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Sierra Nevada Ecological Forecasting

Implementing a Decision Support System for the Sierra Nevada to Monitor, Report, and Forecast Ecological Conditions

**Technical Report Rough Draft**

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# Abstract

The Sierra Nevada is experiencing changes in hydrologic regimes, such as decreases in snowmelt and peak runoff, which affects forest health and the availability of water resources. Currently, the USDA Forest Service Region 5 is undergoing Forest Plan revisions to implement climate change impacts into mitigation and adaptation strategies. However, there are few processes in place to conduct quantitative assessments of forest conditions in relation to mountain hydrology, while easily and effectively delivering that information to forest managers.  To assist the USDA Forest Service, this study is the second part of a three-term project to create a Decision Support System (DSS) featuring data integration, data viewing, and data reporting, and forecasting of ecological conditions within the Sierra Nevada. The Sierra DSS Mapping Viewer will allow users to view spatially represented layers of historic and forecasted hydrological, climate, and land surface conditions for the entire Sierra Nevada. The purpose of this Viewer is to provide an online integration of satellite, modeled, and field-derived datasets. This integration will allow users to select, view, and analyze specific variables based on their questions of interest. Additionally, projected climate conditions and vegetative properties derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5), the Lund-Potsdam-Jena Dynamic Global Model (LPJ), and the California Basin Characterization Model (BCM) will be summarized and available for viewing for each watershed within the Sierras. The second term of the project focused on further identification and processing of hydrological, climatic, and land surface data sets of interest, and the creation of a Sierra Nevada DSS Mapping Viewer prototype.

**Keywords:** ecological forecasting, forestry, Sierra Nevada, decision support system, remote sensing, climate change, water resources, web GIS, web mapping application

# 1. Introduction

## 1.1 Background

Water resources within the Sierra Nevada region are essential for supporting many wildlife habitats and necessary forest components. The Sierra Nevada relies heavily on snowpack for sustainable water resources and is the primary source of water in California (Hunsaker et al., 2013). According to the USDA Forest Service, the region faces unexpected changes in hydrological and ecological processes due to potential impacts of climate change (Hunsaker et al., 2013). Long-term changes in temperature and precipitation will reduce spring snowpack, affecting water quality and quantity, biodiversity, wildfire frequency and duration, and vegetation distribution. Therefore, continuous ecosystem monitoring is necessary to guide agencies that are responsible for managing the land and water resources of the Sierra Nevada. Forest managers require information pertaining to climate change impacts on forest health, hydrology, various vegetation communities, spread of invasive species, and changes in landscape dynamics in order to develop comprehensive adaptation strategies (Ghilarducci et al., 2012). Producing knowledge specific to water resources and forest health requires many complex data sets that are time consuming and difficult to obtain and process with limited state and federal resources (Nemani et al., 2007).

In order to assist in water resource management and climate change adaptation in a large ecological region such as the Sierra Nevada, a decision support system (DSS) will be implemented to facilitate multifaceted research. This Sierra Nevada Decision Support System (Sierra-DSS) establishes a viewing and monitoring system, integrating historic and forecasted ecological and climate variables using NASA Earth observations, modeled data, and *in situ* measurements. The Sierra-DSS is an integrated online mapping tool featuring various components as well as a multitude of historic and forecasted ecological datasets spanning from 1982-2100. Users are able to spatially visualize and analyze climate, hydrology, and vegetation datasets that are necessary for ecological research and management decisions.

The Sierra-DSS is modeled in part after the Appalachian Trail Decision Support System (A.T.-DSS) that is currently in operation (Wang et al., 2010). The A.T.-DSS is an internet-based implementation and data integration toolset meant to improve and guide management decisions for multiple agencies including the United States Department of Agriculture (USDA) Forest Service, as well as provide the general public with ecological and climatic information (Wang et al., 2010). The A.T.-DSS features NASA multi-platform sensor data, NASA Terrestrial Observation and Prediction System (TOPS) products, and *in situ* measurements.

## 1.2 Objectives

This project addressed the Ecological Forecasting application area within NASA’s Applied Sciences Program.  Projects within this application area are expected to provide reliable ecological forecasts allowing decision makers access to science-based tools in order to predict the impacts of environmental change on ecosystems (Friedl, 2013). The Sierra-DSS is a unique ecological forecasting tool specifically designed to support climate change adaptation processes that are required in current forest planning and management practices.

This project is in the second phase of a three-term research effort, focused on the planning, design, and implementation of a DSS framework. The objectives for the first phase of the project were to: 1) meet with partner agencies and discuss future needs and expected outcomes of the Sierra-DSS, 2) download ecological, hydrological, and climatic datasets while creating methodological tutorials, 3) learn how to operate the Lund-Potsdam-Jena (LPJ) vegetation forecasting model, and 4) create a Sierra-DSS framework that will ultimately lead to an internet-based DSS.

The second phase of the project focused on designing and creating sub-components of the Sierra-DSS. Specific objectives were to: 1) acquire additional datasets from the California Basic Characterization Model (BCM) 2) process key hydrological, climate, and surface datasets, 3) collaborate with clients to identify user needs and functional requirements, and 4) implement a beta version of the browser-based mapping viewer of the Sierra DSS.

Upon completion of phase three during the summer of 2014, this tool will provide a coherent framework for data integration, monitoring, and access to data reports and forecasts of ecological and hydrological conditions within the Sierra Nevada. For more information on Sierra-DSS components two and three, refer to section 4.2.

