Correlation of 700 mb height data with seasonal temperature trends in the Great Basin (western USA): 1947-1987

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Abstract:
Temperature trends that are part of short-term climatic changes are often explained by a variety of theories, including changes in mean atmospheric pressure patterns. Seasonal 700 mb height data from grid points on the western (40° N, 120° W) and eastern side (40° N, 100° W) of the Great Basin, USA, were correlated with seasonal mean surface temperature data from Nevada and Utah, respectively, for a 41 yr period. Results from bivariate linear regression indicate that strong associations exist between height and surface data for all seasons except winter. The influence of persistent snow cover and topography may have a major influence on low wintertime associations. Trends in 700 mb height data are significantly correlated to seasonal temperature trends as measured by Spearman rank correlation. These results suggest that upper air trends are consistent with and supportive of the trends observed at the surface, and so lend credence to surface trend existence.

Article:

INTRODUCTION

Few subjects have garnered as much attention in the last decade as the possibility of a human-induced climate change, particularly changes in temperature. Short-term climatic changes, on the order of decades to centuries, are arguably the most important to humankind (Stockton 1990). Societies often rely on 30 yr temperature and precipitation means for water resource planning as these climate variables affect population growth plans, irrigation demands, stream-flow variability and rates of potential evapotranspiration (Stockton 1990). While year to year variability is expected, distinct trends from the mean are a source of considerable concern.

A variety of theories have tried to explain short-term climatic variability although there is little agreement on which theory is most applicable (Thompson 1989) or even valid (Mitchell 1976, Reifsnyder 1989). The potential causes of short-term climatic variability have been grouped into 3 categories: internal stochastic mechanisms, external forcing mechanisms, and a combination of the first 2 mechanisms (Mitchell 1976). Internal forcing mechanisms are feedbacks in the earth-atmosphere-ocean system (Mitchell 1976). For example, van Loon & Labitzke (1988) have shown a likely association between changes in 700 mb temperature and the 11 yr solar cycle in the Northern Hemisphere. External forcing mechanisms are largely associated to fluctuations in constituent gases and particulate matter, and alternatively have been attributed to variations in solar output, changes in the alignment of planets, and the strength of the earth's magnetic field (Thompson 1989).

Changes in upper atmospheric patterns are a part of short-climatic variability that may very well be the result of one or more of the commonly suggested causes. Changes from zonal to meridional flow often cause unusual temperature or precipitation patterns on daily, weekly, monthly, and multi-monthly scales (Wagner 1985, 1986). In some instances however, the changes may last for several decades (Fritts et al. 1979, Eriksson & Alexandersson 1990).

The relationship between 700 mb circulation and temperature has been extensively studied since the 1940s

(Klein & Kline 1984). A strong, positive correlation between surface temperatures and 700 mb height data exists within 1200 km of the pressure reference (grid) stations, and a negative correlation occurs about a half wavelength upstream (3000 km northwest) from the grid station (Martin & Hawkins 1950, Klein 1983, Klein & Kline 1984). Seasonal correlations have been shown to be somewhat variable, with winter surface temperatures often showing the least correlation with 700 mb circulation (Walsh et al. 1985).

Observations of 700 mb height data have shown that both interannual and interdecadal height fluctuations occur and exhibit distinct spatial patterns known as teleconnections (Esbensen 1984, Leathers et al. 1991). Yarnal & Leathers (1988) examined interdecadal climatic variations and their effect on wintertime temperature in Pennsylvania, and concluded that interdecadal variability was sensitive to hemispheric changes in large-scale mid-tropospheric flow. Further, periods of zonal flow contributed to above-normal temperatures while meridional flow caused below-normal temperatures. Other studies that have analyzed decadal temperature fluctuations (e.g. Balling & Lawson 1982, Skeeter & Parker 1985) also have shown that temperature trends can be associated with observed changes in mid-tropospheric flow.

