JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. D14, PAGES 15,699–15,712, OCTOBER 20, 1992

Climatology of Surface-Based Inversions in the North American Arctic

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The annual cycle of surface-based inversions at nine Arctic weather stations is examined, based on a 20-year set of daily 1200 UT significant level radiosonde data. All stations are at or near the coast. Inversions in winter months are primarily the result of strongly negative net radiation at the surface, whereas in summer, inversions more commonly result from near-surface cooling of warm air masses. Inversion frequency is at a maximum in winter (generally >70% of days) when inversions range from ~400 to ~850 m in thickness. Inversion thickness and strength (temperature change across the inversion) are strongly related to surface temperature. Inversions may involve temperature changes of >30°C in <1 km, with gradients of >6°C 100 m^{-1} during periods of extreme warm air advection aloft. Midwinter inversions commonly persist for 2-4 days, but may remain undisturbed for several weeks, affecting lower tropospheric chemistry.

1. INTRODUCTION

Temperature inversions based close to the surface are a characteristic feature of Arctic regions, particularly in the low-sun (or no-sun) period when the ground is snow-covered. Temperature changes within the lowest 2-3 km may exceed 30°C on individual days in winter months. Extremely stable conditions may persist for weeks, essentially decoupling the surface from conditions in the lower troposphere only 1 km or so above. This has important implications for energy exchange across the boundary layer and for the dispersal of both local air pollutants and long-distance "arctic haze." An understanding of inversion climatology is also important for general circulation modeling of climatic changes resulting from greenhouse gas buildup in the atmosphere; all current models indicate that the maximum changes of temperature can be expected to occur in polar regions, especially in winter in the lower troposphere. This must involve changes in arctic inversion structure. Here we examine the annual cycle of surface-based inversions in the North American Arctic, based on a 20-year set of daily, significant level 1200 UT soundings.

2. DATA

Significant level radiosonde data were obtained for a set of nine stations north of the Arctic Circle (Figure 1). Stations selected are listed in Table 1. It should be noted that all stations are in coastal locations and at relatively low elevations. There are no high elevation, inland upper air stations in the region studied. In winter months, the adjacent ocean is covered by sea-ice and the land is 100% snow-covered. The period used was 1967-1986 and the 1200 UT soundings were selected (representing the low-sun period in these longitudes). Soundings correspond to local apparent times of approximately 0100 in the western part of the study area (Kotzebue) to 0730 in the east (Alert).

Data quality control procedures are described in the appendix. Overall, approximately 6% of records were discarded because of missing values or obvious errors. This ranged from a minimum of 3% of daily soundings at Alert, Mould Bay, and Inuvik to a maximum of 11% at Resolute and Kotzebue.

3. TYPES OF ARCTIC INVERSION

Low-level inversions may result from two basic conditions: (1) a radiative imbalance, in which surface energy emission exceeds that received directly from the Sun and/or from the atmosphere (this condition is common in the Arctic from late September to April when net radiation is negative (Table 2) and sometimes even on summer days, during that part of the day when the Sun is lowest in the sky), and (2) warm air advection over a cooler surface layer. Such conditions may occur at any time of year. During late spring and early summer months this may involve the formation of shallow inversions with only slightly cooler temperatures near the surface as melting snow and ice act as a heat sink. In winter, warm air aloft can create extremely stable conditions with temperature gradients in the lower troposphere of >+6°C 100 m^{-1}. However, warm air advection is uncommon at high latitudes in midwinter (see section 5, below).

In both conditions, the inversion depth may be increased by subsidence and adiabatic heating of descending air in the overlying atmosphere. More commonly, however, subsiding air results in an elevated inversion layer above the surface, separated from a surface-based inversion by a layer in which temperatures decrease with elevation. Turbulence near the surface can destroy surface-based inversions, leading to elevated inversions separated from the ground by a shallow mixed layer. Thus the near-surface atmospheric structure is often complex, representing a combination of dynamical and radiative influences [cf. *Busch et al.*, 1982].

4. PREVIOUS RESEARCH

In previous research on arctic inversions, the way in which the inversion layer is defined often differs, making comparisons difficult. For example, in Bilello's comprehensive study of arctic inversions, "any layer having more than 1°C increase in temperature per kilometer was considered to be an inversion layer" [*Bilello*, 1966, p. 4]. This implies that isothermal and

Paper number 92JD01451.
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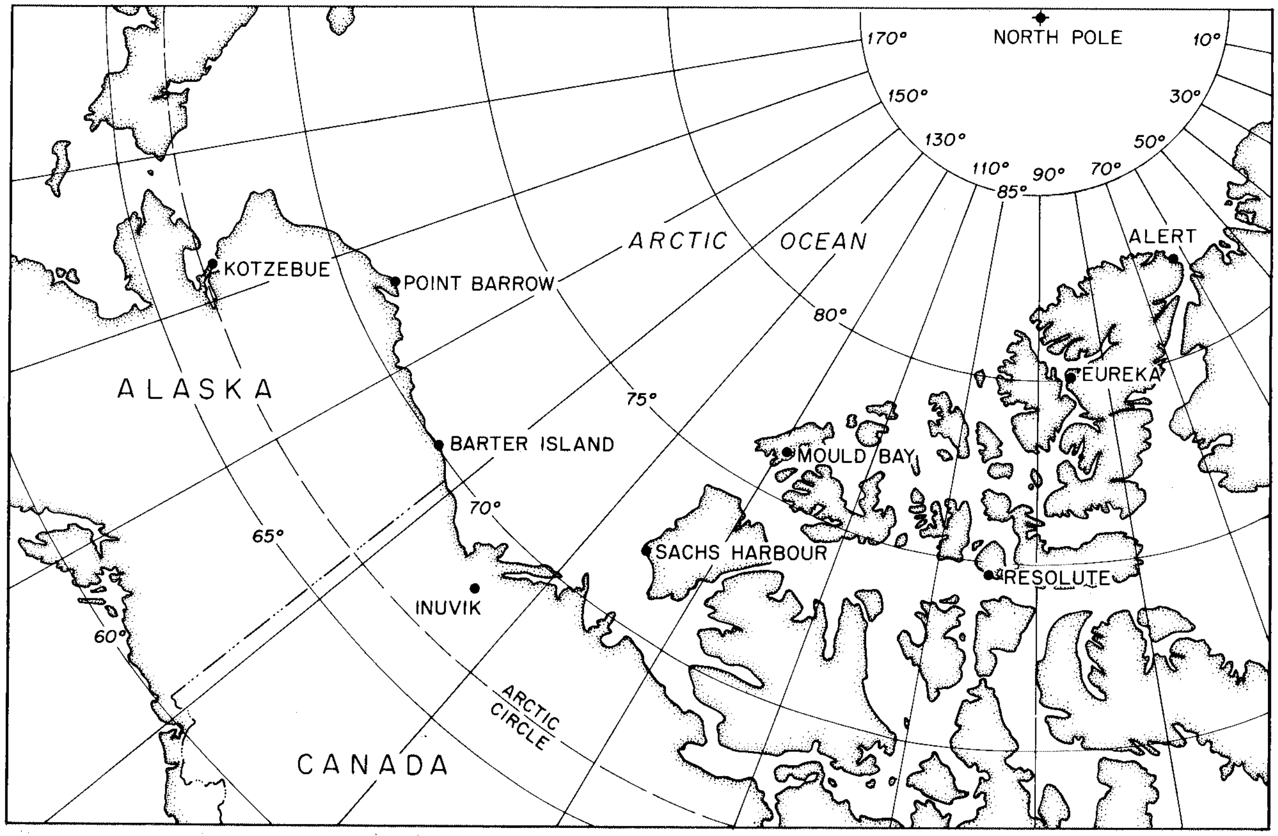

Fig. 1. Location of upper air stations in the study.

near-isothermal layers were not included in his statistical analysis. By contrast, *Maxwell* [1982] recognizes two parts of low-level inversions; he defines surface-based inversions as those in which the rate of temperature increase is >2°C 100 m^{-1}. Above this layer, temperature gradients are commonly less. Isothermal layers are included in his definition, but any decrease in temperature with altitude is recognized as the top of the inversion layer (J. B. Maxwell, personal communication, 1990). More recently, *Kahl* [1990] and *Serreze et al.* [1992] define inversions as layers in which temperature increases with altitude, but include thin embedded layers with negative lapse rates, providing they are not more than 100 m in depth.

