An Uncommon Period of Cold and Change of Lapse Rate in the Rocky Mountains of Colorado and Wyoming

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ABSTRACT: Temperature and lapse rate show extreme departures from mean values for May 1981 through October 1986 at the high-elevation station D1 on Niwot Ridge in the Front Range, Colorado. If the D1 record is accurate, this period may present an opportunity to identify factors that influence temperature at high elevations, but not necessarily at low elevations. This paper focuses on four questions: (1) Is the D1 temperature record accurate? (2) What is the geographical extent of this anomalous cold period? (3) Are there any identifiable contributing factors or physical events relating to this period? (4) Is there evidence of a similar anomalous period in the past? Review of temperature data from other sites supports the accuracy of the D1 record and suggests that this cold period occurred at elevations above 3,000 meters at latitudes north of Berthoud Pass, Colorado, or roughly 40°N latitude. Additional data suggest that temperatures at these high-elevation locations may be related to conditions in the lower stratosphere as well as extreme temperature anomalies in the eastern Pacific Ocean. A possible physical explanation for this cold event is the sequential occurrence of the explosive volcanic eruptions of Alaid in 1981, then El Chichon in 1982, followed by the strong El Niño event of 1982-83. Tree-ring width chronologies from a high-elevation northern Colorado site suggest that the frequency of such cold periods is rare in the 20th century but was relatively common in the 19th century.

Introduction

The D1 climatological station is an alpine site at 3749 meters on Niwot Ridge, in the Front Range, Colorado, about 2 kilometers east of the Continental Divide and 27 kilometers west of Boulder and Longmont, Colorado (Figure 1). Annual temperature at D1 is variable, with a mean of –3.92°C, standard deviation of 1.10°C, and no significant long-term trend ($p<0.40$).

Mean annual temperature (Figure 2) for 1982-1985 is 2.5 standard deviations less than the 45-year mean. The lapse rate, defined here as the temperature difference between D1 and Longmont as a function of elevation, increased more than 20% during this same period. An examination of records from several climate stations at lower elevations, just a few kilometers east of D1, including Longmont and Waterdale, indicate no similar decrease in temperature. Lapse rate changes are climatically important because they reflect changes in atmospheric water vapor, cloud cover, and atmospheric stability; all are factors in feedback processes involving precipitation and temperature.

Evaluation of temperature and geophysical data validate the D1 cold period and suggests the following working hypothesis: high-elevation temperatures in the northern Colorado/southern Wyoming Rockies are

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inversely related to lower stratospheric temperature anomalies (LST) and atmospheric turbidity (TB) and directly related to the Southern Oscillation Index (SOI). Further, this relationship is enhanced when it occurs during the positive phase of the quasi-biennial oscillation (QBO).

Data

Surface temperatures: The D1 and C1 data are from the University of Colorado, Mountain Research Station, Mountain Climate Program. Periods of record are 1951-1995 for D1 and 1953-1995 for C1. Other Colorado temperature data were provided by the Colorado Climate Center, Colorado State University, Department of Atmospheric Sciences. Wyoming temperature data were provided by the University of Wyoming, Wyoming Water Resources Center. The periods of record for the other Colorado and Wyoming data are variable and generally shorter than the D1 record length.

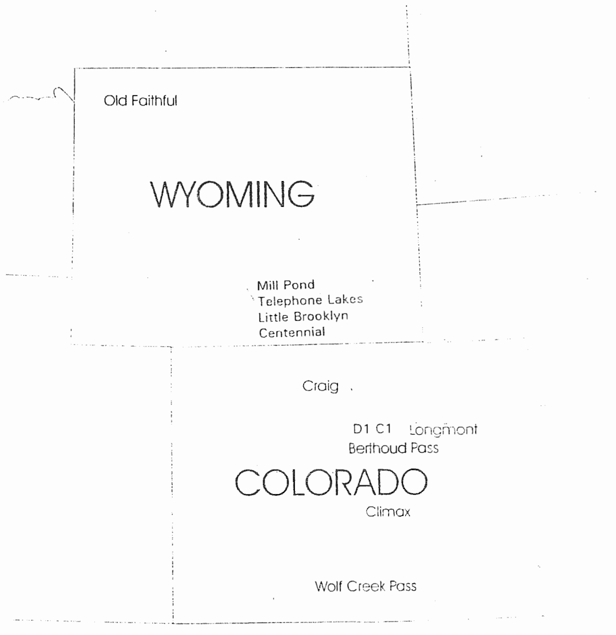

Figure 1. Map showing the areal extent of the cold period.

