IGODS: An Important New Tool for Managing and Visualizing Spatial Data

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Abstract- **The Interactive Graphical Ocean Database System (IGODS) is a complete software solution to support studies of ocean, coastal, and inland waters using profiling instrumentation such as a conductivity-temperature-depth (CTD) instrument. If you routinely conduct surveys where you are profiling at a set of geographic locations, collecting CTD profiles, and perhaps also collecting water samples for additional analyses, then the IGODS program is an ideal way for you to manage your datasets. IGODS is an easy to use tool that includes functions to optimize the import of data, including both electronically recorded CTD data and discrete sampling results. Final IGODS data files integrate all data for a survey into a single file, for easy archiving. The program provides a wide variety of data analysis and reporting tools.**

Numerous entities conduct surveys of water bodies as a requirement in a permit for discharge, to monitor for impacts as well as to characterize background conditions. Coastal discharges of sewage effluent, surface effluent discharges, associated with pulp mills or mining operations, river outflows, enclosed bays, estuaries, harbors, and reservoirs, all can have programs either requiring monitoring, or may have environmental issues that require studies and data gathering to support management efforts.

How the Program Works

IGODS is designed to work directly with the electronic file formats of the leading CTD manufacturer. Immediately after a survey is completed and data files are generated into engineering units, a full survey worth of CTD files can be automatically imported into your survey workspace. You will see a display that incorporates a grid array showing results from all survey sites, and a map of the locations. Profiles of one or multiple variables can be viewed in this display.

As soon as data are imported a one page report statistically summarizing all variables can be generated. If wanted, a batch report generator allows options of generating full survey or overlaid data views for one to all parameters. Average depth weighted profiles, comparisons of selected individual profiles, overlay of multiple parameters, X/Y plotting of any variable against another, and calculation of anomaly between any parameter, and the mean profile for that parameter can then be directly plotted. In addition, a very simple, yet versatile plotting interface allows plotting of 2D and 3D transects and constant depth surface representations of data. Finally, in addition to direct output for reports, all the 3D data visualizations produced by IGODS can be exported to Google Earth, and saved as KMZ files.

Every survey is defined using a workspace file, which defines station locations, parameters, and ranges for each parameter. Once it is created the workspace file makes managing data from subsequent surveys even easier, and assures consistency in the comparison of statistics and graphical representations between surveys.

IGODS is easy to learn and can be easily scaled to either very small or extremely large projects. It can also be used for data without a depth component, for example, benthic species or chemistry data. In projects involving multiple agencies the program makes it easy to distinguish between participating entities. Graphics production is extremely fast and can be produced either singly or in a batch process.

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I. INTRODUCTION

The Interactive Graphical Ocean Database System (IGODS) has been designed to offer complete support for studies of ocean, coastal, and inland waters using profiling instrumentation such as a conductivity-temperature-depth (CTD) instrument. IGODS is an ideal way to manage datasets for surveys at a set of geographic locations, where both CTD profiles and discreet water samples are collected. IGODS is an easy to use tool that includes functions to optimize the import of data, including both electronically recorded CTD data and discrete sampling results. IGODS data files integrate all data for a survey into a single comma separated variable file for easy archiving. IGODS also provides a wide variety of data analysis and reporting tools.

Numerous cities and counties that produce waste or thermal dischargers are required to conduct surveys of water bodies as a requirement in their permits for ocean or fresh water. These surveys are designed to not only monitor for discharge impacts but to characterize background conditions as well. Coastal discharges of sewage effluent, surface effluent discharges associated with pulp mills or mining operations, river outflows, enclosed bays, estuaries, harbors, and reservoirs all require monitoring or may have environmental issues that require studies to support management efforts.

The IGODS program brings efficiency to all aspects of the process, from developing the sampling arrangement for a new survey, to extracting the relevant downcast portions of the individual cast data and bin averaging to get one meter interval data, to arranging all the data in a single file for archiving. For example, a batch function enables the user to import the data from the individual CTD files of all stations with one click (but individual data points for every parameter at every site can also be directly examined during this import step if desired). It makes the import of discrete data into the final survey file very easy. A CSV file containing discrete analysis results such as microbiological data or chemistry data with each result identified by station, depth, and parameter can be selected and all discrete data are then merged into the CTD survey data file with a single click. For analysis and reporting survey data files are then immediately ready to be viewed in a multiquadrant, XY, or 3D mode. The program can be used in the field to process and load the individual site data immediately as a survey is underway so that the data can be visualized during the survey. This is a big advantage during adaptive sampling surveys.

The primary function of IGODS is to enable the user to interpret and analyze data through the production of graphical representations of data sets consisting of one to an unlimited number of variables sampled at an unlimited number of discrete sampling locations. Typically this type of data set is obtained using sensors on a package inserted into an otherwise difficult to view medium. The subsurface ocean is the particular case for which IGODS was intended, however, a number of other environments are sampled in similar ways. For example, lake and river environments, sub-surface geology/groundwater - using well log data, sediment layers - using core profiles, atmospheric distributions of materials, and the distribution of benthic biota, could also be examined using IGODS. IGODS has even been used to map distributions of suspended solids and dye in the clarifier tanks at a sewage treatment plant. The distance scales used by IGODS are flexible, and automatically adjust to the appropriate settings for stations clustered together within a few meters of each other, to stations spread over hundreds of kilometers.

IGODS survey data files use an easy to read and edit ASCII or CSV file format, with no restrictions on the number of descriptive header lines, number of columns of data, or number of sampling locations. Every record in the survey data files includes the station ID, date, and time of sampling and the exact depth of the sampling, other commonly recorded description information includes time in seconds from start of electronic recording, the descent rate, and directly logged latitude and longitude position information. An unlimited number of measured parameters can be maintained in any survey data file. Data formats are user defined, and specific information such as the number of variables, their names, and information about locations sampled is maintained in a separate workspace support file which is referenced by the IGODS data file. For standard surveys, multiple IGODS survey data files can reference a single workspace file.