In this study, the focus is on surface-based inversions (SBIs). The base of the inversion layer is defined by the station elevation, and the top of the inversion is the height of the last temperature measurement which exceeds, or is equal to, the preceding measurement. Isothermal layers at the base, atop, or embedded within an inversion layer were included, as shown schematically in Figure 2. Isothermal layers without any adjacent inversion layer were not included. Such cases were generally very shallow (<75 m at Alaskan stations, <30 m at Canadian stations) and occurred most commonly in summer months, though even in these months they never exceeded 2% of days per month. The occurrence of surface-based inversions, as so defined, ranges from 50% (Kotzebue) to 66% (Eureka) of all available days during the period of record.

The only previous studies which deal explicitly with the region considered here are those of *Bilello* [1966] and *Maxwell* [1982], but direct comparisons of their results are confounded by important differences in definition of surface-based inversions (Bilello's "Type I" condition). For example, Bilello considers data from Alert, Barrow, Mould Bay, and Nome (comparable to Kotzebue in this study). He finds lower inversion frequencies and greater mean temperature gradients,

TABLE 1. Upper Air Stations Used in the Study

Station Number	Name	Latitude, N	Longitude, W	Elevation, m
2400300	Alert, Northwest Territories, Canada	82° 30'	62° 20'	66
2401200	Eureka, Northwest Territories, Canada	80° 00'	85° 56'	10
2502700	Mould Bay, Northwest Territories, Canada	76° 14'	119° 20'	58
2403500	Resolute, Northwest Territories, Canada	74° 43'	94° 59'	40*
2503650	Sachs Harbour, Northwest Territories, Canada	72° 00'	125° 16'	84
027502	Point Barrow, Alaska	71° 18'	156° 47'	12*
027401	Barter Island, Alaska	70° 18'	143° 38'	15
2202570	Inuvik, Northwest Territories, Canada	68° 18'	133° 27'	103*
026616	Kotzebue, Alaska	66° 52'	162° 38'	5

Resolute: 66 m until November 1980; Point Barrow: 8 m until June 1977; Inuvik: 68 m until April 1973.

TABLE 2. Mean Daily Totals of Net Radiation for Each Month at Selected Canadian Stations

	Alert	Eureka	Mould Bay	Resolute
January	-1.056	-1.442	-1.357	-2.123
February	-1.327	-1.231	-1.366	-1.942
March	-1.177	-1.672	-0.663	-1.812
April	-1.414	-0.954	-0.166	-0.523
May	0.031	4.097	1.446	2.258
June	5.692	12.537	9.166	7.773
July	10.639	9.867	10.285	8.686
August	3.931	4.476	5.252	4.568
September	-1.253	-1.048	0.555	0.196
October	-1.671	-1.481	-0.699	-1.623
November	-1.401	-1.594	-1.229	-1.966
December	-1.425	-1.409	-1.287	-2.008

Measurements are in MJ m^{-2}, period of record to 1980; 1 MJ m^{-2} d^{-1} = 11.574 W m^{-2}. From *Monthly Radiation Summary*, Atmospheric Environment Service, Downsview, Ontario, Canada.

as a result of using more restrictive criteria for defining inversions than those used here. Similar differences between Maxwell's results and ours result from contrasting definitions of the inversion, as noted above. Nevertheless, all studies show a strong seasonal change in inversion frequency and depth, as discussed further below. Bilello's study, like this one, uses primarily 1200 UT radiosonde data, but he does include data for 2400 UT at Fairbanks and Nome, Alaska. These data are of interest in showing significantly lower inversion frequencies from March to October at the time of the 2400 UT sounding, which approximates 1300 hours local time. However, at Nome, mean inversion depths at 2400 and 1200 UT are quite similar. Diurnal changes in inversion characteristics are not dealt with in this paper, but may be important during the period of solar illumination, as suggested by the analysis of Bilello.

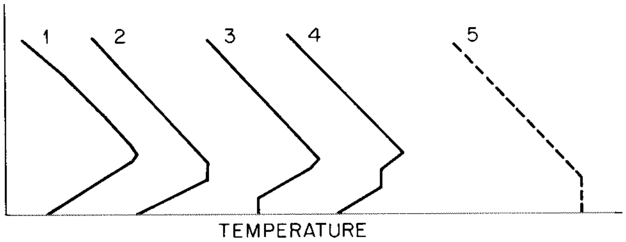

Fig. 2. Schematic diagram to illustrate the types of surface-based inversions discussed. Combinations of profiles 2, 3, and 4 do occur (multiple embedded isothermal layers) and were included in the study. Days with condition 5 (surface-based isothermal layers with no inversion above) were not included.

5. INVERSION FREQUENCY

At the higher-latitude stations, inversion frequency is closely related to net radiation which is in large part a function of solar declination. At Alert, for example, surface-based inversion frequency averages ~80% during the no-sun period but declines markedly once the sun is above the horizon 24 hours per day (Figure 3). At this latitude the change from no-sun to continuous illumination occurs rapidly over a period of only 39 days (from early March to early April). During the first month of continuous solar radiation receipts, SBI frequency declines from >80% to <20%. These changes reflect the effect of solar radiation receipts on surface heating, which reduces stability in the boundary layer. The main changes in inversion frequency at Alert occur during brief transition periods when net radiation changes from being negative at all hours of the (24-hour) day to being positive at all hours. In the spring, this takes place between Julian day (JD) 110 and JD 145; the reverse pattern occurs in the fall from JD 225 to JD 255. Inversion frequency is thus at a minimum during the period when daily totals of net radiation are positive (~May 6 to September 3). In addition, during summer months, the passage of fronts and episodes of strong advection with turbulent mixing often disrupt inversion layers; at this high latitude, such conditions are rare in winter, allowing inversions to persist undisturbed for longer periods.

A similar pattern is observed at Eureka, Mould Bay, Resolute, and Sachs Harbour, but at lower-latitude sites the transition is more gradual and, particularly in the fall, less related to solar declination (Figure 4). At these lower latitudes, the effect of oceanic heat storage may result in a more gradual change in inversion frequency from summer to early winter. Inversion frequency at Inuvik and the Alaskan stations, which are more affected by warm air advection from the south, rarely falls below 20%.

At many sites a secondary SBI frequency maximum occurs in mid-July followed by a drop in the late summer/early fall; this is especially apparent, for example, at Eureka (Figure 4). There is no corresponding increase in mean inversion depth, but the (positive) temperature gradients within the inversion layer do increase. The reasons for these changes are not clear, but they may be related to a continued increase in free-air temperatures while surface temperatures over melting snow and ice surfaces, and over coastal waters, remain at or near 0°C. This was first suggested by *Sverdrup* [1925, 1933] based on a very small number of soundings from the *Maud* expedition to northeastern Siberia. He argued that in spring and fall, though temperatures remain below 0°C, air is heated close to the snow surface, leading to turbulent mixing in the boundary layer. This would

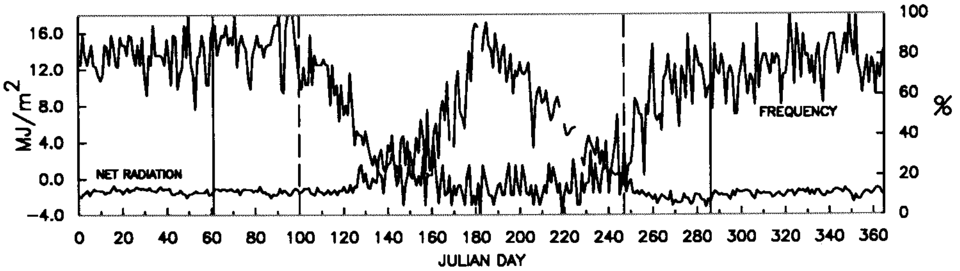

Fig. 3. Mean daily totals of net radiation (in MJ m^{-2}, 1968-1990) on days with surface-based inversions and mean daily surface-based inversion frequency (in percent of available days, 1967-1986) at Alert, Northwest Territories, Canada. Solid vertical lines indicate the dates between which the sun rises above the horizon at Alert; dashed vertical lines indicate the dates between which the sun is continuously above the horizon. (1 MJ m^{-2} d^{-1} = 11.574 W m^{-2}.)