## 1.3 Study Area

The Sierra Nevada Range falls within the M261 ecological region, specifically, within the D, E, and F ecological sections. These sections encompass 63,100 km2 in California with small segments crossing into western portions of Nevada and the lower Cascade Range in Oregon. Vegetation covers approximately 90% of the area (Davis and Stoms, 2004). This region includes oak and shrub-covered foothills, heavily forested middle elevation slopes, and alpine landscapes in regions of high elevation (McNab et al., 2007). Designated by the USDA Forest Service, the Sierra Nevada falls within the M261 ecological region (McNab et al., 2007). An ecological region is a group of ecosystems that share similar terrain and ecological characteristics such as soil and broad vegetation types. Common vegetation types found within the M261 ecological region range from broadleaf and needleleaf woodlands, shrublands, steppe and mixed coniferous forests, and alpine meadows. M261 experiences long cold winters with precipitation and temperature heavily influenced by altitude (McNab et al., 2007). The Sierra-DSS will focus on hydrology; therefore, the team further divided the study area to encompass all intersecting hydrologic units at the HUC-8 level. A HUC is a Hydrologic Unit Code that defines the level of division among USGS hydrologic units and is broken into 6 levels (Seaber, 1987). The levels are identified by the number of digits in their HUC ranging from 2 to 12. The first level, HUC-2, breaks up the United States into 21 major hydrologic regions that are further subdivided in proceeding levels. HUC-8 is the fourth level of division and breaks the United States into 2,150 cataloging units that define drainage basins or distinct hydrological features. This added division will also allow additional analytical flexibility for users. There are 58 HUC-8 units that fall within the M261 D, E, and F ecological sections. These units define the final study extent for the Sierra-DSS (Figure 1).

Figure 1: The three ecological regions that make up the Sierra Nevada (M261E, D, and F) are shaded in green while the 58 watersheds that make up the study area are outlined in black.

# 2. Methodology

The Sierra-DSS is a web-based system, comprised of three components: 1) a browser-based Mapping Viewer, 2) a Report and Forecast Repository, and 3) a Geospatial Data Gateway. The main objective of the Sierra-DSS is to provide quick access to spatial and gridded datasets and statistics to support forest and resource management decisions. In order to meet these needs, the Sierra-DSS utilized web GIS technology. Web GIS is a geographic information system (GIS) that uses web technology to manage, analyze, store and acquire spatial data (Fu and Sun, 2011). The second term of the project focused on data acquisition (section 2.1), data processing (section 2.2) data hosting (section 2.3), and the development of the Sierra-DSS Mapping Viewer. These components are essential for a comprehensive DSS that is catered toward ecological research and natural resource management.

## 2.1 Data

The team incorporated various hydrological, climatic, and surface datasets derived from satellite and modeled products into the Mapping Viewer. These spatial and temporal gridded datasets are comprised of two subcategories historical (1982-2014) and forecasted (2014-2100).

## 2.1.1 Historic Datasets

To best represent hydrological, ecological, and climatic conditions within the study region, a collection of modelled and observed datasets were gathered and incorporated into the Mapping Viewer. Surface observations such as land cover, gross primary production (GPP), net primary production (NPP) products, and vegetation indices were obtained from the MODIS sensor and integrated into the Sierra-DSS Mapping Viewer. Historic wildfire data, such as disturbance, vegetation, and fuel loading products were acquired from Landscape Fire and Resource Management Planning Tools (LANDFIRE) and incorporated into the DSS to interpret patterns of large-scale fires in the region. Additionally, the team gathered and incorporated hydrologic and climatic data into the Mapping Viewer to understand climate change impacts on mountain hydrology. Specific variables include snow cover, modeled snow water equivalent, surface runoff, temperature, precipitation, and evapotranspiration. Data details can be found in Appendix B.

## 2.1.2 Forecasted Datasets

### Coupled Model Intercomparison Project (CMIP)

The World Climate Research Programme (WRCP) develops global climate projections through its Coupled Model Intercomparison Project (CMIP) approximately every half decade (Brekke et al., 2013). CMIP was established in 1995 by the WRCP in conjunction with the Working Group on Coupled Modeling (WGCM) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). CMIP provides a science community- based structure to facilitate Global Climate Model (GCM) improvements via climate model diagnosis, validation, intercomparison, documentation, and data access in a systematic process (Brekke et al., 2013). The vast majority of the international climate modeling community has participated since project initiation.

Global climate projections from CMIP have informed the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports as well as various research and assessment efforts related to climate change processes, outcomes, mitigation and adaptation (Brekke et al., 2013). Phase 3 of the Coupled Model Intercomparison Project (CMIP3), collected by the Program for Climate Model Diagnosis and Intercomparison (PCMDI), consists of climate model outputs from simulations of past, present, and future scenarios by leading modeling centers around the world. CMIP3 results have served in reports since 2007, including the Fourth Assessment Report (AR4) of the IPCC. With the consent of participating modeling groups, CMIP3 is now available and free for non-commercial purposes. In addition, the WCRP released global climate projections from CMIP phase 5 (CMIP5) during 2012-2013.

Two statistical downscaling techniques, monthly bias-correction and spatial disaggregation (BCSD) and daily bias-correction and constructed analogs (BCCA) have been applied to a large set of climate projections within CMIP5 (Brekke et al., 2013). CMIP5 projections were included in the Mapping Viewer for visualization and analysis. The Basin Characterization Model (BCM), described in the following section, utilizes CMIP3 projections, therefore CMIP3 projections are inherent in BCM projections. The Sierra-DSS also incorporates BCM projections.

