HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND
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TECHNICAL REPORT

EP-130

MICROCLIMATOLOGY OF A SUBARCTIC SPRUCE FOREST AND A CLEARING AT BIG DELTA, ALASKA

QUARTERMASTER RESEARCH & ENGINEERING CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

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NATICK, MASSACHUSETTS

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Quartermaster Research & Engineering Center
Natick, Massachusetts

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MICROCLIMATOLOGY OF A SUBARCTIC SPRUCE FOREST AND A CLEARING AT BIG DELTA, ALASKA

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FOREWORD

This report is one in a Quartermaster Corps series dealing with the microclimate and topoclimate of extreme environments, generally those at Department of the Army test sites. As in the case of other similar studies, the measurements and observations were made by personnel of the US Army Signal Corps in accordance with instructions given by the author. Contents of this report are taken mainly from the Ph.D. dissertation completed during the author's graduate training at Harvard University under Quartermaster Corps sponsorship.

The report deals mainly with the vertical distribution of temperature and wind, and of radiation, at two greatly contrasting sites at Fort Greely, Big Delta, in subarctic, interior Alaska. These sites, one in a clearing and the other located nearby in a coniferous forest (taiga), are believed to be representative of much of the subarctic where troops may be called upon to operate and in which Quartermaster Corps clothing and equipment, and materiel developed by other Technical Services (US Army), must function efficiently under extreme conditions.

Results of this study show that large differences in temperature, wind, solar radiation, precipitation, snow cover, and snow depth, occurred between the two stations. In addition, large differences in tempera ture and wind occurred at each station. A knowledge of the variations in climatic elements between the ground and air (within the "climate of the soldier"), and of the differences that occur between the surface and standard weather shelter height as well as differences between the two microclimatic stations, is essential to a complete understanding of the extreme physical environment of the subarctic in which soldiers must operate and survive.

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THE APPENDIX IS AT THE BACK OF THE REPORT. IT CONTAINS RADIATION, TEMPERATURE, AND PRECIPITATION DATA OBTAINED FROM MEASUREMENTS MADE IN 1956 AT THE WOODS AND OPEN MICROCLIMATIC STATIONS AT BIG DELTA.

ABSTRACT

This study deals with the microclimatology of two greatly contrasting sites at Fort Greely, Big Delta, Alaska; one in a coniferous forest (taiga) and the other in an adjacent clearing. Continuous measurements of the vertical distribution of temperature and wind, and the measurements of solar radiation, precipitation, and globe thermometer temperatures, supplemented by the usual visual and manual observations and measurements, such as sky cover, clouds, snow depth, etc., were conducted from June 1956 through September 1957. This report presents an analysis of the data for two months, June 1956 (summer) and December 1956 (winter).

The spruce forest effectively decreased solar radiation received at or near the surface of the ground in both summer and winter. In June, total daily solar radiation in the forest was only one-third that received in the clearings. In December, no solar radiation was measured in the forest, the amounts received being too weak to activate the pyrheliometer, but in the clearing as much as 20 ly were measured in one day. The maximum in the open in any one hour, however, was only 10 ly.

In June, 30 ly or more were measured in the forest during 4 percent of the hours; 60 ly or more were measured in the clearing during 7 percent of the hours.

In December, it was found that ice fogs significantly decreased amounts of solar radiation received, indicating that solar radiation recorded near camps, towns, and cities (areas having the greatest frequencies of these fogs) may not be representative of amounts actually received only short distances away, in the field.

In June, precipitation measured in the clearing (4.65 in.) was about 20 percent greater than that measured in the woods (3.72 in.) because of interception by the trees.

In December, the depth of snow at each station was of greater importance to microclimatic relationships than the amounts of snowfall received. In the forest, the snow cover averaged 43.4 cm* in depth, while in the clearing it averaged only 22.1 cm. The greater insulation afforded by the deeper snow in the forest affected the temperatures measured in the ground, at the surface, and in the snow itself.

The vegetation of the forest and, in winter, the deeper snow, were instrumental in causing very large differences between the stations in soil, ground surface, and above-surface temperatures. Air temperatures

*1 cm = 0.4 inch

ABOVE 50 CM, HOWEVER, WERE GENERALLY NOT GREATLY AFFECTED, AND EXCEPT ON COLD, CLEAR, CALM NIGHTS DURING WINTER, FROM 50 CM TO 400 CM, THERE WERE ONLY SMALL DIFFERENCES IN AIR TEMPERATURES BETWEEN COMPARABLE LEVELS AT THE STATION, OR BETWEEN CONSECUTIVE LEVELS AT THE SAME STATION. AT NO TIME DID A STRONG INVERSION EXIST BETWEEN 50 CM AND 400 CM AT EITHER STATION.

AT BOTH STATIONS, THERE WAS AN INCREASE IN LAG IN SOIL WARMING WITH INCREASING DEPTH DURING JUNE. THIS LAG WAS MUCH GREATER IN THE FOREST THAN IN THE CLEARING.

AT BOTH STATIONS, THERE WAS A DECIDED DAMPING (REDUCTION) OF SOIL TEMPERATURE FLUCTUATIONS WITH INCREASING DEPTH. THIS DAMPING WAS MORE PRONOUNCED IN THE FOREST, AND WAS ESPECIALLY EVIDENCED IN JUNE WHEN TEMPERATURES AT -60 CM REMAINED CONSTANT AT 31 F, WHILE IN THE CLEARING, TEMPERATURES AT THIS SAME DEPTH HAD ALREADY INCREASED FROM BELOW FREEZING (32F) TO BETWEEN 45F AND 50F.

AT BOTH STATIONS, GREATEST VERTICAL DIFFERENCES IN TEMPERATURES OCCURRED IN THE SOIL AND, IN WINTER, IN BOTH THE SOIL AND SNOW, RATHER THAN IN THE AIR.

IN THE FOREST IN SUMMER, HIGHEST TEMPERATURES WERE MEASURED AT THE SURFACE, BUT IN THE CLEARING, HIGHEST TEMPERATURES WERE MEASURED AT -2.5 CM, BECAUSE OF EVAPORATIVE COOLING WHICH DECREASED TEMPERATURES AT THE (GROUND) SURFACE.

SIGNIFICANT INVERSIONS IN AIR TEMPERATURES WERE NOT APPARENT IN WINTER, EVEN DURING IDEAL TIMES OF EXTREME COLD, CLEAR SKIES, CALM AIR, AND LONG NIGHTS. DURING SUCH TIMES, HOWEVER, NIGHTTIME AIR TEMPERATURES IN THE CLEARING WERE USUALLY 5 F DEG. TO 10 F DEG. LOWER THAN THOSE OF THE FOREST, PROBABLY DUE IN PART TO THE LARGER NET NOCTURNAL RADIATION LOSS IN THE CLEARING. RADIATION LOSS WAS CAUSED BY THE SPRUCE TREES AT THE FOREST STATION; IN ADDITION, THE TREES THEMSELVES RADIATED TO THE SURROUNDING AIR.

IN BOTH JUNE AND DECEMBER, WEATHER ELEMENTS SUCH AS CLOUDS, PRECIPITATION, AND/OR STRONG WINDS TENDED TO REDUCE DIFFERENCES IN TEMPERATURES BETWEEN THE STATIONS, PARTICULARLY IN THE AIR AND SNOW. THE OCCURRENCE OF THESE CLIMATIC ELEMENTS IN DECEMBER SERVED TO RAISE TEMPERATURES, WHILE IN JUNE THEY TENDED TO LOWER THEM.

THE MODIFYING INFLUENCE OF THE FOREST ON WIND, ESPECIALLY WIND SPEEDS, WAS QUITE PRONOUNCED. IN JUNE, THE STRONGEST WIND IN THE FOREST WAS ONLY 3 MPH, WHILE IN THE CLEARING THE STRONGEST WAS 11 MPH. IN DECEMBER, THE STRONGEST WIND RECORDED IN THE FOREST WAS 8 MPH, AND IN THE CLEARING, 16 MPH. FROM MEASUREMENTS MADE OF WIND SPEEDS DURING THIS STUDY, IT IS BELIEVED THAT WINDS STRONGER THAN 10 MPH WILL OCCUR VERY INFREQUENTLY CLOSE TO THE GROUND (200 CM OR LESS) IN A SUBARCTIC TAIGA

SUCH AS THAT OF THE FOREST STATION. THE WEAKER WINDS IN THE FOREST RESULT IN LESS WINDCHILL STRESS ON TROOPS, OF CRITICAL IMPORTANCE IN WINTER, AND ALSO IN REDUCED HEATING AND FUEL REQUIREMENTS FOR SHELTERS.

IN THE CLEARING, STRONGEST WINDS OCCURRED AT 200 CM, BUT IN THE FOREST, STRONGEST WINDS OCCURRED MOST FREQUENTLY CLOSER TO THE GROUND, AT 30 CM. ANIMAL TRAILS, THE ABSENCE OF FOLIAGE, AND THE FEWER BRANCHES AT AND NEAR THE GROUND IN THE FOREST, PERMITTED FREER CIRCULATION OF THE AIR CLOSE TO THE GROUND.

MICROCLIMATOLOGY OF A SUBARCTIC SPRUCE FOREST AND A CLEARING AT BIG DELTA, ALASKA

PART I - INTRODUCTION

1. LOCATION AND SIGNIFICANCE OF THE AREA

BIG DELTA, ALASKA, OCCUPIES THAT PART OF THE TANANA RIVER VALLEY NEAR WHICH THE ALASKA AND RICHARDSON HIGHWAYS JOIN IN CENTRAL ALASKA AND CROSS THE TANANA UPSTREAM FROM ITS JUNCTION WITH THE DELTA RIVER (FIG. 1). IT IS LOCATED AT 145°50' W. LONGITUDE AND 64°09' N. LATITUDE IN SUBARCTIC, INTERIOR ALASKA, ABOUT 100 MILES SOUTHEAST OF FAIRBANKS.

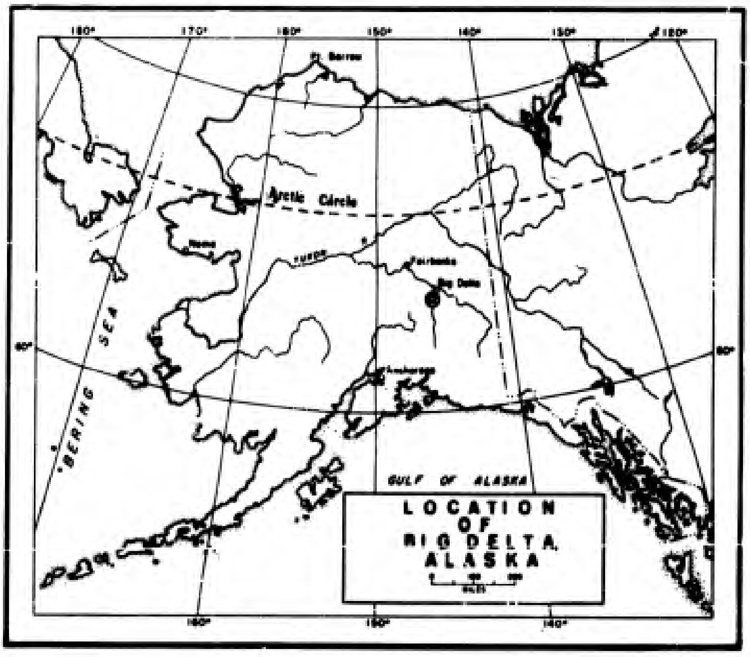


FIGURE 1

BIG DELTA IS USED EXTENSIVELY BY THE UNITED STATES ARMY. THE AREA WAS FIRST USED BY THE ARMY IN JUNE 1942 (U.S. ARMY CHEMICAL CORPS, 1956), AND HAS BEEN USED CONTINUOUSLY SINCE THAT TIME EXCEPT FOR THE PERIOD FROM SUMMER 1945 TO FALL 1947. IN 1948, THE ARMY ARCTIC INDOCTRINATION SCHOOL WAS ESTABLISHED TO TRAIN OFFICERS AND MEN IN ARCTIC TACTICAL CONCEPTS AND SURVIVAL TECHNIQUES. IN 1949, THE POST WAS REDESIGNATED THE ARMY ARCTIC TRAINING CENTER. ON 1 JULY 1955 THE INSTALLATION WAS NAMED FORT GREELY IN HONOR OF GENERAL ADOLPHUS W. GREELY, ARCTIC EXplorer and pioneer of what is now the Alaska Communications System. Fort Greely is the northernmost permanent Army post and has more than 1,000 officers, enlisted men, and civilians engaged in testing, training, and research and development.

