

# ATMOS

## *A Data Collection and Presentation Toolkit for the Nevada Climate Change Portal*

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**Abstract:** Climate change is the subject of intense research, covering a broad range of causes and effects over long periods of time. Large data sources are needed to support this research, prompting scientists to turn to repositories to collect and share data. Many repositories exist with various data formats and access methods, presenting a challenging environment for researchers. Data portals help to address this by providing a central location for data on a specific topic or region. The Nevada Climate Change Portal is one example, which provides data to support research on Nevada's climate. This portal was funded under an NSF EPSCoR grant with a goal of sharing resources with similar portals in New Mexico and Idaho. This paper proposes the ATMOS toolkit to help meet this goal and to address challenges facing climate change researchers. ATMOS is a plugin-based toolkit that provides Access to Map and Tabular Online Services uniformly, regardless of the underlying source. The design and construction of ATMOS are discussed, showing how the toolkit supports the Nevada Climate Change Portal, and how it can meet future needs of researchers.

## 1 INTRODUCTION

Climate change has the potential to have a dramatic effect on people everywhere, and is the subject of intense research by scientists throughout the world. Climate change studies are usually long term in nature and broad in scope, and require data from multiple sources over significant periods of time. It may not be feasible for researchers to collect the necessary data directly, so researchers use existing data repositories as a source of data.

One such data repository is the Nevada Climate Change Portal, which was created through an NSF EPSCoR grant with a goal to be a single access point for climate change research that affects Nevada (McMahon et al., 2011). The portal contains data collected from a set of dedicated sensors deployed in the Nevada desert. There are several other data repositories that contain data related to Nevada's climate, including similar portals in New Mexico and Idaho that were also created under the same NSF EPSCoR grant. It would help achieve the goal of creating a single access point for Nevada's climate change data if this data was available through the Nevada Climate Change Portal.

This paper proposes a toolkit named ATMOS, or Access to Tabular and Map-based Online Services.

This toolkit will be used to collect data from data repositories, combine it with data from other repositories, and present the results to the user via the Nevada Climate Change Portal. It is designed to be extensible in order to support additional repositories in the future. This is transparent to the user, who accesses data through a user-friendly web front end.

This paper is based on work described in (Dittrich, 2012). Section 2 provides a background on climate change data repositories and how they are used in research. Section 3 discusses the motivation for the work and our proposed solution. Section 4 details the design of ATMOS, and Section 5 demonstrates the results. Section 6 compares ATMOS with related software packages. Finally, Section 7 concludes the paper and discusses opportunities for future work.

## 2 BACKGROUND

### 2.1 Climate Change Data

Climate change data can be described as data that is used as the basis for research on the subject of climate change.

Data describing the effects of climate change on physical systems is commonly represented in tabu-

lar form consisting of observations over time. National Weather Service weather stations provide observations of temperature, humidity, and other phenomena sampled over time. Hurricanes can be described by a time-series of data points describing location, wind speed, and pressure.

In some cases, this data occurs over a geographic area, and is better represented as a map or as a geodetic grid, with a row for each discrete latitude and a column for each discrete longitude. For example, sea surface temperature measurements are typically represented as map. Surazakov and Aizen used topographic data to estimate the thickness and extent of glaciers (Surazakov and Aizen, 2006).

Data describing effects on biological systems consists of plant life cycles, animal breeding patterns, distribution of species, migration patterns, and similar data. Although this type of data is not easily standardized, some repositories, such as the National Phenological Network have been successful in storing observations of animal and plant behavior in a standard format.

Data describing the causes of climate change can be represented in tabular form. The the United States Geological Survey provides a rich set of tabular data for a particular volcanic eruption. Greenhouse gas emissions can be represented in tabular form as a series of measurements over time.

