# commentary and analysis

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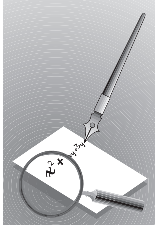

## Comments on "Choice of South Asian Summer Monsoon Indices"

The choice of an appropriate index for the south Asian summer monsoon has been a subject of some controversy and received considerable attention in recent years (Webster and Yang; Goswami et al. 1999). Two major indices are the zonal wind shear index proposed by Webster and Yang (1992, hereafter referred to WYI) and the meridional shear index defined by Goswami et al. (1999, hereafter referred to as GKA; the index is hereafter referred to as MHI). In their recent article in the *Bulletin*, Wang and Fan (1999, hereafter referred to as WF) attempt to provide a dynamical basis for the discrepancies between different indices. Based on outgoing longwave radiation (OLR) data, they define summer monsoon activity in terms of a convection index, CI1, representing OLR anomalies over the center of convective activity around the northern Bay of Bengal. They try to identify centers of circulation variability that are closely associated with the variation of CI1. Based on such examinations, they show that WYI did not represent the first baroclinic response to CI1 correctly, as they averaged the shear over a region where the anomalies were not largest. They recommended the use of a new zonal wind shear index, MCI, a modified version of WYI in which anomalies are averaged over the region where the zonal wind shear response to CI1 is largest. They also take pains to point out that "the southerly shear [i.e., an index like MHI] should be used with caution because the meridional shears do not represent the first baroclinic mode simulated by convective heating" (p. 636 of their article). Here, we argue that WF are incorrect in making this statement and that no higher objectivity is involved in the choice of a zonal wind shear index over a meridional shear index.

We do not understand how WF arrived at the above-mentioned conclusion. In fact, the first baroclinic response to an off-equatorial heat source (Webster 1972; Gill 1980) would certainly have a meridional wind shear associated with it, which is clearly evident in the regression pattern of WF (their Fig. 4c). This basically was the point made by GKA in their paper. It is true that it may not apply as well to an equatorial heat source.

One criticism of the use of the meridional shear (or southerly shear as they call it) is the fact that the "climatological" mean meridional winds are not homogeneous over the region where MHI is defined (see Figs. 1c and 2c of WF). We agree with that. However, MHI is an index for interannual variations of the monsoon and one has to see whether the meridional shear "anomalies" are coherent over this region and not the climatological mean. The meridional shear anomalies are indeed coherent over this region (cf. Fig. 8a of GKA). This must be so, otherwise WF would not get coherent correlation between meridional wind shear and CI1 over this region (Fig. 4b of WF). The fact that MHI and CI1 are well correlated is duly noted by WF on p. 633. Therefore, we do not think that the criticism for using the meridional wind shear index is well founded.

Coming to the question of exercising caution, one has to exercise it in using any index, including the WY index. Wang and Fan show beautifully that the index originally defined by WY, although based on a sound concept, was incorrect in representing the Asian monsoon as they averaged it over a region where the anomalous response to monsoonal heating is neither uniform nor largest! Even now many researchers are blindly using the WY index as defined by WY to define the strength of the Indian monsoon. While WF show nicely why one should exercise caution even using the WY index, they fail to emphasize this point in the article and unduly stress caution for using the southerly shear index.

Finally, what WF recommend as the MCI1 index is nothing but a corrected WY index. The correlations presented in their Table 2 in no way establish that it is a superior index to MHI, as the correlations with AIRI are 0.68 and 0.64, respectively. The fact that MCI1 and MHl correlate significantly (0.51) indicate that they are two aspects of the same first baroclinic response of the atmosphere to an off-equatorial heat source (CI1). This further reinforces our claim that there is no basis for choosing the zonal wind shear index over the meridional shear index.

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## Reply

Dr. Goswami's primary concern is the remarks we made on the "two major indices": the zonal wind shear index proposed by Webster and Yang (1992, hereafter WYI) and the meridional shear index defined by Goswami et al. (1999, hereafter the MHI). He concluded that "while WF (Wang and Fan 1999) show nicely why one would exercise caution even using the WY index, they failed to emphasize this point in the article and unduly stress caution for using the southerly shear index." I appreciate his concern but disagree with his comments on our assessment of the WYI and on our cautious remarks on the use of meridional shear indices. The purpose of this reply is to clarify some misunderstanding in these aspects and to highlight our major points regarding the appropriate choice of the south Asian summer monsoon indices.

