4.3 HIGH RESOLUTION 1971-2000 MEAN MONTHLY TEMPERATURE MAPS FOR THE WESTERN UNITED STATES

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1. INTRODUCTION

An effort to update the PRISM 1961-1990 mean monthly temperature maps for the United States to the 1971-2000 period is now underway. The maximum and minimum temperature maps for the western United States presented here reflect several major improvements over the previous version: improved terrain grid resolution, additional surface observations, adjustments for short-term climate stations, a high-resolution coastal trajectory model, and numerous improvements to the PRISM modeling system. These high-resolution temperature maps capture features including coastal effects, elevational influences, temperature inversions, and others.

2. BACKGROUND

In 1998 the first high-resolution climate maps were produced over the conterminous US (Daly and Johnson 1999) using the Parameter-elevation Regressions on Independent Slopes Model (PRISM), developed at OSU (Daly et al., 1994, 2002). The PRISM model was run at a 2.5 arc-minute resolution resulting in grids with a resolution of about 4 km. At the time, this represented a leap forward in climate mapping technology and these maps became the standard for nationwide climate datasets and were used in the NCDC Climate Atlas.

While 4-km datasets were very useful on a nationwide scale, it became readily apparent that the data were coarse at a small-county scale. Because each grid cell represented about 16 km^2, there were many areas where fine-scale terrain features simply could not be identified. As computer power, DEM resolution, and knowledge of the climate modeling system has increased significantly over the past eight years, the ability to create even higher resolution datasets has now become a practical reality. Also, as the use of PRISM data has become more widespread, the demand for higher resolution datasets has increased.

3. DISCUSSION

The general method to create climate datasets using the PRISM system is well documented in detail in other papers (Daly et al. 1994, 2002). The scope of this paper is to briefly discuss the improvements to the data that were implemented for this 0.8-km modeling effort and to demonstrate how effective this high-resolution dataset is at capturing fine-scale, terrain-dependent temperature features. The modeled region covered the US westward from approximately 101° W including 11 western states and a portion of the central US (Figure 1). For surface climate data, we gathered 30 years (1971-2000) of daily maximum and minimum temperature data summarized by month for over 4,200 climate stations from three different data collection networks: COOP[1], RAWS[2], and SNOTEL[3]. These monthly data were then summarized to produce 30-year normals for each station.

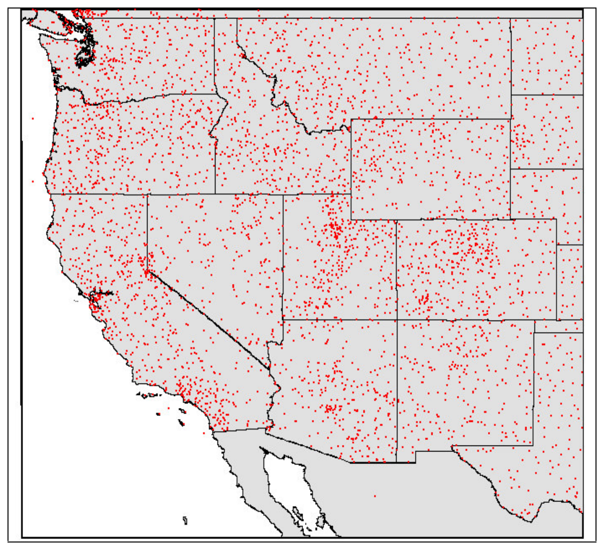

Figure 1. Region modeled by the PRISM system. Red dots show locations of 1971-2000 climate stations used.