When a survey data file is selected, IGODS automatically loads the associated workspace file, and then loads the complete data set into the workspace template, where every value is available instantaneously. All data at all locations can be viewed simultaneously as XY plots either in multiple quadrants or with all stations data overlaid. Clicking on graphed points opens a data form that displays discrete X and Y values as a scroll bar moves up and down the profile. A map window shows the location of the selected sampling location. Multiple variables, distinguished from one another by color and line style, can be overlaid, with each variable using a unique and individually adjustable scale. To further explore relationships between variables, any variable can be plotted against any other. Useful oceanographic examples include plots of temperature versus salinity, percentage light transmissivity versus salinity, and percentage light transmissivity versus dissolved oxygen.

One of the most powerful features of the IGODS program is its color 3-D mapping capability. This allows the user to create a view of the study area from any perspective, e.g., from the perspective of a passenger in a plane flying several kilometers above, and to select combinations of along-shelf, cross shelf, and constant depth surfaces which will then be filled in with interpolated values using a selected color spectrum to map changes in the variable. Transects and surfaces are mapped directly to actual sample locations. A free format transect capability allows any stations to be used to define transects. Transects can be viewed in 3-D space from any perspective or can be flattened into a 2-D representation to aid in interpreting oceanographic structures.

II. How the Program Works

IGODS is designed to work directly with the ASCII electronic file formats of the leading CTD manufacturer. Immediately after a survey is completed and data files are generated into engineering units, a full survey worth of CTD files can be automatically imported into your survey workspace. You will see a display that incorporates a grid array showing results from all survey sites, and a map of the locations. Profiles of one or multiple variables can be viewed in this display.

As soon as data are imported a one page report statistically summarizing all variables can be generated. If wanted, a batch report generator allows options of generating full survey or overlaid data views for one to all parameters. Average depth weighted profiles, comparisons of selected individual profiles, overlay of multiple parameters, X/Y plotting of any variable against another, and calculation of anomaly between any parameter, and the mean profile for that parameter can then be directly plotted. In addition, a very simple, yet versatile plotting interface allows plotting of 2D and 3D transects and constant depth surface representations of data. Finally, in addition to direct output for reports, all the 3D data visualizations produced by IGODS can be exported to Google Earth, and saved as KMZ files.

Every survey is defined using a workspace file, which defines station locations, station depth, group codes, parameters, and data ranges for each parameter. Once it is created, the workspace file makes managing data from subsequent surveys easy, and assures consistency in the comparison of statistics and graphical representations between surveys.

IGODS is easy to learn and can be easily scaled to either very small or extremely large projects. It can also be used for data without a depth component, for example, benthic species or chemistry data. In projects involving multiple agencies the program makes it easy to distinguish between participating entities. Graphics production is extremely fast and can be produced either singly or in a batch process.

A. Main Screen – Multiquadrant View

The Multiquadrant view (Fig. 1) is the first to be displayed when a data or workspace file is opened. The multiquadrant view displays all the sampling sites for the survey. In this view parameters are chosen, scales can be adjusted, lines and symbols customized, and multiple parameters can be overlaid. Both multiquadrant and XY displays are accompanied by a very simple intuitive Location Map display window (Fig. 1, upper right corner). This window always shows the active sampling site. This window can be resized and zoomed. The map window is also an active tool to select and display data for any site. Clicking on a station on the Location Map highlights that station on the grid below. Conversely, clicking on a station in the station grid highlights that station on the Location Map. This enables the user to easily navigate the stations in the survey. This is especially important in a region-wide survey involving many agencies and hundreds of stations over a wide geographic area.

The multiquadrant view can be sized to any number of X by Y cells. Although limited to a rectangular fixed spacing, the multiquadrant display shows the relative positions of the sampling sites roughly comparable to their actual geographic distribution on the Location Map.

B. XY Data Plotting (Fig. 2)

Up to six different variables can be plotted on the multiquadrant and single plot displays (Fig. 3). The program allows each displayed variable to be customized including using differently shaped, sized, and colored symbols to differentiate between variables. The line thickness and color can also be specified for lines connecting data points. Any combination of variables can be plotted against each other, for example, to see the relationship between temperature and salinity, or light transmissivity and chlorophyll fluorescence. An average profile can be overlaid as a reference. The average profile can be reprocessed on the fly using all profiles or a user selected subset. A difference or anomaly version of any parameter, produced by differencing against the average can be displayed. Summary

