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Remote Sensing in Burlington Ship Canal

By:
P.F. Hamblin

95-39

REMOTE FLOW SENSING IN BURLINGTON SHIP CANAL

by

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MANAGEMENT PERSPECTIVE

Measurements of flow in ship channels are needed to fully predict the effects of hydraulic regimes on water quality in harbours. Usually the shipping traffic precludes accurate measurement of flows because current meters cannot be situated in the channels.

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 exchange and its influence on the 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 and was found to be in satisfactory agreement with conventional methods. Degradation of the data quality over the four-month installation period is a potential problem for further investigation by the AFFRA manufacturer. Nonetheless, this new method for the remote sensing of currents could find useful application to other Areas of Concern in the Great Lakes where ship traffic is too dense for standard flow measurements.

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 ben 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 within the statistical uncertainty the two instruments were identical. 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.

1. INTRODUCTION

A feature common to many areas of concern in the Great Lakes is that they are located in bays or harbours where exchange with the open lake is more restricted than in other coastal areas. A case in point, Hamilton Harbour, is connected to Lake Ontario via a relatively long and narrow passage, the Burlington Ship Canal.

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. Flow measurements may be recorded for future analysis. In an intensive study of the two-layer flow regime found in Burlington Canal, Spigel (1989) developed an accurate method for the attended measurement of flow in the Burlington Ship Canal using a conventional profiling current meter. It is the goal of this study to evaluate the field performance of a novel method of remote sensing of flow by comparison with Spigel's more conventional approach. The data collected in this study will also be used to establish the relation between the flow at the level of the acoustic path of the travel time current meter and the cross-sectionally averaged flow that will be required in future investigations. The approach employed herein as similar to that of Miller and Saylor (1994) who compared an advanced ultrasonic current profiler to an array of four standard recording current meters in Green Bay.

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., 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 of the level of the acoustic rays. 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 of 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 to date 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 averaged flow at the e^{-1} depth overestimated the cross-section 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 and after the study and found to be too high by a factor of 1.24. All data collected by this instrument have been corrected for this overestimation.

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 10, 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 of 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. Collection of profile data in the canal was interrupted in March due to drifting ice floes. The AFFRA data were 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.

RESULTS

The AFFRA measurements for the 120-day period are displayed in Figure 3. 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 are measured.

A typical set of current and temperature observations at the lift bridge are shown in Figure 4. 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 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 5. 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 the 40 field experiments shown in Figure 6 the breadth averaged current, measured by the AFFRA flowmeter, is evidently equal to that of the profiler based measurements within the statistical scatter of the observations. A best-fit curve obtained by maximum likelihood analysis (Orear, 1982) established that the AFFRA current is 1.014 ± 0.055 of the standard profiler current with an offset of -0.259 ± 0.861 cm/s. Both the gain and offset indicate that the AFFRA and standard current meter flows do not statistically differ one from another. The correlation coefficient of 0.945 is sufficiently high to enable this conclusion to be drawn.

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 7 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 8. 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 3, there is an indication of lower percentage data return at high speeds, particularly for outflows. This behaviour is supported by the curves of Figure 9, which show a pronounced decrease in the percentage return throughout the experiment but also a tendency for higher returns 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 6 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 technique was found to be an accurate means of the unattended measurement of 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. As passages of ships did not noticeably affect the 15-min averages of flow, this device should be applicable to other areas of concern where ship traffic prevents deployment of more convention instrumentation. A progressive degradation of the acoustic signal quality over the one-layer period requires further investigation. It would be valuable to compare the acoustic travel time technique with other acoustic methods such as the scintillation method (Stronach and Hodgins, 1990). In future applications to investigations which require recorded data, a data storage medium of much expanded capacity would be highly desirable along with a faster transfer capability of such data.

ACKNOWLEDGEMENTS

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LIST OF FIGURE CAPTIONS

Figure 9. Percentage return versus AFFRA flow for five, 20-day episodes.

