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Visualization of limnological data as two-and three-dimensional computer generated animations

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MANAGEMENT PERSPECTIVE

A multitude of data is collected yearly at the National Water Research Institute. These data can be readily understood using computer graphics, sound effects, speech synthesis and animation (Multi-media).

Computer animations, computer graphics, and video technology can be used to present both to the general public and to specialized scientific audiences research results on aquatic environments.

This paper presents an algorithm, LAKEANIM, that can generate computer animations from limnological data. The purpose of the program is to visualize in a dynamical fashion a variety of data collected in lakes. Temperature data collected in Hamilton Harbour, Lake Ontario, have been visualized as examples.

ABSTRACT

LAKEANIM is a software program to develop and display limnological data as computer generated animations. The purpose of the program is to visualize in a dynamical fashion a variety of data collected in lakes. Examples are originated from Hamilton Harbour, Lake Ontario. Data collected at different stations and different times are interpolated in space and in time. Lake topography and lake bathymetry files are used to relate data collected in the lake(s) with topographical features. A graphic user interface allows the user to choose two or three dimensional views, a viewpoint, fonts, colour palette, data and keyframes. A typical 1800 frame animation can be displayed in a minute at 30 frames per second. Rendering time is about 12 hours. Animations can be displayed on a monitor or transferred to video tape.

INTRODUCTION

In the mid–1970's volume visualization was first conceived as a tool for 3D medical imaging (Sunguroff and Greenberg, 1978; Herman and Liu, 1979). Volume visualization implies a display of three dimensional data on a flat, two dimensional, computer screen (Lorensen and Cline, 1987; Wilhelms and Gelder, 1990; Wyvill, Mcpheeters, and Wyvill, 1986). In recent years, this field of research has expanded into many applications: among others, medical diagnostics, the military, and geological surveys (Kaufmann, 1991 for a review).

Data collected in three dimensions are commonly available from limnological research. A ship collects data at several stations, and at many depths. These data can be depicted in two dimensions, along a transect or as a top view, or in three dimensions. When data are collected over time at many locations, a four dimensional picture surfaces. The fourth dimension is temporal. A computer generated animation can visualize the dynamics over time of three dimensional data.

While in the medical field computer imaging is important for diagnostics and planning operations, in limnology computer imaging might be important to visualize the movement of water masses, the development of algal blooms, episodes of oxygen depletion, etc. Advanced methods of computer graphics can help scientists and water managers alike.

LAKEANIM, a new visualization algorithm, was specifically developed for use in limnology. Its purpose is to display data in two– and three dimensions as computer generated animations. The lake bathymetry and topography are also an integral part of the package. Static pictures do not include temporal variations. Thus, the main function of the program is to generate (render) computer animations from the data. These animations can be viewed on the computer or transferred on video. The program has a friendly graphic user interface (GUI) and its design was a prominent part of this project.

DATA REQUIREMENTS

A standard input format was designed (Table 1) to incorporate the data and its geographical and temporal reference. The format is ASCII. Data collected in Hamilton Harbour, Lake Ontario, are used here as an example. The first column in Table 1 is concentration of dissolved oxygen, the second column represents temperature data, the third column is depth from the surface, the fourth is conductivity, followed by transmissivity and pH. The order of the data in the column is immaterial. Depth is just another variable, thus is it possible to visualize, for example, oxygen vs. temperature, pH vs conductivity, etc.

Figure 1 shows the shoreline and station locations for cruise 90051, May 1990. The line indicates an east–west transect. In 1990 several cruises took place. As input to LAKEANIM each cruise data is included in a separate file. At each station an electronic probe collected dissolved oxygen, temperature, pH, etc., and other data at many depths. In the file, the station location is marked by its latitude and longitude co–ordinates.

