WINTER PRECIPITATION
IN CENTRAL ALASKA

AIR MASSES, FRONTS AND WINTER

PRECIPITATION IN CENTRAL ALASKA

Michael A. Bilello

ABSTRACT

This thesis examines the physical, meteorological and climatological aspects of freezing precipitation in the Tanana River Basin of central Alaska. In addition to studies on frequency and duration, periods of inclement weather were evaluated with respect to concurrent measurements of temperature, wind, pressure and visibility.

Although Polar Continental air masses dominate the area in winter, massive intrusions of Maritime air occasionally produce a major snowstorm and in rare instances rain or freezing rain. Due to the surrounding mountain ranges snow occurs most often when the atmospheric pressure is rising and the winds are from the west. Ice fogs are observed at temperatures below -21°F and very few water droplet type fogs are reported at temperatures below -31°F.

The relationships shown between air masses, fronts and local climatic influences may be usefully applied to forecasting winter precipitation in central Alaska. The statistical survey also, is thought to contribute new knowledge on the conditions of winter weather in this region.

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CHAPTER I

INTRODUCTION

The objective of this thesis is to investigate the occurrence of freezing precipitation in central Alaska and analyse the meteorological factors which produce this phenomenon. The subject is approached and developed within the context of three interrelated fields of study, namely: macrometeorology, cyclonic meteorology, and mesoclimatology. In the present study, macrometeorology is considered as being concerned with the large scale aspects of the atmosphere such as the source and movement of air masses and the general circulation which governs the Alaskan climate in winter. By cyclonic meteorology is meant the consideration of migratory high and low pressure systems of the lower troposphere together with the weather fronts associated with them. Mesoclimatology describes the climate of a small area of the earth's surface which differs from that for the general region. The affects of the local climatic influences, at work with and against the background of the larger scale weather systems, are also included within the mesoclimatic scale.

The Tanana River Basin of central Alaska was the region selected in this study for several reasons. Of major importance is the fact that the Basin is geographically finite because of a series of mountain ranges which bound the region. These mountains also influence the weather so that the climate in the Basin is different from that of the surrounding areas. This condition makes the area suitable for a mesoclimatic study. A cursory examination of winter climatic records from several stations within this rather large Basin showed many similarities; this test thus provided additional justification for choosing the region as one of considerable climatic uniformity. Finally, since a special approach in the analysis of the winter climate was planned, records of hourly weather observations were needed. Detailed information for a station within the Basin was available to the author, thus providing another important reason for selecting the Basin.

In his "Review of Climatology", Landsberg (1957) showed that climatological analyses of weather data are generally provided in certain formats such as tables, graphs, charts and atlases. The most popular approach is to compile 10, 20 or 30 years data of temperature, precipitation, wind speed and direction, cloudiness, etc. and provide separate summaries of mean monthly values for each of these elements, as is done by the U.S.

Department of Commerce (1966). Further refinement of this procedure is to present mean monthly maximum and minimum values or the highest and lowest values observed during the period of record. Typical of such a study is the report on "Extremes of Cold in the United States", conducted by Ludlum (1963). Statistical analysis of long term weather records are also beneficial and have been used extensively. Probabilities, frequency percentages, standard deviations and other statistical techniques give the user numerical values on which to base the chances of a certain event occurring. Thom (1970) gives a good example of this analytical approach to climatology in his mathematical evaluation of an observed series of annual average precipitation for Wisconsin. Almost exclusively though, one finds that in these climatic publications each of the meteorological parameters are examined separately.

An important climatological aspect therefore, seldom considered and thus generally lacking in the literature, is the investigation of two or more meteorological elements which occurred concurrently. It is the latter, little-used approach which has been used in the climatic evaluation of the winter precipitation in this thesis. In addition to statistics on frequency and duration, each weather type is evaluated in combination with other observed elements. For example, wind directions during the time of snowfall were investigated together; and air temperatures during periods of ice fogs were investigated together. This work therefore, is different because ordinary mean monthly climatic data were not used. Instead, original meteorological observations were obtained and analysed by considering concurrent occurrences of climatic conditions.

Further, almost all available climatic summaries base their tabulations on data collected during all of the station's hours of operation, and the resulting statistics combine data for climatic conditions which occurred during periods of both good and inclement weather. Since the main theme of the present thesis is centered on events of winter precipitation, the extracted data and subsequent analysis incorporate only the observations recorded during these specific periods. The study consequently, excludes the environmental conditions which occurred during periods without precipitation.

It is hoped that a climatological survey of this kind in addition to its scientific value, will be of potential applied use in activities such as transportation, communications, construction and other fields of engineering. Knowledge of the frequency and duration of various types of winter precipitation in combination with relevant climatic parameters could be applied, for example, toward the design and construction of buildings and roadways. In his report on glaze, Bennett (1959) provides excerpts of letters from state highway officials showing how this winter phenomenon in combination with certain air temperatures is critical in traffic accidents. Such climatic data hopefully could also be used in the development of anti-icing systems or in the design stages of thermal, chemical and mechanical snow removal equipment. In his survey of snow and ice removal techniques, for example, Minsk (1964) shows how important it is to have climatic information at each site before attempting to purchase expensive equipment. One intention of this thesis is to provide such data so that it could be used for these and for many other such purposes.

Another benefit derived from this thesis are the new insights on the interdependence between the sciences of Meteorology and Climatology. This additional knowledge hopefully will be gained from the investigations between the atmospheric conditions and the resultant winter weather. Such information could be used for long range forecasting and in analogue studies to determine the climate in other areas which are geographically and topographically similar to the one under study. The analysis on storms and the accompanying winter precipitation may also provide useful information to meteorologists concerned with forecasting weather in central Alaska.

Previous Studies

A literature review and examination of weather records such as those published by the U.S. Air Force (1944-1963) show that the interior of Alaska experiences long but light snow seasons, periods of blowing or drifting snow and brief occurrences of rain and freezing rain during the winter. Although the average snow depth in the Alaskan interior is generally shallow, heavy snowfalls such as those referred to by Holmes and Benninghoff (1957) occasionally produce abnormally deep covers of snow. These authors reported that frontal conditions in December 1955 caused two major snowstorms and brought 33 inches of snow, which equalled the total normal annual snowfall. In contrast Vaughn (1966) reports that although rainfall in central Alaska decreases markedly during September and October, in some winters rain may occur as late as December. Extended events of ice fog are also observed in central Alaska; a particularly lengthly event which occurred during December 1946 is described in detail by Oliver and Oliver (1949).

These variations in frequency and types of weather suggest that opposing air masses and changing weather patterns influence this Subarctic region of the Northern Hemisphere during the winter. For example, Robinson and Bell (1956) note that ice fogs are observed when the lower atmosphere is extremely stable. Streten (1969) also notes that these periods of marked stability are associated with the cold Polar air masses which dominate central Alaska in winter. Conversely, Nichols (1953) states that rain, freezing rain and heavy snow in winter are produced by moisture laden fronts which originate in the Bering Sea and Pacific Ocean, cross the coastal mountains, and then penetrate into the interior of the state. In this thesis, all the preceding winter weather conditions are examined statistically and analysed with respect to the atmospheric situations which produced them.

It is evident from the study on properties of the North American air masses by Willett (1938), and from Miller's (1952) study on air mass climatology, that research on air mass types has been quite predominant in climatological work. Prior to 1969, weather analysts would identify the air masses on the daily maps, but now the procedure is omitted (U.S. Dept. of Commerce, 1969-1971). As indicated in a seminar in arctic meteorology (McGill, 1955), classification of air masses and attempts to explain their source and modification, once a popular science, is now discussed less frequently, However, even though modern meteorological methods such as cloud photography by satellites as reported by Ruzecki (1963), and construction of prognostic weather maps by computers (Jorgensen, 1963) are currently in mode, air masses continue to influence the weather. Air masses are included in this thesis because it is believed that major changes in winter weather in central Alaska can be attributed to the replacement of air with contrasting properties.

Cyclonic storms and fronts (cold, warm, etc.) and their association with precipitation, as shown by the many text books on the subject such as Petterssen (1950) and Byers (1959), have received considerable attention. The keen interest in this aspect of meteorology is justified because as shown by George (1960) it is the core of weather map analysis and is of primary importance to the weather forecaster. The location and movement of fronts and storms are the principal objectives strived for in predicting precipitation intensity and duration. It is for these reasons that this particular subject is included in this work.

As noted earlier, it is hoped that the special analysis on the winter precipitation given here would help to solve problems in snow and ice control. Typical of some previous research in these areas are given by McKay and Thompson (1969) and Kuroiwa (1965). In these papers the authors describe the hazards of snow and ice accretion and show how climatic data can be used beneficially. McKay and Thompson provide figures to show the economic and social impact of ice accretion and show how climatological records offer considerable promise in estimating the hazards of the phenomena. Kuroiwa discusses the experiments he conducted on ice and snow accretion on electric wires and antennas, and gives information on the contributing effects of wind and air temperatures. Boyd (1970) further points out the costly damage and disruption to communications brought about by ice storms in Canada and discusses the relationships between snow and ice occurrence and other climatic parameters.

Ohtake and Huffman (1969) report that ice fog causes many traffic and health problems to inhabitants, as well as hampering airport activities because of poor visibility. Drifting and blowing snow will also reduce visibility, and freezing rain can create slippery conditions or as reported by Zavarina and Borisenka (1967) can cause structural failures through excessive loading. It is hoped that the detailed climatological information given in this thesis will be useful to the planners, designers and operational personnel of central Alaska, and that the combining of weather elements in the computations will offer new and helpful answers to their problems.

CHAPTER II

THE CENTRAL ALASKA REGION

The principles followed in selecting the area of study were based on practical considerations such as size, location, available data, and manageability in regard to achieving the objectives of the thesis. The area had to be large enough to permit identification of passing fronts and air masses, yet small enough to be positively identified geographically and exhibit a climate different from that of its surrounding areas. The area had to be located in the Subarctic and experience various forms of winter precipitation. Detailed weather information in the area selected was also required in order to conduct the special climatological study. Finally, the area chosen had to show the affects of local climatic influences and yet be of such a size as to make a concurrent investigation of the larger scale weather systems manageable.

Suitability of Selected Study Area

Examination of a relief map of Alaska (U.S. Dept. of Interior, 1954) shows an extensive basin in the interior of the state. This basin (Fig. 1)* is bounded on the south by the Alaska Range, the Kuskokwim mountains on the west

*See Appendix A for all figures.

and a combination of the Ray and White mountains to the north and east. It contains portions of several rivers and their tributaries including western Tanana, central Yukon and the eastern part of the Kuskokwim River. The size and location of this Basin as well as the fact that it can be easily identified geographically made it suitable for use in this study. The Basin is large enough to permit the identification and tracking of fronts and air masses and sufficiently small to display uniform synoptic weather conditions and similar climate. Its Subarctic location also satisfied the requirement for occurrences of inclement winter weather.

Another key point strived for in delineating the zone shown in Figure 1 was to establish an association between winter precipitation observed at one site within the region with that for the region as a whole. Naturally, such an analogy is not perfectly valid and some variations can be expected to occur between points and seasons. The region under study though was purposely limited in size in order to keep these variations to a minimum. Significant precipitation anomalies probably exist when individual winter storms are considered, but differences throughout the region diminish when long term records, i.e., climatic data are used.

The climate at eight stations located throughout this basin is quite similar (Tables Ia, Ib and Ic). Three climatic parameters; mean monthly temperatures, total monthly precipitation and total snowfall, were used in the comparison. The data were taken from the decennial census of U.S. Climate 1951 through 1960 (U.S. Dept. of Commerce, 1964). Some differences in values between stations were noted, for example, colder temperatures at Galena than at Farewell FAA, and greater precipitation amounts at Manley Hot Springs than at Fairbanks. However, the bulk of the data are sufficiently uniform to indicate that the stations are climatically alike.

Data Availability in the Central Alaskan Region

Selection of the geographical region considered in this study was also based on the availability of detailed weather observations. Continuous hourly weather records were required because information on all forms of winter precipitation had to be extracted for the study. Published climatic data are generally in the form of monthly summaries, and funds to obtain long-term, hourly data through magnetic tape or punched card retrieval methods were not available.

TABLE Ia

Climatic Comparison of Interior Basin Stations

Mean Temperature (^{o}F)

Station	Elev(ft)	J	F	M	A	M	J	J	A	S	O	N	D	Ann
Big Delta FAA	1268	-6	2	10	31	47	58	60	56	43	24	10	-4	27
Galena	120	-13	-8	6	25	45	58	59	55	43	24	6	-14	24
Tanana FAA	232	-12	-7	4	25	45	57	58	54	41	22	-2	-12	23
Fairbanks WBAP	436	-11	-3	9	28	48	58	60	55	44	26	3	-9	26
Farewell FAA	1499	-3	2	9	26	42	52	55	51	40	23	10	-3	25
Lake Minchumina FAA	701	-7	-2	9	28	46	58	59	55	43	24	6	-7	26
Manley Hot Springs	325	-10	-4	7	27	45	57	59	53	42	25	2	-10	24
Nenana FAA	356	-10	-4	5	27	46	57	58	54	42	23	5	-9	25

TABLE Ib

Climatic Comparison of Interior Basin Stations

Total Precipitation (inches)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Ann
Big Delta FAA	.37	.41	.25	.12	1.01	2.22	2.20	1.93	1.32	.62	.36	.52	11.23
Galena	.61	.86	.57	.28	.63	.97	2.11	2.61	1.71	.64	.87	.50	12.36
Tanana FAA	.63	.64	.50	.14	.75	1.21	1.98	2.80	1.75	.73	.58	.63	12.34
Fairbanks WBAP	.63	.51	.28	.12	.58	1.38	1.81	1.56	1.39	.62	.41	.58	9.87
Farewell FAA	.55	.73	.46	.39	.97	2.16	3.24	3.75	2.01	.87	.65	.50	16.24
Lake Minchumina FAA	.65	.63	.36	.25	.75	1.49	2.15	2.80	1.37	.54	.58	.45	12.02
Manley Hot Springs	.79	.73	.58	.16	.52	1.41	2.48	3.45	1.84	.65	.61	.78	14.00
Nenana FAA	.70	.67	.26	.15	.62	1.45	1.87	1.94	1.57	.56	.49	.46	10.74

TABLE Ic

Climatic Comparison of Interior Basin Stations

Total Snowfall (inches)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Ann
Big Delta FAA	5.4	5.3	3.9	1.3	1.4	T	0	0	2.0	7.2	4.6	6.2	37.3
Galena	6.3	9.0	6.5	2.3	0.7	T	0	0	0.6	6.6	9.0	5.7	46.7
Tanana FAA	7.7	7.8	10.0	1.2	0.1	T	0	T	1.1	7.2	7.4	9.7	52.2
Fairbanks WBAP	12.0	9.5	5.0	1.7	0.4	T	T	T	0.8	7.5	8.7	9.3	54.9
Farewell FAA	7.0	10.8	6.9	5.8	1.4	T	T	T	1.9	9.8	9.4	8.0	61.0
Lake Minchumina FAA	8.9	9.4	5.5	2.6	0.3	T	0	0	1.3	4.9	8.7	7.2	48.8
Manley Hot Springs	9.9	8.9	7.5	1.7	0.4	T	0	T	0.8	6.1	9.2	9.5	54.0
Nenana FAA	8.5	8.5	3.5	1.4	0.2	T	0	T	0.9	5.9	7.0	6.4	42.3

Fortunately, it was feasible to obtain original weather records for an extended period of time at Big Delta Airport through the U.S. Army Meteorological Support Team at Fort Greely in central Alaska (Fig. 1). This free access to basic data included eleven years of hourly observations on all winter precipitation types as well as concurrent measurements of the various elements such as air temperature, wind direction and visibility.

General Winter Climatic Conditions

The central Alaskan region under study can be identified in a physical sense with the Tanana River Basin. It is a large area covering approximately 50,000 square miles and surrounded by uplands rising to over 20,000 feet (Mt. McKinley) toward its steepest slope to the south, and to heights of 4,000 to 6,000 feet to the east, north and west. These uplands tend to aid the drainage or settling of cold air into the Tanana and Yukon River lowlands (U.S. Dept. of Commerce, 1970). This fact, is substantiated through close examination of the data in Table Ia. The average temperature for December, January and February combined for the 8 stations in the Tanana River Valley (Table Ia) was plotted versus station elevation (Fig. 2). The figure clearly shows that stations at lower elevations experience colder temperatures in winter than those which are higher up. The average increase in temperature is about 0.75°F for every 100 feet increase in elevation for the 3 months. When the data for December, January and February in Fig. 2 are considered separately, one finds that the temperature gradient lines fall on either side of the average line but still maintain similar slopes. These results contribute to the premise that these stations are meteorologically situated within the same basin. In a study on surface inversions at Fairbanks, Alaska the average temperature increase with height above the station for the same three mid-winter months was found to be 1.3°F per 100 feet (Bilello, 1966). Comparing this gradient with that shown in Fig. 2 indicates that in mid-winter the stations in the basin experience surface heat losses both by radiational cooling and cold air drainage (Wexler, 1936).

The total annual precipitation amount observed in the basin is,relatively light (Blair, 1949). Rain showers begin in May and build to a maximum during June, July and August. There is a noticeable decline in precipitation starting in September when the snow season starts. Snow and other forms of frozen precipitation then continues through April with lighter amounts occurring during May (Table Ia). Ice fog and smoke is frequently observed with extreme low temperatures during anticylonic weather. These conditions tend to persist for periods of a few days to one or two weeks and wind speeds are particularly light at these times (U. S. Dept. of Commerce, 1970).

In the western part of the basin in the vicinity of Galena, Alaska, the terrain is quite flat. The maximum elevation within 50 miles of this station is 1000 feet and there are numerous rivers, streams, lakes and ponds in the area. The low ranges of hills in various directions may inhibit advected cloudiness below 1000 feet. But when the clouds are that low, minor changes brought about by radiation, convergence or precipitatinn can alter the heights of the clouds. When the winds are west to northwest in this area, the Nulato Hills offer some protection up to 2000 feet. However, cloudiness that forms in the interior valleys and low ceilings associated with precipitation can move into the area from most directions. Ice fog conditions at Galena are similar to those observed in the Fairbanks area and only seldom do winds present a problem in the western part of the basin.

That part of the basin where the climate is studied in greatest detail for the purposes of this thesis is identified by Big Delta Airport (Fort Greely), Alaska. The station is located near the junction of the Delta and Tanana Rivers in central subarctic Alaska at about

$64^{\circ}00'$N latitude and $145^{\circ}45'$ W longitude (Fig. 1). The surrounding terrain slopes upward from an elevation of about 1,000 feet at the Tanana flood plains in the north to 1,700 feet in the glacial moraine near the foothills of the Alaska Range in the south. Like the other stations of the central Alaskan region, Fort Greely is well sheltered from maritime influence by the mountain ranges on all but the southwest. The area, consequently, experiences a continental climate, conditioned in large measures by the variations in solar heat from the summer to winter. The sun is above the horizon from 18 to 21 hours in June and July but only from 4 to 6 hours in mid winter. Consequently, minimum temperature readings normally fall below zero quite regularly and extremes of near or below -60°F are observed in the three mid-winter months.

Winds at Big Delta during January and February occasionally become quite strong, exceeding 24 mile per hour on about 20 percent of the observations (de Percin, et al, 1955). These strong east-southeast winds, blow down the Tanana Valley, and occur when there is a strong pressure gradient north-south across the Basin. Constriction of the valley near Fort Greely by the Alaska Range and the Yukon-Tanana Upland creates a venturi which accelerates the wind speed (Holmes and Benninghoff, 1957). A similar funneling effect through a gap between the Brooks Range and the Richardson Mountains also is the apparent cause for strong southerly winds near Barter Island on the north-east coast of Alaska (Dickey, 1961). The winds in the Tanana Basin often pass to the sauth of Fairbanks and may continue westward to as far as Nenana (Mitchell, 1955).

The preceding discussion on the general winter weather and climate in the interior Basin and at Fort Greely, Alaska therefore, portrays the local orographic effects and large scale atmospheric influences. This thesis will develop this theme and investigate the processes and results in detail.

CHAPTER III

WINTER AIR MASSES AND FRONTS

An air mass is defined as a widespread body of air that is approximately homogeneous in its horizontal extent, particularly with reference to temperature and moisture distribution (Huschke, 1959). According to Petterssen (1969), "widespread" means a horizontal extent of a thousand miles or more, and "approximately homogeneous" means that the changes over a distance of about 100 miles within the mass are very much smaller than the changes experienced through the border between two adjacent masses, i.e., the frontal zone. Petterssen notes further that because the conductive capacity of air is large, a high degree of adaptation exists between the underlying surface and deep columns of air. Persistent circulation of air around major wind systems will, consequently, gradually acquire the physical properties of the underlying surface. The sub-tropical and the polar continental high pressure zones are examples of regions where these air masses are produced (Hare and Orvig, 1958).

Northern Hemisphere Sources

In the northern hemisphere, the great land masses of Eurasia and North America, are typical areas where large semi-permanent high pressure zones are formed (Fig. 3). These are primary source regions of air masses because during winter they are characterized by uniform surface conditions and distribution of insolation. In these regions the winds are generally light so that the air, in contact with the earth's surface for a long time, becomes cold and dry. The general structure of temperature and moisture in a polar continental and arctic air mass is shown in Figure 4. Petterssen (1969) explains that since sunshine is either absent or sparse, and since the snow cover is a good radiator, any air that invades these regions cools rapidly through outgoing long-wave radiation from the ground. The result is a vertical temperature structure with lower temperatures at the ground and temperatures increasing upward to maximum values at altitudes between 3,000 and 5,000 feet ($\approx$ between 900 and 850 millibars). In these so called "temperature inversion layers", atmospheric heat is conducted downward, and the temperature at the ground evolves as a balance between loss of heat upward through radiation, and gain downward through conduction. The distribution of moisture along the vertical (Fig. 4) shows a similar trend, indicating that the air surrenders water vapor to the ground.

In contrast to this arctic and continental polar air is the sub polar maritime air mass which occasionally affects central Alaska in winter. Where as the arctic and continental polar air is cold and dry and extends to great heights, the subpolar maritime air by contrast is warmer and exhibits high moisture content in at least its lower levels. The local source region for this subpolar maritime air mass is the eastern portion of the north Pacific Ocean low-pressure area usually referred to as the Aleutian Low. The mean wind flow in the region is mainly along the sea-surface isotherms, and when the actual air current takes on the same characteristics as the ocean surface, a typical maritime polar air mass develops. The air thus becomes relatively mild and laden with moisture, and when it moves inland there is a strong tendency for the land surface to adapt itself to the temperature of the invading air (Bryson, 1966).