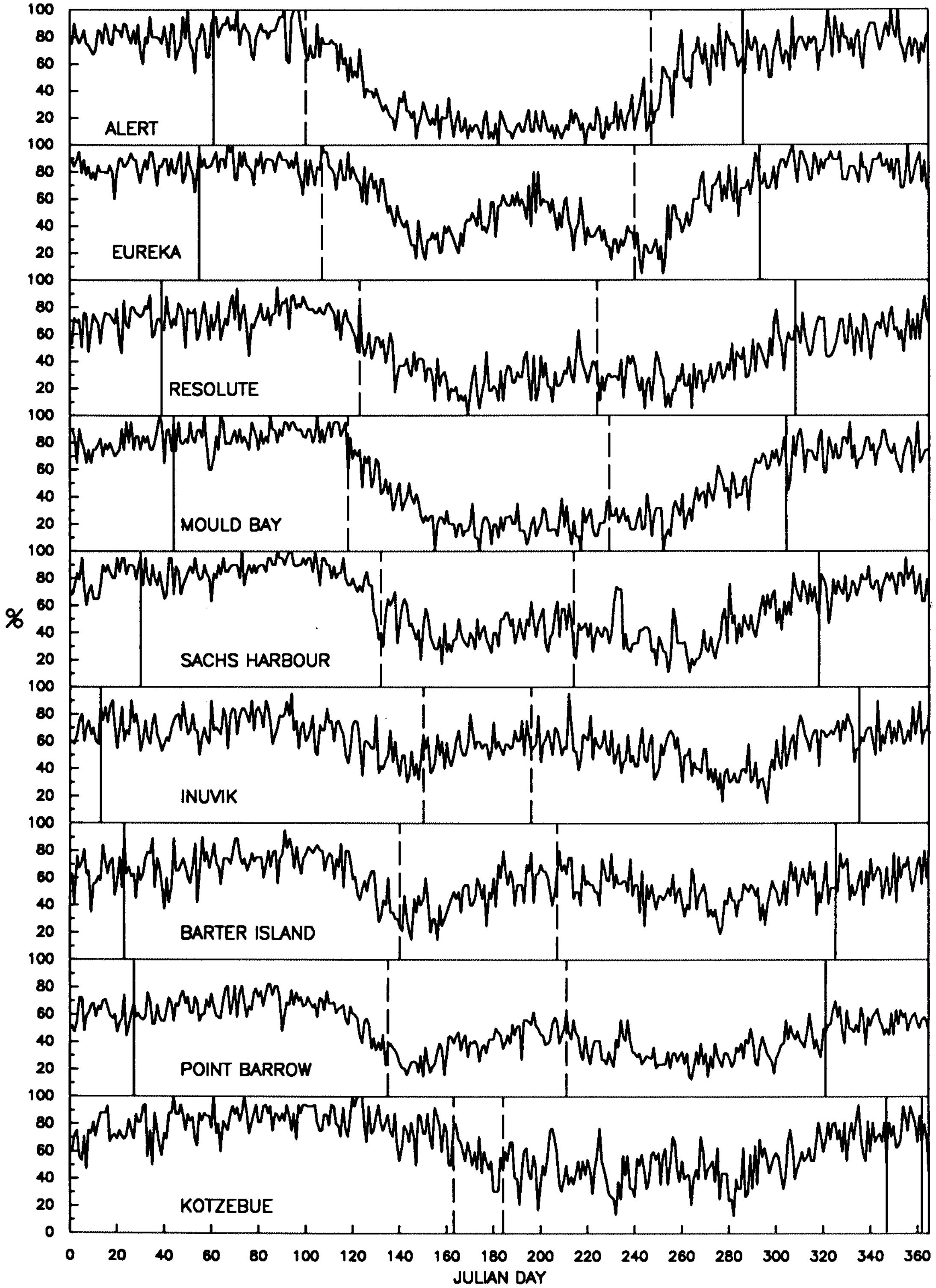

Fig. 4. Mean daily surface-based inversion frequency (1967-1986) at Arctic stations (in percent of available days). Solid vertical lines indicate the dates between which the sun rises above the horizon at the latitude of the station; dashed vertical lines indicate the dates between which the sun is continuously above the horizon at the latitude of the station.

TABLE 3. Relationship Between Mean Daily Surface Air Temperature (°C) and Inversion Depth

Station Number	Name	Depth, m	r^*
2400300	Alert, Northwest Territories, Canada	-10.3T+290	0.77
2401200	Eureka, Northwest Territories, Canada	-13.0T+267	0.93
2502700	Mould Bay, Northwest Territories, Canada	-11.5T+386	0.80
2403500	Resolute, Northwest Territories, Canada	-8.4T+302	0.71
2503650	Sachs Harbour, Northwest Territories, Canada	-9.2T+349	0.72
027502	Point Barrow, Alaska	-13.4T+285	0.77
027401	Barter Island, Alaska	-9.1T+326	0.66
2202570	Inuvik, Northwest Territories, Canada	-11.2T+334	0.83
026616	Kotzebue, Alaska	- 7.7T+222	0.76

All significant at >99.9% level.

