Reply

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ABSTRACT

It has been suggested that previous results indicating an increase in surface temperatures over the past 40 years within the coldest air masses at four stations in the western North American Arctic may be attributed to the shorter residence time of these air masses through the time period. If true, this contradicts the original contention that these air masses have undergone physical character changes, possibly attributed to anthropogenic sources, during the period. A reevaluation of the data at two of these stations indicates that a long-term warming is, in fact, taking place even when residence time is kept constant. Thus, it is suggested that changes in the physical character of these very cold air masses are due to factors other than residence time.

1. Introduction

Burn (1993) offers some important suggestions that relate to results from our previous work (Kalkstein et al. 1990) involving frequency and character changes of very cold air masses in the western North American Arctic. We suggest that the frequency of very cold air masses has generally decreased over the past 40 years, while simultaneously they have become warmer by between 1° and 4°C at selected stations.

Burn suggests that the shorter length of residence time of these very cold air masses may be partly responsible for this apparent increase in temperature. He points out that the lowest air temperatures during cold airmass invasion at valley stations may occur several days after the initial intrusion of the air mass due to enhanced time of longwave radiative loss and cold air drainage into valley floors. Thus, if residence time of these coldest air masses is reduced, the lowest temperatures associated with these air masses may appear to have increased.

Considering that this is a reasonable (but yet unproven) hypothesis, we attempt to perform a few simple empirical tests on two of the sites described in our original manuscript, Fairbanks and Gulkana, Alaska, to determine if Burn's suggestions are valid. Of the four sites originally evaluated, Fairbanks and Gulkana demonstrated the smallest mean character change within the coldest air mass: +2.3°C for Fairbanks and +1.1°C for Gulkana (Kalkstein et al. 1990). Thus, we have put our original contention to a harsher test by selecting these sites.

In this reevaluation we first attempted to isolate periods of similar incursion length of very cold airmass category 11 at Fairbanks and category 21 at Gulkana [refer to Kalkstein et al. (1990) for the meteorological properties of these air masses] through the period of study (1948 through 1986) to determine if the lowest temperatures do, in fact, occur several days after the onset of the airmass invasion. Second, we have evaluated the mean temperatures of the *first day* of each airmass incursion to determine if these temperatures have changed through the time period. The first day may be isolated through the use of our "temporal synoptic index" (TSI), which produces a daily calendar of air masses for each locale (Kalkstein and Corrigan 1986). The calendar is used in this study to determine precisely which day of each incursion represents the first day. Thus, we have controlled for temporal changes in residence time, which Burn believes might be polluting our data. If Burn is correct, we would expect that first-day temperatures during the period would *not* be expected to increase, as the temperature changes that we previously uncovered were artifacts of a shorter residence time of the air masses through the study period. If first-day temperatures do show an increase, however, this indicates that processes other than those associated with residence time are contributing to these thermal changes. Such a finding would add validity to our suggestion that the physical character of these air masses has shown signs of modification over the past 40 years.

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2. Results and discussion

An evaluation of consecutive day runs of each of the coldest air masses confirms Burn's assertion that the lowest temperatures occur several days after the incursion of the air mass (Fig. 1). The lowest temperatures for airmass category 11 in Fairbanks occur six days after the onset of its intrusion. A similar finding was uncovered for category 21 at Gulkana (although the lowest temperature is reached on the third day), lending credence to Burn's suggestion that the persistence of stable conditions associated with the coldest air masses in valley locations is necessary to generate the coldest conditions. We strongly concur with Burn that it is necessary to establish stations at nonvalley sites to evaluate boundary-layer disparities in airmass character that occur between sites at different elevations.

This finding does not, however, in any way eliminate the possibility that temporal modifications in airmass character are occurring at valley locales, which are not related to site-specific boundary-layer conditions. For example, although it is acknowledged that the mass of air becomes colder as residence time increases, this would not explain changes in the physical character of the air mass if residence time is kept *constant.* This is the reasoning behind the first-day evaluation: any long-term thermal changes during the first day of residence could not be attributed to microenvironmental factors unique to valley sites.

The first-day evaluation for coldest category 11 at Fairbanks revealed a statistically significant mean temperature increase during the period of record (Figs. 2 and 3, Table 1). Using the procedure outlined in Kalkstein et al. (1990) to determine temperature change during the period of record, the mean temperature of category 11 for the first day of its residence time increased by 2.82°C during the period of record. This highly statistically significant increase was even greater than the mean temperature change for all days of category 11 noted in Kalkstein et al. (1990). Most of the change was accounted for by minimum temperature, which increased by 3.33°C during the period. Maximum temperature increased by 1.33°C, but the slope of the increase was not statistically significant.

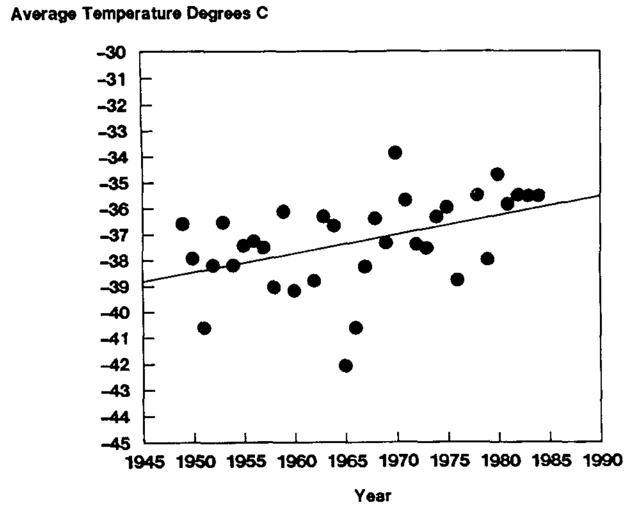

FIG. 2. Mean temperature on the first day of a category 11 intrusion at Fairbanks.