Air Masses Affecting Alaska

In accordance with Bergeron's general classification, the air masses which principally influence the region under study are: continental polar winter (cPW) and maritime polar winter (mPW) (Willett, 1938). Petterssen (1969) introduces a transitional zone which, in Alaska, is a region that separates cPW and mPW air. He notes that this is a region of extremely rapid air-mass transformation, in which heat and moisture are taken up at tremendous rates. The warming from below steepens the lapse rate and increases the mobility of the air along the vertical, so that heat and moisture are brought up to great heights. Under certain synoptic conditions, such as a large active occluded front moving rapidly northward from the Pacific Ocean onto the southern coast of Alaska, this transfer of heat and moisture can be accelerated. The forced upward movement of the ocean air induced by the mountains and the storm's strong horizontal pressure gradient can lift the advancing air over major mountain barriers such as the Alaska Range and produce storminess in the interior.

The arctic front is a semi-permanent, semi-continuous front located between the deep, cold arctic air and the shallower, basically less cold polar air of northern latitudes. Holmes and Benninghoff (1957) note that in winter the arctic front usually lies south of Fort Greely, separating the cold polar continental air of interior Alaska from maritime air in the Gulf of Alaska (mPW). They further point out that this front will dissipate when relatively warm Chinook type surface winds start to blow from the south over the Alaska Range or when warm air moving aloft over Fort Greely transmits heat to the surface by radiation. The effect of the last situation is enhanched when a cloud layer separates the warm air aloft from the air beneath the cloud deck. The result of these air movements is a temperature pattern that is marked by frequent changes, some extreme, especially during the coldest part of the winter (de Percin, 1960). These warm maritime intrusions of air also cause occasional periods of storminess and accumulation of snowfall in the Alaskan interior. Further discussion on the frequency and duration of these storms in this region will be given in a later section.

Air Mass Modifications and Resulting Weather

Since these contrasting winter air masses occasionally replace each other it is worthwhile to note what, if any, modifications of the cPW and mPW air takes place in winter, and show how these changes may affect the region under study. The cPW air mass, as noted earlier, originates over snow and ice covered regions extending from the interior of Canada northwestward over Alaska and northward into the Arctic Basin. The Tanana River Valley of Alaska therefore is part of the source region for cPW air. Since only minor modifications of this air occur at its source one could expect marked stability through the lower 5,000 feet, with rather large temperature inversions (Bell and Robinson, 1954). Precipitation under these conditions is generally absent, except that radiational cooling of the lower strata may lead to the local formation of ice crystals and ice fog at very low temperatures.

Initially, mPW air comes from an arctic source region. However, prolonged heating and moistening over the warm waters of the north Pacific Ocean changes it from a cold, dry stable condition to one of marked conditional instability with comparatively high moisture content in the lower strata. When a strong persistent southerly flow of air moves from the Pacific into the interior of Alaska (Kendrew, 1961) the mPW air is modified in crossing the Alaska range in the following ways:

1) Much of the moisture contained in the lower strata condenses and precipitates through orographic lift and the heat of condensation is supplied to the air mass strata at higher levels.

2) Descent of the air on the northern slope of the Alaska Range dissipates the cloud deck and the heat of condensation and adiabatic compression cause a marked warming of the air mass.

3) The warming of the surface strata is checked by radiational and contact cooling over the cold continental surface and by mixing with remnants of cPW air. This mixing would account for the periods of major winter precipitation in central Alaska.

Winter Fronts

In meteorology, the term "front" defines the transition zone between two air masses of different density. Since temperature characteristics are the most important regulators of atmospheric density, a front accordingly separates air masses of different temperature. Beside density and temperature, many other features may indicate the presence of a front: a pressure trough, a change in wind direction, a moisture discontinuity, and certain characteristic cloud and precipitation forms are all used to define the interface between two contrasting air masses (Huschke, 1959).

A classification and description of the various types of fronts which influence the region under study in winter follows: a) the arctic front: a semi-permanent, semi-continuous front between the deep, cold arctic air and the shallower, basically less cold polar air of northern latitudes; b) the cold front: a non-occluded front that moves so that colder air replaces warmer air; c) the warm front: a non-occluded front, which moves so that warmer air replaces colder air; and d) an occluded front: a composite of two fronts, formed when a cold front overtakes a warm front or stationary front (Berry, et al, 1945).

Frequency and Movement

The frequency and trajectories of fronts are generally associated with low pressure centers and the paths that these cyclonic systems take. Examination of mean tracks of such low pressure centers observed from 1944 through 1951 for October through December (Fig. 5a) and for January through March (Fig. 5b) indicates that cyclonic vortices seldom pass through interior Alaska in winter. A chart showing the normal sea-level pressure for January in and around Alaska, supports this statement (Fig. 6). Figure 6 shows the dominance of the Aleutian Low pressure center southwest of Alaska and the presence of a small high pressure center in the Canadian Yukon and east central part of Alaska. The strongest pressure gradient is generally west to east along southern Alaska and the low pressure tracks presented in Figs. 5a and 5b show that most storms move across southern Alaska. These studies on locatinn and movement of storm tracks imply that weather fronts are not commonly observed in central Alaska in winter. Howevar, the examination of a series of daily synoptic weather maps for this area revealed that such was not the case.

The maps used comprised the daily series of synoptic weather maps for the northern hemisphere for the period 1957-67 (U.S. Dept. of Commerce, 1957-1967). Examples of some of these weather maps showing the passage of various fronts through central Alaska are presented in Figures 7a to 7d. Four years, selected at random from within the period of record, were used in the analysis. Two tabulations were made: 1) a count of the types of fronts observed to pass across central Alaska from October through April; and 2) a summary of the direction in which these fronts moved. The results are shown in Tables IIa, IIb and III. In table IIa seven types of fronts are listed, four of these: cold, warm, the occluded front (or an occlusion, Huschke, 1959), and the stationary front (the latter one is essentially the Arctic Front) have been defined earlier. The remaining three are the dissipating cold front, dissipating occlusion and dissipating stationary front. The prefix "dissipating" refers to the breaking down of a frontal system. In meteorology this process is called frontolysis. This break down of the frontal zone in general, decreases the horizontal gradient of an air mass property, principally density, and disintegrates the accompanying features of the wind field (Huschke, 1959). The values in Table IIa show that occlusions are the most frequent type of front to cross central Alaska in winter. During an average season between October and April a total of 67 fronts are observed, 23 of these are non-dissipating occlusions and 16 are dissipating occlusions. The second most frequent

TABLE IIa

Frequency of Types of Fronts in Central Alaska, October through April

Type	Frequency (Ave. #)
Warm Front	3
Cold Front	3
Occlusion	23
Stationary Front	19
Dissipating Cold Front	1
Dissipating Occlusion	16
Dissipating Stationary	2
Average Total	67 (Oct through April)

TABLE IIb

Monthly Distribution of Fronts, in Central Alaska

Period of Record: Four Random Years Between October 1957 through April 1968

	Oct	Nov	Dec	Jan	Feb	Mar	Arp
Average	13	8	9	8	8	8	13
Average Minimum	12	3	5	5	3	2	9
Average Maximum	14	12	12	11	12	13	15

TABLE III

Directions of Weather Front Movements

(Frequency in %)

Type of Front	South to North	Southwest to Northeast	West to East	Northwest to Southeast	North to South	Northeast to Southwest	Southeast to Northwest
Warm Front	3	4					
Cold Front				4	3	1	
Occlusion	16	16	12	4			0.5
Dissipating Occlusion	18	7	7	1	1		0.5
Dissipating Cold Front				1		1	
TOTALS (%)	37	27	19	10	4	2	1

type of system observed is the stationary (or Arctic) front. On the average, 21 of these stationary fronts are observed per winter, of which some are in the process of breaking up. Well defined cold and warm fronts pass rather infrequently through central Alaska in winter, the survey showing that on the average only 3 or 4 of such fronts occur in the area between October and April (Reed, 1958).

Results of a survey on the number of fronts observed to pass through central Alaska monthly, during a random period of record between October 1957 through 1968, are presented in Table IIb. All the type fronts listed in Table IIa were considered in the survey and three categories of frequency are shown in Table IIb. These are, the average number, the average minimum number, and the maximum number of fronts that pass through the area each month. The results in Table IIb show that frontal activity in the area is uniform from October through March. The average number of observed fronts is about 8 or 9 per month during this period and the average minimum ranges from 2 to 5, and the average maximum number from 11 to 13. The number of observed frontal passages during October and April is decidedly higher than the number observed during the other winter months. The monthly average for these two months is 13 and the survey showed that the average minimum and maximum count for these months ranged from a low of 9 for minimum values to a high of 15 for maximum values.

An examination of the direction in which these fronts move as they cross the region was also included in the survey of daily conditions. Each frontal type, except the stationary ones, observed from October through April during the period of record was considered in the evaluation. The results are given in Table III. Directions are expressed according to an eight point compass and probable occurrence is given in frequency percentages.. The most prevalent front, the occlusion, enters central Alaska predominantly from the south, southwest or west. Warm fronts enter from the south or southwest, and cold fronts between the northwest and northeast quadrants. However, as noted earlier, these two types of front do not occur frequently in the State's interior. The survey also shows that very few, if any, fronts enter the central part of Alaska from between the northeast to southeast quadrant. It is interesting to note that when comparing the two types of occlusions, more of the dissipating type are observed when the systems enter interior Alaska from the south then from the other directions. The fact that the mountains of the Alaska Range are much higher than the mountains to the west and north of the central basin would appear to account for this phenomenon.

Effects of Location

The position of the stationary (or Arctic) front at any given time, as well as the place where it will form, depends upon the wind circulation. The prevailing upper winds (700 mb) over Alaska in winter are generally southwesterly (Dorsey, 1951). The Arctic front therefore would be expected to develop north of its normal position, which in mid winter is generally just to the south of Alaska. How great the northern displacement of this front becomes will depend on several factors, the principal one being the strength of the winds aloft. The air mass north of the front is very stable in the lower levels and consequently the cold air will remain stationary within the confines of the rugged terrain. Once the Arctic Front has moved against the major mountain range, only a vigorous circulation aloft can cause it to move further. With moderate southerly winds, maritime air moves quite freely into the Cook Inlet-Susitna Valley area, and less easily into the Copper River Valley (Fig. 1), and the front then has a tendency to become stationary along the Alaska Range. This location along the Alaska Range is the most common position for the Arctic front in early winter and spring. Strong southwesterly winds however, will occasionally force the front up the Koskokwim and Naskagak valleys (Fig. 1). At this point there is no definite physical barrier to impede further movement of the front so that it can now readily penetrate to the interior of the State and influence the weather accordingly. Nevertheless, exactly how far inland the front moves is dependent almost entirely upon the strength and persistence of the steering level winds.

After the Arctic front has been moved well inland, it may return to a more southerly location by two means; by movement, or by dissipation and redevelopment. In the first case (southward movement) the cause of the shift is usually an intense storm moving into the Gulf of Alaska. The circulation about the storm causes northerly winds over the interior of Alaska, and this usually leads to a rapid southward movement of extremely cold air. In the second case (redevelopment) the warm air to the south of the front becomes stationary over the snow covered land thus by contact with the cold surface, and by radiational heat loss the warm air begins to cool, with the result that the air in the Alaskan interior again begins to acquire the characteristics of an Arctic air mass.

Results of Fronts

Unpublished literature available from the U.S. Air Force-Air Weather Service, on rules for forecasting in interior Alaska, present opposing viewpoints on the effect that fronts have on producing winter weather. Some forecasters insist that due to blocking, genuine fronts which can be followed from map to map are infrequent, so other explanations, such as the affects of convergence due to the mountains, are given for the weather that occurs. Most forecasters, however, agree that the flow of air into the area from the southwest and west is mostly unimpeded and that air from this direction is most likely to produce precipitation. With the north Pacific Ocean and the Bering Sea as moisture sources, such winds are very moist and mechanical convergence alone is sufficient to account for the winter precipitation.

Forecasters note that intense storms which move through the Bering Sea to the west coast of Alaska are preceded by strong southerly winds over central and western Alaska. The air flowing down the north slopes of the Alaska Range will then be warm and dry below about 10 to 12 thousand feet. Under this circumstance the occluded front is preceded by some cloudiness but little or no precipitation, but moisture brought in subsequent to the passage of the front causes considerable snow to fall. This is an unusual weather situation which will be discussed further in a later section. Light to moderate snow will also occur for one to three hours following the passage of either a surface cold front or a cold trough aloft which moves onto the west or northwest coast of Alaska from the Bering Sea and Siberia. The duration of snowfall under these conditions is quite variable and depends largely upon the movement of the system. Snowfall rates and amounts are generally dependent upon the quantity of moisture available in the atmosphere between the 850 and 500 millibar levels (U. S. Air Force, 1969).

In the case when the Arctic front redevelops just north of the Alaska Range, condensation often takes place in the interior. Some of the moisture falls out as light snow or ice crystals and some is deposited as frost. Gradually though, small areas of clearing appear, usually over high ground at first, and radiation, particularly at night becomes more intense, resulting in a more rapid loss in heat. In time the entire mass of intruded warm moist air is transformed into cold dry Arctic air, and the Arctic front in the interior is destroyed. Typical weather during the period of transformation of the air mass is quite local as one small region after another clears, and the clouds and precipitation areas drift more or less aimlessly. The process can of course be interrupted at any time by the intrusion of either warm or cold air.

CHAPTER IV

CLIMATIC DATA

Source Material

The hourly weather records used in this study were recorded at the airport station at Big Dēlta (Fort Greely), Alaska. Data for October 1957 through April 1968 were extracted from the Weather Bureau, Army, Navy Form WBAN-10 used by the U. S. Department of Commerce (1957-1968). A copy of an original form WBAN-10 showing the weather recorded at Big Delta on 9 November 1964 is presented in Figure 8. This form gives detailed hourly observation of all weather elements including the varioas types of precipitation and other obstructions to vision such as fog and blowing snow.

Climatic analysis is usually based on summaries of daily observations such as those given for temperature and precipitation in Figure 8. Compilations from these types of summaries are used in the climatic information available in the literature. As discussed in the introduction, this common approach to climatic statistics was not used in this thesis. Instead, only the periods of precipitation were analyzed and the data were examined in combination with other weather elements which occurred concurrently. For example, all precipitation events reported during November 1964 at Big Delta are listed in Table IVa. The particular type of precipitation and a summary of the accompanying weather observed on each day in the month (Table IVa) was taken from the record given in Form WBAN-10. An example of the procedure followed, can be obtained by noting the values given on 9 November 1964 in Table IVa with the observations recorded on this date in Figure 8.

In Table IVa note that the information on light snow (s- and s--) on 9 November as well as the single occurrence of ice crystals was taken directly from Figure 8. A summary of concurrent temperature, wind and visibility measurements observed during this precipitation period on 9 November were also transcribed on Table IVa. These data extraction procedures then, were followed for the entire month, thus providing a continuous account of the precipitation history at the station. Since only periods of inclement weather were used in this study, the statistical results provide an insight into the climatic conditions which exist during such specific times. An insight of this kind is not readily available in the literature because all meteorological measurements taken at a station are generally included in published climatic summaries without any grouping in terms of distinctive weather types.

TABLE IVa

INCLEMENT WEATHER SUMMARY,

Big Delta, Alaska, November 1964

DATE	WEATHER TYPE	DURATION (hr)	TEMP (°F) Max	TEMP (°F) Min	AMOUNT (inches)	WIND Direction	WIND Speed (kts)	VISIBILITY (miles)
5 and 6	light snow	19	20	15	.10	SW	4 to 9	1 to 10
6	fog	4	20	16	---	SW	4 to 7	1 to 2
7	light snow	2	12	11	Trace	SW	5	10
9	light snow	12	11	1	.03	W	0 to 11	2 to 15
9	ice crystals	1	-2	-2	---	SW	3	15 +
10	light snow	19	7	-5	Trace	Calm	0	7 to 15
10	fog	3	-3	-5	---	Calm	0	1/8
11 and 12	light snow	29	6	3	.02	W	0 to 10	5 to 15
13	blowing snow	3	18	15	---	SE	30	10
14	light rain & snow	1	35	32	Trace	SW	8	7
18	ice pellets	1	32	32	Trace	W	6	10
18 to 20	light snow	36	31	18	.82	W	0 to 8	1/2 to 4
19	fog	11	30	22	---	W	5 to 8	1/2 to 1
21 and 22	light snow	36	20	9	.05	W	4 to 9	2 to 10
23	light snow	8	5	2	Trace	W	0 to 7	5 to 10
24 and 25	light snow	20	11	1	.10	W	0 to 12	3/4 to 5
24	fog	5	6	5	---	W	5 to 7	3/4 to 2
26 to 28	ice fog	31	-27	-44	---	Calm	0	1/4 to 6
28	drifting snow	10	-13	-14	---	SE	15-32	7 to 18
29 and 30	blowing snow	48	-10	-14	---	SE	25-50	7 to 15

Precipitation Types and Descriptions

Included in the weather data extracted from Form WBAN-10 were the following types of precipitation: snowfall (including heavy - moderate and light snow, snow showers, and snow grains); drifting and/or blowing snow; rain and/or drizzle; freezing rain and/or freezing drizzle; fog and/or ground fog; and ice fog and/or ice crystals when observed in the lower atmosphere. In addition, the following meteorological elements occurring during the precipitation period were included in the tabulation: air temperatnre, wind speed and direction, visibility, amount of precipitation and duration of the storm.

A brief description based on Huschke (1959) of some of the above types of weather follows:

1. Drifting Snow. Snow raised from the surface of the earth by the wind to a height of less than six feet above the surface. Drifting snow is not regarded as an obstruction to vision.

2. Blowing Snow. Snow lifted from the surface of the earth by the wind to a height of six feet or more above the surface and blown about in such quantities that horizontal visibility is restricted at and above the height.

3. Freezing Rain. Rain that falls in liquid form but freezes upon impact to form a coating of glaze upon the ground and on exposed objects. While the temperature

of the ground surface and glazed objects initially must be near or below freezing ($32^{\circ}F$), it is necessary that the water drops be supercooled before striking. Freezing rain frequently occurs, therefore, as a transient condition between the occurrence of rain and ice pellets (sleet).

4. Ice Fog. A type of fog composed of suspended particles of ice, partly ice crystals 20 to 100 microns in diameter, but chiefly, especially when dense, tiny particles 12 to 20 microns in diameter. It occurs at very low temperatures, and usually in clear, calm weather in high latitudes. Ice fog is rare at temperatures warmer than $-20^{\circ}F$, and increases in frequency with decreasing temperatures until it is almost always present at air temperatures of $-50^{\circ}F$ in the vicinity of a source of water vapor.

5. Ice Crystals. A type of precipitation composed of slowly falling, very small unbranched crystals of ice which often seem to float in the air. Ice crystals may fall from a cloud or from a cloudless sky. They are visible only in direct sunlight or in an artificial light beam, and do not appreciably reduce visibility. The latter quality helps to distinguish this type of precipitation from ice fog.

6. Snow Grains. Precipitation in the form of very small, white opaque particles of ice. They resemble snow

pellets in external appearance, but are more flattened and elongated, and generally have diameters of less than 1 mm; they neither shatter nor bounce when they hit a hard surface.

Data Reduction Procedures

The following discussion is given in order to show more clearly what was done with the data after they were extracted from Form WBAN-10 and listed in tables IVa and IVb. The example which follows is for the daily weather observed at Big Delta airport during January, 1958 (Table IVb). In this month, light snow was observed on 8 days, drifting or blowing snow on 5 days, ice crystals on 2 days, freezing drizzle on 1 day and fog on 3 days. The total numbers of hours for each of these weather types observed during the month were 121, 48, 17, 2, and 5 hours respectively. The latter summations were those used in most of the analyses conducted in this study. Note that during any one day more than one weather type may occur; for example, on 3 January 1958 both light snow and fog were observed. Occasionally different types of weather may occur at the same time or may follow one another as during 8-10 January 1958.

The concurrent meteorological elements mentioned earlier were then tabulated with each weather category.

TABLE IVb

INCLEMENT WEATHER SUMMARY,

Big Delta, Alaska, January 1958

DATE	WEATHER TYPE	DURATION (hr)	TEMP (°F) Max	TEMP (°F) Min	AMOUNT (inches)	WIND Direction	WIND Speed (kts)	VISIBILITY (miles)
1	light snow	2	-11	-12	Trace	W	3 to 5	7 to 10
2	drifting snow	12	16	11	---	SE	15 to 20	15 +
3	fog	2	-5	-7	---	Calm	0	4
3	light snow	9	-1	-11	.02	W	2 to 10	4 to 7
5 and 6	drifting snow	14	31	17	---	E	22 to 30	15+
6	blowing snow	3	22	18	---	SE	30 to 35	10 to 15
7	freezing drizzle	2	34	20	.02	W	8	10
7 and 8	fog	3	20	9	---	W	0 to 7	5
8 to 10	light snow	54	13	-1	.21	NW	0 to 9	1 to 10
11	light snow	4	-5	-13	Trace	SW	4	12
11 and 12	ice crystals	17	-25	-31	---	Calm	0	15 +
14 and 15	drifting snow	19	-7	-17	---	SE	14 to 28	15 +
16 and 17	light snow	10	-1	-3	Trace	Calm	0	5 to 15
16 and 17	light snow	10	-1	-3	---	NE	5	2 to 10
20	light snow	12	4	-10	Trace	E	0 to 6	3 to 12
30 and 31	light snow	20	11	0	.12	SW	2 to 10	1/2 to 15

In most cases persistent or average values for these meteorological elements were used, as shown in Tables IVa and IVb. This was necessary because the weather event usually lasted for more than one hour. The situation on 3 January 1958 is typical of the procedure followed. The wind on that date (Table IVb) was calm and the air temperature was between -5 and -7°F during the period of fog from approximately 1500 to 1700. Snow then followed and lasted until midnight of the next day. The prevailing wind during this period was from the west, and the temperature ranged from -1 to -11°F. Wind speeds and visibility observed during these periods are also shown in Table IVb. The precipitation amounts presented in Table IVb are given in hundredths of an inch, and the "hours of duration" means the total time the storm lasted. Note that in some cases storms may extend from one day to the next as on 8-10 January 1958 (Table IVb). In the analysis of the total number of hours for the month this situation presents no problem. However, when the total hours of duration for individual storms or fog periods were considered, then the total hours of consecutive stormy days were combined.

