

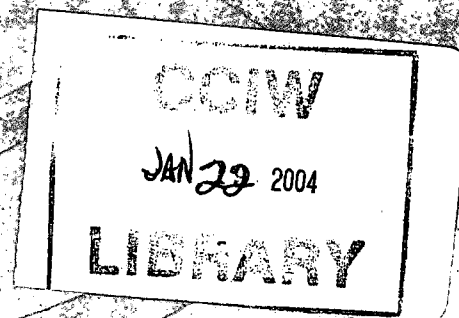
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**PHYSICAL PROCESSES IN WESTERN
LAKE ONTARIO RELEVANT TO TASTE AND
ODOUR EPISODES IN DRINKING WATER: 2002**

M.G. Skafel and R.R. Yerubandi

NWRI Contribution Number 03-175

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RELEVANT TO TASTE AND ODOUR EPISODES IN
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M.G. Skafel and R.R. Yerubandi

**Aquatic Ecosystem Management Research Branch
National Water Research Institute
Burlington, Ontario L7R 4A6**

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Physical processes in western Lake Ontario relevant to taste and odour episodes in drinking water: 2002

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Abstract

The nearshore currents and temperature structure of the western end of Lake Ontario were monitored during the summer of 2002. A downwelling event occurred during the period of elevated geosmin concentration in the intake waters of water treatment plants. The event was characterized by elevated water temperatures, onshore and cyclonic alongshore circulation. The downwelling was relatively poorly developed off Cobourg where the geosmin concentration was the least elevated. The downwelling event was stronger off Mississauga and Grimsby, where the geosmin concentrations were higher. The flow regime supports the hypothesis that the elevated geosmin concentrations originated in the warm offshore waters driven inshore and alongshore during a downwelling event. The same conclusion was reached in a field study conducted in 2000 and reported by Rao et al. (2003).

Processus physiques dans la partie occidentale du lac Ontario, associés à des épisodes de goût et d'odeur désagréables de l'eau potable : 2002

M.G. Skafel et R.R. Yerubandi

Résumé

Les courants et la structure des températures près du littoral de l'extrémité occidentale du lac Ontario ont fait l'objet d'un suivi au cours de l'été 2002. Un événement de plongée des eaux est survenu pendant la période où la concentration de géosmine était élevée dans la prise d'eau des stations de traitement. L'événement était caractérisé par des températures élevées de l'eau ainsi que par une circulation de l'air vers la rive et cyclonique le long de celle-ci. La plongée des eaux était relativement peu marquée au large de Cobourg, où la concentration de géosmine était la moins forte. La plongée était plus développée au large de Mississauga et de Grimsby, où les concentrations de géosmine étaient plus élevées. Le régime d'écoulement confirme l'hypothèse voulant que les concentrations élevées de géosmine soient générées dans les eaux tièdes du large poussées vers la rive et le long de celle-ci lors d'un événement de plongée des eaux. Une étude sur le terrain, effectuée en 2000 et décrite dans un rapport par Rao et al. (2003), en est arrivée à la même conclusion.

NWRI RESEARCH SUMMARY

Plain language title

Physical processes in western Lake Ontario relevant to taste and odour episodes in drinking water: 2002

What is the problem and what do scientists already know about it?

In late summer there is often a musty earthy taste and odour caused by geosmin in drinking water taken from the waters of western Lake Ontario. The Ontario Water Works Research Consortium (OWWRC) is leading a team investigating the origins and transport of geosmin.

Why did NWRI do this study?

This issue is a water quality issue with many unknown factors that need to be resolved before suitable solutions can be found.

What were the results?

This study has found that during 2002 the occurrence of the taste and odour event was coincident with a general downwelling along the northwestern shoreline and transport of warm offshore waters to the intakes of the affected water treatment plants.

How will these results be used?

The result supports the working hypothesis that the source of the geosmin is in the surface waters. This information will be used by researchers working on other aspects of the problem.

Who were our main partners in the study?

The main partners are the OWWRC, which include the OMOE, Ontario Clean Water Agency, and local regional agencies.

Sommaire des recherches de l'INRE

Titre en langage clair

Processus physiques dans l'ouest du lac Ontario associés à des épisodes de goût et d'odeur désagréables de l'eau : 2002.

Quel est le problème et que savent les chercheurs à ce sujet?

À la fin de l'été, on constate souvent que l'eau potable a un goût et une odeur de terre moisie causés par la présence de géosmine dans l'eau prélevée de la partie ouest du lac Ontario. L'Ontario Water Works Research Consortium (OWWRC) a constitué une équipe chargée de retracer l'origine et le transport de la géosmine.

Pourquoi l'INRE a-t-il effectué cette étude?

Ce problème est un problème de qualité de l'eau dans lequel interviennent plusieurs facteurs inconnus qui devront être résolus avant que des solutions acceptables puissent être trouvées.

Quels sont les résultats?

Cette étude a révélé qu'en 2002, l'épisode où l'eau avait un goût et une odeur désagréables a coïncidé avec un phénomène général de plongée des eaux le long de la rive nord-ouest et de transport d'eaux moins froides du large vers les prises d'eau des stations de traitement de l'eau touchées.

Comment ces résultats seront-ils utilisés?

Les résultats appuient l'hypothèse de travail voulant que les eaux de surface soient la source de la géosmine. Ces données seront utilisées par des chercheurs qui travaillent sur d'autres aspects du problème.

Quels étaient nos principaux partenaires dans cette étude?

Les principaux partenaires sont l'OWWRC, qui comprend le ministère de l'Environnement de l'Ontario, l'Agence ontarienne des eaux, et des organismes régionaux.

Introduction

Lake Ontario is an important source of drinking water for millions of consumers. During late summer drinking water from Lake Ontario is susceptible to undesirable properties of earthy taste and odour (T/O). The occurrence of objectionable taste and odour is caused by both anthropogenic and naturally produced chemicals (Ridal et al. 2000). The most commonly identified biological causes of taste and odour events are two moderately volatile metabolites of certain micro-organisms, geosmin and 2-methylisoborneol (MIB). These metabolites can be produced by cyanobacteria and/or actinomycetes in diverse aquatic and terrestrial habitats. Both geosmin and MIB are discernable at extremely low threshold levels (Young et al. 1996) and are widely occurring in lakes and rivers. They resist oxidation and are therefore difficult to remove with typical drinking water treatment.

In the Great Lakes, both production and transport of these metabolites are influenced by large scale meteorological forcing, watershed, basin, diffuse/point source loading and hydrological processes. In response to severe T/O episodes in 1998 and 1999 in western Lake Ontario, a multi-disciplinary research team (Watson et al. 2002) was established to identify the biological sources and environmental triggers of these events, and to develop predictive and remedial tools. Early work identified an abrupt increase in geosmin concentration coinciding with T/O problems in drinking water along the northwestern shores of Lake Ontario. Geosmin production is observed to be indigenous, peaks annually, but only periodically at nuisance levels, and is hypothesized to originate from offshore planktonic cyanobacteria. Based on the evidence of geosmin concentrations and water temperatures at the intakes it was hypothesized that the strong downwelling may favour the transport of geosmin produced at offshore locations to nearshore areas causing the T/O problem.

In 2000 an intensive field investigation was undertaken in the western end of Lake Ontario to gain new information about the source and distribution of geosmin in the coastal waters. As part of that investigation, current meters and temperature sensors were deployed in the vicinity of several water treatment plant intakes as well as other locations. That investigation is reported in Rao et al. 2003, and confirms the correlation of a T/O event (albeit at low concentrations) with a downwelling event along the northwestern shore.

In 2002 another intensive investigation was carried out, and again current meters and temperature sensors were deployed at selected locations. This report documents the circulation and thermal regime and provides another data set to test the hypothesis of offshore produced geosmin being transported onshore during a T/O event.

General Physical Background

The thermal structure and circulation in the Great Lakes generally depends on the season because of the large annual variation of surface fluxes (Boyce et al. 1989). In the

summer and fall there is a distinct thermocline in the upper 30 m in most of the lakes which makes them stratified. During this period of stratification, significant wind events will cause upwelling and downwelling of the thermocline along the shore. The scale of the offshore distance over which these events takes place depends on the wind stress and nearshore bathymetry, and is typically of the order of 5 to 10 km, hence within the coastal boundary layer. During the summer stratified season the temperature variations along the northwest shore of Lake Ontario were found to be linked to the wind, with winds from the westerly direction causing upwelling and cooling, and easterly winds inducing downwelling and warming. Previous studies revealed that the flow and structure within the coastal boundary layer along the north shore of Lake Ontario presents a complex scenario during upwelling and downwelling episodes. The upwelling events are characterized by relatively weak easterly flow, and downwelling events with strong westward currents, sometimes associated with the propagation of internal Kelvin waves due to thermocline oscillations (Simons and Schertzer 1989, Rao and Murthy 2001).

Field Deployment

During the summer of 2002 three pairs of stations were established, one pair each off Cobourg, Mississauga and Grimsby, see Figure 1. Each pair comprised an inshore and offshore station, with a current meter and fixed temperature loggers (FTP) at each. An Acoustic Doppler Current Profiler (ADCP) was deployed at each station except inshore at Grimsby where a Nobska MAVS single point meter was deployed. Similarly, temperature loggers were typically located at 5 m intervals on FTPs except inshore at Grimsby where the temperature sensor on the MAVS current meter was used. Details of the stations are given in Table 1. The reported accuracy of the ADCPs is $0.25\% \pm 2.5$ mm/s and that of the MAVS is 3 mm/s. Several different temperature sensor types were used on the FTPs, but all are accurate to 0.15°C or better. All sensors recorded data at time intervals of 20 minutes or one hour. The east and north velocities were resolved into alongshore and cross-shore components, with positive alongshore values to the east and positive cross-shore values onshore. With this convention, the onshore values at Grimsby are southerly in contrast to the other two stations where they are northerly.

Wind data were obtained from routine observations at Toronto Island Airport, Kingston, Trenton, Cobourg, Burlington, and Port Weller collected by the Meteorological Service of Canada, Environment Canada. The data from the Toronto Island Airport were used as the primary wind data set. The wind stress at the water surface was computed by the quadratic law given as $\tau = \rho_a C_d |W|W$, where $\rho_a = 1.2 \text{ kg/m}^3$ is the air density, W is the wind velocity [m/s]. In general, the drag coefficient C_d increases with the wind speed and is estimated as $C_d = (0.8 + 0.065 W) \times 10^{-3}$ for $W > 1 \text{ m/s}$ (Wu 1980). The stresses were decomposed into alongshore and cross-shore using the general orientation of the shoreline as 80°T at Toronto Island Airport. At Kingston, Trenton, and Burlington the overall orientation of the lake (80°T) was used because the first two are inland and the last is at the end of the lake. The alongshore direction at Cobourg was also taken as 80°T , and at Port Weller 65°T .

Geosmin concentrations in raw water collected at water treatment plants at Cobourg, Toronto (R L Clark) and Grimsby were measured over the summer and fall. The sampling interval was approximately weekly. The samples were analyzed for geosmin by high resolution mass spectrometry using Ontario Ministry of the Environment standard method for taste and odour compounds (Palmentier et al. 1998).

