

2009

## A Century of Climate Change for Fairbanks, Alaska


Gerd Wendler

*University of Alaska, Fairbanks*, [gerd@gi.alaska.edu](mailto:gerd@gi.alaska.edu)

Martha Shulski

*University of Nebraska–Lincoln*, [mshulski3@unl.edu](mailto:mshulski3@unl.edu)

Follow this and additional works at: <http://digitalcommons.unl.edu/natrespapers>

 Part of the [Climate Commons](#), [Environmental Indicators and Impact Assessment Commons](#), [Environmental Monitoring Commons](#), [Meteorology Commons](#), [Natural Resources and Conservation Commons](#), [Natural Resources Management and Policy Commons](#), and the [Other Environmental Sciences Commons](#)

---

Wendler, Gerd and Shulski, Martha, "A Century of Climate Change for Fairbanks, Alaska" (2009). *Papers in Natural Resources*. 563.  
<http://digitalcommons.unl.edu/natrespapers/563>

This Article is brought to you for free and open access by the Natural Resources, School of at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Papers in Natural Resources by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

# A Century of Climate Change for Fairbanks, Alaska

GERD WENDLER<sup>1,2</sup> and MARTHA SHULSKI<sup>1</sup>

(Received 16 June 2008; accepted in revised form 21 November 2008)

**ABSTRACT.** Climatological observations are available for Fairbanks, Interior Alaska, for up to 100 years. This is a unique data set for Alaska, insofar as it is of relatively high quality and without major breaks. Applying the best linear fit, we conclude that the mean annual temperature rose from  $-3.6^{\circ}\text{C}$  to  $-2.2^{\circ}\text{C}$  over the century, an increase of  $1.4^{\circ}\text{C}$  (compared to  $0.8^{\circ}\text{C}$  worldwide). This comparison clearly demonstrates the well-known amplification or temperature change for the polar regions. The observed temperature increase is neither uniform over the time period nor uniform throughout the course of a year. The winter, spring, and summer seasons showed a temperature increase, while autumn showed a slight decrease in temperature. For many activities, the frequencies of extremes are more important than the average values. For example, the frequency of very low temperatures (below  $-40^{\circ}\text{C}$ , or  $-40^{\circ}\text{F}$ ) has decreased substantially, while the frequency of very high temperatures (above  $26.7^{\circ}\text{C}$ , or  $80^{\circ}\text{F}$ ) increased only slightly. Finally, the length of the growing season increased substantially (by 45%) as a result of an earlier start in spring and a later first frost in autumn. Precipitation decreased for Fairbanks. This is a somewhat counter-intuitive result, as warmer air can hold more water vapor. The date of the establishment of the permanent snow cover in autumn showed little change; however, the melting of the snow cover now occurs earlier in the spring, a finding in agreement with the seasonal temperature trends. The records for wind, atmospheric pressure, humidity, and cloudiness are shorter, more broken, or of lower quality. The observed increase in cloudiness and the decreasing trend for atmospheric pressure in winter are related to more advection and warmer temperatures during this season.

**Key words:** climate, Alaska, sub-Arctic, Fairbanks, 100 years, trends

**RÉSUMÉ.** Il existe des observations climatologiques pour Fairbanks, à l'intérieur de l'Alaska, échelonnées sur 100 ans. Cet ensemble de données est unique en Alaska en ce sens que les données sont de relativement grande qualité et qu'elles ne comportent pas d'interruptions majeures. Au moyen du meilleur appariement linéaire, nous concluons que la température moyenne annuelle s'est élevée de  $-3,6^{\circ}\text{C}$  à  $-2,2^{\circ}\text{C}$  au cours du siècle, ce qui représente une augmentation de  $1,4^{\circ}\text{C}$  (comparativement à la moyenne mondiale de  $0,8^{\circ}\text{C}$ ). Cette comparaison montre clairement l'amplification ou le changement de température bien connu des régions polaires. L'augmentation de température qui a été observée n'est ni uniforme pendant la période visée ni uniforme au cours d'une même année. La température s'est en fait accrue pendant les saisons de l'hiver, du printemps et de l'été, tandis que la température a baissé quelque peu l'automne. Pour bien des activités, la fréquence des extrêmes est plus importante que les valeurs moyennes. Par exemple, la fréquence de températures très basses (en bas de  $-40^{\circ}\text{C}$ , ou  $-40^{\circ}\text{F}$ ) a diminué considérablement, tandis que la fréquence de températures très élevées (au-dessus de  $26,7^{\circ}\text{C}$ , ou  $80^{\circ}\text{F}$ ) n'a augmenté que légèrement. Et enfin, la longueur de la saison de croissance a augmenté considérablement (de 45 %) parce que le printemps commence plus tôt et que les premières gelées de l'automne se manifestent plus tard. Les précipitations ont diminué à Fairbanks. Ce résultat est un peu contre-intuitif car l'air plus chaud peut contenir plus de vapeur d'eau. La date de l'établissement de la couverture de neige permanente à l'automne a peu fluctué. Cependant, la fonte de la couverture de neige se produit maintenant plus tôt au printemps, observation qui cadre avec les tendances caractérisant les températures saisonnières. Les données relatives au vent, à la pression atmosphérique, à l'humidité et à l'enneigement s'étendent sur une moins longue période, comportent plus d'interruptions ou sont de moins bonne qualité. L'augmentation d'enneigement observée et la tendance de pression atmosphérique à la baisse l'hiver sont attribuables à une plus grande advection et à des températures plus chaudes pendant cette saison-là.

