Technical Report RT-118

Acquisition and post-processing of bathymetric data in shallow waters for the section of the St. Lawrence River between Cornwall and Trois-Rivières

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February 2002

For reference:

FORTIN, P. (2002). Acquisition and post-processing of bathymetric data in shallow waters for the section of the St. Lawrence River between Cornwall and Trois-Rivières. Technical Report SMC Québec – Hydrology Section RT-118, Environment Canada, Sainte-Foy. 17 pages + appendix.

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1 Introduction

The work presented here was done within the scope of a project that has for main objective the evaluation of the impacts of water level fluctuations on the fluvial ecosystem of the St. Lawrence River. This project involves both the Meteorological Service of Canada (MSC-Quebec, Hydrology section) and the International Joint Commission (IJC).

Fluctuations in the St. Lawrence River's water levels have a potential impact in many public and private sectors. For example, activities like navigation and water supply depend on water levels. Numerical tools that are currently under development for use in evaluating impacts of water level scenarios on various components of the St. Lawrence River require a high resolution digital terrain model as a foundation for eventual hydrodynamic simulations. This information will lead to the development of environmental models to predict and quantify for example : shoreline erosion, flooding risks, impacts of dry periods and the evaluation of water quality.

Knowledge of the precise bathymetry of the bed of the St. Lawrence River is necessary in order to construct a precise digital terrain model including deep and shallow-water bathymetry as well as topographic information to permit correct simulations of variations in water levels and flows.

In the past, the Canadian Hydrographic Service (CHS) and the Canadian Coast Guard have collected much bathymetric information for the deep water sectors of the St. Lawrence River. Surveys have been conducted on a regular basis such that we were able to obtain very good coverage for sectors with average to high depths. As for shallow waters, information is either not very dense or non-existent.

The objective of the work described in this document is thus to fill the information gap for shallow-water sectors. Having past experience in this type of work, the Meteorological Service of Canada was mandated with the logistical planning, acquisition, processing and cartography of bathymetric data in shallow waters for the sector of the St. Lawrence River downstream of the Beauharnois dam. Surveys were conducted with an acoustic echosounder during spring 2001 in order to benefit from high water levels at that period.

In the present document, the different stages of data acquisition and postprocessing will be outlined and the cartography of the bathymetric data that was collected in 2001 will be presented.

2 Acquisition of bathymetric data

2.1 Location of the study area and required surveys

The Meteorological Service of Canada's current digital terrain model was used to determine gaps in coverage that required further surveys. For the area from Cornwall to Trois-Rivières, the existing bathymetry was superimposed with shallow-water sectors. Results of this work are presented in the following sections.

2.1.1 Lake St.François

Bathymetric coverage for this sector is rather complete. The density of the data in shallow waters varies from excellent to acceptable. It was thus established that this sector did not need to be included in the survey carried out in 2001.

2.1.2 Montréal Archipelago

At the extreme west of Montréal's archipelago is the lake des Deux-Montagnes. Existing bathymetric surveys for this sector are of low density. The same situation exists for shallow waters but considering the short duration of the spring freshet, it was decided that this sector was not a priority for 2001 since other more important sectors had to be surveyed at the highest water level possible.

Lake St.Louis is located South of lake des Deux-Montagnes and West of the Montréal Island. Existing bathymetry for this sector varies in density from average to low, particularly south of the lake at De la Paix Islands. This immense zone of shallow water was considered to be a priority sector. As represented in figure 1, most of the area surrounding the islands has been surveyed in 2001 with a density of 50 to 75 meters between every transect. About 10% of the area couldn't be surveyed because the water was too shallow.

As for the remaining sectors, including the outlet of the Châteauguay River, the shoreline near Pointe Claire and a short portion of the river between Verdun and Des Sœurs Islands in the Bassin Laprairie, surveys could not be conducted because of the short freshet which limited the period with high water levels.

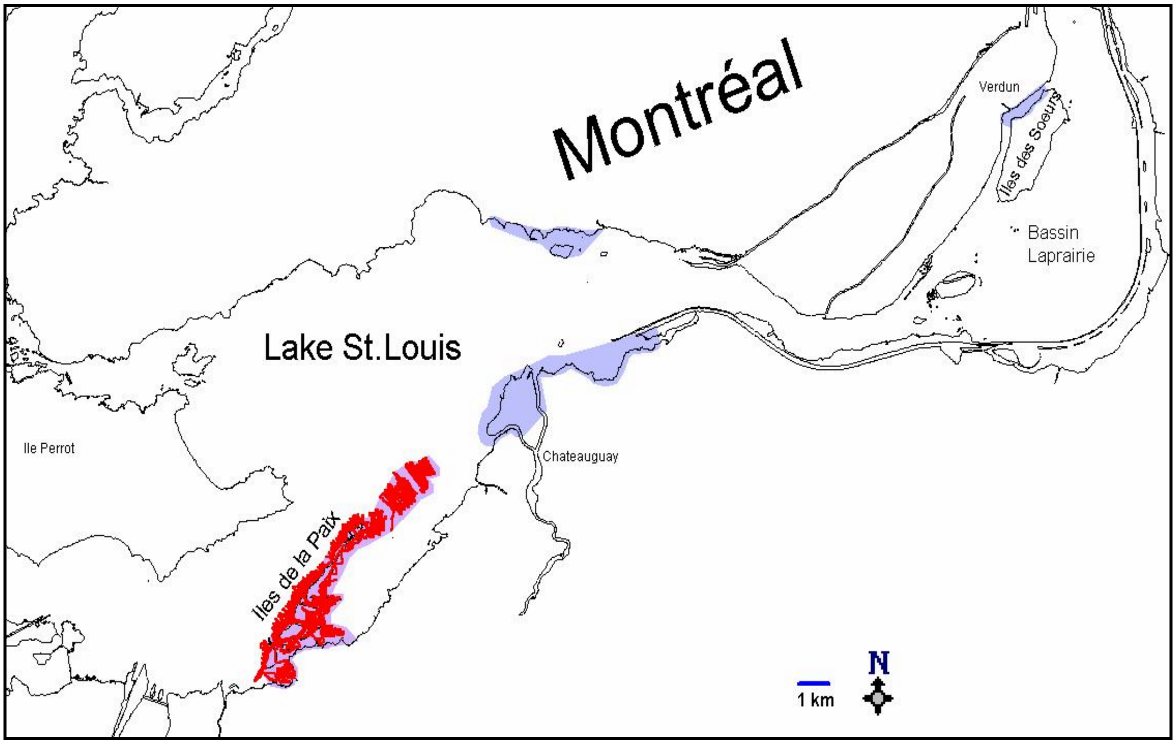

Figure 1 Location of sectors to survey (blue) in the Montréal archipelago. Red points represent surveys that were carried out

2.1.3 Port of Montréal to Varennes

As shown in figure 2, three zones were selected for coverage within the survey. Upstream we find the Boucherville Islands. This zone is considered a priority and was completely surveyed at the beginning of the campaign. Bathymetric data in this area is rare and it was essential to take advantage of the high water levels to gather important data. Because of the impressive density of emerging plants in this section, our surveys proved to be difficult even though water levels were high. To probe this sector completely, higher water levels by about one meter would be necessary.

The second zone is situated between Aux Vaches Island and Ste-Thérèse Island while the third zone is situated to the north of Ste-Thérèse Island (Figure 2). Again, the short freshet prevented us from surveying these areas.

