Observed Climate Change and Transportation

By **David R. Easterling**

Abstract

In this paper the current instrumental evidence regarding climate variations and change during the Twentieth Century is reviewed. The questions addressed include: (1) what is the observational evidence for a changing climate, both globally and in the United States, (2) what are the relevant results from the recently completed U.S. National Assessment examining the potential consequences of climate change in the U.S. Based on global near-surface temperature measurements for the Twentieth Century it is clear that a warming of approximately 0.6 deg C has occurred for the globe and a similar warming has occurred in the U.S. More importantly, however, are the observed asymmetric changes in daily maximum and minimum temperature, with the minimum temperatures increasing at a rate approximately twice that of the maximum temperature. Other temperature sensitive measures, such as glacial and snow cover extent reinforce the observed temperature trends.

Examination of the hydrologic cycle indicates that changes also appear to be occurring, although less confidence can be placed on these analyses than those for temperature. Recent studies suggest that precipitation has increased in higher latitudes, particularly in the Northern Hemisphere. The final question regarding climate extremes is much more difficult to assess due to a lack of high temporal resolution climate databases. Of the few studies that have been performed, however, there is evidence that precipitation extremes, particularly heavy rainfall events are increasing in the U.S., also suggesting an enhanced hydrologic cycle as the planet warms.

Introduction

Over the past decade considerable progress has been made in assembling databases, removing systematic biases from these data, and analyzing records for interannual variability and decadal changes in the mean for large sampling times (monthly to annual) and spatial extent. This paper reviews our base of knowledge about climate variability and change during the instrumental record and examines a few of the relevant results from the U.S. National Assessment of the potential consequences of climate change in the U.S.

Is the Planet Getting Warmer?

There is little doubt that measurements show that near-surface air temperatures are increasing**.** Figure 1 shows the globally-averaged mean annual temperature time series including both land and ocean for 1880-2000. Although the overall trend of this time series is about 0.6 deg C/century, it shows a number of distinct periods with different trends. The characteristics of the

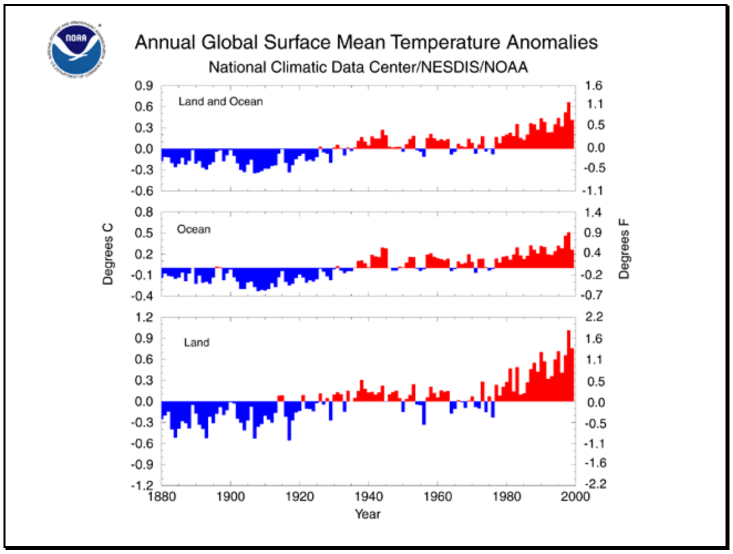

Figure 1. *Global near-surface temperatures for land, ocean, and combined land and ocean.*

time series, as calculated objectively by Karl et al. (1999) shows a cooling of –0.38 deg C / century from 1880-1910, then warming of 1.2 deg C/century from 1911 to 1945, a period of no change to 1975, then strong warming of 1.96 deg C/century since the 1970s. The period since the late 1970s has seen stronger and more frequent El Ninos, which have been shown empirically (Jones 1989, 1994) to add to any warming present due to other factors. One other feature about the time series is the large positive anomaly for 1998, making this the warmest year in the instrumental record due, in part, to the exceptionally strong 1997-1998 El Nino.

The rate and direction of temperature change has not been spatially uniform, as shown in Figure 2. Although much of the globe is warming, portions of the southern U.S., the North Atlantic Ocean, the Middle East and China actually cooled during the twentieth century. Some of the strongest warming is over the mid-to-high latitudes of the Northern Hemisphere, and it is also noteworthy that the magnitude of the warming on regional space scales is often much larger than the global mean.

