SEVEN-YEAR PHENOLOGICAL RECORD OF ALASKAN ECOREGIONS DERIVED FROM ADVANCED VERY HIGH RESOLUTION RADIOMETER NORMALIZED DIFFERENCE VEGETATION INDEX DATA

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ABSTRACT

Seasonal properties of vegetation covering northern boreal and arctic landscapes are considered important as input to numerous climate change studies. In this study, multitemporal phenological characteristics of Alaskan vegetation were studied for the State as a whole, and 19 of 20 ecoregions were studied using seasonally truncated, composited advanced very high resolution radiometer derived normalized difference vegetation index (NDVI) data. Phenological characteristics included four temporal and six greenness metrics derived for each year from 1991 to 1997. Temporal metrics included date of onset of greenness, last day of greenness, date of maximum greenness, and total days of greenness. Greenness metrics consisted of NDVI values recorded during the onset and last day of greenness, maximum greenness, mean greenness for the growing season, and estimated rates of greenup and greendown in the spring and autumn, respectively.

Results indicated that over many areas of Alaska there was a trend toward earlier onset of greenness each spring from 1992 to 1997, but the last day of greenness in the autumn was roughly the same. Earlier greenup dates in the spring resulted in a lengthened growing season greenup of up to 20 days in some areas of Alaska from 1992 to 1997. Climate data, however, did not always corroborate these findings. In general, greenness values dropped from 1991 to 1992 and then increased from 1992 to 1997. Values obtained after 1991 may have been affected by atmospheric perturbations owing to the 1991 Mt. Pinatubo eruption and lasting until at least 1997.

INTRODUCTION

Observations of vegetation pattern and process are important for many different research studies. Land use and wildlife habitat evaluations are by far the most common, extending over scales of meters to kilometers (Jensen, 1983; Gustafson and Parker, 1992; Vogelmann and others, 1998; DeFries and others, 1995; Markon, 1995; Belward, 1996; Saint, 1996). Information about vegetation over the landscape is important for global climatic change studies because it provides links between climate variables and vegetation foliage and the potential sequestration or release of carbon to the atmosphere (Goward, 1989; McGuire and others, 1992; Reed and others, 1994; Pielke and others, 1997). Increasingly, the analysis of vegetation type and extent is used to detect terrestrial surface changes, assess landscape changes over time, estimate crop yields, and predict volatile biogenic emissions (Kinnee and others, 1997).

One important method of assessing vegetation is to study its phenology; that is, the timing and duration of events as they occur for a given plant or plant community. Whereas vegetation maps show a two-dimensional representation of the Earth's surface, the incorporation of phenological information adds a third, temporal dimension. Phenological events normally pertain to specific biological episodes (phenophases), such as spring foliation, budding, flowering, fruiting, and senescence. Plant phenophases can be used to assess the development and classification of plant communities, evaluate plant interactions and their competition for resources, and appraise relationships between animal use and available food and cover (Newstrom and others, 1994; Lynov, 1989). Also, phenological traits of vegetation have been shown to be closely related to lower atmosphere dynamics (Reed and others, 1994), are important in evaluating changes in climate (Lieth, 1998; Kramer, 1997; Myking, 1997), and are used in global change models (Lieth, 1998).

Phenological characteristics of vegetation are normally acquired by direct observation of plants in the field over one or more temporal intervals. These types of information also can be obtained by using remote sensing (aerial photographs and multispectral satellite data), which produces maps that are often more up-to-date than traditional phenological maps (Vinogradov and others, 1995), although the remotely sensed data may rely heavily on field measurements (Lieth, 1998; Schwartz, 1997). More recently, the normalized difference vegetation index (NDVI, equation 1) derived from multispectral scanner data has been used to measure phenological traits of vegetation across the landscape.

$$NDVI = \frac{(r2 - r1)}{(r2 + r1)} \qquad (1)$$

The NDVI is a unitless measure of vegetation greenness, where ρ 2 represents the infrared wavelengths of the electromagnetic spectrum (.73-1.1 Fm) and ρ 1 represents the red wavelengths (.55 - .70 Fm) for the advanced very high resolution radiometer (AVHRR) sensor. The infrared wavelengths (ρ 2) are highly reflective of green vegetation and provide spatial information on plant foliage. The red wavelengths (ρ 1) are highly absorbed by green vegetation and provide information on plant chlorophyll density. Thus, the NDVI can represent the distribution of green (healthy) vegetation covering the Earth's surface. The ability to obtain NDVI with ground-based, airborne, or satellite sensors over different seasonal periods offers high potential to observe the dynamics of major phenological events of plant communities. These recorded data can also be used in assessing environment gradients, studying biophysical processes, such as absorbed photosynthetic active radiation and net primary productivity, measuring crop yields, assessing the effects of drought, predicting insect outbreaks, identifying wetlands, and modeling fire fuels and wildlife habitat (Kasischke and French, 1995; Chapin III, 1986; Cenci and others, 1997; Kramer, 1997; Schwartz, 1997; Madakadze and others, 1998; Schwartz, 1998).

NDVI-based phenological information can be obtained at many different scales. At very large scales (1:10 - 1:1,000), small, boom-mounted sensors can measure the phenological traits of individual plants or small groups of plants (Shibayama and others, 1994). At medium scales (1:10,000 - 1:100,000), aerial photographs, airborne scanners, and Landsat sensors are often used (Vinogradov and others, 1995; Schwartz, 1997; Cohen, 1991). Many studies, however, are performed at small scales (1:100,000 and smaller) and involve the use of AVHRR.

Norwine and Greegor (1983) used AVHRR-derived NDVI data to correlate the changes in plant community phenology across a longitudinal gradient in Texas and found that the values agreed with the phenological nature of vegetation over four major vegetation regions. Goward and others (1985) found that AVHRR NDVI data obtained for the North American growing season were in agreement with the general vegetation phenology in both latitudinal and longitudinal directions. On a global scale, Lloyd (1990) produced a phytophenological map of the Earth's terrestrial vegetation using three phenological metrics derived from global AVHRR NDVI data: time of maximum photosynthetic activity, length of growing season, and annual mean daily maximum potential photosynthetic rate.

More recently, a series of phenological attributes, or metrics, have been derived from annual and multiannual AVHRR NDVI data. Reed and others (1994) produced 12 phenological metrics for 159 land cover classes for the conterminous United States and related them to biophysical qualities (timing, length, and intensity of vegetation phenology, photosynthetic activity, and productivity). Results from this study were further used to assess the production and distribution of C_3 and C_4 grassland cover types in the Great Plains region of the United States (Tieszen and others, 1997). A study similar to Reed's was conducted over Alaska using AVHRR NDVI data from a single, leaf-on growing season (Markon and others, 1995). Five different phenological maps based on vegetation timing and intensity were related to vegetation type and physiognomic location for the entire State.

Schwartz (1997) used AVHRR NDVI data along with site-specific vegetation data to simulate the beginning of the active vegetation period (or green wave) across eastern North America, showing the utility and importance of using field-based phenological data with remotely sensed data for monitoring seasonal changes in terrestrial vegetation. This work was continued by Schwartz and Reed (1999), who used AVHRR NDVI data to document the utility of observing phenological start-of-season dates. Average correlation between the NDVI data and modeled outputs over all land cover types was 0.61.

As global climate change models become capable of incorporating data sets that have smaller time and space scales (for example, spatial resolutions of 1 km and daily to monthly time periods) more importance will be placed on intramonthly to intra-annual changes of vegetation (Henderson-Sellers and McGuffie, 1995). Recording of interannual changes also will be important; especially in high-latitude environments where major changes may take place in decadal periods instead of yearly periods (ARCUS, 1998). Currently, the use of satelliteborne sensors is more appropriate for acquisition of these types of data because of the sensor's synoptic coverage and repeatability.

In this study, phenological characteristics of Alaskan vegetation were produced and analyzed using multitemporal AVHRR NDVI data. Objectives for this study were to derive a series of phenological metrics representing the timing, intensity, and duration of the vegetation growing season over the Alaskan landscape and relate one or more of those metrics to climatic data. Derivation of phenological data from satellite sensors can cover different periods throughout the growing season or span multiple growing seasons, depending on the timeframe of interest and the sensor used, however, the measurement and tracking of phenological events using these types of data can vary, depending on many biological, physical, and spatial qualities or events (table 1). For this study, data are limited to the frost-free, or carbon-production, season. This period also reduces problems resulting from low sun angles, reduced daylight, and off-nadir view angles (Holben, 1986, Markon, 1999).

Table 1. Common biological, physical, and spatial qualities or events that affect the study of vegetation phenology

Biological	Physical	Spatial
Plant species	Local or regional climate (including episodic events)	Latitude
Plant part(s)	Soils/nutrient supply	Slope, aspect, elevation
Plant sociability (individual, group, community)	Water supply	Site (micro, local, regional, global)
Vector induced disturbance (insect and disease)	Natural disruptive events (volcanic eruptions, fire, flooding)	Timeframe (daily, monthly, yearly, decadally)
Anthropogenic disturbance (logging)		

METHODS

AVHRR Temporal Data

Data used for this study were recorded by AVHRR sensors onboard NOAA TIROS 11 (launched in 1988) and 14 (launched in 1994) satellites from 1991 through 1997. These satellites operate in a near-polar, sun-synchronous orbit approximately 833 km above the Earth. NOAA 11 data were used for the 1991, 1992, 1993, and 1994 data sets; the AVHRR sensor subsequently failed in September 1994. NOAA 14 data were used for the 1995, 1996, and 1997 data sets. In both cases, data from afternoon (ascending node, daylight period) overpasses were used. The time of overpass was set to 2:30 p.m. (local solar time) at launch for both NOAA 11 and 14; however, by March 1995, NOAA 11 overpass time had slipped to 5:30 p.m., and it is assumed that the 1994 AVHRR data acquisitions were later than the 2:30 p.m. local solar time (Kidwell, 1997).

The AVHRR sensor collects data over a 2,500-km-wide swath with a nominal picture element (pixel) resolution of 1.1 km at nadir. Off-nadir viewing angles greater than +/- 30 degrees are common (Markon, 1999), producing pixel dimensions as large as 2.4 km (along track) by 6.9 km (across track). These data are coarse compared with other satellite data available (such as Landsat, SPOT, IRS, or IKONOS). The NOAA satellite, however, has a repeat cycle of two to four times per day over Alaska, compared with 16-26 days for some of the other satellites. The increased overpass frequency potentially provides a greater number of possible images to use for detecting phenological events.

The AVHRR sensor is capable of collecting information in five spectral bands or channels (table 2); however, this study used data from the first two channels (visible [ρ1] and near-infrared [ρ2]) to calculate NDVI. Data processing followed standardized procedures for acquisition, georeferencing, and radiometric correction as outlined by Markon (1999), Eidenshink (1992), and Eidenshink and Faundeen (1994).

Data Acquisition

Data acquisition for each of the 7 years began on April 1. At this time, over 90 percent of the State is snow covered. Ending dates varied from September 13 to October 31 because of excessive clouds, the demise of NOAA 11 in late 1994, or low sun angles beginning in October (Holben, 1986; Kidwell, 1997; Jeff Eidenshink, EROS Data Center, Sioux Falls, S.D., written commun.).

The NDVI data used for this study were the result of a maximum value compositing process (Eidenshink, 1992; Holben, 1986). For most biophysical research of the Earth's surface, cloud-free data are needed. Daily cloud-free data are not normally available, however, especially in northern latitudes. Therefore, a series of images are often collected over a predetermined period (for example, 5 to 30 days), with those containing the least cloud cover used in a composited image. AVHRR scenes used during any composite period are based on the maximum NDVI value within any particular scene (Markon, 1999). It should be noted that the purpose of the compositing process is to create minimum residual clouds and not to obtain maximum NDVI (Cihlar and Huang, 1994). For the Alaskan data sets, the composite period varied between 14 and 16 days. The 1991-94 data sets are based on a bimonthly (15 or 16 day) composite period, dictated by early production protocols (Eidenshink and Faundeen, 1994; Holben, 1986) and whether a month contained 30 or 31 days (table 3). The 1995-97 data sets use a 14-day period (table 4) on the basis of current production protocols used for global AVHRR composite data sets (Carolyn Gacke, EROS Data Center, written commun.). The number of composite periods available for any given year varied from 11 to 14 as a result of satellite operation, snow cover, and (or) sun angle.

Table 2. Spectral characteristics and common uses of the NOAA AVHRR sensor

Channel	Spectral Response	Common Uses
1	0.58 - 0.68 Fm	Chlorophyll density, daytime cloud, snow, and ice mapping
2	0.72 - 1.10 Fm	Green leaf density, surface water delineation
3	3.55 - 3.93 Fm	Nighttime cloud mapping, detection of hot spots (fires volcanic activity), sea surface temperature, land/water distinction
4	10.3 - 11.3 Fm	Day/night cloud mapping, sea and land surface temperature, soil moisture, volcanic eruptions
5	11.5 - 12.5 Fm	Sea surface temperature, soil moisture

Phenological Metrics Used

Phenological metrics were derived from each yearly NDVI data set and grouped into three general categories: (1) temporal metrics, (2) value metrics, and (3) derived metrics. In all, 10 different metrics were calculated (table 5).

