Visualizing Change: Using Cartographic Animation to Explore Remotely-Sensed Data

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This research describes a geovisualization tool that is designed to facilitate exploration of satellite time-series data. Current change-detection techniques are insufficient for the task of representing the complex behaviors and motions of geographic processes because they emphasize the outcomes of change rather than depict the process of change itself. Cartographic animation of satellite data is proposed as a means of visually summarizing the complex behaviors of geographic entities. Animation provides a means for better understanding the complexity of geographic change because it can represent both the state of a geographic system at a given time (i.e. its space-time structure) and the behavior of that system over time (i.e. trends). However, a simple animation of satellite time-series data is often insufficient for this task because it overwhelms the viewer with irrelevant detail or presents data at an inappropriate temporal and spatial resolution. To solve this problem, dynamic temporal and spatial aggregation tools are implemented with the geovisualization system to allow analysts to change the resolution of their data on the fly. These tools provide (1) a means of detecting structures or trends that may be exhibited only at certain scales and (2) a method for smoothing or filtering unwanted noise from the satellite data. This research is grounded in a delineation of the nature of change, and proposes a framework of four kinds of geographic change: location, size/extent, attribute and existence. Each of these kinds of change may be continuous (a process) or discrete (an event).

Keywords: cartographic animation, change-detection, temporal and spatial resolution, data filtering, time series analysis, remote sensing, NDVI

INTRODUCTION

It is has been said that the only constant in the universe is change. This is certainly true of geographic systems, many of which are in a constant state of change. As geographers tackle larger and more complex problems—such as global warming—there has been a shift from studying spatial *patterns* to studying space-time *processes* (Graf and Gober 1992). Advanced statistical and computational modeling have allowed geographers to explore and better understand how geographic systems function. As the kind of phenomena geographers study change, so too does the nature of the maps needed by geographers. One reason that studying geographic processes is challenging is the sheer number of interactions that occur within systems and the enormous range of scales over which those interactions take place (e.g. from the molecule to the globe). Representing these interactions graphically is a significant cartographic challenge. Mapping a static world is difficult enough; mapping a dynamic one introduces new orders of complexity to our cartographic abstractions.

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This paper reports on the potential use of animation as an exploratory visualization tool in change detection research utilizing remotely sensed imagery. To this end, a prototype geovisualization environment has been built to allow users to dynamically control both the spatial and temporal resolution of a raster-based animation. This tool is designed to help users visually explore the effects of changing voxel size on multi-temporal remote sensing data (as used here, a voxel is a two-dimensional pixel with a temporal extent). Such explorations are potentially useful in two ways. First, they may allow users to determine the optimal scale of analysis when working with multi-temporal raster data, and second, they may help users to formulate specific hypotheses about the behavior of geographic entities represented within the data.

Tools that allow users to 'see' patterns and extract meaning from large and complex data sets are increasingly necessary as the volume of data collected by satellites (among other sources) increases rapidly. The data amassed by NASA's *Earth Observing System* (EOS) alone exceeds 1250 GB per day (Meisner et al. 1999). Gahegan (1996 and 2000) notes that information filtering is one of the foundational goals of the emerging field of geocomputation. Innovative geographic and statistical representations, such as linked parallel coordinate plots (Edsall 1999), have already proven successful in this regard. The tool presented in this paper was built with a similar goal in mind: to facilitate exploration of large remotely-sensed data sets and to help filter unnecessary complexity from these data.

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Change is one of the fundamental elements of geographic process. The ability to recognize and track changes in complex physical systems is essential to developing an understanding of how these systems work (Yattaw 1999). Many of today's significant research challenges, such as resource management and environmental monitoring, depend upon integrating many kinds of change information collected at a variety of scales. Data collected by satellites is a rich source of spatio-temporal data and meets two necessary conditions for monitoring large-scale geographic phenomenon: (1) it is collected at regular time intervals, and (2) unlike data collected by ground-based observations, it is spatially continuous. In addition, platforms such as Landsat and AVHRR have been operational for over 20 years offering a 'deep' data set both spatially and temporally.

