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A Cartographic Animation of Average Yearly Surface Temperatures for the 48 Contiguous United States: 1897-1986 (91-3)

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A Cartographic Animation of Average Yearly Surface Temperatures for the 48 Contiguous United States: 1897-1986

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ABSTRACT

Animation is an important method of communicating information that lends itself to cartographic display. Exploration of this medium resides at the forefront of cartographic research. The purpose of this project has been to develop a viable cartographic animation process employing hardware and software currently available in the Geographic Information and Analysis Laboratory (GIAL) at the Department of Geography, State University of New York at Buffalo. Successful utilization of the process has produced an animation that displays the spatial distribution of average yearly surface temperatures across the U.S. for the 90 year period, 1897 through 1986.

The production of an animated surface temperature map was prompted by personal concern about the possibility of global warming resulting from increased concentrations of anthropogenic greenhouse gases in our atmosphere. Understanding of this greenhouse phenomenon and its consequences is dependent upon the dissemination of information regarding the event and its consequences. Animated cartography offers the opportunity to communicate in such a manner.

KEYWORDS

Cartographic animation, spatiotemporal. display, real time, computer animation, global warming, greenhouse

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1. CARTOGRAPHIC MOTIVATION

The purpose of this research has been to develop a viable cartographic animation process employing hardware and software currently available in the Geographic Information and Analysis Laboratory (GIAL) at the Department of Geography, State University of New York at Buffalo. Additionally, utilization of the process has produced an animation that displays the spatial distribution of average yearly surface temperatures across the U.S. for the 90 year period, 1897 through 1986.

Animation is an important method of communicating information that lends itself to cartographic display. Cartographers may be delinquent in their utilization of this technique. Meteorologists, medical researchers, and physical scientists, employing mini-, mainframe and super-computers, are creating today's most sophisticated animated maps and continue to develop the most sophisticated systems for display of their data. Though today's cartographers are rightly concerned with the geometric accuracy and computer automation of their map products, they may be overlooking current developments in spatiotemporal display within other disciplines. Creating a method to bridge the current animation gap between cartography and these disciplines has been a primary goal of this project.

Personal computers are the platforms most commonly available to cartographers. The development of animated cartographic displays is feasible with this technology. As a result of this project, a micro-computer animated map of U.S. surface temperatures was designed so as to contribute to an understanding of climatic change during the twentieth century.

The production of an animated temperature map was prompted by personal concern about the possibility of global warming resulting from increased concentrations of anthropogenic greenhouse gases in our atmosphere. Understanding of this greenhouse phenomenon and its consequences by both scientist and general public depends upon the dissemination of information regarding the event and its consequences. Animated cartography offers the opportunity to communicate in such a manner.

Nonlinear feedbacks within atmospheric systems make statistical prediction and observation of the global warming event difficult at best. Therefore, it has been the intention to produce an animation which sheds light upon the event by mapping the distribution of surface temperatures in the forty-eight contiguous United States. The animation reflects not only the yearly temperature increases and decreases, but also highlights the existence of underlying variance in spatial temperature distributions which do not reveal themselves in yearly, average temperature calculations. The animation offers an alternative view by which to recognize sequences of change and thereby affords the opportunity to formulate spatial hypotheses about temperature ranges and distributions. Additionally, the animation technique can provide a mechanism to identify some types of error in spatiotemporal data, demonstrating its utility as a method for display of data and of data quality.

1.1 GLOBAL WARMING

The greenhouse effect is both real and active on our planet. In 1988, the United Nations convened the Intergovernmental Panel on Climate Change to review the existing scientific evidence of global wanrming. The panel's two hundred scientists reported with 95% consensus that, if the current growth rate of 0.4 percent per year continues, tropospheric concentrations of carbon dioxide will double by the third quarter of the 21st century (Flavin and Lessen 1990).

Atmospheric carbon dioxide concentrations of 351 parts per million (ppm) are already higher than at any time in the past 160,000 years (Barnola et al. 1987). Parallel trends in carbon dioxide and temperature records during this period are shown in figure 1.1. Twenty percent of this concentration has accumulated since the beginning of the industrial revolution, and half of this increase has occurred in the past 30 years alone.

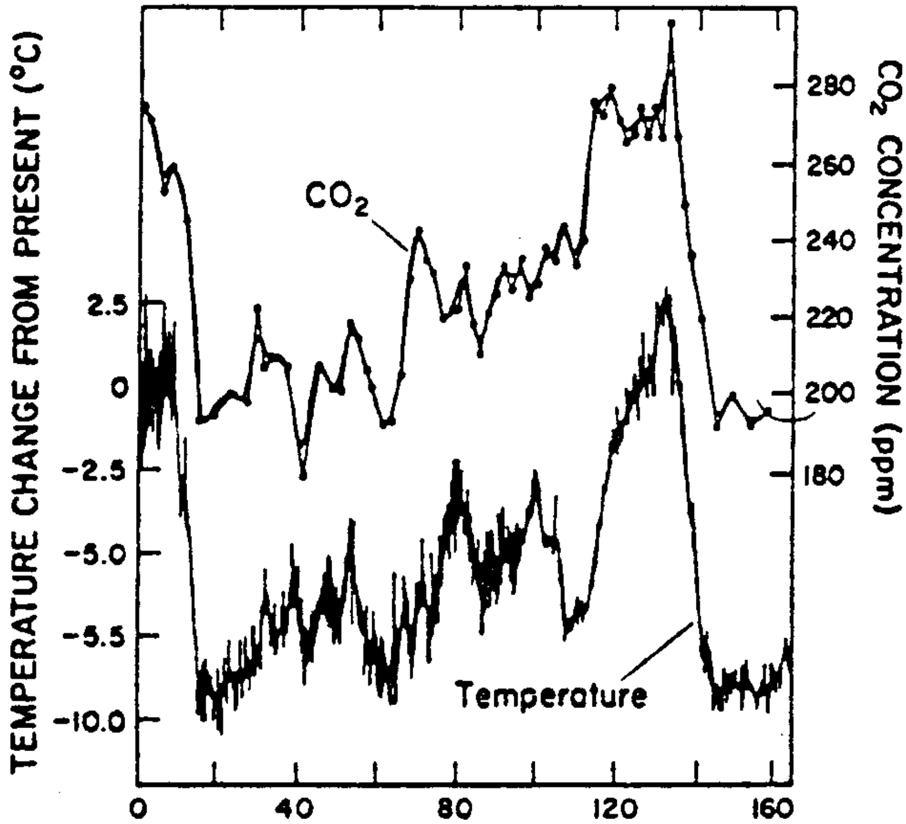
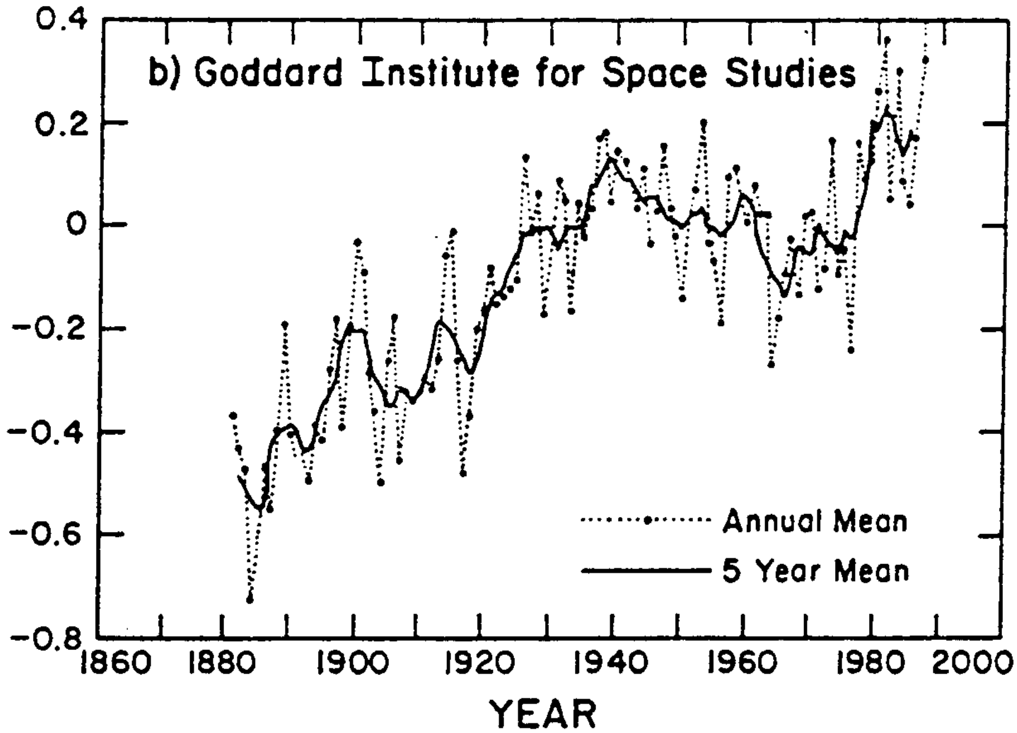


Figure 1.1 Temperature change (degrees C) and Carbon dioxide concentration in parts per million (ppm) for the past 160,000 years (Barnola et al. 1987)

Though the most common, carbon dioxide is not the only greenhouse gas of concern. Atmospheric concentrations of methane have more than doubled their preindustrial levels and are growing at a rate of one percent annually (Houghton and Woodwell 1989). Molecule for molecule, methane is 20 times more effective than carbon dioxide in absorbing terrestrial longwave radiation. Likewise, chlorofluorocarbon (CFC) concentrations are growing at 5% per year. An incremental CFC molecule will trap 20,000 times as much longwave radiation as would a carbon dioxide molecule (Swaminathan 1990).

Recent studies show that, while average global surface temperatures have been on the rise for the past 100 years (figure 1.2, Schneider 1989a), the mean annual temperature of the contiguous United States has not changed significantly during the past 40 years (figure 1.3, Plantico et al. 1990). This local stability may be due to an increase in low level cloud cover over the U.S. (Plantico et al. 1990). Additionally, though large global temperature variability was recorded by satellite on weekly to multi-yearly time scales from 1979-1988, no obvious temperature trend has been noted for this 10-year period (Spencer and Christy 1990). However, this stability appears directly after a sudden jump in U.S. surface temperatures at the end of the 1970's. Global temperature records show that six of the warmest years on record have already occurred within the past 11 years; in descending order they are 1988, '87, '83' 8l' 89'and'80 (Houghton and Woodwell 1989). Such aggregations of record years go beyond the normal variability expected and are in line with warming predictions (Monastersky 1988). If greenhouse gas concentrations reach twice their pre-industrial level in the next century, average global temperatures may increase by 2.7 to 8.1 degrees Fahrenheit. These temperatures will be far higher than any experienced in the previous 10,000 years (Washington Post 1990, Swaminathan 1990).



