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21st Century City Temperature Analogs in the United States

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A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

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Abstract

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by

Mark Deaton

Decades of research now show that the planet is slowly warming and that this trend will affect life on Earth over the long term. Water supply, weather patterns, and disease are examples of the many ways in which climate change will directly affect humans. Mitigation planning efforts will require new ways of thinking about, visualizing, and analyzing the massive amounts of forecast data now available from a multitude of climate models.

Various temperature-forecast models and datasets exist to help analyze climate change effects. This project converted one of those into a spatial database, extracted yearly averages for a selected set of United States cities, and used them to create lists of which cities' temperatures are forecast to be most analogous to which others at various forecast years. A web application built with ESRI's ArcGIS Server and Flex API visually linked these analogs to compare and contrast disparate geographic locations in new ways. A disciplined use of accepted design practices will allow this example to be easily adapted and extended in future analyses.

Table of Contents

Table of Figures

List of Tables

List of Acronyms and Definitions

API Application Programming Interface
An Application Programming Interface is any set of software libraries and tools that help software programmers build new custom tools. ESRI provides programmers a set of APIs that let them build new mapping software using the foundations built into the ArcGIS products.

APL Applications Prototype Lab
The Applications Prototype Lab at ESRI is an applied research and development group. Its mission is to support sales efforts by building, distributing, and showing demonstration applications built upon ESRI's software products.

CMIP3 Coupled Model Intercomparison Project phase 3
The World Climate Research Programme's (WCRP's) collection of multi-model datasets was built and assembled for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). It was the basis for the forecast data ultimately used in the course of this project.

CSIRO Commonwealth Scientific and Industrial Research Organisation
This is an Australian agency devoted to conducting and publishing scientific research in a wide variety of subjects, including climate modeling.

Demo Demonstration application
Demos are applications and/or data packages used to present information or tell a story to actual or potential ESRI customers. A demo should hold the audience's interest and show the capabilities of the software or data upon which it is based.

Downscaling
Downscaling describes a mathematical process by which raster data at a certain resolution is converted into a higher-resolution. In other words, the mathematical algorithm is able to make the raster pixel size smaller and more granular.

GCM General Circulation Model
Often confused with "Global Climate Model", General Circulation Models are mathematical models of the climate as it actually is, and which take into account atmospheric or oceanic movement patterns among other factors. These models are combined into Global Climate Models are Global Coupled Models to make predictions about how the climate may change in the future.

GCM Global Climate Model
Often confused with the similar-sounding "General Circulation Model", a Global Climate Model is a more generalized, complex model, often built atop one or more General Circulation Models and incorporating more involved considerations and computations (Weart, 2009).

GCM Global Coupled Model
A Global Coupled Model is a pairing or merging of General Circulation Models; it is a synonym for "Global Climate Model" (Weart, 2009).

IIS Internet Information Server
This is the web and application server software bundled with Microsoft Windows operating systems.

IPCC Intergovernmental Panel on Climate Change
An international science body affiliated with the World Meteorological Organization and the United Nations Environment Program, the IPCC studies climate change issues and effects.

IPD Information Product Definition
An intermediate step in Tomlinson's (2007) analytical method, an IPD is a detailed description of the output of a particular GIS function. It should include information on how often it is created, the steps involved to create it, and details regarding the output.

MSD Map Service Definition
ArcGIS Server 9.3.1 can publish dynamic services that perform faster than in previous releases as long as the map's author follows certain guidelines. ArcMap can create a Map Service Definition for ArcGIS Server to use when it publishes these faster-performing services (Environmental Systems Research Institute, Inc., 2009).

NetCDF Network Common Data Form
The most common format for climate-related GIS data, NetCDF hosts multiple dimensions of measurements or attributes in a single file. In this project, geographic location, year and month, and temperature are all attributes in the raw NetCDF data files used as input to the system.

WCRP World Climate Research Programme
This is an international, multi-disciplinary organization studying climate predictability and the impact of human activities upon climate.

Chapter 1 – Introduction

Concern over global climate change looms larger in the public mind every year. News media regularly report on climatic changes due to human activities. A strong body of academic research has furnished not only evidence for the existence of climate change, but also models to predict its progress over time.

However, its prominence in the media has not raised great public debate on the practical consequences of climate change. Dangers from temperature changes range from direct effects—such as heatstroke—to indirect effects, such as greater infectious vector virulence, changed rainfall patterns, and violent weather patterns. This project's goals were twofold. It created a repository of continuous average-temperature forecast data for the North American continent. It then created a Temperature Analogs web application with two objectives: to use the forecast data to examine estimated changes in temperature among urban population centers at specific future times, and to visually associate like areas with one another. This effort might serve as a basis for future planning tools in specialties such as population migration, water management, and health care.

1.1 Client

Environmental Systems Research Institute's (ESRI's) Applications Prototype Lab (APL) is responsible for developing demonstration applications (demos) that showcase the capabilities of ESRI's GIS software, known as ArcGIS. The APL, under the direction of Hugh Keegan, has built a number of applications which model the effects of climate on human and animal populations. The APL currently has a set of climate forecast data covering North America for every month through the year 2099.

Keegan acted as the client for this project. In that capacity, he brokered acquisition of climate model data and specified requirements for a mapping application to analyze and visualize the forecast data. He also periodically reviewed progress and suggested changes or corrections to deliverables.

1.2 Problem Statement

Global warming is a problem that will affect life on Earth over the long term and perhaps create long-lasting environmental changes (Harris, 2009). Climate change will mean changes to the resources, economy, and, ultimately, livability of the places where people live and work. This project's main goal was to answer this question, posed by the client: if an individual enjoys the climate where he lives now, at what other geographic locations should he look for a similar climate at various times in the future? Average yearly temperature is far from the only measure of a location's desirability. It is, however, a good way to start thinking about rating population centers' future livability.

1.3 Proposed Solution

At the highest level, this effort aims to achieve these goals:

- Graphically analyze and show the effects of climate-change in ways not seen before
- Save time (and money) when creating new demonstration applications

The application and data will allow for interesting and novel climate comparisons, and aid the client strategically in a number of other ways, as well.

1.3.1 Goals and Objectives

The overall goal of this effort was to save the APL team time and money by helping them create climate-related demos faster and more cheaply. This will ultimately help ESRI sell its products and better meet customers' needs. Specific objectives were to build a repository of data from the original raw, downscaled data, and to build a Rich Internet Application (RIA) to analyze and display the data. The repository can exhibit long-term climate trends at a glance, as exemplified in Figure 1.1. It will be reused for future applications needing temperature predictions for future years.

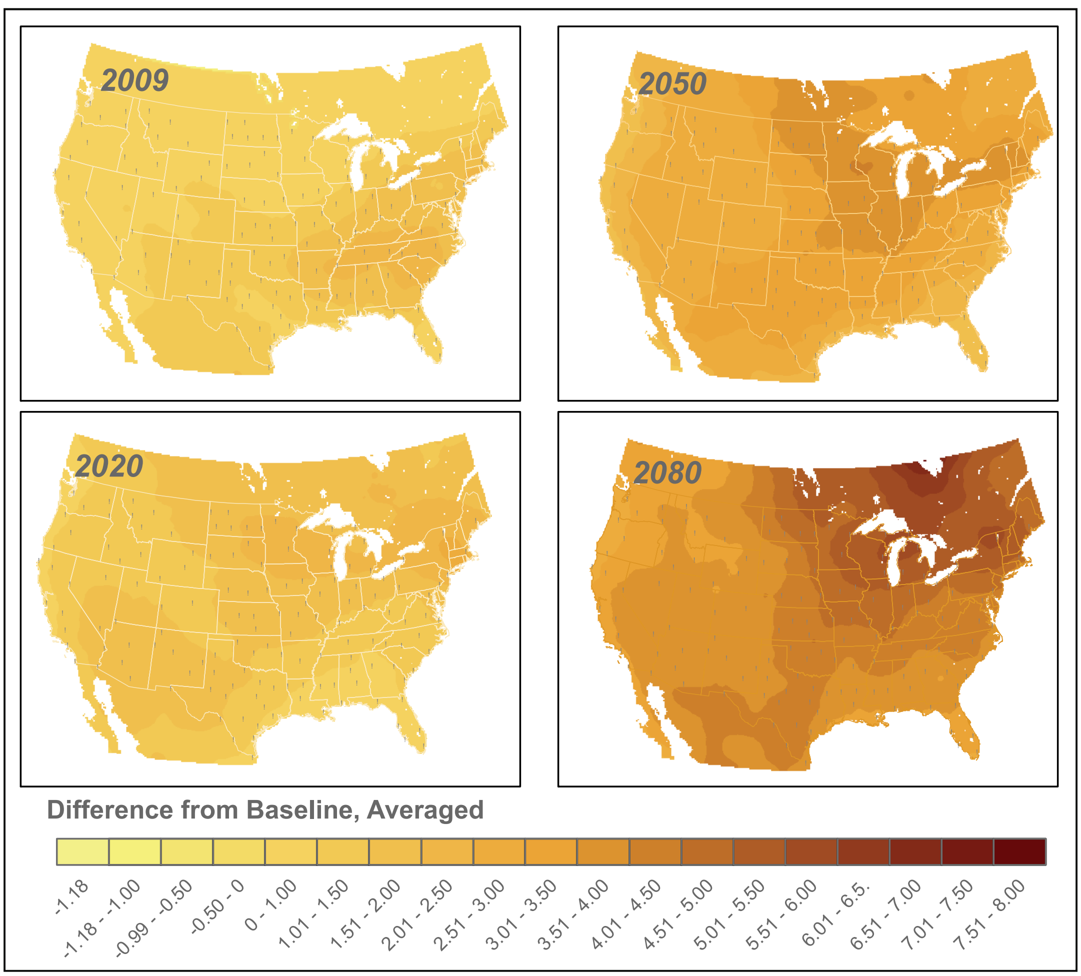

Figure 1.1: Forecast Variation from Baseline, Selected Years

The visualization application will serve as an example of how to programmatically read, analyze, and view the repository data.

Apart from their role as a basis for other applications, the Temperature Analogs web application and data stand on their own as a demo for visitors interested in topics involving weather or the environment. Strategically, this demo could lead to further work. Lab management has expressed interest in directly comparing and contrasting the projections of two or more models or scenarios. A number of application subject areas either previously investigated or currently under consideration by the APL involve climate-comparison data, including:

- Plant-hardiness zones (using minimum-temperature statistics)
- Computer data center cooling and energy-consumption analysis
- Seasonal animal migration patterns and their impact upon humans in the area

While working on this project, I gained valuable experience with climate estimate data and models, geodatabase design, and RIA development. Familiarity with climate data will certainly help with future demos, and the discipline and rigor of documenting the data and the processing methods will help improve future applications and systems.

1.3.2 Scope

This solution ultimately receives and processes material from an upstream source, processes it, and then feeds it to consumers downstream. Additional data came from the ESRI Data & Maps CD.

1.3.2.1 Upstream Data

The current dataset held by the Applications Prototype Lab (APL) originated in the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project, phase 3 (CMIP3) multi-model dataset (Meehl, et al., 2007). Maurer statistically corrected it for model biases and scaled it from a resolution of 1.875 square decimal degrees down to a resolution of one-eighth square decimal degree (roughly twelve kilometers square). The result was stored in a Network Common Data Form (NetCDF) raster dataset (Maurer, Brekke, Pruitt, & Duffy, 2007). ArcGIS Desktop versions 9.2 and up can read this data format, according to a conversation with Mark Smith of the APL; however, there is no assurance that future updates to the data will be available in the same format (Smith, 2009). ESRI's legal team has secured the right for the company to use the data for demo purposes (Schreiber, 2009). This input data is the upstream boundary of this project—an aspect over which the project has no control. Data comes into the system as a NetCDF file on a one-time basis; the next part of the process is to convert them into a format usable in ArcGIS.

Maurer has processed data from sixteen different originating organizations, including the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). He included three different emissions scenarios, representing greenhouse gas emissions in future years (Maurer, Brekke, Pruitt, & Duffy, 2007). The APL previously used similarly downscaled CSIRO data in combination with a middle-of-the-road "A1B" scenario, so this project used the same combination of parameters.

1.3.3 Methods

Data preparation involved a standard mix of technologies. Ed Maurer's datasets are available via File Transfer Protocol (FTP), a widely available file-download technology. In this case, Windows Explorer's built-in FTP facility provided the ability to download the forecast data file.

A variety of custom computations then aggregated the data from months into years and converted it from degrees Celsius to degrees Fahrenheit; ArcGIS geoprocessing tools provided all this functionality, but needed to be tied together in a custom script built with the Python programming language. Similarly, a custom baseline dataset and a series of averaged offsets from this baseline were also computed with Python-invoked geoprocessing tools. Most of these calculations involved averaging of groups of monthly datasets; the Spatial Analyst Cell Statistics tool performed this operation, using the "Mean" parameter. ArcGIS geoprocessing tools also projected the final datasets and imported them into their final geodatabase format.

The data ultimately needed to be made available over the internet to a web-based visualization application. The datasets were published to the web by first loading them into ArcGIS Map documents and then publishing those to ArcGIS Server.

The web application which consumes and displays the forecast data and city analogs was built with Adobe's FlexBuilder 3 tool and the Flex API 3.2, along with ESRI's Flex API library 1.3. In the manner of most Flex-based projects, this effort employed a combination of markup script (called MXML) and Adobe's JavaScript-like programming language, called ActionScript. This architecture helps to separate the user interface from data-manipulation and loading logic.