2. Purpose and objectives

The primary purpose of this study was to obtain a better understanding of the actual environment, close to the ground, in which men, animals, and plants live in the Subarctic. In recent years increasing emphasis has been given to studying this microenvironment, particularly the climate (Baum, 1948a, 1948b, 1949a, 1949b; Baum and Court, 1949; Thornthwaite, 1949 and 1950; F. A. Brooks, 1950; Dodd, 1950). Much of this work has been, and is being, done in tropical and temperate regions, although the International Geophysical Year substantially increased research conducted in polar regions. There is still a critical lack of meteorological and climatological data and information for the Arctic and Subarctic, however, and microclimatic studies of any magnitude and significance are lacking. The need for further research in meteorology, climatology, and microclimatology in the Arctic and Subarctic is discussed in publications by Shelesnyak (1950), Olmstead (1952), University of Alaska (1954), Sverdrup (1954), Dyer (1955), and Thornthwaite (1957). In each, the urgency for further climatological research is stressed as essential for solving problems in many fields of science.

This study is intended as a contribution to a better knowledge of the climate and microclimate of a subarctic area. The objectives listed below reflect this purpose.

a. To analyze data, to determine the differences, and the magnitude and direction of these differences, between a subarctic spruce forest (taiga) and an adjacent, unvegetated area, by

(1) Gathering data on radiation, temperature (air, soil, and snow), wind, precipitation, and snow cover for application to military and other problems.

(2) Noting and emphasizing the differences in the same climatic element between the wooded area and open area.

(3) Comparing the frequency of occurrence and the duration of climatic elements, both singly and combined within specified limits, between wooded and open sites.

b. To aid in the production of climatological estimates by noting the effects of natural vegetation, especially in areas where weather stations are sparse and weather data not available.

3. Topography

The topography, including vegetation and permafrost, of the Big Delta area is described in publications: Bensin (1952), Black (1951a, 1951b), Holmes and Benninghoff (1957), Hopkins and others (1955), Jackman (1953), H. A. Johnson (1953), Kellog and Nygard (1951), Lutz (1956), MacKay (1955), Mendenhall (1898), Mertie (1937), Muller (1944), Palmer (1940), Péwé (1951, 1955a, 1955b), Péwé and others (1953), and Raup (1945a).

The Big Delta area, drained by a major river, the Tanana, includes both multiple-glaciated and unglaciated terrain (Péwé and others, 1953). The area, part of the Tanana River Lowland, slopes upward from an elevation of about 1,000 feet at the Tanana flood plains in the north, to 1,500 to 1,700 feet in the glacial moraine near the foothills of the Alaska Range in the south. Glacial outwash plains (Péwé, 1955a) compose much of the area. It is upon this terrain feature that Fort Greely is located and the microclimatic study discussed herein was conducted. These plains are broad and gently sloping. In many sections there are few or no old stream channels; in a few sections the surface is stream-scarred. In most places the underlying gravel is covered with at least 2 to 6 inches of silt (loess). In silt-filled stream channels, marshes, and muskeg, however, the gravel may be overlaid by as much as 10 feet of organic silt and peat. With few exceptions, the outwash plains are covered with a moderately dense growth of vegetation.

The Big Delta area lies in the region of discontinuous permafrost (Black, 1951b; Hopkins, et al., 1955, p. 116), but permafrost is apparently absent or very deep at the site of the microclimatic stations. These stations, located on the outwash plain, are underlaid by many feet of gravel, and drainage is good.

According to Kuchler (1953), the Big Delta area lies within the broad, needleleaf evergreen forest or taiga, called the lichen woodland by Dansereau (1955), and the forest tundra by Hustich (1953), which extends across the northern parts of the Eurasian and North American continents. With few exceptions, the outwash plains are covered with a moderately dense growth consisting primarily of aspen, white and black spruce, birch, cottonwood, alder, and willows (Fig. 2). Trees are mostly 15 to 25 feet in height, but a few are 30 or 35 feet high. The woods contain an undergrowth of many types of small shrubs, and the ground surface is covered with a moss-lichen mat that varies in thickness from several inches to nearly a foot. One of the microclimatic stations at Fort Greely was placed in such a mixed coniferous-deciduous woods (Fig. 3) and the other was installed in a cleared, open area nearby (Fig. 4).

4. Climate

The climate of the Big Delta area is discussed in detail by Duff and Diehl (1952), Ehrlich (1953), de Percin, Falkowski and Miller (1955),

Figure 2: Vegetation on the outwash plain. Trees are predominantly black and white spruce, and aspen.

Mitchell (1955), de Percin and Falkowski (1956), Evans (1957), Hastings (1959), and de Percin and Parmele (1960), and in publications of the U.S. Army Air Force (1943a, 1943b), and U.S. Air Force (1952).

The Big Delta area has long, cold, dry winters and relatively short, mild, cloudy summers. The climate, like that of other arctic and sub-arctic areas, is characterized by long hours of sunlight during the warm season, May to August, and by a minimum number of hours during the coldest part of the year, November to March. Figure 5 shows about 21 hours of sunlight at the summer solstice, June 21. It is never actually dark, however, for twilight persists during the other three hours.

5. Microclimatic studies

a. General

The Civil Aeronautics Administration (CAA) weather station, located at the Big Delta Airfield, serves as the first-order weather station for the area. This station has been in operation since October 1945 and 15 years of hourly and special weather observations have been compiled. These data provide a long-period record for use when conducting climatic studies of the area.

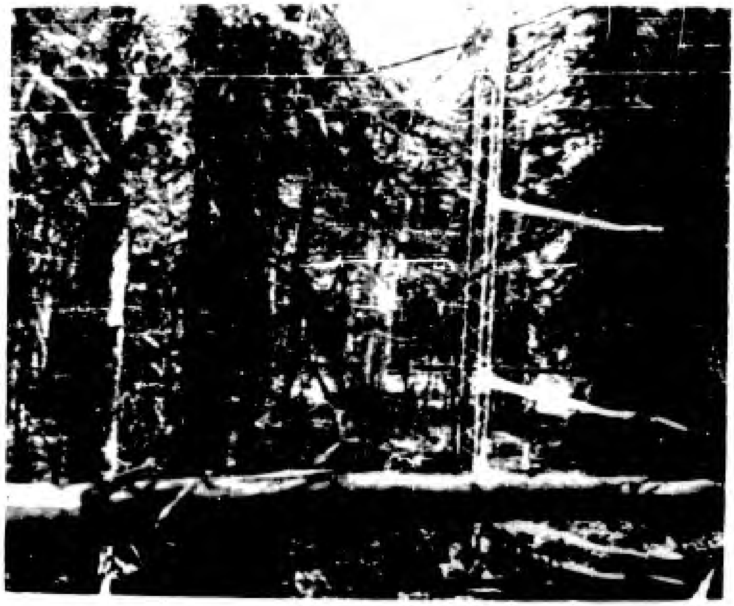


FIGURE 3: WOODS MICROCLIMATIC STATION. TREES ARE MOSTLY BLACK SPRUCE WITH SCATTERED WHITE SPRUCE, COTTONWOOD, AND ASPEN.

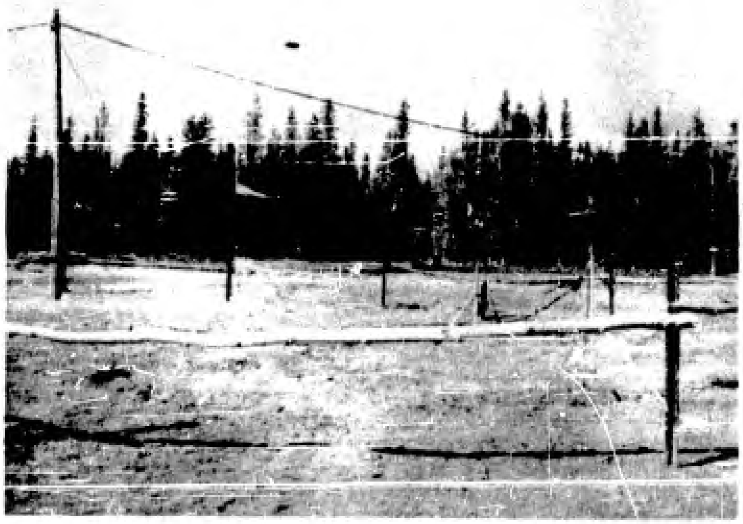


FIGURE 4: OPEN MICROCLIMATIC STATION. THE FEW PLANTS ON THE GROUND ARE GRASSES AND WEEDS, BUT THE SURFACE IS LARGELY BARE.

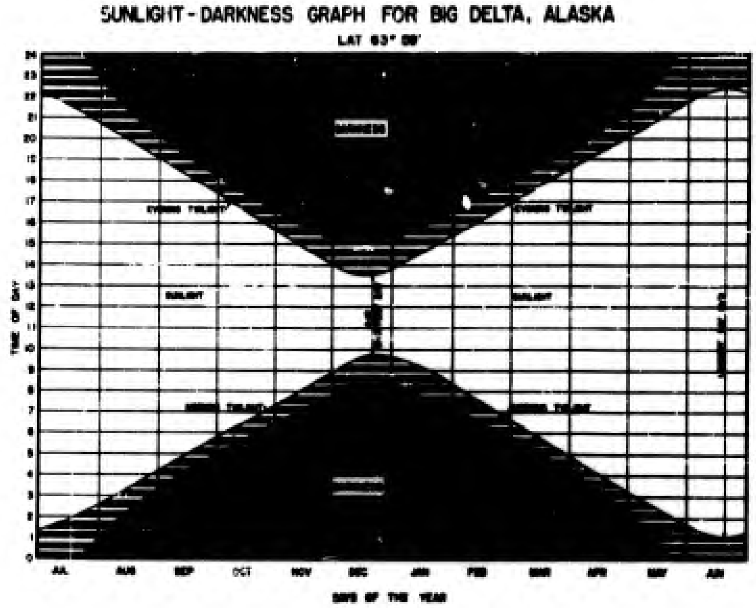


FIGURE 5: SUNLIGHT — DARKNESS GRAPH FOR BIG DELTA, ALASKA

THE TWO MICROCLIMATIC STATIONS WERE PLACED ONLY 1 1/2 MILES FROM THE CAA STATION. DATA FOR SKY COVER, CLOUDS, PRECIPITATION (INCLUDING SNOWFALL), PRESSURE, AND HUMIDITY, ELEMENTS NOT RECORDED AT THE MICROCLIMATIC SITES, WERE AVAILABLE FROM THIS STATION FOR THE ENTIRE STUDY PERIOD (U.S. DEPT. OF COMMERCE, 1956). DATA FROM THE CAA STATION ALSO INCLUDE STANDARD OBSERVATIONS OF TEMPERATURE AND WIND, BUT RADIATION IS NOT MEASURED.

THE CLOSENESS OF THE THREE STATIONS MADE IT POSSIBLE TO USE CAA STATION DATA RELATING TO SKY COVER, CLOUDS, AND PRECIPITATION WITH CONFIDENCE. WIND SPEED AND DIRECTION, AND HUMIDITY ARE STRONGLY INFLUENCED BY LOCAL CONDITIONS, THEREFORE MEASUREMENTS MADE AT THE CAA STATION COULD NOT BE USED TO DESCRIBE ACCURATELY CONDITIONS AT THE MICROCLIMATIC STATIONS, ESPECIALLY AT THE WOODS STATION.

A. <u>MICROCLIMATIC STATIONS</u>

THE MICROCLIMATIC STATIONS ESTABLISHED AT FORT GREELY WERE LOCATED ABOUT ONE-HALF MILE NORTHEAST OF THAT INSTALLATION (FIG. 6). TO REDUCE THE POSSIBILITY OF DAMAGE TO INSTRUMENTS AND EQUIPMENT, A WOODED AREA APPROXIMATELY ONE-HALF MILE SQUARE WAS POSTED AS "OFF-LIMITS" FOR MILITARY AND CIVILIAN PERSONNEL.

