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The Urban Heat Island Effect at Fairbanks, Alaska

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With 6 Figures

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Summary

Using climatic data from Fairbanks and rurally situated Eielson Air Force Base in Interior Alaska, the growth of the Fairbanks heat island was studied for the time period 1949–1997. The climate records were examined to distinguish between a general warming trend and the changes due to an increasing heat island effect. Over the 49-year period, the population of Fairbanks grew by more than 500%, while the population of Eielson remained relatively constant. The mean annual heat island observed at the Fairbanks International Airport grew by 0.4 °C, with the winter months experiencing a more significant increase of 1.0 °C. Primary focus was directed toward long-term heat island characterization based on season, wind speed, cloud cover, and time of day. In all cases, the minima temperatures were affected more than maxima and periods of calm or low wind speeds, clear winter sky conditions, and nighttime exhibited the largest heat island effects.

1. Introduction

"Urban heat island" is a term used to describe the effect a city's urban development and human activities have upon air temperatures in and surrounding a city. Ideally, a urban heat island is the temperature found at a given location within the city subtracted from the temperature that would be measured at that same location without the presence of the city. Since such a measurement is not possible, two surrogate techniques can be applied toward assessing a heat island. The heat island magnitude can be approximated by taking the simultaneous temperature difference between an urban locale and any nearby rural location with similar geographic features. This technique is excellent for determining the magnitude and detailed characteristics of the heat island at any given time, but this type of information is not available outside of case-specific studies. A second approach analyzes the trends of differences in the climatological records between a station within the city and a nearby rural locale. This approach will reflect long term fluctuations in the heat island, but is limited in its ability to assess the magnitude of the heat island by the proximity of the recording station microclimates.

Urban heat islands can develop by any of a number of accepted mechanisms. The most conspicuous influence is the direct release of excess heat by human activities from within the city. This effect, known as anthropogenic heat release, includes heat escaping from cars, homes, factories, or any other human source. Man-made modifications of urban surface characteristics account for a second cause of heat island development. One of these surface modifications includes urban-rural differences in the density of vegetation. Evapotranspiration processes in plants help to cool an area; thus, a significant urban vegetation deficit could result in higher temperatures. Furthermore, the synthetic surfaces of cities differ in surface roughness, thermal conductivity, and albedo; all of which can affect the way incoming solar radiation transfers thermal energy to an area. In addition, any air pollution layers can affect the balance between incoming and reflected solar radiation, leading to temperature fluctuations (Bowling, 1984). The relative influence of each of these mechanisms depends upon the specific area and situation under consideration. For instance, the cold, dark winters of interior Alaska provide a unique way of eliminating almost all possible solar or vegetative contributions to an urban heat island. Thus, during the sub-arctic winter, the relative warming effects of anthropogenic heat release should be isolated (Simmonds and Keay, 1983).

Studies of the urban heat island at Fairbanks, Alaska are not new. Bowling and Benson (1978) conducted in-depth studies of the heat island during the late 1970's, based on the first stratagem described above. In several case studies, they found that under certain conditions, heat islands of as much as 11 °C can develop between downtown and outlying recording stations. Their research was based upon local temperature probes and mobile thermocouple readings taken on traverses across the city on a number of trials. They definitively demonstrated the existence of a strong urban heat island in place by the late 1970's, at least when the right atmospheric conditions prevailed.

By comparison, our study concentrates on the use of comprehensive climatological records for the characterization of the Fairbanks heat island effect. In particular, heat island characteristics and changes were examined as a function of season, temperature, wind speed, and cloud cover. During the last 49 years, the temperatures for all of Interior Alaska increased dramatically. The best historical record of this large-scale climate trend is derived from the weather records at Fairbanks, but any general warming seen in the Fairbanks record can not be isolated from a growing heat island effect when studying Fairbanks alone. For this reason, the weather records from nearby Eielson Air Force Base provide the key to the detection and characterization of the climatological significance of the Fairbanks heat island effect. Only after making comparison with these records can we properly understand the characteristics of the heat island itself or accurately depict the nature of the general warming trend that has been experienced in Interior Alaska.