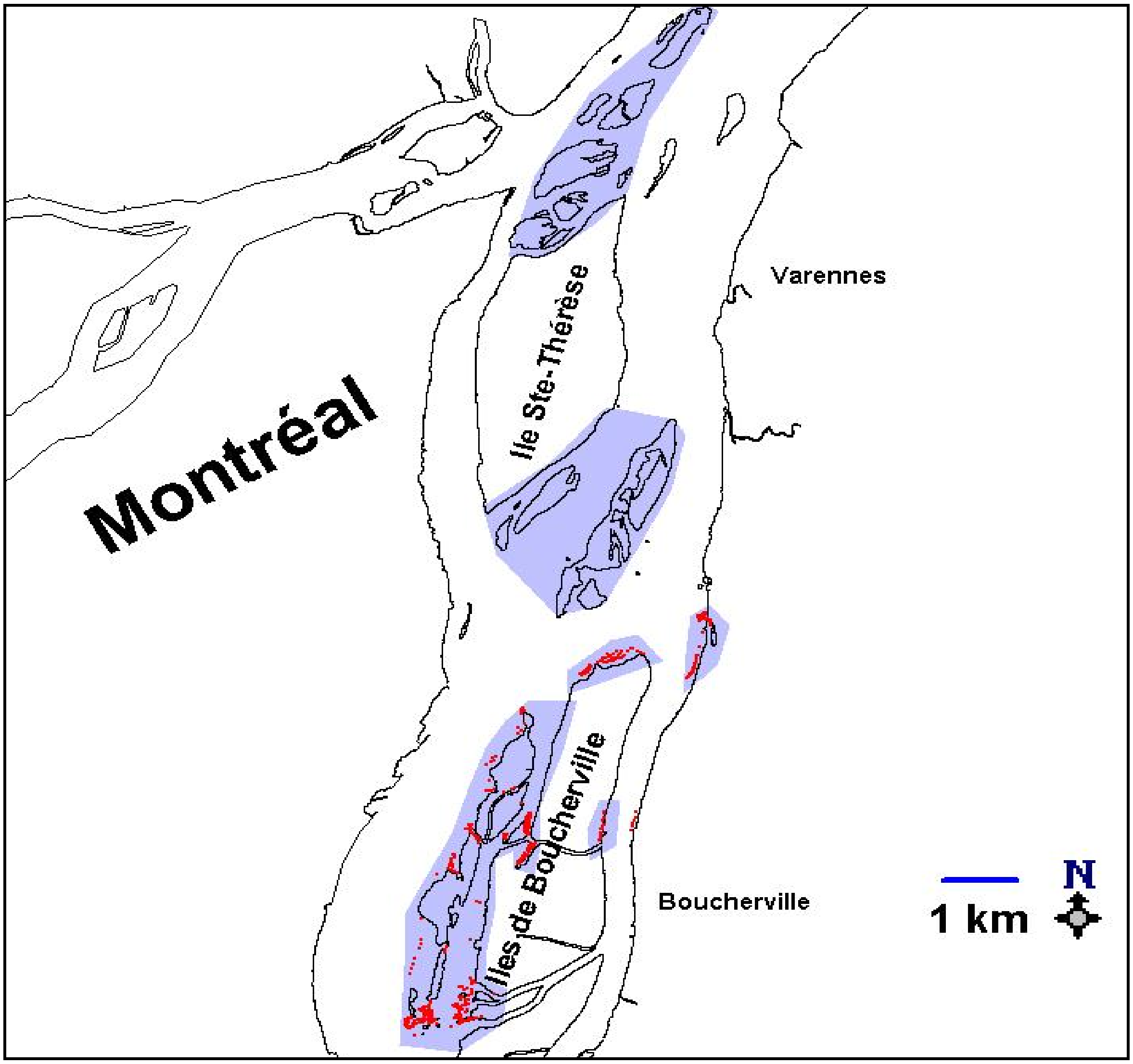

Figure 2 Location of sectors to survey (blue) in the Port of Montréal to Varennes area. Red points represent surveys that were carried out

2.1.4 Verchères to Contrecoeur

Verchères Islands could not be surveyed because of the short freshet and the limited high water level. Water levels measured at the beginning of the campaign were sufficient to survey this sector but it would have been to the detriment of other priority sectors (Boucherville Islands and De la Paix Islands).

Some transects have been done in the Contrecœur Islands sector but water levels were too low so that it was not possible to acquire a significant number of points (Figure 3).

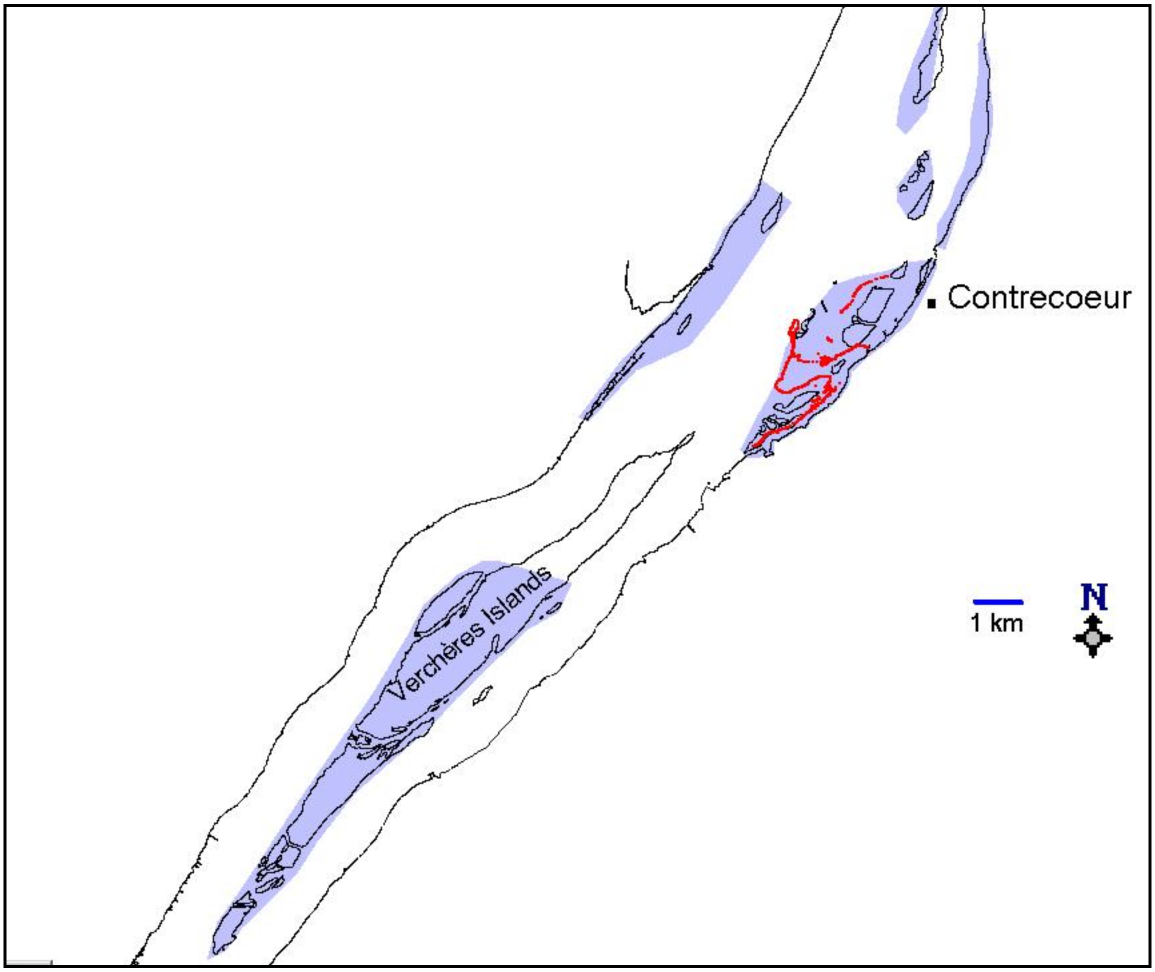

Figure 3 Location of sectors to survey (blue) in the Contrecoeur area. Red points represent surveys that were carried out

2.1.5 St.François Bay and lake St.Pierre

As shown in figure 4, surveys carried out in this sector were completed successfully and cover a broad section of the shallow portion of Lake St.Pierre. Only a few gaps remain upstream and these could not be covered given the low water levels at the end of the campaign.

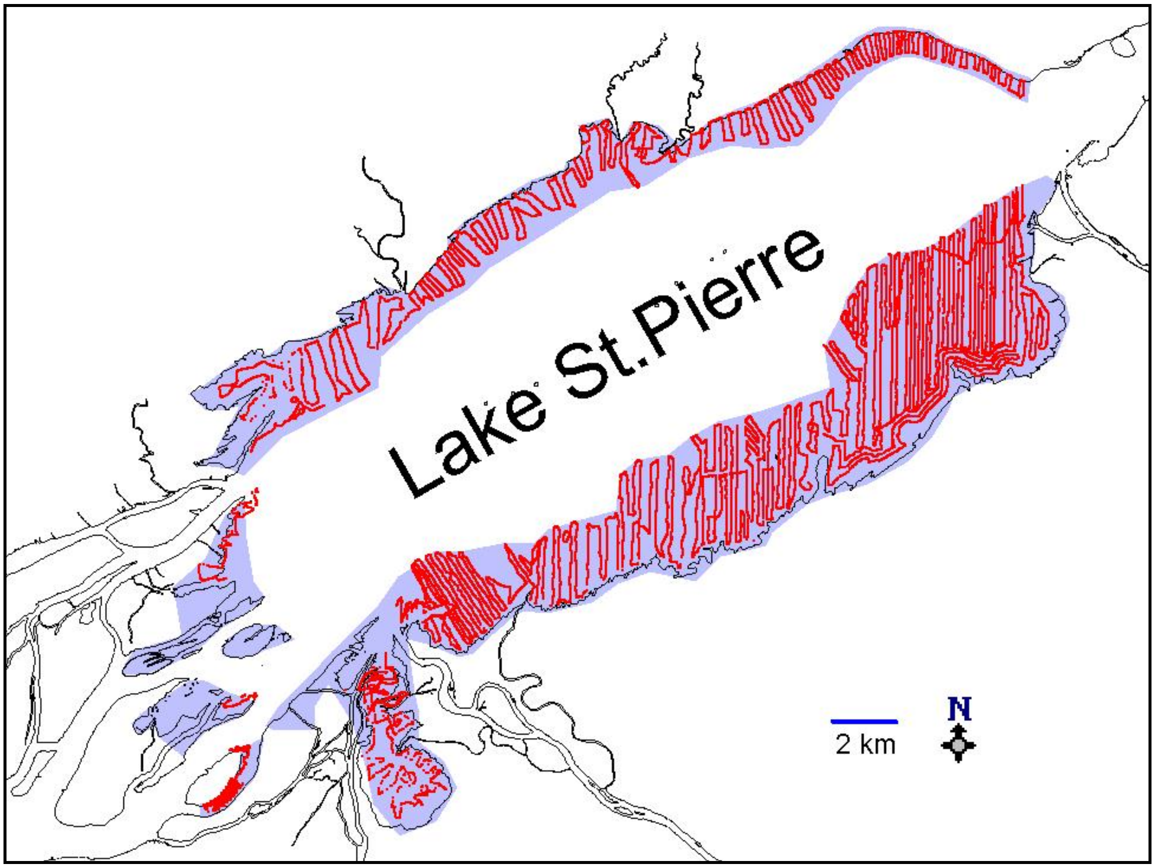

Figure 4 Location of sectors to survey (blue) in the lake St.Pierre area. Red points represent surveys that were carried out

2.2 Equipment used during acquisition of bathymetric data

During the campaign, our boat « Le Pêcheur » was used to carry out the surveys (Figures 5 and 6). This flexible boat with a shallow draught of 45 cm allows us to go about anywhere on the river and its two powerful engines allow safe navigation in bad weather conditions or in the event of equipment malfunction (engine failure for example).