Unfortunately, limnological data are quite sparse in space. While a catscan (a three dimensional x–ray) might assemble information with a size of 512 x 512 x 512 pixels within hours, a limnologist would be hard pressed in collecting data at tens of stations, and at many depths, in less than a few days of field work, plus laboratory time. Lack of data creates problems of interpolation and extrapolation when computer animations are created. Also, to display three dimensional data collected in a lake, the lake bathymetry must be

Table 1: Data format for input to LAKEANIM. The first three lines contain information about the ship and station location as well as number of data points at the station. Not all data are shown for conciseness. The column location and type of data is arbitrary.

```
 Cruise   Year Week Ship name
 90051    90    22      AGILE
 Location                    Latitude     Longitude     Date
 HAMILTON HARBOUR    431828       794645        90/05/28.
Maximum depth    Number of data points   Consecutive number   Station number
 15.4                20                               001                     922
 Oxygen Conc.   Temperature      Depth       % Ox.Conc.  Conductivity      pH
      13.4702       12.8028         .1666        55.3785      342.1523      8.6999
      13.4497       12.8020         .2265        55.6547      342.2434      8.7009
      13.8910       12.7128         .4615        59.3252      342.5407      8.6969
      13.6445       12.5669         .6537        59.8703      342.6462      8.7119
      13.4717       12.5122         .8816        58.6658      342.4359      8.7201
      13.4601       12.3814        1.0810        56.7397      343.2142      8.7305
      13.4271       12.3054        1.2946        55.8208      342.9712      8.7363
      13.4077       12.2173        1.4869        54.8552      343.2144      8.7436
      13.4814       11.9771        1.7219        53.7649      343.8621      8.7531
      13.6989       11.7522        1.8714        52.5033      343.0800      8.7599
      13.9027       11.5596        2.1349        51.0133      342.0019      8.7694
      13.9959       11.4299        2.2346        50.6811      341.2850      8.7761
      14.0133       11.3114        2.4482        49.9023      340.5963      8.7755
      13.8503       11.1442        2.6619        49.9335      339.5258      8.7731
      13.5714       10.7875        2.8898        51.5325      335.9371      8.7729
      13.4407       10.4389        3.1319        53.0173      334.0665      8.7823
      13.3786       10.1693        3.3313        53.9622      330.1324      8.7881
      13.4154        9.8886        3.5164        54.9486      327.8514      8.7973
      13.5339        9.7640        3.7301        55.0109      326.7004      8.8022
      13.5960        9.7579        3.8582        54.8863      326.2054      8.8042
 90051 90 22 AGILE
 HAMILTON HARBOUR 431815   794710   90/05/28
  10.8    12 002 923
      12.7783       16.7100         .1372        88.6272      343.1954      8.0439
      12.6170       15.5236         .2248        69.1195      424.5021      8.2537
      12.7069       13.5336         .5042        68.4677      566.5625      8.6170
      12.6797       13.5498         .6751        61.4278      565.9214      8.6169
      12.6241       13.1141         .8745        58.2505      561.7278      8.6310
      12.6021       12.8709        1.0596        56.7865      545.2267      8.6436
      12.4261       12.6682        1.3302        54.1179      520.7967      8.6515
      12.4196       12.3480        1.5296        51.4598      512.8007      8.6587
      12.3575       12.3571        1.6792        50.4630      503.7487      8.6614
      12.3905       12.3419        1.8714        50.0736      502.2797      8.6621
      12.4196       12.2750        2.0851        49.4195      501.9677      8.6639
      12.4856       12.1656        2.3201        48.3760      498.5956      8.6699
```

included to show the relation of the data to the bottom, and to the shoreline. In computer graphics, this relation takes the form of a mask. No data are shown on land. The development of this three dimensional mask is computationally challenging. A program, MASKGEN, has been developed for this purpose. The output of MASKGEN has been designed as input to LAKEANIM.

COMPUTER REQUIREMENTS

LAKEANIM has been developed on a Commodore Amiga 3000/25 desktop computer with 10 Mb RAM. This hardware is adept at graphics, animation and sound manipulation. The hardware is inhabited by a multi-tasking operating system that can interweave the various media. Both the hardware and the Amiga DOS software have been designed not for business purposes but for multi-media. Many software companies have developed off-the-shelf software to perform complex graphics, animations, audio and video applications. The native video system in the Amiga conforms to the National Television System Committee (NTSC) video standards. The frequency compatibility makes it easy to synchronize, or genlock, the computer's output with a video signal. The display system includes non-interlaced, interlaced and overscan capabilities. Thus, animations can be effortlessly transferred to video. The video strengths of the Amiga have attracted a host of video peripherals, including frame buffers, digitizers, time-base correctors, and special effects devices. Amiga animation files can be viewed on MS-DOS computers by conversion[1] to FLI (320 x 200 x 256 colours) and FLC (640 x 480 x 256 colours) files.