2. Stations, Climate and Data

Alaska has three primary climate regimes – the southern maritime, the northern tundra, and interior continental – which are delineated by the Alaska Range in the south and the Brooks Range in the north, respectively. The maritime zone is a region of mild climate, bounded to the north by the Alaska Range, and it includes the Panhandle, the coast along the Gulf of Alaska, and the Aleutian Islands. Cloudy skies, successive wet days, dampness, fogginess, and occasional gale winds are typical. Annual precipitation is heavy in most of the area, varying from 500 mm at Cook Inlet to 2300 mm in the Panhandle. The southeast coast can receive more than 5000 mm per year and the abundant snowfall feeds the many glaciers in the region. Summers are cool and winters are relatively mild.

The area north of the Brooks Range (northward from 68° N) is the tundra zone, often referred to as the North Slope, where winter is marked by weeks of continuous darkness and summer brings continuous daylight. The winters are cold and long and the summers are very short and cool. The winds of the North Slope are moderate to strong and thereby weaken the surface inversions in winter, especially when compared to the strong semi-permanent winter surface inversions experienced in Interior Alaska. In addition, these strong winds generate extremely cold wind-chill temperatures. When open water is present near the coastlines, advection off the Arctic Ocean can act to ameliorate the extreme winter cold. The warmest month of the year is below 10 °C and the average annual precipitation is less than 200 mm.

The Interior of Alaska is defined as the continental zone, situated north of the Alaska Range and south of the Brooks Range and is characterized by short, relatively warm summers and harsh winters. This zone has an average annual precipitation of about 300 mm. For half of the year, the ground is covered with snow that accumulates to a depth of approximately one meter. Westerly or southwesterly wind advecting warmer air from the Bering Sea may break the extreme winter cold for a week or so at a time. However, the average January temperature is about −23 °C and the extremes can get as low as −51 °C or colder in deeper protected valleys. Unlike the other climate zones, the interior is subject to a strong surface inversion during the winter months when very light winds and extended periods of mostly clear skies prevail (Billello, 1966; Wendler and Jayaweera, 1972). These inversions act to trap anthropogenic emissions near the surface, thereby enhancing the magnitude of the urban heat island effect.

In our study, we examined climate trends and differences between Fairbanks and Eielson Air Force Base (AFB) (Fig. 1). We chose these stations based on population growth differences, similar geography and topography, data continuity and climatology. Originally, we had also used other stations in Interior Alaska, namely Nenana, Ft. Greely, Delta Junction, and Tanana. However, Eielson's climatic data were the most similar to the Fairbanks data set. In Fig. 2, the urban growth of Fairbanks is demonstrated by rapid population growth which began in Fairbanks in the 1970's and has continued over most of the study period. Meanwhile, the Eielson AFB population has remained fairly constant for the last fifty years except for a brief period in the late 1960's during the Vietnam conflict. Both stations are located in the Tanana Valley, separated by 32 km and 35 m of altitude. Because both stations lie on the valley floor, and hence are both affected by surface inversions with lapse rates in excess 10 °C per 100 m near the surface during the long semi-arctic winter.

Meteorological data were acquired from the NCDC's Surface Aviation hourly observation

