

Design of an image analysis website for phenological and meteorological monitoring

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ABSTRACT

Web camera image databases and web-based services can be valuable components for a variety of modelling applications, but are still areas of relatively new exploration. Investigating design and information flow for an online image archive and analysis site for plant phenology and meteorological research has broader relevance to considerations of interoperability and website features. Currently, numerous online weather cameras provide images, but have no or limited-utility archives and do not support quantitative image analysis. We describe the design and implementation of a website (<http://zulu.geog.ucsb.edu/Data/camera.html>) that both provides different display options for archived image review, as well as the ability to chart time-series values extracted for user-specified regions of interest. This interface is distinguished by content-enabled charts with the ability to click on data points and directly access the corresponding image for reference purposes. A linked website to the meteorological data from the camera station further extends the potential for exploratory analysis and pedagogical utility. Online quantification of the color change related to plant senescence and insolation impacts due to cloud cover are demonstrated. We conclude that dynamic web pages are a powerful and useful tool for adding educational and scientific value to repeat digital photography systems.

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1. Introduction

As web camera and web service technology have progressed, there now exists the opportunity to integrate web cameras into a variety of monitoring applications and for accessible and integrated online interfaces. While web cameras have been used in plant phenology and meteorological research and are a central feature in discussions of sensor webs (Liang et al., 2005) they could also be used to further extend knowledge systems for a variety of applications, such as landfill monitoring (Dokas et al., 2009) and flood warnings (Katiyar and Hossain, 2007). Web cameras have tremendous potential, but there exists many challenges shared with other environmental modelling web services including interoperability and standardization (Goodall et al., 2008; Mineter et al., 2003). These issues confound accessing image databases from multiple sources, performing online analysis and implementing automated alerts based on image data. Systematic organization and integration of related products is essential for web services to create a synergistic experience for the user that is more tractable

and readily navigable (Panagos et al., 2008). Similar to other web-based educational tools, such as the 4S forest management software (Kirilenko et al., 2007), web camera interfaces can also serve as an accessible and engaging introduction to more complicated analysis. In doing so, such websites simultaneously transform and re-imagine the technique of repeat photography.

Repeat photography has been a powerful tool for qualitative and, in some cases, quantitative assessment of landscape change and processes. Traditional repeat photography has involved photo-pairs and timescales from months to centuries, where historical photos are compared to new photographs of the same scene (Hart and Laycock, 1996). The applications are numerous (Hart and Laycock, 1996) and include capturing forest succession and glacial recession (Butler and DeChano, 2001) and changes from grass to shrub-dominated landcover (King et al., 2008). It has also been suggested as an engaging means for teaching the concept of movement in physical geography (Butler, 1994).

With the advent of inexpensive and reliable digital cameras, repeat photography has expanded to include web cameras with streaming video and fixed camera applications with increased temporal sampling, such as daily photos for monitoring plant phenology (Crimmins and Crimmins, 2008). Additionally, image processing has become more sophisticated and has led to

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quantitative assessments of landscape features and changes, such as flower enumeration (Adamsen et al., 2000), crop senescence (Adamsen et al., 1999), and the increase in tree cover for an alpine treeline ecotone (Roush et al., 2007). This analysis has capitalized upon the differentiation of objects in the three bands – red, green, and blue (RGB) – of digital images. The ratio of red to green has been used for green vegetation classification (Numata, 2006), as has the sum of the differences between the green band and the blue and red bands (Crimmins and Crimmins, 2008). Astola et al. (Astola et al., 2008) utilized spectral angle conversion (RGB vectors to another color space) in order to control for illumination and shading differences in a study of autumnal color change. Furthermore, they only included images acquired on overcast days in order to avoid image saturation arising from specular reflection.

Indices calculated from time-series photography can be compared and synthesized with other data. Hinkler et al.'s (2002) normalized snow index has a greater temporal resolution than Landsat-derived estimates of snow cover. Richardson et al. (2007) compared the RGB web camera 'green-up' signal to adjacent canopy photosynthesis measurements. Astola et al. (2008) utilized reference classifications from phenology experts to compare to image-derived classifications. Digital image analysis has also been applied for fog detection and daytime visibility assessments (Baumer et al., 2008; Hautiere et al., 2006).

While desktop software packages such as ENVI and Matlab are well suited for analyzing repeat photography images and are widely utilized, image processing via dynamic online interfaces is an alternative method with many potential applications. An online system is not restricted by software licenses and can be readily used by researchers and the public alike. Additionally, environmental monitoring websites with interactive features have had demonstrable success, providing flexibility and generating increased engagement. For example, Sharma et al. (2003) developed an air quality index website that returns information from users' queries in graphical form and supports comparison through multiple result windows. Turner and Anderson (2007) describe an online beach management system, which hosts a calendar-based archive of images from a beach camera network and derived products, such as shoreline position, that are generated weekly by an operator.

However, the majority of web camera applications have focused more on streaming video or current images than on providing archive access and data mining functionality. This reflects the appeal of the immersive aspect of web cameras – the ability to "make us telepresent, in places far removed from our bodies" (Campanella, 2000). Technology for streaming video involves different complications than for image archives. Bandwidth is a particular concern for live imagery, but not storage requirements nor filename conventions for optimized retrieval.

For the limited cases where online image archives do exist, the interfaces reviewed, e.g., www.nature.nps.gov/air/WebCams, www.jamesreserve.edu/webcamfiles, <http://ci.wrl.unsw.edu.au/index.php>, www.wunderground.com, and www.diablo.sbarc.org/imageview.cgi, are *date-driven* as opposed to *data-driven*. Users can access the corresponding image for a given date and time, but not review the image data as a series in order to exploit temporal and spatial modalities. These interfaces demonstrate a propensity for calendar-based hierarchy, where individual images can be viewed by searching by year followed by month, day, and, when available, time of day. This approach is understandable given the interest in observing conditions for a specific date, e.g., "What did it look like when it rained on Wednesday?" However, this approach is limiting, since it constrains the end user's creativity and the ability to truly explore a dataset and investigate more sophisticated questions with filters, e.g., "Do we see more cloud cover on average at 9 am or 3 pm for the month of January?"

