

# VISTED: A Visualization Toolset for Environmental Data

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## Abstract

The Nevada Climate Change Portal (NCCP) has been developed with support from a large, 5-year (2008-2013) NSF EPSCoR Research Infrastructure Improvement (RII) grant to provide data resources and computing support for scientists researching the long-term effects of climate change in Nevada. To achieve its goals, NCCP contains not only environmental datasets but also software tools and services created by Nevada computer engineers to help data acquisition and processing. One such tool is an original web application, entitled VISTED (Visualization Tool of Environmental Data), which enables data selection, extraction, download, conversion, and visualization. Currently, this tool operates on the output of a hindcast NCAR/WRF-based model developed by one of the co-authors at the Desert Research Institute, Nevada. This output contains daily values for six variables and extends over 30 years (1980–2009), so it is fairly large, and data operations like the ones above are needed by scientists who investigate the results of running this model. The paper presents details of VISTED's data processing capabilities as well as of its software model and implementation. The tool's software model is described using use case and design diagrams while its functional capabilities are illustrated through an application scenario. Extension plans for VISTED, also discussed in the paper, include expanding it to operate on a broader range of model outputs, adapting it to individual user preferences, and incorporating more complex visualization capabilities.

**Keywords:** Data Visualization; Human Computer Interaction; Graphical User Interface; HTML; Interaction Techniques.

## 1. Introduction

Climate researchers have been working on assessing the impacts on climate change on human beings and the ecosystems. There is a lot of research going on in this field to minimize the impact that the climate change could cause to the ecosystems. For this purpose, climate related data is collected all over the world. Then, the datasets acquired are analyzed using several climate models to predict the future climate. But analyzing these large datasets containing terabytes (or more) of data to make critical decisions is time

consuming without visualizations. Data visualization helps the climate researchers in identifying the trends, patterns and outliers quickly. The main goal of the VISTED toolset present in this paper is to help the climate researchers in visualizing the datasets of their choice over the web.

VISTED mainly serves the visualization needs of the climate researchers. It provides features such as data extraction, data download, data conversion, and data visualization. Furthermore, it is aimed to support several platforms. It is built using HTML5, jQuery, CSS5, the D3 JavaScript library, and C# for the back end logic. Visual Studio IDE is used to put all the files of the project together.

The users of VISTED are researchers, educators, students, policy makers, and the general public. With it, researchers will be able quickly find the trends, and patterns in the data. Educators can use the toolset in the classroom while teaching the students about the climate change. It also helps the public and policy makers to be more aware of the impact of climate change.

The remainder of the paper is organized as follows. Section 2 discusses the related work, the need for the new tool, and the requirements of the VISTED. In Section 3 we introduce the proposed solution with detailed descriptions of the system by providing the high-level diagram, detail design diagrams, and user interface design snapshots. Section 4 describes several research directions and future work related to VISTED. Finally, in Section 5 we conclude the paper by summarizing the technical details of our approach as well as the contributions of the paper.

## 2. The Problem

Climate data is being collected in massive amounts by many research teams across the globe, and as a result the size of the existing climate datasets is always increasing. With this ever increasing data, the need for new sophisticated data visualization tools and visualization techniques is also increasing.

There are many tools available for the visualization of environmental data. Some of them are desktop standalone applications such as COAST [1] that are designed to serve a special purpose. Other tools are more generic in purpose, such as R [2], Tableau [3], and Visualization ToolKit [4,

5]. These tools are very useful but sometimes they cannot be extended and customized based on the application needs. In contrast to the generic tools, some scripting tools are only used in climate data visualization such as GRADS [6], NCL [7] and SVTL [8]. SVTL is a script-based visualization template library which was designed based on the VisIt [9] visualization tool. It supports addressing topmost challenges of the visualization tools such as parallel execution, interactivity, platform support, and animations. SUNPRISM [10] is another visualization toolset developed in the SOELA research lab at the University of Nevada, Reno. It allows 3D visualizations of modeling scenarios whose output can be projected in virtual reality environments such as CAVE.