Field Data and Discussion

As noted in Rao et al. (2003), the geosmin peak in drinking water typically occurs in late August or early September. Therefore in this paper, the currents and the thermal structure of the lake were analyzed from Julian Day 220 to 270 (8 August to 27 September). Following Rao et al. (2003), the 10°C isotherm is used to identify upwelling and downwelling events.

The wind stress for all stations filtered at 24 hours are plotted in Figure 2. The alongshore wind stress was typically stronger than the cross-shore stress, except for the event on Day 255 when there was a very strong northerly wind. There were two easterly wind events, on Days 234-237 and Days 240-242 that were important in the development of the downwelling along the north shore. These events are quite clear on all the time series at the western end of the lake. Towards the east at Trenton and Kingston (and to some extent Cobourg) the event was weaker. These data suggest that the wind field was relatively homogeneous at the western end of the lake during these events, but was diminished in strength towards the eastern end of the lake.

In Figures 3, 4, and 5 the upper panel shows the Toronto wind stress (not filtered) and the thermal structure offshore (a) and inshore (b) at Cobourg, Mississauga and Grimsby respectively. Comparison of the wind stress and temperature data shows that the variability of the thermal structure is associated with the prevailing winds. Upwelling events are caused by winds from the west and downwelling events caused by winds from the east. Starting about Day 235, in response to the easterly wind event (starting on Day 234), there was a depression of the thermocline first at Cobourg and following within the day at Mississauga and Grimsby, indicating a downwelling event. There was a noticeable relaxing about Day 247 at Cobourg in response to the westerly wind event, it was less pronounced at Mississauga, but more evident at Grimsby a few days later, about Day 250. A second westerly wind event starting at about Day 255 marked the end of the downwelling event and the start of an upwelling event at all three stations, although Grimsby lagged behind the other two. The isotherms show oscillations at about the inertial period (~17 hours) throughout the observation period, which is common during the summer stratified season. Based on these temperature data, the downwelling event was defined to occur from Day 235 to Day 247.

The isotherms off Mississauga on Day 248, developed from four profiles measured that day are shown in figure 6. The depression of the isotherms near the bottom indicates that the warm surface water was being forced downward at the shoreline, characteristic of a downwelling event.

Figure 7 shows the time series of the low-pass filtered (>24 h) currents at 5 m below the surface (7a) and at the bottom (7b) at the offshore stations (at 33 in 71 m of water at Mississauga offshore). The alongshore currents were comparatively stronger than cross-shore currents at all stations. As in 2000 (Rao et al. 2003), the alongshore currents show that the low-frequency oscillations (>3 days) were dominant and were related to alongshore wind stress. The persistent deepening of the isotherms in Figures 3 to 5 from Day 235 to Day 247 are matched by continuous westward and onshore flow in the surface waters at Mississauga and eastward and on shore at Grimsby, as one might expect. However, at Cobourg the westward flow was interrupted by two eastward events (Days 238 and 242), and the onshore flow was not persistent, indicating the downwelling event was not as vigorous there. The alongshore flow at the bottom was westward at Mississauga and eastward at Grimsby, but mixed at Cobourg during the event time period. The onshore-offshore flows at the bottom were small and mixed in direction at Cobourg and Mississauga, but consistently onshore, although small, at Grimsby.

Figure 8 shows the corresponding time series at 5 m below the surface (8a) and at the bottom (8b) at the inshore stations (there is only one depth inshore at Grimsby). Whereas the two westerly directed wind pulses on Days 236 and 242 produced a continuous downwelling event offshore at Mississauga and Grimsby, at the inshore stations the current responded much more quickly and as a result two separate downwelling events were observed, separated by an upwelling event, similar to both offshore and inshore at Cobourg.

In Figure 9 the mean values of the velocity components at the offshore stations are shown for the duration of the event, Day 235 to 247. The cross-shore flow at the surface was onshore everywhere, and at depth the mean flow was offshore at Cobourg and Mississauga, but onshore at Grimsby. The onshore flow at Grimsby is in contrast to the offshore flow at Port Dalhousie reported in Rao et al. 2003. The alongshore flow was counterclockwise everywhere although it was very small at Cobourg. (Recall that Grimsby is on the south shore so that positive alongshore current is cyclonic, consistent with the other two stations, and that onshore here is to the south in contrast to the other two stations where onshore is to the north.) The spatial extent of the downwelling feature appears to start somewhere near Cobourg and extend around the western end of the lake to east of Grimsby on the south shore.

The mean velocity profiles for the whole summer (about Day 110 to 290) and for the event period (Day 235 to 247) are shown in Figure 10 for the offshore stations. Examining the cross-shore flow first, at Cobourg over the summer the flow was onshore to 25 m and modestly offshore below that. During the event period the flow was similar but at lower intensity onshore and slightly higher offshore at the lower depths. At Mississauga the summer flow was small and onshore; during the event there was a pronounced onshore flow near the surface reversing to offshore below about 10 m. At Grimsby there was a modest onshore flow all summer which was greatly enhanced during the event. The alongshore flows were westward both for the whole summer and the event period at Cobourg and Mississauga and eastward at Grimsby. At Cobourg the

alongshore flow was much less during the event than the summer mean. In contrast at Mississauga and Grimsby the event flow was much stronger than the whole summer mean flow.

The inshore mean profiles for the same periods are shown in Figure 11. At Cobourg there was a modest increase near the surface of the onshore flow and some offshore flow near the bottom during the event. At Mississauga the flow was modestly offshore near the surface and onshore below about 5 m for the summer. During the event the flow was smaller and onshore down to about 10 m, below that it was offshore. Inshore at Grimsby there was only one meter. Throughout the summer the mean flow was onshore, and the net onshore-offshore transport vanished during the event. Alongshore at Cobourg the mean summer flow was westward below 5 m with a trend that suggested eastward flow neared the surface. During the event the mean flow was very small and to the east from 5 to 12 m and westward below that. At Mississauga the summer mean alongshore flow was eastward to 10 m and westward below that. During the event the flow was smaller to the east down to about 6 m then westward below that. At Grimsby the summer flow was to the west, and also during the event, but at a much smaller speed. Overall the flows at the inshore stations were much smaller magnitudes than at the offshore stations. These flows did not show the typical downwelling characteristics as well as the offshore stations, in part due to their locations very close to the shore.

The records of geosmin concentration at the intakes of the water treatment plants are shown in Figure 12. Both Toronto and Grimsby show a clear peak between Day 246 and 253. The concentrations peaked at only about 10 ng/L, marking a relatively minor taste and odour event. These concentration peaks occurred at the end of the downwelling event as defined earlier. The physical data suggest that the downwelling event was not strong at Cobourg, that is, the flux of warm offshore surface water was not large. At Cobourg, the event was almost non-existent; no values were reported above about 4.

The surface temperatures of Lake Ontario are shown in Figure 13 for Day 246. The surface waters are above 20°C along the north shore and around the west end of the lake along the south shore as far east as the mouth of the Niagara River. There is evidence of cool upwelling waters along the southeast shore. The lake wide surface temperature distribution is consistent with the temperature observations made during this study.

Conclusions

The current and temperature measurements in 2002 along the north and west shores of Lake Ontario showed upwelling and downwelling of the thermocline. Upwelling was caused by winds from the west generating eastward and offshore flows, and downwelling and strong westward current were caused by winds from the east. The well developed downwelling event from Day 235 to 247 at Mississauga was confirmed by the depressed temperature contours, strong alongshore currents to the west at all depths, and strong onshore flow in the surface waters and offshore flows at depth. This downwelling

correlated with the rise in geosmin concentration at the water treatment plant in Toronto. The geosmin peaked on Day 253, which was after downwelling had stopped (on about Day 245), but the warm waters remained nearshore because the flows were nearly zero until Day 250). The downwelling at Cobourg was relatively strong in terms of thermocline displacement, but poorly defined in terms of flow. The cross-shore flows at Grimsby were onshore throughout the profile and strongest near the surface. Flows alongshore were strongly eastward, which correspond to the westward flow at Mississauga. The geosmin peak at Grimsby occurred on Day 246, within the downwelling event period (235-247).

The 2002 current and temperature data support the hypothesis that a taste and odour event with elevated geosmin concentrations is correlated with a downwelling event along the northwest shore of Lake Ontario. The downwelling was not well established at Cobourg where the geosmin concentrations were low. Although the flow at Grimsby was not classically downwelling, but in a transition between that and upwelling, the flow was of warm surface water flowing onshore and alongshore from the area of strong downwelling around Mississauga, and so also supports the hypothesis.

Acknowledgements

The staff of Engineering Services supplied and prepared the instrumentation, and Technical Operations Services deployed and recovered them. One ADCP and the Geosmin concentration data were supplied by T Howell, MOE. The temperature profile data off Mississauga were provided by M Charlton and T Mamone. D Doede provided technical and data reduction support. Partial funding was provided by the Ontario Water Works Research Consortium.

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Table 1 Deployment Data

Station Number	Name	Location	Depth [m]	Current depths [m]	FTP depths [m]	Angle of shoreline from North [°T]
1	Cobourg inshore	ADCP 43 56 41N 78 09 47W FTP 43 56 37N 78 09 59W	15	13 and 1 m intervals to surface	5, 10	80
2	Cobourg offshore	ADCP 43 55 23N 78 09 19W FTP 43 55 26N 78 09 28W	30	29 and 1 m intervals to surface	5, 10, 15, 20, 25, 30	80
3	Mississauga inshore	ADCP 43 33 16.7N 79 32 09.1W FTP 43 33 16N 79 32 02W	17	15 and 1 m intervals to surface	5, 10, 15	40
4	Mississauga offshore	ADCP 43 27 55N 79 31 37W FTP 43 27 50N 79 31 31W	71	33 and 1 m intervals to surface	5, 10, 15, 20, 25, 30, 35, 45, 55, 65	40
5	Grimsby inshore	MAVS 43 12 12N 79 31 48W	7.3	6.3	6.3	100
6	Grimsby offshore	ADCP 43 15 10N 79 31 23W FTP 43 15 07N 79 31 38W	30	29 and 1 m intervals to surface	5, 10, 15, 20, 25	100

