Title

New Visualization Tools for Environmental Sensor Networks: Using Google Earth as an Interface to Micro-Climate and Multimedia Datasets

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New Visualization Tools for Environmental Sensor Networks: Using Google Earth as an Interface to Micro-Climate and Multimedia Datasets

A Thesis submitted in partial satisfaction
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1. DATA VISUALIZATION AT THE JAMES RESERVE

The James Reserve, located in the San Jacinto Mountains east of Riverside, California (33 º 48' 30" N, 116 º 46' 40" W), is a part of the University of California's Natural Reserve System (UCNRS). It serves as a teaching and research facility for a broad range of biological disciplines. Through participation in a number of high-profile research programs in recent years, the James Reserve has shifted its focus towards becoming a technologically-advanced ecological observation laboratory. Among these programs are the Center for Embedded Network Sensing (CENS) and the National Ecological Observatory Network (NEON). More information about the James Reserve is available at its web-site: http://www.jamesreserve.edu.

1.1 Center for Embedded Network Sensing

As a National Science Foundation *Science and Technology Center*, CENS is aimed at developing embedded network sensing solutions for scientific and social applications. Under the direction of Dr. Deborah Estrin, a professor of Computer Science at UCLA, CENS' interdisciplinary and multi-institutional program includes over a hundred faculty, engineers, graduate and undergraduate students from six academic institutions. These include computer science, electrical engineering, biological and physical science departments from the following universities: the University of California at Los Angeles (UCLA), University of Southern California (USC), University of California Riverside (UCR), California Institute of Technology (Caltech), University of California at Merced (UCM), and California State University at Los Angeles (CSULA).

Some of the applied-technology CENS projects include: automated aquatic microbal monitoring, water contamination assessment, networked seismic monitoring, and sensor networks for terrestrial ecology. Visit CENS online at: http://research.cens.ucla.edu.

The James Reserve serves as the technology field test-bed for the Terrestrial Ecological Observation Systems (TEOS) research area of CENS. Lead by Dr. Michael Hamilton, a CENS Co-PI and the Director of the James Reserve, TEOS has a number of on-going research projects, including: micro-climate sensor and image acquisition networks; the development of automated, automated minirhizotrons for the study of root and mycorrhizae growth and turnover (AMARSS); and acoustic sensor arrays for the identification and localization of animals.

By late 2003, CENS had deployed a small wireless network of micro-climate sensors—the Continuous Monitoring System (CMS)—across parts of the Reserve. At the time the James Reserve also had a Texas Weather Instruments Station, numerous micro-climate data loggers and a system of closed-circuit television cameras for observing avian nest biology and plant phenology processes. Despite this wealth of micro-climate and multimedia data, there existed no centralized visualization tool for these systems. Thus, I was charged with developing an visualization interface for the James Reserve's rapidly expanding sensor and camera networks.

1.2 The Need for Data Visualization Tools

The visualization tools I have built for the James Reserve seek to fulfill two main purposes. The first is to satisfy the practical engineering needs of developing, deploying and maintaining embedded sensor networks. CENS engineers needed a way monitor the functionality and health of our sensor networks by visualizing live and archived data. They also needed a centralized administration gateway to the numerous systems operating at the Reserve. CENS participants also wanted a cohesive way to showcase and demonstrate their sensor networks to both researchers and the general public. Finally, CENS is seeking to develop field-portable tools for *in-situ* data visualization, spatio-temporal modeling and sensor network diagnostic tools. This conceptual product, called *Emissary*, was partially inspired by my early interfaces and leads to the other purpose of my work at the James Reserve: the development of tools for biological research.

Advances in sensing technology, like those being developed by CENS, tend to bombard scientists with vast amounts of observational data. For the past three years systems at the James Reserve have collected micro-climate data at 5-minute intervals, totaling over 50 million measurements. New CENS systems in development can alter their data sampling rates to mere seconds in order to detect rapid changes of condition. Databases at the James Reserve also store snapshots from plant and wildlife-observing cameras at intervals between five and thirty minutes, nearly 1.3 million images to-date. Soon real-time machine-vision analysis will intelligently categorize and store images as the activity inside changes, reducing numbers of redundant images but also increasing the number of dynamic ones. Researchers using the James Reserve need a way to effectively navigate through such large datasets in order to find the patterns of interest.

In addition to much smaller temporal scales of data collection, there is an inherent spatial component to sensor network data. Micro-climate conditions can change dramatically across relatively short distances in heterogeneous environments. Therefore, an efficient visualization interface must allow researchers to peruse the data through space, as well as time. Furthermore, the ideal visualization interface would incorporate on-the-fly statistical analysis of sensor network data, such as the spatial interpolation of point data using Kriging models.

The most exciting potential for the effective use of these new types of datasets is the ability for scientists to ask novel questions. Researchers will be able to discover, model and eventually predict phenomena that were previously unobservable because of insufficient temporal and spatial experimental scope.

1.3 Using Google Earth as a Visualization Platform

As a three-dimensional virtual earth program, Google Earth™ has great potential as a visualization platform for scientific research. The following are some examples of how Google Earth is being used to visualize real-time scientific data.

The Cyberinfrastructure Laboratory for Environmental Observing System (CLEOS), part of the San Diego Super Computer Center (SDSC), is also developing an interface based in part on Google Earth. The first application of this “Cyberdashboard for Observing Systems Management” project is a Google Earth layer and accompanying web-based control panel for visualization of EarthScope's USArray, a nation-wide seismic network. CLEOS is also creating a “Cyberdasbboard” interface for ROADNet, a SDSC program similar to CENS which is developing wireless sensor networks for multidisciplinary science teams.

The Geosciences Network (GEON) is another multidisciplinary collaboration seeking to develop cyberinfrasture for the storage, delivery, analysis, modeling and visualization of North American geoscience datasets. They are also developing web-based data services which support a number of visualization clients, including Google Earth.

Other noteable projects integrating live data into Google Earth include: The United States Geological Service's (USGS) “WaterWatch” project which allows the real-time mapping of streamflow throughout the US; near real-time ocean and weather data from the Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS); and the monitoring of volcano activity by the Alaska Volcano Observatory. Links to all these projects are included in the Glossary section.

1.4 Google Earth at the James Reserve

For the James Reserve I created a dynamically-generated Google Earth layer that represents our embedded sensor networks and provides access to micro-climate data, audio/visual feeds, and GIS layers in a realistic three-dimensional environment. Connected to this James Reserve Google Earth layer (referred to as the “JR GE layer” from this point onward) is a set of web-based graphing and visualization tools that I also developed for the direct exploration of this data.

This thesis is a summary of the data source accessible via the JR GE layer, as well as a description of its creation process, functionality, potential research applications and future directions.

2. DATA SOURCES ACCESSIBLE VIA THE JR GE LAYER

2.1 CENS Micro-Climate Sensor Arrays

The James Reserve has three micro-climate sensor networks developed by the CENS. These include the original Continuous Monitoring System (CMS), the improved Extensible Sensing System (ESS), and the Cold Air Drainage (CAD) transect. Data from the later two networks are sent to a newly developed CENS database—Sensorbase—at UCLA. Their measurements, except for a small subset of the CAD data, are not yet accessible via the JR GE layer. Once all the CMS data, currently stored at the James Reserve, is transferred into Sensorbase the JR GE layer will be modified to use this new database and will provide access to ESS and CAD data.

The CMS micro-climate array includes four wireless weather stations (Figures 2.1, 2.2) and three sensored bird nest boxes (Figure 2.3) which collect data at 5-minute intervals. CENS sensor network platforms, the circuit boards which accept sensor inputs and transmit data via wireless radio, are constructed in-house at UCLA from commercially-available and custom-built hardware components. Commercially-available sensors (e.g., light gauges and digital thermometers) are connected to these platforms. Table 2.1 lists the types of measurements taken by these systems. Sensor data from the CMS network, some 43 million measurements over the past three and a half years, is stored on-site in the Data Management System (DMS). The DMS database will be described in more detail in the Chapter 4.

2.2 Commercial Sensor Systems

The James Reserve also uses commercial sensor systems including: Onset Computer Corporations's HOBO™ Micro Station and HOBO™ Weather Station Data Loggers and a Texas Weather Instruments Station, model WRL-32S. Twelve HOBO data loggers are deployed throughout the James Reserve to collect micro-climate data inside and around bird nest boxes (Table 2.2 , Figure 2.4). Another HOBO data logger monitors soil temperature and moisture at two depths. Data from these loggers must be manually downloaded in the field and inserted into the James Reserve's sensor database.

A Texas Weather Instruments Station that has been collecting data since 1990 (see Table 2.2); data collected since December of 1999 is available in the JR GE layer. This weather station electronically transfers data to our on-site sensor database with the use of proprietary Texas Instruments software.

CENS Devices *(data availability)*		***Sensors***
Nestbox 13	(2003-11-25 to current)	Humidity
Nestbox 47	(2003-05-05 to current)	Inside Humidity
Nestbox 50	(2003-05-06 to current)	Inside Temperature
		PAR Current
		Temperature
Weather 3	(2003-09-24 to current)	Barometer
Weather 4	(2003-09-29 to current)	Enclosure Humidity
Woodland Weather	(2003-08-20 to current)	Humidity
MossCam Weather	(2003-04-29 to current)	Leaf Wetness
		Rain
		Temperature
		Wind Direction
		Wind Gust
		Wind Speed

Table 2.1: Device and sensor list for the CMS micro-climate array

Figure 2.1: CMS micro-climate station

Figure 2.2: Another CMS micro-climate station

Figure 2.3: CMS nest box and camera

Figure 2.4: HOBO bird nest box

Figure 2.5: Pan/tilt/zoom Tower Camera

Figure 2.6: Acoustic Tower

HOBO™ Data loggers		*Sensors*
Nestbox 03	(2004-04-22 to current)	Humidity
Nestbox 08	(2004-04-15 to current)	Inside Humidity
Nestbox 11	(2004-04-22 to current)	Inside Temperature
Nestbox 14	(2004-04-22 to current)	PAR Current
Nestbox 21	(2004-04-22 to current)	Soil Moisture @ 50cm
Nestbox 22	(2004-04-14 to current)	Temperature
Nestbox 27	(2004-04-14 to current)	
Nestbox 31	(2004-04-22 to current)	
Nestbox 45	(2004-04-15 to current)	
Nestbox 48	(2004-04-22 to current)	
Nestbox 54	(2004-04-26 to current)	
Nestbox 55	(2004-05-04 to current)	
Soil 1	(2003-10-22 to current)	Soil Moisture @ 15cm Soil Moisture @ 50cm Soil Temperature @ 15cm Soil Temperature @ 50cm
Texas Weather Instruments Station		*Sensors*
Trailfinder Weather Tower	(1999-12-03 to current)	Barometer Dew Point Humidity Leaf Wetness Lightning Rain Solar Radiation Temperature Wind Direction Wind Speed

Table 2.2: Device and sensor list for the HOBO loggers and Texas Weather Instruments Station

2.3 Web Camera Systems

The James Reserve features twenty fixed-view cameras, including: five un-recorded bird feeder cameras, two recorded moss phenology cameras, and thirteen recorded infrared cameras inside bird nest boxes (Figure 2.3). One of the four tower-mounted pan/tilt/zoom cameras (Figure 2.5) records external views of three nest boxes (every 15-30 minutes) and views of eleven different plant phenology study sites (once to three times daily). The remaining tower cameras provide un-recorded live image feeds.