Temporal metrics are a function of date. They indicate when greenness begins and ends, when maximum greenness may occur, and how long the growing season is. The first three metrics used are individual dates (shown here as Julian dates), and the fourth is a temporal

Table 3. Biweekly periods, corresponding Julian dates, and time period abbreviation for 1991 through 1994 composite data sets (one day was added to the 1992 Julian days to account for leap year)

Time Period	Julian Date	Abbreviated ID
April 01-15	091-105	PD1
April 16-30	106-120	PD2
May 01-15	121-135	PD3
May 16-31	135-151	PD4
June 01-15	152-166	PD5
June 16-30	167-181	PD6
July 01-15	182-196	PD7
July 16-31	197-212	PD8
August 1-15	213-227	PD9
August 16-31	228-243	PD10
September 01-15	244-258	PD11
September 16-30	259-273	PD12
October 01-15	274-288	PD13
October 16-31	289-304	PD14

Table 4. Biweekly periods, corresponding Julian dates, and time period abbreviation for 1995 and 1997 composite data sets (one day was added to the 1992 Julian days to account for leap year)

Time Period	Julian Date	Abbreviated ID
April 01-14	091-104	PD1
April 15-28	105-118	PD2
April 29-May 12	119-132	PD3
May 13-26	133-146	PD4
May 27-June 09	147-160	PD5
June 10-25	161-176	PD6
June 26-July 07	177-188	PD7
July 08-July 21	189-202	PD8
July 22-August 04	203-216	PD9
August 05-18	217-230	PD10
August 19-Sept. 01	231-244	PD11
Sept. 02-15	245-258	PD12
Sept. 16-29	259-272	PD13
Sept. 30-Oct. 13	273-286	PD14

Table 5. Ten seasonal NDVI-derived metrics obtained from the Alaska AVHRR data sets

Metric	Interpretation
NDVI temporal metrics	
Date of initial greenness (ONS)	Earliest recorded date of measurable photosynthesis or spring leaf-out
Date of initial senescence (SNS)	Latest recorded date of measurable photosynthesis or fall senescence
Date of maximum greenness (MJD)	Recorded date of maximum measurable photosynthesis or peak of green
Total days (TDY)	Range between earliest and latest recorded dates; synonymous with growing season
NDVI value metrics	
Maximum value (Max)	Maximum measurable level of photosynthetic activity
Mean value (MEN)	Mean measurable level of photosynthetic activity
Onset value (OND)	NDVI recorded on date of initial greenness
Last value (LND)	NDVI recorded on last day of measurable greenness
NDVI-derived metrics	
Rate of greenup (RGU)	Acceleration of photosynthesis (NDVI per day)
Rate of senescence (RGD)	Deceleration of photosynthesis (NDVI per day)

quantity (in days). The first metric, date of onset of greenness (ONS), indicates when spring foliage became dense enough to be detected by the sensor over background conditions (tree and shrub stems and boles, previous year's dead foliage, barren ground, snow cover). The only exception would be evergreen needleleaf trees, which retain green biomass year round and may indicate greenness early before major photosynthetic activities begin. The second metric, date of senescence (SNS), is recorded at the end of the growing season when leaves begin to lose chlorophyll. This date will vary depending on fall climatic conditions (cloud or early snow cover), leaf type and longevity, or, in the case of the 1994 data, termination of data acquisition because of sensor malfunction. Date of maximum greenness (MJD) indicates that period of the growing season when vegetation is most green or covers the greatest amount of surface area for any given location. The fourth time metric, total days (TDY), represents growing season length and is the number of days from initial vegetation greenup in the spring to senescence in the fall;

it is based on the ONS and SNS metrics.

Greenness metrics contain the NDVI value recorded during a given period. Four metrics were obtained for this study: maximum NDVI, mean NDVI, onset greenness, and end-of-year greenness. Maximum NDVI (MAX) is the maximum measurable NDVI recorded during the year and is normally associated with the peak of greenness during the growing season. Mean NDVI (MEN) is the maximum NDVI value obtained for the growing season divided by the total number of composite periods. The last two greenness metrics, onset (OND) and end-of-year (LND), are the recorded NDVI values that occurred during onset of greenness in the spring, and decline of greenness or leaf-fall in the autumn, respectively. These two metrics are based on the time when greenness values equaled or exceeded 0.09 in the spring and equaled or dropped below 0.09 in the fall. The 0.09 threshold has been shown to indicate when green vegetation is abundant enough to be recorded by the sensor (Lloyd, 1990), although different values have been shown to be more applicable in some situations (Reed and others, 1994; Tieszen and others, 1997). All of the metrics should be considered as relative indicators of actual dates or times. Cloud cover may prevent the sensor from recording the event, or the compositing process may select a higher NDVI value during the 2-week composite time periods, thus bypassing the actual day on which the event occurred (Markon, 1999).

Rate metrics are NDVI values that indicate rates of seasonal activity and are described by rate of greenup and rate of greendown (senescence). Rate of greenup (RGU) is calculated using the maximum NDVI value recorded during the growing season divided by the number of days from date of onset to date of maximum greenness. It is an indication of how quickly vegetation reaches full greenness within a given year. Rate of senescence or greendown (RGD) is the reverse of rate of greenup in that it is the maximum NDVI value recorded during the growing season divided by the number of days from date of maximum greenness to date of senescence. This metric indicates the deceleration of greenness from midseason to the end of the growing season. These two metrics are only relative and do not mimic actual rates of greenup and greendown, which may be faster or slower during any given shorter growing period.

All metrics were derived for Alaska as a whole. In addition, each metric was extracted for each of 19 Alaskan ecoregions (Gallant and others, 1995; fig. 1). The Aleutian Islands Ecoregion (114) was not included owing to excessive cloudiness and lack of geographic extent

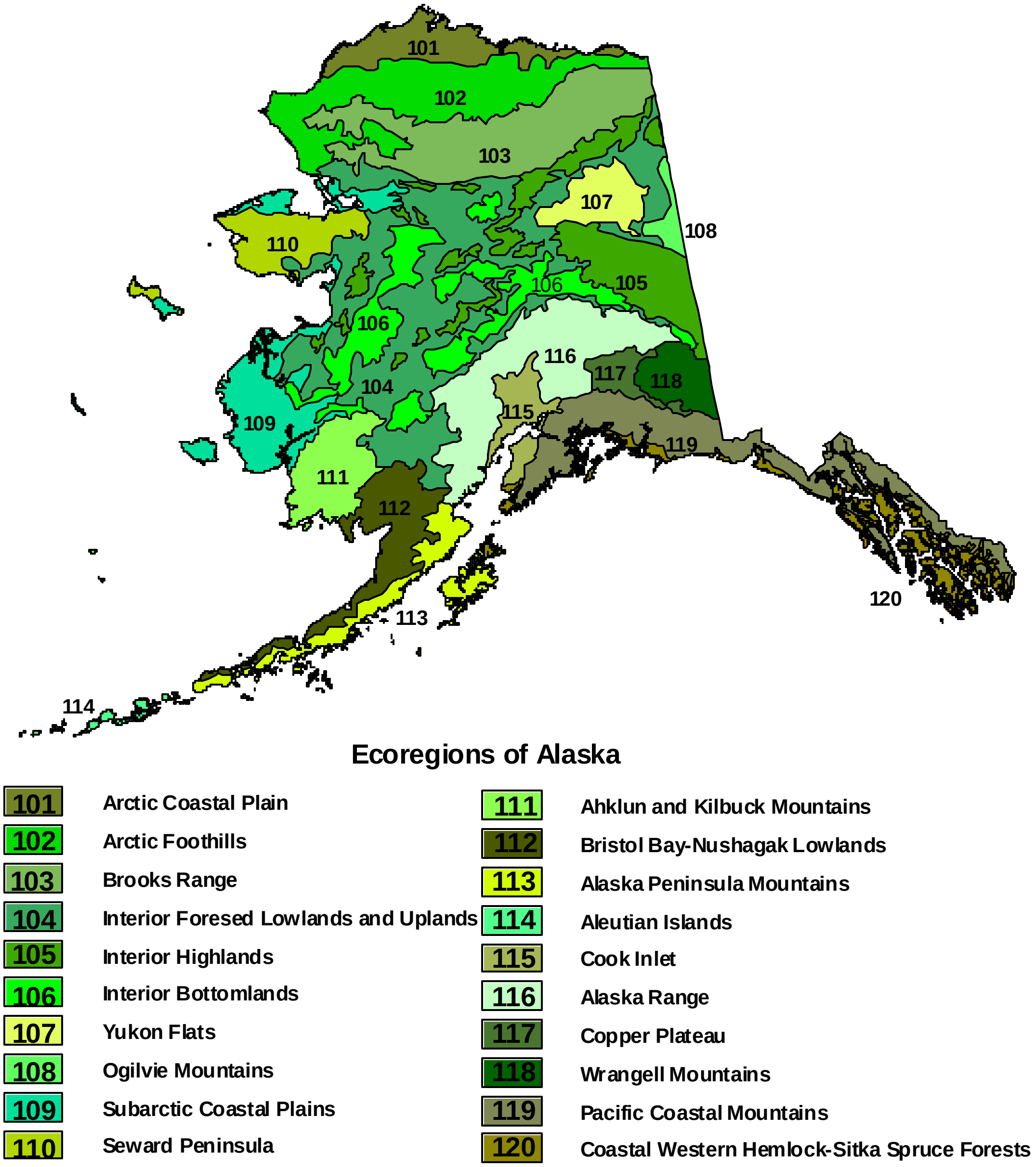


Figure 1. Ecoregions of Alaska (Gallant and others, 1995).

of the AVHRR data sets.

In addition to the satellite-derived phenological metrics, climatic information (temperature, precipitation, and snow depth) from 51 stations (fig. 2) was obtained from the Western Regional Climate Center in Reno, Nev., or the National Climatic Data Center in Asheville, N.C. These data were used to help explain trends in the phenological metric data across the State, as well as for each ecoregion. The number of climate stations used for ecoregion analysis varied from one to six, depending on station location. Some stations were used for more than one ecoregion because they were close to an ecoregion border and were within the same physiographic area. Climate data also were used to calculate growing-degree days (GDD) and growing degree day season (GDD-S). GDDs were calculated following McMaster and Wilhelm (1997) and using a base temperature of 0 ^{o}C. GDD-S was derived by summing the number of days from when daily GDD first attained a value of 1 in the spring to when daily GDD dropped to 1 in the fall; it includes those days when GDD may have dropped below 1 between the spring and fall end dates.

Data Analysis

Two random 1,000-point samples were obtained from each metric. One sample was extracted from the entire State and another separate sample from each ecoregion (twenty 1000-point samples in all). In addition to being random, each sample point had to be located over a vegetated area. Vegetated areas were identified using digital land cover data covering about 77 percent of Alaska (Shasby and Carneggie, 1986; Markon, 1995).

Each year's phenological metric value was based on the mean of the 1,000-point sample. Statistical analysis was obtained using SAS (SAS, 1990). Multiyear trends were considered noteworthy if the slope of the line was significantly different from 0 with a p-value < 0.05.

To assess the importance of composite period values between years, a nested anova was performed on the NDVI values obtained for each year using three different nesting structures. One nested anova involving all years was not entirely applicable because of differences in the number of composite periods for any given year (from 11 to 14) and the dates on which those periods occurred (see tables 3 and 4). The first nested anova used 11 periods from 1991 to 1994, and the second used 14 periods from 1995 to 1997. These two groupings contained a similar number of days for each composite period and provided an equal number of composite periods

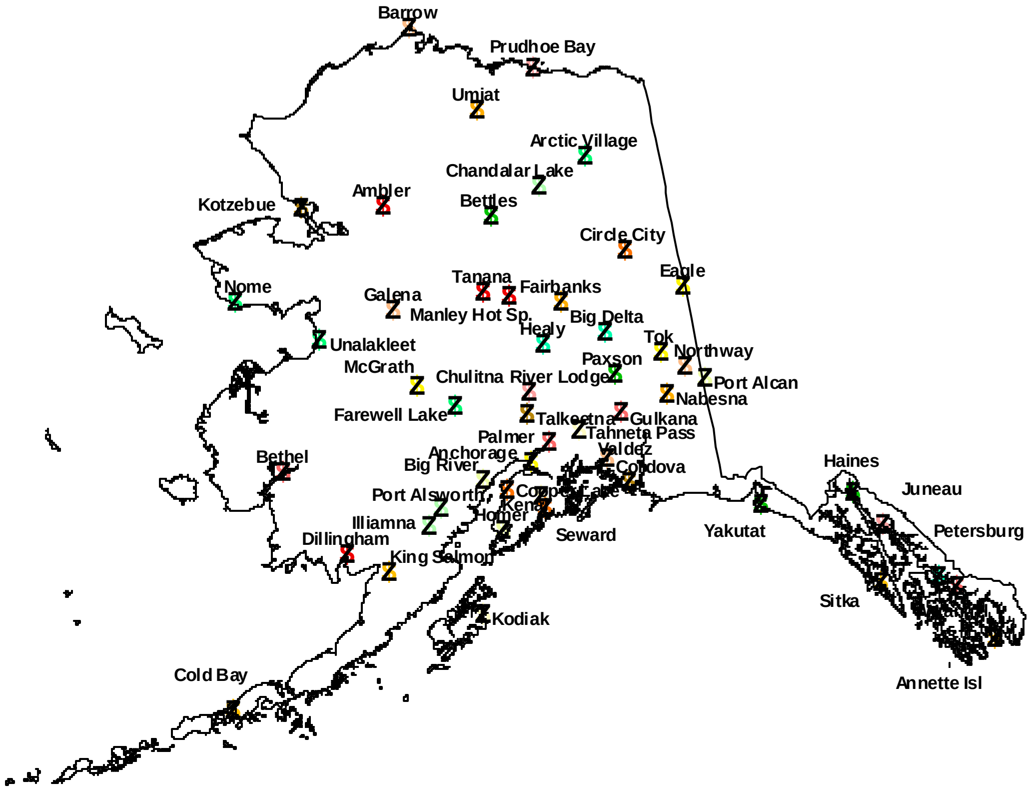


Figure 2. Location of weather stations from which climate data were obtained.

for each year. The third nested anova used all 7 years and 11 composite periods for each year. For the first two groupings, the nested anova was used to examine differences in NDVI values between composite periods and between years. For the third grouping, the nested anova could only be used to look at differences in NDVI values between years.