Both CMIP3 and CMIP5 represent a range of greenhouse gas emissions scenarios, all of which have been included into the Mapping Viewer. Refer to Table 1 for complete list and description of emissions scenarios.

|  |  |  |
| --- | --- | --- |
| **CMIP3 Emissions Scenarios** | **CMIP5 Emissions Scenarios** | **Description of Scenarios** |
| no mitigation scenario exists for CMIP3 | RCP2.6 | Assumes a strong mitigation scenario existing globally with emission peaking in the middle of the century (2050) and becoming negative until 2100. |
| SRES B1 | RCP4.5 | Assumes low emission levels from low fossil fuel use and global population as a constant (best case scenario). |
| SRES A1B | RCP6.0 | Assumes medium-high emission levels from medium-high fossil fuel use and an increase in global population (business as usual). |
| SRES A2 | RCP8.5 | Assumes high emission levels from high fossil fuel use, and an increase in the global population (worst case scenario). |

*source: Brekke et al., 2013*

Table 1. CMIP3 and CMIP5 Greenhouse Gas Emissions Scenarios

### California Basin Characterization model (BCM)

The California Basin Characterization Model (BCM) climate dataset provides historical and projected climate surfaces for the state at a 270 m resolution. BCM uses a regional water balance model that is based on high resolution downscaled precipitation, temperature, elevation, geology, and soils. The model produces historical, climate, and hydrologic projections for a variety of variables using methods developed by the United States Geological Survey (USGS) (Thorne et al., 2012). These forecasted variables include maximum temperature, minimum temperature, precipitation, potential evapotranspiration (ET), runoff, recharge, climatic water deficit, actual evapotranspiration, sublimation, soil water storage, snowfall, snowpack, snowmelt, and excess water. The historical data (1911-1999) are based on 4 km PRISM data, and the projected climate surfaces are based on the A2 and B1 scenarios of the Parallel Climate Model (PCM) and General Fluid Dynamics Laboratory (GFDL) GCMs. The Sierra-DSS includes the monthly average for each of the listed variables of the historical BCM datasets for the time period of 1984-1999 and projected climate surfaces of the A2 and B1 scenarios of the GFDL GCMs for three 30 year time blocks: 2010-2039, 2040-2069, and 2070-2099. The A2 climate scenario depicts a rapidly growing population and globally high CO2 emission levels (19.6 - 34.5 gigatonnes of carbon/year). In contrast, the B1 climate scenario represents a stronger focus on sustainability, clean technologies, and significantly reduced CO2 emissions (2.7 - 10.4 gigatonnes of carbon/year) (Nakicenovic et al., 2000).

### Lund-Potsdam-Jena

Lund-Potsdam-Jena (LPJ) is a dynamic vegetation model which enables users to model vegetation health and hydrologic changes over time (Sitch et al., 2003). LPJ simulates vegetation composition and distribution, as well as water and carbon exchanges. Processes such as photosynthesis, vegetation regeneration, fire disturbances, and runoff are calculated (Sitch et al., 2003). The model requires monthly temperature, precipitation, radiation, and CO2 concentration datasets as inputs in order to accurately model seasonal terrestrial vegetation. The model outputs vegetation properties such as GPP, NPP, and other various vegetation health related variables. GPP represents the amount of organic carbon fixed in an ecosystem by photosynthesis (Hashimoto et al., 2011). NPP is defined as the net flux of carbon from the atmosphere into green vegetation per unit time (Gower et al., 2001).

The Sierra-DSS used the LPJ model to simulate forest health conditions (NPP and GPP) for historical to recent (1982-2009) and future (2010-2099) time periods. The simulation incorporates (PRISM) monthly temperature and precipitation data from 1982 to 2009 to simulate vegetation properties.  Future monthly temperature and precipitation data from the CMIP A1B scenario are used to derive vegetation properties from 2010 to 2099. These future outputs would assume radiation and CO2 concentration remain consistent until 2099. NPP and GPP outputs are related to carbon and water fluxes in an ecosystem; thus, monitoring these parameters helps decision makers identify recent changes in vegetation along with changes according to any specific climate scenario (Hashimoto et al., 2011). The Sierra- DSS will feature NPP and GPP outputs from this model, and will be summarized in the Report and Forecast Repository.

## 2.2 Data Processing

Datasets utilized for the beta version underwent three basic processing steps to allow the team to showcase Mapping Viewer capabilities. First, all datasets were projected into WGS 1984 Web Mercator to match basemap layers utilized in ArcGIS Viewer for Flex. All raster datasets were then clipped to the outer extent of the study area and assigned a symbology unique to each dataset. Shapefiles were clipped to include all lines and polygons that partially and fully overlap the study area. The final processing step converted all datasets to a keyhole markup language (KML) format. The use of the KML format through the ‘From Web’ avenue (section 2.4) eliminated financial commitments for the future host of the Sierra-DSS, but restricts the capabilities of the DSS (section 4.2.1).

## 2.3 Data Hosting

Data for the Sierra-DSS is hosted on the Amazon Simple Storage Service (S3) through the Open NASA Earth Exchange (OpenNEX). Amazon S3 is a storage service that allows users to access data anywhere they have a connection to the web (AWS, 2006). Meanwhile, OpenNEX is a project that aims to improve collaboration between researchers and make it easier and more efficient to work with Earth science data (Nemani, 2014). Given the alignment of goals between OpenNEX and the Sierra-DSS, the team was granted access to the OpenNEX portion of Amazon S3 to store all processed datasets for the DSS. Data can be uploaded to Amazon S3 using a Python script that returns a URL for each uploaded dataset, which allows the Mapping Viewer access to display the data.

