A Tool for Visualising Large Oceanographic, Atmospheric and GIS Datasets

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This paper describes the development and main operational capabilities of Makai Voyager, a geospatially enabled software that can fuse and visualise large, multi-variable data sets that change in space (x,y,z) and time (t) for weather phenomena such as precipitation patterns and typhoons. The new software has the ability to simultaneously visualise imagery, bathymetry/terrain, and true volumetric (voxel) data in a fully interactive geo-referenced mode. In addition to providing global coverage, a key feature of this software is the capability to interactively visualise large data sets while operating on a desktop PC.

Sensing the winds and weather has been important to man over the centuries. Many significant weather events have affected mankind over the years and the debate over the increasing frequency of extreme weather events is growing stronger. An early reference to the importance of the weather comes from the Chinese philosopher Sun Tsu, who once said, "Know yourself and know your enemy, and victory is guaranteed. Know the terrain and know the weather, and you will have total victory". Recent flooding in Thailand and Pakistan has highlighted the requirement to continue to monitor and efficiently visualise weather patterns and phenomena.

Never before in history has there been more data collected from sensors deployed all over the globe for meteorological purposes. Data from these sensors are used in numerical models for oceanographic and meteorological studies in addition to many other applications. The size and complexity of data processed by these models has increased exponentially in recent years. Today it is common for simulations to produce gigabytes or terabytes of data containing multiple variables of interest that change in both space (x,y,z) and time (t). With an increasing demand on the processing and visualisation of these large data sets, meteorologists are facing a fundamental problem in how to efficiently and accurately manage and interpret the vast amount of dynamic oceanographic and atmospheric data being collected and modeled.

Until recently many scientific and meteorological activities were limited to using sub-sets of the data, increasing the possibility of missing important and critical information due to the lack of efficient tools to extract and visualise relevant features of these data sets. Furthermore, most data was, and often still is, being presented using sequences of multiple flat 2D images, which is a very inefficient and time consuming method to extract and analyse information. Therefore, it is critical that new technology be developed which can efficiently fuse and display a richer and more immersive representation of the data in order to improve understanding, whether it is for planning, modeling, simulation, or actual operations (e.g. incorporating real-time meteorological numerical models with GIS data on population centers to produce flash flood guidance and threat information).

In the last several years, efforts to develop better tools to fuse and visualise atmospheric data have been on-going. However, most of these tools are still limited in the amount of data they can load for analysis in an interactive mode. Systems that have the capability to render large data sets still rely on cluster and specialised hardware to run interactively and this has drastically limited their use by the general scientific community.