RESULTS

Baseline Interyearly Differences

Results from the statewide nested anova for the different years and composite periods are shown in table 6. These results indicate that variations among all NDVI values from each composite period for each year were not significant between years. This would imply that major changes in statewide vegetation greenness over the 7-year period were not apparent; that is, no catastrophic events took place resulting in major changes to type, density, structure, and aerial extent. Variation in NDVI values between composite periods within a year was significant for the 1991-94 and 1995-97 groupings. This is noteworthy because it indicates that NDVI is documenting changes in greenness condition (phenological events) across the landscape.

A nested analysis of variance also was performed on each of the 10 metrics by year and ecoregion (table 7). In almost all cases (9 of 10 metrics), there was significant variation from year to year, with results for OND being slightly over the significance level of 0.05. Significant year-to-year variations may indicate relationships between the metrics and bioclimatic events or trends that may have occurred over the 7-year period. Variation from ecoregion to ecoregion within a year also was significant and supports the idea that vegetation occurring in different ecoregions would show different phenological characteristics because of latitude, climate, soils, and other environmentally constraining factors. These findings, however, do not indicate whether the changes are caused by atmospheric perturbations or climatic-related effects on phenology or data acquisition.

Statewide Summary

Results from the statewide metric samples are shown in table 8 and in figure 3. Although all data sets began with an April 1 start date, earliest ONS ranged from April 30 (Julian day 120 in 1996) to May 26 (Julian day 146 in 1992); corresponding OND values were less than 0.20 indicating greenness occurring before the above dates. Beginning in 1992, there was a general trend toward earlier greenup each year (slope=-0.202, p=0.019, α=0.05), although this may be indicative of less cloudy springtime conditions. This is due in part to the compositing process, as well as to clouds occurring during earlier dates. SNS values were somewhat similar for 1991, and 1995-97, perhaps indicating that the onset of autumn is relatively consistent across

Table 6. Nested random effects analysis of variance for different combinations of years and composite periods for composite period NDVI

For 1991-97, 11 composite periods

Variance Source	Degrees of Freedom	F Value	Pr > F	Percent of Total	Error Term
TOTAL	76999			100.000	
YEAR	6	0.428	0.8582	0.0000	PERIOD
PERIOD	70	1016.0	0.0000	50.3711	ERROR
ERROR	76923			49.6289	

For 1995-97, 14 composite periods

Variance Source	Degrees of Freedom	F Value	Pr > F	Percent of Total	Error Term
TOTAL	41999			100.000	
YEAR	2	0.0367	0.9640	0.0000	PERIOD
PERIOD	39	732.1	0.0000	42.2336	ERROR
ERROR	41958			57.7664	

For 1991-94, 11 composite periods

Variance Source	Degrees of Freedom	F Value	Pr > F	Percent of Total	Error Term
TOTAL	43999			100.000	
YEAR	3	0.370	0.7749	0.0000	PERIOD
PERIOD	40	1209.5	0.0000	54.7210	ERROR
ERROR	43956			45.2790	

Table 7. Nested random effects analysis of variance by metric for each year and ecoregion

```
Nested Random Effects Analysis of Variance for Variable Onset

 Variance                       Error  Percent
 Source     F Value    Pr > F    Term  of Total

 TOTAL                                 100.0000
 YEAR         2.084    0.0595  ECO       0.5506
 ECO          107.3    0.0000  ERROR     9.5565
 ERROR                                  89.8929
```

```
Nested Random Effects Analysis of Variance for Variable Max

 Variance                     Error    Percent
 Source    F Value    Pr > F    Term   of Total

 TOTAL                                 100.0000
 YEAR        5.372    0.0001  ECO        7.2179
 ECO         510.2    0.0000  ERROR     31.3062
 ERROR                                  61.4759
```

```
Nested Random Effects Analysis of Variance for Variable Mean

 Variance                     Error    Percent
 Source    F Value    Pr > F    Term   of Total

 TOTAL                                 100.0000
 YEAR       10.615    0.0000  ECO       20.1830
 ECO         997.8    0.0000  ERROR     39.8439
 ERROR                                  39.9731
```

```
Nested Random Effects Analysis of Variance for Variable last

 Variance                       Error   Percent
 Source     F Value    Pr > F    Term  of Total

 TOTAL                                 100.0000
 YEAR         6.277    0.0000  ECO       3.6619
 ECO          158.4    0.0000  ERROR    13.1028
 ERROR                                  83.2352
```

```
Nested Random Effects Analysis of Variance for Variable Lastday

 Variance                     Error    Percent
 Source    F Value    Pr > F    Term   of Total

 TOTAL                                 100.0000
 YEAR       87.652    0.0000  ECO       44.4054
 ECO         212.1    0.0000  ERROR      9.6908
 ERROR                                  45.9038
```

Table 7. Nested random effects analysis of variance by metric for each year and ecoregion (continued)

Nested Random Effects Analysis of Variance for Variable Maxday

```
Variance                          Error    Percent
Source    F Value    Pr > F        Term   of Total

TOTAL                                     100.0000
YEAR       25.830    0.0000  ECO           21.9956
ECO         274.9    0.0000  ERROR         16.7697
ERROR                                      61.2347
```

Nested Random Effects Analysis of Variance for Variable Minday

```
Variance                          Error    Percent
Source    F Value    Pr > F        Term   of Total

TOTAL                                     100.0000
YEAR        4.278    0.0006  ECO            7.0543
ECO         784.7    0.0000  ERROR         40.8386
ERROR                                      52.1071
```

Nested Random Effects Analysis of Variance for Variable TDY

```
Variance                          Error    Percent
Source    F Value    Pr > F        Term   of Total

TOTAL                                     100.0000
YEAR        8.733    0.0000  ECO           16.6891
ECO         968.3    0.0000  ERROR         40.9633
ERROR                                      42.3476
```

Nested Random Effects Analysis of Variance for Variable RGUO

```
Variance                          Error    Percent
Source    F Value    Pr > F        Term   of Total

TOTAL                                     100.0000
YEAR       11.825    0.0000  ECO            0.8450
ECO        15.170    0.0000  ERROR          1.3854
ERROR                                      97.7696
```

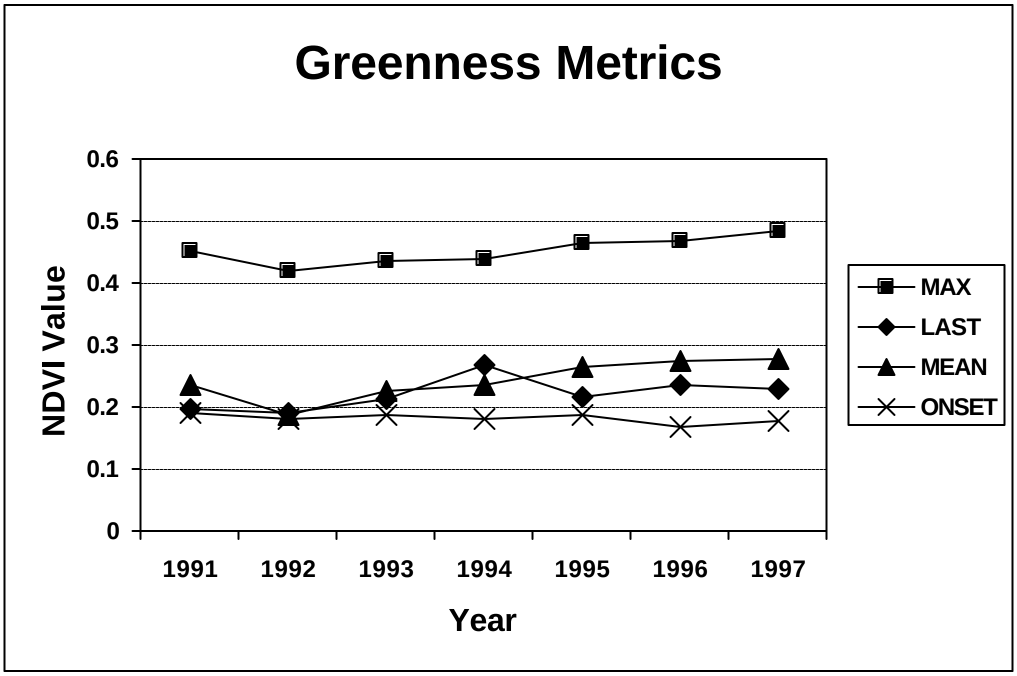
Nested Random Effects Analysis of Variance for Variable RGUS

```
Variance                          Error    Percent
Source    F Value    Pr > F        Term   of Total

TOTAL                                     100.0000
YEAR        8.175    0.0000  ECO            6.9876
ECO         248.1    0.0000  ERROR         18.4288
ERROR                                      74.5836
```

Table 8. Yearly averages for each phenological metric for Alaska derived from random 1,000-point sample (letter indicates interyear metrics that where not significantly different at alpha = 0.05)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Onset	0.19 a	0.18 c	0.19 a b	0.18 b c	0.19 a b	0.17	0.18 c
Max	0.45 a	0.42 b	0.44 b	0.44 a c	0.46	0.47 c	0.48
Mean	0.24 a	0.19	0.23 b	0.23 a b	0.27 c	0.27 c	0.28
Last	0.20 a	0.19 a	0.21 b	0.27	0.22 b	0.24 c	0.23 c
Lastday	256 a b	282	241	232	258 a b	252 b	260 a
Maxday	220	266	214 a	214 a	228 b	227 b	239
Minday	134 a	146	134 a	132 a b	129 b	120 c	122 c
Total Days	123	137 a	107	100	129	133	137 a
RGU	0.0056 a	0.0041 b	0.0055 a	0.0053 a	0.0047 a b	0.0057 a	0.0049 a b
RGD	0.0842 a	0.1555	0.0795 a b	0.0408	0.0600	0.0710 b	0.0798 a b



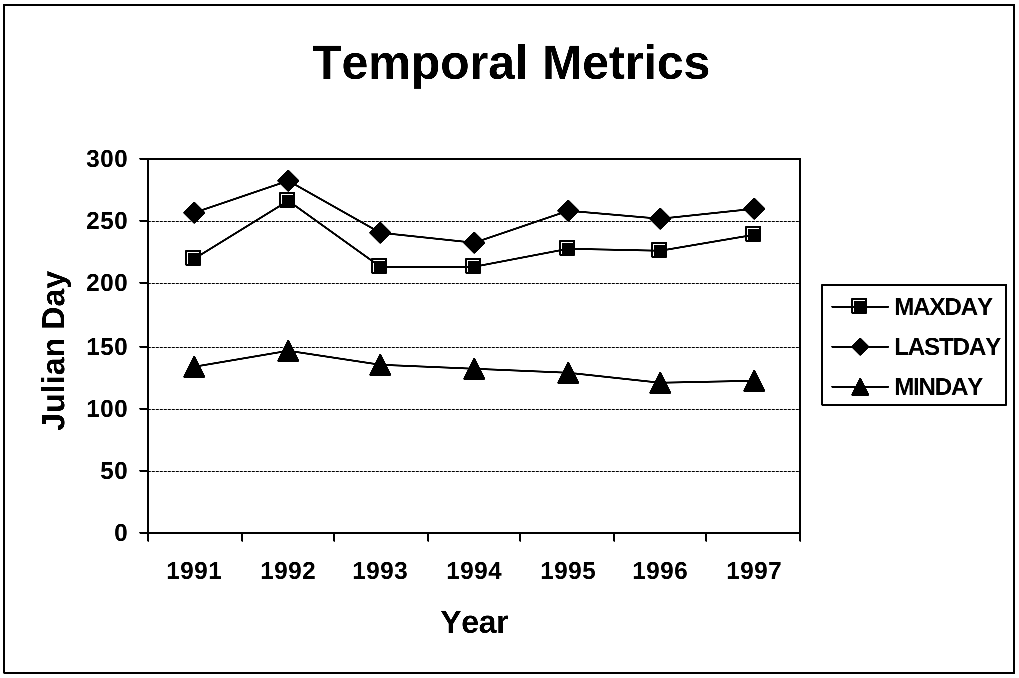


Figure 3. Greenness and temporal metrics for Alaska, 1991-97 (average of 1,000-point sample).

Alaska. The earlier autumn dates in 1993 and 1994 are due to early truncation of the data for those years. The exceptionally late date in 1992 is odd because autumn temperatures were in general slightly cooler than for other years (fig. 4).

MAX for any year never exceeded 0.5. As with the previous metrics, a general trend of increasing NDVI (slope=0.007, p=0.038, α=0.05) occurred for each year following 1992 (with the lowest MAX of any year). MEN showed a small overall greening trend from year to year (slope=0.012, p=0.02, α=0.05), again beginning in 1992. LND values were higher toward the end of the 7-year period than at the beginning. The exceptionally high LND in 1994 was probably due to the September 15 cutoff date for that year.

