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Climatology of Temperature Inversions in Western North Dakota

by
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ABSTRACT

Two towers located near Hannover and Dickinson in western North Dakota were instrumented to determine the climatology of low level temperature inversions. Platinum bulb thermisters were mounted at 1, 2, 5, 14, 35, and 91 m heights at Hannover and at 2, 8, 20, 55, 104, and 157 m heights at Dickinson. Temperatures were recorded continuously for about 37 months on multipoint strip chart recorders and were averaged over 0.5 hr intervals. An inversion condition was defined as a lapse rate ≥1C/100 m.

Definite seasonal trends were observed. Inversion conditions occur about 36 percent of the time on an annual basis ranging from 28 percent in spring to 50 percent in winter. The average duration of a wintertime inversion was two to three times greater than in summer, but their average intensitives were similar. A nearly linear relationship was found between average intensity and duration ($R^2 = 0.58$; significant at 0.01 level). During inversions fumigation conditions occurred about 2.5 percent of the time, varying from less than 1 percent in the summer to over 7 percent in winter. Daytime inversion conditions are rare during the summer but occur with about a 20 percent frequency during the winter. Changes in the inversion commencement and ending times correspond with the seasonal changes in sunset and sunrise times. Inversions occur almost daily during summer nocturnal hours.

Introduction

Coal development in the Northern Great Plains is rapidly expanding and public concern about its impact on air quality is growing. Effluents from coal development could cause changes in cloud and precipitation processes (Hjelmfelt **et al.**, 1978). The atmosphere has always been a convenient medium for disposal of industrial wastes, but their dispersal is limited by the meterological conditions of the area. The occurrence of temperature inversions is one of the most critical meterological conditions influencing the dispersion of air pollutants (Slade, 1968), and only limited information based on radiosonde observations at Bismarck was available for North Dakota (Hosler, 1961). The objective of this study was to characterize the frequency, time of occurrence, intensity, and duration of low-level radiation inversions near existing and proposed coal development sites in western North Dakota.

Site Description and Instrumentation

Two existing towers, one located near Hannover and the other near Dickinson, North Dakota, were used in this study (Figure 1). The 91 m Hannover tower is located on a steep hill with an elevation of 701 m above mean sea level. The surrounding area drops off rapidly to an elevation of 671 m about 400 meters from the tower. The general topography in the area consists of rolling hills with a relief of 640-701 m. These hills are mostly uncultivated prairie grassland interspersed with grain fields and fallowland. The 183 m Dickinson tower is located on top of a flat 450 x 750 m butte which has an elevation of 896 m. Except for a smaller butte to the northwest, the area surrounding the tower butte drops off sharply to an elevation of 807-823 m. The surrounding gently rolling area is dotted by small buttes ranging in elevation from 853 to 914 m and consists of mixed prairie grassland, grain fields, and fallow land.

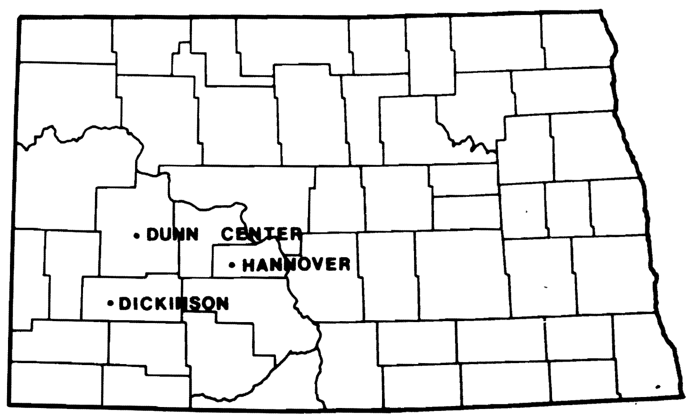

Figure 1. Location of North Dakota study sites.

