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An Overview of the Nevada Climate Change Portal

Sergiu Dascalu[1], Frederick C. Harris, Jr. [1], Michael McMahon, Jr. [1], Eric Fritzinger[1], Scotty Strachan[2], Richard Kelley[1]

[1]*Department of Computer Science and Engineering, College of Engineering, University of Nevada, 1664 N. Virginia St., Reno, NV, 89557 dascalus@cse.unr.edu*

[2]*Department of Geography, College of Science, University of Nevada, 1664 N. Virginia St., Reno, NV, 89557 scotty@dayhike.net*

Abstract: Created with support from an NSF EPSCoR Research Infrastructure Improvement (RII) grant completed in 2013, the Nevada Climate Change Portal (NCCP) serves as a cyberinfrastructure hub that provides data and computing resources for scientists studying the effects of climate change in Nevada. In particular, the NCCP has been designed for data acquisition, storage, access, and processing in support of long-term assessment of climate variability in Nevada and its impact on the state's ecological and hydrological systems. The NCCP also serves as a central repository of climate-related information for other stakeholders, including educators, students, and the public. In this paper we describe the portal's role within the larger Nevada Climate-Ecohydrology Assessment Network (NevCAN), present the architectural solutions employed in building the NCCP, and overview the main components of the portal. These components include data resources available, tools to retrieve and process data, software solutions to facilitate scientific research, information about research sites (transects), people involved, tutorials, and libraries of publications, photos, and videos. Among the tools available for accessing and processing data, the portal's original "data search interface," described in some detail in the paper, enables data selection from sites, downloading, and visualization. Currently, we plan to extend NCCP to incorporate datasets and data processing resources pertaining to new projects. The target of this expansion, the Nevada Research Data Center (NRDC), will include, among other things, a Nevada-wide project focused on researching the interconnections between solar energy production, water, and the environment. A short discussion of this planned expansion is also included in the paper.

Keywords: data portal; climate change; cyber-infrastructure; data resources; software tools; Nevada.

1. INTRODUCTION

The Nevada Climate Change Portal (NCCP) is one of the key products that came out of an NSF EPSCoR RII Track 1 project entitled "Nevada Infrastructure for Climate Change Science, Education, and Outreach." The $21.7 million awarded 5 years was split between six components: hydrology, climate, ecology, education, policy, and cyberinfrastructure (CI). The project as a whole has been a collaboration between the Nevada System of Higher Education; the University of Nevada, Reno; the University of Nevada, Las Vegas; and the Desert Research Institute. The funds received were allocated to create a statewide interdisciplinary program that stimulates transformative research, education, and outreach on the effects of regional climate change to ecosystem services (particularly water resources) and supports the use of this knowledge by policy makers and stakeholders.

The project's major interdisciplinary science questions have been: (1) How climate changes affect water resources and linked ecosystem services and human systems? and (2) How climate changes affect disturbance regimes (e.g., wild land fires, insect outbreaks, droughts) and linked systems?

As of April 2014, the NCCP has collected over 1.2 billion high-quality environmental measurements – a number that is growing every day. These managed measurements come from twelve Nevada Climate-ecohydrological Assessment Network (NevCAN) research sites spread across the state, supplying scientists with the air, water, plant, and soil readings they need to perform numerous long- and short-term analyses.

Data collected by the NCCP are provided openly and freely to all interested researchers, organizations, and members of the public via the http://sensor.nevada.edu website. The manner in which data is collected, handled, and managed ensures that it is clear, documented, and reusable, allowing both current and future researchers to readily take advantage of these high-quality measurements in longer-term studies. In addition to climate data, NCCP makes available information, tools, and other resources useful for a broad range of users, including educators and students.

The CI component, to which all the authors of this paper belong, was responsible for much of the development of the NCCP and its underlying infrastructure. The CI component was responsible for setting up a network of sensors at a series of sites, purchasing and setting up high-powered computing resources, and creating a data portal and accompanying software to support interdisciplinary climate change research. The rest of the paper will focus on these aspects, defining the concepts and describing the design of the NCCP system that is still in use today.