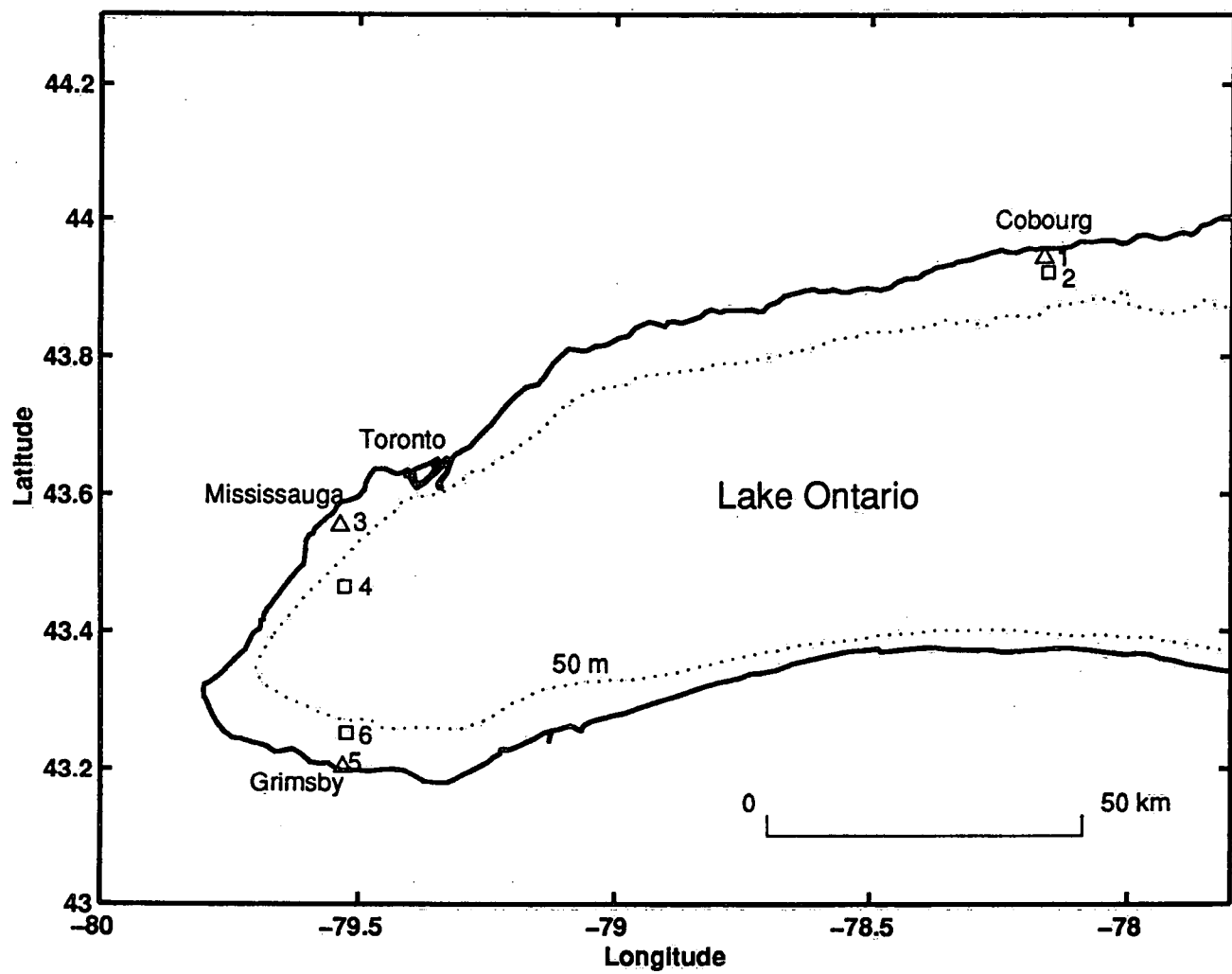


Figure 1. Location map of stations listed in Table 2.

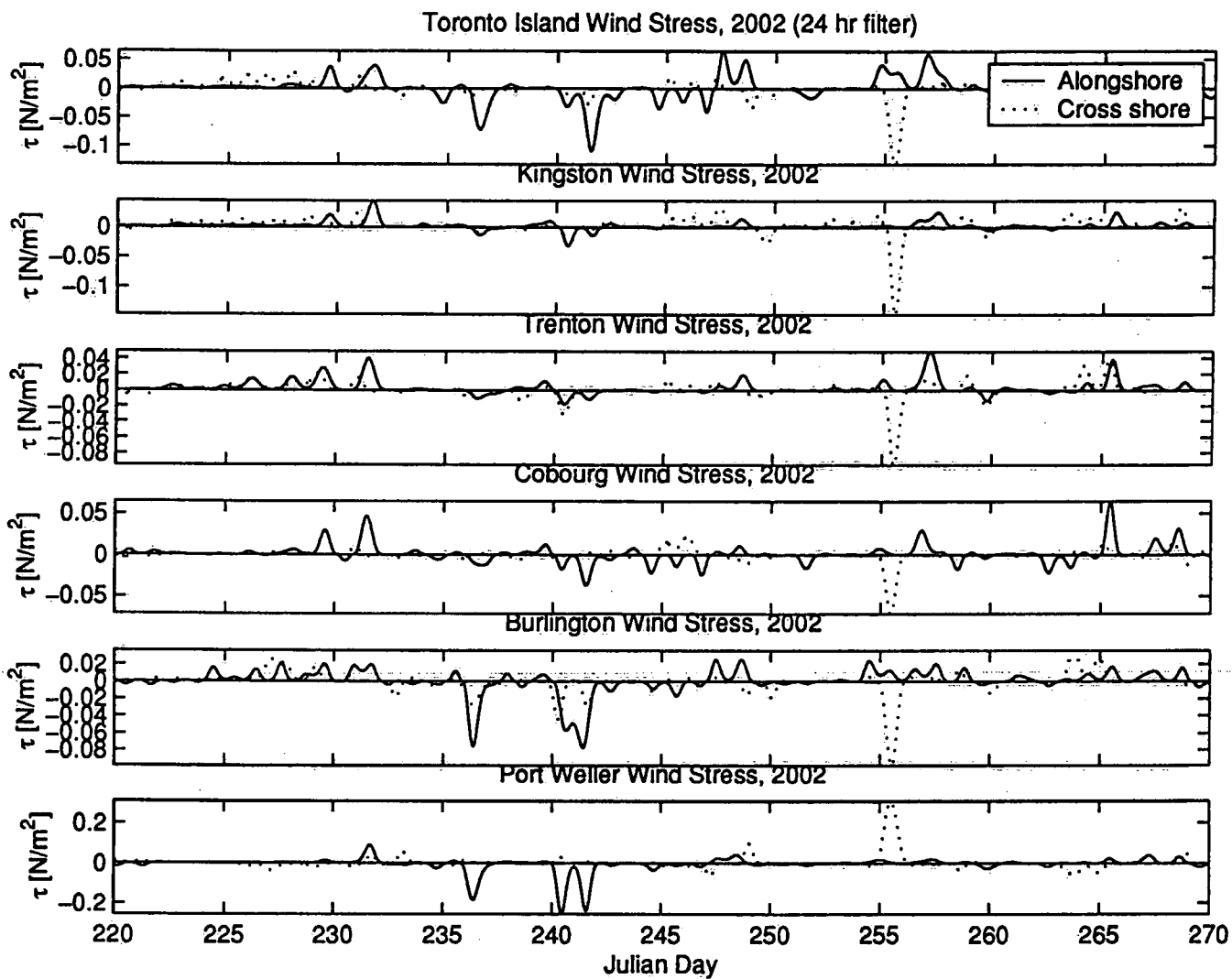


Figure 2. Alongshore and cross-shore (or as noted in the text) wind stress at six meteorological stations.

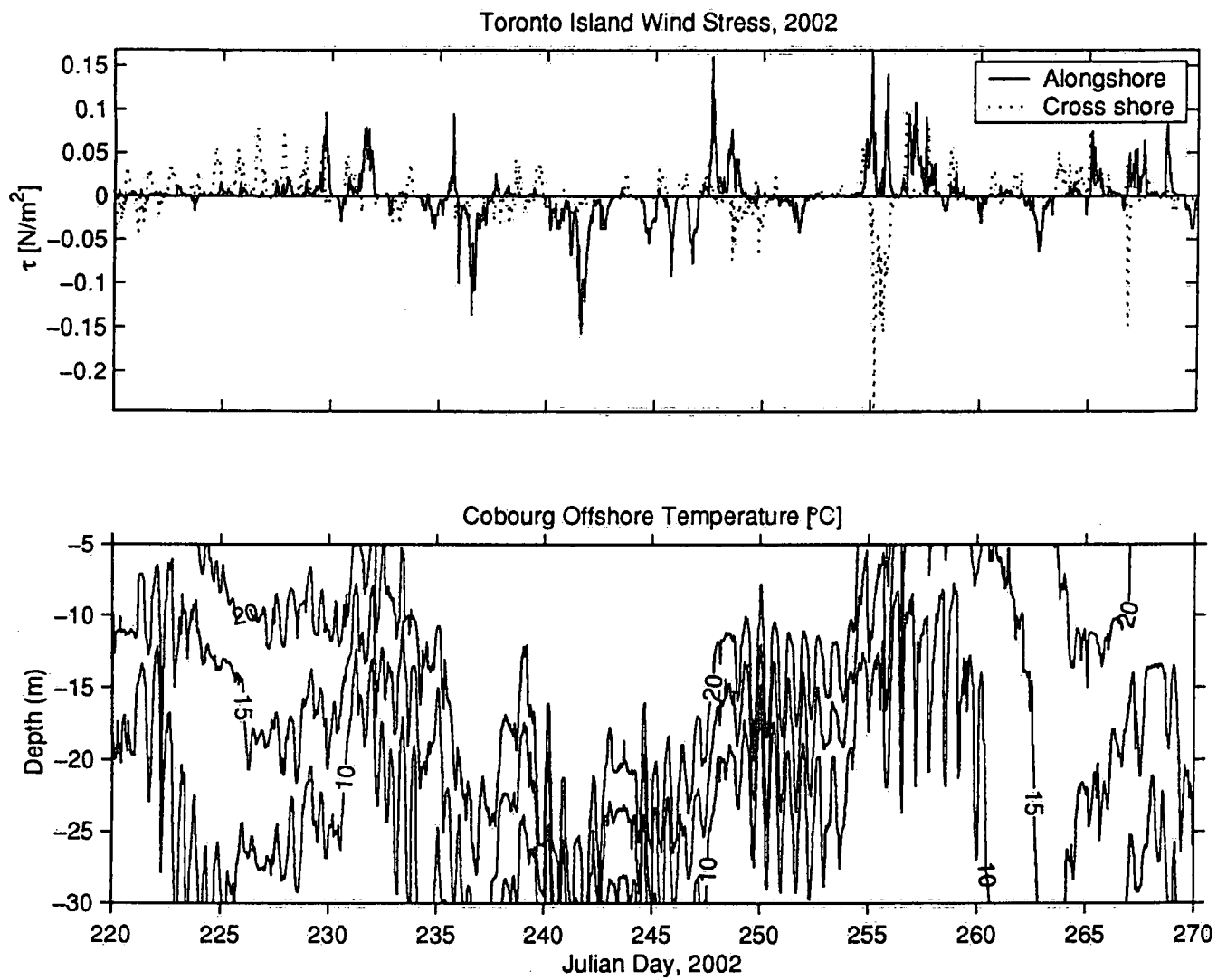


Figure 3a. Toronto Island wind stress and water temperature at the Cobourg offshore station.