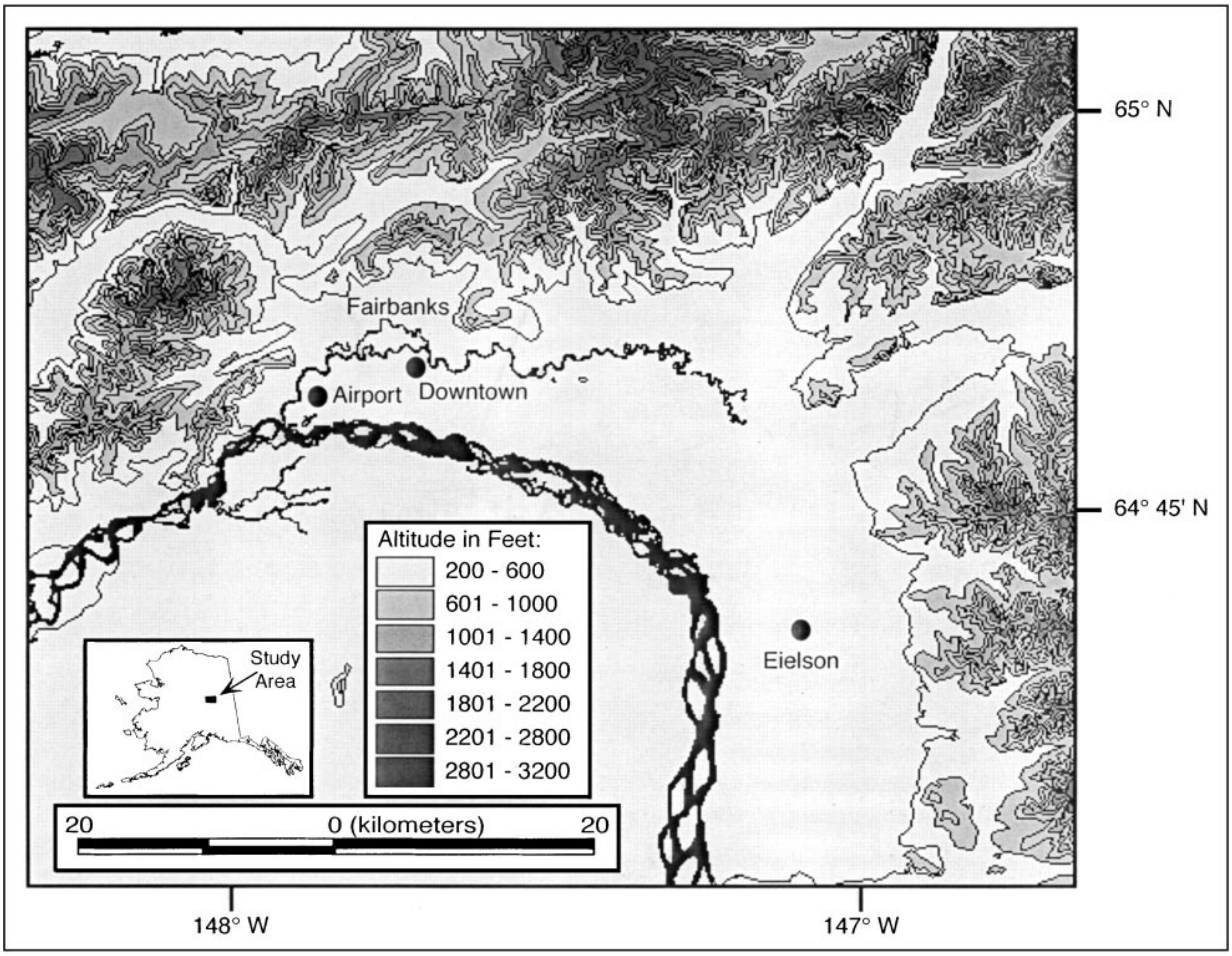

Fig. 1. Map of study area in Interior Alaska, showing the topographic similarity and geographic proximity of the two weather recording stations