The changes in mean temperature are a signal of a more interesting change in the mean daily maximum and minimum temperatures. Easterling et al. (1997) have shown that the rate of temperature increase of the maximum temperature has been about one-half the rate of increase of the minimum temperature. Some regions, including Great Britain, have not shown this global signature of minimum temperatures rising faster than maximums. One other feature about these results is that the possibility of urban contamination of the time series was specifically addressed. This was done by excluding observing stations in larger urban areas (> 50,000 population), and comparing this analysis with the full data set, with the effect being only a very slight reduction in the temperature trends when urban areas are excluded.

The surface temperature warming has been greatest during the winter and spring seasons and least during the autumn. This is true in both global mean temperatures, and in trends in maximum and minimum temperatures (Easterling et al. 1997). Part of this seasonal disparity is related to the snow cover feedback effect as noted by Groisman et al. (1994) in an analysis of the ablation of spring snow cover in recent decades.

Is the Hydrologic Cycle Changing?

Global warming would very likely lead to changes in precipitation due to changes in

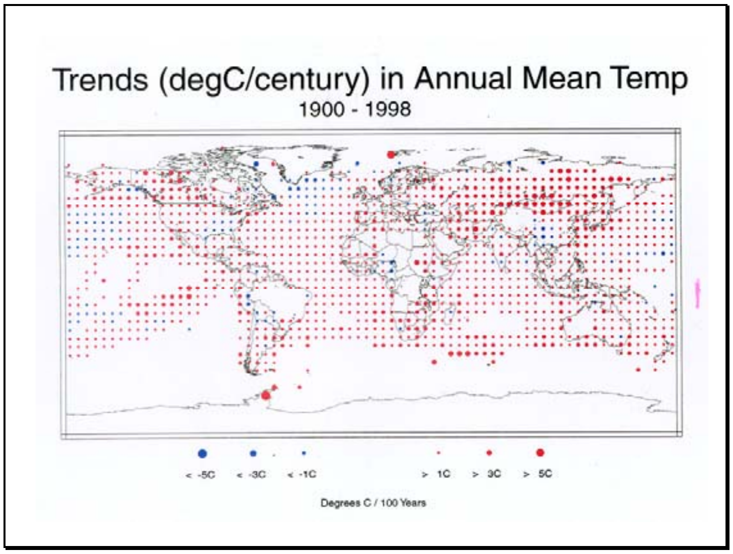

Figure 2. *Map showing trends of temperature change for 1900-1998 in annual average temperature. Magnitude of the trends are reflected by the area of the circles. Red circles reflect increases and blue circles, decreases.*

atmospheric circulation and a more active hydrologic cycle. This would be due, in part, to an increase in the water holding capacity of the atmosphere with an increase in temperature. Figure 3 reflects changes in precipitation for a variety of zones using the GHCN data set (Vose et al., 1992). There is an increase in the mid-to-high latitude precipitation and a notable decrease in subtropical precipitation. Some of the largest tropical decreases have occurred in the Sahel region in Africa due to long-term drought conditions from the 1960s to the mid-1990s. This region, however, has seen an increase in precipitation in the most recent years to a level approximately that of the 20th century average. There is also evidence to suggest that much of the increase of precipitation in mid- to-high latitudes arises from increased autumn and early winter precipitation in much of North America (Groisman and Easterling, 1994) and Europe (IPCC, 2001). Furthermore, large-scale coherent patterns of change in precipitation during the twentieth century are shown in Figure 4, which provides added confidence in the results. This figure shows the sometimes large, but spatially consistent patterns of decrease across the tropical and sub-tropical regions, and increases in most other areas. One other point about Figure 4 is that there are some large areas where we currently do not have reliable enough data to calculate long-term trends. These areas include parts of high-latitude North America and Russia, as well as western China, and the Sahara.

Is the Weather and Climate Becoming More Extreme or Variable?

Perhaps one of the greatest interests in weather and climate relates to extremes of climate. Due to inadequate monitoring as well as prohibitively expensive access to weather and climate data held by the world's national weather and environmental agencies, only limited reliable information is available about large-scale changes in extreme weather or climate variability. The time-varying biases that affect climate means are even more difficult to effectively eliminate from the extremes of the distributions of various weather and climate elements. There are a few regions and climate variables, however, where regional and global changes in weather and climate extremes have been reasonably well-documented.

