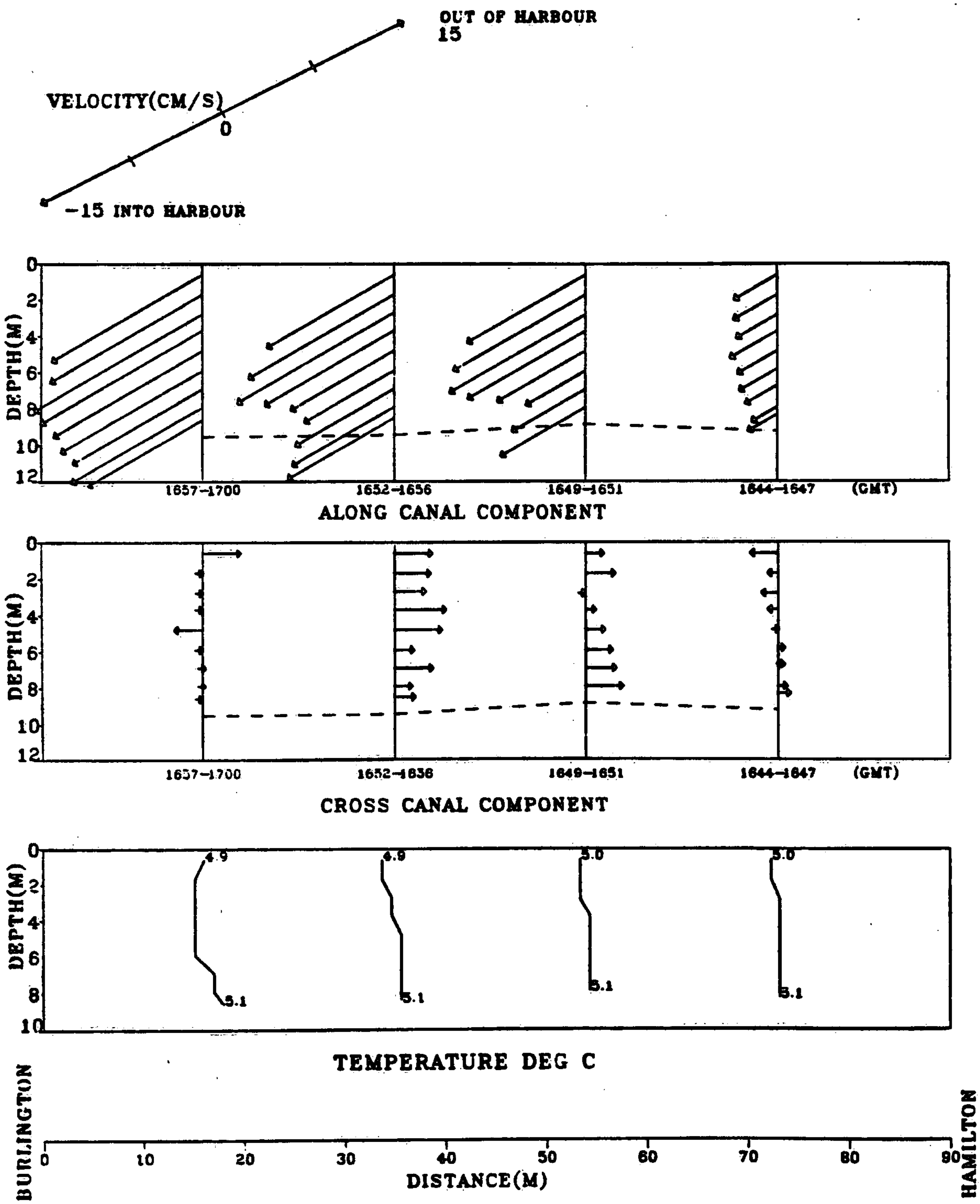
Acoustic cm Measurements, Burlington Ship Canal - April 19, 1989