While an extensive literature exists on information visualization, user interface design, and human-computer interactions, this information has not been fully leveraged in the design of web camera interfaces. One particularly relevant thread of research involves the utilization of animations to aid the learning process (Schnotz and Lowe, 2003). Animations can help facilitate learning by removing the necessity for individuals to construct directly dynamic mental models from static images (Park and Hopkins, 1992) and can be useful for displaying web camera image time series. However, due to the transitory nature of the visuals in animations, there can be increased cognitive processing demand as the viewer struggles to keep pace; this effect can be somewhat modulated by user controls (Lewalter, 2003). Also, Lowe (2003) found a bias towards perceptually conspicuous information as opposed to that of thematic relevance for the dynamic representations and interpretation of weather maps. Similar bias effects could occur in the context of web camera time series; for example, a learner could have difficulty recognizing subtle changes, such as vegetation senescence, in the presence of more dramatic features such as clouds. Lowe (2003) also explains that "components of the animation can attract attention either because they (a) change substantially more than their surroundings, or (b) change substantially less than their surroundings". This should be taken into consideration when assessing web camera animations and also illustrates the utility for quantitative methods, which can extract time-series changes for specific features that would otherwise be overlooked.

While the discussion of the relative merits of animations versus static representations continues (Ploetzner and Lowe, 2004), it seems to be beneficial to incorporate both options in web camera interfaces as well as to support user control of the display. Currently, most interfaces display single images or images from multiple views but for fixed timestamps. When multiple images could be viewed (e.g., www.wunderground.com, <http://www.jamesreserve.edu/webcams.lasso>), it was in a calendar format; again, this is a *date-driven*, rather than a *data-driven*, organizing framework. Also, of those archives that did provide animations, none allowed the user to select what images were to be used. Instead, videos were pre-compiled.

The objective of this study was to create a website to demonstrate the potential of web-based image archives and analysis for phenological and meteorological observations. This website incorporates a dynamic interface, which allows users to view multiple images by filtering by site, date range, and time of day, and returns these images as a matrix or as a time-lapse animation. By replacing the calendar-based hierarchical nesting of links with filters and by returning multiple images, we move towards a more *data-driven*, exploratory framework. Hypertext-enabled charts seamlessly integrate quantitative and qualitative aspects, as images can be opened directly from data points derived from the images themselves. Although not appropriate for intensive processing, e.g., iterative algorithms utilizing Sobel operator-based edge-detection (Baumer et al., 2008), internet analysis can be readily applied for extracting pixel RGB information, and it is adept for creating flexible image displays.

2. Project design

As part of the Innovative Datasets for Environmental Analysis by Students (IDEAS) project funded by the National Science Foundation and UC Santa Barbara, a meteorological tower with a web camera was installed at the Coal Oil Point Natural Reserve adjacent to the campus of the University of California, Santa Barbara (COPR station: 34.41386 N, 119.8802 W). This station is part of a network of stations installed in Santa Barbara county. The camera has a fixed

orientation and zoom and collects images at 9 am, 12 pm, and 3 pm PST. Using LoggerNet 3.4.1 Task Master, meteorological data and images are downloaded each day at noon to the IDEAS web server via the station's cellular connection. The IDEAS website (<http://www.geog.ucsb.edu/ideas>) provides additional project information, along with access to the meteorological data and image archive.

2.1. Equipment and infrastructure

Station equipment was purchased from Campbell Scientific and includes a 10-ft steel tripod, 20-watt solar panel, CR1000 datalogger, CS215 temperature probes at height of 75 and 285 cm, leaf wetness sensor, LI-200X pyranometer (400–1100 nm), tipping bucket, fog collector, CNR-1 four-channel net radiometer, and soil moisture and temperature probes at 10, 20, and 50 cm depth (Fig. 1). Communication with the datalogger is achieved with an Airlink Raven110 digital cellular modem with an AT&T wireless data plan. The schedule task feature in the Campbell Scientific LoggerNet 3.4.1 software initiates the daily downloads of the most recent meteorological data and images.

Vista Engineering's Vista Data Vision 4 software is used to automatically update a MySQL database with current meteorological data and to support online dynamic querying and chart generation as part of the IDEAS website. The data interface allows users to view time-series data for several different stations separately as well as on charts that allow cross-site comparisons (Fig. 2). Additionally, the interface supports histograms and scatter plots for exploratory analysis, and all data can be viewed in table format and downloaded. The software offers excellent flexibility for constraining the data by date and using different timescales from hours to months. This data interface is complemented by the IDEAS website, which provides information on the equipment and surrounding environment for each station. Additionally, the website serves as an excellent resource for background material on the environmental measures recorded at the stations, with a range of pertinent equations, graphical demonstrations, and animations.



Fig. 1. Coal Oil Point research station. Marine-grade anemometer, pyranometer, cellular antennae, solar panel, camera, temperature/relative humidity sensors, and enclosure with datalogger installed on main tripod. Additional instruments include leaf moisture sensor, rainfall tipping bucket, fog collector, four-channel net radiometer, and soil moisture and temperature probes.

The camera at COPR is a CC640 CSC digital camera, which produces time-stamped images with 604×504 pixel resolution. It was installed on 5/24/08, and a second camera was installed at the grassland Airstrip (AIRS) station on 9/18/08. Due to intermittent communication difficulties, multiple iterations of the LoggerNet 3.4.1 download task are specified for different times during the period that the modem is powered. The station solar panel and battery constrain the length of time that the modem can be powered sustainably. For weather stations that have direct Ethernet connections, the datalogger storage would no longer be a constraint since the images could be downloaded immediately following collection.