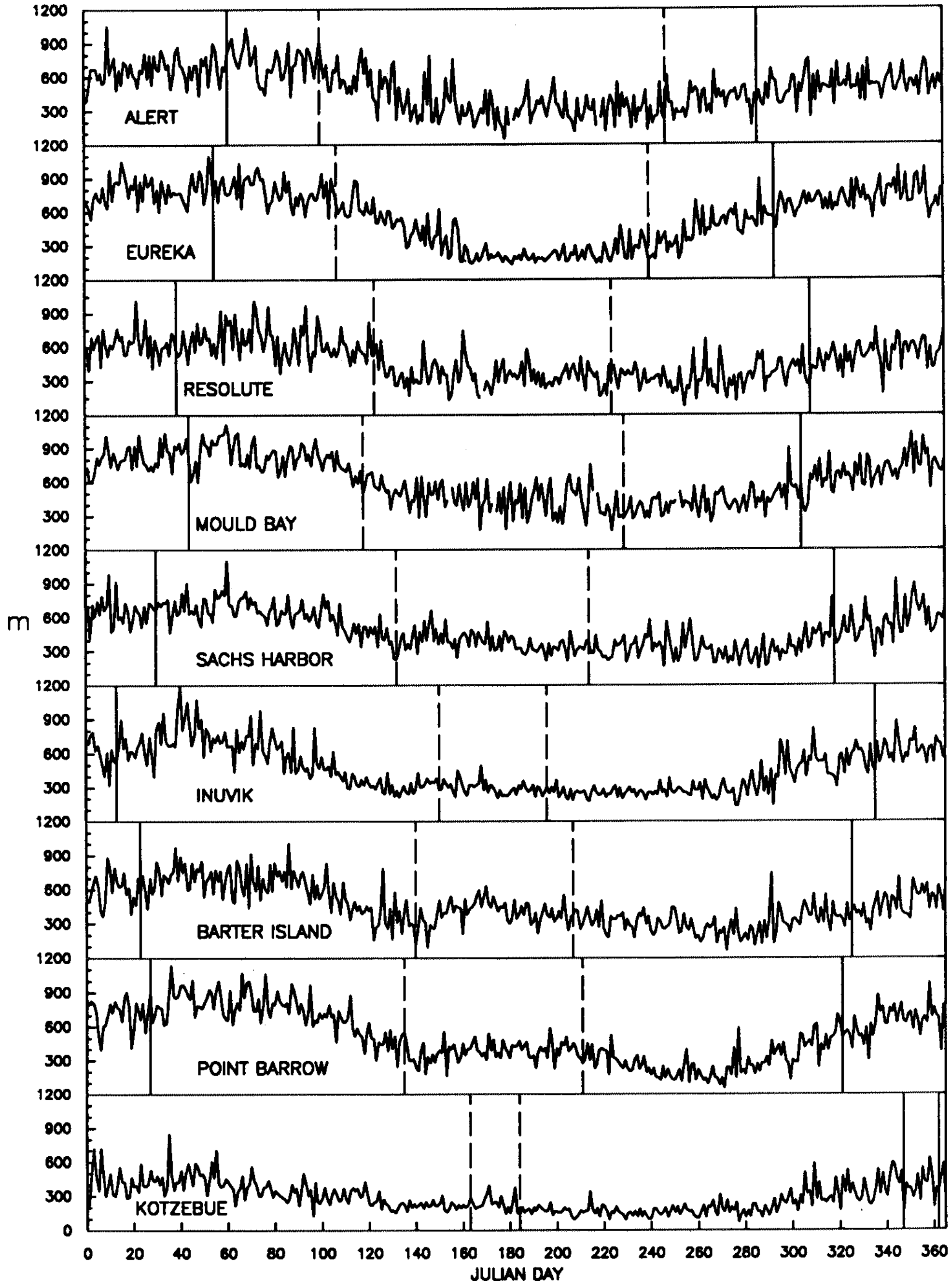

Fig. 5. Mean daily inversion depth (1967-1986) at the stations shown in Figure 1. Solid vertical lines indicate the dates between which the sun rises above the horizon at the latitude of the station; dashed vertical lines indicate the dates between which the sun is continuously above the horizon at the latitude of the station.

result in a reduced frequency of surface-based inversions and an increase in elevated inversions; this appears to be the case, at least in the spring and early summer, according to Bilello's analysis of elevated ("Type II") inversions. He found the highest frequency of elevated inversions at Barrow in May and June, corresponding to the time of minimum "Type I" (surface-based inversions). The same pattern was found at Alert in June and July, and at Nome in July. However, the data do not clearly support the same explanation for late summer/fall decreases in SBI frequency, and further study of these changes is needed.

6. INVERSION DEPTH AND INTENSITY

Surface-based inversion depth is strongly an inverse function of surface temperature (Table 3); inversion depth changes by ~8 to 13 m °C^{-1} at the surface. Hence inversions have the greatest thickness in winter months, particularly February and March when they are also most frequent (Figure 5, Table 4). However, at several stations, the relationship between temperature and inversion depth is not strictly linear; this is particularly apparent at Barter Island and Point Barrow where inversion thickness is increasingly independent of temperature when temperatures

TABLE 4. Monthly Inversion Statistics (1967-1986)

Month	Depth, m	Frequency, %	Temperature Gradient,°C/100 m	ΔT, °C	Surface Temperature, °C
			Alert		
1	641	79	1.7	8.3	-32.2
2	685	78	1.8	8.4	-34.7
3	727	85	1.8	9.1	-33.8
4	662	74	1.4	6.7	-26.6
5	426	31	1.2	3.8	-13.4
6	306	15	1.0	2.7	-1.3
7	324	13	1.1	2.5	3.1
8	319	18	0.8	1.8	0.8
9	382	49	1.4	4.0	-10.9
10	445	69	1.6	5.2	-19.9
11	534	76	1.7	6.2	-28.0
12	551	78	1.8	6.3	-30.0
			Eureka		
1	792	82	2.1	14.3	-37.4
2	798	84	2.0	13.5	-39.7
3	805	87	2.2	14.8	-39.4
4	705	82	1.9	11.4	-31.7
5	498	52	1.2	5.0	-15.6
6	234	37	1.2	2.0	1.2
7	202	56	1.7	2.5	4.6
8	252	31	0.9	1.7	2.7
9	437	42	1.3	5.1	-12.2
10	578	73	1.8	8.9	-23.7
11	712	85	2.0	12.6	-33.8
12	755	82	2.0	13.0	-36.4
			Resolute		
1	621	69	2.0	8.2	-32.2
2	628	71	2.0	8.9	-34.1
3	669	73	1.9	8.8	-33.3
4	598	77	1.8	7.6	-26.9
5	412	45	1.5	4.6	-14.6
6	344	21	1.2	3.2	-2.8
7	348	27	0.9	2.3	3.9
8	329	30	1.0	2.4	2.3
9	295	23	1.2	2.6	-5.8
10	358	43	1.8	4.8	-17.5
11	477	59	1.8	6.4	-26.1
12	542	64	1.9	7.1	-29.8
			Mould Bay		
1	790	78	1.6	10.3	-33.3
2	886	83	1.5	10.7	-34.8
3	830	83	1.5	10.4	-32.9
4	765	88	1.3	8.2	-26.5
5	526	47	1.1	4.8	-14.1
6	462	18	0.8	3.5	-1.1
7	432	19	0.9	3.3	4.2
8	371	21	0.9	2.6	0.8
9	410	29	1.0	3.5	-7.8
10	478	57	1.4	5.3	-18.7
11	631	73	1.5	7.6	-27.3
12	745	74	1.6	9.1	-31.3

TABLE 4 (continued)

Month	Depth, m	Frequency, %	Temperature Gradient,°C/100 m	ΔT, °C	Surface Temperature, °C
Sachs Harbour					
1	654	81	1.9	8.7	-30.3
2	701	82	2.0	9.1	-31.4
3	679	87	1.9	8.9	-29.3
4	575	88	1.7	6.9	-21.8
5	430	55	1.7	5.0	-10.5
6	410	35	1.3	4.2	2.5
7	325	46	1.3	3.5	6.1
8	341	41	1.3	3.2	3.4
9	329	29	1.2	2.8	-1.4
10	294	49	1.7	3.7	-13.0
11	484	69	1.9	6.0	-22.4
12	587	77	1.7	7.4	-28.1
Inuvik					
1	627	70	2.0	9.5	-28.1
2	790	67	1.8	11.0	-29.6
3	655	76	1.8	8.5	-25.7
4	438	68	2.2	6.6	-16.6
5	308	50	1.9	4.6	-2.9
6	302	55	1.4	3.5	8.1
7	270	60	1.5	3.2	10.8
8	249	54	1.6	3.1	8.7
9	273	48	1.6	3.3	2.7
10	380	36	1.4	4.6	-9.7
11	539	64	1.7	7.2	-20.8
12	630	66	1.9	9.4	-26.6
Barter Island					
1	609	63	2.1	9.5	-25.7
2	711	67	2.1	11.4	-30.3
3	695	73	2.0	10.8	-28.5
4	543	75	2.2	8.3	-22.0
5	349	42	2.1	6.3	-8.7
6	453	41	2.4	8.5	1.4
7	383	61	2.2	7.0	3.9
8	322	56	2.1	5.7	3.8
9	265	45	2.2	4.8	-0.2
10	279	43	2.2	4.8	-10.8
11	386	57	2.2	7.2	-19.4
12	513	62	2.3	8.6	-25.3
Point Barrow					
1	660	57	2.1	9.7	-25.7
2	850	62	1.7	10.2	-29.6
3	810	71	1.7	9.6	-27.3
4	627	67	1.8	7.3	-22.3
5	402	32	1.7	5.3	-9.8
6	396	39	1.7	5.5	0.8
7	381	54	1.8	5.6	3.0
8	279	41	1.8	4.0	3.8
9	196	30	1.7	2.7	-0.5
10	338	34	1.6	4.3	-11.9
11	497	49	1.8	6.7	-20.1
12	642	54	1.8	8.3	-25.8
Kotzebue					
1	428	74	2.3	7.0	-18.6
2	474	79	2.2	7.6	-20.7
3	349	84	2.5	6.4	-17.4
4	317	85	2.6	5.9	-14.6
5	225	78	2.6	4.8	-1.9
6	226	62	2.4	4.5	5.8
7	174	48	1.8	2.4	12.3
8	165	42	1.6	2.0	10.9
9	176	48	1.4	1.8	4.8
10	209	44	1.6	2.5	-6.8
11	330	66	2.2	5.0	-14.4
12	417	72	2.1	6.7	-18.1