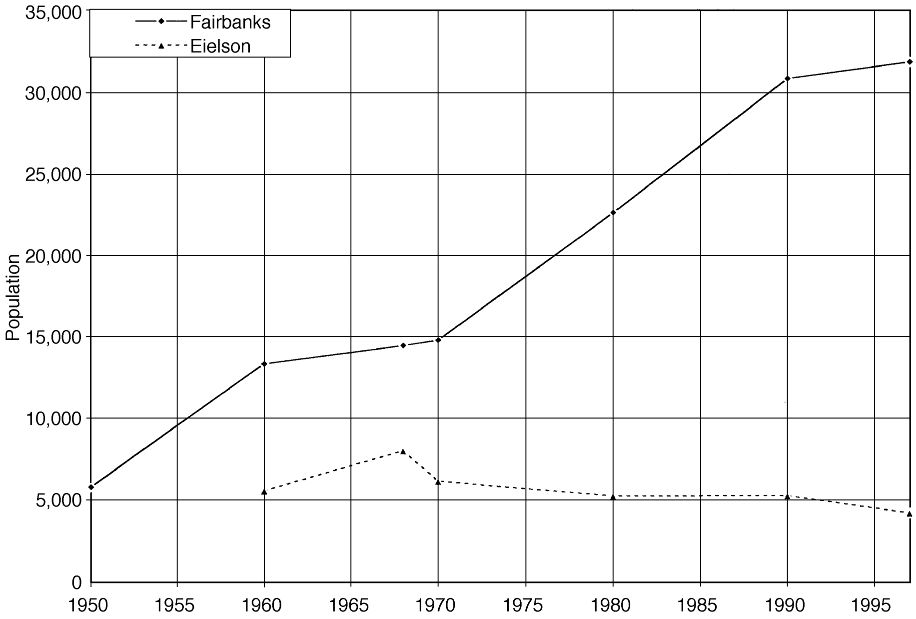

Fig. 2. Population statistics of Fairbanks and Eielson Air Force Base. Fairbanks showed an increase of about 500%, while the population of Eielson was nearly static. Data for Eielson's population were unavailable prior to 1960

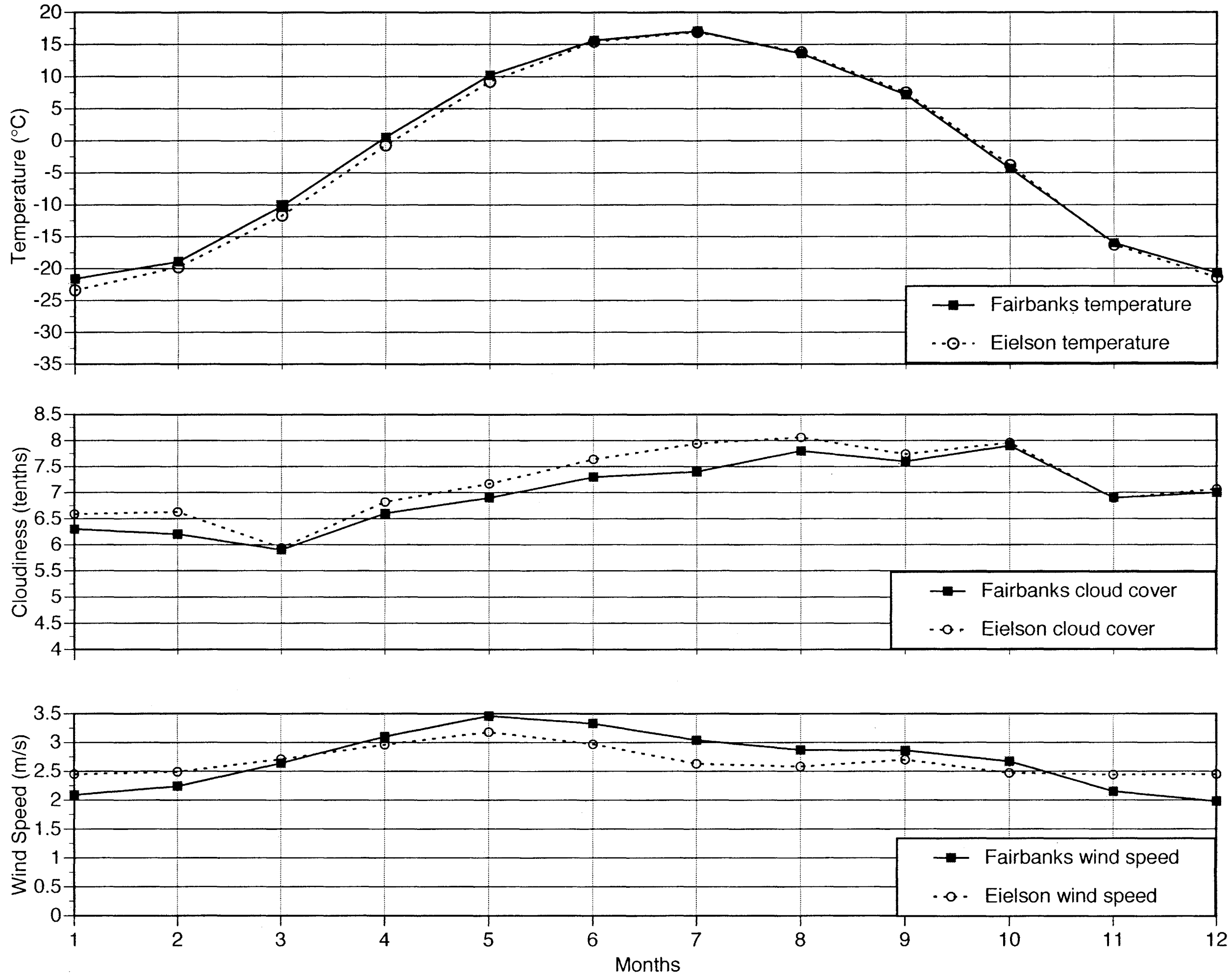

Fig. 3. Annual course of temperature, cloud cover, and wind speed for Fairbanks and Eielson Air Force Base for the period 1949–1997. Note that the conditions of the two climatological stations are very similar