A batch file in conjunction with a Rename Master script (a free utility for renaming groups of files, available at www.joejoesoft.com) is run daily to rename the downloaded files to include temporal information. By including this information in the filename itself it removes the necessity for a database to link images with searchable meta data. Since the datalogger has limited flexibility for specifying filenames, this renaming script is used. The original filenames only include station name and an incremental count (i.e., `copr781.JPG`). The Rename Master script relies upon the date-modified information, which is included with the image file, to create a new filename with parsed timestamp information (`YY_MM_DD_hh`) following the four letter site abbreviation (e.g., `copr_09_03_27_20.JPG` is the image from 3/27/09 at 20 UTC). The date modified is used since it preserves the timestamp of the actual image collection, as opposed to the download time, which is expressed in the file created information. Other approaches to web camera nomenclature have incorporated the timestamp directly, i.e., Unix timestamp in seconds, as opposed to disaggregating into components. Using such timestamps is more accurate and specific; however, it can come at the cost of coding ease and flexibility. For example, the SBARC Diablo Peak Camera (<http://www.diablo.sbarc.org/imageview.cgi>) utilizes filename lists for each day of images. While it makes for easy display of date-specific images, it would be considerably more complicated to show all of the images for a given time of day using this system.

Conversely, a set of daily time-series images can be retrieved easily with an incrementing time variable, which is then parsed to construct the appropriate filename in `YY_MM_DD_hh` format. If filenames have high levels of temporal specificity, i.e., seconds, and if there is any degree of variability in collection timing, then this approach would fail and an alternate method is required. If more specific nomenclature is desired, filename wildcards could be used or also a filename database, which contains information that can be retrieved by specifying month, hour, etc. However, adding a minute variable (`YY_MM_DD_hh_mm`) and utilizing rounding should be sufficient for most image databases with higher temporal resolution.

2.2. Website features

The IDEAS camera interface (<http://zulu.geog.ucsb.edu/Data/camera.html>) is designed to view the images in different formats and support time-series analysis (Fig. 3). The scripting language PHP (www.php.net), with Javascript (<http://www.w3schools.com/JS/default.asp>) for added functionality, was used to create the website, since these languages are well suited for online dynamic content. PHP and Javascript are commonly used, well documented, and have extensive script examples and tutorials available online. Additionally, both languages are recognized as easy to learn. However, in order to incorporate PHP code into a website, PHP must be first installed on the web server and configured. Many commercial and university web servers already have PHP installed.

