REINAS Instrumentation and Visualization

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Abstract

This paper gives a brief system overview of REINAS (Realtime Environmental Information Network Analysis System) and some details on the instrumentation and visualization aspects. REINAS is a continuing engineering research and development system with the goal of designing, developing and testing an operational prototype system for data acquisition, data management, and visualization. As such, it includes a growing web of networked remote and in-situ instruments, a federated geographical database, and an extensible visualization interface. REINAS focuses on the needs of both oceanographers and meteorologists who monitor realtime data or analyze retrospective data that has been collected in the Monterey Bay area. This system is designed to be portable, extensible, and fault tolerant.

Among the collaborators on this project are researchers from the UCSC Computer Engineering and Computer Information Sciences Departments and environmental scientists from the Naval Postgraduate School and the Monterey Bay Aquarium Research Institute.

Keywords: realtime, advanced instrumentation, environmental visualization,

1 Overview of REINAS

REINAS is a multi-year effort of the Baskin Center for Computer Engineering and Information Sciences of the University of California, Santa Cruz (UCSC), in cooperation with environmental scientists from the Naval Postgraduate School (NPS), and Monterey Bay Aquarium Research Institute (MBARI). It is currently in its fourth year, out of a five year development plan. We have gone through the steps of problem and concept identification, requirement specification, system design and implementation, and are currently in the midst of experimentation and evaluation as well as transitioning to an operational version. These stages are documented in the following reports [1, 2, 3, 4] and are summarized below.

The goal of this project is to bring modern technologies to bear upon the problem of realtime environmental (oceanographic and meteorological) data acquisition, management, and visualization/analysis. As an area of focus, we are looking at the phenomena within the regional scale of Monterey Bay. Since physical changes happen at much smaller time scales within our region of interest (compared to global or climate studies), the main challenge of REINAS is to provide realtime environmental information of the physical parameters. The tools that are being used to help realize this goal are a combination of wireless, networked instruments, land and water based mobile platforms, remote instrument steering and control, spatial/temporal database management, artificial intelligence, flexible tool-based visualization, multimedia, collaboration software, and data assimilation of field measurements into numerical models.

While the main driving requirement for REINAS is the realtime measurement and access of field data, it also has to support the needs of three classes of users. These are: operational users, scientific users, and developers/instrumentation engineers. Operational users include forecasters who need the most recent measurements to produce short-range forecasting or nowcasting, policy makers or planners who need a bird's eye view as well as the ability to zoom in an areas of interest, disaster control planners who need current measurements as well as models to compare the impact of various remedial alternatives, and finally a growing list of recreational users who are interested in the current surf, sail [5], or ski conditions. Scientific users include retrospective researchers who need synoptic views for historical analyses, experimental researchers who need to combine current measurements into model runs, and sensor scientists who need to control instruments as the need arises – e.g. adjust sampling rate or point instrument at certain directions as a front approaches. The third class of users are system developers and instrumentation engineers who need to add, recalibrate, or remove instruments from the field, add or remove instruments from the network of instruments without bringing down the entire system, modify or add features to a running system, upload data from other sources into the database, etc.

From the list above, it is clear that the REINAS design must support both realtime and retrospective analyses. It also has to transition smoothly from a development system to an operational system. Finally, the effort here must be easily replicated to other regional areas of interest. Hence, the system must also be portable.

The REINAS system architecture is broken down into three main components: data acquisition, data management, and data visualization. Figure 1 shows a high-level view of the system. Lines indicate physical or wireless network connections. Lines are bidirectional unless indicated otherwise. Data flows generally from left to right, and feedback and control generally flow from right to left.

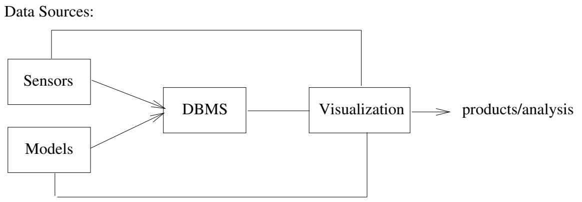

Figure 1: Major REINAS components.