[1]Using the commercial program by Autodesk, Animator Pro

GRAPHICAL USER INTERFACE (GUI)

The LAKEANIM user interface (GUI) was designed as drop down menus, each menu designed for data input, rendering of key frames, keyframe animations or full animations. The GUI also lets the user choose whether the display will be two or three dimensional, the observer viewpoint, the rotation of the lake, the topography and the bathymetry files to use, the fonts to use for titling, the number of colours, the colours and the range of data each colour represents.

LAKEANIM combines spatial and temporal data collected in lakes, elaborates them and visualizes them as computer generated animations. Single frame (key frames) displays are also possible. The main feature is data visualization in three dimensions, including the lake boundaries and bathymetry. Special features include the visualization of different bodies of water on the same screen using interpolation methods that avoid the influence of sets of data spatially close but logically separate.

TWO DIMENSIONAL DISPLAYS

Two dimensional displays are projections of the three dimensional data on one axis. A two dimensional display might be a transect or a top view. Figure 2 shows an east west transect in Hamilton Harbour computed for May 28, 1990. Temperature data are visualized. This transect encompasses several stations in the bay proper, in Lake Ontario (3 stations), and in the channel connecting the two. The vertical scale is exaggerated 200 times since the distance between the two extreme stations is about nine kilometres and the maximum depth is 26 metres.

A transect line (Fig. 1) can be interactively chosen by moving the mouse on the screen to a location, start of the transect, and then to another to indicate the end of the transect. The computer program then identified the closest stations to each point in the transect line to create the desiderate visualization. The number of closest stations can be chosen by the user, usually this number ranges between two and five. This user–definable feature gives the program flexibility to deal with different data set densities. The closest stations, weighted by the inverse of the distance squared, are also used in the top view and in the three dimensional view. Thus, all data visualizations are internally consistent.

Two interpolation methods and one assumption are used to create Fig. 2. Vertical interpolation is done using a spline. Horizontally, the interpolation is linear, but non–linearly modified by the weights (inverse to the square of the distance from the station, as mentioned in the previous paragraph). Once temperatures are computed, a colour is assigned to each pixel, to represent the temperature at that location. A colour map on the right of the screen, describes the relation between temperature and colour. The user can decide the colour palette, i.e. which colour represents which range of data, for example, light blue is 4–6 degrees C.

In this exercise, no observations were available very close to shore, and near the bottom at the west end of the bay. However, given the fact the closest stations are used to estimate the value of a variable at a given location, it is possible to estimate values at all locations in the lake.

A two dimensional display can also be a top view. Figure 3 shows a top view of the same temperature data.

A special case: two bodies of water connected by a channel

Visualization of two water bodies connected by a channel presents additional problems: physical constraints in the real system prevent interpolation across land. Figure 1 shows, on the West, Hamilton Harbour and, on the East, Lake Ontario. Data collected in the bay are not representative of lake conditions, even if only a narrow strip of land separates the two systems. In LAKEANIM it is possible to use only certain stations to identify a water body. We call this choice a group. In this case, lake data from three stations are collected in one group and harbour data in another. The user can choose the station in a group by surrounding the stations to visualize together with a polygon.

TWO DIMENSIONAL ANIMATIONS

Key frames

In computer graphics terminology a frame that is precisely known is called a "key frame." Figures 2 and 3 are key frames. Table 1 shows some of the used to render the figures. Key frames represent real information.

Generation of frames between two key frames: In-between frames

In-between frames visualize the possible evolution of phenomena in the lake. Since in-between frames are computed by interpolation between two key frames, this evolution might not be completely real, however it makes it possible to understand how the lake might have changed over time in between observations.