Fgure 1.2 Global surface temperature deviation (degrees Centigrade) from the Goddard Institute for Space Studies 1988 (as reproduced in Schneider 1989a)

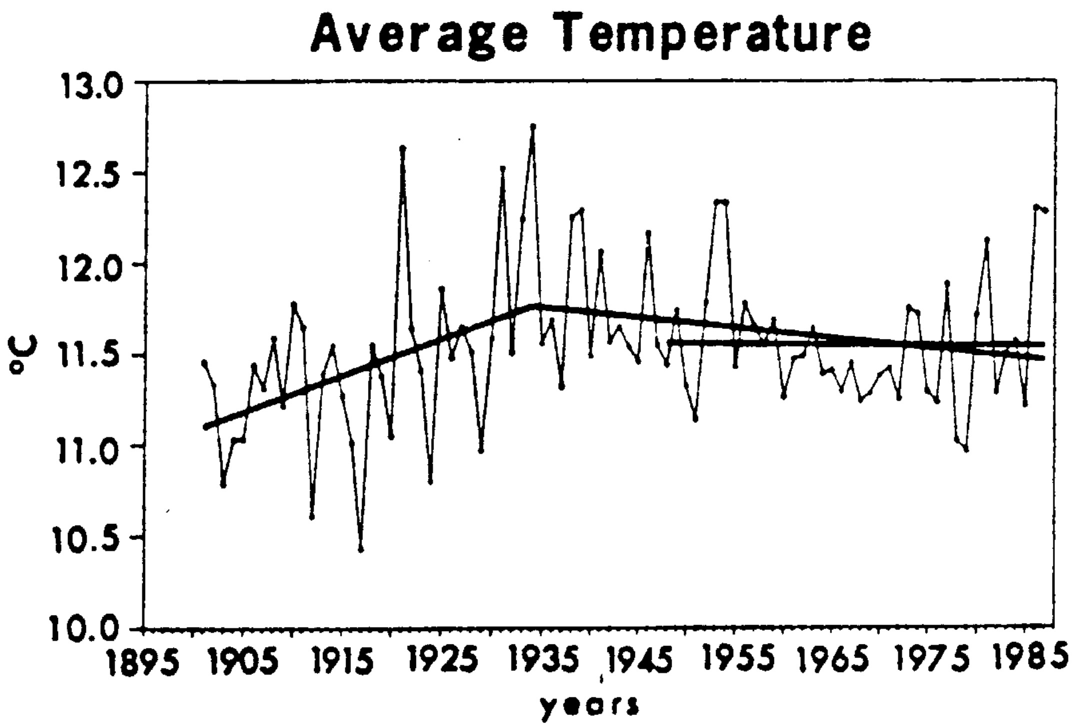


Figure 1.3 Average Contiguous U.S. temperature (degrees C), 1895-1985 (Plantico et al., 1990)

1.2 Nonlinear Possibilities

Is a slow but continuous global warming from greenhouse gas concentrations the only possible scenario? It is important to remember that our atmosphere is only one element of the earth system, and as such is interdependent with the oceans, geo-sphere, and biosphere. It is only one element of an intricate, non- linear system with numerous feedback loops and event cusps (Lorenz 1963, Lovelock 1979, 1988, Lovelock and Whitfield 1982). There are key uncertainties within General Circulation Models (GCMs) due to their inability to account for the complex relationships within the earth system. If these phenomena are not represented accurately in the GCM equations, unforeseen feedbacks may lead to spurious results (Schneider 1987). Furthermore, sudden or very large parameter changes in nonlinear systems can cause chaotic effects (Ruckenstein 1990). Accounting for this myriad of variables is the immediate challenge of GCM research (Schneider 1989b).

1.3 Falling Dominoes

The intricate forces at work within the earth system may mean that the global warming now under way will riot continue in a predictable, linear fashion. Magnification of greenhouse effects could result from feedback loops within ocean, atmospheric and terrestrial realms. Examples of these phenomena are numerous within the climatologic literature, as discussed below:

Initial atmospheric warming could melt sufficient fresh water ice to alter deep water formation, because less saline surface waters at high altitudes might not gain the density needed to submerge. This effect may have precipitated the rapid changes in climatic conditions that have signaled the end of past ice ages (Hileman 1989). Minor changes in ocean temperature could also alter the ocean from a carbon dioxide sink to a significant source emitting enough atmospheric carbon dioxide to dwarf that contributed by man (Swaminathan 1990).

Greenhouse gas concentrations may also increase low cloud cover through enhanced evaporation of ocean water. The greenhouse effects of clouds are large compared with those of the greenhouse gases themselves. A recent satellite-borne experiment showed that on a scale where the warming effect of carbon dioxide doubling is 1, the cooling effect of consequent cloud cover is 11 and the warming effect is 7. The net result is a cooling trend four times as large as the warming expected by the carbon dioxide doubling (Ramanathan et al. 1989).

Plant growth rates can be stimulated by increased carbon dioxide concentrations thereby slowing the build-up by acting as a carbon dioxide sink. Evidence of an increase in Northern Hemisphere carbon dioxide uptake during the growing season may indicate a sink effect (Hileman 1989, Rosenzweig 1990). Alternatively, the uptake may be matched by increased respiration with no net gain in storage. Continued temperature rise would then increase methane and carbon dioxide releases from plant decay. Methane is 20 to 30 times more efficient than carbon dioxide at absorbing longwave radiation and, as a byproduct of decay, would accelerate the warming trend (Houghton and Woodwell 1989). Forest extinction due to temperature rise may not be matched by plant migration from lower latitudes and altitudes, thereby resulting in a gap in surface plant coverage and a loss of a potential carbon dioxide sink. This loss would further accelerate carbon dioxide build-up and temperature rise (Roberts 1989).

These examples show that the myriad of potential climatic states is a factorial product of the forces at work within the earth system. It may never be feasible to accurately predict the yearly, global climate. It may only be viable to predict the possible range of outcomes. Information aiding in the prediction of future trends can often be gained by charting the past. This project's secondary goal has been aimed at fulfilling that demand.

The graphic expression of climatologic data which describe the spatiotemporal phenomena of temperature has been achieved through a cartographic animation. The animation process allows the cartographer to produce a temporal map of past temperature trends from point data. These data have been collected in a systematic method for over 90 years, yet visualization of them has been, until now, primarily limited to static maps. An animated overview of these static representations provides clues as to the type of spatial distribution resulting from the point data, especially during aberrant warm and cold periods. The visualization of these data allow the scientist to explore the virtual world created through the mapping process which, in turn, may lead to new questions and answers to spatial inquiries.

2 THE EVOLUTION OF CARTOGRAPHIC ANIMATION

2.1 Nomenclature

A discussion of the evolution of cartographic animation necessitates an understanding of the varied terminology. The five phrases "cartographic animation", “map animation", "four-dimensional cartography", "dynamic mapping", and "spatiotemporal display" may all refer to cartographic displays having a succession of maps pertaining to the same area whose content changes in relation to the independent variable, time. Beyond this basic definition, however, "dynamic mapping", and "spatiotemporal display" have additional connotations.

In some discussions "dynamic mapping" may refer to a situation in which there exists an interactive capability within a system for altering the portrayal of map data (Dunn 1989, Moellering 1980b). Monmonier (1989,1990) describes "spatiotemporal displays" as multi-windowed displays having animated graphics or statistical diagrams which may replace or supplement the map as temporally dependent elements. Both "dynamic mapping" and "spatiotemporal display" reside within the realm of this research. To alleviate confusion, both terms will refer to their respective alternate definitions.

Another phrase needing clarification in the cartographic animation literature is "real-time". Basically, it implies that some aspect of the animation system responds to user commands without undue delay. It may refer to the state in which cues from interactive drawing capabilities are immediately carried out (Moellering 1980a, 1980b), the ability to animate flip-art images stored electronically in memory on a CRT in a timely fashion (Sherretz and Fulker 1988), or the ability of a system to produce consecutive maps on a CRT directly from data files in an automated, timely fashion (11ibbard 1988).

The increased popularity of computer generated mapping systems during the '70's and '80's pressed the philosophical question of whether or not CRT images, holograms, and animations capable of being manipulated in "real-time" were fundamentally different from paper maps. Their status as "real" map products was at question. To traditional cartographers who valued the detailed intricacies of tangible paper maps it was an important differentiation.

The same characteristics of animated maps that demand specialized symbolization and content have led to a new nomenclature that defines map products according to their permanent tangible reality and their ability to be directly viewed as cartographic images (Moellering 1980b). Moellering has defined **Real maps** as cartographic products that are directly viewable as cartographic images in hard copy. Those that are directly viewable only as a transient CRT image are defined as **Virtual maps-type I. Virtual maps-type II** are those that have a permanent tangible reality but are unable to be viewed without intermediary processing. Computer based information which can be transformed into a real map as easily as the other two classes of virtual maps is classified as **Virtual maptype III** products (figure 2. 1).

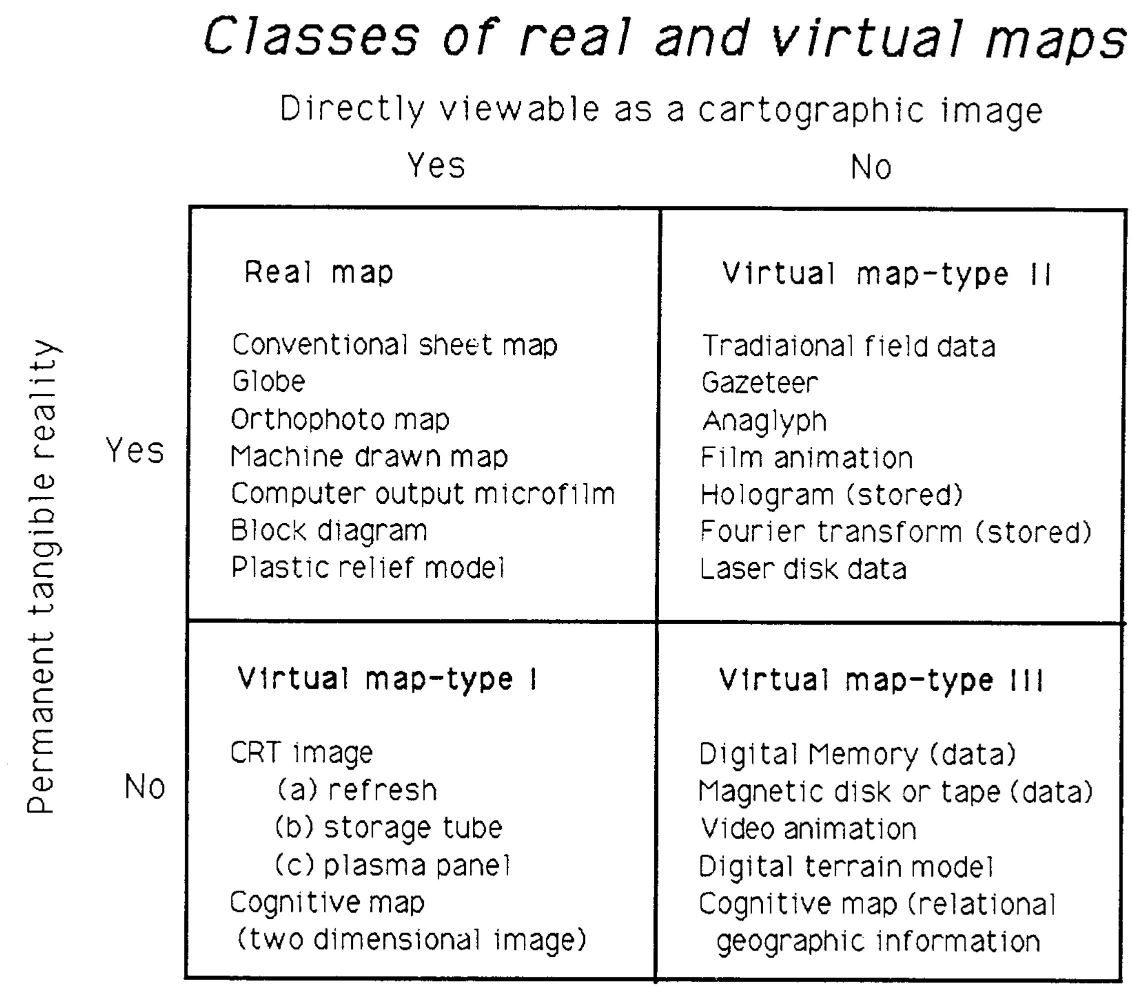


Figure 2.1 (reproduced from Moellering 1980a)

The evolution of animated mapping may be investigated through a series of interrelated topics discussed in the cartographic literature since the early 1960's. Each has contributed to the technological and theoretical conditions that made this project possible. These topics include:

a) the conception of animated mapping and the generation of cel animations by cartographers and meteorologists.

b) changes in hardware and software applications which have. fertilized the evolution, and the demands made by animators that prompted those changes

c) cartographic research on symbolization, color, map content and autocorrelation

d) real-time animations and future research

Each topic will be dealt with in turn, although they are chronologically and substantively related, causing some cross-over in the literature review.