Table 2.3 lists the names and number of images available for these cameras. The JR GE layer displays either live images or the most recently recorded snapshot from each cameras. Links to the archived images stored in the database are also provided.

2.4 Acoustic Tower

One of the camera towers is also equipped with a directional microphone from which ambient audio is continuously streamed live to the internet (Figure 2.6). A link to this mp3 stream is accessible from the JR GE layer.

2.5 Other CENS Datasets

Other CENS sensor networks at the James Reserve stream their data to off-site databases. A few samples of these datasets are statically accessible via the JR GE layer, including: three days of sensor data and 24-hours of Kriging models for the CAD system, Kriging overlays of Lake Fulmor from the Networked Aquatic Microbial System (NAMOS), and measurements from two Roboduck transects across the lake. As these and other CENS systems are configured to store data in Sensorbase, they will be added to the JR GE layer for live visualization.

Recorded web-cams		
Camera	***View***	***Num. images***
Nestbox 03		48,361
Nestbox 08		151,792
Nestbox 11		23,440
Nestbox 14		48,340
Nestbox 21		80,989
Nestbox 22	Inside	106,947
Nestbox 27		71,559
Nestbox 31		126,049
Nestbox 45		48,340
Nestbox 47		46,901
Nestbox 48		48,337
Nestbox 54		48,338
Nestbox 55		48,335
TF Fern 01 – 06 (2004)		16 - 113
TF Fern 07 – 13 (2005)	from	504-509
Manzanita	Trailfinder	3323
Fern1	Tower	11037
Fern2		11041
Champion Pine		11041
MossCam color	outside	94377
MossCam IR		114067
total		1,179,958

Live image feeds only	
Camera	***Num. Images***
Acoustic Tower	
North West Tower	live only
Soil Transect Tower	
Trailfinder Tower	
Feeder Station	
Mealworm Feeder	
Nectar Feeder	live only
Bird Bath	
Close-up Feeder	

Table 2.3: Summary of fixed webcams and pan/tilt/zoom cameras and perspective shots

2.6 GIS Layers and Aerial Overlays

A number of static GIS (Geographic Information System) layers are available in the JR GE layer for the James Reserve and surrounding Hall Canyon. These layers were exported from ESRI's ArcInfo™ 9.1 as either shapefiles or raster images, and imported into Google Earth. These include 2-meter vector contour lines and raster overlays for slope steepness, slope aspect (compass direction of the hill's face), and digital elevation models. In addition to the base satellite and aerial imagery available in Google Earth, 4-inch aerial photography has been acquired for the James Reserve. This high-resolution overlay provides enough detail to distinguish individual trees.

I also created an interaction, vector-based plant community layer for the James Reserve from an ArcInfo™ shapefile. Plant communities are sorted into major types and subtypes (Figure 2.7). Clicking on an area in the map provides representative photographs of the vegetation and links to botanical resources on that plant community.

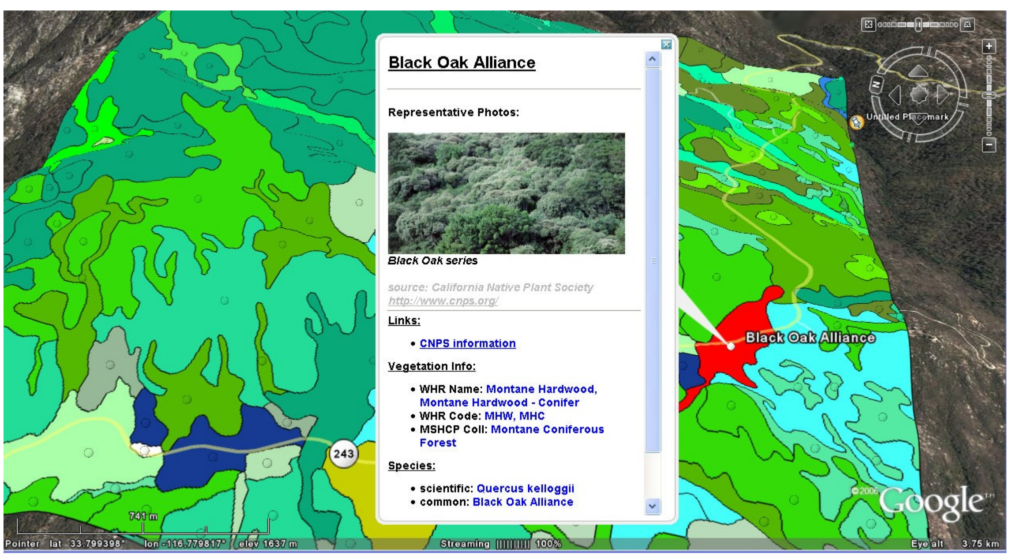


Figure 2.7: Interactive vegetation map with represented photos and botanical links

3. TECHNOLOGIES AND PROGRAMMING LANGUAGES

This section describes the programming languages, database platforms and other applications used at the James Reserve for data storage, visualization, and the generation of the JR GE layer. The database and accompanying code library at the James Reserve are collectively referred to as the Data Management System (DMS). The DMS is covered in more detail in the next chapter.

3.1 PHP and Perl Scripting Languages

PHP (Hypertext Preprocessor) is a scripting language with functionality similar to the open-source Perl language (Practical Extraction Report Language), and the proprietary ASP (Active Server Pages - Microsoft) and JSP (Java Server Pages - Sun Microsystems) languages. PHP is most frequently used to dynamically generate HTML (HyperText Markup Language) and XML (eXensible Markup Language). Though often criticized for inconsistent naming of functions, PHP has a excellent on-line large support manual and community. It is highly adapted for web-technologies and has a range of image processing libraries and graph modules available. PHP runs on all major platforms (Linux, Windows, OS X), and integrates with a number of popular web servers (Apache and IIS for Windows). Though not as universally powerful as a languages like Python, its other strengths made it a natural choice for the DMS code libraries and JR GE layer.

PhpMyAdmin, a web-based front-end for MySQL, was also a strong reason for choosing PHP. Without advanced programmers or database administrators on-site at the James Reserve, having a web-based user interface to our database has been invaluable.

Perl is used instead of PHP in the James Reserve DMS code libraries for system-level tasks, not related to the generation of dynamic web content. Examples include the execution of SQL (Structured Query Language) for the insertion of sensor data into the database, and the periodic harvesting of snapshots from webcams for inclusion in the database.

3.2 JpGraph – a PHP Graphing Module

One of the most compelling reasons for choosing PHP from the beginning of DMS' development was the existence of JpGraph. JpGraph is the most powerful open-source web-based graphing tool available, and is written in PHP. It is object-oriented and easily used to generate the PNG and JPEG image graphs from James Reserve sensor network data. JpGraph can prLanguageoduce a wide range of graphics, including: line, bar, pie, error-bar, Gantt, field and radar charts.

The biggest drawback to JpGraph is that its output is a basic image file. There are some intriguing interactive graphing options built on Flash and Java (such as EasyCharts for the later). These allow post-rendering zooming, panning and styling of datasets. However, these products are proprietary, sometimes costly, and have a higher learning curves.

3.3 MySQL Database

MySQL was chosen as the database for the DMS because it is open-source and widely supported by a large number of computing platforms and programming languages.

As with PHP, we are able to run MySQL on our Windows, Linux and OS X servers. It can also be accessed through any number of programming languages (Perl, PHP, Python, and compiled languages like C#, C++, *etc.*). As mentioned before, the web-based front-end PhpMyAdmin was another reason for our choice of the PHP and MySQL.

The recent release of version 5.0 of MySQL provides some of the advanced features long-present in other professional database platforms. Two of these are procedures (data processing functions built into the database) and views (a method of storing common SQL queries as an a virtual table). Both of these features would replace large portions of the DMS code library (described in Chapter 5), and would make the data insertion and extraction methods more transparent.

Nevertheless, MySQL has a few shortcomings such as poor support for spatial data types and large transactional queries. As CENS sensor networks grow exponentially in the coming years it is unlikely that MySQL will continue to be an appropriate platform. With the development of Sensorbase at CENS' UCLA labs, it is likely that the DMS database will be phased out in the near future.

3.4 Google Earth and KML

Previous to starting work on the JR GE layer, I had struggled with an intuitive way to represent spatial components of sensor network data. Existing two-dimensional internet mapping tools and servers (such as ArcIMS™ Server, from GIS software leader ESRI) were clumsy and provided little in the way of an interactive experience. In late 2004, internet search giant Google Inc. acquired the 3D virtual world program

Keyhole™, at which time it was renamed "Google Earth™." Subsequent improvements in the application's functionality made it capable platform for visualizing James Reserve's sensor and multimedia networks.

At the time there were no other viable three-dimensional "virtual earth" alternatives to Google Earth. NASA is developing a program called World Wind™ which, at the time, offered somewhat similar functionally. World Wind has strong potential for scientific visualization and analysis because its open-source nature allows for the creation of plugins and modules. However, the interface is more adept at visualizing high-altitude satellite datasets and lacked a simple web-friendly data exchange format. Thus Google Earth became the platform of choice.

Google Earth is a three-dimensional world visualization program that drapes aerial and satellite photography over digital elevation models of the Earth. This terrain and imagery data is streamed live over the internet, such that users do not need to host a large base-dataset on their own computers (as with traditional ESRI ArcInfo software)

Although not a fully-functional GIS (Geographic Information System), Google Earth supports many vector and raster GIS data formats. It uses an open-source XML data exchange format called KML™ which allows developers to create image overlays and interactive two and three-dimensional features. Recent versions of the Google Earth program also support time as a dimension and it is possible to create time-animated features by specifying time-stamps or time-spans. XML documents are easy to create with PHP, and thus KML has become the medium for visualizing the various data sources and GIS layers for the James Reserve.

ESRI is creating a three-dimensional “virtual world “ program called ArcExplorer as a part of their fully-featured GIS system. Though not yet released, it potentially offers significant advantages for use in sensor network visualization, primarily the native handling of standard GIS filetypes, and the ability to do spatial queries across different data layers. Nevertheless, Google Earth's KML data format has become ubiquitous in the geo-spatial computing world and will be supported by ArcExplorer and eventually World Wind. This suggests that KML may remain the data transport format for James Reserve and CENS projects. Users could then choose which 3D platform best suites their needs: Google Earth for the general public, and ArcExplorer for scientists wanting to do spatial analysis.

4. THE DATA MANAGEMENT SYSTEM (DMS)

The following is a summary of the James Reserve's sensor and image data storage system and the accompanying code library. These systems predate the James Reserve Google Earth layer (JR GE layer) and provide the foundation upon which it operates.

4.1 DMS Database

The James Reserve's Data Management System (DMS) database stores over four years of webcam images and micro-climate measurements from the Continuous Monitoring System (CMS), HOBO data loggers and Texas Instruments Weather Station. The database is running on MySQL version 4.1 and contains over 50 million records in thirty-one tables totalling over 50 gigabytes of data.

