In Proceedings of the Oceans '99 MTS/IEEE Conference, 13–16 September 1999, Seattle, WA

REAL-TIME 3-D EL NIÑO/LA NIÑA VISUALIZATIONS AND ANIMATIONS FROM THE TAO BUOY NETWORK IN THE TROPICAL PACIFIC

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I. BACKGROUND

The TAO Array (Fig. 1, [1,2]) is a major component of the global climate monitoring system, consisting of approximately 70 moored buoys, spanning the Equatorial Pacific Ocean from 95°W in the eastern Pacific to 137°E in the west, and telemetering atmospheric and oceanographic data in real time to shore-based computers via the NOAA Argos satellite system. Supported by an international consortium, involving cooperation between the United States (NOAA), France (ORSTOM), Japan (STA), and Taiwan (NSC), the TAO array measures oceanographic and surface meteorological variables critical for improved detection, understanding and prediction of seasonal-to-interannual climate variations originating in the tropics, most notably those related to the El Niño/Southern Oscillation (ENSO). TAO data have been provided in real time since the inception of the array, and graphical displays are available at http://www.pmel.noaa.gov/toga-tao/realtime.html ([3,4]).

II. TAO DATA TREATMENT AND GRIDDING

The TAO data shown in the 3-D visualizations include TAO temperatures, dynamic height, winds, and ocean currents.

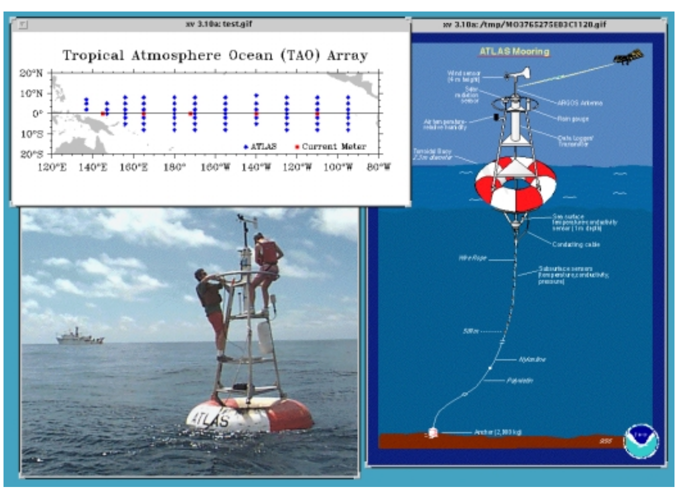

Fig. 1. TAO buoy array map, schematic and photograph of a TAO buoy.

TAO temperature data are gridded to a longitude-latitude-depth-time grid which encompasses the upper 500 m of the ocean and a geographic range from 137°E to 95°W and 8°S to 8°N. The most recent 48 months of data are included. The grid spacing is 1°, 1°, 10 m, and 1 month for longitude, latitude, depth, and time, respectively.

Monthly mean TAO temperatures and dynamic heights are gridded by removing a climatology and interpolating the resulting anomalies to the grid. After smoothing by triangle filters, the gridded anomalies are added back to the climatology to produce the gridded field. For more details on the gridding procedure, see the following web page:

http://www.pmel.noaa.gov/toga-tao/taows-gridding.html

TAO winds are not gridded per se, but are shown as vectors at the buoy locations. TAO ocean currents are a composite of mechanical current-meter data and acoustic doppler current profiler data. Currents are gridded to 10 m in depth, and are shown as vectors at the current meter buoy locations along the equator.

III. TAO 3-D VISUALIZATIONS

The Vis5D viewer (Figs. 2, 3, and 4), IRIS Explorer (Fig. 5), and VRML viewer (Fig. 6) allow many possible visualizations of 3-D fields. We selected a few of the more interesting ones, and combined and animated them in World Wide Web (WWW) pages[1]. A few examples are shown here. Fig. 2 shows a frame from an animation which includes a colored equator-depth slice of upper ocean temperatures, a transparent 20°C isotherm surface, and upper ocean current vectors at several sites along the equator. Fig. 3 shows an animation frame which includes the same data as Fig. 2, but adds latitude-longitude maps of surface wind vectors and sea surface temperatures. Fig. 4 shows an animation frame which includes all of the data shown in Fig. 3, but in this animation the angle of view changes with each frame to give the viewer a more complete perspective. Fig. 5 shows a frame from an animation which includes the exterior of the TAO array domain colored by temperature, from 8°S to 8°N, 137°E