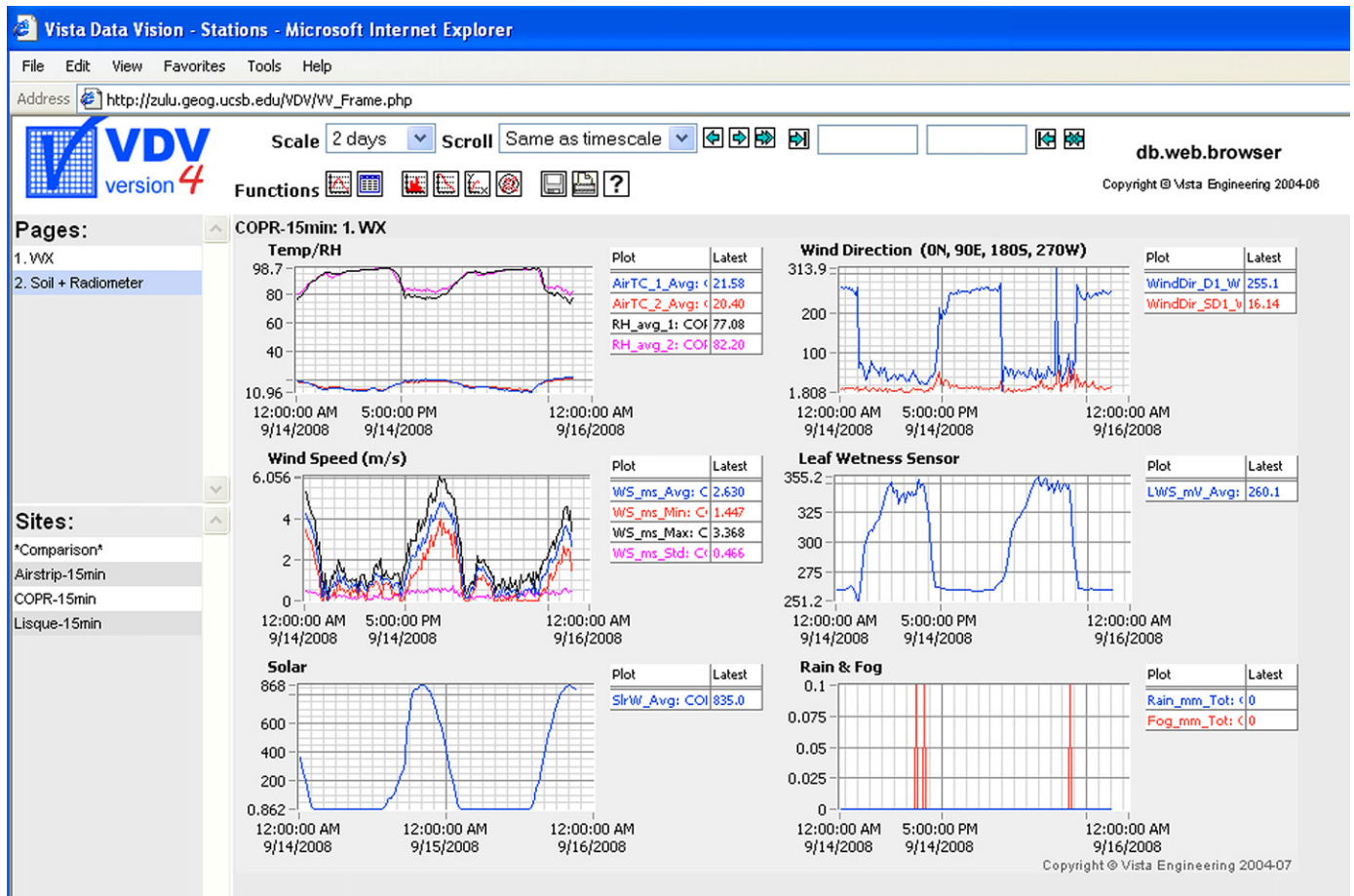


Fig. 2. Online data interface created with Vista Data Vision V4. Time-series charts for different variables are shown in the main frame. The top menu controls time scale and scrolling functionality and restriction by start and end dates. The menu on the left is used to navigate between station pages, with one site for inter-station comparison. Clicking on an individual chart opens a page with the graph maximized and has options for plotting the data as a histogram or scatter plot. Data can be viewed in table format and downloaded as a text file.

The first component of the website is a form, which allows users to filter the images and select how they are presented. Parameters include: start and end date, the scale at which the image should be displayed ($1/2, 1/4, 1/8 \times$ size), the hour (all, 9 am, 12 pm, or 3 pm), the station name, and the date increment. The user can select the 'Images' button to view all of the selected images in a matrix format (rows being dates, columns being hours and station names), with the ability to click on each image to see it at full scale. This design provides a panoptic view for visually identifying general trends, i.e., differences in sky color, as well as meteorological events like rainfall and fog immersion. Additionally, this format is ideal for cross-site comparison, which can be further refined for a particular time of day or part of the year.

The day increment variable is an important component, because it is used to vary the temporal resolution for the returned images, e.g., from images every day to images every month, etc. This is particularly apt for investigating low-frequency variations and trends over longer time periods. Additionally it can be utilized to create less intensive server requests without sacrificing temporal extent.

In addition to the option to view images in a matrix form, users can elect to view selected images as animations, which could be a more efficient means to identify trends. These time-lapse movies are generated dynamically using Javascript code adapted from jsImagePlayer 1.0 (modified by Ron Wells, Texas Commission on

Environmental Quality, 2002) with PHP to access the selected images. Controls allow the user to specify the speed of the animation and stop, start, and skip frames.

To further extend the utility of this interface, a time-series analysis component has been developed to quantify changes for regions of interest (ROIs). Originally, users could select a ROI from a set of fixed options, which included the sky, trees in the background, and grassland in the foreground. This was subsequently adapted to allow users to specify their own ROIs and select the base image for this process by site, date, and time of day. Additionally, users can select a filtered version of the image, which emphasizes edges, to be used as the background. Filtering occurs via the `IMG_FILTER_EDGEDETECT` command in the PHP5 GD graphics library (<http://us.php.net/manual/en/function.gd-info.php>) and is based upon a convolution kernel that highlights variation between the central and surrounding pixels.

The ROI selection utilizes the `imgAreaSelect` script (downloadable from <http://odyneic.net/projects/imgareaselect/>) written by Michal Wojciechowski. It is a jQuery plugin, which refers to a JavaScript library freely available from <http://jquery.com> that simplifies event handling and animations. The user can resize and move the ROI across the background image, automatically updating the parameter listing (Fig. 4). A zoom window adjacent to the background image provides more detail. While the dynamic interface is limited to square ROIs, the user can circumvent those limitations by

The screenshot shows a web browser window with the URL <http://zulu.geog.ucsb.edu/Data/camera.html>. The page features a blue sidebar on the left with the 'IDEAS Images' logo and a search form. The search form includes fields for Start date (Mar 7, 2009), End date (Mar 17, 2009), Scale (1/4), Hour (PST) (ALL), Station (COPR), and Day Increment (1). There are buttons for 'Images' and 'Movie', and a 'TIME SERIES ANALYSIS' section with a 'GO!' button. Below the search form, there is text providing information about the start dates for COPR and AIRS, and the time of day for the images. The main content area on the right displays a grid of images for the period Mar-07-2009 to Mar-17-2009, with a period length of 11 days and an increment of 1 day. The grid has columns for 'copr_9AM', 'copr_12PM', and 'copr_3PM', and rows for dates from 03/07/09 to 03/11/09. Each image shows a grassy field with trees in the background.

Fig. 3. Online portal for reviewing weather camera images and investigating temporal changes. The form is used to filter images based on start and end date, hour, day increment and station, with a scaling option for the display size. The 'Images' button generates a matrix of images, with date down the rows, and station and hour across the columns. The 'Movie' button generates an animation with frame control options from the images selected.

directly inputting the ROI coordinates (although the ROI display will not update).

After the ROI has been specified, the pixel values for each image in the time series are extracted. With the PHP GD graphics library, the red, green, and blue value for the ROI pixels can be evaluated and summary statistics (minimum, maximum, mean, and standard deviation) for each color can be calculated. The red, green, and blue values are derived from the camera's color filters and hence are device dependent. As a digital 8-bit per channel system, the range in values is from 0 to 255, with black expressed as the RGB triplet (0,0,0), white as (255,255,255), and pure red as (255,0,0). In the resultant output, these values have been standardized so that the range is from 0 to 1 for each color (i.e., 0/255 to 255/255).