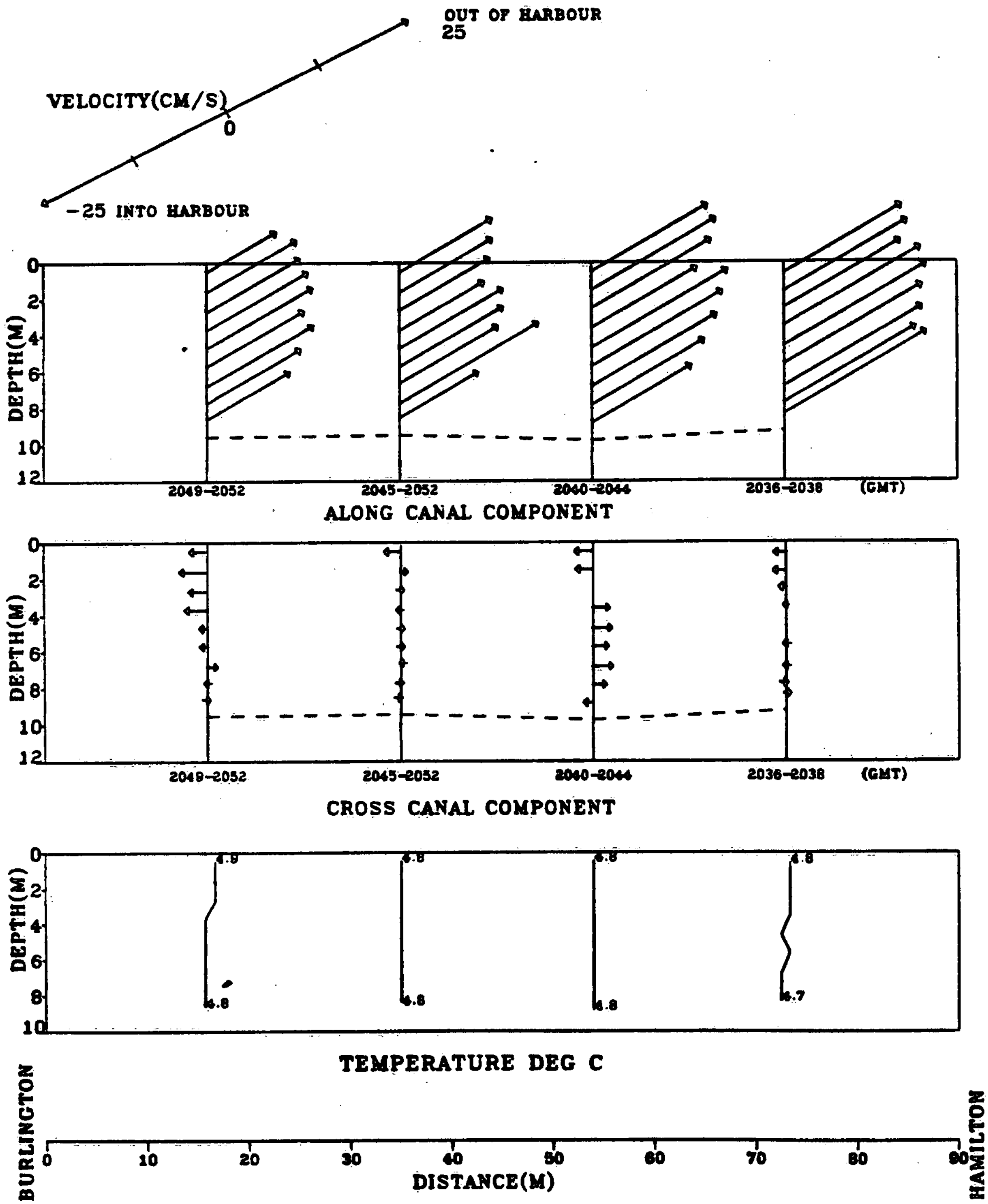
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 19 1989



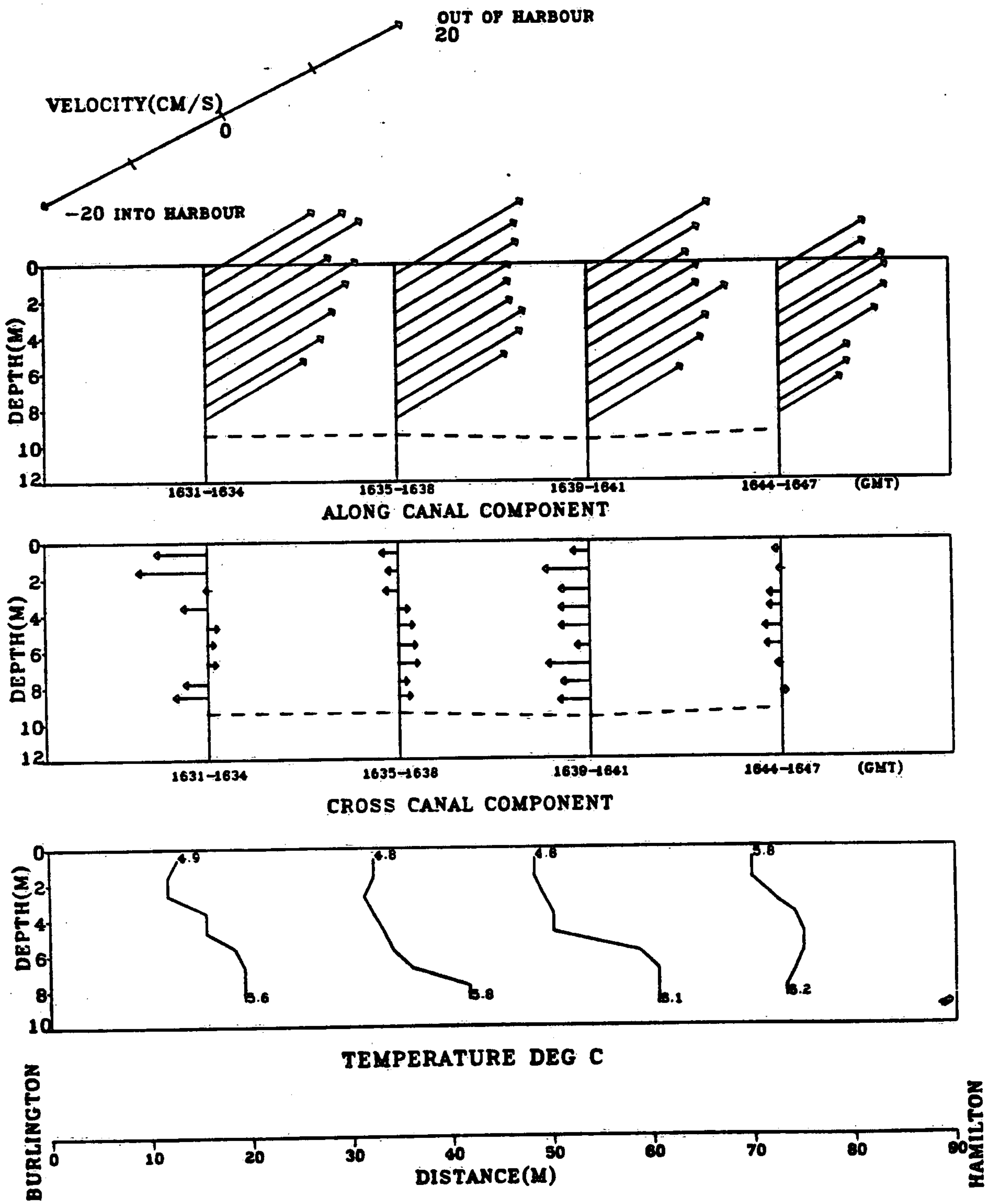
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 19 1989