HOW DO WE CONCEPTUALIZE CHANGE?

Representing geographic change on maps requires an understanding of the various ways in which change can be conceptualized and measured. 'Change' is a vague word. A useful definition is "change refers to the fact that an object or phenomenon is altered or transformed into something different through the result of some action or process" (Hornsby and Egenhofer 2000, p. 210). At scales larger than the sub-atomic, change cannot take place without time.

Broadly speaking we can make a distinction between c*ontinuous change* (e.g. stream discharge) and *discrete change* (e.g. change in ownership of a parcel of land). Within these two categories, I propose there are four basic kinds of geographic change: location, shape/size/extent, attribute, and state/existence. These are defined in Table 1 and examples of each are provided. This is an object-oriented worldview, that is, the world is assumed to be composed of identifiable geographic objects such as trees, lakes and thunderstorms which can be distinguished from—and compared to—other objects. We notice a change in location when something moves *relativ*e to another object. In contrast, change in shape/size/extent is self-referential and does not require an external spatial referent, although it does require that we remember previous states against which we can compare the current state (t_1 versus t_2). Not all change requires motion. Change in attribute can occur in stationary objects or fields (i.e. temperature). A change of existence occurs when something is present that wasn't before (or *vice versa*). Change in existence is unlike the others in that it is measured at a nominal level.

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Change in . . .	Example	Level of Measurement
Location	The path of a hurricane	ratio data
Shape/Size/Extent	The areal extent and shape of a hurricane	ratio data
Attribute	Decreasing wind speed	ratio data
State/Existence	Downgraded to tropical storm	nominal data

Table 1. Types of Geographic Change

An important issue is whether cartographic animation is equally good at depicting each of these kinds of change. Furthermore, given that geographic systems usually exhibit multiple kinds of change simultaneously, how do we represent these changes *simultaneously* in an animated map?

CARTOGRAPHIC ANIMATION AND CHANGE DETECTION

Animation as a visualization technique has been widely studied and supported in cartography and geovisualization (Monmonier 1990, Slocum and Egbert 1993, Openshaw et al. 1994, Kraak and MacEachren 1994, Edsall et al. 1997). The idea of using a cartographic animation to *map time with time* is intuitively a good idea. Animations are "a scale model in both space and time" (Monmonier 1990, p. 40) and as such are powerful tools for depicting change information. Almost a decade ago Koussoulakou and Kraak (1992, p. 101) noted, "During the nineties important challenges to cartography will be related to mapping spatial data's multi-dimensional and temporal component. From a cartographic point of view it is necessary to look at the implications of the use of animated maps." However, as a recent research agenda by the ICA Commission on Visualization notes (MacEachren and Kraak 2001), progress during the past decade has been sporadic and many unanswered questions remain regarding the use of animation in geovisualization and the representation of dynamic geographic phenomena.

"The dominant approach in digital remote sensing has been to extract the change information computationally and then visualize the output as a single image, rather than as an animation."

Although a significant amount of research in digital remote sensing over the last 30 years has been directed toward developing robust change detection techniques (Jenson et al. 1997), very little of this work makes use of animation. The dominant approach in digital remote sensing has been to extract the change information computationally and then visualize the output as a single image, rather than as an animation. There are numerous change-detection techniques and according to Sunar (1998) most fall into one of the following categories: (1) classification comparisons, (2) principal components analysis (PCA), (3) image overlay, and (4) image differencing. New techniques continue to appear in the literature and some recent work has assessed the relative merits of the various techniques focusing, in particular, on accuracy and sensitivity (Collins and Woodcock 1996, MacLeod and Congalton 1998, Mas 1999). The popularity of these techniques stems from the fact that they work with a variety of data sets, provide replicable results and off-load much of the work to computers.

