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Growing Season Trends in the Alaskan Climate Record

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ABSTRACT. Linkages between presumed global climate change and agricultural production will enable the development of management strategies to meet the needs of a diverse and future world agricultural enterprise. This study evaluated characteristic trends in the growing season length and dates of the last spring and first fall freezes at eight climate stations in Alaska between 1924 and 1989. Two minimum temperature criteria of 0° and –3°C were used in assessing freeze dates. Half of the stations had no change in growing season length over the last 65 years, whereas the other four stations had a lengthening of the season. Tendencies for longer seasons were in part a result of earlier spring freezes. The growing season shortened at three stations during the period 1940-70, which corresponded with declining Northern Hemisphere temperatures. The presence of changes in the growing season over the last 65 years was apparent in Alaska temperature records.

Key words: frost-free season, spring freeze, fall freeze, frost, climate change

RÉSUMÉ. Les liens entre les changements climatiques auxquels on s'attend au niveau planétaire et la production agricole permettront d'élaborer des stratégies de gestion en vue de répondre aux besoins futurs d'une agriculture mondiale diversifiée. Cette étude a évalué les tendances caractéristiques de la durée de la saison de croissance ainsi que les tendances des dates des dernières gelées printanières et des premières gelées automnales à huit stations climatiques de l'Alaska, entre 1924 et 1989. Deux critères de températures minimales de 0 ° et de -3 °C ont été utilisés pour déterminer les dates de gel. La moitié des stations n'ont pas connu de changements dans la durée de la saison de croissance au cours des 65 dernières années, alors que les quatre autres stations ont montré une prolongation de la saison. Les tendances vers des saisons plus longues sont dues en partie au fait que les dernières gelées printanières ont eu lieu plus tôt. La saison de croissance a raccourci à trois stations durant la période allant de 1940 à 1970, ce qui correspond au déclin des températures de l'hémisphère Nord. La présence de changements dans la saison de croissance au cours des derniers 65 ans est nettement visible dans les annales de température de l'Alaska.

Mots clés: saison libre de gel, gelée printanière, gelée automnale, gel, changement climatique

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INTRODUCTION

Analysis of the Northern Hemisphere mean temperature record has indicated trends for increased temperatures during the last century (Hansen and Lebedeff, 1987; Jones *et al.*, 1986). Similar tendencies have been found in the Alaskan temperature record (Juday, 1984). Climate simulations using general circulation models project the possibility of the warming trend to continue with a more pronounced increase in temperature at higher latitudes (Manabe and Stouffer, 1980; Meehl and Washington, 1990; Schlesinger and Mitchell, 1987).

Limitations to agricultural diversity and production in the Subarctic are largely temperature related. The shortness of the growing season is a major constraint to the maturation and harvest of many crops grown in regions such as interior Alaska. Warmer and longer growing seasons are projected using crop model simulations that account for increasing global temperatures (Adams *et al.*, 1990; Cooter, 1990). Indeed, the diversity and production of crops grown at northern latitudes may also be expanded with warmer or longer growing seasons (Rosenzweig, 1985; Wittwer, 1990).

The crop growing season apparently lengthened from about 1900 to 1980 in the midwestern United States (Changnon, 1984; Skaggs and Baker, 1985). In Wisconsin, Brinkmann (1979) found a lengthening of the growing season using a maximum temperature criterion and shortening of the season using a 0°C minimum temperature criterion for determining the season length. The tendency for longer growing seasons was primarily attributed to earlier spring freezes (Changnon, 1984; Skaggs and Baker, 1985). Since the peak of the Northern Hemisphere temperature in 1940, a shortening of the growing season has been observed in the midwestern (Brown, 1976; Moran and Morgan, 1977) and eastern United States (Pielke *et al.*, 1979). No evidence for a shortening of the growing season since 1940 was noted in the Minnesota record (Skaggs and Baker, 1985).

Additional evidence of global climate change in polar regions is needed to evaluate climate simulations using general circulation models and to assess possible ramifications to enterprises such as agriculture. The characteristic trend of the growing season in an arctic and subarctic region was determined by using the Alaska temperature record. Tendencies in the season length may be more dramatic than previous studies indicate due to the projected latitudinal differences in temperature.

METHODS

The source of data used for this study was Climatological Data, Alaska (U.S. Department of Commerce, 1917-89). The temperature record was hand searched to ascertain climate stations having a long, homogeneous and stable history. Eight stations were found with these criteria. The length of record common among the stations was 1924 to 1989. Climate station characteristics are tabulated in Table 1 and locations within Alaska mapped in Figure 1.

Most of the climate stations used in this study are rural sites located near villages or towns. The Fairbanks and Juneau stations are located near cities that may influence temperature trends as a result of urban growth since 1924. The Fairbanks station is located 5 km from the center of town at the Agricultural and Forestry Experiment Station farm and clearly is a rural site. The Juneau station is located in town and is the most suspect to urban growth.

