A PC based Visualization System
for Coastal Ocean and Atmospheric Modeling

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Abstract
This paper summarizes the multi-dimensional data (variable) graphical representations and introduces a new powerful visualization system based on PC-Windows NT operating system. In addition, two applications for multi-dimensional simulation data sets produced by numerical models are presented, one is for coastal ocean and the other is for atmospherics.

Key words
Scientific visualization, numerical simulation, multi-dimensional data, computer graphics, personal computer

Introduction
Scientific research with spatial/temporal distribution of physical variables and modern numerical simulations are all based on integration over time of a number of variables on a multi-dimensional grid, which represents the physical procedure (e.g. atmosphere and coastal ocean). Their outputs are huge, three-dimensional and time-evolving data sets (figure1).

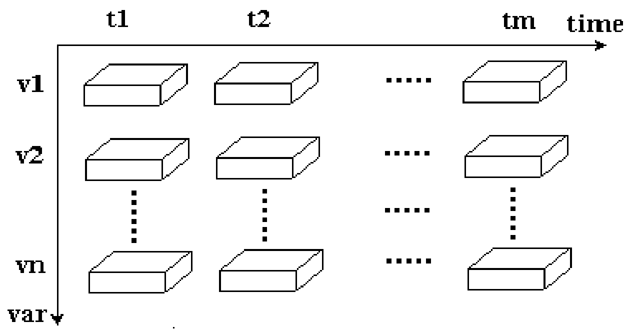

Figure1: the structure of model output (five-dimensional data set)
(Every small cube represents a three-dimensional grid)

So *how can we go about presenting these kinds of data sets in the most easily understand manner*? It's difficult to use traditional 2-dimensional methods to extract knowledge and scientific information efficiently from these data sets. It is necessary to employ more sophisticated computer display techniques. It presents a substantial challenge for scientific visualization application.

In recent years, computer techniques and facilities are both developed rapidly. Several much powerful scientific visualization systems were developed by

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scientists in past several years. For example, VIS5D (Hibbard, university of Wisconsin' s space science and engineering center) is a popular and powerful visualization system in earth science now. As we know, most of the current visualization systems (include VIS5D) are only running on Unix workstation, that because a typical visualization study was done with a high-power *Unix workstation* in few years ago. Now, *personal computer* operating systems - especially Windows NT - can rival Unix environments. They also support multi-processors, powerful development tools and networking. User and developer can add a *3-D graphics accelerator* offering pipelined rendering, full texture mapping, and a complete set of graphics tools with performance that completes with midrange graphics workstation with the significantly lower price. In addition, software systems that were solely available to workstations are now available to personal computers as well. A typical example is *OpenGL*. OpenGL is the premier environment for developing interactive 2D and 3D graphics applications and provides the rendering algorithms in Unix workstation. After 1993 OpenGL has become the industry' s most widely used applications and it across all PC based system platform.

Nowadays a computer algorithm such as volume rendering, which requires a *high-speed CPU*, can also be performed at the personal computer level. Therefore, in considering a visualization system, the personal computer can actually exhibit a good design. In this paper, we will summarize the multi-dimensional data (variable) graphical representations and then introduce a new powerful visualization system, which is based on PC (Windows NT operating system) environment. At last, two applications of multi-dimensional simulation data sets produced by numerical models will demonstrate its powerful functions, one is for coastal ocean (Pearl River Delta pollutant transport by POM), and the other is for atmospherics (a recent South China Sea Typhoon by MM5).

Data (variable) graphical representations

Before introducing visualization system, we summarize the data (variable) graphical representations. Variables that describe physical procedure can be divided into ***scalar*** and ***vector***; each of them can be 2-dimensional, 3-dimensional, 4-dimensional, and 5-dimensional in deep. Their graphical representations are different.

1) ***Two-dimensional data***: For two-dimensional scalar variables, *contour lines* can be drawn to simplify the job of analysis for them in nature. Large two-dimensional arrays of data can be depicted as gray-scale or *color images* for ease of interpretation. *Arrows*, *barbs* and *streams* can be used to represent vector variables. These traditional presentations are still the predominant way of sharing visual information.