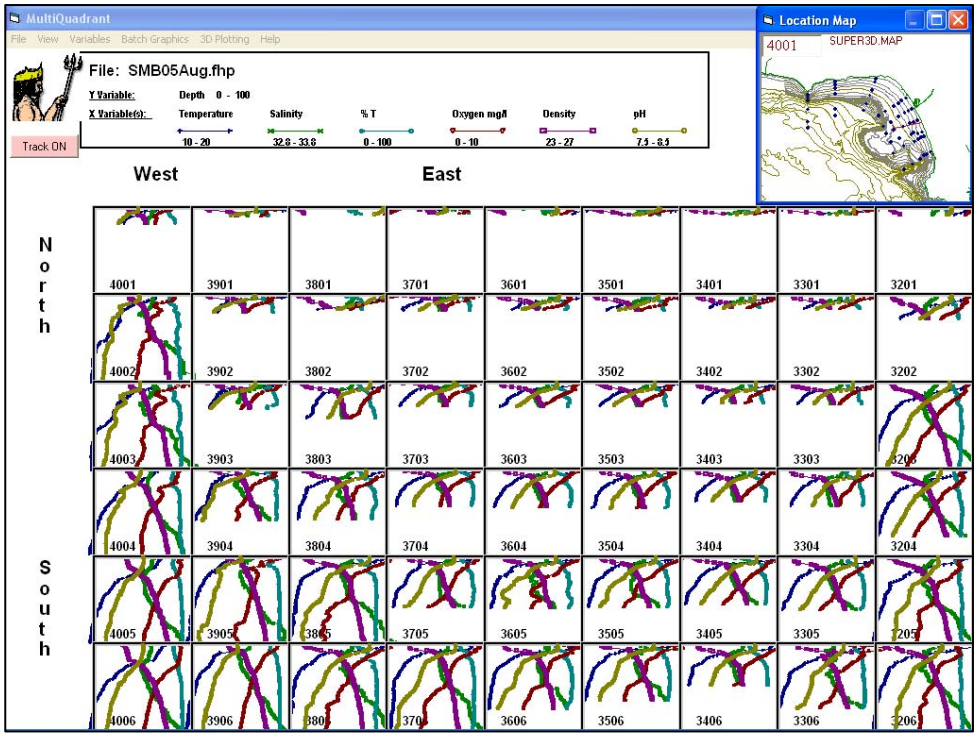

FIGURE 1. MULTIQUADRANT SCREEN DISPLAYING MULTIPLE VARIABLES.

statistics are displayed in real time corresponding to the exact data currently displayed in the XY view. A very effective use of the XY display is to overlay all sites, and then use the map interface to select individual sites - the selected site is highlighted on top of all the others (see pink trace in Fig. 2) clearly showing how it compares.

C. The Overlay Function

Another useful feature of IGODS is the Overlay function which overlays the data for up to six parameters for all stations. The Overlay function does not affect the multiquadrant display, but will cause the single quadrant display to show all data simultaneously (Fig. 4). In addition to overlaying data from all stations, it is possible to select any subset of the stations and overlay on the single quadrant screen just the data from these stations.

D. 2D Graphics

A flattened 2D view of one or multiple transects can be produced by one check on the advanced options menu. Up to six 2D transects that can be any combination of cross-shelf, along shelf or free format, can be shown on one screen/page (Fig. 5). In 2D mode transects do not get obscured as in Fig. 6, and the distance between stations (in kilometers) and depth scales are plotted to standardize and assist comparisons between transects.

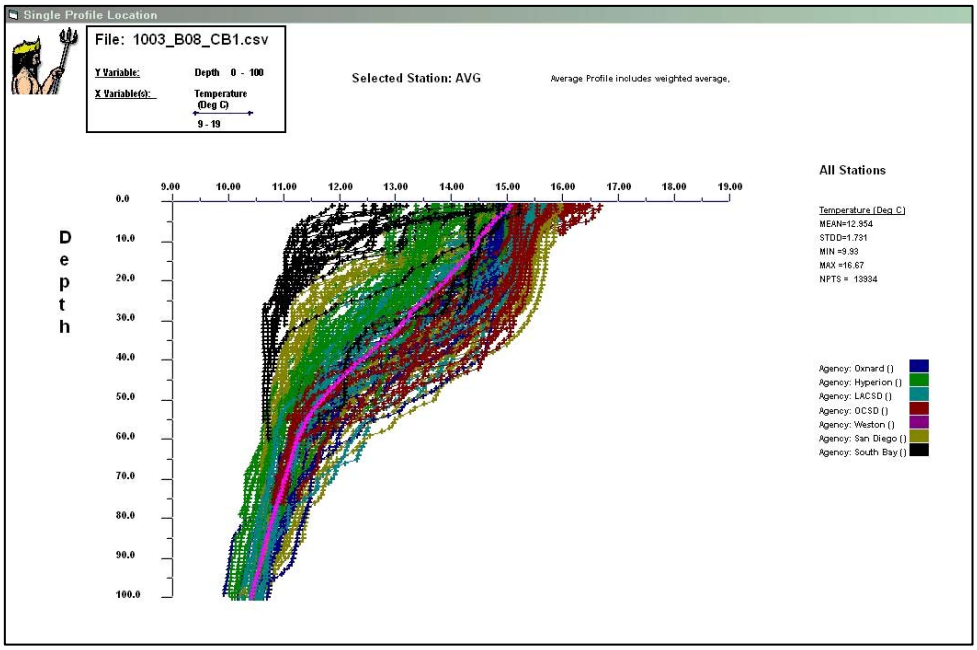

FIGURE 2. X-Y SCREEN DISPLAYING A SINGLE VARIABLE SAMPLED BY MULTIPLE AGENCIES.

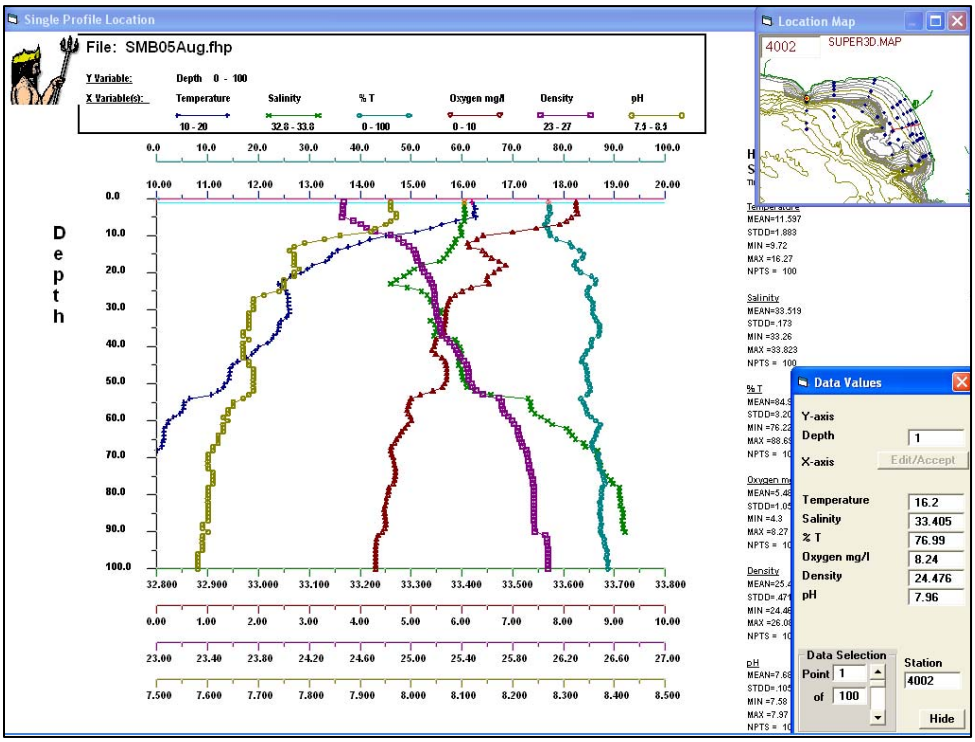

FIGURE 3. X-Y SCREEN DISPLAYING MULTIPLE VARIABLES.