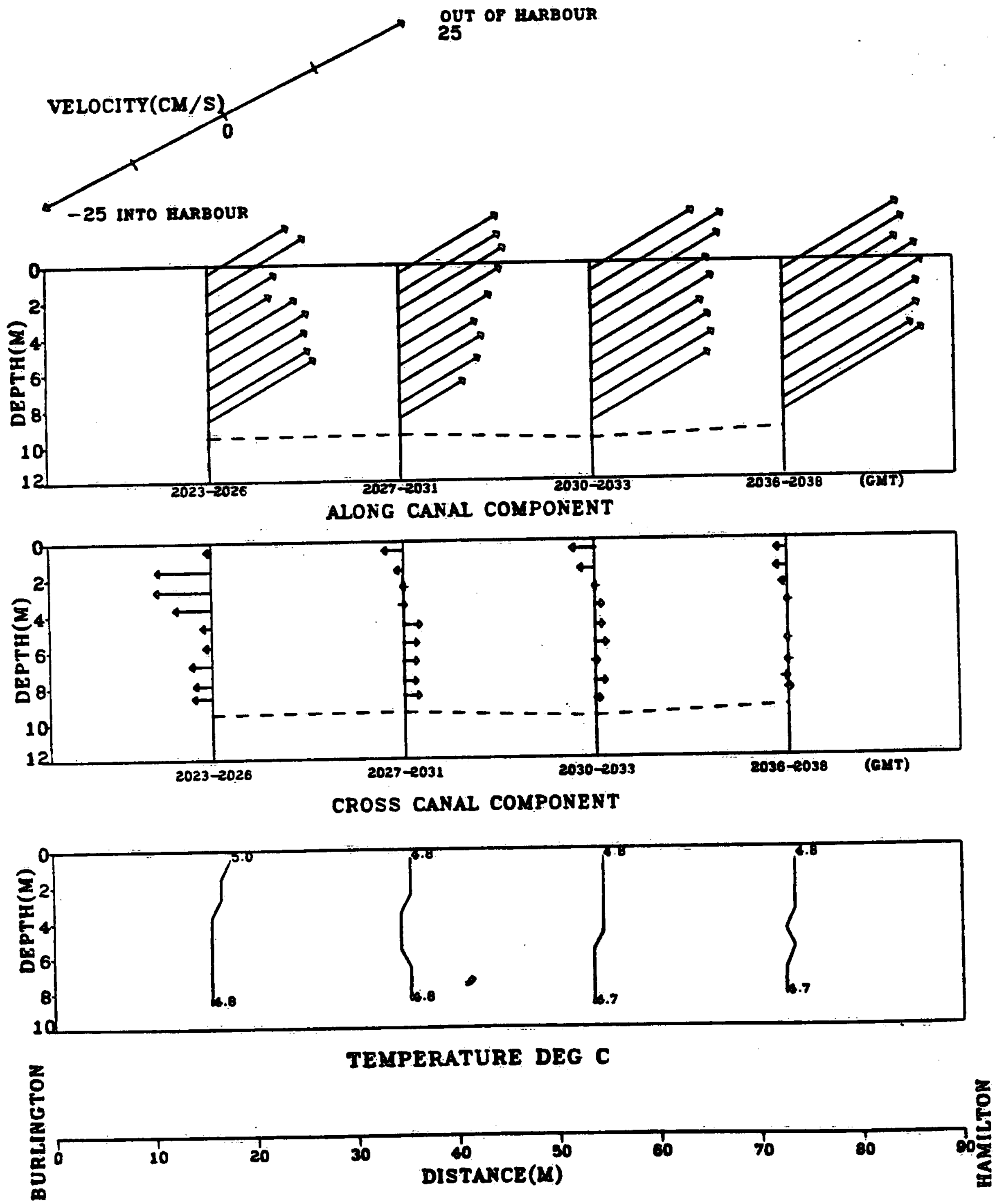
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 20 198?