### 1. Assessment of the WY index

How should we assess the WYI? Have we failed to emphasize the caution with use of the WYI?

To assess the value of any index, it is essential to first understand the meteorological meaning of the index. One of our major endeavors was to interpret the meaning of the WYI in terms of observed correlation between convection and circulation and based on our theoretical understanding of the tropical atmospheric response to imposed heating. We pointed out that the westerly shear associated with the Indian summer monsoon (ISM) convection is primarily confined to the west of 80°E (Fig. 4 of WF), while the westerly shear associated with the Philippine convection is mainly found east of 80°E (Fig. 6 of WF). Therefore, the WYI defined by the westerly shear from 40° to 110°E in longitude reflects the variability of the convection centers at both the Bay of Bengal (and India) and the vicinity of the Philippines. That also explains in part why the WYI has a relatively low correlation with AIRI (all Indian summer rainfall index). The WYI is, therefore, a measure of the combined convective variability in the two major convection regions in the Asian summer monsoon. It quantifies the variability of the entire tropical Asian monsoon without considering regional differences. The WYI is also adequately defined in the core region of the zonal wind shear (Fig. 1 of WF), thus reflecting well the variability of the large-scale Asian monsoon westerly shear. As long as one understands the meaning of the WYI, one can make good use of it. In this sense, use of WYI need not be cautious unless one decides to use WYI to measure *Indian monsoon rainfall variability*, which, I believe, was not the intention of the original authors.

However, we did point out the limitation of the WYI. We showed that the two convection centers are not significantly correlated in their interannual variations. Therefore, we recommend use of two indices to measure separately the variability of the ISM and the SEASM (southeast Asian summer monsoon). Lau et al. (2000) came up with essentially the same recommendation. This point is one of the primary conclusions of WF, stated in the abstract. Therefore, we did not fail to emphasize the limitation of the WYI.

In summary, the WYI is a useful index that represents the variability of the action center of the Asian monsoon westerly shear and the convective variability of the entire south Asian monsoon region, including both the convection centers located in the Bay of Bengal and the vicinity of the Philippines. It is a meaningful measure of the strength of the broad-scale south Asian summer monsoon. The weakness of WYI is its inability to reflect the regional characteristics. The poor correlation between the two major convection centers suggests the necessity of introducing two regional indices to quantify the ISM and the SEASM. Note that we consider the south Asian summer monsoon to consist of two regional components. The AIRI is a measure of the ISM but not the entire south Asian summer monsoon.

## 2. Remarks on the meridional shear indices

How have we assessed the adequacy of the meridional shear index such as MHI? In the first place, we helped to interpret the meaning of the meridional shear index such as MHI. The MHI is not merely a measurement of the thermally driven Hadley circulation. It is part of the Rossby wave response to the heat source variability over the ISM region and it reflects primarily the rotational component of the winds. By presenting Figs. 3 and 4 in WF, we made it clear that "the MHI defined by Goswami et al. (1999) using the southerly shear averaged in the region (10°–30°N and 70°–100°E) does correlate well with CI1 [the ISM convection index]" (p. 633). We also concluded in our recommendation section (p. 636) that "the ISM circulation indices corresponding to the convection index CI1 can be defined using either westerly shear averaged over (5°–20°N, 40°–80°E) (hereafter WSI1) or southerly shear averaged over the combined region (15°–30°N, 85°–100°E) and (0°–15°S, 40°–55°E) (hereafter SSI1)." Our meridional shear index SSI1 is averaged over two regions, one located at the head of the Bay of Bengal and the other in the western Indian Ocean cross-equatorial flow region. The former overlaps with the area where MHI is defined. The MHI and SSI1 are highly correlated with a linear correlation coefficient of 0.72. The above two statements clearly indicate that we did not place higher objectivity on the choice of a zonal wind shear over a meridional shear index.

On the other hand, we also noted from Fig. 1 of WF that the region where the MHI is defined "is not located at the action center of the meridional vertical shear" (p. 632). We regard this as an undesirable property. Hence, the southerly shear we defined, SSI1, represents not only the variability center but also the action center of the vertical meridional shear: the vertical shear defined in the western Indian Ocean cross equatorial flows is located very close to the maximum monsoon meridional shear (Fig. 1 in WF).