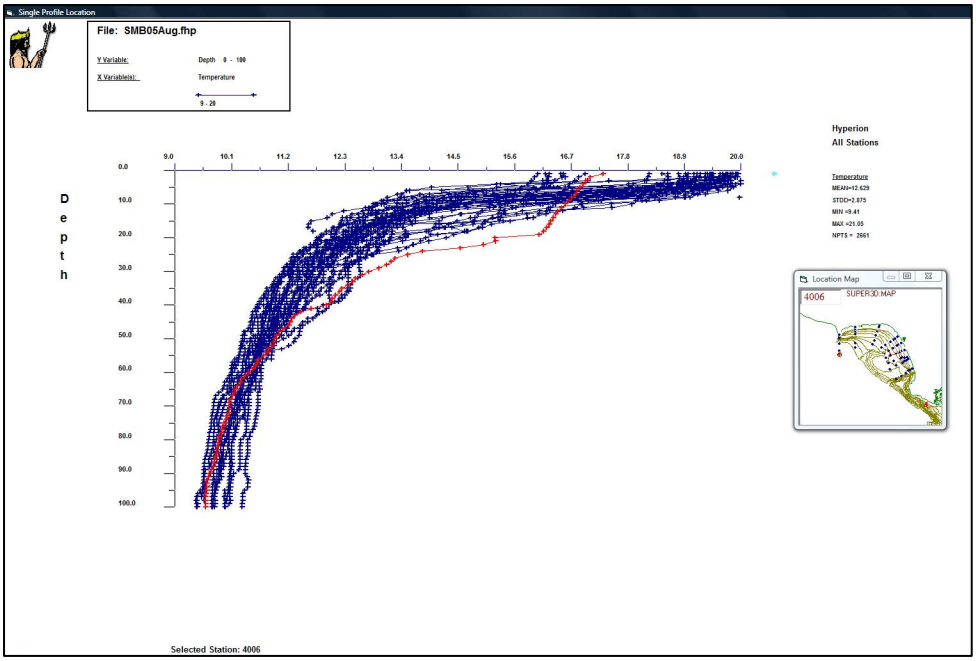

FIGURE 4. X-Y SCREEN DISPLAYING ALL SURVEY STATIONS OVERLAID.

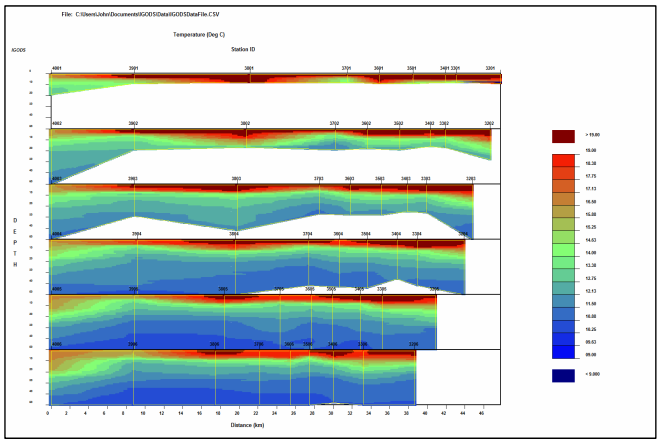

FIGURE 5. 2D PLOT OF ALONG SHORE TRANSECTS.

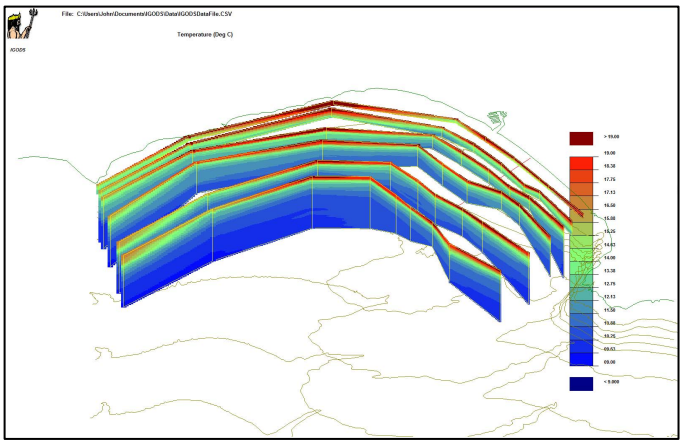

FIGURE 6. 3D PLOT WITH THE SAME ALONG SHELF TRANSECTS SELECTED AS IN THE FIG. 5.

E. 3D Graphics

Transects and surface planes defined in the workspace file (Fig. 7) enable the user to plot all data immediately in 3D modes from any angle of view. Direct editing of the scale on the 3D interface allows easy optimal mapping to identify features. Multiple palettes can be selected for viewing data. With one click on the advanced 3D features the program will produce KML files and send them directly to Google Earth (Fig. 8) where they can be saved in the Google Earth KMZ format complete with title information and color scales. Refinements can be made interactively with IGODS and Google Earth running simultaneously. These files can be posted on the web to allow viewing survey results. In addition to predefined transects, by clicking on a series of sites, a unique transect can be very quickly laid out interactively on the map, and can then be immediately plotted in 3D.