Bathymetric surveys were made with a Knudsen acoustic echosounder. The model that was used was a 320B. This model can accomodate surveys in shallow waters (+ 0.50 cm). The precision of this instrument is plus or minus 10 cm for surveys of less than 30 cm in depth. The Knudsen 320B functions with a transducer that emits at a frequency of 200 hz. This transducer emits an acoustic pulse that is reflected by the bottom. The time between the emission of the pulse and the return echo is used to calculate the depth of water under the probe.

Figure 5 The survey platform : "Le Pêcheur"

Figure 6 Work Environment and installation at the time of data acquisition

The echosounder is coupled to a Global Positioning System (GPS, Novatel) that uses differential corrections for higher precision (DGPS). This positioning technology (DGPS) corresponds to the determination of differential corrections applied in real time at a GPS reference station whose coordinates are known with precision. The reference station calculates differential corrections that are applied to the GPS pseudo distances associated with each satellite. These differential corrections are applied in real time since they are transmitted by a marine radio beacon. In terms of quality, the DGPS allows a horizontal precision that is within one meter which is much better than the simple GPS (within 10 m). For this study, Saint-Jean-sur-Richelieu was the differential station that was used as a reference.

Finally, as a means to validate acquired data, a graduated bar of more than 2 meters in length was used to gauge the echosounder and to measure water depths in a manual way.

The equipment discussed above was used throughout the data acquisition. A second field team took part in the campaign for a period of one week to maximise data acquisition during the short freshet and the equipment used by this team was similar to what was described above.

2.3 Methodology for data acquisition

Data acquisition was conducted over a period of 5 weeks, between April 23 and May 11 2001. At the beginning, water levels were high, that is to say nearly 2 meters above chart datum for certain stations. Since the spring freshet of 2001 was short, it became necessary to prioritize the areas that were surveyed. We began with the Boucherville Islands, followed by the De la Paix Islands in lake St.Louis, then by the Contrecœur Islands and finally by the lake St.Pierre area.

For optimal coverage of the identified sectors, we worked by transect. We didn’t have prior information related to each sector’s bathymetry and this made the pre-field planning more difficult. In most areas, the possibility to acquire data was determined by conditions found in the field. Transects were done when the water level was sufficiently high to allow the boat to pass without hitting the bottom and when passage was not hampered by various debris (branches, emerging plants) left by the rising waters.

In order to position our displacements with precision and to respect a minimum distance of 50 m and a maximum distance of 100 m between each transect, we used the MapInfo software coupled to the GeoTracker module. Using DGPS data in real time, this module allows the visualization of spatial positioning on a map and the recording of the boat’s position in real time. With one layer representing the shore and another representing existing bathymetric data, our displacements were optimized such that we surveyed only the required areas.

The echosounder was calibrated at the beginning of each day. Several parameters had to be adjusted depending on water temperature, the quantity of suspended sediment in the water, the boat draught, etc. These adjustments had to be made several times a day to ensure the proper functionning of the echosounder.

Each transect began with the uninterrupted recording of the echosounder's high frequency signal. The signal is recorded on a laptop at the same time as the DGPS coordinates. Many times during the same transect, the boat is stopped with the echosounder and DGPS still acquiring data. We then measure the water depth in a manual way with our graduated bar to calibrate the echosounder in order to ensure the reliability of the bathymetric data.

3 Data post-processing

Various stages of post-processing are required to produce reliable datasets that can be used within other applications. These post-processing steps include :

- Transformation of raw data to a MapInfo database.
- Change of projection. Geographic (lat/long WGS84) to Cartographic (MTM (Modified Transverse Mercator) zone 8, NAD 83).
- Filter data by statistical methodologies and data verification by superimposing new data with existing bathymetric data layers.
- Transformation of altimetric data (z) to chart datum.
- Reduction of the data referenced to chart datum towards main sea levels (MSL).

3.1 Transformation of raw data to a MapInfo database

Raw data produced by the echosounder are in ASCII format. The information contained in the files is described in table 1. The format of the acquired data is as follows :

« LSP-0501AM,35762,------,01052001,123115.365,HF,00002.92,1,46 8.371035N,072 52.467320W »

Table 1 Raw data fields in the bathymetric data file

Column	Content
1	Identifier of the day and the sector
2	Single identifier of measurement
3	Date (ddmmyyyy)
4	Hour (hhmmss.sss)
5	Frequency used: HF (High Frequency)
6	Depth measured
7	Quality of measurement (1=good; 0=nil)
8	Latitude (degree minute)
9	Longitude (degree minute)

These data are transformed into MID/MIF file that are then imported in the MapInfo software. This Geographic Information System (GIS), with its visualization capabilities, makes it easy to display the data acquired during the surveys for validation purposes.

3.2 Change of projection

In addition to facilitating the visualization of the data, MapInfo also allows reliable changes in projection. All surveyed data were transformed from a geographical projection (lat/long WGS84) to a cartographic projection (MTM zone 8, NAD83). The data are transformed into cartographic coordinates (Cartesian) to facilitate the next steps in the post-processing which involve a number of calculations.

3.3 Data filtering by statistical methods

The echosounder recorded two depth measurements every second. For each transect, the amount of raw data collected is much larger than what is required for the digital terrain model. It is thus necessary to impose a filter on the raw data. The filter that was used is in fact a program developed by MSC-Quebec region.

The algorithm initially uses the cumulative distance concept. This concept represents the true distance travelled along the trajectory between the measured point and the initial point of a transect (not a straight line between the two points). The cumulative distance is calculated for each point of each transect.

Following this, average depths are calculated over a cumulative distance of 16 m. The 16 m value, which is 8 meters on either side of a middle value, was chosen as being most relevant for our needs following various tests on real world cases. The standard deviation is calculated on the sample constituted by values within the 16 m window. All depth values not included in the range defined by the average plus or minus one standard deviation are excluded. Finally, the median is calculated from remaining data to determine the most representative value within the 16 m distance.

With the objective of preserving a measurement at every 5 meters, the following sample will have, as a middle value, an observation that is 5 meters away from the previously calculated point.

When the probed zone is flat, without any topographic accident, without any plants and on sandy bottom, the algorithm sorts the data perfectly (Figure 7). But when we find ourselves in zones where there are many aquatic plants, debris, branches or simply when the substrate of the bottom is porous, the algorithm cannot adequately filter the data.

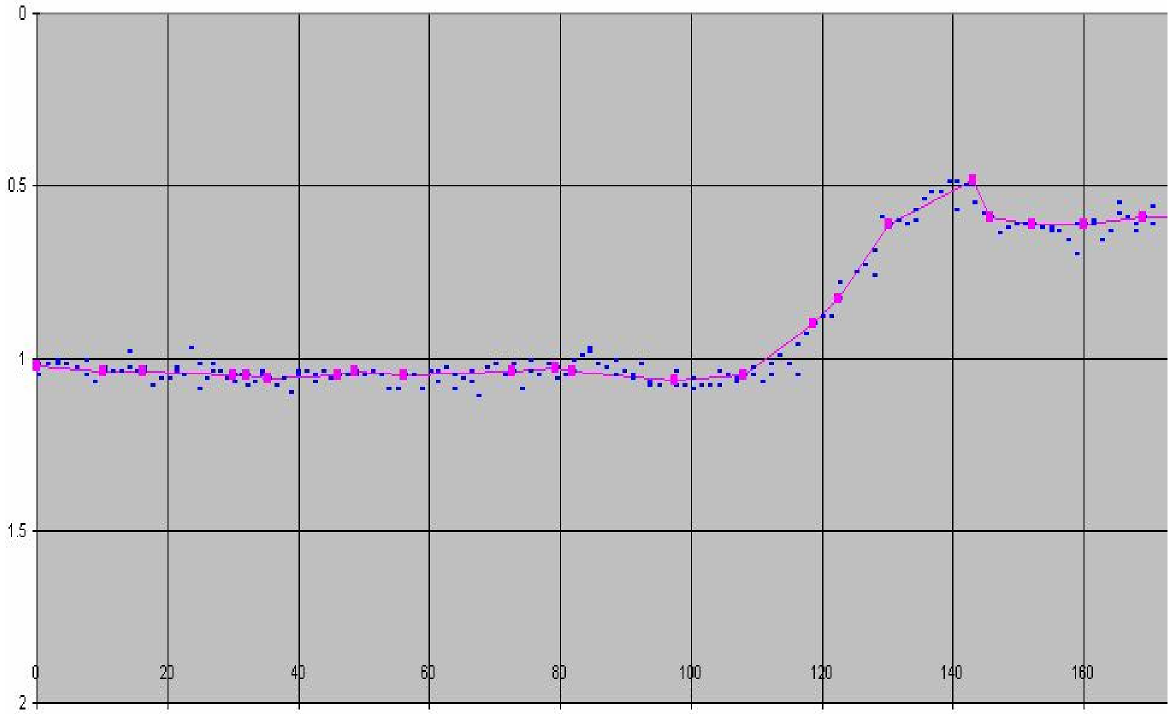

Figure 7. The X-coordinate illustrates the cumulative distance (m) between each survey. The ordinate illustrates survey depth (m). The blue points represent raw data for depth and the pink points are the points filtered by the algorithm

(see Figure 8).