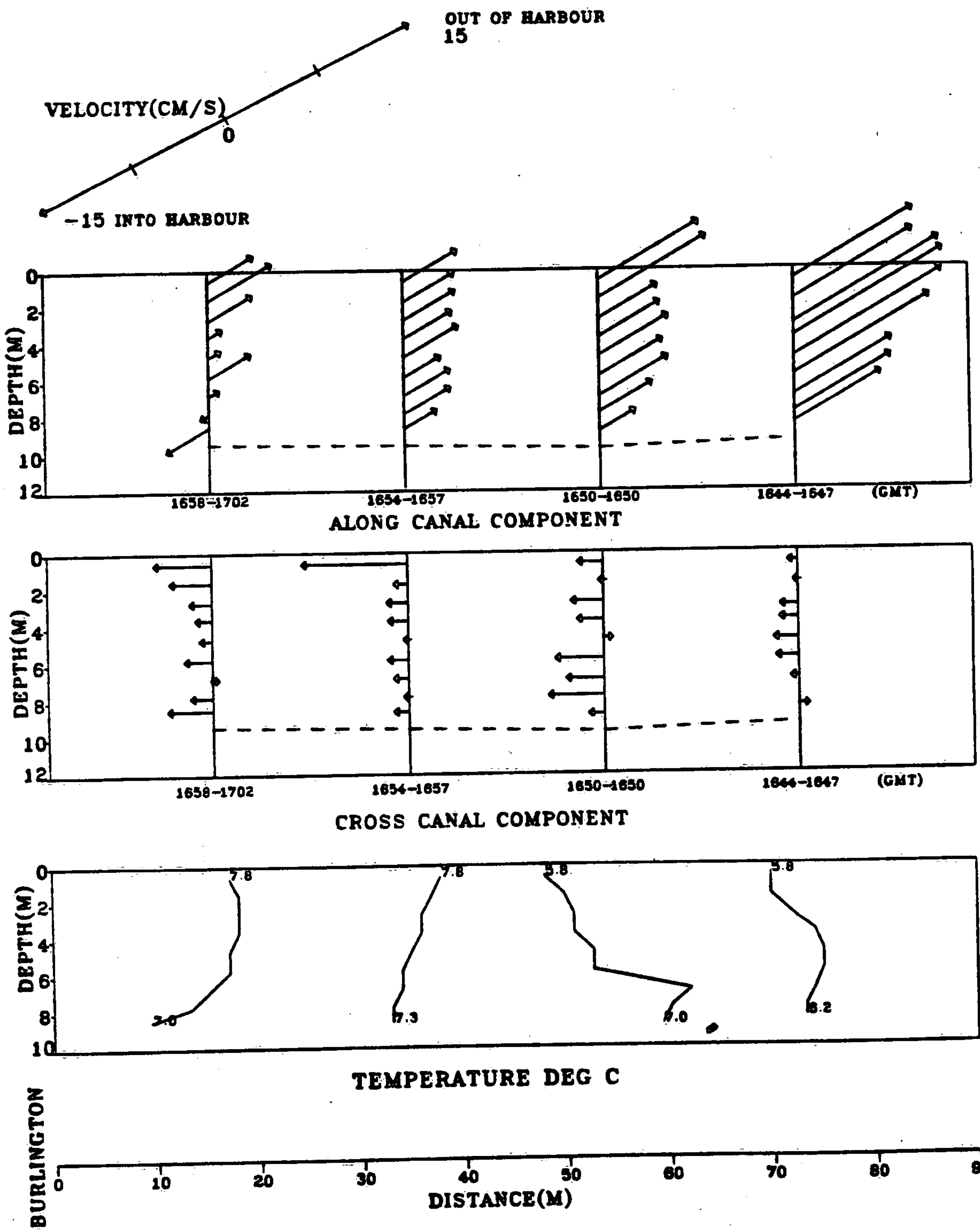
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 20 1989