3.1. Surface data improvements

Surface station data is a critical piece to an accurate representation of climate at high resolutions. Generally, the higher the data density, the better the data set. In the previous PRISM maps, 3,040 COOP, SNOTEL, and some RAWS station data were the main components that went into the model. Since then, an additional 1,200 sites have become available, including about 500 more RAWS stations. In all, over 4,200 stations were used to model the domain, a 42% increase over the 1961-1990 normals. COOP data represents mainly the

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[1] NCDC TD3220 monthly summary COOP data
[2] Western Regional Climate Center (WRCC), http://www.wrcc.dri.edu
[3] National Resources Conservation Service (NRCS), http://www.wcc.nrcs.usda.gov

lower-elevation sites that are in populated areas. SNOTEL sites are placed in remote mountainous locations that represent higher-elevation terrain. In-between are the RAWS site, which are located generally in rural, mid-elevations. RAWS data provide an important addition to the other data networks. Previously, only about 250 RAWS sites were used for PRISM modeling. The 1971-2000 modeling effort now includes over 650 RAWS sites, a 160% increase in representation of the mid-elevation climate.

In addition to more data, better metadata were available for accurately placing the available stations at the correct location. Many sites have been "relocated" using very-accurate GPS guidance. Having accurate site positions is critical to determining correct elevation regression relationships.

Finally, the data were passed through a very rigorous QC process ensuring only the best data were used by PRISM.

Before the modeling effort could even begin, issues with these surface climatological data had to be addressed. One adjustment that was made was to correct for short-term biases in stations that had less than a complete period of record (POR). The POR used in the model was the 30 years from 1971 to 2000. Many of the surface data had a POR with fewer years. Most RAWS data are only available from about 1984 and SNOTEL data are only available after 1981. In order to remove any biases from these short-POR sites, these data were adjusted to an approximate 30-year normal by using nearby stations that did have a full POR. First, a PRISM pre-processor was run to produce a list of the three highest weighted stations[4] for each short-POR station. These "anchor" stations were then used to

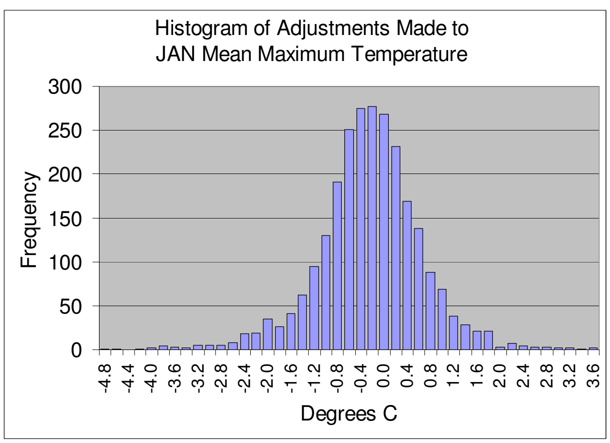


Figure 2. Histogram of adjustments made to the January mean maximum temperature observed by short-term POR stations.

compute the difference between the long-term mean and the short-POR mean. This difference was then applied to the short-term station's data so that it better reflected a true 30-year normal. Short-POR stations had to have a minimum of two years of data to be used in the model and qualify for this adjustment. Figure 2 shows an example of the magnitude of these adjustments applied to the short-term POR stations for January mean minimum temperature. It shows a near-normal distribution with a mean adjustment of -0.3 C and a standard deviation of 0.9 C. Adjustments were as low as -4.8 C and as high as 3.5 C.

In order to validate this adjustment methodology, we first experimented with stations that had a complete POR where the true 30-year mean was known. These complete stations were simulated as short-term sites by using a reduced 5, 11, and 21 years of data to compute a short-POR mean. The adjustment was calculated using between 1 and 5 anchor stations and was applied to each of the short-POR means. By applying this adjustment, we arrived at an adjusted 30-year mean. This adjusted mean was then compared with the known (true) 30-year mean to produce a departure value that represents how effective the adjustment process was at reproducing the true 30-year mean.