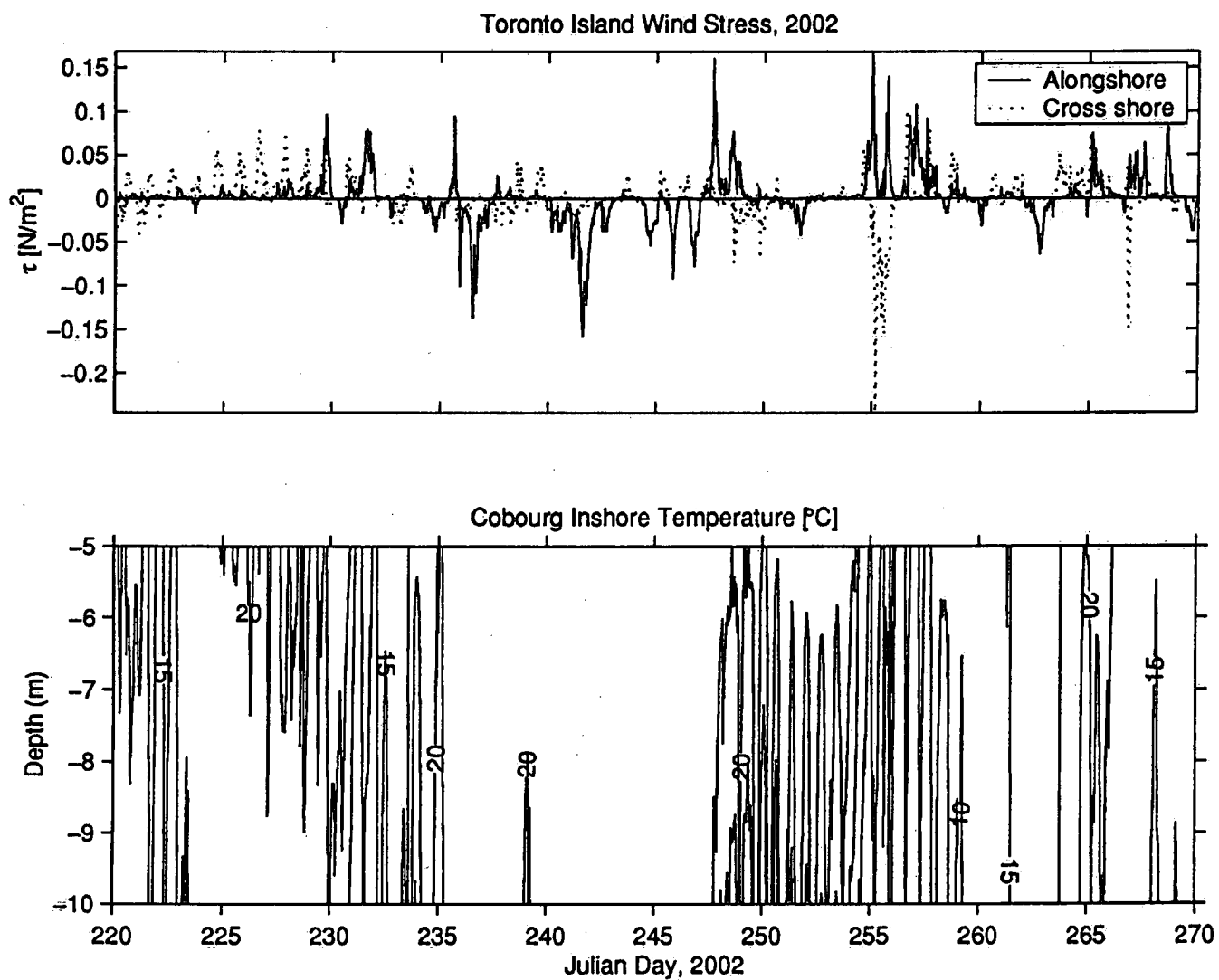


Figure 3b. Toronto Island wind stress and water temperature at the Cobourg inshore station.

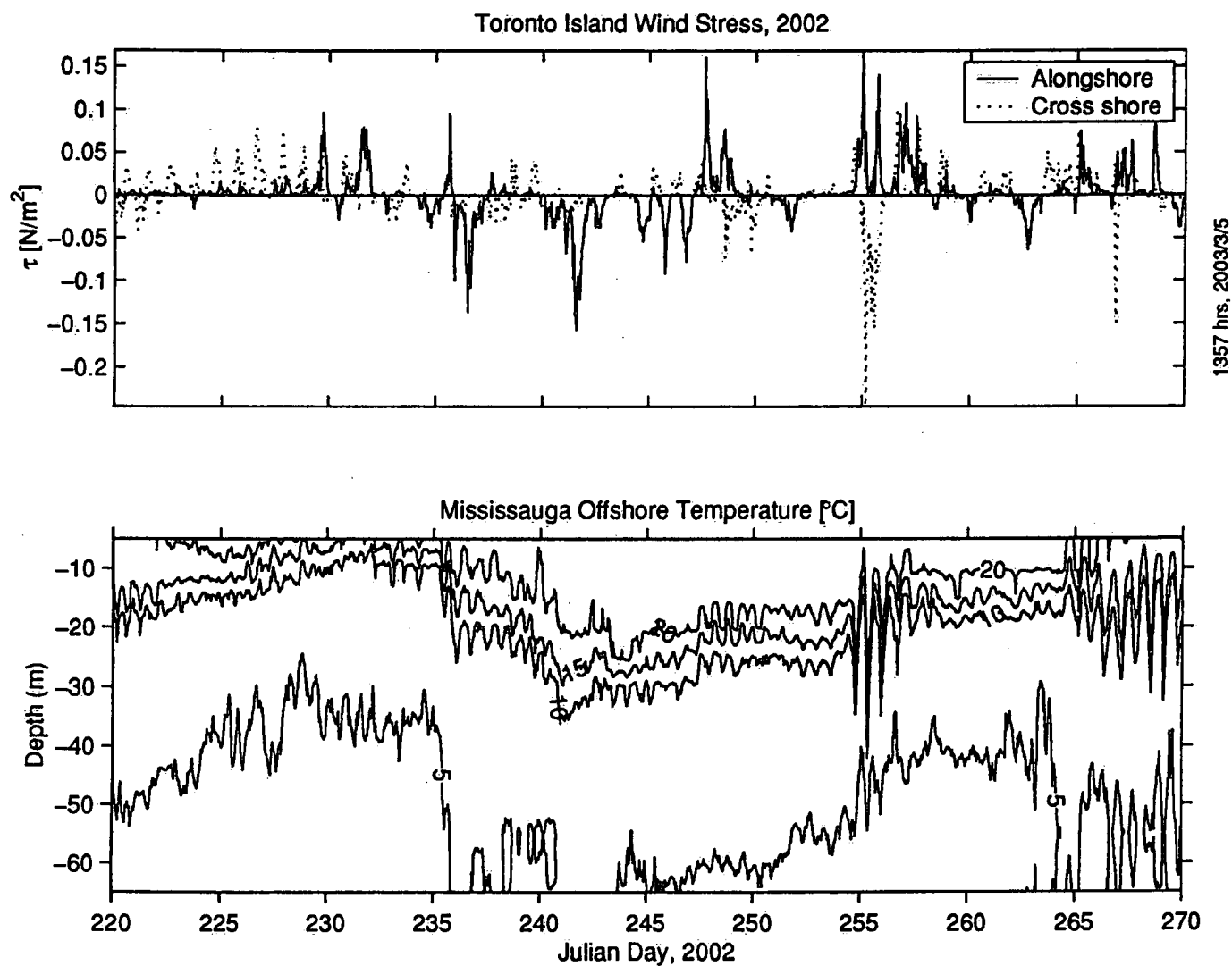


Figure 4a. Toronto Island wind stress and water temperature at the Mississauga offshore station.

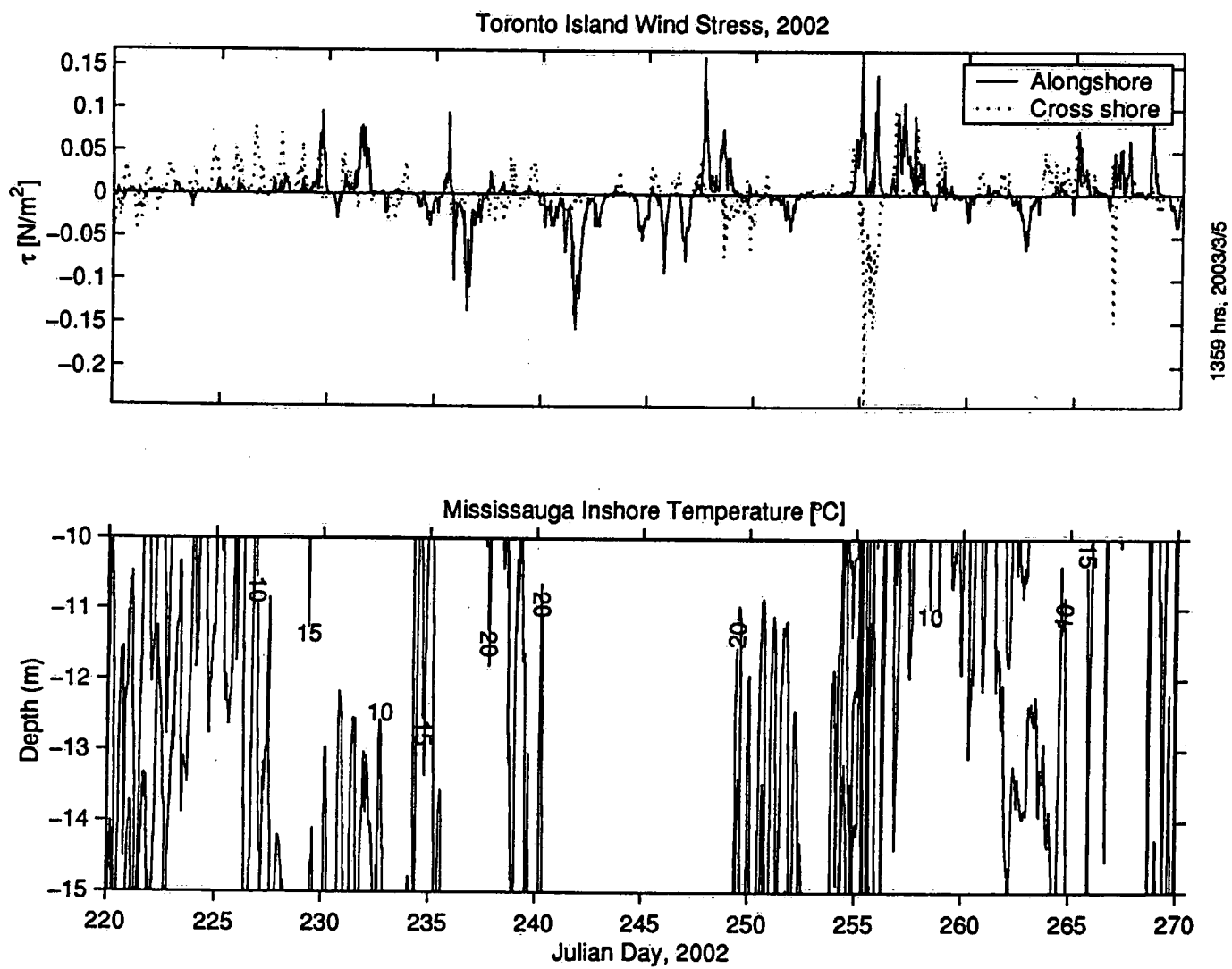


Figure 4b. Toronto Island wind stress and water temperature at the Mississauga inshore station.