**Mots clés :** climat, Alaska, subarctique, Fairbanks, 100 ans, tendances

Traduit pour la revue *Arctic* par Nicole Giguère.

## INTRODUCTION

Fairbanks ( $64^{\circ}49' \text{N}$ ,  $147^{\circ}52' \text{W}$ ) is the only climatological station in Interior Alaska with an unbroken 100-year record of meteorological parameters. It is fairly centrally located

in a low-lying river valley (altitude 141 m) at the confluence of the Chena and Tanana rivers. Interior Alaska, which stretches from the Alaska Range in the south to the Brooks Range in the north, covers some  $800\,000 \text{ km}^2$ —almost half of Alaska's land area. In general, the climate is continental,

<sup>1</sup> Alaska Climate Research Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska 99775, USA

<sup>2</sup> Corresponding author: gerd@gi.alaska.edu

© The Arctic Institute of North America

with relatively warm summers and very cold winters (Shulski and Wendler, 2007). Fairbanks was not the first meteorological station to have meteorological observations in Interior Alaska: Eagle, Circle City, Ft. Yukon, Tanana, and Nulato, all located on the Yukon River, started earlier with their observations. However, the data sets from those stations are plagued with breaks, relocations, and discontinuations, while Fairbanks has a complete time series for 100 years and is one of the 21 first-order stations currently in service in Alaska. First-order stations have identical instrumentation and systematic calibrations and are operated by professional meteorologists of the National Weather Service. Good data from these first-order stations, available in digital format for the years from 1949 onward, have been analyzed previously (Stafford et al., 2000). The Fairbanks observational site was relocated several times. Early in the century, it was called the University Station, but it is believed to have been located in what is now downtown Fairbanks, close to the Episcopal Church, since the Episcopal Mission carried out the observations. In 1942, it was moved to a site 7 km east of Fairbanks at Ladd Field, now Ft. Wainwright. In 1951, the station was moved again, this time to a site 6 km west of Fairbanks, where a new airport had been built. The station always stayed in the valley bottom, where the temperatures are more uniform, whereas large temperature differences can be observed over short distances in the hilly topography surrounding Fairbanks, especially in winter. Further, since 1942 the station has always been located away from downtown, where the largest heat island effect is being observed (Benson and Bowling, 1975); in 1942, Fairbanks was small, with fewer than 5000 inhabitants, and the heat island effect is believed to have been limited. Since that time, the population has grown to seven times its 1942 size. More details on the history of Fairbanks and other stations were accumulated by S.A. Bowling and are given at our website: <http://climate.gi.alaska.edu/history/History.html>.

## RESULTS

### Temperature

Fairbanks, the largest settlement in Interior Alaska, has a continental sub-Arctic climate. The mean annual temperature is just below the freezing point, and the annual temperature variation is large. To determine how representative Fairbanks is of Interior Alaska, we compared the mean annual temperatures of four additional stations in Interior Alaska. Although the absolute values differ, the overall patterns are quite similar, which might be seen best from Bettles, a station located some 300 km to the NNW of Fairbanks (Fig. 1). The significance of the correlation coefficients between Fairbanks and the four other stations is higher than 0.99 in all cases.