Data describing causes of climate change are commonly represented in map form. Solar irradiance data is spatial in nature, and well described on a map. The National Land Cover Database provides a map of the land cover for the United States, such as forestation or urban areas, and changes over time (Fry et al., 2011). A portion of this data is shown in Figure 1.

## 2.2 How Climate Change Data Is Used

The broad scope and extensive time scale of climate change research requires multiple large data sets. For example, Scuderi analyzed tree rings to reconstruct temperature records for the Sierra Nevada over the last 2000 years (Scuderi, 1993). Crowley's work analyzed the causes of climate change over 1000 years using data reconstructed from ice cores and trees (Crowley, 2000). Vermeer and Rahmstorf identified a relationship between global temperature and sea levels (Vermeer and Rahmstorf, 2009) using temperature data from NASA's Goddard Institute for Space Studies and sea level data from Church and White (Church and White, 2006). Bowerman and Clark used sediment cores from alpine lakes to reconstruct glacier activity over several millennia (Bowerman and Clark, 2011). Rosenzweig et al. used over 29,000 series of

data from over 80 studies to demonstrate the results of climate change on both physical and biological systems (Rosenzweig et al., 2008).

Small, focused studies can gather data directly from the field, or reconstruct data from available sources such as ice cores. In many cases researchers turn to data repositories as a primary source of data.

## 2.3 Data Repositories

Many climate related data repositories are available, ranging from massive government-backed repositories to smaller repositories focused on a single area or topic. These data repositories provide data in a similarly wide range of data formats, metadata standards, and access methods.

NOAA's National Climatic Data Center provides the world's largest selection of data products covering current and historical precipitation, temperature, sea surface temperatures, soil moisture, and observations of the physical environment. The National Snow and Ice Data Center is focused on data describing the cryosphere, including current and historical information on the extent and location of sea ice, glacier inventories, snow cover maps, and frozen ground maps. The National Phenological Network provides a database of observations of plants and animals from a network of scientists and researchers throughout the United States. This includes observations on migrations, nest building, flowering, and falling leaves.

The New Mexico and Idaho EPSCoR data portals are focused on providing a single point of access for each state's climate. These portals provide access to map-based and tabular data describing each state's climate (New Mexico EPSCoR website, 2011) (Idaho EPSCoR website, 2011). The New Mexico EPSCoR and Idaho EPSCoR data portals, as well as the Nevada Climate Change Portal were funded in part by a National Science Foundation EPSCoR grant. This grant creates a 3-state consortium, and seeks to improve the connectivity infrastructure and bandwidth, enhance data interoperability, and utilize this infrastructure to integrate research with education (Western Consortium website, 2011).

The data in these repositories is available in a variety of formats and access methods ranging from self-describing formats to unstructured data. Raster images in standard formats like JPEG and PNG are used for map-based data. Some image formats, like GeoTIFF contain additional geographical data that allow precise overlay with other images or maps. The WaterML format is a self-describing XML based format developed by CUAHSI for hydrologic data sources

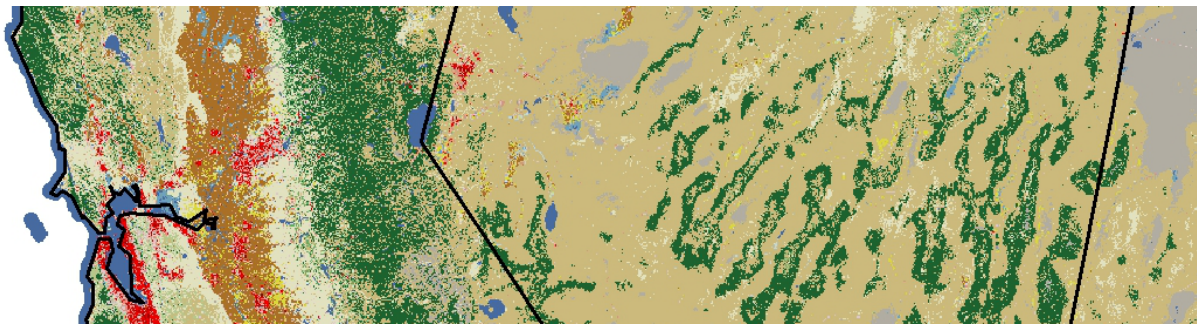


Figure 1: A portion of the National Land Cover Database data for Northern Nevada and California, United States.