Ultrascale Visualization Climate Data Analysis Tools (UV-CDAT) is another powerful climate data visualization tool. It integrates other visualization tools such as VTK, Paraview, VisTrails [11], and DV3D. Its interface also allows users to use tools such as R and Matlab for the data analysis purpose. Furthermore, it provides high quality performance with the support for parallel computing [12].

Apart from standalone applications, there are several web-based tools that allow users to upload their own datasets to the server and visualize them over the web. Specifically, ManyEyes [13] and Cal-Adapt [14] offer powerful web based applications for visualizing the datasets. For example, Cal-Adapt provides climate datasets from several decades [15]. The decadal climate data of several locations in California are visualized on a map and also a time series line chart is provided on their website. This also what the research work presented in this paper is aiming for. In addition, VISTED aims at allowing users to extract data of their choice from the NCCP repository and visualize the selected data using several new visualization techniques. This will give a great deal of flexibility to the users as they will be able to visualize the data of their choice driven by their research questions instead of having to analyze data only based on the visualizations that are provided by the website.

Initially, the main goal of the project was to visualize the climate modeling data provided by the Nevada Climate Change Portal [16]. However, based on the interviews conducted with researchers, technology experts, and teachers, several more features such as data extraction, data conversion and data download were added to the requirements [17] of VISTED. As researchers collect various types of data from several places, it is desirable that data can be saved in various formats. Thus, supporting several data formats such as NetCDF, ASCII, and binary formats [18] has become another requirement for the tool. Also, to meet technology trends, VISTED is platform independent and supports animation and interactivity.

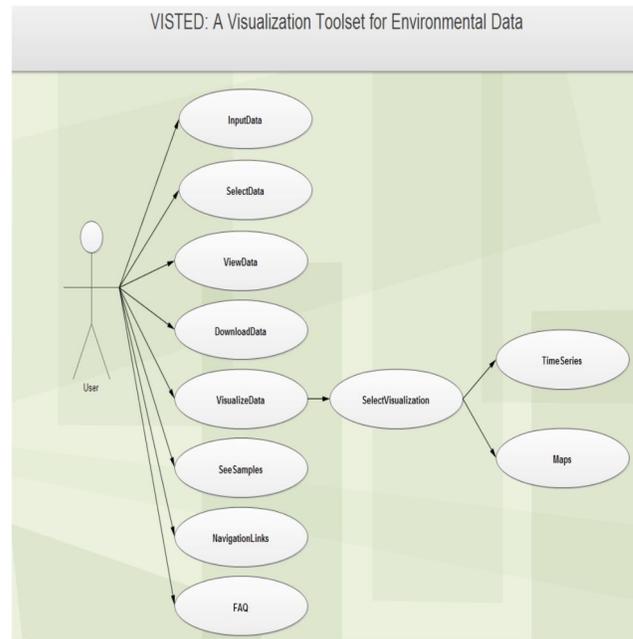
The use case diagram in the Figure 1 depicts the user interaction with the VISTED. The description of each use case is given below.

*InputData*

This will let the system to input data from the repository based on user selections. The users will select data of different formats such as ASCII, binary, and NetCDF.

*SelectData*

Users select the variable/variables and the time period of their choice to visualize the data or download data.



**Figure 1.** Use Case Diagram of VISTED

*ViewData*

Users will be able to view the data that they have extracted in a table. A separate window will be opened to display data.

*DownloadData*

Users will be able to download the selected data. The download options for the data are in ASCII, binary, and NetCDF file formats.

*VisualizeData*

Users will be able to visualize the selected data. Many options such as bar charts, line charts, area charts, difference chart, wind history, heat maps, pie chart, contour plot and scatter plot are provided. Also some of the usual data interaction techniques such as displaying the value on mouse focus and zooming are provided.

*SeeSamples*

Users can see some sample graphs and charts before they choose a dataset. This gives them an idea of what

visualizations are available.

#### *NavigationLinks*

Navigation links to VISTED website and some other links to the NCCP website and other similar tools are presented.