A time series of the mean annual temperature in Fairbanks from 1906 to 2006 shows substantial variation not

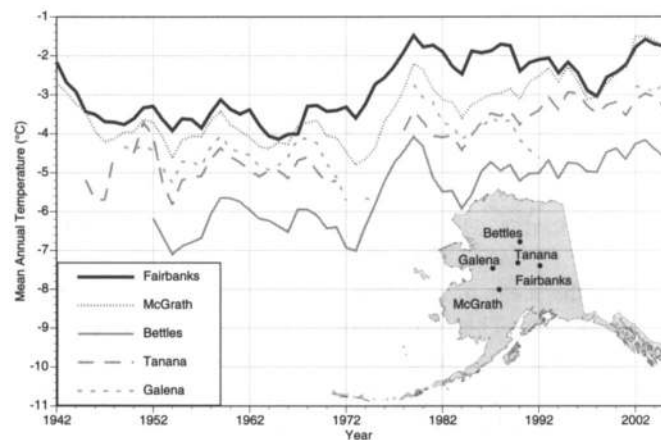


FIG. 1. Comparison of mean annual temperatures at Fairbanks and four other Interior Alaska stations, 1942–2006. Note that there are some breaks in the data.

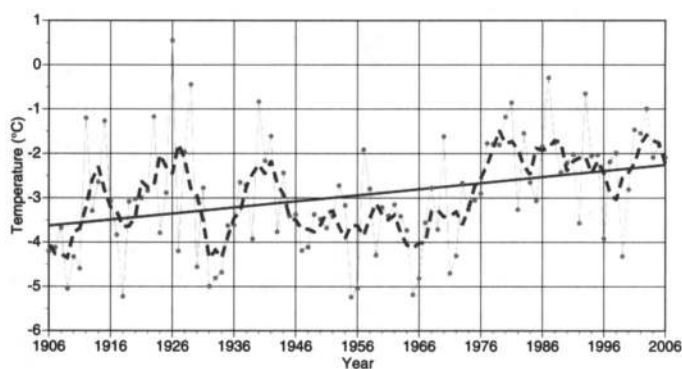


FIG. 2. Time series of mean annual temperatures at Fairbanks from 1906 to 2006. The points represent the annual values; the broken line, the five-year running mean; and the solid line, the best linear fit.

only from year to year, but also in the five-year running mean of the temperature (Fig. 2). The 1920s were generally warm, and 1926 is the warmest year on record, with a mean annual temperature just above the freezing point. The temperature dipped in the mid-1930s, but recovered later in the decade. An extended cold spell of three decades started around the middle of the 1940s. The sudden warming observed in the mid 1970s is attributed to a change in circulation patterns (Hartmann and Wendler, 2005), and the last three decades combined have on average the highest temperature of the record. The annual temperature, while showing a general increase (which could be expected from the semi-linear increase of carbon dioxide), also shows multi-decadal variability.

The 1980s were the warmest decade in Fairbanks, followed by the 1920s (Table 1). The best linear fit of the time series results in a total temperature increase for the century of 1.4°C in Fairbanks, well above the mean increase of 0.8°C observed worldwide (Hansen et al., 2006). The observed heat island effect of a growing Fairbanks in the later decades might have contributed somewhat to the increase (Magee et al., 1999). The value is in agreement with most other investigations and is referred to as *polar amplification*.

TABLE 1. Mean decadal temperatures in Fairbanks (°C).

| 1910s | 1920s | 1930s | 1940s | 1950s | 1960s | 1970s | 1980s | 1990s |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| -3.33 | -2.39 | -3.89 | -3.00 | -3.67 | -3.78 | -2.89 | -1.94 | -2.56 |

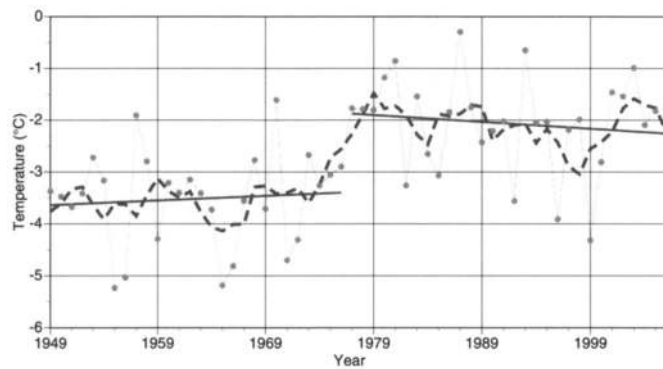


FIG. 3. Mean annual temperature for Fairbanks, 1949–2006. The dashed line represents the five-year running mean. Solid lines represent trends for the periods 1949–76 and 1977–2006. Note the sudden temperature change experienced in 1976.

Polyakov et al. (2003) carried out a substantial investigation on temperature trends in the maritime Arctic, analyzing 75 stations. They found a mean value of 1.2°C over 125 years (1875–2000), a value slightly lower than the one found for Fairbanks. However, this increase was a somewhat expected result, as maritime climate variations and changes are suppressed in comparison to continental climates.