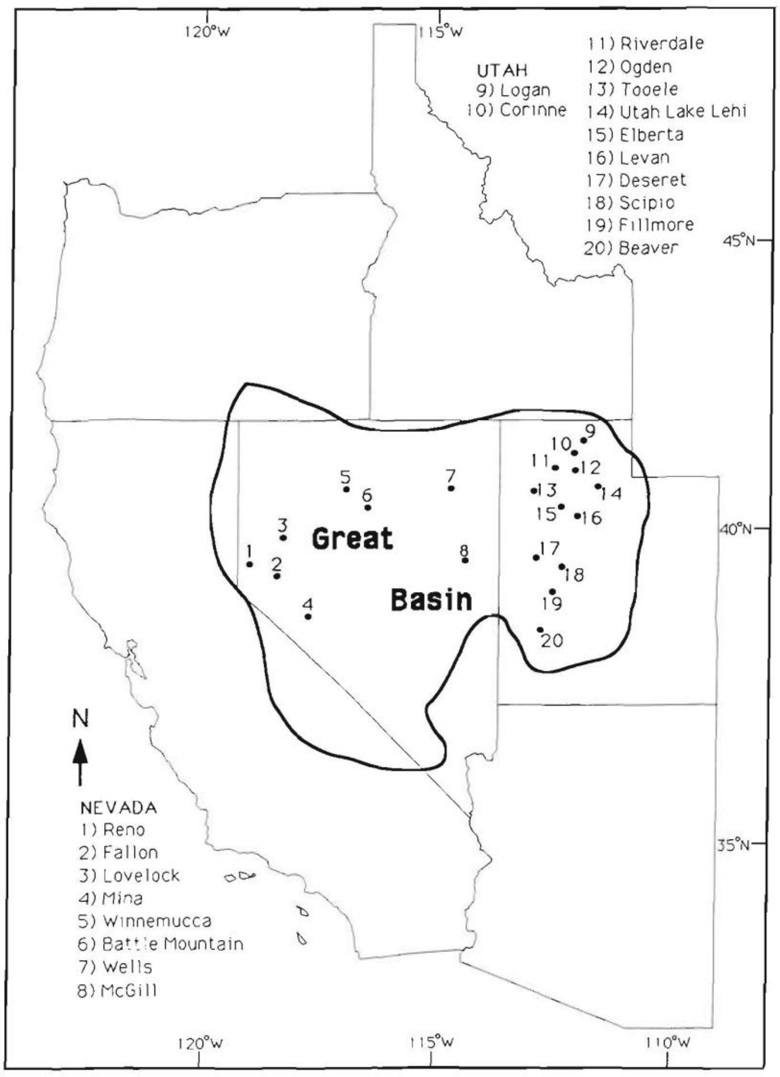

Fig. 1. Boundary of the Great Basin (western USA) and location of recording sites

Complicating the detection of climatic variability has been the question of data accuracy. Until recently, the detection of actual temperature changes was difficult because of 'polluted' data sets where the data may have been biased because of urban heat islands, time-of-observation differences, station moves and instrument changes. Several similar studies have compensated for these errors by using temperature data adjusted to account for these biases. Jones & Wigley (1990) found that the earth had warmed by ca 0.5 °C in the last 100 yr, though they did not attribute the warming to a specific cause. They also found that the warming trends varied considerably from region to region and that some places even experienced cooling, although the change in mean temperature in the Northern Hemisphere approximated that of the planet. Hansen & Lebedeff (1987) also measured global trends of surface air temperature and found warming of between 0.5 and 0.7 °C from 1880 to 1985. Characteristic of the temperature record in North America over the last century have been considerable fluctuations with warming trends occurring from 1880 to 1940 (0.6 °C) and from 1970 to present (0.3 °C), and a cooling trend occurring from 1940 to 1970 (0.3 °C) (Hansen & Lebedeff 1987).