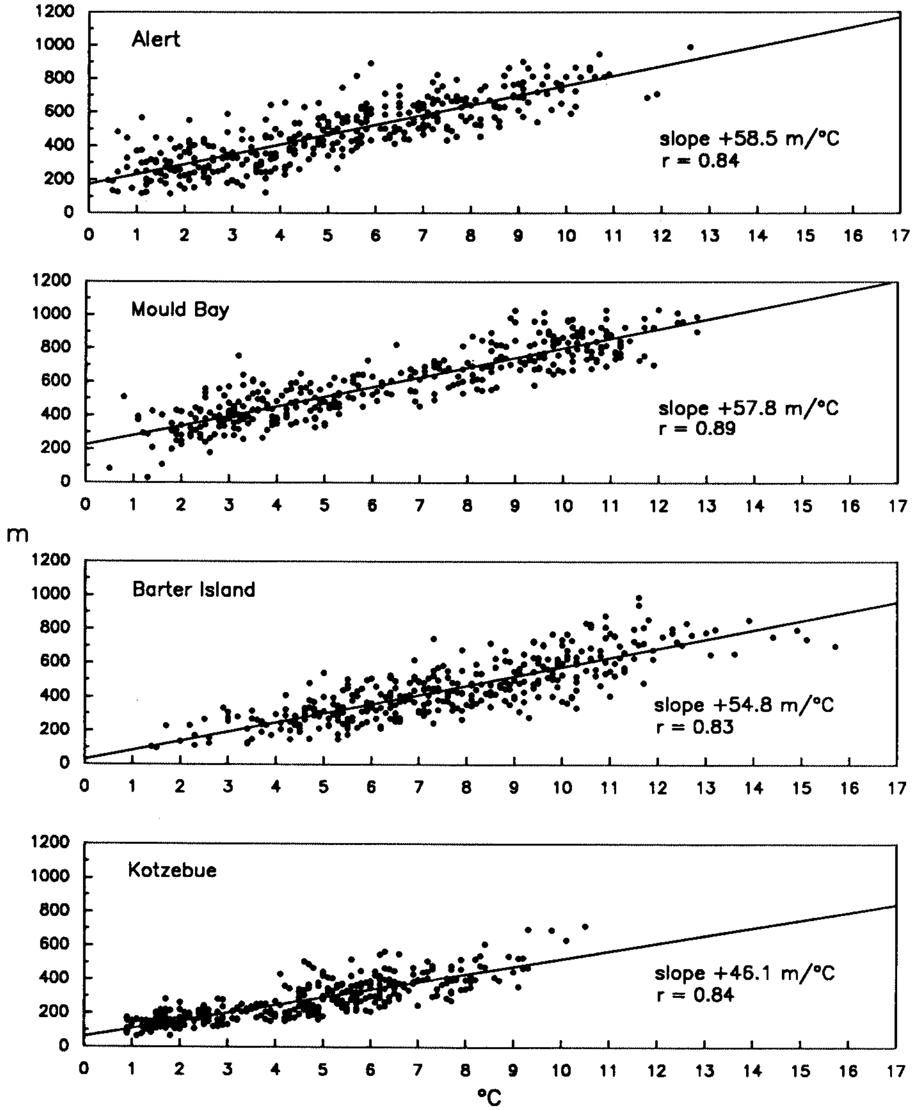

Fig. 6. Relationship between surface-based inversion depth and temperature change across the inversion (ΔT) for selected stations, based on average values (1967-1986) for days with surface-based inversions.

approach or exceed 0°C (Figure 5). This points to the greater importance of radiative effects on controlling inversion characteristics in the colder winter months, and a greater influence of advective effects in summer.

Mean monthly SBI thickness is greatest (886 m) at Mould Bay in February (on 83% of available days) with surface temperature averaging -34.8°C. In the same month, the southernmost station, Kotzebue (with a mean surface temperature of -20.7°C), has an average surface inversion depth of 474 m (on 79% of available days). From December to March, the top of the inversion layer is, on average, close to the 950-mbar level at Kotzebue and 900 mbar at Mould Bay. During these months the surface-based inversion is a quasi-permanent feature of the atmosphere, essentially isolating the surface from conditions aloft for most of the time. SBI thickness is lowest in summer months; mean monthly minima range from 165 m at Kotzebue (on 42% of days in August) to 371 m at Mould Bay (on 21% of days in August).

Temperature changes across the inversion layer (referred to as "inversion strength" by *Phillpot and Zillman* [1970] and given as ΔT in Table 4) are highly correlated with inversion thickness, and inversely related to surface temperature (Figures 6 and 7). Thus inversions are strongest and deepest in winter months when surface temperatures are lowest. The largest increase in temperature through the SBI is found at Eureka where, on those December-March days which have surface-based inversions (84% of days), temperatures at the top of the inversion (755-805 m) average 13.9°C higher than at the surface (Table 4). At other stations the absolute differences across the inversion are generally less than at Eureka, but temperature gradients within the inversion are fairly consistent across the region. These tend to be steep in winter months (~1.8 to 2.3°C 100 m^{-1}) and less stable (~0.8 to 1.6°C 100 m^{-1}) in the summer period (Table 4). Temperature gradients are generally higher at the southernmost stations in all months, perhaps reflecting their proximity to milder air that is advected aloft. Hence although surface-based inversions at lower-latitude sites are shallower and less frequent than those farther north, those that do occur are extremely stable.

An examination of individual daily soundings indicates that the greatest depths of SBIs observed during the 20 years studied range from ~2 km at Kotzebue to ~3 km at Sachs Harbour (Table 5). In such cases, the temperature gradient is relatively weak (0.4 to 0.9°C 100 m^{-1}). However, in extreme cases, ΔT