LIST OF TABLE CAPTIONS

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
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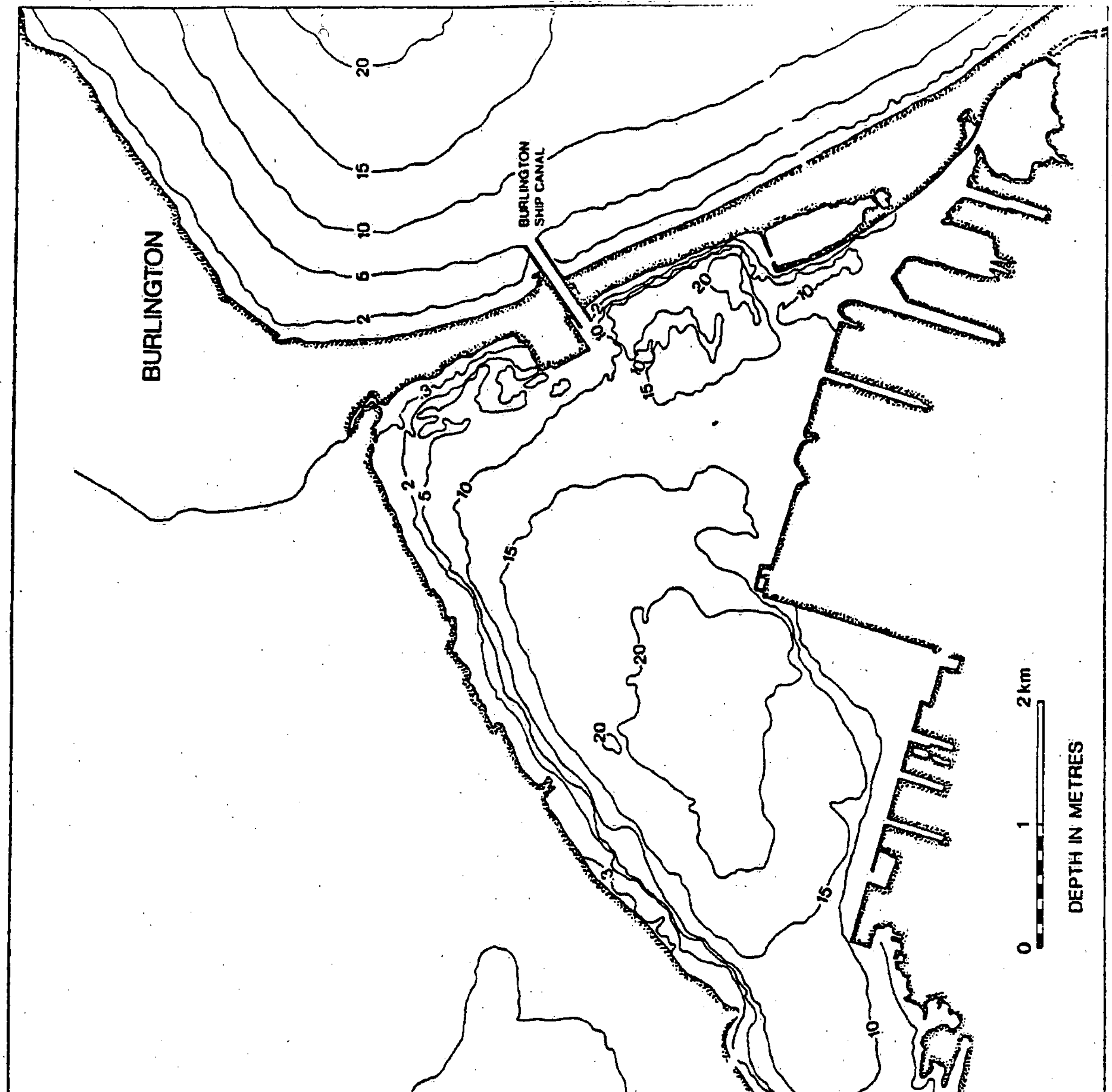
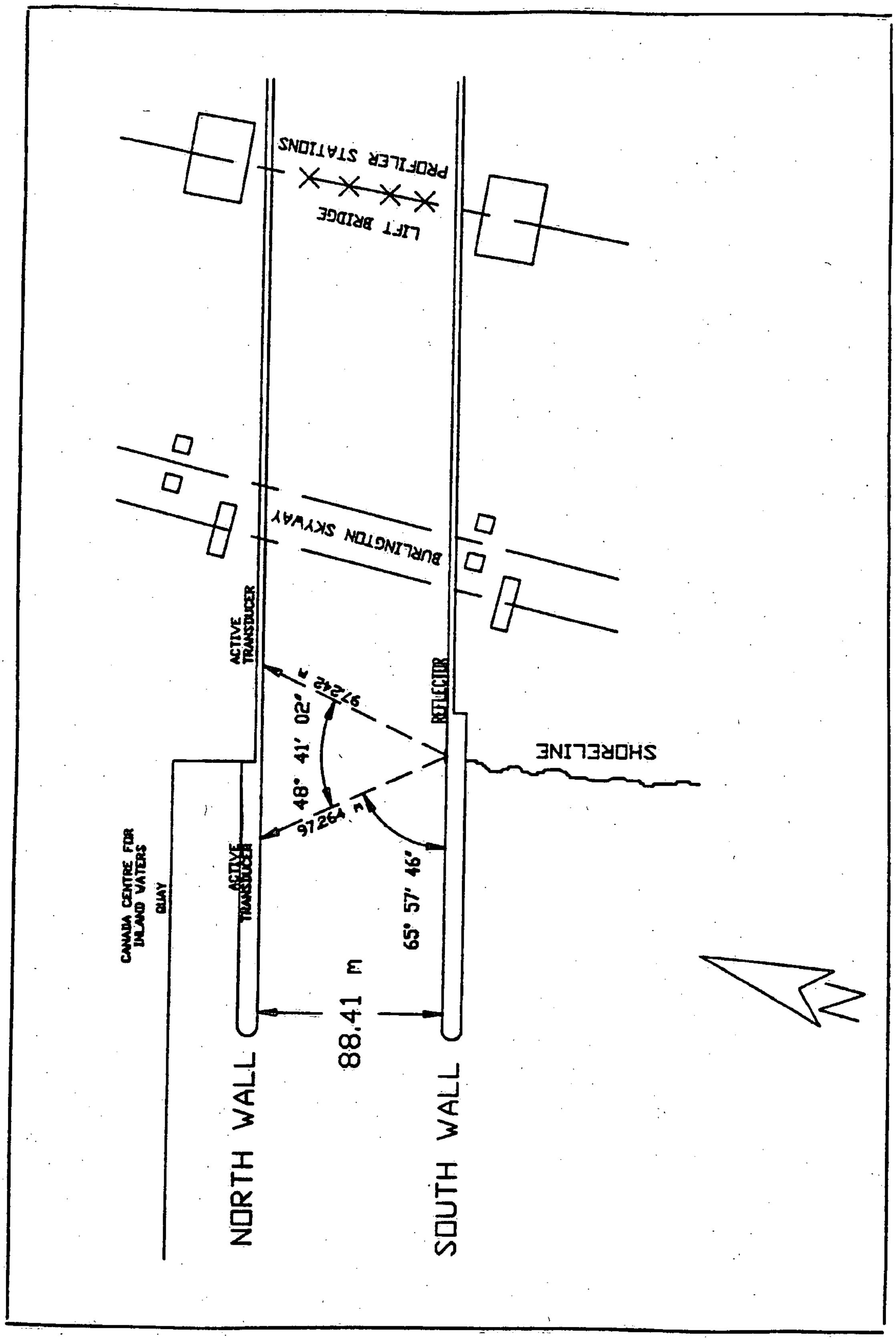

BURLINGTON
BURLINGTON SHIP CANAL
HAMILTON HARBOUR/THE BAY
HAMILTON
COOTES PARADISE
DEPTH IN METRES