It is obvious that detailed weather such as that given in Tables IVa, and IVb can only be compiled by visual inspection and extraction from original hourly records. The microfilm data for the 11 years of record for each station provided the necessary information for this. Although some frozen precipitation occurs in September and May in interior Alaska it was considered minor and only the period October through April was used. This period of record produced 77 tables similar to those shown in Tables IVa and IVb. However, the inclusion of all these basic data in this report would create excess bulk. Therefore, the tables have been omitted and the information in the 77 tables have instead been summarized in the present study.

CHAPTER V

DATA ANALYSIS

The statistical analysis of the hourly weather observations in central Alaska first considers precipitation frequency, the number of winter storms that could be expected, and their probable duration. The investigation then surveys in detail the climatic conditions which occurred concurrently with the various types of winter precipitation. The climatic parameters studied are air temperature, visibility, wind speed and wind direction. The results are given in three forms: as the number of observed events and their frequency (in percent); seasonal distribution, by months; and as data means and extremes in the form of class intervals. The summaries finally, appear in figures either as bar graphs, pie diagrams and wind roses or in tables showing the number of observed events or their frequencies in percent.

Precipitation Frequency

The 11 years of winter precipitation data extracted from the records for Big Delta (Fort Greely) Alaska*

*A portion of the results obtained in this analysis was also used in an environmental Guide Report for Arctic test activities (U. S. Army, Natick Laboratories, 1971).

showed that snowfall, including occurrences of snow grains and snow showers, is observed on the average for 78 hours in April the month of lowest average value, and and for 150 hours in November the month of highest average value (Figure 9). Note that these average values incorporate periods when only a trace (less than .01 in) of precipitation was recorded. The maximum and minimum number of hours of snowfall for individual months throughout the 11 years of record was also surveyed (Figure 9). The highest maximum, 286 hours, occurred in October, and the lowest minimum, 13 hours, occurred in April. Note that the maximum hours for the months November through March is very uniform, $\approx$ 200 hours. The bar graphs in Figure 9 are divided to show the number of hours with a trace of snow as compared with the hours with greater than a trace of snow. The graphs show that during those periods when snowfall is reported at Big Delta, amounts greater than a trace are recorded during only 60 to 80% of the time.

Two graphs, one showing the maximum and average number of hours with fog and another, the maximum and average number of hours with ice fog during each winter month were drawn (Figure 10a — 10b). The minimum number of hours was not included in the graphs because in the 11 years of record no fog and ice fog was observed at least once during each month throughout the period..

The bar graphs in Figure 10a show that on the average, fog at Big Delta decreases in frequency from 71 hours in October to 36 in April. However, November appears to be an important month for water droplet fog occurrence, because a maximum of 210 hours was recorded during one year. During the other winter months the maximum number of hours with water droplet fog observed during the 11 year record ranges between 97 and 122 hours.

Ice fog at Big Delta is predominant during December, January and February (Figure 10b). December is especially prone to such conditions as indicated by the yearly average of 66 hours and a maximum of 240 hours of ice fog was recorded during this month over the 11 year period. Ice fogs taper off in frequency during January and February, and occur only occasionally during November and March.

Since rain, freezing rain, blowing and drifting snow and ice crystals occur rather infrequently, the number of hours per month when these conditions were observed are shown in a table (Table V) rather than in graph form as was done for other more frequently occurring conditions. The values in Table V show that rain and freezing rain (and/or freezing drizzle) occur, on a seasonal average, during eight or less hours per month and on the maximum for less than 50 hours during any month over the 11 year period. Although both phenomena occur somewhat infrequently

TABLE V

Frequency of Inclement Weather, Big Delta, Alaska (hours)

October 1957 through April 1968

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Rain							
Max. for 11 yrs	25(24)*	1(0)	5(0)	2(0)	2(0)	49(32)	14(9)
Avg. per yr	8(5)	0.2(0)	0.5(0)	0.2(0)	0.2(0)	5(3)	5(2)
Freezing Rain							
Max. for 11 yrs	41(0)	11(1)	1(0)	24(16)	9(0)	0(0)	4(0)
Avg. per yr	6(0)	2(0.2)	0.1(0)	3(2)	1(0)	0(0)	0.5(0)
Ice Crystals							
Max. for 11 yrs	6	9	96	16	6	8	4
Avg. per yr	1	3	18	3	3	1	0.5
Blowing Snow							
Max. for 11 yrs	14	51	21	19	2	8	4
Avg. per yr	2	8	5	5	0.5	2	0.5
Drifting Snow							
Max. for 11 yrs	54	73	90	182	41	20	0
Avg. per yr	7	20	20	39	17	6	0

*Values in parentheses indicate the number of hours in which greater than a trace of precipitation was recorded.

from November to February, an isolated freezing rain storm could be lengthy and dangerous with respect to icing on wires, antennae, roads and runways. Despite the fact that the values in parentheses (Table V) show that very few storms accumulate more than a trace of precipitation during the freezing rain storms, a series of such storms such as the ones observed in January 1958 and January 1963 indicate instances of major icing. The synoptic weather conditions which accompanied one of these storms will be discussed in a later section.

Drifting snow occurs more frequently than blowing snow at Big Delta. The values given in Table V show that for the months November through February drifting snow can be expected to average 17 to 39 hours each year. The predominant month is January, when during one year an extreme value of 182 hours of snowdrifting was observed. Blowing snow occurs most frequently during November, December and January. The maximum value for a single month observed over the 11 years of record totaled 51 hours and it occurred during November.

Ice crystals are observed mostly in December (Table V), when a yearly average of 18 hours during the month can be expected. A maximum number of hours with ice crystals (96) for the years of record was also recorded during this month. It may be of interest to note again that ice fogs, a condition related to extreme cold, also are most prevalent in December (Fig. 10b).

Except in two instances (freezing rain during March and drifting snow during April) the five weather conditions shown in Table V can be expected to occur sometime during the winter at Big Delta within an 11 year period. However, for some conditions the number of occurrences is small. For example, rain (and/or drizzle) was observed only six times between November through February throughout the 11 year record, and the longest of these storms lasted only 5 hours.

<u>Number of Storms and Their Duration</u>

The probable number of winter storms which occur in central Alaska and how long they last are other useful statistics for planning and operations personnel. Consequently, a survey was made: 1) to establish the numbers of times each weather type was observed throughout the 11 year record; and 2) to analyse storm duration in terms of intervals of < 6 hours, 6 to < 12 hours, up to ≥ 30 hours. The results for snowstorms are shown in Figure 11. In the survey the number of storms with a trace of snow were separated from those with greater than a trace. The bar graphs in Figure 11 show that 33 or more snowstorms of less than 6 hours duration; and 22 or more storms of 6 to 12 hours in length were observed during every month in the 11 years of record. Snowstorms of 18 hours or more duration occur less often, totalling between 2 and 16 per month for the entire 11-year record. However, about 75% of the storms which last for 12 hours or more yield more than a trace of precipitation, whereas only 45% of the storms of < 12 hours duration yield more than a trace of snow.

Bar graphs similar to those used in the above analysis were developed for fogs and ice fogs (Figure 12a — 12b). Information on a trace or more of accumulation was omitted from these figures because traces are not recorded during fogs (Nikandrov, 1959). The bar graphs in Figure 12a show that fogs of < 6 hours duration occur most frequently in October when 49 occurrences were observed during the 11 year record, and gradually decreased through the winter months to 20 occurrences in 11 years in April. Fogs of longer than 6 hours duration also diminish in frequency each month to where only 1 to 3 fogs of 30 or more hours in length were observedpper month throughout the 11 year record. The longest water droplet fog (72 hours) observed during the 11 years of record occurred in November 1958; but brief periods of clearing were also recorded during the event.

During any month, less than 15 ice fogs in each class interval were observed throughout the period of record (Fig. 12b). Although ice fogs of less than 18 hours duration occur most often, the phenomenon can, on occasion, be expected to last much longer. For example, 10 ice fogs of 30 hours duration or longer were recorded in December during the 11 year record. The longest period of almost continuous ice fog (about 2 weeks) was observed in December 1961.

The number and duration of rain, and freezing rain storms observed during the 11 years of record are given in Table VI. These storms usually last $<$ 6 hours; rain is most prevalent in October and April, and freezing rain in October, November and January. Of the 44 rainstorms observed 18 produced more than a trace of precipitation. Of the 31 freezing rain storms reported, only two produced more than a trace of precipitation. From the data given in Table VI, it appears that rain and freezing rain are comparatively infrequent in winter at Big Delta, Alaska. On rare occasions though, a mid-winter thaw period, particularly in January will cause an ice storm.

A tabulation giving the number and duration of drifting and blowing snow storms is given in Table VII. Most blowing-snow storms last longer than 6 hours, whereas many drifting snow storms are of longer duration. Blowing snow is a random event but has been observed at least once in all winter months during the 11 year record.

TABLE VI

Number and Duration of Rainstorms and Freezing Rainstorms, Big Delta, Alaska

October (1957) through April (1968)

Rain

Duration (Hours)	Oct		Nov		Dec		Jan		Feb		Mar		Apr	
	Trace	> Trace	T	> T	T	> T	T	> T	T	> T	T	> T	T	> T
< 6	8	5	2		2		1		1		2	1	9	2
6 to < 12	*	4									1	1		1
12 to 24		1										1		1

Freezing Rain

Duration (Hours)	Oct		Nov		Dec		Jan		Feb		Mar		Apr	
	Trace	> Trace	T	> T	T	> T	T	> T	T	> T	T	> T	T	> T
< 6	3		6		2		4	1	3		None		3	
6 to < 12	4		2				1							
12 to 30	1							1						

*Blanks mean zero events

TABLE VII

Number and Duration of Drifting and Blowing Snowstorms

Big Delta, Alaska October 1957 through April 1968

Drifting Snow

Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr
< 6 hr	2	6	8	18	7	6	None
6 to 12 hr	3	11	5	6	3	3	
12 to 18 hr	2	0	2	3	3	1	Observed
18 to 24 hr	1	3	1	0	1	0	
24 to 30 hr	0	1	3	0	0	0	
30 hr or more	0	1	0	5	2	0	

Blowing Snow

Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr
< 6 hr	2	9	4	9	4	6	1
6 to 12 hr	0	1	4	1	0	0	0
12 to 18 hr	1	0	0	1	0	0	0
18 hr or more	0	1	1	0	0	0	0

Drifting snow was not observed during any April but otherwise it is rather common. January is a peak month of occurrence, 18 storms of drifting snow lasting less than 6 hours and five of 30 hours or more duration were observed in this month during the 11 year record. The longest reported blowing snow storm (48 hours) occurred in November 1964, and the longest intermittent drifting snow storm, reported in January 1966, lasted for 4 days. Wind speeds at Big Delta differ somewhat from other stations in central Alaska and more on this subject will be discussed in a later section.

Concurrent Climatic Conditions

A. Air Temperature. One of the more important climatic parameters associated with winter weather is air temperature. It is well known, for example, that ice fog occurs at much lower temperatures than warm fog, and that the snow falling in mid-winter is colder than that observed during October or April. However, the magnitude of these differences and the frequency of occurrence at specific sites, such as Big Delta, is not well documented. Consequently, an analysis of the air temperatures observed at the time the various winter weather types occurred was made.

Temperature ranges in intervals of 10 degrees were selected, extending from -40 to -31°F, at the cold extreme, and +30 to + 39°F at the other extreme. To begin with the average air temperature observed during each snow storm was noted and a count was made in the proper interval. Monthly tabulations were made and the combined frequencies of the intervals in each month were totaled and recorded as 100% (Figure 13). The bar graphs in Figure 13 show that the air temperatures during snowfall in October, November and April fall mostly between +10 and +39°F. During December, January and February the air temperatures ranged from -40 to +39°F during periods of snowfall, but occur mostly between -10 to +9°F. It is interesting to note that the snow falling in March is still associated with rather low temperatures, thus reflecting the extended winters experienced in this area.

A comparison of air temperatures observed during fog, ice crystals and ice fog is shown in Figure 14. The temperature intervals used for snow, were also used in this analysis. However, the totals representing 100% frequency for each of these weather types combine all months (October through April) instead of each month. Note the progressive shift from higher to lower air temperature during periods of fog, observed ice crystals, and ice fog respectively (Fig. 14). The maximum temperature frequency obtained for each weather type occurred at; 10 to 19°F for fog, -11 to -20°F for ice crystals and -31 to -40°F for ice fog. Ice fogs are confined to the most narrow range in air temperature, whereas during periods of water droplet fog (as opposed to ice fog) the observed air temperature extended over a wide range.

The average air temperature observed during the 44 instances of rain (Table VI) reported during the eleven years of record was 37°F. Higher temperatures (up to 48°F.) occurred during October or April and lower values (down to 28°F) recorded between November and March. The average air temperature observed during the 31 freezing rainstorms (Table VI) was 25°F. The highest and lowest temperatures reported during this weather condition were 37 and 15°F respectively. A study on mean monthly air temperatures during freezing rain and/or drizzle at cities in northeastern United States and southeastern Canada showed a similar relationship existing between these two climatic parameters (Bilello, 1971).

B. Windspeed and Direction. Information on windspeed and direction during periods of snowfall, drifting snow, fog and ice fog would be of value for several reasons. For example, the prevailing wind direction during drifting and blowing snow would help designers determine the layout and orientation of buildings and provide data for use in snowdrift control. The prevailing wind direction at the time of fog and ice fog would be important in airfield operations and ground fog dispersal systems to locate the correct up-wind positioning of the equipment.

Consequently, the average wind direction and wind-speed during the above winter weather conditions were tabulated and analyzed. The results on wind during snowfall are given in Figure 15. Since there is little month-to-month variation in the prevailing wind direction during periods of snowfall, the wind-rose given in Figure 15 considers all observations between October and April for the 11-year record. It was found that winds during snowstorms are from the west, southwest and northwest during 66% of the time at Big Delta. Calms are recorded during 11% of the snowfall period; otherwise the average wind speed is 5.5 knots. The highest average wind speed during snow (6.8 knots) was recorded in April, the lowest (4.7 knots) in December and January.

The wind direction during blowing and drifting snow storms in the Big Delta-Fort Greely area, however, is predominantly from the southeast (U.S. Army ECOM, 1966).. A frequency analysis showed that the wind can be expected from this direction during 88% of the blowing and drifting snowstorms, and that during the remaining 12% of such storms the direction is east or south. A comparison of the windspeeds during blowing and drifting snowstorms is shown in Figure 16. The diagram shows that blowing snow is associated with stronger winds, 21 to 25 knots, as compared with 16 to 20 knots for drifting snow. It also shows that blowing snow does not occur with winds under 11 knots, and for only 3% of the time with winds under 16 knots. It should be pointed out that during periods of blowing snow, the snow is also probably drifting. Usually, but not always, both phenomena were reported simultaneously by the observer.

Kungurtsev (1937) reports that the transfer of loose snow begins with surface wind speeds of about 5 knots. For hardened snow the required surface wind is stronger (10 knots). A study on the physical properties of the snow cover at Fort Greely (Bilello, et al, 1970) showed that the snow density was generally low. For example, the average density in the forested area did not exceed 0.24 g/cm^3; but at certain exposed locations densities of up to 0.33 g/cm^3 could be expected. At these levels of snow compactness the wind speeds observed during periods of drifting snow at Big Delta (Fig. 16) are higher than those given by Kungurtsev. When the snow was lifted to heights of a few feet above the surface, Kungurtsev found the wind speeds reached 30 to 40 knots. Winds in this range were observed during 15% of the time when blowing snow was observed at Big Delta (Fig. 16). Variations in these wind relationships can be expected though, because of changes in the structure and size of the surface snow crystals, the variations in vegetation and features of the terrain and variability in the wind such as gustiness and direction.

It is generally believed that the wind during periods of ice fog are usually calm. Survey of the data for Big Dèlta showed that this i.e. calm condition, is true during 24% of the time (Figure 17b). Otherwise, the average wind is generally light being 2.9 knots, and with a direction at these times which is generally from the south. The average windspeed during periods of fog or ground fog is 5.3 knots and conditions were calm during 12% of the time (Figure 17a). Note that the dominant wind direction during these types of fog is from the west, which is quite markedly different from the direction for ice fog.

It now becomes apparent that from the climatic information given in this section, a forecast based on statistical probability becomes possible. For example, it has been shown that ice fogs at Big Delta occur most often in December (Fig. 10b), that in that month the condition can persist for over 30 hours once a year (Fig. 12b), that it does not occur at air temperatures above -21°F. (Fig. 14), and that the winds are calm or light and from the south (Fig. 17b).

Thus to forecast ice fog at Big Delta one should first consider the previously discussed macrometeorological and synoptic meteorological conditions which produce ice fogs. The statistics given here show that the required cold arctic air masses occur most frequently in central Alaska during December. Statistics further show that, on the average, 50 out of the 744 hours (or about 7% of the time) in December one can expect ice fogs to occur. However, records also showed that in one winter out of eleven Big Delta experienced a December with 240 hours of ice fog or for about 32% of the time (Table 10b).

A similar analysis can be conducted by forecasters to determine the probability of blowing snow occurring at Big Delta, Alaska. As shown in the following Chapter, blowing snow storms develop when a steep pressure gradient forms over southeast Alaska. The results presented in Table V show that such synoptic meteorological conditions can occur during any month between October and April. However, most storms apparently take place in November, when in one year out of 11 blowing snow was recorded during 51 out of a possible 720 hours (Table V). The additional concurrent climatic statistics conducted in this thesis, also provides some other useful information on blowing snow storms. The diagram in Figure 16b, for example, shows how strong the wind has to be at Big Delta to generate such a storm ($\approx$ 16 to 35 knots) and the figures in Table XI show that the prevailing wind during the event is almost always from the east-southeast.

C. Visibility. Finally, it is of interest to know the reduction in visibility one can expect during each type of winter weather condition. The results of the survey made on this particular parameter are shown in Table VIII. It is significant to find that the visibility during water droplet type fogs at Big Delta is slightly poorer than during ice fog. Only during 1% of the time was the visibility better than 5 miles in warmer fogs, whereas it was 6 or more miles during 17% of the time in ice fogs. The frequency, for both types of fogs of visibility being under 1 mile was comparable ($\approx$ 30%); for the 1 to 3 mile range and frequency was higher for water droplet fogs than it was for ice fogs (51 and 27% respectively).

Visibility during snowfall and blowing snow is not as poor as it is during fog. The frequency for visibilities less than 1 mile is only 9 to 12% of the time; and for 6 miles visibility it is 49% for snowfall and 32% for blowing snow. The tabulation also shows that the visibility during blowing snow is not as good as it is during periods

TABLE VIII

Visibility during Water Droplet Fogs, Ice Fogs, Snowstorms, Blowing Snowstorms, and Ice Crystal Occurrences, Big Delta, Alaska October (1957) through April (1968)

Visibility (miles) during Water Droplet Fogs

	< 1 mile	1 to 3	4 to 5	> 5 miles
% of time during fog periods	29	51	19	1

Visibility (miles) during Ice Fogs

	< 1	1 to 3	4 to 5	6 to 10	> 10
% of time during ice fog periods	30	27	26	12	5

Visibility (miles) during Snowfall

	< 1	1 to 3	4 to 5	6 to 10	> 10
% of time during snow-fall periods	9	26	16	28	21

Visibility (miles) during Blowing Snowstorms

	< 1	1 to 3	4 to 5	6 to 10	> 10
% of time during Blowing snow periods	12	31	25	18	14

Visibility (miles) during Ice Crystal Occurrences

	< 1	1 to 3	4 to 5	6 to 10	> 10
% of time during observed ice crystals periods	3	15	14	28	40

of snowfall. The reason for the smaller frequency value obtained for 4 to 5 miles visibility during snowfall (Table VIII) is not apparent. It may be due to the arbitrary ranges of visibility which were selected, or to the method of determining the averages of the visibility observed during the storm.

As noted in the definition of ice crystals, the presence of such crystals does not appreciably reduce visibility. The values given in Table VIII verify this statement, since during 82% of the time ice crystals were observed, the visibility was better than 4 miles, and it was over 10 miles for 40% of the time.

CHAPTER VI

AIR MASSES, FRONTS AND CLIMATIC RELATIONSHIPS

In the preceding sections the large scale winter weather controls which affect the central region of Alaska were introduced and examined. This was followed by a detailed analysis of the various forms of frozen precipitation produced by these meteorological conditions and an investigation of observed concurrent climatic parameters.

In this section, some interesting and significant interrelationships between the macro/synoptic scale weather phenomena and the resulting winter climate observed at Big Delta and other locations in central Alaska will be discussed. Since each of the observed forms of frozen precipitation were caused by or associated with different weather conditions, they will be considered separately in this chapter.

Snow and Snow Showers

As noted in Figure 9, snow and snow showers are the most prevalent form of frozen precipitation occurring in the interior Basin of Alaska. Such precipitation starts as early as September and lasts until April or May.

Winter cyclonic storms moving onto the west coast of Alaska (such as the one shown in Figure 7b) will initially produce southerly winds over central and western Alaska. The occluded front accompanying these storms generally produces high thin clouds over the interior, but no snow. When the front approaches the Big Delta area it has passed the peak of development and usually a deep cold low is left over the Bering Sea. When this cold low moves far enough to the north the winds over Central Alaska veer from the south to a westerly direction and snow will start to fall (see Fig. 15). This precipitation is due to the moisture brought in by the frontal system, the funnelling effect of the topography and the lifting of the warm air by the invading cold air. Since large amounts of snow in Central Alaska are not observed until after the winds shift, the pressure changes to the rear of the front become important. In fact forecasters in the area have noted that when moisture moves into the interior from the southwest in winter, snow will not occur until the pressure begins to rise and will continue until the barometer starts to level off.

This reported meteorological sequence was tested here by examining a series of daily synoptic weather maps for the northern hemisphere (Dept. of Commerce, 1957-1967). Four random years, within the period of record were used in the analysis. The tabulation consisted of: 1) a count of the hours when snow was observed, and 2) the amount of pressure increase or decrease during the same three hours. Two stations in the Basin were used in the survey, one on the west end (Galena) and another on the east end (Fairbanks).