## 2.4 Mapping Viewer Component

The Mapping Viewer is a browser-based interactive mapping tool that allows users to pan and zoom to areas of interest, turn data layers on and off, as well as integrate and overlay datasets. The Mapping Viewer was developed using ArcGIS Viewer for Flex, a web mapping application that utilizes ArcGIS API for Flex. ArcGIS Viewer for Flex allows users to easily develop new visualization and/or analysis tools as priorities change (ESRI, 2003). Specific tools within the Mapping Viewer are useful for decision-making, such as the time-series slider for visualizing change over time. These tools are called widgets. A widget is a block of code that can be added, edited, or removed from the Mapping Viewer in a modular fashion. Functionality of the widgets within the ArcGIS Viewer is defined in Appendix C. Widgets consume datasets through set operational layers. Operational layers are created by pulling data into the Mapping Viewer interface from one of three sources: 1) ArcGIS Online, 2) ArcGIS Server, and 3) From Web (Figure 2). While all three data avenues enable users to gain access to a multitude of hosted datasets, ArcGIS Online and ArcGIS Server provide functionality for integrating and optimizing datasets for geoprocessing. Benefits of creating a Mapping Viewer with this technology include quick and efficient access to ecological information via a cloud environment, potentially optimizing geographically dispersed management, and planning resources.



Figure 2: Screenshot of the ArcGIS Viewer for Flex user interface for adding layers to the Mapping Viewer. The three sources for pulling data into the Mapping Viewer are shown in the red box.

# 3. Results & Discussion

## 3.1 Beta Mapping Viewer

Implementation of the Beta Mapping Viewer brought several improvement areas to attention. Use of the OpenNEX cloud environment enabled the hosting of large amounts of raster data. KML layers were brought into the browser-based web mapping application using the ‘From Web’ source avenue (sections 2.3, 2.4, and 3.1). While this avenue was free of financial obligation, it has presented possible limitations.

KML, while widely used as a cross platform GIS data format, was developed primarily for use within Google Earth. The utilization of this file format has produced a northward shift in raster data within the Mapping Viewer. This shift is not inherent with vector data or when displaying hosted KML layers in Google Earth. ArcGIS Viewer for Flex is an Esri product and Esri has limited support for file formats not their own. ArcGIS Viewer for Flex utilizes KML as a third option for data integration with limited capabilities, thus creating data translation issue s. Moving forward, it may be possible to manually georeference the raster data to display correctly. Additionally, the use of KML layers within ArcGIS Viewer for Flex requires that all layers be pre-classified and symbolized prior to uploading on OpenNEX. Without the ability to interactively symbolize and classify data variables within the application itself, available through the use of geoprocessing capabilities within ArcGIS Online and ArcGIS Server, the user is limited to viewing only the previously established symbology. Furthermore, Esri does not support time enable-abled KML layers within the time series slider widget.

## 3.2 Project Partner Meetings

During phase two of the Sierra DSS project, two meetings with the USDA Forest Service were held to enhance collaboration and prepare for implementation and future partner handoff. The first meeting was held at the USDA Forest Service Offices in Vallejo in early February to discuss the project’s objectives, to address data storage and hosting concerns, and to focus the overall scope of the project to highlight water resources and wildfire in the region. In order to address the concerns from the first meeting, the team agreed to create a beta version of the Sierra-DSS Mapping Viewer as a prototype for review by the USDA Forest Service prior to implementing a full-scale DSS.

The second meeting was held at the DEVELOP offices at NASA Ames Research Center in early March to showcase the capabilities of the Beta Mapping Viewer and discuss the future version of the application. Website hosting of the Sierra-DSS was the main concern following the second meeting and will be the point of focus in future terms of the project.

# 4. Conclusions and Future Work

## 4.1 Conclusions

The second phase of the Sierra-DSS featured project partner meetings that successfully identified the need for a refined data focus and concerns about data hosting options. Further discussions with the USDA Forest Service indicated a need for a hydrologic and wildfire data focus that the team addressed in the beta Mapping Viewer (Figure 3). The team also addressed the data hosting concerns through a successful partnership with the OpenNEX project that provided access to the Amazon S3 cloud environment.  These successes further allowed the identification of future objective for the team to address during the third phase of the project.



Figure 3: Screen capture of the Beta Mapping Viewer zoomed in on the California Rim Fire (outlined in red). The screen capture highlights the Swipe Spotlight Widget (upper right), Enhanced Layer List Widget (lower right) and the Bookmark Widget (lower left), which are outlined in Appendix C.

## 4.2 Future Work

## 4.2.1 Mapping Viewer Improvements

Data shift, symbology, and time enablement limitations require the Mapping Viewer to utilize a single platform, ArcGIS. ArcGIS Online for Organizations, available for a yearly subscription fee, enables ArcGIS Desktop optimization and publication of both raster and vector data types as well as geoprocessing services to the cloud environment. These published geospatial data services can then be imported for use within ArcGIS Viewer for Flex widgets. Importing these services allow data layers to be queried within the Mapping Viewer, providing ‘on the fly’ analysis (data crunching in the cloud) and visualization of analysis results within the viewer/browser interface. ArcGIS Server is the second, more costly, management heavy solution that provides a locally hosted digital environment for data and geoprocessing services.

## 4.2.2 Report and Forecast Repository

In order to assist future decision-making, the Sierra-DSS will include supplemental information in the form of graphs and statistics. These products will be incorporated into the Report and Forecast Repository component of the DSS. Monthly statistical values (minimum, mean, maximum, and standard deviation) for climatic and surface variables within each of the 58 selectable watersheds will be available and summarized in a lookup table. These variables include historic and forecasted datasets pertaining to climatic, hydrologic, and vegetative health scenarios per watershed. Graphs will represent individual variables, and will aid users in understanding historic trends as well as their respective projected scenarios. Graphs will be standardized so that users can compare different datasets within this repository. The final DSS will include a more diverse array of datasets from BCM and satellite sensors than the current Beta version.

## 4.2.3 Geospatial Data Gateway

The Geospatial Data Gateway will allow users to download processed datasets that are included within the DSS. This will enable viewers to further explore and condition datasets through the use of a desktop GIS. The data gateway will provide information such as dataset descriptions, file formats, metadata, spatial and temporal resolutions, and a link for downloading. The download section will also allow users to download and select geospatial and remote sensing data by date and by HUC-8 watershed code. The ability of the Data Gateway to provide quick and easy access to important ecological, hydrological, and climatic variables within the Sierra Nevada will streamline future research in the region.