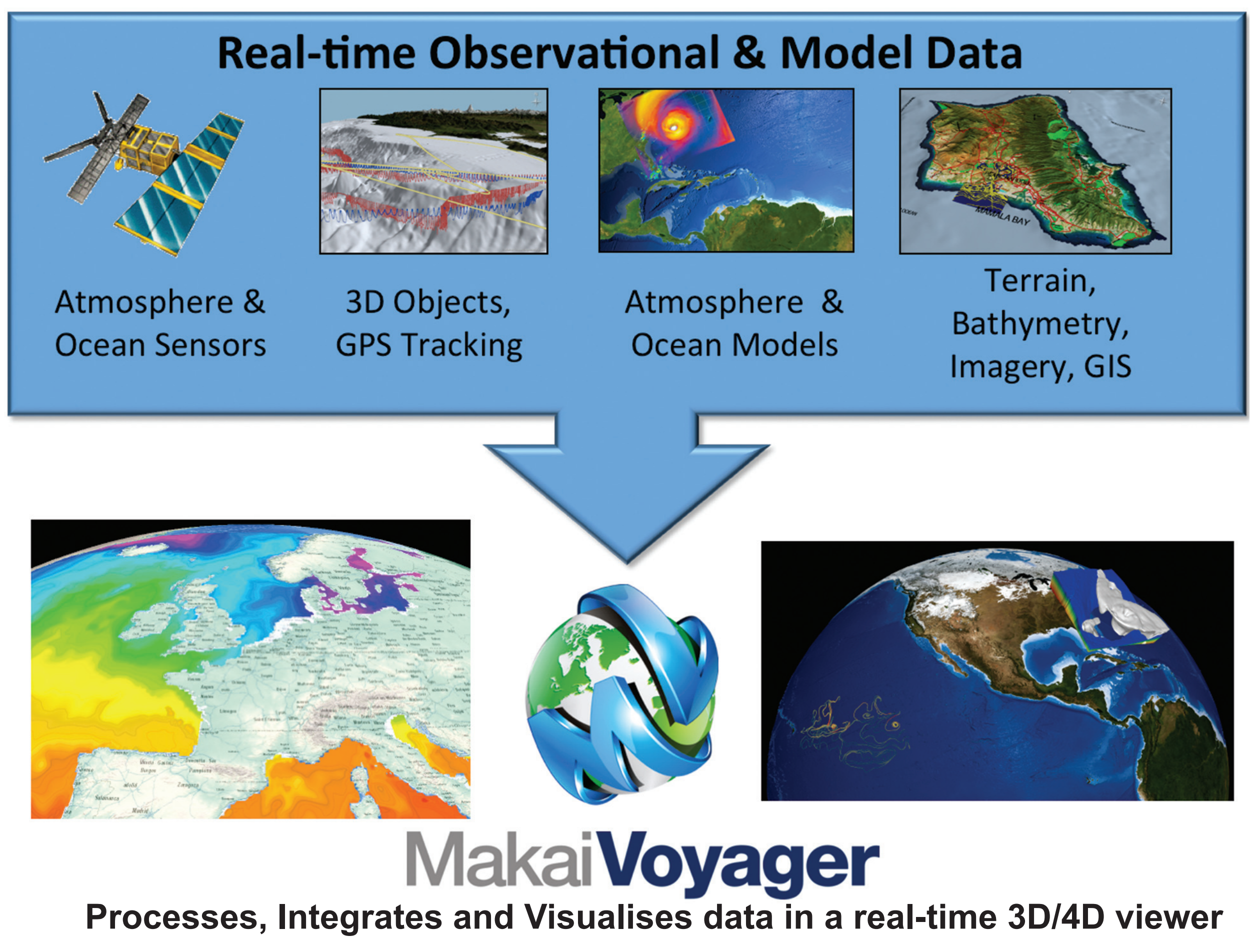

Figure 1: Software combines visualisation of terrain/bathymetry, imagery, 3D/4D time dependent iso-surfaces and volume data, asset tracking, and a wide variety of GIS data; all in a complete geo-referenced environment.

Other well known, highly interactive software systems used to view large amounts of terrain and image data (e.g., Google Earth, Microsoft and Virtual Earth) and the true GIS software (e.g., ESRI and Intergraph products) are still not capable of displaying large scientific data sets, such as volumetric data, that change in time. They are restricted primarily to display imagery, terrain, and 3D objects. Many existing scientific programs were not designed to easily incorporate geo-referenced data such as large image files, elevation/bathymetry and the large number of commonly used GIS data.

Motivation and Design Specifications

In addition to the limitations mentioned for existing visualisation software packages, meteorologists are often forced to use a large variety of tools to pre-process their different data sets before they can input them into existing visualisation and GIS programs. The shortcomings in existing data fusion and visualisation technology motivated the creation of a single product that would eliminate most of the above limitations.

Over the last 5 years, Makai Ocean Engineering, with funding from the Defense Advanced Research Projects Agency (DARPA), the National Defense Center of Excellence for Research in Ocean Sciences (CEROS), and the Office of Naval Research (ONR), has developed a PC-based software tool that provides interactive visualisation of large amounts of time-varying volumetric data at interactive frame rates. The goal of this software was to create a stand-alone software package that combines the visualisation of imagery, terrain, and volumetric data (both scalar and vector) into a single geo-referenced environment.