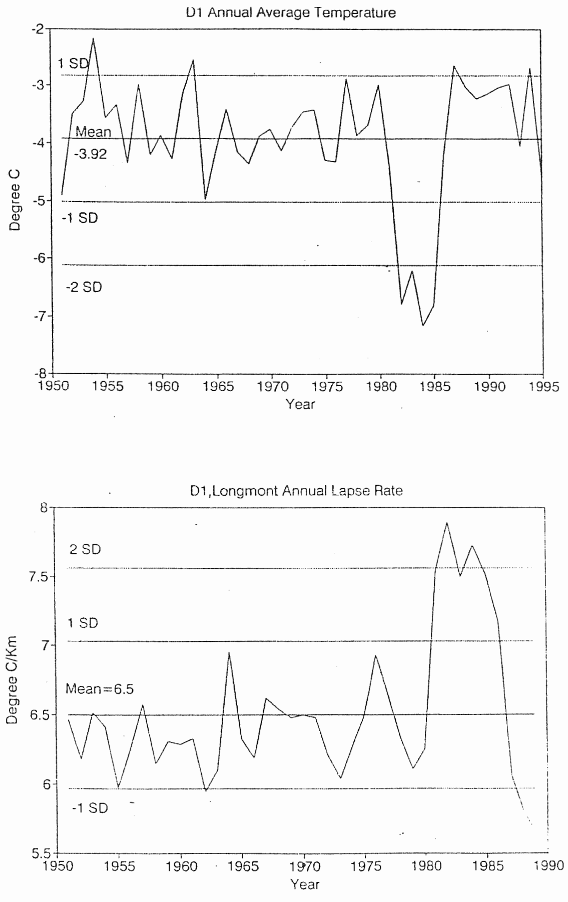

Figure 2 Temperature and lapse rate records.

Top: D1 Mean Annual Temperature (3749 meters).
Bottom: Lapse rate, D1 minus Longmont, in °C/Km.

Annual atmospheric Linke Turbidity (TB) index, Tucson, Arizona (Wm. Sellers, Institute of Atmospheric Physics, University of Arizona): This index is a general measure of aerosols and water vapor in the total atmospheric column and is greatly affected by volcanic activity. The TB index at Tucson is more sensitive to high-latitude volcanic eruptions than the Mauna Loa index (Sellers and Liu 1988). The period of this record is 1957-1995.

Lower stratospheric temperature anomalies (LST): These are northern hemisphere annual temperature anomalies at the 100-50 millibar height. The period of this record is 1959-1989 (Oort *et al* 1994).

Southern Oscillation Index (SOI): This index is the Tahiti-Darwin sea level pressure, obtained from the University of Washington Joint Institute for the Study of the Atmosphere and Ocean. A seasonal running mean of 3 months is used for the period of this record, 1951-1996.

Quasi-biennial oscillation (QBO): This phenomenon is represented by the 50-mb winds at Singapore. This paper uses a winter average (DJF). The period of this record is 1954-1995.

Results and Discussion

Anomalously cold temperatures occurred at D1 in 61 of the 66 months from May 1981 through October 1986. Twelve months are more than two standard deviations colder than the 45-year mean. Annually, the 1981-1985 temperatures average 2.5 standard deviations below this mean. Monthly maximum and minimum temperatures were equally depressed during this period. Thus, this cold period appears to have occurred evenly over all seasons and all diurnal cycles. In contrast, this cold period is not recorded at stations only 20-30 kilometers east and two kilometers lower than D1. This dichotomy is reflected in an increase in the D1-Longmont lapse rate of more than 20% in the early 1980s (Figure 2), and suggests a change in the overall climate regime of the area for this period.