Interannual temperature variability has not changed significantly over the past century. However, on shorter time-scales and higher frequencies; e.g., days to a week, there is some

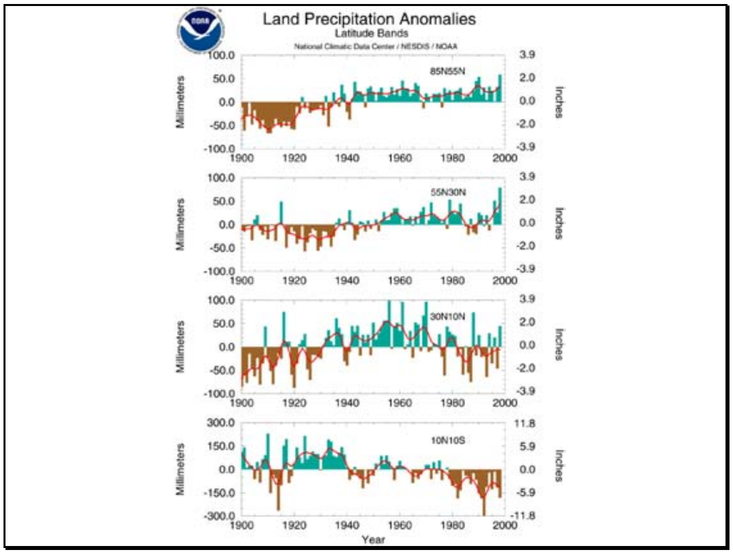

Figure 3. *Zonally-averaged annual precipitation anomalies (using 1961-90 as base). Smooth curves were created using a nine-point binomial filter. Anomalies are based on the Global Historical Climatology Network data set.*

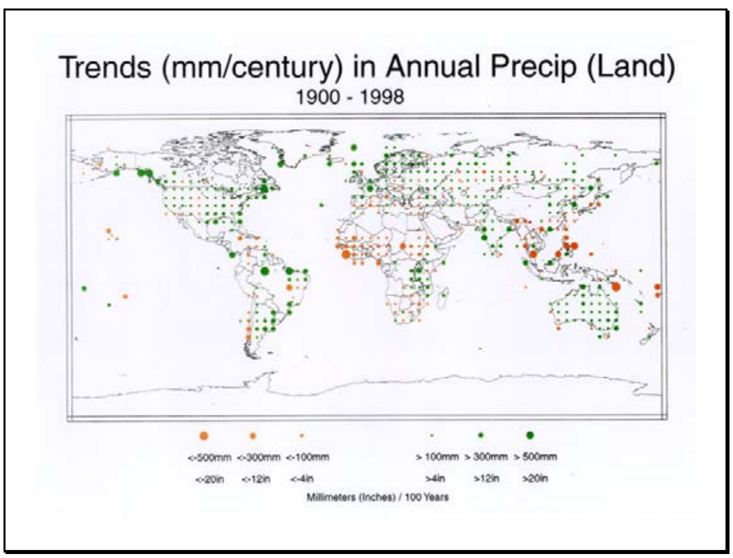

Figure 4. *Map showing trends in annual precipitation over land, 1900-1998.*

evidence for a decrease in temperature variability across much of the Northern Hemisphere (Karl and Knight, 1995). Related to the decrease in high-frequency temperature variability there has been a tendency for fewer low temperature extremes and a reduction in the number of freezes in disparate locations like the U.S. (Easterling 2002), and Queensland, Australia. Further, Easterling (2002) found a significant shift to an earlier date of the last spring freeze resulting in an increase in the frost-free season in most parts of the U.S. Widespread changes in extreme high temperatures, however, have not been noted.

Trends in intense rainfall events have been examined for a variety of countries (Karl et al., 1996; Suppiah and Hennesy, 1996). There is some evidence for an increase in intense rainfall events (U.S., tropical Australia, Japan, and Mexico), but analyses are far from complete and subject to many discontinuities in the record. Some of the strongest increases in extreme precipitation are documented in the U.S. Figure 5 shows annual trends in the contribution of heavy precipitation, defined as daily values above the 90 percentile, to the annual total for a number of countries. Results from this figure show that heavy precipitation amounts are increasing, in some areas by as much as 12 percent. However, in some areas of the U.S. this is being offset by decreases in more moderate events, and in other areas of the country (e.g. the Northwest, Southeast and Northeast) both amounts are increasing. Such increases, at least in the U.S., have been supported by an observed increase in water vapor (Ross and Elliott, 1997) and total precipitation.