record (SA). The data included over 400,000 hourly observations in which comparisons between the two stations were made from 1949 to 1997. The Eielson AFB record was briefly broken in 1971–72 when no observations could be obtained and only 8 observations per day were available for Fairbanks from 1965–70. Through 1950, Fairbanks instrumentation was located at Weeks Field located 6.5 km to the east-northeast of what was to be the International Airport. On 22 August 1951, Fairbanks weather equipment was moved to the newly built airport. During the next four decades, there were minor relocations and changes to the sensors. The HO6 series hygrothermometer was moved 45 m to east-northeast on 21 August 1963 and then was replaced by the HO8 series on 5 November 1984. The instrument was moved an additional 2 km to the northeast on 28 June 1991 because of problems associated with snow removal equipment. For Eielson AFB, we were unable to obtain specific descriptions of station equipment and location; however, discussion with Air Force weather personnel at Eielson AFB indicated that the weather sensors were always located within visual proximity of the runway.

In Fig. 3, long term monthly averages of wind speed, cloud cover, and temperature show a nearly identical climate for the two stations. Fairbanks is slightly windier than Eielson AFB between April to October, whereas Eielson AFB is more than five percent cloudier than Fairbanks over most of the year. Annually, the average temperature at Fairbanks is 0.33 °C warmer than that at Eielson.

3. Results

We examined the time series of temperatures and temperature differences between Fairbanks and Eielson AFB for all hours, independent of weather conditions. By subtracting Eielson AFB rural temperature from the Fairbanks urban temperature, an increasing temperature difference over the time series indicates a growing heat island effect. Although considerable scatter occurs in the annual temperature differences, the data show evidence for the growth of Fairbanks heat island, particularly during the winter season.

Figure 4 highlights the large general wintertime warming trend found through the period. The regression lines of Fairbanks and Eielson diverge, indicating that both the minimum and the maximum temperatures at Fairbanks are increasing more rapidly than those at Eielson. This implies the growth of the urban heat island at Fairbanks. In Fig. 5 the growing heat island

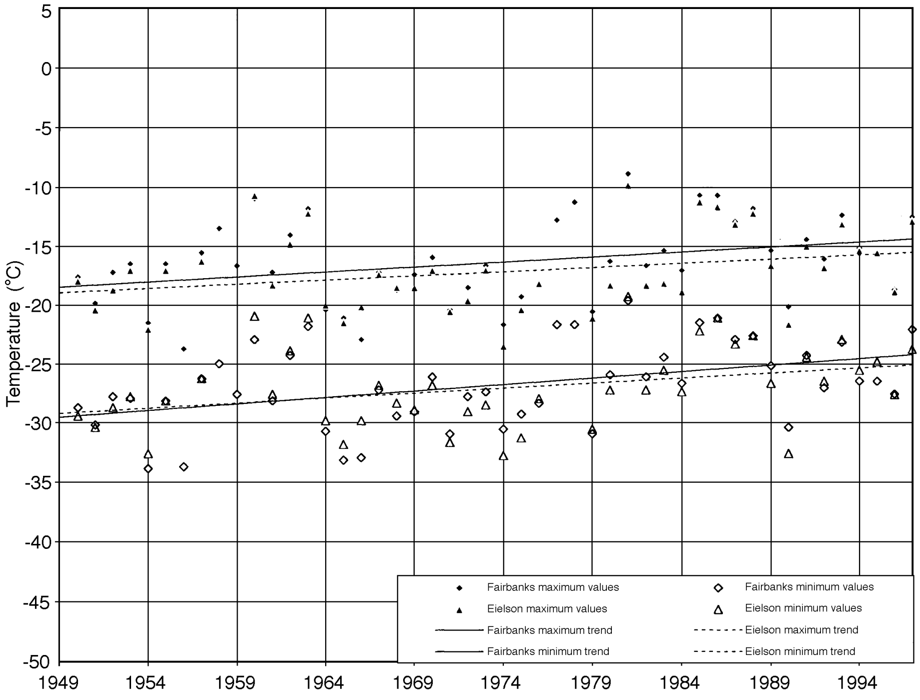

Fig. 4. Trend analyses of winter temperatures for Fairbanks and Eielson over the period 1949–1997. Note that both stations show a temperature increase with time, the temperature increase being larger for Fairbanks than for Eielson, and the minima being more affected than the maxima