The largest and most sudden temperature change occurred in the mid 1970s. This change occurred for all first-order weather stations in Alaska, with the exception of Barrow (Shulski and Wendler, 2007). This sudden increase is clearly evident for Fairbanks (Fig. 3) and is due in large part to a change in atmospheric circulation, demonstrated by the Pacific Decadal Oscillation (PDO) index, which changed from dominantly negative values to dominantly positive values. The PDO, which is related to the sea surface temperature in the northern Pacific Ocean, was developed by Mantua et al. (1997) in an examination of the relationship between Pacific climate variability and salmon production in Alaska and the Pacific Northwest of the United States. Positive values are associated with a stronger Aleutian Low, which advects more relatively warmer air into Alaska (particularly in winter, when this semipermanent feature is the strongest). Winter, defined as December, January and February, is also the time when the maximum temperature increase was observed both for Fairbanks and for Alaska overall.

A calculation of temperature changes for 1906–2006 by season shows a substantial increase for all seasons except fall, which had a slight decrease (0.1°C). However, the warming observed for each season is anything but uniform. There are two maxima in the monthly temperature-change data (Fig. 4), the first in December and January and the second in April. The midwinter increase is believed to be caused by increased advection due to a more intense Aleutian Low, while the April maximum might be caused by a

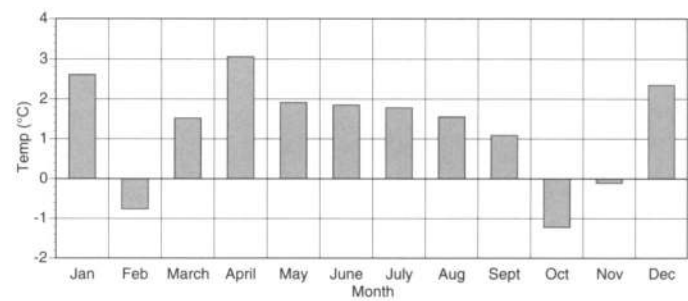


FIG. 4. Change in mean annual temperature at Fairbanks from 1906 to 2006, calculated for each month.

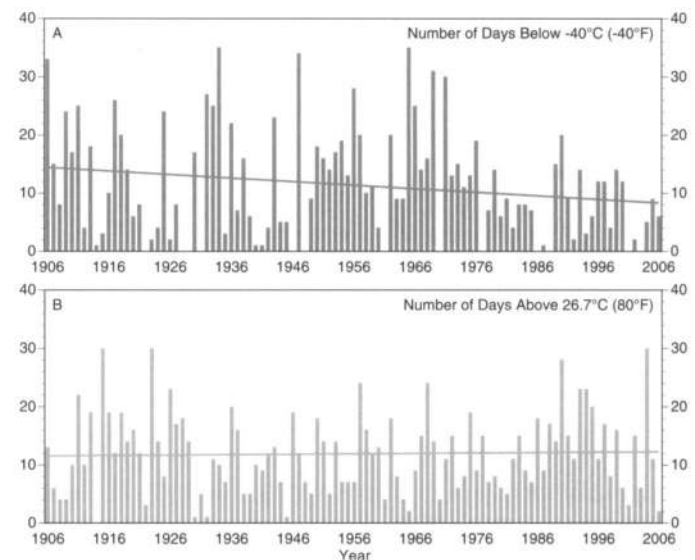


FIG. 5. Frequency of the occurrence of (A) very cold days (below  $-40^{\circ}\text{C}$ , or  $-40^{\circ}\text{F}$ ) and (B) very warm days (above  $26.7^{\circ}\text{C}$ , or  $80^{\circ}\text{F}$ ) for Fairbanks, Alaska. The lines represent the best linear fit.

change in the radiation budget. An earlier snowmelt lowers the albedo of the surface, causing additional warming: this is the well-known snow-albedo feedback mechanism.

For many purposes, mean values are of less importance than the occurrence of extreme values. The number of days with very low temperatures (less than  $-40^{\circ}\text{C}$ , or  $-40^{\circ}\text{F}$ ) has decreased, on average, from 14 to 8 days annually (Fig. 5a). However, the decrease is not linear, and a relatively large number of such events occurred in the 1960s. Such days are quite unpleasant, because ice fog often forms along with the cold, reducing visibility and making travel hazardous. This pattern can be also seen indirectly in the visibility observations (since 1946), which have increased more in winter than in the other seasons. Warm days with temperature above  $26.7^{\circ}\text{C}$  or  $80^{\circ}\text{F}$  increased slightly (Fig. 5b), but this increase was smaller than the decrease in cold days. At the beginning of the time series, an average of 11 warm days a year occurred, while more recently 12 days are being observed annually. This difference is to be expected, as January, the coldest month of the year, warmed the most of all months of the year (Fig. 4). The large midwinter increase also resulted in a decreasing mean annual temperature variation, which is not presented in graphical format.