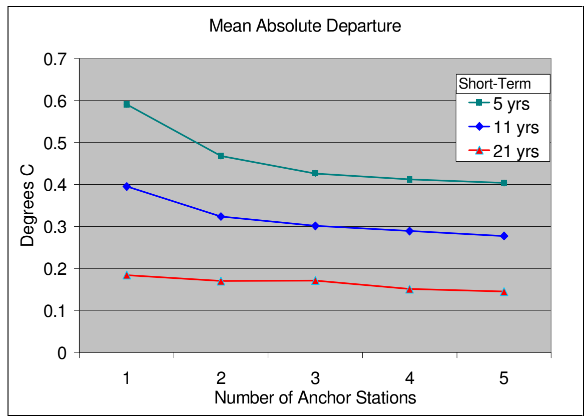


Figure 3. Mean departure of the adjusted mean July maximum temperature from the known 30-year mean vs. number of anchor stations used to compute the adjusted mean. Three different cases were tested using a short-term POR of 5, 11, and 21 years.

Figure 3 shows how the mean absolute departure of July maximum temperature varies as the number of anchor stations used increases. Separate lines indicate the effect of POR on the adjustment. The departure increases with fewer anchor stations and shorter PORs. As the number of anchor stations used in the adjustment increases, the departure from the true mean decreases, but essentially levels off at about 3 anchor sites. There were some instances, however, that using more than 3 anchor sites actually caused the departures to increase. Because of this and since very little change occurs between using 3 and 5 anchor stations, it was decided to use 3 anchor sites to compute the POR adjustment for all short-term stations.

One example of adding addition station data, in this case RAWS sites, is found in the mean July minimum temperature map over the coastal mountains about 160 km north of the San Francisco Bay area. Figure 4 compares the 4-km with the 0.8-km PRISM model results for this analysis. One feature that is readily

[4] Only stations with more than 23 years of data were used as anchor stations for computing the adjustment.

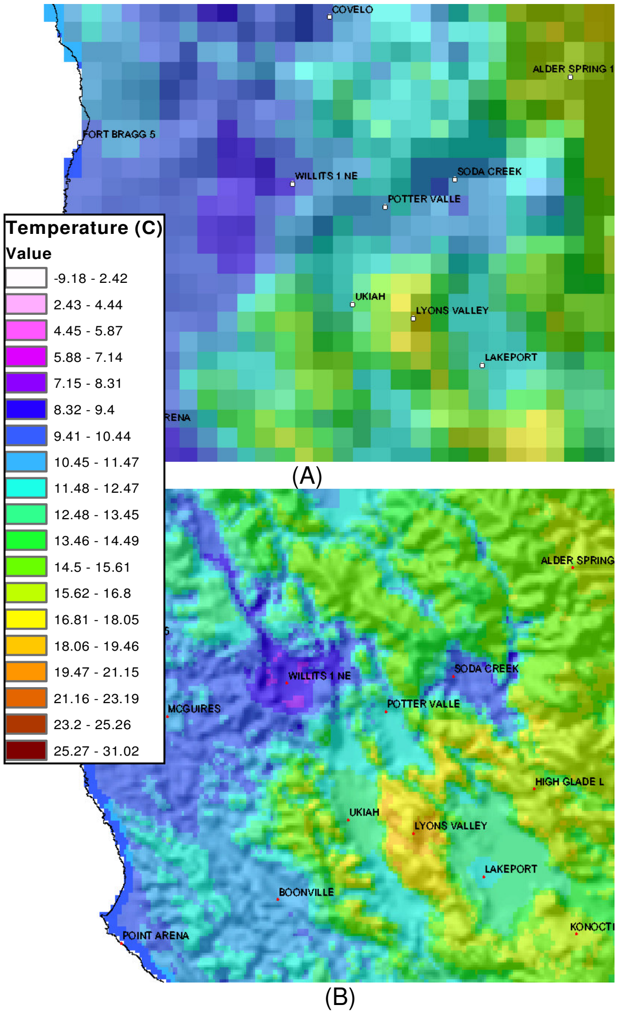


Figure 4. July mean minimum temperature. Region depicted is over northern California about 160 km north of San Francisco. (A) is the 1961-90 4-km map and (B) is the new 1971-2000 0.8-km map. Surface stations used in the maps are labeled.

apparent at the higher resolution is the presence of a temperature inversion. Many of the low-lying areas experience a “pooling” of cooler minimum temperature as cool air drains from the surrounding higher terrain while the higher hills and ridge-tops remain above this temperature inversion. While the previous 4-km data did show some evidence of this inversion, there are many features that were missed both due to resolution issues and a lack of some RAWS data. These features are very apparent in the newest PRISM output.