Temperatures were measured for six levels using shielded, non-aspirated, fast response, platinum bulb, resistance thermometers. The data were recorded continuously with six channel strip chart recorders and were averaged over 0.5 hour intervals. The resistance thermometers were mounted at 1, 2, 5, 14, 35, and 91 meter heights at Hannover and at 2, 8, 20, 55, 104, and 157 m heights at Dickinson. The thermometers were calibrated before installation and periodically throughout the duration of the study. Both the sensor specifications and data system resolution limited the accuracy of the temperature readings to ±0.4C and delta temperatures to ±0.9C. Therefore, an inversion was defined as a lapse rate of 1°C/100 m or greater. This means that actual inversion frequency would be slightly greater than that reported in this study.

Data Collection and Analysis

Temperatures were recorded from June 27, 1974 to August 18, 1977 at Hannover and from September 4, 1974 to June 1, 1977 at Dickinson, but equipment failure was a severe and continuing problem. Ultimately, the equipment was operational 58 percent and 62 percent of the time at Hannover and Dickinson, respectively. In most cases equipment failure resulted in a loss of data from one or all levels for several days or weeks and these occurrences were not seasonally related (Table 1). To account for the unequal observation times in each month, the inversion frequencies are expressed as a percentage of operational time. However, in months with very little data, such as November at Dickinson (Table 1), some qualification of inversion statistics may be necessary.

Table 1. Percent time that temperature measuring equipment was operational at Hannover, N.D. (27 June 1974-18 August 1977) and Dickinson, N.D. (4 September 1974-1 June 1977).

	Hannover		Dickinson	
Month	Potential half-hours	Percentage of half-hours operational	Potential half-hours	Percentage of half-hours operational
January	4464	82	4464	77
February	4080	78	4080	96
March	4464	56	4464	98
April	4320	38	4320	71
May	4464	65	4464	90
June	4464	67	2928	49
July	5952	53	4464	42
August	5328	72	4464	67
September	4320	51	4128	54
October	4464	66	4464	51
November	4320	41	4320	15
December	4464	30	4464	33
Total	55104	58	51024	62

The 5 and 91 m levels were used to determine inversions at Hannover 76 percent of the time, but due to equipment failure other levels, mainly 14 and 91 m, were used 24 percent of the time. Similarly, at Dickinson the primary levels of 8 and 157 m were used 74 percent of the time while alternate levels, mainly 2 and 104 m, were used 26 percent of the time. Because the temperature changes with height most rapidly near the surface, the use of these alternate levels will change the inversion statistics. Thus, as the height of the lower measurement increases, fewer inversions will be found. For example, when several months of the Hannover data were analyzed using the 14 and 91 m heights instead of the 5 and 91 m heights, about 10 percent fewer inversions were found. A similar comparison of Dickinson data showed that about 10 percent more inversions were identified when the alternate levels, which were closer to the surface, were used. Since these alternate levels were used about 25 percent of the time, the inversion frequencies could be decreased about 2.5 percent at Hannover and increased about 2.5 percent at Dickinson. This may also influence the intensity and duration of inversions, but the inclusion of the additional data was deemed more important than the small effect they would have on final inversion statistics.

Inversion Frequency

Inversion-days, defined as days in which at least one inversion existed, occurred more frequently during the summer than in other seasons. For example, at least one inversion occurred on 98 and 92 percent of the summer days at Hannover and Dickinson, respectively, but one occurred on only 91 and 87 percent of the remaining days in the year. Results from a one-year concurrent study (Ramirez, **et al.**, 1976) at a nearby site (Figure 1) near Dunn Center are very similar to those found at Hannover (Table 2). It is apparent from these results that an inversion condition may be expected nearly every night in these rural areas, especially in the summer. The 100 percent noted for Dickinson in November probably results from the small sample size for the month.

Using radiosonde data, Hosler (1961) determined the frequencies of inversion conditions in the lowest 152 meters for various Weather Bureau Stations. The maximum occurrence of inversions at any one of the four daily radiosonde observation times was determined and the results were shown on seasonal maps. Hosler reported that inversions in western North Dakota occurred on about 70 percent of the days on an annual basis and that they were least frequent in spring and most frequent in summer. The frequencies were 15-25 percent less than those obtained in this study (Table 2). In this study measurements were made continuously while Hosler (1961) used predetermined times, which may explain his lower frequencies.