These problematic situations are solved by superimposing all raw and filtered data to manually correct errors induced by the filter. The manual correction considerably prolongs the post-processing but completely corrects the errors induced by the filtering procedure.

3.4 Transformation of altimetric data to chart datum

All surveyed data are referenced to the water surface whose level is obtained through a number of gauging stations along the survey area. As illustrated in table 2, the discharge as well as the related water levels, varied quite a bit during data acquisition. The bathymetric data needs to be transformed into a unique vertical reference which is in this case chart datum. Chart datum is a vertical reference that is sloped and that roughly follows the natural slope of the river at low water periods. Chart datum basically represents the level below which water rarely goes during the navigation season.

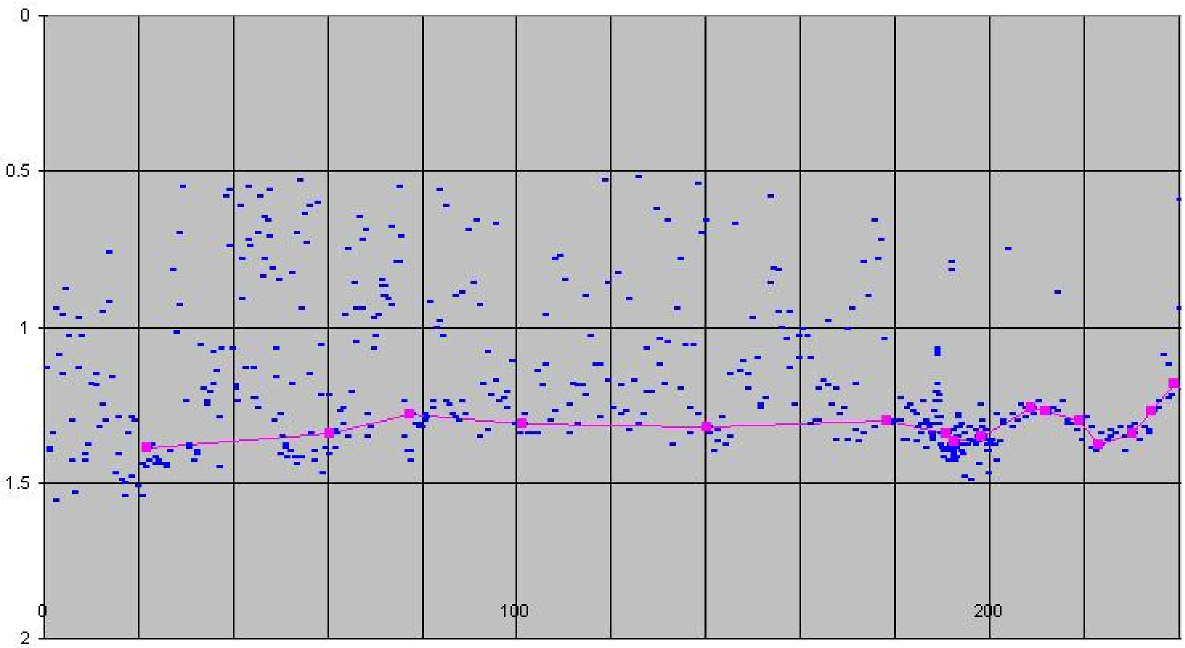

Figure 8. Example of a situation where the algorithm cannot filter adequately. Zone of survey where the density of aquatic plants is very high. X-coordinate: depth (m), Ordinate: cumulative distance (m)

Table 2 Daily flows at the Lasalle (02OA016) and Sorel (15975) stations (Sorel is estimated) for the period from April 28 to May 11 2001

Date	Lasalle Flow(m^3/s)	Sorel Flow (m^3/s)
2001-04-28	8700	11061
2001-04-29	8710	11042
2001-04-30	8730	11000
2001-05-01	8690	10933
2001-05-02	8480	10707
2001-05-03	8630	10846
2001-05-04	8530	10698
2001-05-05	8370	10421
2001-05-06	8220	10090
2001-05-07	8060	9781
2001-05-08	7880	9492
2001-05-09	7820	9303
2001-05-10	7650	9051
2001-05-11	7550	8916

To reduce data referenced to the water's surface to chart datum, we use measurements of water levels at certain stations dispersed along the river. These stations (exhaustive list in table 3) record water level data referenced to chart datum in real time. By knowing the hour of each measurement, we can obtain the chart datum level for a station located upstream and downstream of the surveyed area. Linear interpolation between the stations is then used to obtain the level of the water surface as referenced to chart datum. On some occasions, we compared water levels produced by hydrodynamic simulations of flows similar to those of the survey period to make sure that the interpolation between two stations gave us valid results.

Table 3 Hydrometric stations used for the correction of bathymetric data

Station	Name	Longitude	Latitude	CD	MSL
15975	Lac Saint-Pierre	-72.883	46.183	6.537	
15930	Sorel	-73.100	46.033	9.713	13.518
15780	Contrecoeur (IOC)	-73.267	45.817	12.559	16.992
15660	Varennes	-73.433	45.683	8.721	13.594
15540	Rue Frontenac	-73.533	45.517	9.887	15.242
15330	Pointe-Claire	-73.817	45.417	5.295	25.647
15220	Pointe-des-Cascades	-73.950	45.333	3.652	24.144
3360	Trois-Rivières	-72.540	46.341	4.732	7.700

3.5 Reduction of data referenced to chart datum towards main sea level (MSL)

The depth data referenced to chart datum must be reduced to the mean sea level (MSL) to properly integrate it within the digital terrain model. To this effect, we use the reduction zones worked out by the Canadian Hydrographic Service. These zones are based on the value of the difference between chart datum and the MSL measured for many stations along the river. The reduction zones make it possible to establish the link between each station while taking the slope of the river into account. To facilitate the use and application of these reduction zones, we transformed them into a T3 grid which can be imported in the Modeleur software (Secretan *et al*., 1998).

The resulting reduction grid allows to project, on each survey point, the interpolated value of the difference between chart datum and MSL. Figure 9 illustrates by isosurfaces the difference between chart datum and mean sea level for the Port of Montréal - Trois-Rivières section. At this point, it is sufficient to subtract the depth from the chart datum to the projected difference.

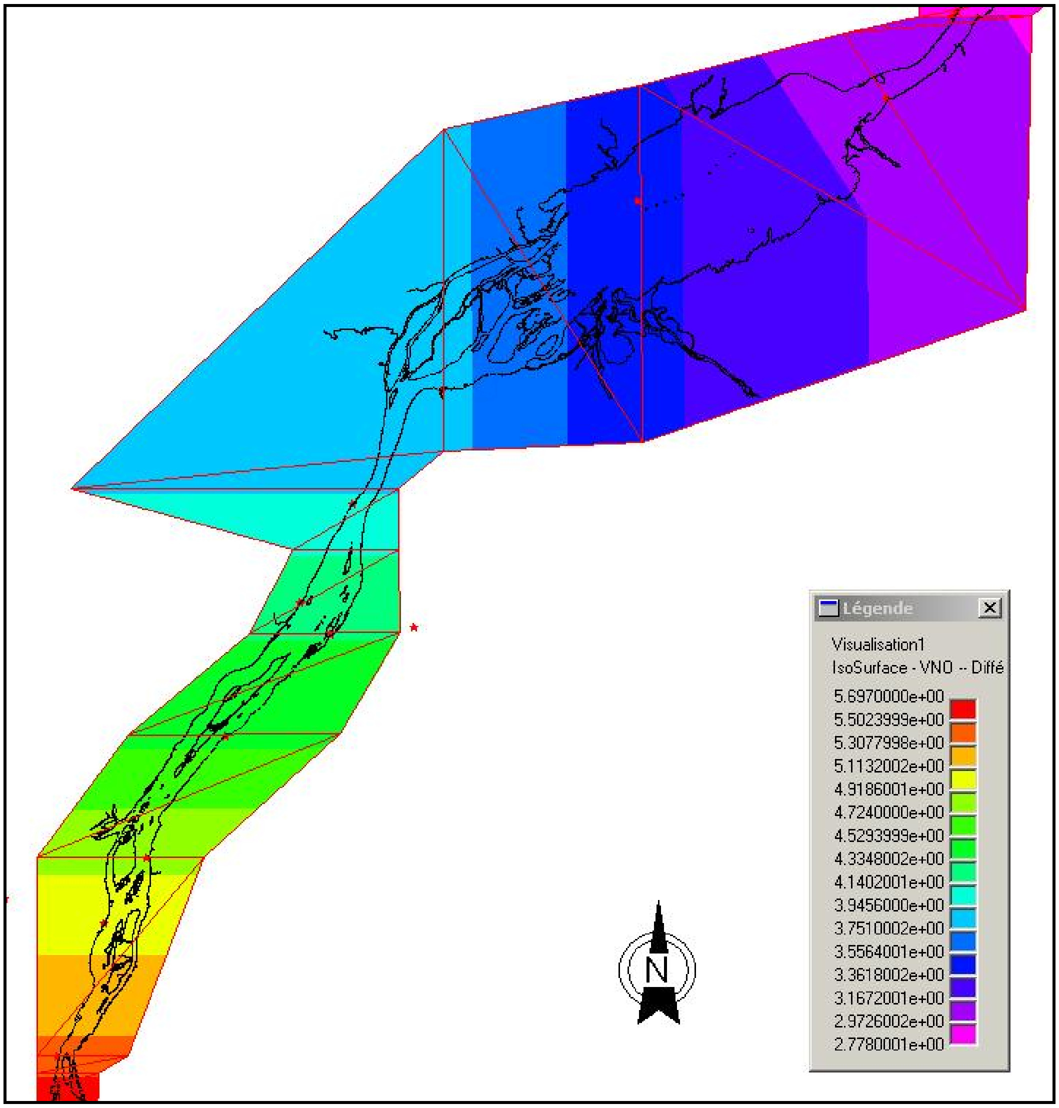

Figure 9 Illustration by isosurfaces of the difference between chart datum and mean sea level for the Port of Montréal to Trois-Rivières section