1.4 Audience

This document is of greatest use to programmers who develop software using ESRI's GIS products, since it outlines development of a software demo using that skill set. Portions may interest those who frequently work with historical or predicted climate data—especially those interested in performing spatial and temporal analysis on such data. The approach described herein goes into some detail on the use and extraction of data in NetCDF format, which may interest GIS specialists in scientific and academic fields.

Technical and managerial staff in GIS sales and marketing divisions may also be interested in reading about the planning and development effort involved in creating a GIS sales demo application.

1.5 Overview of the Rest of this Report

This document is organized in seven chapters, of which this overview is the first. Chapter Two clarifies the problem this project solved. It describes the business case driving this effort, as well as some of the research previously done into the causes of and possible solutions to this problem.

Chapter Three outlines the preliminary planning and analysis that drove the solution to the problem. It describes the client's requirements, the design of the system, and the master plan developed for the effort.

Chapters Four and Five are the most technically detailed of the document. Data is a critical component of any GIS, and chapter Four describes the data design, sources, processing, and other considerations. This will be of interest to those planning on working with climate data, especially with data furnished in NetCDF format. Chapter Five details the building and testing of the solution, including the visualization web application. This should be read by system analysts, application project planners, architects, or developers.

Chapter Six presents the detailed results of the effort: what information the solution provides. Chapter Seven examines the outcome of the project, looking at how well the solution solved the problem, as well as what aspects didn’t work as expected, and some of the lessons learned. It also makes suggestions for building on this project in future efforts.

Chapter 2 – Background and Literature Review

Climate change is a topic of increasing public concern, ranging among such diverse subjects as droughts in Australia or the western United States, changes in food crop growing patterns, and disease vector migration. The effort to model those changes dates back to well before the advent of computing, though only the most modern computers have facilitated the kind of mathematical formulas required to make useful climate predictions. Climate analogs are just one of an array of techniques researchers have developed to help imagine and visualize the geographic components of climate change and its effects on humans.

2.1 Climate Change as Crisis

The notions of climate change and greenhouse gases are not new. John Tyndall proved in 1859 that certain atmospheric gases—primarily water vapor and carbon dioxide (CO_2)—absorb thermal radiation. Researchers in the 1950s recognized that the oceans cannot remove carbon dioxide from the air as quickly as humans and human-related activities produce it. Furthermore, the resulting climate changes may further slow the rate at which the ocean removes CO_2 in a kind of vicious circle. It was proposed in 1938 that a doubling of CO_2 would raise the planet's temperature by around two degrees Celsius (Le Treut, et al., 2007). A paper by Manabe and Weatherald (1967) set forth a model confirming this figure. More recent research suggests that the warmer temperature patterns resulting from the greenhouse effect will be in place for at least the next thousand years (Solomon, Plattner, Knutti, & Friedlingstein, 2009).

Various studies have looked at what temperature actually means to humans. Steadman (1984) proposed a measure of "apparent temperature" which includes humidity, wind speed, cloud cover, and various forms of solar radiation. He went on to state, however, that these factors affect temperature by a range of less than -5 to +7 degrees Celsius and that "dry-bulb temperature correlates most strongly with apparent temperature" (p. 1694).

Ailments attributed directly to temperature extremes are one way in which climate change can endanger humans: most notably, heatstroke, heart attacks, and strokes in the elderly (Kalkstein & Greene, 1997). Some evidence suggests that humans are already adapting to climate change, as shown by declining relative mortality figures in this category (Davis, Knappenberger, Novicoff, & Michaels, 2002). On the other hand, when considering various global climate models (GCMs), Kalkstein and Green (1997) conclude that: "Increases [in summer mortality rates] using 2050 models range from 70% for the most conservative GCM to over 100% for the other GCMs, even if the population acclimatizes to the increased warmth."

Further temperature-related threats come from disease vectors and infectious diseases such as encephalitis (Mogi, 1983). Yet others come from climatic and weather-related disasters, including drought (Gato, Jayasuriya, & Roberts, 2007) and hurricanes (Ryan, Watterson, & Evans, 1992). One study found that a "one degree increase in average spring and summer temperature is associated with a 305 percent increase in area burned, and a 107 percent increase in home protection costs" (Gude, Cookson, Greenwood, & Haggerty, 2009). Only 18 fires were used as a sample for this study, but the researchers used conservative parameters where possible.

2.2 A Brief History of Climate Modeling

Human well-being has always been closely linked to weather patterns and climate, so people have long hoped to be able to forecast and even control the weather. The large number of variables, vast amounts of data, and great volume of calculations involved in even the most primitive models, however, required digital computing; substantial progress only began with advances in computing power and data storage capacity in the 1970s (Weart, 2009). Early models worked on simplistic problem definitions and assumptions, such as carbon dioxide levels increasing at a steady one percent per year (Meehl, et al., 2007, p. 1384). Some of the earliest usable models covered only isolated phenomena (e.g. ocean currents or atmospheric circulation) in highly localized areas; these models were referred to as general circulation models (GCMs). Throughout the 1990s, organizations, such as the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC), have conducted coordinated modeling runs and have created archives of models and data. In an iterative fashion, these have served as bases for more complex models and simulations. One of those archives—the WCRP's Coupled Model Intercomparison Project phase 3 (CMIP3)—is the original source of the temperature forecast data used in this project (Meehl, et al., 2007).

In order to perform more global predictions, researchers mathematically linked multiple circulation models into global coupled models or global climate models (both, confusingly, along with general circulation models, are termed GCMs) (Weart, 2009). Recently, climatologists have taken the notion of amalgamating models a step further; by averaging together two or more coupled models, they have created *ensembles* with the aim of overcoming the weaknesses of any single model (IPCC Third Assessment Report: Climate Change 2001 [TAR], 2001, pp. 535-536).

2.3 Climate Analogs

Regional comparisons of areas affected by climate change are not new. Most of these efforts have gone into predicting climate's effect on agriculture and food production over time. One study looked at how agricultural output in different regions can vary due to increasing levels of atmospheric carbon dioxide. Despite considering a large number of variables—including various side-effects of CO_2 levels, population growth, economic growth, and trade practices—that study found similar agricultural yields among regions at roughly similar latitudes (Rosenzweig & Parry, Potential Impact of Climate Change on World Food Supply, 1994).

Shortly afterward, a study for the U.S. Department of Agriculture compared agricultural zones—specifically, the mix of crops and livestock raised on a given unit of farmland—and treated them as "analogous regions". That work took a pragmatic look at how to optimize farm land and water usage, yet it offered no new ways to visually analyze those analogs (Darwin, Tsigas, Lewandrowski, & Raneses, 1995).

Kopf, Ha-Duong, and Hallegatte (2008) compared European metropolitan regions to what they call "climate analogues" (p. 906). Their work went into considerable statistical detail and considered aridity along with heating and cooling trends. It explicitly drew no conclusions about climate change's societal effects, citing cities' tendency to adapt to temperature extremes (p. 905). It employed the relatively aggressive A2 emission scenario along with an ensemble of circulation models based on data from the Hadley Centre; temporally, it compared two thirty-year spans, with 1961-1990 representing the present and 2071-2100 representing the future. That approach lends itself to a variety of distribution analyses, as well as a range of analog quality comparisons, but is poorly suited to interactive or exploratory visualization. It covered only twelve European cities and provided no direct visual linkages between geographic climate analogs.

2.4 Visualizing Climate Change

Research into means for visualizing climate change is less extensive than research into its causes and effects. Climate change visualization efforts tend to focus on showing how the same location or region changes over time. In contrast, the goal of this project was to point out similarities in different regions over time.

One common climate-visualization technique is to render snapshots of historical data. This can be as straightforward as presenting side-by-side photographs of a landscape or glacier taken at different times (Molnia, Karpilo, Pfeiffenberger, & Capra, 2007). When larger numbers of raster datasets are available, they can be blended into animations. Weber and Buttenfield produced a good example of this approach (1993); their work performed an animation of data ranging from 1897 to 1946. Another creative effort used GCMs to predict good vacation conditions, involving a wide study area, highly granular pixel sizes, and multiple climate variables (Mankoff, 2006).

2.5 Summary

Changes to the world's climate, then, are widely accepted as inevitable and as already under way. Their effects range from inconvenient to dire. Current coupled models represent great progress in the science of forecasting climatic changes, but although researchers have done good work building tools to visualize and analyze forecast data, much more must be done. It is the APL's job to design, build, and demonstrate such tools. A repository of data and an example of how to use it will help the lab's staff to generate the kinds of creative ideas needed to combat the effects of global warming.

Chapter 3 – Systems Analysis and Design

This project ultimately produced two main deliverables in two related design-and-development efforts: a repository of climate projection data, and a visualization application. This chapter looks at the functional and nonfunctional requirements each part was crafted to meet, as well as the design criteria used in the making of each.

3.1 Problem Statement

ESRI's Applications Prototype Lab (APL) produces sales demonstration applications. Effective demos generally highlight innovative analysis and visualization, but data is the heart of most applications. With a base of climate data in the proper format, lab staff can spend their time building creative applications instead of hunting for data sources. The challenge here was to create a reusable repository of data and an example of how to use that data in a demo application.

3.2 Requirements Analysis

This project's original plans called for a waterfall methodology, in which requirements would be gathered, reviewed, signed off, and made final before design or development work would commence. This plan failed to consider the APL's fundamental culture. The client works much better in an idea-driven prototyping environment; indeed, "prototype" is part of the APL's very name, so this project adopted a prototyping methodology instead.

Requirements, both functional, and non-functional, were gathered from a series of conversations and meetings with Hugh Keegan, manager of the APL. These sessions generally used one or more early application prototypes as a basis for discussion.

3.2.1 Functional Requirements

Functional requirements were gathered conversationally while reviewing early prototypes. The APL is different from most kinds of clients in that the only constant rule is that its applications may be called into service at any time, even after months or years of disuse. The functional requirements, listed in Table 3.1, reflect Keegan's vision for this application.

Table 3.1: Functional Requirements

Requirement	Comments
Report various United States cities' current and future forecast temperatures.	
Use three temperature-forecast years to compare future city temperatures with contemporary temperatures.	No further requirements were provided on choice of years; assumption is that chosen forecast years should be spaced evenly throughout the 2009-2099 time period.
Chosen cities should have large populations.	No official definition of the term "large population" was given.
Display and report analysis results on-screen.	No need to print or export results to electronic output formats.
Allow standard basic map-navigation operations, including pan and zoom.	
Allow the user to select a city (representing a favored contemporary temperature profile) for comparison with other cities.	
Display a set of cities whose future forecast temperatures are most similar to that of the selected city today.	
Use straight one-segment lines to visually link cities with forecasts similar to the chosen city's temperature	

Requirement	Comments
Steps to import and process the temperature data from NetCDF format to ESRI format should be automated for easy repetition with future, updated datasets.	

3.2.2 Non-Functional Requirements

Most of the non-functional requirements listed in Table 3.2 concern the final form of the data repository. One standard requirement for all APL demo applications comes from Keegan's often-repeated comment to never break a functioning demo (Keegan, comments during team meeting, 2009). The group makes frequent configuration changes to its machines, a situation normally hostile to applications' stability. Simplicity and robustness of design were used as a primary strategy in countering this effect.

APL applications must conform to the APL's operating environment and standard practices, which emphasize Microsoft technologies where possible:

- Windows 32-bit operating systems for ArcGIS Desktop
- Windows 32- or 64-bit operating systems for servers (ArcGIS, file, database, web)
- Internet Information Server (IIS)
- ArcGIS Server for .NET
- Visual Studio/Silverlight for Rich Internet Application (RIA) development (though Adobe Flex may be used instead)
- As an exception to this pattern, Firefox is the standard web browser because of its greater compatibility with the ESRI JavaScript Application Programming Interface (API)
- Another exception to the Microsoft paradigm is using Python for data geoprocessing; though Microsoft's Visual Basic Scripting language could be used, ESRI recommends Python for a variety of reasons (Environmental Research Institute, Inc., 2009)

Table 3.2: Non-Functional Requirements List

Requirement	Comments
Data must be in a format used by ESRI software.	A current list of supported formats is available in ESRI's web-based help (Environmental Systems Research Institute, Inc., 2008).
Perform all data importing, processing, and manipulation using ESRI software.	

Requirement	**Comments**
Temperature data's geographic extent must cover the United States of America.	
Temperature data scale must be degrees Fahrenheit.	
Temperature data must not be displayed or analyzed with more than one digit after the decimal point.	The source data has six digits after the decimal point; but it strains credibility to ask consumers of the application to believe that any forecast model can really accurately predict temperatures that finely.
Forecast data temporal range must cover as much of the 21st century as possible.	
Data repository must include yearly averages for all temperature source data.	
Host the application and data within the APL environment.	This means running on a Microsoft Windows platform.
Demo must require minimal maintenance over time to keep it running.	
Include ten-year rolling average datasets.	Requested for use in animation applications; not strictly needed for this project, but easily accommodated.
Combine temperature data with precipitation and evapotranspiration data to create a "comfort index".	Deferred as future work.
Chosen cities should, if possible, be evenly spaced geographically for pleasant on-screen viewing.	

3.3 System Design

System analysis and design proceeded in the manner recommended by Roger Tomlinson: define the system's information products and then use those to gauge the system's scope (Tomlinson, 2007, pp. 8-9). Relevant information product descriptions (IPDs) are listed in tables below, along with their subtasks' expected frequency of use.