0
1
2 km
N

Figure 1


PROFILER STATIONS
LIFT BRIDGE
BURLINGTON SKYWAY
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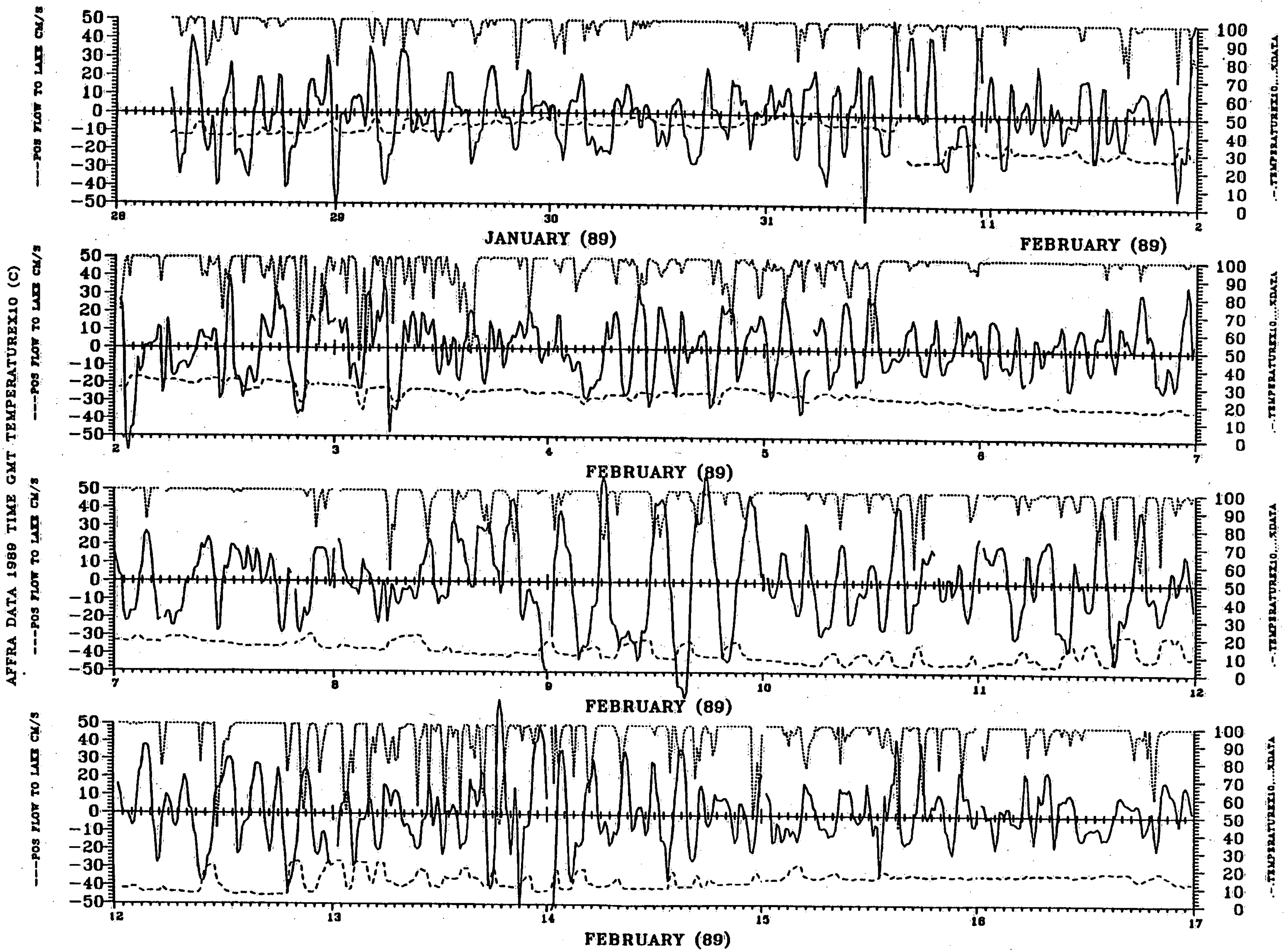
REFLECTOR
SHORELINE
97242 m
48° 41' 02"
97264 m
65° 57' 46"
ACTIVE TRANSDUCER
CANADA CENTRE FOR INLAND WATERS QUAY
88.41 m
NORTH WALL
SOUTH WALL