2.2 The Conception of Animated Mapping and Early Productions

The advantages of cartographic animation have been propounded since the early 1960's. Thrower (1959, 1961) recognized the importance of sequential map series for showing changing phenomena, but also noted that the viewer needed to infer continuity between the individual maps. He promoted the use of animated cartography to achieve an impression of continuous temporal change. Thrower's conceived map animations were of the cel type, i.e. individual maps were to be photographed and displayed as celluloid movies with hand drawn symbolization or directional arrows added in cartoon style. He hailed the efforts of meteorologists who had immediately caught on to this new concept and were concurrently preparing animations for display of their research. By 1965, Kenneth Knowlton of Bell Telephone Laboratories was touting the advantages of computer techniques for the production of animated movies modeling physical forces. The movies produced at Bell Labs were not cartographic displays, but their publication engendered important research by future creators of computer generated maps. He and other physicists were producing cost effective procedures for automated capture of CRT images on 35mm. Computer Output Microfilm (COM) recorders (Knowlton 1965). The 35mm images were then transferred to 16mm movie film for viewing. As a result of this research, COM recorders became the standard output memory device for cartographic animators.

Meteorological cartographic animation was well under way by the mid '60's. A film entitled "Weather Map # 1 " mimicked the gross behavior of the atmosphere in the northern hemisphere as described by a mathematical model (Cornwell and Robinson 1966). Consecutive plots of colored isolines were used to show the progression of temperature, surface pressure, precipitation and other variables. Two years later, meteorologists were producing color movies of computer-generated isoline maps of weather phenomena (Washington et al. 1968). They were still utilizing cel techniques, but had enhanced their animations with color overlay techniques that aided in the viewers differentiation of multiple layers of computer-produced line art.

In 1970, geographer Waldo Tobler announced "A Computer Movie Simulating Urban Growth in the Detroit Region" (Tobler 1970). 'Me movie was a cel animation of digitally produced, 3-D CRT displays of modeled population growth in Detroit. These maps took the form of Z-values representing population plotted over an X Y coordinate map of the Detroit area. The resulting animated frames resembled temporally changing digital terrain model of the region.

Concurrently, geologists at the University of Michigan were creating a motion picture of the earth's seismicity for the years 1961 through 1967 (Levy et al. 1970). Their cel animation portrayed the location, chronology, and magnitude of seismic events through the use of an innovative symbolization technique. The brightness of the symbol at the epicenter of an event was governed by the magnitude of the event using a brightness factor akin to the Richter scale. Furthermore, that brightness would diminish over successive frames until the symbol disappeared. Thus, the stronger the event, the longer the symbol would remain in sight of the viewer.

These flip-art animations of cels photographed from CRTs were problematic productions at best. Each CRT display had to be individually programmed by the user whether he be geologist, meteorologist or cartographer. A shortcut involved capture of one depiction of an object on a master cel and mechanical registration of the object in successive frames of animation. In the late '70's a new technique replaced these master Celluloids with "electronic cels" held in computer memory (Hunter 1977). These "cels" were stored point data describing line art that could be moved around on the CRT until the artist was satisfied with his composition. CRT compositions were then downloaded to COM devices.

In 1978, cartographer Harold Moellering produced and distributed a video titled "A Demonstration of the Real Time Display of Three Dimensional Cartographic Objects". Complete with musical soundtrack, the author demonstrated a COM system that employed a vector CRT for real-time, 3-D image generation and perspective rotation. A raster CRT was employed for color shading and COM input.

Early in the 1980's direct transfer to 16mm film became possible with DICOMED, an updated COM device (Grotjahn and Chervin 1984). Major advances in animated cartography were made by meteorologists who quickly latched on to the newest technologies (The National Center for Atmospheric Research had by this time produced over 600 cel animations of weather data). Color, three-dimensional portrayals of weather systems over line maps were the standard. Stereo images, produced using an anaglyphic technique employing red and cyan filters, were found to be more dramatic and communicative and provided a better sense of the relative distributions of volumes and trajectories in space.

The sophistication of meteorologic cartography continued to grow. Within two years, the McIDAS (Man -computer Interactive Data Access System) began incorporating visual cues including depth precedence, stereo, perspective, motion parallax, texture, brightness, color, shadows and transparency (Hibbard 1986). Meteorologists began creating displays that appeared all but tactile in nature. A typical display contained a rectangular box drawn in 3-D perspective around the image. Tic marks added scale to the vertical and horizontal edges. To further impart a 3-D image the light source would be registered with the viewers eye position to enhance the sense of depth produced by shadows. Weather variables including fractally enhanced clouds would be displayed over topographic maps or digital terrain models. Stereoscopic views were produced using red and green filters over the display (for lack of a regularly available cross-polarized CRT).

One of the last cel animations produced with McIDAS can be seen in a video generated of the President's Day Cyclone of 1979 (Hibbard et al. 1989b). The modeling and visual production of the system had become so complete that the user was faced with "the real possibility of being overwhelmed by the model data" (Hibbard et al. 1989a, p. 1394).

In the late 1980's, changes in hardware and software brought an end to the era of cel animations. Increased processing speeds and improvements in raster output devices led to real-time dynamic interfaces and real-time displays. Maps could be held in memory or constructed on-the-fly from external data files. Animations dependent on COM devices became a thing of the past.

2.3 The Evolution of Animation Hardware and Software

Advances in computer animation have been directly dependent upon improvements in hardware and software. These improvements have been nurtured by the demands of animators for systems which would meet their creative needs. Visual quality has always been a top priority in cartographic animation. COM devices developed at Bell Labs in the mid- 1960's solved early storage-medium problems, but display quality remained crude and dissatisfying (Knowlton 1965). CRT output devices became the focus of hardware research and development. Software developers strove for faster, more efficient interactive algorithms.

The advent of the light pen revolutionized computer drawing. Punch card and magnetic tape procedures for programming one-of-a-kind images on the CRT could be replaced by the wave of a hand. Software support allowed the animator to see his images in real-time on vector CRTs (Cornwell and Robinson 1966). Research on mechanically interfaced "shaping gloves" (precursors of today's "data glove") had already begun.

Colorization was developed for both raster and vector displays, though the vector displays suffered from mechanically induced "flicker". The demand for color CRTs that would eliminate "flicker" and the desire to eliminate tedious color overlay techniques propelled raster CRT research. The demand was reinforced by a colorization technique developed by Kubitz and Poppelbaum (1969) for display of "Tri-color cartographs". If employed in an interactive movie system, the technique would allow the animator to see the results of his creativity on-screen dynamically.

Both the allure and the expense of creating computer animated maps during the late '70's was revealed in an article featured in Science (Robinson 1978). With high performance computers it was then possible not only to draw, but also to animate cartographic wireframe images in real-time on vector displays. (The extensive computation and memory for real-time raster displays could not yet be supported.) The costly technique was already at work in the aerospace industry where pilots in training flew crude flight simulators.

Users of state-of-the-art, albeit low-resolution (512 x 512 pixel) raster outputs were plagued by COM recorder registration problems and the jaggies. Raster displays were, therefore, not considered to be cost effective (Robinson 1978). The expense of COM recorders (200,000 1978 dollars) and 256 color raster displays (down forty percent from the previous year to 40,000 1978 dollars) kept animation technology beyond the reach of the average cartographer wanting to make an occasional film.

Lower hardware costs were realized by the beginning of the next decade. Raster displays became the standard output device for computer animations (Moellering 1980a). Supporting software gave them the capability to mimic shaded, 3-D surfaces. Rotating these surfaces in animation solved the problem of choosing a proper viewing angle for Z-surface data on static maps (Moellering 1978). Cartographers could display complex Z-surfaces having no single viewing angle adequate to understand the surface.

Accounting for existing hardware and software capabilities, Moellering (1980a) outlined a twelve step strategy for the creation of cartographic animations:

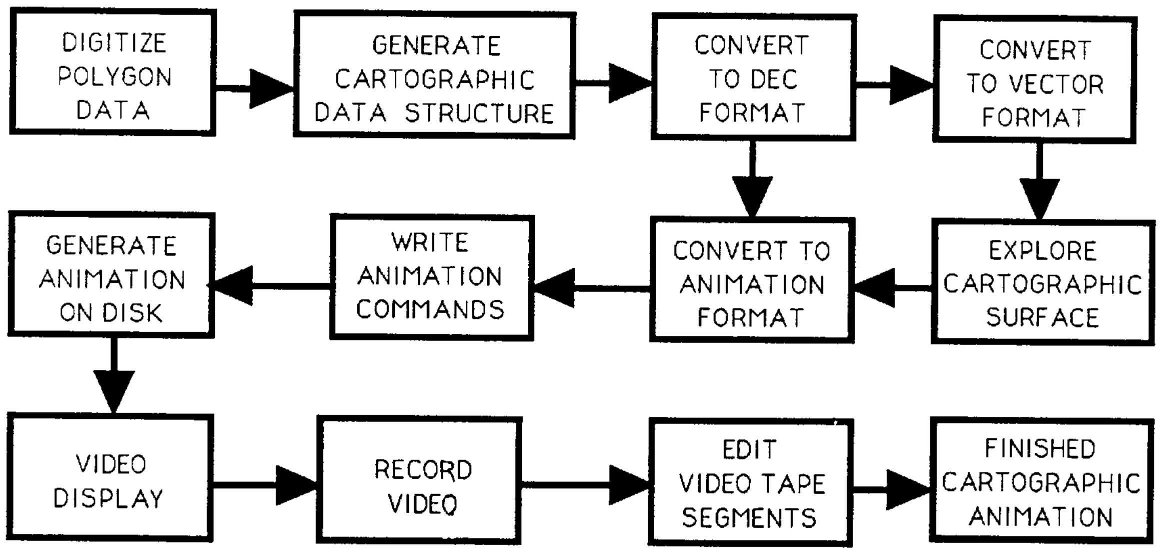


Figure 2.2 Flow chart of the procedures for developing a cartographic animation (adapted from Moellering 1980a)

During the 1980's as in the 1960's, major advances in animated cartography were made by meteorologists. Unfortunately, the graphics software available to most meteorologists hadn't changed in ten years. They looked forward to the dissemination of experimental shaded-volume and "high-level" graphics concurrently being developed in the television industry (Grotjahn and Chervin 1984).