#### *FAQ*

Frequently asked questions section provides detailed instructions for using the tool as well as solutions to more frequently occurring problems.

#### *SelectVisualization*

Users are provided with several visualization options. They can choose the one they need.

#### *TimeSeries*

Time series chart such as line chart, bar chart, and area chart are provided to the users.

#### *Maps*

A map is used to display the locations in the dataset.

### 3. The Solution

A 3-tier client/server architecture is used to build the proposed VISTED application. The components of a 3-tier architecture include Presentation layer, Application and Business logic layer, and the Repository. The presentation layer provides support for the interaction between the users and the application by sending the requests from the client to the server. The business logic layer ensures the interaction between client requests and the database. This layer has the capability of getting data from different servers. In VISTED's case, it also supports the statistical computation and conversion of the climate data. Finally, the repository makes the data available to the top tiers. This architecture helps improve the system's performance because it is scalable, maintainable, and its components can be easily reused.

#### 3.1 System-level Diagram

The system block diagram gives the description of how a software system is organized [19]. Figure 2 presents the system level block diagram of VISTED.

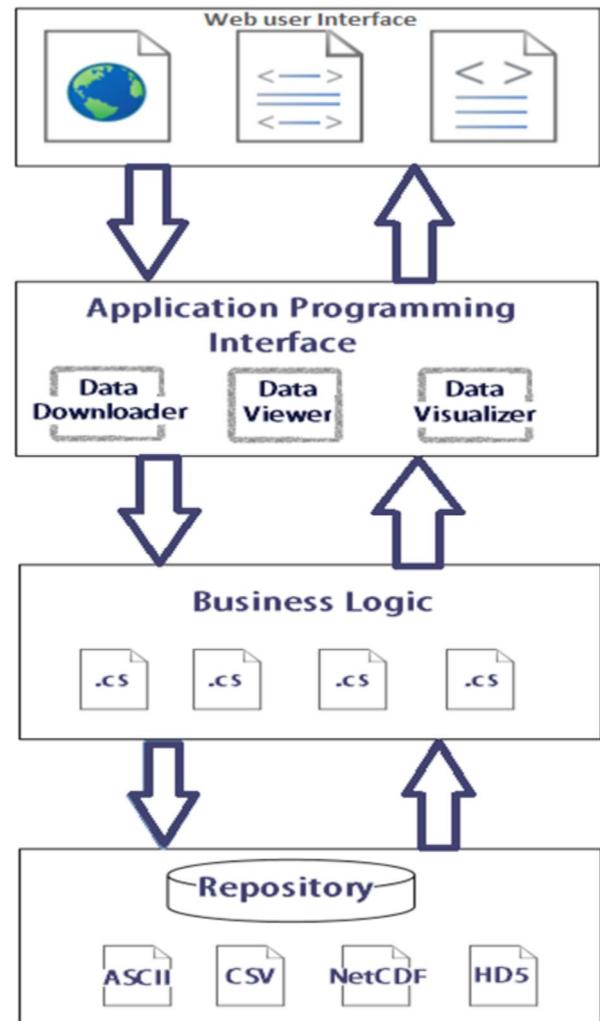
The description of VISTED components is as presented next.

#### *Web User Interface*

Users of VISTED interact with the system through the web user interface. This involves development of web pages using HTML5, visualizations using the D3 JavaScript Library, and the creation of styles using CSS5.

#### *Application Programming Interface (API)*

API is a library that contains classes, functions, objects and variables to provide VISTED's functionality for data extraction, download, and visualization. Libraries also contain code to read and write the NetCDF, ASCII, and HD5 files.