Early in the developmental stage, specifications for the final software were established. Main requirements included:

- The ability to simultaneously visualise imagery, bathymetry/terrain, and true volumetric (voxel) data in a fully interactive geo-referenced environment;
- The ability to efficiently fuse geo-referenced terrain and imagery data from different sources with different datum/projections, and create image and terrain tiles at a desired resolution;
- The ability to easily load multiple terrain and imagery tile-sets and perform quantitative analyses with them;
- The ability to render dynamic iso-surfaces and full volumes (i.e., voxel rendering) of large grids (> 5123), including visualisation of scalar as well as vector (e.g., flow) data;
- Incorporate multiple tools for user interaction (e.g., distance measurement, cutting planes, slicing, graphing); and
- Be designed to be easily expandable into a web-based system.

Figure 1 summarises the main visualisation components of the software. The software provides a complete dynamic operational view of the 4D environment by combining and rendering imagery, elevation, GIS vector and raster data, with multi-variable time-dependent data sets that change in both space and time. The software can also incorporate real-time observational data streamed from sensors and GPS. This interactive viewer enables a quick and intuitive understanding of all available and relevant geospatial data for informed decision-making.

In order to combine terrain, imagery, and volumetric data while still maintaining interactive frame rates on a PC workstation, the software makes use of several important techniques. These include efficient compression algorithms, multi-threading capabilities of modern PCs (GPU processing), and tiling technology (i.e., breaking up 2D and 3D data into "chunks" to be accessed only when needed for a particular view).

Meteorologists are faced with the task of gathering and analysing data from many different sources, each having different formats, resolutions, and areas of coverage. To simplify the pre-processing of these data sets, this software provides powerful, yet simple, tools that allow the user to resample and merge imagery and elevation data from a variety of sources in order to have complete coverage of an area of interest. In this way, the software can stream and fuse enormous GIS data and resample them (i.e. break them into chunks) so the user is able to interactively zoom around the data to inspect or customise its appearance.

Operational Meteorology Applications

One of the primary strengths of the software lies in its ability to visualise multiple time-varying 3D numerical models of atmospheric parameters at interactive rates. While it does not perform numerical modeling, volumetric data output from large and complex models can be streamed into the 3D viewer and viewed interactively in real-time. This visualisation can be complimented with the addition of other real-time datasets, such as a streaming map of the weather radar readings in the area of interest. In Figure 2, a Geo-TIFF (a geo-referenced image) from NASA Earth Observatory shows Typhoon Roke headed northeast toward the Japanese island of Honshu on September 20, 2011, where 80,000 people were evacuated from Nagoya city for fear of flooding. This Geo-TIFF is overlaid on a streaming web map showing the 8 day average land temperature for the earth. Any models, imagery, or GIS data relevant to flood risks that are available can be imported and fused with these data to aid in forecasting and emergency warning intelligence.

Numerical models typically output many parameters, each of which is evaluated at the nodes of a large predefined grid, and these simulations may involve many time steps. Given the large amount of output data, it is critical that visualisation software includes tools to quickly analyse and simplify the understanding of these data. Specific tools in the software include the ability to: (a) apply lighting and calculate gradients 2interactively, (b) use cutting planes and slices to better visualise the interior of a volume, (c) show specific parameter ranges depending upon the values of other parameters (e.g., show the data for wind speeds greater than 50 meters per second for those areas with a pressure range between 955 and 975 milibars), and (d) numerous graphing capabilities. The software can also export high-resolution imagery and movies of the 3D viewer, making aesthetically pleasing presentation of meteorological data easy.

