The PRISM Climate and Weather System – An Introduction

Christopher Daly and Kirk Bryant (June 2013)

Weather and climate are arguably the most powerful drivers of both agricultural and natural systems, and have profound effects on how our society functions. Weather is what we experience day to day, while climate is a longer-term summary of expected weather conditions. In other words, climate is what you expect, and weather is what you get. Both are important in determining what crops can be grown successfully, what plants will thrive in your garden, how roads and buildings are constructed, and even the clothes you wear.

With the advent of computer-based geographic information systems (GIS), global positioning systems, and remote sensing technologies that help us describe and visualize the earth's surface, many planning and decision-making activities have gone spatial. A wide variety of agricultural, hydrologic, ecological, natural resource, and economic decision support tools are now linked to these technologies in new and exciting ways.

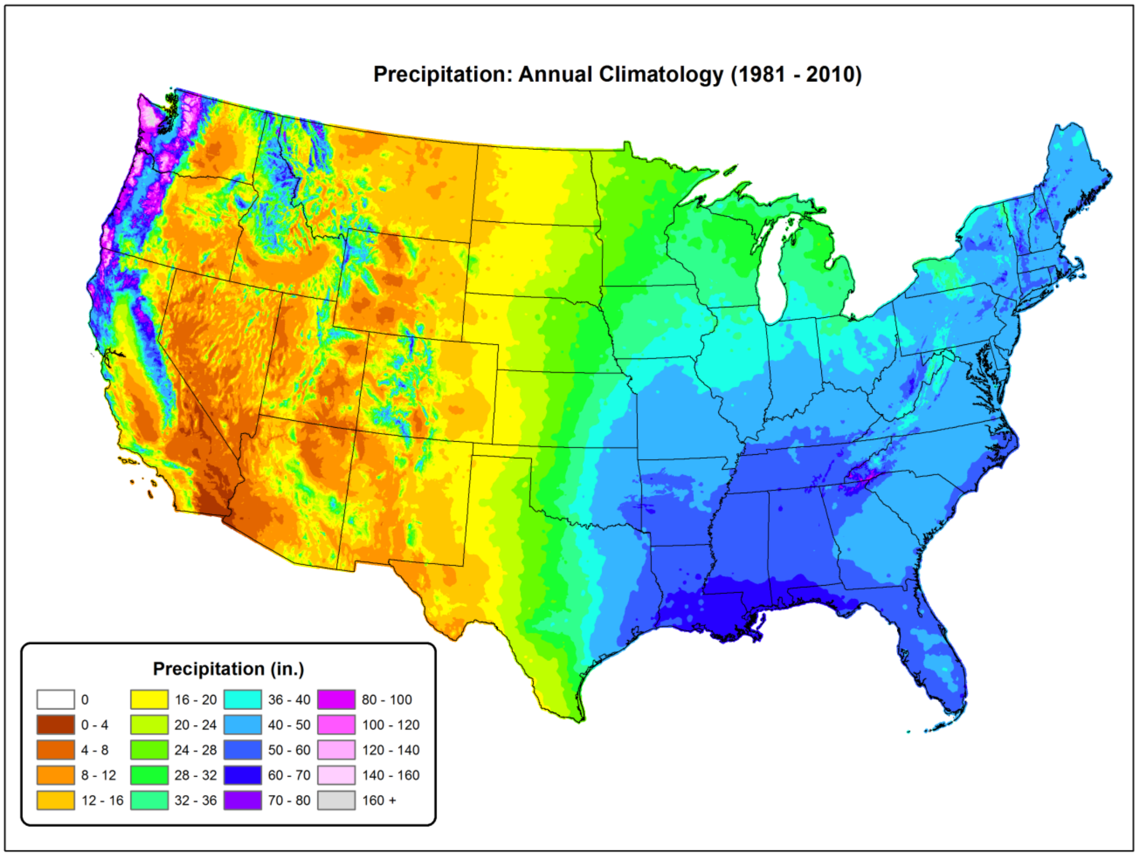
Spatial decision support tools have an insatiable thirst for spatial data sets. Spatial weather and climate data, usually in the form of continuous grids of pixels, are often key inputs to these tools, and form the basis for scientific conclusions, management decisions, and other important outcomes. These grids typically describe minimum and maximum temperature and precipitation over a monthly or daily time step, and are especially useful because they provide wall-to-wall estimates of climate conditions, even where no weather stations exist.