The results, summarized monthly from October through April, are given in Table IX. The investigation showed that rising pressure tendencies in central Alaska are definitely more highly associated with snow occurrence than are pressure falls. In one of the summarized tabulations (Galena in April, Table IX), the pressure falls during periods of snowfall exceed pressure rises. In all other cases, especially at Fairbanks or when snow was falling at both stations, the pressure rises exceeded the falls by a ratio of two or three to one. The amount of pressure change also supports this circumstance--only one of the 21 summarized events given in Table IX, showed a smaller net increase in total pressure change, Galena in February: 84 tenths of millibars versus 96.

Nichols (1953) notes that the intensity and duration of snowfall in interior Alaska is also related to the degree and persistence of the pressure rise subsequent to a frontal passage. Minor troughs moving rapidly through the area produce only light and brief periods of snow from a relatively high deck of clouds (bases 8,000 to 10,000 ft). Moderate to heavy snowfalls on the other hand

TABLE IX

Atmospheric Pressure Changes during Periods of Snowfall in Central Alaska

Month	Station	No. of Press. Rises	No. of Press. Falls	Total Amt. of Press. Increase (tenths of mbs)	Total Amt. of Press. Decrease (tenths of mbs)
Oct.	Galena	8	8	77	65
	Fairbanks	15	5	221	55
	Both	5	0	47	0
Nov.	Galena	8	7	121	68
	Fairbanks	10	3	199	33
	Both	9	4	123	54
Dec.	Galena	7	5	117	56
	Fairbanks	10	6	172	60
	Both	7	3	72	19
Jan.	Galena	9	9	144	84
	Fairbanks	6	3	89	26
	Both	2	0	23	0
Feb.	Galena	9	6	84	96
	Fairbanks	9	3	100	14
	Both	12	0	183	0
Mar.	Galena	10	3	81	29
	Fairbanks	6	0	109	0
	Both	3	0	40	0
Apr.	Galena	10	11	142	131
	Fairbanks	7	2	83	10
	Both	8	2	112	19

are associated with slow moving major troughs in which the mixing ratio values for moisture in the lower levels of the system are quite high (Cobb, 1970). However, storms which produce large amounts of snow occur infrequently in the interior Basin. Normally, the area experiences numerous snow events each month and the amounts during each event generally total less than two inches and often only a trace (Fig. 11).

Rain and Freezing Rain

Rainfall rarely occurs during December, January and February in central Alaska. It was observed only four times in eleven years during these months and produced only a trace of precipitation in each case (Table VI). Rain events increase only slightly in November and March, and, on the average, can be expected to occur only about once or twice a year during October and April.

A significant lengthy period of rain however, was observed between 22 and 27 March 1965 at Big Delta when discontinuous rain was observed for a total of over 45 hours. The weather map for 1200 hours GMT, 22 March 1965 showed two intensive north-south blocking high pressure systems located east and southeast of Alaska (Fig. 18). The isobaric pattern which formed on the west side of these high pressure centers brought an abnormally large amount of warm moist air from the Pacific Ocean to the Alaskan interior. The 500 millibar upper air weather map for 1200 hours GMT, 22 March 1965 (Fig. 19) also shows this unusual south to north transfer of air to Alaska. The lower portion of the deep upper trough in the west central Pacific Ocean on this map reaches the Hawaiian Islands while the upper portions of the wedge east of this trough extends northward into the Arctic Ocean. The rather steep pressure gradient existing between 155 and 160°W longitude clearly shows how the observed anomaly of warm, moist air was able to move rapidly from a mild oceanic region to the Arctic.

Overcast skies and rain or drizzle with abnormally high air temperatures were observed everywhere in the interior at this time. In fact, the five major weather stations in the interior basin reported values of 16° to 19°F above normal for March 1965; and 15 other stations in the Basin reported maximum temperatures for the month occurring between March 23 and 27th (U.S. Dept. of Commerce, 1965). Macrometeorologically speaking, this is a good example of an unseasonal intrusion of relatively warm sub-polar maritime air into Alaska. Although frontal systems did not actually traverse central Alaska during this interval, rainfall amounts were relatively high. Similar weather situations in this area rarely occur in mid-winter, but are observed occasionally at the start or end of the season.

Freezing rain and freezing drizzle occur more frequently during the mid-winter in central Alaska than does rain (Table VI). Studies conducted by Johnson and Pazeretsky (1968) have shown that the thickness of the warm layer (above freezing temperatures) of air over Eielson Air Force Base in winter will determine the form of precipitation that reaches the ground. If the depth of the warm air aloft is sufficiently deep to allow complete melting of the snow particles falling through from higher levels then freezing rain or drizzle will occur at the surface. The assumption is that the shallow freezing layer of air, below the thicker warm layer, will supercool the water droplets but not refreeze them. These supercooled droplets, will, however, freeze immediately when they come in contact with exposed objects on the ground. If the warm layer of air aloft is shallow, then the snow particles falling through it will just partially melt. These particles would then refreeze as they pass through the thicker cold layer of air below to form ice pellets or snow grains.

An extended period of freezing rain and freezing drizzle was observed at Big Delta and Eielson Air Force Base Alaska in January 1963. The surface weather map for 1200 hours GMT, 15 January 1963 (Fig. 20) shows a high pressure cell which had formed off the west coast of the U.S. This cell remained in this region for most of the last half of January 1963. In conjunction with this blocking high, frontal systems of one type or another stalled or lingered in central Alaska during most of the same period. The fronts caused cold air to remain near the surface in the interior, while warm-moist air was being advected into the upper layers via the north-south pressure gradient from the Pacific Ocean (Hare and Orvig, 1958).

The results of this synoptic weather situation are shown by the data (Table X) compiled by Johnson and Pazeretsky (1968). On 11 days between 16 and 31 January 1963, 17 separate events of freezing rain or freezing drizzle were recorded at Eielson Air Force Base. During this period, this form of precipitation was observed for 50 hours and 34 minutes and the surface air temperatures at these times averaged 20.8°F, the highest temperature being 31°F and the lowest 13°F. The warmest temperature observed aloft during this same precipitation period averaged 34.5°F, with a maximum temperature of 41°F and a minimum of 29°F. A plot (Fig. 21) of the mean temperature lapse rate observed during periods of freezing rain or drizzle at Eielson Air Force Base shows that the lower freezing layer generally extends from the surface to about 950 millibars or approximately 1600 feet thick. The layer over this cold air, in which the temperatures are above freezing, usually extends from about 950 to 820

TABLE X

Freezing Drizzle, Freezing Rain, and Concurrent Temperatures, Eielson Air Force Base, Alaska, January 1963

Date	Type (Fr. Rain (ZR) (FR. Drizzle (ZL)	Duration (hrs + min)	Sfc Temp (°F)	Warmest Temp aloft (°F)
14	ZR	6 + 13	19	29
14	ZL	6 + 15	16	29
15	ZL	1 + 07	19	29
16	ZR	0 + 23	26	37
16	ZL	1 + 41	28	34
19	ZR	10 + 02	28	36
20	ZR	1 + 04	31	38
24	ZR	0 + 20	17	37
24	ZR	2 + 10	19	37
25	ZR	0 + 15	20	36
25	ZR	0 + 24	21	36
25	ZL	2 + 00	21	32
25	ZL	3 + 07	22	34
26	ZL	0 + 10	14	36
29	ZL	1 + 15	13	41
30	ZL	13 + 18	15	36
31	ZR	0 + 50	24	29

millibars or approximately 3600 feet thick (ESSA, NASA and USAF, 1966).

In another survey on the occurrence of freezing rain or freezing drizzle at Eielson Air Force Base, Alaska, Johnson and Pazeretsky (1968) found that over a period of several winters (1958 through 1964) the phenomenon was observed during 29 days for a total of 87 hours and 34 minutes. During this period (1958-64) this form of precipitation occurred most frequently during the 1962-63 winter, when it was observed on 14 days, and least frequently the following winter when no such events were observed. These values re-emphasize the fact that this form of winter precipitation in central Alaska is relatively uncommon and extremely variable in terms of expectancy.

Fog and Ice Fog

Frequency and duration values on fog (or ground fog) and ice fog at Big Delta in winter are given in Figure 10 and 12 respectively. Except for the maximum November value observe in 11 years of record (Fig. 10a) the expectancy level for fog and ground fog occurrence is quite uniform from October through April. Generally, the formation of fog and ground fog is a localized phenomena. Low lying regions with extensive marshes, lakes, or rivers are particularly prone to fog formation. The beginning of winter in this case is naturally a more favorable time for fog formation because these sources of water have not yet become frozen over.

Most of the winter fogs in this region, especially ground fogs, are identified as radiation fogs (Falkowski, 1957; Hastings, 1959). This type of fog is common over land areas, and is produced when radiational cooling reduces the air temperature to or below its dew point (Huschke, 1959). There are several conditions which favor the formation of radiation fog: (1) the air during the day has been under a cloud cover thus retaining as much moisture near the ground as possible; (2) clear skies at night permit rapid long-wave terrestrial cooling; (3) the shallow surface layer of relatively moist air cools to an excessive degree; and (4) the surface winds are calm or quite light.

Topographically, the central Alaska basin is also an ideal location for fogs formed by cold air drainage. River valleys and low lying regions immediately adjacent to ponds or lakes are frequently subject to this type of fog. The gradient wind direction and moisture content of the air are important factors involved in forecasting this type of fog (George, 1951, Nikandrov, 1959). In the western part of the basin near Farewell (Fig. 1), fog can be expected if the low level drift is from the southwest;

in the eastern part of the basin (at Big Delta) the prevailing wind during periods of fog or ground fog is westerly and light (Fig. 17a).

The most prolonged periods of ice fog in Central Alaska occur during the months of minimum insolation. Strong radiative inversions will drop surface temperatures to below -35°F and locally stagnant air will result in air pollution in the form of ice fog (Robinson, et al. 1957; Benson, 1970). This feature is most pronounced in major settlements, such as in the Fairbanks-Fort Wainwright area, but can occur in other locations where excessive amounts of water vapor are released from such sources as automobiles, power plants and household chimneys (Gotaas and Benson, 1965).

Bowling, et al (1968) report that in 12 of the 15 ice fog events at Fairbanks, the synoptic weather maps showed a north-south surface ridge forming from Siberia to the Pacific before each event. This surface ridge generally breaks away from Siberia and moves into Alaska and an upper ridge forms over the Bering Strait. The surface ridge then grows rapidly into an intense anti-cyclone in the inland valleys of Alaska and moves slowly eastward into Canada after a few days. Two other ice fog events were associated with a continuous belt of high surface pressures extending from Siberia into Alaska and Canada. The surface temperature during one of these events was extremely cold (below -58°F), and produced an extended period of ice fog from about 15 to 30 December 1961 at both Fairbanks and Big Delta (Gotaas and Benson, 1965).

<u>Drifting and Blowing Snow</u>

As discussed earlier, wind speeds of about 10 to 20 knots will cause snow on the surface to drift. One of the longest periods of drifting and blowing snow at Big Delta occurred during 2 to 6 January 1966. A high pressure cell entered over interior Alaska in conjunction with a cyclonic system off the west coast of Canada caused a steep pressure gradient to form over southeast Alaska (American Meteorological Society, 1966). The wind speed on this occasion averaged 20 to 30 knots at Big Delta during most of the snow moving period and the direction was predominantly from the east-southeast (Table XI).

An almost exact replica of the synoptic situation described above also occurred on 29 and 30 November 1964 (American Meteorological Society, 1965). Blowing snow at Big Delta was recorded during most of this storm, in which wind speeds of 50 knots with gusts of 62 knots were recorded. The wind direction during this period was the same as during the other storm, being from the

TABLE XI

Wind Speed and Direction during Drifting and Blowing Snowstorms, Big, Delta, Alaska November through December 1964 and January 1966*

November - December 1964

Date	Type Drifting Snow (DS) Blowing Snow (BS)	Duration (hrs)	Ave. Wind Speed (Knots)	Prevailing Wind Direction (36 point compass)
Nov 28	DS	10	22	10
29	BS	10	30	12
29	BS	6	33	10
29	BS	8	28	11
30	BS	9	33	12
30	BS	15	38	11
Dec 1	BS	7	25	11

January 1966

Date	Type Drifting Snow (DS) Blowing Snow (BS)	Duration (hrs)	Ave. Wind Speed (Knots)	Prevailing Wind Direction (36 point compass)
2	DS	6	19	111
2	BS	10	23	12
3	BS	8	24	11
3	DS	16	22	11
4	DS	6	25	10
4	BS	18	40	11
5	DS	18	28	11
5	BS	2	42	11
6	DS	6	25	11
19	DS	5	13	12
21	DS	8	25	11
22	BS	3	29	11
22	DS	4	27	11
23	BS	3	36	11
23	DS	55	32	11
25	BS	8	40	10
25	DS	9	28	11
26	DS	7	30	11
26	BS	6	37	12

*Taken from U. S. Dept. of Commerce (1957-1968) Weather Bureau, National Weather Records Center. WBAN -10, ATCS, Big Delta, Alaska, November 1964 and January 1966.

east-southeast (Table XI). It is of interest to note that at most stations in Canada and conterminous U.S. periods of snowfall are associated with winds from the south to northeast, and drifting or blowing snow are associated with winds from the southwest to north (Koeppe, 1931; Berry, et al., 1945). At Big Delta almost the opposite is true: snowfall winds are predominantly southwest to northwest (Fig. 15) and drifting and blowing snow is accompanied by winds from the southeast to east. However drifting and blowing snow is less common at other stations in the Alaskan interior because winter winds at these locations do not blow as strongly as they do at Big Delta (Mitchell, 1955; Ehrlich, 1953).

CHAPTER VII

CONCLUSIONS AND DISCUSSION

This thesis investigated the occurrence of freezing precipitation in central Alaska and analyzed the meteorological conditions which produced the winter climate. The extensive Tanana River Basin in the interior of Alaska was selected because it was easily identified and because the climate differed from its surrounding areas. The study showed that this difference in climate was mainly due to the major mountain ranges which surround the Basin.

The interdependence between Meteorology and Climatology is pointed out in this thesis by way of statistical analysis and the discussions of the influence of air masses, and fronts on the resultant winter precipitation. It was found that most of the winter weather is related to the Polar Continental air mass which dominates the area during this time of the year. The main exception was the occasional influx of Polar Maritime air which produces a major snow storm or warm fogs. The remaining forms of precipitation, namely rain and freezing rain or freezing drizzle, occur during massive intrusions of Subpolar or even Temperate Maritime air. A late winter rainstorm observed in central Alaska, for example, was analyzed and the weather pattern at the time showed a major south to north flow of warm, moist air reaching Alaska from Pacific Ocean latitudes of 35°N. However, the investigation showed that this particular atmospheric condition happens only rarely during the winter in the area studied.

When warm, moist air does penetrate into central Alaska in mid-winter it generally remains aloft over a denser layer of air in which the temperatures are below freezing. It was found that this superpositioning of two contrasting air masses would then produce freezing rain or freezing drizzle. During January, 1963, freezing rain and/or freezing drizzle was recorded on 11 days in a consecutive 18 day period. Fortunately, most of the moisture had been removed from the overlying air mass during its passage over the Alaskan coastal range so the accumulation of ice was minimal. Such information is vital to the inhabitants of central Alaska in order to determine the potential danger associated with such storms.

In the climatic evaluation of the hourly weather observations presented in this study two different approaches were used. One approach was to provide statistics on two or more meteorological parameters which occurred together and secondly, the periods when no precipitation was observed were excluded in the computations. The results showed that freezing air temperatures extend from October through April in central Alaska and produce various types of freezing precipitation. The most dominant form is snow; and although the snow season is long the amounts per storm are generally light thus resulting in moderate covers. It is concluded that this condition exists because the moisture laden storms moving into Alaska from the south expend their energy and water content against the Alaska Range. However, the study also showed that frontal systems do traverse the interior of the state, and that the ones which move in from the west or southwest yield appreciable amounts of snow. The investigation revealed that these snowfall events were more directly associated with rising atmospheric pressures and that the predominant wind direction at the time is westerly. These are uncommmon features of winter climate in subpolar and northern mid latitudes regions of North America.

The second most common inclement weather event observed in the Alaskan interior are water droplet fogs and ice fogs. Investigation of concurrent air temperatures showed that both types have been observed between -21 and -31°F. No ice fogs were recorded at temperatures above -12°F and very few water droplet fogs at below -31°F. The fogs are classified as the radiation type and are formed by surface heat losses due to cold air drainage or long-wave terrestrial radiation. Studies by several authors point out that the ice fogs occur when cold high pressure systems develop over the Alaskan interior and that ice fogs can be considered to be another form of atmospheric pollution. Aside from local sources of water vapor, such as hot springs and caribou herds, ice fogs generally are found in populated areas. It is produced by the water vapor and minute particulate output from automobile exhausts, power plant stacks, household chimneys and other sources associated with urban environments.

Besides air temperature, another meteorological element which differred during water droplet and ice fog events was uncovered in this study. Wind speed and direction recorded during these fogs at Big Delta, Alaska showed the wind to be light and southerly during ice fogs, and stronger and westerly during water droplet fogs. Suspended ice crystals in the lower atmosphere also were found to be quite common during December at Big Delta. The survey of air temperatures observed during this event indicated that ice crystals occur as a transitional phase between incidents of warm fog and ice fog.

This thesis also showed that when a steep pressure gradient develops south of the Tanana Basin in winter, strong east-southeast winds develop and drifting and blowing snow occur. The typical synoptic weather pattern causing this gradient is a high pressure cell migrating eastward along the Arctic coast while a low is moving slowly northeast or becomes blocked in the Gulf of Alaska.

When the center of the high is northeast or east of Big Delta, air moves down the Tanana Valley parallel or nearly parallel to the isobars. It is believed that the constriction of the valley creates a venturi effect and also helps to accelerate the wind speed.

When carrying snow, this strong stream of air has been observed to be about five miles wide at Big Delta and approximately 2,000 feet deep. It normally dissipates after passing Big Delta, but may continue westward to Nenana, passing to the south of Eielson Air Force Base and Fairbanks. Results obtained in this study showed that drifting snow occurs more often than blowing snow at Big Delta, and that in either case the wind is almost always from the east-southeast. Although drifting and blowing snow were observed at wind speeds between 16 and 30 knots, few cases of drifting snow were reported at speeds greater than 30 knots and very few blowing snow events at speeds of less than 16 knots.

The results given in this thesis can be applied in many fields and in various ways. For example, the frequency and duration values on snow events can be used in the planning and construction of roads, airfields and structures. The data also could be used in the design of anti-icing devices to control accretion on wires and antennae. The information on wind speed and direction during periods of snow, fog and drifting snow would be useful in the positioning of buildings, the location of doorways and entrances, and as an aid in solving traffic and communication problems experienced during periods of inclement weather.

The examination of air masses, storms and fronts which produce the winter climate in central Alaska could be used by weather forecasters. It has been shown that the Polar Continental air mass dominates the area in winter, but that intrusions of warm, moist Pacific Ocean or Bering Sea air into the interior can occasionally be expected. Snowfalls in central Alaska occur most often after a front passes the region and are associated with rising atmospheric pressures.

The discussion on the location and movement of the high and low pressure cells, which in one case brought rain, and in another a lengthy blowing and drifting snow storm to the interior of Alaska, is also beneficial to a forecaster. A repeat of these weather patterns could provide the clue for providing a correct prognosis of inclement weather in the area. Likewise, a massive incursion of cold air with an associated intense high pressure cell in central Alaska, will forewarn the inhabitants of a populated region that ice fogs are imminent and according to statistics the event could last for an extended period of time.

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APPENDIX A

Figures 1 through 21

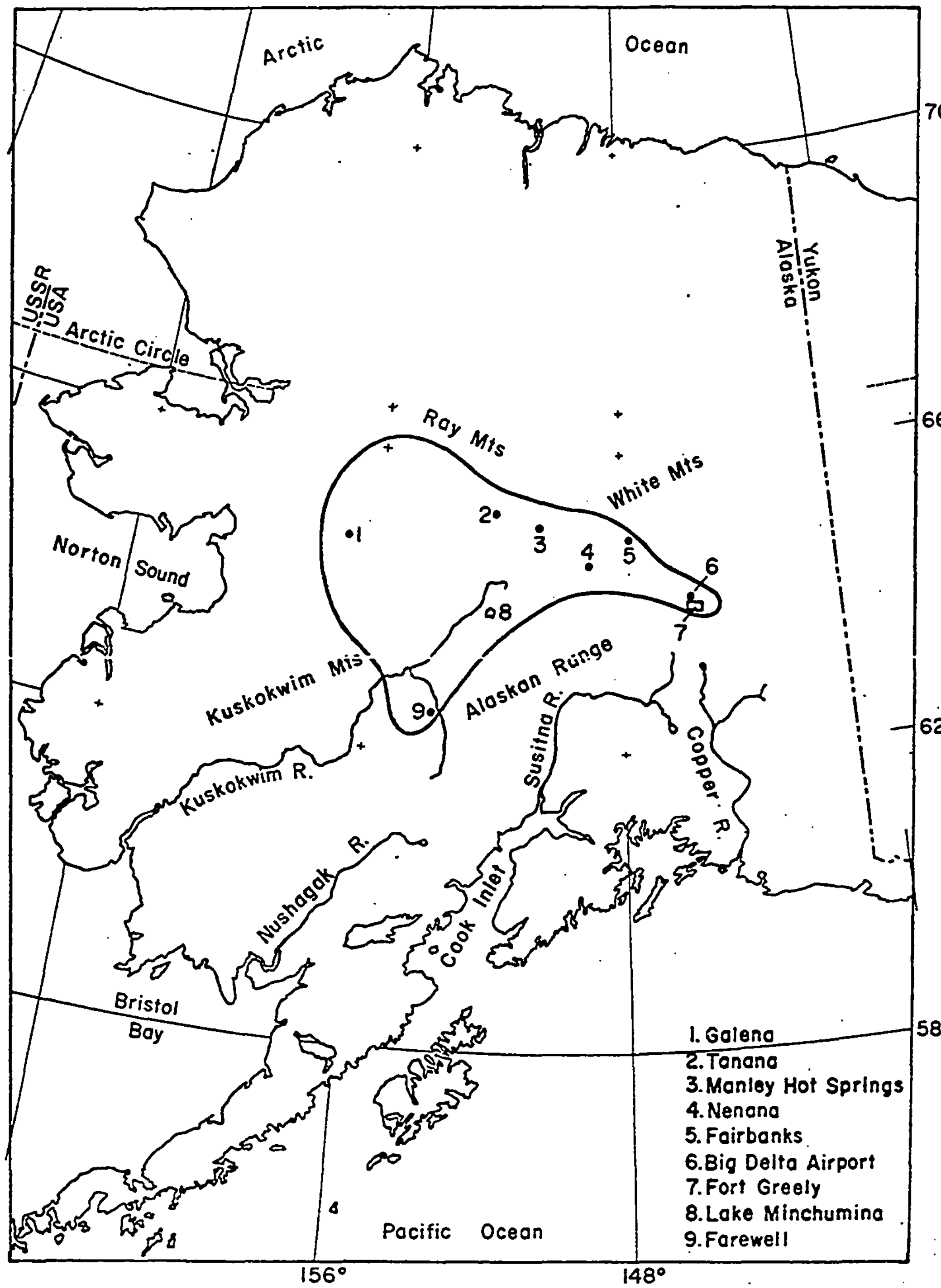


Fig. 1. Map of Alaska, with location of the Interior Basin.