As a primary dispute, Dr. Goswami said that "they (WF) take pains to point out that 'the southerly shear (i.e., index like MHI) should be used with caution because meridional shears do not represent the first baroclinic mode simulated by convective heating.'" Unfortunately, this is a distorted and incomplete quote. The original sentence is stated as follows: "The southerly shear should be used with caution because the meridional shears do not represent *well* the first baroclinic mode stimulated by the convective heating, *especially* since *the SSI2* is dominated by upper-tropospheric circulation anomalies and strongly influenced by the south Asian subtropical high" (emphasis added).

Here, we emphasized that the meridional shears do not represent *well* the heating-induced baroclinic mode but did not say they *do not represent* the first baroclinic mode. Furthermore, we particularly refer in this problem to the SSI2, which is the southerly shear index defined over the Philippine Sea, not the MHI defined over the Bay of Bengal. We do not see anything wrong with the above statement given the fact that we have already clearly interpreted the meaning of MHI in section 3 of WF.

The reasons we said that the meridional shears do not represent well the convective heating-induced lowest baroclinic mode follow. The vertical shear between 850 and 200 hPa observed in the Asian monsoon region is not only stimulated by latent heat released in convection but also by other heat sources such as strong sensible heat over the Plateau of Tibet (Li and Yanai 1996), which contributes to the upper-tropospheric circulation but has little effect on the low-level circulation. The vertical shear is, therefore, stimulated not only by the convective heating. In this sense, the vertical shear does not always represent the first baroclinic mode stimulated solely by the convective heating. Figure 2 of WF indicates that for the mean monsoon, the low-level and upper-level meridional winds are far from the structure of the first baroclinic mode. In the correlation maps (Figs. 3 and 5 of WF), the 180° out-of-phase relationship between 850 and 200 hPa is better for zonal wind than meridional wind component, especially for the Philippine Sea heat source. Our cautious comment particularly refers to the weakness of the meridional shear response to the Philippine convection heat source.

## 3. Appropriate choice of the south Asian summer monsoon indices

After he mentioned two major indices for the south Asian summer monsoon, Dr. Goswami stated, “WF attempts to provide a dynamical basis for the *discrepancies* between different indices” (emphasis added). In fact, we were not interested in comparing the discrepancy between the WYI and the MHI. As stated in our paper (p. 630), “Our focus is placed on understanding the dynamical basis for adequate choice of meaningful indices.” Our results, shown in section 3, “provide a basis for defining dynamically coherent monsoon indices [between convection and circulation]” (p. 630).

Our major conclusion reflect our purposes. One of our major conclusions is that the variability in convection exhibits a high degree of coherency with circulation variability. This can be understood, in the lowest order, as a Rossby wave response to heat source. This provides a physical basis for choice of circulation indices dynamically consistent with convection and for understanding of the meanings of various indices. In this sense, the south Asian monsoon can be described by either circulation index or convective index. However, as we discussed in our paper, discrepancies can exist between the indices defined using circulation and convection. We have speculated on three possible sources for the discrepancies and pointed out that it is important to understand their physical cause.

After we unravel the meaning of the WYI and MHI, it is obvious that they are not comparable, because they represent variability in different domains. If one subjectively uses AIRI as a test base to judge the usefulness of a proposed index, the MHI is perhaps better than WYI, because the MHI–AIRI correlation appears to be significantly higher than the WYI–AIRI correlation (Goswami et al. 1999). But, as mentioned earlier, the use of AIRI as an index for the south Asian summer monsoon is inadequate. Furthermore, if one finds an index (such as MHI) that is highly correlated with AIRI, why do we need two for the same ISM? The indices of AIRI and MHI belong to the same set of indices that measures the variability of the Indian summer monsoon, whereas the WYI represents a broader-scale south Asian summer monsoon.

*Acknowledgments.* This is the School of Ocean and Earth Science and Technology Publication No. 5012 abd IPRC Publication No. 40.

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*The International Pacific Research Center (IPRC) is sponsored in part by the Frontier Research System for Global Change.

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## A New Minimum Temperature Record for Illinois

A recent article in the *Bulletin* (Schmidlin 1997) described state minimum temperature records that were tied or broken in six Midwestern states in January 1994 and February 1996. Among those records was –35°F (–37.2°C) at Elizabeth 5S, Illinois, on 3 February 1996, which tied the Illinois cold record set on 22 January 1930 at Mount Carroll. A temperature of –36°F (–37.8°C) was reported at Congerville 2NW, Illinois, on 5 January 1999, thus establishing a new state cold record. The purpose of this note is to update the 1996 Illinois cold record reported by Schmidlin (1997) and describe the circumstances of the new record.