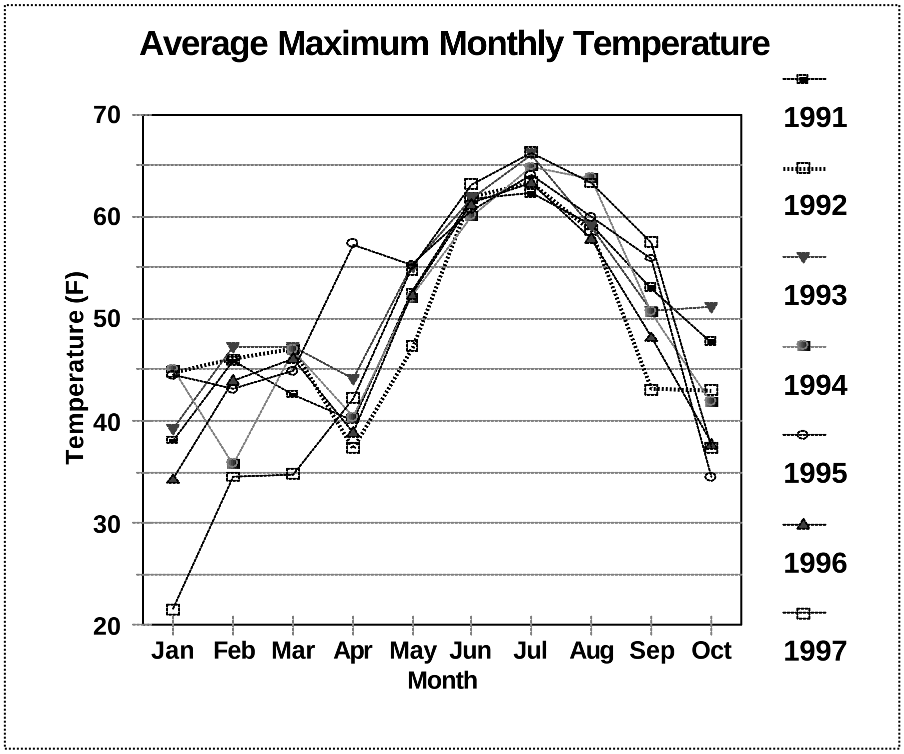
TDY ranged from 123 to137 days (excluding 1993 and 1994 because of fewer composite periods available). Longer growing seasons toward the end of the 7-year period are partially due to earlier greenup dates in the spring.

RGD was significantly faster than RGU over the Alaskan landscape. This is somewhat reasonable because of lingering snow patches in the spring and the rapid onset of lower temperatures and reduced light levels beginning in August. RGU values for 1991 and 1993 through 1997 were not significantly different across the State.

Although there appeared to be some trends in MAX and ONS, this was not reflected in averaged climate data. Figure 5 shows minimum and maximum temperature departures from a 7-year average (1991-97) by year for each month. As can be seen, there were no observable trends during the 6- to 7- month period that the AVHRR data were acquired for any given year. Similar results are shown in figure 6 for temperature departures from a 30-year average (1961-90). It is interesting that temperatures during the 7-year period were lower than the 30-year average, with a slight trend toward increasing temperatures from 1992 to 1997.

ANALYSIS BY ECOREGION

Commentaries for each ecoregion will include a brief description of location, vegetation, and climate. Only those metrics showing significant or interesting trends will be mentioned, although all metric values are present in the tables.



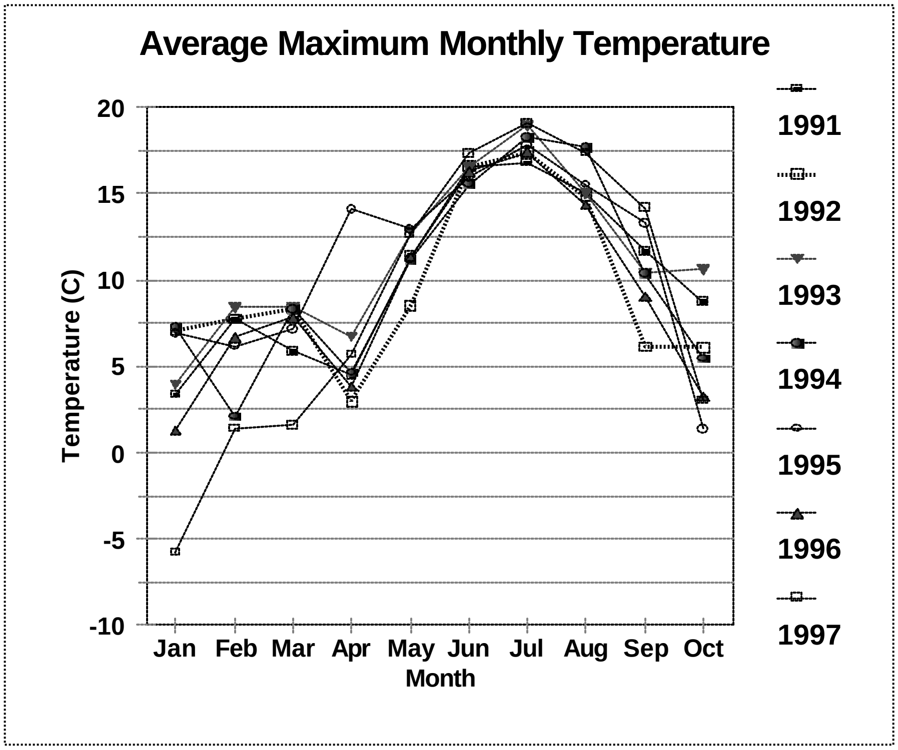
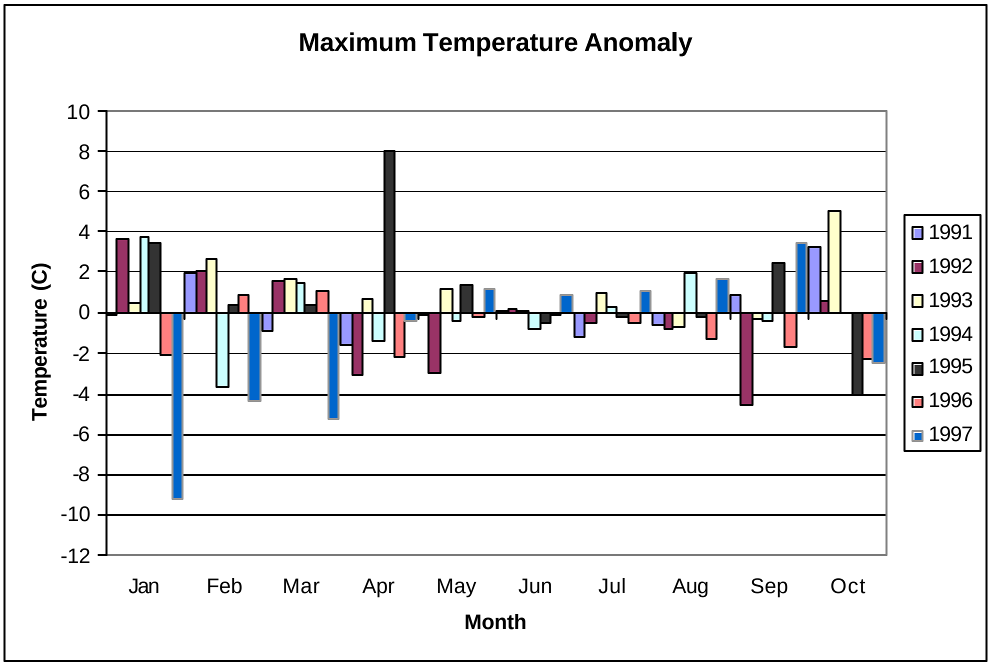


Figure 4. Maximum and minimum average statewide monthly temperature for each of the years of climate data from all stations.



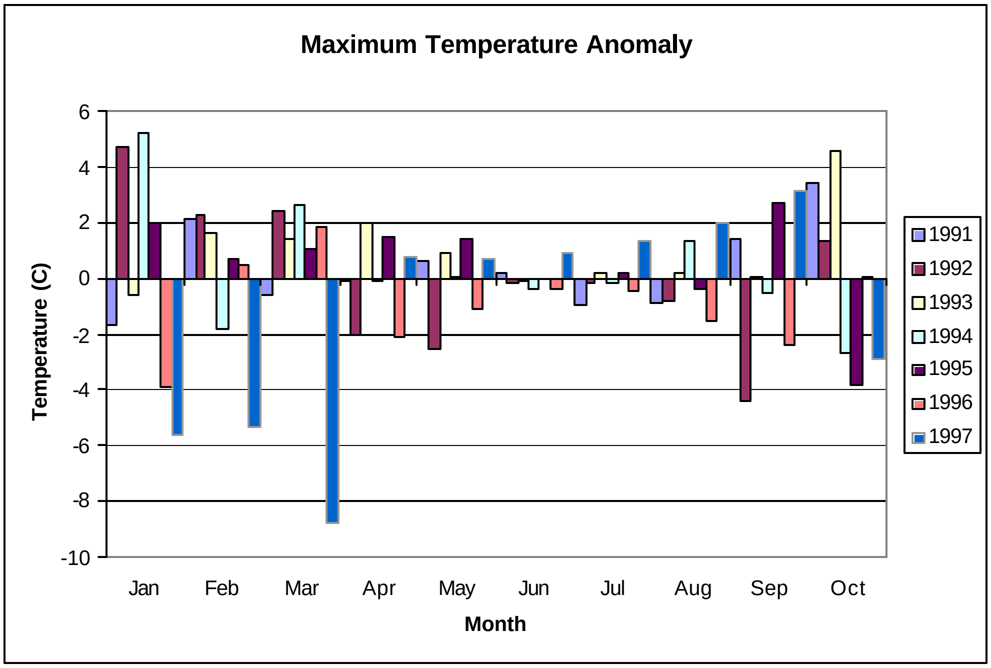
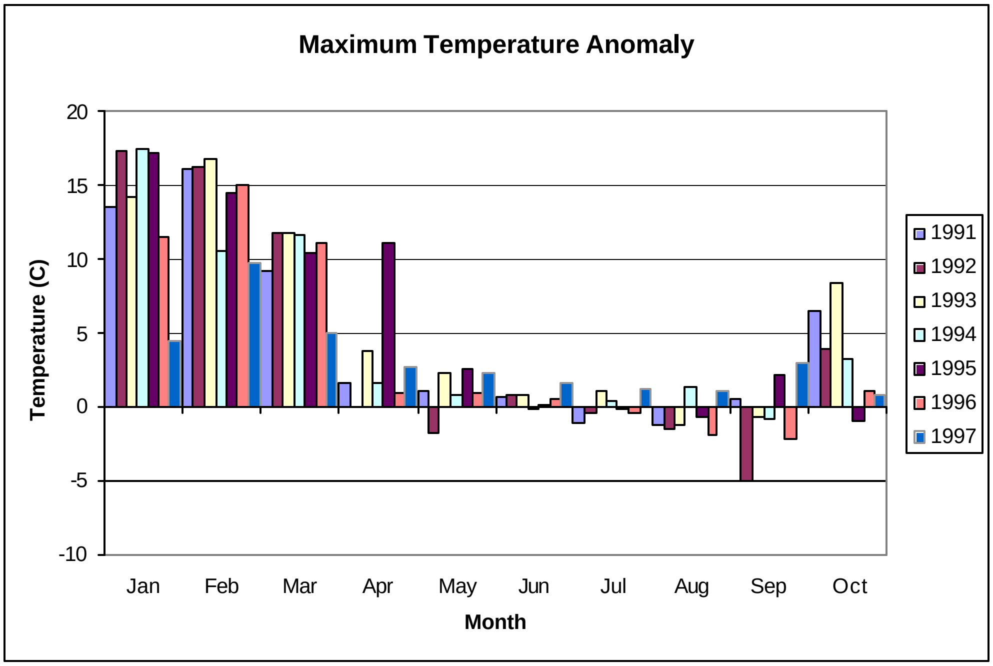


Figure 5. Average maximum and minimum statewide monthly temperature anomalies for 1991-97 (number of climate stations = 51).



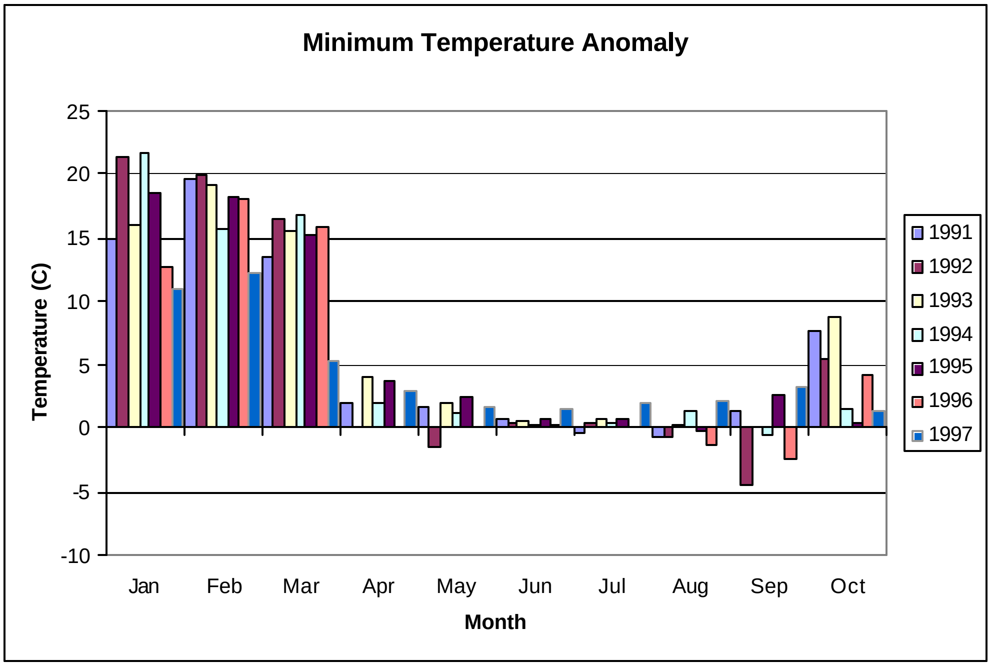


Figure 6. Average maximum and minimum monthly temperature departures from 30-year average (1960-91) for all stations.

Arctic Coastal Plain (101)

The Arctic Coastal Plain is the northernmost ecoregion, generally residing above 70° north latitude, and is in an arctic climatic zone (Tuhkanen, 1998). General climate is largely controlled by the yearround frozen portion of the Arctic Ocean and open water along the shoreline during the summer months. Temperatures are often cool (0° to 9° C), with clouds or fog near the coast, gradually increasing to 18° C, with less clouds inland (Selkregg 1975). Snowmelt and greenup are highly variable, depending on proximity to the coast and local topography. Snow cover may be 50 percent or less by the end of the second week of June near the coast, to less than 5 percent inland; most areas are snow free by mid-June. The ecoregion is dominated by graminoid communities with low and dwarf shrubs, intermingled with extensive wetlands, ponds, and lakes. Climate information was obtained from Barrow and Prudhoe Bay.