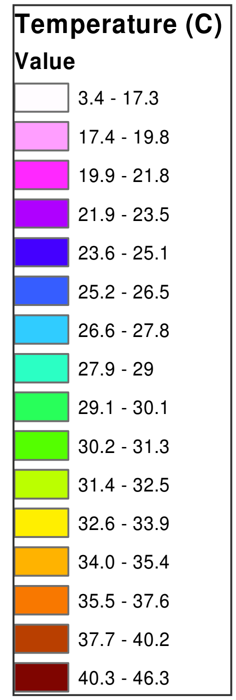
The new, high-resolution, data set allows for the effective use of 3D visualization tools to render these maps. Using 3D visualization is useful and instructive for clarifying the effects of the terrain on temperature. Figure 8 shows what this area looks like when viewed from the southeast looking northwest towards the ocean on the horizon. Near the center foreground of the image it is evident that the cold air drains into the mountain valleys (blues/greens) while the ridge tops above the inversion have a warmer temperature (yellows/orange).

3.2. Resolution Improvements

The greatest fundamental improvement to the temperature maps was the use of a high-resolution DEM. It is the terrain that forms the basis for nearly all decisions made by the model. The terrain data used was GTOPO30, a global, 30 arc-second DEM.

In the rugged terrain of the mountainous western US, there are many features that simply cannot be captured at 4-km resolution. An example of capturing dramatic differences in temperature and terrain is found in the map of July Mean Minimum temperatures in the Grand Canyon area of northern Arizona (Figure 5). At 4-km resolution, while the main canyon is discernable, there are some areas where it becomes indistinct and discontinuous. The 0.8-km data, however, show clearly the fine details, not only of the main canyon itself, but also of numerous tributary canyons.

Another example is the Bitterroot Mountains bordering Idaho and Montana. In this region the mountains are oriented North-South with