2. NEVCAN, RESEARCH SITES AND EQUIPMENT

From 2009 - 2013, the National Science Foundation EPSCoR (Experimental Program to Stimulate Competitive Research) program in Nevada funded (among other efforts) the construction of 12 field observation stations in eastern Nevada, the heart of the Great Basin region (Fig. 1; Mensing et al 2013). These stations (christened “NevCAN”: Nevada Climate-ecohydrological Assessment Network) were built across the elevational gradient in the Snake and Sheep mountain ranges, and all contain similar instrument packages for purposes of elevational and latitudinal comparisons of climatic, ecologic, and hydrologic variables (Fig. 1). The stations range in elevation from 800m to 3300m above sea level, from the Mojave Desert Shrub vegetation zone into the Great Basin Subalpine vegetation zone. It is expected that these stations will be capable of capturing variability in the winter-dominated climate of the Snake Range as well as the bi-modal winter- and summer monsoon-driven regime in the Sheep Range.

Included on the NevCAN stations in the Snake Range are atmospheric/meteorological sensing systems comprised of 9 different physical sensors, including free air temperature at 10m and 2m heights, relative humidity, air pressure, incoming and outgoing long- and short-wave solar radiation, wind speed/direction, and snow depth. Precipitation is measured with 2 different sensors at the higher elevations, which can differentiate rain vs. snow. Basic shallow soils conditions are monitored at all stations using 9 sensors, including temperature and water content in a vertical array to a depth of 50cm. High-frequency (e.g. 1-minute) data logging of these variables allows investigation into the characteristics of processes at short timescales across the landscape (such as individual storm characteristics).

In addition to these uniformly-installed sensor packages, some sites possess experimental science deployments ranging from 2-48 sensors in size, monitoring variables such as tree sap flow, snow water equivalent, distributed soil moisture and temperature, incremental tree growth, and Normalized Differential Vegetation Index (NDVI). All told, NevCAN supports over 240 “standard” sensors and over 150 “experimental” sensors. More experimental deployments are added each year.

Each station also possesses a controllable Point-Tilt-Zoom (PTZ) camera, which automatically capture up to 20 pre-set images per hour. These images are invaluable for visualizing conditions and processes on the landscape (Fig. 1). These cameras each capture between 100 and 160 images per day, with over 1300 images per day being captured across the whole station network. The image collection currently contains over 1.57 million individual photographs.

Connectivity to the NevCAN stations and real-time control of the field devices is made possible through use of long-distance terrestrial wireless networking. Hundreds of kilometers of data radio links operate to extend internet connectivity to the remote sites, and to connect field data loggers and cameras with servers at the University of Nevada, Reno. The field networks contain parallel links and routing failovers in critical areas to ensure that connectivity is maintained as much as possible in the

