Disappearing “alpine tundra” Köppen climatic type in the western United States

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1 We examine changes in the areal extent of the Köppen “alpine tundra” climate classification type for the mountainous western United States following the work of Kottek et al. (2006). We find a significant decline in the area occupied by this climate category. In the late decades of the 20th century, the mean temperature of the warmest month in the areas of the western U.S. with nominal alpine tundra climates ranged largely between ~8.5°C and 9.5°C. In the last 20 years (1987–2006), rising temperatures have caused a significant fraction of these areas to exceed the 10°C threshold for alpine tundra classification. The result has been a 73% reduction in coverage of this climatic type. The remaining classified alpine tundra in the last 20 years now averages between ~9°C–10°C during the warmest month, so that continued warming past the classification threshold, would imply that areas where this climate type is found today in the West will no longer be present.


1. Introduction

2 A number of studies have been published in the past decade that indicate that the world’s mountain regions comprise an area where the effects of global warming is likely to be amplified. In particular, many of these studies have documented an amplification of temperature trends with height [Diaz and Graham, 1996; Liu and Chen, 2000; Diaz et al., 2003; Bradley et al., 2004]. To examine changes in climatic types that may have occurred during the past century, we make use of the Köppen climate classification system, which has been used to evaluate ongoing and future climate change impacts on characteristic regional climatic types [Lohmann et al., 1993; Fraedrich et al., 2001; Kottek et al., 2006; see also Dang et al., 2007]. Recent strong warming trends in the western United States [Mote, 2003] and associated impacts on vegetation [Cayan et al., 2001; Breshears et al., 2005; Westerling et al., 2006] and streamflow [Stewart et al., 2005; Regonda et al., 2005] suggest that climatic types in the region may also be changing.

3 We have used the Köppen climate classification system to evaluate changes in climatic types across the United States. The classification algorithm was applied to the PRISM (Parameter-elevation Regressions on Independent Slopes Model) gridded data set of surface temperature at 4-km resolution [Daly et al., 2002]. We have also used the PRISM temperature data to evaluate maximum and minimum temperature trends with elevation in the West; a comparison of means and trends in the PRISM data set with other data sets is given in the auxiliary material.1 Here we report on changes in one particular phenotype—the alpine tundra, which is equivalent to Köppen type-E (polar climates). Briefly, polar climates are defined as occurring if the mean temperature of the warmest month is less than 10°C.

In the West, only the tundra climate sub-type is present, which is defined as occurring when the mean temperature of the warmest month lies in the interval (0°C, 10°C). We note that the percent area coverage of this climate type is rather small, occupying only about 0.2% of the area of the western United States, or about 15,000 km². There were 1226 4-km pixels classified as “alpine tundra” in the 1901–30 period, whereas in 1987–2006, there were only 336 thus categorized—a decline of ~73%.

4 We also calculated linear temperature trends for the period 1979–2006 for mountainous areas in Colorado, the Pacific Northwest and the Sierra Nevada, which contain most of the areas classified as “alpine tundra”. This period was chosen for two reasons. First, it corresponds to a period of rapidly warming surface temperatures in the West (see below). Second, it enabled us to compare elevational differences in temperature changes in PRISM with changes derived from two independent data sets: the MSU lower troposphere satellite-derived temperatures [Spencer et al., 2006] for the domain of the western US that starts around 1979, and a homogenized version of the SNOTEL temperature record provided by the Natural Resources Conservation Service, USDA, which also starts around this time.

2. Analysis

5 To illustrate the recent warming trends across the entire West, Figure 1 shows mean annual temperature changes for the U.S. region west of about 102°W longitude. The last 20 years of record (1987–2006) is a period of consistently higher temperatures—an increase of ~1°F (0.6°C) averaged over the entire region compared to the long-term (period-of-record) mean. This in turn has resulted in a dramatic reduction—as much as 73%—in the area classified as alpine tundra in the West, compared to the first decades of the 20th century (Figure 2). This relatively large change in the coverage of alpine tundra climate in the western U.S. is quite remarkable. We should note that the mean monthly temperature of the warmest month in most of the areas we classified as alpine tundra (the key parameter in

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1Auxiliary materials are available in the HTML. doi:10.1029/2007GL031253.
Western U.S. Annual Temperature Departures

Figure 1. Time series of annual mean temperature anomalies (°C) for the western United States, 1901–2006. (top) Values computed from divisional data (blue curve) available from the National Climatic Data Center, NOAA in Asheville, NC, and from PRISM. (bottom) Difference between the two curves above. The mean difference between the two curves in the period 1901–1930 (1987–2006) is 0.2°C (0.05°C).