2) ***Three-dimensional data***: For a complexity and three-dimensional array data sets of scalar variable, the contour on various horizontal and vertical *cross-sections* are generally used to help one digest the results. This needs

to make many cross-sections to analyze the three-dimensional data sets, and do many comparisons between them in spatial. The *iso-surfaces* of interpolated values and the *volume renderings* are the better way to represent the spatial distribution of physical variable. Same as two-dimensional variables, *arrows*, *barbs* and *streams* also can be used to represent three-dimensional vector variables, especially arrows. In addition, *vertical profile* is a very useful way to presents the data sets. In vertical profile, the different values associated with one single point in the earth surface are shown in graph, where the horizontal axis shows the variation of the variable, and the vertical axis is associated with different vertical levels.

3) ***Four- and five-dimensional data***: For four-dimensional (one variable) and five-dimensional (more than one variable) data set, there are many three-dimensional grids in it. It presents the space distribution and time evolution of physical variables (e.g. temperature) and procedures (e.g. weather). There are many different ways to represent this data set. For spatial distribution, they are similar to *three-dimensional data visualization* described before. For time evolution, *time animations* of three-dimensional spatial distribution are very useful to compare the three-dimensional data grid of different time step. In fact, multi-dimensional data sets are time sequence of three-dimensional data sets. In addition, there are two special ways to represent the four- or five-dimensional data set. One is *meteogram* and the other is *trajectory*. Meteogram shows the time evolution of one single location, on a fixed vertical level. In this case, the horizontal axis is associated with time and the vertical axis indicates the variation of the variable. Trajectory is a complex way to represent vector variables; it shows the time evolution of one particle in three-dimensional field. Complex algorithms for tracing particles in forward and backward direction will be needed.

   For five-dimensional data set that includes multi-variables, there are several ways to represent the relations between physical variables. For example, An iso-surface usually is drawn entirely in one color. It also can be colored according to the values of another physical variable. This iso-surface has two representations, one is the spatial distribution of variable and the other is the relation between variables.
   These different types of graphical representations are widely used in the earth science. In multidimensional data visualization, users would like to combine these types of representations.

4) ***Vertical coordinate system, map projection, and geographical information***: In earth science, many vertical coordinate system (e.g. equally spaced levels in *km*, unequally spaced levels in km or *mb* et al) and many map projections (e.g. Lambert conformal, azimuthal stereographic et al) are used. In data graphical representations, all data must be in same map projection and vertical coordinate system, avoid making errors. In addition, space distribution is based on geographical coordinate,

geographical information (e.g. earth topography, map, et al) is very useful for understand the physical situation.

A visualization system based on PC-Windows NT

After summarizing the data graphical representation, we introduce a powerful visualization system that is based on PC-Windows NT operating system. This system is used to analyze multi-dimensional data made by numerical models and similar sources. It was designed to manage and analyze very lager data sets and to produce complex, 3-D multivariate images from these data sets. The real power of it involves the time animation of these fields and the ability to change the perspective so that the scientists are provided to "observe" the field in motion from various points of view. Most of its functions are same as popular *Vis5D* (Hibbard, university of Wisconsin's space science and engineering center), but it works with personal computers (***Windows 98/NT/2000*** operating system) and has many new functions. So we named it as PC-Vis5D.

Similar to Vis5D, PC-Vis5D is also a set of software integrated within the systems, a development guided by their application to numerical model data sets. It provides *tools* to manage data as 2- and 3-D grids, as trajectories, as images, and as collections of data without any spatial order. The grid structure can be grouped to manage very large data sets spanning multiple physical variables and sequences of times. These data-management tools include file structures for storing data, libraries of routes for accessing those files, converting external data to their file formats. PC-Vis5D provides a convenient on-line HTML help document and a powerful movie player that can play stereo movies made in visualizing.

PC-Vis5D includes ***variety of commands*** for analyzing data in their file structures. These include:

1) re-sampling grids to a different spatial resolution, or time resolution
2) re-sampling grids to a different map projection, or vertical coordinate
3) transforming grids to a move frame of reference
4) generating general arithmetic grid operators
5) interpolating non-uniform data to a grid
6) deriving trajectories from grids of vector components (many algorithms for tracing particles are added, e.g. tracing multi-particles trajectories at same time)
7) creating images from grids
8) cloning new variables or making new variables by typing in a formula involving values of existing variables
9) generating grided fields from irregular sounding observation data

They are used to produce animated sequences of 3-D images from data. The ***visual elements*** of these images include:

1) shaded relief topographical maps with physical and political boundaries, and time sequence of satellite or radar images can be mapped onto flat or topographical map near the bottom of 3-D box.