4 Cartographic representation of the bathymetric data

Map sets representing the 102,000 survey points were prepared using the Modeleur software (Secretan *et al*., 1998). The 4 survey areas are represented by means of maps that one may find in the appendix to this report. Bathymetric surveys are illustrated with the vertical reference being the main sea level. Grey survey points come from MSC's existing digital terrain model.

5 Conclusion

This work made it possible to fill in gaps in coverage within MSC’s digital terrain model covering the Cornwall to Trois-Rivières sector. Thus, these values could be integrated into the existing bathymetric data.

In terms of quality and precision of the acquired data, the overall assessment is very positive. On the other hand, the weak spring freshet prevented us from probing all the sectors that were initially identified.

APPENDIX : Plates of bathymetric data

Plate 1 : De la Paix Islands, Lake St.Louis - 18,747 sounding points

Plate 2 : De la Paix Islands, Lake St.Louis - Southwest sector (zoom)

Plate 3 : De la Paix Islands, Lake St.Louis - Northeast sector (zoom)

Plate 4 : Boucherville Islands – South sector

Plate 5 : Boucherville Islands - North sector

Plate 6 : Contrecoeur Islands - 1,693 sounding points

Plate 7 : Lake St.Pierre - 80,867 sounding points

Plate 8 : Lake St.Pierre - Southwest sector (zoom)

Plate 9 : Lake St.Pierre - Northwest sector (zoom)

Plate 10 : Lake St.Pierre - Southeast sector (zoom)

Plate 11 : Lake St.Pierre - Northeast sector (zoom)

De la Paix Islands, Lake St.Louis

18,747 sounding points

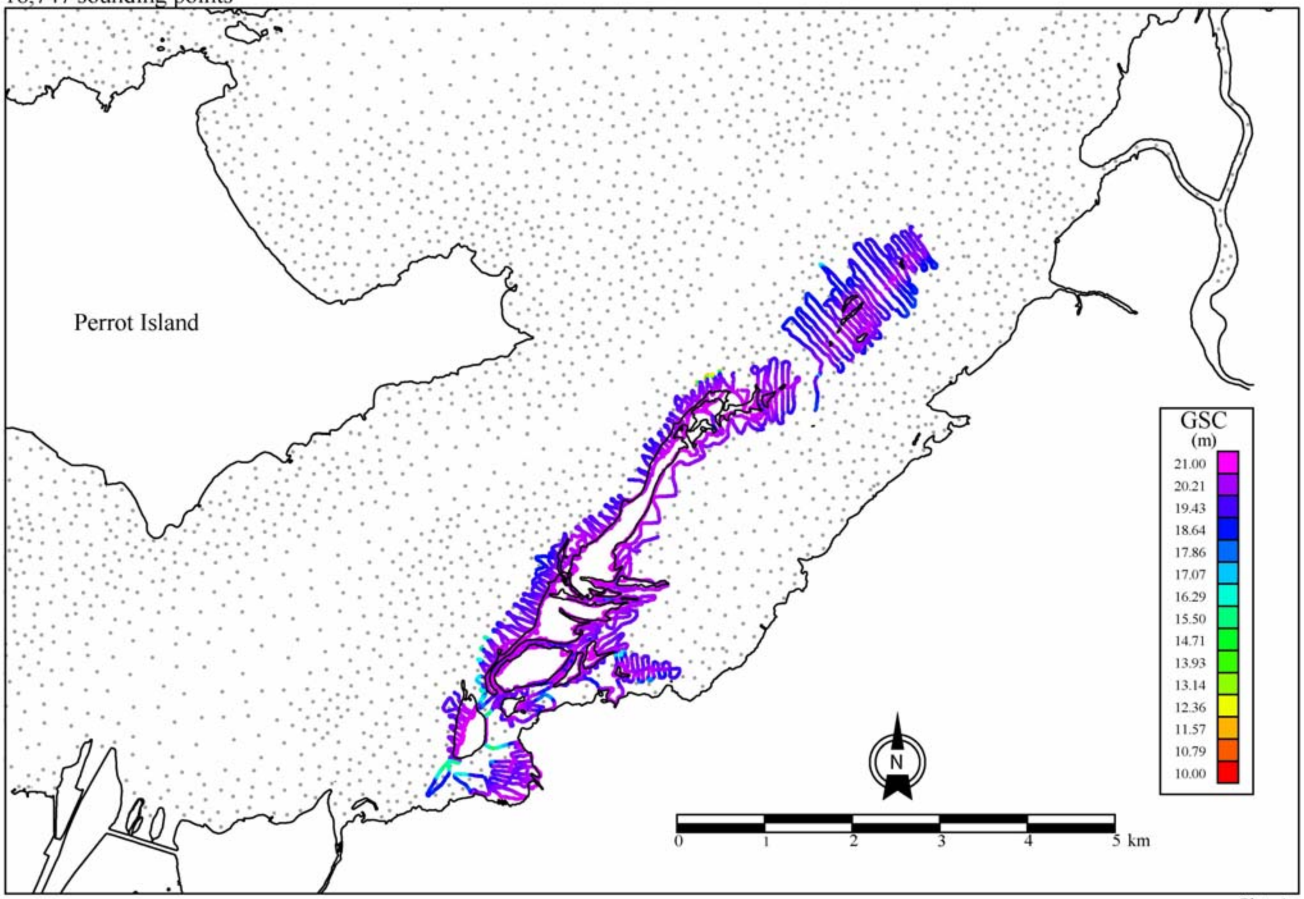

Plate 1

De la Paix Islands, Lake St.Louis

Southwest sector (zoom)

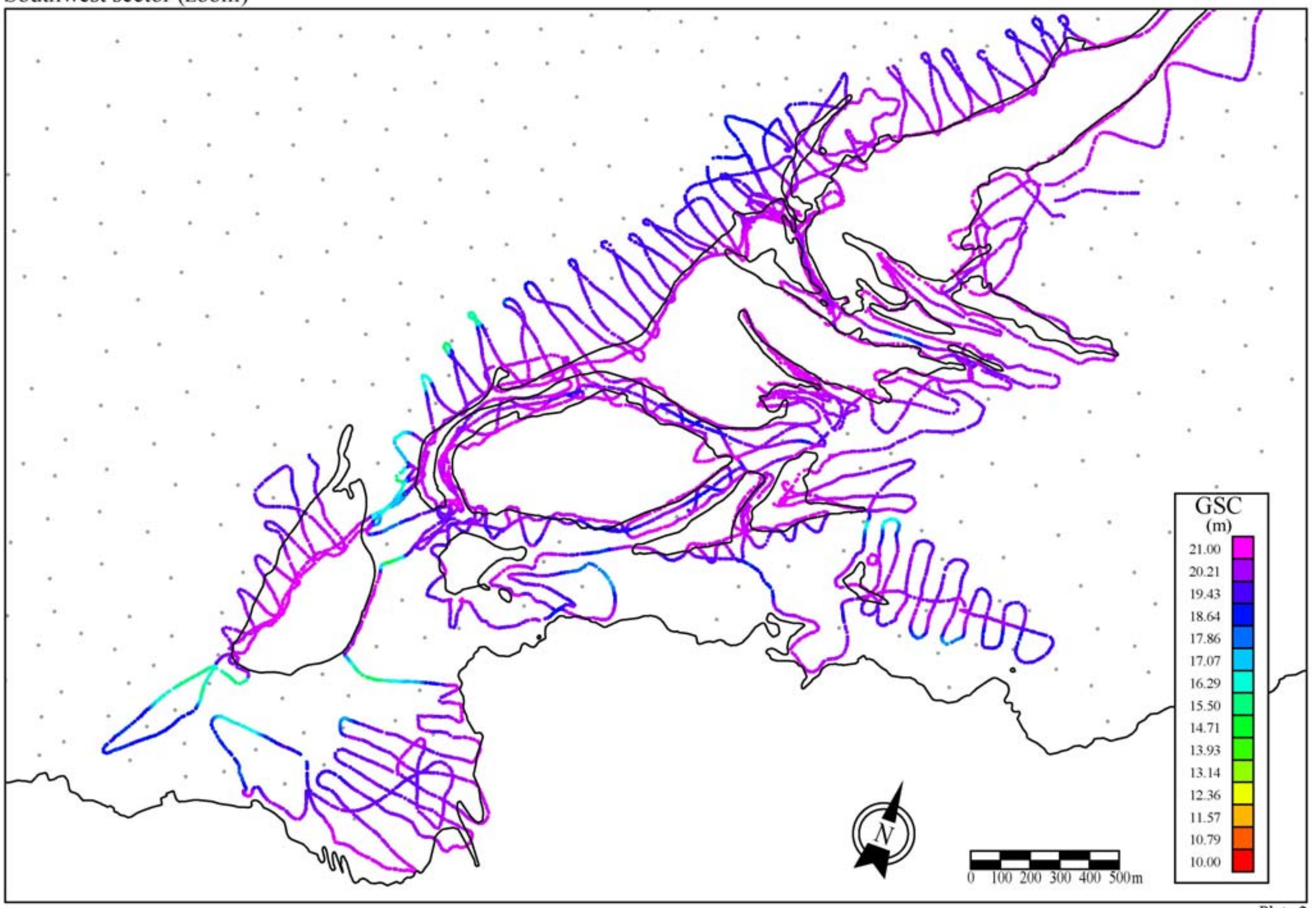

Plate 2

De la Paix Islands, Lake St.Louis

Northeast sector (zoom)