"A serious limitation of traditional approaches is their emphasis on measuring the outcomes *of change rather than representing the* process *of change itself."*

A serious limitation of traditional approaches is their emphasis on measuring the *outcomes* of change rather than representing the *process* of change itself. For example, classification comparisons can calculate how many pixels (and hence total area) have changed from wetlands initially (t_1), to farmland subsequently (t_2). This approach says nothing of what happened *between* t_1 to t_2, *how* the sequence of events unfolded, or *why*. Additionally, these techniques focus on only one kind of change: change in attribute (as measured by change in surface reflectance values) making it difficult to characterize motions or rates of change.

In most geographic phenomena change is ongoing (e.g. atmospheric motions, economic trends) and it is difficult to identify a discrete "beginning" and "end" to these processes. Change detection techniques such as image differencing and classification comparison work better with a discrete view of change ("an event," "before and after") than with a continuous view of change ("a process"). Current techniques that emphasize the outcomes of change and ignore the process itself seem insufficient if we wish to describe the behavior of geographic phenomena and their relative motions, or provide a visual summary of temporally-dependent interactions. An animation, it is argued, is a much better tool for depicting and understanding more abstract notions of change—such as the behavior of an El Ninõ—than a single "difference image" derived from two time periods.

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How Animation Can Contribute

Methodologically, this paper proposes a union of the computational rigor of remote sensing with the exploratory power of geovisualization. Geovisualization is fundamentally concerned with leveraging the pattern-recognition and information-extracting abilities of the eye-brain system and giving the user the tools to visualize and explore complex data sets in the hopes of discovering new insights (MacEachren 1995). In the early stages of research, geovisualization can be used to form hypotheses about the behavior of complex geographic systems especially when formal (i.e. testable) hypotheses about those systems are lacking (MacEachren et al. 1992, Hearnshaw and Unwin 1994, Gahegan et al. 2001). Later in the research process, geovisualization may be used to confirm, synthesize, and ultimately present ideas and information (DiBiase 1990). Thus, visualization is potentially helpful in all stages of the knowledge construction process.

Animation is a visual tool that is well-suited to qualitative analysis. Preliminary research has shown that animation can reveal subtle space-time patterns that are not evident in static representations, even to expert users who are highly familiar with the data (MacEachren et al. 1998). As conceived here, animation can be used as an exploratory first step in the change detection process. Because cartographic animation by itself does not generate quantitative data—such as a count of the number of pixels that have changed from wetlands to farmland—it cannot replace numerical/computational techniques. Rather it is a complementary "first look" allowing analysts to *see* what is happening in a data set before performing image analysis.

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This "first look" may be helpful in two ways. First, it may help to reveal complex behaviors or patterns not evident in static representations or that might be missed with traditional change-detection algorithms. For example, there may be small regions within the imagery that behave atypically, perhaps only during certain time periods, and this insight might get lost in a non-visual approach. Second, animation may be used to establish formal model parameters, such as optimal pixel size, which can lead to better results with traditional change detection techniques. The prototype visualization system presented below is designed to illustrate both of these advantages.

EXAMPLE PROBLEM: SCALE OF ANALYSIS

The are two kinds of scale in multi-temporal satellite imagery. The spatial resolution is determined by the pixel size, which with the current generation of civilian satellites ranges roughly from 1 meter (IKON sensor) to one kilometer (AVHRR sensor). The temporal resolution is determined by the orbital characteristics of the platform, which ranges from continuous with geostationary satellites (e.g. GOES weather satellites), to 18 days (e.g. Landsat). How often a satellite passes over a certain area determines the base sampling rate for change detection research. The more often a satellite surveys a region, the more temporal information is available to the analyst, and the chances of collecting cloud-free imagery are increased which decreases the likelihood of long gaps in the temporal record. Persistent cloud contamination is a serious issue in maritime and tropical regions and temporal and spatial interpolation is often required to fill the gaps (Meisner et al. 1999). In addition to interpolation, raw satellite data can also be aggregated spatially to create larger pixels, and temporally to create temporal averages.