The most widely used spatial climate data sets in the United States are those developed by Oregon State University's PRISM Climate Group, named for the PRISM climate mapping system. PRISM products are the official spatial climate data sets of the USDA, and are used by thousands of agencies, universities, and companies worldwide. Now, PRISM is being put to work to improve the efficiency and integrity of the US crop insurance program. In this article, we introduce you to the history of climate mapping, how the PRISM weather and climate mapping system was developed, and how it works.

A Little History

Beginning in the early 20th century, official, 30-year average climate maps within the US (most done by state), were created by expert climatologists with pen and paper. Observations from weather stations were plotted on a map, and generalized contours of temperature and precipitation drawn between the stations, based on the subjective opinion of the analyst. The process was tedious and time-consuming. It is not surprising that these maps were updated infrequently throughout the 20th century.

By the early 1990s, the most recent official precipitation maps for many states were thirty years out of date. GIS was gaining rapid acceptance, and the demand for digital climate maps was growing rapidly. Computerized statistical algorithms that interpolate values between point observations had become available, but these were generalized functions that were "climate challenged." They produced unrealistic maps because they lacked information on how the physiographic features of the earth's surface (such as mountains and coastlines) affected climatic patterns. In other words, there was a wide divide between what we knew about climate patterns and what computerized tools could produce. The timing was right for a new method of creating climate maps that would bring some intelligence to the process.



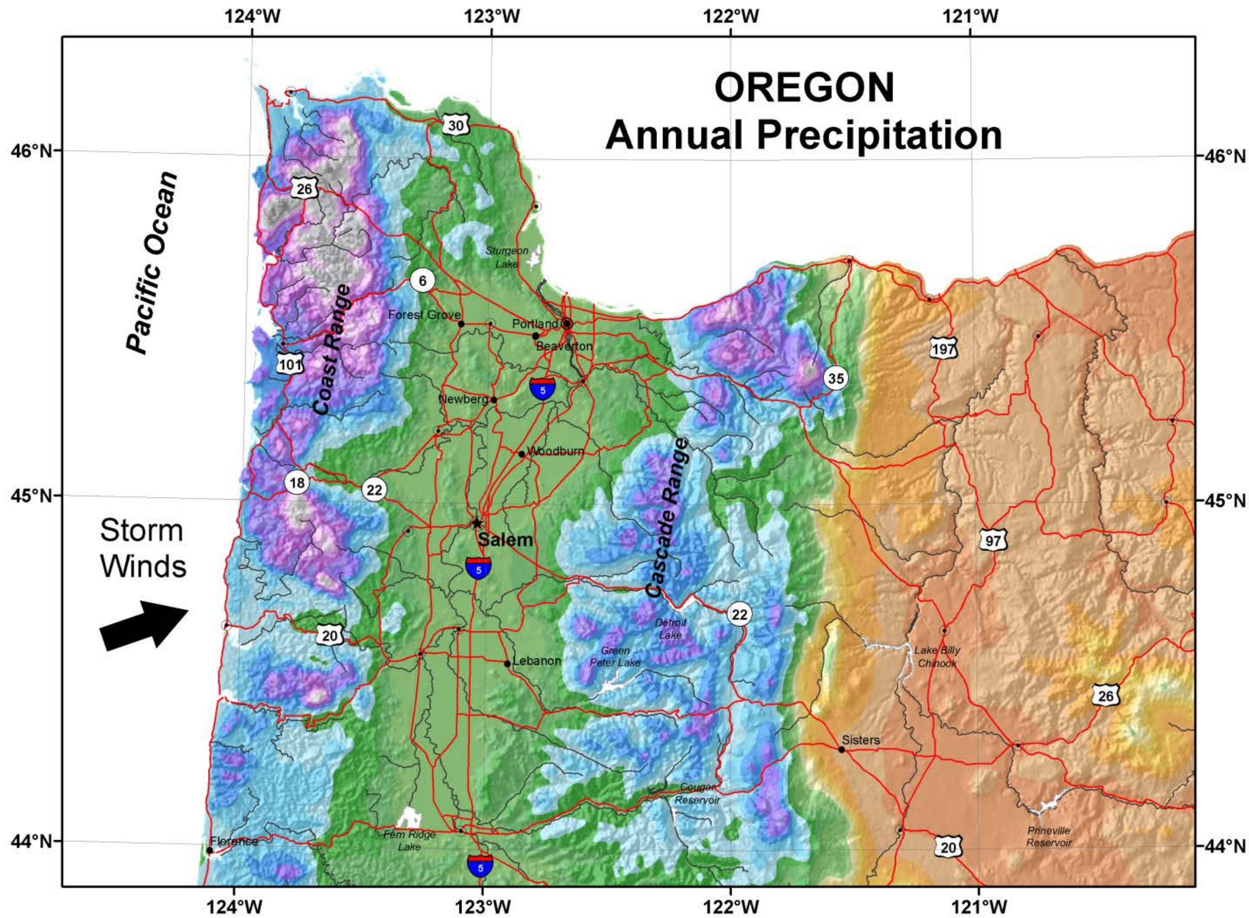
PRISM map of mean annual precipitation, averaged over the years 1981-2010. Thirty years is considered the standard averaging period for describing the long-term climate of a region. The period typically moves forward once per decade (the next official period will be 1991-2020). This map is made up of over 20 million grid cells, each about ½-mile on a side.