LOCATION OF MICROCLIMATIC STATIONS

BIG DELTA, ALASKA

WOODS ✪ OPEN ★

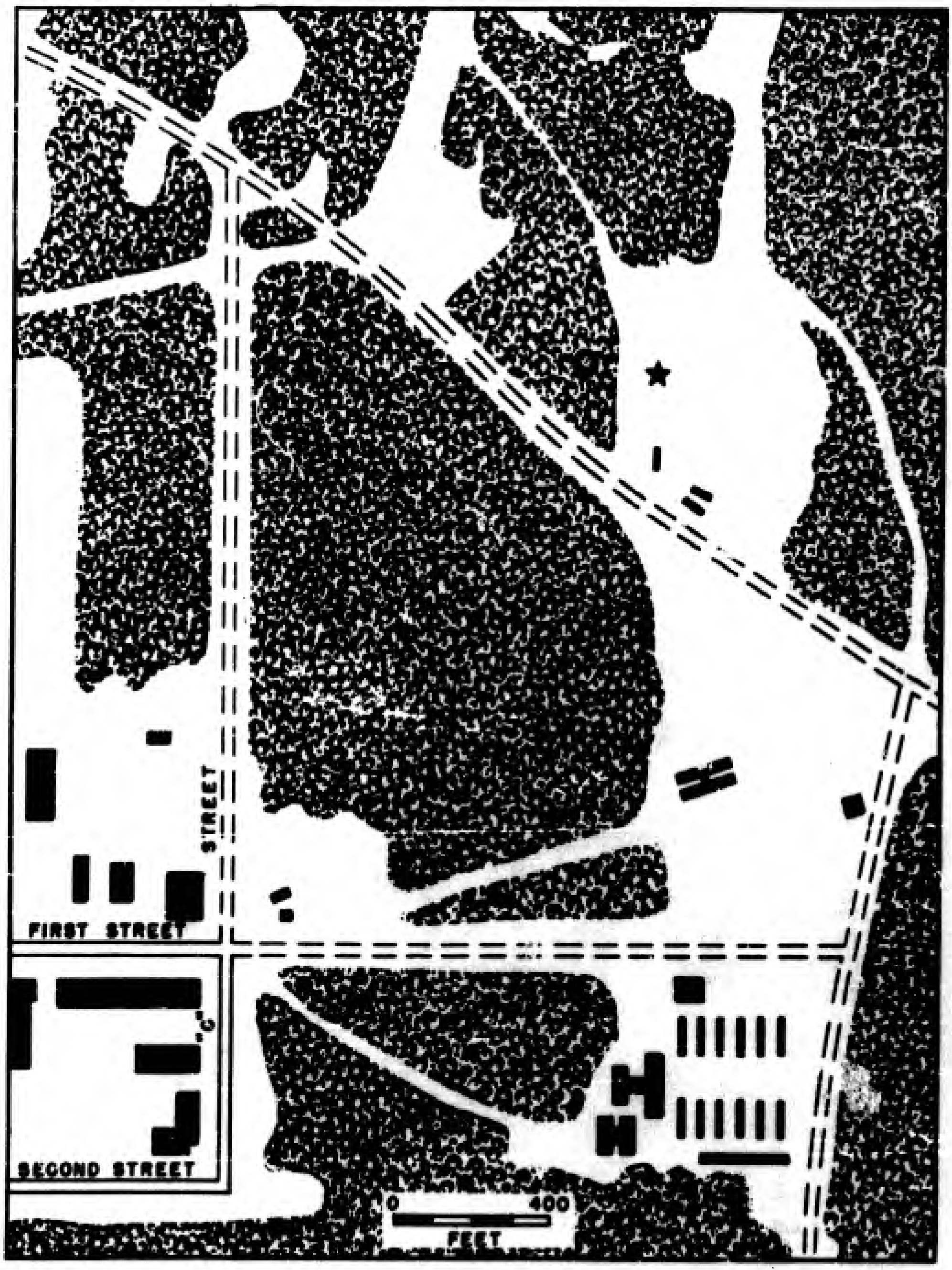


Figure 6

Selection of the exact location of each station was governed by a need for a heated shelter (during winter) which had a constant source of electric power for housing the recording elements of electrical instruments. The location finally selected was the best available for providing these facilities and was situated sufficiently far from the main concentration of buildings to make their influence upon the weather elements being measured negligible. An insulated Jamesway shelter was used to house recorders (Fig. 7). This shelter served also as an office for members of Signal Corps Meteorology Team Number 4, who were responsible for maintaining and servicing all instruments, and for making manual and visual observations and measurements of conditions such as precipitation, snow depth, and snow cover.

(1) Description of sites

(a) Woods station

This station was located in a moderately dense spruce forest in which are found several deciduous types. The trees are 20 to 30 feet tall, with a few reaching 35 feet. The station was about 50 yards inside the eastern edge of the woods. The distance of the station into the forest was limited by a maximum distance of 500 feet over which

Figure 7: Arrangement of recording instruments in Jamesway shelter.

THERMOCOUPLES COULD NOT BE PLACED FROM RECORDERS.

DURING THE INSTALLATION OF INSTRUMENTS EVERY EFFORT WAS MADE, AND PRECAUTION TAKEN, NOT TO DISTURB THE NATURAL SETTING. THE ONLY ARTIFICIAL FEATURES WERE THE BARRIER AND FENCE REQUIRED TO PREVENT DAMAGE BY WILDLIFE.

(B) OPEN STATION

THIS STATION WAS LOCATED IN AN OPEN AREA ABOUT ONE-QUARTER MILE SQUARE. THE SURFACE COVER IS COMPOSED OF A FEW GRASSES AND WEEDS INTERSPERSED WITH LARGE PATCHES OF BARE GROUND. THE OPEN STATION WAS ABOUT 150 YARDS DIRECTLY EAST OF THE WOODS STATION, AND ABOUT 100 YARDS FROM THE EDGE OF THE FOREST.

TO FACILITATE COMPARISONS, INSTRUMENTS USED, AND MEASUREMENTS AND OBSERVATIONS TAKEN AT THE STATIONS WERE IDENTICAL. PROCUREMENT OF INSTRUMENTS, THEIR INSTALLATION AND MAINTENANCE, AND THE ACCURACY AND RELIABILITY OF MEASUREMENTS AND OBSERVATIONS WERE THE RESPONSIBILITIES OF SCIENTISTS AND OBSERVERS OF THE SIGNAL CORPS. ALL SERVICES WERE PROVIDED IN ACCORDANCE WITH REQUESTS AND INSTRUCTIONS RECEIVED FROM THE AUTHOR, WHO ALSO PREPARED THE OPERATING PROCEDURE TO BE FOLLOWED BY MEMBERS OF THE SIGNAL CORPS METEOROLOGY TEAM AT BIG DELTA DURING THE STUDY.

(2) METHODS USED IN MEASURING CLIMATIC ELEMENTS

(A) RADIATION

CONTINUOUS RADIATION MEASUREMENTS WERE MADE AT THE SITES WITH AN EPPLEY PYRHELIOMETER, EXPOSED HORIZONTALLY, AT A HEIGHT OF ABOUT 6 1/2 FEET (2 METERS). THIS INSTRUMENT MEASURES TOTAL INCOMING SHORTWAVE SOLAR RADIATION (SUN AND SKY) ON THE HORIZONTAL SURFACE AND IS SENSITIVE TO ALL WAVELENGTHS LESS THAN 2.5 MICRONS. ITS USE IN THE ARCTIC IS DISCUSSED BY MACDONALD (1951).

IN THIS STUDY, ALL RADIATION VALUES ARE EXPRESSED IN LANGLEYS (LY), ONE GRAM-CALORIE PER SQUARE CENTIMETER, OR 3.69 BRITISH THERMAL UNITS (BTU) PER SQUARE FOOT AND THE PERIOD, HOUR OR DAY, IS INDICATED. A POTENTIOMETER WAS USED FOR RECORDING MEASUREMENTS MADE BY THE PYRHELIOMETERS. THIS INSTRUMENT PROVIDED A CONTINUOUS RECORD OF SOLAR RADIATION FROM SUNRISE TO SUNSET. FROST ON THE GLASS BULB IS ONE OF THE MOST SERIOUS SOURCES OF ERROR WHEN USING A PYRHELIOMETER IN COLD REGIONS. SIGNAL CORPS OBSERVERS AT BIG DELTA MADE EVERY EFFORT TO KEEP THE PYRHELIOMETER FREE FROM FROST OR SNOW AND RECORDED THE FEW OCCASIONS WHEN THIS WAS NOT POSSIBLE.

(B) TEMPERATURE

TWELVE TEMPERATURE MEASUREMENTS WERE MADE AT 11 DIFFERENT LEVELS at each site by using thermoelectric thermometers, or thermocouples, as measuring junctions. These thermocouples, of copper and constantan wire, were fabricated and calibrated at the Army Electronic Proving Ground, U.S. Army Signal Corps, Fort Huachuca, Arizona. Copper-constantan wire was used because it affords a large electromotive force per degree difference of temperature, about 40 microvolts per degree Celsius at meteorological temperatures (Dike, 1954, pp. 8-19). Although the relation between e.m.f. and temperature difference is not actually linear, its departure from linearity is seldom of importance over the range of temperatures measured in meteorological work (Middleton, Knowles and Spilhaus, 1953, pp. 88-91). Measurements were recorded by means of 12-point recording potentiometers. These instruments, calibrated for use with copper-constantan wire and thermocouples, have a print carriage speed of 12 seconds, a print speed of 15 seconds, and a chart speed of 10 inches per hour. To facilitate compilation of the data from the charts, uni-colored numbered print wheels were used; a timing attachment limited recording by each instrument so that a temperature measurement cycle was made only once each hour. Two recorders were in use at all times and a third was available for use as a spare.

Air temperatures were measured at the following heights: 7.5 cm (3 inches), 25cm (10 inches), 50 cm (20 inches), 100 cm (40 inches), 200 cm (80 inches), and 400 cm (160 inches). In addition, during summer, continuous black globe temperature measurements, of interest to bioclimatologists and physiologists, were made at each site at the 200 cm level. The globe thermometer is an instrument used for measuring the temperature of a body exposed in the open not only to the air temperature and wind, but also to solar radiation and reflected ground radiation. Measurements made with this instrument provide data which can be used to illustrate the effects of and exchange of, radiation between man and his environment. Woolock et al. (1957, pp. 1-9) have shown that in sunlight a gray-colored globe, having a reflection coefficient of 50 percent, gives a more representative reading than the black globe.

In winter, the thermocouples used for measuring the globe temperatures were removed and used to measure the snow temperature. During this season, globe measurements were made with a standard alcohol thermometer which was read three times each day at 0815, 1215, and 1630. Locations of thermocouples (in shields) and globe thermometer are shown in Figures 3 and 4. The heights selected for measuring air temperatures, except for the 400 cm level, are those within which most human activity takes place (200 cm and below). Most rapid temperature changes and significant differences in temperature are experienced close to the ground and, for this reason, the majority (4 of 6) of the air temperature measurements were made between the ground surface and the 100 cm level.

Soil-temperature measurements were made in a manner identical to those made for air temperatures. Thermocouples were placed at the following depths: -60 cm (-24 inches), -30 cm (-12 inches), -15 cm (-6 inches), and -2.5 cm (-1 inch), and at the surface. For convenience, the surface thermocouple is sometimes referred to as the 0 cm thermocouple, but it must be emphasized that at this and the other levels some small variation is to be expected from the depths and heights indicated.

The surface thermocouple was covered very thinly with soil at the OPEN station. At the WOODS station, the thermocouple was imbedded in the moss cover just below its surface. The measurement of surface temperatures, especially of a snow surface, is extremely difficult. It has been the experience of the author, and of others with whom he has discussed the problem, that there is no agreement as to what constitutes the surface, and the accurate measurement of surface temperature on a continuous basis is difficult with current techniques and instrumentation.

Thermocouples remained fixed during the period of the study except for the one used for black globe and snow-surface temperature measurements. When there was a snow cover, thermocouples at the lowest levels were covered with snow, usually to a greater depth at the WOODS than at the OPEN station. Because men, animals, and plants are active in or under snow (Pruitt, 1957; Beckel, 1957) snow temperatures are of interest and importance. They provide information concerning the insulating properties of a snow cover, that is, the protection afforded by the snow to the ground surface beneath from the extreme cold air above. Snow, especially new snow, has air trapped within it, and serves as an excellent insulator for the ground (and plants and animals) beneath.

(c) Wind

Continuous measurements of wind speed were made at levels of 30 cm and 200 cm. Measurements were made by four Beckman and Whitley Climatic Survey Systems. Each of these systems consisted of wind-speed and wind-direction transmitter units, each having a 3-cup anemometer made of light plastic and a simple wind vane, and two Esterline-Angus Recorders. The anemometers had threshold values of 1/2 mile per hour, and values obtained were accurate to very low wind speeds.

In order to maintain heights above the snow surface during winter, the wind-direction and wind-speed transmitter units (wind vanes and anemometers) at the 200-cm and 30-cm levels were placed on wooden platforms. Each day the wind instruments were checked to make certain that these platforms were kept at the same height as the snow surface.