These global studies have examined the temperature changes using a grid pattern with resolutions from 2500 × 2500 km (e.g. Hansen & Lebedeff 1987) to 550 × 1100 km (e.g. Jones & Wigley 1990). In either case, the macro-scale nature of such measurements provides limited specific information about the nature of temperature change for smaller areas. The purpose of this study is 3-fold: first, to examine trends in both surface temperature data and 700 mb height data; second, to examine the strength of association between 700 mb height data and temperature data; and third and most importantly, to focus on the correlation between these synoptic-scale trends for 2 regions of the Great Basin, USA.

STUDY AREA

The Great Basin is primarily a mid-latitude desert characterized by cold, snowy winters and dry, hot summers. The east side of the basin, particularly along the Wasatch Front, receives about twice as much precipitation (ca 40 cm yr^{-1}) as the west side (ca 20 cm yr^{-1}), but mean annual temperatures are comparable (ca 9 °C). The boundaries of the Great Basin are generally defined as the east side of the Sierra Nevada, the west side of the Wasatch Mountains, south of the Snake River Plain and north of the creosote bushes and Joshua trees of the Mojave Desert (Fig. 1; Trimble 1989). The Great Basin topography is typified by hundreds of north-south trending fault-block mountains that rise a thousand meters or more above the surrounding basins.

DATA AND METHODS

Temperature data used represent mean seasonal values for each of the study locations. The seasonal data represent averages of March, April and May for spring; June, July and August for summer; September, October and November for autumn; and December, January and February (of the next year) for winter. Annual temperatures represent the average of the 12 months as opposed to averaging the 4 seasons.

Table 1. Geographic coordinates and elevation of towns

Location	Latitude (N)	Longitude (W)	Elevation (m)
Nevada			
Battle Mountain	40° 35′	116° 54′	1384
Fallon	39° 27′	118° 47′	1208
Lovelock	40° 11′	118° 28′	1212
McGill	39° 24′	114° 46′	1921
Mina	38° 23′	118° 06′	1388
Reno	39° 30′	119° 47′	1342
Wells	41° 07′	114° 58′	1723
Winnemucca	40° 54′	117° 48′	1310
Utah			
Beaver	38° 17′	112° 38′	1801
Corinne	41° 35′	112° 08′	1293
Deseret	39° 17′	112° 39′	1398
Elberta	39° 57′	111° 57′	1430
Fillmore	38° 57′	112° 19′	1561
Levan	39° 33′	111° 52′	1620
Logan	41° 45′	111° 48′	1460
Ogden	41° 15′	111° 57′	1326
Riverdale	41° 09′	112° 00′	1341
Scipio	39° 15′	112° 06′	1616
Tooele	40° 32′	112° 18′	1546
Utah Lake Lehi	40° 22′	111° 54	1371

The data were acquired from the United States Historical Climatology (HCN) tapes (Karl et al. 1990). The data were fully adjusted for urbanization effects as well as station moves, instrument changes and time-of-observation biases. All adjusted data were given a consistency for the station with respect to the station's nearest

20 neighbors for the last 40 yr. Stations were ranked 0 to 20 with lower numbers indicating greater consistency with other stations than higher numbers. No station with a rank higher than 16 was chosen for analysis. In addition, these stations were selected because they provide a broad geographic representation of data points and have serially complete records beginning no later than 1947. Analysis included data from 1947 through 1987. The stations are located between 38° 17' and 41° 45' N latitude, and 119° 47' and 111° 52' W longitude. Elevations of the sites range from 1208 to 1921 m (Fig. 1, Table 1).

The 700 mb height data used were in seasonal format identical to that of the surface data, and were provided by the Scripps Institution of Oceanography. Seasonal data from 4 grid points corresponding to 130, 120, 110 and 100° W intersecting 40° N were used.