## 4.2.4 Solution Deployment

Future work and collaboration is needed to pinpoint and refine the functional requirements desired by the end user, the USDA Forest Service. Not only will this ensure a successful handoff of the DSS to the future hosting agency, but define the infrastructure requirements for the permanent home of the Sierra-DSS. As mentioned in section 4.2.1, there are several technological options for supporting geoprocessing and data storage that may be essential to the continued use of this tool. Continued collaboration and thorough communication is vital to the successful deployment of this decision support system.

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# Appendix A. Master Data List

Table 2: Datasets to be incorporated into the final version of the Sierra-DSS.

|  |  |  |  |
| --- | --- | --- | --- |
| **PROVIDER** | **DATA SET** | **TEMPORAL RESOLUTION** | **SPATIAL RESOLUTION** |
| CMIP-5 | Precipitation, Min & Max Temp | 2000 - 2090 | 800 m |
| BCM | Precipitation | Monthly average for 2010 - 2099 projections available. The current plan is to provide 30 year average per month - e.g. 30 year ave. for Jan. (2010 - 2039, 2040 - 2069, 2070 - 2099) | 270 m |
| BCM | Actual Evapotranspiration | 270 m |
| BCM | Runoff | 270 m |
| BCM | Snowmelt | 270 m |
| BCM | Soil Water Storage | 270 m |
| BCM | Precipitation | 270 m |
| BCM | AET | 270 m |
| BCM | Runoff | 270 m |
| BCM | Snowmelt | 270 m |
| BCM | Soil Water Storage | 270 m |
| LPJ | GPP, Fire, Insect Risk, NPP | 2010 - 2100 | 10 km |
| NLCD | Land Cover Types | 1990, 2001, 2006 | 30 m |
| PRISM | Max Temp, Min Temp, Total Precipitation | Jan 1981 - Mar 2013 | 4 km |
| NSIDC | SNODAS Snow Water Equivalent (SWE) | Oct 2003 - Jan 2014 | 1 km |
| CalFire | Wildfire Burn Perimeters | 1982 - Present | N/A |
| Calveg | Vegetation type  | 1982 - Present | N/A |
| LANDFIRE | Monitoring Trends in Burn Severity (MTBS) | 1982 - Present | 30 m |
| LANDFIRE | Biophysical Settings (BPS) | 1982 - Present | N/A |
| LANDFIRE | Fire Regime Groups | 2001, 2008 | N/A |
| LANDFIRE | Fuel Loading Models (FLM) | 2001, 2008 | N/A |
| LANDFIRE | Scott and Burgan Fire Behavior Models | 2001, 2008 | N/A |
| LANDFIRE | Anderson Fire Behavior Fuel Models | 2001, 2008 | N/A |
| LANDIFRE | Disturbance Data | 1999 - 2008 | 30 m |

*Table 2 continued.*

|  |  |  |  |
| --- | --- | --- | --- |
| LANDIFRE | Existing Vegetation Type (EVT) | 2001, 2008 | 30 m |
| LANDIFRE | Existing Vegetation Cover (EVC) | 2001, 2008 | 30 m |
| LANDIFRE | Canopy Height (CH) | 2001, 2008 | 30 m |
| LANDIFRE | Existing Vegetation Height (EVH) | 2001, 2008 | 30 m |
| LANDIFRE | Canopy Cover (CC) | 2001, 2008 | 30 m |
| MODIS | Gross Primary Production (GPP) | 2000 - 2012 | 1km  |
| MODIS | Leaf Area Index (LAI) | 2000 - 2013 | 1 km |
| MODIS | Fraction of Photosynthetically Active Radiation (FPAR) | 2000 - 2013 | 1 km |
| MODIS | Land Cover Data (LCD) | 2001 - 2009 | 500 m |
| MODIS | Land Surface Temperature (LST) | 2000 - 2012 | 1 km |
| MODIS | Normalized Difference Vegetation Index (NDVI) | Feb 2000 - Present | 250 m |
| MODIS | Enhanced Vegetation Index (EVI) | Feb 2000 - Present | 250 m |
| MODIS | Land Cover Dynamics (LCD) | 2000 - 2010 | 500 m |
| MODIS | Snow Cover | Feb 2000 - Present | 500 m |
| VIIRS NPP | Land Surface Temperature | 2012 - Present | 750 m |
| VIIRS NPP | Normalized Difference Vegetation Index (NDVI) | 2012 - Present | 500 m |
| AVHRR | Normalized Difference Vegetation Index (NDVI) | 1982 - 2000 | 1.1 km |
|  |  |  |  |

# Appendix B. Historic and Forecasted Data

## NLCD

National Land Cover Dataset (NLCD) is a land cover classification scheme designed by the Multi-Resolution Land Characteristics Consortium (MRLC), which is a group of federal agencies, including NASA and the USDA Forest Service (Homer et al., 2007). The 30 m resolution Landsat satellite datasets were used for calculating these classifications (Homer et al., 2007). NLCD datasets are only available for the years 1992, 2001, and 2006. These datasets were selected for the Sierra-DSS to characterize land surface types by thematic class (forest area, urban, etc.), percentage tree canopy cover, and percentage of impervious surfaces (Homer et al., 2007). This information enables users to assess the status and health of ecosystems, identify and understand spatial patterns in biodiversity, and visualize the effects of climate change (Homer et al., 2007).  NLCD datasets will also be used to help construct elevation profiles of mountainous regions in the Sierra Nevada.