"Scale is a critical and difficult issue to resolve in geographic analysis because scale constrains the questions we can ask and the answers we are likely to generate."

Raw satellite data is often very "noisy" and both spatial and temporal aggregation is necessary to extract a more "stable signature" and eliminate short-term and random fluctuations. The amount of aggregation is related to what the analyst is studying: how large the phenomenon of study is and how quickly it changes. For example, continental-scale landcover studies do not require 1-meter daily imagery. Temporal composites of 10-day (Yang *et al.* 1997), 30-day (Anyamba and Eastman 1996), or even yearly averages (Batista *et al.* 1997) are more appropriate to study long-term surface variations in landcover. Similarly, the spatial resolution of landcover studies is typically fairly coarse (1km to 100 km pixel).

Scale is a critical and difficult issue to resolve in geographic analysis because scale constrains the questions we can ask and the answers we are likely to generate (either visually or numerically). With satellite imagery it is difficult to determine the optimal scale of analysis for a specific research investigation. For example, what is the best pixel size to study the effects of forest fires? What is the optimal sampling frequency for monitoring ocean temperatures? Does it matter what part of the globe is being monitored (e.g. arctic versus tropical)? Does the optimal scale of analysis change throughout the year (e.g. winter to summer)? There are few rules to guide the selection of appropriate pixel size in change-detection research. Choosing the optimal scale of analysis depends largely on experience, convention and the nature of the raw data. One solution presented here is to employ dynamic temporal and spatial filtering tools that allow users to easily change the resolution of their data and view the results.

VOXELVIEWER: A PROTOTYPE VISUALIZATION SYSTEM

The VoxelViewer is a prototype visualization system designed to let analysts explore the effects of temporal and spatial scale in multi-temporal satellite imagery. It is also designed to afford analysts the opportunity to visually explore their data and observe how features change over time and across space. Figure One shows the system interface.

"Choosing the optimal scale of analysis depends largely on experience, convention and the nature of the raw data."

VoxelViewer was built using Macromedia Director 8 multimedia software. This raster-based authoring environment allows for the rapid development of multimedia cartographic tools that integrate maps, sounds, text, and movies. Unlike a GIS-based mapping system, Director is not data-driven and there is no georeferenced database underlying the map. Instead, the various elements of the animation (movie clips, sound files) are created elsewhere and assembled in Director. Director's scripting language *Lingo* is used to coordinate the various elements and determine how the system behaves, for example, when a user clicks on a button. Director gives the cartographer greater flexibility than a typical GIS package in designing the "look and feel" of the system. Building applications in Director is also significantly faster than working in a full programming language