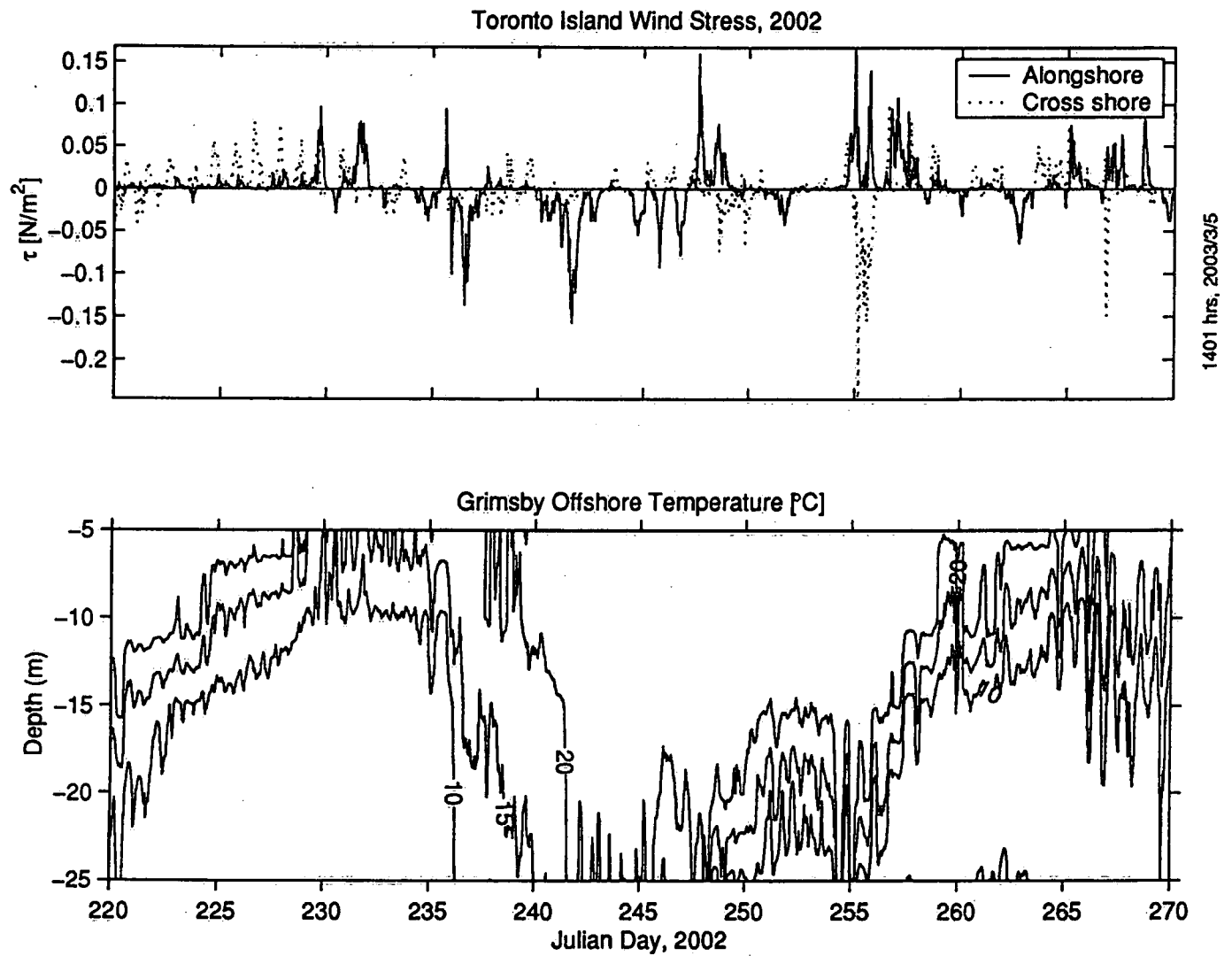


Figure 5a. Toronto Island wind stress and water temperature at the Grimsby offshore station.

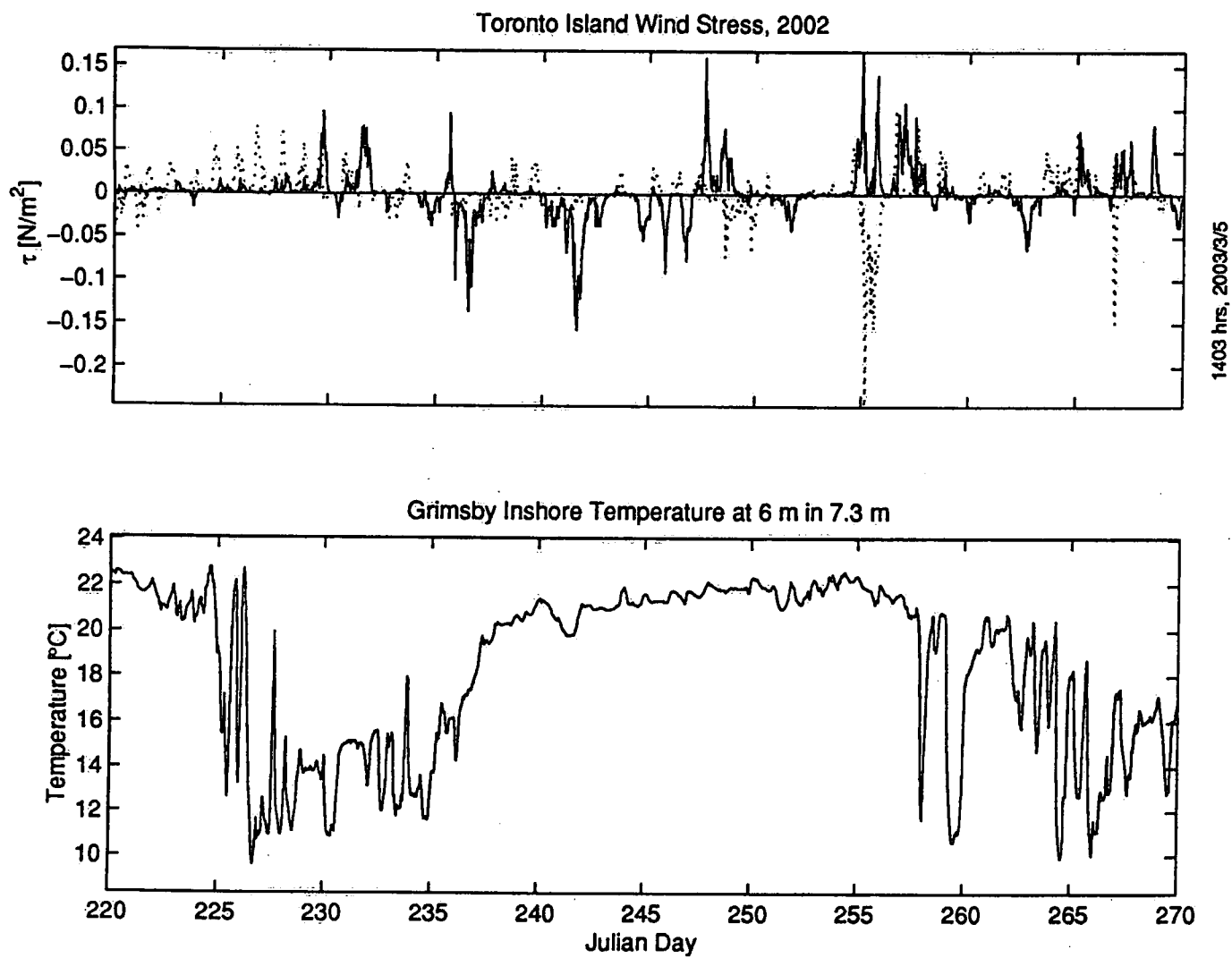


Figure 5b. Toronto Island wind stress and water temperature at the Grimsby inshore station.

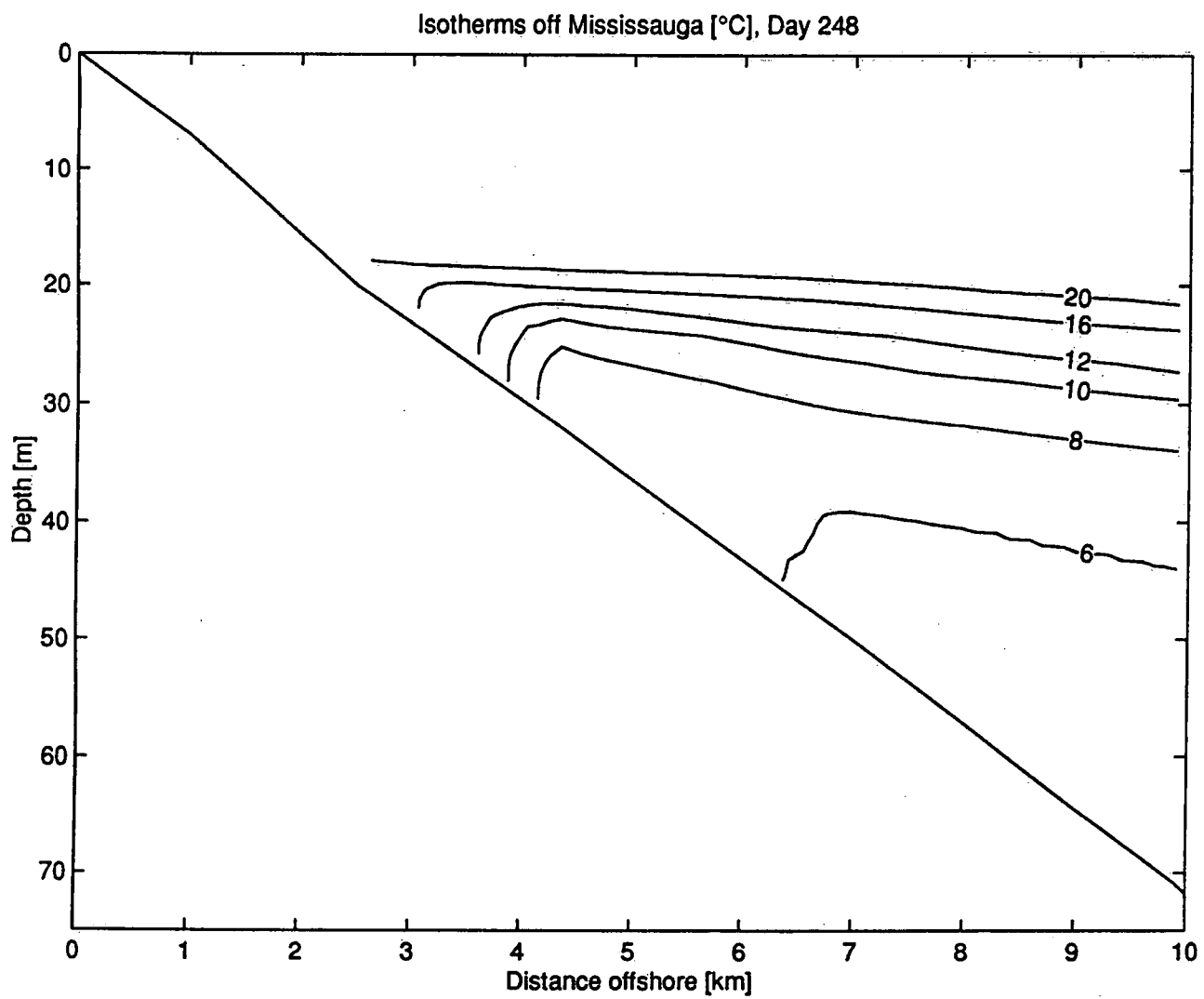


Figure 6. Isotherms off Mississauga on Day 248, derived from temperature surveys.