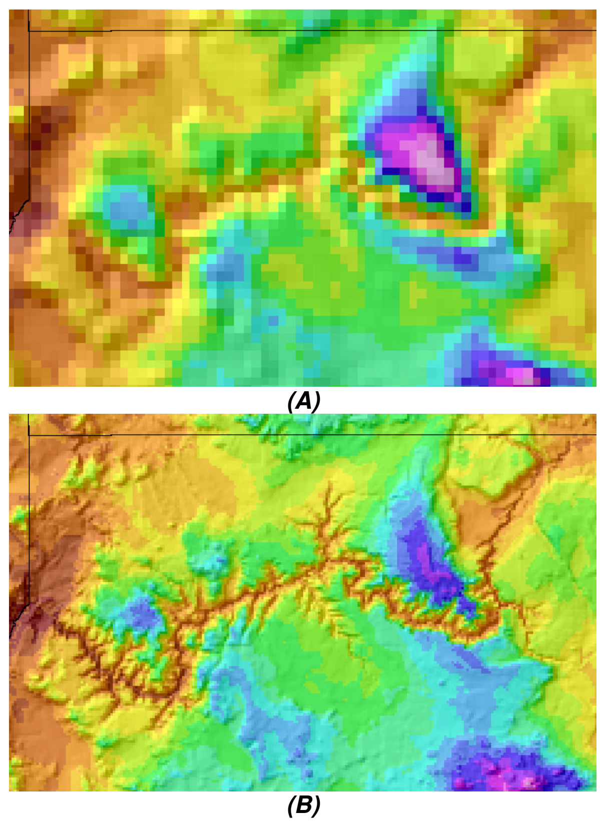
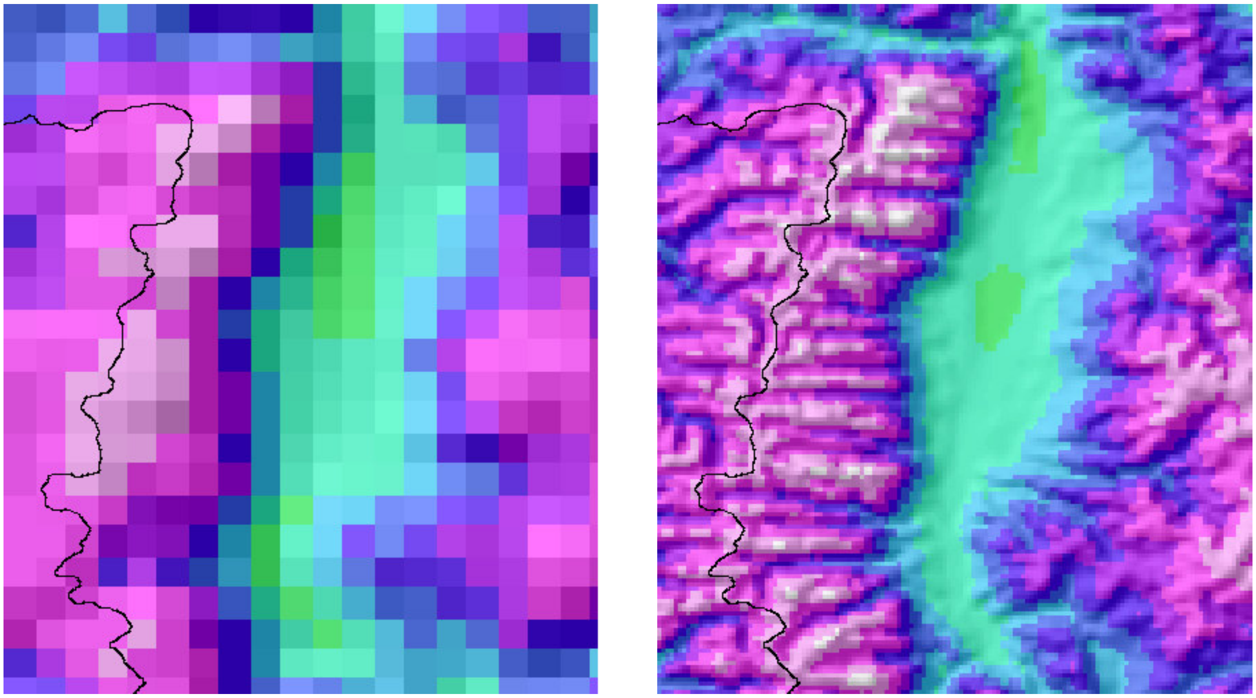


Figure 5. Mean July Minimum Temperature, Grand Canyon, AZ. (A) is the 1961-90 4-km resolution grid. (B) is the 1971-2000 0.8-km resolution grid.



(A) (B)

Figure 6. July Mean Maximum temperature at the Bitterroot Mountains along the Idaho/Montana border. (A) is the 1961-90 4-km resolution grid, (B) is the 1971-2000 0.8-km resolution grid.

numerous deep canyon valleys extending eastward into the Bitterroot River valley. These deep valleys are about 1000 meters deep and only about 2 km or less across. This degree of complexity could not be captured in the previous PRISM dataset (Figure 6a.). However, in the new 0.8-km data, the ridge-valley couplets are clearly visible in the July maximum temperature map shown in Figure 6b. The colder ridge tops stand out in strong contrast to the warmer valley bottoms. This dendritic pattern of colder temperatures appears very similar to those patterns seen in the 1-km GOES 10 visible satellite imagery over snow-covered mountains.

3.3. Coastal Trajectory Model

The PRISM model is very accurate in depicting the effects of coastal proximity on the climate. One of the reasons it is so successful is the use of a coastal proximity grid, which assigns each grid cell in the domain with a value representing the "proximity" of that pixel to the coast. This proximity value is calculated by running an advection model that traces the path an air parcel would have to follow to move from the coast to reach the given pixel (Daly, 2003). The proximity value is the result of a cost-benefit analysis that balances the cost in momentum of an air parcel traveling over terrain features to reach a pixel with the cost in air mass modification by taking a longer, but flatter path around a terrain obstacle to the pixel.