These demands were met by the McIDAS weather mapping system (Hibbard 1986). The McIDAS system evolved over several years to a high state of sophistication and continues to be used today. It has the ability to manage and analyze remotely sensed or numerically modeled data sets and to produce animated, 3-D multivariate images. Journal photos of McIDAS displays attest to the description, though VCR transcripts of McIDAS animations are disappointing. The images portray shaded relief topographical maps with delineation of physical and political boundaries over which are projected atmospheric trajectories, isolevel contours, radar images, and 3-D translucent volumes depicting vorticity potential. The images are assembled into animation sequences depicting the time evolution of the data or rotating views of individual data moments. In addition, McIDAS 3-D enhancement software now includes a slight rocking motion applied to the image that helps trick the eye into perceiving three spatial dimensions. After the "President's Day Cyclone" project (Hibbard 1989b), real-time animation from raw data became a feature of the system. Images can be drawn at the animation rate, and immediate feedback to trial and error adjustments by the user are possible.

An essential element in producing animated cartographic displays is the acquisition and manipulation of data for display. In 1988 the Division of Atmospheric Sciences of the National Science Foundation began distributing meteorologic data for computer analysis and display through the Unidata Program Center in Boulder, Colorado (Sherretz and Fulker 1988). Though originally conceived for the atmospheric sciences, Unidata systems are now being designed for acquiring and analyzing many other kinds of earth-science data. Unidata is designed for computers utilizing MS DOS, VAX/VMS and AT&T's UNIX operating systems. The data will transmitted electronically and be distributed at each site by Ethernet local-area networks (LANs) to reduce redundancy. Costs will be dependent on users needs. Single microcomputer users without the need for a LAN will be accommodated.

Such databases are revolutionizing animation system development. High performance animation systems such as McIDAS have utilized medium size computer systems and specially engineered satellite data acquisition systems to supply a continuous stream of data for real-time displays of meteorological phenomena. Unfortunately, such systems take ten years or more to develop. Because micro-computer devices with expanded RAM and math coprocessing capabilities are readily available platforms for most graduate students and university teachers, a system dubbed MIDGET has been developed that allows the micro-computer user to access large meteorological databases and interface with super-computers, various workstations and file servers through DECNET/TELNET communication systems (Smith et al. 1989).

A similar system called 4DCAP exploits the graphic capabilities of an IBM PCAT with extended RAM for real-time viewing of meteorological data at up to 20 frames per second. Fast communication software connects the PC to mainframe computers employed for number crunching and data storage (Neeman and Alpert 1990). Future prospects include adapting the program to a small computer not requiring a mainframe computer, thus enabling it to service a broader range of users.

Dunn (1989) describes a highly-interactive, two-variable color mapping system for statistical analysis of bi-variate data. The entire system is confined to an IBM/AT PC with a color monitor having a minimum of 256 colors. Compared to the meteorological systems described above, it is primitive. The resulting cartograms are not designed for animation (the "dynamic approach" refers to the interactive capabilities of the system for altering the portrayal of the data). It is an important step for cartographers, however, in that the system maps physical and non-physical data interactively and is, furthermore, confined to a micro-computer platform.

The availability of off- the- shelf micro-computer animation packages and the design metaphors they support is a continually updated theme in animation literature (Hoffman and Temple 1990). Reiteration of this theme without the production of any visible cartographic product for the purpose of identifying "design issues that are relevant to four-dimensional cartography" can be found in the cartographic literature as well (Gersmehl 1990, p.3).

It is unfortunate to note that today's most sophisticated animated maps are not being developed by geographic cartographers. Existing systems are in use in meteorology, physics and even medicine, but their assimilation by mapmakers remains a future event. The magnitude of real-world, geographic data may be an overwhelming concern . Developments in GIS have been geared to solving this problem, but in the interim, cartographic animation suffers. For the past several years the cartographic literature has reported few actual animated productions (MacEachren and DiBiase 1990).

Continual migration towards micro-computer platforms will soon make sophisticated animation systems readily available to most cartographers. Along with the availability, though, is the necessity of developing cartographic techniques which enhance data portrayal in non-static maps. Computer capabilities must be used intelligently in order to fully realize their potential. Research into symbolization, color choice, map content and analysis must keep pace with hardware and software developments.

2.4 Cartographic Research

It is of note that animators Tobler and Levy recognized the need to adapt traditional symbolization for their animations. Tobler's growing population Z-surface and Levy's fading epicenters gave a comparative temporal perspective to data values that were otherwise temporally independent. Early cartographic animators quickly discovered that complex images not only complicated animation production, but also overwhelmed viewers. Moellering (1980a) stressed the need for further research into figure-ground relationship, color choice, viewing angle and light source. Proper choice of symbol, color, and volume of information and data correlation continue to be pressing issues for animated mapmakers.

Much cartographic research on symbolization has been directed towards symbol design (Hsu 1979, Cuff and Mattson 1982, Dent 1985). The bulk of this research has dealt with static map symbolization in isolation (Patton and Slocum 1985, Gilmartin and Shelton 1989).

Early focus on symbolization within animated cartographic products can be seen in the development of systems allowing information retrieval and display in graphic or textual form on a home television set or other CRT (Sigel 1983). VIDEOTEX became a generic term for such systems as were being developed in Europe and North America. These interactive television systems were predicted to become commonplace in a substantial number of homes by 1990. Though the prediction has not come true, preparation for the advent of these systems led to further research into virtual maps (Moellering 1980b) that were to be seen and not "read". Taylor (1984) emphasized simplicity of map design, color choice constraint, and selective use of text. For animation purposes, it was found that reduction of text size could increase reading speed, while enlargement and blinking effects reduced search time for randomly located characters and symbols.

Tufte (1983) indirectly dealt with symbolization in animation in his now famous book, **The Visual Display of Quantitative Information**. Selecting 23 frames from an animated air pollution map of Los Angeles (McRae et al. 1982), he composed a single image of a genre he referred to as "Small Multiples". The author's purpose in constructing the image was to reveal the fact that a consistent design throughout all the frames allowed the viewers attention to be devoted entirely to changes in the dependent variable.

Monomonier (1989) promoted the use of additive symbol sequencing whereby the appearance of a symbol is dependent upon a temporal or categorical variable. MacEachren and DiBiase (1990) developed a hybrid chorodot symbol which bridges the continuous-discrete and abrupt-smooth continua described by Hsu (1979). Its incorporation in a map animation describing the spread of AIDS is aimed at making the spatial characteristics of the mapped phenomena the primary factor in symbol selection. Yellow dots representing individual AIDS cases are placed within county boundaries until the county is filled. Seven additional occurrences of the disease within the county cause one of the dots to change its color to orange. When the county is filled with orange dots, 56 additional cases will cause a dot to change its color to red. Ile geometric progression and choice of color is determined by the cartographer's subjective impression of the data.

Until recently, color has been selected by cartographers almost exclusively in a qualitative rather than a quantitative fashion (Murch 1985). Differentiation has taken precedence over relationship even though gradient color schemes were found to be easier to read than hue-based schemes (Keates 1962). Changing hues were associated with qualitative rather than quantitative change (Olson 1981, 1987). Tufte pointed out that "shades of gray provide an easily comprehended order" to data measures (1983 p. 154) and criticized two variable color mapping techniques such as those in continued use by Dunn (1989) whose spectral relationships may overwhelm viewers.

Cognitive principles for color selection are now taking precedence in the cartographic and animation literature. Color-appearance systems are being developed which provide systematic, palettes of color examples with in a uniform sampling of psychological color space (Brewer 1989). Color mnemonics and variation of hue can quickly communicate information to map viewers (Heyn 1984, Murch 1985). Care in color selection must be taken because perception of color can vary as a result of juxtaposition and variation of output device (Carter 1988, Salomon 1990). Color choice can also alter time and intensity perception (Poynter and Homa 1983, Heyn 1984, Block 1990).

Sheer volume of information may be a pitfall for many animators. Viewer comprehension can be affected by quantity of data, and that quantity can be exaggerated by symbology and color as discussed above.

Tufte's principle of minimizing "non-data ink" is important for cartographic animators. Viewer comprehension can be complicated by added data dimensions. Symbolic visualization strategies for managing voluminous data sets in various dimensions can be seen in Grotjahn and Chervin (1984). The implications of map viewing time, position, viewer expectation, and scaling are discussed in Carter (1988). Monmonier (1990) addresses multi-dimensional data handling with a visualization strategy for expert systems. A graphic script controls multi-window animations of maps, text, statistical diagrams and other illustrations. In essence it is a score which controls the size, position, duration, design and content of screen elements, and possibly the real time exploration of data. Such an interface would allow user selection of viewing angle, statistical analytic technique, zoom, scaling, and animation rate, all from appropriate menus presented for a particular type of geographic data set.

Statistical rendering of the autocorrelation of animated variables is a fairly new type of analysis and the methods involved are not often applied in a cartographic context. Spatial autocorrelation is "the degree of influence exerted by something over its neighbors" (Goodchild 1986). It affords a deeper understanding of geographic landscapes and processes (Griffith 1987) but the intricacies of scale dependency may leave interpretation up to the expert. Use of these techniques on temperature data would be especially appropriate since temperature data, when collected for contiguous periods, are autocorrelated (Skeeter 1990). Animation affords the opportunity to view temporal autocorrelation without a either quantitative analysis or an understanding of autocorrelation techniques by the viewer.

2.5 Real-time Animations and Future Research

Animations utilizing real-time visualization directly from computer CRTs, and visualization of data processed in real-time on mini-, mainframe and super-computers are now possible (Magnenat-Thalmann and Thalmann 1985). Recently, a very efficient mainframe system was developed to animate meteorological episodes with realistic, stereo scene rendering (Papathomas et al. 1990). Though designed specifically for meteorological animations, the display algorithm is general enough to be used in cartographic depictions that involve varying data in four or more dimensions.

Super-computer processing abilities are now being utilized for dynamic steering of simulations through modification of model parameters. A cartographic simulation of a turbulence model of Lake Erie has been created from satellite data and employs such dynamic steering (Marshal et al. 1990). Researchers are thus able to debug and extend the model by greatly decreasing the time interval between changes to the simulation and the viewing of the results.

Real-time dynamic control of 3-D, color rendering for mapped variables has been achieved on a Pixel mini- computer platform (Rheingans and Tebbs 1990). Joystick control has been incorporated so that the user can achieve a better understanding of the data through optimum 3-D display and color combination.

Circumventing the need for large computer platforms, cartographers are combining micro-computer analysis, mapping, and animation software to create hybrid systems (MacEachren and DiBiase 1990). Alternatively, the output from separate software packages can be incorporated under the umbrella of Hyper-card based programs (Beekman 1990) to mimic graphic scripts (Monmonier 1989). Though these hybrid systems are accessible solutions to large platform dependency and software customization, cartographic animation production remains at a low level.