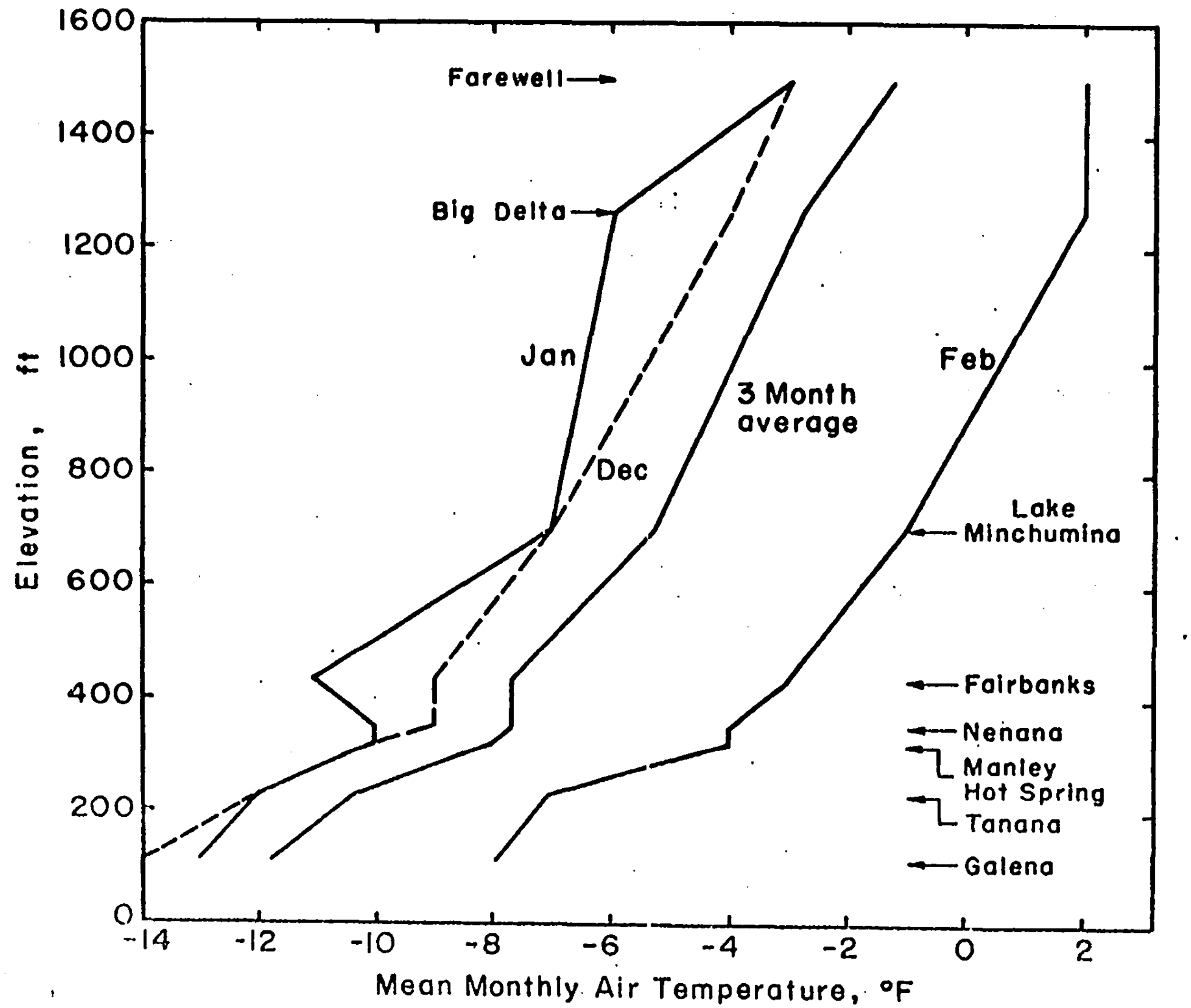


Fig. 2. Air temperature and elevation relationships for Interior Basin weather stations.

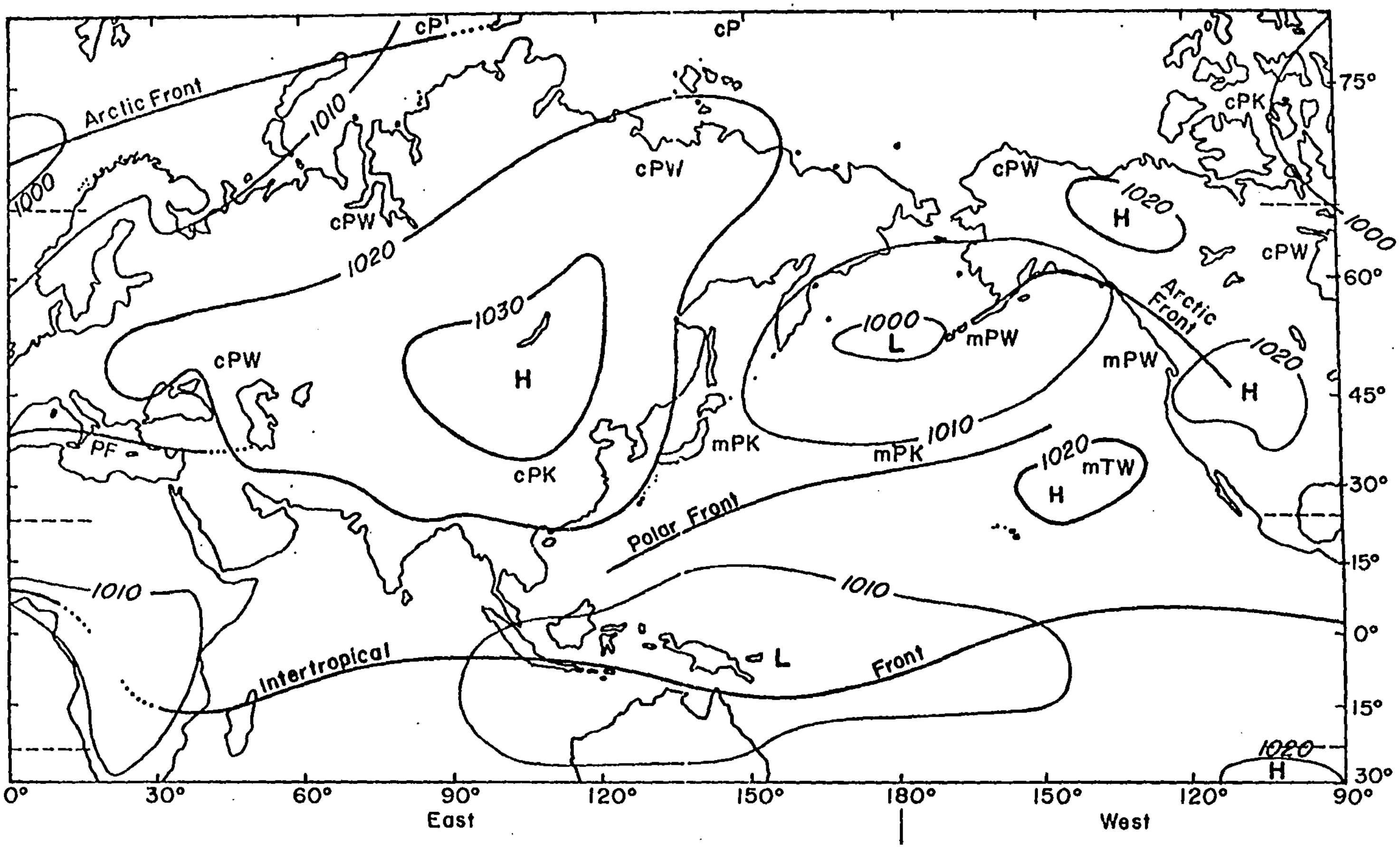


Fig. 3. Air mass source regions in January (after Willett, 1944).

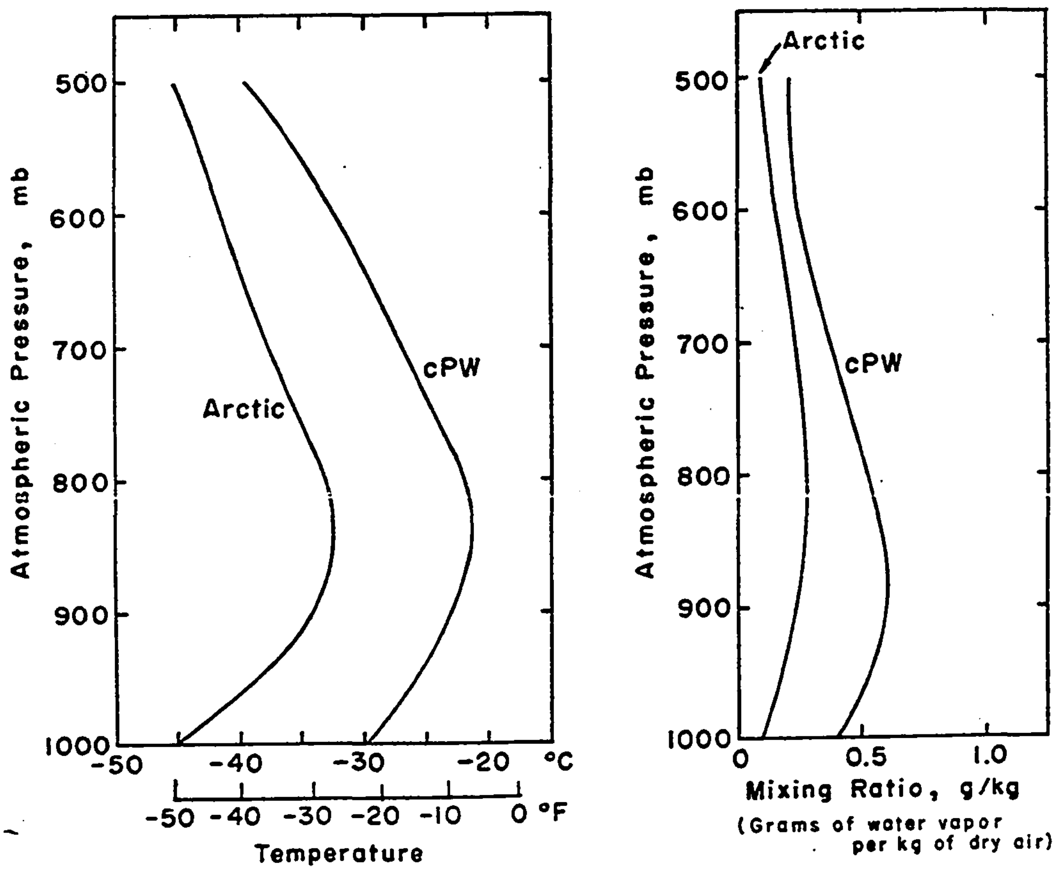


Fig. 4. Typical winter profiles of temperature and humidity in arctic and polar continental air masses (after Petterssen, 1969).

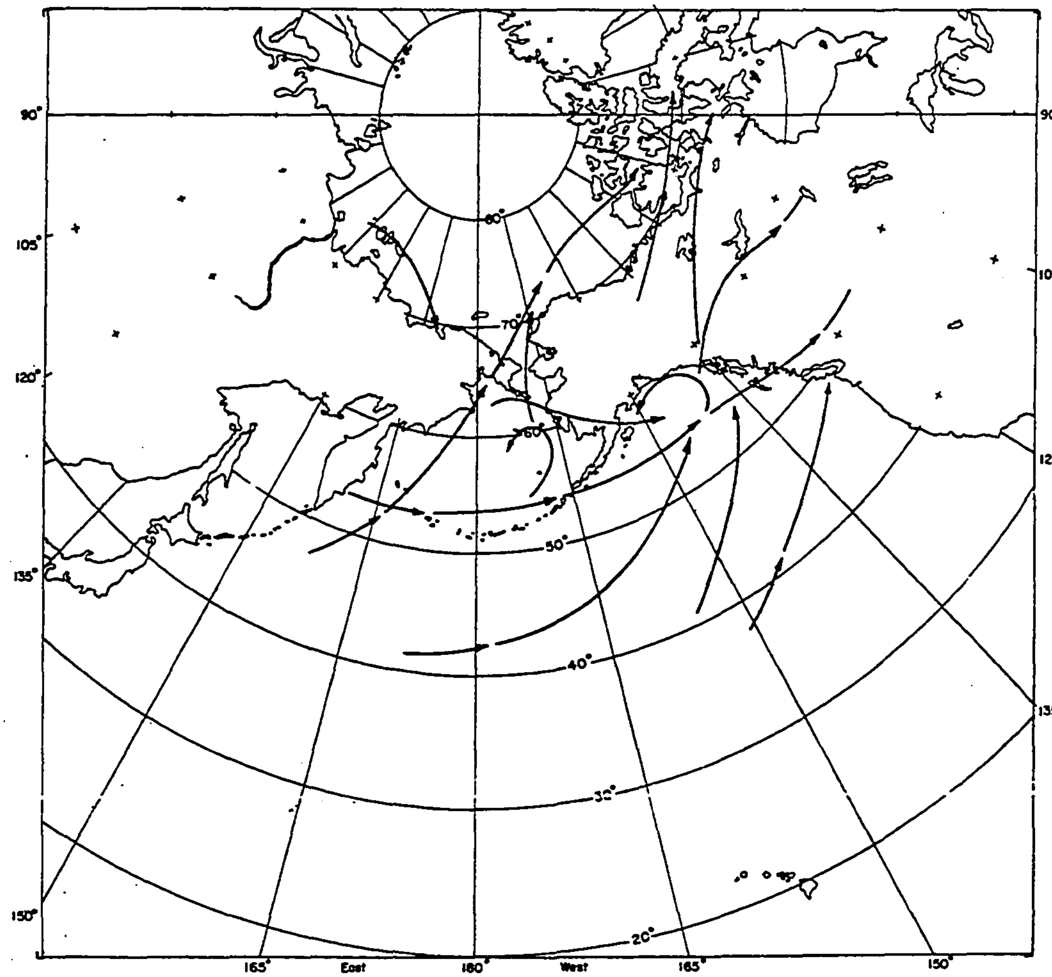


Fig. 5a. Mean tracks of low pressure centers, October through December, 1944-1951 (after U. S. Navy, 1952).

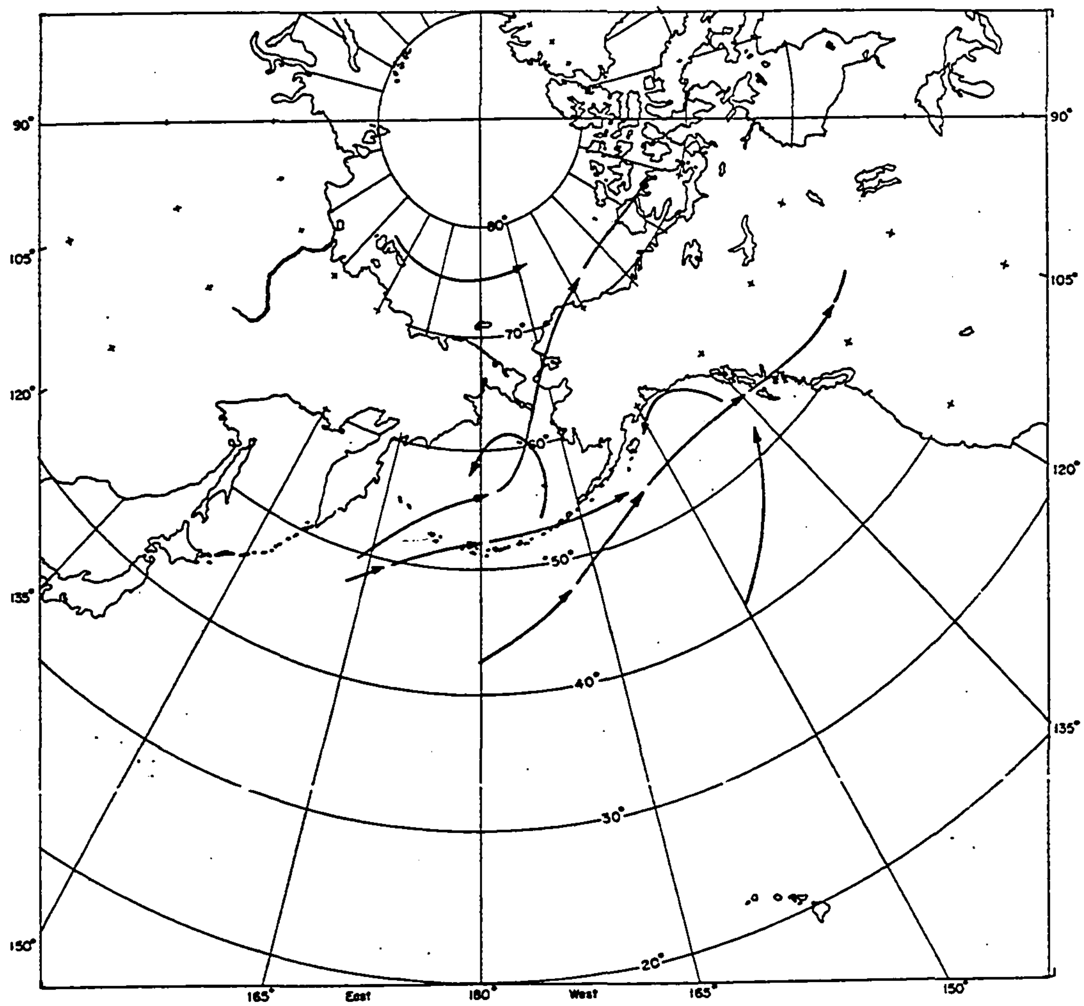


Fig. 5b. Mean tracks of low pressure centers, January through March, 1944-1951 (after U. S. Navy, 1952).

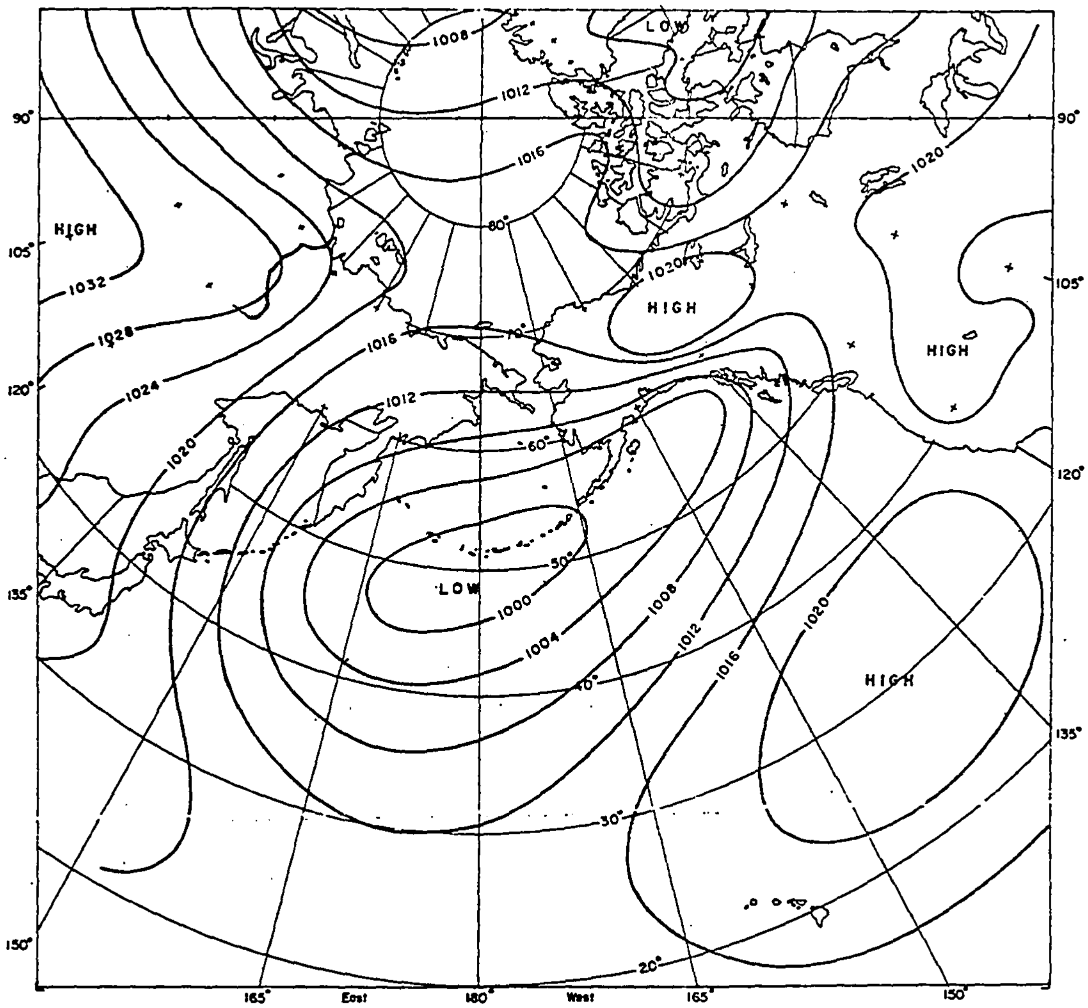


Fig. 6. January normal sea-level pressure (after Byers, 1959).