Generation of in-between frames is the time consuming part of creating an animation. Each pixel on the screen has to be generated by linear interpolation in time (interpolation in space is used for key frames). The number of in-between frames was chosen with the following formula. We wanted to create an animation that lasts one minute to describe the evolution of the temperature field from May 12 to November 23, 1990. In countries with the NTSC standard (e.g., North America and Japan), televisions display 30 frames per second, thus, to create an animation where each frame was rendered separately, an 1800 frames animation had to be developed (Of course it is also possible to play an animation at a slower rate, so that each NTSC frame corresponds to more than one rendered frame). To compute the number of in–between frames a simple proportion was made to accommodate these boundaries. Since cruises did not take place at the same time intervals, the number of in–between key frames changes according to the cruise date. Thus, in between May 23 and June 17 there are 345 in–between frames and between June 17 and July 5, there are 231 in–between frames.

THREE DIMENSIONAL DISPLAYS

The simplest display involves the visualization of data with no boundaries, like, for example, in an open ocean. This process can be implemented using volume visualization algorithms. The second step is to include boundaries, this process is called masking. A mask is a 2D digitization of the shore as well as a 3D bathymetry of the lake. For Hamilton Harbour we had a 14000 points shoreline data file, and a 2500 points bathymetry data file.

Data that can be represented might be commonly available limnological parameter's, e.g., water temperature, oxygen, pH, etc., as well as toxic contaminants concentrations. Physical data, for example current fields could also be superimposed.

The user can also choose his viewpoint. The lake can be rotated in three dimensions to choose the best perspective. If the viewpoint is perpendicular to the x, y plane then the 3D view becomes a 2D top view. If the viewpoint is perpendicular to a y,z plane then the output is a 2D longitudinal transect.

Colour choice is very important in 3D visualization, some colours might be set to be completely transparent, and some might be translucent so that it is possible to visualize data in different planes.

THREE DIMENSIONAL ANIMATIONS

Three dimensional animations are created in the same fashion as two dimensional animations. Key frames are originally developed and the in–between frames are created by interpolating each pixel in time.

Figure 4 shows a three dimensional view of temperature data collected in May 1990. The three dimensional view is difficult to visualize statically. Usually, three dimensional visualizations are best viewed as animations. The continuous motion or the change in view point helps the user understand the data. Animations viewable on PCs or on tape are available for a nominal duplication fee.

DISCUSSION

In Hamilton Harbour data have been collected for over a decade, at over 30 stations, 10 to 30 times a year. The amount of data is large considering the fact that at each station, five variables, dissolved oxygen, temperature, conductivity, transmissivity and pH, were collected. Visualization permits a dynamic comparison of data collected over a season or over several years. Several animations can be run in different windows at the same time.

LAKEANIM was initially developed for use by the scientists who collected the data. Computer animation, computer graphics, video technology can also be used to present both to the general public and to specialized scientific audiences research result on aquatic environments. The use of animation can expand to include other scientific information and preparation of interactive information tools.

LAKEANIM is not the only program being developed for use by ecologists working in aquatic environment. LAKEANIM was developed specifically for lakes research. Land boundaries and features to render animations for several lakes near each other are included in the program. Also, as the name shows, the emphasis is on dynamics, i.e., animations, rather than on static views of the data. At the Institute of Naval Oceanography, Stennis Space Centre, Mississippi, the Ocean Modeling and Prediction Research and Development Group developed a program to integrate an oceanographic data base with visualization techniques. This program runs on powerful Silicon Graphics workstations while LAKEANIM was developed on a desk top computer.

Commercial programs, such as Dynamic Graphics, are also available for workstations. These programs however are quite expensive and require fast workstations. The availability of commercial software, for scientific visualization in the form of animations, indicates the raising interest of users in this field.

ACKNOWLEDGEMENTS

Murray Charlton kindly provided temperature data he collected in Hamilton Harbour. Fausto Chiocchio processed and refined the data.

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FIGURE LEGENDS

Figure 1: Shoreline and station locations for cruise 90051, May 1990. The line indicates an east–west transect (see Fig. 2).