Figure 2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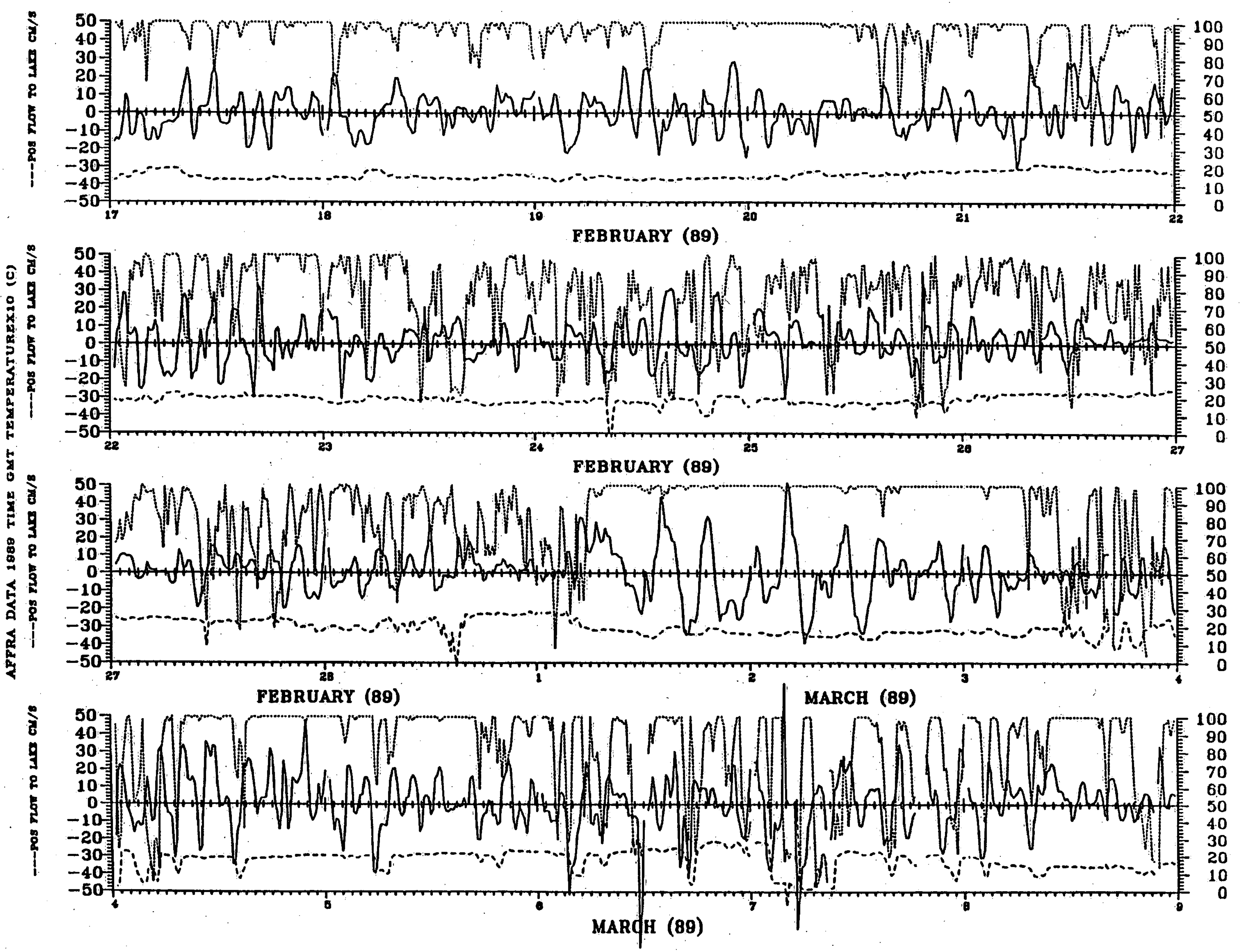
FEBRUARY (89)
FEBRUARY (89)
FEBRUARY (89)

Figure 3



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MARCH (89)

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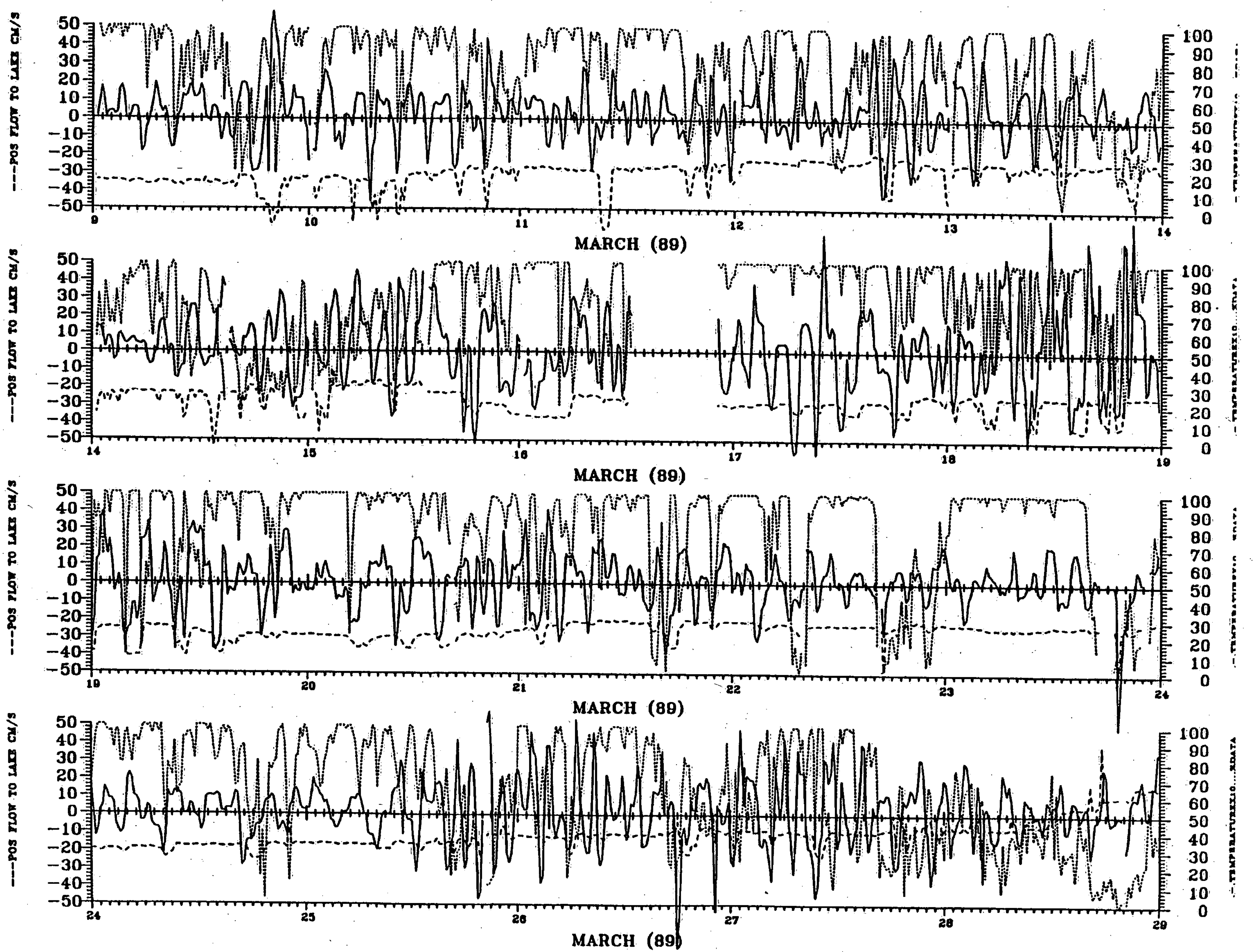