Part of the strategy for smooth transition into an operational system is to build the components incremental and refine iteratively. Figure 2 shows the currently implemented components and connections. In this case, as the incremental database is refined, it will be integrated into the system DBMS.

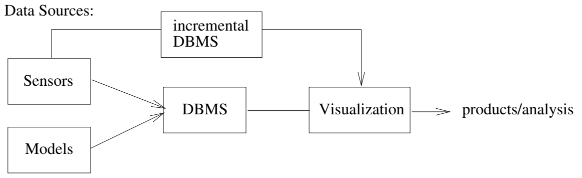

Figure 2: Currently implemented components.

We now turn our attention to the network of instruments (sensors) in REINAS and then on to the visualization component.

2 REINAS Instrumentation

The data acquired within the REINAS system come from a variety of instruments and other sources. Any instrument whose data comes directly into REINAS requires a dedicated personal computer (PC) that is Internet accessible at the instrument site. Data collected by the instruments is fed to the PC serially where REINAS system software formats and logs the data appropriately, and ships the data to the database. In many cases, the personal computers are connected to REINAS (and are thus Internet accessible) via a network of radio links. Data that does not come directly to the REINAS system may come from a number of different paths (or "virtual" instruments), such as archival files, UNIDATA, or anonymous FTP.

The types of instruments that are currently connected directly to the REINAS system are standard research quality meteorological (MET) stations, CODAR (Coastal Ocean Dynamics Applications Radar) high-frequency (HF) current measuring radars, wind profilers, and CTD's (Conductivity, Temperature, Depth sensors), although the system is not limited to these types of instruments. Any instrument that can provide a serial output stream or file can potentially be connected to the REINAS system in a realtime fashion.

The standard REINAS MET station consists of a number of individual sensors that include wind speed, wind direction, air temperature, barometric pressure, and humidity. Additional sensors that some sites are equipped with are rain gauge sensors and solar irradiance sensors. The outputs of these sensors are hooked to a data logger (Campbell Scientific CR-10/CR-21 data loggers are the standard ones used by REINAS). Currently, there exist approximately nine MET stations that are connected directly to REINAS. Of these, two are deployed on moving vessels. One is currently aboard the vessel R/V Pt. Lobos and is Internet accessible via their existing network shipboard microwave connection. The other has recently been deployed aboard the NOAA research vessel R/V McArthur and was Internet accessible via a UHF radio link from UC Santa Cruz to the MET station aboard the vessel. One of the other MET stations in the realtime network was built on a trailer and is easily deployable to a location of interest.

Wind profilers provide a measurement of the horizontal winds as a function of height to a maximum height of approximately 4 km. These instruments utilize the scattering that occurs off of turbulent moisture fluctuations in the atmosphere to estimate the Doppler shift and thus the radial component of the wind speed in a given direction. By combining measurements made in three (or more) orthogonal viewing directions at varying heights, the horizontal component of the wind speed at a given height may be estimated. A realtime link existed at two distinct wind profiler locations in the Monterey Bay area, one at

Santa Cruz and the other at Point Sur. A realtime link to a wind profiler results in moments (from which wind vectors may be computed) that are received approximately each minute. Receipt of the data in this fashion results in the capability to estimate the wind speed and direction vs height on a much more regular basis than the hourly data provided by the NOAA wind profilers. Two other wind profilers exist in the Monterey Bay area (both of which are at Fort Ord and are owned by the Navy Postgraduate School). Realtime data from these instruments will become available when a network link is established at Fort Ord.