Although the character change was not as dramatic at Gulkana, a mean temperature increase during the first day of residence time was noted for coldest category 21 through the period of record (Table 1). The mean temperature of this category increased by 2.22°C during the period of record, which was also greater than the change noted for all category 21 days in Kalkstein et al. (1990). Much like the Fairbanks results, mini-

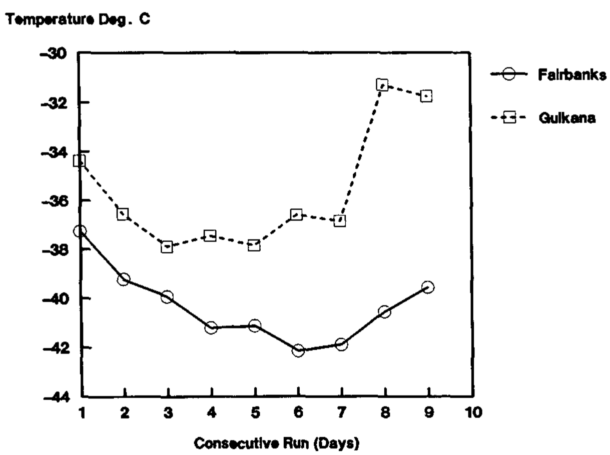

FIG. 1. Mean daily temperature trends during outbreaks of the coldest air masses at Fairbanks (category 11) and Gulkana (category 21).

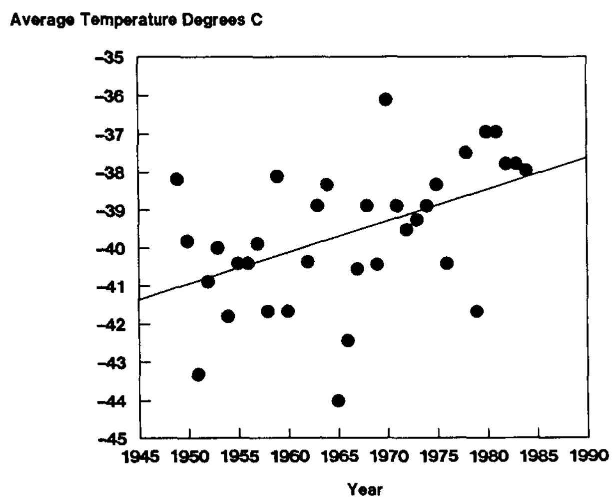

FIG. 3. Mean minimum temperature on the first day of a category 11 intrusion at Fairbanks.

TABLE 1. Summary statistics for first-day airmass temperature trends: Fairbanks and Gulkana.

Category	Change: 1948 through 1986[a]	b*	F value	Prob > F
Fairbanks: Airmass category 11				
Mean daily temp.	+2.82°C	0.072	7.65	0.0093
Mean minimum temp.	+3.33°C	0.085	9.97	0.0035
Mean maximum temp.	+1.33°C	0.034	1.06	0.3108†
Gulkana: Airmass category 21				
Mean daily temp.	+2.22°C	0.057	2.05	0.1637†
Mean minimum temp.	+2.61°C	0.067	2.11	0.1573†
Mean maximum temp.	+1.17°C	0.030	0.44	0.5110†

[a] Refer to Kalkstein et al. (1990) for calculation of these values.
* Positive slopes indicate upward temperature trends.
† Relationship is not significant at the 0.050 level.

mum temperature accounted for most of the change. The level of significance for the Gulkana results, however, was lower than Fairbanks, although these values were considerably more robust than those found for all category 21 days within our original manuscript.

The results of this brief reevaluation strongly suggest that the physical character of the coldest air masses at these two locales is changing. It is possible that in Fairbanks a portion of the change is attributed to local urban effects. This is certainly not the case, however, for Gulkana, which is distant from any urban area. In any case, these alterations appear to be independent of microenvironmental factors common to valley sites and are not influenced by the residence time of the air mass as suspected by Burn. As stated in our original manuscript, we are still unprepared to attribute these physical changes to anthropogenic sources, but steps are presently under way to examine this question more precisely. Dunne (1991) has recently completed a detailed synoptic-scale study using procedures from our original manuscript for six additional sites in the Canadian Arctic: Norman Wells, Mould Bay, Fort Reliance, Cambridge Bay, Coral Harbour, and Clyde. Dunne notes that, ". . . the frequencies of the coldest synoptic categories appear to have decreased while . . . the temperatures of the coldest air masses seem to have increased . . ." at these stations. In addition, he notes that the majority of these changes were determined to be statistically significant (Dunne 1991). These sites, along with the four evaluated in our original manuscript, are also located at lowland elevations and valley sites, underscoring the importance of Burn's concern pertaining to the paucity of upland locations. In addition, the Climate Change Division of the U.S. Environmental Protection Agency is funding a study to develop a circumpolar airmass evaluation using additional data from eight sites in the Russian Arctic. If similar results are uncovered for the coldest air masses there, this will provide strong evidence that a long-term climate change is under way at high latitudes. The final step of this evaluation will be an attempt to link the detected warming to human activity using a zonality index of large-scale circulation patterns aloft. As pointed out in our original manuscript, if thermal characteristics of these very cold air masses are changing independent of general circulation pattern changes, ". . . this will add credence to the notion that the changes in meteorological character within these air masses are anthropogenically derived" (Kalkstein et al. 1990).

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