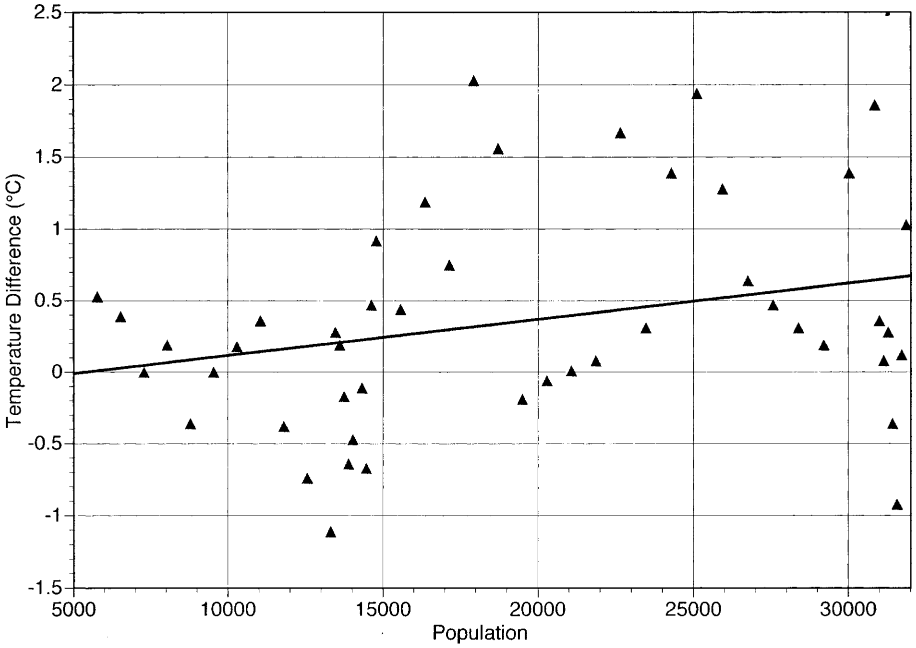

Fig. 5. The winter temperature difference for Fairbanks minus Eielson is plotted against the number of inhabitants of Fairbanks. Note the increasing difference in temperature with increasing population

(mean winter temperature difference) is plotted against the population of Fairbanks. The number of the people is taken as an approximation of the energy consumption in Fairbanks. This is not necessarily a linear relationship, as the sizes of houses and also the relative number of cars has increased with time, which should result in a accelerated increase. On the other hand, increased insulation of buildings, reduced fuel consumption of cars and urban sprawl will reduce the effect. Looking at Fig. 5, there is a large amount of scatter in the data. A correlation coefficient of 0.274 is found, and by applying the two-tailed confidence test, a level of 0.93 is calculated. Until the population reached 15,000 inhabitants, no increase in the heat island effect was observed. The strongest increase occurred during the time period from 1970 to 1990, which is the time of largest growth. More recently the increase has slowed down, which could be due to the sprawling of the town into the surrounding hills, or might be the influenced by the relocation of the weather station in 1991.

For the year and for each season, Table 1 provides values describing the magnitude of the general warming trend and also isolates the portion of this warming trend that can be attributed to the Fairbanks heat island effect. With the exception of fall, all seasons experienced significant overall warming and some growth of the urban heat island effect, with greatest increases in the winter heat island. In winter approximately 20% of the large general wintertime warming at Fairbanks over the last 50 years can be attributed to the growth of the heat island. During fall, the trend lines for both stations show identical decreases with very little apparent indication of Fairbanks heat island. The decreasing fall temperature trends where also identified by Chapman and Walsh (1993) for the Arctic from 1961–1990 and by Curtis et al. (1998) for Barrow and Barter Island, Alaska from 1949–1988.