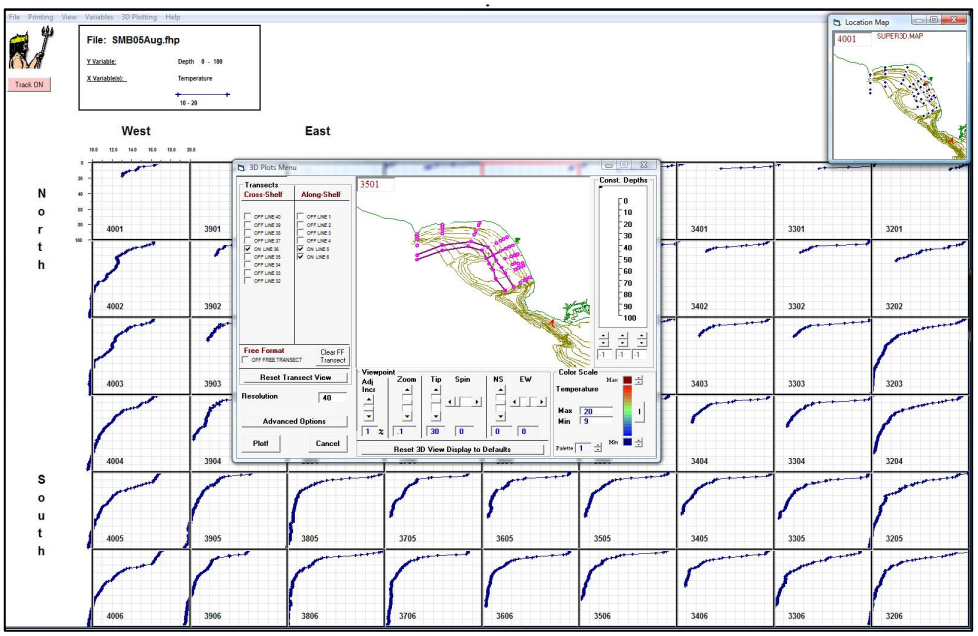

FIGURE 7. 3D MENU SCREEN WITH SEVERAL TRANSECTS CHECKED.

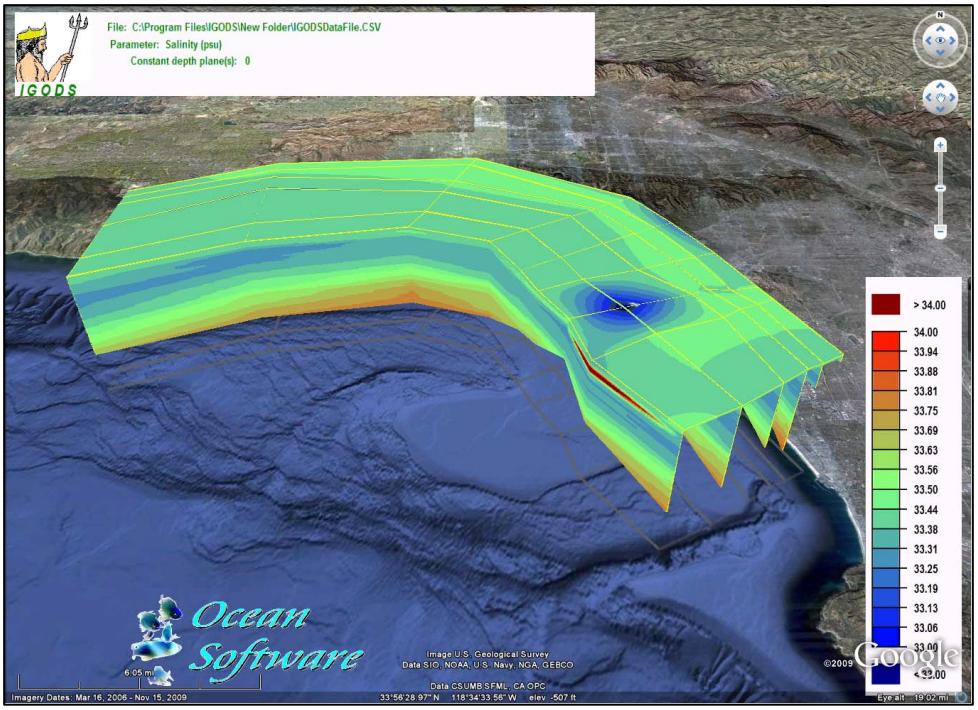

FIGURE 8. 3D PLOT OF SURFACE PLANE AND ALONGSHORE TRANSECTS EXPORTED TO GOOGLE EARTH

The following types of output materials can be generated using IGODS:

1. Final CSV data sets containing fully processed final data -
2. When distributed with their workspace files these can be viewed by any IGODS user.
3. A statistical summary of the survey including of all parameters that can be sent either to a printer or a CSV file.
4. Batch printouts of one or multiple parameters overlaid on an XY plot with statistics for all or selected sites.
5. Batch report generation of multiquadrant and XY overlay view including summary statistics (all data points are shown in each view).
6. 2D and 3D transect graphic views and plane surface views with unlimited options to control which transects are used, the point of view, scaling, and color palette.
7. To obtain a temporal comparison between surveys the same view can be plotted for multiple surveys.
8. Google Earth outputs can be produced either for printout or as electronic KMZ files that can be posted online.
9. High quality animations using the Google Earth movie recording feature.

II. How IGODS has been used to visualize data in local, regional and Bight-wide surveys

In southern California a large population living in the coastal region is served by multiple wastewater treatment agencies. Approximately one billion gallons of effluent is discharged from ocean outfalls into the coastal ocean each day. State and federal regulations mandate extensive monitoring programs for these discharges. The California Ocean Plan includes prohibitions on discharges reducing oxygen by more than 10%, changing pH by more than 0.2 pH units, or significantly reducing natural light. For over three decades, CTD surveys supplemented with discrete sampling have been the method by which these and other potential impacts have been assessed.