**Figure 2.** System level diagram of VISTED

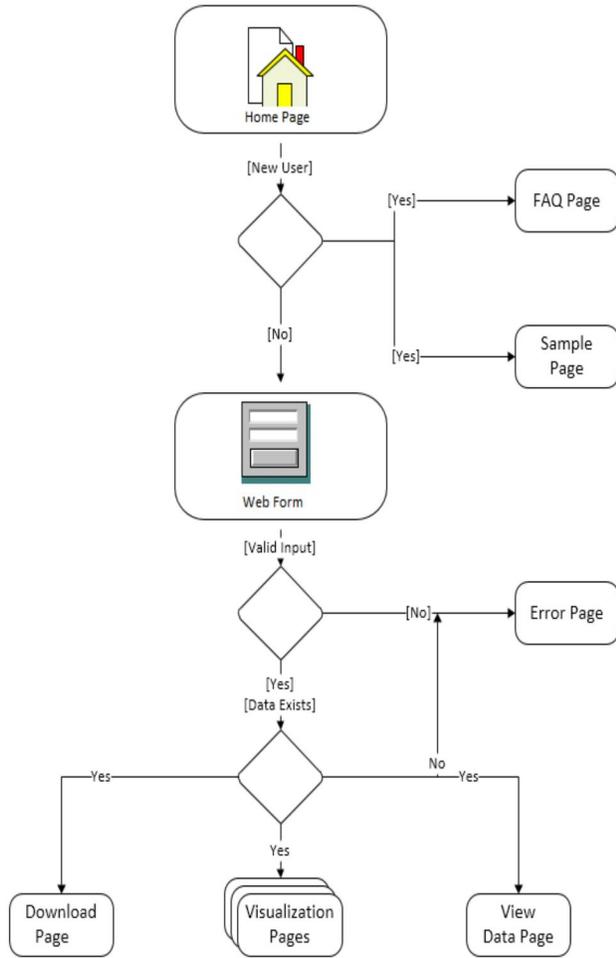
#### *Business Logic*

This layer handles the communication between the web user interface and the repository. C# code is used for implementing the logic of VISTED toolset's capability. It also contains the logic needed to perform basic statistical functions such as mean, average, minimum, and maximum.

#### *Repository*

Repository contains the data sets in ASCII, CSV, NetCDF and HD5 formats. The data can be from different data sources.

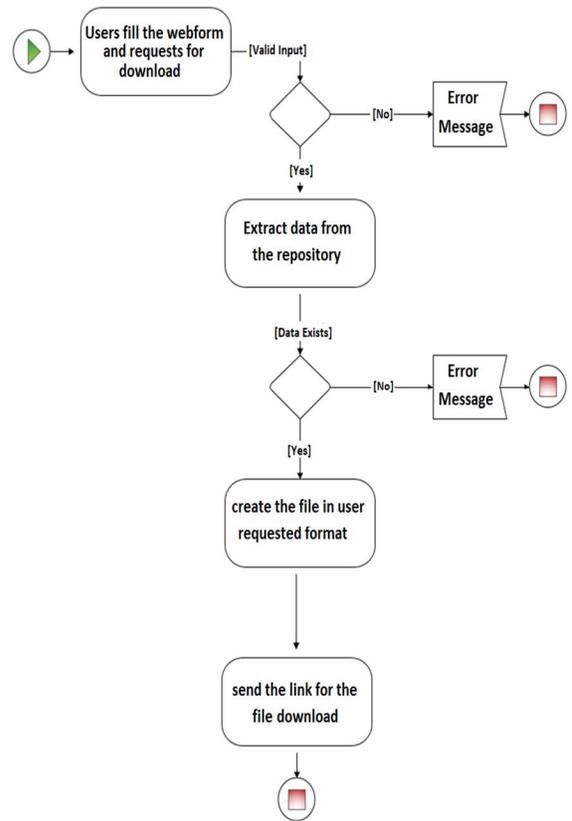
### 3.2 Detailed Design



**Figure 3.** Detailed Design of VISTED

The flow chart in the Figure 3 describes the behavior of the VISTED web application. The user starts using the application from the Home page. New users are rerouted to FAQ and Sample pages. Otherwise, if the user is already familiar with the application, he or she will fill the form based on the needs of his or her research question and the system will send the request to the server. If the request is valid and if the requested data is available, the user will get an output otherwise an error message describing the error will be sent to the user.