Inversion conditions were also evaluated on a percentage of possible time basis. Throughout the year inversion conditions existed about 36 percent of the total time at all sites (Table 3). Their frequency varied from 28 percent in the spring to 50 percent in the winter. Based upon radiosonde data, Hosler (1961) plotted seasonal isopleths of inversion frequency expressed as a percentage of total hours. Hosler's estimates for western North Dakota ranging from 30 percent in spring to 45 percent in winter are similar to those found in this study. Both studies also show that inversion conditions occur most frequently in winter and least frequently in spring. Mixing-depth data from Montana (Holzworth, 1962)

Table 2. Percent frequency of inversion day occurrence at Hannover, Dickinson and Dunn Center, N.D.

Month	Hannover Total Possible Days	Hannover Inversion Days (%)	Dickinson Total Possible Days	Dickinson Inversion Days (%)	Dunn Center[1] Total Possible Days	Dunn Center[1] Inversion Days (%)
January	78	91	73	95	31	87
February	66	89	82	85	29	86
March	51	88	90	84	31	87
April	34	97	64	78	29	90
May	62	95	84	89	31	97
June	64	94	30	93	29	100
July	68	100	40	93	31	100
August	80	99	62	89	31	94
September	49	98	47	81	30	87
October	62	84	50	84	31	87
November	38	89	13	100	30	90
December	29	97	31	87	31	87
Monthly Avg.	—	93	—	87	—	91
Total-Avg.	681	93	666	88	364	91

[1]Ramirez et al. (1976).

Table 3. Percent frequency of occurrence of inversion conditions at Hannover, Dickinson and Dunn Center, N.D.

Month	Hannover Number half-hrs possible	Hannover Inversion Freq (%)	Dickinson Number half-hrs possible	Dickinson Inversion Freq (%)	Dunn Center[1] Number Half-hrs possible	Dunn Center[1] Inversion Freq (%)
January	3664	49	3443	47	1488	49
February	3163	43	3915	35	1392	33
March	2479	39	4364	28	1466	31
April	1632	30	3050	27	1270	30
May	2896	30	3994	26	1429	34
June	2980	28	1424	26	1296	28
July	3170	34	1859	30	1470	36
August	3809	34	2972	29	1482	34
September	2203	42	2207	26	1424	36
October	2930	38	2290	32	1478	30
November	1767	32	641	41	1439	45
December	1359	57	1487	45	1482	46
Monthly Avg.	—	38	—	32	—	36
Total-Avg.	32052	38	31646	33	17116	37

[1]Ramirez et al. (1976).

support these results. Holzworth found mixing depths averaged only about 300 m in winter compared to 2300 m in July.

The percent frequency of inversion occurrence at various times throughout the day is depicted in Figure 2 for each month at Hannover. Definite daily and seasonal patterns exist. Inversion conditions are almost nonexistent during the late morning through early evening hours of mid-spring through autumn but are quite common at night. During these months strong surface heating causes most inversions to dissipate a few hours after sunrise and strong lapse conditions prevail throughout the day. One or two hours before sunset, the surface cools and inversions begin to form again. This is indicated by the strong gradient around 20:00 to 22:00 (Figure 2). In winter and early spring the low solar elevations and snowcover result in less surface heating so inversions are able to persist into and throughout the daylight hours more often.

At Dickinson, the pattern is very similar (Figure 3) except most of the March through November inversions do not form until after sunset, about two hours later than they do at Hannover. However, this is probably a result of the greater sensor heights at Dickinson and does not represent a different regime. Since the lower sensor is 3 meters higher than the one at Dickinson, an inversion must be at least 3 meters deeper before it is recorded. This would take longer and accounts for the later occurrence times.

The tendency for inversions to form around sunset in rural areas was previously noted by De Marrais and Islitzer (1960) based on results of a study near Idaho Falls, Idaho. They also found that an inversion occurs on nearly 100 percent of the nights during the summer.