All stations were relocated since establishment. The homogeneity of the growing season length time series was evaluated using data from neighboring stations. Five to ten years of data prior to and after the station move year were available for two

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TABLE 1. Characteristics of climate stations used in the analysis of growing season duration in Alaska

Station	Latitude[1]	Longitude[1]	Elevation[1] (m)	Years no data	Moves[2] No.	Moves[2] Range of elevation (m)	Moves[2] Range of distance (m)	Description
Annex Creek	58°19′N	134°06′W	7	6	2	0	5*	Present population 100. Located on boardwalk approximately 10 m above water (Taku Inlet). Surrounding area mountainous and forested.
Barrow	71°18′N	156°47′W	10	1	4	3	400	Present population 2200. Located over tundra, 1 km from Arctic Ocean. Surrounding topography level.
Bethel	60°47′N	161°48′W	38	0	3	35	3600	Present population 3600. Located 5 km from village over tundra.
Fairbanks	64°51′N	147°52′W	140	1	2	8	100	Present population 22 600. Located 5 km from town, at farm over sod. Surrounding terrain is rolling with forest and cropland.
Juneau	58°18′N	134°24′W	7	4	3	20	330	Present population 19 500. Located in town over sod. Surrounding terrain is steep and heavily wooded. Proximity to ocean.
Ketchikan	55°21′N	131°39′W	25	3	4	18	3600	Present population 7200. Located at airport over asphalt. Surrounding terrain is mountainous and forested.
Sitka	57°03′N	135°20′W	20	0	3	11	1610*	Present population 7800. Located over sod. Surrounding terrain is rolling and wooded. Proximity to ocean.
Talkeetna	62°18′N	150°06′W	105	2	3	3	800	Present population 300. Located at airport over sod. Surrounding terrain is rolling and forested.

[1]Current location.
[2]Since 1917.
*Approximate.

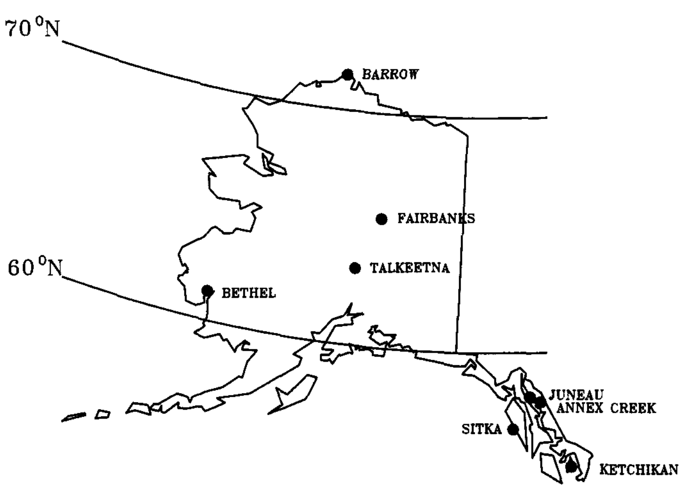

FIG. 1. Locations of climate stations in Alaska used to determine trends in the growing season length between 1924 and 1989.

to three neighboring stations. A t test ($P < 0.05$) on the difference series formed between the station used in this study and each neighboring station indicated homogeneity for all comparisons.

The growing season length was defined as: 1) the number of days between the last occurrence in spring and the first in fall of a 0°C minimum air temperature; and 2) the same as the previous definition except for an occurrence of a –3°C minimum temperature. The first definition was used by others (Brinkmann, 1979; Moran and Morgan, 1977; Skaggs and Baker, 1985) and the last corresponded to the approximate temperature at which alfalfa tissue freezes (Nath and Fisher, 1971). All months of the growing season were searched for the occurrence of the minimum temperatures. In the event that a minimum temperature (0° or –3°C) occurred in all months (most frequently at Barrow), the length of the growing season was the greatest number of consecutive days between the occurrence of the minimum temperature.

The eight stations varied in the number of years with missing data (Table 1). The beginning and end of the growing season in years with missing daily temperatures were interpolated from a neighboring station with similar minimum temperatures. Data analysis with and without the reconstructed freeze dates indicated nearly identical trends in growing season length. For example, the slope estimates of the Ketchikan 0°C growing season time series with and without reconstructed freeze dates were 0.27 (SE = 0.17) and 0.30 (SE = 0.18) days/yr respectively. Time trends in the growing season length and dates of the last spring and first fall freeze were evaluated using two methods. The first consisted of a linear regression analysis on the unsmoothed, reconstructed data of growing season length versus year. In the second, the data were split in half (1924-56 and 1957-89) and the means compared using a small sample t test.