OND values were roughly half of MAX (table 9) for this ecoregion, perhaps because of the rapid rate at which greenup occurs and the composite period being too long to record initial greenness values. There was an increasing trend in MAX from 1992 to 1997 (slope=0.011, $p=0.003$, $\alpha=0.05$), with 1997 having the highest MAX of any of the 7 years, and MJD occurring roughly over a period from the end of July to early September. MEN values were somewhat low and similar to OND, probably because of the large amount of surface water present during the growing season. LND showed an odd alternating pattern of low and high values over the 7-year period, peaking in 1996.

Earliest ONS occurred on June 1 in 1996, although for most years, ONS occurred during the second week of June. During this time, snow was absent from Barrow and Prudhoe Bay, except for 1994, when Barrow reported significant snowfall in mid-June. The latest dates for MJD and SNS occurred in 1992. These values are suspect, however, owing to the ›terminator effect' of declining sun angles (Holben, 1986) or perhaps sensor problems. During the last 2 weeks in August 1992, average maximum and minimum temperatures were 10 °C and 1 °C, respectively, for Barrow and Prudhoe Bay along the coast and at Umiat 150 km inland. Both maximum and minimum temperatures dropped and remained below 0 °C during the first 2 weeks in September 1992.

TDY averaged 92 days for the 7-year period and is higher than the average GDD-S of 88 days for Barrow and Prudhoe Bay during the same period.

Table 9 Yearly averages for each phenological metric for the Arctic Coastal Plain Ecoregion (101) and the Arctic Foothills Ecoregion (102).

101

	1991		1992		1993		1994			1995		1996		1997	
Onset	0.1964		0.1570		0.1602		0.1593			0.1822	a	0.1684	a	0.1921	
Max	0.3537	a	0.3264	b	0.3297	c	0.3427	b	c	0.3643	a	0.3762		0.4051	
Mean	0.1592		0.1247		0.1202	a	0.1305	a		0.1605	b	0.1760	b	0.1607	b
Last	0.1616	a	0.2102	a	0.1566	a	0.2192			0.1611	a	0.2423		0.1613	
Minday	167	a	168	a	171	a	178			172		152		171	
Maxday	213		293		211		237			240		216		240	
Lastday	262		296		245		250	a		265		248	a	261	
Total days	94		129		73	a	72	a		92		96	b	89	b
RGU	0.0043	a	0.0015		0.0050		0.0036			0.0030		0.0046	a	0.0035	
RGD	0.0264	a	0.1438		0.0155	b	0.0471			0.0787	a	0.0185	b	0.0619	

102

	1991		1992		1993		1994			1995		1996		1997	
Onset	0.2507	a	0.1975	b	0.2124	b	0.2336	b		0.1845		0.1852		0.2645	a
Max	0.4918		0.4830	a	0.4759	a	0.4793			0.4956		0.5062		0.5294	
Mean	0.2448	a	0.1948		0.2136		0.2141			0.2597	a	0.2567		0.2570	a
Last	0.2103	a	0.2174	b	0.2171	a	0.2922	b		0.2206	a	0.3085		0.2496	a
Minday	159	a	158	a	158	b	161			147	b	143		155	b
Maxday	220	a	291		210	a	238			229	b	215		246	b
Lastday	271	a	296		250		251			269		252		264	a
Total days	112	a	140		91	b	90	b		121		108	a	109	
RGU	0.0051	a	0.0024		0.0054	c	0.0035	b	c	0.0043		0.0050	a	0.0031	b
RGD	0.0667		0.2423		0.0193	a	0.0848			0.0704		0.0269	a	0.0443	

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, Lastday are represent Julian dates.

Rate of greendown was an order of magnitude slower than greenup, with the slowest (or longest) greening down occurring in 1997. RGD for 1992 is suspect because of the extreme late SNS date (October 23) when 8-10 cm of snow were recorded as being on the ground.

Arctic Foothills (102)

This ecoregion forms the transition from the Arctic Coastal Plain to the north and the rugged Brooks Range Mountains to the south; it also includes the Noatak River Valley to the southwest. It is dominated by low shrub and graminoid communities over low rolling hills that are predominantly north facing. Climate conditions are generally warmer than the Arctic Coastal Plain, with mean monthly temperatures for June through August being 16 ^{o}C. Average temperatures at Umiat in April are about –12 ^{o}C and may reach or be slightly above freezing during May. Snow can occur anytime of the year, but the ground surface is generally snow free from the end of May through September 1.

OND values were roughly half of MAX values, with both metrics being higher than those of ecoregion 101 (table 9). Value metrics were somewhat similar, with slightly higher MAX, MEN, and LND values during the last 3 years. ONS dates were not significantly different for 1991 through 1993 and were about 10 days earlier than for ecoregion 101. The earlier greenup is expected, being further away from the influence of the arctic ice pack. MJD and SNS values did not show any trends for the 7-year period and were similar to those for ecoregion 101. TDY averaged 110 days and mirrors the average GDD-S of 111 at Umiat for the same period.

Brooks Range (103)

The Brooks Range Ecoregion extends over the northern end of the Rocky Mountains and is more or less contained within 30 minutes of latitude. The area has a wide variety of climate conditions: arctic in the north, continental in the south, and arctic maritime in the west. Much of the area is composed of barren mountain tops and upper slopes. Lower slopes and valleys contain a wide variety of plant communities, including conifer forests, tall and low shrubs, and dwarf shrubland. Very little climatic data exist for this ecoregion, and the two stations used for climate data (Arctic Village and Chandalar Lake) were incomplete for the 7-year period.

Phenological metrics for this region are shown in table 10. OND values were slightly lower for this ecoregion than for the two previous ecoregions, probably owing to the effects of early season mountain shadow. MAX and MEN were slightly higher than in ecoregion 102.

Table 10. Yearly averages for each phenological metric for the Brooks Range Ecoregion (103) and the Interior Forested Lowlands and Uplands Ecoregion (104)

103

	1991			**1992**		**1993**			**1994**			**1995**		**1996**			**1997**
Onset	0.1999	a		0.1949	a	0.1904	b		0.1871	b	c	0.1687		0.1807	c		0.1957
Max	0.4363	a	b	0.4400	a	0.4297	b	c	0.4217	c		0.4520	d	0.4571	d		0.4882
Mean	0.2166	a		0.1664		0.1883			0.1987			0.2386		0.2149	a		0.2451
Last	0.1748	a		0.1974		0.2286			0.2474			0.1860		0.2722			0.1733
Minday	150	a		166		155	b		155	b		140	a	149			149
Maxday	216			295		206			227			236		222			241
Lastday	267	a		296		241			244			269	a	249			268
Total days	116			132		85			89			129		100			119
RGU	0.0050			0.0021		0.0055			0.0041	a		0.0037	b	0.0043	a		0.0035
RGD	0.0424	a		0.2516		0.0175			0.0747			0.0667		0.0386	a		0.0409

104

	1991			**1992**		**1993**			**1994**			**1995**		**1996**			**1997**
Onset	0.2018	a		0.1814	b	0.2039	a		0.1780	b	c	0.2132		0.1724	c	d	0.1678
Max	0.5233			0.4792		0.5066	a		0.5069	a		0.5376	b	0.5368	b		0.5542
Mean	0.3119			0.2475		0.2907			0.3161			0.3497		0.3454			0.3552
Last	0.2253	a		0.1679		0.2330	a		0.2968			0.2522		0.2294	a		0.2614
Minday	128			132	a	132	a		122	b		123	b	115			108
Maxday	234			281		240			226			237		245			256
Lastday	280			297		266			250			276	a	275	a		278
Total days	151	a		165		134			127			152	a	160			169
RGU	0.0035			0.0021		0.0032	a		0.0033	a		0.0031		0.0030			0.0027
RGD	0.0751			0.2033		0.1294			0.0322			0.0580		0.1032	a		0.1011

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

There were no significant trends in any of the metrics for this ecoregion. TDY was highly variable between years, in part because of differences in the number of composite periods or because of variable climate conditions. GDD-S for the two stations and 6 years (1991-96) was 122 days, compared to an average of 108 TDY for the same period.

Rates of greenup (RGU) were much slower than rates of greendown (RGD) in this ecoregion. The slow greenup may be due to the amount of lingering snow, seasonal shadow, and colder air temperatures in many of the valleys in the spring.

Interior Forested Lowlands and Uplands (104)

This ecoregion is the largest of the 20 Alaskan ecoregions. It occurs over extensive tracks of interior Alaska and is characterized by a continental or boreal type climate (Gallant and others, 1995; Tuhkanen, 1998). A wide range of graminoid, shrub, and forest types occurs over variable topographic relief. Temperature ranges can be highly variable, and in the summer, afternoon convection clouds (often subpixel) frequently occur. Snow depth ranges from 50 cm on April 1 to 0 cm by the second week in May, depending on location, and this ecoregion is generally snow free until middle to late September. Monthly average temperatures for April and May are 0 ^{o}C and 9 ^{o}C, respectively. July is the warmest month with a monthly average of 17 ^{o}C, falling to 9 ^{o}C in September, and below 0 ^{o}C in October. Climatic data for this ecoregion were based on seven stations: Bettles, Fairbanks, Farewell Lake, Northway, Port Alsworth, Tok, and Unalkleet.

OND varied during the 7-year period, alternating high and low values between years (table 10), with low values corresponding to slightly cooler, average minimum temperatures (3-5 ^{o}C) for those years. MAX values generally were midrange, with somewhat higher values occurring by 1997, although yearly variations were not always significantly different. LND for 1992 was much lower than in the other years, being recorded late in the year (October 24). Climate data indicated average temperatures at or below 0 ^{o}C, snow on the ground in late September into October, and late greenness values that may be coming from the extensive conifer forests in the region.

ONS dates were generally earlier each year following 1992 (slope=-2.44, p=0.036, α=0.05), with an overall increase of 24 days between 1993 and 1997. MJD dates were slightly later dates from 1994 to 1997. TDY was variable during the first 4 years, then showed a change toward longer seasons during the last 3 years, with an overall average of 151 days. Average GDD-S length was slightly higher, with 164 days. Both estimates are much higher than the 92 frost-free days reported for Fairbanks (Slaughter and Viereck, 1986).

Rates of greenup (RGU) appeared to slow down over the 7-year period, and if 1992 RGU is removed, there is a slowing trend (slope=-0.0001, p=0.001, α=0.05). Average minimum and maximum monthly temperatures did not show similar trends. There were late season snowfalls, however, occurring during the last 2 weeks of May for 1994-96 (data missing for 1997).

Interior Highlands (105)

Ecoregion 105 occurs predominantly in the east-central part of the State, although small areas extend across the southern face of the Brooks Range and into the central and west-central parts of the State. This ecoregion occupies areas generally above 500-m mean sea level. The landscape is vegetated by low and dwarf shrubs at upper elevations and forests and tall and low shrubland at lower elevations. Climate data are sparse, and only two climate stations (Eagle and Port Alcan) were used; both are located in east-central Alaska.

OND did not show any trends over the 7-year period for this ecoregion (slope=-0.003, p=0.43, α=0.05), but MAX had an increasing trend from 1992 to 1997 (slope=-0.010, p=0.02, α=0.05; table 11). MEN appeared to show a similar trend; however, MEN values for 1994, 1995, and 1996 were not significantly different. LND showed a rise from 1991 to 1994 and fell from 1995 to 1997. The two date groupings match the data groupings for composite period length and satellites used.

ONS showed a trend toward earlier onset dates (slope=-3.53, p=0.02, α=0.05) from 1993 (May 15) to 1997 (April 24), a change of 21 days that extends over two composite periods. MJD and SNS dates from 1994 to 1997 occurred later each year, an overall change of 18 days and 28 days, respectively. Consequently, growing seasons were slightly longer during the 7-year period, although this was not reflected in GDD-S for each year. A GDD-S 5-year average (1991, 1992, 1995, 1996, 1997) of 150 days compares well with a TDY average of 152 for those same years (1993 and 1994 are missing because of insufficient climate data).

Interior Bottomland (106)

This ecoregion occurs in the central part of Alaska, buffering major rivers, with much of the vegetation and local topography being influenced by the river systems. As with the two previous ecoregions, the area is largely controlled by a continental climate and has similar vegetation types, although there may be more forests and tall and low shrub types.

Temperatures are highly variable throughout the year, with lows of –35 °C to highs of 22 °C. Depending on location and year, the ground surface is snow free from late April to late September. Spring snows may occur in late May, although average temperatures are usually well above 15 °C. Data from five climate stations were used for this ecoregion: Big Delta, Fairbanks, Galena, McGrath, and Tanana.

OND alternated with low and high values from year to year (table 11), and MAX did not show any significant increase in greenness as it did for the previous five ecoregions. MEN appeared to increase from 1991 to 1997, although the trend was not significant (slope=0.011, p=0.0581, α=0.05).

ONS showed a trend toward earlier dates (slope=-3.75, p=0.01, α=0.05) from May 11 in 1993 to April 15 in 1997, resulting in a change of 26 days and extending across two composite periods. Recorded Julian dates for MJD and SNS were similar to those for other interior Alaska ecoregions, showing later dates from 1994 to 1997. Changes in ONS and SNS from 1995 to 1997 were reflected in TDY, with a general lengthening of the growing season by 10 days. Average GDD-S the same period was 158 days, slightly less than the164-day average for the same period using TDY.

Yukon Flats (107)

This ecoregion is located in a broad basin in east-central Alaska. It may have some of the highest temperature ranges in the State, from –34 °C in the winter to 22 °C in the summer. Wide ranges of vegetation types occur over low rolling hills, river floodplain, and bottom lands. Most common are large areas of needleleaf forest, shrub-dominated tundra, and wetlands. Two climate stations were used for this ecoregion, Fort Yukon and Circle City, although Fort Yukon could only be used for long-term climate histories because data were missing for years after 1990. Average monthly temperatures are below 0 °C in April, rising to 3 to 6 °C in May; snow is normally gone by the end of May. Snowfall is rare during the summer and often begins again by mid-September.