In this current online version, images have not been corrected to adjust for variable illumination. However, users can specify band ratio outputs, which modulate variability. Additionally, for the ratio option an atmospheric variability mask can be applied. The mask utilizes a sky transect to exclude cloudy images from the analysis (if red range is larger than 0.035 or if the maximum red value is greater than 0.94). However, this approach will be confounded with partial cloud cover. The third output option extracts pixel values

from the edge filter image and calculates the percentage of pixels that are classified as "edges" (filtered image pixel value greater than 0.5). While this option is the most computationally intensive, it does provide useful information that can be used to differentiate between overcast and clear days, where on clear days the contrast and percentage edge are increased.

Even for a single image, this array of ROI measurements are valuable as they offer quantitative measures and differentiation between image features, such as the increased blue values for the sky and the greater standard deviation across the forest transect as opposed to the sky transect. However, it is of particular interest to quantify how features change temporally, e.g., grass green-up and senescence, low-lying clouds occurrence, differences in visibility, etc. Using the same form of filters as for the image matrix, a user can select a period of record, time of day (certain hour or all hours), station, and day increment and output metrics for a given ROI. Users can select any permutation of the possible colors and statistics for the table format, with each column label expressing the color and statistic combination. The band ratios and edge filter values can be output in HTML or CSV table format as well.

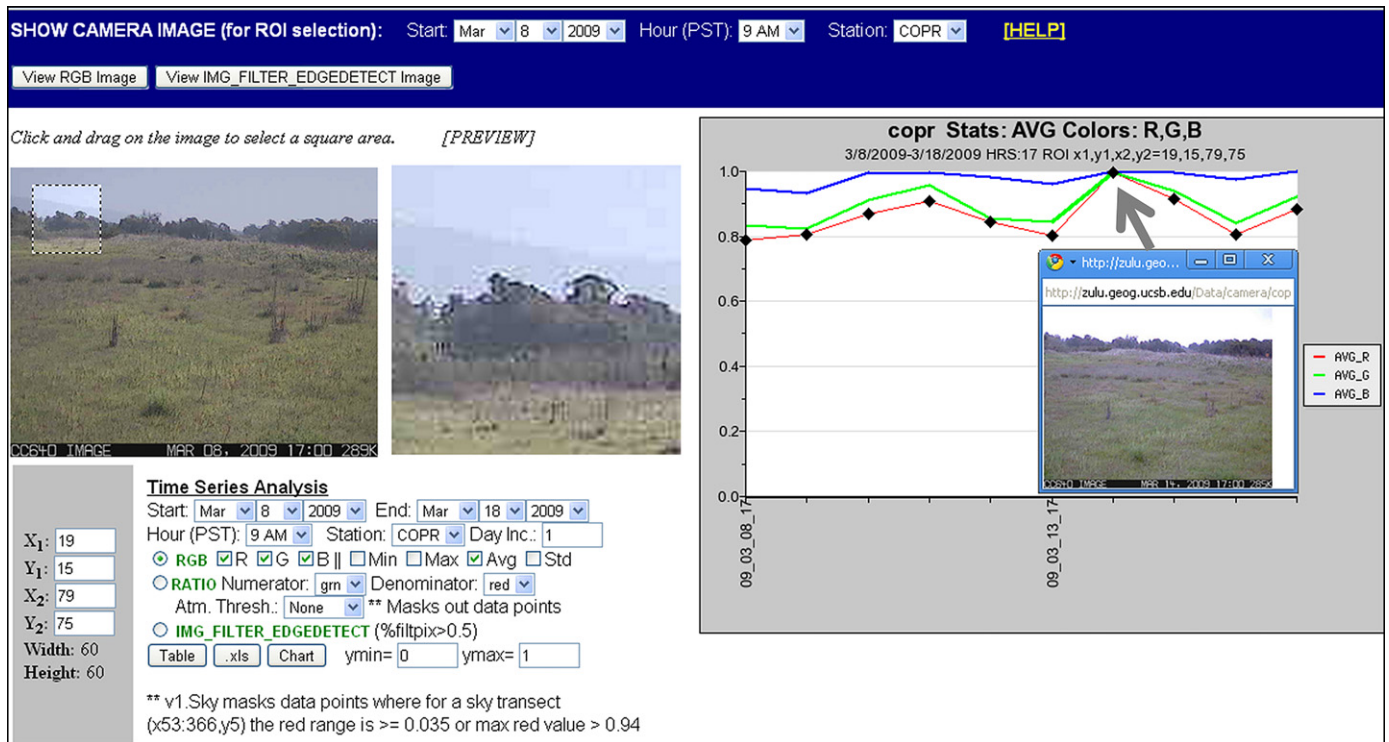


Fig. 4. Online portal for image time-series analysis. The user selects a base image and then specifies a square ROI by clicking and dragging on the image. The ROI can be moved and resized, with the ROI specifications updated in the gray box below the image. A zoomed view of the ROI is shown to the right of the base image. After the ROI has been specified the user selects the dates for the time-series analysis, the time of day, the station, and the day increment. Three output options are available: RGB statistics, color ratios, and values extracted from the edge-detection filtered images. The output can be viewed as an HTML table, a downloaded Excel file, or in graphical format. Clicking on the black data points opens the corresponding image.

The user can also elect to view this information directly in graphical format, although there is a stipulation that only four lines can be plotted on a chart, either of one color and multiple statistics or multiple colors and one statistic selected under the RGB option. Dynamic-chart generation further expands the utility of the website and its singularity, allowing users to rapidly assess visual trends without first exporting the data to Excel or other software. Charts are created using JpGraph, a PHP graph-creating library (<http://www.aditus.nu/jpgraph/>). The user can specify the y-axis limits for the graph, and if the image processing times out, the user is prompted to increase the day increment value or output the data to table format. Over 160 images can be processed at a time when outputting RGB values for a relatively small ROI (30 × 30 pixels); other processes take longer. In particular, the edge filter detection is best applied to smaller time series, less than 70 images.