3.3.1 Building the Base Data Archive

The first data-processing activity—initially building the base data archive from raw NetCDF source data files—should happen one time only or at most on a yearly basis when the authors of the global climate model (GCM) produce updates to their model and data. The processing chain involves a number of steps and can take significant time. Its logic is highly sequential, so adding extra computers will not improve processing speed. Data processing time is not generally a concern for the APL, however; because this operation is infrequent, it represents no problem for the client.

Data extraction involves 1800 raster extractions (twelve months x 150 years), 150 raster averaging computations, and 150 raster arithmetic operations (to convert Celsius to Fahrenheit). Once saved to disk, a month of projection data takes 453 KB of disk space. Each averaged year's data should take no more than that, for a storage requirement of (150 years of data) x (453 KB per year) = 67950 KB or nearly 70 MB. Even considering the host of temporary rasters that will be produced during conversion, disk requirements are quite modest and can be met by any of the APL's current servers.

3.3.2 Preparing Data for a Demo Application

The second data-processing activity was to prepare the base archive data to support a new demo application. Though demos vary widely and their nature cannot be reasonably predicted, their data-processing requirements are generally light (see Table 3.3 for an example). Assuming a new demo will be created every other month, thirty projection operations will be expected per year in the worst case. If three additional data layers are used in each demo, eighteen layers total will added to a map document (for use in ArcMap or in publishing to ArcGIS Server). Twelve spatial analysis operations (e.g., extracting the temperature data to vector datasets) will be expected. Other application-dependent operations will likely be employed to further refine the data, but these must be considered on a case-by-case basis. This assumes new demos will use five years of temperature forecast data each. Even if more are needed, an ESRI developer-level workstation should handle the processing requirements.

Table 3.3: IPD Functions for New Demo Creation

Function	Times / year	Number
Project raster	6	5
Add thematic data	6	3
Spatial analysis	6	2
Publish to server	6	0.5

3.3.3 Preparing Data for Custom Analysis

The APL does more than produce demo applications; it occasionally performs specialized analyses for various organizations internal to ESRI, some of which might make use of the temperature forecast data. These analyses are done in ArcGIS Desktop and require custom preparation of the data. Without knowing in advance the details of these analyses, site suitability was assumed to represent the typical level of processing effort.

Table 3.4 lists the number and frequency of processing steps for a hypothetical suitability analysis. If this were done six times per year, it would entail thirty projection operations, eighteen add-data operations, twelve computations for normalizing raster values (a critical part of suitability analysis), and six executions of the suitability tool. This is a light load for any modern desktop computer.

Table 3.4: IPD Functions for Custom Analysis

Function	Times / year	Number
Project raster	6	5
Add thematic or raster data	6	3
Normalize layer values	6	2
Define and run suitability analysis	6	1

3.3.4 System Design Summary

The APL has several robust server machines to host ArcGIS Server, the viewer application, and the data services behind it. Communication and interfaces between computers rely on standards, including Windows and Ethernet connections between workstations and file/database servers and TCP/IP connections to the internet for FTP clients to download the raw datasets. Usage levels are inherently unpredictable, but are often low with spikes coinciding with sales efforts and events. This demo's usage is similar to that of other APL demos; no hardware or software was needed above what the APL already had in place.

3.3.5 Project Architecture

Figure 3.1 shows the basic elements inside and outside the scope of this project. Standard tools and protocols were used as much as possible to minimize complexity and maximize extensibility.

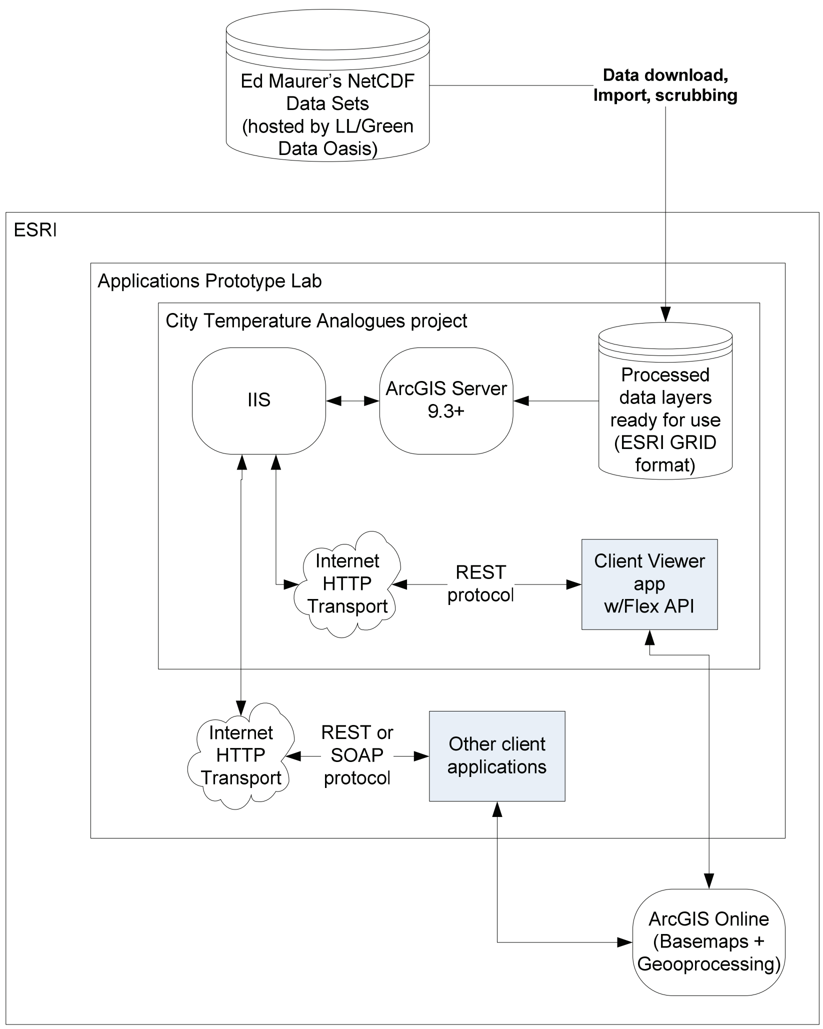

Figure 3.1: Project Architecture

ArcGIS Server is a highly complex system requiring auxiliary components, such as a web server and application server. Both Microsoft and non-Microsoft options are available for use in these roles; but Microsoft operating systems and software integrate most easily and are well supported by ESRI in conjunction with its products. Windows and Internet Information Server (IIS) were the web and application server environment for this project.

As the second stage of the process, the NetCDF data must be turned into raster layers, one per forecast year. An ArcMap document is created to contain a given year's layer; this must be done in order to publish the raster data to ArcGIS Server so it can be made available over the Internet.

The APL owns and maintains multiple instances of IIS in order to host its demo applications, including the viewer application. The Temperature Analogs application performs attribute queries in order to determine which cities should be linked for visualization. These kinds of queries can be done in various ways; ArcGIS Server spatial queries are a standard and easily extensible option. For portability, performance, and robustness, however, this application consumes XML data stored as a compiled resource, requiring an extra pre-processing step.

3.3.5.1 Downstream Data

Explicit security restrictions aside, once the forecast data has been published to the ArcGIS Server, it will be available for a variety of uses by a multitude of network-based clients. Although this project does serve as an example of how to use the climate forecast data, it should not be considered the only way to work with the data. It should not restrict other uses of the data.

3.4 Project Plan

No significant effort ever goes as originally planned; this was no exception. What began as a standard waterfall approach changed into an iterative prototyping approach; however, the original time estimates proved relatively accurate.

3.4.1 The Original Plan

The waterfall methodology is an attractive one during the initial planning phases of a project; its well-defined phases leave little room for changes or surprises. The original plan proposed seven phases. The project assigned a single resource to nearly every task, but scheduled the client as a resource for a number of short interviews or reviews. The plan also assumed no more than three hours of work time each weekday, with weekends and university break periods scheduled as non-work time.

The problem definition phase involved research and client conversations to get a sense not only of what needed to be done, but also of what could not be done in the available time. Analysis covered gathering requirements for both the data repository and the visualization application by way of interviewing the client and writing documents for those requirements. A separate phase—data procurement—focused on gathering, documenting, and archiving the downscaled climate forecast data. All design work was slated for the fourth phase, including: application, data storage, processing design, and corresponding design documentation.

The development phase included: building and loading the geodatabase, creating and packaging all data loading tools, coding and unit-testing the visualization application, and writing a system document. Development was the longest phase, at 148 person-hours or 173 elapsed days. A testing phase included debugging and fixing problems not addressed during development. Functional testing and integration testing were also planned—important tasks in an environment that places great stock in preserving its functioning applications. Testing also involved a user acceptance test with the participation of the client. Finally, the delivery phase involved writing and revising the final project report.

3.4.2 A New Approach

Midway through the project it became clear that the waterfall methodology was a poor choice. The APL is organized around prototypes: its demos are designed and created iteratively around evolving requirements, and its staff and management use an evolutionary approach in their daily work. From the outset, Keegan expected to hold all discussions in front of an application running on-screen.

The project analysis and design phase proceeded more smoothly using a methodology adapted to the group's demonstration-oriented mentality. The prototypes served first to stimulate discussion about the possibilities and limitations of current ESRI technology; and second as a framework onto which further functionality could be added as needed or discovered. For example, an initial effort produced a geoprocessing script to import the raw NetCDF data into ESRI Grid format. The client then wanted to see the same data converted from degrees Celsius to degrees Fahrenheit; this turned out to be a simple two-line addition to the script and became an additional official requirement. Other additions to the prototype—e.g., a ten-year rolling average for smoothness in animations—were included but intended for use in other, future applications.

Since the goal was not to produce a production-grade application, the tail-end maintenance portion of the life cycle was excluded. Roughly, here are the steps:

1. Research available climate-change models and emission scenarios.
2. Gather requirements by building a prototype application and repository from a climate-forecast dataset delivered for an earlier demo in 2007.
   This stimulated a discussion on geographic limits—extent of choice of cities—and temporal limits—choice of forecast years—for the study data. Decisions from this phase included geographic extent of the study area, units of temperature measurement, parameters controlling the cities to be used for comparison, and temporal limits of the comparison (the amount of data available was large and unwieldy, necessitating careful selection in order to craft an effective demo).
   - North American extent only, using only cities from the United States
   - Fahrenheit as the temperature unit of measurement
   - Use the most populous cities where possible, but for appearance's sake, choose ones that are spread out geographically

   No projection requirements were specified. No map projection can represent distances between all the chosen cities with no distortion; as a compromise, the USA Contiguous Albers Equal Area Conic projection was chosen for the data. It preserves scale well across the United States background layers and also highlights ESRI software's ability to draw projected data—an advantage over its competitors. (U.S. Geological Survey, 2006)

3. Gather the data.
   This was a critical point in the process; if the data were unavailable or corrupt, the requirements would need to be revisited and updated. Data were reviewed for legal restrictions that might make them unsuitable for use.
4. Prototype a procedure for processing the data.
   Technology constraints and requirements from the initial prototype dictated the final form of the data. Data should integrate as closely as possible with other, related client datasets. Any geographic tool's usefulness depends in great part on its underlying data; therefore the climate-projection data for this effort must be extracted, processed, and stored in a repeatable, documented way.
5. Update the visualization application to use the new data.
   Deliverables from this phase included a geodatabase specific to the application.
6. Test and fix the visualization application.
   This included several rounds of refinement and bug fixes. Because the APL does not generate production or industrial-strength applications, neither a test plan nor test cases were created. This also included deploying the application to one of the client's demo servers to make sure it would function properly alongside other existing demos and data—a form of integration testing. Testing was to be performed to ensure that the application can be viewed from outside the ESRI firewall.
7. Document the visualization application.
   Deliverables from this phase included a working web application with commented source code, and documentation.

3.4.3 Lessons Learned

Despite structural mid project changes, the overall scope and length of the project remained nearly the same; what prototyping added in effort up front, it removed from the development phase. In effect, most of the development and requirements-gathering work merged into prototyping work with almost no net change in effort-hours. Testing and debugging remained the same at forty hours. In a small change unrelated to project methodology, the delivery phase was shortened by four hours upon the realization that packaging the deliverables and creating a CD-ROM would take a half day instead of a full day.

Another potential problem was the initial assumption that the APL's archived climate data would be used for this project. Conversations and meetings with the original datasets' creators revealed a new effort to downscale the climate forecast data in more scientifically rigorous ways; the client wanted to use this newer data. It turned out not to be a problem to do so because the change came early in the project and because the new data came in the same NetCDF format as the original data.

Microsoft Project is an excellent tool for tracking progress, but it has some problems which manifested during the course of the project. Realistically, drafts of the final report needed to be turned in sequentially one-by-one during September to allow adequate time for edits and revisions. If there even exists a way to model this kind of schedule in Project, it is not readily apparent.

3.5 Summary

Although prototyping lacks the waterfall method's sense of structure, it can be an extremely effective approach in the proper environment. In this case, simple augmentations to a prototype added a lot of useful functionality with little effort, and it made requirements gathering far more straightforward than would have been the case in a formal interview approach.