It is possible to explain the different magnitude of the seasonal heat island growth values by analyzing the seasonal relevance of the accepted heat island mechanisms. In spring and fall, anthropogenic heat pollution is still of slight importance while growing daylight requires that the other solar-related causes such as evapotranspiration and surface characteristics be considered. During the summer, the significance of anthropogenic heat loss is minimal compared to the strength solar radiative warming. Mechanisms related to pollution, surface characteristics, and vegetation are maximized with the long periods of daylight. The winter months isolate the influence of anthropogenic heat loss as the short days make solar influences practically negligible. Because solar radiative heating

Table 1. *Average Maximum and Minimum Temperature (°C) Trends from 1949 to 1997 for Fairbanks and Eielson AFB*

Station	Start	End	Change	ΔT
Spring				
Fairbanks, avg max	4.04	6.77	2.73	
Eielson AFB	3.81	6.04	2.23	0.50
Fairbanks, avg min	−9.30	−6.10	3.20	
Eielson AFB	−9.23	−6.46	2.77	0.43
Summer				
Fairbanks, avg max	20.69	21.57	0.87	
Eielson AFB	19.73	20.58	0.85	0.02
Fairbanks, avg min	8.55	10.60	2.04	
Eielson AFB	8.43	10.00	1.56	0.48
Fall				
Fairbanks, avg max	0.81	−0.32	−1.13	
Eielson AFB	0.65	−0.50	−1.14	0.01
Fairbanks, avg min	−8.89	−9.19	−0.31	
Eielson AFB	−8.90	−9.25	−0.35	0.04
Winter				
Fairbanks, avg max	−18.40	−14.33	4.07	
Eielson AFB	−19.00	−15.63	3.37	0.70
Fairbanks, avg min	−29.54	−24.29	5.26	
Eielson AFB	−29.17	−25.09	4.08	1.18
Annual				
Fairbanks, avg max	2.46	4.10	1.64	
Eielson AFB	1.25	2.57	1.32	0.31
Fairbanks, avg min	−9.79	−7.25	2.55	
Eielson AFB	−9.67	−7.65	2.02	0.53

The ΔT column reflects the urban heat island growth over the period by season and year

during high-latitude winters is so slight, the heat island should become particularly intense. The expected winter heat island intensity is further heightened by the frequent occurrence of strong surface inversions during the winter (Wendler and Nicpon, 1975). Surface temperature inversions help trap heat and pollution near the surface, suggesting a further intensification of the winter heat island. Because the least-squares linear trends through non-winter temperature differences show less significant heat island effect growth (Table 1), it is to be assumed that Fairbanks is not large enough, or has not grown enough, to induce intense changes in the summer heat island.

It is expected that calm winds and clear skies at night will promote the intensity of the heat island. Under these conditions, strong surface inversions develop, especially during winter. Hence, the buoyant transport of anthropogenic waste heat is subdued. Among urban heat island models (Oke, 1973), wind speed is taken as a key determinant of heat island levels. Moderate and high wind speeds promote mixing and cause the dispersal of heat islands, inherently reducing the possibility of intense heat island development. Low wind speeds allow heat to accumulate near the surface without extensive mixing. In particular, low wind speeds and surface inversions can combine to trap heat (or pollutants) very effectively. Further, during dark sub-arctic winters, cloud cover plays a very significant role in the energy balance. Due to a long wave radiative loss, clear sky conditions create heat-trapping intense surface inversions. Table 2 confirms both of these expected relationships, demonstrating that the Fairbanks heat island is strongly dependent on wind and cloud conditions. As expected, in each season, when wind speeds exceeded 2 m/s, the heat island observed at Fairbanks dropped markedly, with the winter months experiencing the greatest impact. The heat island's dependence on cloudiness is somewhat less dramatic, but as expected, clear to partly cloudy conditions favor a stronger heat island than mostly cloudy or overcast skies.