Duckworth and Sandberg (1954) suggested that such a situation is not a normal occurrence in the heat island over an urban area. Two studies have been reported that confirm this observation. De Marrais (1960) found that for heights of 18 to 157 m in Louisville, Kentucky nocturnal inversions occurred only about 15 percent of the days throughout the

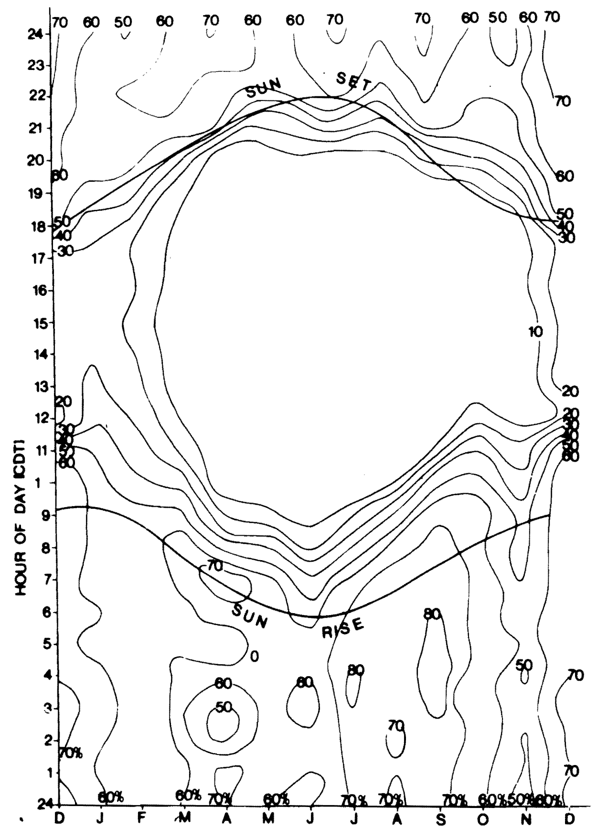

Figure 2. Percent frequency of inversion occurrence during one-half hour intervals throughout the day for each month at Hannover, N.D. June 1974-August 1977.

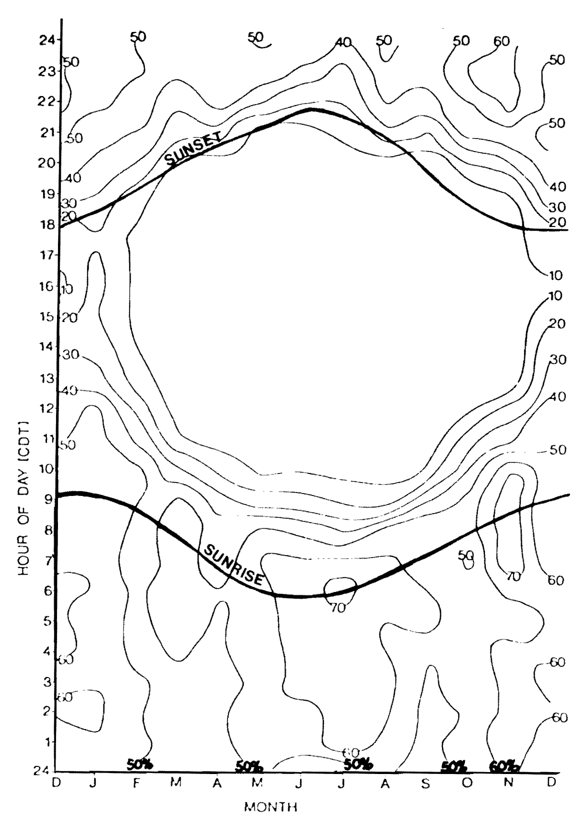

Figure 3. Percent frequency of inversion occurrence during one-half hour intervals throughout the day for each month at Dickinson, N.D., September 1974-June, 1977.

year. Using almost identical heights, Baker **et al.** (1969) showed inversions occurring on only about 45 percent of the days in Minneapolis-St. Paul compared to a frequency of over 90 percent found in this study. However, even though the frequencies are much lower in urban areas,the seasonal variations are similar to those found in rural areas.

Inversion Duration.

Most inversions were of short duration; 48 percent at Hannover (Table 4) and 50 percent at Dickinson (Table 5) were ≤2 hours. At the other extreme, only about 15 percent at Hannover and 13 percent at Dickinson were >12 hours duration. Results from another inversion study (Ramirez **et al.**, 1976) conducted from September, 1975 to August, 1976, near Dunn Center, North Dakota are similar; 43 percent of the inversions lasted ≤3 hours and only 17 percent were >12 hours.