CODARs are a version of high-frequency radar manufactured by CODAR Ocean Sensors, Ltd. Three CODAR instruments, two of which are a newer version called SeaSonde, are deployed in the Monterey Bay area. The two newer units are deployed at Long Marine Lab (Santa Cruz) and Point Pinos, which is at the southern tip of Monterey Bay. These newer units provide measurements of radial ocean surface currents on an hourly basis. An older CODAR unit exists at the MBARI Moss Landing facility and it provides measurements of ocean surface currents every two hours. Data from two or more of these CODAR sites are combined hourly at UC Santa Cruz, which provides maps of ocean surface currents with a resolution of approximately 3 km. HF radar systems measure radial ocean surface currents by measuring the Doppler shift associated with radar energy that is scattered off of ocean gravity waves that are between 5 and 50 meters in length. The difference between the Doppler shift of the returned signal and the expected Doppler shift of the ocean gravity wave allows an estimate of the value of the advection of the waves by the ocean surface current over the patch of ocean that the radar observes.

Data from the CODAR units is copied to the REINAS system hourly, where it is then combined to form the vectors.

Other instruments that are part of the current data feed into REINAS include CTD's, ADCP (Acoustic Doppler Current Profiler), thermistor chains, and assorted biochemical sensing instruments, such as those that measure Chlorophyll-A or trace gases. Instruments that make these measurements exist both along the coast (CTD at Granite Canyon) and (more generally) offshore, such as on the MBARI buoys M1 and M2.

One of the unique and useful features of the REINAS system is that it is designed to be mobile, modular, and extensible. This essentially means that new instruments can be added/deleted and the size of the instrumentation pool can be increased without changing the basic system architecture.

Other data feeds that are anticipated within the near future are data collected from UNIDATA as well as GOES-8 and (soon) GOES-9 data that will be collected from the National Weather Service.

The data sources available from within the current instrumentation network coupled with the anticipated sources, provide valuable information for regional studies of the local oceanography and meteorology of the Monterey Bay area, and we anticipate increasing utilization of the current suite of REINAS data by the scientific community.

3 REINAS Visualization

The highlights of the visualization system include: an integrated interface for users to display their three-dimensional time-dependent data; support for real-time monitoring and retrospective analyses of model and sensor data; extensible system to explore different ways of visualizing data; support for incorporating uncertainty information in the visual displays; and support for collaborative visualization among geographically dispersed scientists and data sets.

The visualization component of REINAS is designed to meet the various needs of its target users as identified in section 1. As such, it is organized into three modes: monitor, forecast and analysis corresponding to the needs of instrumentation engineers, operational users, and scientific users. These are described below.

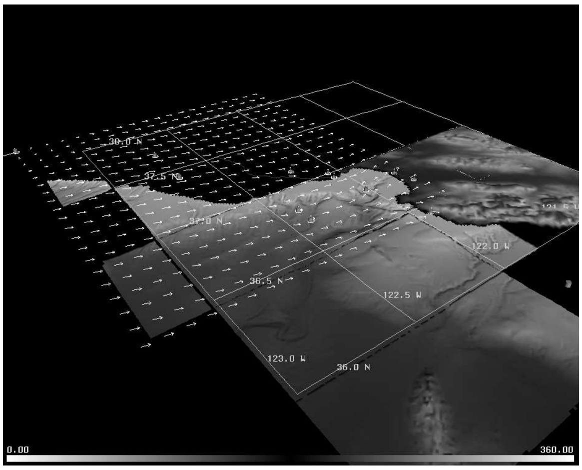

Figure 3: View of the Monterey Bay showing location of some sensors and an interpolated wind field from a subset of these sensors.

Monitor Mode

The purpose of monitor mode is to allow users to watch the most current state of the environment. See Figure 3. Users have a bird's eye view of the region of interest. Environmental sensors are represented by simple icons. By selecting one or more of these sensors using a point and click interface or through a pulldown menu, users can view interpolated fields of a physical parameter (e.g. humidity, wind vector, etc.) or query individual sensors for time plots of the parameters they measure. The list of sensors currently supported include: fixed and portable meteorological stations, NOAA buoys, CODARS, wind profilers, seal tracks, and ADCP. We also plan to include other instruments as they become available and accessible such as LIDAR and Nexrad.