2) trajectories draw as shaded ribbon, which may be either opaque or semitransparent, and may be long and tapered or shot with the length made proportional to motion speed.
3) iso-level contour surface of 3-D scalar variables, which may appear smooth with natural shading, may be semi-transparent.
4) iso-level contour lines, drawn either on the topographical surface or on a surface in the atmosphere (such as isobaric or theta surface) or ocean
5) colored slices, may be semitransparent
6) 3-D translucent volumes with opacity proportional to some scalar physical variables
7) vector fields can be shown in arrowheads, barbs or streams
8) inspect individual data values at various probe locations and time step
9) vertical profile of every spatial location in data set.
10) meteograms for showing the time evolution of one single spatial location.

These 3-D images are assembled into animated sequences showing the time evolution of a data set, or showing a rotating view of a single time within a data set. The animated sequences are loaded into computer where they can be viewed directly or recorded onto videotape.

All the visual elements can be showed in ***stereoscopic*** or ***monocular*** viewing mode. Stereoscopic viewing enhances visualization by displaying images with true depth perception. It works by displaying left and right eye views "simultaneously". In stereoscopic mode, user also can control the viewpoint and the scale of the depicted spatial region. The 3-D images also can be assembled into stereo animated sequences played by our ***stereo-movie*** player. PC-Vis5D can support the ***virtual reality environment*** in real-time stereoscopic display.

All of these 3-D images can be saved as standard format (e.g. SGI RGB, Windows bitmap, Targa TGA et al.) image files or *VRML*(***Virtual Reality Modeling Language,*** version 2.0) format files. *VRML* files can be used for interactive visualization by navigator through network.

Systems provide a variety of means to increase viewers comprehension of the images they produce. The images are generated in color, and the user can control the color of each physical variable. The user can also control the scale of the depicted spatial region and the rotation of the user' s viewpoint. In monocular viewing mode, depth information is somewhat ambiguous in 3-D images, and a rotating perspective or stereoscopic viewing can help resolve this ambiguity.

PC-Vis5D also supports scripting facility. That is, user can control PC-Vis5D with a text file of commands using the *Tcl* (***Tool command language***) language, specify a PC-Vis5D/Tcl script to execute automatically.

PC-Vis5D currently works with following system. In all cases, at least 64MB of memory is recommended and at least 16-bit color display is required:

1) Microcomputer (personal computer): operating systems are windows 98/NT4.0/2000.
2) DEC Alpha workstation: operating system is windows NT4.0/2000.
3) Silicon Graphics visual workstations: operating system is windows NT4.0/2000.

Notice: stereoscopic viewing mode needs high-performance 3-D graphics accelerator and an infrared emitter with glasses (for example, Crystal-eyes of StereoGraphics Corporation).

Applications

In HKUST, the visualization system is used to study model output from our Coastal ocean and atmospheric prediction system. Our prediction system is a coupled coastal ocean and atmospheric modeling system based on the Princeton Ocean Model (POM) and the 5^{th} generation NCAR/PSU Meso-scale Model (MM5). The prediction system runs twice daily, and makes a 72-hour forecast of the state of the coastal ocean and atmospheric system near the Pearl River Delta. In the conference, we shall show case studies of our prediction system for study of local pollutant transport, and for a recent South China Sea (SCS) Typhoon, Leo, which affected Hong Kong in early May.

1) Visualization of MM5 output

Typhoon Leo formed in the SCS at 10 UTC on April 26 1999. During the formative stage, it was difficult to pinpoint the position of the cyclone and the center of Leo was relocated a number of times during the next 2-3 days. After that, the storm strengthened very rapidly. The maximum wind estimated for Leo at 06 UTC on April 30 was about 100 knots, up from a maximum of 45 knots 24 hours before. As Leo moved closer to the coast of Guangdong, strong upper level westerly acted to shear off the organized convection, resulted in an exposed eye and the cyclone dissipated rapidly before it make landfall about 50 km east of Hong Kong. Most of the aforementioned features were successfully predicted by our near real-time numerical weather prediction (NWP) system operating at the Hong Kong University of Science and Technology (HKUST). Our NWP system makes forecasts two times daily and is based on the 5th generation NCAR/PSU mesoscale model (MM5).

The generated data consist of 11 three-dimensional variables (temperature, cloud water, ice water, rain water, u, v and w wind components, et al) for all 29 levels of model, 26 two-dimensional variables (terrain topography, surface pressure and pressure tendency, surface temperature, et al) for 1 level. These grids computed at 1 hour intervals over a 72-h period from 1200 UTC April 29 to 1200 UTC May 2 1999. The 2- and 3-D grids are in lambert conformal projection of 63 ? 81grid points. Output data set size is about 128MB.