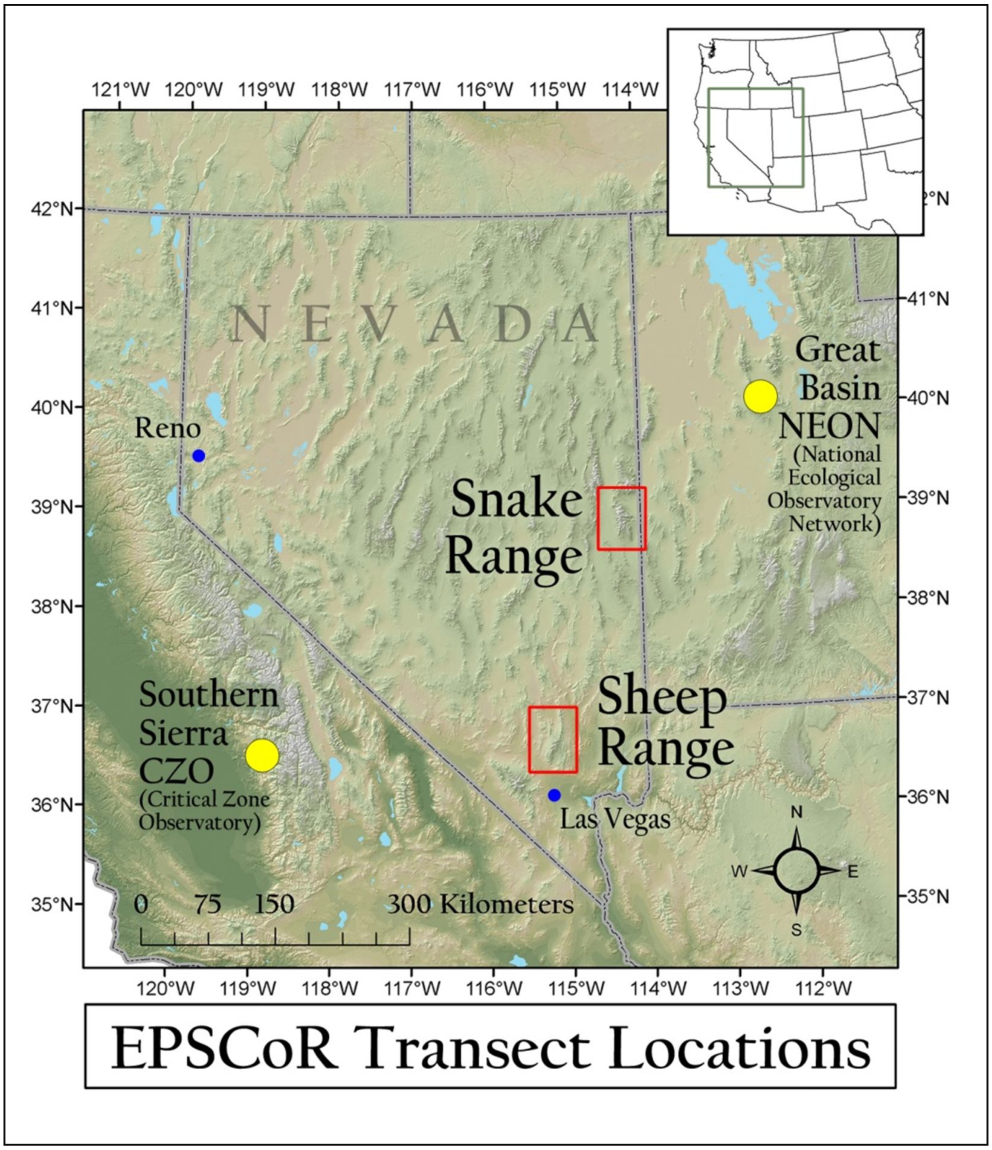

Figure 1. Location of the EPSCoR – NevCAN stations, one transect of 8 stations traverses the Snake mountain range, and another transect of 4 stations is situated at the Sheep Range.

event of interference or failure. Besides accessing cameras and science equipment, NevCAN personnel are able to connect directly to IP-compatible devices, such as remote relays and solar charge controllers, in order to closely monitor infrastructure health and condition of support systems.

3. NCCP: MAIN COMPONENTS

The Nevada Climate Change Portal (NCCP) serves several communities with varied interests in climate science. These interests range from the educational (in the case of teachers at both the K-12 and post-secondary levels) through the scientific (in the case of researchers in such fields as geology, hydrology, and climate modeling), to the political (in the case of researchers and policy-makers). The portal also serves as a central location for users to find out about the people behind Nevada's climate science research, education, and cyberinfrastructure. The organization of the site reflects the desire to effectively serve all of these populations with their differing goals and interests.