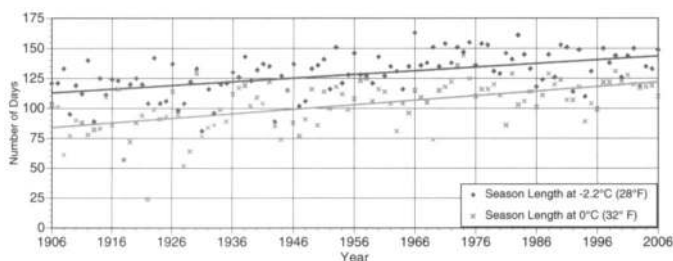


FIG. 6. Length of the growing season in Fairbanks, 1906–2002. Grey squares represent the number of days when the temperature remained above 0°C, or 32°F, and the black diamonds show the number of days above -2.2°C, or 28°F. The lines represent the best linear fit. While there is a large variation from year to year, the average length of the growing season has increased substantially.

The length of the growing season, which is the time period when the temperature in summer never dips below the freezing point, was also calculated. As a number of plants are somewhat frost-resistant, we calculated it both at the freezing point (0°C, or 32°F) and at the threshold of -2.2°C, or 28°F. For the 0°C freezing point, the time period increased from 85 to 123 days over the century (45%), while for the threshold of -2.2°C, the increase was from 113 to 144 days, or 27% (Fig. 6). An earlier spring and a later fall contributed about equally to the overall increases. The length of the growing season is of immense importance for agriculture; certain crops, such as potatoes, barley, cabbage, and carrots, grow very well in Interior Alaska. The growing degree-day total (using a base of 10°C, or 50°F) increased by 21% from 1906 to 2006. The graph (not shown) is similar to Fig. 6; however, the trend line is less steep. The larger increase for the length of the growing season (using the 0°C threshold) was caused by mid-season frosts, which occurred less frequently in the later years.

### Precipitation

The precipitation database is not as complete as the one for temperature. Since the data for the first decade are either missing or incomplete, we started the time series with the year 1916, when relatively good data became available. Fairbanks is sheltered by the Alaska Range to the south and the Brooks Range to the north, so advection of moist air is hindered and the annual precipitation is low. The mean annual value for the whole time period is only 280 mm, with annual values varying widely, between 150 and 450 mm. Summer is the wettest season, and on average, the highest monthly value is observed in August. In summer, localized convective-type precipitation adds to the precipitation caused by frontal systems. Total precipitation decreases from summer to fall and from fall to winter, and spring is the driest season. Winter and spring also demonstrate very low snowfall, as the atmosphere is cold and can hold only a small amount of water vapor.

The decrease in precipitation for the 90-year period is 11%, which is not statistically significant (Fig. 7). This decrease is strongest in spring, followed by winter (Table 2). The decrease is small in summer, when almost one-half of

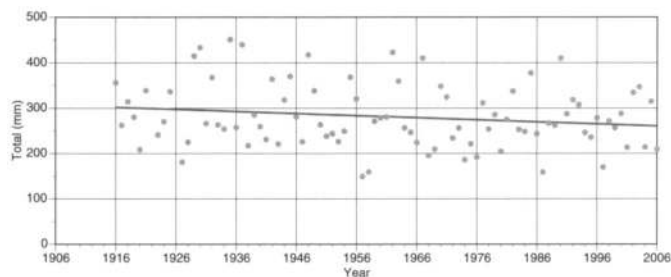


FIG. 7. Time series of the annual precipitation values for Fairbanks, Alaska, 1916–2006. The solid line represents the best linear fit. Note the decrease in the amount of precipitation.