Figure2(a) shows iso-surfaces of cloud water(0.2k/kg), ground(red arrows) and 200mb height level wind field(green streams) and colored horizontal slice of sea level pressure (bottom) at 0000 UTC on May 1 1999.
Figure2(b) shows air particle trajectories(lines and small ball) with coloring by w wind component (red: go upward, blue: go downward) and topography (bottom) at 0000 UTC on May 1 1999.

2) Visualization of Coastal Model

Pearl River is the 16th largest river in the world with an annual averaged discharge rate of ~10,000 m^3 per second. Its drainage area covers some of the most densely populated regions in China that gives rise to a severely polluted river system. The Center for Coastal and Atmospheric Research (CCAR) at the Hong Kong University of Science and Technology (HKUST) is building an extensive monitoring system in the Pearl River Estuary and Hong Kong and hope that the system will eventually be able to assimilate multi-disciplinary observations and experiments that can be used as an early warning system for storm surge and red tide.

To have a better understanding of the tidal circulation pattern in the Pearl River, we based on the generic Princeton Ocean Model (POM) (Mellor, 1996) to develop our own Pearl River Estuary Hydro-dynamic Model and we use PC-Vis5D to visualize the climatological circulation pattern and the corresponding sea temperature and salinity.

From our visualization animated tools, it was clearly found that the area seaward from the Dan-Gang Islands is strongly influenced by the Guang-Dong Coastal Current that flows from northeast towards southwest and passes the mouth of Ling-Ding-Yang in winter circulation pattern. In additional, river plume hugs the western shore of the Pearl River estuary, generally moves in southwest direction, and eventually meets the coastal current. We also found that there was a rather different flow regime in summer period due to much higher discharge rates and excessive river outflow of the Pearl River. *Figure3(a)* illustrates a circulation tidal flow of 5m below sea surface and distribution of salinity of 8m below sea surface in summer period. *Figure3(b)* illustrates the circulation tidal flow of 5m below sea surface, salinity contour at 8m below sea surface and distribution of temperature surface across the Ling-Ding-Yang vertically in winter period.

The generated data consists of 5 three-dimensional variables (tidal flow vector, salinity, temperature etc) with using 16 levels of 222x242 three-dimensional grided data to represent the tidal data under the sea.

Summary

The rapid increase in computational power has enabled researchers to perform intensive scientific computations on workstations and personal computers (PCs). However, the large amount of analyzed or modeled data makes it increasingly more difficult to extract and present the relevant scientific information. More and more, sophisticated visualization and 3-dimensional (3D) graphics tools are needed to help depict the important scientific contents. It presents a substantial challenge for scientific visualization application. In this paper, we introduced a powerful visualization system based on PC-Windows environment. Two applications in coastal ocean and atmospherics were given to prove the power of our PC-Vis5D.