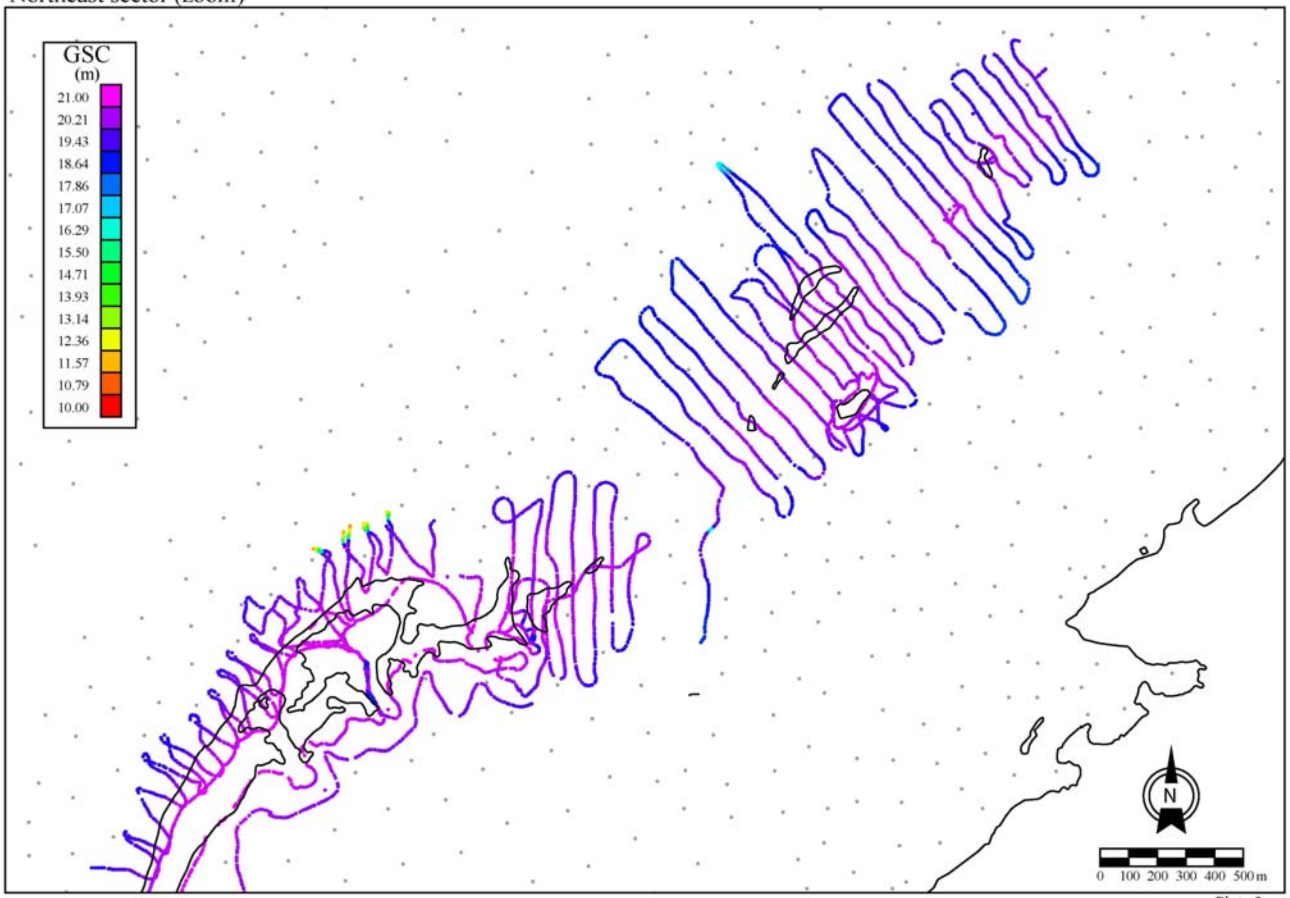

Plate 3

Boucherville Islands

South sector

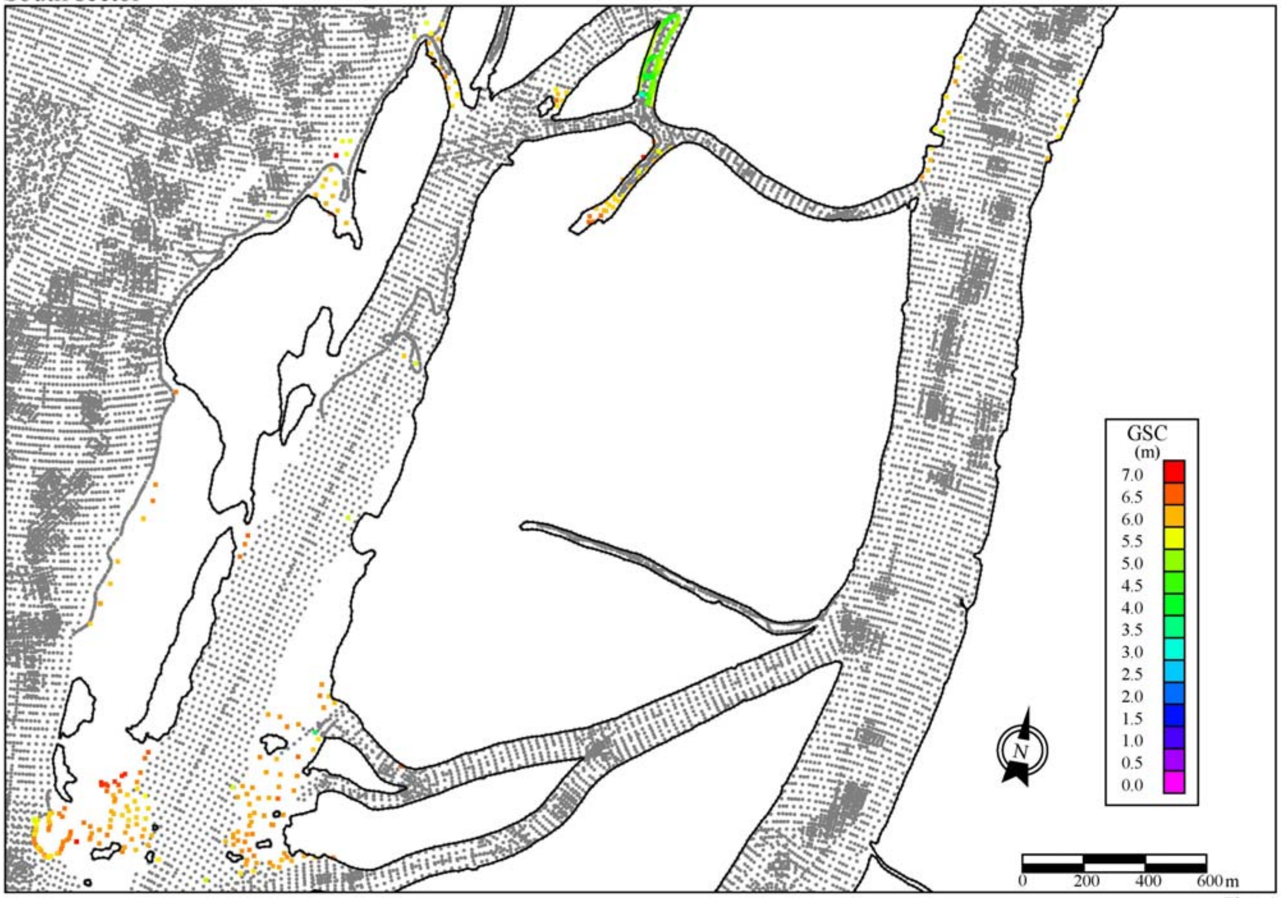

Plate 4

Boucherville Islands

North sector

Plate 5

Contrecoeur Islands