The DMS database stores metadata and configuration information for many aspects of the James Reserve sensor networks and camera systems. Individual sensors, CENS sensor platform hardware, and HOBO data loggers are periodically removed, replaced, or relocated due to the transitory nature of prototype deployments and occasional equipment failure. Whereas the majority of our sensor location names (e.g., Nestbox 14 or Woodland Weather) remain constant, the equipment in operation at that location does not. For quality assurance purposes, sensor data is often stored with the serial or identification number of the equipment that recorded it. Therefore, the DMS database must transparently keep track of these serial number and device configuration changes in order to properly deliver the data a user expects.

Configuration tables in the DMS database store a variety of information, including: records of individual pieces of sensor hardware (e.g., HOBO rain bucket), sensor platform equipment (e.g., a CMS wireless mote to which sensor attach), sensor measurement types (e.g., temperature in degrees Celsius), site and deployment information (e.g., Nestbox 14), and camera capture configurations.

In addition to the sensor network and camera configuration information, the DMS database naturally stores the raw sensor measurements and webcam images. Individual sensors report values in units of microvolts which are converted into recognizable measurement units (such as degrees Celsius) by conversion factors specific to the make and model of sensor. This conversion step takes place at the final link in the CENS equipment chain before it is sent to James Reserve computers for processing.

The raw data from the Continuous Monitoring System (CMS) system stored in the DMS database is collected at approximately 5-minute intervals. Though this high data resolution is useful for looking at small time scales, without some sort of data summarization database queries and the generation of web-based graphs over long time periods would be incredibly slow. For this reason the database also stores calculated hourly, daily, weekly, and monthly data summarizations. These are further divided into basic aggregation methods such as the averages, maxima and minima, and summations for each of the aforementioned time intervals.

The DMS database also contains post-processing configurations so that out-of-bound measurements (e.g., a relative humidity value of 110%) can be clipped to a maximum/minimum value, or marked as “faulted” and thus not reported to an end-user.

This faulted data is retained so that system administrators and designers can troubleshoot problems. The system also supports on-the-fly adjustments for retroactive sensor calibration (e.g., if one temperature always reports values 5% higher than actual).

Webcam capture configurations in the DMS database allow James Reserve staff to designate which cameras should be recorded, how often, and in which months of the year. This allows for the advanced control over the recording process, for example: images can be captured at faster rates during the bird nesting season versus the winter; images can be taken according to solar time instead of clock time (e.g., one hour after and one hour before sunset, despite the changes in sun rise/set); and pan/tilt/zoom cameras can be set to take a snapshot of a particular perspective at a designated time. Images are stored at full resolution and as thumbnails in the database for faster access when low-detail is sufficient.

The James Reserve will continue to use the DMS database until the new 'Sensorbase' database at UCLA is prepared to house all CENS sensor network data. Despite the mention of numerous sensor network and camera configuration tables in the DMS database, the actions of data collection, processing, retrieval, and presentation cannot be carried about by the database itself. A large library of PHP and Perl scripts use this configuration information in order to carry out these many tasks.

4.2 DMS Code Library

Most of the initial sensor data insertion processes are handled by scheduled Perl scripts. Most of the data retrieval processes are programmed in PHP. The path sensor and camera data takes from initial capture to end-user is beyond the scope of this summary. In short, micro-climate data streams in from the CENS sensor network to a central data gateway and is then sent via FTP (File Transfer Protocol) to an on-site server. A scheduled task periodically executes a Perl script on this Windows Server which reads and inserts the raw data into a temporary table in the DMS database using with SQL (Structured Query Language). A second Perl script executes more SQL for quality-control assurance (out-of-bounds clipping and and data "faulting" as described earlier). More SQL is used to add the processed data from the temporary table into a permanent table which stores the full-resolution (un-summarized/aggregated) data. Additional Perl scripts periodically execute the SQL-based hourly, daily, weekly, and monthly summarizations and aggregations and store this data in additional tables. Once data is ready for consumption, there are a variety of different ways to access it.

Dynamically generated, web-based measurement and image catalogs are available for DMS database at the following URL: http://cens.jamesreserve.edu. These allow users to browse through datasets by location and approximate date. The DMS code library also provides methods for accessing the data directly, as used when generating the JR GE layer and the attached web-based graphing and visualization interfaces. These libraries, written for the retrieval and presentation of DMS data, are written in the scripting language PHP. They provide an abstraction layer between higher-level applications and the database itself, such that programmers writing programs on top of the library do not need to understand understand the entire schema of the DMS database.

5. THE JAMES RESERVE GOOGLE EARTH LAYER

The many features of the JR GE layer are difficult to present in with images on a paper medium. Please visit the James Reserve's Data Management System web-site to download the KML layer to experience it firsthand: http://dms.jamesreserve.edu.

5.1 Three-Dimensional Representation of Sensor Network Equipment

The sensor networks, weather stations, camera towers, and other CENS deployments at the James Reserve are represented in Google Earth with either three-dimensional polygons or models (Figures 5.1, 5.2).

The KML 2.0 compliant version of the JR GE layer uses simple, color-coded geometric polygons to represent devices (Figure 5.1, 5.3). The vertices of these polygons are calculated on-the-fly, centered around a feature's latitude and longitude coordinates. This makes the addition of new systems very easy. Customizable styles specify the number of sides, dimensions and colors of each equipment type and are easily adjusted.

For the KML 2.1 compliant version of the layer I used Google Sketchup to create realistic 3D models for all the major devices (Figure 5.2, 5.3). Models are stored in the "Collada" format, a standard data format in the 3D modeling world. Though currently styled with simple colors, Sketchup models support photo-textures for an even more realistic look. Collada models are placed dynamically in the KML layer and have their scale and orientation determined individually to accurately represent physical deployment (e.g., the compass direction an entrance to a bird next box faces).

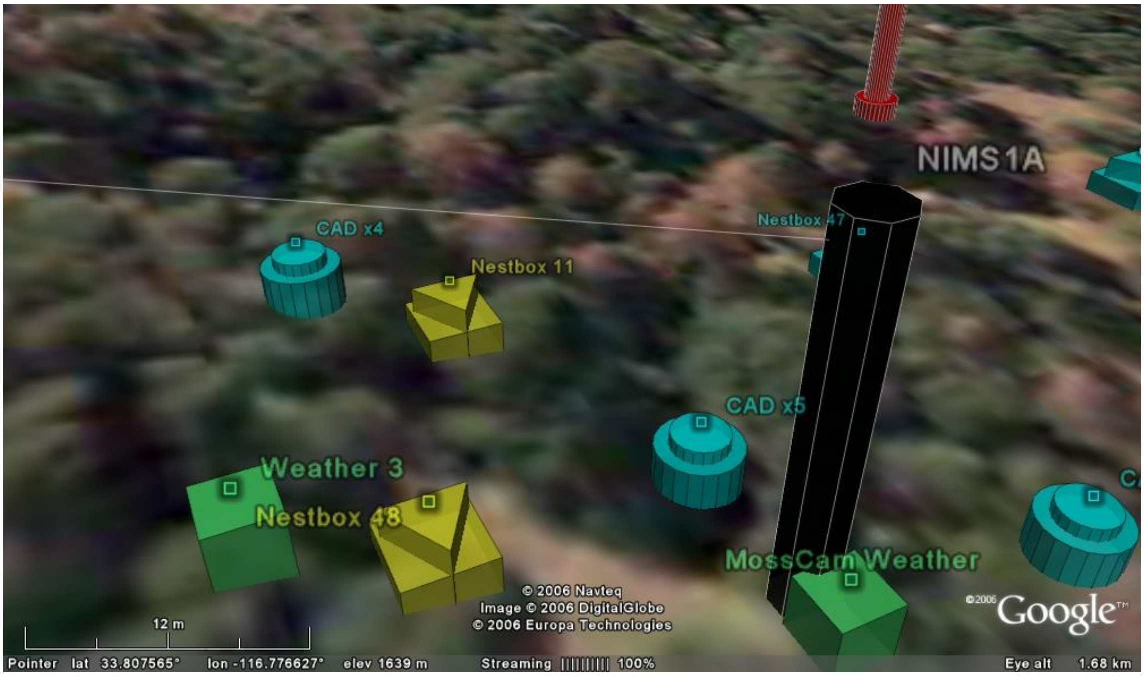
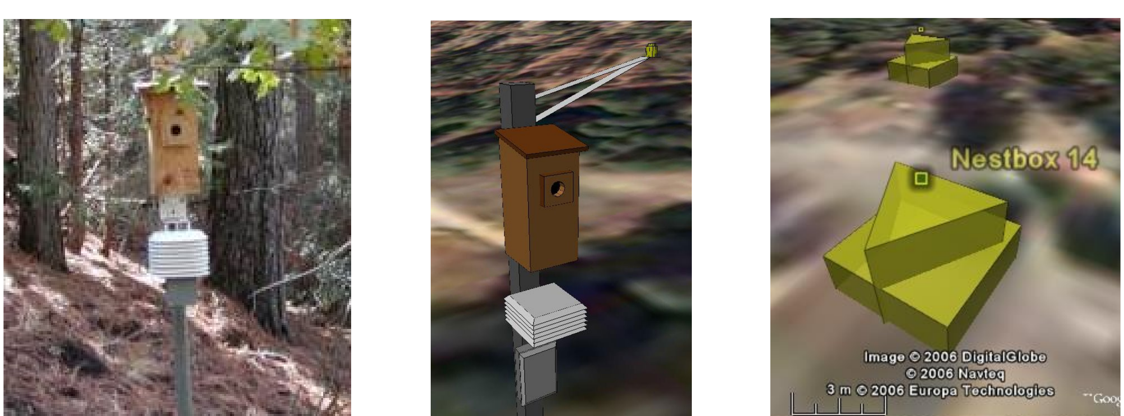


Figure 5.1: Simple, color-coded representation of James Reserve devices for KML 2.0

Figure 5.2: Google Sketchup "Collada" models of equipment for KML 2.1. Note each Nestbox and Weather Station are oriented individually according to deployment characteristics


Nestbox 14
Image © 2006 DigitalGlobe
© 2006 Navteq
3 m © 2006 Europa Technologies