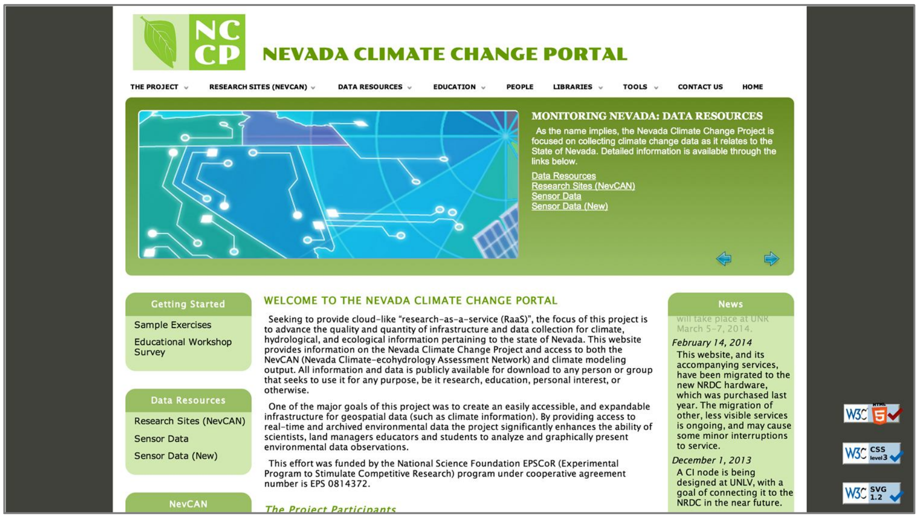

Figure 2. The landing page of the Nevada Climate Change Portal. The NCCP landing page provides quick access to everything that the portal has to offer.

Upon reaching the landing page of the site, the banner at the top of the page provides quick access to resources that many segments of users are likely to find valuable – as can be seen in Figure 2, where the banner provides quick access to data resources. The landing page also includes news events related to portal development and operations, a summary of the project and available resources, and links to several frequently used pages. As an example of such a page, we can see in Figure 3 below the "Equipment and Sensors" page, which is an interactive visualization of a typical sensor site deployed in Eastern Nevada. Through this page, users are able to learn about the technology that enables the NCCP to monitor climate conditions, and are able see how modern climate science is done.

Figure 3. The "Sensors and Equipment" page shows users the hardware that we have deployed to the field.

The NCCP provides a number of other resources beyond interactive visualizations; as discussed in Section 5.1, there is a fully featured data search system, which allows researchers to access climate data collected across Nevada for the past three years. For educators, we have lesson plans developed as collaborative effort among curriculum specialists and climate scientists. The site also provides an easy listing to the numerous publications that have resulted from portal data and portal operations.

4. DATA ARCHITECTURE AND MANAGEMENT

Beneath the public-facing website of the NCCP lies a sophisticated set of hardware and software systems that comprise the core infrastructure. The architecture of the NCCP infrastructure is organized into distinct components (comprised of hardware and / or software systems), each of which provides a specific set of functionality and interacts with related components via clearly defined mechanisms (McMahon, Dascalu, et al 2011). The single common, cross-cutting principle present across all components is the preservation of high-quality measurements and associated metadata.

Describing the system by the flow of measurements, the data collection component is responsible for obtaining measurements from remote sensing equipment and persisting it to the data storage component. While the data storage is comprised of a fault-tolerant, redundant storage system (e.g. a RAID-6 file server), the data collection component is a more varied system that houses the vendor-specific software that interfaces with remote monitoring systems (e.g. data loggers). This component encompasses the connectivity that allows the software to reach the remote system, the software, and the configuration of the software in such a way that it retrieves the highest-quality data possible, storing it in the most interoperable and manageable format.

The data import layer is comprised of software services that monitor for newly-retrieved measurement files that are exposed by the data storage component. As the measurement files arrive, the service verifies the integrity and format of the file, decomposing the measurements it contains into a set of measurements suitable for submission to the database component. In addition to submitting the measurements to the database component, the service handles rejected submissions, managing the collection of submitted and rejected files and measurements to ensure that the import process continues efficiently.

The database component – as its name implies – is comprised of a database that forms the heart of the system. The database component accepts measurement submissions from the data import layer and integrates them into its collection, performing any required / supported unit and format conversions as appropriate to ensure that the data complies with its standards; if the submission cannot be integrated; the data import component is notified of the failure. The database component provides extremely high-speed, multi-dimensional access to all integrated measurements to the data access component.

The data access component provides structured access to the database component for consumption by other system services, simplifying access to database component features such as geospatial searches, data retrieval, value aggregation, and unit conversion. This component serves as a security layer, ensuring that only read operations are permitted and that data is never modified by external entities. Multiple NCCP features utilize this data layer to disseminate measurements, including the NCCP website, data search interfaces, and (in-development) data interoperability services. The data access component is meant to serve as an easily-extensible part of the overall architecture, safely incorporating new access mechanisms as they are needed to support researchers and their ever-changing analysis technologies.