(Whiteaker and To, 2008). The CSV format is commonly used for tabular data, but lacks the additional information provided by other formats. Knowledge of the data source is needed to properly interpret the CSV data. The RDB format is similar to CSV, but adds some metadata that specifies the data type of each column. It also provides a comments section to provide context for the data. Human readable data formats are also commonly used, such as tables embedded in web pages. Data can be extracted from these sources by parsing the page and extracting the desired data, when permissible, but this is not a robust method for extracting research-grade data.

Metadata is data describing data. This may describe the data format itself, such as the units of measurement, ranges, and data types. It may describe how the data was gathered such as the equipment used, storage devices, and researchers involved. Metadata is unlimited in the type and quantity of data, and adds to the usability and reliability of the data. For example, Inouye's data on flowering of *Helianthella quinquevervis* includes metadata describing the site where the data was collected, including the type of GPS unit used, whether the site was near a road, and the names of the data collectors (Inouye, 2008).

There are several standard metadata formats. One common standard is the Federal Geographic Data Committee's Content Standard for Geospatial Metadata. This defines a naming convention for attributes, a standard structure, and a standard schema for the data values. All United States federal agencies that produce geospatial data are required to use this standard for metadata, and many other organizations use this standard, such as the National Phenological Network. A similar metadata format is described in ISO standard ISO-19115.

Metadata plays a critically important role in defining the meaning of data and where it came from. This is especially true in research where several parties compile data in a collaborative effort. Metadata allows data to be combined uniformly to allow for larger scale studies. Metadata also establishes data

provenance and identifies the parties that are accountable for the accuracy and reliability of the data, allowing the research to stand up to scrutiny from the scientific community.

Numerous data repositories and data formats lead to a similar range of data collection methods. For small scale research, data can be collected directly by navigating to the data repository's web interface, and downloading the desired data. This paper focuses on the automatic, large scale collection of data, which is only feasible with standardized interfaces.

OPeNDAP is a general purpose protocol for the exchange of scientific data that has been widely adopted (Cornillon et al., 2009). A client requests data from an OPeNDAP server using an HTTP request with a standard format that allows working with multiple repositories. The Open Geospatial Consortium publishes multiple standards, including standards for the Web Map Service (WMS) protocol. This web service is widely used for the exchange of geospatial data. Requests for a Web Map Service consist of a URL followed by several parameters in a query string (Beaujardiere, 2006).

### 3 MOTIVATION AND PROPOSED SOLUTION

The primary motivation for this paper is to extend the capabilities of the Nevada Climate Change Portal. This portal is funded through a NSF EPSCoR grant along with similar portals in Idaho and New Mexico, and has a goal to provide Nevada climate change research results and data to members of the research community as well as the public. It also strives to create an infrastructure that can support this type of research, and can be reused by other systems in the future (McMahon et al., 2011).

The Nevada Climate Change Portal already collects data from equipment deployed in the field (Nevada Climate Change Portal website, 2011). Ad-

ditional data relevant to Nevada climate change research should be available directly through the Nevada Climate Change Portal to better support researchers. To help achieve this goal, a software toolkit has been developed called ATMOS, or Access to Tabular and Map-based Online Services. This toolkit can be used to collect climate change data from multiple repositories, and present it for use by the end user. A plugin-based framework provides extensibility to support multiple data sources and support future expansion. This work will be integrated into the Nevada Climate Change Portal to support collecting data from multiple sources.