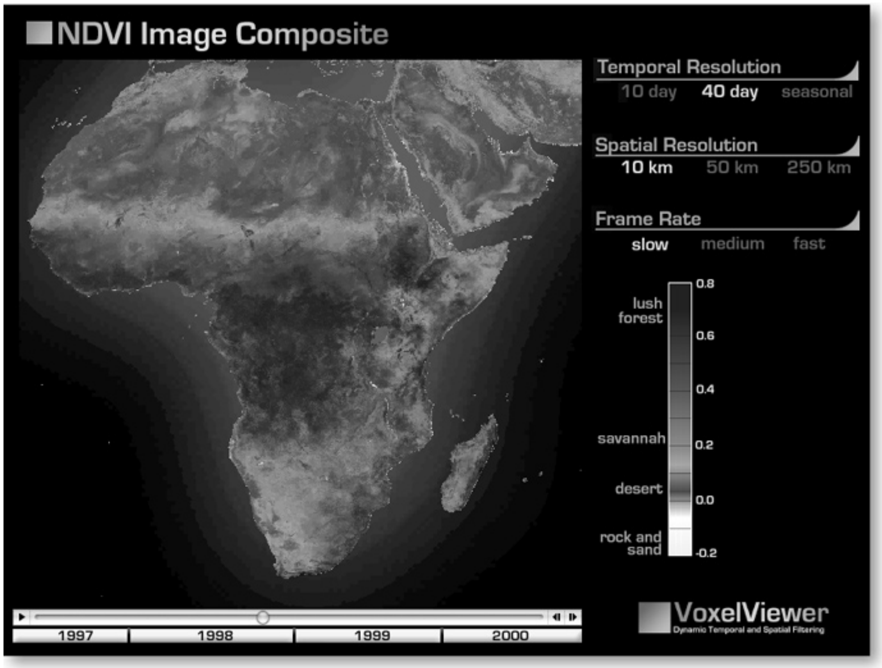

Figure 1. The VoxelViewer interface allows users to watch an animation and control the pace, pixel size, and temporal resolution of the data.

such as Java or Visual Basic because (1) it is at least an order of magnitude less complex and (2) Macromedia includes numerous "libraries" which contain pre-scripted behaviors and graphics (such as roll-over buttons). Lastly, Director creates web-friendly applications which can be viewed by any web browser with the *Shockwave* plug-in (currently estimated to be installed on 95 percent of web browsers) reassuring the designer that their work will be easy to disseminate and viewable by many.

Photoshop 6 was used to storyboard the VoxelViewer and design the various interface components. This raster artwork was imported into Director and used as "cast members" in the animation. The faded ocean halo in each image was created in Photoshop (see Figure One), which was saved as an "action" and used to batch process the remaining images. Approximately one thousand images were created and the powerful batch processing capabilities of Photoshop were an asset in this project. The individual images were converted to QuickTime movies using GraphicConverter 4.0. These files were further compressed and optimized for web-delivery using Media Cleaner 5. The VoxelViewer has a total size of 35MB due to the size and number of raster movies it contains.

"Any time-series satellite data could be used with the VoxelViewer."

The Data

Any time-series satellite data could be used with the VoxelViewer. For demonstration purposes the Normalized Difference Vegetation Index (NDVI) was chosen. The NDVI has become an increasingly popular tool for studying climate variations (Carleton and O'Neal 1995) and changes in landcover characteristics (Ehrlich and Lambin 1996, Liu and Kogan 1996). The NDVI was originally designed for measuring biomass and plant vigor. Common space-borne platforms that can be used to create NDVI images include Landsat TM and MSS, Spot, and AVHRR. Of these, AVHRR is perhaps best suited to long-term surface change studies because of its unparalleled daily global coverage, suitable resolution of 1.1 km at nadir, and an unbroken 20+ year record from the entire fleet of AVHRR satellite. Best of all, the data are available free of charge.

The base data in the VoxelViewer are 10-day cloud free composites with approximately a 10km resolution. These particular data cover the entire continent of Africa over a 3 year period from July 1997 to July 2000 — a sufficiently long sample period to capture both short- and long-term variation. Due to cloud cover it is not possible to study continental-scale phenomena using daily imagery. Instead, cloud-free 10-day NDVI composites are used and represent the finest temporal granularity of the data in the VoxelViewer. These composites are produced by retaining the single highest NDVI value for each location per 10-day period. This ensures that the retained pixels represent surface features because clouds produce low NDVI values and only vegetation produces high NDVI values. The final images use a false color assignment that reflects perceptions of landcover — regions with abundant vegetation are dark green (positive NDVI values), grasslands are light green, and rock and sand are white and gray (negative NDVI values).

"Spatially re-sampling imagery—such as changing 1km pixels to 10 km pixels—is a computationally intensive process."