The activity diagram presented in Figure 4 shows the data conversion and data download features of VISTED. The user will fill the web form and send the request for downloading data. If the form is valid the data is extracted from the repository and converted to the format selected by the user before the download.



**Figure 4.** Activity Diagram of User Downloading Data Using VISTED

### 3.3 User Interface Design

The snapshots of the initial user interface of the VISTED are shown in Figures 5–8 [20]. Figure 5 shows the VISTED Home page with its logo at the top left, while the navigation links to sample visualizations and frequently asked questions are provided at the top right.

The user will follow certain steps while selecting the data. First, the parameters of the desired dataset such as temperature, precipitation, and radiation are selected. Next, the user will select the resolution, 36 km or 12 km, and then he or she will select the time period from the calendar. The calendar is preset to the start date and end date based on the available data, but the user can choose any time period from the available dates. Also, the user selects a location by entering the latitude and longitude of that particular location.

After selecting the details for the data extraction, if the user wants to download data he or she selects the data download format or if he or she wants to visualize the data,

then he or she selects the visualization type and submits the form. Figures 8 and 9 show the area chart generated by VISTED. Figure 10 shows the comparison chart that displays the difference between the variables umean and vmean.



### View Results

Date	swdownmean	tmean	precip	u10mean	v10mean
2003-10-21	254.287	299.9764	8.297246	-4.56807	0.8759568
2003-10-22	252.2742	299.8232	10.68144	-5.180373	0.4309136
2003-10-23	263.3149	299.7603	6.506785	-4.552943	0.3791432
2003-10-24	262.6633	299.6977	8.103071	-4.832751	0.3066522
2003-10-25	248.4034	299.7213	13.05509	-1.95043	1.230054
2003-10-26	253.55	299.7175	8.130133	-1.144788	1.283818
2003-10-27	238.1863	299.3645	6.828519	-1.782746	-1.732893
2003-10-28	235.1347	298.89	4.358342	-1.510755	-1.74528
2003-10-29	241.7952	298.7677	4.369047	-1.497845	-2.146062
2003-10-30	258.4532	298.836	3.978445	-1.911354	-0.8470587
2003-10-31	252.8045	299.1758	8.172831	-1.00771	0.8411654
2003-11-01	236.3689	299.4461	8.779589	1.541789	1.871366
2003-11-02	239.3684	299.5045	7.65413	2.693034	0.2249712
2003-11-03	247.7312	299.4396	6.205556	1.279704	-1.139209
2003-11-04	219.5558	299.5068	13.48866	-1.769879	-1.577923
2003-11-05	222.2677	299.7109	16.64837	-3.382682	0.4091133
2003-11-06	237.3696	299.6734	14.96368	-3.470801	1.520718
2003-11-07	246.4293	299.6737	10.51724	-3.567556	1.444888
2003-11-08	259.5348	299.7582	3.384817	-4.100821	1.033597
2003-11-09	253.9759	299.6512	1.969267	-5.044628	0.7310037
2003-11-10	254.3943	299.4468	2.687387	-4.634799	0.6420231
2003-11-11	258.2757	299.485	1.016182	-4.766118	0.917113
2003-11-12	251.2834	299.2934	2.901267	-5.285383	-0.5190949
2003-11-13	243.1345	299.2104	4.308982	-5.903834	-0.4267966
2003-11-14	234.441	299.2411	7.437814	-6.268383	-0.733511