Actual Photo ***Sketchup Model (KML 2.1)*** ***Simple Polygon (KML 2.0)***

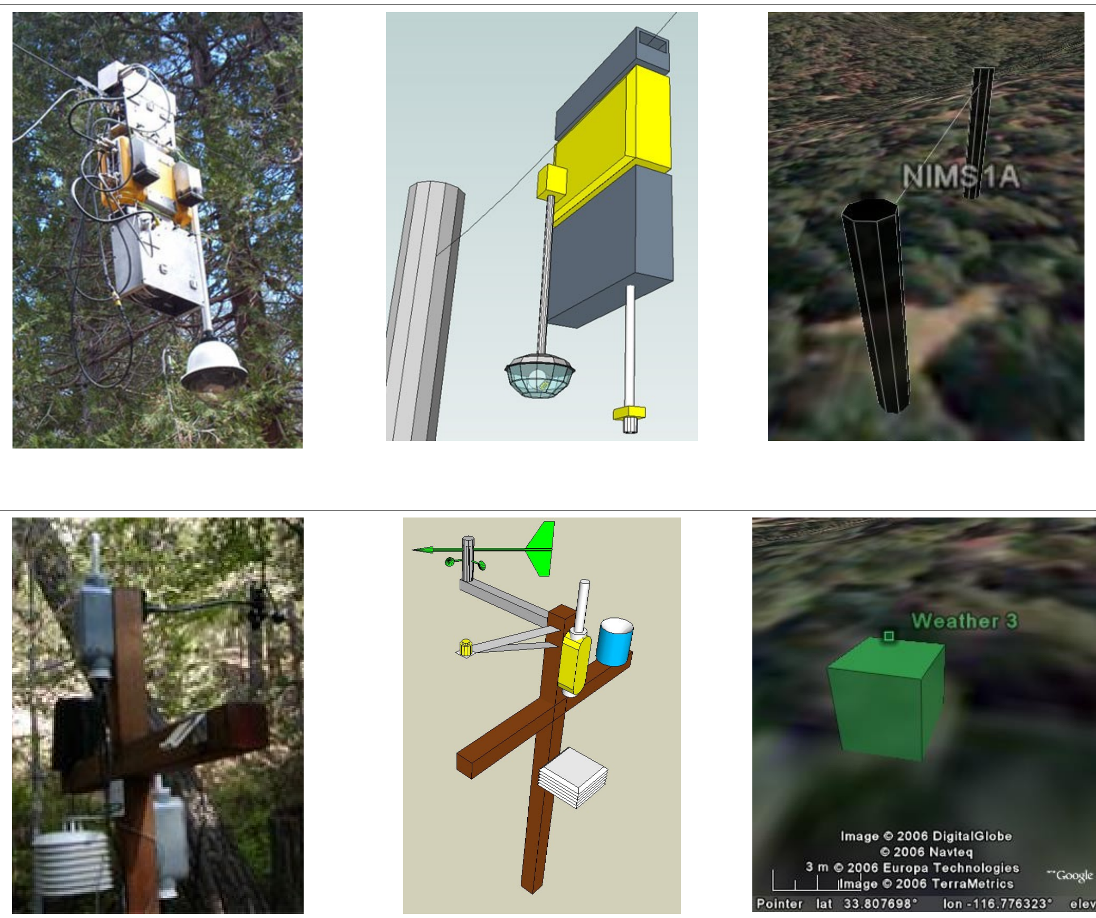


Figure 5.3: Photos, 3D Models and Simple Polygons. Columns, left to right: Actual photo, Google Sketchup "Collada" model, and simple polygon representation. Rows, from top to bottom: HOBO sensored Nest Box, Networked Info-mechanical System (NIMS) – mobile sensor platform on high-tension cables,and CMS Micro-climate station.

5.2 Heads-Up Display of Web Cameras

The JR GE layer provides access to over thirty-two webcams in the three-dimensional Google Earth environment (Figure 5.4). Live feeds are provided for the fixed-position cameras and the current perspectives of the pan/tilt/zoom tower cameras. For the archived perspective shots taken periodically by the tower cameras, the most recent image is displayed and a line-of-sight represents the camera's viewing direction.

There are thirteen nest box cameras, four pan/tilt/zoom tower cameras, five bird feeder cameras, and eight plant phenology camera perspectives available.

This heads-up display of webcam images is particularly useful for monitoring bird nest boxes. Users can quickly survey all thirteen nests to see if mothers are incubating their eggs or out feeding, if the nest has overnight roosting visitors, or when the eggs hatch and chicks fledge.

Figure 5.4: Heads-up display of James Reserve webcams. Note roosting bird in Nestbox 21.

5.3 Detailed Description for Sensors Locations and Cameras

Clicking on any of the fifty-six sensor locations or thirty-two webcam thumbnails brings up a detailed description bubble (Figure 5.4). The content of these bubbles depends on the particular sensors and cameras installed at any one location. These descriptions include some or all of the following: a) a large webcam image preview with links to image archives in the DMS database; b) Sensor information, including: current values where available, “sparklines” or micro-graphs showing the 24-hour condition trends, links to an interactive graphing tools, and the dates of data availability; c) GIS information for the location including GPS coordinates in latitude and longitude and UTMs, elevation, slope and aspect. A special version of the JR GE layer provides access to direct control of pan/tilt/zoom cameras and other administrative features for JR staff.

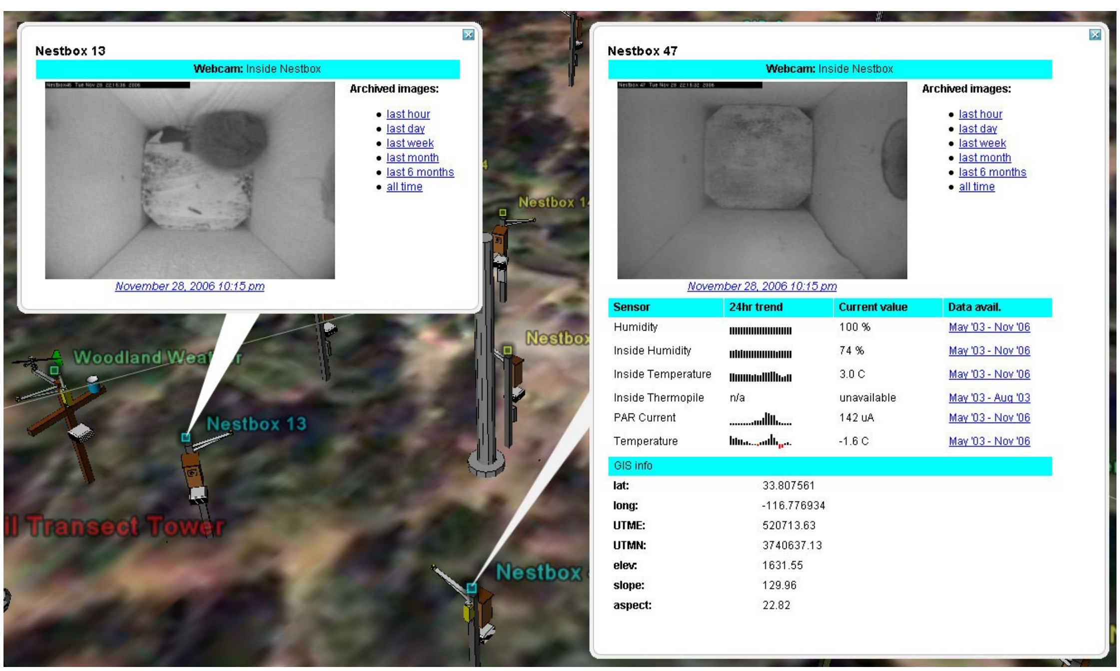


Figure 5.5: Detailed Description Bubbles. Clicking on a sensor location or webcam provides current measurements and snapshots. Minature trendlines ("sparklines") show the 24-hour measurement trends. Dates of data availability are also provided.

5.4 Web-Based Graphing and Visualization Tools

Prior to developing the JR GE layer, I created a number of web-based graphing and visualization tools for the James Reserve's sensors systems and webcams. Built with the JpGraph graphing module for PHP, these tools allow the user to graph any number of sensor measurements from various locations around the Reserve (Figure 5.6). Webcam time-series from any of the Reserve's cameras can also be added in-sync with the sensor graphs (Figure 5.7). This allows for direct comparison of plant phenology or wildlife behavior to the simultaneous micro-climate conditions.

These visualization tools can be used on their own or via links in the description bubbles of the JR GE layer. A number of web-based "wizards" are available so that users can generate more complex graphs and image sequences than are available through the Google Earth interface. Figure 5.8 shows the six-step process for one such wizard. This enables users to compare measurements from different sites, and look for the interactions between climate measurements (e.g., solar radiation, temperature and relative humidity).

These visualization tools also allow the user to browse through the data archives by zooming in and out to alter the time scale, or by panning back and forth through time. Option windows (Figure 5.9) allow users to perform such tasks as: add, hide or delete sensor measurements from the graph; change the data's summarization intervals (monthly, weekly, daily, hourly and raw data); and change data's aggregation methods for these time intervals (averages, maxima and minima,sum, etc.). Users can also control the graph's dimensions, and units of measure (metric or english). When combining sensor measurement graphs with synchronized image time-sequences, users can alter the thumbnail size to show fewer pictures with more detail or visa versa. When graph width limits the number of images to fewer than are available for that time period, horizontal markers appear representing all the available images and those that are currently displayed (Figure 5.10). Clicking on a bar shows the missing image in a new window.

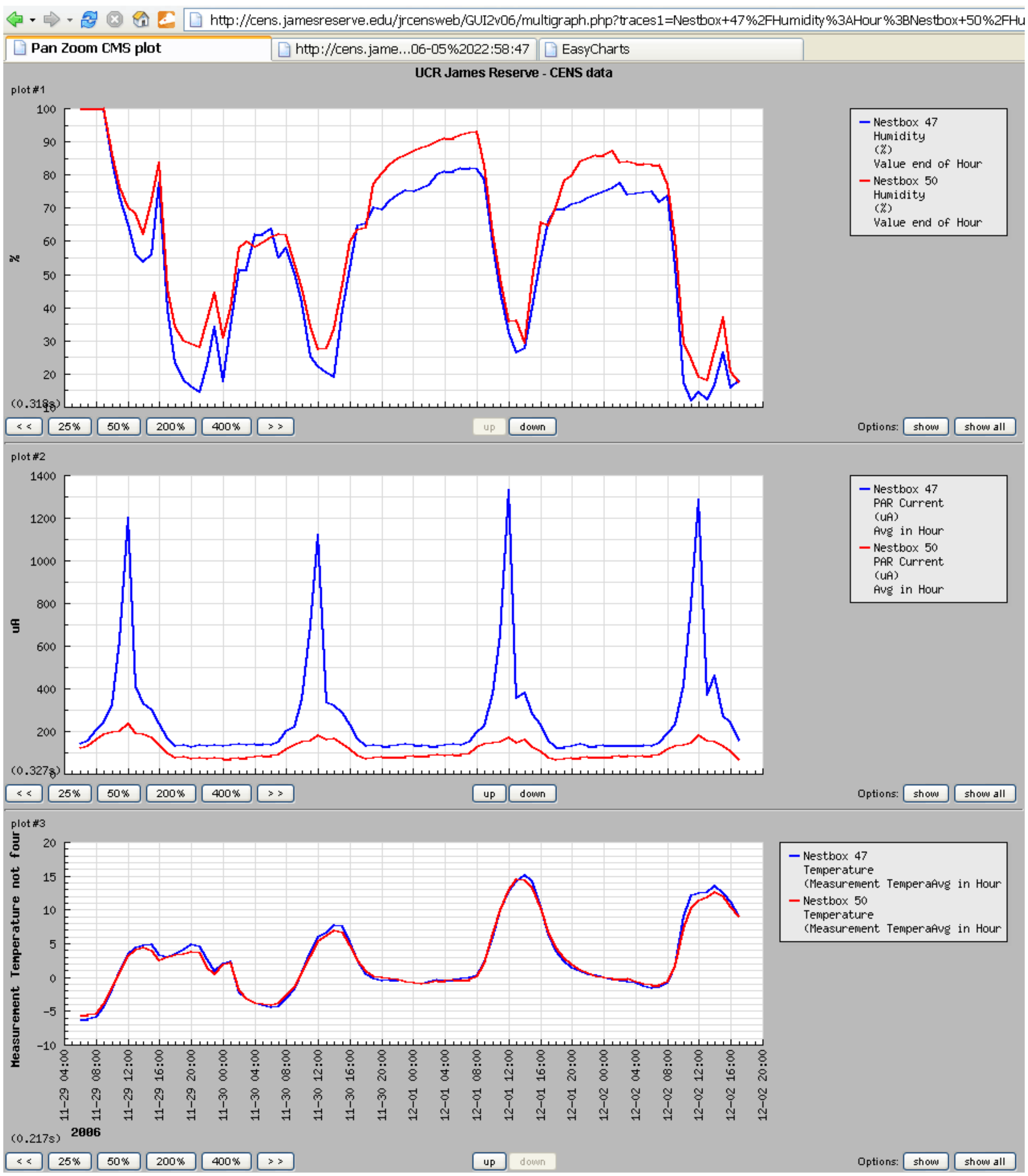


Figure 5.6: Stacked graphs of humidity, Photosynthetically Active Radiation (PAR), and temperature at CMS-sensored Nestboxes 47 and 50.