The images used in the VoxelViewer were retrieved from the Goddard Space Flight Center Earth Sciences Data and Information Services Center Distributed Active Archive Center (DAAC). This organization produces many kinds of free and web-accessible AVHRR products as part of its Global Biosphere Program. Daily and ten-day NDVI products of each continent can be found at http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/BRS_SRVR/avhrrbrs_main.html.

Since the VoxelViewer is a prototype system built in Director 8 there is no real-time interpolation of the raster imagery. Instead, the VoxelViewer gives the impression that the data are interpolated on-the-fly by swapping in the appropriate QuickTime movie. Each frame of every animation had to be created beforehand which is clearly not practical for a functional visualization system. Spatially re-sampling imagery—such as changing 1km pixels to 10 km pixels—is a computationally intensive process. Re-sampling the imagery through time (across frames) makes this task even more demanding. In batch-processing mode, each frame in the VoxelViewer took approximately 5 seconds to be re-sampled on a fast desktop machine. It would be impossible to generate 15 frames-per-second animation rates on anything less than a SGI supercomputer if the imagery had to be read, re-sampled, colored, and rendered on-the-fly. With current desktop hardware this kind of performance is impossible. However, it is likely that at the current rate of CPU development, affordable desktop computers capable of such "supercomputer" feats are not far away. The VoxelViewer is designed as a "proof of concept" for dynamic spatial and temporal resolution tools: do they help analysts, do they compliment current tools, and if so, could such tools be built into future releases of visualization software such as GeoVISTA *Studio* developed at Penn State (http://www.geovistastudio.psu.edu).

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The Visualization Tools

The VoxelViewer incorporates two kinds of dynamic temporal and spatial filtering tools (Figures Two and Three). These allow users to adjust the pixels size from 10 km to 250 km, and the temporal interval from 10 days to 80 days. Increasing the spatial resolution of the data reduces spatial heterogeneity and creates more stable NDVI signatures. There is an inverse relationship between pixel size and NDVI signature stability: larger pixels are larger spatial samples which average together a greater variety of landcover types. Unfortunately, this decreases the chance of a single pixel representing one landcover type (i.e. the entire pixel is urban). Increasing the temporal resolution has a similar effect. Pixels which are derived from more samples over time reduce shorter-term fluctuations and create smoother looking animations, albeit animations with less temporal resolution. The user is encouraged to download a copy of the VoxelViewer from http://www.geovista.psu.edu/members/harrower/voxelViewer.html

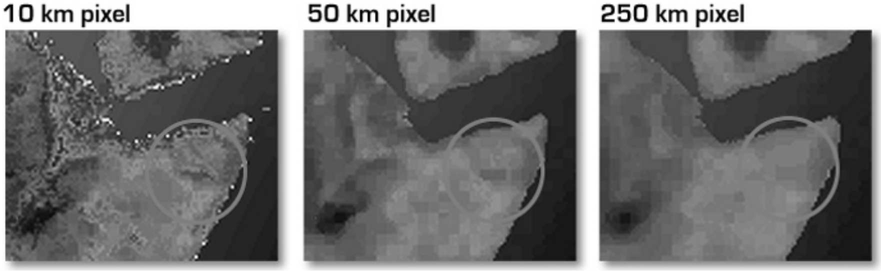

Figure 2. The effect of changing pixel size, or spatial resolution, is apparent with the successive loss of fine details in the Horn of Africa.

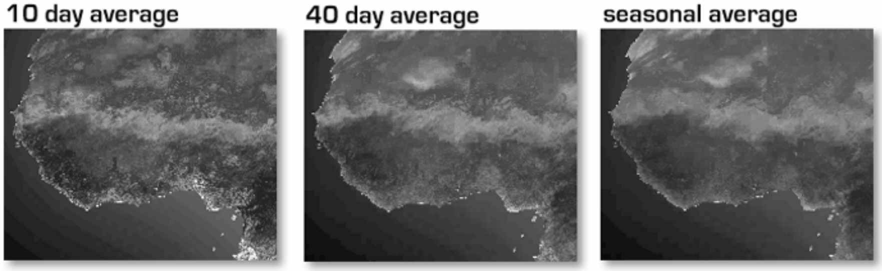

Figure 3. Spatial heterogeneity decreases with temporal aggregation. The ability to filter short-term fluctuations in the NDVI results in smoother looking maps of vegetation.