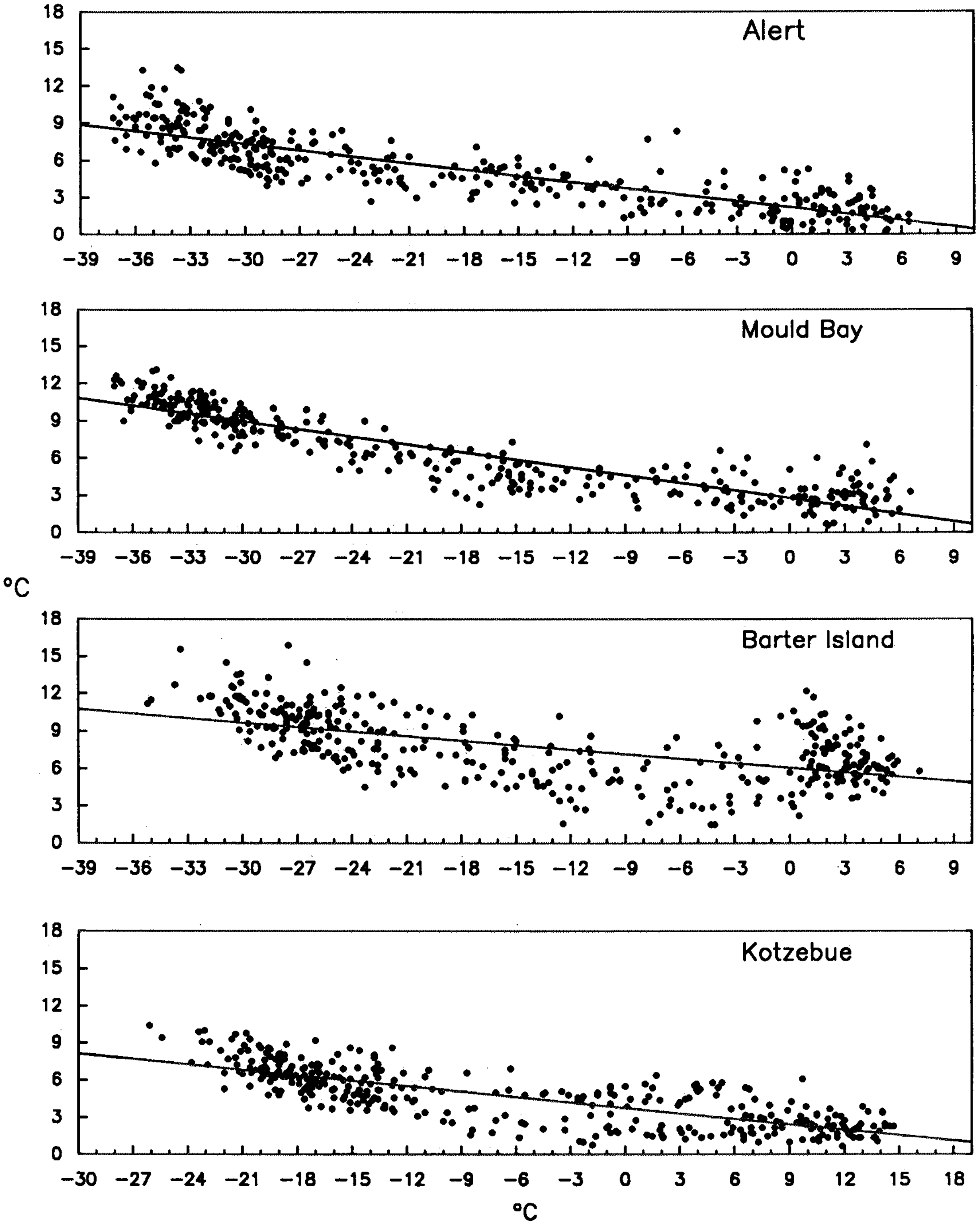

Fig. 7. Relationship between surface temperature (x -axis) and inversion strength (ΔT) for selected stations, based on average values (1967-1986) for days with surface-based inversions.

may exceed 35°C, with temperature gradients >6°C 100 m^{-1}. These cases often involve very strong anomalous southerly airflow in midwinter. Occasionally, such conditions may lead to temperatures aloft exceeding 0°C. For example, for several days in January 1977, temperatures aloft at Alert, Eureka, and Resolute all exceeded 0°C, reaching +4.6°C at 1.2 km above Alert (82° 30'N) on January 12 when surface temperatures were -15°C.

7. WIND SPEED AND DIRECTION

To investigate the relationship between seasonal changes in airflow and inversion characteristics during the year, individual soundings were inspected for all available wind speed and direction measurements within the SBI. For each profile with an SBI, the mean wind speed and mean wind direction within the surface inversion layer were calculated. Mean daily wind speed was then computed (Figure 8). In the case of wind direction, daily means were classified into octants for each day in the 20-year sample (Figure 9).

Daily wind speeds within the inversion layer average 3-6 m s^{-1}. Several stations register lowest wind speeds within the inversion layer during summer months, increasing by ~20-25% in the midwinter. This may reflect both the thinner SBI in summer (and therefore greater frictional retardation on the smaller mass of air within the boundary layer) and a higher

TABLE 5. Extreme Daily Surface Based Inversion Conditions (1967-1986)

	Alert	Eureka	Resolute	Mould Bay	Sachs Harbour	Inuvik	Barter Island	Point Barrow	Kotzebue
Maximum depth, m	2697	2582	2635	2388	3069	2912	2758	2726	2071
Date	March 11, 1978	March 14, 1980	Dec. 30, 1971	Feb. 27, 1971	Dec. 10, 1974	Feb. 21, 1968	Jan. 13, 1975	Feb. 27, 1968	Feb. 22, 1984
Surface T, °C	-39.5	-44.3	-37.8	-33.2	-38.7	-39.6	-44.0	-32.9	-39.0
ΔT, °C	16.2	20.8	11.6	11.3	15.2	16.8	16.8	13.9	17.7
Temperature gradient, °C/100 m	0.60	0.81	0.44	0.47	0.50	0.58	0.61	0.51	0.85
Maximum T, °C	31.1	33.7	25.6	24.8	23.2	30.2	35.7	28.9	25.3
Date	Feb. 17, 1970	Jan. 24, 1978	March 14, 1978	Feb. 13, 1980	Jan. 29, 1985	Feb. 9, 1968	Jan. 25, 1983	Jan. 24, 1983	Dec. 23, 1967
Depth, m	1973	1538	1069	809	838	656	530	977	585
Surface T, °C	-39.8	-38.3	-41.9	-30.5	-37.6	-28.2	-26.6	-26.7	-23.3
Temperature gradient, °C/100 m	1.57	2.19	2.39	3.07	2.77	4.60	6.70	2.96	4.32

surface drag in summer once snow cover has disappeared. Some stations (particularly Resolute) show highest average wind speeds in fall and early winter months when synoptic activity in the region is most active; in some cases mean winds in excess of 20 m s^{-1} have been recorded without disruption of the inversion (e.g., at Point Barrow, January 7, 1970, winds within the inversion layer ranged from 10 to 33 m s^{-1}). At several of the high-latitude stations, mean wind speeds within the SBI are often quite high in summer, but this only reflects the fact that daily averages in summer are based on fewer days than in winter when inversion frequency is much higher. For example, at Alert, on many summer days the frequency of SBIs within the 20-year sample period drops to <10% (Figure 4).

Data on wind direction frequency (Figure 9) reveal seasonal wind direction changes which seem to reflect (on the large scale) a shift toward more southerly and/or more onshore airflow in summer months at most stations, modified by local topographic effects in each case. The increase in onshore winds may result from removal of snowcover on adjacent land areas, producing a local sea-breeze effect. At Mould Bay, for example, the predominant winter airflow from the sector 315°-360° is replaced by more cases from 135°-225° which involves airflow along the fiord toward the warmer, snow-free interior of Ellef Ringnes Island to the north of the station. Similarly, at Resolute, the prevailing northwesterly winter airflow is matched by onshore southeasterly airflow from Lancaster Sound in summer months. At Eureka, winds back to the sector 270°-315° in summer, aligned with the adjacent Slidre Fiord and moving inland toward central Ellesmere Island. At northern Alaskan stations, as well as Inuvik and Sachs Harbour, winds more commonly have an easterly component, reflecting the east-west orientation of the coast at these sites. In summer months, there is generally an increase in airflow from the southeast, though at Kotzebue, onshore (westerly) airflow predominates on days with SBIs in the early summer.

8. INVERSION PERSISTENCE

An assessment of the persistence of SBIs can be gained by examining the frequency of runs of days which recorded inversions. It should be noted that by only analyzing one sounding per day (1200 UT) any afternoon breakdown of the surface inversion would be missed, particularly during summer months. However, diurnal heating effects can be neglected in midwinter months and so the analysis has been restricted to the months of December-March. Runs starting before December 1 and those continuing after March 31 were not counted and neither were runs which were interrupted by a missing day. Assuming such runs are a representative subset of the days sampled, the results provide an interesting perspective on SBI persistence during winter months (Figure 10). The median midwinter inversion duration varies from 2 to 4 days (2 at Kotzebue, Point Barrow, Inuvik, Barter Island, and Resolute, 4 at the other sites). In Alaska, inversions generally tend to persist for less than 10 days but at the more northern Canadian sites, inversions may persist for several weeks (Figure 11). This has significance for lower tropospheric chemistry since prolonged isolation of the surface boundary layer from the rest of the troposphere can lead to extreme depletion of O_3 levels [*Barrie et al.*, 1988].