(d) Precipitation

Precipitation measurements were made with standard, non-recording, 8-inch precipitation gages. Measurements made at the OPEN station during the warm months, May through August, were considered to be accurate. The 8-inch gage without windshield is the standard instrument used for measuring rainfall at many official U.S. Weather Bureau stations. The use of this instrument at the WOODS station may not have provided an accurate measure of the rainfall in the forest as a whole, but it did provide information as to the actual fall at that site. These data proved of particular significance when analyzing and interpreting soil temperatures compiled from measurements made only a few feet from the gage. The catches of the gages during the cold part of the year were not reliable, as they were not equipped with windshields and amounts of drifting snow caught could not be determined. The difficulties encountered in measuring snowfall and its water equivalent, and errors involved, have been the subject of much discussion (Alter, 1937; C. F. Brooks, 1938a, 1938b, 1940; Kurtyka, 1953; Middleton, Knowles, and Spilhaus, 1953, pp. 126-29; Warnick, 1953; Black, 1954). Also, it has been demonstrated by Horton (1919), who conducted very complete experiments, that the use of the standard precipitation gage is unsuitable for measuring precipitation in forests. In forests, trough-type gages are required, and several of these gages should be scattered throughout the wooded area in which precipitation is to be recorded. At the CAA station, gages were shielded and data available for this station were used as a measure of the precipitation received in the area during the colder periods of the study. Snow depths were required in interpreting the temperature measurements, and these observations were taken daily at 0815. During periods of snowfall, or of blowing snow, however, measurements were made three times daily, at 0815, 1215, and 1630.

Snow cover strongly influences the temperatures of the air and ground. Snow-depths were required for each station in order to determine which of the thermocouples at the lower levels were covered by the snow.

(e) <u>Sky cover, clouds, and humidity</u>

Data on clouds and sky cover were obtained from the CAA station. These data were representative of conditions at the microclimatic stations because of the closeness of these to the CAA station.

Humidity measurements were not made at the microclimatic stations. Rae (1954) considers the measurement of humidity at extremely low temperatures to be one of the most difficult and least accurate of the meteorological observations made with the usual station equipment in the Arctic and Subarctic in winter. At very low temperatures, a difference of only 0.1 F deg. in the depression of the wetbulb temperature corresponds to a difference of 10 per cent or more in relative humidity. Fergusson (1937) discusses various methods of making accurate humidity measurements, but as Rae points out, adequate instruments are generally lacking, or observers do not have the skill or desire to make reliable measurements in the extreme cold.

PART II - FINDINGS AND ANALYSIS

Microclimatic investigations began at Fort Greely, Big Delta, on 8 June 1956 and measurements and observations continued through 30 September 1957. The study extended through summer, 1957, in order to obtain a complete record during the warm part of the year, May through September.

In this report, data for June 1956 and December 1956 are analyzed. June and December are the months usually having the greatest and least solar radiation and longest and shortest days, respectively, during the year. Because measurements did not begin until 8 June 1956, and continuous measurements until 12 June 1956, the period 12 through 30 June is used, allowing approximately the same number of days before and after the summer solstice. Measurements and observations for the entire month of December were used and are presented in the following analysis.

Data used in preparing some of the graphs presented in the text are also included in tabular form in the Appendix.

1. <u>Weather during June 1956</u>

Weather during June 1956 was controlled by an unusual number of low-pressure and frontal systems moving east from the Bering Sea. These systems were responsible not only for the considerable precipitation and cloudiness, but also for the prevailing northeast winds. The records of the CAA station show that June 1956 was 3.1 F deg. colder and 67 per cent wetter than an average June.

The mean daily radiation of 515 ly was larger than the average of 505 ly for this month based on the Fairbanks, Alaska, record. Skies were broken (6 to 9 tenths) and/or overcast (10 tenths, including obscured), about 75 per cent of the time. There were few hours and no days without clouds; sky cover was usually 0.6 or more during any hour, and daily mean amounts were greater than 0.6 on all but four days.

Mean daily maximum, mean, and mean daily minimum temperatures were 56.6 F, 53.1 F, and 49.7 F, respectively, compared with 65.4 F, 56.2 F, and 47.0 F for an average June. Cool maritime air and attendant cloudiness were largely responsible for this lowering of the mean daily maximum temperature 8.8 F deg. below the average, the raising of the mean daily minimum temperature 2.7 F deg. above the average, and the resulting depression of the mean temperature by 3.1 F deg.

Precipitation recorded at the CAA station totaled 3.85 inches for the month, or 167 per cent of the average rainfall (2.30 inches). The greatest June amount prior to 1956 was 3.70 inches. At the OPEN microclimatic

STATION, 5.08 INCHES WERE MEASURED, BUT AT THE WOODS STATION ONLY 3.85 INCHES WERE RECORDED.

2. MICROCLIMATIC MEASUREMENTS, 12 THROUGH 30 JUNE 1956

BROKEN AND OVERCAST SKIES (INCLUDING OBSCURED) OCCURRED 88 PERCENT OF THE TIME DURING THE 19-DAY PERIOD; ONLY SEVEN DAYS HAD A DAILY MEAN CLOUDINESS OF LESS THAN 8 TENTHS. MOST OF THE RAIN RECEIVED DURING JUNE WAS ALSO RECORDED DURING THIS TIME. OF THE TOTAL OF 3.85 INCHES MEASURED AT THE CAA STATION, 3.80 INCHES FELL DURING THE PERIOD. AT THE OPEN STATION, 4.65 OF THE 5.08 INCHES, AND AT THE WOODS STATION 3.72 OF THE 3.85 INCHES MEASURED FROM 1 THROUGH 30 JUNE WERE RECORDED FROM 12 THROUGH 30 JUNE.

A. SOLAR RADIATION AND CLOUDINESS

CHURCH (1951) POINTS OUT THAT SOLAR RADIATION IS PERHAPS THE MOST IMPORTANT OF THE MICROMETEOROLOGICAL ELEMENTS IN THE ARCTIC AND SUBARCTIC, AND FURTHER, THAT RADIATION CONDITIONS IN THESE REGIONS DIFFER GREATLY FROM THOSE OF MIDDLE AND TROPICAL LATITUDES. ACCORDING TO BRUNT (1946), THE MOST FUNDAMENTAL FACTOR WHICH MUST BE TAKEN INTO ACCOUNT IN MICROCLIMATOLOGY IS INCOMING SOLAR RADIATION BY DAY AND OUTPUT OF HEAT BY LONG-WAVE RADIATION BY NIGHT. BRUNT FURTHER STATES:

"WHEN SOIL HAS VEGETATION THE EFFECTIVE LOCUS OF BOTH ABSORPTION AND RADIATION IS NO LONGER THE SURFACE OF THE GROUND, BUT IS SOMEWHERE WITHIN THE LIMITS LAID DOWN BY THAT SURFACE AND THE UPPERMOST PARTS OF THE VEGETATION. THE LOCUS OF ABSORPTION AND RADIATION IS THEN NOT A HORIZONTAL SURFACE, BUT A LAYER OF DEPTH DEPENDING UPON THE VEGETATION."

SIGNIFICANT DIFFERENCES OCCURRED IN THE AMOUNTS AND INTENSITIES OF SOLAR RADIATION RECEIVED AT THE MICROCLIMATIC STATIONS, ALTHOUGH THE HIGH PERCENTAGE OF CLOUDS DURING THE PERIOD TENDED TO LESSEN THESE DIFFERENCES. MEAN DAILY RADIATION WAS ONLY 452 LY, CONSIDERABLY LESS THAN THE AVERAGE OF 505 LY FOR JUNE. TOTAL RADIATION VALUES FOR THE PERIOD AND MONTH ARE PRESENTED IN TABLE I, AND MORE COMPLETE DATA, IN TABLE A-1 (APPENDIX). SKY COVER DATA FOR THE PERIOD ARE LISTED IN TABLE II AND ARE SHOWN IN FIGURE 8.

THE INFLUENCE OF TREES AT THE WOODS STATION IS IMMEDIATELY APPARENT. MEAN RADIATION WAS ONLY 165 LY IN THE FOREST AS COMPARED TO 452 LY IN THE OPEN. D. H. MILLER (1956A) DISCUSSES THE EFFECTS OF AN OPEN PINE FOREST IN THE SIERRA NEVADA ON SOLAR RADIATION AND TEMPERATURE. AT BIG DELTA, WHERE THE DENSITY OF THE FOREST IS GREATER AND THE ALTITUDE OF THE SUN MUCH LESS, THE INFLUENCE OF THE SPRUCE FOREST UPON SOLAR RADIATION IS PROBABLY GREATER. MEASUREMENTS MADE AT THE WOODS STATION ARE INDICATIVE OF CONDITIONS IN THE CONIFEROUS FORESTS (TAIGA) WHICH EXTEND OVER MUCH OF THE SUBARCTIC, BUT LOCAL VARIATIONS PLAY A SIGNIFICANT ROLE AT ANY ONE PLACE. STUDIES BY SAUBERER AND TRAPP (1934) SHOW THAT THE INTENSITY OF

TABLE I
DAILY GLOBAL SOLAR RADIATION FOR JUNE 12 THROUGH 30, 1956,
JUNE 1956, AND AN AVERAGE JUNE
FAIRBANKS AND WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA

	Radiation (Langleys)*		
Period	Fairbanks	Open	Woods
Av. June	505	--	--
June 1956	535	515	193
June 12-30, 1956	508	452	165

*Langley (ly) = 1 gm-cal/cm^2.

TABLE II
FREQUENCIES OF SKY CONDITIONS*
BIG DELTA, ALASKA

	Frequency (percent)	
Sky Cover (tenths)	Average June	June 12 - 30, 1956
Clear (1)	3.3	none
Scattered (1 - 5)	19.3	12.0
Broken (6 - 9)	31.6	45.8
Overcast (10, including obscured)	45.8	42.2

*Data from Civil Aeronautics Administration weather station, Big Delta, Alaska. Average cloudiness for period June 12 - 30, 1956, was 84 percent.

FREQUENCY OF SKY COVER
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

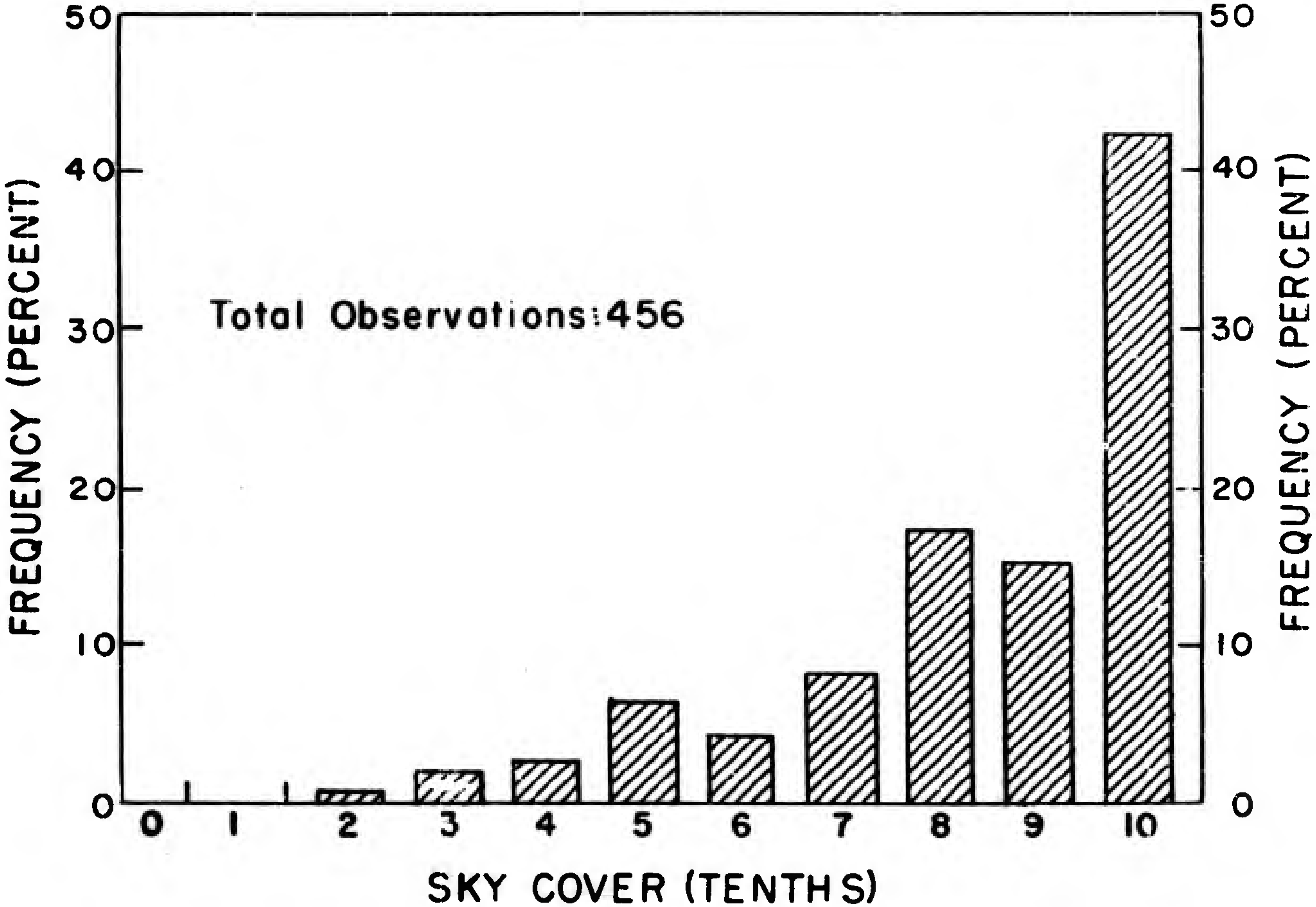


FIGURE 8

light penetrating an oak forest in full leaf amounts to only 13 percent of the total received at the canopy, and Lauscher and Schwabl (1934) found that light received at the ground surface beneath a dense pine forest was only 6 to 17 percent of that received in the open. More recently, Billings and Morris (1951) discuss the reflectance properties of green leaves, and investigations by Ovington and Madgwick (1955) show that conifers give relatively intense shade throughout the year. In their measurements, the canopies of the conifers absorbed and reflected much of the incoming solar radiation, only 0.5 to 6.7 percent reaching the forest floor.