TABLE 2. Precipitation amount (mm) for the four seasons and the year obtained from the trend analyses over the time period 1916 to 2006.

|        | 1916 | 2006 | % Change |
|--------|------|------|----------|
| Winter | 51   | 41   | -20%     |
| Spring | 43   | 28   | -35%     |
| Summer | 138  | 130  | -6%      |
| Fall   | 66   | 66   | 0%       |
| Annual | 298  | 265  | -11%     |

the annual precipitation occurs, while for the fall season no change was observed. A possible explanation might be that for the last three decades, the PDO index has been dominantly positive. The result for the cold seasons was a stronger Aleutian Low, which changed the wind to a somewhat more southerly direction, and therefore the Alaska Range has sheltered Interior Alaska from this moist air. At the same time, winds from a more westerly component, which can advect moisture more easily into the Interior of Alaska, have been reduced. A previous investigation of the snow cover of Arctic North America by Curtis et al. (1998) also found a decrease in winter precipitation, which agrees with our findings.

### Atmospheric Pressure and Wind

Data on sea level pressure for Fairbanks are available starting in 1946. The maximum atmospheric pressure is found in late winter, when the atmosphere is very cold (Fig. 8a). In fall, the temperature contrast between the still open water to the south and west of Alaska and the already cold Interior is large. Cyclones move into Alaska in fall, and strong and frequent storms are observed in the coastal areas. Consequently, in late fall the lowest pressure of approximately 1007 hPa is also observed in Interior Alaska. Finally, for spring and summer, the course of atmospheric pressure is fairly flat, with values around 1012 hPa.

Mean annual values of atmospheric pressure vary widely, from 1007 to 1015 hPa. A slightly decreasing trend was observed. The best linear fit through these data points of 60 years results in an overall lowering of 0.7 hPa (Fig. 9). In addition, the standard deviation of the annual course of the atmospheric pressure showed a well-defined sine curve (Fig. 8b), with the maximum in winter and minimum in

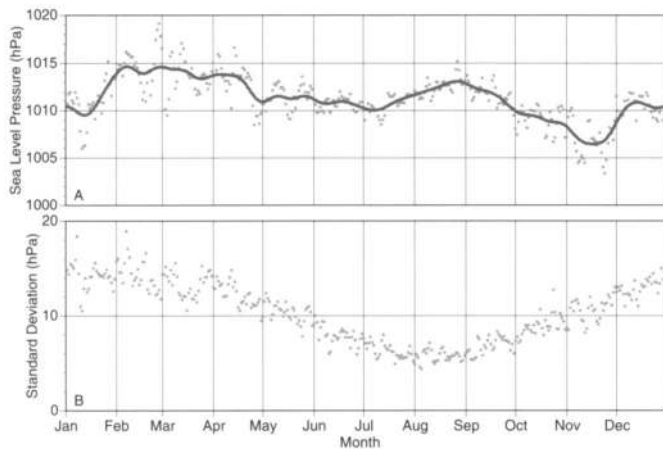


FIG. 8. (A) Mean annual course (mean daily values) of the atmospheric pressure for Fairbanks, 1946–2006. The solid line represents the 11-point smoothed values. (B) Standard deviation of the annual course of atmospheric pressure. Note the difference between summer and winter.

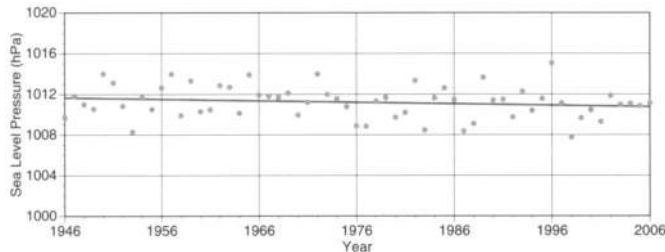


FIG. 9. Mean annual atmospheric pressure trend for Fairbanks, 1946–2006.

summer. The winter standard deviations were about three times the summer values (Fig. 8b).

This annual trend in atmospheric pressure was caused mainly by a decrease in winter, while the other three seasons showed little change (Fig. 10). The fairly strong decrease in pressure in winter over the 60-year time period is believed to be related to the change of the PDO value in the mid-1970s, which led to a strengthening of the Aleutian Low and the consequent lowering of the atmospheric pressure in Interior Alaska. An additional sign of the change in PDO is the observed increase in cloudiness, which increased from 61% to 64% in winter, the highest change of all seasons. Furthermore, the relative humidity of the four seasons also demonstrated the greatest increase in winter.