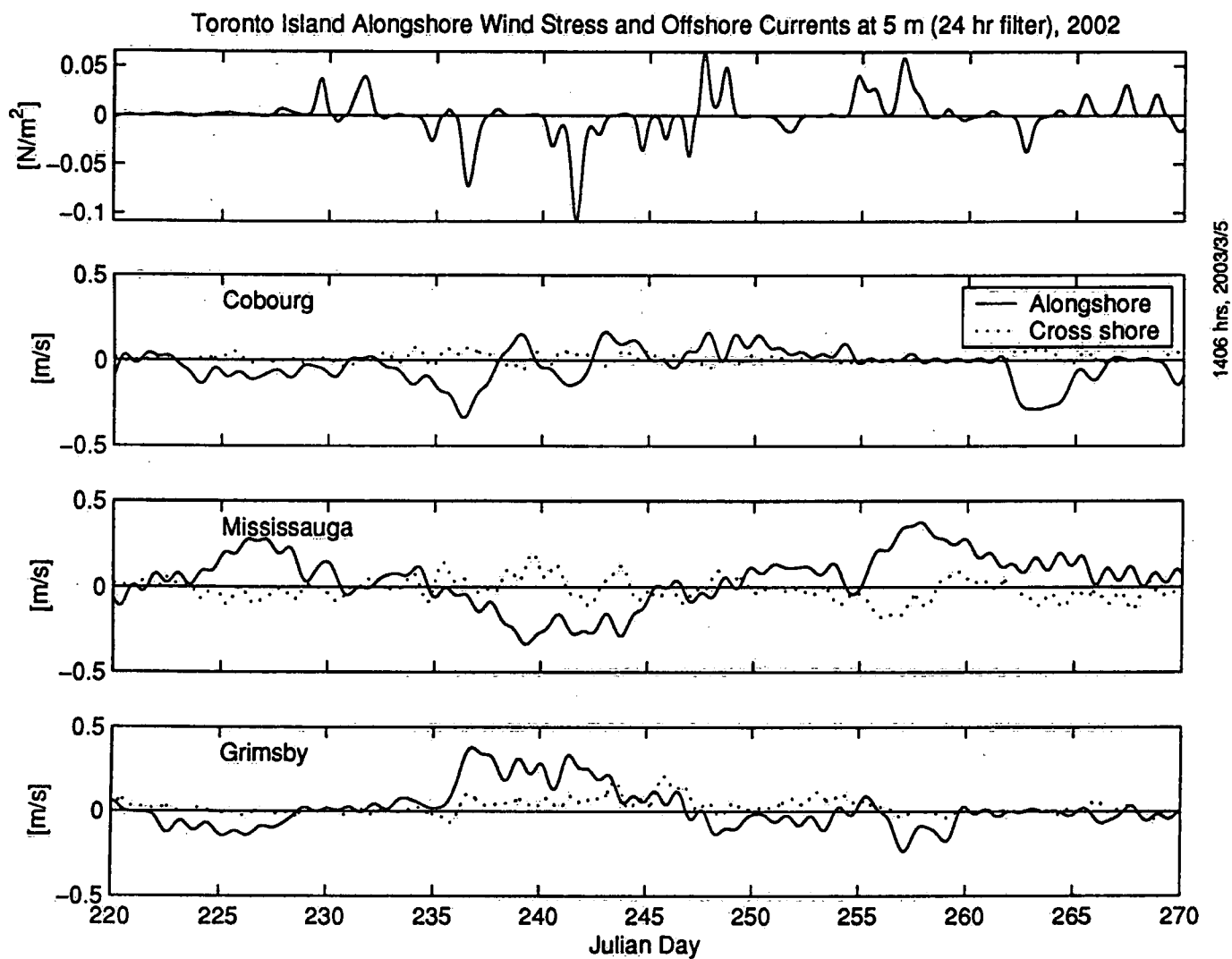


Figure 7a. Filtered Toronto Island wind stress and filtered offshore station currents at 5 m.

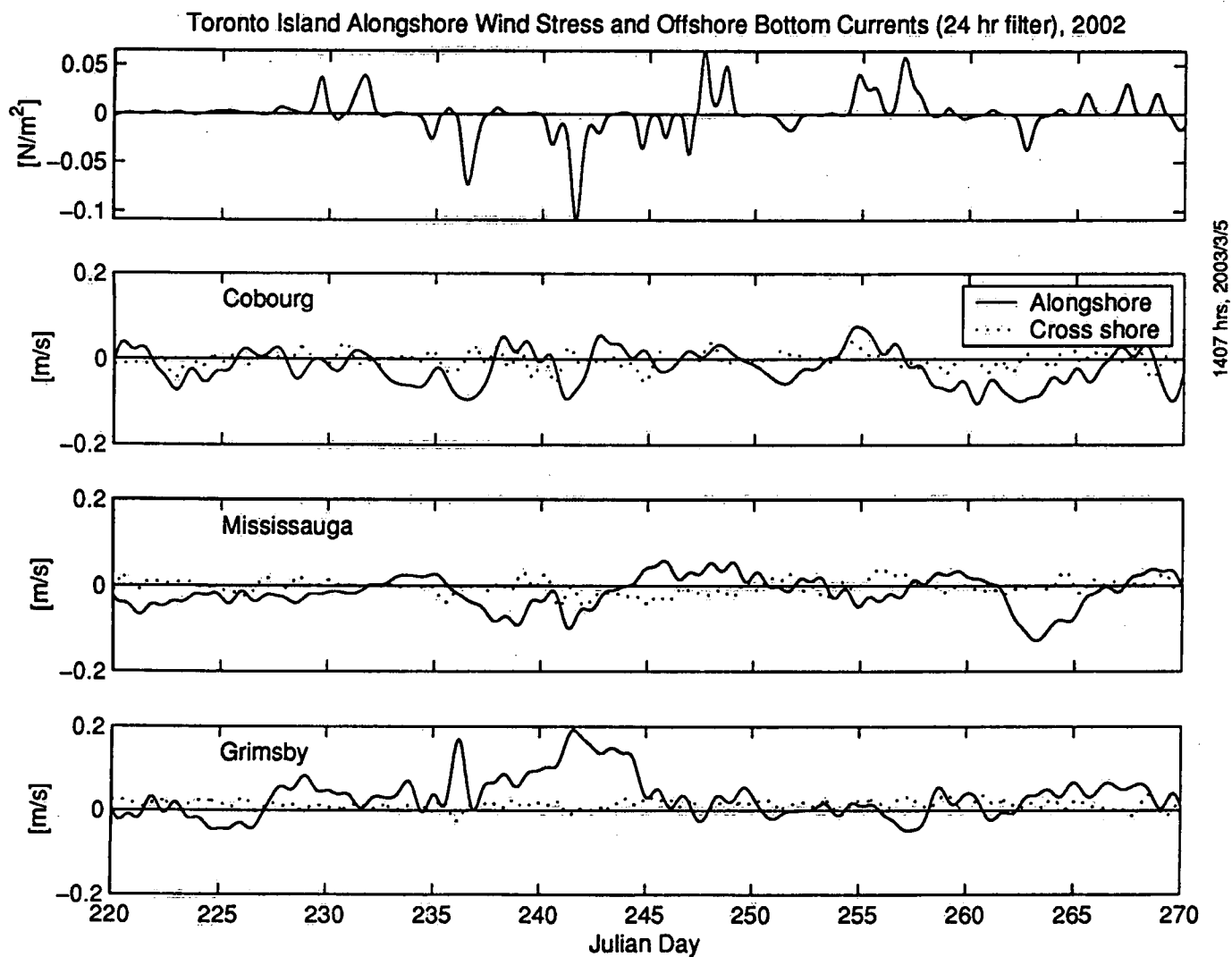


Figure 7b. Filtered Toronto Island wind stress and filtered offshore station currents at the bottom.