The surface data were classified into 2 groups. The Nevada group (western Basin) data included the mean, seasonal temperature for the 8 Nevada stations. The Utah group was the mean, seasonal temperature for the 12 Utah stations (eastern Basin). Correlation of surface trends with 700 mb data were statistically analyzed in 2 ways. In both ways, surface data from the Nevada group corresponded with 700 mb height data from the 40° N, 120° W grid point, while surface data from the Utah group corresponded with 700 mb height data from the 40° N, 110° W grid point. First, aggregate (by state), seasonal temperature data were correlated with 700 mb data using simple bivariate regression with temperature as the dependent variable. Second, bivariate regression was used to produce linear trends for both seasonal 700 mb height data and seasonal temperature data using time as the independent variable in each case. The linear trends of both the height and temperature data then were correlated using Spearman rank correlation. Regression diagnostic tests were also conducted by examining Cook's D and studentized residuals values (SAS 1985).

One caveat of time-series analysis is that the data may exhibit persistence. That is, the data may be serially correlated, therefore exhibiting non-randomness. Persistence was checked using Box-Jenkins time-series models (AR, MA ARMA, and ARIMA) with lags running approximately a quarter (10 yr) of the record length (Brocklebank & Dickey 1986). Analyses of the data, however, show that pre-whitening the residuals to ensure randomness actually removes the trends that this study was designed to examine by stabilizing the variance about a mean of zero (Graumlich 1991). Therefore, the residuals were not pre-whitened but instead were checked for autocorrelation to determine if the underlying assumptions of ordinary least squares regression were violated.

RESULTS

Trends

The mean seasonal temperature trends were highly variable. For winter means, there was a highly significant increase in temperature for the Nevada group (1.27 °C), while there was no significant increase for the Utah group (0.34 °C). For spring means, both stations had positive trends, 0.59 °C and 0.28 °C for Utah and Nevada respectively, but neither trend was significant. The Nevada group had a significant increase in the summer (0.84 °C) but the Utah group did not (0.22 °C). Nevada experienced a non-significant decline in the fall mean temperature (-0.33 °C), while Utah had a significant decrease in fall mean temperature (-0.71 °C) (Tables 2 & 3).

Observed trends in seasonal 700 mb height data show that decreases in winter mean height occurred at 130 and 100° W, and that increases occurred at 120 and 110° W. During the spring just the opposite conditions prevailed. In the summer, only 120° W had an increase in mean height. Fall mean heights decreased at all 4 longitudes and the decreases were significant at 120, 110, and 100° W (Table 4).

Correlations

Correlation of seasonal, mean temperatures with seasonal, 700 mb height data was highly variable for the seasons and regions (Table 5). Winter correlations were low with the response of temperature to 700 mb height data having r^2 values of 0.04 for Nevada and 0.01 for Utah. However, 700 mb height data explains a substantial proportion of the variance in mean seasonal temperatures for all other seasons. Springtime r^2 values for Utah

(0.69) were the highest for any season and were second highest for Nevada (0.59). Summer r^2 values were the highest for Nevada (0.69) and second lowest for Utah (0.39). Finally, fall r^2 values were 0.40 for Nevada and 0.56 for Utah.

Table 2. Observed linear trends (°C/41 yr) of mean seasonal surface air temperature at the Nevada sites

Station	Winter	Spring	Summer	Autumn	Annual
Battle Mt.	1.40	0.74	0.45	−0.45	0.54
Fallon	2.24*	0.61	0.94	0.20	1.00**
Lovelock	1.00	1.02	0.78	−0.41	0.60
McGill	0.92	−0.12	0.04	−1.56*	−0.18
Mina	1.92*	1.56*	0.78	0.20	1.11**
Reno	0.76	0.41	1.19*	0.00	0.59
Wells	0.56	0.12	1.11**	−0.49	0.33
Winnemucca	1.32	0.37	1.44**	−0.08	0.76**
Average	1.27**	0.59	0.84*	−0.33	0.59