## PRISM

Monthly maximum temperature (MaxT), minimum temperature (MinT), and total precipitation (TP) for the years 1982 to 2013 were obtained through Oregon State University’s Parameter-elevation Regressions on Independent Slopes Model (PRISM) website (PRISM Climate Group, 2013). PRISM is an analytical model that uses *in situ* point data and a digital elevation model (DEM) to generate gridded estimates of monthly and annual average daily maximum/minimum/dew point temperatures and annual average daily total precipitation. PRISM is well suited to regions with mountainous terrain because it incorporates a conceptual framework that addresses the spatial scale and pattern of temperature (PRISM, 2013). The data is available for download in an ASCII format that is ready for conversion to raster in ArcGIS and will serve as historic climatic information layers in the Sierra-DSS as well as historical inputs for climate models.

## SNODAS

The National Weather Service’s Snow Data Assimilation (SNODAS) model provides daily, gridded estimates of snow depth, snow water equivalent (SWE), and related snow parameters at a 1 km² scale (Clow et al., 2012). SNODAS includes procedures to use and downscale output from Numerical Weather Prediction (NWP) models; a physically based, spatially-distributed energy-and mass-balance snow model. Additionally, SNODAS assimilates satellite-derived, airborne, and ground-based observations of snow covered area and snow water equivalent (Barrett, 2003). SNODAS SWE data were obtained through the National Snow and Ice Data Center (NSIDC) website (NSIDC, 2013). To ensure a proper temporal resolution, weekly measurements were averaged into a monthly time step for January 2003 to December 2013. These datasets allow Sierra-DSS users to view historic SWE to help assess hydrological conditions in high elevation mountainous terrain, such as the Sierra Nevada.

## MTBS and CALFIRE

Monitoring Trends in Burn Severity (MTBS) is a project that provides burn severity and fire perimeter data nationally from 1984 to present. This information is determined by taking pre and post-fire Normalized Burn Ratios (NBR) to calculate differenced NBR using 30 m resolution Landsat imagery (NILS, 2013). This data was designed to serve four primary user groups (NILS, 2013). These groups include policy makers, field management units, existing databases (e.g. LANDFIRE), and academic and agency research entities, all of which benefit from an improved understanding of fire patterns on the landscape (Mckelvey and Busse, 1996). The development of a Sierra-DSS allows accessibility of this information to forest managers for enhanced risk assessment in the Sierra Nevada.

The California Department of Forestry and Fire Protection’s (CALFIRE) Fire Resource and Assessment Program (FRAP) maintains the most comprehensive, long-term database of fire polygons in California. It is also considered mostly complete for fires larger than 4 ha from 1950 to 2012 (Miller et al., 2009). The addition of this dataset provides a more comprehensive list of fires for the Sierra Nevada preceding 1984 when MTBS began collecting data.

## LANDFIRE Products

Landscape Fire and Resource Management Planning Tools (LANDFIRE), sponsored by the Department of the Interior(DOI), is a program that provides many geospatial data products, such as vegetation composition and structure, canopy fuel characteristics, and fire regime groups at the landscape level (Bastian, 2013). LANDFIRE data products are used extensively in fire modeling and land management analysis for strategic fire and vegetation management planning. LANDFIRE Vegetation, fuel, and disturbance products were downloaded and incorporated into the Sierra-DSS.

***LANDFIRE Vegetation data*** featured in the DSS includes a variety of historic vegetation products, such as Existing Vegetation Type (EVT), Existing Vegetation Height (EVH), Existing Vegetation Cover (EVC), and Biophysical Settings (BpS). The Existing Vegetation Type (EVT) layer represents the complexities of plant communities and species composition, where the EVH and EVC layers represent percent cover and average height of the dominant vegetation for a 30 meter grid cell and can mapped alongside LANDFIRE disturbance and fuel data to forecast future ecological conditions (LANDFIRE, 2001). The BpS data layer is a representation of dominant vegetation across landscapes prior to European settlement (LANDFIRE, 2001).

***LANDFIRE Fuel data*** featured in the DSS includes an array of data layers that describe the composition and characteristics of forested areas to support fire analysis and planning (LANDFIRE, 2001). LANDFIRE fuel products include Canopy Cover (CC), Canopy Height (CH), Fuel Loading Models (FLM), the 40 Scott and Burgan Fire Behavior Fuel Models (FBFM40), and the 13 Anderson Fire Behavior Fuel Models (FBFM13) (LANDFIRE, 2001).

Both Canopy Cover and Canopy Height are modeled datasets describing the composition and characteristics of live canopy fuel to understand fire behavior. The FLM, FBFM40, and FBFM13 datasets describe the characteristics and composition of the most common fuel types based on live and dead surface components (LANDFIRE, 2001).

***LANDFIRE Disturbance data*** included in the DSS provides temporal and spatial  information of landscape change in relation to vegetation transitions from 1999-2010. This dataset represent disturbance by type, year, and severity (LANDFIRE, 2001). Subsets of disturbance and fire data include; Fire Regime Groups, Fuel Loading Model, vegetation and fuel disturbance, and other related categories. Data from The Fire Regime Groups are intended to characterize historical regimes within landscapes based on interactions between vegetation dynamics, fire spread, fire effects, and spatial context (Anderson, 1982). The Fuel Loading Model classification system characterizes wildland surface fuel types into four groups, grasses, brush, timber, and slash, and provides a simple and consistent way for managers to describe the onsite fuel load (Anderson, 1982). LANDFIRE Disturbance data describe natural and unnatural disturbance regimes and based on the use of the landscape, can assist in the implementation of management strategies (Bastian, 2013).