In the early 1990s, four of the largest dischargers began to use the IGODS program to manage their individual survey data sets. At about the same time regional scale studies in the southern California bight were initiated with coordinated sampling amongst many participants to address specific questions. The IGODS program was found to be an excellent way to manage the combined data sets of multiple agencies [1], [2], [3], [4]. The visualization power and the ease with which data could be compared between agencies led individuals involved in the monitoring of the central southern California bight to develop a standardized layout of sampling sites that incorporated key sites that each agency continued to use for assessment of near field effects, with a far field array of stations that effectively filled in and provided continuity up and down the coast, while also locating some sampling sites to capture coastal outlets that might also be significant contributors to water quality. Fig. 9 illustrates the result of regulators and agencies successfully working together to reallocate monitoring resources. Since July 1998 Central Bight Cooperative Water Quality surveys (CBCWQS) have been completed on a quarterly basis.

Each agency uses it's own or a contractor's vessel and CTD and completes surveys at predetermined sites for their region. IGODS workspace files enable detailed examination of the survey data files for each individual agency. Due to the nature of the survey file design, this group of local survey files are easily assembled into a single regional file, comprising more than 200 sites, that associates the entire data set with a regional workspace file.

In the case of the Orange County Sanitation Districts (OCSD), the current NPDES discharge permit requires quarterly water quality monitoring at a fixed, 29-station grid. For the CBCWQS, the required stations are incorporated into a larger 66-station grid. This increases the area sampled by the District from

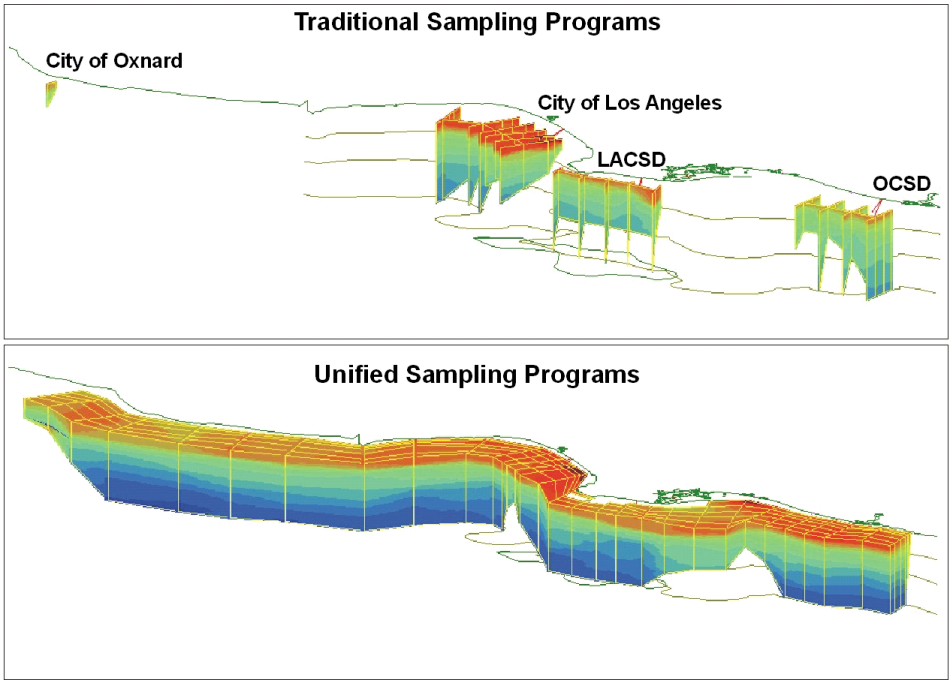

FIGURE 9. EVOLUTION OF THE SAMPLING PROGRAMS OF CENTRAL BIGHT COOPERATIVE WATER QUALITY SAMPLING MEMBERS

roughly 30 mi^2 to 90 mi^2. The standardized station arrangement shared by OCSD and the other CBCWQS participants uses cross-shelf transects perpendicular to the coastline. These consist of six sampling locations at selected depths on each transect and offshore sampling on each transect out to 8-10 kilometers. The transects are approximately evenly spaced to assure balanced coverage of the region, however, each discharge outfall is directly traversed by one cross-shelf transect, and all four outfalls are traversed by a continuous along shelf transect at outfall depth, assuring that near field effluent plume dynamics can be documented. All transects start near the coast, in 10m of water, and transects are positioned immediately offshore of all significant coastal sources (harbor and river mouths and significant storm runoff points) in the area between the Ventura River and Crystal Cove State Beach. Although only a few of these sources, such as Ballona Creek, Newport Harbor, and the San Gabriel River have a detectable effect during dry weather, these transects also make possible the characterization of coastal runoff after winter storms [5], [6]. The four agencies conduct each quarterly survey over a two to three day period.

The greater spatial extent of the area sampled (roughly ten times the area previously surveyed by the four individual agencies): (1) increases the ability to evaluate wastewater discharge effects as the discharge moves away from the discharge areas; (2) allows more definitive identifications of the non-outfall sources1 (both natural and anthropogenic) since variables can be mapped further; and (3) provides better context for each individual discharge. Each agency now has the ability to evaluate profile data from approximately five times the number of their previous sampling locations after each quarterly survey. This combined data set enhances the relative understanding and characterization of each individual discharger's environment in both a local and regional context. The coordinated sampling and data provided the impetus for increased cooperation between agencies to ascertain that sensors are calibrated to assure data consistency in the combined data sets. One example of potential benefits from the coordinated programs is the IGODS graphic showing the variability in pH when the sampling of each of the agencies is compared (Fig. 10). As a result of such data displays, the agencies are currently working together to develop improved calibration procedures and contacting manufacturers as a group to seeking improved agreement between sensors.

Historically the OCSD had observed low salinity waters near their outfalls during summer months, possibly suggesting reduced dispersion of the effluent field. However, examining the regional scale survey data it became clear that the reduced salinity seen in summer is part of a natural, large-scale phenomena of reduced mid-water salinity, probably associated with the increased thermal stratification and enhanced surface evaporation during summer months when there is also very little precipitation or coastal runoff. Fig. 11 shows how the localized transects of OCSD data near their discharge contrast seasonal patterns (a) and (b) with the regional pattern (c).