[1] http://www.pmel.noaa.gov/toga-tao/vis/

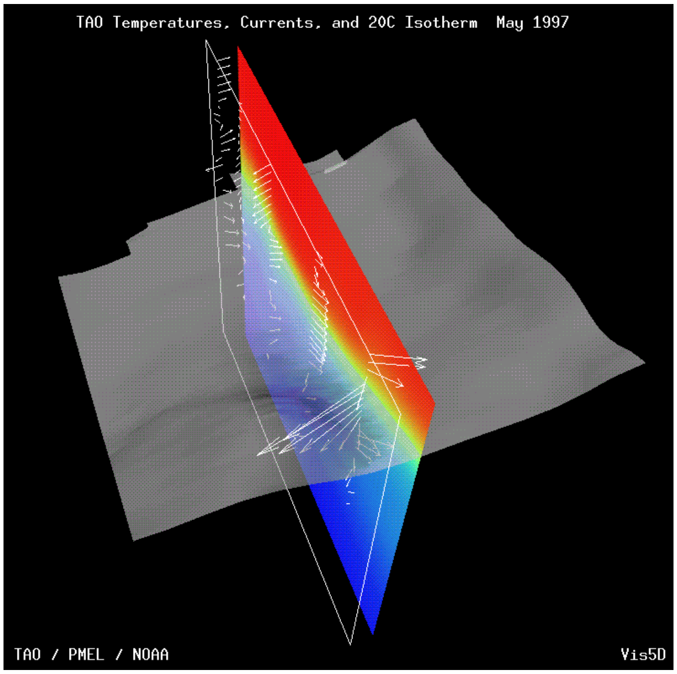

Fig. 2. TAO 3-D visualization showing an equator-depth slice of temperature to 500 m depth, a transparent 20°C isotherm surface extending from 8°N to 8°S and from 137°E to 95°W, and ocean current vectors (white) from the surface to 300 m depth for May 1997.

to 95°W, and from the sea surface to 500 m depth. The shape of the sea surface was defined by the dynamic height as described in next section. Fig. 6 shows a snapshot of the VRML viewer displaying TAO data. The upper colored surface is deformed by dynamic height, and color contoured by sea surface temperature. Depth sections of temperature are also shown at the equator, the dateline, and at 125°W. A transparent grey surface represents the depth of the 20°C isotherm, and wind vectors are shown in a grid at the top of the figure.

These 3-D visualizations of TAO data are striking because they allow simultaneous display of multiple ocean and atmosphere data sets. When these visualizations are animated, the relationships between data sets are clearly revealed.

The animations of these 3-D visualizations of TAO data are available in a JavaScript animator on this web page:

http://www.pmel.noaa.gov/toga-tao/vis/

and the TAO VRML data set is available at

http://www.pmel.noaa.gov/vrml/

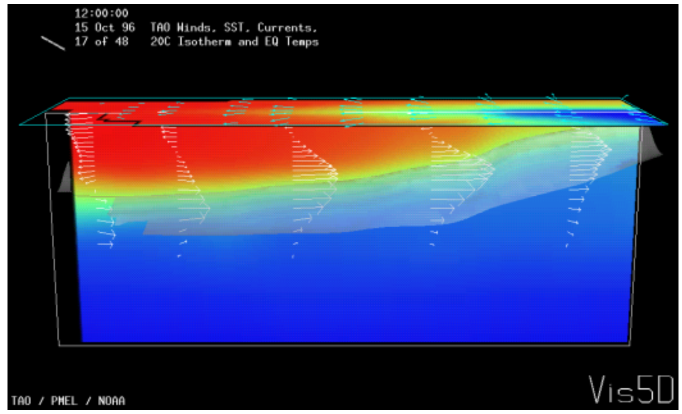

Fig. 3. Same as Fig. 2 but also including surface wind vectors (blue) and sea surface temperature.

IV. VISUALIZATION SOFTWARE

A. Vis5D

Vis5D[2] is a desktop 3-D visualization software package freely available for most Unix workstations, as well as PCs running Linux. Vis5D was used for visualizations of TAO temperatures, winds, and ocean currents. These TAO data were combined into a single Vis5D-format file using the Vis5D software library.

The Vis5D viewer provides extensive interactivity on the desktop, including the ability to rotate the image, zoom in and out, combine different data sets, animate, and much more. The viewer controls are intuitive and easy to use.