The U.S. National Assessment: The Potential Consequences of Climate Variability and Change in the United States

In 1997 the U.S. Global Change Research Program (USGCRP) undertook the task of organizing a major assessment of the potential consequences of climate change on the United States. This report (NAST 2001) is the product of input from hundreds of researchers and stakeholders in the U.S. and was first released in the fall of 2000. Below is a summary of some of the points relevant to this audience.

A unique aspect of the U.S. National Assessment is the combination of a national-scale analysis with an examination of potential impacts of climate change on a regional level. For example, in the southeastern U.S., increasing sea-level has already impacted coastal areas such as Louisiana by causing coastal wetlands losses, which then puts these areas at a greater risk from storm surges associated with tropical and extratropical storms.

What are some other aspects of this Assessment that are directly relevant to transportation? First, future conditions were evaluated by using results from state of the art climate model simulations in impacts studies, and by using results from the current scientific literature. Some of the relevant results include:

- Some climate models show a reduction in soil moisture in many areas resulting in decreases in ground and surface water supplies. This could result in a decrease in the levels of the Great Lakes by as much as a meter or more. However, other model results suggest little change in lake levels. Reductions in base stream flow could cause problems with transportation such as barge shipping, infrastructure, and reductions in water supply. However, warmer winter temperatures could result in a longer ice-free season thereby extending the shipping season on the Great Lakes.

- A possible reduction in Western U.S. snowpack that would impact water supply and streamflow. This could result in a seasonal redistribution of water availability.

- In Alaska, permafrost has already undergone extensive melting and if future projections of high-latitude warming hold, then melting would continue.

- Heavy precipitation events in the U.S. have increased over the 20th century, and could

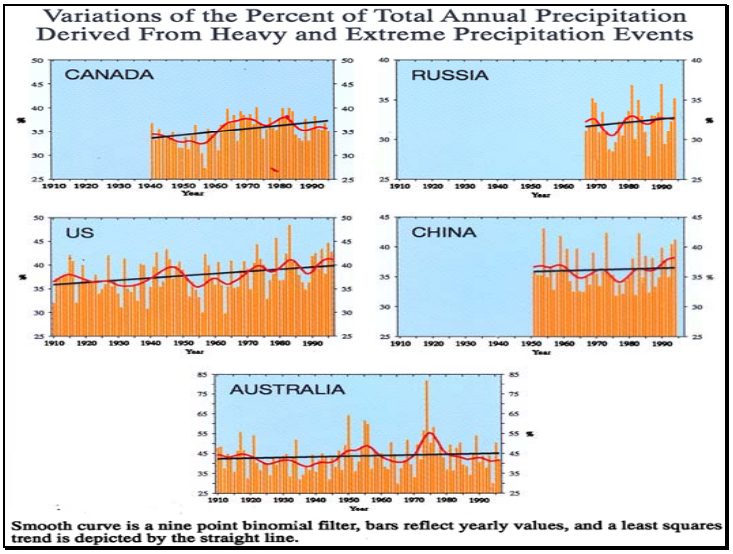

Figure 5. *The trends in the percent of the annual total precipitation derived from heavy precipitation events for Canada, the United States, Russia, China, and Australia.*

continue with a more vigorous hydrologic cycle as projected by model scenarios.

- Increasing summer temperatures, coupled with increasing water vapor, would likely result in increases in the summer-time heat index in many parts of the country.

Other Relevant Results

The U.S. National Climatic Data Center (NCDC) provides climate information in a variety of ways that are relevant to transportation. These include the calculation and distribution of Climate Normals, and climate data intended for engineering purposes. The NCDC has recently recalculated and released the 1971-2000 Normals of temperature and precipitation for the U.S. These Normals are used by a variety of industries for use in activities such as calculating energy demand and energy rate setting as well as the rapidly growing weather derivatives market. Figure 6 shows the difference between the 1961-1990 Normals of temperature and the 1971-2000 Normals. The decade of the 1990s in the U.S. was one of the warmest, only equaled by the Dust Bowl decade of the 1930s. The difference map (Figure 6) shows that the Normals of annual average temperature have increased by as much as 0.6 deg C (1 deg F) or more in some areas with the biggest increases occurring in the winter. Precipitation Normals (Figure 7) have also shown increases over the previous Normal of as much as 50 mm (2 inches) or more.