Interactivity can be enhanced if interface elements provide both visual and audio cues (i.e. simultaneously 'flash' and 'beep' when pressed). This is important (1) to help distinguish interactive elements (e.g. slider bars) from non-interactive elements (e.g. a color legend); (2) to provide unambiguous feedback to the user that their action (a button press) has initiated a response (load a new movie); and (3) to prevent users from clicking on multiple elements in frustration or ignorance, especially if the system does not respond immediately to all requests. A system that provides immediate responses—even if it is a simple as a "loading data" message—should increase user confidence in a new system.

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Previous research (Harrower et al. 2000) has demonstrated the importance of interface elements that provide clear "on" and "off" states. The VoxelViewer relies on a scheme of "grayed-out" buttons for the off state and white buttons for the on state. In addition, the decision was made to display all of the possible spatial, temporal, and tempo choices on the screen at once, arranged in a line under subheadings (Figure One). This approach is favored over pull-down menus because it acts as both an interface and a data legend: the entire range of possible settings is always displayed and the current setting (e.g. 10km) can be compared to the entire range at a glance. By comparison, pull-down menus only communicate the current selection while in their rest state. One advantage of pull-down menus is their smaller footprint in the interface.

Example Insights – Changes in the Sahel

One of the most dynamic features in the imagery of Africa is the region called the Sahel that separates the Sahara Desert to the north from to the south. The Sahel is a semi-arid region that periodically experiences drought causing hardship to the rural poor who live there. The location of the semi-arid transition zone between the Sahara and the forest of central Africa shifts with the seasons, moving north during the monsoon summers and south during the winter. By animating images over many years it is possible to see that the annual migration of this transition zone is different year-to-year, which is related to—at least in part—larger climatic teleconnections (e.g. El Ninõ - Southern Oscillation events). Moreover, the north-south extent of this transition zone varies from year to year, being more compressed in wet years, and less compressed in dry years (Figure Four).

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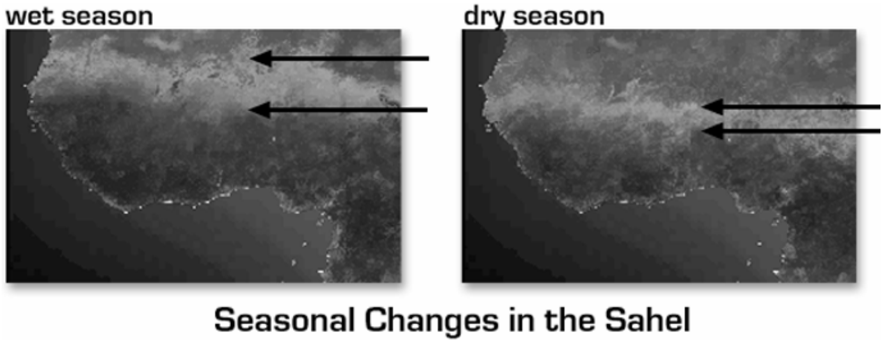

Figure 4. The complex changes of the Sahel region can best be seen in a 15 fps animation loop using 40-day averages with a 10 km pixel. The areal extent and latitudinal position of the upper and lower boundaries of the semi-arid region fluctuate seasonally and yearly.

The motion of this semi-arid transition zone is most vividly depicted at a spatial scale of 10 km and a temporal scale of 40 days, animated at high speed. With this presentation a new behavior emerges. The northern and southern boundaries do not move in unison. Rather, there is a temporal lag in which the southern boundary moves northward first (since the monsoon rains arrive from the south) compressing the region before the northern boundary expands into the desert. The southern boundary is also the first to retreat southward with the onset of the dry season. It is difficult to see this space-time pattern at other resolutions and it would be easy to miss the behavior entirely if not for animation. This demonstrates that some space-time patterns and behaviors are more readily observed at certain spatial and temporal resolutions than others.