1,693 sounding points

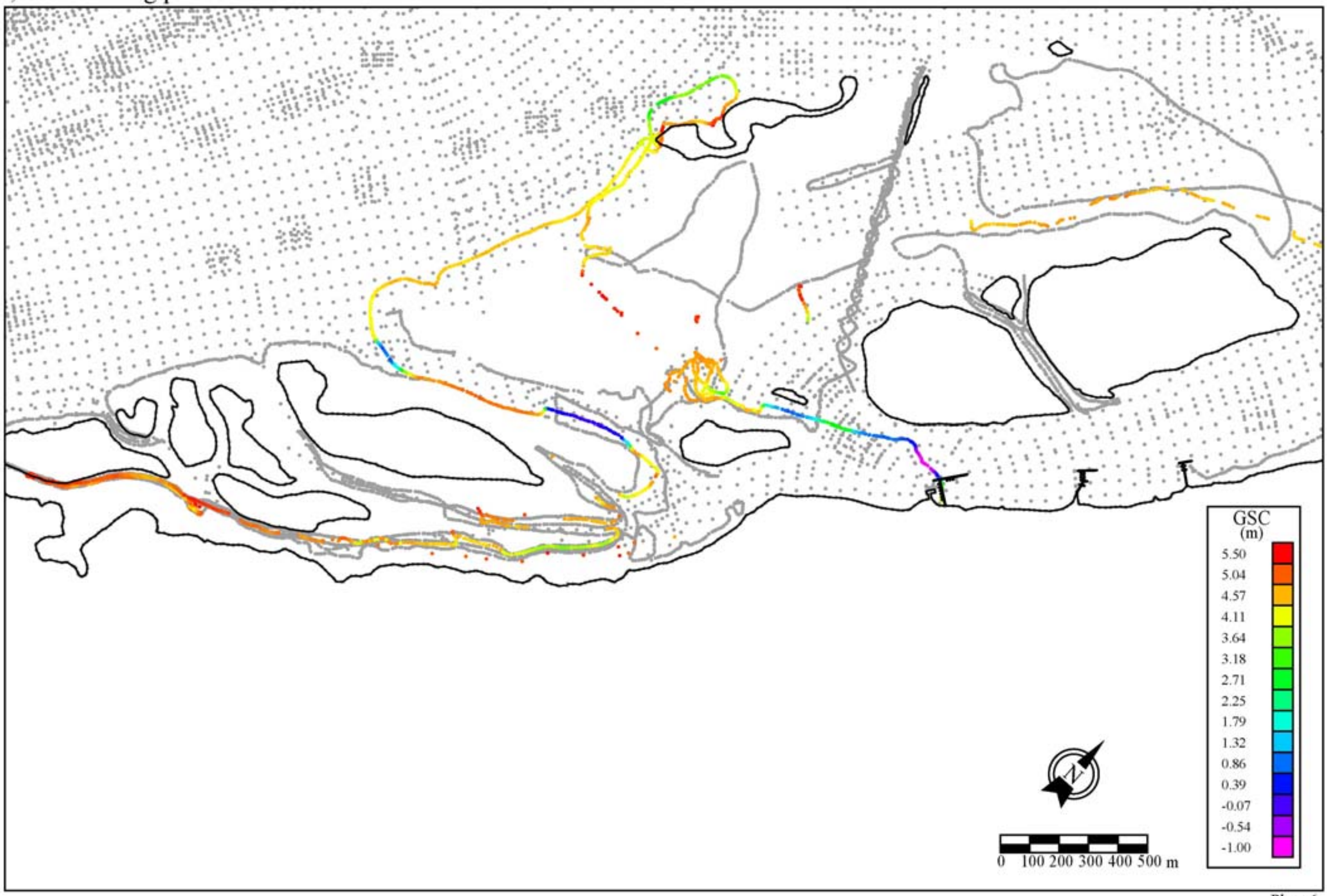

Plate 6

Lake St.Pierre

80,867 sounding points

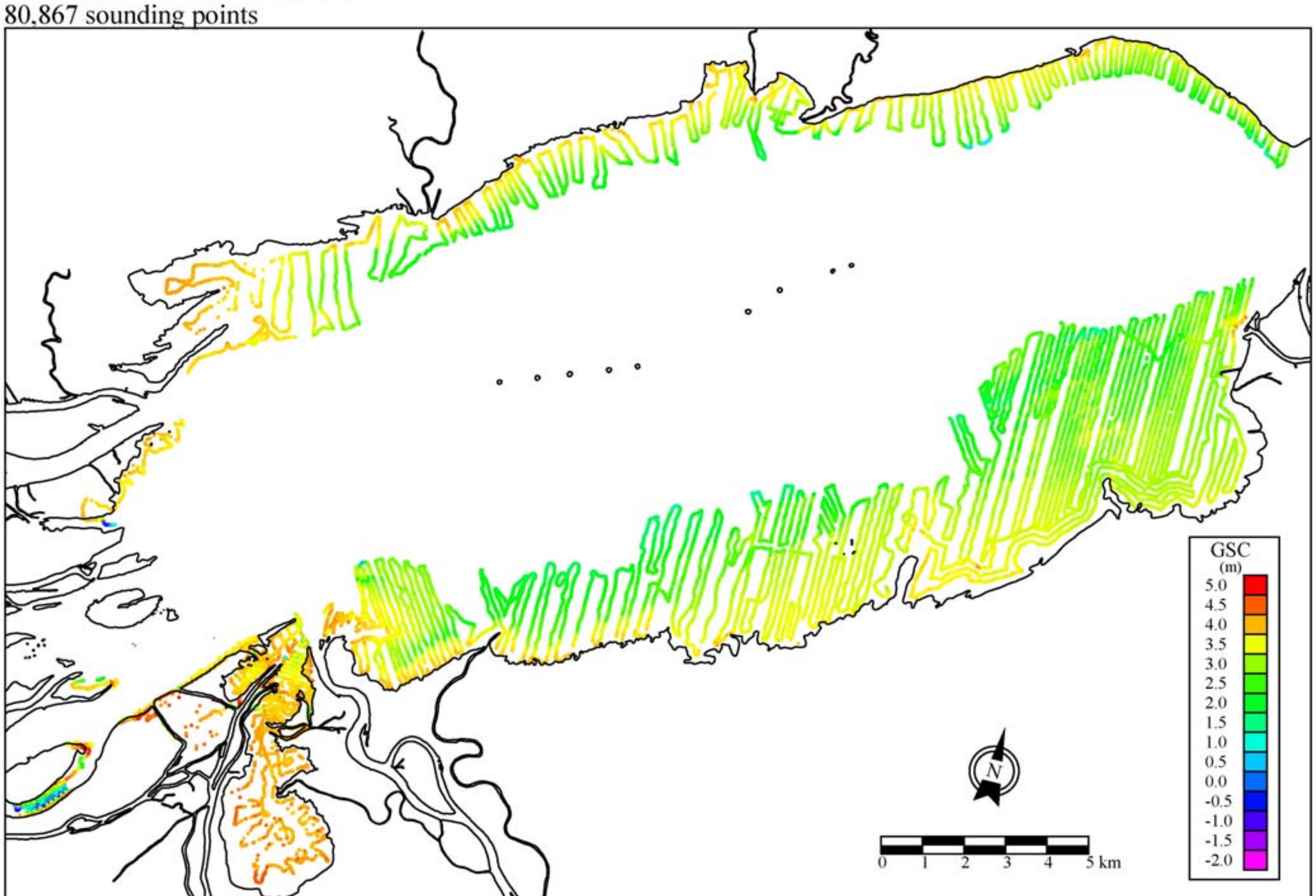

Plate 7

Lake St.Pierre
Southwest sector (zoom)