Table 11. Yearly averages for each phenological metric for Interior Highlands Ecoregion (105) and the Interior Bottomlands Ecoregion (106)

105

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.1823	a	0.1893		0.2047		0.1762	a	0.2231		0.1545		0.1636	
Max	0.4979	a	0.4507		0.4903		0.4982	a	0.5075		0.5184		0.5490	
Mean	0.2875		0.2112		0.2764		0.3161	a	0.3197	a	0.3174	a	0.3415	
Last	0.2062	a b	0.1762		0.2332	c	0.3099		0.2237	d c	0.2145	a d	0.1956	b
Minday	128		142		135		123	a	124	a	119		114	
Maxday	219		283		227		223		239	a	235		241	a
Lastday	277		295		262		248		275	a	271		276	a
Total days	148		153	a	126	b	124	b	150	c	152	a c	161	
RGU	0.0040		0.0020		0.0036	a	0.0034	a b	0.0026		0.0034	b	0.0031	
RGD	0.0278	a	0.2205		0.0710		0.0266	a	0.0431		0.0609		0.0302	a

106

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.1905		0.1641	a b	0.2119		0.1676	a	0.2234		0.1702	a	0.1578	b
Max	0.5223		0.4710		0.4965	a	0.5000	a	0.5356	b	0.5155		0.5360	b
Mean	0.3200	a	0.2547		0.2950		0.3229	a	0.3529	b	0.3454		0.3511	b
Last	0.2195		0.1574		0.2330	a	0.2762		0.2353	a	0.2554		0.2637	a
Minday	125		128		131		118		122		110		105	
Maxday	237		276		243		223		229		253		258	
Lastday	281		296		267		249		276		277		279	
Total days	156		167	a	136		131		153		166	a	173	
RGU	0.0034	a	0.0022		0.0029		0.0033	a	0.0031		0.0025	b	0.0025	b
RGD	0.0933		0.1783		0.1399	a	0.0239		0.0413		0.1325	a	0.1120	

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

OND was similar from year to year in this ecoregion, although there appeared to be a slight increase from 1993 to 1997, and MAX showed a small increasing trend (slope=-0.007, p=0.027, α=0.05) from 1992 to 1997 (table 12).

ONS dates ranged from April 11 to April 16, with a slight trend (slope=--3.8, p=0.015, α=0.05) toward earlier dates from 1993 to 1997. Climate records for Circle City indicate that for all years average monthly temperatures were below 0 ^{o}C for April. The earlier dates are probably due to the extensive needleleaf forests in the area (masking snow on the ground) and generally cloud-free conditions in April 1997.

There were no significant patterns for MJD and LND, although MJD did show an advance toward earlier dates for 1995 through 1997 by about 10 days. This probably resulted in slightly longer growing seasons for those years (from 165 to 177 days), which is much longer than the 154 GDD-S calculated for Circle City for 1995 and 1997.

Ogilvie Mountains (108)

The Ogilvie Mountains Ecoregion is the smallest of the Alaskan ecoregions occurring in the far east-central part of the State. It encompasses a low hilly plain that rises slowly out of the Yukon Flats region to the west. It has a continental climate and vegetation similar to the Yukon Flats, although it lacks the extensive river bottoms. There were no climate stations available for this ecoregion.

ONS showed a trend (slope=-3.57, p=0.015, α=0.05) toward earlier dates from 1993 to 1997, resulting in an earlier seasonal greenup of 26 days (table 12). MAX showed a slight increase from 1994 to 1997, although the date on which MAX occurred (MJD) was variable between the years. LND showed a dramatic drop from 1994 to 1997, as well as on later dates (SNS). The outcomes of ONS and SNS resulted in a longer overall growing season of 38 days. Again, this may be due to extensive conifer forests in the region that can potentially extend the greenness timeframe at either end of the growing season.

Subarctic Coastal Plains (109)

This arctic and subarctic, maritime-influenced ecoregion occurs in western Alaska and is largely affected by the Bering and Chukchi Seas. The bulk of the ecoregion occurs across the extensive Yukon-Kuskokwim River delta in southeast Alaska, although a small part of it is east

Table 12. Yearly averages for each phenological metric for the Yukon Flats Ecoregion (107) and the Ogilvie Mountains Ecoregion (108)

107

	1991		1992		1993		1994			1995			1996			1997	
Onset	0.1536		0.1373	a	0.1395	a	0.1699	b	c	0.1733	c	d	0.1677	b		0.1752	d
Max	0.4700	a	0.4350		0.4643		0.4743	a	b	0.4784	b		0.4844			0.5054	
Mean	0.2923		0.2380		0.3006		0.3166	a		0.3183	a		0.3123			0.3310	
Last	0.1827	a	0.1546		0.2054		0.2864			0.1859	a		0.1656			0.1803	a
Minday	109	a	116		111	b	113			110	b		108	a		101	
Maxday	214	a	274		218		212	a		244			234			231	
Lastday	280		300		268		249			276	a		276	a		279	
Total days	171		184		156		135			165			168			177	
RGU	0.0033	a	0.0022	b	0.0034	a	0.0034	a		0.0024	b		0.0033	a		0.0026	b
RGD	0.0255		0.1599		0.0421	a	0.0442	a		0.0644			0.0744			0.0159	

108

	1991		1992		1993		1994			1995			1996			1997	
Onset	0.1728	a	0.1304	b	0.1680	a	0.1327	b	c	0.1802			0.1385	c		0.1372	c
Max	0.4731	a	0.4488		0.4799	b	0.4729	a		0.4766	a	b	0.4854			0.5210	
Mean	0.2917		0.2264		0.2962		0.3134	a		0.3156	a		0.3148	a		0.3345	
Last	0.1860		0.1653	a	0.2340		0.3055			0.2409			0.1607	a		0.1613	a
Minday	117		110	a	120		106			111	a		99			94	
Maxday	211		285		216		235			256			229			239	
Lastday	282		301		268		251			276	a		275			277	a
Total days	164	a	191		148		144			165	a		176			182	
RGU	0.0036		0.0019		0.0034		0.0028	a		0.0021			0.0027	a	b	0.0027	b
RGD	0.0076	a	0.1954		0.0155	b	0.0759	c		0.0797	c		0.0073	a		0.0140	b

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

and south of Kotzebue Sound in northeast Alaska. Vegetation is predominantly low shrub and graminoid-dominated tundra. May through August climate conditions are cool (5 – 15 ^{o} C) and moist (2-6 cm precipitation per month). The area is generally snow free by mid-May and often remains snow free until late September, although snowfall may occur in early September. Two climate stations were used for this ecoregion; Bethel, in southwest Alaska, and Kotzebue, in northwest Alaska.

There were no significant trends in any of the NDVI value metrics (OND, MAX, MEN, LND) over the 7-year period, except perhaps for MEN, which showed a slight increase from 1992 to 1996 (table 13). The date on which onset of greenness occurred, however, did show a trend (slope=-3.71, p=0.015, α=0.05) from 1992 to 1997, resulting in a 23-day change. Associated warming trends in temperature, however, were not apparent for the same period

The days on which MAX and LND were recorded represented earlier dates from 1992 to 1994 when compared with 1995 through 1997. These values follow a slight drop (although perhaps not significant) in average August monthly temperatures for Bethel from 1991 to 1994 and then a slight rise in average August monthly temperatures for 1995 to 1997. The combination of earlier greenup and later senescence dates contributed to a slightly longer TDY of 7 to 9 days from 1995 to 1997. The range in TDY of 131 to 140 days is close to the 145 GDD-S calculated for Kotzebue but much shorter than the 152 GDD-S for Bethel.

Seward Peninsula (110)

This ecoregion makes up the bulk of the Seward Peninsula, with the exception of the northern coastal tundra. It is characterized by low, rolling hills with shrubby and graminoid tundra and mountains with dwarf shrubs and forbs or talus slopes. Small stands of needleleaf and deciduous forest occur in the south and east. Climate is similar to that of the previous ecoregion, with temperatures in the minus 20's ^{o}C in winter and midteens in summer. The landscape is normally snow free by June 1, although snow may fall at any time during the summer, depending on location and local climate conditions. Snow may begin falling in early September, with ground accumulations remaining by late September. Nome was the only climate station used for this ecoregion.

Patterns for NDVI values during the 7-year period were similar to those of the previous ecoregion, although generally higher (table 13). There were not any noticeable trends in any of

Table 13. Yearly averages for each phenological metric for the Subarctic Coastal Plains Ecoregion (109) and the Seward Peninsula Ecoregion (110)

109

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.1892		0.1789	a	0.2015	b	0.2213		0.1983	b	0.1735	a	0.2078	
Max	0.4737	a	0.4372	b	0.4415	b	0.4488		0.4886		0.4676	c	0.4728	a c
Mean	0.2680	a	0.2017		0.2117		0.2035	a	0.2737		0.2875		0.2511	
Last	0.2234		0.1910		0.2360	a	0.2516		0.2388	a	0.2725	b	0.2649	b
Minday	143	a	152		147		143	a	139		125		129	
Maxday	245	a	284		250	b	228		244	a	248	b	271	
Lastday	279		294		265		238		276		274		281	
Total days	136	a	141		117		94		137	a	148		151	
RGU	0.0032	a	0.0020	b	0.0026	a b	0.0031	a	0.0030	a	0.0044		0.0019	b
RGD	0.0990		0.1798		0.1317	b	0.0802	a	0.0613		0.0845	a	0.1255	b

110

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.2218		0.2011	a	0.2097		0.2291	b	0.1973	a	0.1814		0.2290	b
Max	0.5026		0.4942	a	0.4845	b	0.4480		0.4951	a	0.5096		0.4809	b
Mean	0.2628		0.2045		0.2181		0.1880		0.2828	a	0.2819	a	0.2680	
Last	0.2092	a	0.1530		0.2078	a	0.2349		0.2132	a	0.2230		0.2034	a
Minday	155	a b	155	a	154	b	153		142		135		140	
Maxday	220		278		213		230		215		248		257	
Lastday	274		292		252		240		275		266		281	
Total days	118		136		98		87		133		131		140	
RGU	0.0046		0.0025		0.0049		0.0034		0.0044		0.0032		0.0022	
RGD	0.0153	a	0.1947		0.0176	a	0.0880		0.0206	a	0.1674		0.0635	

Letter indicates interyear metrics that were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

the NDVI values, although MEN and LND appeared to level off during the last 3 years. ONS showed a general trend (slope=-3.46, p=0.005, α=0.05) toward earlier dates, from June 4 in 1991 to May 20 in 1997. The dates on which MJD and SNS occurred were generally later each year from 1993 to 1997, resulting in changes of 44 and 29 days, respectively, for the two metrics. The combination of ONS and SNS dates for the last 3 years resulted in a slight lengthening in TDY. An average TDY of 120 for the 7-year period is much lower than the 144 GDD-S calculated for Nome.

Ahklun and Kilbuck Mountains (111)

This ecoregion occurs in a steep, rugged mountain area in southwest Alaska with elevations extending from sea level to over 1,500 m. Vegetation on the lower slopes may include needleleaf and deciduous forest, with dense stands of alder or willow on the midslopes, and low and dwarf shrub communities, often dominated by lichen, on the upper slopes. Climate conditions are controlled, in part, by the Bering Sea to the south, continental climate to the north, and orographic lift. Climate conditions for Dillingham, to the southeast near the ocean, indicate that the ground may be snow free in May at lower elevations and remain snow free until early September; increases in elevation and areas inland undoubtedly have a more truncated period.

OND showed a slight increase in greenness from 1992 to 1997, although most inter-yearly values were not significantly different (table 14). ONS showed a slight trend (slope=-4.17, p=0.014, α=0.05) toward earlier dates from 1992 through 1997, with 1993 through 1995 being roughly the same. The change in ONS from 1992 (May 21) to 1997 (May 3) was approximately 26 days. This period extended across two composite periods, indicating that an actual change may have occurred that was not due to cloud conditions within a period. MJD and SNS dates were all significantly different from each other; however, only the last 4 years showed a trend toward later greenness dates.

TDY indicated a lengthening of the greenness season during the 7-year period, from about 140 days in 1991-92 to 150 days in 1996-97. This is somewhat less than an average of 157-day GDD-S for the same period at Dillingham, probably because of the ameliorating effects of the ocean.

RGD showed a slowing trend from 1991-94 (slope=-0.056, p=0.021, α=0.05), and then a trend toward faster greendown from 1994-97 (slope=0.0567, p=0.022, α=0.05).