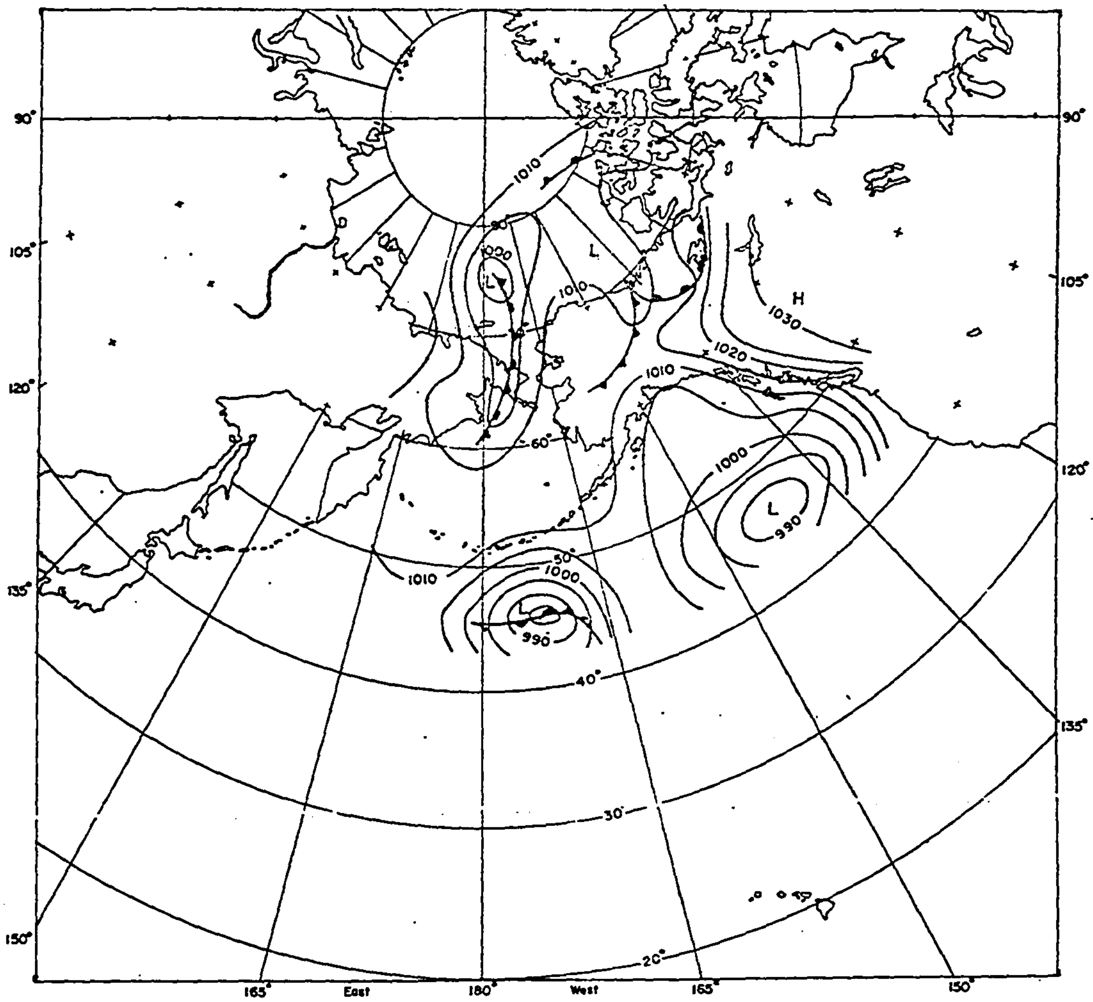


Fig. 7a. Synoptic weather map, sea level, 1200 Greenwich Time, 26 October 1957.

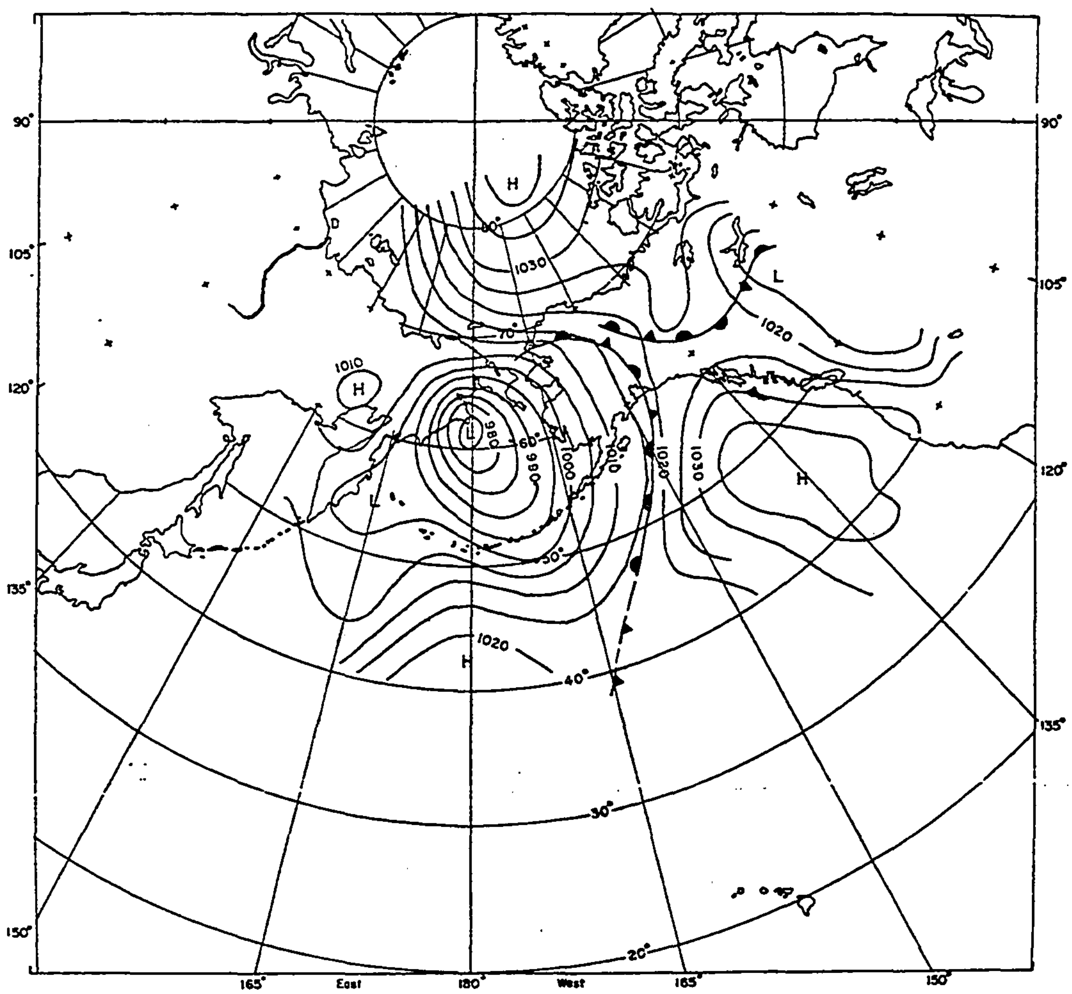


Fig. 7b. Synoptic weather map, sea level, 1200 Greenwich Time, 21 February 1960.

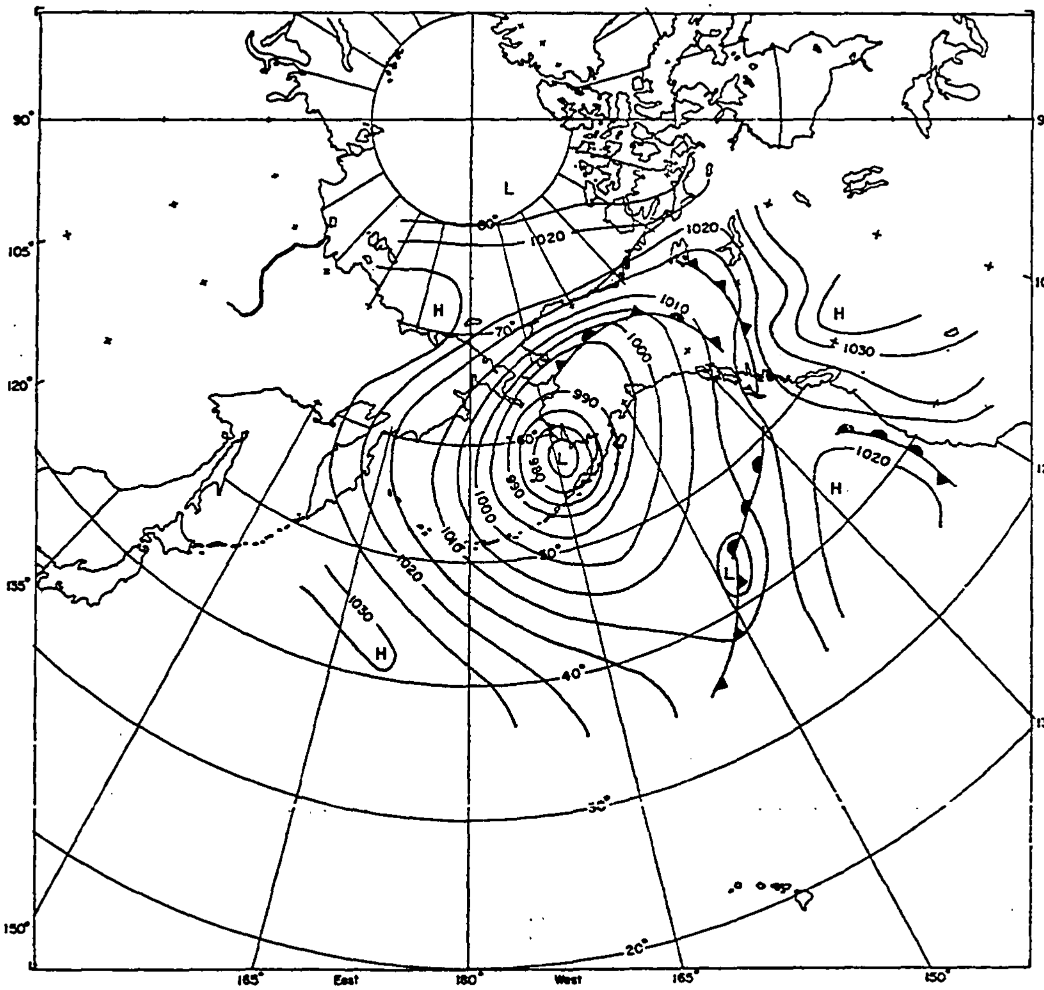


Fig. 7c. Synoptic weather map, sea level, 1200 Greenwich Time, 7 November 1961.

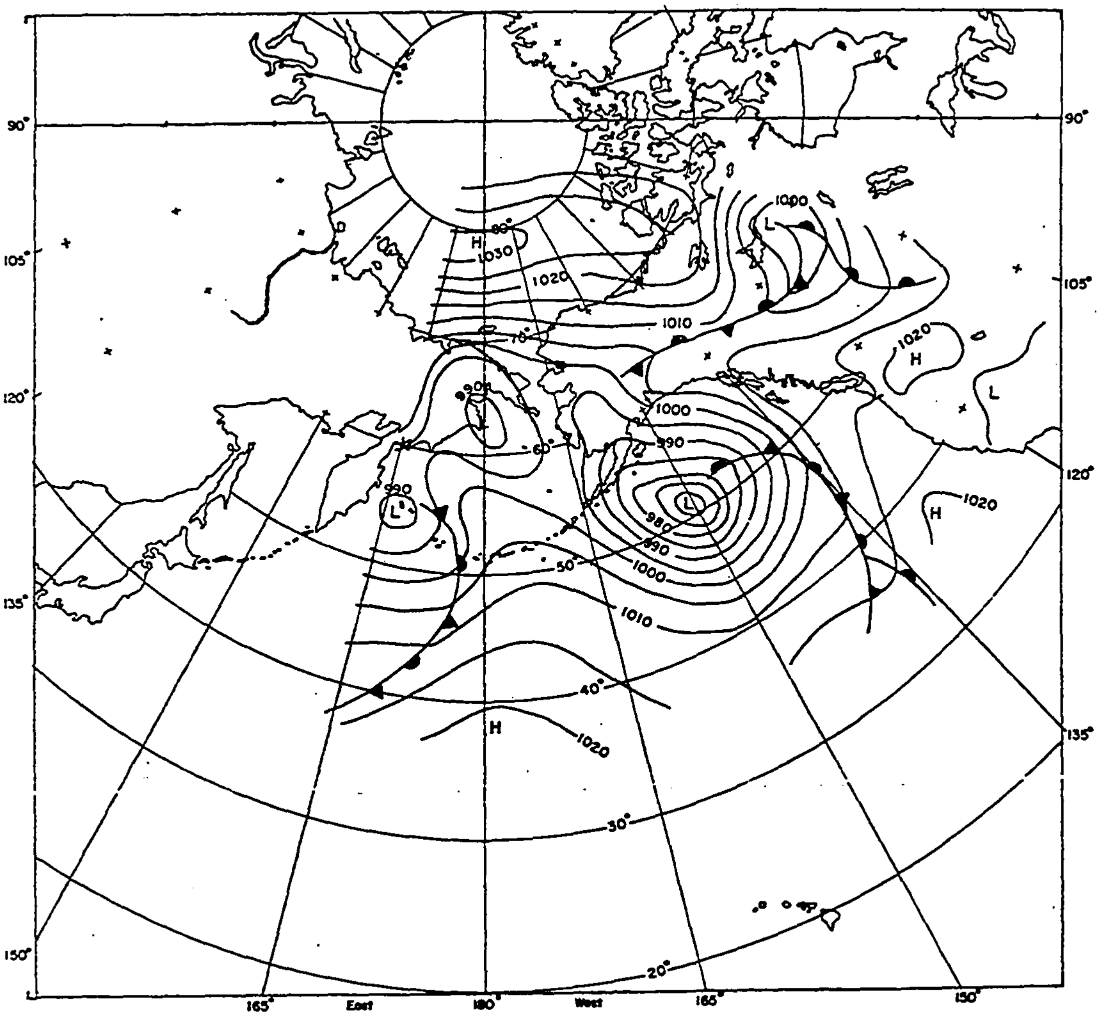


Fig. 7d. Synoptic weather map, sea level, 1200 Greenwich Time, 20 January 1965.

WBAN Form 10 (FAA)

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

SURFACE WEATHER OBSERVATIONS
(Abridged form for use at designated FAA stations)

Station: FAA, BIG DELTA, ALASKA
Date: 11/9/64

Type (1)	Time (l.s.t.) (2)	Sky and ceiling (Hundreds of feet) (3)	Visibility (Statute miles) Surface (4)	Visibility Tower (4a)	Weather and obstructions to vision (5)	Sea-level pressure (mb.) (6)	Temp (°F) (7)	Dew point (°F) (8)	Wind Direction (9)	Wind Speed (Kts.) (10)	Wind Character and shifts (11)	Altimeter setting (In.) (12)	Remarks and supplemental coded data (13)	Station pressure (In.) (17)	Dry bulb (°F) (18)	Wet bulb (°F) (19)	Total sky cover (21)	Total opaque sky cover (24)	Observer's initials (25)
R	0055	1-⌀	15			872	17	10	11	20	G28	904		27.730	17.3	16.0	7	3	CB
R	0155	1-⌀	15			876	17	10	12	15	G25	905	307 16	27.740	17.0	15.7	8	4	CB
R	0259	U⌀	15			885	17	8	12	12		908		27.770	17.2	15.5	8	6	CB
R	0355	1⌀	15			898	8	3	27	06		910		27.790	7.8	7.5	5	3	CB
R	0452	1⌀	15			910	6	2	27	06		913	227	27.820	6.2	6.0	4	3	CB
R	0555	1⌀	15			920	6	3	25	07		916		27.850	6.0	6.0	3	2	CB
R	0655	E70⊕	50			932	7	3	24	05		920		27.885	7.1	6.8	8	6	CB
R	0755	E70⊕/⊕	15+			943	9	5	24	08		923	232 06 90403	27.915	9.4	9.1	10	10	CB
R	0858	50⌀E70⊕/⊕	15+			949	11	7	26	10		926	SWU SE	27.940	11.4	11.0	10	10	LT
R	0955	40⌀E60⊕/⊕	15+			955	11	6	26	10		928	CONDS LWR SE /	27.960	10.8	10.3	10	10	LT
R	1056	40⌀E60⊕/⊕	15+			968	10	6	26	12		931	CONDS LWR SE /225	27.990	10.0	9.7	10	10	HA
R	1157	E40⌀60⊕/⊕	12		S--	971	10	7	28	11		932	SC35 CONDS LWR S	28.000	10.1	9.9	10	10	HA
R	1257	E25⌀60⊕	12		S--	978	11	6	30	08		934		28.020	10.6	10.1	10	10	HA
R	1355	-XE25⊕	3		S-	981	11	6	27	07		935	S3 HIR CLDS VSB / 21400 17	28.030	11.0	10.5	10	10	LT
S	1425	-XE25⊕	2		S-				28	08			S4	—	—	—	10	10	LT
R	1457	-XE25⊕	2		S-	985	10	7	28	08		936	S4	28.040	10.4	10.2	10	10	HA
R	1556	-XE25⊕	2		S-	993	10	7	26	06		937	S1 HIR CLDS VSB	28.050	10.1	10.0	10	10	HA
RS	1657	-XE25⊕	3		S-	995	10	7	25	04		937	S2 107	28.050	10.4	10.2	10	10	MO
R	1759	-XE25⊕	3		S-	995	10	7	25	03		937	S2	28.050	10.3	10.2	10	10	MO
R	1857	-XE25⌀K⊕	4		S-	997	10	7	00	00		938	S4	28.060	10.2	10.1	8	7	MO
R	1958	25⌀100⌀	7		S--	996	10	7	00	00		938	10303 18	28.060	9.8	9.7	4	3	MO
R	2056	100⌀1-⌀	10		S--	997	7	4	24	04		938		28.060	7.0	7.0	4	1	MO
R	2155	100⌀1-⌀	15		S--	000	1	-4	23	05		938		28.060	1.2	1.0	3	1	MO
R	2257	1-⌀	15+		IC	004	-2	-6	24	03		939	S1 10ICB35 303	28.070	-2.1	-2.1	2	0	MO
R	2356	1-⌀	15+			007	-5	-9	25	06		939	IC E20	28.070	-5.0	-5.0	3	1	MO

Time (G.c.t.) (41)	Time (l.s.t.) (42)	No. (43)	Precip (In.) (44)	Max. temp. (°F) (45)	Min. temp. (°F) (46)
	Mid. To	X	C	17	17
	0116	1	C	17	16
	0455	2	0	17	6
	1355	3	T	11	9
	1658	4	.03	11	10
	Mid.	X	T	10	-6

Station pressure computations

Time (L.s.t.) (59)				
Att. Therm. (60)				
Observ'd. Bar. (61)				
Total Corr. (62)				
Sta. Press. (63)				
Barograph (64)				
Bar. Corr. (65)				

Summary of day (Midnight to midnight)

24-Hr. max. temp. (°F) (66)	24-Hr. min. temp. (°F) (67)	24-Hr. precip. water equiv. (In.) (68)	24-Hr. snowfall unmlt'd. (In.) (69)	Snow depth (In.) (70)
17	-6	.03	.4	3

Remarks, notes and miscellaneous phenomena

WBAN 10 (FAA) 10-62 USCOMM-WB-DC

Fig. 8. Sample of Form WBAN-10 Surface Weather Observations, Big Delta, Alaska, 9 November 1964.

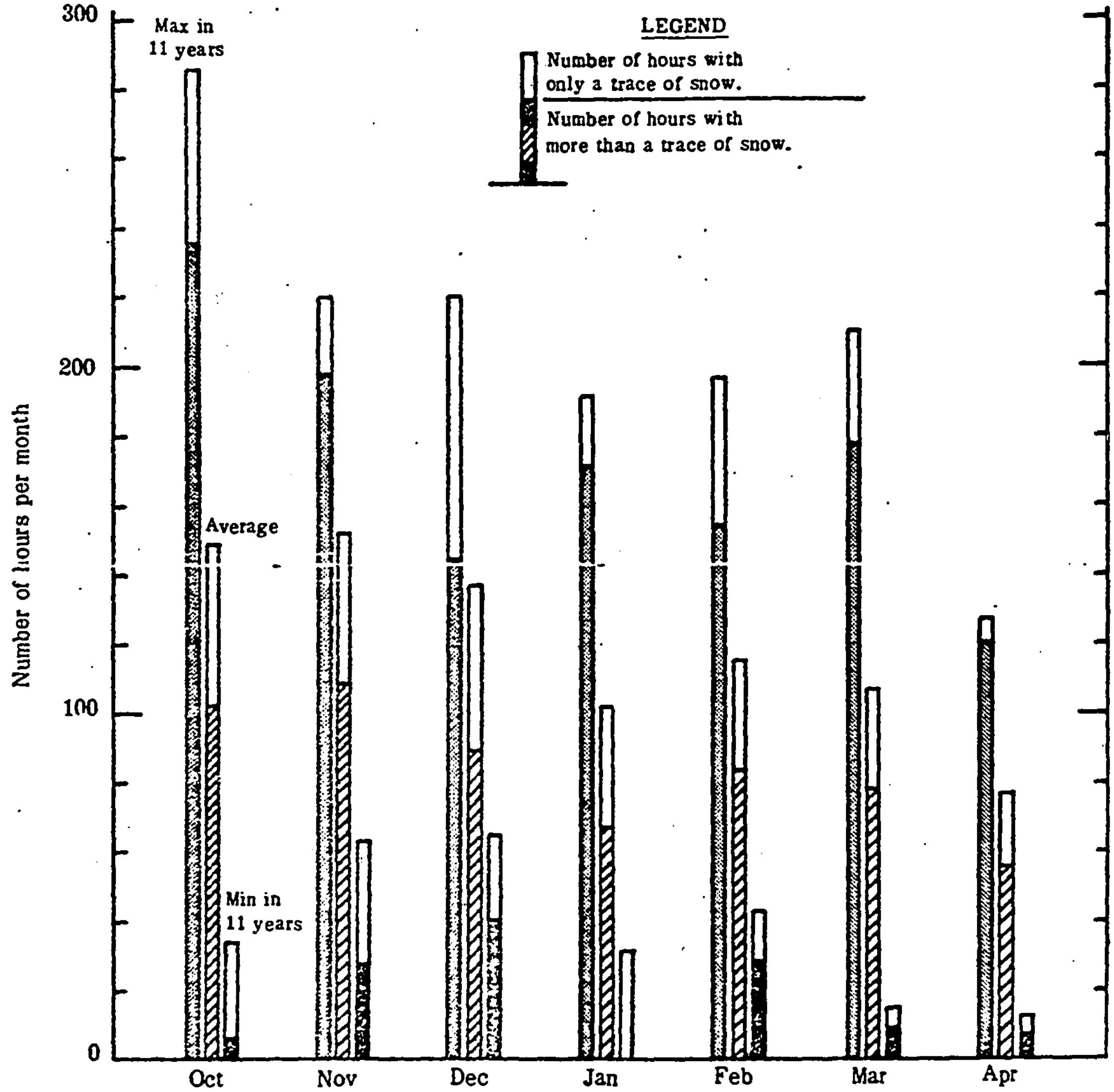


Fig. 9. Snowfall frequency, Big Delta, Alaska, October through April, 1957-1968.