Köppen Type E) in the West is close to the critical threshold of 10°C. This is illustrated in Figure 3 (left), which shows the temperature changes in pixels that exceeded the classification threshold in the 1987–2006 period compared to the earlier (1901–30) period. Figure 3 (right) also indicates that below elevations of about 3000 m, the mean temperature of the warmest month today is quite near the critical 10°C threshold, and so one would expect that a continuation of the recent warming trends will cause further reductions in the areal coverage of this climate type.

We further illustrate the warming at high elevations in Figure 4, which show the distribution of linear trends for annual mean minimum and maximum temperatures as a function of ground elevation for areas where the highest mountain regions in the West are located. The results are presented as distributions of linear trends computed for successive 250 m elevation bins. In all three cases, the trend in minimum average temperature increases with elevation, while the trends in the mean maximum temperature increases with height only in the Colorado Rockies. The trend in the other two mountain ranges is positive, but rather more uniform with height. We also note that precipitation trends in the West over the period 1979–2006 (not shown), using a data set of snow water equivalent values from snow-depth measurements together with collocated PRISM data show declines during this time. The drier conditions prevalent over the last few decades in the West would also have contributed to the decline in the areal extent of the alpine tundra in this region.

[7] We also examined spring season (March–May, MAM) temperature trends for the same three regions because generally the largest climate trends and impacts signals in the West reported in the literature are associated with this transition season, and because a connection can be made between amplification of the warming trends in the West with elevation and surface changes related to diminished western snow packs [Mote et al., 2005]. The results...

Figure 2. Distribution of Köppen classification “E” (tundra climates, E-T) corresponding to the “alpine tundra” climate in the western United States considered in this study. (top) Areas classified as K-E for the period 1901–1930. (bottom) Same as for Figure 2 (top), except for the period 1987–2006. These areas are colored red and comprise all the 4-km pixels in the PRISM data that are classified as E-T.
Figure 3. (left) Distribution of mean annual temperature of the warmest month for pixels that were classified as “alpine tundra” in 1901–1930 (blue curve) and for the subset of pixels that exceeded the 10°C threshold, and hence were no longer classified as such in 1987–2006. (right) Temperature distribution of pixels that are still classified as alpine tundra in both periods. Note the elimination of this category at the lowest elevation bin. Solid dots represent the median value in each 250-meter bin.

3. Summary and discussion

Average temperature in the western United States has risen considerably in the last 20 years—about 0.6°C. This period is the warmest such interval in the instrumental record. Based on the PRISM data set, the warming has generally been accentuated at the higher elevations (above about 2000 m) where trends in excess of 1°C are calculated. Using the Köppen climate classification system, an area of the western US of around 20,000 km² was typed as alpine tundra for the period 1901–30. In contrast, for the period 1987–2006, the same climate type covered only 336 4-km pixels—a decline in area coverage of about 73%.

The U.S. Climate Change Science Program recently took up the question of whether there was agreement between observations and climate model simulations on the nature of temperature changes at the surface and in the troposphere [Karl et al., 2006]. In particular, for global average temperature, 1979 through 2004, the report concluded that they could not state definitively whether trends at the surface were different from those in the troposphere. The results presented here are for the mountainous regions of the western United States since 1979, where studies have documented significant changes to snow packs and the timing of the seasonal melting [e.g., Stewart et al., 2005; Mote et al., 2005], and where these hydroclimatic changes have been associated with significant vegetation-related impacts [cf. Breshears et al., 2005].

We have focused here on one particular western U.S. ecotone—the alpine tundra—as defined by a simple metric, namely the mean temperature of the warmest month. A range of different observations indicate that environmental aspects of global warming are beginning to show, with significant impacts already documented in a number of phenological, biological, and hydrological indicators in the West. These include earlier blossoming of shrubs in spring, massive infestations of western forests by insect pests, intensified wildfire seasons, and earlier spring runoff. Our results suggest that the prevailing climate associated with alpine tundra landscapes in the West may soon be out of equilibrium with present climate and may largely disappear.

References


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