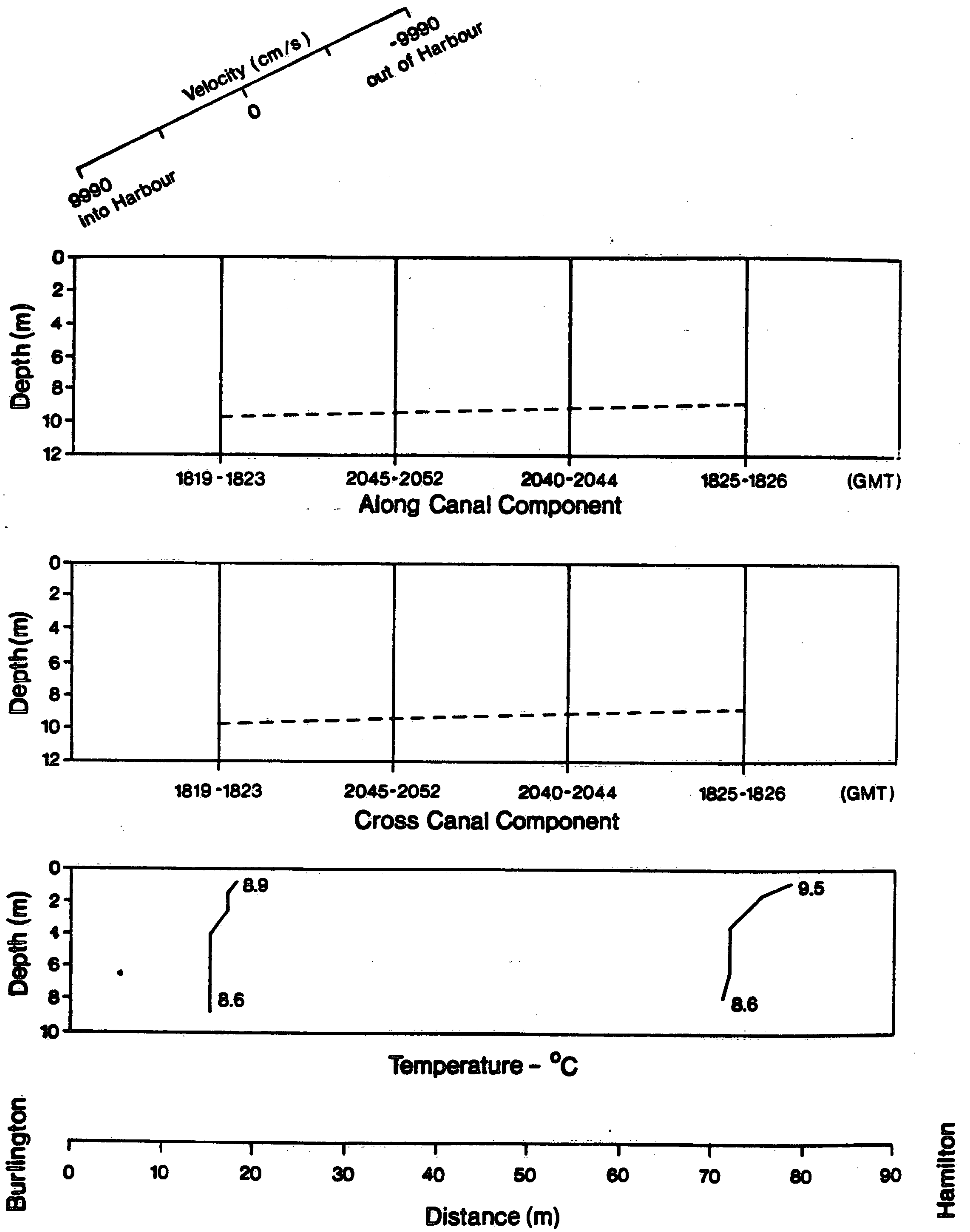
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 20 1989



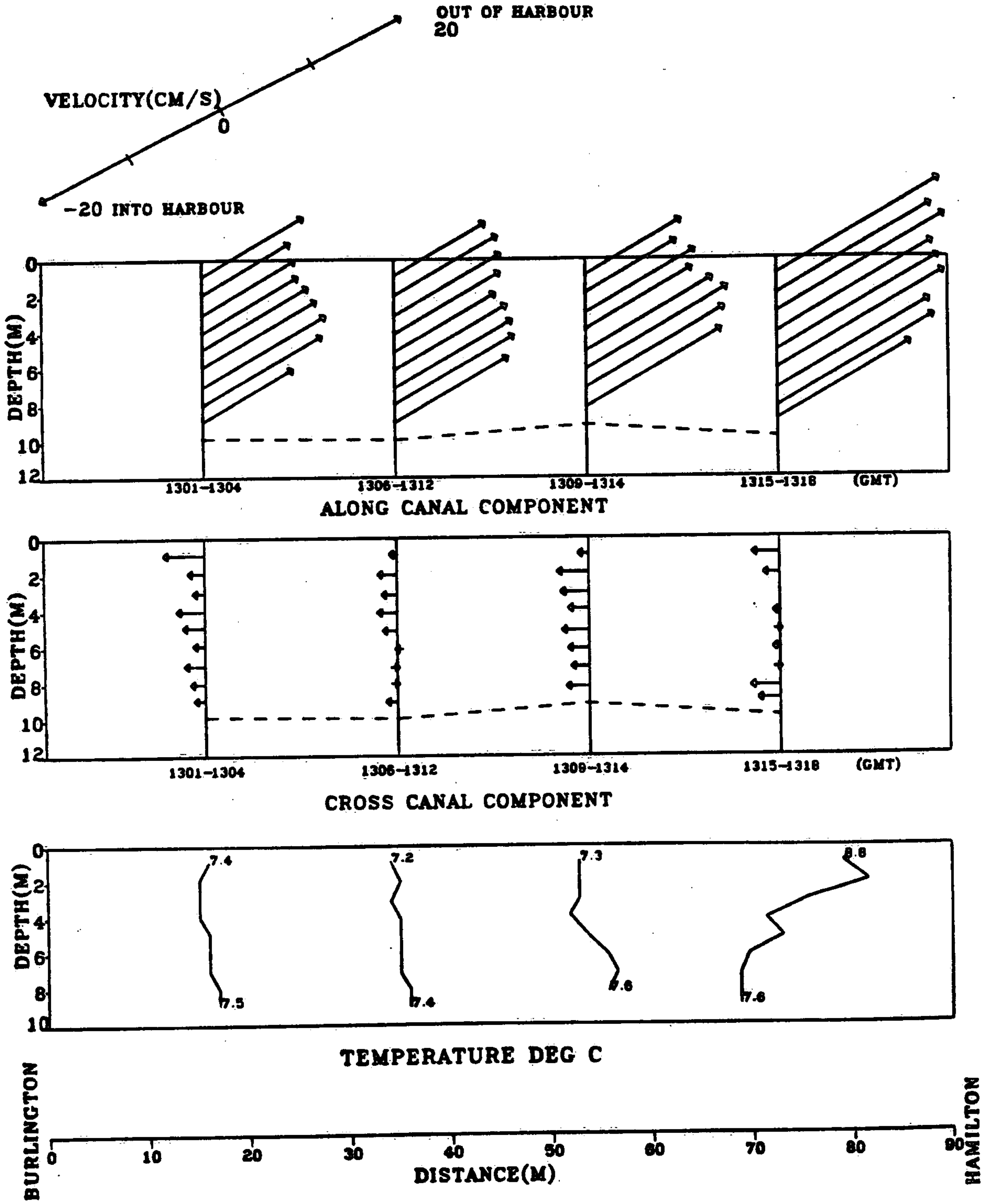
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL APR 20 1989