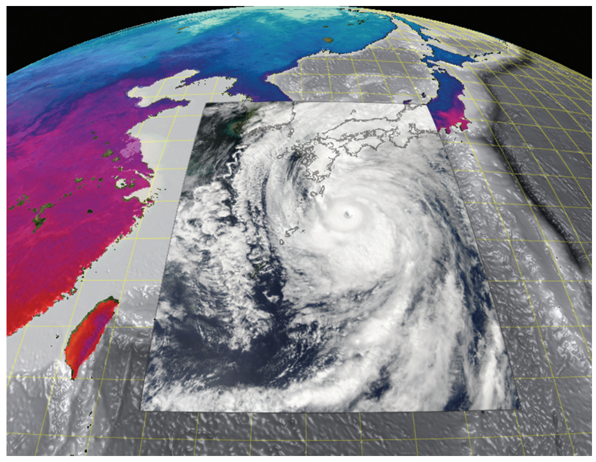

Figure 2: This is an image of Typhoon Roke from September of this year, overlaid on realistic topography, and a streaming web map service for the land temperature of the world. Free meteorological resources, such as NASA's Earth Observatory, provide streaming web maps, which can be viewed in conjunction with user-specific data sets, such as a model of a typhoon or flood.

In order to distinguish between the visualisation of multiple parameters, each parameter has its own colour map graph. In Figure 3, wind speed and precipitation of a hurricane – (the equivalent of a typhoon in Asia) are visualised, each using a separate colour map. Thus, the appearance of each visualisation (as well as the terrain), is fully customisable.

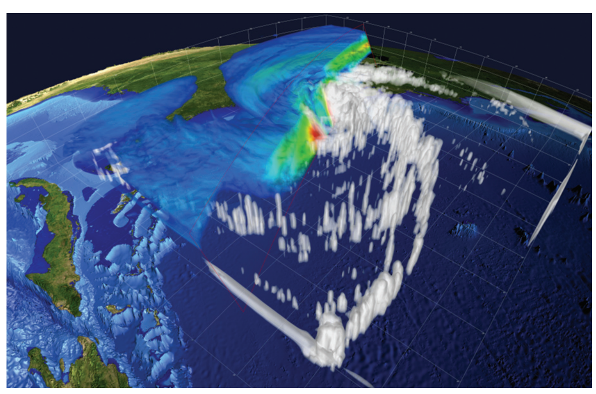

Figure 3: Colour and opacity control help provide a clearer understanding of volumetric data. Shown is a volume rendering of Hurricane Isabel; wind speed is shown as a semi-transparent coloured volume which is transected by a tool to reveal a second volume for precipitation, coloured semi-transparent white. Data courtesy of NCAR and NSF.

LIDAR Point Clouds: The software can also import and visualise large LIDAR datasets at interactive rates. LIDAR data can exist in many forms, including: (a) LIDAR surveys can provide extremely accurate 3D mapping of terrain and objects, (b) Differential Absorption LIDAR can be used to measure a particular gas in the environment, (c) Doppler and Rayleigh LIDAR can be used to measure atmospheric temperature or wind speed and are often used by airport terminals to detect wind hazards. An example of a survey is shown in Figure 4 as a LIDAR point cloud of a section of Ottawa, Canada.

Web-Based Application: Finally, the software can be used collaboratively and remotely over the internet via a web browser. In this type of system, a server runs the software which then streams rendered images to a lightweight client application operating within a user's web browser. Thus, the software can effectively perform on a low-powered laptop or tablet with limited graphic computing power (e.g., Apple iPad, as shown in Figure 5), regardless of the size of the data being visualised. This feature will allow a user to access the highest caliber 3D models and geospatial data available interactively from anywhere in the world.