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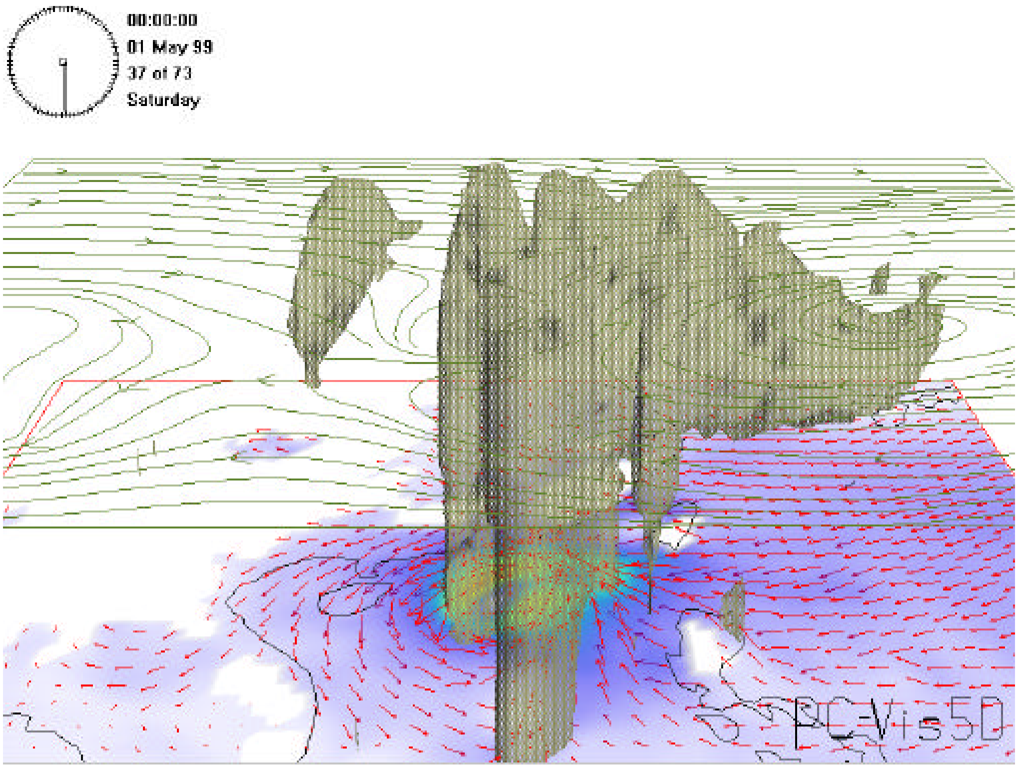
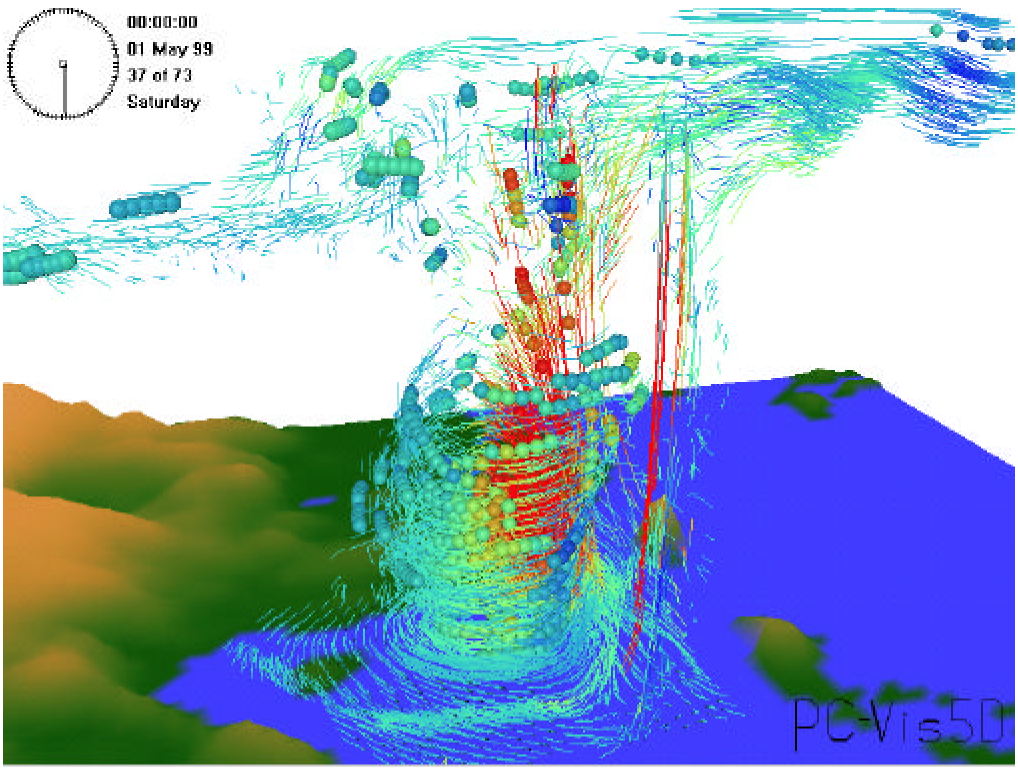
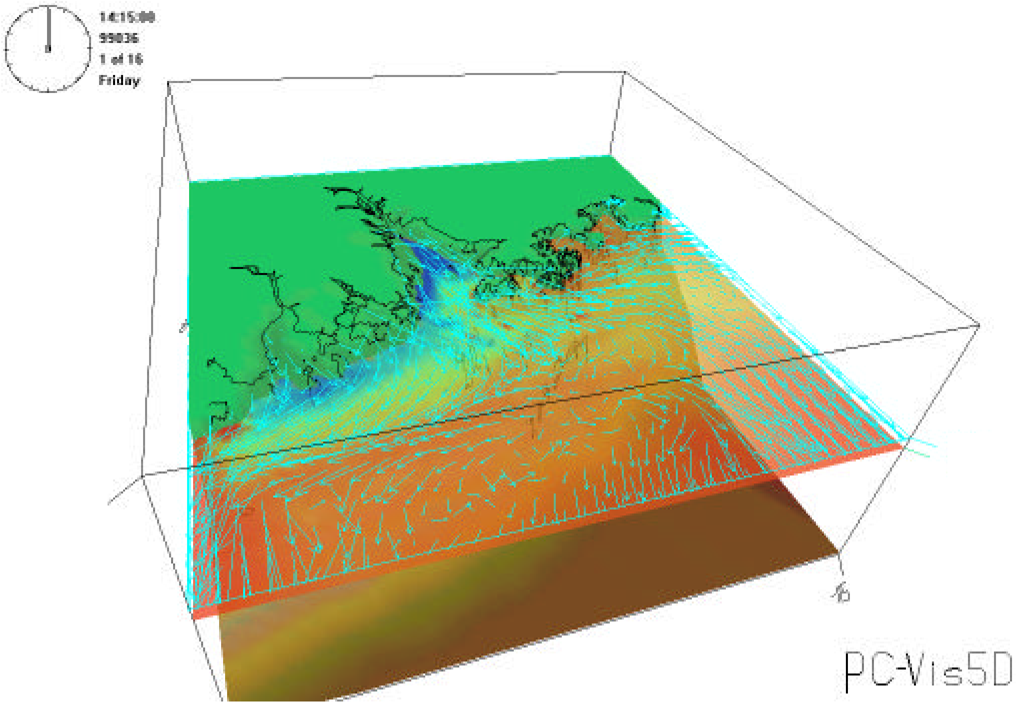