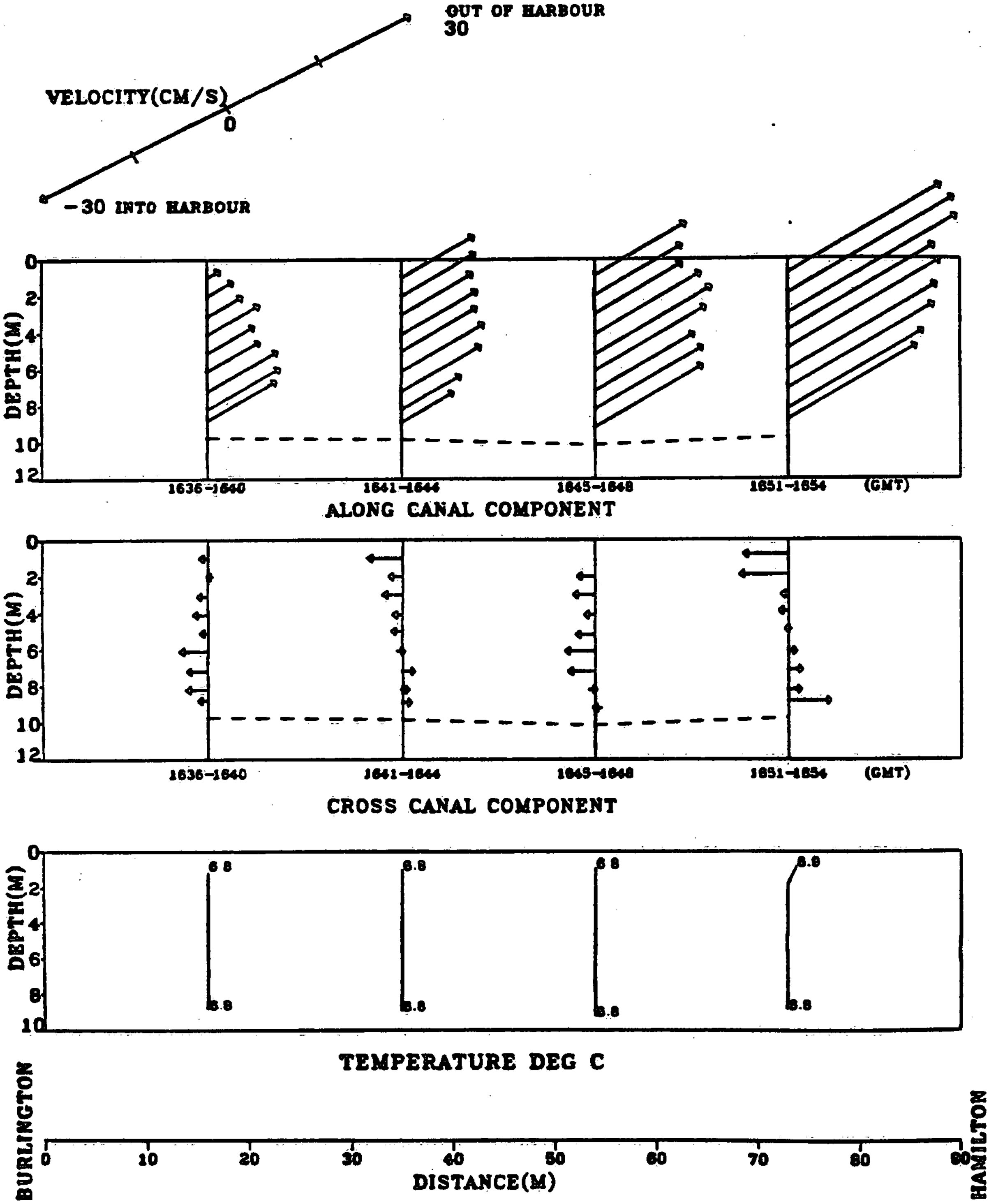
Temperature Measurements, Burlington Ship Canal-April 26,1989