## MODIS Land Products

The Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA’s Aqua and Terra satellites provides daily coverage of the Earth surface (NASA LP DAAC, 2001). MODIS acquires data in three spatial resolutions; 250 m, 500 m and 1000 m, and multiple temporal resolutions from daily to yearly observations (NASA LP DAAC, 2001). Datasets provided by MODIS such as Vegetation Indices (VI), Leaf Area Index (LAI), Fractional Photosynthetically Active Radiation (FPAR), Gross Primary Production (GPP), and Land Surface Temperature (LST) are used to better understand historic vegetation health.  Derived terrestrial products such as land cover, burned area, and fractional snow cover (Nemani et al., 2007) are also important information necessary for researchers and managers to analyze ecosystem processes and trends in the Sierra Nevada (NASA LP DAAC, 2001). These products are assigned a product number and were downloaded for 2000 to 2013 to be featured in the Mapping Viewer.

***MODIS Vegetation Indices (VI)* *(MOD13Q1)*** included in the Sierra-DSS are 16-day products at 250 m spatial resolution (NASA LP DAAC, 2001). MODIS vegetation indices produce two important ecosystem variables, Normalized Difference Vegetation Index (NDVI), and (EVI) Enhanced Vegetation Index. Both NDVI and EVI variables measure vegetation greenness or biomass by red and near infrared spectral bands (NASA LP DAAC, 2001). The reflection in the red (R) and infrared (IR) bands allows vegetation growth and density to be monitored using spectral reflectivity of solar radiation (ESRI, 1995).

***MODIS Leaf Area Index (LAI)*** and ***Fraction of Photosynthetically Active Radiation (FPAR)*** ***(MOD15A2)*** obtained for the Sierra-DSS are 8-day products at 1 km spatial resolution (NASA LP DAAC, 2001). The MODIS LAI dataset defines vegetation canopy as one-sided leaf area per unit ground area and FPAR measures the proportion of available radiation in photosynthetically active wavelengths that are absorbed by vegetation canopy (Myneni et al., 2003). Photosynthetically active radiation specifies the spectral range of solar radiation (from 400-700 nm) that photosynthetic organisms can use in the process of photosynthesis (Myneni et al., 2003). LAI and FPAR are important variables used to describe canopy structure and are essential in calculating terrestrial energy, carbon, and water cycle processes, such as NPP (NASA LP DAAC, 2001).

***MODIS Gross Primary Production (GPP)*** ***(MOD17A2)*** obtained for this project is the 8-day, 1 km spatial resolution product. The MODIS GPP product is designed to provide a reliable gauge of vegetation health by measuring kilograms of carbon dioxide per meters squared (kgCO2/m2) in an ecosystem (NASA LP DAAC, 2001). Including the MODIS GPP product in the Sierra-DSS will enhance the understanding of ecosystem production in the Sierra Nevada, which is a key component in measuring forest health (Wang et al., 2010).

***MODIS Land Surface Temperature (LST*) *(MOD11A2)***included in the Sierra-DSS are 8-day products at 1 km spatial resolution. MOD11A2 datasets are comprised of daytime and nighttime land surface temperatures (LSTs) emitted from land cover types and are represented as average temperature values in Kelvins (NASA LP DAAC, 2001). These values will be converted in to Celsius.

***MODIS Land Cover (MCD12Q1)*** products are yearly datasets at 500 m spatial resolution. MODIS Land Cover will provide the Sierra-DSS with a classification system featuring 17 classifications of land cover varying from vegetation type, developed land, snow, ice, and barren land (NASA LP DAAC, 2001). The land cover classification scheme utilized by MODIS is defined by the International Geosphere Biosphere Programme (IGBP) and is described by MODIS land cover type (NASA LP DAAC, 2001).

***MODIS Land Cover Dynamics (MCD12Q2)*** is a modelled dataset of yearly vegetation phenology at 500m spatial resolution. MODIS Land Cover Dynamics provides estimates of the timing and length of seasons, as well as information pertaining to vegetation growth, maturity, and end-of-life (NASA LP DAAC, 2001).

***MODIS Snow Cover (MOD10A2)*** products are 500 m gridded datasets containing snow cover, snow albedo, and fractional snow cover, which is an estimation of percent snow cover. The MODIS (MOD10A2) snow cover data is based on snow mapping algorithms that uses a Normalized Difference Snow Index (NDSI) and other tested criteria. It is the most current version available and therefore recommended for use in any form of research (Hall et al., 2006).

## Suomi National Polar-orbiting Partnership (NPP)

The recently launched 2011 Suomi NPP (National polar-orbiting partnership) NOAA/NASA mission improves climate and weather monitoring and forecasting, and is part of the Joint Polar Satellite System (JPSS). Several sensors are featured on Suomi NPP that are useful for monitoring climate and surface conditions within the Sierra Nevada.

***CrIS (Cross-Track Infrared Sounder)*** is a Fourier Transform Spectrometer with 1305 spectral channels, and produces high-resolution temperature, pressure, and moisture profiles (Tobin et al., 2013). It has 14 km nadir spatial resolution and three wavelength ranges. CrIs is an extension of the climate variation data provided by NASA’s 2002 Atmospheric Infrared Sounder (AIRS) on the Aqua satellite. Carbon dioxide and monoxide, ozone, methane, storm prediction, and future weather conditions are available datasets from CrIS. This sensor can observe cloud properties and has cloud-penetrating capabilities.  The Sierra-DSS utilizes the CrIMSS data for brightness temperature, water vapor, and cloud data to better inform forest managers regarding the effects of climate change on hydrologic and vegetative components of the Sierra Nevada.

***ATMs (Advanced Technology Microwave Sounder)*** is a 22-channel cross-track scanner that improves upon the 1998 Advanced Microwave Sounding Unit (AMSU) NOAA sensor. When paired with the CrIS on the Suomi NPP satellite, they become the Cross-track Infrared and Microwave Sounder Suite (CrIMSS). These coupled sensors provide atmospheric temperature and moisture data, which are useful in assessing the onset and potential impact of climatic events such as tropical cyclones, hurricanes, and other heavy precipitation events (Weng et al., 2012). For the purposes of the DSS, ATMs provides precipitation, temperature, atmospheric moisture and water vapor, and could cover data that can be used in climate forecasting.