Real-time animated maps produced on larger platforms are being distributed on video tape by government supported agencies and book distributors. Unfortunately, transfer from CRT to video tape often degrades animation quality. NTSC standards do not match those of high-resolution CRTs. Recent examples include animated maps of seasonal vegetation productivity (CERL 1990), fire dynamics in Yellowstone park (NCSA 1990), and simulation of the global climatic effects of increased greenhouse gases (NCSA 1990).

Information representation through symbolization, color, and map design may never be perfected as long as the types of information presented continue to multiply. The application and evolution of general principles, however, must continue. Tufte's data-ink to non-data-ink ratio can be extended to the animation realm. Generally, graphic simplification for animated map and spatiotemporal frames should be inversely proportional to the duration of those frames. Thus, as the complexity of a graphic increases, the time that graphic is displayed increases and conversely, lower graphic content results in a lower frame duration. This relationship is not necessarily linear as either dependent term may be exponentially related to the other.

Expert systems interpreting graphic scripts and systems offering autocorrelation analysis may be offered in the near future. Quantifying the degree of clustering or dispersion, in fact to measure the spatial autocorrelation in animations, is possible by counting the number of joins between polygons representing measured data values (Ebdon 1988). Autocorrelation analysis of animated frames through pixel adjacency counts may be possible with the use of Screen-reflection algorithms (Weber 1990). A hybrid utilization of animated visualization and autocorrelation analysis would benefit the common viewer and statistician alike.

Propelling geographic cartography into both the present realm of animated mapping techniques and the public eye should be a top priority for research. The above literature review reveals that advances in software, hardware, and representation have nearly all been the result of the needs and demands of animators producing for viewers. Theoretical journal articles in cartography seldom foresee advances in technology and interfaces independently of their development in other disciplines. Advancements in and popularization of cartographic animation will more likely be the result of cartographic creativity and the dissemination of cartographic creations.

3 ANIMATION METHODOLOGY

3.1 Data Acquisition, Condensation and Formatting

For this animation project, temperature data symbolized in isoline maps was chosen as a result of meteorological tradition and consideration of data availability. The tradition of depicting temperature distributions as contours is based on the fact that atmospheric forces, over time, create a continuous temperature gradient. Physical forces demand that warn and cold air masses mix at their point of contact. The atmospheric circulation may support a delineation of air masses, but mixture at some scale must exist. Averaged data as described for this animation are of a scale independent of any localized effects.

The data set used for this animation was acquired from the National Oceanic and Atmospheric Administration (NOAA) as a series of 50 ASCII files comprising three megabytes of information. 48 of the files contained monthly average temperature records for each of the contiguous states. An abbreviated portion of the New York file is shown below (table 3. 1).

State div #	Climate	YR	J	F	M	A	M	J	J	A	S	O	N	D
30	1	1895	18.9	13.3	23.9	43.1	55.6	67.3	63.9	65.9	61.2	41.7	37.6	31.1
30	1	1896	20.3	22.0	22.1	47.4	59.3	63.1	68.1	66.7	58.1	44.1	40.9	32.9
30	1	1897	20.8	22.1	31.4	42.1	50.1	59.7	69.0	63.1	58.3	49.0	36.4	28.7
30	1	1898	24.5	24.8	39.6	40.2	54.8	65.5	70.1	67.6	61.6	49.7	35.5	24.0
30	10	1985	19.3	24.7	34.9	47.8	57.0	60.6	67.8	67.2	62.0	49.7	41.6	32.7
30	10	1986	24.3	23.5	35.7	47.0	59.5	63.2	69.1	65.3	59.4	49.4	35.9	20.4
30	10	1987	23.5	21.4	36.6	48.1	57.7	66.7	71.8	66.1	60.2	45.8	39.8	22.0
30	10	1988	22.1	22.9	32.7	43.7	57.1	63.0	72.1					

Table 3.1 New York Monthly Temperature (degrees F.) Data File

One of the two remaining files contained X,Y coordinates in spaghetti format forming an outline map of the contiguous U.S. The other contained identification numbers and X,Y coordinates corresponding to the 344 climate division centroids within the outline map.

As can be seen in the sample portion of the N.Y. data file (table 3.1 above), January through December mean monthly temperature data was provided for the years 1895 through 1988 in degrees Fahrenheit, calculated to one decimal place (NOAA 1983). The data were compiled from 344 climate division regions whose collection sites were subjectively determined prior to 1965. Each state has 10 or fewer regions. The region centroid acts as the representative data point location. The data have been corrected for missing observations, variations in collection time, and physical movement of collection stations using a model published by Karl et al. (1986).

For the purposes of this project, the volume of monthly data values needed to be reduced to local yearly averages. This process raised the question of whether to use January through December calendar year averages, or yearly averages based on some other twelve month period. In order to preserve yearly highs (summers) and lows (winters) in seasonal groupings, October through September years were chosen for averaging. October is a month during which radically different interannual temperatures can occur across large areas (Skeeter 1990) signaling a transitional mid-tropospheric turnover in the atmosphere. Unlike the arbitrary calendar year, the October through September year marks a natural break in 12 month weather patterns.

These yearly values were smoothed using a moving three-year window. The purpose of this smoothing was to remove prominent spikes in the data which would be detrimental to smooth transitions in a flip-art animation. Initial examination of graphs depicting values for highly variable and relatively stable collection sites, in the Rocky Mountains (Colorado) and Great Plains

(Kansas) respectively, revealed that a three-year window was sufficient for smoothing spikes without substantial obscuring of temporal data.

Both averaging and smoothing processes were carried out in Lotus123 (Lotus Development Corporation, release 2), a spread-sheet software package designed to run on MS DOS personal computers. Along with the three-year averages, local 92 year means were computed. Finally, still using Lotus 123, local yearly average temperatures were translated into positive and negative deviations from local 92 year means. An abridged portion of a labeled, sample file for climate division #1 of New York state is shown below (table 3.2). The OctYrIyAvgs are calculated from two consecutive years, beginning in the month of October of the first year and ending in the month of September in the subsequent year. Thus, no OctYrIyAvg exists for the years 1895 and 1988. The 92 YrMean is the mean of the OctYrIyAvg's. The deviations are calculated by averaging three consecutive years and subtracting the 92 YrMean from the result, producing a total of 90 deviation values for the years 1897 through 1986.

OctYrlyAvgs	92 YrMean	wndw3y deviations	ST#	climate div. #	year
			30	1	1895
44.658	45.013		30	1	1896
43.917		0.120	30	1	1897
46.825		0.273	30	1	1898
45.117		0.907	30	1	1899
45.817		0.332	30	1	1900
================					
46.558		-0.530	30	1	1983
43.608		0.090	30	1	1984
45.142		-0.321	30	1	1985
45.325		0.318	30	1	1986
45.525			30	1	1987
			30	1	1988

Table 3.2 Sample Lotus123 workfile calculating yearly deviations from a 92-year mean for N.Y. climate division #1.

As previously stated, this animation has been designed for the better understanding of the consequences of the greenhouse effect. The detrimental effects of global warming are most often described in terms of an increase or decrease of temperature (Rosenzweig 1990, Swaminathan 1990). Non-standardized data, in the form of degrees Fahrenheit deviations from local 92-year means, have therefore been chosen for animation. A Fahrenheit format has been selected over a Celsius (Centigrade) format because the map has been designed to be viewed within the United States where the public has not yet accepted the Celsius standard. Fahrenheit designations better lend themselves to immediate interpretation by the layman. For those unfamiliar with the Fahrenheit scale, it should be remembered that this contour map is not intended for examination of individual climatic division values but rather for viewing spatiotemporal temperature deviations and trends. The spatial distribution will impart the same effect regardless of temperature measurement scale.

A consequence of the October through September yearly averages and the smoothing process is a reduction in the number of available data years for animation. Data for the year 1988 were already incomplete, ending in the month of July. The October through September parameter thereby reduced the available years from January 1895 through December 1987 to October 1895 through September 1987. The three-year smoothing window further reduced the available number of years to October 1896 through September 1986. Each map in the animation has been labeled with the year corresponding to the January values that are included in the data used to construct the map. Thus the first map is labeled " 1897", having been constructed from data values beginning in October 1896 and ending in September 1897.

A final manipulation of the data was necessary to format it for direct input to the contouring package Surfer (Golden Software Inc., version 4). Surfer accepts Lotusl23 files directly but demands that the data be in a specific read-in format. Reformatting the data in Lotus 123 was a simple matter of executing a few customized macros and extracting yearly data input files for Surfer.

3.2 Isoline Map Production

Contouring as a mapping technique is dependent upon the degree of approximation of the "surface" being depicted. The accuracy of depiction is dependent upon the density of the distribution of point values representing the phenomena of interest (Yoeli 1983). Because of the high density of climatic divisions in the contiguous U.S. (344 divisions), and because the map is designed to depict trends and not point data, contouring of surface temperatures is certainly acceptable. (A map of state climatic divisions can be found in Appendix A, figure A. 1.)

To utilize the automated contouring capabilities of Surfer, the "surface" must be represented in the computer as a rectangular grid of points. These establish the locations and dimensions of the areal statistical units in which the data are to be plotted. The grid is interpolated from X, Y, Z data point values directly input from a data file. The density of the grid can increase the accuracy and smoothness of the final plot. However, the grid density should not imply a higher accuracy than the point data can represent. Because of the relatively dense but uneven distribution of climatic divisions, a 25 by 25 rectangular grid was chosen. The gridding method used was an inverse distance formula with a weighting power of 2:

$$Z = \frac{\sum_{i=1}^{n} Z_i / (d_i)^2}{\sum_{i=1}^{n} 1 / (d_i)^2}$$

where Z_i is a neighboring point
where d_i is distance
where n is the number of Z elements

Formula 3.1 Inverse distance weighting formula for grid interpolation in Surfer.

Data points considered in the inverse distance equation are weighted such that the influence of one data point on another declines with the distance from the point being estimated. The smaller the weighting power, the slower the decline in influence and the more effect points further out will have on the interpolation. These influential data points were found using a "normal" search method in which the closest 10 (X,Y,Z) data points at every interpolated grid location were considered. If fewer than 10 data points existed within the search radius, all point were considered.

In order to keep a visible distance between contour lines for subsequent isopleth filling, a contour interval of 0.5 degrees was chosen. Points within the grid which have values corresponding to the interval breaks were automatically connected. Additional “smoothing" of the contour lines was carried out with automated spline interpolation techniques offered in Surfer. The erratic placement of climate divisions necessitated a tension factor of 4 in order to smoothly follow the grid cells. Output tests confirmed these parameters to be sufficient for animation purposes.

3.3 Platform Downloading

Two sets of contour maps needed to be produced for each three-year window. One had to be produced with and one without contour labels. The maps produced without labels were used in the actual animation process. The labeled maps were used as keys for colorizing the unlabeled maps (see sample labeled map in Appendix A, figure A.2).