(a) Cloud Water, ground and 200mb wind field, ground pressure

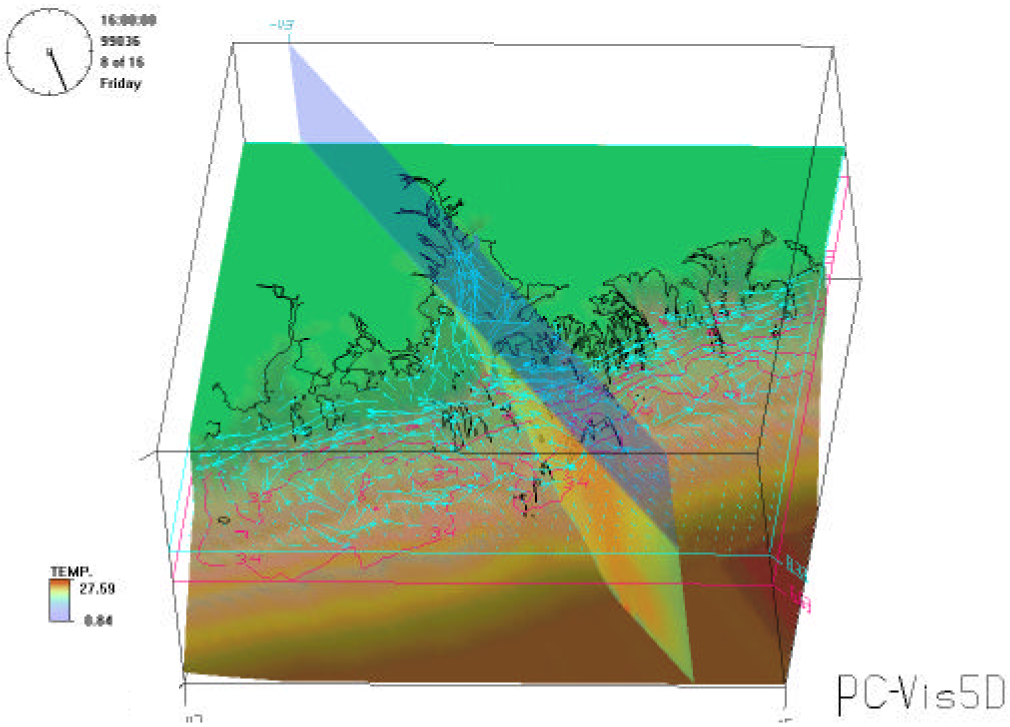


(b) Typhoon Leo air particle trajectories

Figure 2: Typhoon Leo visualization



(a) the circulation tidal flow of 5m below sea surface and distribution of salinity of 8m below sea surface in summer period.



(b) the circulation tidal flow of 5m below sea surface, salinity contour at 8m below sea surface and distribution of temperature surface across the Ling-Ding-Yang vertically in winter period.

Figure 3. Ocean Model Visualization