9. SUMMARY

Surface-based inversions in the North American Arctic result either from a radiative imbalance at the surface (negative net

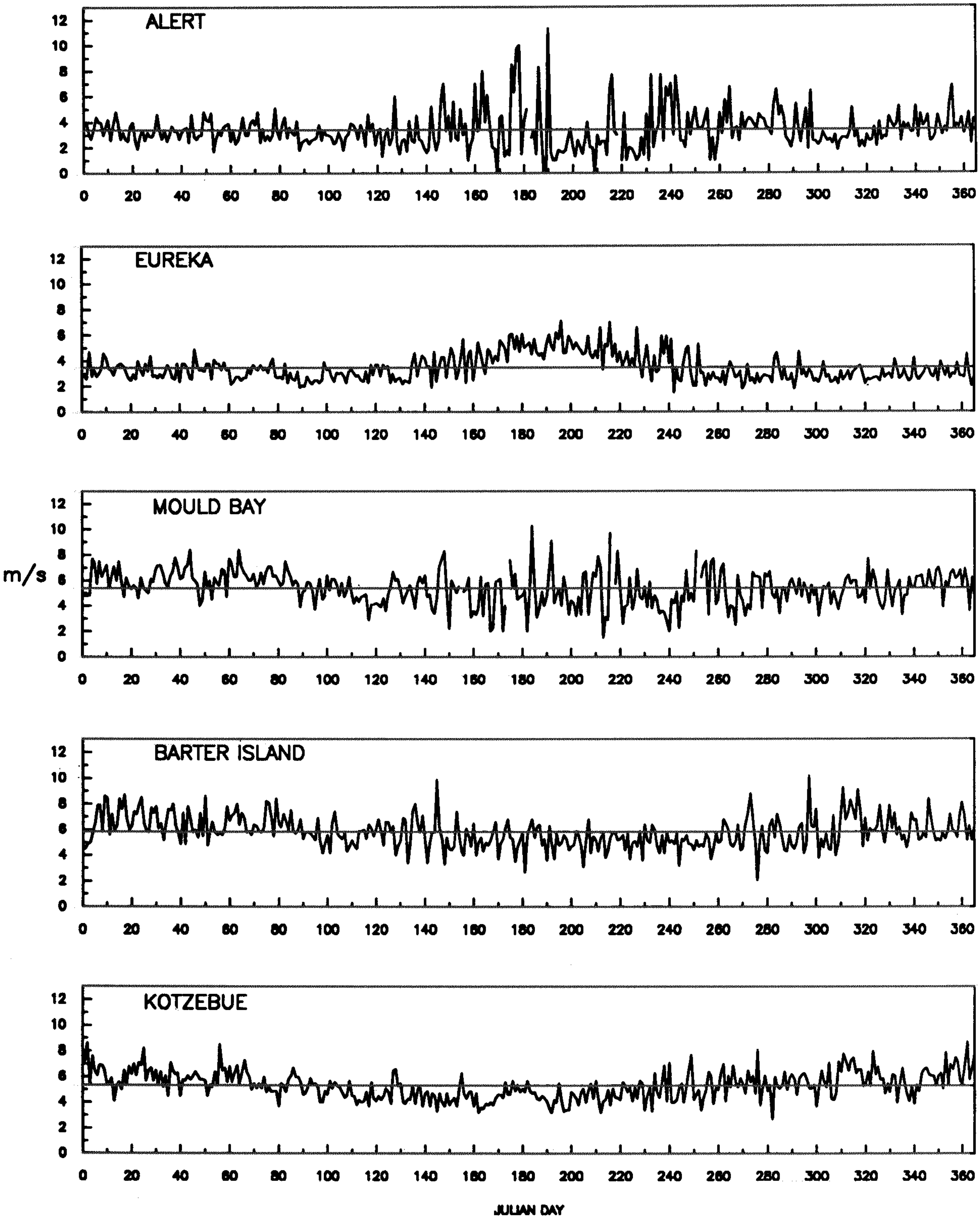

Fig. 8 Mean daily wind speed within the inversion layer, on days with surface-based inversions (1967-86). Horizontal line is mean annual wind speed within the SBI (based on all available recorded levels).

radiation) or from near-surface cooling of a warm air mass. During the dark, winter months the former condition prevails, but such inversions decline in frequency as solar radiation receipts increase in the spring and net radiation becomes positive, leading to a strong seasonal cycle in frequency, depth, and strength. Surface-based inversions are most common in winter months when they are also deepest and have the largest temperature difference between the surface and the top of the inversion. Surface-based inversion frequency reaches 88% of days at some stations in midwinter months, and mean monthly thicknesses can exceed 850 m. Inversion depth and strength are strongly (inversely) related to surface temperature at all stations, but become increasingly independent of temperature at lower-latitude sites when temperatures approach or exceed 0°C. This reflects the increased importance of advective, rather than radiative, effects in summer. Inversion depth is closely related to the temperature difference across the inversion layer; this may be >30°C on individual days, with very deep inversions, but is more commonly in the 7°-15°C range in winter and 1°-5°C range in summer months. Inversions commonly persist for several days, but in some areas may be undisturbed for several weeks in midwinter.

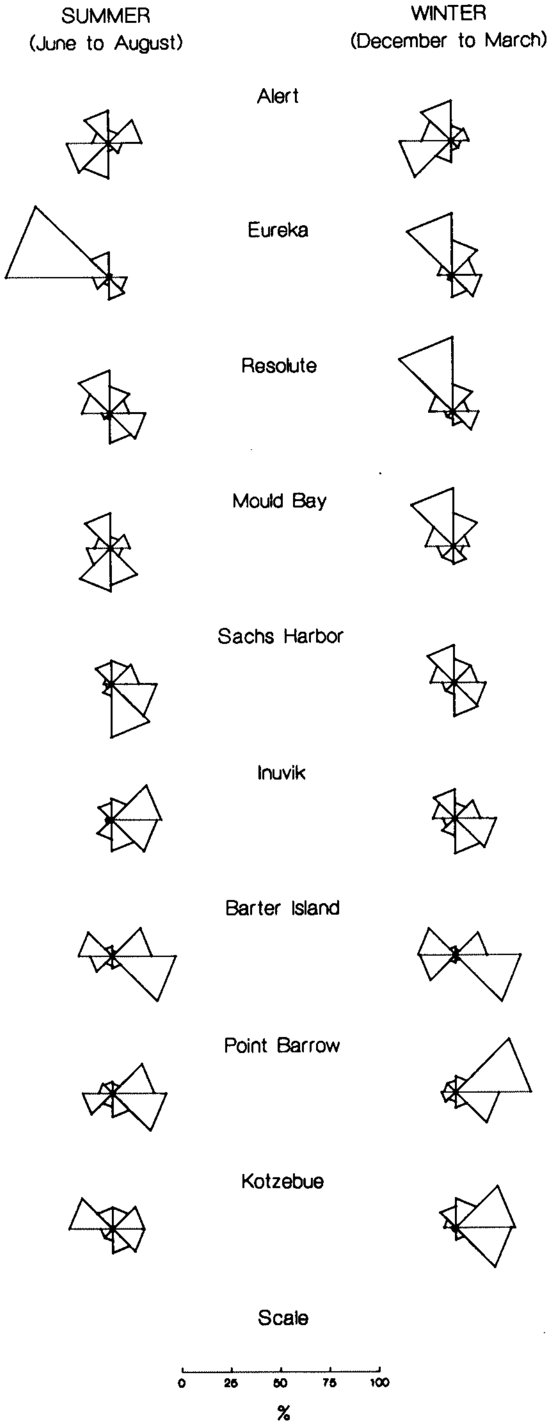

Fig. 9. Percentage frequency of daily mean wind direction within the surface-based inversion layer by octant, for midwinter (December-March) and summer (June-August) conditions, 1967-1986.