Summary and Conclusions

The suite of available climate data can be used to assemble a coherent, quantitative description of variations and changes during the instrumental climate record. These data indicate that the planet has warmed by approximately 0.6 deg C during the past century, and this temperature increase has been strongest at night and over the mid-to-high latitude continental areas. The warming has tended to occur in jumps rather than in a continuous fashion with the most recent jump(s) occurring in the late 1970s and perhaps around 1990 (subsequent data will affirm or contradict this recent jump). Global data are available from these analyses, but are largely based on monthly means which are often unsatisfactory in capturing extreme climate and weather events. Exceptions to this occur primarily on a national basis. That is, high resolution daily temperatures are available on a country-by-country basis, but have not been assembled into a consistent long-term data base. In the U.S. reductions in the number of frost

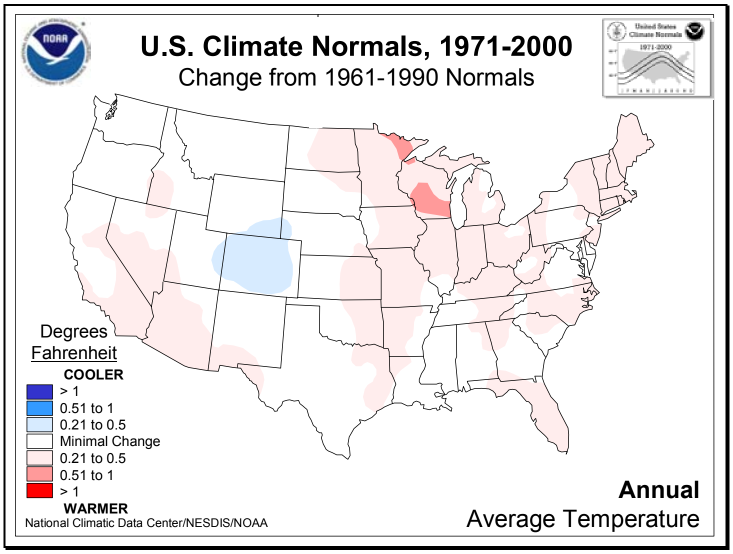

Figure 6. *Map showing the difference between the 1961-1990 normals of temperature and the 1971-2000 normals. Areas in red show warming; blue shows areas with cooling.*

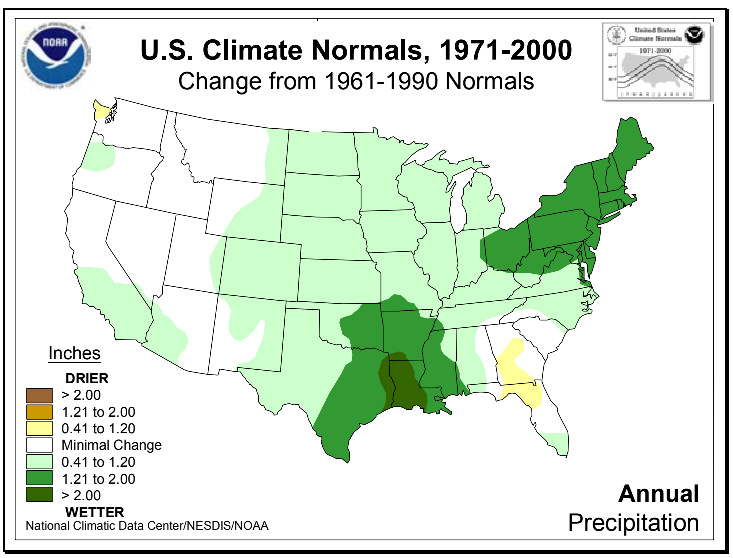

Figure 7. *Map showing the difference between the 1961-1990 normals of annual precipitation and the 1971-2000 normals. Areas in green show precipitation increases and light brown show decreases. The western Gulf Coast and the Northeast have experienced the largest increases.*

days and an increase in the length of the frost-free season have occurred over the latter half of the 20th century.

Precipitation has increased in the mid-to-high latitudes and has tended to decrease in the subtropics. High-resolution daily precipitation data is also available for a few countries, and has been analyzed for changes in extremes. Significant increases in extreme precipitation rates are apparent in the U.S.

Results from the U.S. National Assessment indicate that potential problems exist in sea-level rise, water supply, and warming in higher latitudes (Alaska) resulting in permafrost thawing. Warming winter temperatures also may lead to a decrease in winter-time energy demand but an increase in summer energy demands as the differences in the new U.S. Climate Normals suggest.

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