Figure 6. Results of the Extracted Data Are Viewed in the Client Browser

The screenshot shows the VISTED home page with a navigation bar (Home, Samples, FAQ) and a main content area. A blue box contains the VISTED logo and a description: "VISTED helps the climate researchers in identifying the trends, patterns and outliers quickly. The main goal of VISTED is to help the climate researchers in visualizing the datasets of their choice over the web." Below this is a note about the data source: "This tool visualizes the climate modeling data during the period 1980/01-2009/12 NCEP/NCAR reanalysis and CCSM3 and 2040/01-2069/12 for CCSM3 based on the A2 Scenario. To download the complete dataset visit [NCCP Website](#)." The main section is titled "Please follow the below steps to visualize the data." and contains six numbered steps: 1. Select the parameters (swdownmean, tmin, tmean, tmax, precip, omean, u10mean, v10mean); 2. Select a resolution (36km, 12km); 3. Select the time period (Select start date: 10/21/2003, Select end date: 10/21/2005); 4. Select the latitude and longitude (Latitude min: 3 3 6, Latitude max: 21 5 0; Longitude min: 9 27 8, Longitude max: 51 14 3); 5. Select the required statistics (Maximum, Minimum, Mean, Variance, Standard Deviation); 6. Select an output format (CSV, NetCDF, ASCII, HDS). At the bottom are buttons for "View", "Visualize", and "Download".

Figure 5. The Home Page of VISTED

Users can provide the input for data extraction by following the instructions given on the home screen of the VISTED main user interface. The user interface displayed in Figure 5 presents an example of specific user selections. First the parameters swdownmean, tmean, precip, u10mean, and vmean are selected. Then a resolution of 36 km, the time period from Oct '03 to Oct '05, the latitude range from 3° 3' 6" to 21° 5' 0", and the longitude range from 9° 27' 8" to 51° 14' 3" are also selected. Finally, Mean is selected from available statistics and the CSV file format is chosen from available download output formats.

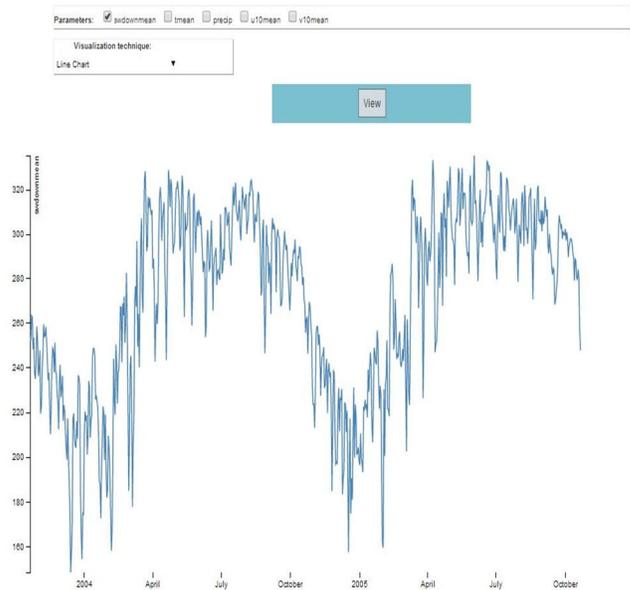
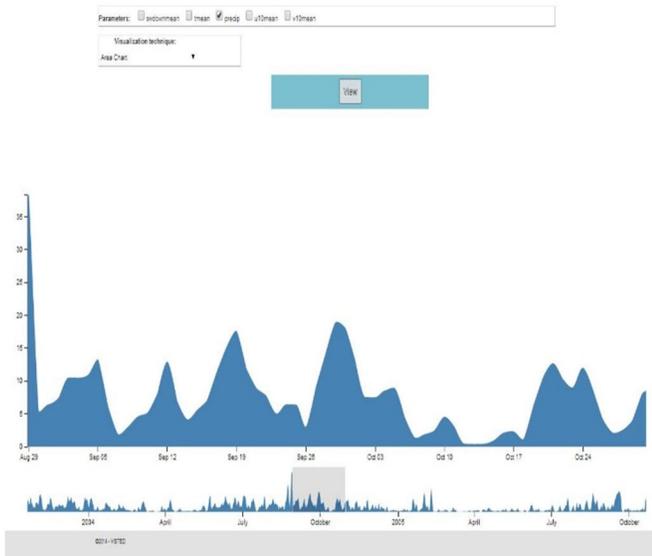


Figure 7. Example of VISTED Visualization: A Line Chart of Climate Variable Snowdown from October 2003 to October 2005