Congerville 2NW is located in the central region of Illinois in Woodford County (40°37′N, 89°14′W) at an elevation of 194 m. The station is on a farm in the flat bottom land along the Mackinaw River with hills rising 40 m above the valley within 1–2 km of the station. The surrounding terrain is rolling farm land and moderately wooded. The station opened in 1978 recording precipitation only and began recording temperature in 1996. Maximum and minimum temperatures are read daily at 0800 LST from liquid-in-glass max/min thermometers in a cotton region shelter, all supplied by the National Weather Service (NWS). The last full inspection of the station by the Data Acquisition Program Manager (DAPM) at the NWS Office at Lincoln (ILX), Illinois, was on 20 November 1997 and the last station visit was on 20 August 1998, when equipment was observed to be in good condition.

A snowstorm on 1–3 January 1999 was followed by an intensely cold and dry air mass. On the morning of 5 January, high pressure (103.6 kPa) was centered over the Gulf of Mexico coast of Alabama with a ridge northward across Illinois. Temperature at the 850-mb level was −14°C with a dewpoint of −38°C. Clear skies and calm conditions allowed maximum radiational cooling and cold air drainage into valleys. The temperature at Congerville 2NW at the 0800 observation on 5 January 1999 was −31°F (−35.0°C) with a minimum of −36°F and maximum of 3°F (−16.1°C) in the previous 24 h. The minimum at Congerville 2NW was the coldest temperature in the contiguous United States that day (D. H. Hickcox 1999, personal communication). Snow depth was 33 cm on the morning of the record, mostly due to 31 cm of new snow that fell during the 1–3 January storm. A nearby official station, Havana 4NNE, with an exposure similar to that at Congerville 2NW reported a low of −30°F (−34.4°C) on 5 January. An unofficial station about 1 km from the Congerville 2NW site reported −34°F (−36.7°C) and another unofficial station about 10 km from Congerville reported −33°F (−36.1°C). The minimum of −25°F (−31.7°C) at Urbana–Champaign tied the cold record for that site, where temperature data extend back 111 yr. The mean temperature for the month at Congerville 2NW was 21.2°F (−6.0°C), which is near normal for the region.

On the morning of the record, the observer called the NWS ILX office concerning the extreme temperature. The hydrometeorological technician on duty questioned the observer about the time of observation, location of equipment, any recent moves, validity of the thermometers, and whether the observer checked the backup thermometer for comparison. The DAPM contacted the observer by telephone to ensure that proper observing and recording practices were followed and to inquire about any recent moves of equipment or changes in equipment status. These checks verified that valid procedures were followed before, during, and after the record observation, and that the cooperative station had recently been visited and subjected to an inspection.

The Congerville 2NW station has official equipment supplied by the NWS, the observer followed correct procedures, the station was inspected by the NWS about 5 months earlier, and all equipment was in good working order. The −36°F temperature at Congerville 2NW on 5 January 1999 is accepted as a new state cold record for Illinois.

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# Spatial Representativeness of Temperature Measurements from a Single Site

## Abstract

This paper discusses the spatial distribution of the early spring minimum temperature and the length of the growing season in eastern Colorado. It is shown that even in the relatively homogeneous landscape, there are significant differences in long-term trends of these data. The authors conclude that the direction and magnitude of regional climate trends cannot be reliably inferred from single-site records, even over relatively homogeneous terrain.

## 1. Introduction

It is common practice to use single-station weather data to characterize the climate over a region. Examples include Alward et al. (1999), Williams et al. (1996), and Singer et al. (1998). In this correspondence, we report on the representativeness of a single weather station within a region of reasonable uniform vegetation and topography. Such a region should provide one of the better locations to evaluate the representation of weather data from one location.

Warming has been documented at the Central Plains Experimental Range (CPER) site in northeast Colorado. There is a concern with respect to the consequent potential effects on the short grass steppe of Colorado associated with an increase in average minimum temperature for this region (Kittel 1990; Alward et al. 1999). An inference of the Alward et al. (1999) paper was that the density of *Bouteloua gracilis*, a dominant native grass of the region, would decrease as a result of only a few degrees increase in the average spring minimum temperature, while the density of exotic grasses and forbs would increase. Melillo (1999) amplified on the results of Alward et al. (1999) to emphasize the significance of an increase in minimum temperature as an example of the relation between climate change and the earth's ecosystem.