Chapter 4 – Database Design

One of this project's major goals was to build a data repository that could be reused in many ways by many applications. A useful and long-lived repository certainly demands careful attention to its location, storage format, and spatial reference; careful thought certainly went into those aspects. In addition, the scope of the data—150 years' worth of it—made it doubly important to design a logical directory hierarchy. Data acquisition and preparation accounted for the bulk of the effort in designing and implementing this project, but the structure of the data itself ended up being quite simple.

Supporting data also played a background role in the application and had to be prepared for use. These additional datasets provided vital context regarding the forecasts' location and orientation with respect to well-known geographical bounds and landmarks. But again, these background layers' relationships, both among one another and with the climate forecast repository, ended up being relatively straightforward.

4.1 Conceptual Data Model

Conceptually, the data needs for this project were quite modest. Consider the question addressed by the application portion of this project: how to link a city of interest to other cities with similar characteristics at various forecast dates. In other words, what cities should have future temperatures similar to that of a given city today?

The number of entities in this use-case is small: city, temperature forecast model with many various temperature forecasts, and year (see Figure 4.1). An additional requirement came from prototyping: to use larger, well-known cities where possible. This added another attribute for consideration: population. The important concept for this use-case was the relationship between cities in different years. Location turned out, naturally, to be a critical attribute of both cities and temperature forecast values; it allowed a spatial join between field and object data types.

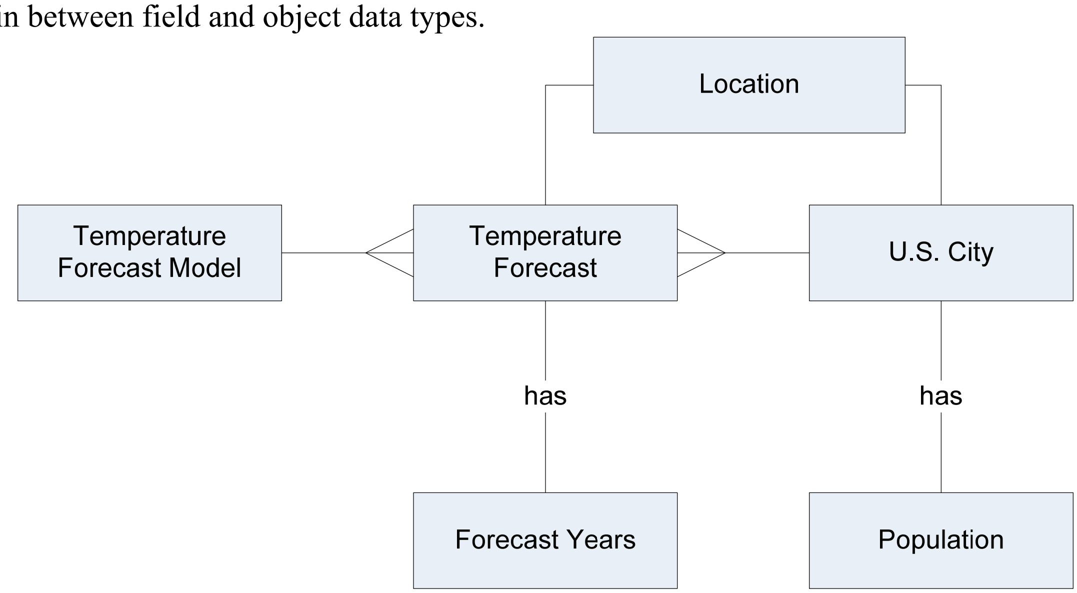

Figure 4.1: Conceptual Data Model

4.2 Logical Data Model

The logical data model (Figure 4.2) clarified the relationship between cities and forecast values. Each city has a unique location on the Earth's surface; furthermore, that location coincides with a specific temperature forecast value for every forecast year. So each city has a number of forecasts, but any given forecast location has at most one city—often none (this assumes that no two cities have exactly the same location—generally a safe assumption, but was verified with a script (see Table 5.3 for details).

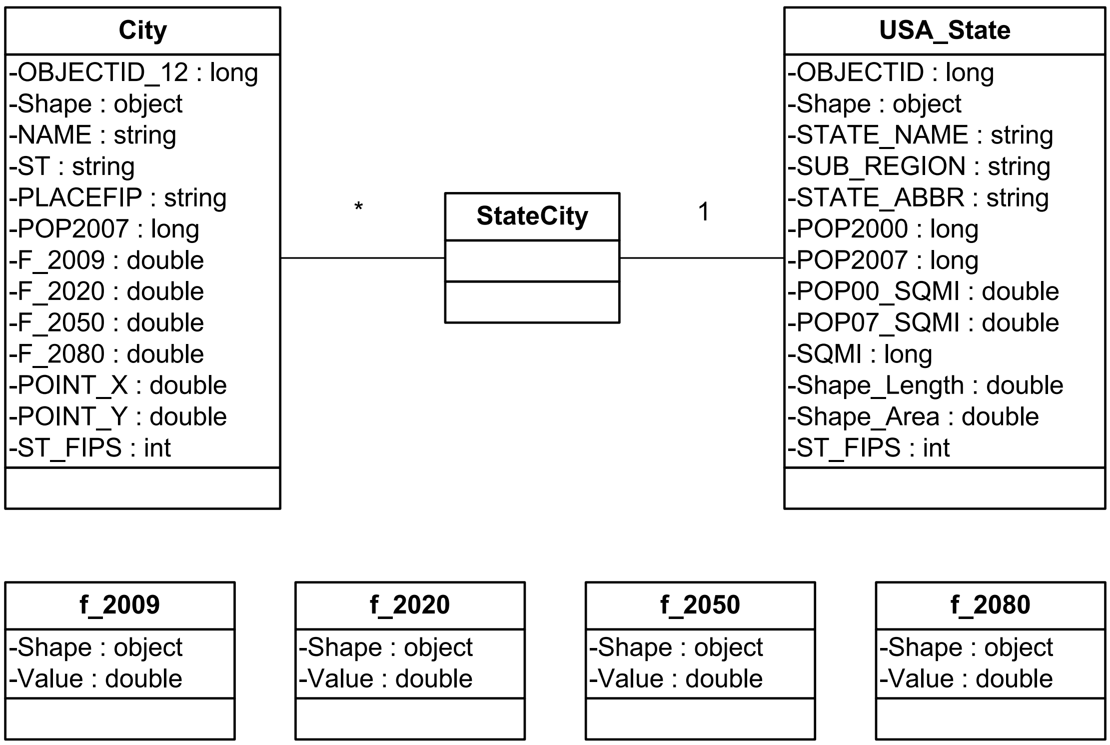

Figure 4.2: Logical Data Model

The main difficulty with this model is that it tries to represent not only object (or vector) data, but also field (or raster) data. Since fields are not normally table-based, they're generally unsuitable for direct comparison with vector entities—at least in a traditional database paradigm. As will become clear, much of the effort in building the physical data model involved running spatial analysis operations to effectively join city objects to the temperature forecast fields.

4.3 Data Sources

Data for this effort came from a variety of sources and can be grouped into three major categories:

- Climate forecast data
- City points, which ultimately ended up absorbing climate forecast values for intercity comparison
- Other data for display, provided by United States governmental agencies by way of ESRI

4.3.1 Climate Forecast Data

The heart of this project was the raster forecast data used to draw comparisons between disparate cities. Ultimately this data came from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), though Maurer further updated it from its original form.

Marine and Atmospheric Research is one of CSIRO's sixteen fundamental divisions; and one of that division's recognized achievements has been to produce its *Mk3.0* coupled model. The results of that that model were given to the Intergovernmental Panel on Climate Change (IPCC) (Torok, 2006). Mk3.0 eventually became one of 24 models, submitted by organizations worldwide, taking part in the Coupled Model Intercomparison Project phase 3 (CMIP3) and finally archived at Lawrence Livermore National Laboratory's Program for Climate Model Diagnosis and Intercomparison (PCMDI) (Meehl, et al., 2007).

From those 24 models, Ed Maurer of Santa Clara University selected sixteen (See Appendix A for a complete list of available models and emission scenarios). His two-part methodology first measured and corrected model bias against a baseline of measurements from 1950 to 1999. Then he applied downscaling logic to the data to reduce it to a resolution of 1/8 degree square (Maurer E. , About -> Methodology, 2008). This is the final product that was downloaded and used in this project. The various processing steps are summarized in Figure 4.3.

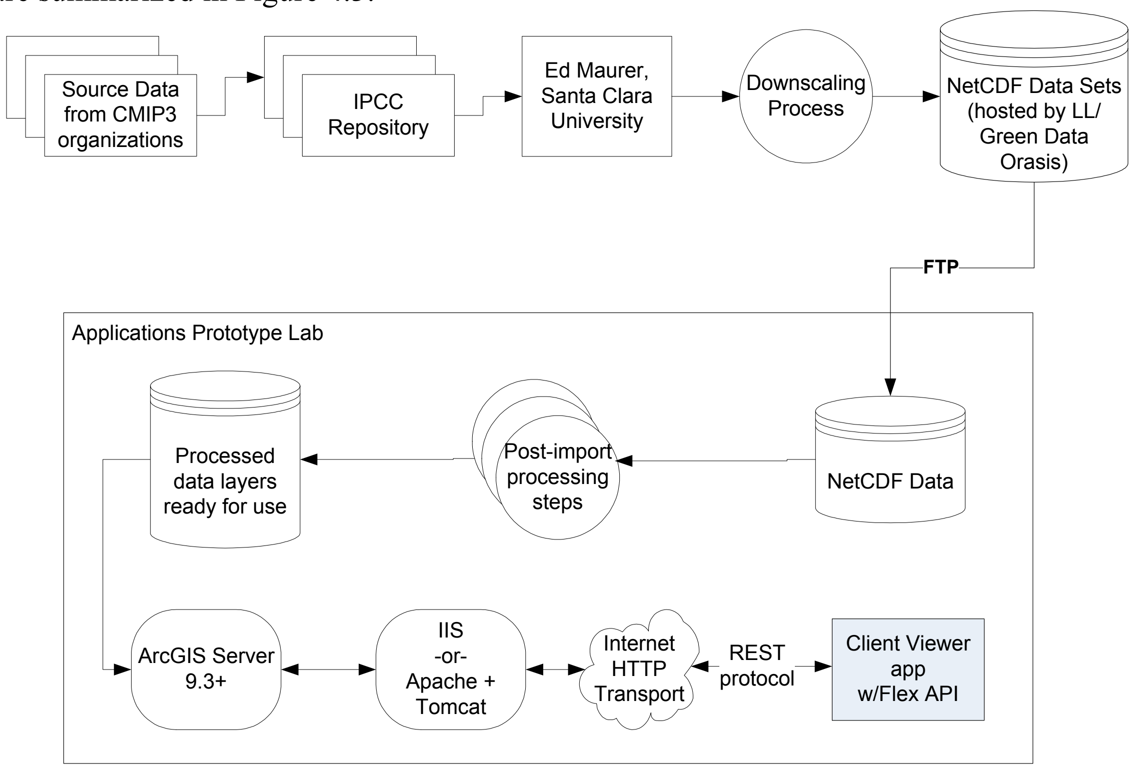

Figure 4.3: Climate Forecast Data Provenance

4.3.2 City Points

The main idea behind this demo being to compare cities of different times and average temperatures, one critical step was to select a set of reference cities from the larger set of all available United States city locations. The reference set used here was the cities.sdc dataset from the 2008 ESRI Maps & Data CD, which was in turn based upon data produced by the year 2000 U.S. Census. Once those locations were selected, coincident temperature forecasts were extracted as vector attributes for use in intercity comparisons.

4.3.3 Other Reference Data

Beyond the climate forecast model data, these datasets participated as reference or background data in the visualization application:

- State outlines for the continental United States (taken from the 2008 ESRI Data & Maps CD)
- Background imagery (*Earth with Ice*, taken from the 2008 ESRI Data & Maps CD)

4.4 Summary

The data model for this project turned out to be quite uncomplicated. The complexity came in adapting the data for use in an application. Because applications vary widely in scope and purpose, each application will require work to prepare the climate data repository for its use. In some cases a great number of detailed steps may compose such preparatory groundwork.

Chapter 5 – Implementation

In keeping with this project's two major goals, its implementation tasks broke down naturally into two categories: preparing the repository data and building the application. Building the repository involved a great number of processing steps; they will be covered in detail, but were mainly implemented in two separate Python scripts. Implementing the application meant not only designing and building a Rich Internet Application (RIA), but also preparing the data especially for it, entailing these tasks:

- Preparing a set of city points and extracting coincident temperature values as attributes
- Projecting reference imagery to serve as the application's base or background map layer
- Preparing other background data

5.1 Data Repository

Each application using these data will employ a projection and coordinate system suited to its particular purpose; in this case, it was impossible to choose one single spatial reference that would make the data accessible to all future applications. Any application built to use the unprojected repository data would need to perform numerous on-the-fly transformations just to display it alongside any other projected data layers. As a compromise, the repository itself remained unprojected with geographic coordinates. The work of projection will fall upon each application's author as a project-specific data preparation task.

Converting Maurer's NetCDF-based monthly forecasts to a set of ESRI Grid-based yearly forecasts outstripped the abilities of a single geoprocessing tool or even a model. A Python script does this work, following the sequential algorithm in Table 5.1. The bulk of the work came from extracting 1800 monthly forecast Grids from NetCDF using ESRI's Multidimension geoprocessing tools. These were averaged into 150 yearly forecast Grids and converted from degrees Celsius to Fahrenheit. A final step was to establish a baseline from the data. Baselines are historical norms or standards, based on a reference series of years. Prediction data is often expressed as offsets or delta values from a given norm (IPCC Third Assessment Report: Climate Change 2001 [TAR], 2001, p. 95).