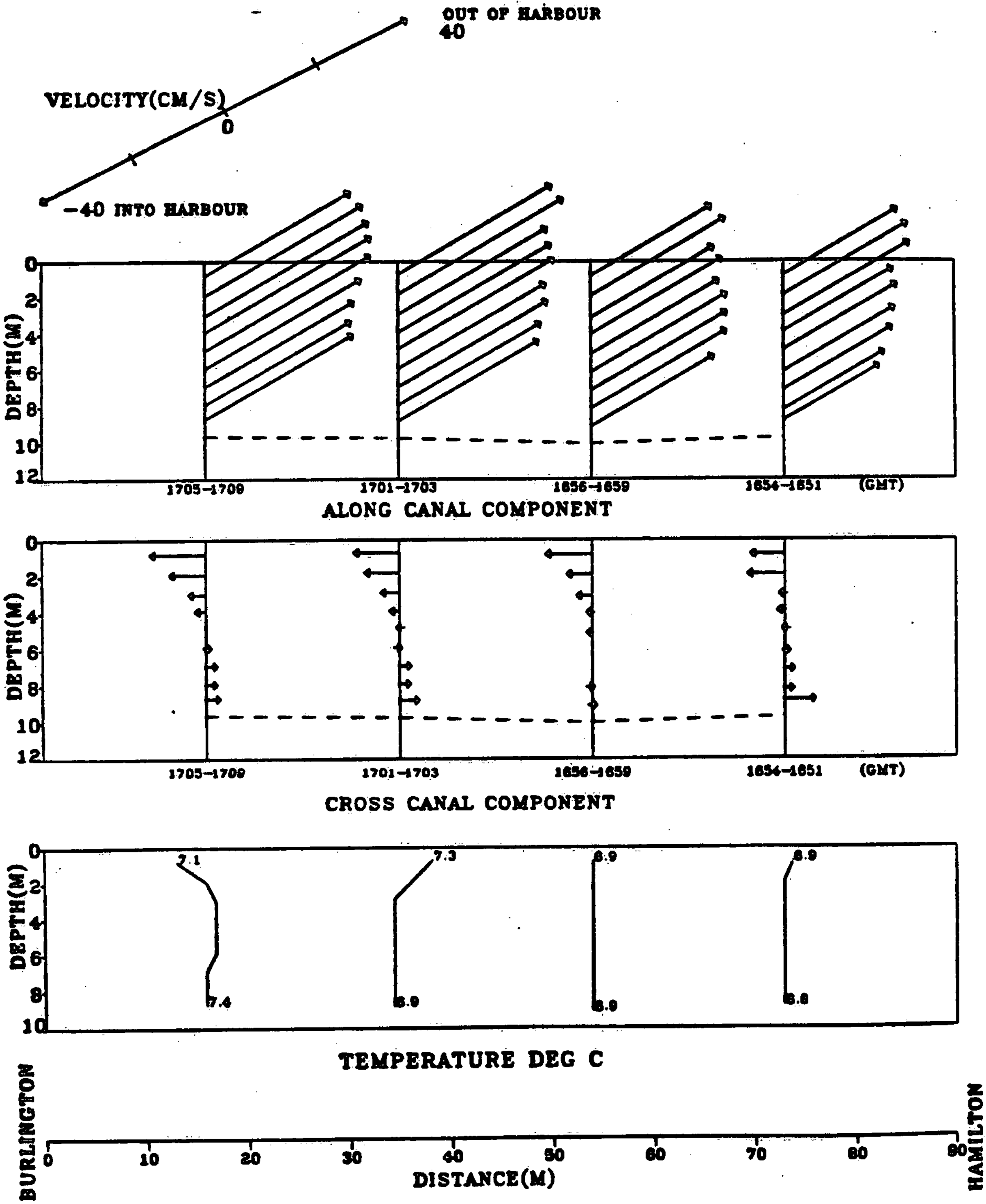
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAY 1 1989