(1) Mean hourly global solar radiation

Figure 9 shows the mean hourly radiation at the micro-climatic stations and the difference in amounts received. At this time of year there is almost continuous daylight, and solar radiation was sufficiently intense to activate the pyrheliometer for about 20 hours each day (approximately 0200 to 2200) at the OPEN station. In the forest, however, sunshine was not recorded until later in the morning, and ended earlier at night.

Greatest differences between the stations, 15 ly or more, occurred from 0700 to 1800, the time of day when solar radiation was usually most intense. A maximum difference of slightly more than 32 ly is noted at 1400. Of particular interest are the abrupt decreases in differences in amounts received at the stations from 1100 to 1200, and again at 1600. The noonhour decrease is associated with simultaneous occurrence of a sudden and considerable increase in radiation received at the WOODS station and a small decrease in radiation at the OPEN station. The abrupt decrease in the difference in the afternoon at 1600 is due to a rapid and continuous decrease in radiation at the OPEN station beginning at 1400, and a small, secondary maximum of radiation in the forest.

These abrupt changes may be caused in several ways. The rise in insolation at the WOODS station is most likely caused by the sudden penetration of the rays of the sun through an opening in the forest canopy, thereby decreasing differences in the amounts received at the stations. The decrease at 1600 at the OPEN station is associated with a normal decline in intensity during the late afternoon hours. In addition, the relatively small number of observations available (407 for the WOODS and 446 for the OPEN) must be considered when attempting to explain irregularities in the curves, such as the small decrease at the OPEN station at 1100. It is believed that this partly accounts for the variations in the amounts of radiation received at the stations.

Correlation with hourly cloudiness is difficult, principally because all hours had a high percentage of sky cover. Increased cloudiness resulted in either an increase or decrease in solar radiation at the stations,

MEAN HOURLY GLOBAL SOLAR RADIATION AT MICROCLIMATIC STATIONS
AND MEAN HOURLY CLOUDINESS AT CAA STATION
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

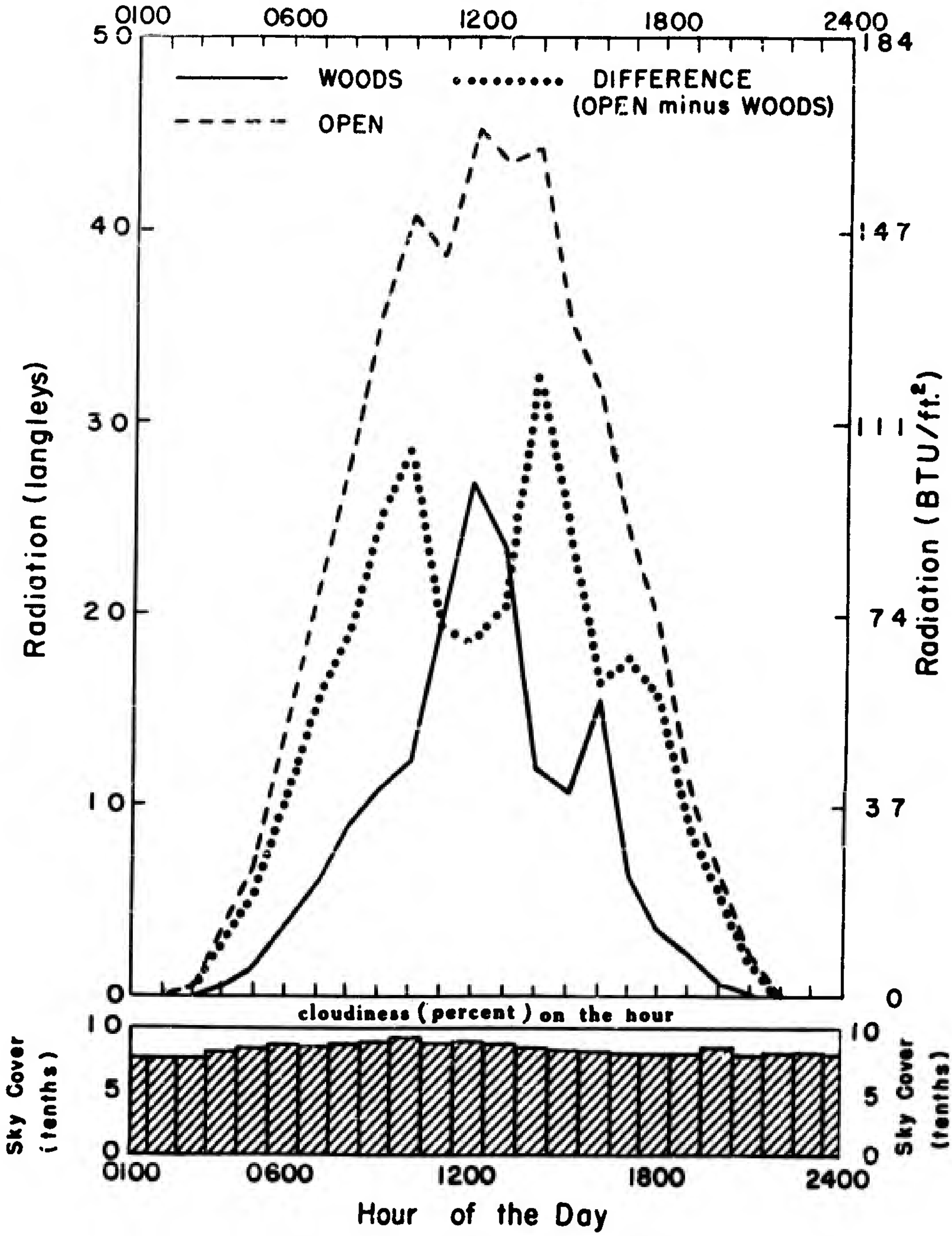


FIGURE 9

depending upon the amount and type of clouds. Overcast skies, with clouds thick and low, tended to decrease insolation at both stations, but the decrease was much greater at the OPEN station, thus decreasing the differences between amounts received in the forest and clearing. If clouds were thin, or of the cumulus type, and did not cover the entire sky, the increased diffuse radiation increased global solar radiation in the forest. This also increased the insolation in the open, but by not as much as in the forest, where penetration of the forest canopy was greater than with the low-angle, direct solar radiation, and differences between the stations, therefore, decreased. Figure 9 shows the mean hourly sky cover at the CAA station during the period. These values show that the greatest mean hourly sky cover, 94 percent, was at 1000, whereas values for 1400 and 1700 were only 85 and 82 percent, respectively.

The possibility of shadowing effect from nearby obstacles at the OPEN station can be eliminated. The only obstacles at this station were the temperature gradient tower and the telephone pole supporting wires from the Jamesway shelter to the instruments. These were southwest of the pyrheliometer and could not affect the instrument in the morning or evening when the sun was low in the horizon. Both pole and mast were too far away to shadow the Eppley, which was at a height of 200 cm, during the rest of the day when the altitude of the sun was still relatively high.

(2) Total daily global solar radiation

Total daily global solar radiation and differences in amounts received are shown in Figure 10; data are given in Table A - 1 (Appendix). This graph shows the close relationship between daily mean sky cover and total daily solar radiation. Although there were no clear days during the period, differences in radiation between the stations on the days having least cloudiness (12 - 18; 23 - 26; and 29 and 30 June) are notable. With increasing cloudiness, differences become much less, and on 21 June, a day that was overcast and rainy, they were almost negligible.

(3) Frequencies of hourly amounts of global solar radiation

Figures 11 and 12 give the relative and cumulative frequencies of hourly solar radiation amounts at the microclimatic stations. The large frequency of low radiation received at the WOODS station is easily seen. At this station, 58 percent of the hours had four ly or less, as compared to only 37 percent at the OPEN station. In the open, as many as 80 ly were received in one hour, and seven percent of the hours had 60 ly or more. The greatest solar radiation measured in the forest in any hour was 59 ly, and only four percent of the hours received 30 ly or more.

TOTAL DAILY GLOBAL SOLAR RADIATION AT MICROCLIMATIC STATIONS AND DAILY MEAN CLOUDINESS AT CAA STATION
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