*$p < 0.05$; **$p < 0.01$

Table 3. Observed linear trends (°C/41 yr) of mean seasonal surface air temperature at the Utah sites

Station	Winter	Spring	Summer	Autumn	Annual
Beaver	1.28	0.49	1.35**	−0.86	0.57
Corinne	0.36	0.32	0.86*	−0.29	0.31
Deseret	0.00	0.25	−0.49	−1.07*	−0.33
Elberta	−0.32	0.29	−0.33	−0.66	−0.26
Fillmore	0.92	0.16	−0.73*	−1.39*	−0.26
Levan	0.20	−0.12	0.00	−1.19*	−0.28
Logan	0.73	0.57	0.73	−0.21	0.46
Ogden	1.00	0.94	0.86*	0.25	0.76
Riverdale	−0.08	0.08	0.29	−1.11	−0.21
Scipio	0.16	0.25	−0.08	−0.29	0.01
Tooele	0.00	0.25	−0.25	−1.15	−0.29
Utah L. Lehi	−0.16	−0.04	0.41	−0.41	−0.05
Average	0.34	0.28	0.22	−0.71**	0.03

* $p < 0.05$; ** $p < 0.01$

Table 4. Observed linear trends (m/41 yr) in seasonal 700 mb height data at 40° N

Longitude	Winter	Spring	Summer	Autumn
130°	−12.2	1.6	−0.8	−6.5
120°	6.2	−1.4	2.4	−17.0*
110°	3.1	−6.3	−4.8	−23.4**
100°	−3.2	0.1	−2.7	−15.4*

* $p < 0.05$; ** $p < 0.01$

Table 5. Results of regression analyses predicting seasonal temperature as a function of seasonal 700 mb height data by state. *F*-statistic value is shown on top while corresponding r^2 value is shown parenthetically

	Winter	Spring	Summer	Autumn
Nevada	1.55	55.28**	88.24**	25.79**
	(0.04)	(0.59)	(0.69)	(0.40)
Utah	0.55	88.34**	24.42**	49.01**
	(0.01)	(0.06)	(0.38)	(0.56)

** $p < 0.01$

One alternative method to examine the relationship between 700 mb height data and temperature is the Spearman's rank-order coefficient (r_s). This coefficient measures the association of variables whose scores (as measured by trends from simple regression) are in order (Clark & Hosking 1986). Hence, seasonal 700 mb height trends based on the 41 yr record were ranked 1 to 8 (4 seasons × 2 grid intersections) based on absolute value and compared to temperature trends ranked likewise. The significant r_s value of 0.90 suggests that height and temperature undergo simultaneous changes in time.

DISCUSSION

Several dendrochronological studies have examined climatic changes in the western United States and have suggested that temperature variability can be attributed to changes in atmospheric patterns. Fritts et al. (1979) compared regional reconstructions of temperatures in the 17th, 18th and 19th centuries based on tree-ring chronologies and compared these to 20th century means derived from regional weather stations. Their results show that strong meridional flow occurred during the 17th and 20th centuries characterized by a ridge of high pressure centered over Vancouver Island (49° N, 122° W). During the 18th and 19th centuries, however, this pattern appeared to be less distinct and was characterized by greater zonal flow. Woodhouse & Kay (1990) used 11 tree-ring chronologies, 7 of which were in the Great Basin, to show the spatial and temporal changes of a winter air mass boundary in the western United States. Their results show that the climatic boundary was more meridional in the 20th century and more zonal in the 18th and 19th centuries.

The strong association between 700 mb height and surface temperatures, with the exception of winter, suggests that 700 mb height patterns vary together with surface trends. This association was best expressed for fall in the

Utah group. Both the 700 mb height data at 100° W and surface temperatures underwent significant decreases. This relationship suggests that during the 41 yr observation period a significant increase in meridional flow occurred with troughing in this region. The 700 mb height data from 120 and 100° W also show significant decreases in mean height with positive correlation with temperature.