The machine being used for Lotus 123 and Surfer functions was a Hewlett Packard 486 computer with a 487 math co-processor. Acceptable contouring software was not available on MacIntosh platforms though they were the preferred platforms for animation applications. Using PizazzPlus screen-capture software (Application Techniques, Inc., version 1.3 1989) on-screen maps were captured as PCX files. These on-screen maps had been scaled in Surfer to fix their destination screens on Macintosh II graphic workstations. An average production and capture speed of two maps per minute was maintained. The images needed to be downloaded to the MacIntosh environment so that they could be incorporated into MacroMind Director (MacroMind version 1.0. 1 1989), an animation software package. The PCX files were downloaded to the MacIntosh environment using MacLink Plus/PC software (DataViz, Inc., version 4.12) running between an 8086 IBM PC and a MacPlus PC. The MacLink software automatically converted the PCX files to PICT files which were readily acceptable in Director. Though the process was slow, all of the screen captures were successfully downloaded.

3.4 Animation in Director

Unlabeled contour maps were imported to Director as cast members. Each unlabeled map was then positioned in a keyframe and incorporated into a flip-art animation. In order to minimalize jagged transitions between successive frames and to create the illusion of temporally moving contour lines, a pixel dissolve technique was utilized. Each map fades as its successor melts into view.

The first maps to be downloaded into Director were the labeled copies. Each image required approximately 57,000 bytes of memory. Thus, less than 20 of the unaltered PICT files could be maintained in memory at a time. These were entered as cast members, and hardcopy was produced via LAN on a high volume AGFA laser printer. After each group of 20 were printed, they were deleted from the Director program in order to make room for the next group. The unlabeled versions were likewise downloaded via MacLink and diskette. The inability of Director to maintain the full set of 90 maps necessitated the creation of 4 separate movies to be run sequentially in order to mimic a movie with all 90 years of data. Colorization of the unlabeled maps was a slow and tedious process completed using Director's paint and palette options. A sample, colored map for the year 1917 is shown in figure 3. 1, below.

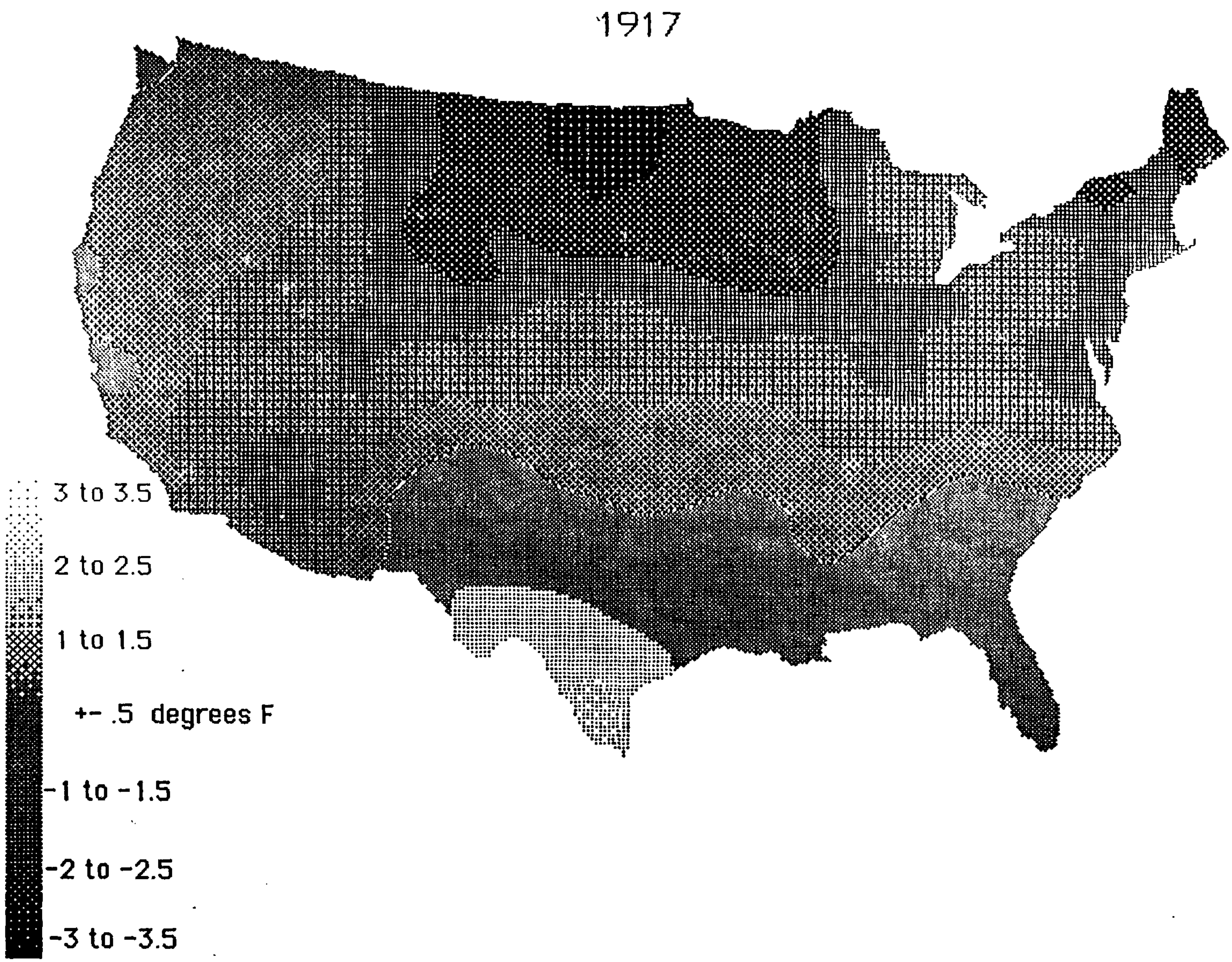


Figure 3.1

3.5 Color

Perception research and cartographic color research points to several variables applicable to animation of temperature isolines. Pattern complexity can affect perception of duration (Poynter and Homa 1983, Block 1990) as a result of number of stimuli and intensity of stimuli. Previous experience with the Director revealed a propensity for the animation speed of the software to be slowed by large images. Thus, pastel hues were chosen in order to minimize the perceived duration of individual frames.

Color as a mnemonic can be a powerful tool in graphic design (Tufte 1983, Salomon 1990). Red is commonly associated with heat and fire, while blue is associated with cold and ice. These associations were utilized in the animation. Pastel shades of red represent degrees above the mean and pastel shades of blue degrees below. It has been found that edges differing only in the amount of blue will appear indistinct (Murch 1985). This lack of distinction in the blue shades aided the visual continuity of the negative temperature gradations. Furthermore, highly saturated, spectrally extreme colors (such and blue and red) cannot easily be seen simultaneously (Murch 1985). Pastel shades alleviated this problem.

Continuous saturation progressions can provide easily comprehended order to data measures (Tufte 1983). A continuous progression between red and blue, however, results in a median value of violet, an unsatisfactory choice to represent a near-mean local value. A choice of white was found to be a good median value in that it best created a gradient from deep reds to pinks for degrees above the mean and deep blues to faded blues for degrees below. Unfortunately, initial reaction from viewers was that white median zones seemed to imply a lack of data rather than no significant deviation from the mean. In order to maintain the favorable gradation effect but lose the implication of a lack of data, a pastel shade of gray was used to act as the median value.

This double-ended color scheme reaped additional benefits. Related elements have been represented by similarity of hue, separated by a median hue thereby cuing viewers to "the norm" (plus or minus .5 degrees from the average), values "above the norm" and values "below the norm" (Olson 1987). The use of a single color for the halfdegree range surrounding the zero contour line also facilitated the suppression of a rapidly fluctuating median contour. Median contours tend to change position rapidly in this type of meteorological data (Grotjahn and Chervin 1984).

This gradient color pattern fits well into normal cognitive expectations of temperature symbology (Murch 1985). The most saturated hues (greatest deviations above and below the average) immediately draw the attention of the viewer. The gradient format evokes immediate recognition on the part of the viewer without the necessity for excessive interpretation (Grotjahn and Chervin 1984).

A black background coupled with a darkened viewing environment was chosen for the animation, because higher perceived brightness levels as a result of darkened surroundings aided viewers in selectively distinguishing between pastel hues and in focusing on map edges (Murch 1985).

3.6 Map Composition

The production of maps which are intelligible and unambiguous to all with a minimum of training has been dismissed as unattainable (Board 1980). Cartographic research has long sought to defy this maxim. The most effective maps in animation may not be the most realistic but rather those which distort reality by eliminating unnecessary information and exaggerating useful data (Taylor 1984). The previously described color choices in combination with a minimalistic map composition, have been employed in an attempt to present an animation whose content is readily apparent to a maximum number of viewers trained and untrained alike. The dominant element in the animated frames is the colored isoline map series. Similar to common television weather maps, they have been placed in the upper center of the "stage", and occupy a full two-thirds of the display screen. Yearly labels transferred with the maps directly from Surfer scroll in a consistent position above the U.S. outline. A vertical, labeled temperature deviation color key is positioned in the lower left comer. The vertical layout was chosen for its resemblance to a common thermometer. A time graph of the cumulative positive and negative deviations from the 90 year means (from Lotus 123) is displayed in the lower right center. It has been colored with a dithering technique that imparts an image of warmer and cooler years as a result of their cumulative total temperature deviations. Years which are split in positive and negative deviations are easily distinguished (figure 3.2).

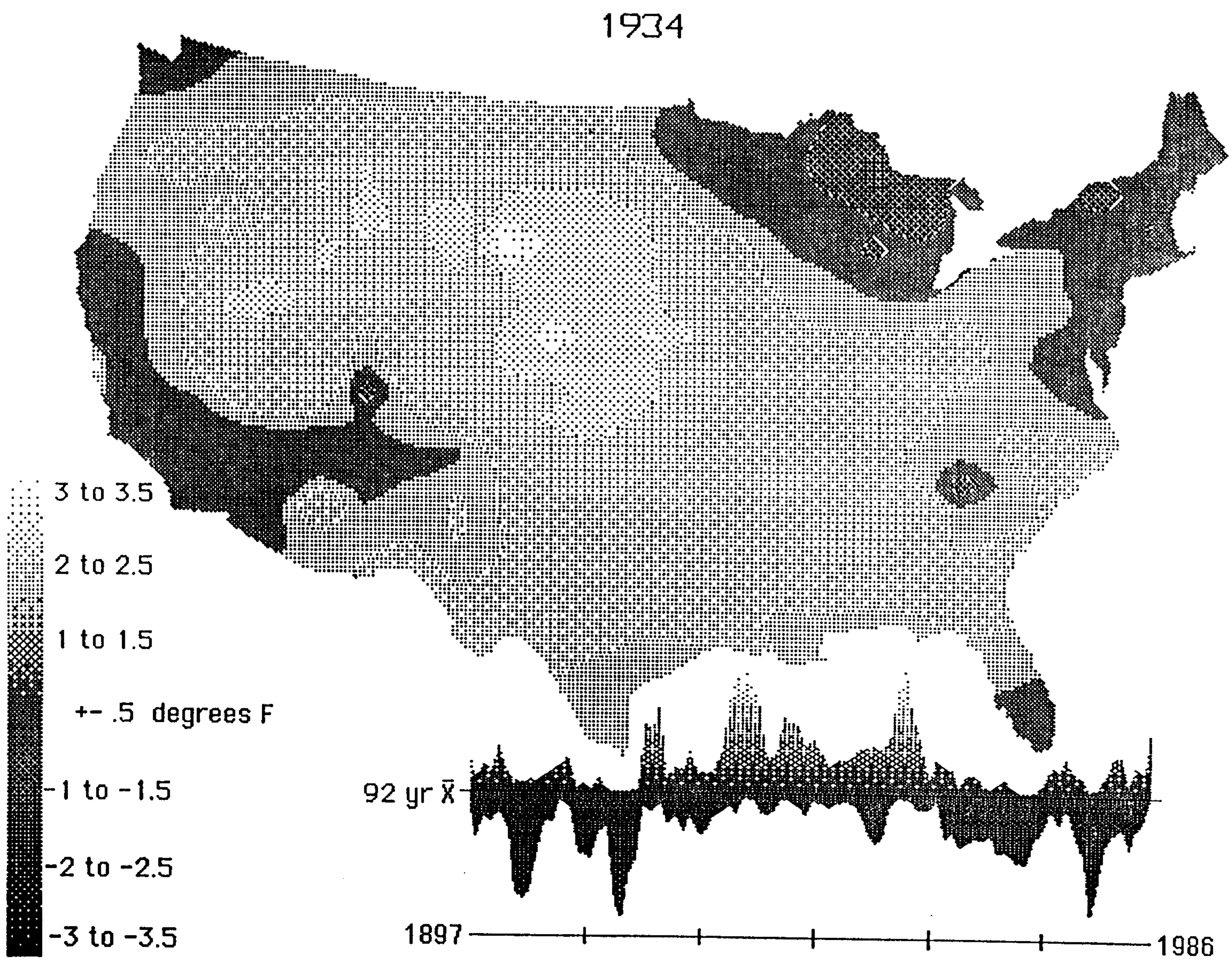

1934
3 to 3.5
2 to 2.5
1 to 1.5
+- .5 degrees F
-1 to -1.5
-2 to -2.5
-3 to -3.5
92 yr X̄
1897
1986