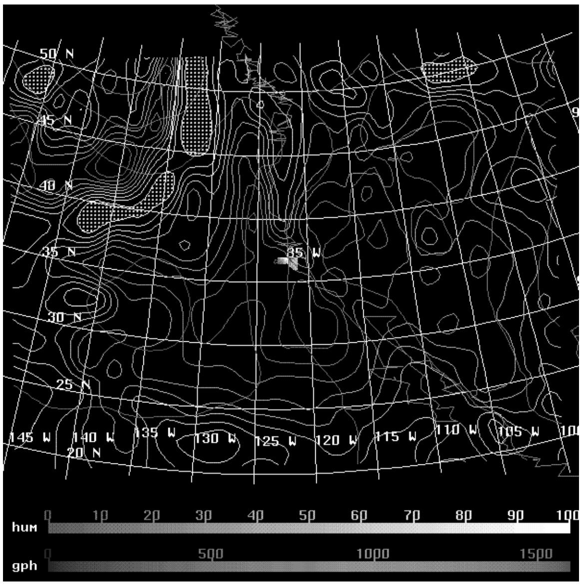

Figure 4: Sample standard forecast product where regions of relative humidity above 90% are cross-hatched.

Forecast Mode

Operational forecasters are interested in generating standard products from forecast models and satellite observations. These products may include animated GOES satellite images, as well as maps that show contours of 500mb pressure field at 60m spacing of geopotential height against vorticity, 850mb pressure field at 30m spacing of geopotential height against relative humidity (shaded above 90%), and others. Aside from standard products, users can also generate customized products e.g. different projections, different contour spacing, and heights. One can also register and overlay observation data with products e.g. wind barbs and animated GOES images. Figure 4 shows a typical forecast product.

Analysis Mode

This mode allows the scientific users to perform retrospective analysis on synoptic data. It allows users to explore large data sets interactively using different visualization techniques. It is also extensible and can easily grow with users' needs. The underlying mechanism that provides the visualization capability in analysis mode is based on spray rendering [6]. Spray rendering provides the users with the metaphor of spray painting their data sets as a means of visualizing them. In its simplest form, data are painted or rendered visible by the color of the paint particles. By using different types of paint particles, data can be visualized in different ways. The key component of spray rendering is how the paint particles are defined. They are essentially smart particles (or sparts) which are sent into the data space to seek out features of interest and highlight them. Among the advantages of this visualization framework are: grid independence (sparts operate in a local subset of the data space and do not care whether data is regularly or irregularly gridded), ability to handle large data sets (sparts can be "large" and provide a lower resolution view of the data set or they can be "small" and provide a detailed view of an area of interest), extensible (it is easy to design new sparts). Sparts can also travel through time-dependent data sets. Figure 5 shows the interfaces available in analysis mode as well as illustrate some of the possible visualization methods.

Spray is similar to other modular visualization environments (MVE) like AVS, Explorer, Data-explorer, in terms of extensibility, modularity and drag and click interface[7]. Spray differs in terms of execution flow – active agents vs data-flow and finer granularity making it more flexible.

Region Selector

Originally, the design of the visualization component assumed that the physical scale of study would be comparable to the Monterey Bay. This has since been expanded, at the request of some of our users, to a larger area. We have added two mechanisms to allow users to navigate through the larger space. The first method allows the user to zoom in/out and pan around using a combination of mouse and button selections. This is desirable for looking at regions close to the current area of study. The second method provides a tool for selecting a region of interest from a 3D globe. This method is preferable when the user wants to jump around and look at geographically distant data sets. It allows REINAS visualization to examine registered data sets from different localities. Users can save and use user-defined regions of interest. One can also select among different projection methods and specify vertical exaggeration.