Table 14. Yearly averages for each phenological metric for the Ahklun and Kilbuck Mountains Ecoregion (111) and the Bristol Bay-Nushagak Lowlands Ecoregion (112)

111

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.1945	a	0.1815	c	0.1912	a b	0.1853	b c	0.1828	c	0.1935	a	0.2186	
Max	0.5384	a	0.4960		0.5253		0.5314		0.5588	a	0.5433	a	0.5576	a
Mean	0.2869		0.2198		0.2642	a	0.2629	a	0.2983		0.3384		0.3259	
Last	0.2946		0.2167	a	0.2225	a	0.2043		0.2150	a	0.2810		0.3511	
Minday	141		149		136	a	136	a	137	a	117		123	
Maxday	272		279		238		226		251		246		274	
Lastday	281		292		264		247		278		274		275	
Total days	140	a	142	a	128		111		140	a	156		152	
RGU	0.0030	b	0.0026	b	0.0042	a	0.0043	a	0.0037	a	0.0046	a	0.0023	b
RGD	0.2007	a	0.1688		0.1321		0.0256		0.0401		0.0978		0.1942	a

112

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.2032	a	0.1720		0.2024	a	0.1819		0.1969	a	0.2446	b	0.2427	b
Max	0.5262	a b	0.4639		0.5168	c	0.5140	c	0.5295	b d	0.5332	d	0.5217	a
Mean	0.3074		0.2667		0.3111		0.2854		0.3526	a	0.3823	a	0.3540	
Last	0.3266		0.2543		0.2759		0.3393	a	0.3060		0.3396	a	0.3360	
Minday	118		127		115		116		109		99		105	
Maxday	279		264		256		228		243		252		270	
Lastday	281		293		265		249		277		278		274	
Total days	162		166	a	150	a	132		167		179		169	
RGU	0.0021	a	0.0022	a b	0.0024	b	0.0031		0.0026		0.0023	a b	0.0018	
RGD	0.1864	a	0.0698		0.1878	a	0.0180		0.0366		0.0800		0.1360	

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

Bristol Bay - Nushagak Lowlands (112)

This ecoregion along the western edge of the Alaska Peninsula in southwest Alaska is bordered on the west by the Bering Sea and on the east by the Aleutian Mountains. Vegetation consists of low and dwarf shrub, lichen-dwarf shrub, and graminoid tundra. Climate is largely controlled by the Bering Sea and orographic lifting. Four climate stations were used for this ecoregion: Cold Bay, Dillingham, Iliamna, and King Salmon. Temperatures may range from -11 ^{o}C in the winter to 15 ^{o}C in the summer. Snow often remains on the ground until mid-April at Cold Bay in the south, to early May at Dillingham in the north. Snow may return and stay on the ground beginning in late October. Occasional snowfall can occur as late as June and as early as September.

OND appeared to be slightly higher for the last 3 years, but only 1997 was significantly different from other years (table 12). MEN and LND had similar changes, showing a slight drop in from 1991 to 1992 and then a gradual rise from 1992 to 1997.

ONS showed a slight trend (slope=-3.60, p=0.012, α=0.05) toward earlier dates for the 7-year period, although 1993, 1994, and 1995 values were not significantly different. The earliest average onset date was April 28 for 1996, when average temperatures during this composite period were about 3 ^{o}C. In general, the earlier onset dates follow increasingly warmer, average monthly May temperatures for Dillingham and Cold Bay (roughly a ½- to 1-degree increase per year).

MJD and SNS showed earlier dates occurring from 1991 to 1994 and then later dates from 1994 to 1997. This is somewhat predictable since the 1993 and 1994 data had early cutoff dates. An average TDY for the 7-year period of 161 days emulates the 162 GDD-S averaged for the four stations.

From 1994 to 1997, RGU showed a significant decreasing trend (slope=0.0004, p=0.000, α=0.05) for greenup and RGD showed a significant increasing trend (slope=0.039, p=0.006, α=0.05) for the same period. Similar trends were not found in the temperature data, however.

Alaska Peninsula Mountains (113)

The Alaska Peninsula Mountains Ecoregion occupies the eastern half of the Alaska Peninsula and includes the Kodiak Island Archipelago. It is bordered on the west by the Aleutian Mountains and on the east by the Gulf of Alaska. Vegetation consists of dwarf shrub on upper slopes, tall and low shrub thickets on midslopes, and open tall shrub/graminoid meadows on lower slopes and valleys. Small stands of deciduous forest occur along floodplains, and dense conifer forests may occur on a variety of hill slopes and in lowlands. Temperatures may range from –11 °C in the winter to 18 °C in the summer. Snow cover may last until late March in the southern areas to late April in the north, although snowfall can occur as late as May throughout the ecoregion, especially at higher elevations. Lower elevations are normally snow free for the months of June through September, with autumn snows beginning in late September in the north and early to mid-October in the south. Climate stations used for this ecoregion include Kodiak Airport and Intricate Bay.

MAX for the period was 0.608 in 1997; this is, in general, a high greenness value (table 15). NDVI normally becomes asymptotic at values of around 0.60 to 0.65. Dates on which NDVI values were recorded were similar to those for other ecoregions, with MJD and SNS indicating earlier dates from 1991 to 1994 and then later dates from 1995 to 1997. Temperatures from the two climate stations did not show any similarities to this pattern. August temperatures for Intricate Bay, however, were progressively warmer from 1991 to 1994 (11.1, 12.0, 12.5, 13.5 °C), cooler for 1995 and 1996 (12.7, 12.1 °C, respectively), and then much warmer for 1997 (14.2 °C).

TDY showed a slight increase of about 6 days in growing season length. The average TDY of 146 days is much shorter than the 170 GDD-S calculated for the two climate stations.

As with the previous ecoregion, RGD showed a trend toward faster greendown from 1994-97 (slope=0.020, p=0.006, α=0.005). This is primarily because MJD occurred later each year, but SNS remained roughly the same.

Cook Inlet (115)

The Cook Inlet Ecoregion is contained in a large basin oriented north-south in south-central Alaska. It is enclosed by the Alaska Range to the north and west, the Talkeetna Mountains to the north, and the Kenai Mountains to the south; it encompasses Cook Inlet. Average temperatures may begin rising above 0 °C in April and fall below 0 °C in October. Snow cover disappears in early May and returns in early to mid-October, depending on latitude, elevation, and local climatic conditions. Six climate stations were used in this region: Anchorage Airport, Big River Lakes, Chulitna River Lodge, Kenai Airport, Palmer Airport, and Talkeetna

Table 15. Yearly averages for each phenological metric for the Alaska Peninsula Mountains Ecoregion (113) and the Cook Inlet Ecoregion (115)

113	**1991**		**1992**		**1993**		**1994**		**1995**		**1996**		**1997**	
Onset	0.1844		0.1723	a b	0.2105		0.1933	a	0.1711	c	0.1965		0.1870	b c
Max	0.5842		0.5038		0.5590		0.5438	a	0.5825		0.5931	a	0.6082	
Mean	0.2652	a	0.2260		0.2581	a	0.2358		0.2915		0.3616		0.3265	
Last	0.2981	a	0.1980	b	0.2613	c	0.3473	b	0.2645	c	0.3156	a	0.2981	b
Minday	135		147		137		142		132		103		127	
Maxday	274	a b	269		242	a	230		247		246	b	257	
Lastday	278	a	289		255		245		274	b	274		274	a b
Total days	142	a	141	a	118		102		141	b	170	b	146	
RGU	0.0032	a	0.0030		0.0044	a b	0.0047	a	0.0042	b	0.0047	a	0.0035	b
RGD	0.2470	a	0.1409		0.2076		0.0608		0.0865	a	0.0959		0.1276	

115	**1991**		**1992**		**1993**		**1994**		**1995**		**1996**		**1997**	
Onset	0.2242	a	0.1998		0.2600		0.1726	b	0.1930	a	0.1796	b	0.1806	b
Max	0.5943		0.4992		0.5692		0.5780		0.6004	a	0.6012	a	0.6024	a
Mean	0.3151		0.2515		0.3383		0.3520		0.3598		0.4052	a	0.4049	a
Last	0.2262		0.1344		0.2936		0.4512		0.2462		0.2719		0.3114	
Minday	136		142		132		125		128		115		113	
Maxday	255		258	a	244	b	224		245	b	232		260	a
Lastday	282		292		266		248		278		276		279	
Total days	145		150	a	134		123		149	a	160		165	
RGU	0.0035		0.0027		0.0031	a	0.0049		0.0038	b	0.0039	b	0.0030	a
RGD	0.2134		0.0806		0.1807	a	0.0378	b	0.1053		0.0462	b	0.1741	a

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

Flight Service Station.

ONS values for this region trended toward earlier dates (slope=-5.51, $p=0.001$, $\alpha=0.05$) from May 22 in 1992 to April 23 in 1997 (table 15). This is somewhat consistent with climate data that show snow lasting into May for 1991-94 but disappearing by May 1 for 1995-97.

MAX values for the period generally ranged from 0.56 to 0.60, with no significant difference between the last 3 years. MJD dates were generally late in the growing season, the earliest being on August 13 in 1994 and the latest about September 15 in 1992 and 1997 (the later 2 years were not significantly different).

Recorded SNS typically extended into late September and early October. The latest day recorded occurred on October 19 in 1992. This, however, did not coincide with climate data, which showed minimum temperatures dropping below 0 °C and snow falling during the last half of September 1992.

There was a general increase in the TDY during the 7-year period, from 145 days in 1991 to 165 days in 1997 (0 = 149). This is somewhat lower than a 7-year average GDD-S of 164 days. In addition, GDD-S did not show a similar pattern of increasing number of days: 164, 153, 169, 173, 171, 161, 156 for 1991 through 1997, respectively, based on five stations.

Alaska Range (116)

Ecoregion 116 is centered over the rugged Alaska Mountains that make a broad east-to-west arcuate barrier in south-central Alaska between the continental climate to the north and the predominantly maritime climate to the south. A variety of vegetation types occur in this ecoregion, from dwarf and low shrub tundra at upper elevations, to open needleleaf and deciduous forest and tall and low shrubland in the lower broad valleys. Temperatures are more indicative of a continental climate, with winter lows of –25 °C and summer highs of 18 °C. Ground surfaces are normally snow free from mid-May (except at higher elevations and interior valleys) to early October, although some years have snow lasting until June. Snow may begin falling in late August or early September, but normally it melts during midday except in closed canopy needleleaf forest and on north-facing slopes. Stations used for this ecoregion included Gulkana, Paxson Lake, Healy, and Tahneta Pass.

OND values were somewhat similar for the 7-year period, ranging from 0.16 in 1996 to 0.22 in 1993 (table 16). Dates on which these values occurred (ONS) showed a trend toward

Table 16. Yearly averages for each phenological metric for the Alaska Range Ecoregion (116) and the Copper Plateau Ecoregion (117)

116

	1991			**1992**			**1993**			**1994**		**1995**		**1996**			**1997**		
Onset	0.2085	a		0.1803	b	c	0.2212	a		0.1748	b	0.1901		0.1664			0.1871	c	
Max	0.5240	a		0.4305			0.5060	a		0.5340	b	0.5450	b	0.5360	b		0.5572		
Mean	0.2472			0.1767			0.2470			0.2846	a	0.2939	a	0.3093			0.3304		
Last	0.2004	a	b	0.2623			0.2329	b	c	0.3860		0.2424	c	0.2091	a		0.2747	c	
Minday	150	a		157			146	a		144		138	b	130	b	c	132	c	
Maxday	237	a		261			238			226		252		236	b		247	a	b
Lastday	276			281	a		257			247		277		268	a		276		
Total days	125			125	a		111			103	a	139		138			143		
RGU	0.0045	a		0.0027	c		0.0039	a	b	0.0046		0.0034	c	0.0042	d		0.0034	b	d
RGD	0.1036			0.1259			0.1598			0.0168		0.1046		0.0422	a		0.0875	a	

117

	1991			**1992**			**1993**			**1994**		**1995**		**1996**			**1997**		
Onset	0.1899			0.1578			0.1666	a		0.1677	a	0.2188		0.1498	a		0.1499	a	
Max	0.4721	a		0.3751			0.4512			0.4722	a	0.4903		0.4850			0.4956		
Mean	0.2649			0.1843			0.2726			0.2961		0.3018		0.3283			0.3387		
Last	0.1639			0.1277			0.2331	a		0.3254		0.2492		0.2257	a		0.2818		
Minday	126	a		142			127	a		119		122		106			110		
Maxday	222	a		265			244	b		221	a	259		245	b		238		
Lastday	276			292			265			249		281		275			279		
Total days	149	a		149	a		138			130		158		169	b		168	b	
RGU	0.0033			0.0019			0.0026			0.0030		0.0021		0.0025			0.0028		
RGD	0.0391			0.1172	a		0.1120	a		0.0083		0.1157	a	0.0524			0.0220		

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

earlier greenup (slope=-4.14, p=0.001, α=0.05), from May 30 in 1991 to about May 15 for the last 3 years. The 15-day change may not be significant because it is within the range of the 16-day composite period for May 1991 through 1994.

No trends were shown for MJD or SNS. TDY for this ecoregion ranged from about 125 days in 1991 and 1992 to 140 days for 1995 through 1997, compared with an average GDD-S of 146 for 1991 and 1992 and 149 for 1995, 1996, and 1997.

<u>Copper Plateau</u> (117)

The Copper Plateau Ecoregion is located in eastern south-central Alaska and generally occupies the basin of a large Pleistocene glacial lake. This broad boreal-forested region is characterized by black spruce forest and woodland growing over extensive areas of permafrost. Average monthly temperatures begin to rise above 0 ^{o}C in April and drop below freezing by late September or early October. Snow-free periods generally begin in May and will last until mid-September or late October, although periodic snowfall may occur from early September on, leaving trace amounts on the ground. Climate stations used for this ecoregion include Gulkana, Paxson Lake, and Tahneta Pass.

Some of the earliest recorded OND occurred in this ecoregion. In 1996, an average value of 0.14 was recorded on April 15, followed in 1997 by similar values on April 20 (table 16). For these years, daily maximum temperatures were above freezing, minimum temperatures were below freezing, and snow was on the ground. In all likelihood, the greenness values came from the needleleaf evergreen vegetation rather than new biomass. The 1992 onset date (May 23) occurred as much as 2 weeks later than in the other years, perhaps owing to a relatively large snowfall in April that year (snow depth of 50 to 67 cm for the month).

MAX was high in 1991 (0.47), dropping to a low of 0.37 in 1992 and then generally increasing in value toward the end of the 7-year period. MJD did not follow the same trend but fluctuated, with differences of 20 to 40 days between years, ranging from August 9 to September 22. MEN showed a significant increase (slope=0.019, p=0.021, α=0.05) over the 7-year period.

LND increased slightly from 1991 to 1997, with the values recorded predominately in October (Julian dates 274 to 304). During October, snowfall normally increases significantly and temperatures are below freezing. The late season greenness values, which are probably due to a high needleleaf forest component in the ecoregion, may have falsely extended TDY up to

169 days in 1994; however, average TDY values of 151 days are comparable to the 147 GDD-S calculated for climate stations.