Through novel use of client-side image map (CSIM) functionality, the time-series color statistics chart has data points that are hyperlink enabled. When the mouse scrolls over black data points, a pop-up label provides the data value. Concurrently, in the status bar, in the bottom left of the browser window, information appears with the corresponding image filename, providing the station name and timestamp.

Clicking on a data point on the chart opens a pop-up window of the corresponding image. This enables a user to easily identify anomalous image values via the ROI time-series chart and then open the images directly from the chart. The result is a content-enabled graph that provides synthesis and ease of exploration of the very data that it expresses. Multiple images, differentiated by the image timestamp and page title, can be opened and arranged by the user for comparative purposes.

3. Case study

There is currently a disconnect between the wealth of online camera content and the scarcity of accompanying image analysis capabilities. While there are many software packages for image analysis, it is also useful to provide an online interface that is not software dependent. This both broadens the utility to the general public as well as serves as an excellent tool for preliminary analysis. Additionally, the ease of linking between chart data points and time-series images is a feature not intrinsic to desktop-based image processing software.

As a demonstration of this interface's potential, two investigations into time-series changes are discussed: (1) vegetation senescence and green-up and (2) insolation. To explore senescence and green-up at the COPR site, we plotted the green/red ratio for a foreground grass ROI from 5/5/08 to 3/19/09, 20:00 UTC (noon PST) images (Fig. 5). While the average values for the red and green channels are influenced by sky conditions and are therefore variable on a day to day level, the general trend in the ratio shows a decrease in the early summer, followed by an increase after October due to winter precipitation. Clicking on data points to show earlier and later images was useful for visually verifying this trend as shown for the May 12th, September 14th, and March 17th images. This trend agrees with the expected phenology of grasses in a Mediterranean climate that lacks summer rainfall, as chlorophyll in live grass leaves will reflect more green photons and absorb more red photons compared to senesced leaves. To control for the atmospheric variability throughout the time series, values for the sky or tree ROIs could be used to create a mask for cloudy days. Additionally, this highlights the utility of having standards in the field of view for image correction. The senescence

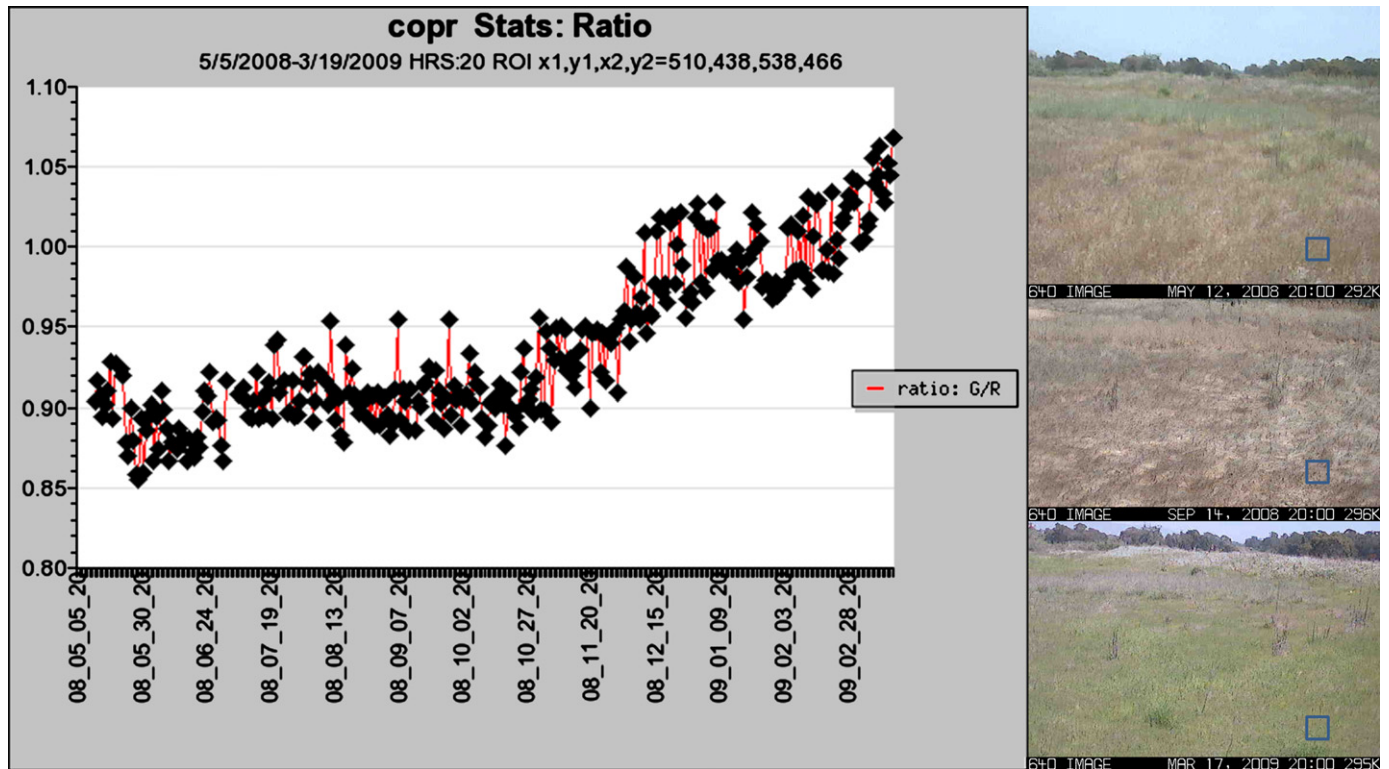


Fig. 5. Phenology example, time-series chart of average Green/Red ratio for ROI (grass) noon image, with example image 5/12/08 (Top), 9/14/08 (Middle) and 3/17/09 (Bottom). As the season progresses and the grass senesces and then green-up occurs, the green/red ratio decreases and then increases for the winter months following precipitation. Variability in the daily values is linked to lighting conditions (overcast, etc.). These anomalies could be pre-screened using meteorological measures from the tree and sky transect. Additionally, the trend would be more apparent with a moving average.

and green-up trend can also be highlighted by using a moving average, which although not currently part of the online interface, can be readily implemented with other software after the data are downloaded.