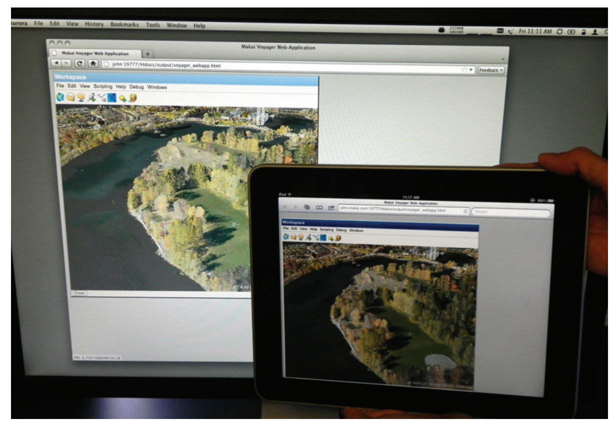

Figure 5: Server-side rendering allows massive models or datasets like this LIDAR survey with 1 billion points (mentioned above) to be visualised remotely at interactive frame rates on low-powered desktops, tablets, and smartphones.

Conclusion

This software provides meteorologists with a tool to simplify and integrate all relevant data (atmospheric, oceanographic, GIS, or otherwise) into one easy-to-use interactive 3D environment. Having the most up-to-date images, terrain, maps and weather data available allows meteorologists to contextualise their environmental models in order to make the most informed and accurate forecasting and emergency warning decisions. As extreme weather events world-wide increasingly threaten public safety, the ability of meteorologists to make efficient use of all geospatial data available can literally mean the difference between life and death. A demonstration copy of the software can be downloaded from voyager.makai.com

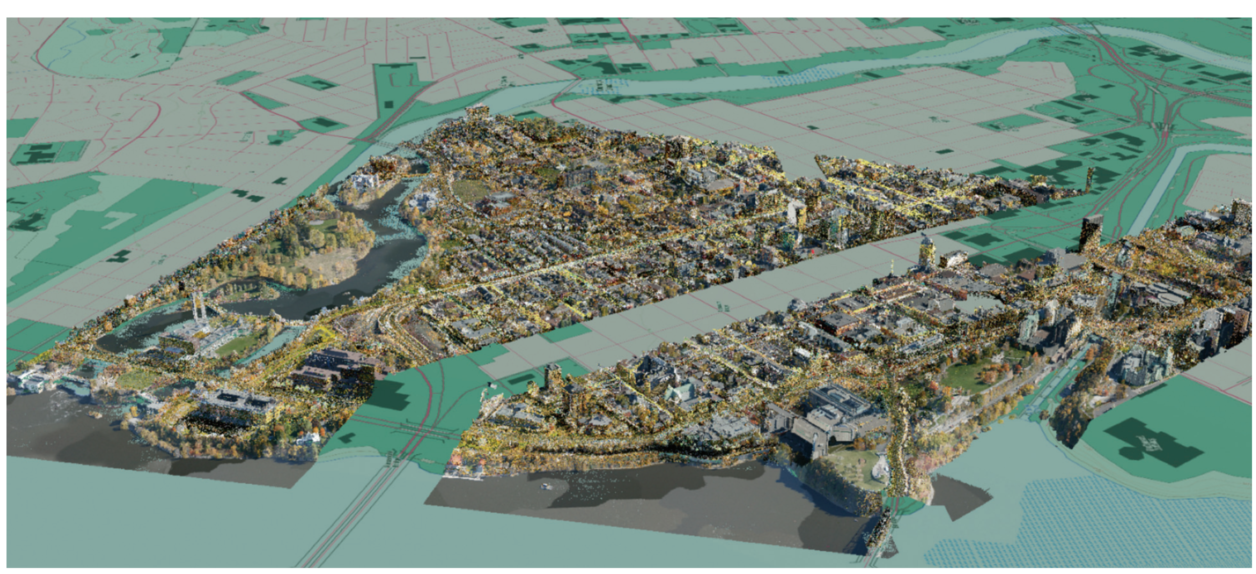

Figure 4: A screen shot of a colour point cloud consisting of over 1 billion individual points from a LIDAR survey of downtown Ottawa, Canada which is overlaid on a map streamed via a web map services provider. Trees, people, and cars are visible at close range. LIDAR data provided by dayta Ohio.