Figure 2: East west transect in Hamilton Harbour. Temperature data are visualized. This transect encompasses several stations in the bay proper, in Lake Ontario (3 stations), and in the channel connecting the two. The vertical scale is exaggerated 200 times since the distance between the two extreme stations is about nine kilometres and the maximum depth is 26 metres. The black vertical lines identify the station locations.

Figure 3: Top view of temperature data displayed in Fig. 2.

Figure 4: Three dimensional view of temperature data displayed in Fig. 2.

Hamilton Harbour, Lake Ontario

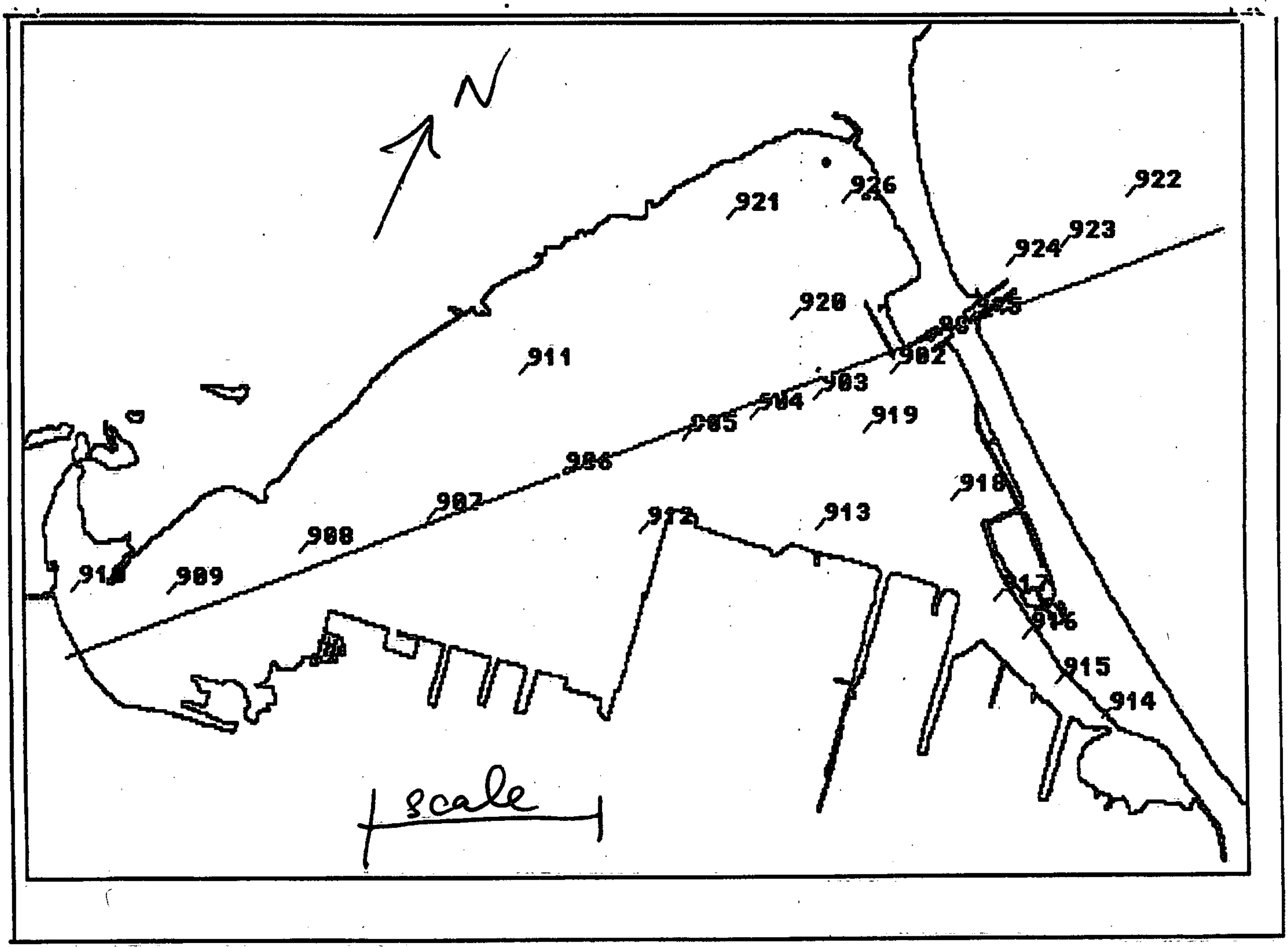

Figure 1: Shoreline and station locations for cruise 90051, May 1990. The line indicates an east–west transect (see Fig. 2).