Lack of significant correlation of 700 mb height data with winter seasonal temperatures may be explained by boundary layer phenomena associated with snow cover. Snow-covered surfaces, common at all of the Great Basin stations, modify atmospheric heating by changing the emissivity of terrestrial wavelengths, increasing the reflection of solar radiation, and altering conductive and latent heat fluxes (Klein 1985, Walsh et al. 1985). Further, the majority of the stations are located in low-lying areas and are often affected by cold air drainage and especially temperature inversions that are enhanced by short, winter days. Subsequently, virtually no correlation exists between winter temperature and 700 mb height data, suggesting that winter seasonal temperature trends may reflect site-specific conditions. This exception is well-illustrated in the Nevada group, where there is a significant increase in temperature, yet the changes are not supported by significant increases in 700 mb height data.

A second influence that may decrease the association between 700 mb height data and seasonal temperature is soil moisture, particularly in the summer (Walsh et al. 1985). Soil moisture modifies the Bowen ratio and may further influence surface temperature by increasing relative humidity, haziness and cloudiness (Walsh et al. 1985). The effects of this relationship are apparent when comparing r^2 values for summertime between Nevada and Utah. The influence of significant summer rain in the Great Basin is generally divided at 115° W. West of 115° W there is a lack of moist air streaming into the region during the summer, while east of 115° W summer showers are a result of moist air from the Gulf of Mexico (Houghton 1969). Consequently, the eastern Great Basin is characterized by July and August rainfall totals 2 to 3 times that of the western Great Basin (Houghton 1969). Hence, r^2 values are lower in Utah than in Nevada because of more moisture variation in Utah.

Soil moisture variations may also be responsible for lower r^2 values for the Nevada group in the autumn. The western side of the Great Basin is characterized by both spring and autumn continental moisture influences (Houghton 1969). Upper-level lows trigger rainfall during both seasons, but autumn rainfall occurs when surface temperatures are still warm enough to cause substantial evaporation and to alter the Bowen ratio.

Spearman rank order test results support the idea that trends in 700 mb height data are positively associated with trends in surface temperatures. This test decreases the emphasis on differences between scores or their absolute value, but rather examines their rank order. In 7 of the 8 matched pairs, the magnitude of the rank of 700 mb height trends directly corresponded with surface temperature trends. These results further suggest that trends in the upper atmosphere currents are significantly correlated to surface temperature trends with the noted exceptions, and may be an important contributing factor to temperature variability.

CONCLUSIONS

There is a strong association between seasonal 700 mb height data and surface temperature data in the Great Basin. Only winter surface temperatures fail to be strongly associated to the upper atmospheric heights. The influence of rainfall, in either the summer for the eastern Great Basin or autumn for the western Great Basin, likely decreases the overall association. Regression analysis indicates that significant trends in the mean height of 700 mb pressure occurred during the 41 yr period of observation. These mean height trends are significantly correlated with surface temperature trends when using Spearman rank-order correlation and give credence to the existence of temperature trends.

Short-term temperature changes on the order of decades to centuries will only increase in importance to humankind. Changes in 700 mb height patterns are an important part of these changes and should be accounted. Shifts toward increased meridional flow for any particular region should provide greater temperature variability, depending upon the locations of ridge and trough axes. While there should be commensurate changes within the areas of ridging and troughing, the influence of surface material (e.g land vs water) could dampen the signal.

Hence, ridging off the west coast of the United States would not have as great a surface temperature signal as would the troughing inland. If this is the case, then global temperature trends may be partially a function of grid cell resolution as much as actual temperature changes.

Future studies should address whether 500 mb height trends would correspond with surface temperatures as well, since these height patterns have a greater correspondence to standing (Rossby) waves. In addition, 500 mb height data may give a better perspective on regional scale changes in surface temperatures than 700 mb height data and could provide additional insight into the nature of temperature trends.

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