Table 5.1: Extraction and Yearly Averaging

Description	Comments
For each of 1800 months (1950 – 2099):	
Convert NetCDF slice to raster dataset	Use *MakeNetCDFRasterLayer* geoprocessing tool (Multidimension tools). Parameters supplied: • Variable = "Tavg" • X Dimension = "longitude" • Y Dimension = "latitude" • Band Dimension = <blank> • Dimension Values: Dimension = "time"; Value = month (1 to 1800) • With the particular NetCDF files supplied, it was necessary to set "Value Selection Method" to "BY_INDEX" • Output Raster Layer: a Universally Unique Identifier (UUID) was generated and used to form a layer name in this format: "NC<UUID>" to guarantee unique layer names for each month
Add resulting raster layer to a value table (essentially a list of rasters)	
For each year (12 months) of layers:	
Average the rasters	Use *CellStatistics* geoprocessing tool (Spatial Analyst tools). Parameters supplied: • Input rasters: value table containing 12 months of raster layers • Output raster: a filename calculated from the numeric year representing the 12 months being averaged • Overlay statistic: "MEAN" Note that the NetCDF pixel values are in degrees Celsius, as are the averaged rasters produced here.

Description	Comments
Convert the year's raster values from degrees Celsius to degrees Fahrenheit	Use *SingleOutputMapAlgebra* tool (Spatial Analyst tools). Parameters supplied: • Map Algebra expression: "(" + outYearRasterC + " * 9 / 5) + 32" where outYearRasterC is the name of the raster produced in the previous step • Output raster: a filename calculated from the numeric year representing the 12 months represented, plus the fixed extension "_F"
If the year is part of a specified baseline period, add the year's raster to a baseline list	Baselines are common in climate data; forecast values are often specified as offsets above or below a specified baseline.

The Applications Prototype Lab (APL) previously built a demo which animates a series of yearly temperatures built upon an earlier generation of Maurer's forecast data. The goal of that demo was to produce a smooth series of visual patterns that demonstrated a progressive change across time and space; but the developer who built that earlier application discovered that the forecast values change a great deal from year to year and do not produce a smooth visual progression. Therefore, the original was processed with a ten-year averaging window, wherein each forecast year was averaged along with the preceding five years and with the following five years, creating a smoother, more gradual series of rasters. Figure 5.1 shows a graph of yearly forecast values for Wichita, Kansas, with rolling averages superimposed. While values vary greatly from year to year (creating a jagged appearance in the graph), the averaged values produce a far smoother line right through the middle of the year-over-year values.

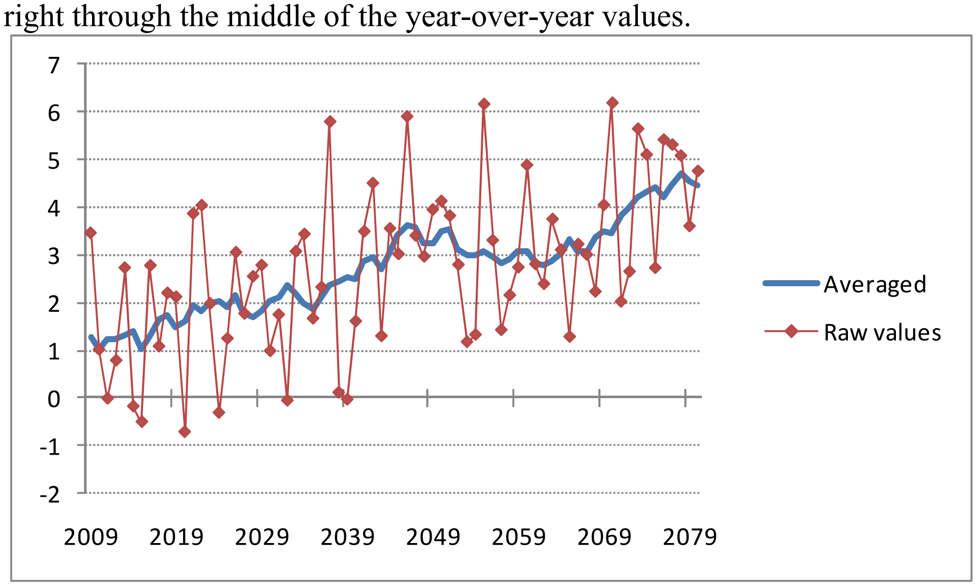

Figure 5.1: Difference-From-Baseline Values vs. Rolling Averages (Wichita, KS)

Anticipating similar future demos, Hugh Keegan requested that the new data also be put through a ten-year averaging algorithm. Though the results were not used for this particular project, the algorithm was simple to design and implement once all 150 years were extracted and converted. Table 5.2 outlines the logic involved in creating these rolling averages. This was implemented as a separate Python script that can be run on any directory containing raster datasets. It looks for a four-digit year value within each file name and uses those year values to build its ten-year windows of datasets for averaging.

Table 5.2: Rolling Averages Algorithm

Description	**Comments**
Calculate a set of years to be averaged	The beginning and end years are parameters to the script.
For each year in the set:	
Look for a raster dataset containing that year in its name	The ESRI geoprocessing scripting object has a ListRasters method which accepts wildcards.
Calculate an averaging window of years around the dataset: five years before and five years after. Add those years' raster datasets to a value table	If the target year is 1965, the averaging logic uses the years 1960-1970.
Calculate the mean raster for the chosen window	Use *CellStatistics* geoprocessing tool (Spatial Analyst tools). Parameters supplied: • Input rasters: the value table of rasters in the window • Output raster: a filename calculated from the target year • Overlay statistic: "MEAN"

These scripts were designed to run inside ArcGIS Desktop as geoprocessing script tools. While they could be invoked in this manner, in practice, they consumed memory quite rapidly and eventually stopped running. In fact, the Extraction and Yearly Averaging script would consistently crash around halfway through processing the 1800 months of forecasts. Running the script from the Windows command line instead (without invoking the ArcGIS framework) performed significantly more quickly, used less memory, and ran to completion.

After this step, the climate forecast repository was complete on disk in its final format. A number of intermediate datasets were created in the process, some of which were worth keeping with the assumption they might help in constructing future demos (see the directory hierarchy in Figure 5.2).

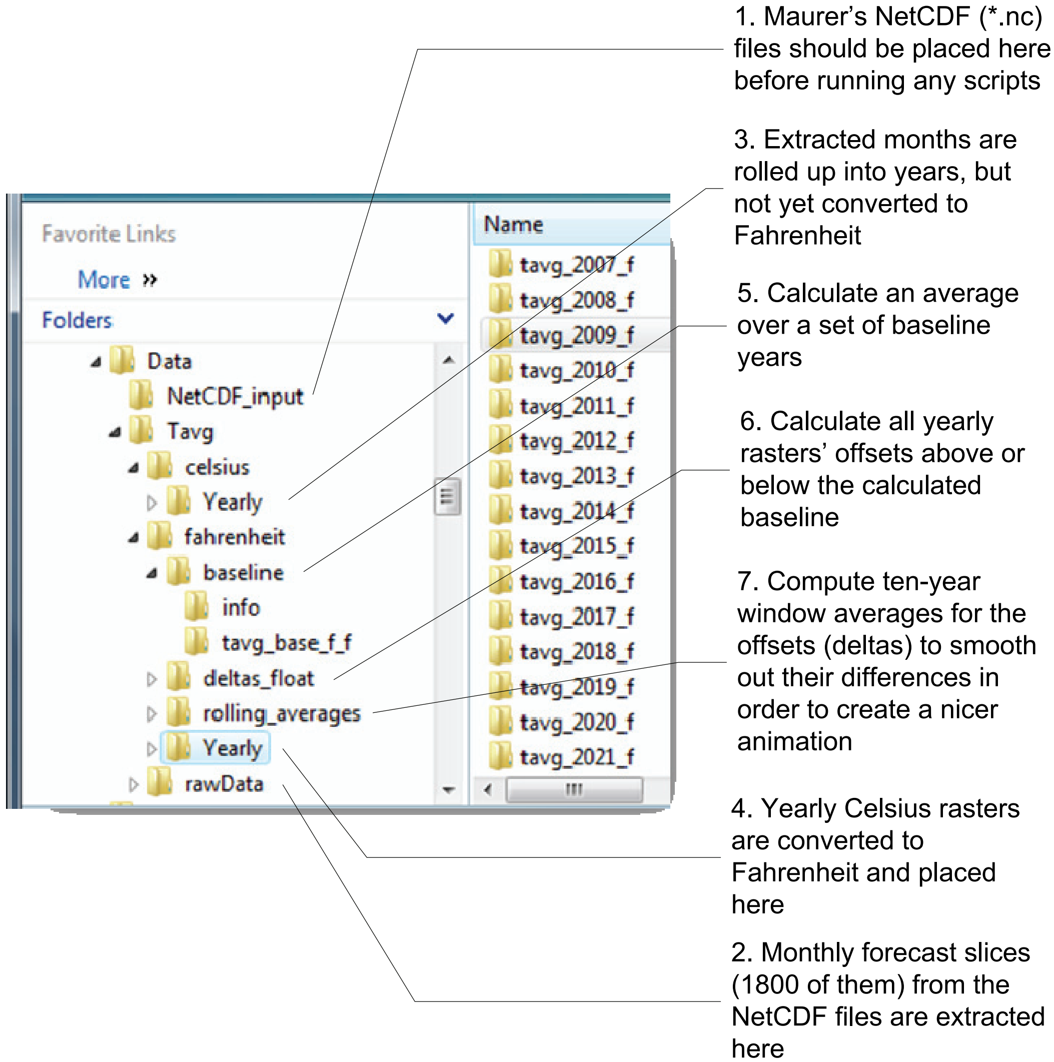

Figure 5.2: Forecast Data Directory Structure

5.2 Temperature Analogs Application

Building the application took place in two main stages: preparing and publishing all data layers (including projecting the needed subset of the forecast temperature repository); and writing the application itself. This section concerns how the several data layers were prepared, how they were published, and finally with certain key topics regarding the application's graphical user interface (GUI) and internal structure.

5.2.1 Preparing City Points

The Temperature Analogs application was designed to serve as an example of how the repository data can be adapted, used, and displayed for geographic analysis. At its heart lies a fusion of city locations and their coincident temperature forecasts. A series of processing steps yielded a specially augmented city point dataset that would meet the project's non-functional requirements. Table 5.3 lists the steps needed to prepare the cities dataset.

Table 5.3: Preparing City Points Data

Description	Comments
Create new personal geodatabase	Personal geodatabase chosen for Microsoft Access's advanced SQL capabilities
Import ESRI cities.sdc dataset from Maps & Data DVD	
For each forecast year, extract forecast values to points	Use *ExtractValuesToPoints* geoprocessing tool (Spatial Analyst tools, Extraction toolset). Parameter values: • Input points: the geodatabase-based city points from the previous iteration of this loop (cities.sdc for the first iteration) • Input raster: desired forecast raster Grid • Out point features: new, temporary feature dataset name in the geodatabase After each execution, the chosen forecast year's values are in a field named "RASTERVALU".
For each forecast year, rename "RASTERVALU" field before the next iteration overwrites it	• Add a new floating-point attribute field named for the year of the forecast (e.g. "F_2050" for Fahrenheit, year 2050). • Use the field calculator to set this new field's values equal to those of the existing field "RASTERVALU". • Delete the field "RASTERVALU".
Delete the intermediate point feature classes created during the iterative loop.	

Description	**Comments**
Delete all records where at least one forecast year temperature is -9999 (NoData)	Used an ArcMap attribute selection query; this could also be done using SQL in Microsoft Access.
Project the points to North American Equal Area Conic	
Add an attribute to each city indicating its distance to its nearest neighbor	Use the *PointDistance* tool (Analysis toolbox, Proximity toolset). Parameter values: • Input features: projected city points (e.g. "City_eqa") • Near features: projected city points (the same as the input points) • Out_table: a unique table name in the geodatabase (e.g. "City_eqa_PointDist_125km") • Search radius: 125 km
For each pair of cities that are closer to one another than 125 km, delete the one with the smaller population	The goal is to ensure a less-crowded and more uniformly distributed set of points. Run a SQL command in Microsoft Access: DELETE * FROM City_eqa AS C0 WHERE C0.ObjectId in (SELECT distinct i.objectid FROM (City_eqa AS i INNER JOIN City_eqa_PointDist AS d ON i.objectid = d.input_fid) INNER JOIN City_eqa AS f ON d.near_fid = f.objectid where i.pop2007 < f.pop2007);

Description	Comments
Verify that there are no duplicate cities (that every city has unique X and Y coordinates)	First, extract X and Y coordinates as attributes using the *Add XY Coordinates* tool (Data Management toolbox, Features toolset). Next, run a SQL query in Microsoft Access: SELECT Cities_1.NAME, Cities_2.NAME FROM City_eqa AS Cities_1 INNER JOIN City_eqa AS Cities_2 ON (Cities_1.POINT_Y=Cities_2.POINT_Y) AND (Cities_1.POINT_X=Cities_2.POINT_X) WHERE (((Cities_1.OBJECTID)<>[Cities_2].[ObjectID])); This query joins the cities table to itself, reporting cities with different Object IDs but identical coordinates. None were reported.
Export city records as an XML file that the FlexBuilder Integrated Development Environment can easily read and use	See section 5.2.6 for details on the choice to use cities in eXtensible Markup Language (XML) format instead of a more traditional ESRI data format.