". . . perceptual theory and experimental testing indicate that people can both understand and utilize animated graphics."

DISCUSSION

Although this paper does not present the results of formal user testing, perceptual theory and experimental testing indicate that people can both understand and utilize animated graphics. Perceptually, human vision is "hardwired" with special sensors to detect motion (Gregory 1998). Motion, such as that exhibited by the shifting vegetation patterns in Africa, is a powerful visual cue that allows us to identify objects as separate from background and to create perceptual groupings of objects. It stands to reason that because we live and function in a dynamic world, we have the required perceptual and cognitive abilities needed to understand dynamic maps. So what evidence exists to support this belief?

The Conceptual Congruence Hypothesis states that static graphics such as maps should be effective in conveying concepts that are literally or metaphorically spatial, and animated graphics should be effective in conveying concepts that are dynamic (Morrison 2000). In other words, the concept of change is *more cognitively congruent* with an animated map than it is with a static map or a textual description. This sentiment is shared by Blok et al. (1999, p. 140) who state, "In animation, a direct link can be made between the changes of characteristics in world time and their representation in display time…animated mapping thus allows a person to see the data in a *spatial* as well as a *temporal* context." Experimental evidence exists that teaching information about motion (e.g., Newton's laws of motion) with animation leads to better performance than teaching the same information with text or static graphics (Rieber 1990, Hays 1996). Evidence also exists that animation results in better performance on memory-recall tasks as compared to learning from static graphics (Rieber 1990). Animated graphics thus seem better able to communicate concepts of motion and change than static graphics.

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Within cartography, the effectiveness of animated maps has been demonstrated by Patton and Cammack (1996) who found that sequenced choropleth maps resulted in better map-reading performance among non-experts than traditional static maps, in terms of both speed and accuracy on skill-testing questions. Koussoulakou and Kraak (1992) found that animated maps resulted in faster response times to questions than did static maps, but only when the users could control the animation. These results were supported by Monmonier and Gluck (1994) who noted that viewers are often frustrated by complex changing maps that they cannot control, with the map proceeding too slowly for some tasks and too quickly for others. This frustration has lead most cartographers to recognize the need for some form of user control including at least stop, start, and temporal navigation controls. VoxelViewer incorporates these basic navigational controls in addition to innovative temporal and spatial filtering mechanisms. Interactive animated maps draw viewers "into the map" and allow them to become active participants in the display of the information rather than merely passive observers. It has been demonstrated that animated maps "enhanced" with innovative temporal and spatial controls can lead to more detailed understandings, but only if the participants know *how* and *when* to use those tools (Evans 1997, Harrower et al. 2000). The potential power of animated maps lies in their ability to represent change over time and thus facilitate an understanding of process rather than state.

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CONCLUSIONS

Change detection is an important area of research relevant to many geographic fields. Current change detection techniques that stress the *outcomes* of change rather than the *process itself* make representing the complex and dynamic behavior of geographic entities difficult. Animation is a tool that is well-suited to representing dynamic phenomena. Animation used as an exploratory geovisualization tool allows users to analyze their data in a qualitative (visual) manner and potentially generate new insights related to motion and space-time patterns. However, animation by itself is insufficient for the task of change detection as the sheer size and complexity of raw satellite imagery would most likely overwhelm the perceptual abilities of the user with random and short-term fluctuations. Tools that allow users to "filter out the noise" are needed. This paper has presented a geovisualization system that can adjust the temporal and spatial resolution of satellite data and perform this data filtering. This system can also be used to determine the optimal spatial and temporal resolution for a given phenomena, region or data set.

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