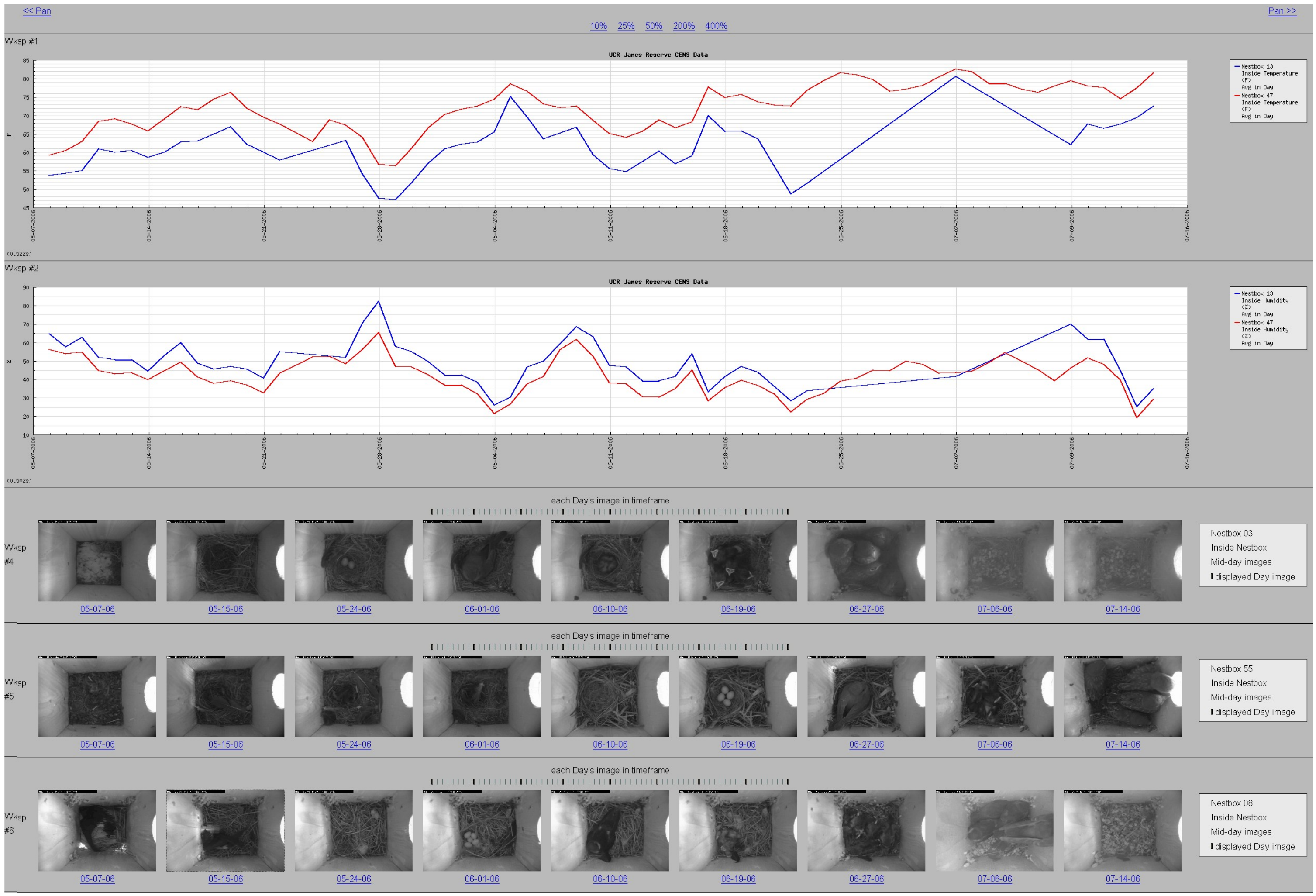


Figure 5.7: Inside temperature and humidity for two nestboxes graphed with synchronized time-lapse webcams images from three other nestboxes. Clicking on a thumbnail provides a pop-up enlargement of that image. Clicking on the date of the image will refocus the entire page to view sensor data and images from that day. Users can also pan forwards and backwards in time, and well as zoom in and out.

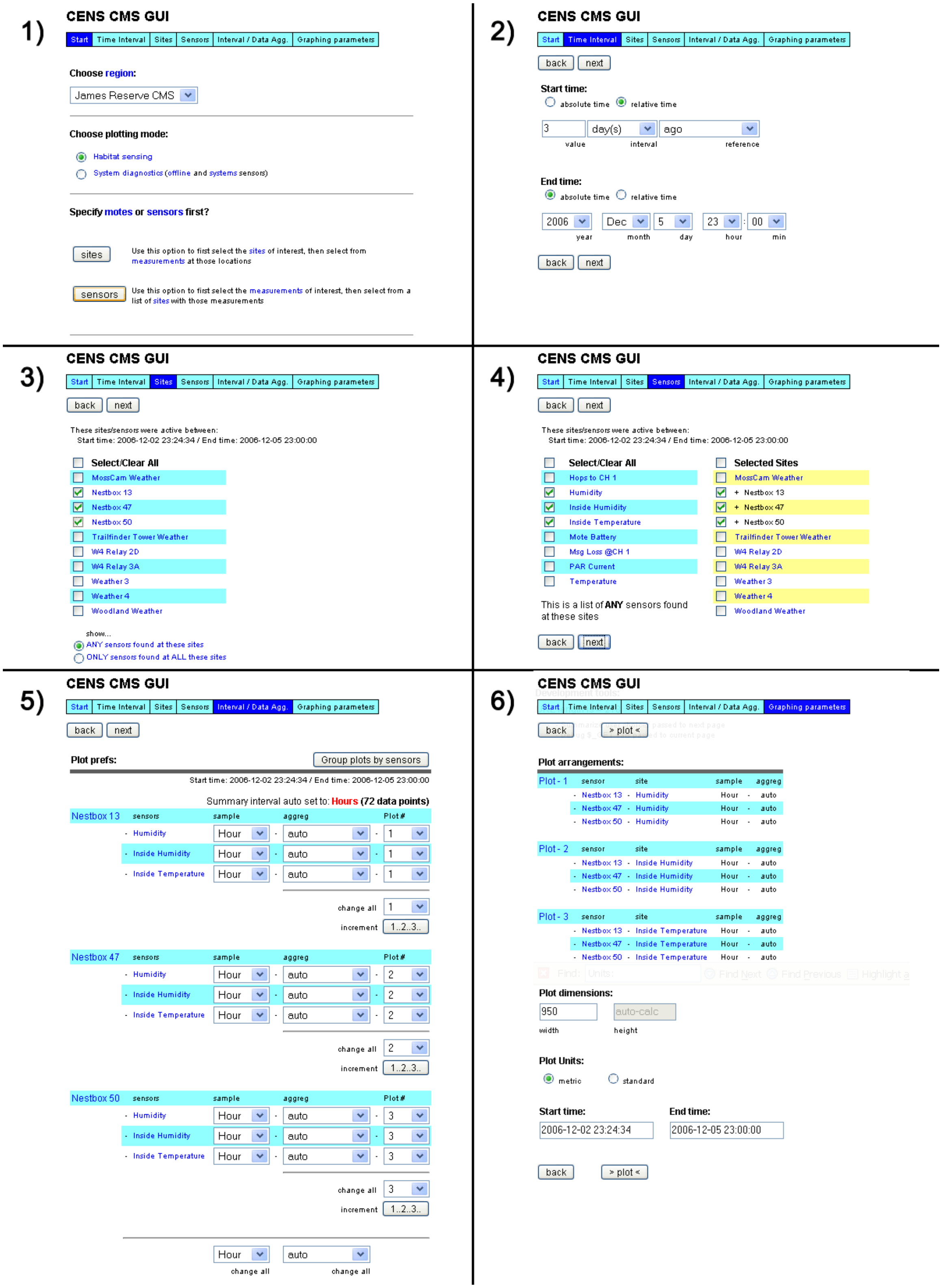


Figure 5.8: Six-step wizard for making complex graphs.

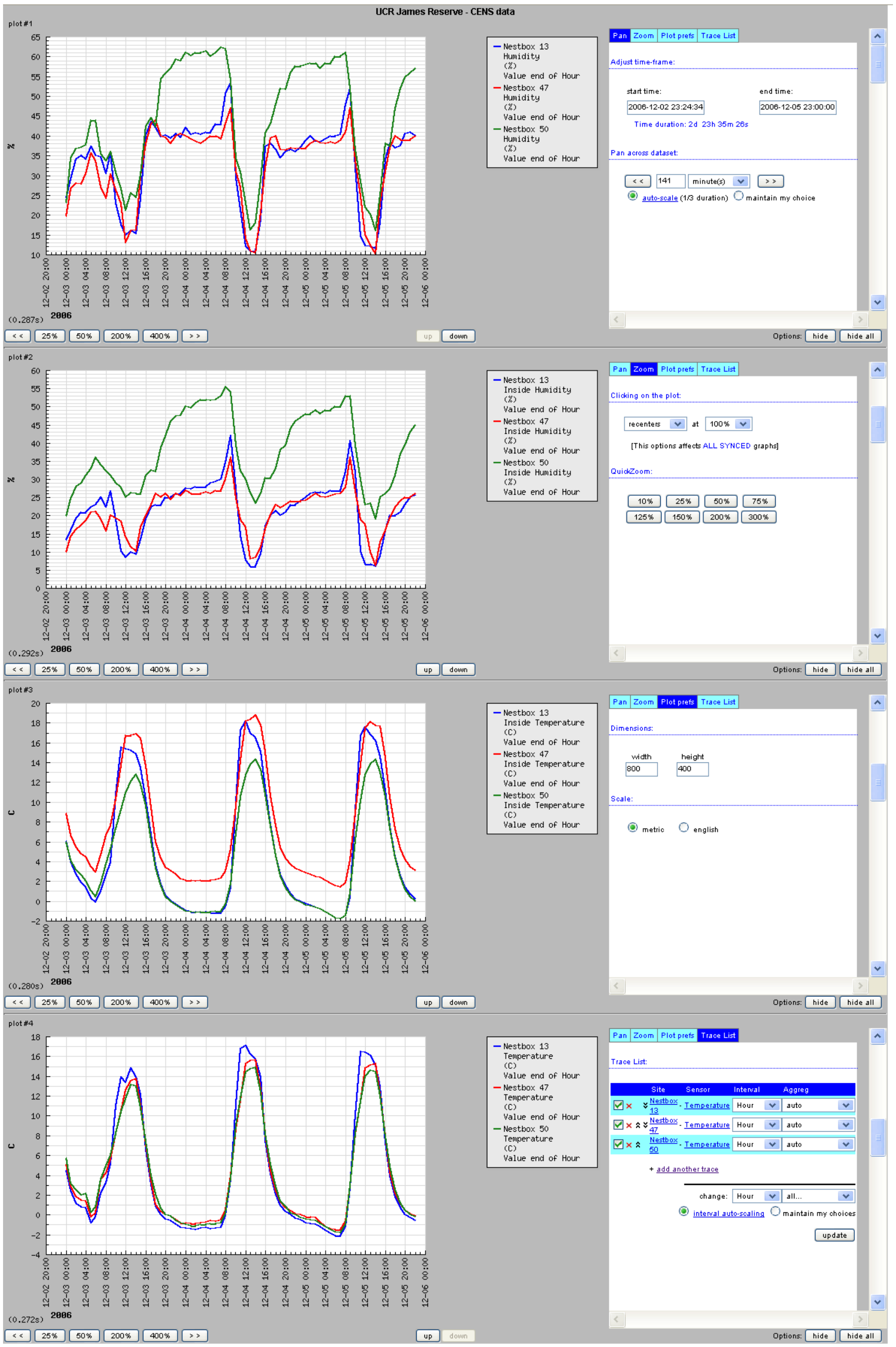


Figure 5.9: Four measurements over three sites. Each options window show one of the four option tabs: Pan, Zoom, Plots Preferences, and Trace List for adding, deleting and hiding measurement values.

