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RECENT CHANGES OF WEATHER PATTERNS IN NORTH AMERICA

PROGRESS REPORT FOR PERIOD

Ending 4/1/94

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The research is a continuing effort built on the results of previous work under contracts DE-FG02-85ER60372A through C in which several data bases for North America have been compiled, quality tested, corrected, and in part analyzed. The following results were obtained.

1) Using the Historical Climatology Network and a supplementary set of 24 National Weather Stations we investigated the interrelationships between the trends of temperature, cloudiness, sunshine and precipitation over the 1948-1987 interval for 23 individual regions of the contiguous USA. Our objective was to gain a better understanding of why the temperature record of the United States does not reflect the anticipated greenhouse warming. Both seasonal and annual trends for 23 geographic regions were calculated. Averaged over the contiguous United States, the annual mean temperature showed little change, although cooling has occurred across the eastern half of the country, and warming dominates in the West. Cooling trends were found for winter and autumn, and warming trends in spring and summer. The decrease of the maximum temperature and daily temperature range in autumn is associated at a statistically significant level with increasing cloud amount and precipitation, and with decreasing sunshine. It was also shown that the decrease in the daily temperature range demonstrated earlier (Karl et al., 1984; Karl et al., 1986) is apparently related to an increase in low (< 6000') cloud cover (Plantico et al., 1990). Considerable effort was extended to detect and minimize the inhomogeneity in the data due to the urban heat island effects (Karl et al., 1988). These efforts still continue (Gallo et al., 1993a; Gallo et al., 1993b; Johnson et al., 1993).

2) Although several characteristics of the recent climate change across the United States agree qualitatively with the model-predicted impact of increasing anthropogenic greenhouse gases, the regional and seasonal distribution of the observed trends do not appear in line with the projections derived from equilibrium $2 \times \text{CO}_2$ model results. We concluded that either the recent changes of temperature cloud amount, sunshine and precipitation over the United States are as yet unrelated to the increasing anthropogenic greenhouse gases, or that the transient

response of regional climates to the greenhouse effect is not proportional to the modeled difference between the 1 x CO₂ and 2 x CO₂ equilibrium climates (Plantico et al., 1990).

3) Trends of seasonal surface air temperature compared with those of the free atmosphere between the 500 and 850 mb level in several geographic regions of the contiguous United States over the 1948-86 interval showed a slight relative warming of the mid troposphere with respect to the surface in winter. Relative cooling of the upper air was found in the West in summer and slight warming in the East. No differences in trends were noted between the upper air and surface temperature for the transitional seasons (Gavin et al., 1989).

4) The geographic and seasonal distribution of major features of the observed surface temperature anomalies were compared with years 26 to 30 of the NCAR coupled ocean-atmospheric circulation model of Washington and Meehl (1989) which adjusts to the gradual CO₂ increase by 1% per year. Although the variability of the observed trends as well as the model changes are large and the statistical significance of the correlation is low, the general pattern of positive and negative anomalies is similar (Kukla, Snowwatch 1993).

5) Because of the discrepancy between the paleoclimatic evidence and the GISS general circulation model of the onset of the last glaciation (Rind et al., 1989), we paid increased attention to the climatology of the precipitable water in North America. The concentration of atmospheric water vapor has a pronounced seasonal cycle which is significantly delayed behind the seasonal insolation forcing. We found that the thermal effect of this phase shift, which is as yet insufficiently reflected in the climate models, can provide further insight into the climatic impact of orbital changes (Kukla and Karl, 1991). When analyzing the geographic pattern of the current 1945-1986 surface air temperature trends over USA and the rest of the globe, we noted qualitative but not quantitative resemblance to some aspects of the ongoing insolation shifts, and proposed that the mechanisms through which the climate system can shift from an interglacial into a glacial mode can be detectable in the current seasonal cycle of atmospheric and oceanic circulation (Kukla et al., 1992; Kukla and Gavin, 1992).

6) In order to find out whether the relative cooling of the eastern United States with respect to the western part of the country could relate to the increased concentrations of industrial aerosols, we have first made a preliminary test of the relationship on the hemispheric scale. We compared Hameed and Dignon's (1988) data set on the SO_x emissions to the departure of surface temperature trends in the 1945-1986 interval from the corresponding zonal means. Generally, we found that the zones with higher emissions were cooler than expected from chance only.