## 4 SOFTWARE SPECIFICATION AND DESIGN

The ATMOS toolkit uses a layered architecture, as shown in Figure 2. This incorporates the classic presentation, data access, and business logic layers (Fowler, 2003), and adapted for ASP.NET (Esposito, 2011). The presentation consists of ASP.NET web pages and the corresponding C# code-behind. The data access layer provides strongly-typed interfaces to external data sources including web services and the database of available services. The business logic layer provides methods to send requests to web services and process the corresponding responses.

### 4.1 Providing Extensibility

The ATMOS toolkit uses plugins to support new data sources without changes to the core logic. These plugins use the .NET Managed Extensibility Framework, or MEF (Griffiths et al., 2010), which allows ATMOS to automatically discover new plugins. A set of interfaces allows uniform treatment of both map and tabular data sources.

Every plugin implements the *IService* interface. The *requestServiceInformation* method is retrieves service metadata and returns an updated *Service* object with normalized data.

Plugins that access map based data implement the *IMapService* interface. The *requestLayers* method returns a list of *Layer* objects for a service, which contain map properties including a geographic bounding box and a unique internal name. Layers implement the composite design pattern (Gamma et al., 1995), and support hierarchical organization of layers. The *requestMapImage* method retrieves a *Bitmap* image from a service.

Plugins that access tabular data implement the *ITabularService* interface. The *requestSeriesGroups*

method returns a list of *SeriesGroup* objects that represent a logical group of data, such as a data collection site. The *requestSeries* method takes returns a list of *Series* from a series group. The *requestData* method returns a *DataTable* object, which must have one column named *Time* with a *DateTime* type to support combination with data retrieved from other services.

The ability to combine and correlate data from multiple sources is a key, distinguishing feature of the ATMOS toolkit. Accomplishing this for maps is relatively straightforward, and can be done by overlaying several map layers. Combining data from tabular services is more challenging. The ATMOS provides default time-based combination, and allows flexibility by using plugins for more complex data combination. These plugins use the MEF framework, and implement the *ITableCombiner* interface. This interface has a single *combine* method that takes two *DataTable* objects and returns the combined *DataTable*.

### 4.2 Included Plugins

Several plugins were developed and included in the implementation of the ATMOS toolkit.

First, a Web Map Service plugin provides access to several sources including NOAA and New Mexico EPSCoR data sources. This plugin constructs the appropriate HTTP requests, and parses XML responses in order to retrieve requested map images.

Second, an ArcGIS map service plugin provides access to maps served by the ArcGIS MapServer (Kennedy, 2006), which is used by several repositories, including the Idaho EPSCoR website. This plugin constructs HTTP requestes and parses JSON responses in order to retrieve requested map images.

Third, a local map service plugin is included to retrieve map data stored in a local file system. This serves images created from Stewart and Carlson's Geologic Map of Nevada (Stewart and Carlson, 1978), and formatted into a set of tiles using the Map Cruncher tool from Microsoft Research (Elson et al., 2007). This simplified plugin provides an example showing how to extend the toolkit.

Fourth, a USGS Water Data plugin provides access to time series water data for numerous sites throughout the United States. This plugin constructs HTTP requests to retrieve RDB format site data or WaterML format data series (Reston, 2003). The plugin parses the responses to create strongly typed data tables.

Finally, a WaterOneFlow plugin provides access to multiple hydrologic sources, including the Boise State Hydrosriver. WaterOneFlow provides a standard interface to hydrologic data services that hides