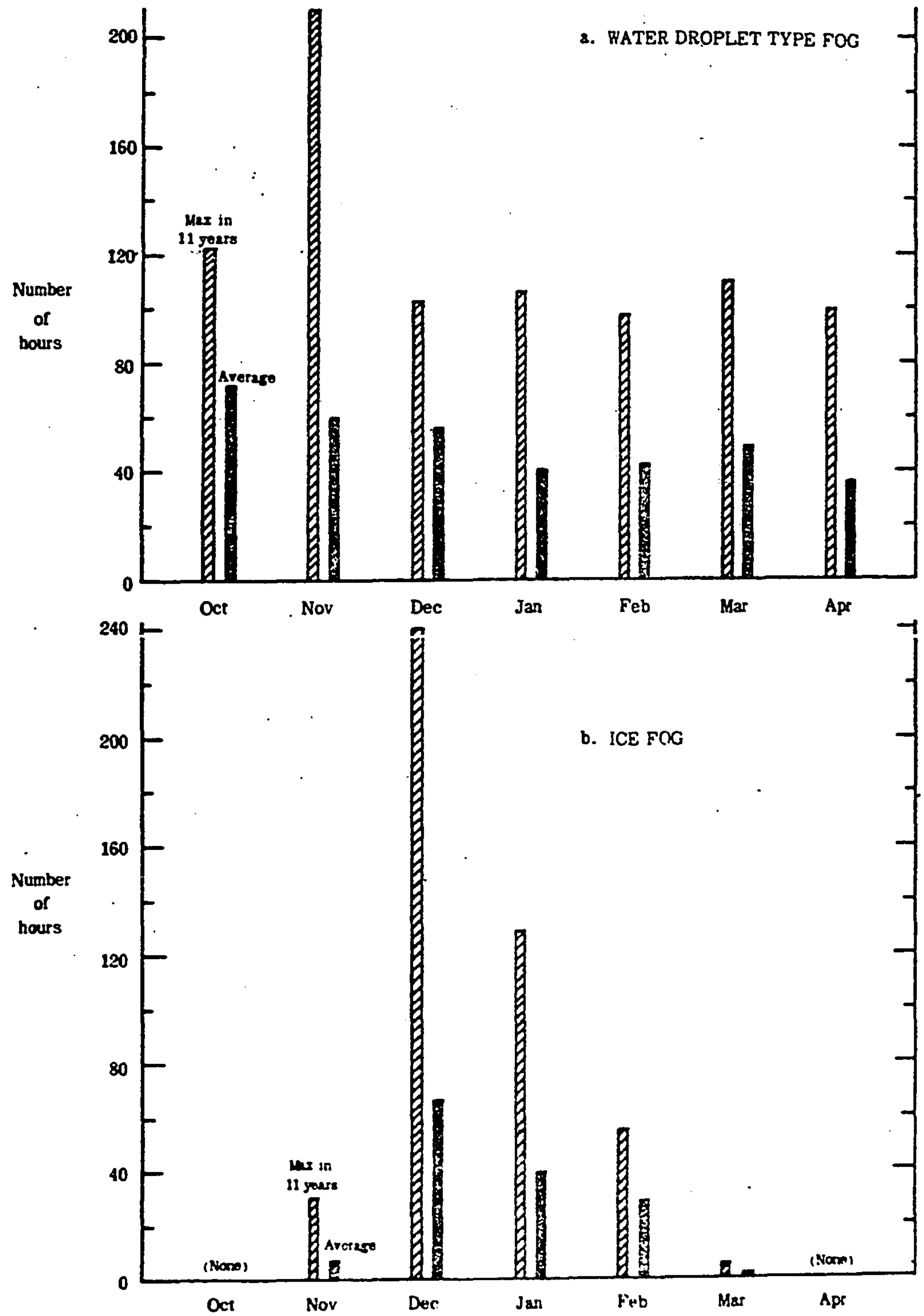


Fig. 10. Frequency of: a) water droplet fogs, and b) ice fogs, Big Delta, October through April, 1957-1968.

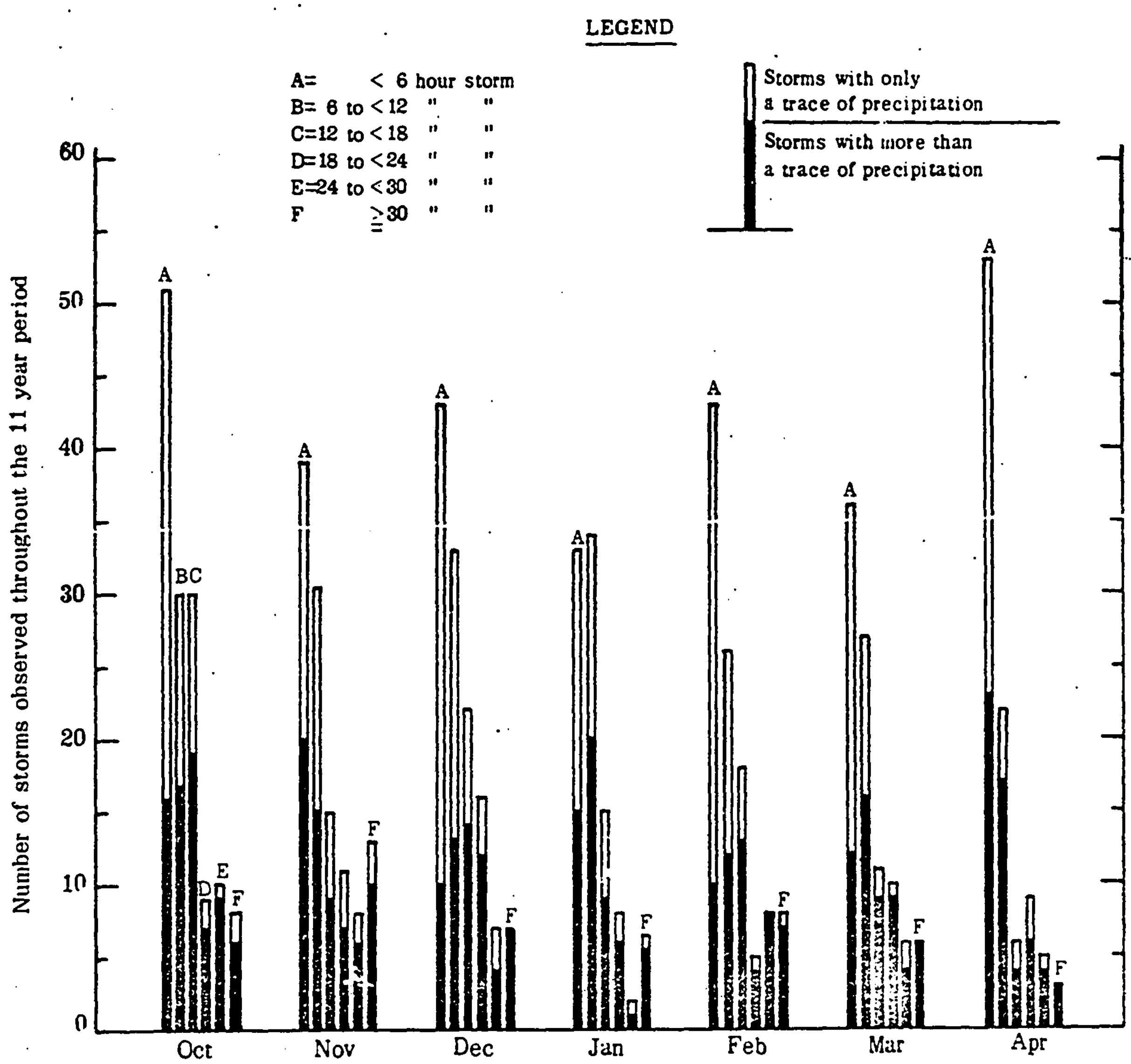


Fig. 11. Number and duration of snowstorms, Big Delta, Alaska, October through April, 1957-1968.

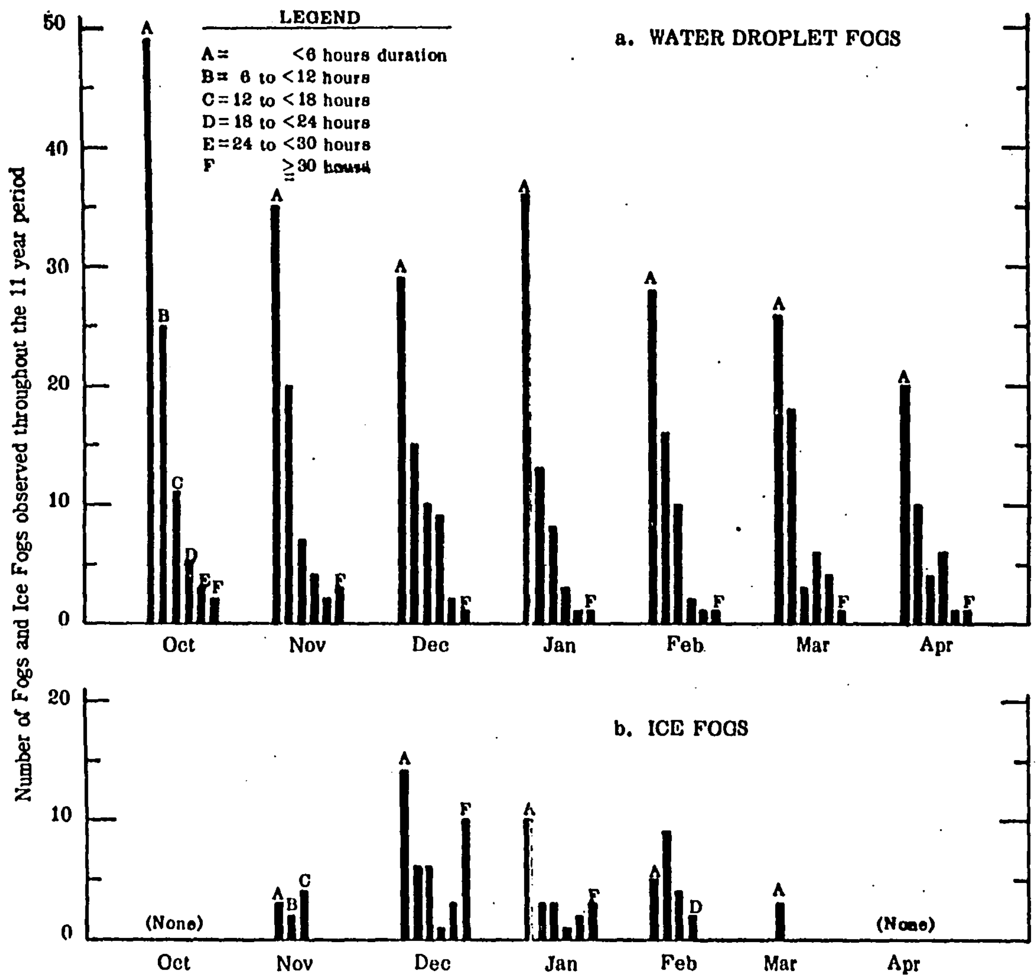


Fig. 12. Number and duration of: a) water droplet fogs and b) ice fogs, Big Delta, Alaska, October through April, 1957-1968.

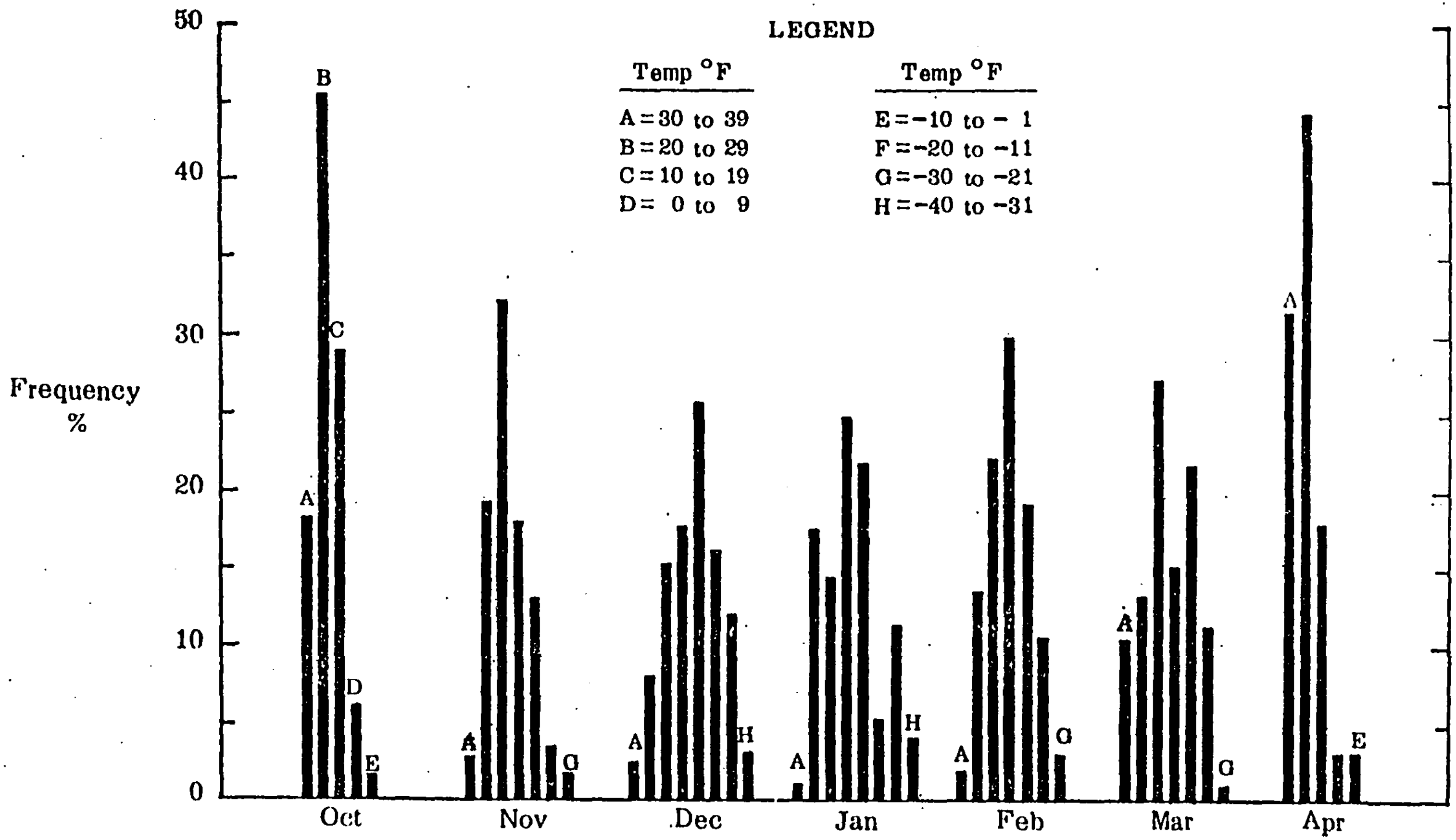


Fig. 13. Air temperatures during snowfalls, Big Delta, Alaska, October through April, 1957-1968.

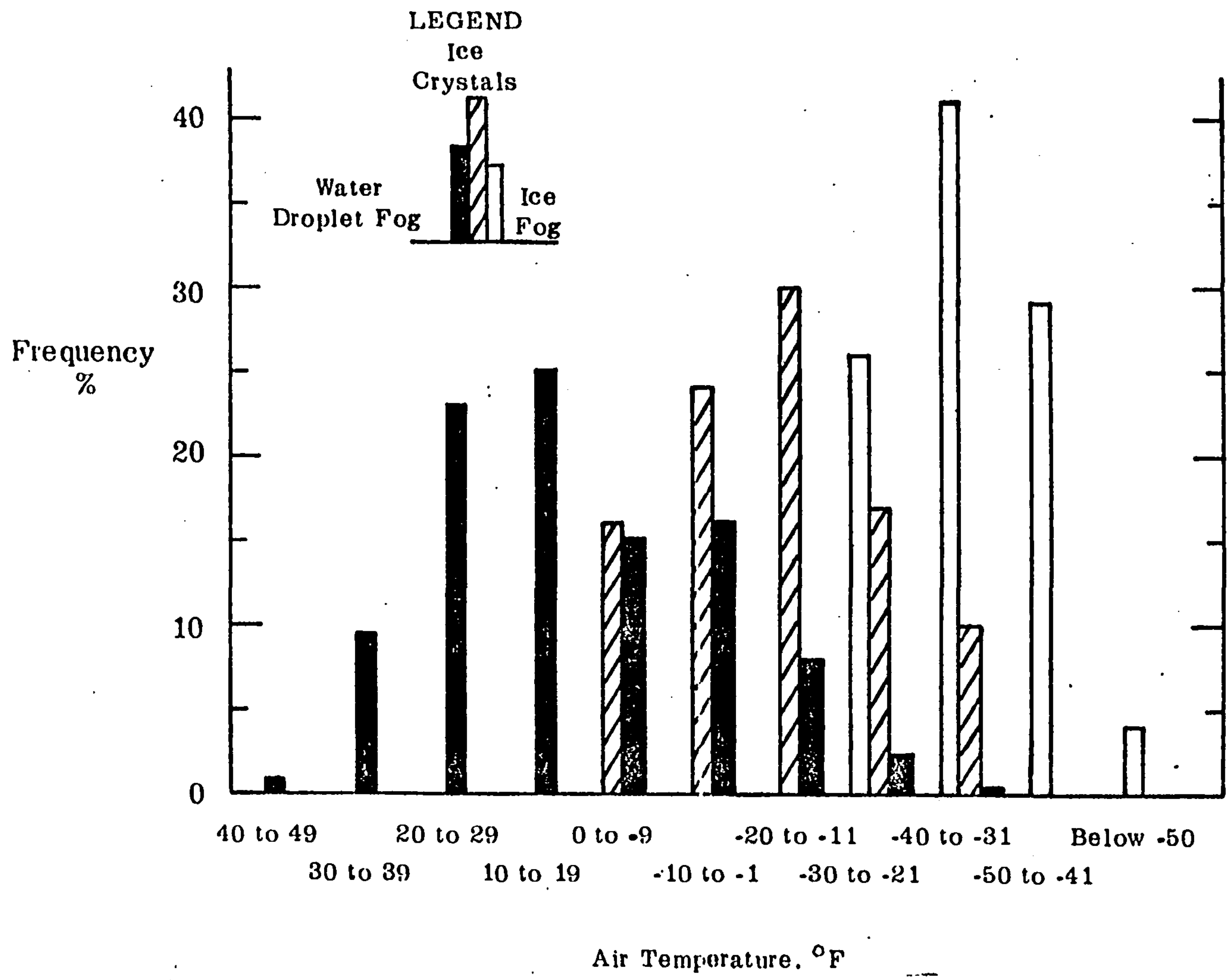


Fig. 14. Air temperatures during water droplet fogs, ice crystal occurrences and ice fogs, Big Delta, Alaska, October through April, 1957-1968.

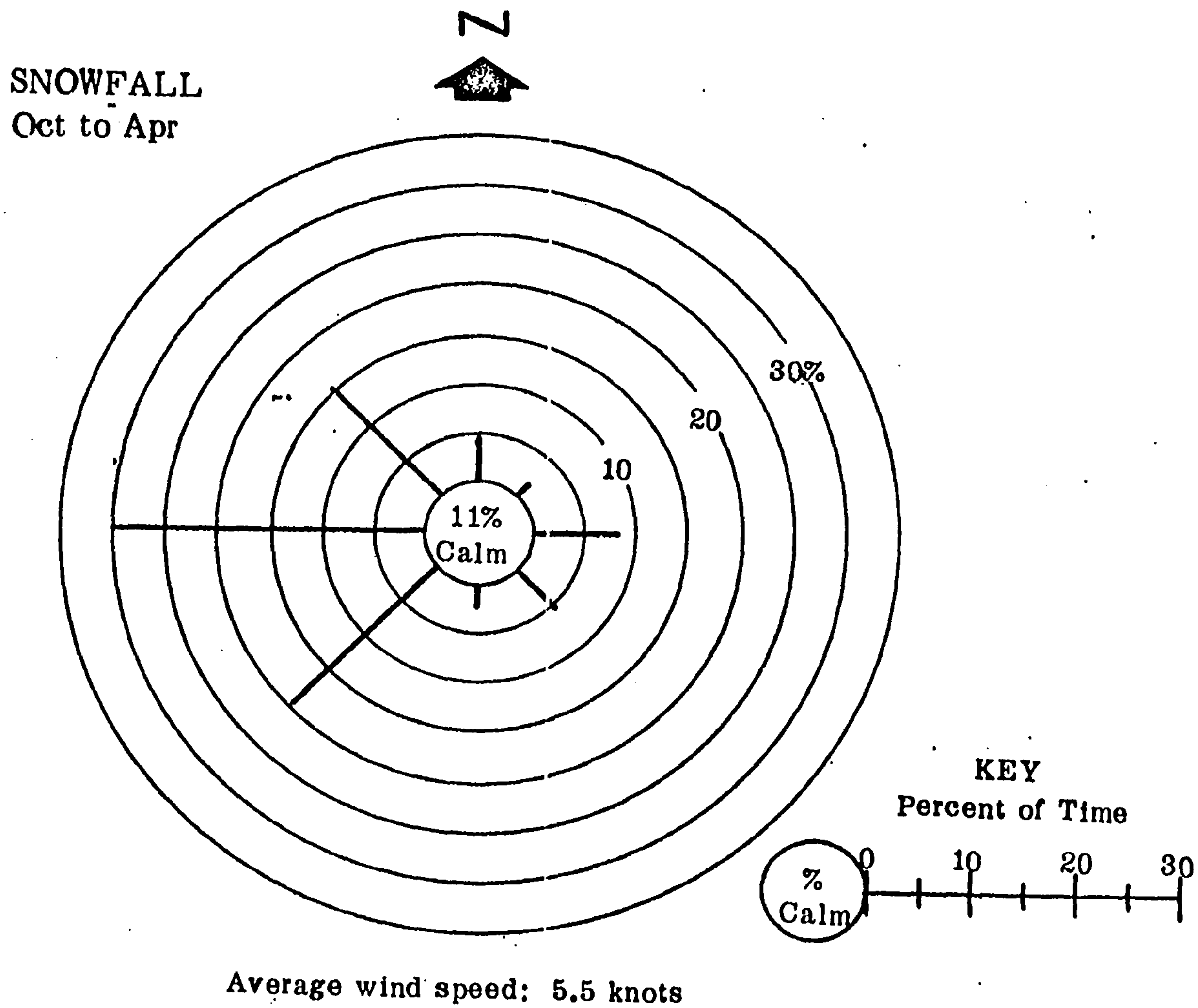


Fig. 15. Wind direction and average speed during snowfalls, Big Delta, Alaska, October through April, 1957-1968.