The Advent of PRISM

A new approach to computerized climate mapping was first developed by Chris Daly in 1991 when he was a Ph.D. student at Oregon State University. The algorithm was written to mimic the thought process an expert climatologist goes through while drawing a climate map. This kind of a program is called an "expert system" in computer science circles.

Precipitation was the most difficult variable map, so he started there. He knew that elevation was the main determinant of precipitation patterns. In fact, many hand-drawn maps were sketched onto topographic maps, because the contours of elevation and precipitation had such similar patterns. The initial program he developed "visited" each pixel on an elevation grid and developed a local statistical relationship for that pixel, called a regression function, between precipitation and elevation, using data from stations in the immediate vicinity. The regression function was used to predict precipitation at the elevation of the pixel.

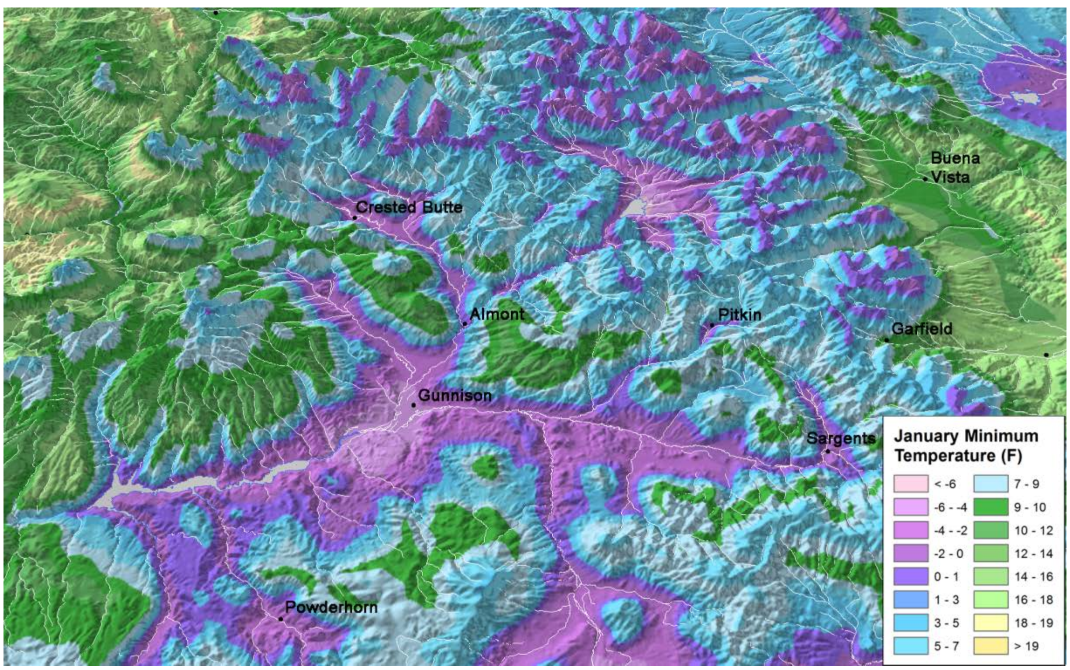
It turned out that the relationship between precipitation and elevation varied a lot across the landscape, sometimes quite sharply, as in the case of rain shadows. An algorithm was written to automatically divide the terrain into "topographic facets" with several slope orientation categories (hill slopes facing W, NW, N, NE, etc.). Available weather stations were grouped onto these facets, and the precipitation-elevation regression function calculated for stations on each facet separately. In this way, his model did not mix stations on windward and leeward slopes of mountain ranges, which, even at the same elevation, had very different precipitation amounts. Little by little, other enhancements were made, until the program could recognize and troubleshoot problems as they arose, like an expert climatologist might do. This expert system was called PRISM (Parameter-elevation Regressions on Independent Slopes Model).