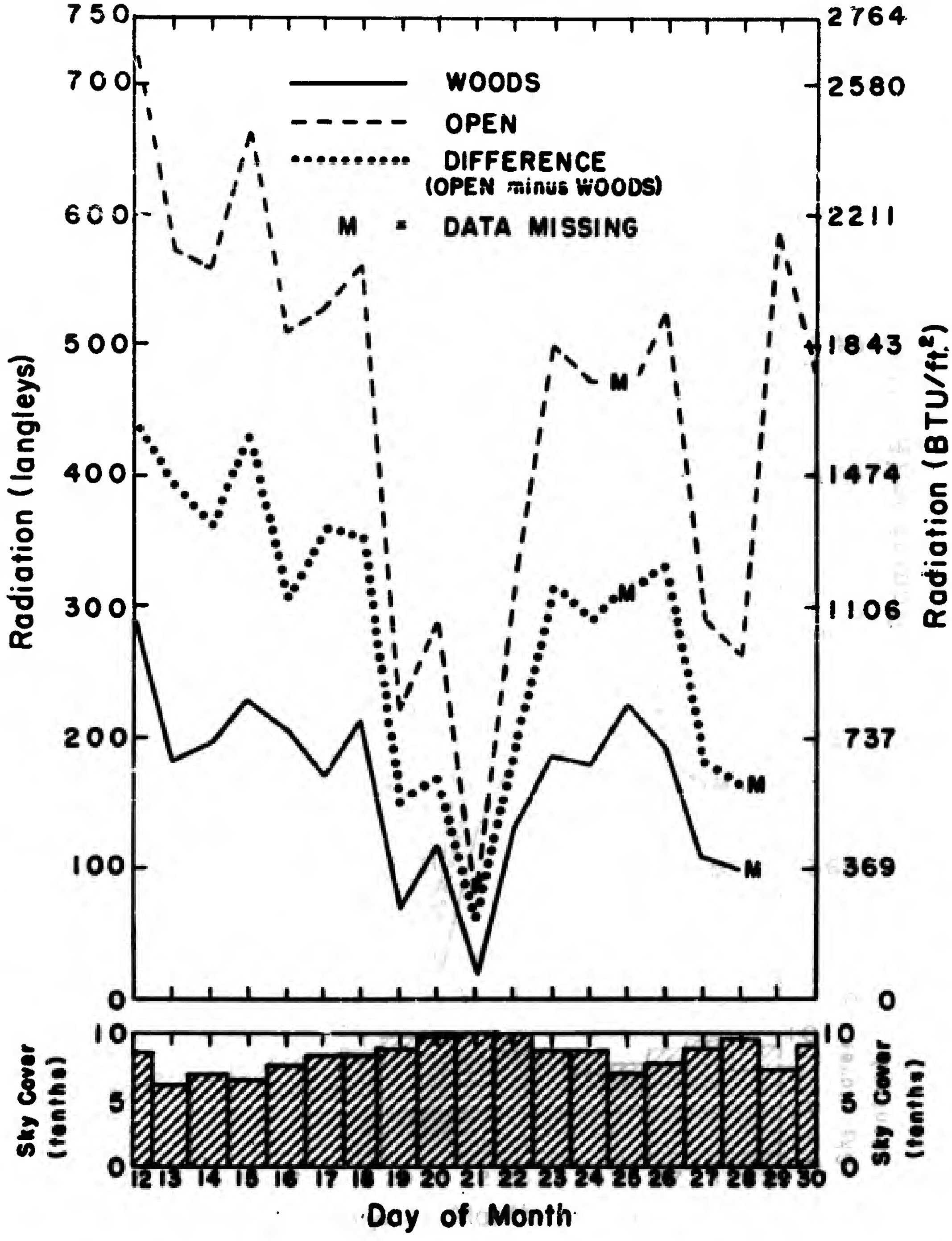


FIGURE 10

RELATIVE FREQUENCIES OF HOURLY GLOBAL SOLAR RADIATION
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

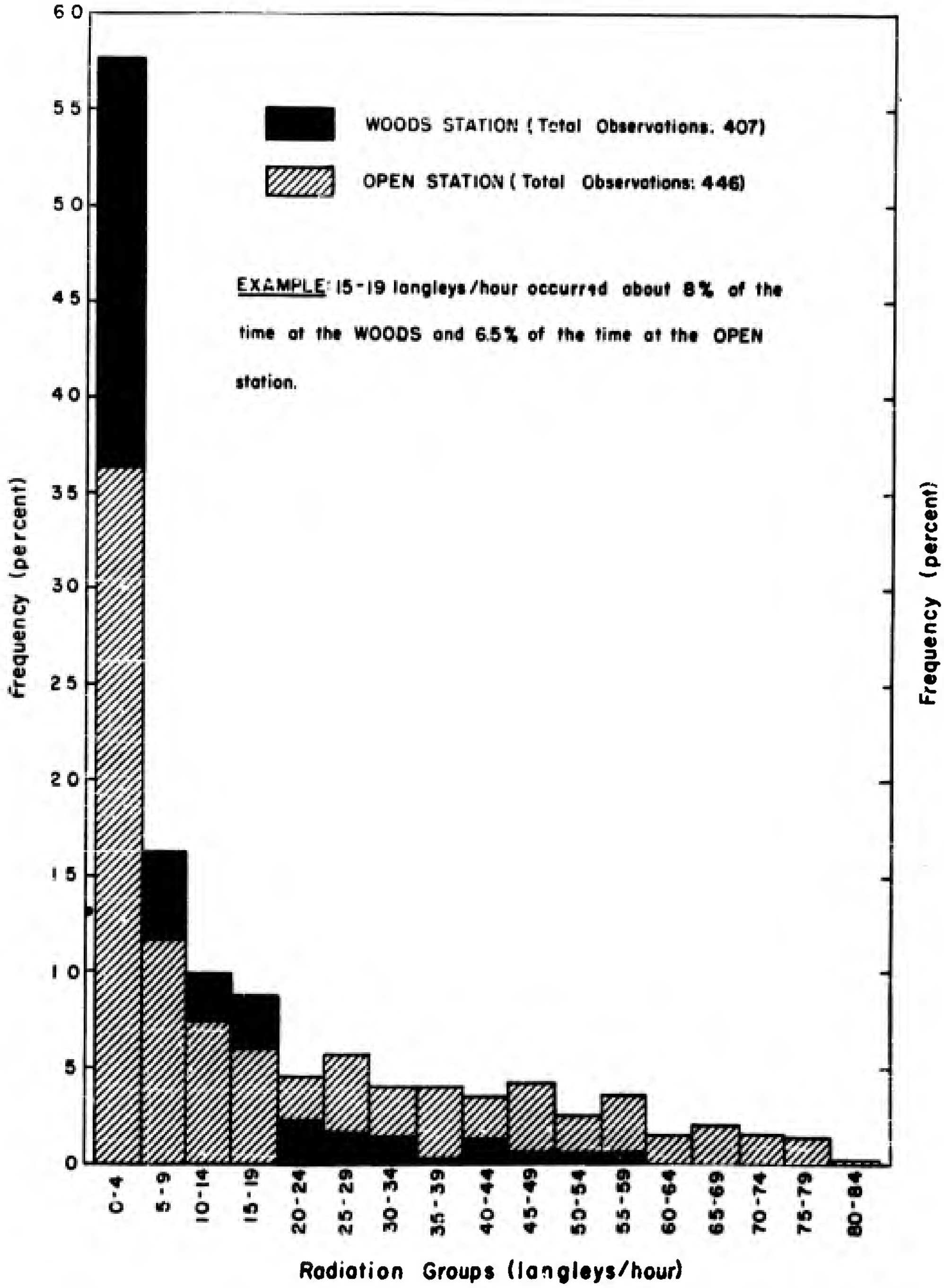


FIGURE 11

CUMULATIVE FREQUENCIES OF HOURLY GLOBAL SOLAR RADIATION
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12-30, 1956

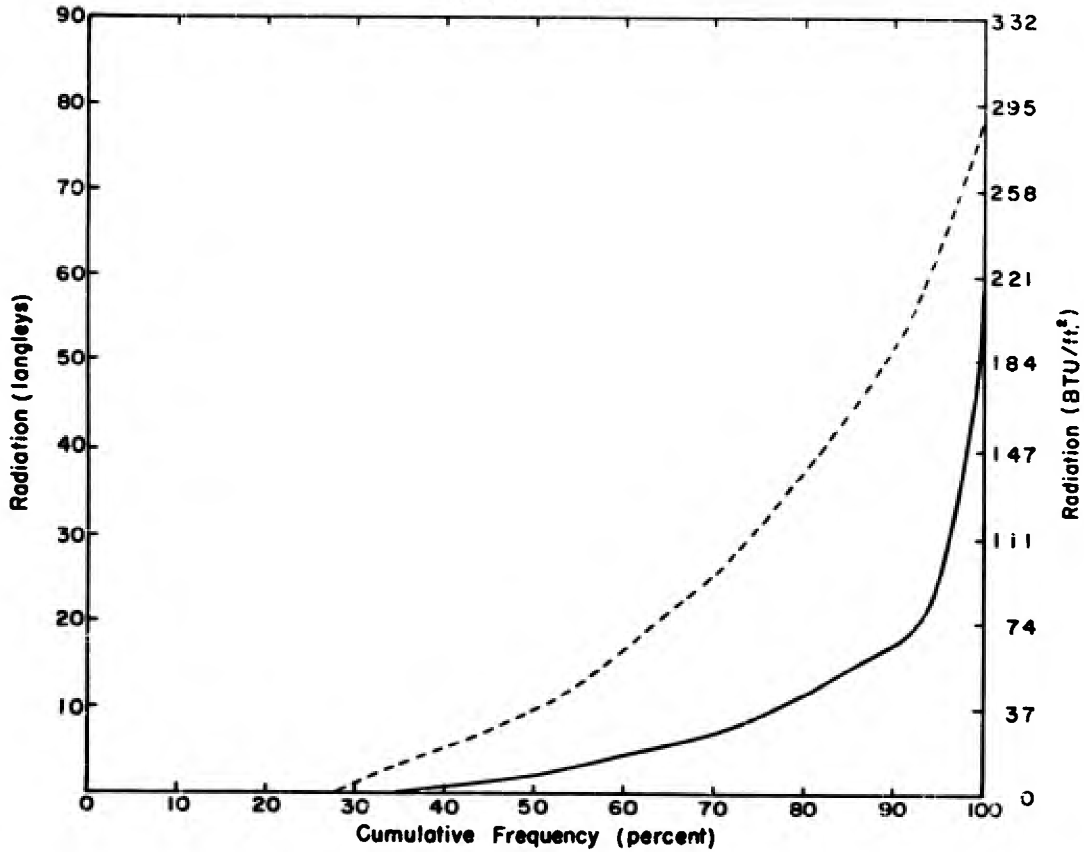


FIGURE 12

D. H. Miller (1956a) in his investigations found that much of the solar radiation absorbed by the needles of conifers serves indirectly to raise the ambient air temperature. This probably occurs at the WOODS station and in the subarctic coniferous forests (taiga) in general. In these forests, however, trees are closer together. This, combined with the generally horizontal path of the rays due to the low altitude of the sun, results in absorption taking place mainly in the canopy (except at the edge of the forests), and temperatures near the ground are not as greatly affected as were those in Miller's study.

Miller also found that, at night, trees reduce the net long-wave radiation from the ground. The canopy acts as a heat source, radiating heat to the sky and ground. This phenomenon is not as apparent in the Subarctic in summer because nights are very short.

The virtual lack of solar radiation at the ground in the coniferous forests of the north greatly influence the soil and air temperatures, and probably humidity, and thereby the plant and animal life that lives within. At Big Delta, few small trees or bushes are found; the surface cover is mainly a mat of mosses, lichens, and other plants that are tolerant to a shady, cool, moist environment. At the warmer, drier OPEN station the plant cover was not representative of that found in other open areas because plants were not allowed to occupy the area at will.

B. Temperature

Temperature is the most easily understood and, together with precipitation, the most universally measured of all climatic elements. It results from the total interaction of the other climatic elements (for example, radiation, wind. and cloudiness), and is used extensively in climatic classifications, and in determining and explaining the distribution and limits of vegetation. In general, mean and extreme values have received greatest emphasis.

It has been shown by Roberts (1943), Went (1944) and Balchin and Pye (1950) that the more outstanding results from recent experimentation in thermoperiodicity are the pronounced effect of night (minimum) temperature on plant growth. In contrast, A. Miller (1950) criticizes climatic classifications, pointing out that climate is only one of the several elements in the environment of plants, and, further, that temperature and precipitation have been the climatic elements most frequently employed, implying that they have been used too exclusively. Later, however, Miller (1951) proposes new climatic maps based on temperature duration and cumulated temperatures, using a base of 6 C (42.8 F) proposed by Merriam (1894).

Whatever their advantages or limitations, temperature data are readily available for most regions of the world, and, together with precipitation data, have provided an easy and widely-used means of describing climate and for making climatic comparisons. Temperature data are also used extensively, in the Subarctic and elsewhere, by scientists dealing with problems in biology (Court, 1950; Waterhouse, 1955; H. M. Johnson, 1957), engineering (Hay, 1945; Sissenwine and Court, 1950), human physiology (Revesman et al., 1953; Carlson, 1954), agriculture and botany (Salisbury, 1939), communication (Schilling et al., 1946), and is even used in the formulation of government policy (Boughner and Thomas, 1956). In every field of science, temperature plays an important role.

Recently, the attention and interest of scientists engaged in meteorological and climatological research has rightfully been concentrated toward studying intensively the heat exchange and radiation balance near the ground (Brunt, 1946). Because of the difficulties involved in making accurate solar radiation measurements (Möller, 1957), and even those that will be comparable, it must be expected that some time will elapse before radiation data become available in sufficient quantity to allow worldwide comparisons. In this study, as in most previous microclimatic investigations, primary emphasis is given to measuring temperatures at the microclimatic stations, to analyzing these data, and to explaining the differences.

The importance of ground or soil temperatures in agricultural and other problems has resulted in many detailed studies. Bouyoucos (1913, pp. 1-2) considers soil temperatures one of the essential limiting factors of plant growth, affecting the biological, chemical and physical functions. This contention is supported by Smith (1939, p. 49), who points out that the effect of soil (and air) temperatures on crop growth is of greater importance in some districts than the morphological or chemical characteristics of the plants. In an earlier paper, Smith (1929b) discusses the time and rate of germination of seeds, showing that germination is largely dependent upon soil temperatures and that growth of cultivated plants does not begin until soil temperatures are 40 F to 50 F. He points out that essential, soil-nitrifying bacteria are most active at temperatures of 65 F to [illegible] F. Later, Wager (1938) concludes that the poor growth and survival of arctic plants is caused by the inactivity of nitrogen bacteria and lack of nitrogen in arctic soils, and suggests that the effect of temperature, both soil and air, upon parasites and fungus diseases of insects might be different from the direct effect on the insects themselves.

Algren (1949) points out that ground temperatures are becoming increasingly important in heat ventilation and air condition engineering, where direct application is made to 1) the ground as a heat source for heat-pump application, 2) perimeter and ground slab heat loss for floor-panel heating systems, and 3) heat losses to the ground and resulting floor slab temperatures in basementless houses. In the Arctic and Subarctic, where frozen ground and/or permafrost are prevalent, soil temperature is more critical for solving engineering problems.