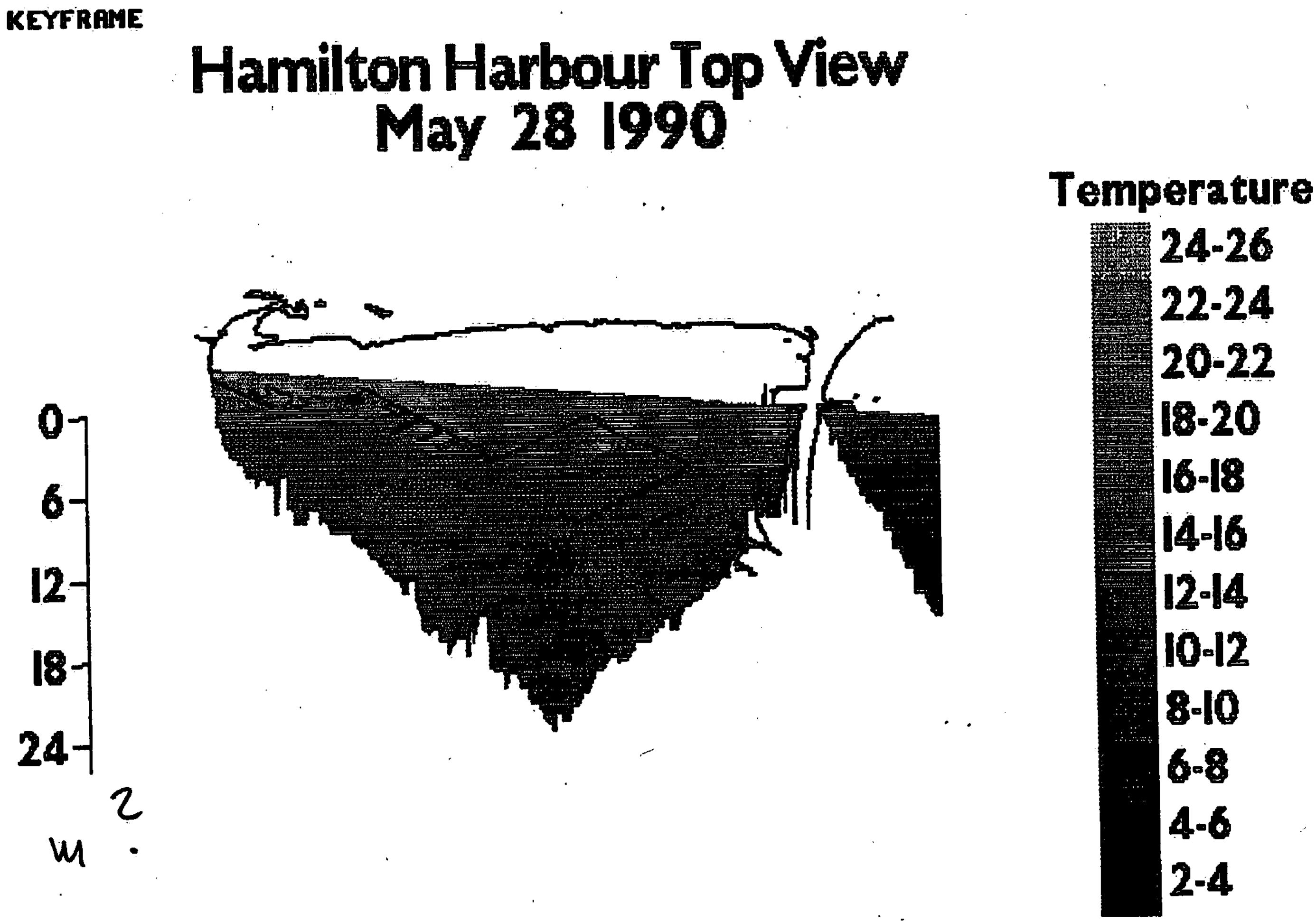

Figure 2: East west transect in Hamilton Harbour. Temperature data are visualized. This transect encompasses several stations in the bay proper, in Lake Ontario (3 stations), and in the channel connecting the two. The vertical scale is exaggerated 200 times since the distance between the two extreme stations is about nine kilometres and the maximum depth is 26 metres. The black vertical lines identify the station locations.