***VIIRS (Visible Infrared Imaging Radiometer Suite)*** is a scanning radiometer on Soumi NPP that provides data for ocean, land, and cloud science. VIRS measures land surface properties such as surface albedo, land surface temperature, evapotranspiration, vegetation dynamics, land cover change, and snowpack and ice extent. VIRS also provides cloud cover and aerosol data. This sensor improves upon existing atmospheric and Earth-observing sensors due to its extended coverage over the MODIS and SeaWiFS sensors. VIIRS also features higher spatial resolution for cloud products over AVHRR, HIRS, MODIS, and AIRS at 750 m resolution. This DSS will use VIIRS evapotranspiration data, vegetation index values, leaf water content, leaf area index, vegetation disturbance, and fire extent and severity data.

## AVHRR NDVI

Historical NDVI data is acquired using the Advanced Very High Resolution Radiometer (AVHRR) instrument in the National Oceanic and Atmospheric Administration (NOAA) family of polar orbiting platforms (Tucker et al., 2004). AVHRR NDVI data covers a time span of over of 25 years, ranging from 1982 to 2000 (Zhao et al., 2012), whereas MODIS NDVI products are current datasets ranging from 2000–2013. AVHRR NDVI in combination with MODIS NDVI allows users to visualize over 30 years of vegetation change.

# Appendix C. Widgets

Table 3: Widgets to be considered for the final version of the Sierra-DSS.

|  |  |
| --- | --- |
| **Widget Name** | **Widget Description** |
| Attribute Table | Displays a tabular view of a feature layer's attributes |
| Header Controller | The top "banner" for quick access to widgets, also includes search functionality |
| Mapswitcher | Easily switches between two or more base maps |
| Splash | Enables a splash screen to appear when the Viewer application is first opened |
| Static Image | Enables a static image (for example, a logo) |
| Layer List | Displays the operational data in the Viewer application |
| Legend | Displays a legend for the user-chosen layers  |
| Print | Advanced or simple printing of the current map |
| Chart | Display charts for selected features |
| Data Extract | Extracts data (export) |
| Geoprocessing | This tool allows users to complete any geoprocessing task, and may reqire ArcSERVER. |
| GeoRSS | Creates layers based on a GeoRSS feed (Fire Feed) |
| Search | Allows users to select a clickable feature to display on the map |
| Time (Slider) | Enables time animation of time-aware layers |
| Draw | Quick drawing (i.e., redlining) |
| Bookmark | Spatial bookmarks for quick navigation (use cases, ie: Rim Fire) |
| Enhanced Layer List | Extended layer menu that contains collapse all, expand all, zoom to make visible, and changed behavior on the description option. The enhanced version also supports legends for CSVLayer and GeoRSSLayers as well a default legends for basemap rasters, annotation, and raster catalogs. |
| Enhanced Search | Allows users to open a datagrid from the Search Widget that has its own specified fields that are independent of the fields that are specified for the Search Widget. |
| Enhanced Time Slider | Use more than one time enabled layer in the widget |
| Enhanced Draw | Enhanced version of the standard ESRI Draw widget that add several new features and fixes on significant issue with original. |
| Enhanced Splash | A splash screen that requires the user to accept or decline a usage agreement and have other buttons that allow of various other links to be displayed. |
| Enhanced Bookmark | Allows users to add comments to bookmarks and save and/ or share their bookmarks with other users of the Enhanced Bookmark Widget |

*Table 3 continued.*

|  |  |
| --- | --- |
| **Widget Name** | **Widget Description** |
| Enhanced TOC/Legend | A widget with both TOC and legend for FlexViewer |
| Swipe Spotlight | Allows users to compare two layers side-by-side, by selectively masking the top-most of the two layers & allows users to see through a circular "cut out" of one map layer onto any layers below. |
| Measure | Displays segment measurements as they are being drawn |
| Link List | Drop down of links to other sites and document |
| Basemap Fader | Slide/fade between two basemap styles. Example:50% Topo, 50% Terrain w/Labels (Basemaps) |
| Basemap Style Effect | Change basemap (background) to grey, desaturated or blank with button selection. Allows data viewing without basemap. |
| Export Map (img) | Exports a screen shot of the map as a jpg to user specified location on local computer. Enables quick/simple reference documentation. |
| Save to PDF | Illustrates how users can create a widget for the ArcGIS Viewer for Flex to add basic 'ExportToPDF' functionality into web applications with ArcPy.Mapping. |
| Import Data File | Allows users to upload a .xls or csv file into the flex viewer |
| Coordinate Menu | (c/p xy, project xy(config), go to xy location) |
| US National Grid | National Grid/Military Grid Reference System layer with graticule for a WGS84 Geographic based map. |
| MGRS Coordinate Panel | Displays a coordinate panel along the bottom of the application that shows Map Coordinates, MGRS and Scale. Check boxes to turn on/off MGRS and Graticule Grid. Zoom to MGRS Function. |
| Viewer State Manager | Sets a default layout of all wigets/tools of the viewer for a common operating picture (COP). |
| Flicker Photo Viewer | Connects to Flicker Database, search for California fauna and flora geolocated images already on the net, plots them on the map/click/viewable. |
| WMS Radar Layer | Imports live feed of current radar reflectance (precipitation) |
| Elevation Profile | **May require ArcServer.** Generates and displays an elevation profile chart for a line on the map. |
| Thematic | **May Require ArcServer.** Allow users to dynamically generate symbology from an ArcGIS service and use that symbology with a dynamic map service to create a thematic layer. |