Most of the effort required to create the TAO 3-D visualizations using Vis5D was directed toward putting the gridded data into Vis5D format. Some experimentation with the configuration of the Vis5D file was required to produce the desired result, particularly for the current vectors, which required extending the current data meridionally for vectors to appear. This is probably related to the relative

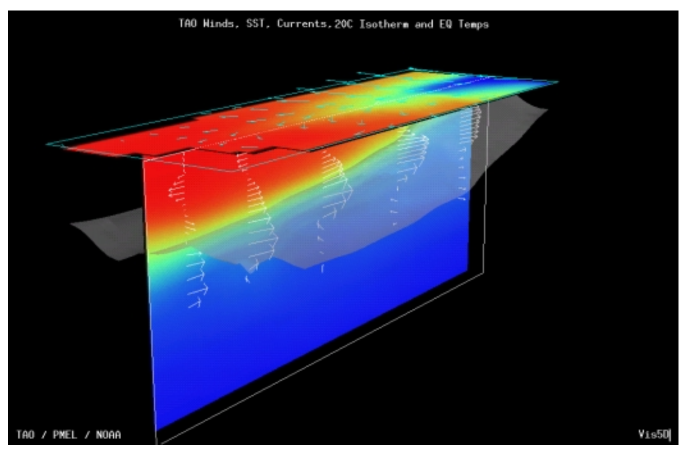

Fig. 4. Same as Fig. 3, but with the angle of view changing between animation frames.

[2] http://www.ssec.wisc.edu/~billh/vis5d.html

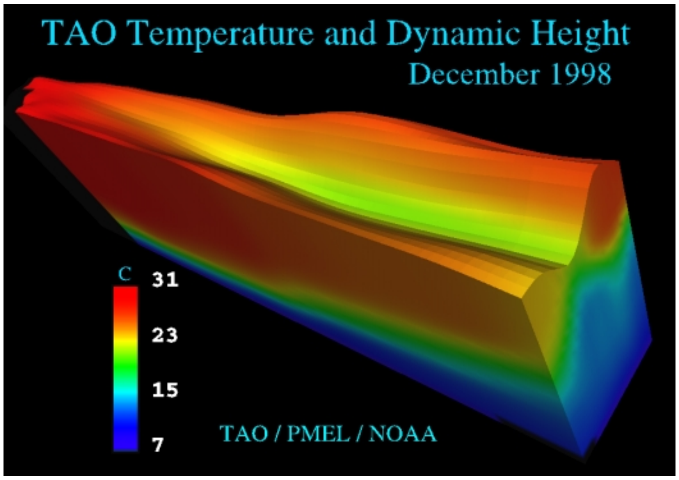

Fig. 5. TAO 3-D visualization showing temperature and dynamic height for December 1998. The colored surfaces show TAO ocean temperatures. The top surface is the sea surface, from 8°N to 8°S and from 137°E to 95°W. The shape of the sea surface is determined by TAO dynamic height data. The wide vertical surface is at 8°S and extends to 500 m depth. The narrower vertical surface is at 95°W.

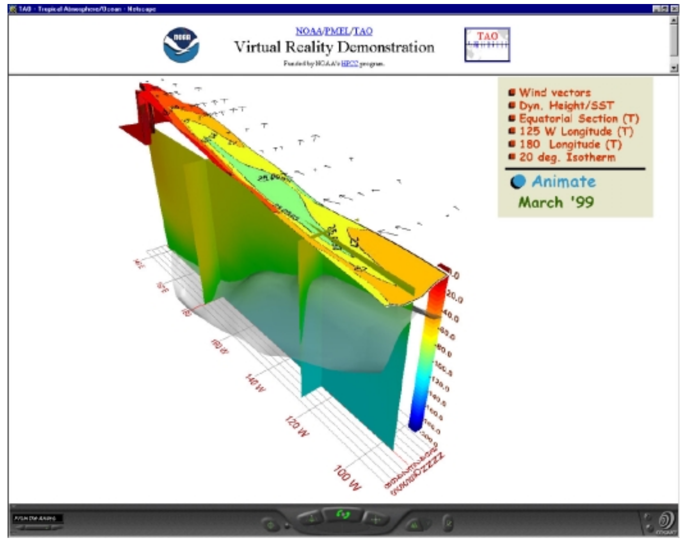

Fig. 6. VRML viewer showing TAO wind vectors, sea surface temperatures, dynamic heights (for sea surface shape), transparent 20°C isotherm surface, an equator-depth slice of temperatures and meridional-depth slices of temperature at 180°W and 125°W. Interactive controls are at bottom.

sparseness of the current data compared to temperatures. The Vis5D viewer has a very nice feature whereby you can save the colors, orientation, opaqueness factor, labels, etc. to a file, and restore them in a subsequent session at the click of a button. It also has a nice scripting capability using the tcl language, which one can use to produce a series of image files, or change the angle of view or zoom in an out in an animation. To create a WWW animation, the xwd format image files are converted to gif format using the unix Imagemagick package, and displayed in a JavaScript animator.