The cumulative frequency distributions (Tables 4 and 5) show that there are large seasonal differences. Maximum durations during the summer months were 10-12 hours, which corresponds to the number of hours of darkness. This correspondence to hours of darkness directly illustrates the effect solar radiation has on the dissipation of inversions. However, in winter the reduced surface heating because of lower solar altitude angles and high reflection due to snow cover allows many inversions to persist into and through the daylight hours. The longest inversions recorded were 54 hours in December at Hannover and 55.5 hours in January at Dickinson. The average duration of inversions was greatest in December, January, and October at both locations (Table 6). It was shortest in spring at Hannover and in summer at Dickinson.

October stands out as a very unusual month because longer inversions are more common than shorter ones. Data in Table 4 show that 50 percent of the October inversions at Hannover were longer than 12 hours. The 9.6-hour October average duration at Hannover was second only to December (Table 6). Apparently, the combination of large high pressure systems with clear skies and low humidity, typically found in October, is conducive to inversions lasting 12-16 hours. The unusual character of October also existed at Dickinson but was not as dramatic (Tables 5 and 6).

Table 4. Average monthly cumulative percent frequency distribution of the duration of inversions, Hannover, N.D., June, 1974-August 1977.

Duration hours	Jan	Feb	Mar	Apr	May	Month Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
2	49	56	48	54	55	57	39	45	40	23	69	33	48
4	57	66	58	68	63	67	55	54	53	29	69	41	58
6	58	76	63	76	72	71	63	62	63	32	69	44	65
8	61	81	67	82	75	78	71	71	71	38	77	50	71
10	67	83	73	86	83	88	83	78	76	41	85	58	78
12	70	86	79	94	97	95	96	87	81	50	93	64	85
14	73	89	86	98	100	100	100	100	100	61	93	70	92
16	78	89	90	98						95	93	73	94
18	83	93	100	100						100	100	87	97
20	90	97										93	97
22	91	97										96	98
24	92	97										100	99
>24	100	100											100
Average dark hrs	15.1	13.7	12.1	10.4	9.0	8.1	8.5	9.8	11.4	13.0	14.6	15.5	

Table 5. Average monthly cumulative percent frequency distribution of the duration of inversions, Dickinson, ND, September 1974-June 1977.

Duration hours	Jan	Feb	Mar	Apr	May	Month Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
2	47	63	44	—	66	46	53	46	59	38	54	36	50
4	57	69	59	—	73	59	69	66	69	52	61	41	61
6	63	75	74	—	80	66	81	76	76	59	65	51	69
8	68	80	87	—	83	79	85	80	80	61	83	58	75
10	75	83	95	—	100	86	89	88	83	67	87	65	82
12	77	83	100	—		95	96	100	95	72	87	67	87
14	79	91				100	100		98	83	91	79	91
16	84	96							100	97	95	81	94
18	90	98								99	100	83	96
20	92	100								100		90	97
22	92	100										95	98
24	92											97	98
>100												100	100
Average dark hrs	15.1	13.7	12.1	10.4	9.0	8.1	8.5	9.8	11.4	13.0	14.6	15.5	

Table 6. Average monthly duration (hr) of inversions at Hannover, N.D., June 1974-August 1977, and Dickinson, N.D., September 1974-June 1977.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
						Hannover						
8.2	5.6	5.5	3.9	4.1	4.0	4.8	5.0	5.4	9.6	4.2	10.4	5.9
						Dickinson						
7.4	4.7	4.1	—	3.1	4.3	3.7	4.0	3.8	6.5	5.3	8.7	5.0

Inversion Intensity

Inversion intensity, defined as the average of the half-hour temperature differences for the entire inversion condition, was consistently greater at Hannover. Average intensities were 2-3°C/100 m at Hannover and only 1-2°C/100 m at Dickinson (Table 7). The lower average intensities and lack of variation at Dickinson probably reflect the greater height of the tower and not an areal difference. Maximum intensitive ranged from 1 to 7°C/100 m at both sites.