Horn (1952) summarizes information on soil temperatures, listing 186 publications. It is interesting to note that comparatively few studies have been made in northern latitudes and the writer has found listed no studies conducted in the Arctic or Subarctic where simultaneous measurements have been made of the vertical distribution of soil and air temperatures and wind, and of solar radiation and precipitation, at 2 greatly contrasting sites such as those at Big Delta. Harrington's investigations (1928) in Saskatchewan were excellent, but limited mainly to a study of ground temperatures. Russian scientists have displayed great interest in microclimatology and many of their studies have been carried out in arctic and subarctic Russia. The works of Blagovidov (1935), Formozov (1946), Rozanov and Spaskii (1947), Sapozhnikov (1947, 1953), Aderikhin (1952), and Danishevskii (1955) contain discussions of the microclimate and its significance, as well as analyses of data obtained from measurements. Other Russian scientists are carrying out intensive microclimatic studies, the results of which have not yet been published. Dalrymple* (personal communication) reports that Russian scientists in the Antarctic during the International Geophysical Year (1957 - 1958) emphasized microclimatic investigations in their program.

Bliss (1956) and Conover (1957) report on the results of a microclimatic study conducted at Umiat, Alaska, and in the summer of 1956 Thornthwaite and his associates began an intensive microclimatic program at Point Barrow, Alaska (Mather and Thornthwaite, 1956). These studies were carried out in the arctic tundra, an environment considerably different from the taiga of the Big Delta area. where the potentials for human settlement, based mainly on agriculture, are much greater. At Fairbanks, in interior Alaska, Pruitt (1957) and H. M. Johnson (1957) studied winter microclimates of the soil surface and snow cover of importance to small mammals and birds as an aid in determining winter survival techniques for downed airmen.

(1) Mean hourly temperatures

Mean hourly ground and air temperatures for each thermocouple height are shown graphically in Figure 13 and are listed in Table A-2 (Appendix). Differences in mean hourly temperatures for comparable thermocouple levels, and between consecutive (adjacent) heights at the same station, are shown in Figure 14.

The most striking features of these graphs are the very slow warming

*Paul C. Dalrymple, Meteorologist, Quartermaster Research & Engineering Command, Natick, Massachusetts, conducted microclimatic measurements for the Quartermaster Corps at Little America V and at Amundsen-Scott Station, South Pole, from 1956 through 1958.

MEAN HOURLY GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

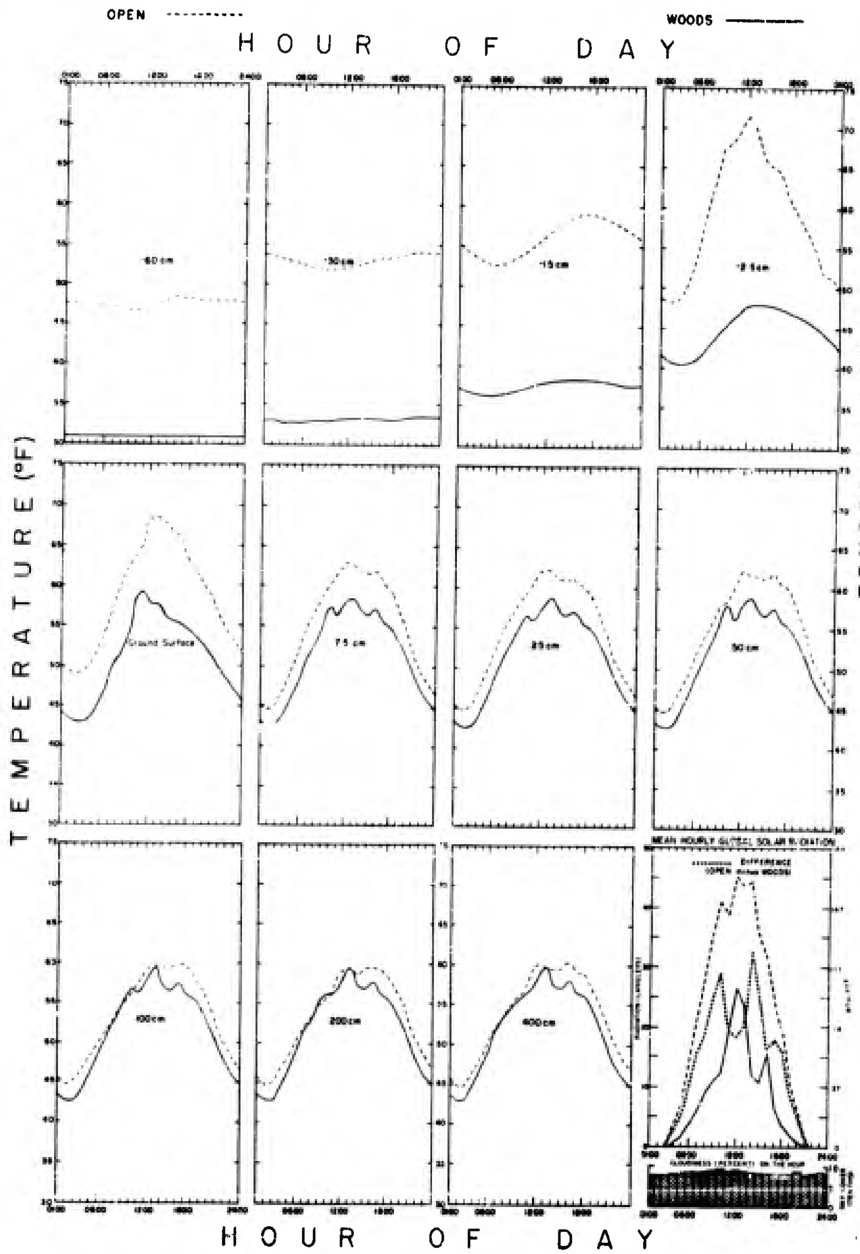


FIGURE 13

DIURNAL COURSE OF DIFFERENCES (F°) BETWEEN SIMULTANEOUS MEAN HOURLY TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS BIG DELTA, ALASKA
JUNE 12 - 30, 1956

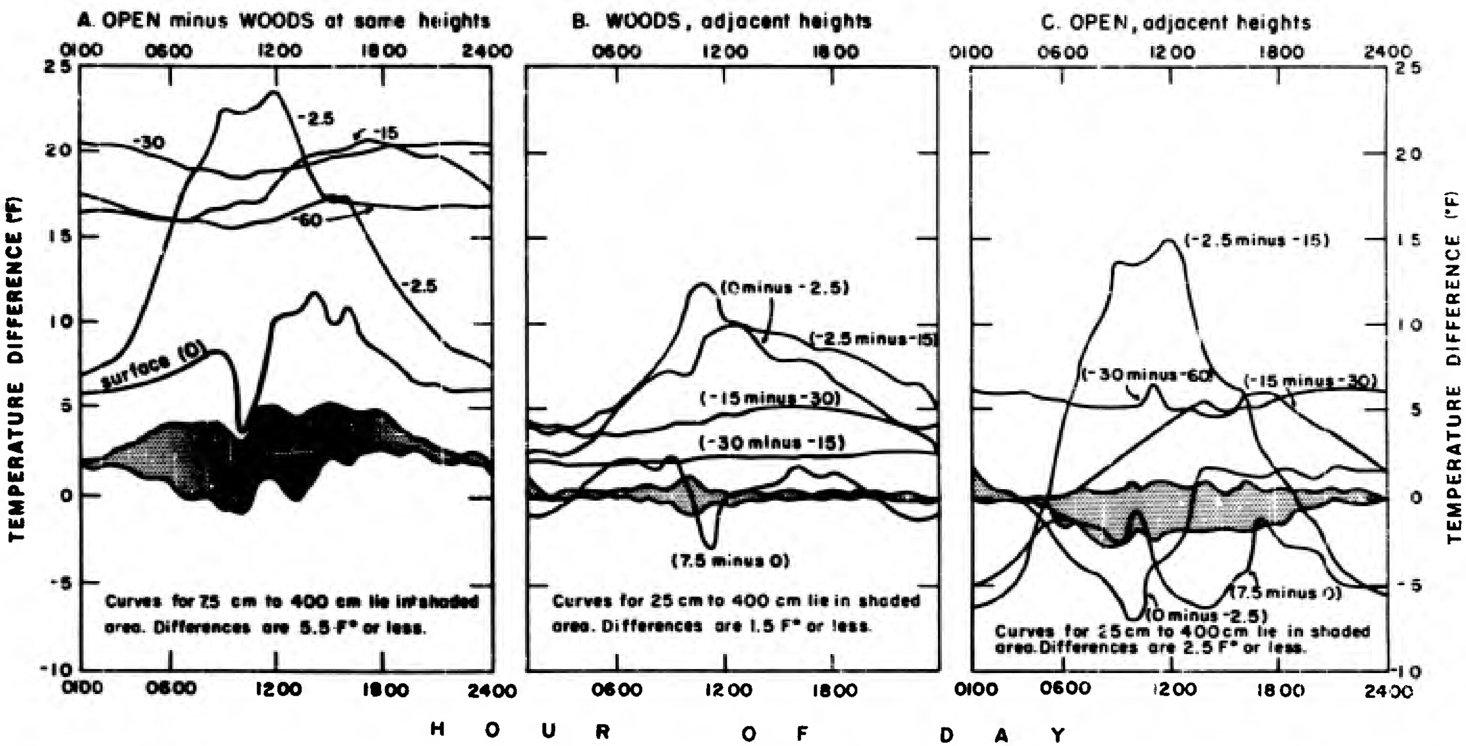


FIGURE 14

OF THE SOIL AND SOIL-SURFACE IN THE FOREST, THE LARGE DIFFERENCES IN SOIL TEMPERATURES AND SMALL DIFFERENCES IN AIR TEMPERATURES BETWEEN WOODS AND OPEN, THE HIGH TEMPERATURES RECORDED AT -2.5 CM IN THE OPEN, AND THE LAG IN THE MAXIMUM AND MINIMUM TEMPERATURES AT DEPTHS OF -15 CM AND BELOW.

THE MOSS-LICHEN CARPET ON THE GROUND SURFACE AT THE WOODS STATION SERVED AS AN EXCELLENT INSULATOR, STRONGLY RETARDING WARMING OF THE SOIL. AT -60 CM, TEMPERATURES REMAINED BELOW FREEZING AND THAWING BARELY BEGAN AT -30 CM. HEATING OF THE SOIL AT THIS TIME OF THE YEAR IS FURTHER RETARDED BECAUSE MUCH OF THE HEAT RECEIVED IS USED AS THE LATENT HEAT OF FUSION TO MELT ICE IN THE SOIL, AND THEN IS REQUIRED TO HEAT BOTH SOIL AND WATER ONCE THE ICE NEAR THE SURFACE IS MELTED. AT THE OPEN STATION, THE SOIL WAS ALREADY WARMED CONSIDERABLY AND A DIURNAL TEMPERATURE COURSE WAS ESTABLISHED AT ALL DEPTHS MEASURED.

THE LAG IN SOIL WARMING, INCREASING WITH DEPTH, AND THE DAMPING OF THE CURVES WITH DEPTH (REACHING 0 AT -60 CM IN THE FOREST), TYPIFY THE VARIATIONS AND FLUCTUATIONS OF TEMPERATURES IN THE SOIL. AT BIG DELTA, MAXIMUM AIR TEMPERATURES OCCURRED AT NOON OR IN THE EARLY AFTERNOON, AND MINIMUM AIR TEMPERATURES OCCURRED JUST BEFORE SUNRISE, NEAR THE END OF THE SHORT SUBARCTIC NIGHT.

AT THE OPEN STATION, <u>MAXIMUM</u> TEMPERATURES AT -15 CM LAGGED FOUR HOURS BEHIND MAXIMUM AIR TEMPERATURES; AT -30 CM THIS LAG WAS 10 TO 12 HOURS, AND AT -60 CM, 24 TO 26 HOURS. IN THE FOREST, MAXIMUM TEMPERATURES AT -15 CM AND -30 CM LAGGED 24 TO 26 HOURS BEHIND MAXIMUM AIR TEMPERATURES, SHOWING THE COMBINED EFFECTS OF LACK OF INSOLATION ON THE GROUND AND THE INSULATING PROPERTIES OF THE MOSS-LICHEN COVER.

<u>MINIMUM</u> TEMPERATURES OCCURRED SIMULTANEOUSLY IN THE AIR, AT THE SURFACE AND AT -2.5 CM AT THE OPEN STATION, BUT MINIMUM TEMPERATURES LAGGED BEHIND THREE HOURS AT -15 CM, 7 TO 8 HOURS AT -30 CM, AND ABOUT 30 HOURS AT -60 CM. IN THE FOREST, THE LAG WAS ONE HOUR AT -2.5 CM, 2 TO 3 HOURS AT -15 CM, APPROXIMATELY 26 HOURS AT -30 CM, AND THERE WAS NO VARIATION AT -60 CM.