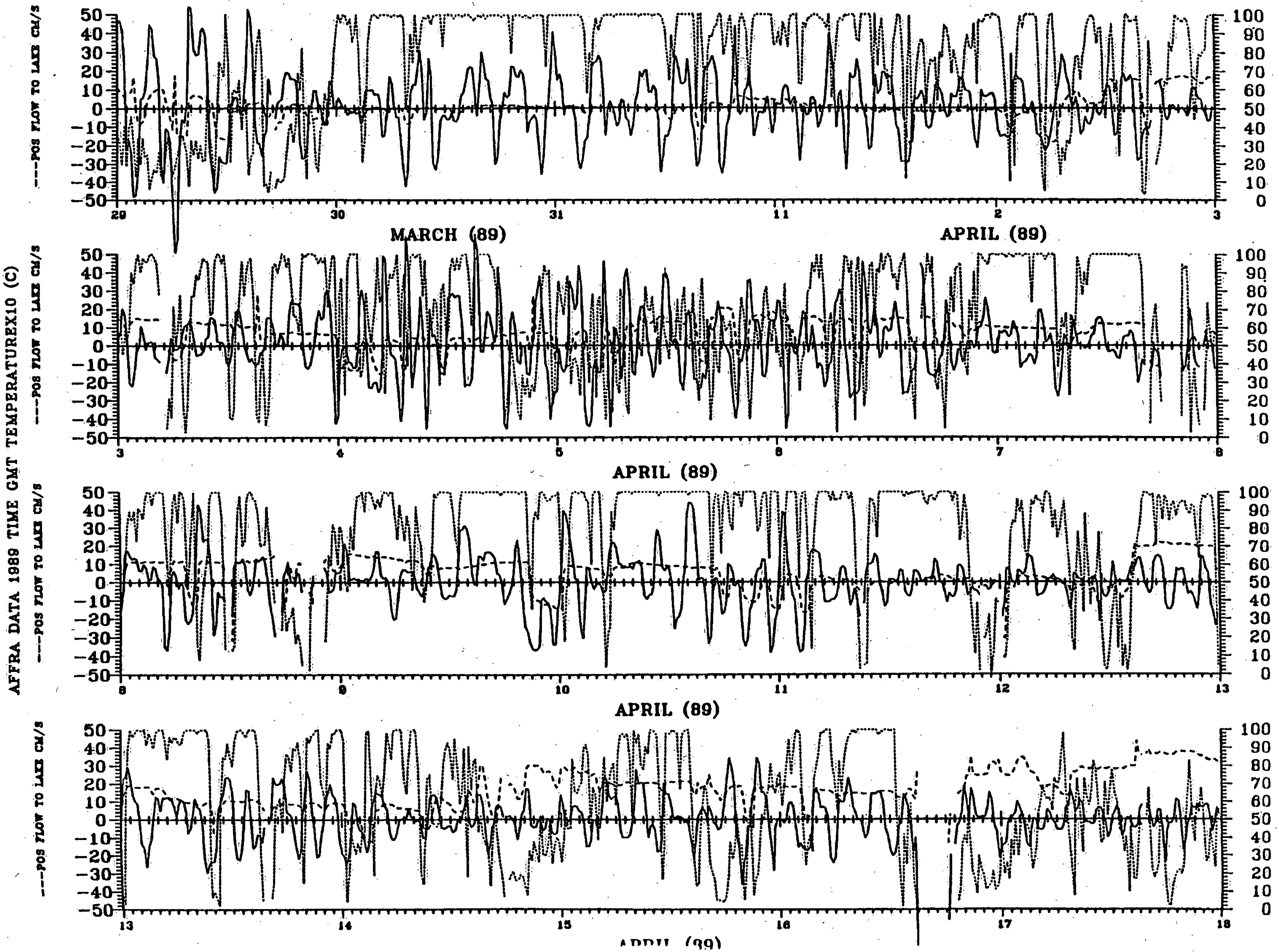
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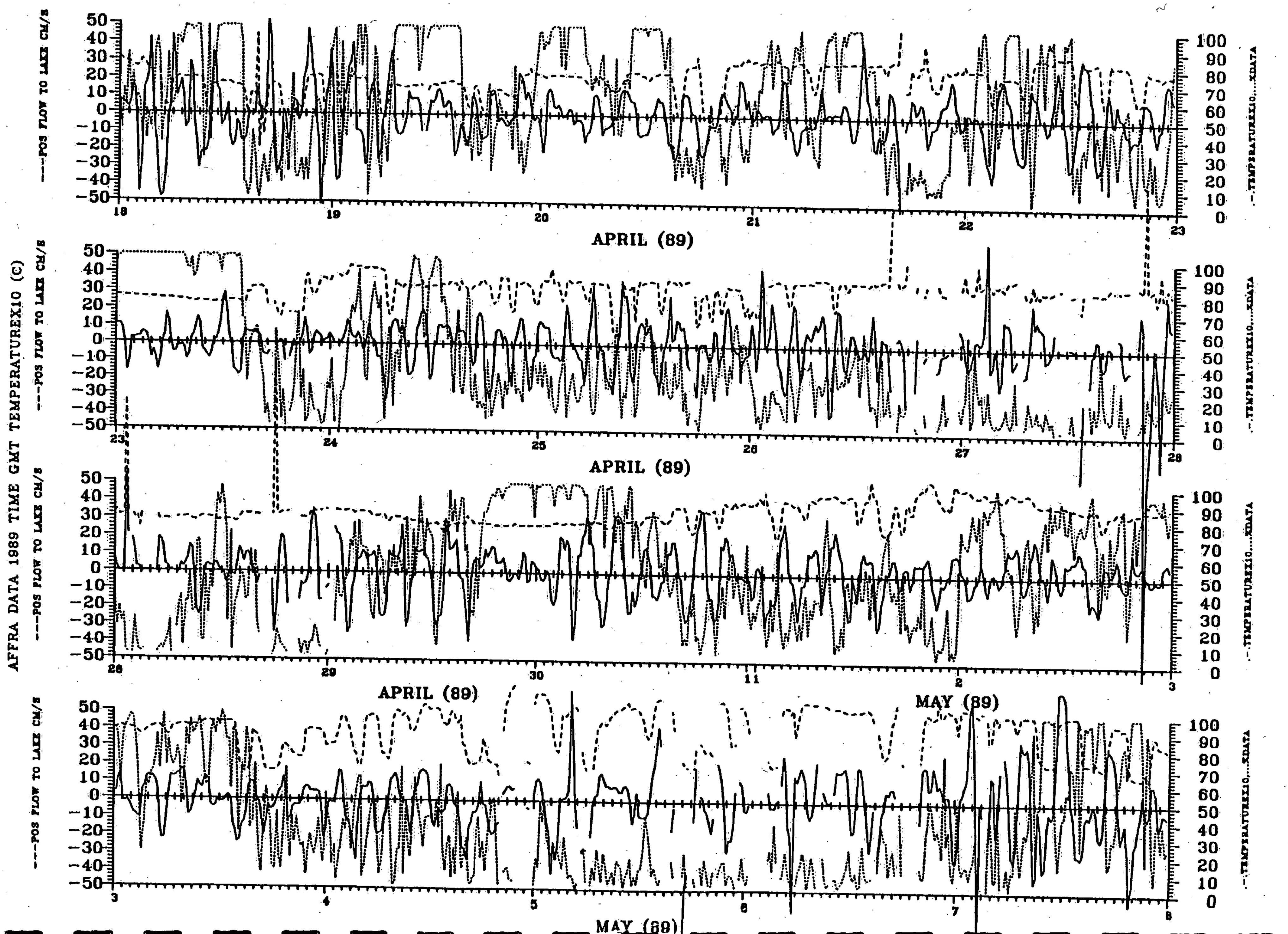
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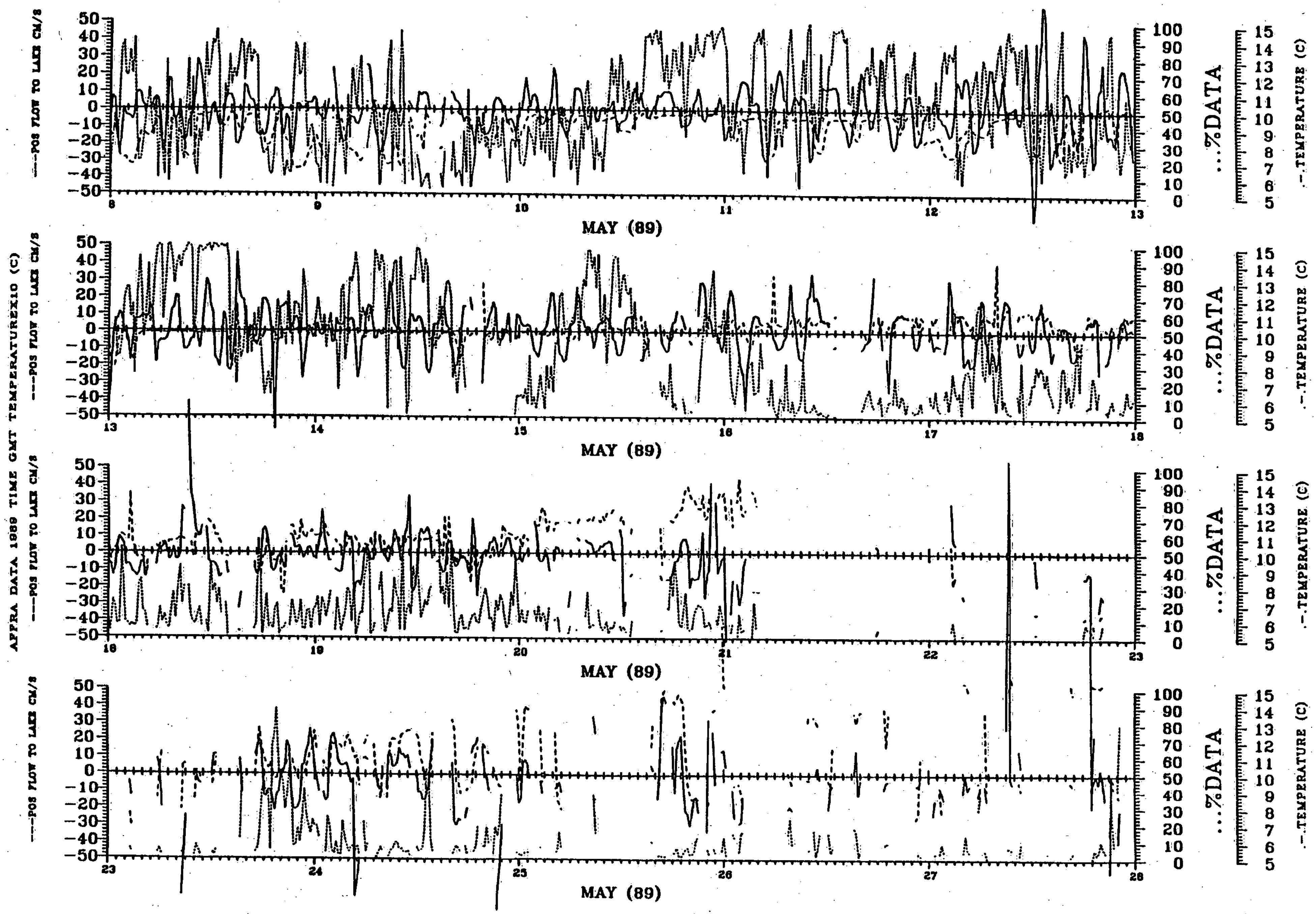
MAY (89)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Acoustic cm Measurements, Burlington Ship Canal - May 7, 1989