Wrangell Mountains (118)

The Wrangell Mountains Ecoregion is small and centered over the Wrangell - St. Elias Mountains in eastern Alaska. It is largely covered by ice and snow, although dwarf and low shrublands occur along the lower flanks of the mountains, merging into open needleleaf forest on lower toe slopes. Deciduous forest and tall shrubs grow along the many river valleys as well. Temperatures in the lower elevations are similar to ecoregion 117, ranging from –34 ^{o}C in the winter to 22 ^{o}C in the summer. The upper slopes and mountaintops contain permanent snow and ice. Lower elevations are often snow free from the end of May to the first week of October, although snow may fall in June, August, and September. Climatic data were obtained from one station, Nabesna.

Only MEN showed any trends (slope=0.019, p=0.024, α=0.05), increasing in value from 1991 to 1997 (table 17). LND for 1992 was odd because of its exceptionally high value (0.47) and late date (October 7). Average temperatures for August, September, and October in 1992 were well below freezing (-16, -12, -9 ^{o}C, respectively).

ONS indicated earlier dates throughout the 7-year period, from May 17 in 1991 to May 7 in 1997. Although this pattern was not observed in the temperature record for May, a late recorded ONS date of June 6 for 1992 did follow a generally colder April and May for that year (about 1 to 3 degrees colder than 1991).

TDY was extended from 1991 to 1997 by about 30 days, with the 1997 TDY of 148 being comparable to the 146 average GDD-S for Nabesna.

Pacific Coastal Mountains (119)

The Pacific Coastal Mountains form an arcuate glacier-capped mountain range that extends from southeast Alaska to south-central Alaska. Vegetation is relegated primarily to the lower slopes and valleys. Vegetation consists of tall and low shrub (primarily alder) on upper slopes, and needleleaf and deciduous forest and tall and low shrubland on lower slopes and in valleys. Temperature is highly variable throughout this ecoregion, ranging from –2 ^{o}C in the winter to 19 ^{o}C in the summer, generally becoming cooler at higher elevations and farther away

Table 17. Yearly averages for each phenological metric for the Wrangell Mountains Ecoregion (118) and the Pacific Coastal Mountains Ecoregion (119)

118

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.1835	a	0.1634	b c	0.1835	a	0.1669	b	0.2004		0.1491		0.1579	
Max	0.4536	a	0.3671		0.4510	a	0.4885	b	0.4854	b	0.4838	b	0.4978	
Mean	0.2214		0.1427		0.2462		0.2718	a	0.2698	a	0.2843		0.3051	
Last	0.1907	a b	0.4719		0.2072	b	0.2878		0.2326	b	0.1711	a	0.2366	b
Minday	137	a	157		139	a	131		129	b	128	b c	127	c
Maxday	237	a	257		224		220		266		240	b	239	a b
Lastday	269		273	a	260		247		280		272	a	275	
Total days	131		117	a	121		115	a	150		144		148	
RGU	0.0037	a	0.0024	b	0.0035	a c	0.0040		0.0022	b	0.0031		0.0032	c
RGD	0.0647		0.0969		0.0467		0.0122		0.1503		0.0275	a	0.0246	a

119

	1991		1992		1993		1994		1995		1996		1997	
Onset	0.2027	a	0.1711		0.2101	a	0.2011	a	0.1836	b	0.1800	b	0.1825	b
Max	0.5060	a	0.3788		0.5095	a	0.5097	a	0.5431		0.5533	b	0.5581	b
Mean	0.1924		0.1442		0.2435	a	0.2436	a	0.2541		0.3042		0.3181	
Last	0.2201		0.2707	a	0.2471	b	0.3649		0.2504	a b	0.2642	a b	0.3014	
Minday	154		159		149	a b	151	a	147	b	133	c	134	c
Maxday	244		258		234		227		250	a	250	a	250	
Lastday	266		280		259		247		272	a	270	a	276	
Total days	112	a	121	b	110	a	96		124	b	136		142	
RGU	0.0020	a	0.0025		0.0044	b c	0.0049	b	0.0040	b c d	0.0034	a d	0.0036	c d
RGD	0.1198		0.0674	a b	0.0944	d	0.0272		0.0856	c d	0.0618	b	0.0773	a c

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

from the coast. Although no climate stations occur in this ecoregion, five stations that border it were used: Cooper Lake, Haines, Juneau Airport, Seward, and Valdez. Except at higher elevations and ice fields, above-freezing temperatures normally occur from April to October, and snow-free conditions occur from early May through September. Snowfall may occur as late as mid-May and begin again in mid-September, especially at the higher elevations.

OND values in this ecoregion were similar for the 7-year period (table 17). This was also true for MAX, with most values in the 0.50 to 0.55 range. LND showed a slight increase in greenness from 1993 to 1997, with a spike in 1994. The 1994 spike is odd because average temperatures for September and October were 1 to 3 ^{o}C cooler in 1994 compared with 1993 and 1995. The lower 1994 temperatures are reflected in earlier dates on which MAX and LND occurred (MJD and SNS, respectively).

TDY increased from 110 days in 1991 to 142 days in 1997. This is much shorter than the 173 average GDD-S for the climate stations used, probably because of their coastal location. RGU showed a significant slowing trend from 1991-94 (slope=0.001, p=0.014, α=0.05).

Coastal Western Hemlock - Sitka Spruce Forests (120)

This last ecoregion occupies the coastal and lower slope areas of southeast and southern south-central Alaska. As the name implies, this area is dominated by needleleaf forest, although upper slopes may be dominated by tall shrub thickets, with dwarf shrub tundra occurring on the upper slopes of mountains. The maritime climate ameliorates yearly temperatures, with lows of –3 ^{o}C to highs of 18 ^{o}C. Snow-free periods range from April to late October in the north and from March to December in the south. Five climate stations were used to represent this area: Cordova, Homer, Petersburg, Wrangel, and Yakutat; all are coastal airport monitoring stations.

This ecoregion showed a slight increase in OND from 1992 to 1997, with corresponding earlier onset dates (ONS; table 18). ONS ranged from May 12 in 1991 to April 14 in 1996, a change of 23 days over three different composite periods. Both MEN and LND showed similar and increasing greenness values from1992 to 1997. This may be reasonable if the values were obtained from areas that are dominated by closed needleleaf forest, which would retain greenness for much of the year.

MJD and SNS followed patterns similar to those of the two previous ecoregions; that is, a

Table 18. Yearly averages for each phenological metric for Coastal Western Hemlock-Sitka Spruce Forests Ecoregion 120)

120																				
	1991			**1992**		**1993**			**1994**				**1995**			**1996**		**1997**		
Onset	0.1831			0.2112	a	0.1942			0.2289				0.2129	a		0.2526		0.2401		
Max	0.5303	a		0.4301		0.5409			0.5259	a			0.5596			0.5838	b	0.5816	b	
Mean	0.2165	a		0.2148	a	0.3219	b		0.3076				0.3192	b		0.3871	c	0.3857	c	
Last	0.2410			0.1850		0.2977			0.3907				0.3382			0.3680		0.4118		
Minday	131			119	a	119	a		113				119	a		104		108		
Maxday	256	a		270		233	b		232	b			254	a		249		264		
Lastday	269			291		261			250				271			274		277		
Total days	137	a		171		141			137	a			152			170	b	169	b	
RGU	0.0036	a	b	0.0016	d	0.0034	b	c	0.0028	b	c	d	0.0027	c	d	0.0047	a	0.0024	c	d
RGD	0.1713			0.0829		0.0574	a		0.0450	b			0.0655	a		0.0442	b	0.0964		

Letter indicates interyear metrics were not significantly different at p=0.05.
Minday, Maxday, and Lastday represent Julian dates.

slight change in values from earlier dates in 1991-94 to later dates in 1995-97, a trend not observable in the temperature data.

TDY values for 1991 and 1995 were low (137 and 152 days, respectively) compared with 1996 and 1997 (169 days). The low values for 1991 and 1995 may be due to cloud cover at either end of the season. The 169 TDY compares well with a 170 GDD-S for Homer in the north but is slightly less than the 182 GDD-S for Wrangel in the south.

DISCUSSION

Actual onset and senescence of green vegetation across the landscape will vary from place to place and will be recorded differently by different sensors, depending on geographic location, sensor resolution, means and types of measurements, atmospheric attenuation, bi-directional reflectance, and periodicity of sensor overflight. During this study, the phenological seasons were confined to the following conditions and assumptions:

(1) biological events occurring over the Alaskan landscape at the nominal resolution of 1 square km

(2) seasonally based threshold values

(3) seasonally truncated data at the end of the growing season owing to low solar zenith angles or data loss

Because of these attributes, some of the small observed trends may be residual artifacts rather than actual changes in vegetation state (Cihlar and others, 1998). Changes caused by artifacts may be due to incomplete data processing (removal of atmospheric and bidirectional reflectance affects), sensor calibration (between AVHRR sensors and for each channel over time), and knowledge on the buffering capability of different types of vegetation to change (Paruelo and Lauenroth, 1998)

Data used here were composited every 14 to 16 days, and many areas may have been green before the date actually recorded by the sensor because of the selection of maximum NDVI for any composite period. In addition, an NDVI threshold of 0.09 was used to indicate vegetative activity, although different values and models have been used by others (Reed and others, 1994; Tieszen and others, 1997). Green vegetation may have been present over the landscape before this value was reached but was not recorded because of the amount of brown (previous season) vegetation present, the amount of soil or snow present, and illumination conditions (Reed and others, 1994). Therefore, it is not possible to give exact dates as to greenup or senescence, and changes within the composite period are probably not significant. Therefore, the dates used for the different metrics should be considered general in nature and used as indicators of interyear changes over a longer term than 1 or 2 years.

Because of Alaska's northern geographic extent, low solar zenith angles can become a problem, especially late in the growing season. Beginning in September, solar angles begin to drop significantly, and by October, low angles begin to affect the return signal to the AVHRR sensor. Goward and others (1991) reported that the precision of AVHRR measurements decreases to levels below +/- 1 percent at solar zenith angles above 80 degrees for latitudes north of 45 degrees. Longer path lengths can potentially lower NDVI through increased atmospheric scattering and lower surface backscatter (Moody and Strahler, 1994, Liu and others, 1997). The data used here had solar zenith angles of less than 80 degrees, although most of the data for late September (the last 2 weeks) and early October (first 2 weeks) had solar zenith angles of 65 to 75 degrees (Markon, 1999). Although end-of-season greenness dates (SNS) were similar during this study period, comparison of actual site greenness with the end-of-season NDVI would be worthwhile to ensure that lower solar angles are not affecting the metrics used.

The 1992 growing season had some of the lowest greenness values and latest dates recorded for onset, maximum, and late-season greenness. It is speculated that this may be due to excessive atmospheric haze resulting from the 1991 Mt. Pinatubo volcanic eruption (McCormick and others, 1995). Upper atmospheric haze has the effect of reflecting incoming sunlight back into space, as well as reducing solar heating of the Earth's surface. Both effects may have impacts on vegetative growth and phenology, especially in northern latitudes where growing seasons are already short and often cool. This may help explain the 1992 lower NDVI values and later metric dates because less reflected radiation reached the sensor. As the atmospheric haze began to dissipate following the eruption, one might have expected a slow but steady increase in NDVI values or dates, as was shown in most of the graphs between 1993 and 1997, both on a statewide and ecoregion basis. The presence of atmospheric haze did not appear to have much effect on end-of-year greenness dates, however, perhaps because fall temperatures and light levels drop rapidly in September and October.

CONCLUSIONS

Phenological information is important because the timing and duration of vegetation over the landscape are dependent on the integration of atmospheric and terrestrial conditions, as well as energy exchanges through the development, succession, and physical disturbance of vegetation across the landscape (Goward, 1989). This latter thought offers an understanding of the importance of phenological information in estimating various landscape vegetation biophysical parameters and in studying of climate change. Information on the intensity, timing, and duration of vegetation should assist in predicting important parameters such as biomass accumulation and productivity throughout the growing season. These data may also help determine the effects of different bioclimatic interactions across the landscape, as well as energy exchanges with the atmosphere.

The types of phenological characteristics estimated here can be derived more efficiently through remote sensing on regional, landscape, and global scales and perhaps to a better degree than could be determined by field-based studies owing to efficiencies of cost, time, and scale. Depending on the type of biological parameter of interest, and the scale being looked at, these data also may help in scaling from region to globe (Curran, 1994; Foody and Curran, 1994).

Currently, climate change models are more adaptable to coarse-scale global parameters. As these models become more efficient, they will be more adaptable to larger scale information, such as that provided by the 1-km data presented here. Also, a better understanding of the usefulness of the AVHRR-derived phenological data over northern areas will provide a better understanding of landscape changes that take place, especially if the data can be obtained over a number of years.

Although the data presented here provide fairly good indications of general phenological characteristics of Alaskan vegetation, two caveats must be observed when using the data. The metric data are based on maximum value composited imagery, and changes in greenness dates or values between years should not be taken as actual changes if they fall within a composite period. In addition, the greenness metrics should be considered as a measurement of relative events, rather than actual changes in the plant canopy, and are probably more suited to the study of long-term changes, rather than short term (2-5 years).

Plant phenological activity can be due to local weather conditions, as well as regional or global activities. This may be especially important when studying phenological activities over boreal forest and shrub types. Post and Stenseth (1999) reported that woody plants displayed less sensitivity to climate variability than did herbaceous species, which may be why some of the metrics used here did not have any direct relationship to local climatic data. Therefore, other studies looking at possible links to boreal phenology should be initiated, such as relationships between landscape phenology and small-scale phenomena, which could include continental mass air movements, timing of sea ice advance and retreat, the El Nino Southern Oscillation, or the North Atlantic Oscillation.

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