The final architectural element is the data curation component. Unlike previously-discussed organizational units, the data curation component operates parallel to (but in concert with) the data storage and data import components. The purpose of this component is to ensure the long-term viability and quality of the collected measurement files by deduplicating and archiving the collected and / or imported measurement files. In addition to performing "cleanup" operations, this component generates archive collections of imported "raw" data files that researchers can access if they wish, providing a secondary data access route, though vastly less robust than that provided by the database component.

As one might expect, managing a system with this ever-increasing number of software services and supporting computing hardware requires careful planning. To this end, all software services generate detailed operational logs that simplify the identification of import component rejections and provide constant feedback regarding data curation component activities. In addition, most components are hosted by their own virtual machines, providing enhanced security, isolation, and simplified manageability.

5. SOFTWARE RESOURCES

In addition to providing climate data, scientific imagery, and educational materials, the NCCP also provides an assortment of software tools made freely available to the public. These software tools provide a variety of services, several of which directly utilize the underlying architecture and web services of the NCCP. The core resources offered are first and foremost the Data Search Interface, which allows users to search and visualize the climate data streams, and also the Demeter Framework, which is a tool developed to allow for general model and data coupling.

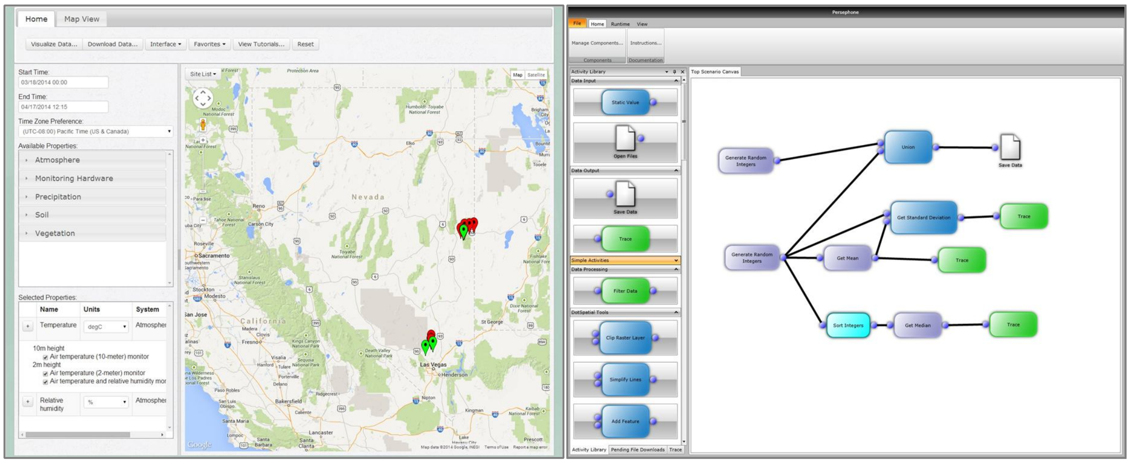

Figure 4. The Data Search Interface (left) allows the user to query and download the available climate data. Persephone (right) is a web-based scenario creation interface for the Demeter Framework.

5.1 The Data Search Interface

The Data Search Interface is a quick and easy way to get access to the climate data by allowing the user to build their own data sets via queries created in the interface. The interface features a map-based site selection, each site containing dozens of properties and sensors measured at a variety of intervals, and easy aggregation selection (e.g. creating a daily aggregate of 10-minute data). Users also have the ability to specify the units for their measurements as well as individual sensor selection for finer control over the data set.

In addition to its searching capabilities, the Data Search Interface (Figure 4 - left) is able to perform simple visualizations on the data streams by creating a query and then choosing to visualize it instead of downloading it. Right now, the interface only supports a simple line graph showing the values of the data streams over time. The user can alter the color and visibility of the lines for each sensor they are visualization, view the data point values by hovering the mouse over the graph, and download the data as they are currently seeing it via a simple button click. The visualization enforces aggregation intervals based on the potential number of data points, which was done in an effort to maintain performance since the visualizations are done client-side.