At Hannover the average monthly intensity was nearly equal during the spring and summer and increased slightly in winter. However, October's average intensity (3.3°C/100 m) is nearly a degree larger than any other month (Table 7). Since maximum intensitives in October were about the same as other months, this means that most of October's inversions would be more intense. At Dickinson the average October intensity was only slightly higher than the other months.

The data in Tables 8 and 9 indicate that almost invariably the intensity of an inversion increases as its duration increases. The relationship between duration up to 18 hours and intensity at Hannover and Dickinson is illustrated in Figures 4 and 5, respec-

Table 7. Average monthly inversion intensity (°C/100 m) at Hannover June 1974-August 1977 and at Dickinson September 1974-June 1977.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Hannover					
2.6	2.1	2.3	2.2	2.4	2.4	2.3	2.1	2.4	3.3	1.8	2.7
						Dickinson					
1.6	1.5	1.3	—	1.0	1.4	1.3	1.3	1.3	1.7	1.6	1.6

Table 8. Average monthly invensity (°C/100 m) of inversions for indicated durations, Hannover, ND, June 1974-August 1977.

Duration						Month						
hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.5-2	1.6	1.3	1.6	1.6	1.7	1.7	1.5	1.4	1.4	1.3	1.5	1.5
2.5-4	2.1	1.8	2.0	2.1	2.3	2.3	2.0	1.9	2.1	2.8	—	1.8
4.5-6	1.6	2.6	2.4	2.8	2.8	2.3	2.2	2.0	2.2	2.7	—	1.4
6.5-8	2.7	2.0	2.0	2.3	3.5	3.1	2.6	2.9	2.1	3.0	1.7	2.7
8.5-10	2.4	2.5	3.3	2.4	3.3	3.4	3.4	2.5	1.9	1.9	2.4	2.7
10.5-12	3.5	3.3	2.8	4.0	3.5	4.0	3.3	3.6	3.8	3.9	3.3	3.5
12.5-14	2.7	4.3	4.6	3.4	6.1	4.1	2.8	3.4	4.6	3.5	—	3.1
14.5-16	5.1	6.2	3.8	—	—	—	—	—	—	4.5	—	3.9
16.5-18	5.0	5.1	3.6	6.4	—	—	—	—	—	6.3	3.3	3.8
18.5-20	4.5	4.8	—	—	—	—	—	—	—	—	—	3.6
20.5-22	5.3	—	—	—	—	—	—	—	—	—	—	—
22.5-24	5.9	—	—	—	—	—	—	—	—	—	—	5.6
>24	3.7	4.9	—	—	—	—	—	—	—	—	—	4.2

Table 9. Average monthly intensity (°C/100 m) of inversions for indicated durations, Dickinson, ND, September, 1974-June, 1977.

Duration						Month						
hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.5-2.0	0.9	1.0	0.9	—	0.8	1.2	1.0	1.1	0.9	0.9	1.0	0.9
2.5-4.0	1.4	1.2	1.3	—	0.8	1.3	1.2	1.1	0.9	1.2	0.8	0.9
4.5-6.0	1.3	—	1.6	—	1.6	1.2	1.5	1.6	1.5	1.1	1.5	1.6
6.5-8.0	1.5	2.0	1.5	—	1.5	1.7	1.7	1.9	1.8	1.4	2.4	1.2
8.5-10	2.4	2.0	1.3	—	1.5	1.8	1.8	2.0	1.8	3.2	1.4	2.0
10.5-12	2.1	2.0	2.6	—	—	2.0	2.0	1.9	2.2	1.7	—	1.3
12.5-14	2.2	—	—	—	—	1.9	3.2	—	2.9	2.8	6.7	2.0
14.5-16	3.1	2.7	—	—	—	—	—	—	4.2	3.3	1.4	1.5
16.5-18	2.9	3.2	—	—	—	—	—	—	—	2.1	2.3	2.2
18.5-20	3.0	5.2	—	—	—	—	—	—	—	3.2	—	2.9
20.5-22	—	2.9	—	—	—	—	—	—	—	—	—	3.1
22.5-24	—	—	—	—	—	—	—	—	—	—	—	2.0
>24	2.9	—	—	—	—	—	—	—	—	—	2.8	4.2

tively. At Hannover the average intensity increases about 0.2C/hr of duration and the observed range increased also. Inversions lasting longer than 18 hours comprised only about 3 percent of the observations and were most unpredictable. Their intensities were generally less than those for 18-hour durations. At Dickinson the average intensity increased only 0.13C/hr of duration reflecting the lower average intensities found there.