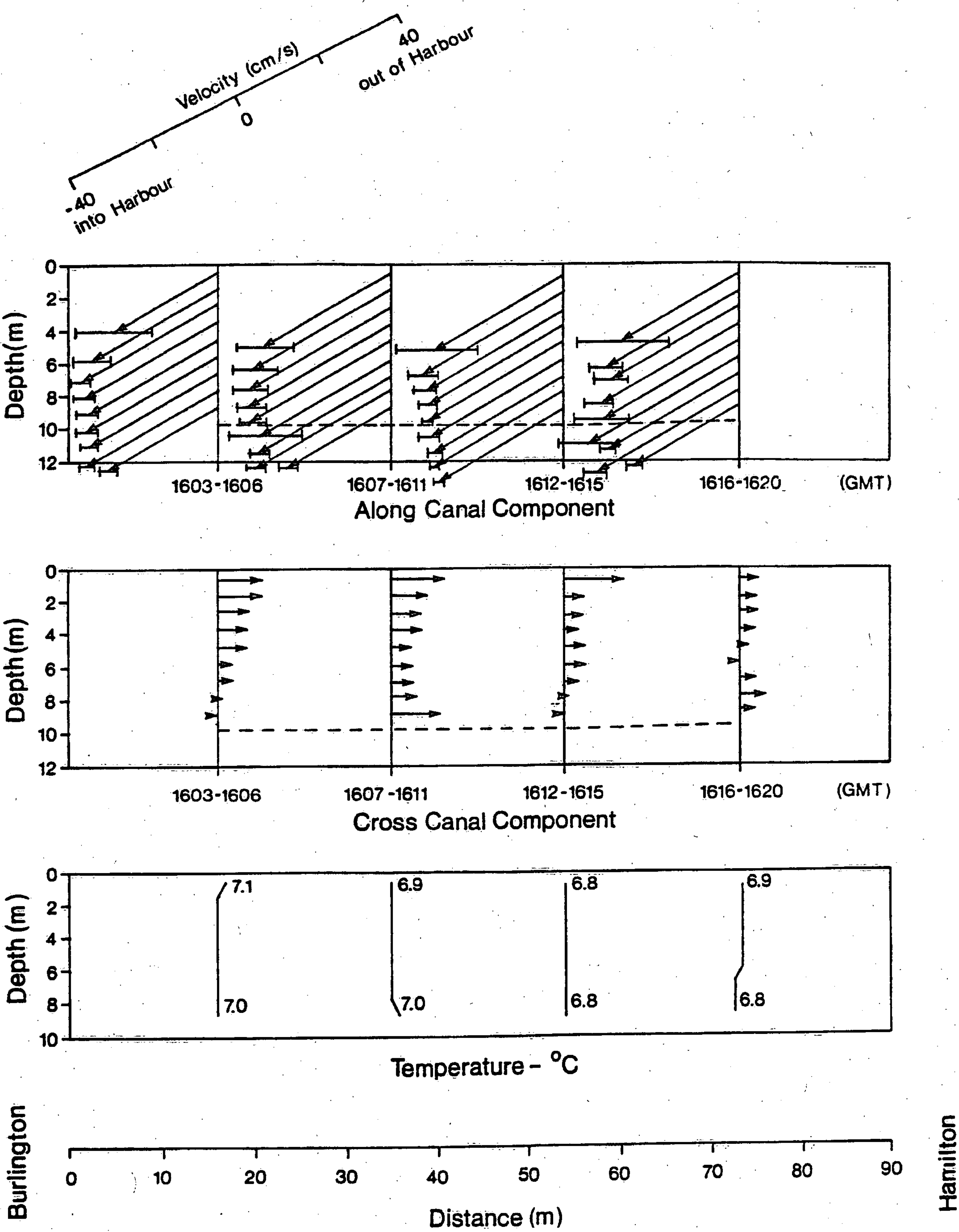
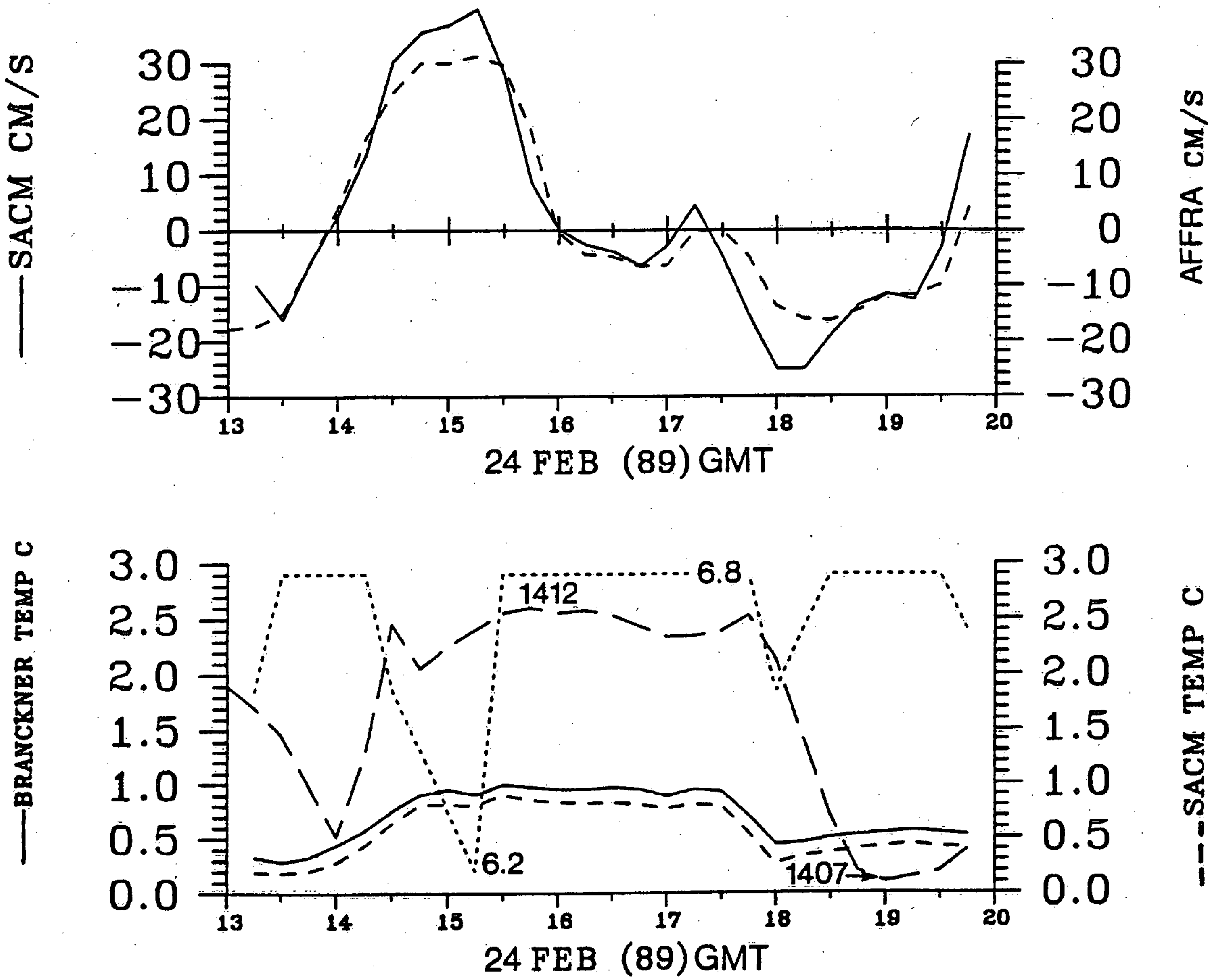
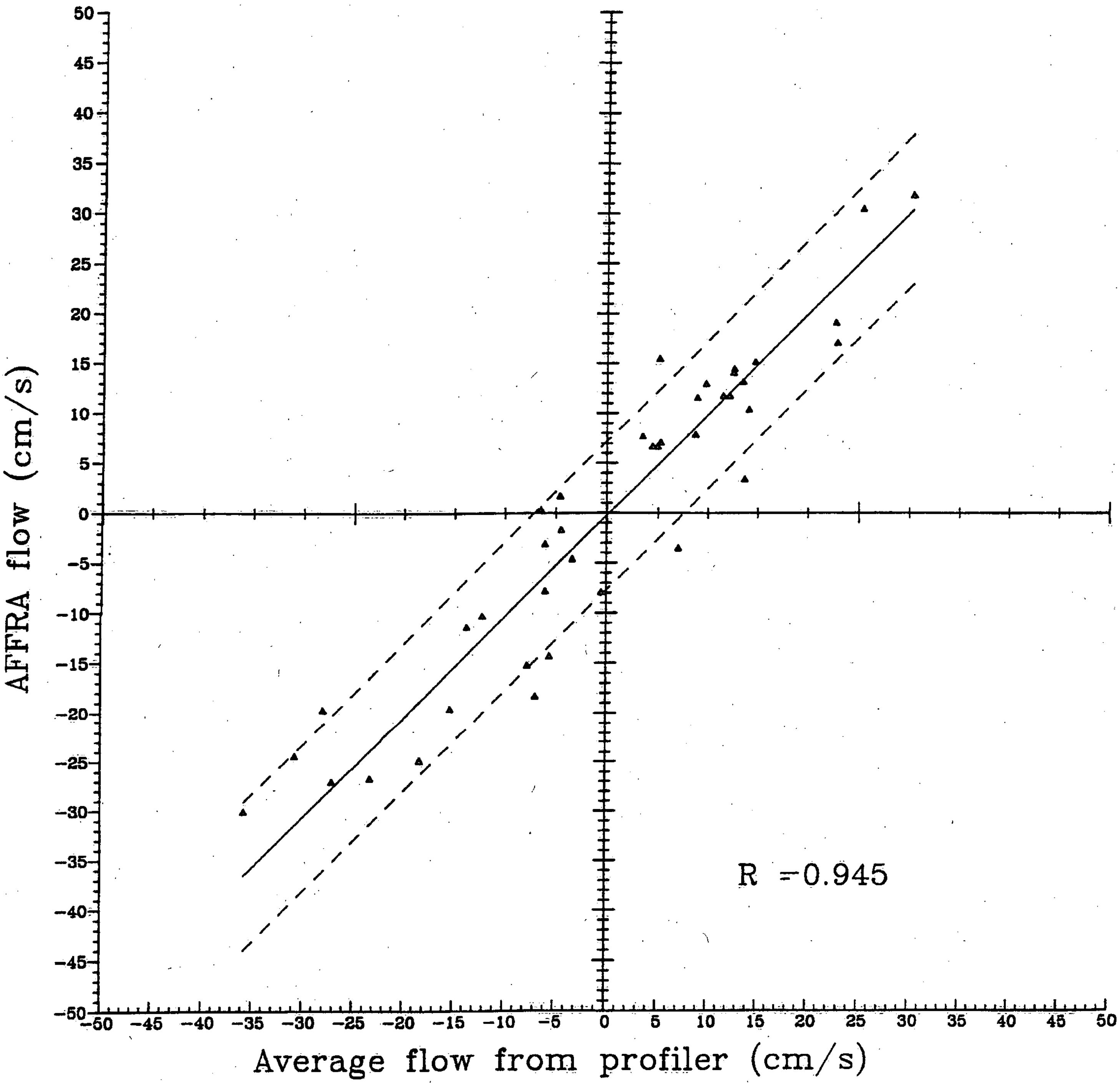