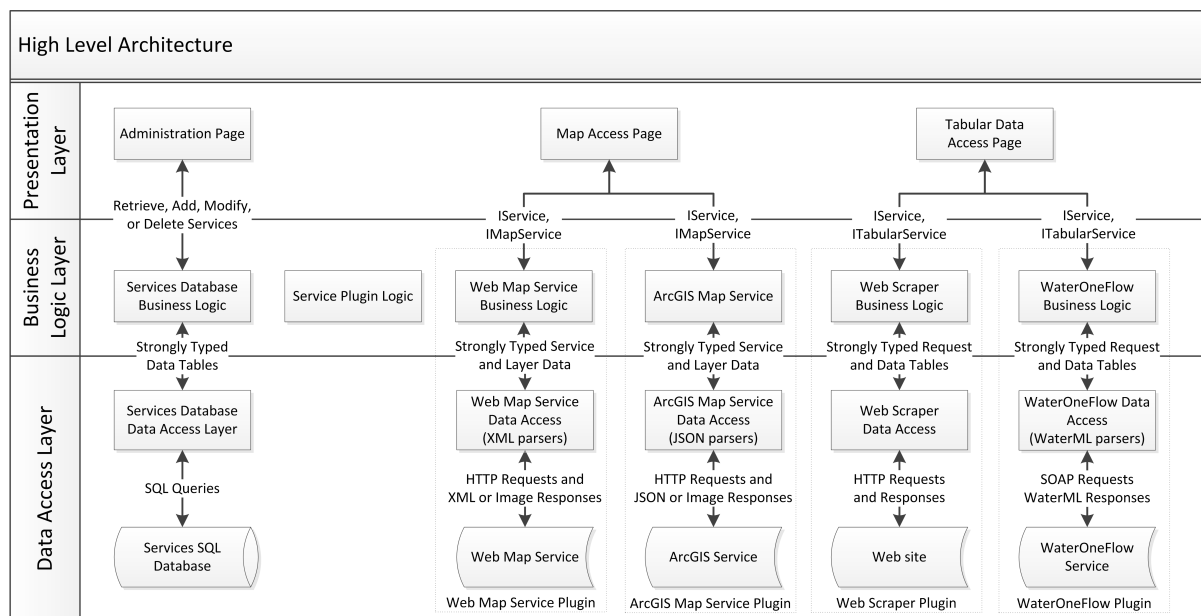


Figure 2: A diagram of the ATMOS toolkit showing the layered architecture. Plugins are enclosed in dashed-line rectangles.

complexity from end users through the use of a SOAP interface (Whiteaker and To, 2008) (Tarboton et al., 2011). The plugin leverages Visual Studio's service reference support to automatically generate code based on a WSDL description (Daigneau, 2011). The plugin parses WaterML responses to generate strongly typed data tables.

### 4.3 Database Design

The toolkit uses a database to store service information, as shown in Figure 2. Only the minimum data required to contact the service is stored. This includes the title of the service, the URL, the associated plugin, and an optional version. All other data is retrieved directly from the service.

## 5 APPLICATION EXAMPLE

The ATMOS toolkit's functionality is exposed through a web site. This contains an administration page, a map access page, and a tabular data access page. This section walks through how to use the ATMOS toolkit, highlighting the implementation results and demonstrating the value it provides to researchers.

### 5.1 Administration

The administration page allows adding new services, updating existing services, or deleting services. To add a new service, the user has to enter the url for the service metadata. The exact location will vary by service, and each plugin provides specific details in help text to aid users. When the user clicks insert to add the service, the toolkit queries the provided URL, performs corrections as necessary, including URL canonicalization, and lists the service capabilities.

### 5.2 Map Access

The map access page displays a wizard-style interface that initially lists the available map services in a hierarchical format. The user expands the service nodes to reveal supported layers, and selects the layers to be displayed. When the user clicks the next button, the details of the selected layers are displayed along with a link to the metadata associated with the service. Clicking on the finish button will display an interactive map with the selected layers. An example showing an ArcGIS-served map of agroclimate zones in Idaho, a WMS-served map showing soils in New Mexico, a local set of tiles showing a geologic map of Nevada, and WMS-served radar conditions from NOAA's NowCoast service is presented in Figure 3.