Inversion Index

In order to compare inversion statistics and pollution potential between months, Baker **et al.** (1969) developed a monthly inversion index which consists of the product of average monthly frequency, duration, and intensity. This index is particularly useful for comparing months at a given site, but caution should be used when direct comparisons of different sites are made. Since the temperature gradient changes most rapidly close to the surface, small differences in the height of temperature measurements can cause large differences in measured lapse rates and inversion statistics. This will make valid comparisons between Hannover and Dickinson impossible. The inversion index implies that pollution potential in October, December, and January is four to five times greater than in the period April through August at both sites (Table 10). The November index at Hannover reflects the low average intensity and duration found in that month and little explanation seems possible, unless it was simply normal variation.

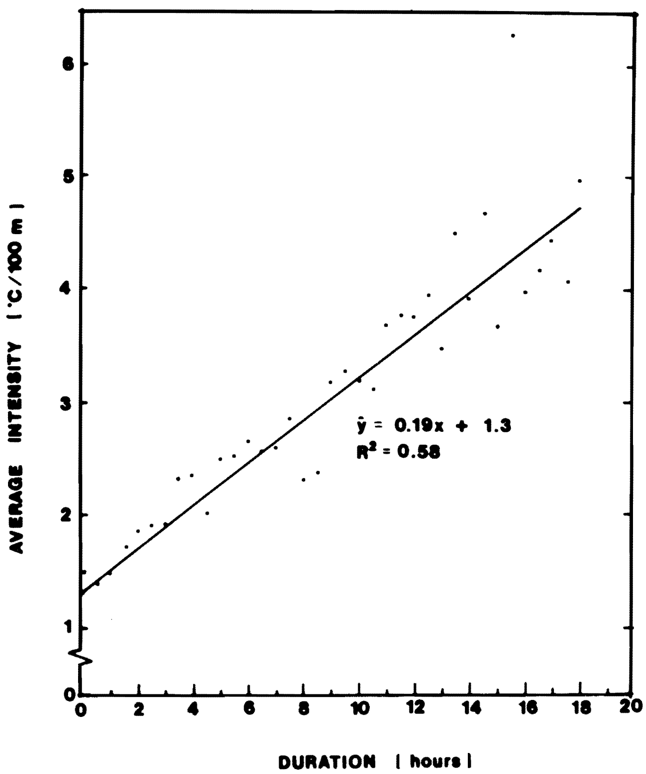

Figure 4. Relation of average inversion intensity and duration at Hannover, N.D., June 1974-August 1974.

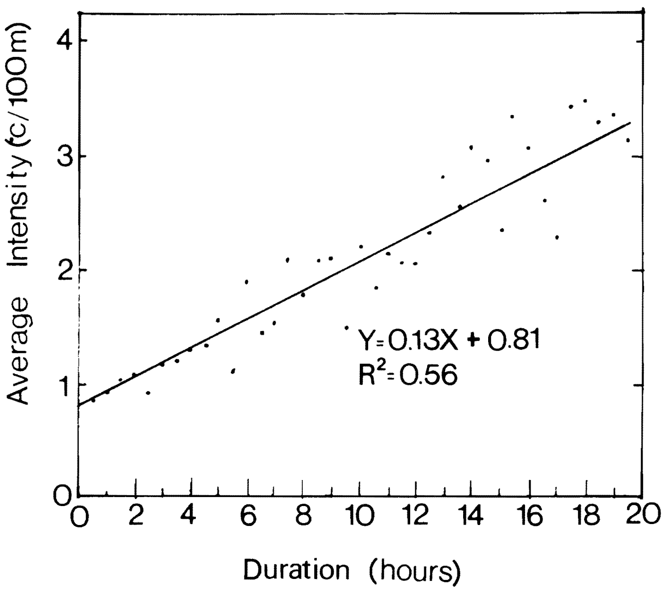

Figure 5. Relation of average inversion intensity and duration at Dickinson, N.D., September, 1974-June, 1977.