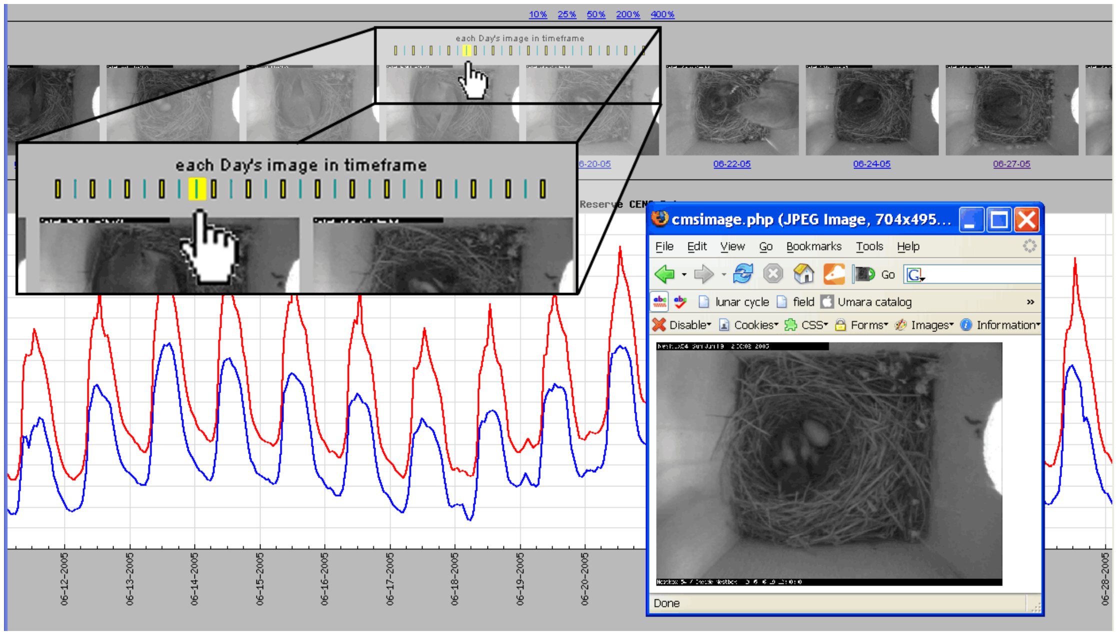


Figure 5.10: Access to all images in the time-frame. Yellow bars with black outlines represent images displayed next to the graph; thin black bars denote un-displayed images. Clicking on any vertical bar brings a pop-up window with the correpsonding image. In this case the pop-up window shows a baby bird that hatched between the two adjacent displayed images.

5.5 GIS Layers and Image Overlays

The JR GE layer also includes a number of vector and raster image overlays. New overlays are easily added by copying them into a special directory on the webserver. This directory is searched and automatically added to the JR GE layer.

The overlays and GIS layers currently available for the James Reserve include: a) 2-meter contour lines for the entire Hall Canyon (Figure 5.11); b) simple terrain models of slope (Figure 5.12), aspect, hillshade, and a digital elevation model (DEM); c) 4-inch aerial photographs (Figure 5.13); d) an interactive vegetation map of Hall Canyon's specific plant communities with description bubbles containing representative photographs and botanical resource links (Figure 5.14).

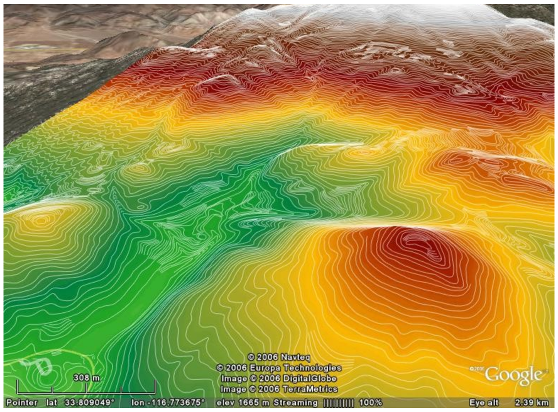


Figure 5.11: 2-meter contour and DEM model

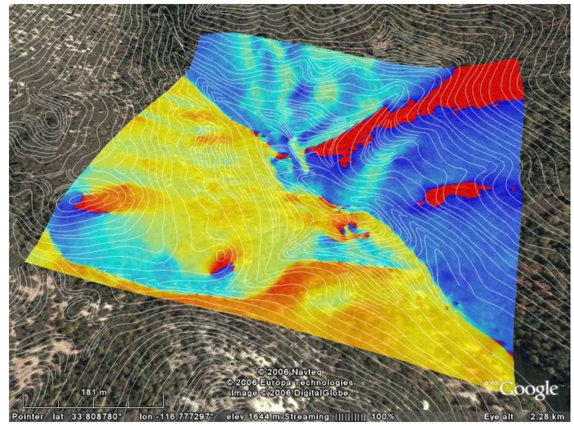


Figure 5.12: GIS aspect model

Figure 5.13: Four-inch aerial photographs

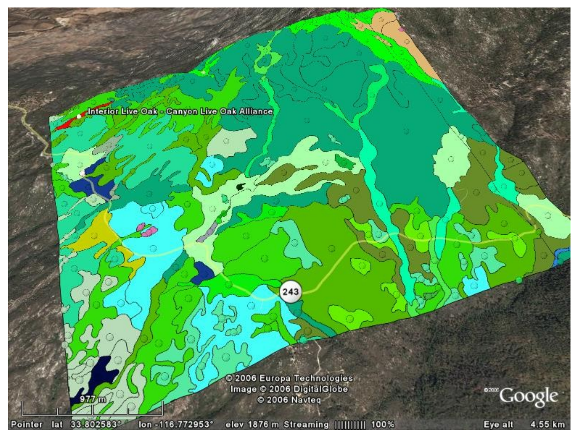


Figure 5.14: Interactive vegetation map

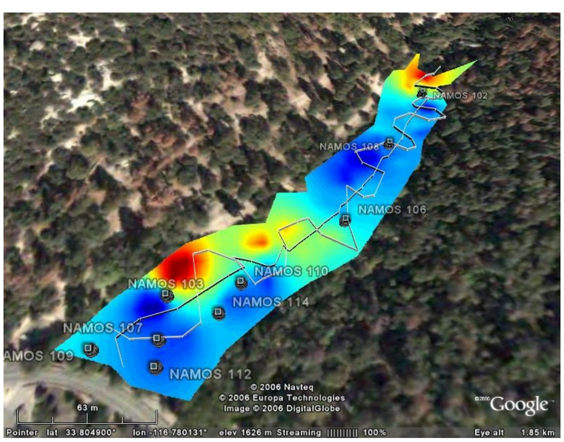


Figure 5.15: Kriging model of florometery on Lake Fulmor; taken by NAMOS and Roboduck

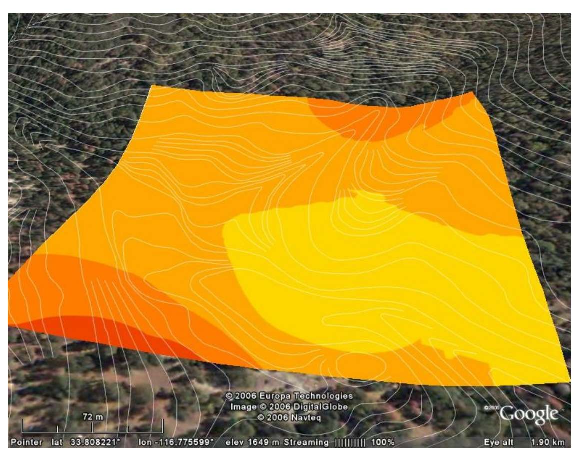


Figure 5.16: One of 24 frames available for the Cold Air Transect time-animation

5.6 Kriging Models

Kriging models allow the two and three-dimensional spatial interpolation of point data. Such models allow us to consider terrain and other environmental factors in predicting micro-climate conditions in between actual sensor locations. Two CENS projects at the James Reserve have produced Kriging models using ESRI's ArcGIS Spatial Analyst™, and are included in the JR GE layer.

The first of these is the Cold Air Drainage (CAD) project. This system was developed to document and quantify the phenomena of night-time cold air drainage events through mountainous air-sheds. These dramatic drops in air temperature could affect the distribution of sensitive plants, and behavior of animals (e.g., nest location preference in mating birds). A time-sequence of Kriging models over a 24-hour period was produced from one of the CAD datasets, and can be animated in Google Earth (Figure 5.15).

Secondly, the Networked Aquatic Microbial Observing System (NAMOS) is periodically deployed on Lake Fulmor. Sensors on stationary buoys taken a different depths, are complimented by an autonomous, GPS-driving water-sampling boat. Two transects of the “Roboduck” with point measurements are available in the JR GE Layer. Data from these two sources was combined to produce a few kriging models of temperature and florometry, a measure of chlorophyll amounts in the water (Figure 5.16).

With the addition of GIS server applications at the James Reserve, time-lapse Kriging models will soon be generated on-demand to help researchers model and visualization the dynamics of heterogeneous environments.

6. RESEARCH AND EDUCATIONAL APPLICATIONS

6.1 Potential Research Projects

The James Reserve Google Earth layer has strong potential for both the immediate application and future development of novel scientific research. With nearly four years of sensor and camera network data, the James Reserve could host a suite of investigations of micro-climate's influence on both wildlife and plant biology.

One such project could investigate avian nest preference as related to micro-climate conditions. Nest boxes at the James Reserve tend to exhibit one of the following histories: relatively consistent clutch success every mating season; periodic use and occasional failure of some or all of the clutch; and frequent initial investigation of mating couples and/or abandonment early in the nest building process, but no documented history of egg-laying. It is possible that the particular micro-climate conditions of these nest boxes and the immediately surrounding area (e.g., localized temperature extremes) play a part in these patterns of behavior.