Figure 3.2

The rising and lowering curve of the graph mirrors the shape of the Caribbean Gulf under which it has been placed. This position is aesthetically pleasing and cues the viewer as to the overall rise and fall of the average U.S. surface temperature over the 90 years animated. The time-graph is a source of both statistical and temporal information. A moving needle over the graph is positioned over the portion of the curve representing the current year being displayed in the isoline map. It highlights both the relative position of the current year and cues the viewer as to what to expect in the following frames.

A second series of the 4 movies comprising the entire 90 year map series were copied from the originals. These were then tagged onto the original series but with an added data dimension. Five out of every fifteen years have the 344 climatic division data sites portrayed as small stars in their respective positions. Recurrent peaks in the isoline maps can thus be attributed to their source collection sites.

The blackened background of the map display has been designed to be used in conjunction with a darkened room during viewing. This allows the viewer to concentrate solely on the animation, increases the perceived depth of saturation of the pastel color scheme, and removes the physical CRT from the sight of the viewer. On-screen text is enhanced by the loss of ambient glare and heightened relative brightness.

The processing capabilities of Director are hampered by large-volume keyframe images, in-betweening, and castmember deformation. A consequent decrease in the animation tempo results. The tempo of this animation has been set to a maximum level in order to overcome these limitations as much as possible. Dynamic viewer adjustment of this parameter is not presently available but is a predicted enhancement of future Director releases.

3.7 Production Efficacy

The effective implementation of the previously described hybrid animation system was predetermined by the availability of software and micro-computer platforms. These conditions were beyond the control of the researcher, and a successful implementation utilizing the available resources was one of the goals of this project. In every instance, software performed as designed. Likewise, there were no breakdowns in hardware.

A great deal of time could have been saved not only through hardware connections but also through slight modifications in the software employed. Large spreadsheets comprised of complicated averaging formulas cannot be handled by Lotus 123 in 640K of RAM. Lotus 123 should be modified to automatically access extended RAM, and thereby be able to complete in one spreadsheet processes which took several spreadsheets in this project.

Surfer contouring software should be able to alter map background colors. The background color is currently determined by the machine in use. Drawing maps on the black background of the 486 unnecessarily complicated matters when the maps were incorporated into Director, Also, an extended 256 color palette would significantly enhance Surfer’s output map appearance. Automated colorization of isoline intervals from such a palette would have saved over twenty hours of manual colorization in Director.

Pizazz Plus screen-capture software should contain procedures that automatically query micro-computers for hardware specifications, much like those available in Turbo Pascal (Borland International 1989, version 5.5). Screen resolutions and hardware configurations could remain hidden from users.

Though software barriers cropped up from time to time, none were insurmountable, and the improvements recommended above are of the type that software developers eventually incorporate if their products are to remain in the marketplace. A new, improved version of Director has already arrived on site.

It is of note that the animation process outlined by Moellering (chap. 2, fig. 2.2) has been greatly simplified. His 10 to 12 steps have been reduced to 5 or 6 (figure 3.3). Videotaping of the animation is still the most viable option for distribution:

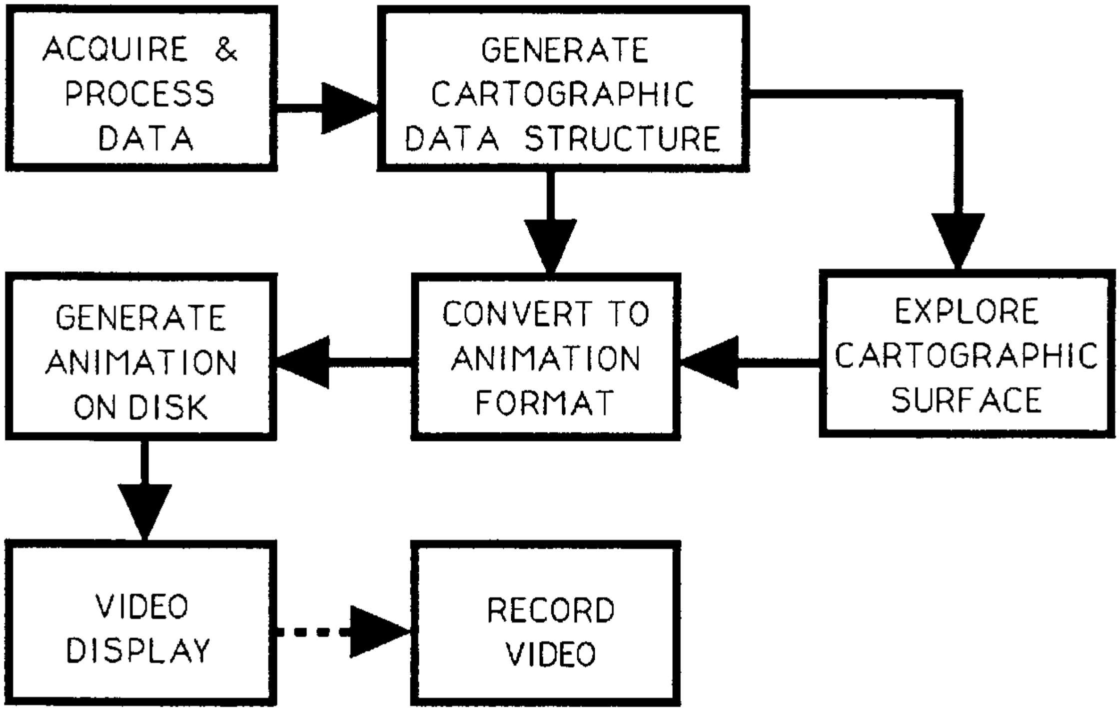


Figure 3.3 Flow chart of the procedures for developing the cartographic animation (adapted from Moellering 1980a)

The conclusion to be drawn from this discussion is that hybrid animation systems can work, and that they can be readily customized to the needs of the user. Such systems can play an important part in the evolution of cartographic animation. Manipulation and substitution of their component parts creates the demand for blanket systems with interfaces that meet the needs of cartographers. Thus, their continued utilization can support the demand for animations and add to the development of cartographic-specific animation systems.

4 THE ANIMATED MAP

4.1 Observations

"Effective communication by means of maps may be said to depend on (a) the adequacy of the instrument itself, in which we must consider how accurately the map depicts the conditions that actually exist on the earth's surface, (b) the environmental conditions surrounding the viewer in the viewing process, and (c) the capacity of the viewer to receive an accurate mental image of the message incorporated in the map" (McCarty 1961 pp.6-7). Each of these issues has been addressed in the afore mentioned animation process. The success of this process can been ascertained from the animation itself. It clearly presents the areal arrangement of averaged surface temperatures interpolated from the available data.

Though no testing of the animation's accuracy and communicative quality has been undertaken, initial observation of both the isoline surfaces and the accompanying cumulative deviation graph reveal trends which support the notion that average U.S. temperatures do not account for regional variability. The animation affirms a strong regional pattern of cooling in the East and warming in the West over the last 20 years (Plantico et al. 1990), as well as a general cooling trend over the past 35 years. Similarity between the animated depiction of cumulative deviations and the findings of various meteorological studies (chap. 1, figures 1.2 and 1.3, and figure 4.1 below) lend credence to the accuracy of depiction.

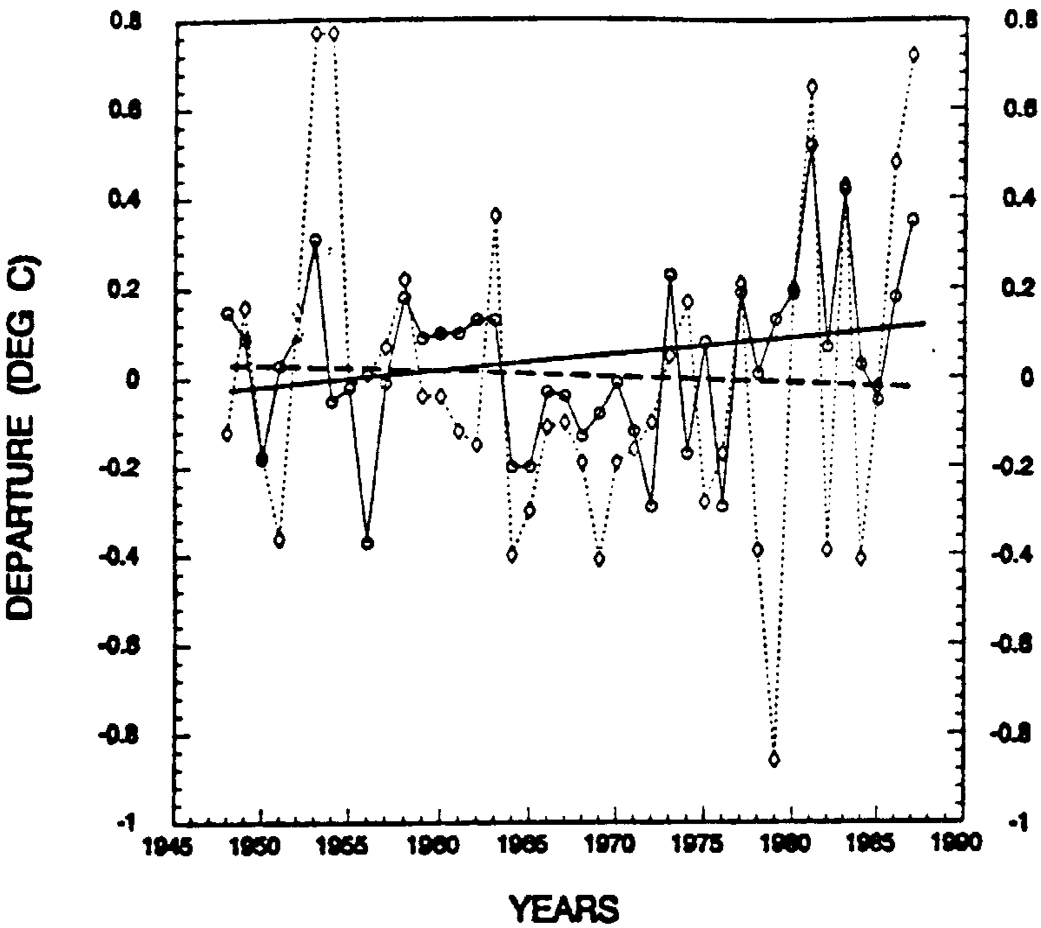


Figure 4.1 Departures of the northern hemisphere (solid line) and United States (dashed line) mean annual surface temperatures along with their corresponding trend lines (Plantico et al. 1990)

Regional temperature variability appears to be spatially distributed in a manner that mimics closed, turbulent systems. The spatial variability in years having large cumulative positive deviations (for example 1917, figure 3. 1) cannot be found in years having similarly large cumulative negative deviations (for example 1934, figure 3.2). The isoline patterns of the coldest years are generally concentrated in a few deep troughs while the patterns of peak warm years are spotty and curled into Paisley-like shapes. Comparison of the cold years 1915 through 1920 to the "dust bowl" years 1931 through 1935 reveals this phenomena. The spiraling patterns of the peak warm years are reminiscent of those generated in closed-system turbulence experiments in which stable fluids bifurcate into chaotic states as a result of sensitive reactivity to small increases in energy input (Lorenz 1963, Glieck 1987).