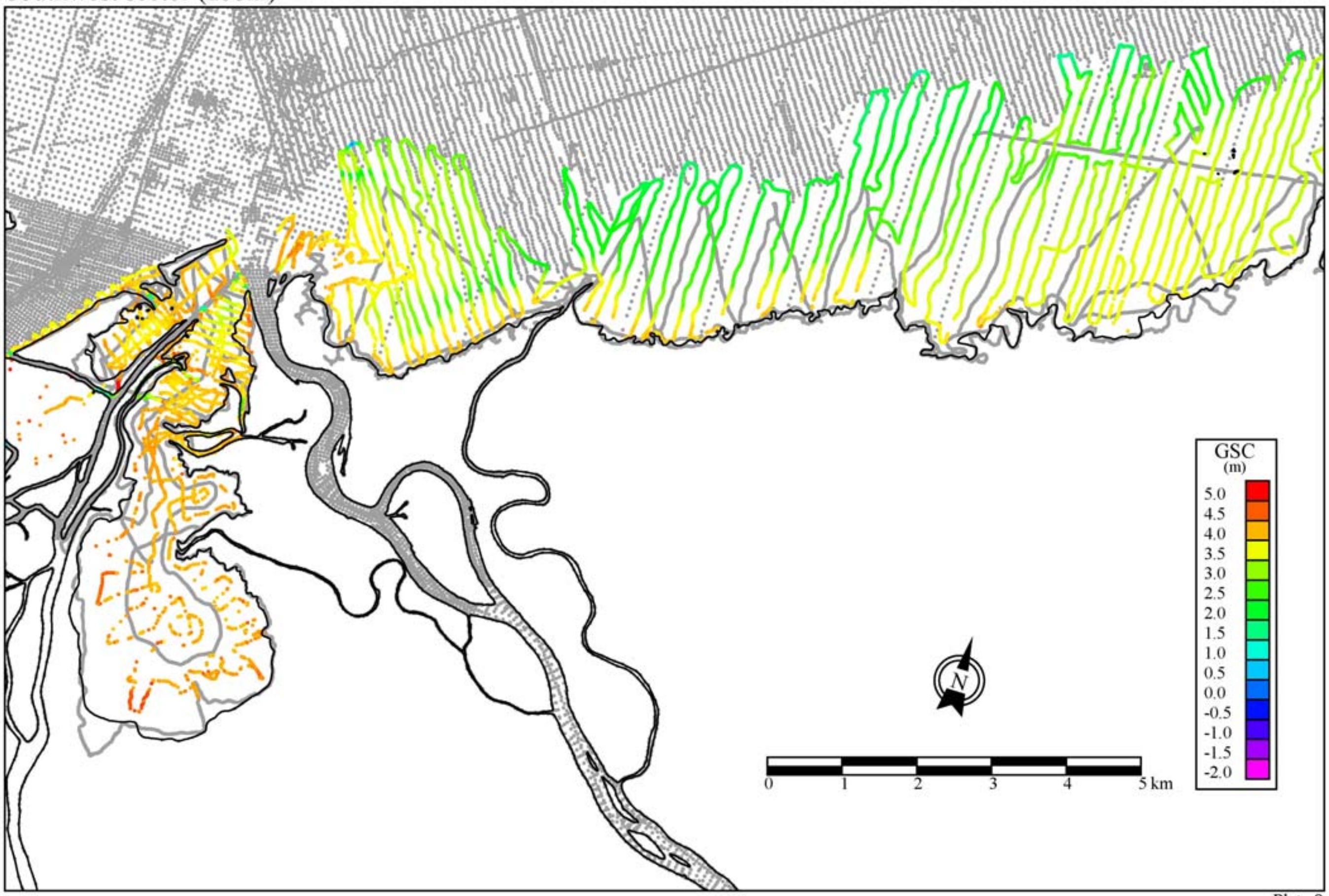

Plate 8

Lake St.Pierre

Northwest sector (zoom)

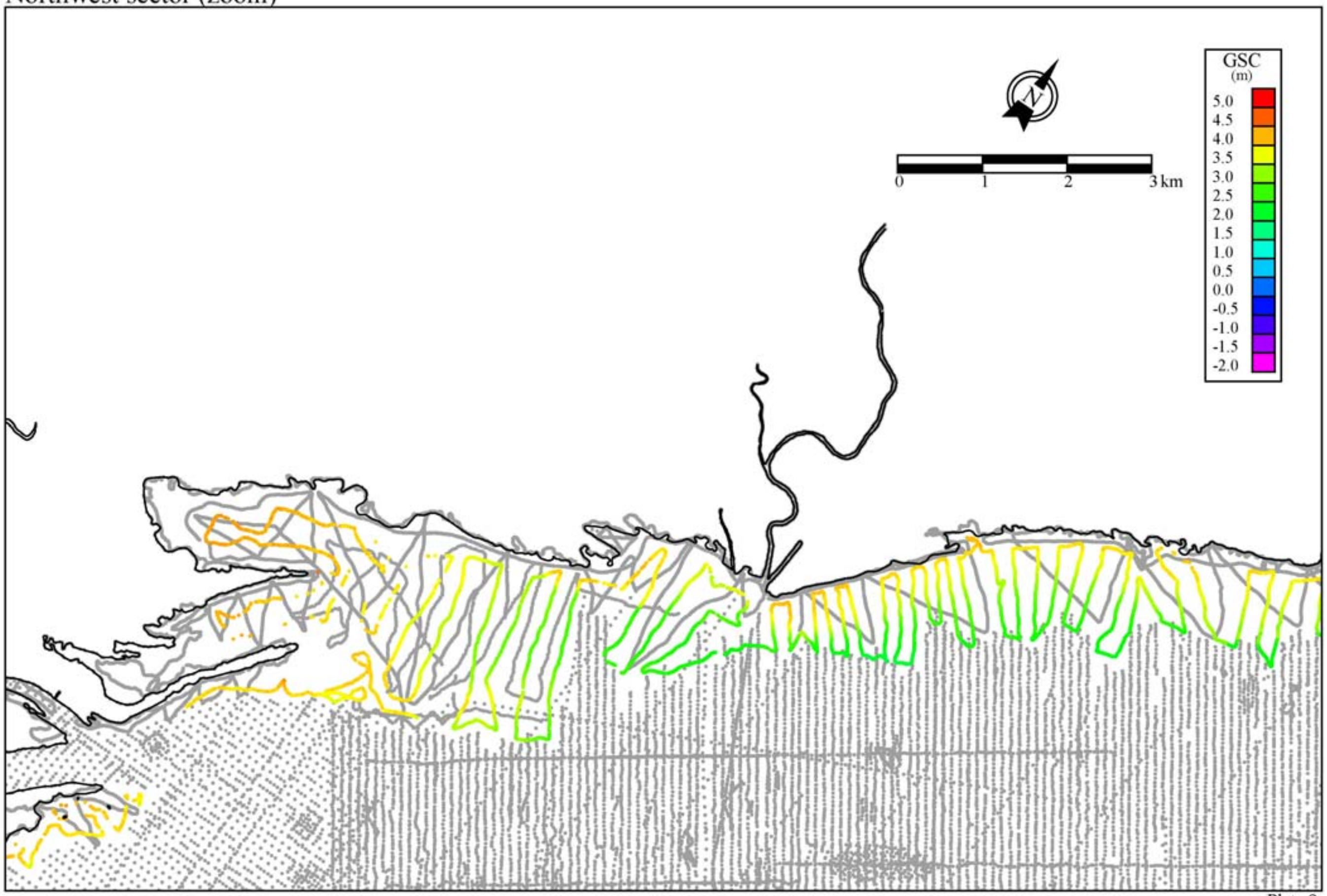

Plate 9

Lake St.Pierre

Southeast sector (zoom)

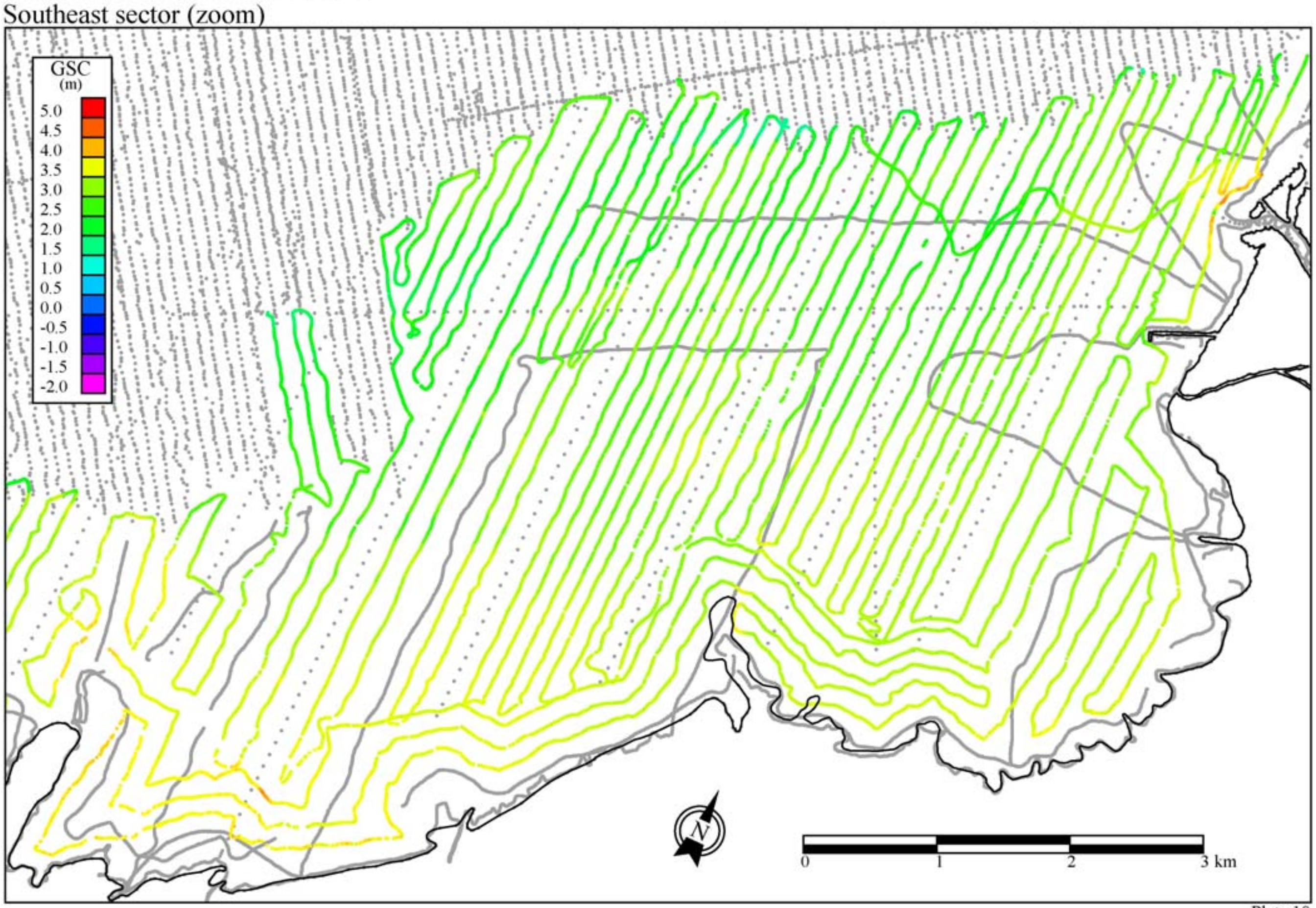

Plate 10

Lake St.Pierre

Northeast sector (zoom)