Another potential project could investigate the phenology of plants as related to micro-climate, such as the as the spring-time emergence and re-growth of annual and perennial plants, and the re-hydration of drought-tolerant mosses. The James Reserve has daily recorded images of fern emergence at several locations over the course of two and three seasons. If emergence is asynchronous across different areas of the reserve, micro-climate data could also be investigated as a potential cause of this phenomena (e.g., differences in Growing Degree Days, soil moisture, and total availability of sunlight).

The James Reserve also has a series of close-up infrared and color images taken at 15-minute intervals of a dessication tolerant moss population (*Tortula princeps*). An immediately adjacent weather station provides micro-climate data for the vicinity. Studies could investigate re-hydration cycles and long-term growth rates of this moss over the four and a half years of available data.

A final suggestion, also relating to plant biology, is the influence of micro-climate on plant community distributions across the James Reserve. Using data from the interactive vegetation layer, additional vegetation surveys, and sensor network data, researchers could investigate how the micro-climate conditions influence the types of plants found in those regions. Cold air drainage events, as monitored by the CENS CAD system, could also be considered as a potential cause for differences.

6.2 Educational Outreach Programs

The CENS Education program is aimed at creating learning opportunities for various levels of secondary education by integrating embedded network sensing technology into dynamic science lessons and projects. The JR GE layer's interactive nature offers a engaging educational opportunities for 6-12th grade teacher and students.

With easy access to the James Reserve's cameras and micro-climate data, students can search for simple biological phenomena. A few examples of potential school projects include the investigation of: the relationships between micro-climate conditions, such as temperature and relative humidity, and rainfall and soil moisture; seasonal changes in plant phenology (e.g., spring-time emergence, life cycles of annual plants, etc.); avian feeding behavior and inter/intra-species dominance interactions at our various bird feeders; and basic avian nesting behavior, such as the the times a mother first leaves the nest in the mornings, the duration of nest-building, incubation and time to final fledging.

The following links provide more information about the CENS' Education program and act as a starting point for teachers and students to use the JR GE layer and various graphing wizards at the James Reserve: CENS Education Program (http://research.cens.ucla.edu/education); James Reserve Data Management System and the James Reserve Google Earth layer (http://dms.jamesreserve.edu); Graphing wizard for sensor measurements: (http://cens.jamesreserve.edu/jrcensweb/GUI/start.php).

7. LIMITATIONS OF GOOGLE EARTH

Google Earth has some limitations which should be considered when developing scientific data interfaces. Most relevant to the CENS sensor network visualization is the limitations of simultaneously displaying many thousands of densely placed “placemarkers” and three-dimensional objects. This is not only an issue of degraded performance; when visualizing ten to hundreds of thousands of individual features those closest to the camera tend to disappear.

This problem was particularly evident while assisting the Cornell Lab of Ornithology optimize their KML layer with over 130,000 data points. Their problem was temporarily solved by creating raster image overlays of points, as they did not need interactive description bubbles for each of these points. However, for a system needing interactive description bubbles this remains a problem. The use of “regions” in KML 2.1 can alleviate some of these problems; “regions” specify an visibility area for each placemark such that they are displayed only when the camera is nearby. However, if the designer wants many thousands of points visible simultaneously, the problem remains.

The current version of Google Earth (4.0) is also limited in terms of the intractability between features within a KML layer. Although the description bubbles allow for links to a web browser, there is currently no way for description hyperlinks to directly enact change within a KML layer itself (e.g., turning on and off features and folders from within the description bubble). This will become increasingly important when trying to represent and navigate through the complexity of larger sensor networks. Without finer control over the user's experience, using such datasets will be a challenge.

The representation and handling of time as a dimension is also a shortcoming of the current Google Earth client program. By attributing time stamps to features in the KML, and by specifying an active time range, users can alter the visibility of those features. Though this provides some functionality in the display of time-sensitive information, it requires all the possible features to be present in the original KML file. Hence, this is not a practical solution for the displaying of large amounts of sensor network data and expecting the user to smoothly glide through large time scales. Whereas it is possible trigger the loading of dynamic data when the Google Earth camera moves to a new perspective, it is not possible to do this when changing the currently active time range. Such functionality would partially improve this shortcoming.

8. THE JAMES RESERVE CONTENT MANAGEMENT SYSTEM

In addition to the JR GE layer, I am also developing a new dynamic website for the James Reserve. In an effort to empower the entire James Reserve community—staff, biologists, CENS engineering teams, and the general public—to interact and contribute to our online presence, I am moving the James Reserve's web content to Drupal, a leading open-source content management system based on PHP and MySQL. Users will not only have access to the web-pages showing current and archived webcam images, micro-climate measurements and other CENS deployments, but also the contextual information about the technology and biological research driving these projects.

8.1 Creation of Web Content without HTML Experience

The primary advantage of using a content management system for a dynamic web-site is that non-technical users can easily generate web content without a working knowledge of HTML. For example, scientists can update the research objectives and findings of their ongoing projects on their own web pages; James Reserve staff and technicians can update information about the sensor systems available for researcher use; and users can communicate directly with each other through the use of forums and posting of announcements.

8.2 Access to Metadata and Contextual Information

The JR GE layer serves primarily as a spatial representation of the sensor and multimedia systems at the James Reserve, and provides access to the collected data via visualization tools. However, it does not provide any of the contextual or metadata information for the actual devices used (e.g., models and brands of sensors, wireless radios, etc.), the related research projects, and the people involved with the development and use of these systems.

With the development of this content management system, it is possible to organize this breadth of information at many hierarchical levels. For example, starting at the top, a user will be able to browse through the various CENS projects at the James Reserve, such as the Terrestrial Ecological Observation System (TEOS). Information can be provided on the researchers and engineers who work on this project, as well as information on the types of biological studies being conducted with TEOS systems. This project page will provide links to the various sensor networks that are a part of TEOS. Drilling down further, links can be provided the individual sensor platforms, and finally the individual sensor devices that make up these sensor networks. For all the active equipment at the James Reserve, users will be able to view such information as: deployment dates for particular locations, the make and model of equipment used, where an individual piece of hardware has been previously deployed, who installed the device, the date of the last battery change, and access to live measurement values. Interactive web-based maps will also show the locations of the current device, or all the devices in a sensor network or research project.

In addition to browsing the website vertically through a hierarchical structure, links are provided for jumping laterally to related topics. For example, clicking on the name of a researcher participating in a TEOS project will link to that person's other past and present projects at the James Reserve. Clicking on a particular measurement, such as temperature, would provide a list of all the temperature sensors across all sensor networks regardless if they are affiliated with TEOS. Clicking on a type or model of equipment would provide a list of all the other projects and locations where it is being used. Clicking on a deployment date could reveal all the sensors installed within a particular time. In this manner, all of the projects, participants, and devices at the James Reserve are interconnected for easy access.

The new James Reserve web-site will also offer additional services such as: an integrated photograph image gallery, events calendar for James Reserve activities and visitors groups, mailing lists for various research groups, and a bibliography database for all research publications related to the James Reserve.

9. CONCLUSION

The James Reserve Google Earth layer (JR GE layer) provides a cohesive visualization interface to the various sensor and multimedia networks at the James Reserve. It has potential to serve a wide range of users in the areas of scientific research, educational and public outreach, and systems deployment and administration at the James Reserve.

Access to the wealth of available micro-climate data, and the plant phenology and avian nest behavior image series offers immediate possibilities for novel scientific research. With the standardization of CENS sensor network data storage via Sensorbase, the inclusion of addition CENS datasets will further expand the potential for cross-project data sharing and insight into biological phenomena on small spatial and temporal scales.

With the continued improvement of its user-friendly interface, the JR GE layer is not limited to scientific researchers and engineers alone. Access to dynamic and captivating biological processes, such as bird mating and nesting, creates opportunities for secondary education programs. Teachers can build dynamic, real-world science projects that allow students to explore data on their own. The James Reserve web-site is also home to a large online community of amateur birders, which can also make use of the JR GE layer.

CENS engineers and James Reserve Staff can also make use of the JR GE layer for the deployment, monitoring and administration of sensor networks. Easy access to live data values aid in diagnosing communication problems, equipment failure and the routine changing of wireless sensor platform batteries. With the added value of the new

James Reserve website and Drupal content management system, logs recording equipment and battery changes and configuration information will be centrally located and easily updated.

Finally, the continued development of the JR GE layer will play a role in the tools developed for the National Ecological Observatory Network (NEON). The James and other reserves in the University of California National Reserve System (UCNRS) will serve as the testing grounds to the ecological sensor networks that will eventually be deployed throughout the nationwide NEON network. As visualization interfaces based on “virtual world” technologies develop to suite these dense, distributed sensor networks, their utility will expand beyond the study of small-scale ecological processes to that of regional and continental-scales.

APPENDIX A

GLOSSARY

Apache	An open-source HTTP webserver for most major platforms (Windows, Unix/Linux, Mac OS X). A product of the Apache Software Foundation. http://www.apache.org/ The Apache Software Foundation 1901 Munsey Drive Forest Hill, MD 21050-2747 U.S.A.
ArcExplorer	Also, ArcGIS Explorer. A three-dimensional “virtual earth” program, similar to Google Earth. Part of ESRI's most recent version of their complete GIS software product line, ArcGIS 9.2. Also see ESRI. http://www.esri.com/software/arcgis/explorer/
ArcGIS	ESRI's product line of desktop and server fully-featured GIS software. Also see ESRI. http://www.esri.com/software/arcgis/
ArcIMS	Also, Arc Internet Mapping Server. ESRI's server product for delivering dynamic maps, GIS data and services via the Web. Also see ESRI. http://www.esri.com/software/arcgis/arcims/
ArcInfo	ESRI's desktop suite of GIS programs. The most fully-featured versions of of the ArcGIS Desktop product line. Also see ESRI. http://www.esri.com/software/arcgis/arcinfo/
ASP	Active Server Pages. A scripting language developed by Microsoft for the dynamic generation of web-content generated from databases or other server-side programs. An alternative to CGI scripts and JavaServer Pages (JSP). http://msdn.microsoft.com/asp.net/
CAD	Cold Air Drainage. Part of the TEOS division of CENS, the CAD project seeks to investigate the phenomena of cold air drainage events, in which cold banks of air move downhill through a mountainous air/watershed during the nighttime hours. CAD also refers to the micro-climate sensor transect that is used to document these events. http://research.cens.ucla.edu/projects/2006/Terrestrial/Microclimate/

CENS	Center for Embedded Network Sensing. A 10-year National Science Foundation *Science and Technology Center*. Aimed at developing embedded network sensing solutions for social and scientific applications. National Science Foundation Cooperative Agreement #CCR-0120778 Title: Center for Embedded Networked Sensing (CENS) PI Names: Deborah L. Estrin, Christine L. Borgman, Paul M. Davis, Michael Hamilton, Ari Requicha Effective Date: August 1, 2002. Expiration Date: July 31, 2007 Center for Embedded Networked Sensing UCLA 3563 Boelter Hall Los Angeles, CA 90095-1596 Tel. (310) 206-2476 Fax. (310) 206-3053 http://research.cens.ucla.edu/
CLEOS	Cyberinfrastructure Laboratory for Environmental Observing Systems. Division of the San Diego Super Computer Center (SDSC). Aimed at developing cyberinfrastructure for a wide range of science and engineering applications. Specific activities include the statistical modeling of complex data analysis problems with datasets such as remote sensing imagery, large text collections and real-time sensor streams. Also see SDSU. http://scirad.sdsc.edu/datatech/cleos.html
CMS	Continuous Monitoring System. Part of the CENS micro-climate sensor arrays installed at the James Reserve. Deployed as both weather stations, and at bird nest boxes for inside and outside climate monitoring. Records measurements such as temperature, relative humidity, Photosynthetically Active Radiation (PAR), rainfall, etc. Also see CENS. http://research.cens.ucla.edu/projects/2006 /Terrestrial/Microclimate/
Collada model	An XML-based, open-source 3D modeling data format, common in the 3D modeling industry. Models created in Google Sketchup can be exported in this format so that Google Earth can render them in its 3D virtual earth environment. Used to model devices in the JR GE layer. https://collada.org/

CSULA — California State University, Los Angeles. One of the institutional participants in the CENS programs.