The conclusions of the Alward et al. study, however, are based on weather data from only one location. The question of the spatial representativeness of the CPER weather data remains unanswered. We used other available sites in eastern Colorado for the years for which CPER climate data are available to investigate this question (Tables 1 and 2 and Figs. 1 and 2 show the stations used).[1]

## 2. Analysis

We analyzed the trends for the period of early spring (15 March–30 April) for the years 1970–96, since the temperatures at the beginning of the growing season would have the most effect on the growth of cool-season grasses. We also included length of the growing season to provide another perspective on this subject. We analyzed two periods of records corresponding to the first year when CPER climate data became available and the first year used in the Alward et al. (1999) study. The values of the trends and their statistical significance of average minimum temperature and the length of growing season[2] for the two periods of record for each of the stations are shown for eastern Colorado. The longer period of temperature record is shown graphically in Figs. 1 and 2, in order to show how the shorter period of record relates to the weather data collected earlier in this century.

The average minimum temperature for early spring for the period 1948–96 has a mixed signal, although most stations show a slight increase in average minimum temperatures. The statistically significant trends ($p \leq 0.2$; this value of $p$ is used to define significance since the sample size was relatively small) are for Fort

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[1] These include sites used in the National Climatic Data Center U.S. Historical Climatology Network [Cheyenne Wells, Eads 2S (2 mi south of Eads), Fort Collins, Fort Morgan, Holly, Lamar, Las Animas, Rocky Ford 2SE (2 mi southeast of Rocky Ford), and Wray, Colorado] and one other [Akron 4E (4 mi east of Akron), Colorado]. The number of years for which data are available at each site is also presented. There are, unfortunately, changes in the time of observation (Karl et al. 1986) and the type of thermometer used (Quayle et al. 1991) at several of the stations. A change from an afternoon daily observation to a morning observation, for example, causes a cool bias in minimum temperatures. The conversion of thermometers to the new electronic maximum–minimum temperature system produces less than 0.5°C differences in the minimum temperature with the older system, although their tendency to be placed closer to buildings to minimize the amount of electrical cable that needs to be buried would tend to produce warmer temperatures. Each of these effects, of course, confounds further the interpretation of trends from just one site.

[2] The growing season is defined as the number of days between the last and first 0°C date during a year. This definition, of course, is actually the number of days without a freezing temperature at the height of the thermometer at the weather observation site.

Table 1. Trends in spring daily mean minimum temperature in degrees Celcius per year (15 Mar–30 Apr 1948–96) and number of growing season days per year (1940–96) for weather stations in eastern Colorado. Here, *n* = years of data. Values of *n* less than 49 indicate data for one or more years were missing.

| **Spring daily mean minimum temperature** | | | | **Number of growing season days** | | | |
|---|---|---|---|---|---|---|---|
| **Station** | **Slope** | ***p* <** | ***n*** | **Station** | **Slope** | ***p* <** | ***n*** |
| CPER | 0.06 | 0.1 | 49 | CPER | 0.75 | 0.001 | 57 |
| Fort Collins | 0.10 | 0.001 | 49 | Fort Collins | 0.42 | 0.002 | 57 |
| Fort Morgan* | 0.06 | 0.02 | 48 | Fort Morgan* | 0.07 | 0.5 | 43 |
| Akron 4E | 0.01 | 0.5 | 49 | Akron 4E | –0.03 | 0.5 | 57 |
| Wray | 0.02 | 0.5 | 44 | Wray | 0.37 | 0.05 | 37 |
| Cheyenne Wells | 0.07 | 0.01 | 48 | Cheyenne Wells** | 0.12 | 0.5 | 40 |
| Eads 2S | 0.00 | 0.5 | 45 | Eads 2S | 0.08 | 0.5 | 41 |
| Holly* | –0.03 | 0.5 | 47 | Holly* | 0.11 | 0.5 | 41 |
| Lamar | 0.01 | 0.5 | 47 | Lamar | 0.09 | 0.5 | 51 |
| Las Animas | 0.06 | 0.01 | 47 | Las Animas | 0.24 | 0.2 | 45 |
| Rocky Ford 2SE | 0.03 | 0.5 | 49 | Rocky Ford 2SE | –0.04 | 0.5 | 56 |