5.2.2 Preparing Base Map Imagery

Maps are often built layer by layer from the bottom up, starting with the background and ending with the most important, thematic data in the foreground; this application was no exception. The base layer originally was to come from ArcGIS Online, as do many of the APL applications' base layers. ArcGIS Online is a free and bountiful source of background streets, topographic, and satellite imagery; however, all its imagery is tiled and pre-rendered in the WGS 1984 coordinate system and cannot be changed or projected on-the-fly. Therefore, using an ArcGIS Online layer would require that all the application's map layers have the WGS 1984 coordinate system, an onerous restriction (Environmental Systems Research Institute, Inc., 2009, How to build online base maps).

ESRI's Data & Maps DVD is another source of data and imagery, which can be projected as needed. A glance suggested that the *Earth with Ice* dataset appears similar to ArcGIS Online's *ESRI Imagery World 2D* dataset. A simple raster projection rendered it ready for use in this application.

5.2.3 Preparing Background Temperature Layers

Other layers needed to be projected from their native geographic coordinate systems into the chosen USA Contiguous Albers Equal Area Conic projection:

- U.S. State outlines – from the ESRI Data & Maps DVD
- Forecast raster layers for 2009, 2020, 2050, and 2080 – from the Grid datasets calculated during the *Extraction and Yearly Averaging* stage

The raster and vector projection geoprocessing tools in ArcGIS Desktop easily performed this task.

5.2.4 Data Services Preparation

The application would be an ArcGIS Server client application, so all data needed to be published to ArcGIS Server before use, as detailed in Table 5.4.

Table 5.4: Preparing and Publishing Data Services

Task	Comments
Fuse base image and USA states	USA states dataset is for visual reference, not spatial analysis, so merging it with the background image improves performance and reliability.
Symbolize forecast layers with Temperature color ramp	By default, raster images are symbolized with a grayscale color ramp; but the *Temperature* ramp has more visual appeal and conveys a temperature scale more intuitively.
Save Map Service Definitions (MSDs)	Fast, optimized map services require MSDs.
Publish to ArcGIS Server	
Set tiling	ArcGIS Server performs its fastest when serving pre-rendered, tiled, data.

A word about performance: At release 9.3.1, ArcGIS Server services comprise three types; from slowest-performing to fastest, they are dynamic, optimized, and tiled. The base map layer and the four temperature forecast layers were first published as optimized services and later configured to run as tiled services, a seeming waste of effort. Tiles can be generated in different ways, however: all at once before the service is published, or on demand. In the on-demand option, ArcGIS Server checks each client image request. If a pre-rendered tile is available to fulfill the request, it is sent to the client. If not, the tile is generated then and there, and then sent on to the client. In this case, the chosen option was on-demand, so an optimized map service speeds up on-the-fly tile generation.

5.2.5 User Interface

Since the application was meant to showcase the climate data, one logical objective was to allow users to explore forecast values interactively. With that in mind, the application was laid out as a simple map with city points (see Figure 5.3). A panel along the top displays the title and information on the currently selected city; a panel along the left displays tables of related cities at various forecast times in the future.

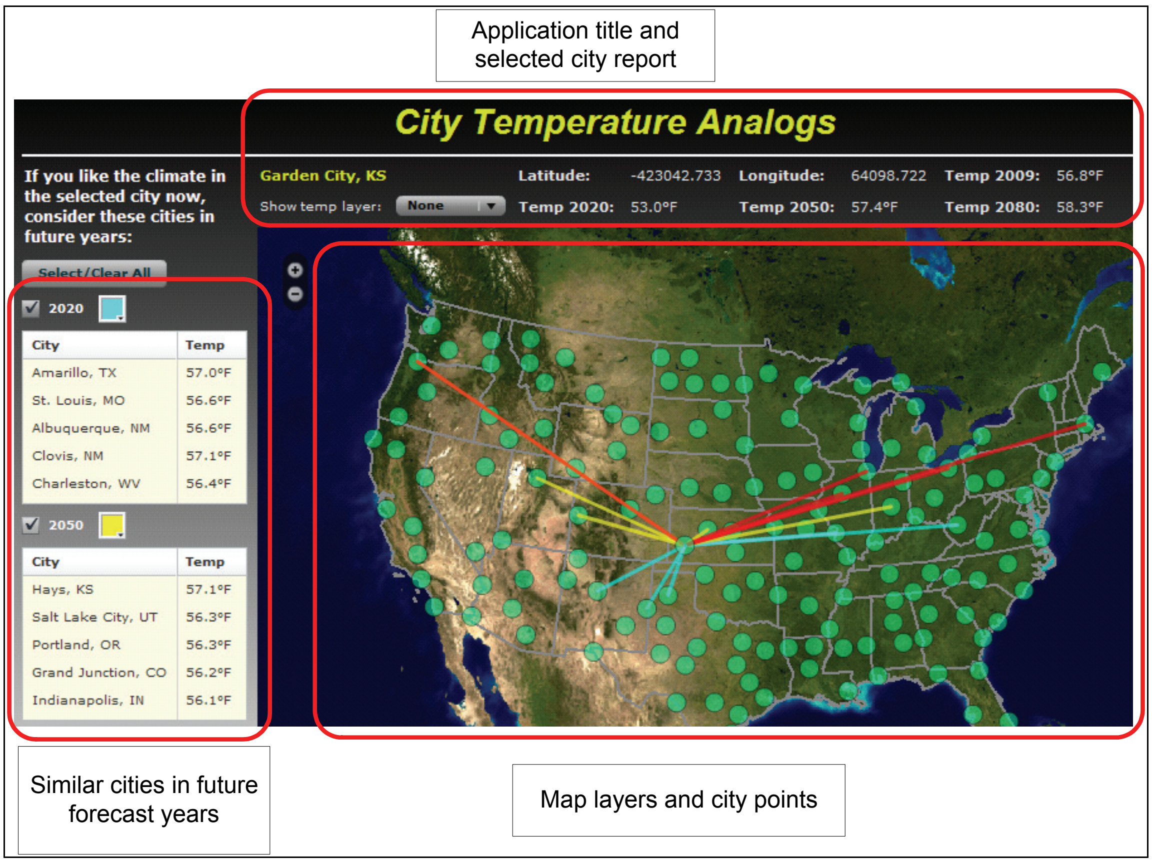

Figure 5.3: Application User Interface Layout

The user selects a single city by positioning the mouse pointer over its location for at least one half second. The city summary panel (along the top, just below the application title) displays the selected city's current and future average temperatures (Figure 5.4).

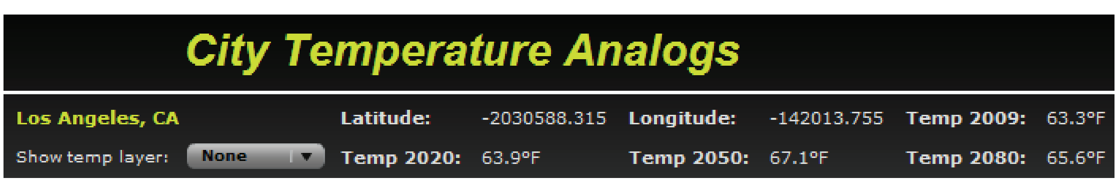

Figure 5.4: Selected City Summary

Three checkboxes (Figure 5.5) in the left-hand panel let the user pick one or more future years for which to find cities comparable to the selected city. With one or more of these boxes checked, the application provides two additional pieces of information to the user once they select a city. For each selected year, it shows a table of the five cities whose forecast temperatures most closely match those of the selected city in 2009. It also draws a colored line between the selected city's location and those of its matching cities. Each line to a matching city is drawn with a particular color representing the forecast year for that particular match. Application users may click a color panel to activate a color selector and choose a new color to represent a forecast year, as shown in Figure 5.6.

Figure 5.5: Forecast Year Checkboxes

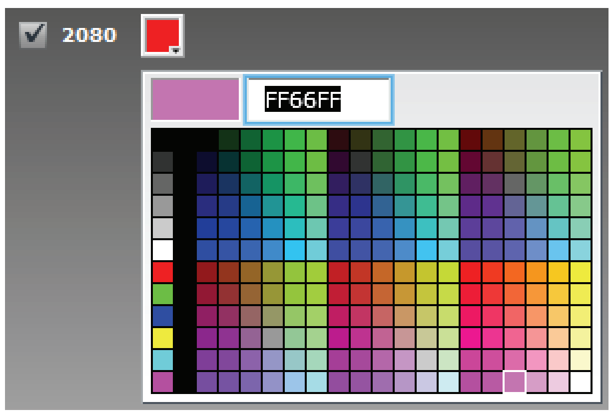

Figure 5.6: Forecast Color Selector

One particular advantage of the Flex development environment is its strong graphics engine. Another is its adherence to object-oriented principles. Most graphical objects in Flex can be animated or moved around the screen according to logical rules. Because all ESRI geometries inherit from Flex objects, it was straightforward to build a software class to animate the city-linkage lines upon selection of a new city point. When each linkage line is created in code, Flex is instructed to associate a new instance of the custom animation class with the line object and to begin animating it for the next two seconds. During that time, Flex makes one hundred separate method calls to tell the animation class the percentage of the animation to compute.

Figure 5.7 shows an animation at an intermediate point, between zero and one hundred percent completion. The animation class computes the geometry of the corresponding portion of its city line and displays it on the screen. Because this is done frequently and smoothly, the line appears to stretch from its origin to its destination over the course of two seconds. A pulsing yellow halo highlights each selected city point; this animation requires a mere five lines of markup code in the main application class.

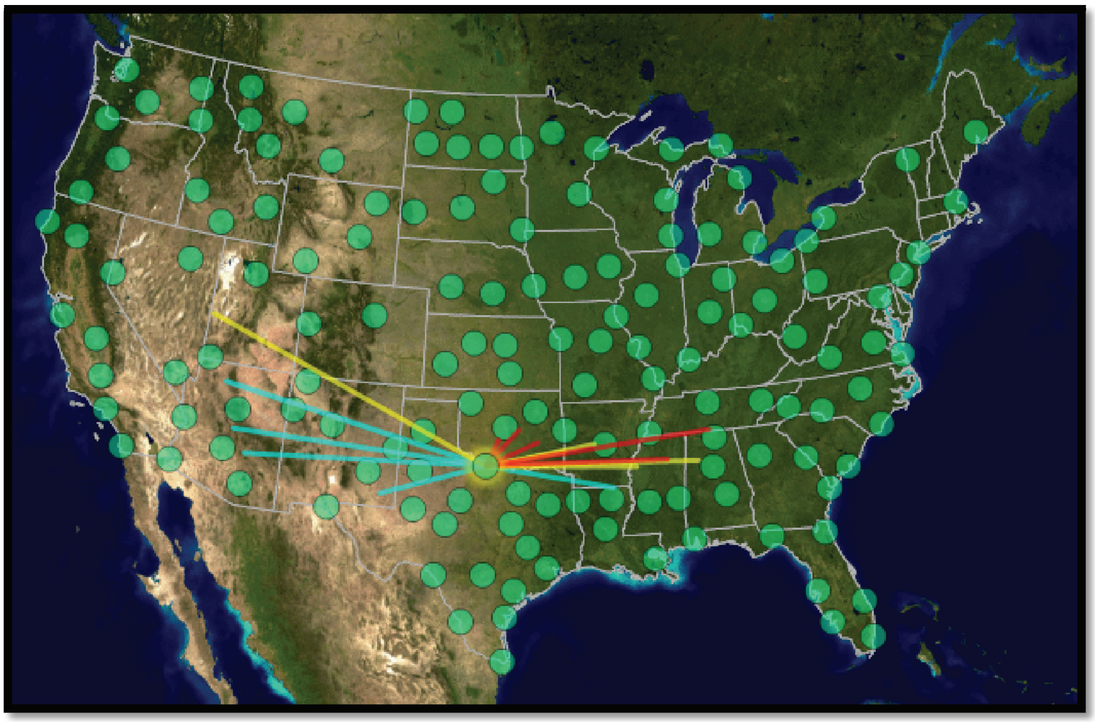

Figure 5.7: Linkage Animation in Intermediate State

5.2.6 Using XML City Data

The decision to convert the city points and forecasts to XML may seem unusual since most ArcGIS Server applications rely heavily on ArcGIS Server-based data. ArcGIS Server is a powerful platform for hosting and serving data, but its attribute query capabilities—at least those available through the REST APIs, including the Flex API used in this application—are limited to simple SQL *where* clauses (Environmental Systems Research Institute, Query Layer (Operation)). Such a clause acts as a filter; it does not perform the sorting and ordering necessary to find the five temperatures nearest to a chosen target city temperature. Some possible approaches to this sorting problem are listed in Table 5.5.

Table 5.5: Possible Methods for Finding Cities with Analogous Temperatures

Description	**Benefits and Drawbacks**
Build an ArcGIS Server extension to perform the sorting on the server	This would use the resources of a powerful server computer; but since server extensions cannot be invoked through the REST API, the application would need to be designed and built on the .NET or Java APIs. This would significantly increase the application's complexity.
Store city forecast data on the server; download it to the client, and sort it whenever a new city is selected	Frequent queries would frequently transport city data over the network from server to client, resulting in poor performance and inefficient use of network resources.
Store city forecast data on the server; download it to the client once; store the downloaded data on the client and sort whenever a new city is selected	Allows for city data updates while using network resources efficiently. The application cannot run when the city data service is offline.
Compile city forecast data into the application as a static resource; access and sort it whenever a new city is selected	Allows for city data updates (since the Flex application and compiled city data are downloaded from the server by the client browser). Uses network resources efficiently. The application can access city data even during network outages.