The California Ocean Plan sets limits for oxygen reduction and excess plant growth caused by dischargers. The Regional graphics in Fig. 12 demonstrate how effectively the distribution patterns of oxygen and chlorophyll fluorescence can reveal that background distribution patterns are widespread and not perturbed nearby to the three major and several minor POTW discharges along this portion of the coastline. Storm runoff, shore erosion, resuspension of bottom material, upwelling, and plankton blooms all have significant effects on coastal waters and are more effectively characterized with a combined coordinated survey.

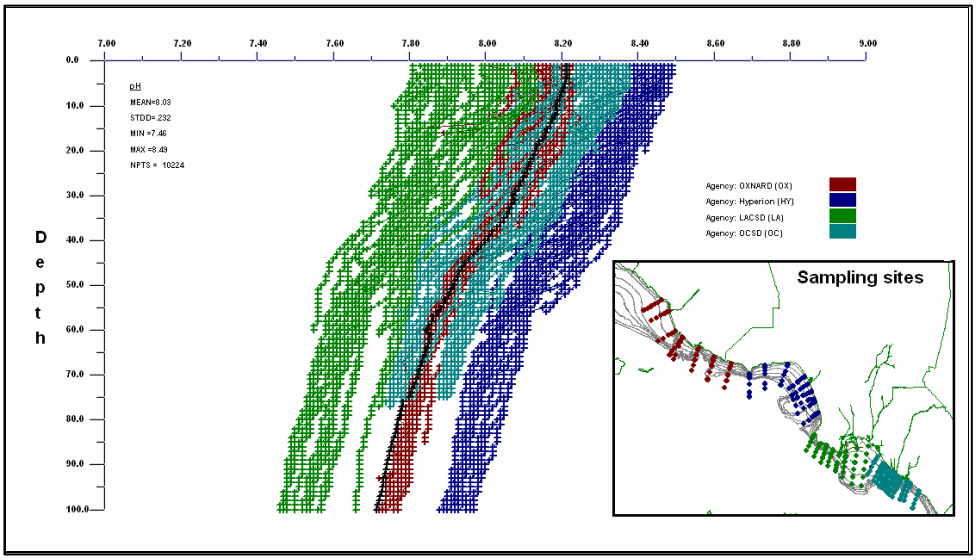

FIGURE 10. COMPARISON OF PH BETWEEN CBCWQS PARTICIPANTS

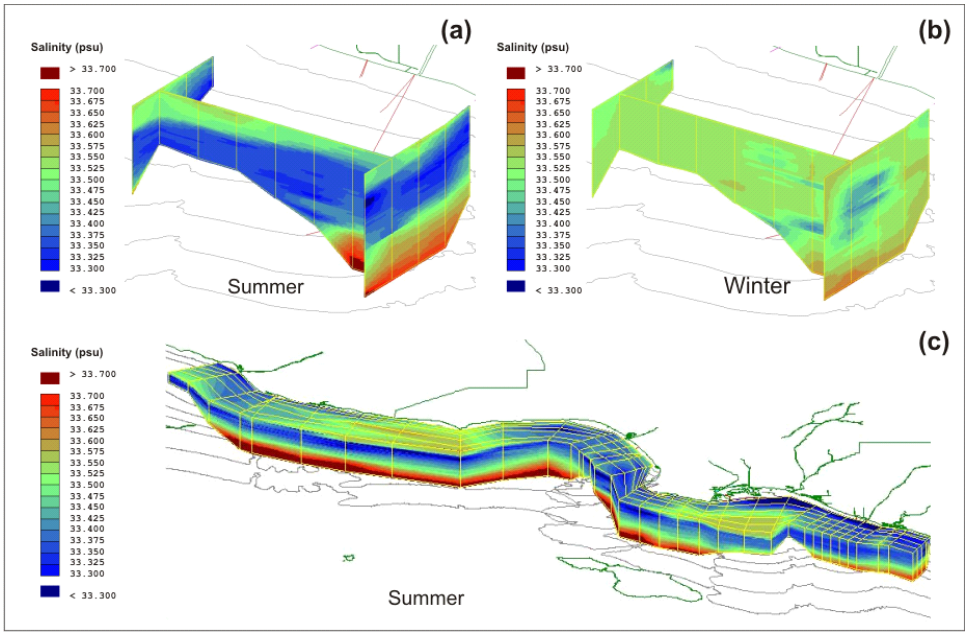

FIGURE 11. SEASONAL SALINITY PATTERNS NEAR THE OCSD DISCHARGE COMPARED WITH REGIONAL SALINITY

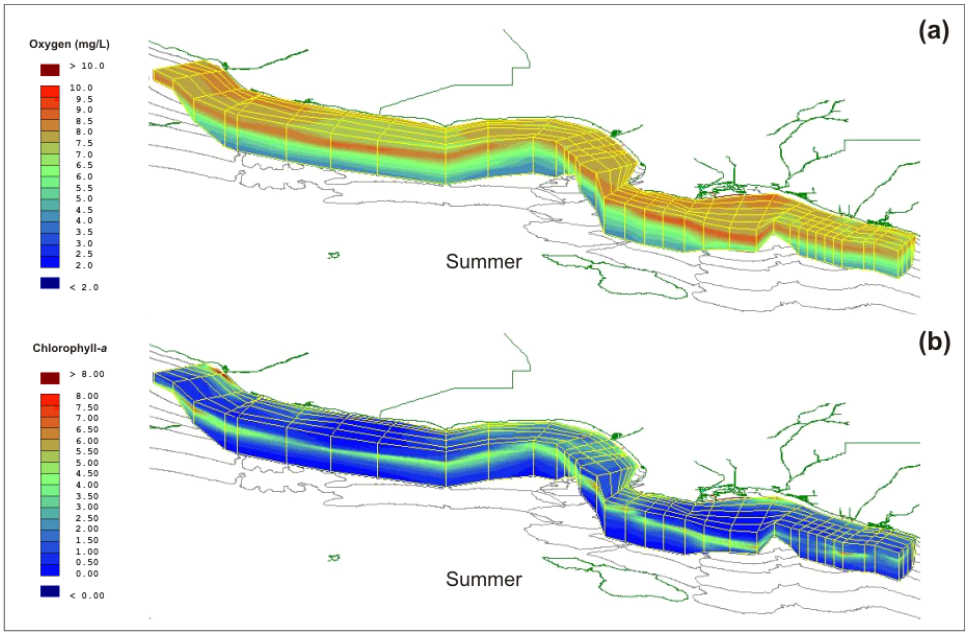

FIGURE 12. REGIONAL DISTRIBUTION OF DISSOLVED OXYGEN AND CHLOROPHYLL FLUORESCENCE

The final combined survey data sets are uploaded onto the Southern California Coastal Ocean Observation System (SCCOOS) website for public dissemination, and in conjunction with SCCOOS, Project participants are developing a long-term analysis of this data set. IGODS was used to produce integrated data sets and visualizations of results from Regional Bight wide studies in 2003. IGODS graphics clearly showed the patterns of surface runoff following major winter storms, and the distributions of indicator bacteria in surface waters.

In 2010 the agency sampling the southern part of the southern California bight began using IGODS for their offshore sampling and also began to coordinate sampling schedules with the CBCWQS bringing the total number of sampled sites for each quarterly survey to more than 300. During previous regional special studies more than 500 sites were incorporated into IGODS survey data files.