This cold period is recorded at the following sites above 3,000 meters: Berthoud Pass, D1, and C1, Niwot Ridge, in Colorado, and Mill Pond, Little Brooklyn, and Telephone Lakes in Wyoming (Figure 3). This cold period is not recorded at the following mountain sites, which are below 3000 meters: Centennial, Wyoming, and Estes Park and Grand Lake, Colorado. The four Wyoming sites illustrate the elevational character of this cold period, as all are very close; however only Centennial is below 3000 meters, and the cold period is absent only at Centennial. The D1, C1, Berthoud Pass, Estes Park, Grand Lake, Longmont, and Waterdale records exhibit the same elevational departure; all are spatially close, but D1, C1, and Berthoud Pass are above 3000 meters and show the cold period whereas Estes Park, Grand Lake, Longmont, and Waterdale are below 3000 meters and the cold period is absent.

Latitudinally, Climax and Wolf Creek Pass stations are south of 40°N latitude and are higher than 3000 meters. The cold period is absent in these two records. In summary, a review of the 23 records in the Colorado/southern Wyoming area suggests that this cold period occurred above 3000 meters elevation and north of about 40°N latitude.

The working hypothesis — that high elevation temperatures in the northern Colorado/southern Wyoming Rocky Mountains are inversely related to lower stratospheric temperature anomalies and atmospheric turbidity and directly related to the SOI, with an enhanced relationship during the positive phase of the QBO — is based on several geophysical indices. Figure 4 shows temperature anomalies at the 100-50 millibar height in the Northern Hemisphere, anomalies of atmospheric turbidity, the SOI, and the phase of the QBO. Extreme departures occur in the SOI, TB, and LST in the early 1980s. At no other time of period of common record are all these anomalies so extreme and in near-synchrony. This period coincides with the cold period of the high-elevation Rocky Mountain locations discussed here, as well as two explosive volcanic eruptions, Alaid in 1981 and El Chichon in 1982, and the powerful El Niño event of 1982-83. This sequence of physical events may have perturbed the climate system sufficiently to result in this cold period.

A question, then, is how frequently do such extreme conditions occur? Due to the short record of instrumented data, a proxy temperature record has been used — the Fool Creek (Fraser, Colorado) tree-ring chronology. This chronology, recently developed by Brown and Shepperd (1995), is at a treeline site between D1 and Berthoud Pass and correlates with late spring temperature (r^2=0.36). The tree-ring record reflects the cold period of the early 1980s and shows that other cold periods have not occurred since 1906 but may have been relatively frequent between 1800 and 1906.

Summary

There are four main points to this study:

- The 1981-1985 cold period presents an opportunity to investigate factors that may influence climate at high elevations in the Rocky Mountains of northern Colorado and southern Wyoming.
- The D1 temperature record is validated, indicating the cold period is not due to instrumental error or microsite conditions. Results of analysis also show a greater than 20% increase of the lapse rate in the study region. This anomalous cold period appears to have occurred in the Rocky Mountains above 3000 meters, approximately bounded on the south at 40°N latitude, but the northern boundary is yet to be determined.

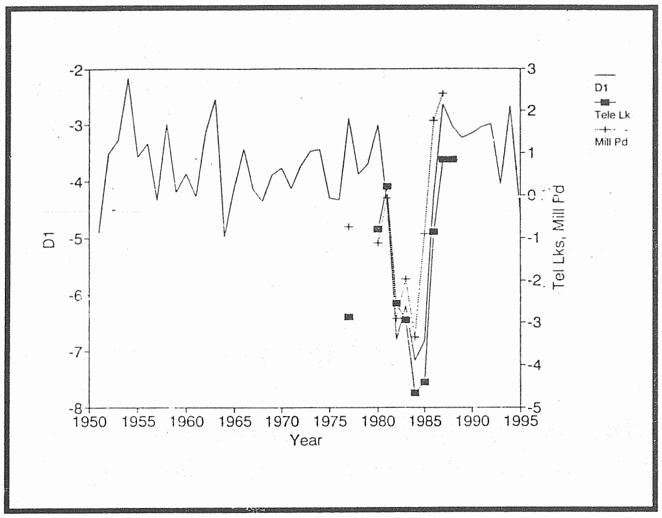

Figure 3. A selection of three mean annual temperature records that show the cold period.

The D1 record is plotted against the left side abscissa;
Telephone Lakes and Mill Pond are plotted against the right side abscissa.