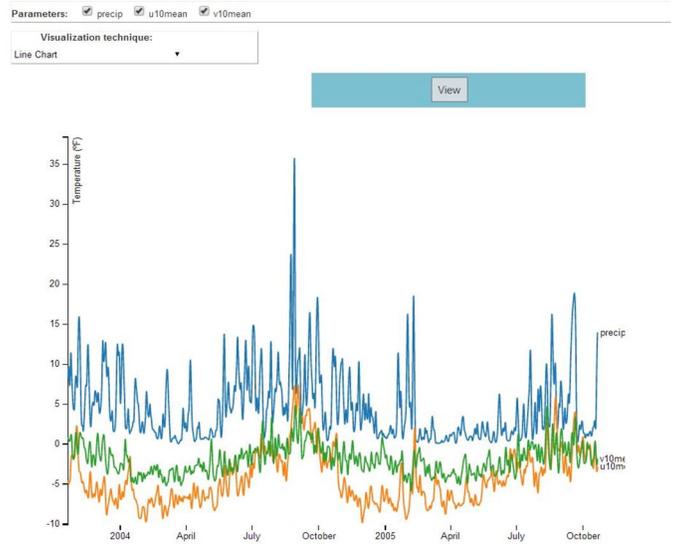


**Figure 8.** VISTED Area Chart Showing the Visualization of Climate Variable Precipitation between October 2003 and October 2005



**Figure 9.** The Area Chart of Variable Precipitation is Zoomed-in to View Data from September 2004 to October 2004 Day-wise

The difference in two variables is shown using a line chart for each variable with contrasting colors, as depicted in Figure 10. In VISTED, the user has the possibility to compare more than two variables using the same difference chart.



**Figure 10.** The Differences between Climate Variables Precipitation, U-radiation, and V-radiation are Visualized Using a Multi-Series Line Chart

Figure 11 shows the downloaded CSV file with data extracted from NetCDF files. The downloaded file shows the extracted data based on the user input. In Figure 8, the user selected the variables swdownmean, precip, and u10mean from the dataset. The time period selected was from 8/18/1988 to 8/18/1998.

	A	B	C	D	E	F	G
1	date	swdownmean	tmean	precip	u10mean	v10mean	
2	10/21/2003	254.287	299.9764	8.297246	-4.56807	0.8759568	
3	10/22/2003	252.2742	299.8232	10.68144	-5.180373	0.4309136	
4	10/23/2003	263.3149	299.7603	6.506785	-4.552943	0.3791432	
5	10/24/2003	262.6633	299.6977	8.103071	-4.832751	0.3066522	
6	10/25/2003	248.4034	299.7213	13.05509	-1.95043	1.230054	
7	10/26/2003	253.55	299.7175	8.130133	-1.144788	1.283818	
8	10/27/2003	238.1863	299.3645	6.828519	-1.782746	-1.732893	
9	10/28/2003	235.1347	298.89	4.358342	-1.510755	-1.74528	
10	10/29/2003	241.7952	298.7677	4.369047	-1.497845	-2.146062	
11	10/30/2003	258.4532	298.836	3.978445	-1.911354	-0.8470587	
12	10/31/2003	252.8045	299.1758	8.172831	-1.00771	0.8411654	
13	11/1/2003	236.3689	299.4461	8.779589	1.541789	1.871366	
14	11/2/2003	239.3684	299.5045	7.65413	2.693034	0.2249712	
15	11/3/2003	247.7312	299.4396	6.205559	1.279704	-1.139209	
16	11/4/2003	219.5558	299.5088	13.48866	-1.709879	-1.577923	
17	11/5/2003	222.2677	299.7109	16.64837	-3.382682	0.4091133	
18	11/6/2003	237.3696	299.6734	14.96368	-3.470801	1.520718	
19	11/7/2003	246.4293	299.6737	10.51724	-3.567556	1.444888	
20	11/8/2003	259.5348	299.7582	3.384817	-4.100821	1.033597	
21	11/9/2003	253.9759	299.6512	1.969267	-5.044628	0.7310037	
22	11/10/2003	254.3943	299.4468	2.687387	-4.634799	0.6420231	
23	11/11/2003	258.2757	299.485	1.016182	-4.766118	0.917113	
24	11/12/2003	251.2834	299.2934	2.901267	-5.285383	-0.5190949	
25	11/13/2003	243.1345	299.2104	4.308982	-5.903834	-0.4267966	
26	11/14/2003	234.441	299.2411	7.437814	-6.268383	-0.733511	
27	11/15/2003	237.8486	299.2053	7.334468	-5.688667	-1.855444	
28	11/16/2003	224.3121	299.0918	7.022422	-5.901047	-2.156558	
29	11/17/2003	210.4176	299.184	12.94103	-6.453085	-2.674247	
30	11/18/2003	221.0095	299.0175	12.32146	-6.967226	-1.732004	
31	11/19/2003	241.303	299.0405	7.361794	-5.953396	-0.1721015	
32	11/20/2003	248.8332	299.1252	4.313715	-3.511799	0.4672425	
33	11/21/2003	247.8458	298.9415	1.665761	-3.249623	0.08440311	
34	11/22/2003	237.9729	298.6151	2.592562	-5.093719	-2.193618	
35	11/23/2003	251.3317	298.6484	4.926105	-6.813131	-3.356248	
36	11/24/2003	238.3698	298.6539	4.994947	-6.691672	-1.27231	
37	11/25/2003	237.3288	298.8087	5.467113	-6.181977	-1.396422	
38	11/26/2003	228.2881	298.7709	4.287811	-6.214821	-1.358624	
39	11/27/2003	224.2426	298.5809	6.961995	-6.831852	-2.820059	
40	11/28/2003	212.554	298.5875	6.457955	-5.963801	-2.617232	