B. IRIS Explorer

IRIS Explorer[3] is a commercially available desktop 3-D visualization software package for SGI and other Unix workstations, as well as Windows NT machines. IRIS Explorer (footnote 3) is somewhat more difficult than Vis5D to learn to use but appears to be more flexible and powerful.

IRIS Explorer was used for visualizations of the gridded TAO temperatures and dynamic heights. A short program written by the principal author was used to define the sea surface shape as the TAO dynamic height multiplied by an exaggeration factor. The resulting curvilinear lattice of temperature was stored as a series of ascii files which could easily be read into IRIS Explorer.

In addition to the effort required to create the curvilinear grid files for input to Explorer, one has to create a "map" in the map editor to connect the various object modules for reading files, processing data, and rendering the display. Using the map editor requires more effort to learn than does the Vis5D viewer. However, the Explorer map editor is a truly remarkable user interface. One can symbolically connect object modules in various combinations to produce the desired results.

To create a WWW animation, images are saved as rgb format files and converted to gif format for animation in a JavaScript animator.

C. VRML

VRML[4] [5] (Virtual Reality Modeling Language) is a web-based file format that allows interacting with 3-D objects through common web browsers. Both Netscape and Internet Explorer come with the ability to read VRML, and give the user a "dashboard" of navigation controls (Fig. 6, bottom) that are fairly intuitive and allow rotating and zooming objects on the screen. VRML also supports animations, video, audio, and touch sensors, and can utilize Java and JavaScript routines to extend data access capabilities. The TAO VRML demo[5] (Fig. 6) was made utilizing the gridded monthly TAO data. Five surfaces were created for each month (3 depth sections, the 20°C isotherm, and dynamic height) as well as a grid of wind vectors. These surfaces (each a VRML file) were linked together and animated through the use of a VRML script node (for more information on the VRML specifications see http://www.vrml.org). A control panel (Fig. 6, upper right) allows the user to start this animation, and to turn on or off each of the five surfaces or the wind. For more information

[3] http://www.nag.co.uk/Welcome_IEC.html

[4] http://www.pmel.noaa.gov/vrml/

[5] http://www.pmel.noaa.gov/vrml/taonew/vrml/taodemo.wrl.z

on creating VRML for scientific applications, see NOAA's VRML page at http://www.pmel.noaa.gov/vrml.

D. Comparisons

All of the visualization software packages offer basic desktop interactivity, i.e., the ability to zoom in and out, rotate the view, combine different data sets, make 2-D slices of 3-D fields, and more. Vis5D and IRIS Explorer provide their interactivity directly on the desktop, while VRML provides its interactivity in a WWW environment, which allows interactive access to a much wider audience. Note that using the utility ivToVRML on SGI machines, one can also create VRML format files from IRIS Explorer objects[6]. VRML files created using ivToVRML tend to be very large, but can be reduced by software such as the VTK toolkit to make them more easily used in a VRML viewer or web browser. At the time of submission of this paper, we were not aware of a utility for creating VRML files from Vis5D files. In any case, one can still create JavaScript animations of the Vis5D and Explorer images, but the only user controls are for one visualization. Interactivity provides access to all possible visualizations.

All of the software packages have significant challenges involved in putting the data into the proper format, although one can locate utilities on the WWW for IRIS Explorer for reading NetCDF files, for example. So, some of these challenges may be minimized as the expert user base grows larger.

At the time of writing, our experience with all of these packages was in a somewhat preliminary stage. We suspect that with more experience, many of the processing steps can be done more elegantly using features of the software which are at present not fully exploited.

V. CONCLUSION

The TAO moored buoy array in the Equatorial Pacific Ocean is a major component of the global climate monitoring system, extending from 95°W in the eastern Pacific to 137°E in the west, and telemetering data to shore via the NOAA Argos satellite system. 3-D visualizations of TAO data offer striking examples of unified coherent presentation of multiple data sets, which fosters improved insights into the ocean, atmosphere, and climate systems. Animations of these 3-D visualizations are available at http://www.pmel.noaa.gov/toga-tao/vis/. In the future, our 3-D visualizations will be improved as the visualization technology advances, and new visualizations will be created to meet the evolving needs of the scientific community.

[6] http://www.pmel.noaa.gov/toga-tao/vis/vrml/

VI. REFERENCES

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