*from 1949 to 1996
**from 1941 to 1995

Table 2. Trends in spring daily mean minimum temperature in degrees Celcius per year (15 Mar–30 Apr 1948–96) and number of growing season days per year (1970–96) for weather stations in eastern Colorado. Here, *n* = years of data. Values of *n* less than 27 indicate data for one or more years were missing.

| **Spring daily mean minimum temperature** | | | | **Number of growing season days** | | | |
|---|---|---|---|---|---|---|---|
| **Station** | **Slope** | ***p* <** | ***n*** | **Station** | **Slope** | ***p* <** | ***n*** |
| CPER | 0.09 | 0.5 | 27 | CPER | 0.84 | 0.1 | 27 |
| Fort Collins | 0.12 | 0.1 | 27 | Fort Collins | 0.47 | 0.5 | 27 |
| Fort Morgan | 0.03 | 0.5 | 27 | Fort Morgan | 0.51 | 0.2 | 22 |
| Akron 4E | 0.01 | 0.5 | 27 | Akron 4E | –0.03 | 0.5 | 27 |
| Wray | 0.01 | 0.5 | 24 | Wray | 0.39 | 0.5 | 17 |
| Cheyenne Wells | 0.09 | 0.2 | 26 | Cheyenne Wells | 0.21 | 0.5 | 20 |
| Eads 2S | 0.06 | 0.5 | 27 | Eads 2S | –0.20 | 0.5 | 15 |
| Holly | –0.02 | 0.5 | 26 | Holly | 0.44 | 0.5 | 24 |
| Lamar | –0.13 | 0.1 | 27 | Lamar | –0.25 | 0.5 | 24 |
| Las Animas | 0.07 | 0.5 | 26 | Las Animas | 0.48 | 0.2 | 21 |
| Rocky Ford 2SE | 0.06 | 0.5 | 27 | Rocky Ford 2SE | 0.04 | 0.5 | 26 |

Collins, Cheyenne Wells, Fort Morgan, and Las Animas, Colorado, as well as at CPER. The remaining six sites have statistically insignificant trends. Based on the regression, the CPER has warmed by 3.0°C (Fort Collins by 4.8°C), while Holly, Colorado, cooled by 1.4°C since the late 1940s. Fort Collins's minimum temperature trends are atypical in the magnitude of change as the slope is almost three times as great as the average slopes at the other sites. Holly can be viewed as atypical in the direction of change (i.e., the only site with a negative slope in minimum springtime temperature).

CPER, Fort Collins, Las Animas and Wray, Colorado, show a statistically significant ($p \leq 0.2$) lengthening of the growing season during the period 1940–96, although five of the remaining seven sites had positive slopes. Based on the regression line slopes, the growing season at CPER has lengthened by 43 days, while it has shortened at Rocky Ford, Colorado, by 2 days. The increase of growing season length at CPER was about 2.5 times the average of the other sites; at Rocky Ford and Akron 4E, Colorado, the growing season had shrunk.

Table 1 shows that 9 of the 22 trends are statistically significant ($p \leq 0.2$). Fort Collins is a large, rapidly growing city and is presumably showing an urban heat island effect. Excluding