RESULTS AND DISCUSSION

The average duration of the growing season (defined using the 0°C minimum temperature criterion) from 1924 to 1989 ranged from 187 days at Ketchikan to 16 days at Barrow. The growing season averaged 170, 152, 148, 107, 90, and 89 days at Juneau, Annex Creek, Sitka, Bethel, Talkeetna and Fairbanks respectively. The yearly variation in the length of the season is represented in Figure 2 by a seven-year running mean. Trends in the full length of record are apparent at Barrow, Bethel, Ketchikan and Talkeetna. The growing season has apparently lengthened at these stations.

The slope estimates of the time series analysis of the duration of the growing season at the eight stations are reported in Table 2. There was no change in the length of the season at Annex Creek, Fairbanks, Juneau and Sitka; however a change had occurred at Barrow, Bethel, Ketchikan and Talkeetna. The latter four stations vary over 16° of latitude and 30° of longitude and provided evidence for growing season changes in subarctic and arctic regions. The lengthening of the growing season (0°C) at these four stations ranged from 18 days at Bethel to 44 days at Talkeetna. Tendencies for longer seasons in Alaska concur with findings of Skaggs and Baker (1985) that a lengthening of the season had occurred at three of five Minnesota stations and of Changnon (1984) in Illinois.

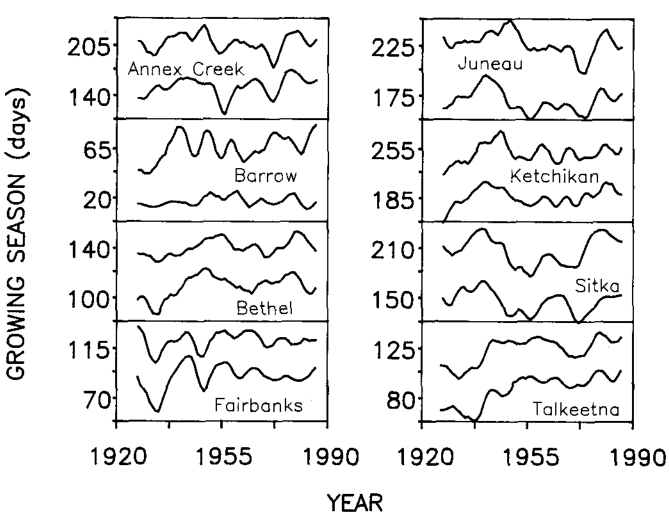

FIG. 2. Variation in the length of the growing season (criteria: 0°C lower line, –3°C upper line) at eight locations in Alaska, 1924-89.

Longer temperature records were available beginning in 1917 at Annex Creek, Fairbanks, Juneau, Ketchikan and Sitka. Time series analysis using the seven additional years (1917-23) of freeze data indicated similar trends to those in Table 2. However, the slope estimates were significant for the 0°C Fairbanks time series of 0.19 (SE = 0.11) days/yr, 0°C Ketchikan time series of 0.47 (SE = 0.15) days/yr and 0°C Sitka time series of –0.25 (SE = 0.11) days/yr.

Inconsistencies were found in the lack of systematic change (no trend) in the Annex Creek and Juneau time series compared to the other six station time series. In addition, trends are opposite for the Sitka and Ketchikan growing season time series, as are the apparent but nonsignificant trends for Annex Creek and Juneau, despite the close proximity of these stations. No evidence was found to explain these inconsistencies based on spurious records or inhomogeneities associated with station relocations. However, difficulty arises in comparing trends among stations because minimum temperatures are sensitive to local site characteristics and are not representative of regional climate patterns (Brinkmann, 1979). Thus, assessing regional growing season trends from a limited network of stations is audacious because of the localized responses in minimum temperature to the same variation in regional climate.

The change in the length of the growing season was associated with a change in the date of the last spring and first fall freeze (Table 2). Progressively earlier dates of the last spring freeze were found at Barrow and Ketchikan during the 1924-89 period, thus resulting in a longer season. The lengthening of the season at Bethel was because of later freezes in the fall. Tendencies for earlier spring and later fall freezes at Talkeetna had resulted in a lengthening of the growing season from 1924 to 1989. Later fall freezes were apparent for the Annex Creek and Fairbanks record, but no trends in the growing season length were found for these stations.

Differences in the characteristics of the growing season when grouped by first and second halves of the record (1924-56 and 1957-89) are summarized in Table 3. Talkeetna was the only station with a difference in the growing season length between the first and second halves of the record. The season was longer for the second half of the record as a result of earlier spring freezes during the 1957-89 period. The first freeze in fall was later for the second half of the Annex Creek record, but no change was apparent in the growing season length.

Fewer stations had significant changes in season length and freeze dates using the t test (Table 3) compared to trend analysis (Table 2). Data from Skaggs and Baker (1985) also indicated similar inconsistencies using these same test statistics.