To investigate atmospheric conditions, we extracted RGB values from sky (Fig. 6), tree, and mountain ROIs to compare with insolation as measured at the station at noon (20 UTC) for the period 1/1/09 to 3/1/09. This period of two months was selected in order to limit the influence of seasonal insolation variation and because of the high frequency of cloud events. It was hypothesized that decreases in insolation due to cloud cover would correspond to an increase in RGB values as clouds are brighter features than all of the study targets, which were in the background of the image. The results corroborated this, with insolation and RGB average values negatively correlated for all three targets (all correlation coefficients were negative with magnitudes between 0.42 and 0.80 with p -value < 0.05, Table 1).

Brightened targets were caused by cloud cover (including fog) and the presence of droplets on the camera enclosure from recent precipitation events. These droplets resulted in bright spots in the image, e.g., 2/5/09, and would also be likely to correspond to periods of decreased insolation as cloud cover can persist after rain events. Outlier images in the insolation and sky ROI scatter plot, such as 2/9/09, occurred because the insolation was low and the sky pixel values were also low (dark cloud underside), wherein low pixel values typically correspond to clear blue skies and high insolation (Fig. 7). Other outlier images, e.g., 2/5/09 (Fig. 7), did not indicate low insolation values based on the sky region of interest, which was relatively dark, however the mountain and tree ROIs were brightened.

A stronger correlation with insolation was found for red and green values than for blue for the sky ROI, i.e., -0.80 for the red value compared to -0.42 for blue. This is because the red band was highly correlated with the green band (>0.95 for all targets), while blue showed a weaker relationship because it tended to saturate. The mountain and tree ROIs had similar correlation values with insolation for all bands. These values were lower than the sky target for red and green and higher for blue, indicating lack of blue saturation and overall lower sensitivity to insolation. This points the way for further research with large sets of ROIs and longer periods of record with varied classification techniques, yet as an exploratory research example, the benefit of online tools is apparent. Particularly it demonstrates the value added from content-enabled charts, which bridge the gap between data points and the original images and greatly aids interpretation.

4. Discussion

These examples illustrate the potential explanatory power and manifold opportunities for data exploration and synthesis offered by an online meteorological data interface coupled with image trend analysis software. Patterns and anomalies in the image series data can be related to meteorological and ecosystem property data, and investigations of natural patterns can be made more tangible. This expedites and enriches exploratory analysis in both educational and research settings. This approach supports the results of Sumner (1984), who found that a combination of time-lapse imagery and weather data has tremendous pedagogical utility. Additionally, the potential research applications are numerous, e.g., direct

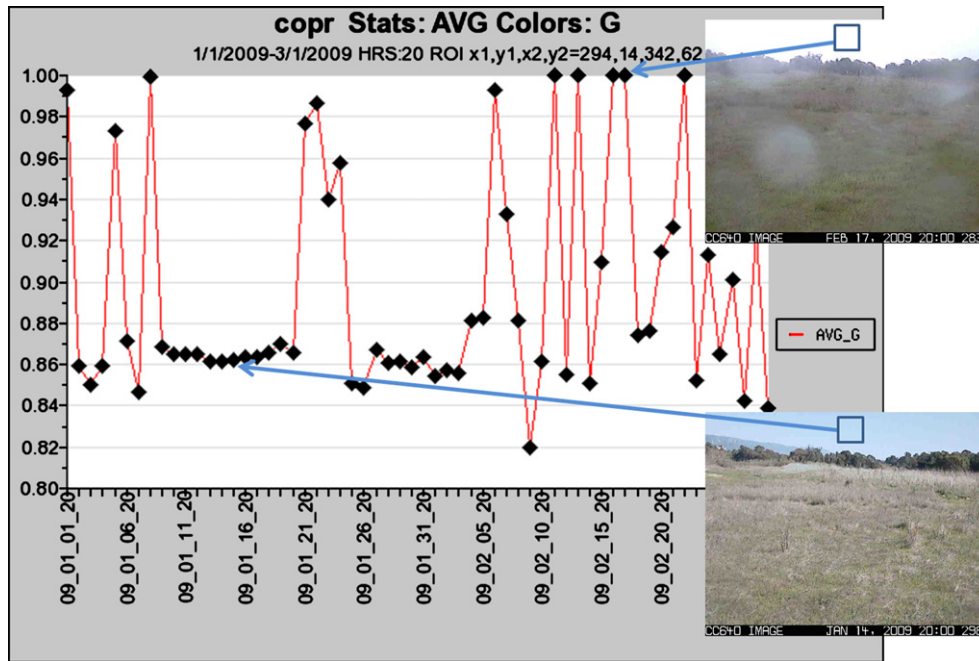


Fig. 6. Sky color variability for the months of January and February 2009 (noon PST, 20 UTC). High green values for a sky ROI on 2/17/09 corresponded with cloudy conditions, with lower values (1/14/09) occurring under clear conditions.

comparison between webcam-based phenology, soil water balance and evapotranspiration. Also, data on atmospheric conditions are critical for improved analysis of phenological data, such as automated tools for pre-screening to remove atmospherically contaminated imagery. This is likely to be critical for more automated analysis of phenology from webcams and is an elegant solution, which incorporates the same data-flow but focuses on different features.