The last two options both perform well and use resources efficiently. The last option, however, would be more robust in the unlikely event a network outage occurred after the client had downloaded the Flex application and the ArcGIS Server-hosted base map layers. Flex handles XML data quite well internally at a low level. Its XML data classes sort and filter the city records quickly enough that the application user perceives no processing delay when making a new city query.

Flex's sort mechanism makes a series of comparisons between pairs of list objects, determining which item of each pair is greater or lesser, and using that information to create the final sorted list (Adobe Systems, 2009). The Temperature Analogs application provides a custom comparison function for Flex to use in sorting the list. Flex passes two cities in to this function; the function returns an indicator of which of the two cities is closer to the target 2009 temperature; and Flex uses this result to sort the list. No information is available about what Flex does if two cities have equal temperature forecasts. It could happen that two cities with equal forecast values could be candidates for the last analog slot for a selected city. In that case, Flex's sorting logic determines which of the two candidates is chosen and which is rejected; the choice is out of the application's control.

5.3 Summary

Clearly, data preparation was a large part of this project and occupied multiple stages, from extracting and summarizing the temperature forecast data to gathering the base layers and thematic layers to combining, symbolizing, and publishing them to ArcGIS Server. The project requirements could have been met in a number of ways, and a good deal of deliberation and debate went into the final decisions.

The web application provides some advanced examples of the kind of visualization techniques available in modern Rich Internet Application (RIA) environments. More importantly, however, it gives users a specialized view of Maurer's temperature forecast data with the goal of drawing conclusions which might not have been apparent from the raw datasets. The interface's simplicity encourages the user to explore relationships among the data.

Chapter 6 – Results and Analysis

This section discusses the degree to which the client ultimately adopted and used the repository and application. It also discusses some of the more interesting patterns the application makes visible.

6.1 Client Acceptance

The client ultimately deemed the application acceptable. It has been shown to several visiting ESRI customers as well as some ESRI staff. It serves as an example of the sort of creative analysis and visualization capabilities available to ESRI's customers. The repository certainly has a place as the basis for the City Analogs demo, and ESRI may ultimately make the data available to the public through ArcGIS Online.

6.2 Qualitative Results – Web Application

This section deals with readily apparent results of looking at city forecasts and relationships in the web application. This really represents the culmination of this project, since it brings together the two main project deliverables.

In examining the linkages between different cities at various forecast years, some qualitative patterns seemed to emerge. For one, there seems to be a subtle relationship between the forecast year of a given city's analogs and the latitude of those analogs. Figure 6.1 shows Columbia, Missouri, and its analogs; the blue lines for 2020 analogs are generally located at lower latitudes than the yellow lines for 2050 and the red lines for 2080. This pattern is far from universal, but it is common enough to be noticeable. Also, it manifests more frequently in Midwestern cities than in coastal ones.

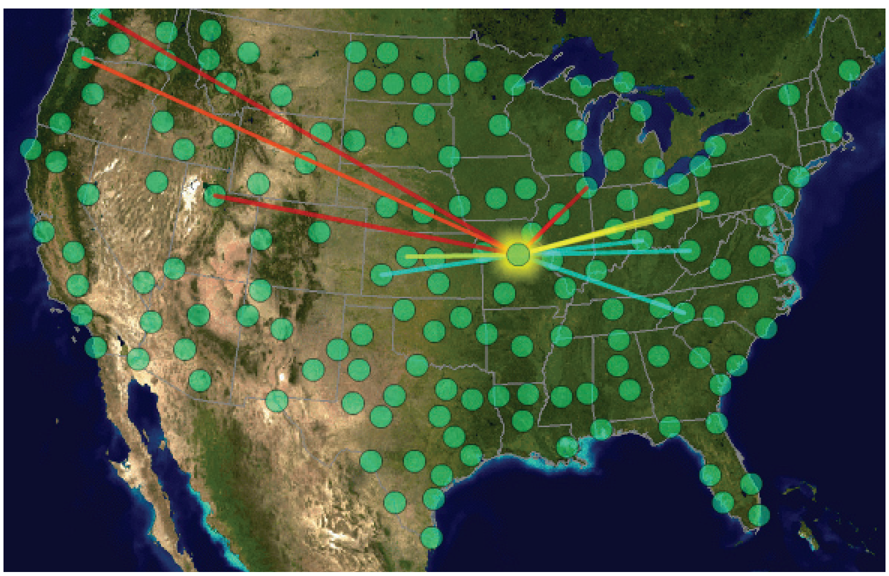

Figure 6.1: Increasing Latitude in Analogs for Columbia, MO

6.3 Selected Cities Comparison

One of the final steps in preparing the cities dataset for use was to trim it down from 3443 initial points to a final 154. The resulting dataset was more evenly distributed and pleasing to the eye. This section examines several characteristics of the dataset before and after the thinning operation, in an attempt to evaluate how the character of the data changed in the process.

ArcGIS includes an Average Nearest Neighbor tool (Spatial Statistics toolbox, Analyzing Patterns toolset). It reported a significant amount of clustering in the original, un-thinned cities dataset (Figure 6.2). It measured an average distance of 14.38 km from each city to its nearest neighbor, versus an expected average of 29.03 km with a high level of significance ($p < 0.01$).

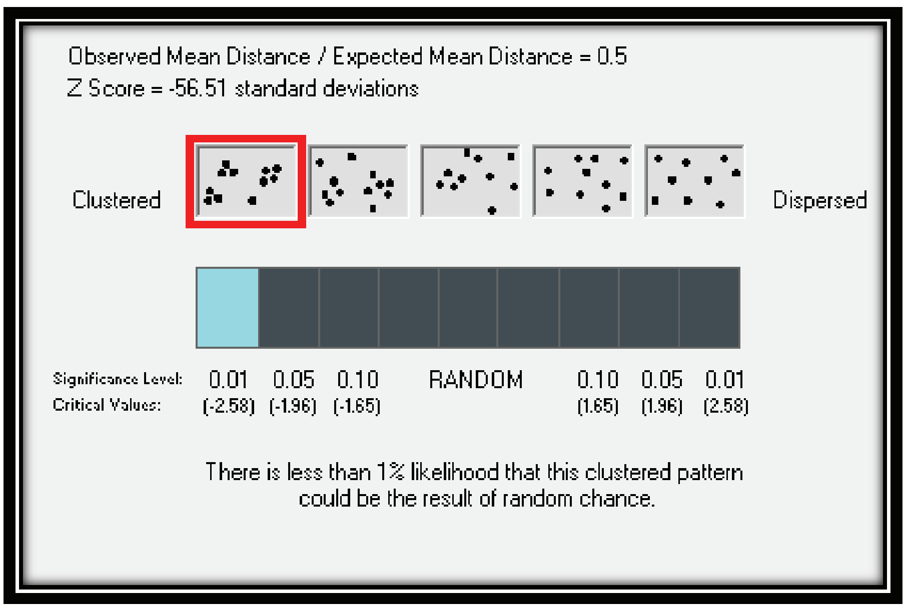

Figure 6.2: City Average Nearest Neighbor results before thinning

In the final, thinned dataset, the same tool found a significant amount of dispersal (Figure 6.3): an actual average distance of 170.79 km versus an expected average of 127.73 km. The thinning logic clearly produced an evenly distributed set of city points.

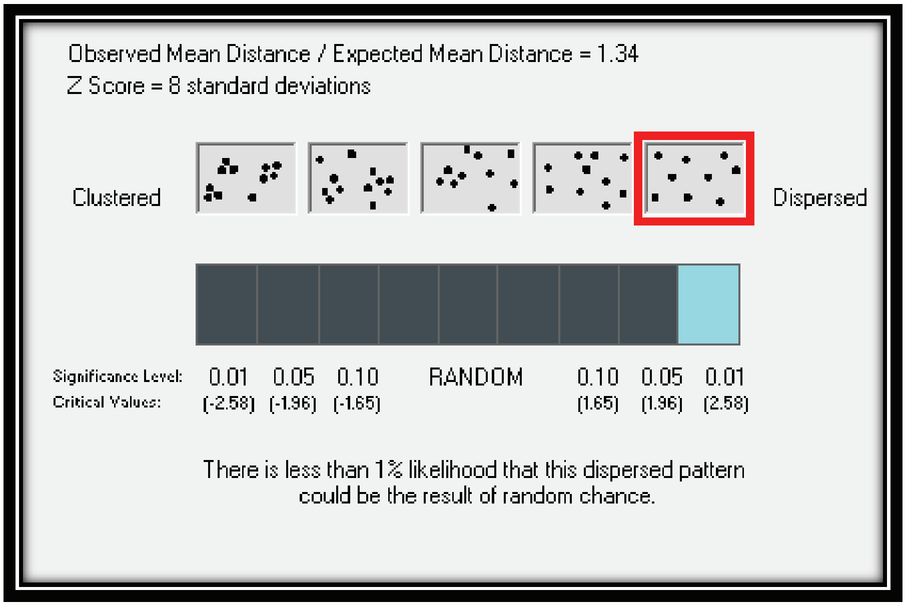

Figure 6.3: City Average Nearest Neighbor results after thinning

Table 6.1 summarizes some city attributes whose averages were changed by the selection logic. Average population increased dramatically; this is expected because the thinning logic selects cities of larger population by design. Many cities in the final dataset have names unrecognizable to those who do not live nearby, however, because large cities tend to be clustered geographically in metroplexes along the coasts. Choosing only the largest, best-known cities would have resulted in a geographically homogeneous dataset and would have defeated the purpose of comparing climate forecasts among distributed urban areas.

Table 6.1: Average city elevation, temperature, population before and after thinning

	Original Dataset	Thinned Dataset
Average Elevation (m)	242.2	460.3
Average Yearly Temperature, 2009 (°F)	58.3	57.9
Average Population, 2007	50,384.4	344,948.7

Average yearly temperature for 2009 was barely affected by the process. Average elevation, however, went up; the selected set of cities has an average elevation of just over 460 meters, compared to 242.2 meters for the original dataset. Figure 6.3 gives an indication of why this might be. The selection logic attempts to ensure a consistent distance between cities, so it does most of its deletion where cities are most dense. Cities are most densely located along coasts, at low elevations, so the thinning would be expected to remove more cities at lower elevations than it would at higher elevations, thus raising the average elevation of the final dataset.

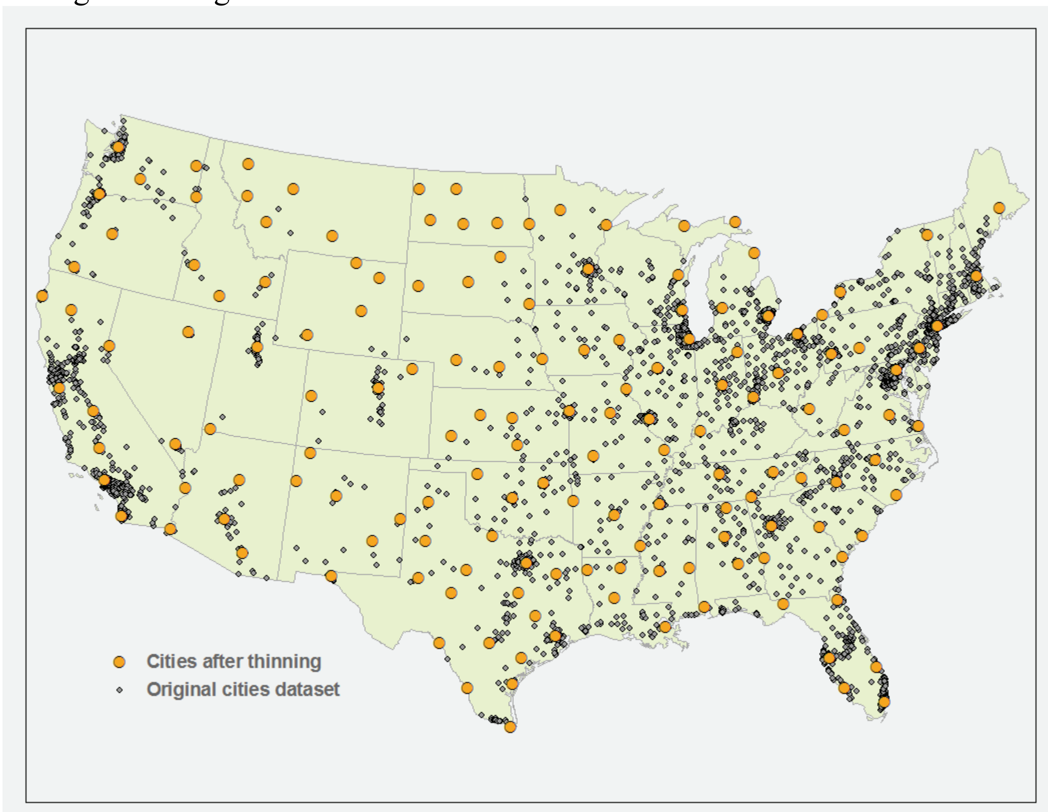

Figure 6.4: Cities before and after thinning

Chapter 7 – Conclusions and Future Work

Any project should include a review of what went well, what went wrong, and what should be done differently in similar, future efforts. While the client, Hugh Keegan, has expressed satisfaction with this phase of the project, he has also indicated a desire to expand it into a more compelling and realistic demo. This section will attempt to describe lessons learned in the course of this project, as well as to suggest similar projects that might extend the themes examined herein.