APPENDIX

Data Sources

Significant level upper air data were obtained from the Atmospheric Environment Service, Downsview, Ontario (for Canadian stations), and the National Center for Atmospheric Research and the National Climatic Data Center, Asheville (for Alaskan stations). Standard level data are not sufficiently detailed to enable the surface-based inversions (which occur generally below the 900-mbar level) to be adequately studied. Only the first 30 reported levels of the 1200 UT soundings were analyzed; these comprise data for at least the lowest 3 km and include all surface-based inversions in the study area. The period of record discussed here is January 1967 to December 1986 (20 years). At Kotzebue, however, no soundings were available from January 28, 1972, to January 2, 1975; thus statistics for Kotzebue are based on ~17 years of data.

Data Quality and Quality Control Procedures

Each raw data file was checked for missing altitudes. Where an altitude was missing at a given level, but the pressure and temperature at that level were not, and the pressure, temperature, and altitude at the previous level were all present, the missing altitude was reconstructed by use of the hydrostatic equation. This procedure, when checked against days where all data were present, proved to be accurate to within a few meters. In constructing graphs showing the annual cycle of inversion characteristics, soundings for February 29 in all leap years were discarded.

Soundings with the following criteria were considered to have inadequate or erroneous data and were rejected from further analysis: (1) base (surface) level missing, (2) temperature at base (surface) level missing, (3) missing temperature at some level within a surface-based inversion, (4) altitude at a level less than altitude of the previous level, and (5) rate of the temperature increase between any two consecutive levels within the surface-based inversion was greater than 10°C 100 m^{-1}. This condition may in fact be correct in some cases, but is clearly in error in others. To be consistent, this quality control was introduced. In general, it resulted in <1% of soundings being rejected. As a check on the impact of this procedure, Barter Island (the station with the most cases of these apparently strong temperature gradients) was examined in more detail. In this case, 1.2% of records were rejected for this reason. Of these, about half had gradients in the 10°-13°C 100 m^{-1} range and two cases were in excess of 100°C 100 m^{-1}! Recomputation of the daily statistics with and without these cases produced insignificant differences.

Collectively, these quality control procedures resulted in rejection of records as follows (based on 20 year records at all stations except Kotzebue (17 years)): Alert, 3%; Eureka, 4%; Resolute, 10%; Mould Bay, 3%; Sachs Harbour, 4%; Inuvik, 3%; Barter Island, 5%; Point Barrow, 7%; Kotzebue, 11%.

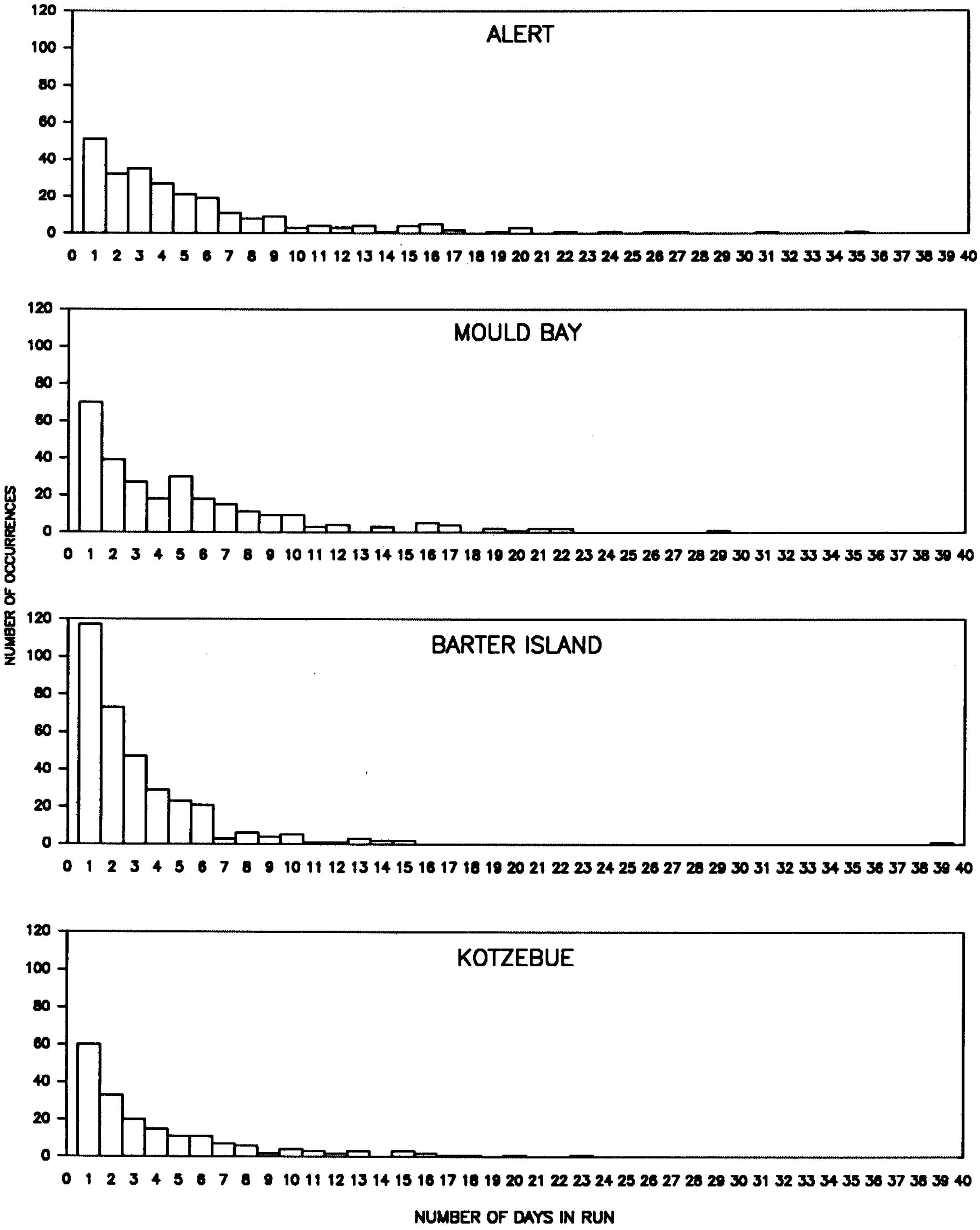

Fig. 10. Frequency histograms of inversion duration (days) in the December-March period (1967-1986).

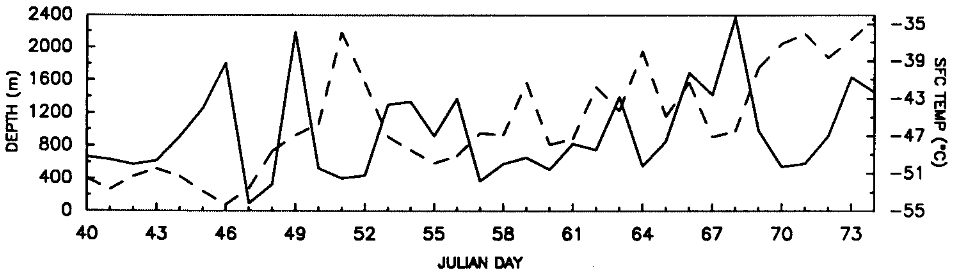

Fig. 11. Daily 1200 UT inversion depth in meters (solid line) and 1200 UT surface temperature in degrees Celsius (dashed line) at Eureka, Northwest Territories, Canada from February 9 to March 15, 1979. This was one of the longest uninterrupted periods of surface-based inversions in the region during the 20 years studied.

Acknowledgments. This work was supported by the Department of Energy. We thank Paul Doyle for his efforts in the early stages of this work, and for the reviewers' comments on the manuscript.

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(Received February 3, 1992;
revised June 19, 1992;
accepted June 24, 1992.)