Close up of a PRISM mean annual precipitation map for northwestern Oregon. Cool colors denote wet regions and warm colors denote dry regions. The Coast Range and Cascade Range both act to increase precipitation on their windward slopes, effectively 'wringing out" moisture moving inland off the Pacific Ocean, and leaving relatively little on their leeward slopes. East of the Cascades, only about 10 percent of the original moisture is left.

Shortly after the development of the initial version of PRISM, the USDA Natural Resources Conservation Service (NRCS) became interested in this work, because they were implementing GIS in their field offices and had a great need for updated, digital, precipitation maps. The NRCS offered to provide funding for the development of proof-of-concept PRISM precipitation maps for Oregon, Idaho, Nevada, and Utah. These were some of the most complex states to map, with snowy mountains, alkali deserts, and everything in-between. The State Climatologists from these states were asked to scrutinized the results, compare them with their own hand-drawn maps, and offer suggestions for improvements. At the end of two years of scrutiny, criticism, and re-dos, they finally agreed that PRISM had produced precipitation maps that equaled or exceeded the quality of their own maps. This led to a multi-year NRCS program to map 1961-90 averages of both temperature and precipitation over all of the lower 48 states. Daly began to collect a team of talented scientists and programmers around him, which would become the PRISM Climate Group. The success of the NRCS project opened the door to many other climate mapping projects, some outside the US, including Canada, China, Mongolia, Taiwan, SE Asia, and Europe. Funding came from a wide variety of sources, including many agencies within the USDA and NOAA, NASA, NPS, USFS, USEPA, NSF, The Nature Conservancy, and others. These analyses and data sets underwent an unprecedented level of peer review, sometimes involving dozens of reviewers. Each map product represented the state of the science for that area.