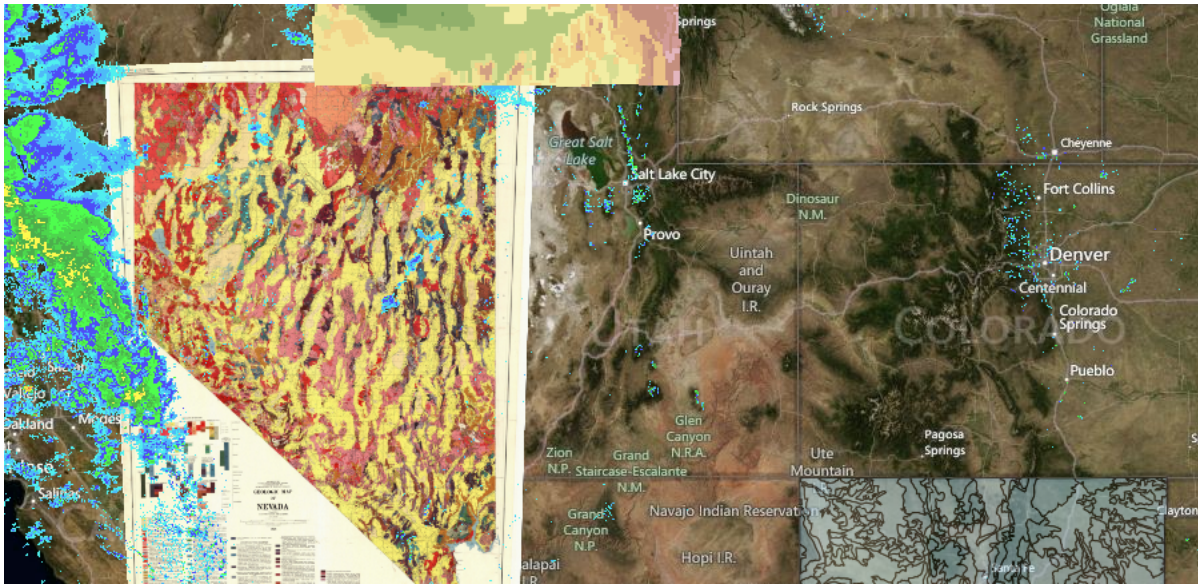


Figure 3: Results of a map request for a Nevada geology, Idaho agroclimate zones, New Mexico soils, and radar conditions.

### 5.3 Tabular Data Access

The tabular data access also displays a wizard-style interface with a hierarchy of available services, sites, and data series. The user selects the data to retrieve and clicks next. A table is displayed showing the selected series and details for each, including the available date range and a link to the metadata. The user selects the date range to retrieve and clicks the get data button to display the results in a table. A save button allows the user to save the data as a CSV file. An example showing streamflow data served by the WaterOneFlow plugin from the Boise State Hydroserver, and two locations served by the USGS water data plugin is presented in Table 1.

## 6 COMPARISON WITH RELATED WORK

ATMOS attempts to meet the unique needs of the Nevada Climate Change Portal, but there are several other software packages and websites that provide similar functionality and more. This section explores some of these alternatives and compares them to ATMOS. Table 2 summarizes the feature set of ATMOS as it compares to these software packages. It should be noted that we are not claiming that the ATMOS toolkit has the same level of sophistication and technical capabilities as the related software packages surveyed in this section, which were created by teams of people over many years. Rather, we

would like to show that the ATMOS toolkit, developed essentially by a single person over a relatively short period of time, has the core functionality needed for its purpose. What distinguishes our solution is in fact that it is a customized and highly focused solution for the specific needs of the Nevada Climate Change Portal. This gives a greater level of control over future development of the toolkit and allows for a straightforward extension of our project.