Lastly, the Data Search Interface provides full-fledged video tutorials on how each aspect of the interface works. These tutorials are able to walk the user through the process of creating and submitting a query to the servers in order to download the data.

5.2 The Demeter Framework

The Demeter Framework (Fritzinger et al 2012) is a model and data coupling framework that exists largely in the cloud. The servers host a series of web services that provides the basis for the framework and allows the scenario created to be executed on the servers where high performance computing (HPC) is available. At the present, a Microsoft Silverlight-based interface called

"Persephone" exists (Figure 4 – right), which allows users to create scenarios and interact with the web services.

The framework takes a component/schedule-based hybrid approach to model coupling, allowing for disparate component standards to interact with each other as individual processes. The key to this is a Demeter component called a "Translator", and, for example, it allows an "Activity" written in OpenMI to communicate with an "Activity" written in the Common Component Architecture. During this communication between the Activities, a "Data Format Converter" is executed which converts the data from the output Activity to a usable form that the input Activity is expecting. These Data Format Converters can also be daisy-chained; making use of the idea of "reusable components" that is popular in software engineering.

The Demeter Framework was built from the ground up with the idea of utilizing web services as part of the normal scenario execution, and its structure makes that aspect easy. There are many other HPC resources on the Internet which contain web services that are useful to the scientific community, and they can be accessible as an Activity in the execution of a scenario.

Lastly, the Demeter Framework also contains a catalog of pre-existing components for use in scenarios. For example, many of the DotSpatial Tools (Ames 2014) are available for use within the framework. The user is also able to provide their personal components to be integrated into a scenario's execution. Eventually, the option will be presented to allow users to share their components with other users of Demeter, thereby expanding the component catalog significantly.

5.3 Other Software Tools

In addition to Demeter, several other software tools were created as part of the NCCP. SUNPRISM provides tools aimed at supporting scientific investigation via new capabilities for combining data transformations, model simulations, and output visualizations in application scenarios developed for climate change research. WEDMIT is a web application aimed at addressing data and model interoperability challenges via allowing users direct control of the data processors and automated code generation. VISTED is a web application that provides visualization of a climate modeling data set provided to us by our partners in the project at Desert Research Institute. Lastly, ATMOS is an open source tool which aggregates various climate change data sources, established a consistent interface between them, and provides metadata and links that can help the data sets stand up to scrutiny from the scientific community.

6. FUTURE WORK AND CONCLUSIONS

Last year, the NSF awarded a new grant as part of their EPSCoR RII program – the title of this one being "The Solar Energy-Water-Environment Nexus in Nevada." The focus of this project is multi-faceted, with a heavy focus on studying solar energy and its impacts on the flora, fauna, and water resources of an environment. The award of $23 million is split between three groups: the scientific nexus (solar energy-water-environment research), CI, and human infrastructure/workforce development. The CI component will be able to continue their maintenance of the NCCP, while expanding on the idea of a centralized data center entitled the Nevada Research Data Center (NRDC), which is currently supporting several projects.

A 3-year NSF grant to develop palaeoclimate datasets and establish modern baseline monitoring was funded for the Walker River Basin, California-Nevada, USA in 2013. This large watershed comprises several communities of agriculturalist, tribal, and mining populations, all which depend on water recharge from snowpack in the upper elevations. The Walker Hydroclimate grant (NSF #1230329) will improve knowledge of past precipitation and drought conditions across the watershed, as well as provide new sources of observational climate data. A long-term, full-service climate station has been constructed at mid-elevation in the center of the watershed, filling a spatial gap in instrumental data for the region. These data are being streamed back in near-real-time to the developing NRDC for archival, QA/QC processing, scientific use, and dissemination to local and regional parties of interest.

In addition, climate and hydrological data from Lassen National Forest is in the process of being verified and imported into the system, to be made available as a CUAHSI WaterOneFlow web service data source. This particular project represents a departure from the previously detailed method of how data was gathered and handled, as it is a very different data source with different processes and infrastructure. The success of this project will show the variability that the NRDC systems can handle, and will open it up to further expansion into disparate and important sources of data.

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