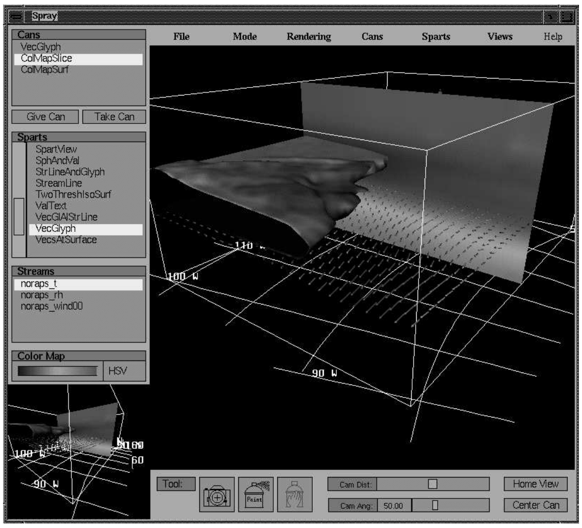

Figure 5: Sample visualization in analysis mode using spray rendering.

3.1 Visual Programming and Spray Rendering

At the onset, it was clear that it was impossible to identify and anticipate all the needs and requests of the visualization users. Thus, it was a major design goal to make the system flexible and extensible allowing it to grow with the needs of the users as they arise. Efforts were also made to make sure that the added flexibility does not sacrifice ease of use. The result is a visual programming extension to spray rendering that allows users to graphically create new sparts (and hence, new visualization methods) using a mix and match paradigm [8]. Sparts are created by hooking up different components. These components are organized into four categories.

1. *Target* components are functions that detect features in the data set.
2. *Visual* components are functions that describe the graphical representation of the feature that was detected.
3. *Position* functions update the current position of the spart. These can be absolute movements or dependent on the data, as in vector fields.
4. *Death* functions determine when the spart should die. There is also a birth function in this category that spawns new sparts.

A spart composition is the specification of the components that make up the spart and the connections between them. Users can select components from a browser, drop it onto a canvas and graphically connect them. This composition defines how the spart behaves at the current location. The compositions and the components are usually quite simple. However, complex visualizations can be obtained by multiple applications of several sparts.

3.2 Collaborative Visualization

To facilitate the sharing of data and collaboration among science colleagues, we have also added a collaborative feature to the REINAS visualization system, enabling geographically distributed researchers to work within a shared virtual workspace and create visualization products [9]. There are several components that are needed to make this feasible: session manager, sharing data/cans, floor control, multiple window, audio/video support, and different collaboration/compression levels.

The session manager is a piece of software that maintains a list of ongoing sessions and the participants in each session. A session consists of a group of participants working on a common theme or problem. Participants may join or leave the session at any time. Thus, the session manager needs to inform the application programs of any changes so that traffic delays are minimized and also so that late comers may easily catch up with what is going on.

Users can collaborate at different levels. Sharing can occur at the image (visualization product) level, spray can (abstract visualization objects – AVOs) level, or data stream (raw data) level. At the image level, participants can see what the other participants see and may perhaps be able to change view points. At the can level, participants have access to a list of public spray cans put up by other participants. These public cans will generate AVOs from the remote hosts and distribute them to other participants. Users may also give permission to other participants to have direct access to data streams and replicate those on local machines for faster response times. The different levels of collaboration also imply different requirements for compression. Tradeoffs will have to be made between graphics workstation capabilities, network bandwidth and compression levels. Objects that need to be transmitted can either be images, AVOs (together with can parameters and other transformation matrices), or raw data.

In single user mode, users may create multiple cans, but can control only one can at a time. With multiple users and sharing of spray cans, it is possible that more than one user want to use a particular spray can. Floor control software regulates the use of spray cans. We use a stop light analogy to provide visual cues to the users to indicate if a spray can is in use by others (red), available (green), or being requested (yellow). Release of the can is then made explicitly with a button click or implicitly with a timeout after a period of inactivity.