An example of the effects of coastal proximity modeling is shown in Figure 7, which is a map of July mean maximum temperature over the San Francisco Bay and Monterey Bay areas in central California. The coastal areas experience much cooler high temperatures than inland areas or the higher terrain of the coastal foothills above the marine layer. Also note that while some grid cells may be physically distant from the coast, their climate is still modified by the coastal effects because of gaps in the mountains, which would otherwise block the effects of the maritime climate. In addition, some grid cells which are near to the coast, because they are elevated or surrounded by mountains, the coastal influence is essentially blocked and the sheltered grid cell experiences a warmer climate. While the older 4-km data showed similar features on a macro-scale, it could not resolve the finer details of narrow ridge tops or steep valleys. The greater resolution of the 0.8-km coastal proximity grid allowed a much finer analysis of these complex land-ocean temperature gradients.

4. CONCLUSIONS

It is clear that the step up to 0.8-km resolution has resulted in a dramatic improvement in the mapping of temperature climate in the western US. In addition to higher resolution DEM, RAWS stations were used to help fill in middle-elevation areas. Adjustments were made to short-term POR stations so that the data better reflected a 30-year normal.. Examples were shown of how coastal effects, elevation differences, and smallscale features were all more accurately depicted by the PRISM model. Besides creating very detailed climate maps, these data are also being used as the predictor grids for PRISM in a new probabilistic spatial quality control system being developed for USDA-NRCS Snotel observations (Daly et al. 2004, Gibson et al. 2004).

5. REFERENCES

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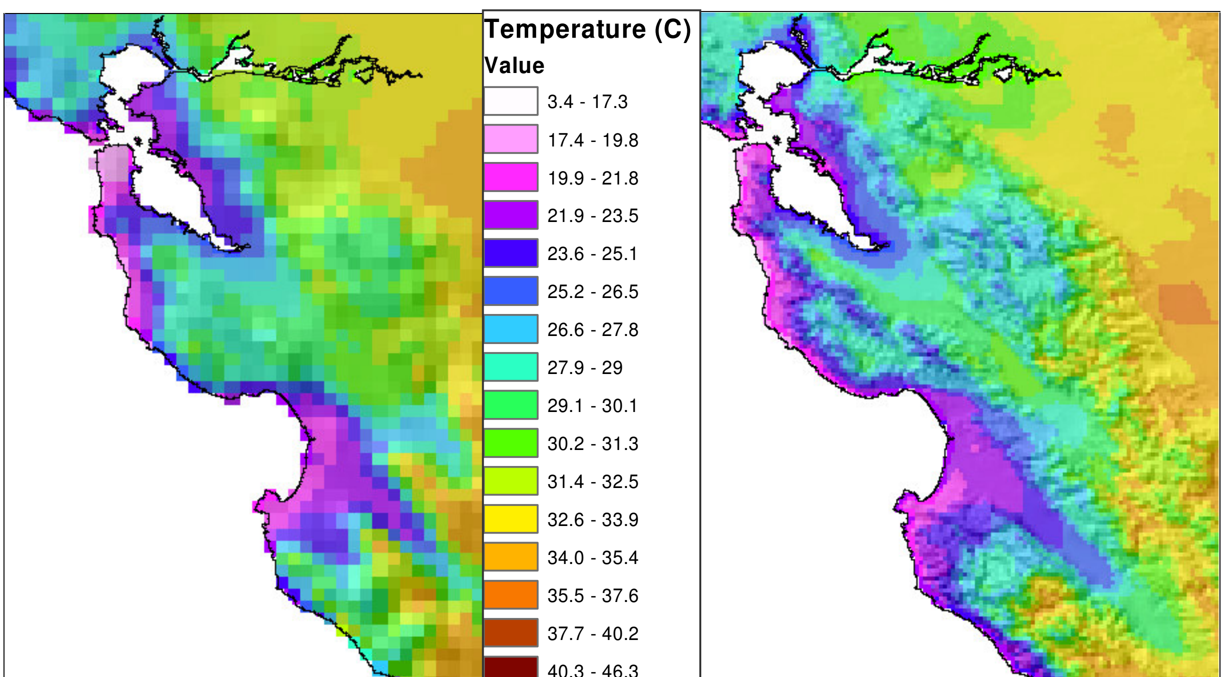