Long-term trends in the wind speeds were considered unreliable. For example, to conform to international standards, the anemometer at Fairbanks International Airport was moved to a height of 10 m above the surface on 1 December 1997. This change made comparisons between stations more meaningful, but made long-term trends questionable. The mean annual wind speed is low, just below 2.5 m/s (Fig. 11). The maximum wind speed of 3.2 m/s is observed in early summer. At this time of year, the sun is above the horizon for more than 21 hours a day, hindering the formation of a surface inversion. In winter, when the surface inversion is strong (Wendler and Nicpon, 1975), the surface layer is semi-decoupled from the winds aloft, and

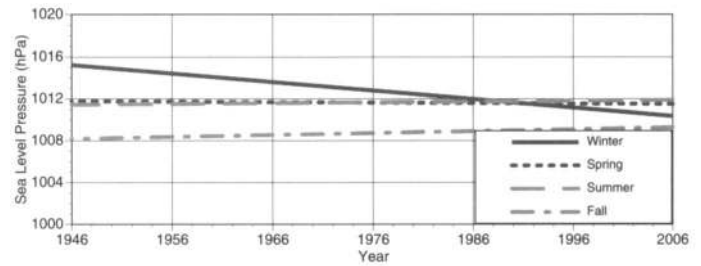


FIG. 10. Mean atmospheric pressure trend for Fairbanks, 1946–2006, by season.

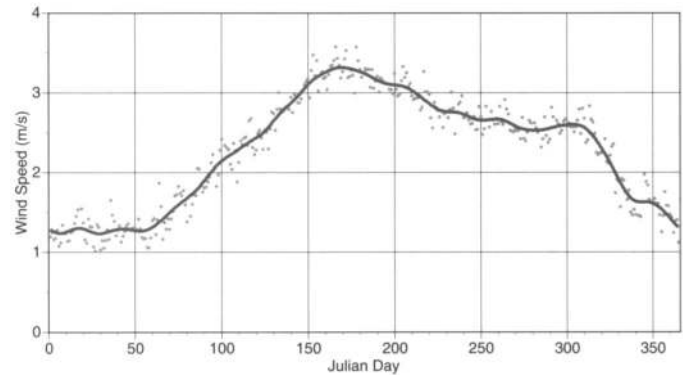


FIG. 11. Mean annual course of the mean daily wind-speed values for Fairbanks, 1946–2006. The solid line represents the 11-point smoothed values.

the minimum wind speed of 1.2 m/s is observed. It is interesting to note that a secondary maximum occurs in late fall, the same time at which the minimum in atmospheric pressure was observed.

#### *Potential Causes of Climate Change*

In 1958, Keeling (1960) began making continuous measurements in Hawaii of atmospheric carbon dioxide ( $\text{CO}_2$ ), which after water vapor is the most radiatively important greenhouse gas. Figure 12 shows the mean annual temperature, atmospheric  $\text{CO}_2$  concentration, and the PDO index from 1958 to 2006. The mean annual temperature varies fairly widely from year to year, but shows an overall increasing trend. In contrast to temperature,  $\text{CO}_2$  values show a steady, slightly exponential increase over the same time period. The PDO index, like the temperature, varies widely, with dominantly negative values before 1976 but dominantly positive values thereafter. If the temperature warming in Fairbanks is radiatively caused, it should correlate well with the  $\text{CO}_2$  values. On the other hand, if transport processes to Alaska are of major importance, indices such as the PDO might reflect this. A visible inspection of Fig. 12 shows large variations between the three data sets.

We carried out a regression analysis of the different data sets. Such an analysis is a good statistical measure of how two or more curves relate to each other, but it does not say much concerning causality. The variance between  $\text{CO}_2$  and temperature is low, with a value of 0.24; in other words,

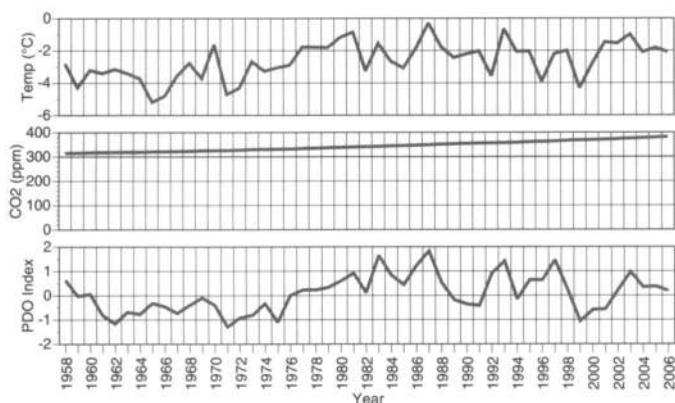


FIG. 12. Time series of mean annual temperatures ( $^{\circ}\text{C}$ ) at Fairbanks, carbon dioxide content (ppm) of the atmosphere, and the Pacific Decadal Oscillation index for the time period 1958–2006.