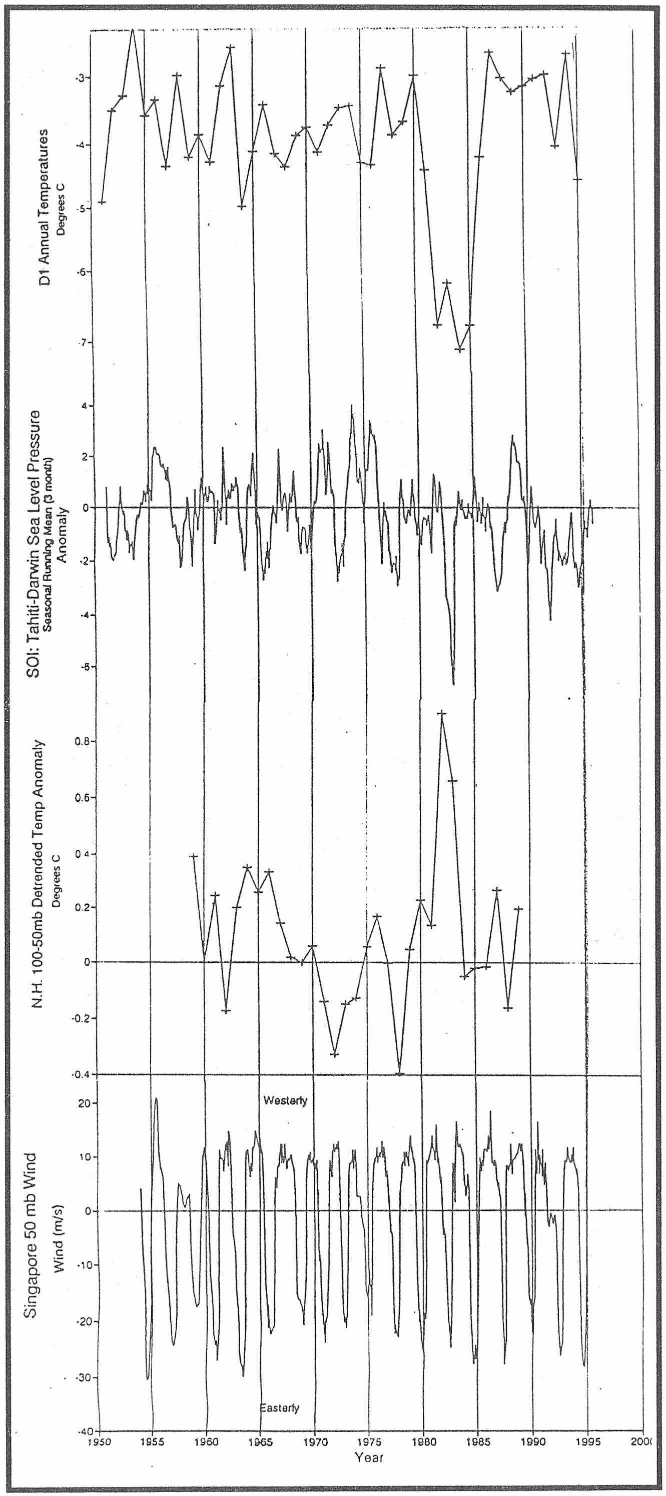

Figure 4 Goephysical Indices. From top to bottom: Atmospheric turbidity index at Tucson, Arizona; SOI; lower stratospheric temperature anomalies (°C); Singapore 50-mb wind (meters/second) representing the QBO.
Turbidity and SOI are standardized values.

- A measurable relationship may exist between these high-elevation temperatures and conditions in the lower stratosphere and temperature extremes in the eastern Pacific Ocean, as indicated by the SOI. Additionally, the positive phase of the QBO appears to be related to these relationships.
- Evidence from a tree-ring chronology suggests that such cold periods have been rare in the 20th century but relatively frequent in the 19th century.

Implications of this study include the suggestion that climatic conditions at high elevations can differ from those at lower elevations; therefore, caution should be exercised when adjusting for the paucity of high-elevation data by extrapolating from low-elevation data. Also, physical events such as volcanic eruptions and shifting positions of the Pacific Ocean equatorial warm pool may contribute to climate changes in this study region by destabilizing the upper atmosphere, a result of colder temperatures aloft.

Future work includes better defining the geographical extent of this cold period by analyzing more surface site records and comparing surface conditions to radiosonde data at 700 millibars. Also, analysis of synoptic-scale patterns using daily surface and 500-mb maps and pressure anomaly maps may be informative.

References

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