CSULA
5151 State University Drive
Los Angeles, CA 90032
http://www.calstatela.edu/

DMS — Data Management System. Refers to both the MySQL database and accompanying PHP and Perl code libraries that store, insert and retrieve sensor data stored at the James Reserve.
http://dms.jamesreserve.edu

Drupal — An open-source Content Management System. Used for developing dynamically-generated, database-driven content for web-site. http://www.drupal.org/

Earthscope USArray — Earthscope seeks to “apply modern observational, analytical and telecommunications technologies to investigate the structure and evolution of the North American continent and the physical processes controlling earthquakes and volcanic eruptions.” The USArray is a nationwide system of seismometers which monitor activity for North America. In the context of this thesis, with the help of CLEOS, Earthscope created a Google Earth layer for the USArray network.
Earthscope's web-site http://www.earthscope.org/
USArray web-site: http://www.iris.edu/USArray/
Google Earth layer: http://www.iagt.org/earthscope/es-app_ge.asp

EasyCharts — A web Java-based applet for creating interactive charts on the web. A product of Object Planet Inc.

ObjectPlanet AS
Øvre slottsgate 5
NO-0157 Oslo
Norway
http://www.objectplanet.com/

ESRI	Environmental Systems Research Institute, Inc. A software company producing the world's most popular proprietary GIS (Geographic Information System) software for desktop computers and servers. ESRI – California Office 380 New York Street Redlands, CA 92373 http://www.esri.com/
ESS	Environment/Extensible Sensing System. A wireless sensor network developed by CENS as the successor of the CMS system. Some feature highlights include power-saving and sleep modes, and improved efficiency for inter-node communication. http://research.cens.ucla.edu/projects/ 2006/Systems_Infrastructure/ESS/
Flash	Also, Adobe Flash. A multimedia authoring program used to create content for web applications, games and movies. Useful for creating highly interactive web-based interfaces. http://www.adobe.com/products/flash/flashpro/
GEON	Geosciences Networks. Aimes to develop cyberinfrastructure in support of an environment for integrative geoscience research. http://www.geongrid.org/
GIS	Geographic Information System. A desktop or server program used to store, view, and analyze geographical information, particularly maps.
Google Earth	A 3D "virtual world" program which allows the user to view aerial and satellite images of the earth's surfaces draped over realistic three-dimensional terrain models. Also supports user-generated content, such as placemarks, 2D/3D polygons, Collada models, etc. Google, Inc. 1600 Ampitheater Parkway Mountain View, CA 94043 http://earth.google.com/
Google Sketchup	A user-friendly program for creating accurate three-dimensional models. Models can be textured with photographs, and can be exported to Google Earth. http://sketchup.google.com/

GPS	Global Positioning System. Uses satellites in stationary orbit to triangulate one's position on Earth with great accuracy. Used to assign latitude and longitude coordinates to the locations of sensor equipment at the James Reserve for accurate portrayal in Google Earth.
HOBO	Brand-name of multi-sensor data loggers produced by the Onset Computer Corporation. Micro and Weather Station HOBO data loggers are capable of accepting 4 or 8 dual-channel, propriteary Onset sensors. Onset Computer Corporation 470 MacArthur Blvd. Bourne, MA 02532 http://www.onsetcomp.com/
HTML	HyperText Markup Language. A language used to structure text and multimedia documents and to set up hypertext links between documents, used extensively on the Internet.
IIS	Intenet Information Server. A web-server product produced by Microsoft. http://www.microsoft.com/windowsserver2003/iis/
James Reserve	Part of the University of California's Natural Reserve System, administered through U.C. Riverside. Also the field-test site for CENS. The James Reserve PO Box 1775, Lake Fulmor - Trailfinder Lodge 20950 HWY 243 Idyllwild, CA 92549 http://www.jamesreserve.edu/
Java	A compiled programming language develop by Sun Microsystems which can be used for creating web-applets and desktop applications, such as EasyCharts. Also see Sun, Inc. http://java.sun.com/

JpGraph	A freeware PHP-based module for the creation of graphs from data points. Used extensively to display sensor data from the James Reserve. Aditus Consulting Emågatan 16 SE-128 46 Stockholm SWEDEN Tel: +46 8 391 180 http://www.aditus.nu/jpgraph/
JR GE layer	James Reserve Google Earth Layer. A KML layer for Google Earth that displays the sensor locations, current and archived measurements, web-cam images, and other information from the James Reserve. http://dms.jamesreserve.edu/
JSP	Java Server Pages. Similar to PHP and ASP, A scripting language used to generate dynamic web-content. Created by Sun Micosystems. shttp://java.sun.com/products/jsp/
Keyhole	The company which originally developed the Google Earth program until its acquisition by Google Inc. in 2004.
KML	Keyhole Markup Language. The XML-based data for which is used to represent features in Google Earth. http://earth.google.com/kml/
Kriging model	A regression technique used in geostatistics to approximate or interpolate data. Used at the James Reserve to model expected climate conditions inbetween the point locations of sensor data collection.
Microsoft	Microsoft Corporation One Microsoft Way Redmond, WA 98052-6399 http://www.microsoft.com/
NASA	National Aeronautics and Space Administration. NASA Headquarters Suite 1M32 Washington, DC 20546-0001 http://www.nasa.gov/

NEON	National Ecological Observatory Network. Slated to become the, "first national ecological measurement and observation system designed both to answer regional- to continental-scale scientific questions and to have the interdisciplinary participation necessary to achieve credible ecological forecasting and prediction." James Reserve is slated to be one of the participating locations for NEON. The JR GE layer has generated great interest among members, and will likely be used as one of the visualization interfaces for the entire system. National Ecological Observatory Network 1444 Eye St NW, Suite 200 Washington, DC 20005
Perl	An open source, high-level scripting language useful to performing numerous file handling and database tasks at the James Reserve. The Perl Foundation PO Box 4353 Ann Arbor, MI 48106-4353
PHP	Hypertext PreProcessor. Similar to ASP and JSP, this open-source scripting language is used to generate dynamic web-content. Used extensively at the James Reserve for data retrieval and presentation. http://www.php.net
ROADNet	Real-time Observations, Applications and Data management Network. Affiliated with San Diego Super Computer Center (SDSC). From their web-site: "[a] multidisciplinary science and technology team is building upon currently deployed autonomous field sensor systems, including sensors that monitor fire and seismic hazards, changing levels of environmental pollutants, water availability and quality, weather, ocean conditions, soil properties, and the distribution and movement of wildlife. ROADNet scientists are also developing the software tools to make this data available in real-time to a variety of end-users, including researchers, policymakers, natural resource managers, educators and students." RoadNet University of California, San Diego 9500 Gilman Drive La Jolla, CA 92093-0225 http://roadnet.ucsd.edu/

San Diego Super Computer Center

UC San Diego, MC 0505
9500 Gilman Drive
La Jolla, CA 92093-0505
http://www.sdsc.edu

Sensorbase — A data management system developed by CENS to house sensor network data. Database abstraction allows for data to be inserted to retrieved as XML data. Provides a way to publish, share, and manage sensor data much in the same way that one can publish, share, and manage journal entries in a blog. Also see CENS. http://sensorbase.org/

Shapefile — An ESRI proprietary data format used to create vector graphics features for Geographic Information Systems. Can be read and edited by a number of other software programs, including importation by Google Earth Pro.

Sparklines — Term coined by Edward Tufte as a "data-intense, design-simple, word-sized graphic." Used in the JR GE layer as simple bar charts to show 24-hour trends in climate measurements.

Spatial Analyst — An extension to ESRI's ArcGIS Desktop programs which allows for the analysis of spatial datasets. Also see ESRI. http://www.esri.com/software/arcgis/extensions/geostatistical/

SQL — Structured Query Language. A query language used to retrieve and insert data into a database, such as MySQL.

Sun Microsystems, Inc.

4150 Network Circle
Santa Clara, CA 95054
http://www.sun.com/

TEOS — Terrestrial Ecological Observing Systems. A division of CENS. It's goal is the "design, develop, deploy, evaluate, and support Embedded Networked Sensors and instrumented platforms for in-situ continuous measurement of environmental, physiological and ecological variables within diverse terrestrial ecosystems. Also see CENS. http://research.cens.ucla.edu/areas/2006/Terrestrial/

Texas Weather Instruments Manufacturer of the weather stations.

5942 Abrams Road #113
Dallas, TX 75231
http://www.txwx.com/

UCLA University of California, Los Angeles. One of the institutional participants in the CENS programs.

Los Angeles , CA 90095
http://www.ucla.edu

UCM University of California, Merced. One of the institutional participants in the CENS programs.

5200 North Lake Road
Merced, CA 95343
http://www.ucmerced.edu

UCNRS University of California, Natural Reserve System. A system of natural reserves and research stations that are administered by various campuses of the University of California.

1111 Franklin Street, 6th Floor
Oakland, CA 94607-5200
http://nrs.ucop.edu/

UCR University of California, Riverside. One of the institutional participants in the CENS programs.

900 University Ave
Riverside, CA
http://www.ucr.edu

USC University of Southern California. One of the institutional participants in the CENS programs.

University of Southern California
Los Angeles, CA 90089
http://www.usc.edu/

USGS	United States Geological Survey USGS National Center 12201 Sunrise Valley Drive Reston, VA 20192, USA http://www.usgs.gov/
Virtual globe	3D software model or representation of the Earth or another world which allows its users to navigate freely in the virtual environment by altering the viewing angle and position. Such programs include ESRI's ArcGIS Explorer, Google Earth, and NASA's World Wind.
WaterWatch	A USGS (U.S Geological Survey) program that monitors the flow rates of North American streams in real-time. In the context of this paper, WaterWatch has a Google Earth layer for the viewing of its real-time data. http://water.usgs.gov/waterwatch/
World Wind	A open-source "virtual globe" program developed by NASA, in part to aid in the viewing of satellite images and remote sensing layers. Similar to Google Earth. NASA Ames Research Center MS 226-8 Moffett Field, CA 94035 USA http://worldwind.arc.nasa.gov/
XML	eXtensible Markup Language. A metalanguage that allows one to design a markup language, used to allow for the easy interchange of documents on the Internet.