24% of the observed temperature change can be explained radiatively by increasing  $\text{CO}_2$  values. Of course, there are other important radiative processes besides those associated with  $\text{CO}_2$ , such as changes in cloud type and amount. The PDO index correlates somewhat better with the observed temperature change, with a value of 0.37. Furthermore, we carried out multiple regression analyses with both  $\text{CO}_2$  and the PDO index. The combined parameters resulted in the higher value of 0.45. In other words, the combination of increasing  $\text{CO}_2$  and the observed circulation changes expressed by the PDO could explain 45% of the observed temperature change of Fairbanks.

Naturally, the increased  $\text{CO}_2$  could have also affected the circulation index; however, the statistical evidence is weak, with a variance value of only 0.14 between  $\text{CO}_2$  concentration and the PDO index. In conclusion, the variation in the mean annual temperature of Fairbanks correlates poorly with the increasing  $\text{CO}_2$  values and somewhat better with the PDO index. Even combined,  $\text{CO}_2$  and the PDO index can explain only slightly less than half of the observed variation. We also looked at other atmospheric indices besides the PDO, and relatively high correlations with the Fairbanks temperatures were also found for the West Pacific Pattern and the Aleutian Low Pressure Index.

### CONCLUSION

The climate of Fairbanks was analyzed for a century ending in 2006. The temperature has increased by  $1.4^{\circ}\text{C}$ , almost twice the global increase, which is expected as a result of the polar amplification in temperature change. While the overall trend is positive, as expected from increasing greenhouse gases, the temperature increase is non-linear, with multi-decadal variations. Auto-correlation analyses showed a weak, non-significant cycle of 11 years (sunspot cycle). Furthermore, there was a sudden temperature increase observed in 1976, which could be related to circulation patterns as expressed in the PDO index. The strengthening of

the Aleutian Low in winter led to more advection of warm air and a decrease in atmospheric pressure for Fairbanks.

Over the century, the growing season increased in length by 45%, a substantial value and highly important for agriculture and forestry. The 11% decrease in precipitation (data available since 1916), together with increasing temperatures, makes the occurrence of droughts and wildfires more likely.

### ACKNOWLEDGEMENTS

V. Sharpton, Vice Chancellor for Research, and D. Julius, Vice President for Academic Affairs and Research, supported this investigation through the University of Alaska Foundation with funds given by BP and Conoco-Phillips. B. Moore carried out the statistics and produced the figures. To all of them, our thanks.

### REFERENCES

- Benson, C., and Bowling, S.A. 1975. The subarctic urban heat island as studied in Fairbanks, Alaska. *Climate of the Arctic: Proceedings of the 24th Alaska Science Conference*, August 1973, Fairbanks, Alaska. 309–311.
- Curtis, J., Wendler, G., Stone, R., and Dutton, E. 1998. Precipitation decrease in the Western Arctic, with special emphasis on Barrow and Barter Island, Alaska. *International Journal of Climatology* 18:1687–1707.
- Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D., and Medina-Elizade, M. 2006. Global temperature change. *Proceedings of the National Academy of Sciences* 103(39):14288–14293.
- Hartmann, B., and Wendler, G. 2005. The significance of the 1976 Pacific climate shift on the climatology of Alaska. *Journal of Climate* 18:4824–4839.
- Keeling, C.D. 1960. The concentration and isotopic abundance of carbon dioxide in the atmosphere. *Tellus* 12:200–203.
- Magee, N., Curtis, J., and Wendler, G. 1999. The urban heat island effect at Fairbanks, Alaska. *Theoretical and Applied Climatology* 64:39–47.
- Mantua, N., Hare, S., Zhang, Y., Wallace, J., and Francis, R. 1997. A Pacific interdecadal climate oscillation with impact on salmon production. *Bulletin of the American Meteorological Society* 78:1069–1079.
- Polyakov, I.V., Bekryaev, R.V., Alekseev, G.V., Bhatt, U.S., Colony, R.L., Johnson, M.A., Maskhtas, A.P., and Walsh, D. 2003. Variability and trends of air temperature and pressure in the maritime Arctic, 1875–2000. *Journal of Climate* 16(12): 2067–2077.
- Shulski, M., and Wendler, G. 2007. *The climate of Alaska. Fairbanks: University of Alaska Press.* 216 p.
- Stafford, J.M., Wendler, G., and Curtis, J. 2000. Temperature and precipitation of Alaska: 50 year trend analysis. *Theoretical and Applied Climatology* 67:33–44.
- Wendler, G., and Nicpon, P. 1975. Low-level inversions in Fairbanks, Central Alaska. *Monthly Weather Review* 103(1):34–44.