7) The most robust temperature change in recent decades is the decrease of the daily temperature range, particularly during summer and autumn since the late 1940's. The finding was first made in a set of selected high quality rural stations for North America (Karl et al., 1984; Karl et al., 1986). It was later confirmed for other parts of the Northern Hemisphere and sections of the Southern Hemisphere continents including the Soviet Union, China and Africa (Karl et al., 1991; Karl et al., 1993; Kukla and Karl, 1993; Karl, 1993). A compilation of temperature maximum, minimum, mean, and range is currently available for 37% of the global land area. Overall, the decrease of the diurnal temperature range over land is approximately equivalent to the increase in the mean temperature. Much of the reported increase of the mean air temperature over land in the last five decades is due to the increase of the daily minima, not maxima. Only over the low latitude oceans have we found a uniform increase of minimum as well as maximum temperature.

8) We attempted to determine to what degree the observed decrease of daily temperature range can be explained by increasing cloudiness. Although the oscillatory drop of the diurnal temperature range was especially strong under overcast conditions, it has also been detected under clear skies (Plantico et al., 1990). Since these data were stratified by dew point, the changes could be explained by increased humidity. A close correlation of daily temperature range with cloudiness has been also reported by researchers analyzing data in other countries (cf. e.g. Bücher and Dessens, 1991; Wang et al., 1993).

9) Temperatures simulated by three general circulation/mixed-layer ocean models have been compared with the observed seasonal surface air temperatures over three regions of the central United States. The models, which include the diurnal cycle, are the Oregon State University (OSU), Canadian Climate Centre second generation (CCC) and the United Kingdom Meteorological Office (UKMO). The observations are based on the HCN stations data averaged for the 1966-75 interval. During this interval the CO₂ concentrations as recorded at Mauna Loa approximate those used in the model control runs. The simulated temperatures represent a 10-15 year average after reaching equilibrium. Averaged over all models, seasons and regions the simulations show a smaller temperature range by 3.2°C than the observations. Additionally, spring maxima are consistently cooler in all of the models in each region by an average 4.1°C (Kukla et al., in print). This indicates a potential problem with the handling of atmospheric water vapor in construction of the models. Another factor contributing to the observed difference could be the impact of tropospheric aerosols unaccounted for in the models, especially in summer (Hansen et al., in print).

10) Following further the change of the daily temperature structure we assembled an international body of climate change analysts and convened a workshop from September 27-30, 1993 in Maryland, where 37 participants concluded that the warming of the last four decades over land has occurred mainly at night, with less change in the afternoon temperatures. While part of the observed change could be due to the urban growth, most of it is clearly unrelated to an urban warming bias and is closely associated with increasing cloudiness. Climate models have shown that a decrease of the day-night temperature difference and nighttime warming may be expected to accompany an increase of atmospheric greenhouse gases. However, the magnitude of the modeled change is substantially smaller than observed. It is speculated, however, that the cause of regionally increasing cloudiness may be related to rising sulfur emissions due to the burning of fossil fuels. A NASA climate model which took into account not only the increase of greenhouse gases, but also the industrial sulfuric emissions and the potentially related increase of cloud cover over land came

closer to simulating the observed temperature change than any previous model based projection (Hansen et al., in print).

We are currently assembling the contributions presented by the participants of the MINIMAX Workshop for publication in the DOE/Conference Series and in a reviewed special Issue of the Journal of Atmospheric Research.

Since the global warming of recent decades is most prevalent over the low latitude oceans whereas little warming if any, is taking place in the Arctic (Karl et al. 1993; Ye et al., in print), we are now concentrating on the effects of the increased meridional temperature gradient on the atmospheric circulation and the properties and vertical structure of the air masses over the North American continent with particular focus on water vapor.

In preparation for the comparison of the free atmosphere moisture variables with the surface climate we are analyzing the daily fluctuations of air masses defined by surface dew point with changes of water vapor aloft at selected upper air stations.

The on-going analysis of the upper air data, designed to investigate variations of the atmospheric water vapor content and the changes of its vertical distribution is designed to test how reliably moisture is represented in climate models and also what progressive changes if any, occurred in geographic as well as vertical distribution of water vapor in recent decades.

The question we are addressing is to what degree the on-going changes in the geographic and time related distribution of water vapor are related to surface climate. In particular we are trying to learn whether the changed moisture supply to northern latitudes results in longer or shorter duration of snow cover (Karl et al., 1993) or higher runoff into the Arctic Ocean and whether the formation of dry continental air masses and their intermittent outbreaks to lower latitudes could become more or less frequent and/or intense.

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