ArcGIS server is part of a suite of commercial product created by ESRI. The server component allows creating, editing, managing, and deploying web imagery and other GIS data to end users through various web APIs and services. There are associated client components to allow access to this data, including ArcGIS Viewer and ArcGIS Explorer. The ArcGIS server provides other functionality that is well outside the scope of ATMOS, including geoprocessing and web editing (ESRI, 2011). The ArcGIS suite of products is designed for large clients such as municipalities, large scale research data providers, or corporations.

HydroDesktop is a desktop application used to access data cataloged by CUAHSI's Hydrologic Information System. It supports discovery of available data sources, and allows users to download time series data. Although HydroDesktop uses maps to discover available data, it does not serve maps, and doesn't interface with map-based web services (Tarboton et al., 2011) (Ames et al., 2012).

MapServer is an open source server application that provides tools for constructing maps from files including GeoTIFF and ERSI Shapefiles. It sup-

Table 1: Results of a tabular data request from the Boise State Hydrosriver and the USGS Water Data service.

Time	Boise State Hydrosriver-Dry Creek Experimental Watershed-Lower Gage-Streamflow	USGS Water Data-LAMOILLE CK NR LAMOILLE, NV-Discharge	USGS Water Data-GALENA CK AT GALENA CK STATE PARK, NV-Discharge
1/10/2010 12:00:00 AM	2.22	3.3	5.7
1/11/2010 12:00:00 AM	2.22	3.3	5.7
1/12/2010 12:00:00 AM	2.41	3.4	5.9

ports accessing maps through OGC Web Map Services (Mitchell, 2005), and can be extended to support more formats. Unlike ATMOS, MapServer only serves maps, and doesn't have support for time series tabular data.

Table 2: A comparison of the feature set of ATMOS and several related software packages. An 'X' indicates that the software supports that feature.

	ATMOS	ArcGIS	MapServer	HydroDesktop
Access map services	X	X	X	
Access Web Map Service	X	X	X	
Access ArcGIS Map Service	X	X		
Access local maps	X	X	X	
Provides web services		X	X	
Access tabular services	X			X
Access WaterOneFlow service	X			X
Access USGS Water service	X			X
Tabular data discovery				X
Enterprise GIS management		X		
Geospatial analysis		X	X	
Extensible	X	X	X	X
Web-based interface	X	X	X	
User support		X		
Free	X		X	X
Open source	X		X	X

## 7 CONCLUSIONS AND FUTURE WORK

This paper has described a proposal to achieve the goal of sharing data between the Nevada, Idaho, and New Mexico EPSCoR web sites to support climate change research as it applies to Nevada. The result was ATMOS, a plugin-based toolkit for Accessing

Tabular and Map-based Online Services. A web front end was created based on these components, and was designed to be integrated with the Nevada Climate Change Portal in the future.

ATMOS is not unique in its abilities to provide map data or explore tabular data, as discussed in Section 6. However, ATMOS is unique in its applicability to the specific needs of the Nevada Climate Change Portal, as well as in providing a uniform interface for working with both map-based and tabular based services. This capability of combining map-based and text-based services distinguishes ATMOS from existing similar toolkits.

ATMOS is a fully functional web-based application designed to meet the needs of climate researchers. However, there is room for improvement, and further work that needs to be done before it is a viable product for large scale public consumption.

The performance of the toolkit should be improved by caching recently retrieved map layers or time series data to avoid duplicate requests for data. The user interface could be enhanced through the use of more client side processing and asynchronous updates. A usability study should also be performed to make the most robust and usable interface possible. More plugins should be written to support additional data sources, including a plugin to access geodetic gridded data from the INSIDE Idaho data repository.

It is the ultimate goal of ATMOS to be integrated into the Nevada Climate Change Portal. This work will include updating the user interface to match the look and feel of the portal through the use of CSS, and merging the underlying database with existing databases on the portal.

This work will contribute to the Nevada Climate Change Portal's goal of becoming a central point for climate change research in Nevada, and to share data with related portals in New Mexico and Idaho. This will support researchers in the daunting task of collecting data for their work on climate change in Nevada.

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