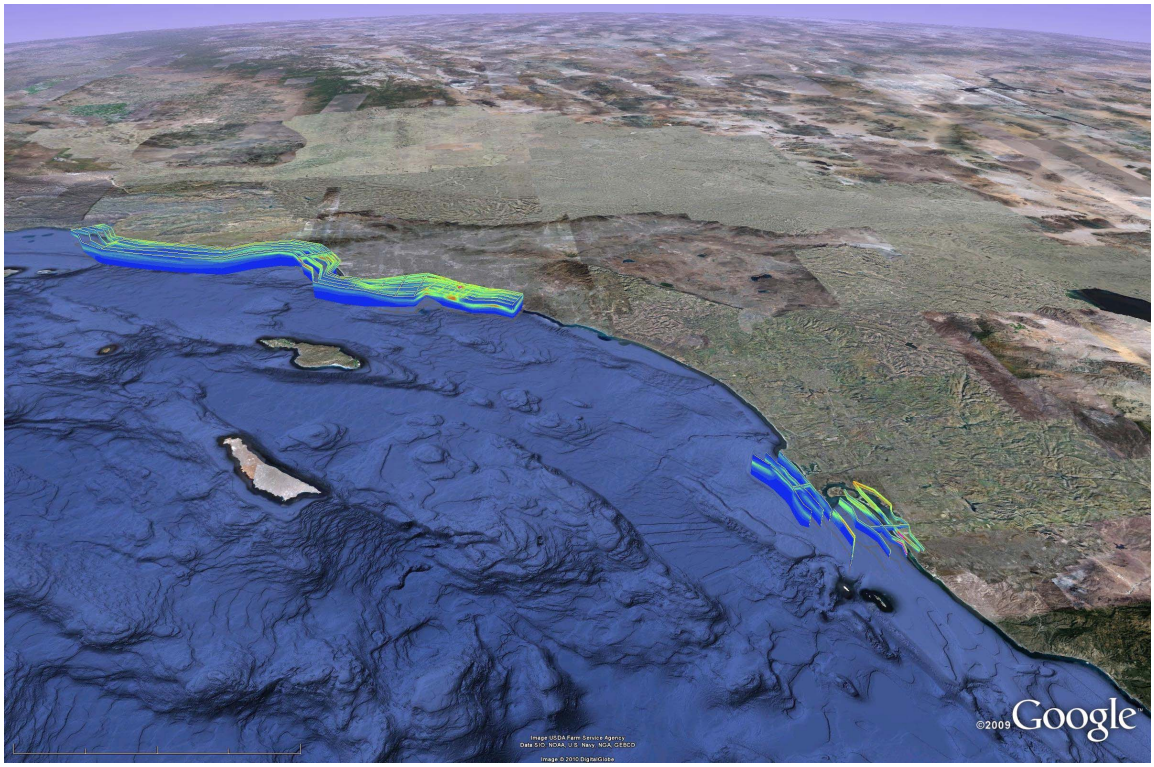

FIGURE 13. COVERAGE OF THE COOPERATIVE SAMPLING PROGRAM IN SOUTHERN CALIFORNIA IN 2010

III. CONCLUSION

The IGODS program is a powerful, optimized tool to support water quality sampling using a vertical profiling device like a CTD. The program has a minimal learning curve, and yet provides sophisticated capabilities to import data, merge discrete results, and archive entire surveys of results in standard format. Workspace files, which can be directly edited or generated from groups of CTD profile files for a new survey, add additional efficiency to the sampling and management of data from routine surveys. The IGODS environment provides three different interfaces for supporting easy examination of the complete survey data sets. Extensive analytical investigations are available using three different interface modes, a multiquadrant view of the entire survey, an XY interface with great flexibility for graphical and statistical examination of data, and a 3D interface for immediate examination of spatial patterns using transects and depth surfaces. A wide variety of report outputs can be produced, notably the 3D representations are directly exportable to Google Earth.

In the southern California bight the program has helped foster a cooperative relationship between multiple agencies, it directly supports individual agency monitoring efforts, and assures that combined data sets can be readily assembled into regional sets with hundreds of stations. IGODS has also made possible the detailed comparison of water quality parameters from multiple agencies, which makes it easy to quickly identify calibration or instrument issues and to distinguish regional scale phenomena from localized water quality characteristics.

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