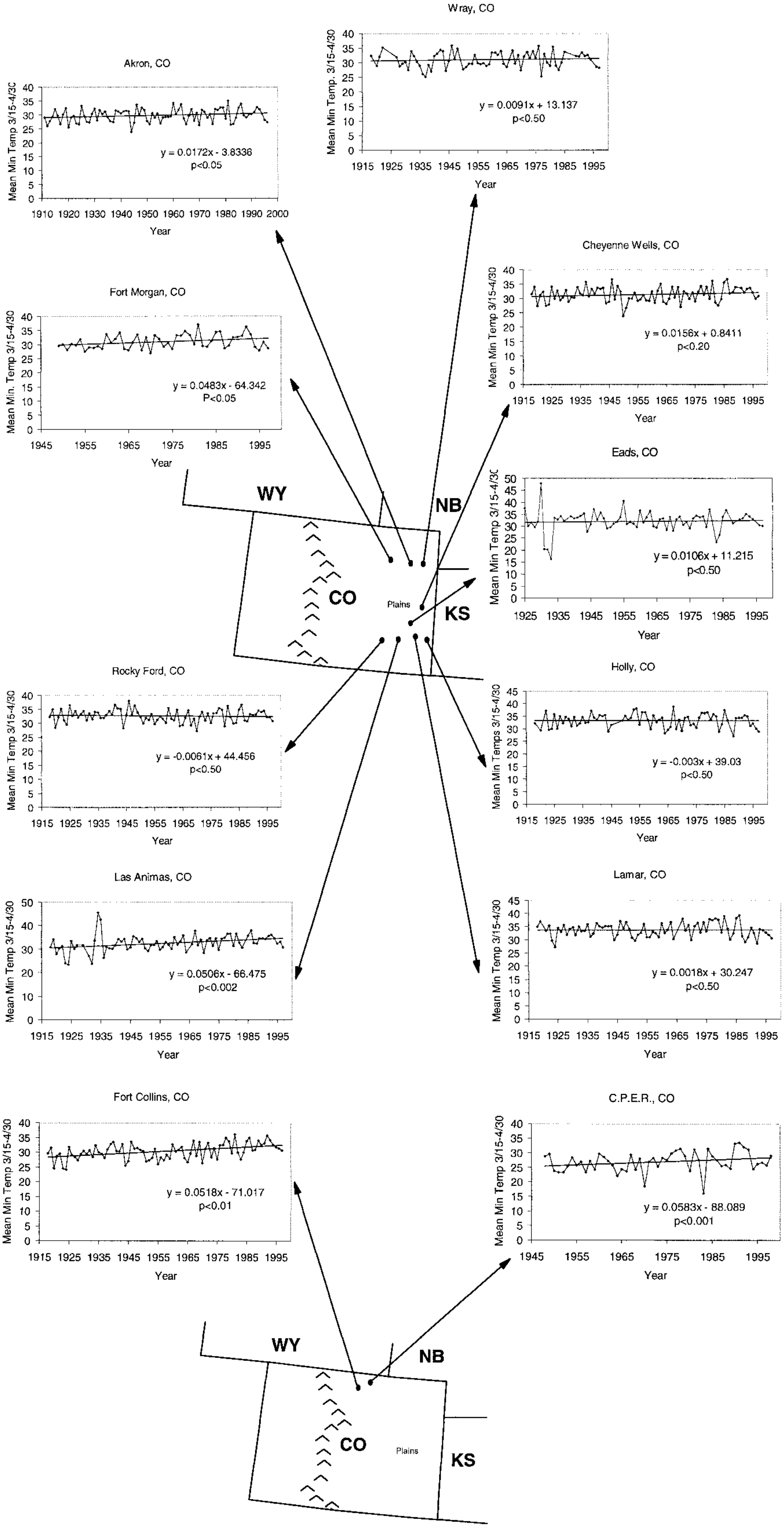

FIG. 1. Spring mean minimum temperatures (°F) for 15 Mar–30 Apr for eastern Colorado locations.

Fort Collins, 7 of the 20 trends in the rural and small-town portions of eastern Colorado show statistically significant warming of which CPER is the most pronounced.

Shorter-term trends were also spatially variable. For the period 1970–96 (Table 2), only Fort Collins, Cheyenne Wells, and Lamar, Colorado, have statistically significant trends ($p \leq 0.2$) in early spring minimum temperature. Fort Collins and Cheyenne Wells have increases in early spring minimum temperature, while Lamar has a cooling. The changes over the 27 years, based on the trend analysis, range from +3.1°C at Fort Collins to –3.6°C at Lamar. The length of growing season trends for the period 1970–96 show a statistically significant ($p \leq 0.2$) lengthening of 23 days for CPER, 13 days for Fort Collins, and 10 days for Las Animas. Of the 22 trends, 6 are statistically significant at $p \leq 0.2$, with 5 showing a warming and 1 a cooling trend. Excluding the urbanized Fort Collins site, 5 of the remaining 20 trends are statistically significant.

This analysis leads to several conclusions. Only about one-third of the nonurban sites exhibit significant positive slopes for minimum early spring temperature and growing season duration. Also, since 1970, the CPER site has an atypical trend in the weather data analyzed.