(A) (B)

Figure 7. Maps of July mean maximum temperature demonstrates the effects of the coastal proximity grid. (A) Is the 1961-90 4-km resolution grid, and (B) is the 1971-2000 0.8-km resolution grid.

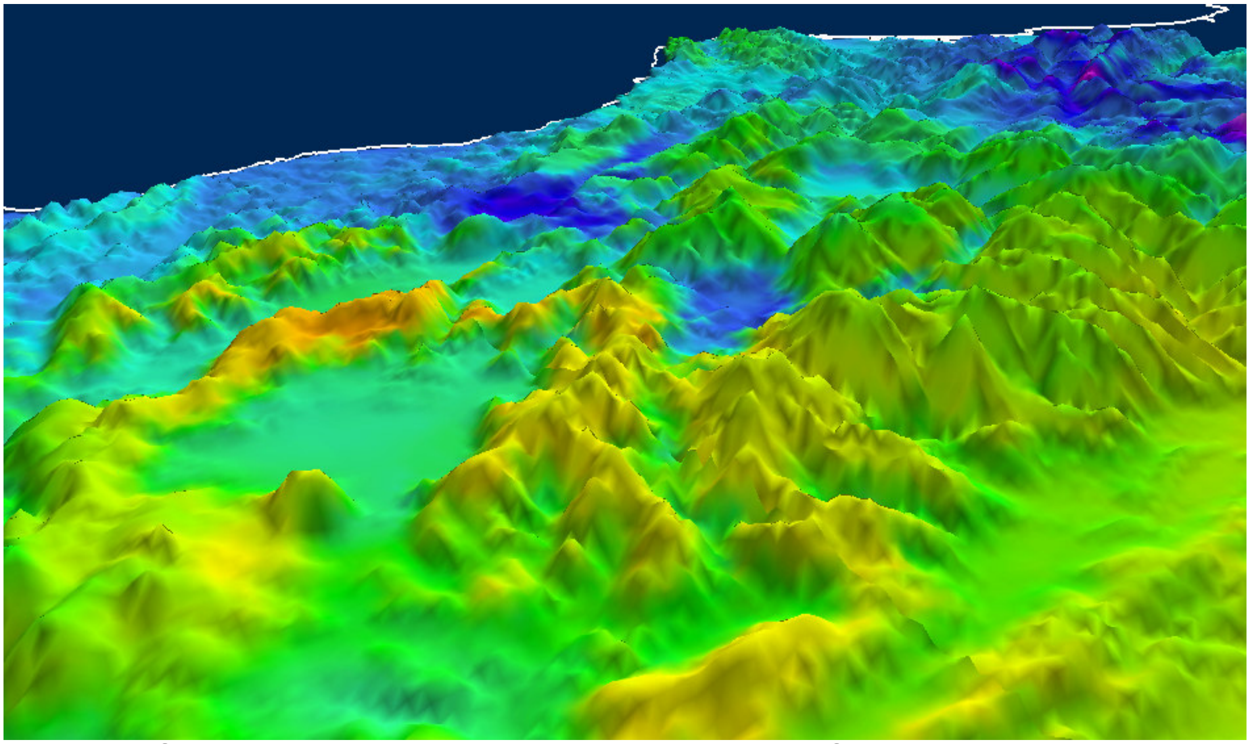

Figure 8. PRISM July mean minimum temperature at 0.8-km resolution. Same region as in Figure 4 except a 3D visualization viewed from the southeast looking northwest. Cooler temperatures are in blue, warmer temperatures in green to yellow. The Pacific Ocean is the black area in the background.