Just as users can have local and public spray cans, they can also have local and public windows. Users work in their local window and may once in a while look at the public window to see what others are doing. Figure 6 shows how the two views are presented on the screen. The public window is also where one might do a broadcast as in during a briefing mode to show other users an item of interest.

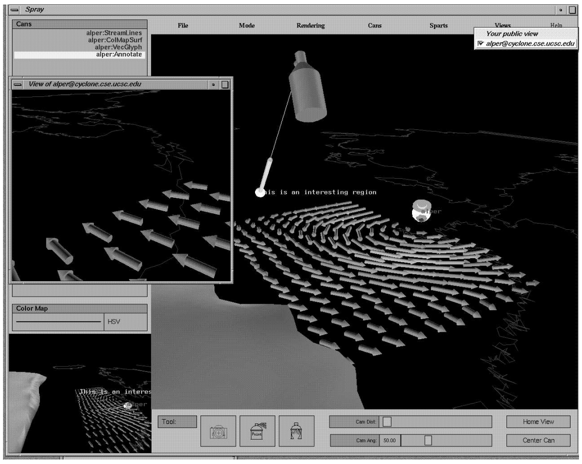

Figure 6: Collaborative visualization. The large graphics window shows the viewpoint of the local user. The smaller window shows what the collaborator is looking at. The "eye-con" shows the location of the other participant.

3.3 Visualization of Uncertainty

Visualizations without any indication of data quality are often misleading and may lead to erroneous conclusions. We are investigating a variety of techniques that will visually present data together with its quality information [10]. A specific example is our work on uncertainty vector glyphs which indicate vector direction and magnitude as well as uncertainty in direction and magnitude, together with the median direction and length [11].

This work is particularly important with environmental data since measured environmental data have inherent uncertainty. Radar, light, and sound are used to remotely sense physical phenomena, but because of instrument limitations the measurements are approximate. For example, wind measurements from meteorological stations have good accuracy, but to compare winds from many sites, winds are often averaged over minutes or hours. The variation during an hour is an uncertainty in time. Often, the sparsely located sites are interpolated, which adds a derived uncertainty in space. A similar processing method is used with radars. Each radar, whether a wind profiler or a CODAR, takes a volume sample, which averages the returns. The time series data has a wealth of information, which may be examined in detail, but is not used in the vector visualizations. Wind profilers have weak scattering from dry air, and measurements are also influenced by airplanes and migrating birds [12]. Ocean surface current radars have varying performance depending on the ocean conditions. Current methods of display simply threshold or ignore uncertain vector component measurements.

Figures 7 and 8 illustrate the difference between traditional vector field plots and those using uncertainty glyphs. Here, the vector field is interpolated from a few sensors (represented as cones and cylinders) and uncertainty is made to increase with distance from the measurement sites.

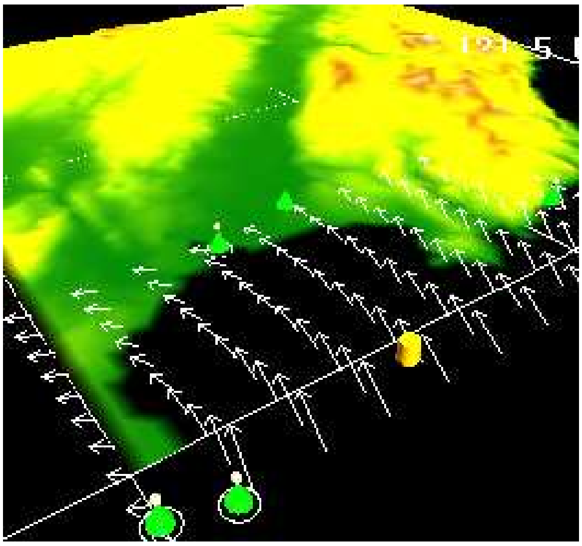

Figure 7: Interpolated winds over the Monterey Bay region looking south-east near Santa Cruz, on a regular grid using vector glyphs.