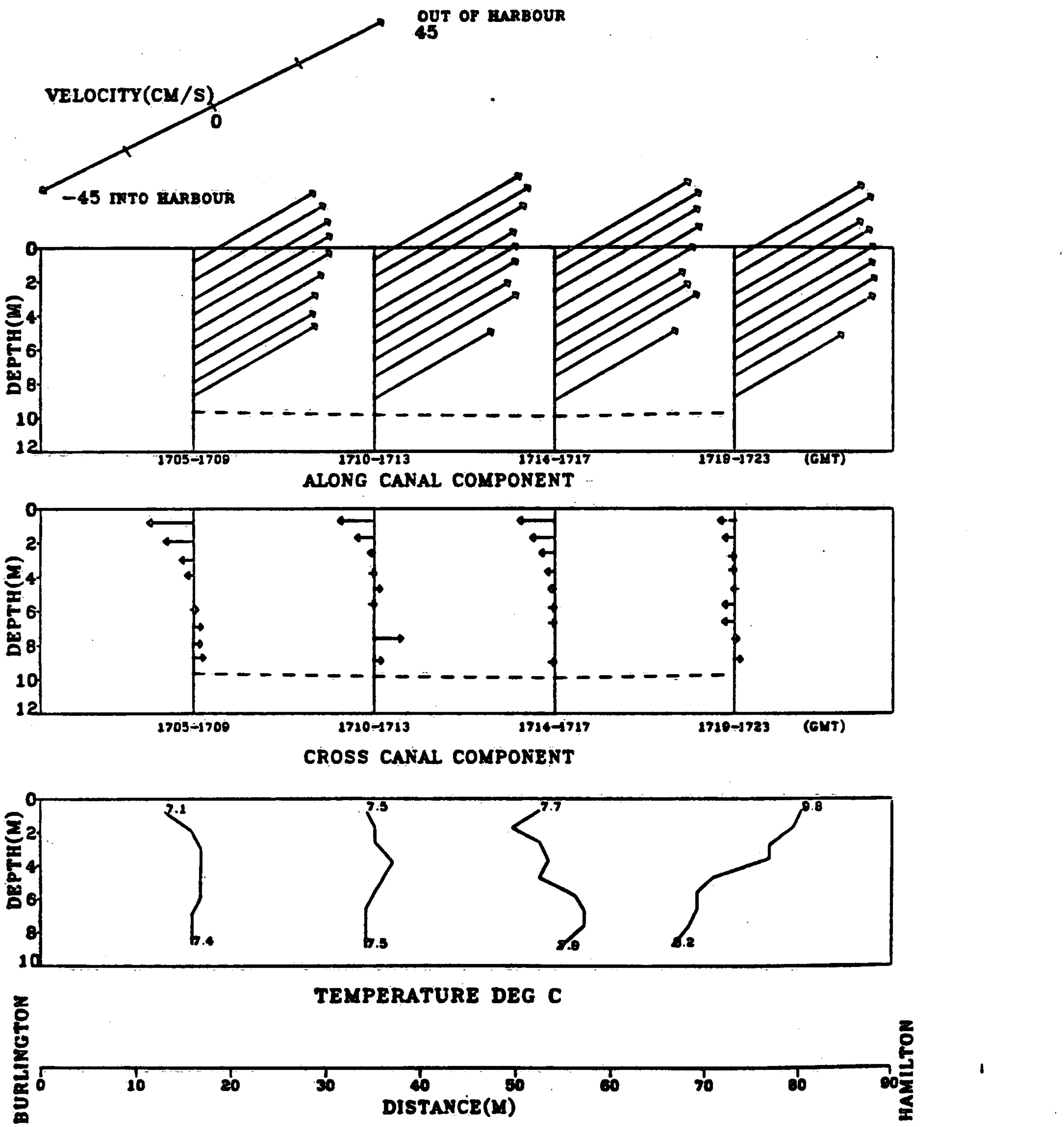
ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAY 7 1989



ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAY 7 198



ACOUSTIC CM MEASUREMENTS, BURLINGTON SHIP CANAL MAY 7 1989



APPENDIX II

Archival Notes on Canal Data

APPENDIX II

Archival Notes on Canal Data

Data files BURT, BURT2, BURT3, BURT4, BURT5 are on magnetic tape VSN = WA342 together with programs SUBCUR, BRIFT, SORTP, PIP, and HAMHBR. These were written on magnetic tape as a reclaim file. Reclaim Z./DUMP, TN = WA342, FN = * BURT,.....SORTP.

Program SUBCUR provides the vector plots and temperature profiles. Note the variables R1 and R2 in the JCL .Eg. R1 = 1 and R2 = 49 would cause the program to be executed 49 times on whichever data file is attached in the JCL (e.g., BURT). Also, if user wishes to skip files with the data file (e.g., BURT), he must insert the statement SKIPF, Tape, # of files to skip, C.

Note: Check user password and charge numbers before running programs.

Program SORTP sorts the time in ascending order and outputs sorted AFFRA data on direct access file called YYY (also stored on WA342). Check for data input wanted in JCL.

Notes: Program SUBCUR also outputs data to a direct access file called CTEST. This file can then be appended to the following JCL to provide contour plots of depth, temperature, distance. (Note: This was tried but was not successful due to not enough data points).

CTEST would be appended to the following JCL:

USER ____ , ____

CHARGE, ____ , ____

Get, P44SET/UN = LIBRARY.

ATTACH, GPCP = CPCP44/UN = LIBRARY.

BEGIN, I, P44SET, USR = ____ , CH = ____

GPCP. ____

/EOR

"CONTENTS of CTEST."

If CTEST is not wanted, then in program SUBCUR one can comment out the statements which refer to CTEST. This is documented in the SUBCUR program. Also, the Define Tape 9 = CTEST can come out of the JCL, as well as Tape 9 in the program statement of the program, if contour plots not required.

To retrieve one or more files from reclaim, use the statement,

RECLAIM,Z./$\left\{\begin{matrix}\text{COPY}\\ \text{LOAD}\end{matrix}\right\}$, TN = WA342, FN = *

SUBCUR, BURT, - - - ,

COPY makes the file(s) local whereas LOAD makes them permanent.