Table 2. *The Difference in the Magnitude of the Heat Island Effect by Season and the Year*

	ΔT (°C) by wind speed conditions <2 m/s minus >2 m/s	ΔT (°C) by cloud cover conditions <3 tenths minus >3 tenths
Winter	1.04	0.46
Spring	0.20	0.27
Summer	−0.23	0.02
Fall	0.60	0.59
Annual	0.40	0.33

The first column shows the dependency on wind speed, the second column on fractional cloud cover

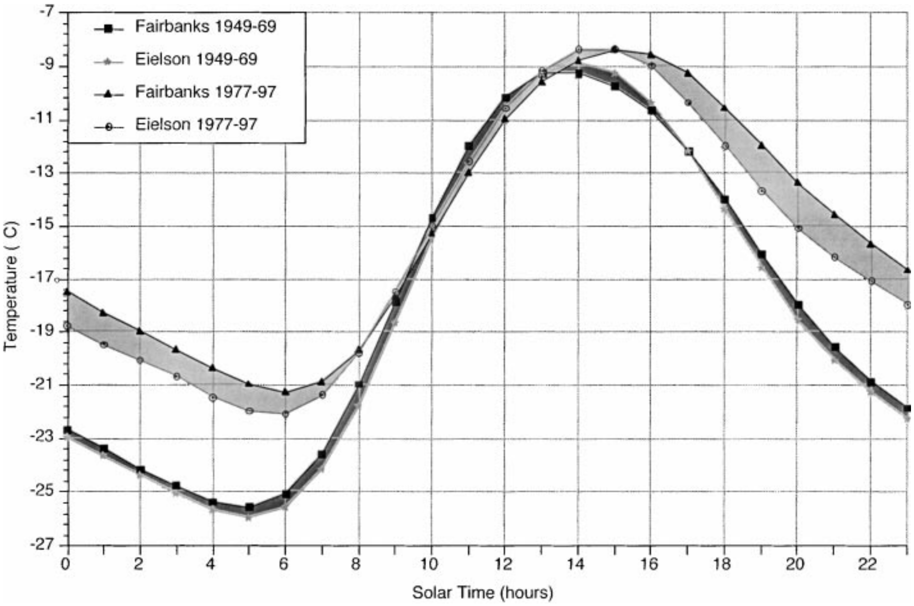

Fig. 6. The diurnal variation of the March temperatures at Fairbanks and Eielson for the first 20 and last 20 years of the observational period. Only data were selected when both stations experienced light wind and clear or partly cloudy conditions. The light and darker shaded regions represent the heat island magnitudes for the last 20 and first 20 years, respectively. The light shaded region is largest at night, indicating that the heat island effect is most pronounced in the absence of solar radiation

Figure 6 demonstrates the diurnal variation of the growth of the heat island from the first twenty years of the period to the last twenty years. It shows that the heat island has experienced the most significant growth under nighttime conditions. This plot takes temperature information solely from the month of March when clear to partly cloudy skies and calm or light winds prevailed at both locations. In this manner, we were able to isolate instances when surface inversion and cold temperatures insured the relevance of the anthropogenic heat island effect. In Fig. 6, the last twenty years of the period are clearly much warmer than the first twenty years, particularly during the nighttime hours. The magnitude of the heat island effect is represented by the shaded regions in Fig. 6. The shaded region for the last twenty years is much larger than that seen for the first twenty years, but only during the nighttime hours. These results indicate that both the general warming trend and the growth of the heat island effect have taken place largely at night when solar radiation and surface heating are absent.

4. Conclusions

Fairbanks experienced a substantial mean annual temperature increase of 2.1 °C from 1949 to 1997. By comparing Fairbanks to a nearby station, which did not grow in size, about 4/5 of the total warming can be attributed to a general, widespread warming, while 1/5 of the warming is due to an increasing heat island effect. During times of frequent surface inversions, which are most common in winter, the growth of the heat island effect was most pronounced (about 1 °C). Winter was also the time when the largest absolute temperature increase was observed (over 4.5 °C). Relatively, the heat island effect in winter contributed again 1/5 of the total temperature increase, a similar value as for the mean of the year.

The temperature increase due to the heat island effect was not linear with time. Before 1970, when the total population was less than 15,000 inhabitants, no heat island effect was being observed. For the period from 1970 to 1990, when the largest increase in population occurred (it more than doubled), we found the strongest increase in temperature. Recently, no additional heat island effect is being observed. It is difficult to judge if this is due to the decreased rate in population growth or to the relocation of the weather station in Fairbanks, which occurred in 1991.

Acknowledgements

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