Figure 4



SACM CM/S
AFFRA CM/S
24 FEB (89) GMT
BRANCKNER TEMP C
SACM TEMP C
1412
6.8
6.2
1407
24 FEB (89) GMT

Figure 5



AFFRA flow (cm/s)
Average flow from profiler (cm/s)
R =0.945

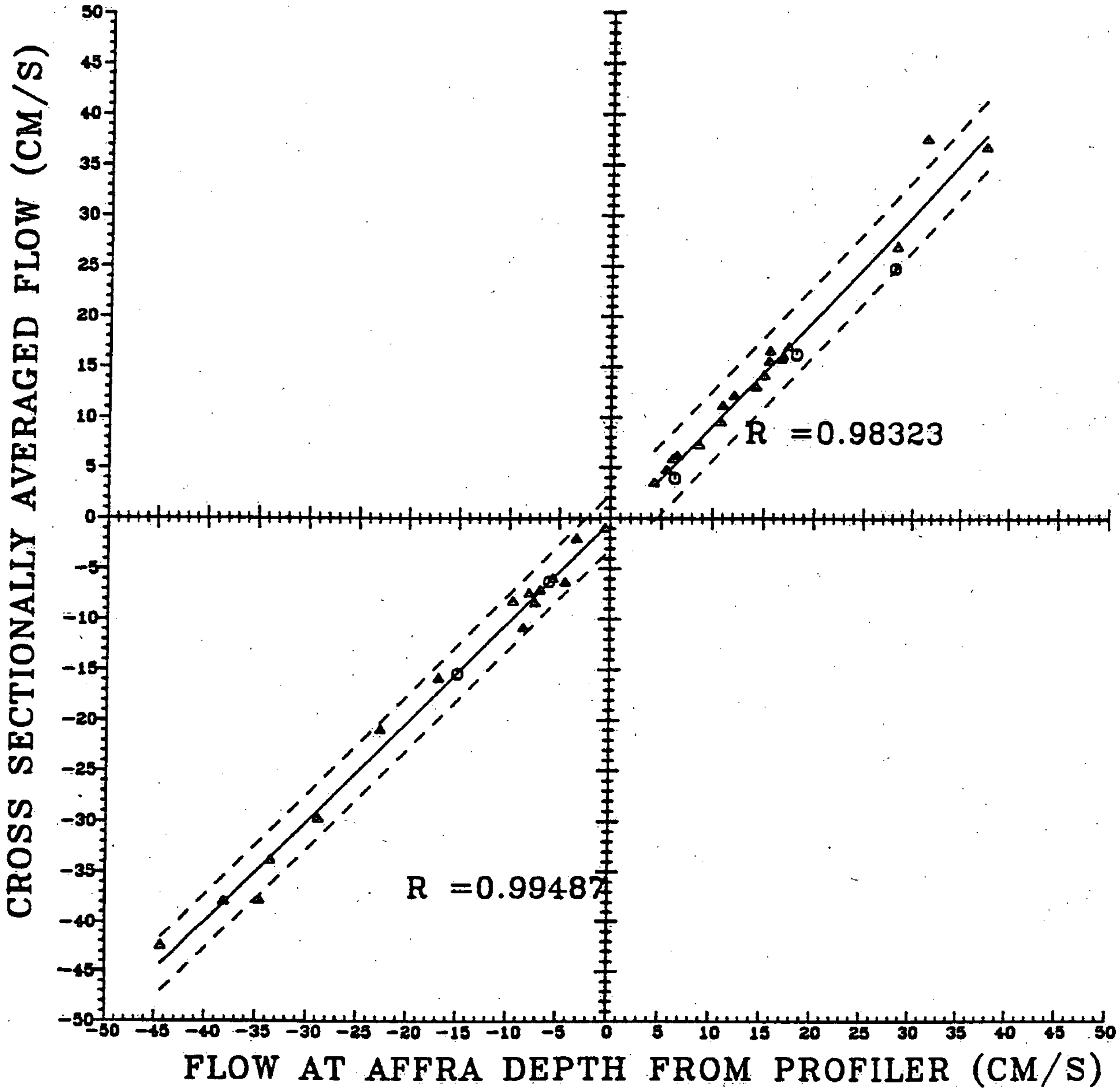

CROSS SECTIONALLY AVERAGED FLOW (CM/S)
FLOW AT AFFRA DEPTH FROM PROFILER (CM/S)
R =0.98323
R =0.99487
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50