KEYFRAME

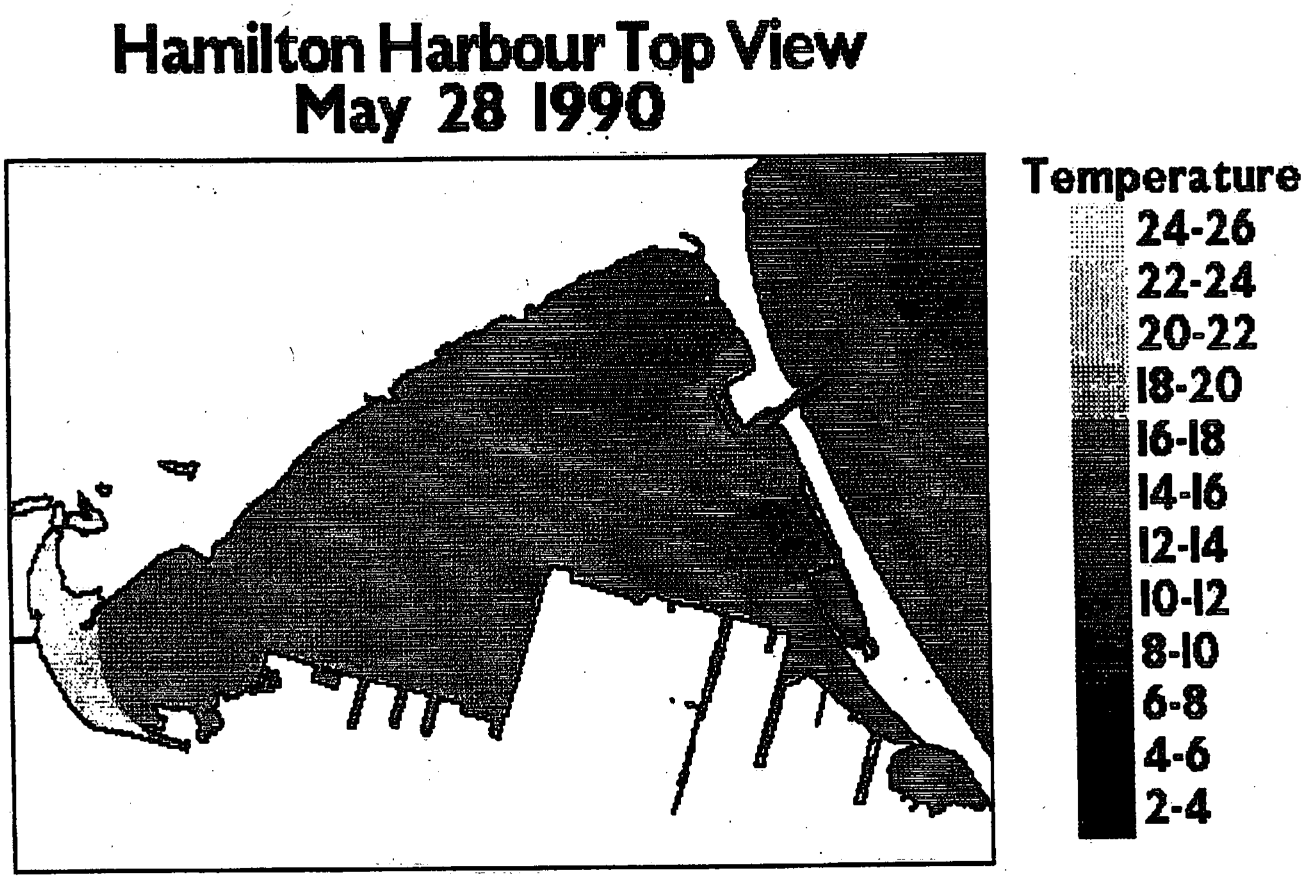

Figure 3: Top view of temperature data displayed in Fig. 2.