A project involving only yearly temperature averages is limited in its practical utility. San Diego in 2009, for example, may have a similar year-round average temperature to Meridian, MS in 2020, but it does not follow that a significant number of San Diego residents will be anxious to move to Mississippi in the future. Predicting urban migration patterns requires some notion of how badly people in general want to live in a particular location—of a location's livability. One useful extension to this project would be to incorporate additional variables, such as evapotranspiration, precipitation, or humidity, into a broader composite index indicating a city's livability or comfort index. An application built on such an index would be a more compelling and interesting demo, and would also serve as a foundation for future research and projects predicting urban migration patterns. Maurer's datasets already provide precipitation data; perhaps other kinds of forecasts could be derived from temperature and precipitation, or could be obtained from other sources.

Another limitation of this project was in using only one of the forty-eight combinations of Global Climate Models (GCMs) and emission scenarios available in Ed Maurer's datasets. Aggregating multiple models together results in *ensembles*, which climatologists consider to be more reliable than single models are by themselves. In fact, users of the Climate Wizard application are strongly urged to use ensembles when making decisions based on climate data (The Nature Conservancy, University of Washington, University of Southern Mississippi, 2009). A future project should use a series of subsets of Maurer's available models, combine them into ensembles, and compare their respective predictions.

This project used only a fraction of the time spanned by the available climate forecasts. A future project might use the full span of forecast data through 2099. One could visualize the 1,800 months' worth of data in a variety of animations and explore the impact of different-sized averaging windows. Alternatively, the availability of both historical and predicted data could allow for some interesting statistical analyses along the lines of the wildfire regression study mentioned in the Background and Literature Review section.

Human activities, and their effects on the very humans performing those activities, are mentioned in the news daily. Climate change, pollution, and extinction of species are but a few of the many topics affecting the future of both humanity and the ecosystem which supports it. Debate may rage about the political and theoretical results of these issues, but only careful, reasoned study and experimentation will offer conclusive information about them.

Works Cited

Berger, W. H., & Michaelis, H. W. (2002, 07 02). *Global Warming: The great experiment on planet Earth.* Retrieved 01 09, 2009, from Global Change: http://earthguide.ucsd.edu/globalchange/global_warming/01.html

Darwin, R., Tsigas, M., Lewandrowski, J., & Raneses, A. (1995). *World Agriculture and Climate Change: Economic Adaptations.* United States Department of Agriculture, Economic Research Service. Herndon, VA: ERS-NASS.

Davis, R. E., Knappenberger, P. C., Novicoff, W. M., & Michaels, P. J. (2002). Decadal changes in heat-related human mortality. *Climate Research , 22*, 175-184.

Environmental Research Institute, Inc. (2009, May 13). *About getting started with writing geoprocessing scripts.* Retrieved September 15, 2009, from ArcGIS Desktop 9.3 Help: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=About_getting_started_with_writing_geoprocessing_scripts

Environmental Systems Research Institute. (n.d.). *Query Layer (Operation)*. Retrieved 10 4, 2009, from ArcGIS Server REST API: http://resources.esri.com/help/9.3/arcgisserver/apis/rest/index.html?query.html

Environmental Systems Research Institute. (2009, July 10). *Types of Geodatabases*. Retrieved October 5, 2009, from ArcGIS Desktop 9.3 Help: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=2480&pid=2474&topicname=Types_of_geodatabases

Environmental Systems Research Institute, Inc. (2008, November 25). *Data formats supported in ArcGIS.* Retrieved September 14, 2009, from ArcGIS Desktop 9.3 Help: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Data_formats_supported_in_ArcGIS

Environmental Systems Research Institute, Inc. (2009, March 16). *How to build online base maps*. Retrieved October 6, 2009, from ArcGIS Desktop 9.3 Help: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=How_to_build_online_base_maps&anchor=GIS%20base%20maps%20based%20on%20ArcGIS%20Online

Environmental Systems Research Institute, Inc. (2009, April 24). *Publishing optimized map services*. Retrieved October 3, 2009, from ArcGIS Desktop 9.3 Help: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=546&pid=545&topicname=Publishing_optimized_map_services

Gato, S., Jayasuriya, N., & Roberts, P. (2007). Temperature and rainfall thresholds for base use urban water demand modelling. *Journal of Hydrology , 337* (3-4), 364-376.

Gude, P. H., Cookson, J. A., Greenwood, M. C., & Haggerty, M. (2009, April 24). *Homes in Wildfire-Prone Areas: An Empirical Analysis of Wildfire Suppression Costs and Climate Change.* Retrieved December 11, 2009, from Headwaters Economics Nonprofit Regional Economic Research in the Western US and Canada: http://www.headwaterseconomics.org/wildfire/Gude_Manuscript_4-24-09_Color.pdf

Hallegatte, S., Hourcade, J.-C., & Ambrosi, P. (2007). Using climate analogues for assessing climate change economic impacts in urban areas. *Climatic Change , 82* (1-2), 47-60.

Harris, R. (2009, 01 26). *Global Warming is Irreversible, Study Says*. Retrieved 01 27, 2009, from NPR All Things Considered: http://www.npr.org/templates/story/story.php?storyId=99888903

IPCC Third Assessment Report: Climate Change 2001 [TAR]. (2001). *Working Group 1: The Scientific Basis.* Cambridge, United Kingdom: PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE.

Kalkstein, L. S., & Greene, J. S. (1997). An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. *Environmental Health Perspectives , 105* (1).

Keegan, H. (2009, 03 16). Climate Change web application. (M. Deaton, Interviewer) Redlands, CA, USA.

Keegan, H. (2009, September 11). comments during team meeting. (M. Deaton, Interviewer)

Kopf, S., Ha-Duong, M., & Hallegatte, S. (2008, 05 15). Using maps of city analogues to display and interpret climate change scenarios and their uncertainty. *Natural Hazards and Earth System Sciences* , 905-918.

Lawrence Livermore National Labs. (2007, January). *About WCRP CMIP3 Model Output*. Retrieved September 24, 2009, from PCMDI: http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php

Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., et al. (2007). Historical Overview of Climate Change Science. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, et al. (Ed.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 94-127). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Manabe, S., & Wetherald, R. T. (1967). Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity. *Journal of the Atmospheric Sciences , 24* (3), 241-259.

Mankoff, K. (2006, 05 12). *A Climate Model Vacation Planner.* Retrieved 02 08, 2009, from edGCM: Educational Global Climate Modeling: http://edgcm.columbia.edu/outreach/showcase/cambodia.html

Maurer, E. (2008, January 15). *About -> Methodology*. Retrieved September 24, 2009, from Statistically Downscaled WCRP CMIP3 Climate Projections: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#About

Maurer, E. (2008, January 15). *About -> Scope*. Retrieved September 23, 2009, from Statistically Downscaled WCRP CMIP3 Climate Projections: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#About

Maurer, E. P., Brekke, L., Pruitt, T., & Duffy, P. B. (2007, November 20). Supplementary material to "Fine–Resolution Climate Projections Enhance Regional Climate Change Impact Studies". *Electronic Supplement to Eos, Transactions, American Geophysical Union* . Washington, D.C., District of Columbia, United States of America.

Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J. F., et al. (2007). The WCRP CMIP3 multi-model dataset: A new era in climate change research. *Bulletin of the American Meteorological Society , 88*, 1383-1394.

Mogi, M. (1983). Relationship between number of human Japanese encephalitis cases and summer meteorological conditions in Nagasaki, Japan. *The American Society of Tropical Medicine and Hygiene , 32* (1), 170-174.

Molnia, B. F., Karpilo, R. D., Pfeiffenberger, J., & Capra, D. (2007). *Visualizing Climate Change—Using Repeat Photography to Document the Impacts of Changing Climate on Glaciers and Landscapes.* Retrieved December 5, 2009, from National Park Service: http://www.nps.gov/akso/AKParkScience/ClimateChange/molnia.pdf

Myrup, L. O. (1969). A numerical model of the urban heat island. *Journal of Applied Meteorology , 8* (6), 908–918.

National Oceanic and Atmospheric Administration. (2006, 04 05). *WWW animations of the CRU-UK temperature record:1856 to 1997 (CRU - Climate Research Unit).* Retrieved 02 09, 2009, from NOAA Paleoclimatology Global Warming - Animation: http://www.ncdc.noaa.gov/paleo/globalwarming/animation/animation.html

Obama, B. H. (2009, 01 21). *President Barack Obama's Inaugural Address*. Retrieved 01 27, 2009, from The White House Blog: http://www.whitehouse.gov/blog/inaugural-address/

Parson, E. A., Burkett, V. R., Vanden-Fischer, K., Keith, D. W., Mearns, L. O., Pitcher, H. M., et al. (2007, 07). *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations; and Review of Integrated Scenario Development and Application.* Retrieved 02 08, 2009, from US Climate Change Science Program: http://www.climatescience.gov/Library/sap/sap2-1/finalreport/sap2-1b-final-all.pdf

Rosenzweig, C., & Parry, M. L. (1994). Potential Impact of Climate Change on World Food Supply. *Nature , 367* (6549), 133-138.

Rosenzweig, C., & Solecki, W. (2005a, 03 29). *What is a global climate model?* Retrieved 01 27, 2009, from Climate Change Information Resources, New York Metropolitan Region: http://ccir.ciesin.columbia.edu/nyc/ccir-ny_q1d.html

Rosenzweig, C., & Solecki, W. (2005b, September 15). *What is being done in other major urban areas to adapt to climate change?* Retrieved 01 27, 2009, from Climate Change Information Resources, New York Metropolitan Region: http://ccir.ciesin.columbia.edu/nyc/pdf/q3b.pdf

Ryan, B. F., Watterson, I. G., & Evans, J. L. (1992). Tropical cyclone frequencies inferred from Gray's yearly genesis parameter: Validation of GCM tropical climates. *Geophysical Research Letters , 19* (18), 1831-1834.

Schreiber, P. (2009, June 25). FW: Data Permission Request. Redlands, California, United States of America.

Smith, M. (2009, 03 16). Questions about TNC Temperature Forecast Data. (M. Deaton, Interviewer) Redlands, CA, USA.

Solomon, S., Plattner, G.-K., Knutti, R., & Friedlingstein, P. (2009). Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences of the United States of America , 106* (6), 1704-1709.

Steadman, R. G. (1984). A universal scale of apparent temperature. *Journal of Applied Meteorology , 23* (12), 1674-1687.

The Nature Conservancy, University of Washington, University of Southern Mississippi. (2009). *Use and Misuse of Climate Wizard*. Retrieved 11 15, 2009, from Climate Wizard: http://www.climatewizard.org/use and misuse.html

Tomlinson, R. (2007). *Thinking about GIS.* Redlands, California: ESRI Press.

Torok, S. (2006, October 17). *CSIRO climate model results used for international benchmarking studies*. Retrieved September 24, 2009, from CSIRO: http://www.csiro.au/science/climate-model-results.html

U.S. Geological Survey. (2006, August 03). *Map Projections*. Retrieved December 27, 2009, from USGS Eastern Geographic Science Center: http:// egsc.usgs.gov /isb/pubs/MapProjections/projections.html

Weart, S. (2009, 05). *General Circulation Models of Climate.* Retrieved 09 06, 2009, from American Institute of Physics: http://www.aip.org/history/climate/GCM.htm

Weber, C. R., & Buttenfield, B. P. (1993). A cartographic animation of average yearly surface temperatures for the 48 contiguous United States: 1897-1986. *Cartography and Geographic Information Science , 20* (3), 141-150.

Appendix A. Downscaled Coupled Models

Though a single model and emission scenario (CSIRO Mk3/A1B) was used in this project, sixteen models were downscaled for each of three emission scenarios, for a selection of 48 possible forecast datasets. Here is the complete list of the models Ed Maurer downscaled for each of three emission scenarios (A2, A1B, and B1) (Maurer E. , About -> Scope, 2008):

Modeling Organization	**Abbreviation**
Bjerknes Centre for Climate Research	BCCR-BCM2.0
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)
Meteo-France / Centre National de Recherches Meteorologiques, France	CNRM-CM3
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies, USA	GISS-ER
Institute for Numerical Mathematics, Russia	INM-CM3.0
Institut Pierre Simon Laplace, France	IPSL-CM4
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)

Modeling Organization	**Abbreviation**
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM
Meteorological Research Institute, Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research, USA	CCSM3
National Center for Atmospheric Research, USA	PCM
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3

Appendix B. Dataset Spatial References

Here is a list of the datasets used in the Temperature Analogs application along with their original spatial references, as supplied by their vendors.

Dataset	**Spatial Reference**	**Vendor**
Maurer's downscaled temperature forecasts	None	Ed Maurer and Commonwealth Scientific and Industrial Research Organisation (CSIRO)
U.S. States	North American Datum (NAD) 1983, geographic coordinates	ESRI
U.S. Cities	World Geodetic System (WGS) 1984, geographic coordinates	ESRI
Earth With Ice (imagery)	WGS 1984, geographic coordinates	ESRI, NASA