Figure 7

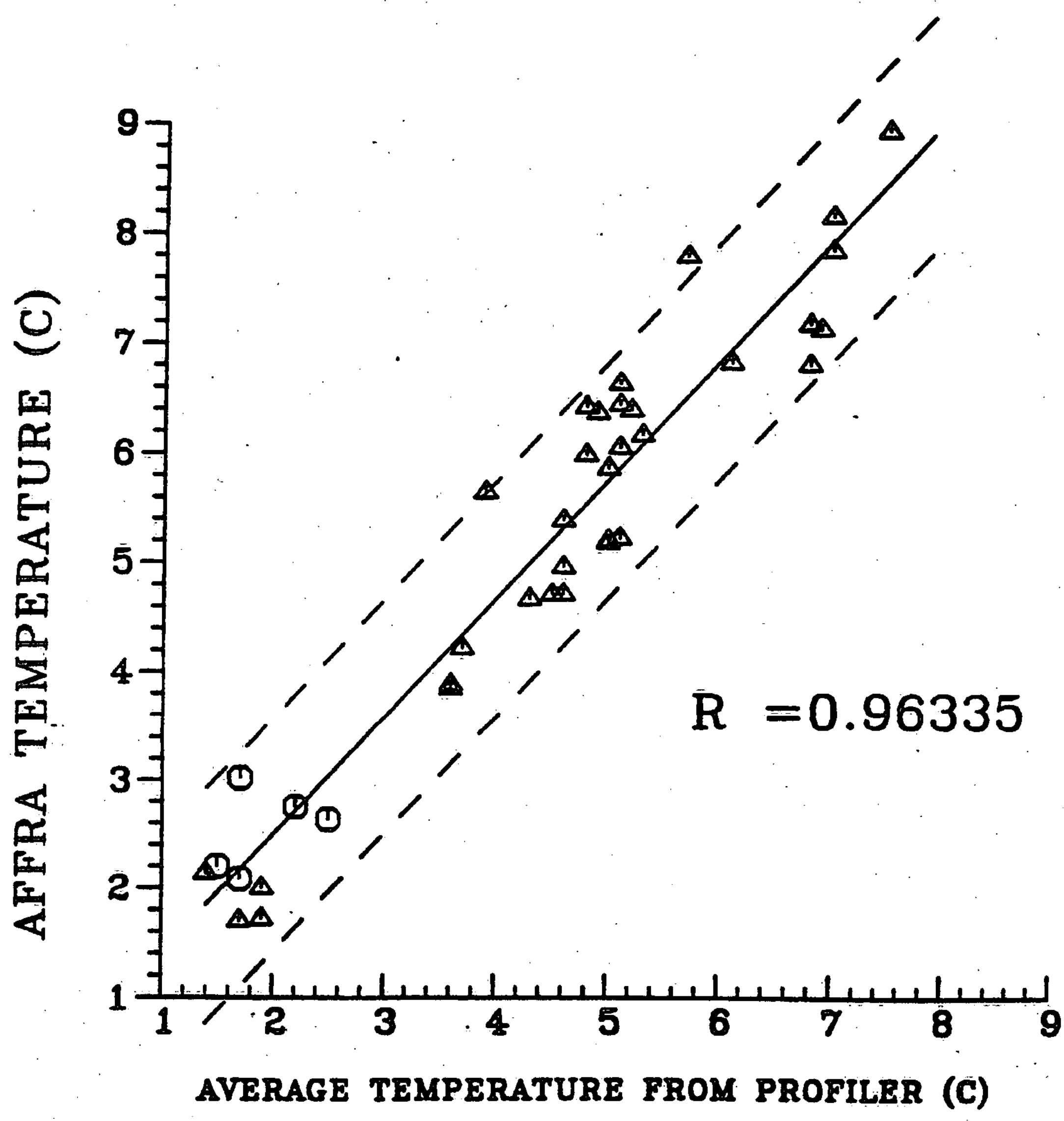

AFFRA TEMPERATURE (C)
R =0.96335
AVERAGE TEMPERATURE FROM PROFILER (C)

Figure 8

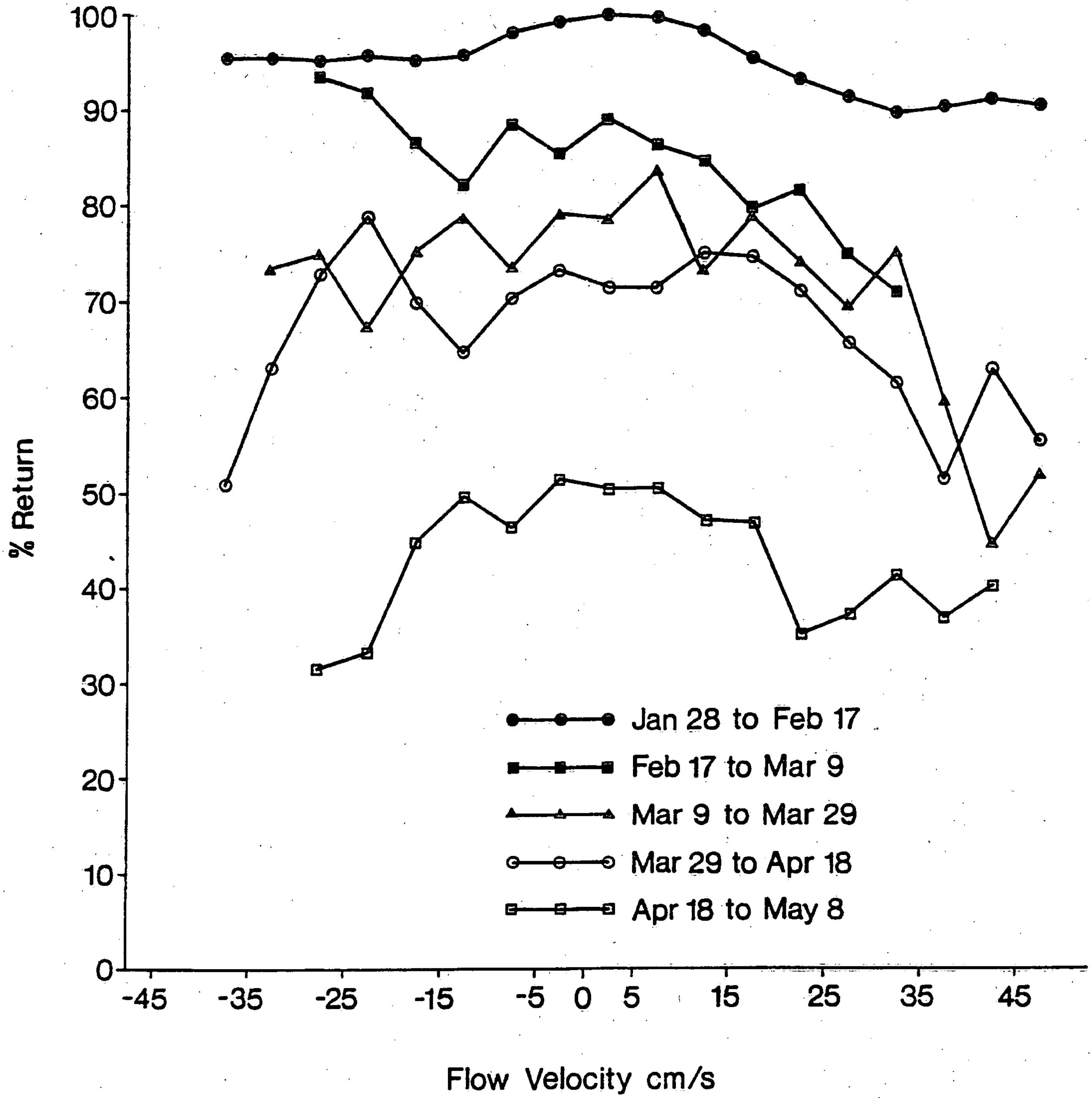

100
90
80
70
60
50
40
30
20
10
0
% Return
-45
-35
-25
-15
-5
0
5
15
25
35
45
Flow Velocity cm/s
Jan 28 to Feb 17
Feb 17 to Mar 9
Mar 9 to Mar 29
Mar 29 to Apr 18
Apr 18 to May 8

Figure 9

Environment Canada Environnement Canada

Canada

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