4 Project Status

The visualization effort has made significant progress along several fronts. However, the current version is considered a "throw-away" prototype. We are currently implementing a re-designed version which takes into account the user feedback and evaluation from the prototype. The main limitation with the current implementation is that the separation into three modes of use seem to be unnecessary. That is, users want to have access to all the data from different modes. They

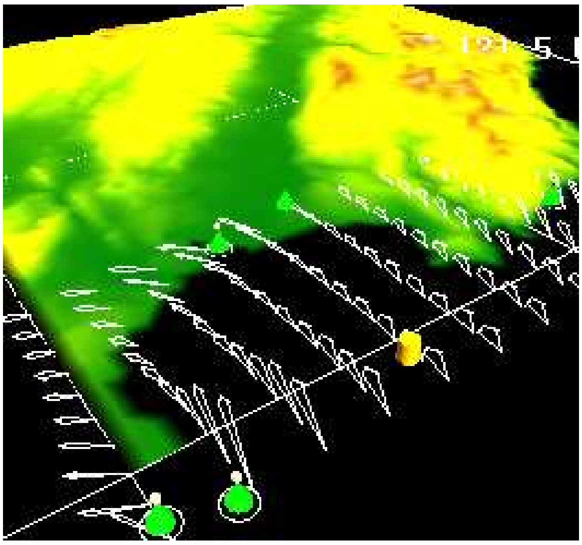

Figure 8: Interpolated winds over the Monterey Bay region, on a regular grid with uncertainty angle glyphs. Uncertainty grows with distance from meteorological stations giving a much different impression from the traditional vector glyphs.

want to do field interpolation outside of monitor mode; they want to overlay sensor data with synoptic data; etc.

In order to satisfy these requests without entirely throwing away the prototype system, we modified the visualization to be a tool-based system as opposed to a mode-based system. The idea behind a tool-based system is that users will activate different tools (software components) to do different tasks. These tools may perform data operation or transformation such as deriving vorticity fields from wind components, or they may output graphics primitives such as isosurfaces for the renderer to display in the graphics window. The different user classes identified earlier will simply prefer different sets of tools, but all will have access to all the data sets as their permission allows. To encourage code re-use, each tool is built from simpler elements. That is, a tool is a collection of one or more elements. A graphical tool builder that wires up different elements together will also be provided. Adding new elements requires programming but is facilitated by an element template and minimal (two) file updates. Spray rendering will still co-exist within the new design where the sparts can exists as elements or tools. Finally, the new version is being implemented in C++ and OpenGL.

On the instrumentation/system front, instrumentation and data feeds will continue to be added. These include a number of MET stations currently in existence within the Monterey Bay area, satellite data, such as that collected from GOES-8 and eventually GOES-9, weather radar data, and extensive data sets covering the local area from Unidata feeds as well as from the local NWS branch. Further work will involve incorporating applications that take available data and perform a nowcast, such as the LAPS software package.

The REINAS system will continue to develop in terms of incorporating the feeds required to load the data from this suite of instruments. Improvements and refinements will also be made to the interfaces necessary to pull data out of the system database. These interfaces will eventually be general enough to allow a variety of typical user applications (such as Matlab, or AVS, as well as our own visualization applications) to interact with the database, extracting data as necessary.

Finally, further work is being done to include additional products derived from the instrumentation suite connected to the REINAS system. As an example, we are looking at incorporating algorithms to compute the wind vectors more regularly from moment data collected each minute by the wind profiler at Long Marine Lab. We are also working to incorporate wind direction measurements derived from CODAR spectra. This will provide additional measurements that can later be used for improved local nowcasting and forecasting within the region.

5 Conclusions

We have presented an overview of the REINAS system with emphasis on its instrumentation and visualization aspects. We also outlined the plans for transitioning to an operational system. As different parts of the REINAS system go into operational use, it will fill the need for users doing realtime study of regional scale phenomena.

6 Acknowledgements

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