Fumigation

As solar heating increases after sunrise, an unstable turbulent layer is formed in the lower part of the inversion. When the eddies of the turbulent unstable layer reach plume height, high concentrations of pollutants may be carried to the ground. Hewson (1945) called this condition fumigation. Fumigation conditions were evaluated using the temperatures at 5, 14, and 35 m heights at Hannover and 20, 55, and 104 m heights at Dickinson as the inversion base levels. The layer below the inversion must have had a superadiabatic lapse rate in order for the event to be classified as a fumigation condition.

Fumigation conditions are more common in winter than other seasons but make up a relatively small proportion of the time (Table 11). On the average, fumigation conditions occur only 1.9 and 3.2 percent of the total inversion time at Hannover and Dickinson, respectively. Time periods with fumigation conditions were most common from 0800 to 1100 CDT in the summer, but in winter they usually occurred from 1300 to 1600 CDT. In addition, individual fumigation events tended to be of short duration. For example, in a 13-month period March 1, 1975 to March 31, 1976 at Dickinson 86 percent of 258 fumigation events had durations of one hour. The longest recorded event was 4.5 hours.

Table 10. Monthly inversion index for Hannover June 1974-August 1977 and Dickinson September 1974-June 1977.

Month	Hannover	Dickinson
January	10.5	5.5
February	5.2	2.4
March	5.1	1.5
April	2.6	—
May	3.0	0.8
June	2.6	1.6
July	3.7	1.5
August	3.6	1.6
September	5.4	1.2
October	11.9	3.5
November	2.5	3.5
December	15.9	6.3

Table 11. Percent frequency of occurrence of fumigation conditions at Hannover and Dickinson

	Percent of Time	
Month	Hannover	Dickinson
January	5.8	5.8
February	1.7	3.0
March	3.0	3.6
April	0.6	—
May	2.1	—
June	1.7	1.6
July	1.6	2.9
August	0.9	0.9
September	0.7	1.9
October	0.9	3.0
November	1.8	1.7
December	1.5	7.2

Conclusions

To develop the climatology of temperature inversions, three inversion characteristics were analyzed for each month. The evaluation of these characteristics — frequency, duration, and intensity — indicates that limited atmospheric mixing is most common during the winter season and during the month of October. In the winter months inversion conditions existed 40 to 50 percent of the time and fumigation conditions were observed 3 to 7 percent of that time. During the rest of the year, inversions were observed only about 25 to 35 percent of the time. The average duration of a winter time inversion was two to three times greater than in summer, but their average intensities were only slightly greater than those from the other seasons. During October, average inversions were nearly as long as they were in winter and were more intense. The average intensity during October was 3.3 C/100 m at Hannover, nearly a degree more than any other month.

An evaluation of the inversion statistics between Hannover and Dickinson shows that inversions were apparently less frequent, less intense, and shorter at Dickinson. However, because of topography and sensor height differences, it is impossible to compare these two sites. Since the temperature gradient changes most rapidly near the surface, small increases in the height of temperature measurements can cause decreases in measured lapse rates. Due to the Dickinson tower's greater height, temperature sensors were higher and further apart. Thus, surface based inversions had to be deeper to be identified. A second problem is the effect of terrain on the inversion statistics. The Dickinson tower is lcoated on a butte that is about 80 meters higher than the surrounding area while the Hannover tower is located on a steep hill that is 30-45 meters above the surrounding area. Perhaps, because of cold air drainage and stratification, these locations make the effective heights of the towers greater. Due to the greater height of the butte, this would affect the Dickinson site more than the Hannover one. It is impossible to quantify the effect these two conditions may have on inversion statistics. However, it is probable that the differences in inversion characteristics found between Dickinson and Hannover are due entirely to topography and sensor height effects and do not represent an areal difference between the two sites.

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