This system does have the advantage that it can easily be adapted to provide other value-added metrics, such as the difference index (Richardson et al., 2007) for vegetation analysis. Furthermore, the image analysis website could also directly incorporate the meteorological data, retrieving all variables with only one form submission. Also with PHP coding, email alerts for various conditions could be enabled. This would be useful both for quality control as well as for scheduling field campaigns to capture phenological and meteorological changes.

The online interface described here does have several limitations at present. While the image display, animations, and tabular analysis component works well for Mozilla Firefox, Internet Explorer, and Google Chrome, the CSIM-enabled graph does not have full functionality on Internet Explorer. Although internet-based tools are valuable in that they are readily available to the public, ensuring that the application is compatible with a wide array of browsers is challenging and must be a sustained effort.

Table 1
Insolation correlation coefficients with 95% confidence intervals for image targets.

Image Target	Red (95% CI)	Green (95% CI)	Blue (95% CI)
Sky ^a	-0.80 (-0.88; -0.68)	-0.79 (-0.87; -0.67)	-0.42 (-0.61; -0.19)
Mountain ^b	-0.58 (-0.72; -0.38)	-0.58 (-0.73; -0.38)	-0.61 (-0.75; -0.42)
Tree ^c	-0.62 (-0.76; -0.44)	-0.62 (-0.75; -0.43)	-0.66 (-0.78; -0.049)

^a ROI: [294 - 14 - 342 - 62].

^b ROI: [48 - 58 - 66 - 76].

^c ROI: [414 - 102 - 436 - 124].

Additionally, there can be security concerns with online applications and scalability issues. To support heavy traffic, it may be desirable to pre-process images to create databases of extracted metrics. However, this database option could restrict the user's flexibility.

Another consideration is query constraints, i.e., areal coverage statistics will time out for the graph due to processing limitations. While a graph of RGB average values can be returned for a 30×30 pixel ROI for 305 noon images, this query will time out when expanded to include 9 am and 3 pm. When designing queries, users must balance the size of the ROI, the length of record, times of day, and the type of output (less intensive for single color average, most intensive for edge filter values). However, with the additional flexibility of user-specified ROIs and date increment, this situation is improved and in using the software, we found it rare for the graph to time out.

Lastly, image normalization is a key component of quantitative web camera analysis and should be further explored. It is a complicated issue since the camera is adjusting its exposure times based on scene content and as a result, it is actually inherently normalizing the output. Complications arise when a change in scene content, such as a bright cloud covering a part of the scene, causes the exposure to be lowered, thereby darkening other features. This can confound analysis of vegetation targets senescence and green-up, creating invalid data points. While allowing users to specify ROIs anywhere in the scene is a first step for filtering data, further editions of this online tool will explore the use of multiple invariant targets and regressing scenes against one another for each time of day. Code could be designed to create a best fit equation and residuals could be used to identify outliers and exclude these from the equation (in the case of targets that are blocked by a cloud, person, etc.). When an equation cannot be fit to the data, that would be an indication of poor atmospheric conditions. There is tremendous opportunity to construct sophisticated online tools for image processing, which build upon the framework described in this paper.

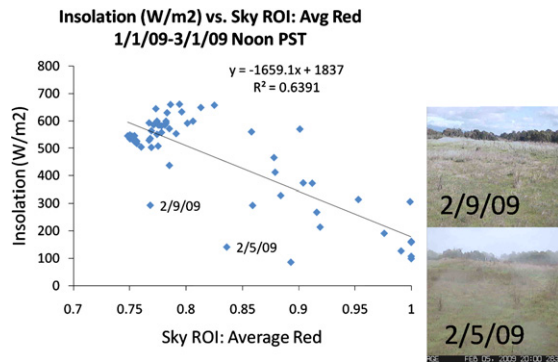


Fig. 7. Scatter plot of insolation (W/m²) at the COPR station compared to a sky ROI average red value for January and February 2009 at 20 UTC. This period was selected because of the high frequency of cloud events and to narrow the influence of seasonal insolation variations. Insolation and the ROI red values were negatively correlated, with outliers occurring for 2/5/09 and 2/9/09 as low insolation occurred but the sky ROI appeared relatively dark.

We believe that online archive interfaces and analysis tools can be useful for a variety of image databases and are relatively easy to implement given parsed filename conventions. At this time, while we are not able to support users processing other images directly on our server, we have made the documented source code available on request. Adaption of the code for a different image database is trivial although implementation requires that the server have PHP5 configured with the GD library for full functionality. We have tested the adaption process for an image database that has multiple view angles and higher collection frequency and found that it went quickly. Also many of the design elements discussed (CSIM-enabled graphs, matrix and animation image displays, etc.) can also be enacted using other scripting languages.

For a wider user base, a general online tool that supports user-specified image databases would be very valuable. This would involve a form to input the online image database directory with filenames in a consistent form (*site_YY_MM_DD_hh_ii.jpg*) and the user would specify the times of day when the images were collected and what date collection started. The coding would need to be more complicated to support user-specified filename nomenclature, nested file directories, or inconsistent image collection.

As the use of web cameras for environmental monitoring is quickly rising in prominence (Richardson et al., 2007; Turner and Anderson 2007; Astola et al., 2008), there is a clear need for tools to support exploratory analysis and to bridge the gap between extracted data and images. Additionally, given applications that do not depend on expensive software, web camera archives provide an excellent opportunity to engage students and the general public in the scientific process. In this paper, we have described the design and implementation of an online archive and analysis interface written with PHP and Javascript. Although this particular infrastructure might not be the best solution for a given web camera project, it does provide insight into design elements, filename approaches, and visualization strategies that are generalizable. This type of discussion is necessary as part of the larger dialogue on how best to use cameras for environmental monitoring, which includes camera orientation and placement, lens filters and image standards, and atmospheric corrections.

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