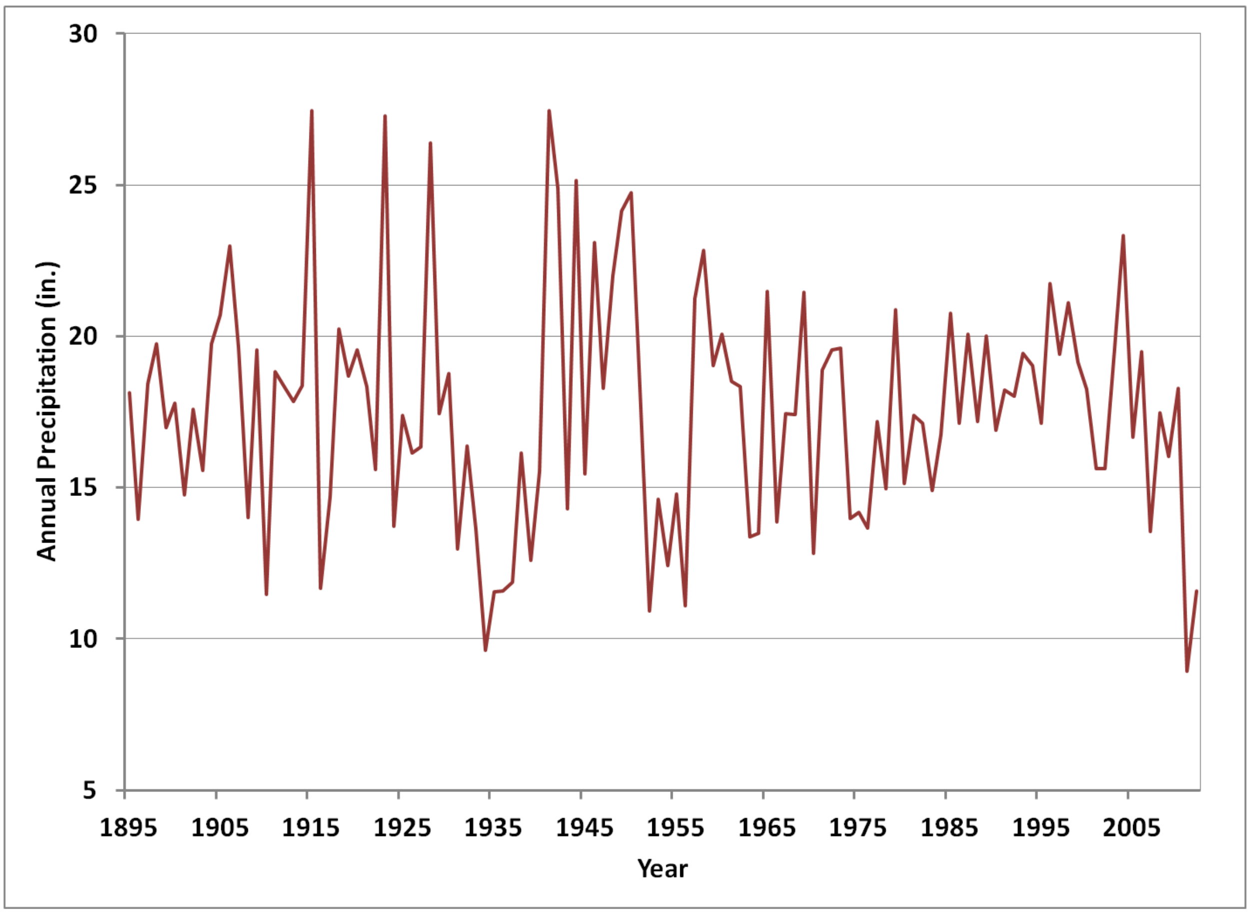
In the years since its inception, PRISM has undergone nearly constant development, and is now a large, mature model. Some things have remained essentially the same; PRISM still adopts the assumption that for a localized region, elevation is the most important factor in the distribution of climate variables. PRISM still calculates a local climate-elevation relationship for each grid cell, whether it be for precipitation, temperature, dew point, or other variables, and uses nearby station data to populate the regression function. What has changed is that when PRISM does its climate-elevation regression calculations, it now weights the station data points to control for the effects of a wide variety of physiographic variables. In addition to topographic facets, PRISM now has station weighting functions that account for proximity to coastlines, the location of temperature inversions and cold air pools, and several measures of terrain complexity.



Oblique view (looking from south to north) of PRISM January 1971-2000 mean minimum temperature in the Gunnison, Colorado area. Complex relationships between elevation and temperature are due to cold air pooling in valley bottoms (purple colors) and warmer "banana belts" at mid-slope locations above the cold air pools (green and yellow colors). Temperatures become colder again on the highest peaks.

Time Series Mapping and the Climate Fingerprint

So far, we have been learning about how PRISM creates long-term climate maps, such as mean monthly and annual precipitation over a thirty-year period (for example, 1961-1990, 1971-2000, etc.). But there is more to climate than long-term averages. Users wanted to know: how variable is the climate? When were the droughts and heat waves and how severe were they? The next logical step was to create a time series of grids where each grid represented one month in one year, not a 30-year average month. PRISM's first foray into time series mapping was supported by NOAA in the late 1990s, and was quite ambitious: create a 100-year time series of monthly grids, starting in 1895. The problem was that there were few weather stations in 1895, and it was unlikely a map for 1895 would have the same accuracy and detail as one produced using data from, say, 1995. This eventually led to a new interpolation technique that did not rely directly on elevation, but instead relied on what is termed the "climate fingerprint." The idea behind the climate fingerprint is that patterns in climate caused by the earth's physiography tend to be repeatable over time. For example, a location that is in a rain shadow today most likely behaved in a similar way 100 years ago. To implement climate fingerprint interpolation, the elevation grid normally used in the PRISM regression calculations was replaced with long-term climate maps, e.g., 1971-2000 averages, which already had the effects of physiographic features built in. The method allowed the creation of climate maps of similar detail, no matter what the year or density of weather stations, because the long-term climate patterns took over where there were no stations.



PRISM one-hundred eighteen-year time series of annual precipitation for a grid cell in Texas County, western Oklahoma, derived from PRISM time series grids for the conterminous United States. Multi-year droughts in the 1930s, 1950s, and 2011-2012 are clearly visible.