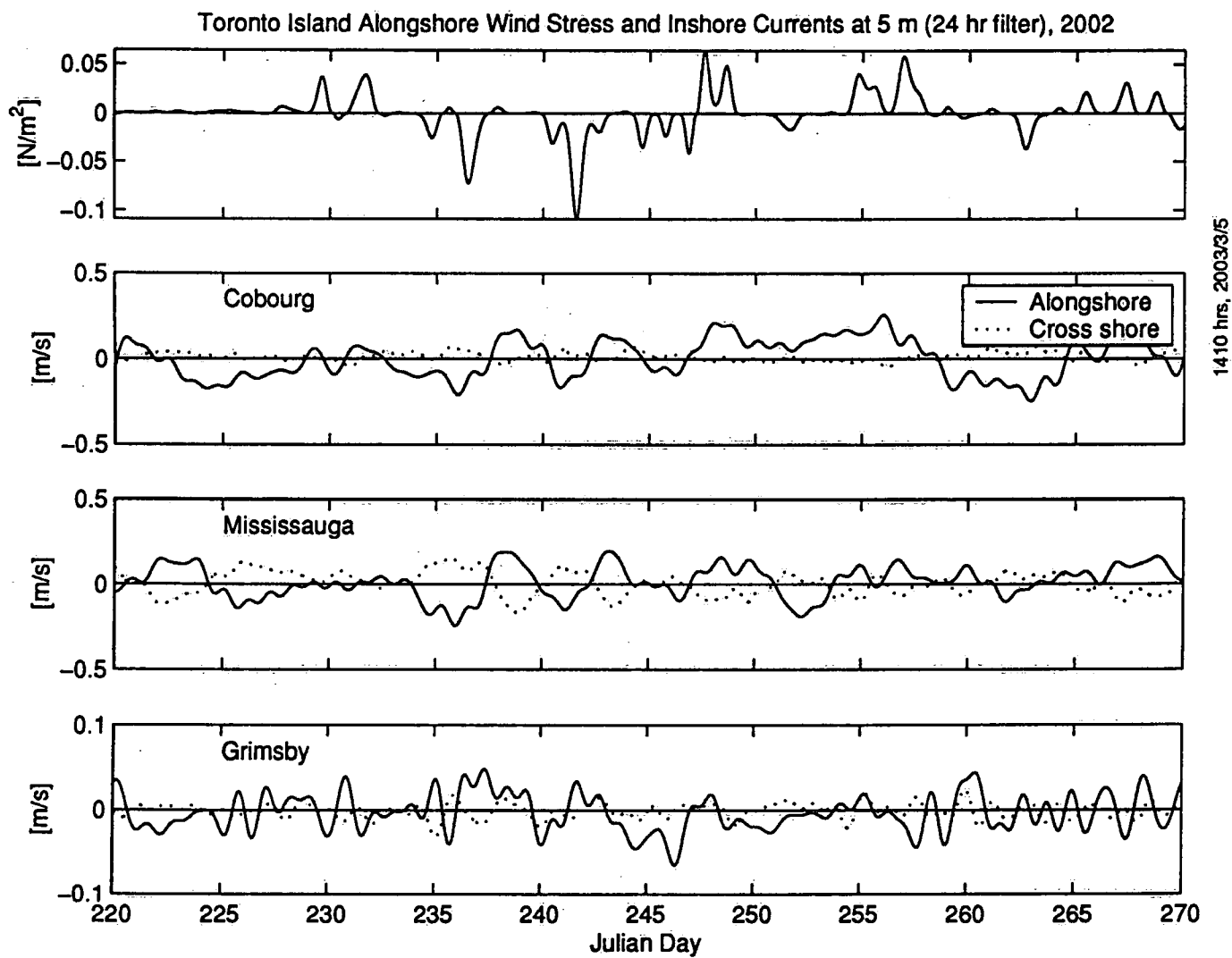


Figure 8a. Filtered Toronto Island wind stress and filtered inshore station currents at 5 m.

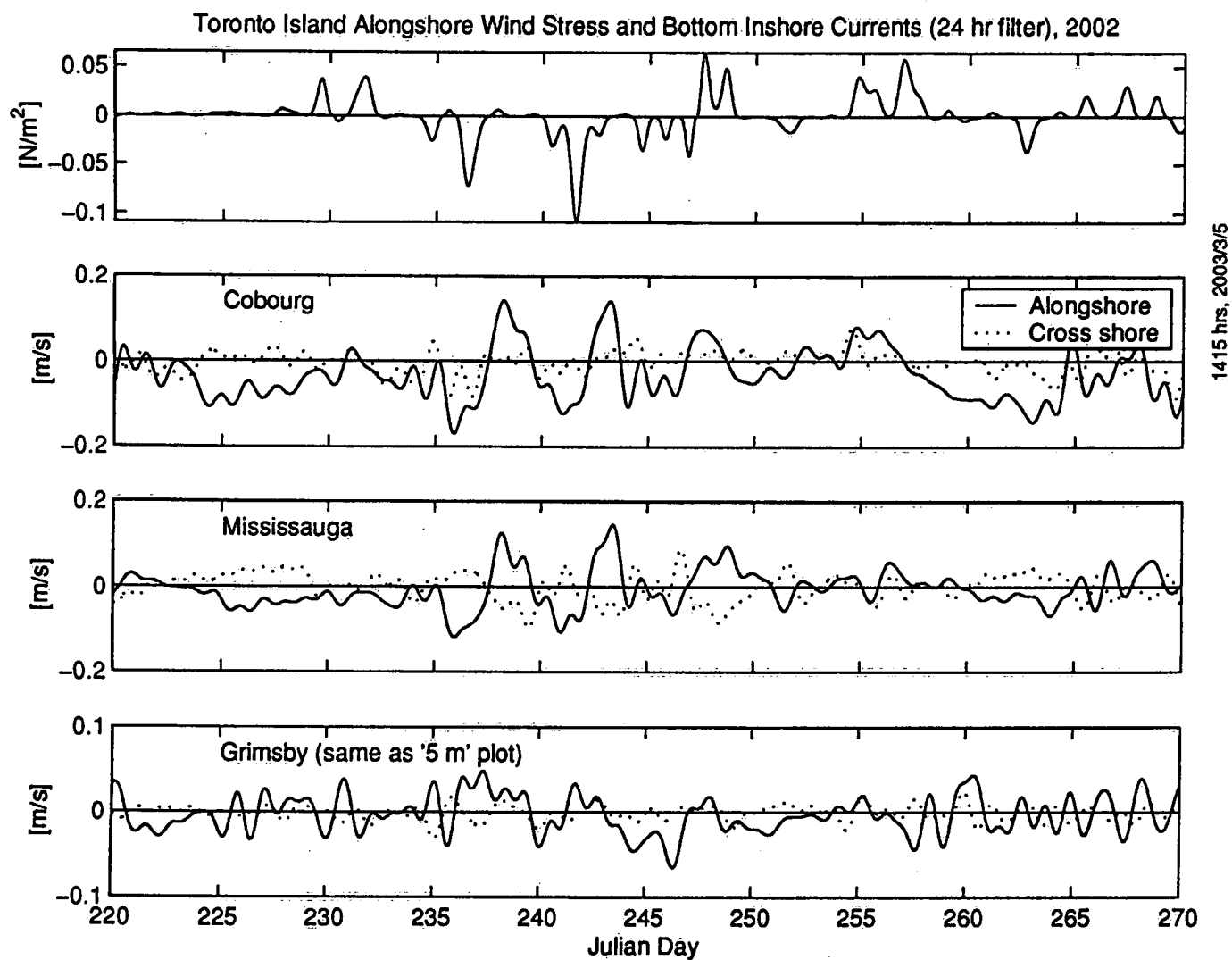


Figure 8b. Filtered Toronto Island wind stress and filtered inshore station currents at the bottom.

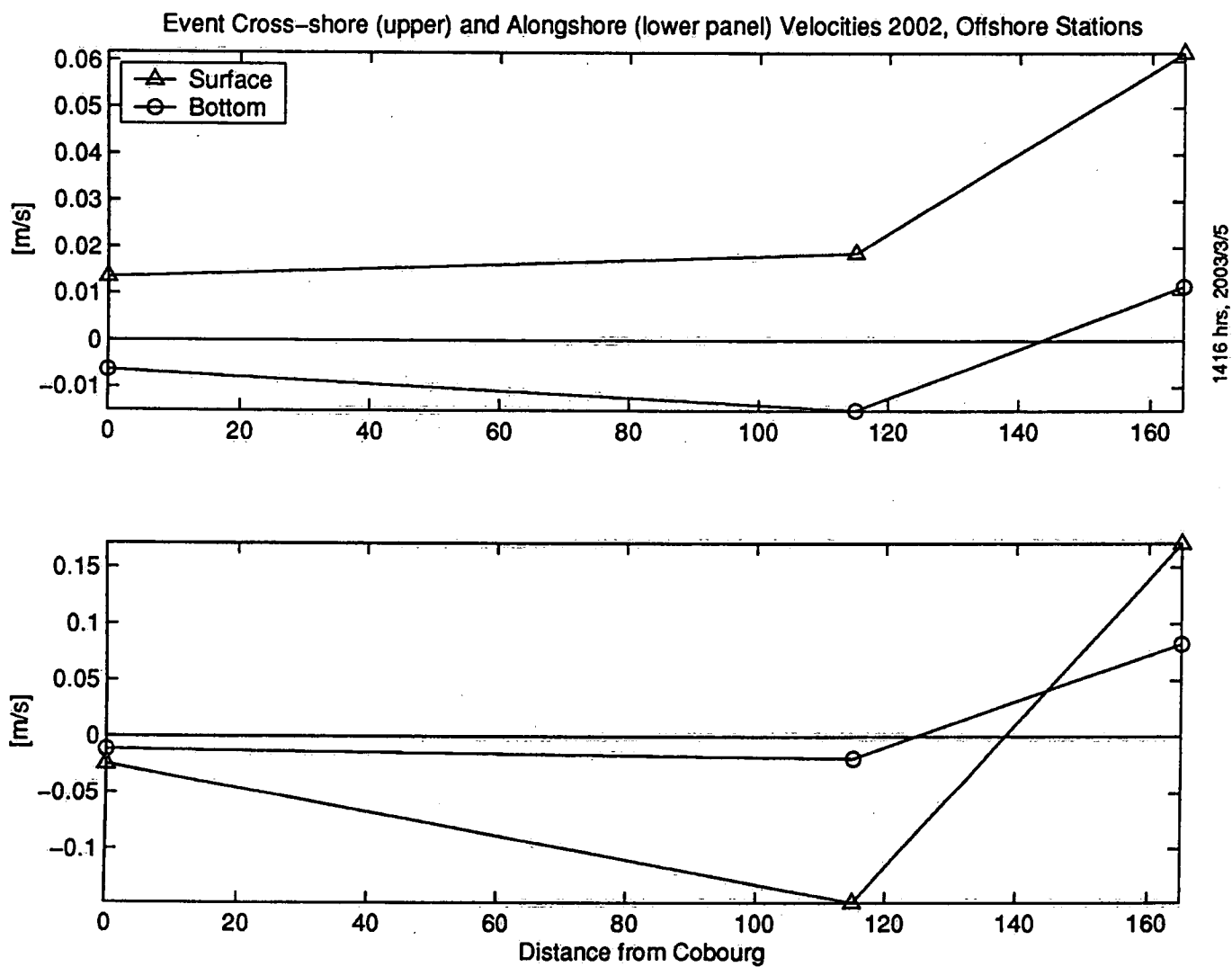


Figure 9. Event cross-shore (upper) and alongshore (lower panel) mean velocities as a function of distance: Cobourg, Mississauga, and Grimsby.