**Figure 11.** The Extracted Data Converted from the NetCDF Format to the CSV Format is Downloaded in the User's Machine and Viewed in a Microsoft Excel File

NetCDF files can be viewed using a Microsoft Excel add-in. Figure 12 shows an excerpt of the metadata associated with the climate modeling output dataset available on the NCCP.

	A	B	C	D	E	F	G
1	msds.nc?file=C:\Users\lravi\Desktop\hourly_output_d01_lat.lon.elev.land.nc						
2	Global metadata		<a href="#">Add new variable</a>				
3		Key	Type	Value			
4		Name	String				
5			Auto				
6	Variables						
7	ID	Name	Type	Dimensions	Size	Data	Display range
8	4	xland	Single	latdim,londim	139x139	<a href="#">Show data</a>	
9		Name	String	xland			
10		units	String	1_land mask			
11			Auto				
12	3	elevation	Single	latdim,londim	139x139	<a href="#">Show data</a>	
13		Name	String	elevation			
14		units	String	m_ASL			
15			Auto				
16	2	latitude	Single	latdim,londim	139x139	<a href="#">Show data</a>	
17		Name	String	latitude			
18		units	String	north-south			
19			Auto				
20	1	longitude	Single	latdim,londim	139x139	<a href="#">Show data</a>	
21		Name	String	longitude			
22		units	String	west-east			
23			Auto				
24							

**Figure 12.** NetCDF File Showing Parameters Latitude, Longitude, Elevation, and Xland

## 4. Future Work

The proposed VISTED application, which is still under development, is planned to be a generic visualization web application in the future. In this paper, we presented the basic and core functionalities of VISTED. At this time, this toolset is under preliminary review by NCCP researchers, teachers, students, and the general public. In the future, VISTED will include more data visualization techniques, interaction capabilities, animation, and will improve the data extraction time from NetCDF files by implementing the extraction process in parallel.

## 5. Conclusions

This paper presented VISTED, a new toolset for data visualization. The main features of VISTED include data extraction, data conversion, data download, and data visualization. It supports several input data formats such as NetCDF, CSV, HD5, and ASCII. Several data visualization techniques such as area charts, difference charts, and contour charts are also supported. The technologies used in VISTED's development include HTML5, the D3 javascript library, and C#.

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## Disclaimer

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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