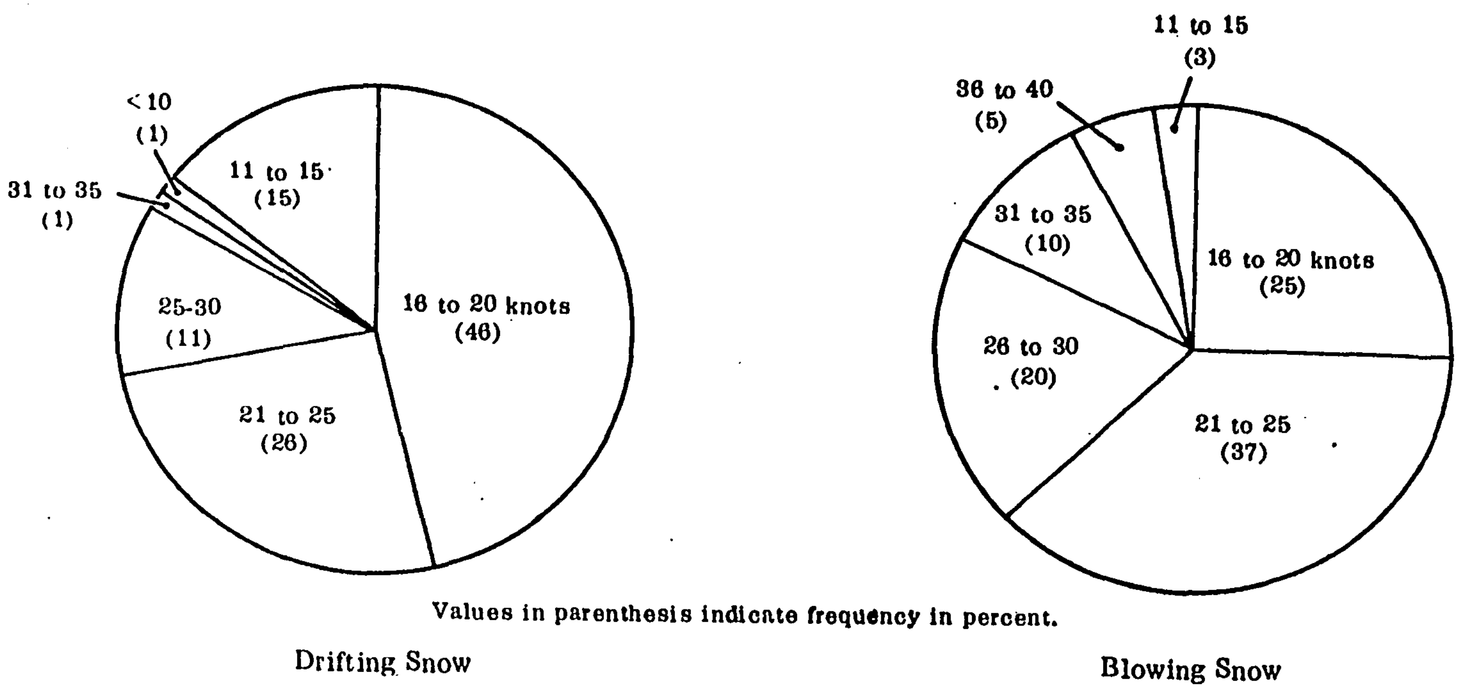
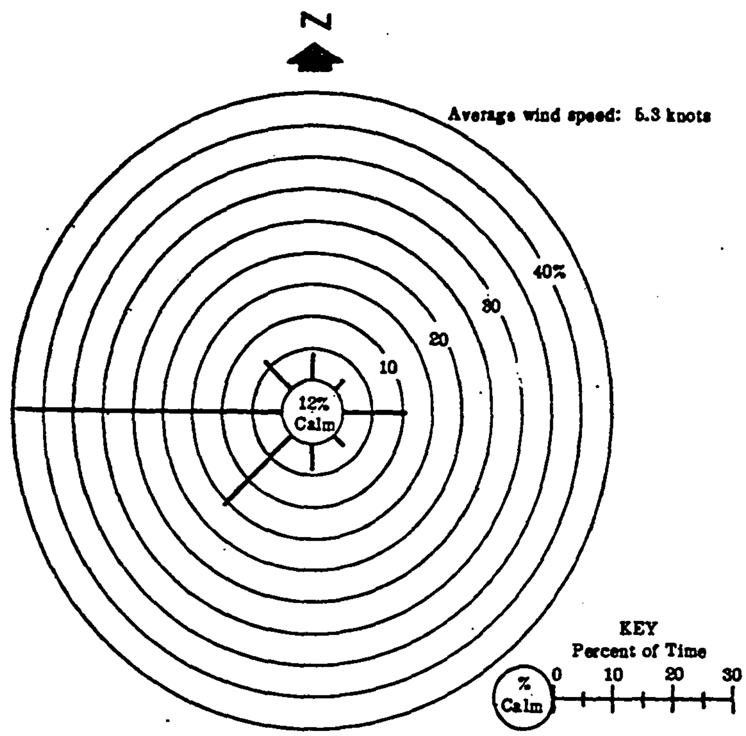
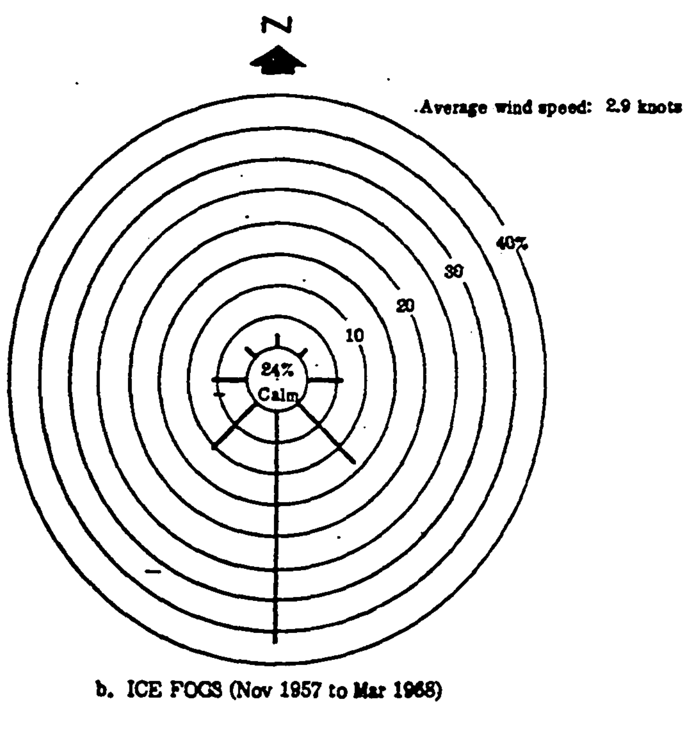


Fig. 16. Wind speeds during drifting and blowing snowstorms, Big Delta, Alaska, October through April, 1957-1968.



a. WATER DROPLET FOGS (Oct 1957 to Apr 1968)



b. ICE FOGS (Nov 1957 to Mar 1968)

Fig. 17. Wind direction and average speed during: a) water droplet fogs and b) ice fogs, Big Delta, Alaska, October through April, 1957-1968.

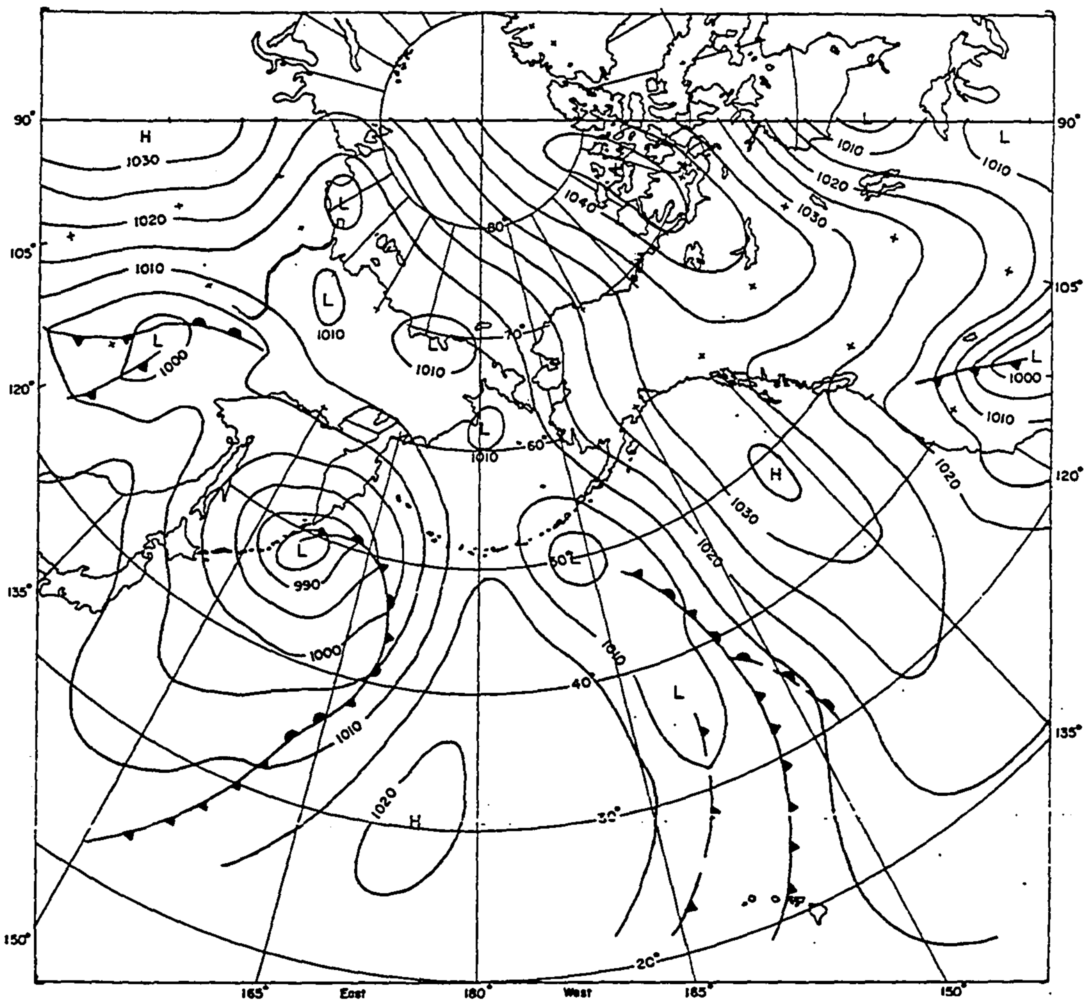


Fig. 18. Synoptic weather map, sea level, 1200 Greenwich Time, 22 March 1965

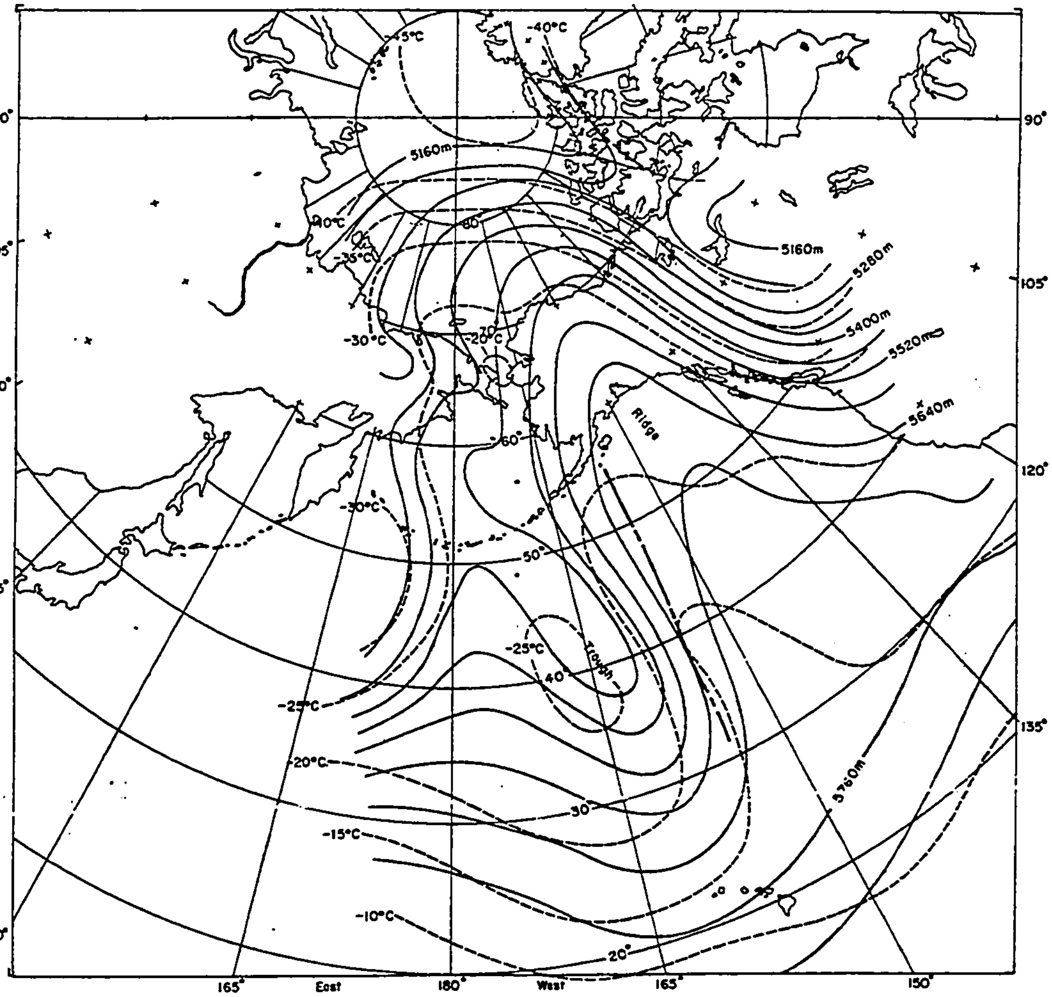


Fig. 19. Upper level (500 mb) weather map, 1200 Greenwich Time, 22 March 1965.

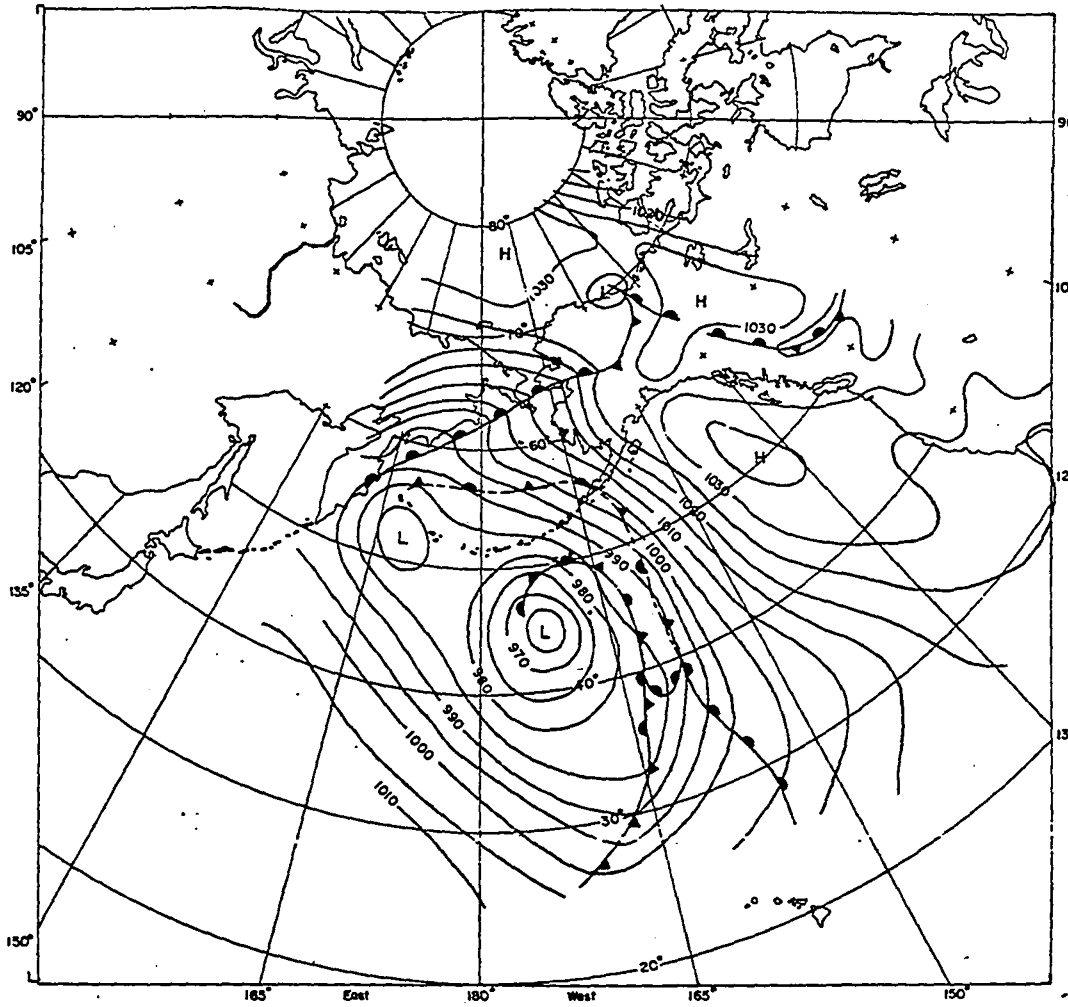


Fig. 20. Synoptic weather map, sea level, 1200 Greenwich Time, 15 January 1963.

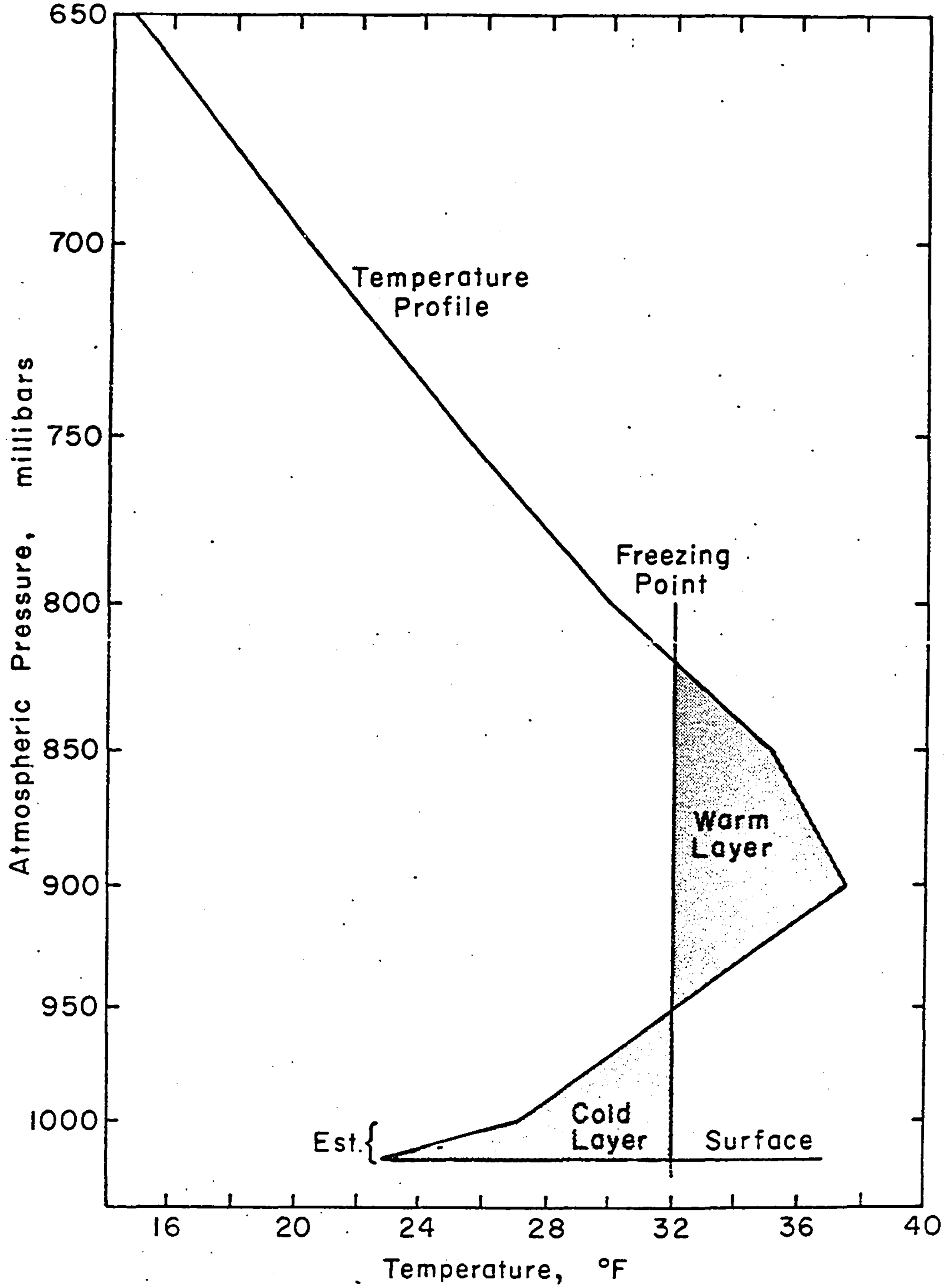


Fig. 21. Average temperature lapse rate during freezing drizzle and freezing rain, Eielson Air Force Base, Alaska, January through December 1958-1964.