TABLE 2. Time series slope estimates of growing season length and dates of last and first freeze based on two minimum temperature criteria at eight stations in Alaska, 1924-89

	Length (days/yr)		Last freeze (days/yr)		First freeze (days/yr)	
Station	–3°C	0°C	–3°C	0°C	–3°C	0°C
Annex Creek	0.03	0.23	0.06	0.06	0.09	0.28 **
Barrow	0.40 **	0.07	–0.18 *	0.06	0.22	0.14
Bethel	0.14	0.28 **	–0.08	–0.13	0.05	0.15 **
Fairbanks	0.06	0.19	–0.02	0.04	0.04	0.23 **
Juneau	–0.25	–0.06	0.11	0.06	–0.14	0.0
Ketchikan	0.35 *	0.27	–0.27 **	–0.05	0.08	0.22 *
Sitka	0.04	–0.22	0.07	0.18 **	0.11	–0.03
Talkeetna	0.48 **	0.68 **	–0.33 **	–0.43 **	0.14 *	0.25 **

**,*Indicate significance at a probability level of 0.05 and 0.10 respectively.

TABLE 3. Difference in the growing season length and last and first freeze dates between the periods 1924-56 and 1957-89 at eight stations in Alaska

	Length (days)		Last freeze (days)		First freeze (days)	
Station	–3°C	0°C	–3°C	0°C	–3°C	0°C
Annex Creek	1.7	–10.4	–3.9	–1.6	–2.1	–12.0 *
Barrow	–10.9	–2.5	5.5	0.0	–5.4	–2.6
Bethel	–2.1	–5.7	0.1	0.2	–2.0	–5.5
Fairbanks	–2.5	–4.8	0.1	–1.8	–2.5	–7.2
Juneau	11.2	4.7	–4.0	–2.6	7.3	2.2
Ketchikan	–7.9	–4.2	6.6	0.0	–1.2	–4.2
Sitka	0.8	5.9	–3.7	–4.8	–2.9	1.1
Talkeetna	–13.8 **	–21.5 **	10.9 **	13.8 **	–2.9	–7.7

**,*Indicate probability levels of 0.05 and 0.10 respectively.

These inconsistencies may be inherent in the assumptions used in each test statistic. For example, successive growing season lengths are assumed independent in the t test for comparing the season length for the first and second halves of record. However, systematic changes in climate can influence successive season lengths and thus may lead to erroneous conclusions. Therefore, trend analysis that accounts for systematic changes may be the most appropriate statistic for assessing changes in growing season length.

Observations of the Northern Hemisphere mean temperature had indicated a warming from the 1880s to 1940s and a cooling from the 1940s to the early 1970s (Hansen and Lebedeff, 1987; Jones *et al.*, 1986). Similar temperature characteristics were observed in Alaska with a recent warming since the early 1970s (Juday, 1984; Kelly *et al.*, 1982). The period of cooling during 1940-70 was portraited by the growing season variation in Figure 1. A shortening of the season was apparent during those years. A time series analysis of the growing season duration and frost dates are tabulated in Table 4. A shortening of the season from 1940 to 1970 was found at all stations except Talkeetna, and the slope was discernible only at Juneau, Ketchikan and Sitka. The shortening of the season resulted from the later occurrence of last spring freezes (Table 4).

TABLE 4. Time series trend in length of growing season and dates of last and first freeze at eight stations in Alaska during 1940-70

	Length (days/yr)		Last freeze (days/yr)		First freeze (days/yr)	
Station	−3°C	0°C	−3°C	0°C	−3°C	0°C
Annex Creek	−0.47	−0.36	0.27	0.11	−0.20	−0.25
Barrow	−0.70	0.05	0.08	−0.40	−0.62	−0.35
Bethel	−0.13	−0.16	0.18	0.47 *	0.06	0.31
Fairbanks	0.11	−0.33	0.01	0.24	0.12	−0.09
Juneau	−0.63	−1.06 **	0.26	0.64 **	−0.36	−0.42
Ketchikan	−0.32	−0.97 **	0.32	0.54 *	0.00	−0.43
Sitka	−1.10 *	−0.37	0.85 **	0.17	−0.24	−0.20
Talkeetna	0.03	0.46	−0.26 *	−0.27	−0.23	0.19

**,*Indicate significance at a probability level of 0.05 and 0.10 respectively.

CONCLUSIONS

The growing season has lengthened at several Alaskan stations during the last 65 years but regional trends were inconclusive. The predominate reason for longer growing seasons was the occurrence of earlier freezes in the spring. Trends in the season length are consistent with other mid-latitudinal locations. Projected latitudinal differences in air temperature have not given rise to an amplification in the trend of growing season length.

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