A sudden, disturbing fluctuation between cold and warmth can be observed beginning in 1917. A rapid warming took place which culminated in the maximum warmth of the 1930's. If interannual average temperatures are related, such a cusp might signal the presence of non-linear forces at work. This characteristic alone could have far reaching consequences on resource management and planning. The assumption that the broad environment is stable permeates range science, architecture, agronomy and other disciplines where average climatic parameters are incorporated into yield models or design criteria (Riebsame 1990). The threat not only of global warming but of global temperature instability may call for a new paradigm in resource planning.

4.2 Future Research

"The images produced from scientific data should not be viewed as the end result of an analysis. Visualization is more than a compilation of techniques for the display of data, and should allow the scientist to explore the virtual world created from a mathematical model or to examine the huge quantities of data from laboratory experiments or remote sensing devices" (Marshall et al. 1990, p. 89).

Quantification of the spatial variation in the contoured frames of the temperature animation may be possible through autocorrelation methods. Isoline values interpolated from the climatic division data points are portrayed on the CRT as groupings of colored pixels. Raster and areal adjacency counts for autocorrelation analyses have been demonstrated in the statistics literature (Goodchild 1988, Ebdon 1988). These methods may be applicable to the interpolated data depicted in animated frames. Autocorrelation analyses of surface temperature distributions during the warm and cold spells described above may yield valuable insight as to the nature of climate change.

The development of graphic scripts and multiple-dynamic-maps as described by Monmonier (1989, 1990) may realize the potential for automated analyses of animated data. In the meantime, however, hybrid systems incorporating ready-made and custom software must bridge the gap for cartographers. It is important for cartographers to press ahead in the production of animations. No purely statistical or static mapping method can readily portray the amount of information such temporal displays contain. Their use as a commnicative medium walks hand-in-hand with their ability to provide insight for the scientist curious about a spatiotemporal phenomenon. Increased application of the medium to the myriad of spatial phenomena can only lead to new applications, better systems and truly utilitarian understanding of the world that surrounds us.

APPENDIX A

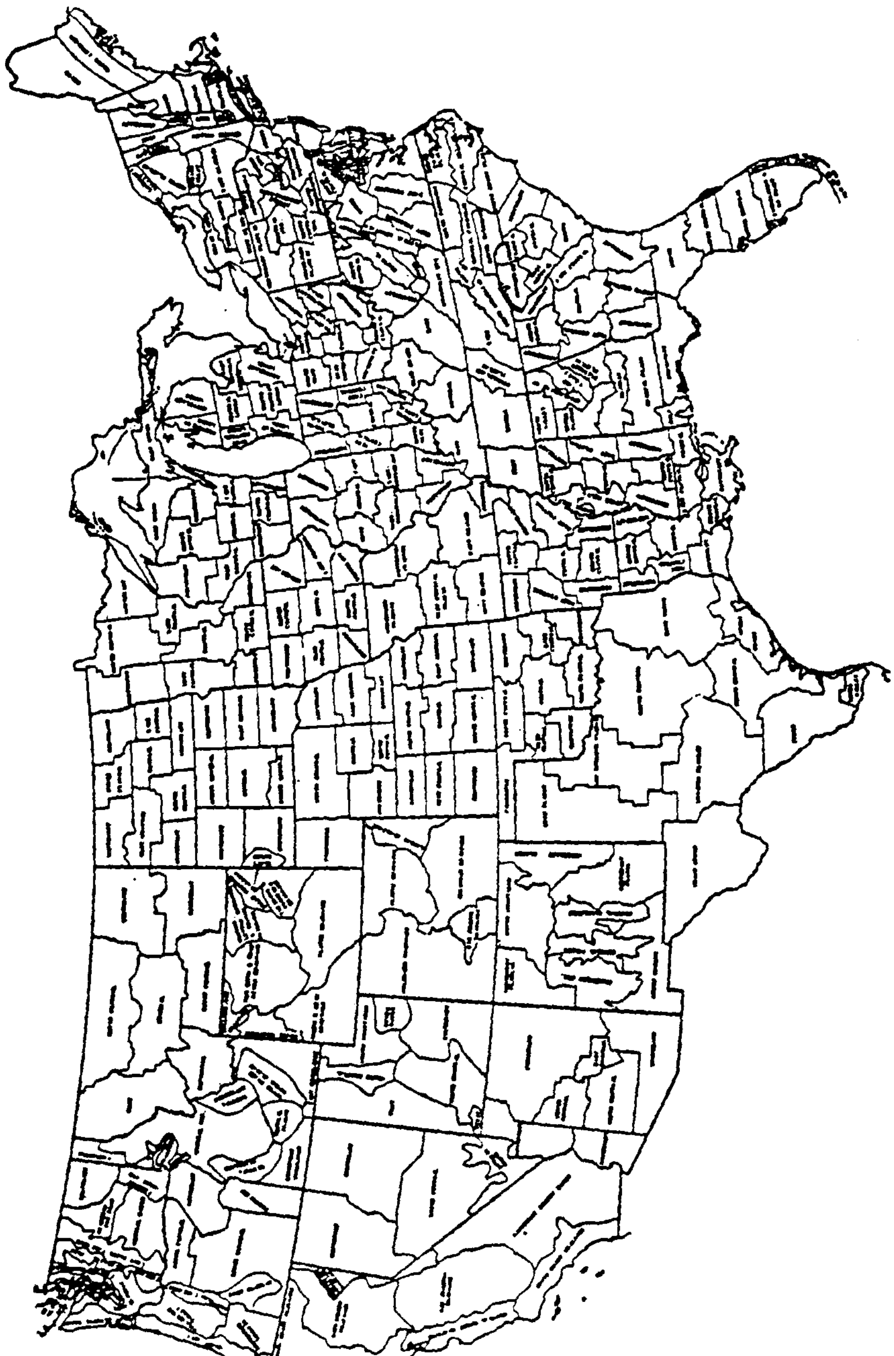


Figure A.1 State Climatic Divisions

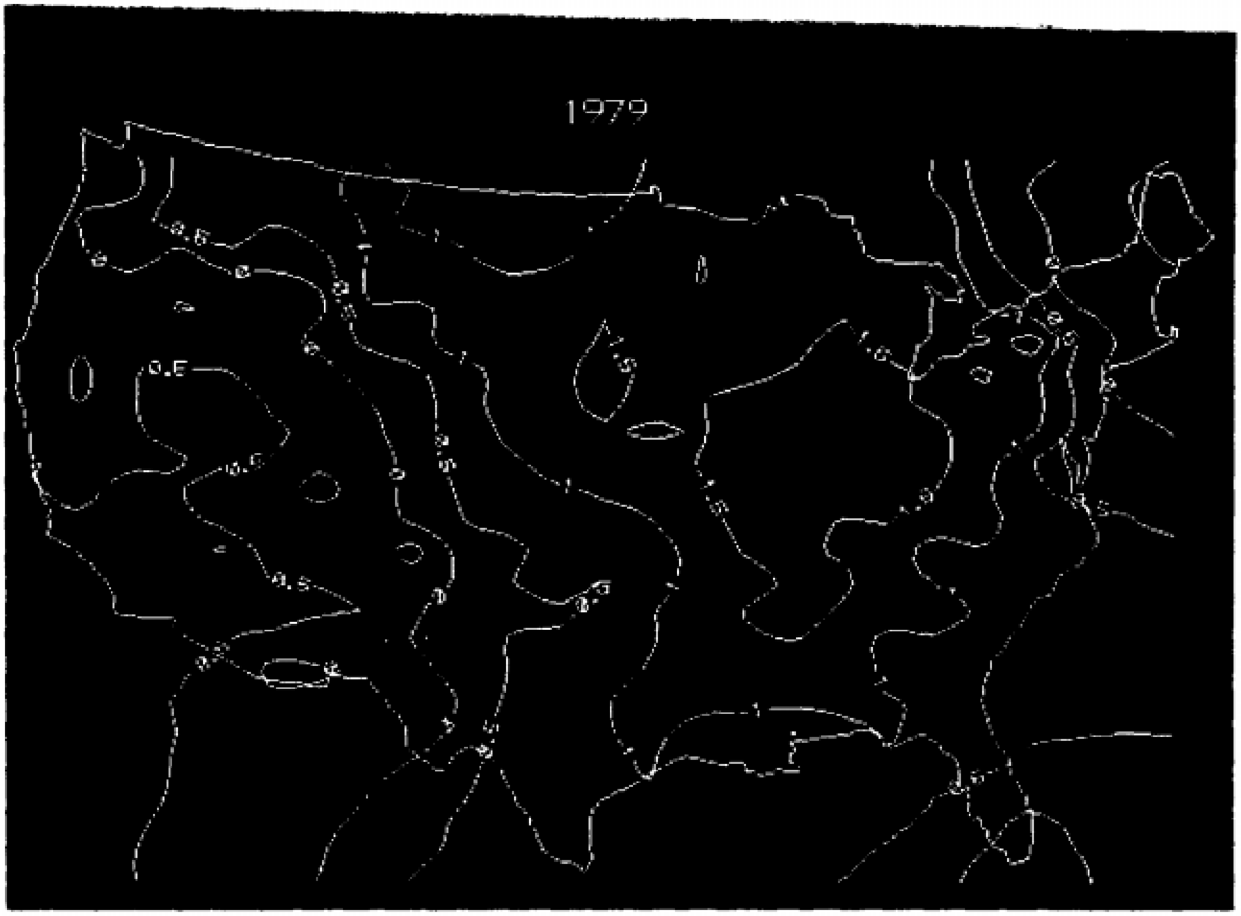


Figure A.2 Sample Labled Contour Map

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