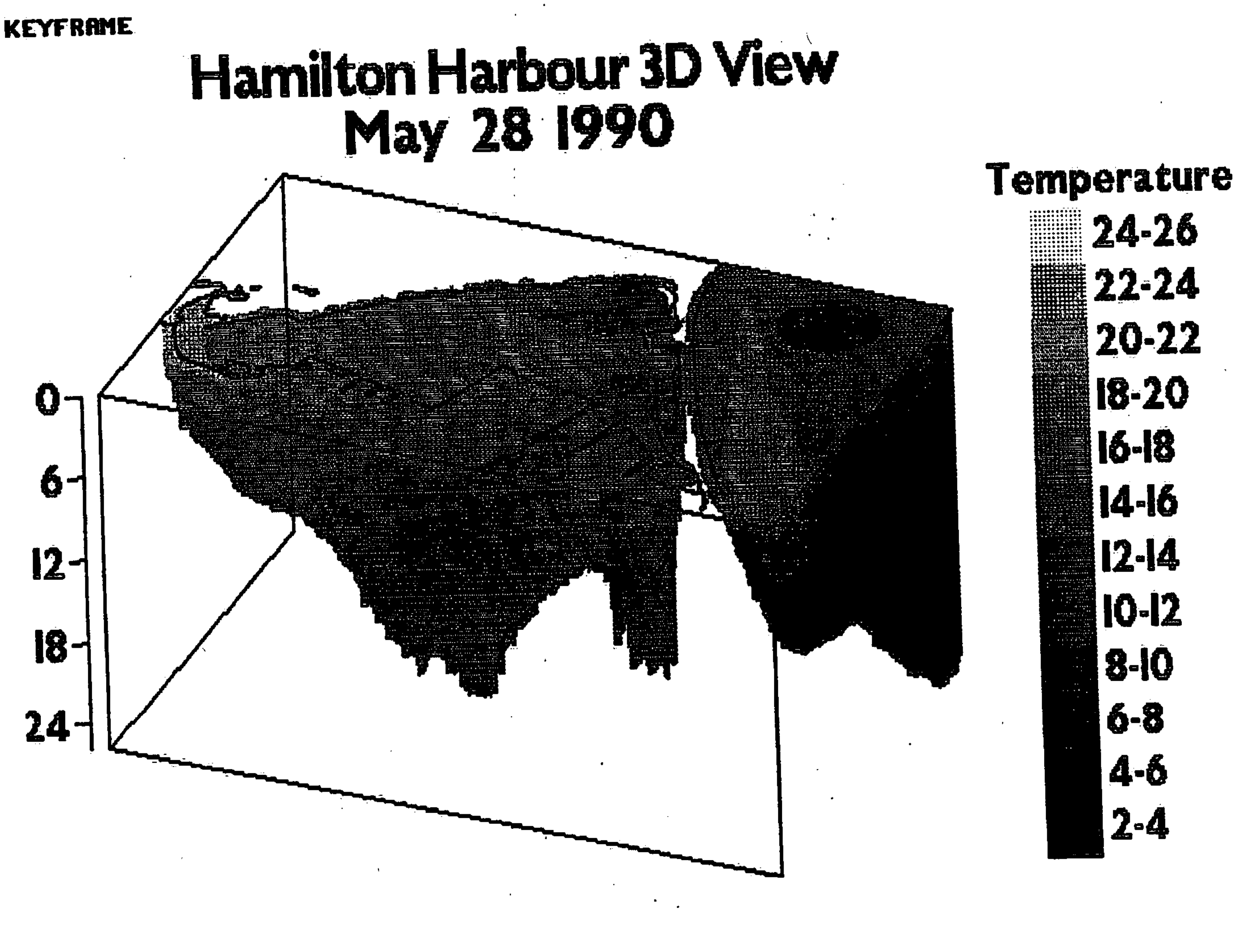

Figure 4: Three dimensional view of temperature data displayed in Fig. 2.

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