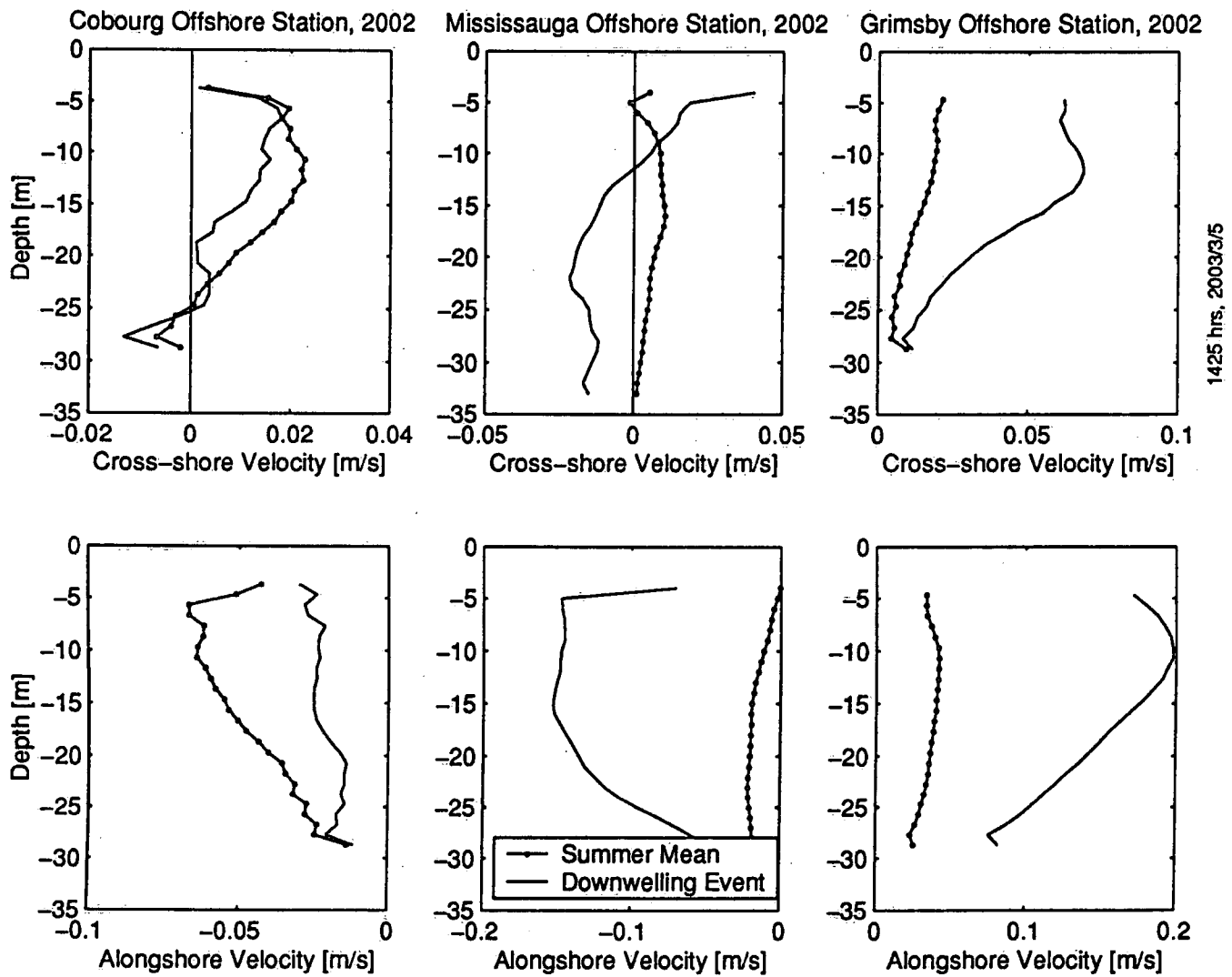


Figure 10. Mean summer and event velocity profiles at the offshore stations.

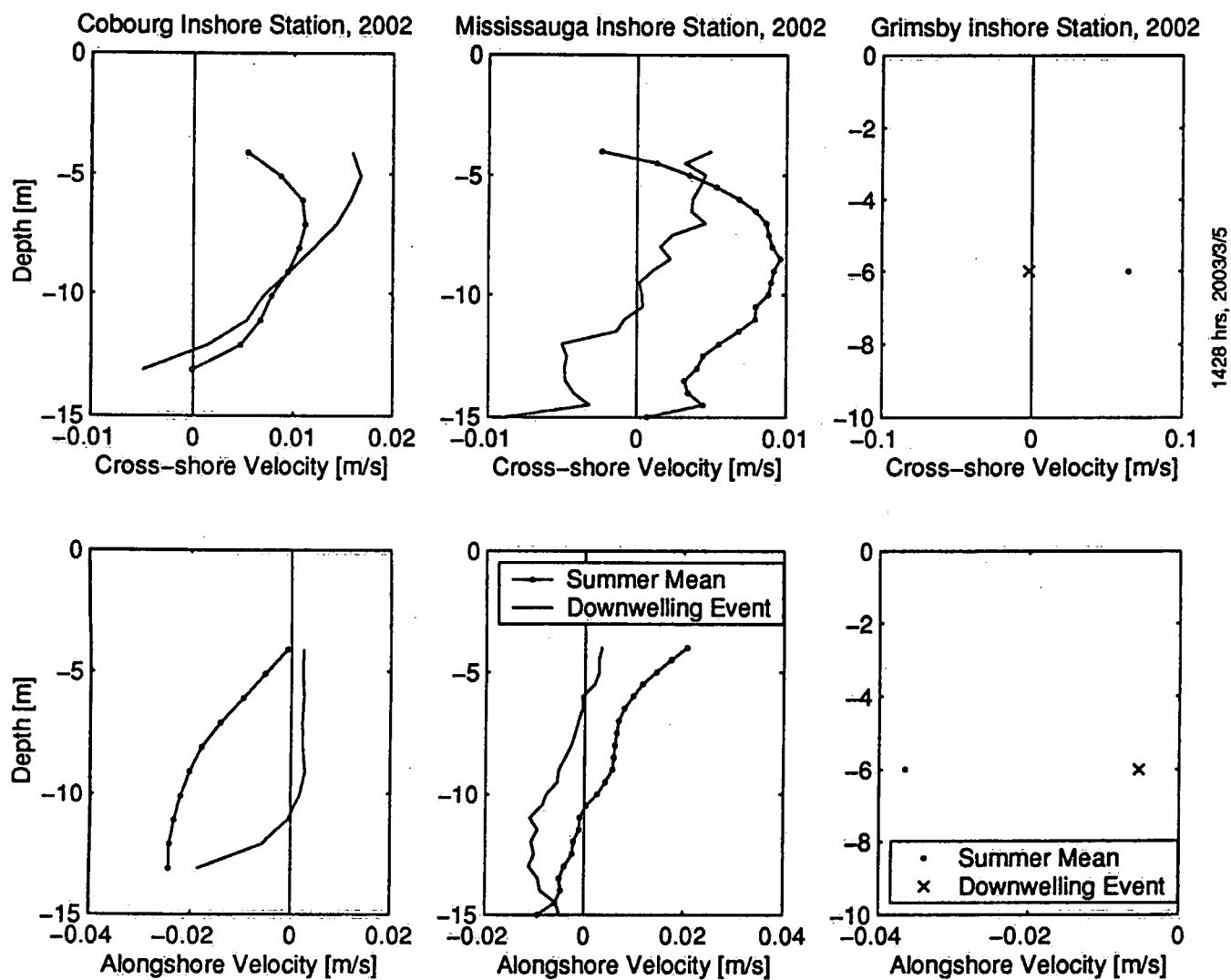


Figure 11. Mean summer and event velocity profiles at the inshore stations.

Geosmin Result for Raw Water

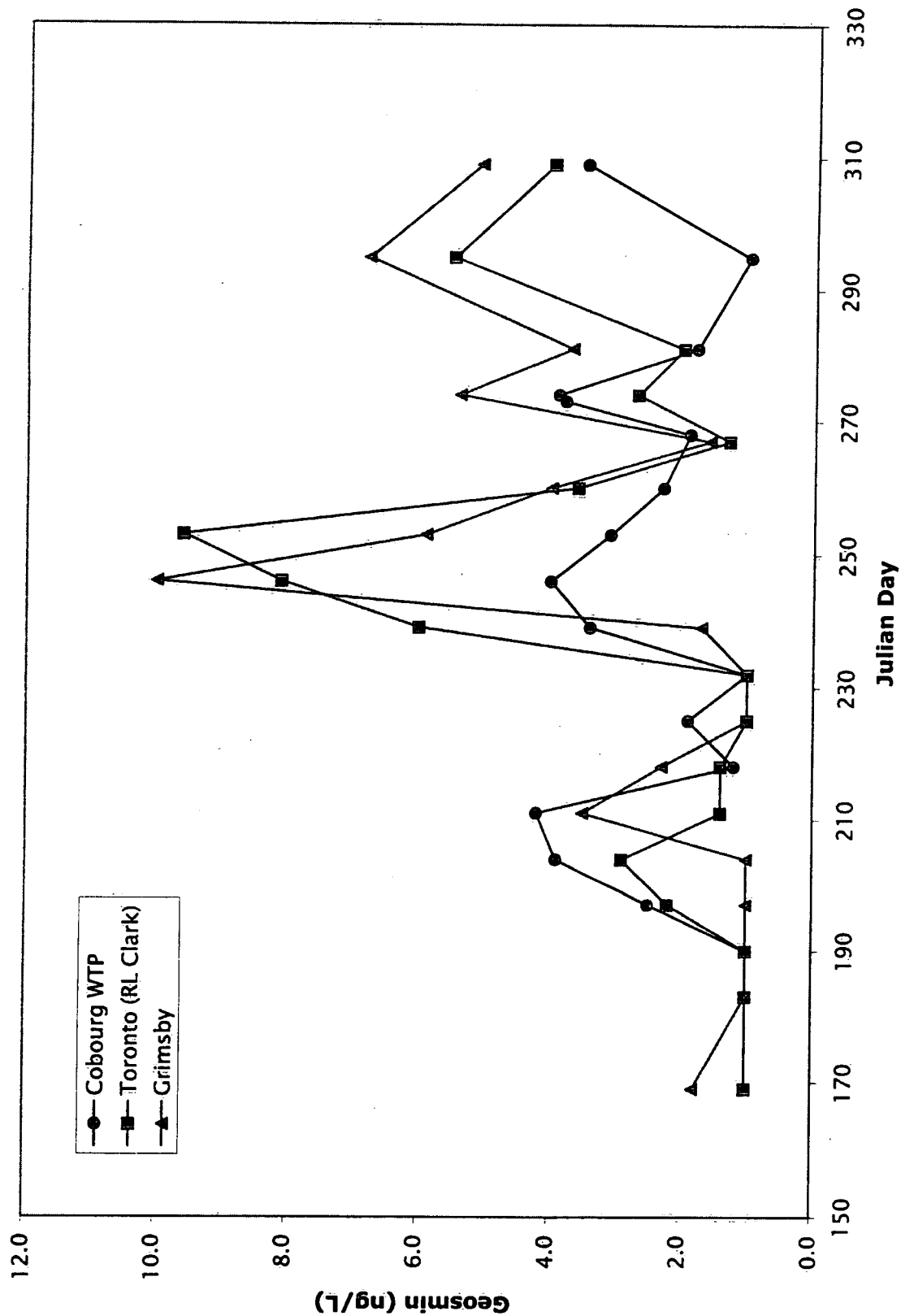


Figure 12. Geosmin concentrations at three Water treatment plants showing the small but distinct peaks at Toronto on Day 253 (10 Sept) and at Grimsby on Day 246 (3 Sept).



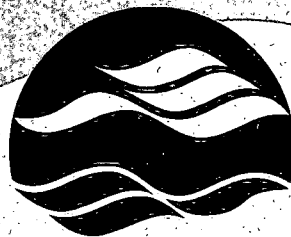
Figure 13. Surface temperature of Lake Ontario on Days 246 and 248 (3 and 5 Sept).

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National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada



**NATIONAL WATER
RESEARCH INSTITUTE**
**INSTITUT NATIONAL DE
RECHERCHE SUR LES EAUX**

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada



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