Regional averages constructed from such point mea-

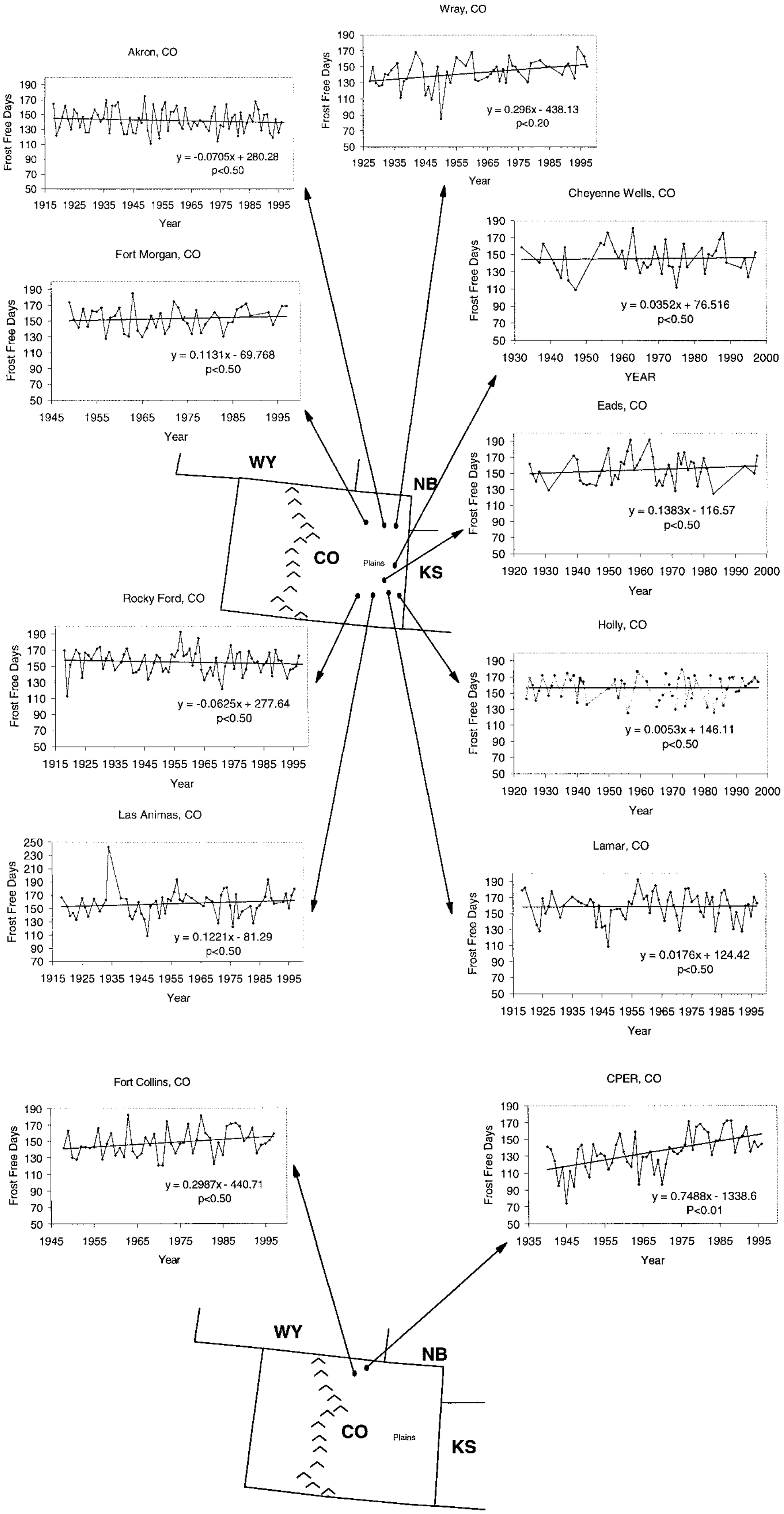

FIG. 2. Growing season days for eastern Colorado locations.

surements can, therefore, be misleading. The lack of regional consistency in early spring temperature trends at nonurban sites in eastern Colorado supports caution in drawing inferences about temporal change in regional grassland vegetation from individual localized measurements of climatic and ecological state variables.

## 3. Conclusions

As a general conclusion, the spatial variations in climate variables indicate that the direction and magnitude of regional climate trends *cannot be inferred from single-site records, even over relatively homogeneous terrain.*

*Acknowledgments.* This paper was supported in part by the National Science Foundation Long-Term Ecological Research Grant No. DEB-9424129.

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