THE TEMPERATURE LAGS OBSERVED AT THE VARIOUS SOIL DEPTHS AT BIG DELTA AGREE WELL (EXCEPT AT THE WOODS STATION) WITH RESULTS OF OTHER INVESTIGATIONS. SMITH (1929A) FOUND CORRESPONDING LAGS OF FOUR HOURS AT -6 INCHES (-15 CM) AND EIGHT HOURS AT -12 INCHES (-30 CM). THOMSON (1934) OBSERVED A LAG OF ABOUT THREE HOURS AT -4 INCHES (-10 CM).

LI (1926, P. 53), AS WELL AS SMITH AND THOMSON, FOUND THAT NEAR-SURFACE TEMPERATURES (SURFACE TO -2.5 CM) RESPOND ALMOST IMMEDIATELY TO CHANGES IN INSOLATION AND WIND WHEN THERE IS LITTLE OR NO VEGETATION COVER. MAXIMUM SOIL-SURFACE TEMPERATURES GENERALLY PRECEDE, BY AN HOUR OR TWO, MAXIMUM AIR TEMPERATURES, BUT MINIMUM SOIL-SURFACE TEMPERATURES AND MINIMUM AIR temperatures usually occur simultaneously. Li (1926, p. 53) mentions the effects of soil moisture in increasing lag and reducing the amplitude of soil temperatures. His observations are supported by Rider (1957) who found that the thermal conductivity of wet soil was greater than that of dry soil. Rider also found that when the soil was wet, the heat received from the sun was more readily dissipated, thus keeping soil-surface temperatures lower than those of dry soil. Moisture, in the form of rain, was more important in lowering ground surface temperatures at Big Delta than in lowering temperatures at greater depths.

Highest temperatures occurred at -2.5 cm rather than at the surface at the OPEN station. This was caused by a combination of factors. During, or following, the frequent intermittent showers, the surface was cooled through evaporation or by conduction from the relatively cool air. The soil below, at -2.5 cm and perhaps somewhat deeper, warmed during times of sunlight and insolation, still retained its heat. As the soil was warmed for about 18 to 20 hours during the long summer days, it retained much of its heat during the short night or periods of clouds and rain although the very surface may have been quickly cooled. The possible influence of plants cannot be overlooked, however, for the ground was not completely bare, and the surface thermocouple, although close to the -2.5 cm thermocouple (only 2 to 3 feet away), may have been shadowed by plants during certain hours of the day, while the -2.5 cm thermocouple may not have been.

The studies by Smith, Thomson, and Li were conducted in temperate or cold temperate regions. Investigations have been conducted in the arctic tundra and subarctic taiga, by Bliss (1956) and Conover (1957) at Umiat, Alaska, by Cook (1955) at Resolute Bay, Cornwallis Island, by Beckel (1957) at Fort Churchill, Canada, and by Pruitt (1957) near Fairbanks, Alaska. Results from Big Delta support the findings contained in these studies. Bliss and Conover found a temperature lag of two hours from surface to -1 inch (-2.5 cm), and a lag of five hours from surface to -4 inches (-10 cm). Daily fluctuations in temperatures near the surface at Big Delta were reflected in the soil below in a manner conforming with the findings of Cook, who observed a soil temperature lag of about four hours at -4 inches (-10 cm) and about 27 hours at -8 inches (-20 cm).

Temperatures at -60 cm at the OPEN station were strongly influenced by the cold ground below. Li (1926, p. 58) and Smith (1929a) found temperature lags of 1 to 3 days at -24 inches (-61cm), and Thomson (1934), in his studies at Winnepeg, found that diurnal variations were scarcely noticeable at -40 inches (-102 cm) during summer.

Soil temperatures at the OPEN station conformed more closely to air temperatures than did those at the WOODS because there was little vegetation cover in the opening as compared with the forest. In spite of rainy and cloudy weather, the soil at the OPEN station was usually drier, due to the better drainage and more rapid evaporation. At the WOODS station, conditions were more like those encountered by Cook and Bliss, and because of the interception of solar radiation by the conifers (spruce), may have been somewhat less extreme.

(2) Differences in mean hourly temperatures

(a) OPEN compared to WOODS

Temperatures at -15 cm, -30 cm and -60 cm were usually 15 to 20 F deg. lower in the forest than at the same depths in the opening (Fig. 14). Belotelkin (1941), observed that frost remained in the ground considerably longer under softwood stands than under hardwoods or in the open. This same condition was found at Big Delta, and differences in soil and ground surface temperatures may be attributed entirely to the vegetation cover at the WOODS station. In addition to the spruce trees which shielded the ground from solar radiation, the moss layer served to impede thawing, acting as an insulator against insolation and warm air. It should also be pointed out that both the spruce trees and moss-lichen mat intercepted much of the rainfall, especially when rainfall was light. In this manner too, the vegetation cover prevented more rapid thawing in the forest because much of the relatively warm rainwater did not reach the ground.

Figure 14 shows that 1) the ground from the surface to -60 cm differed more between the forest and opening at all times of the day (24 hours) than the air temperatures did, and further, these differences in ground temperatures were very large compared to the defferences in air temperatures, 2) the mean difference for 24 hours was greatest at -30 cm, 3) the largest difference, 23.5 F deg., occurred near midday at -2.5 cm, and 4) between 0900 and 1300 the differences at -2.5 cm exceeded those at any other depth.

The low soil temperatures in the forest are easily explained by the protective, insulating properties of the vegetation cover and by the frozen ground near -60 cm. The high temperatures at -2.5 cm in the open are rather distinctive, but by no means uncommon. Normally, the highest temperatures are measured at the surface, but at Big Delta, because of the frequent precipitation, wind, and evaporative cooling, this was not the case. Cook (1955) believes the effects of precipitation to be negligible at Resolute Bay. At Resolute, however, rainfall contributes little to the wetness of the ground, the moisture content of the soil being derived mainly from melting within the soil itself and from the thin snow cover that accumulates during winter. The water remains at or near the surface owing to the permafrost which lies below. At Big Delta, permafrost was lacking or was very deep (25 feet or greater) at the stations (Holmes and Benninghoff, 1957, p. 169) and rainfall during the 19-day period

EXCEEDED THE AVERAGE ANNUAL PRECIPITATION AT RESOLUTE BAY. RAIN FELL ON 15 OF 19 DAYS AND THE GROUND SURFACE WAS WET OR DAMP MUCH OF THE TIME. AT LEAST BY DAY, SURFACE TEMPERATURES AT THE OPEN STATION, THEREFORE, WERE LOWERED THROUGH EVAPORATIVE COOLING WHICH WAS INCREASED BY THE WIND. ACCORDING TO CHANG (1957)*, THE OCCURRENCE OF HIGHEST TEMPERATURES JUST BELOW THE SURFACE RATHER THAN AT THE SURFACE IS NOT UNCOMMON WHEN CONDITIONS ARE SIMILAR TO THOSE AT BIG DELTA. IN ADDITION TO THE COOLING EFFECT OF EVAPORATION, SURFACE TEMPERATURES AT THE OPEN STATION WERE ALSO LOWERED MOST OF THE TIME BY CONDUCTION TO THE AIR, WHICH WAS GENERALLY COOLER.

AT THE WOODS STATION, SURFACE TEMPERATURES WERE HIGHER THAN THOSE AT -2.5 CM. EVAPORATION WAS SMALL BECAUSE SURFACE HEATING WAS LIMITED AND WINDS WERE WEAK. AIR TEMPERATURES WERE NEARLY THE SAME AS THOSE AT THE SURFACE, AND THE FROZEN SOIL BETWEEN -30 CM AND -60 CM SERVED AS A COLD SOURCE, TEMPERATURES DECREASING RAPIDLY FROM THE SURFACE TO THESE DEPTHS.

AIR TEMPERATURES, EVEN ONLY 7.5 CM ABOVE THE SURFACE, DID NOT DIFFER MARKEDLY AT THE STATIONS. THIS CAN BE ATTRIBUTED, IN MAIN PART, TO AIR CIRCULATION (WIND) CLOSE TO THE GROUND WHICH KEPT DIFFERENCES UNDER 5 F DEG. SHREVE (1924) POINTS OUT THAT INSOLATION IS OF PRIMARY IMPORTANCE IN DETERMINING SOIL TEMPERATURES, AND BRUNT (1945) STATES THAT AIR TEMPERATURES ARE DIRECTLY DEPENDENT UPON SURFACE TEMPERATURES. RAIN, CLOUDS AND WIND, RESPONSIBLE FOR THE LOW SURFACE TEMPERATURES AT THE OPEN STATION, WERE ALSO INSTRUMENTAL THEREBY IN MINIMIZING TEMPERATURE DIFFERENCES. FURTHERMORE, THE WIND, BY BRINGING GREATER VOLUMES OF AIR INTO CONTACT WITH THE SURFACE AND BY PREVENTING ANY AIR FROM REMAINING LONG IN CONTACT, HELPED TO REDUCE THE CONTRAST.

(B) VERTICAL GRADIENTS

THE GREATEST DIFFERENCES IN MEAN HOURLY TEMPERATURES AT CONSECUTIVE THERMOCOUPLE LEVELS OCCURRED IN THE SOIL AT BOTH STATIONS. AIR TEMPERATURES WERE WITHIN 3 F DEG. AND DIFFERENCES WERE NEGLIGIBLE. THE LARGEST DIFFERENCE NOTED, NEARLY 15 F DEG., WAS BETWEEN -2.5 CM AND -15 CM AT THE OPEN STATION; A DIFFERENCE OF ONLY 6 F DEG. WAS NOTED BETWEEN -2.5 CM AND 0 CM. IN THE FOREST, THE INSULATING PROPERTY OF THE SURFACE COVER WAS AGAIN IN EVIDENCE. THE MOSS-LICHEN COVER LIMITED HEAT CONDUCTION FROM ABOVE AND THE GREATEST DIFFERENCE, 12.5 F DEG. AT MIDDAY, WAS BETWEEN 0 CM AND -2.5 CM, IN CONTRAST TO THE CLEARING.

(3) VERTICAL TEMPERATURE DISTRIBUTION ON SELECTED HOURS AND DAYS

FIGURES 15 AND 16 SHOW THE VERTICAL DISTRIBUTION OF TEMPERATURE FOR SELECTED HOURS (0100, 0700, 1300, AND 1900) AND DAYS (JUNE 15 AND 21).

*PERSONAL COMMUNICATION FROM DR. JEN-HU CHANG. DR. CHANG, OF THE HARVARD BLUE HILL METEORLOGICAL OBSERVATORY, RECENTLY COMPLETED (1957) A WORLD-WIDE STUDY OF GROUND TEMPERATURES FOR THE QUARTERMASTER CORPS.

Differences in air temperatures at the same levels at the stations were small, usually only 1 or 2 F deg., with those at the OPEN station generally being the higher. Exceptions occurred near and at the ground surface, where heating during the earlier part of June 15 caused temperatures to be much higher, and at 0600 to 0700 on the same day when air temperatures above 100 cm in the forest were higher than those in the open.

The distribution of temperature at 0600 to 0700 on June 15 is of special significance, for at that time the largest differences between the stations occurred at and near the surface; temperatures above the 100 cm level were higher in the forest, and the largest vertical temperature differences occurred at each station.

Air temperatures at the OPEN station, lowered by radiation during the short night, were not yet high, although surface heating had begun. In the forest, interception and absorption of solar radiation by higher parts of the spruce trees may explain the sharp increase (12 F deg. to 16 F deg.) in air temperatures during the 6-hour period 0100 to 0700. This increase cannot be attributed to surface heating, for at the surface the temperature increased only 5 F deg. during the six hours. The rise in temperature at the surface may have been caused in part by the warmer air above, as the low altitude of the sun at these hours precluded the possibility of much insolation reaching the ground in the forest.

In the open, the effect of insolation on 0 cm and -2.5 cm temperatures was quite pronounced. The highest recorded were at -2.5 cm, for reasons previously explained. The -2.5 cm and 0 cm temperatures were 26 F deg. and 13 F deg. higher, respectively, than those at -2.5 cm and 0 cm in the forest. Later in the day (June 15), surface heating progressed in the forest and the temperature difference at 0 cm was reduced to 10 F deg., but at -2.5 cm the difference was still considerable, 24 F deg., at 1300.

An interesting and distinctive feature of these profiles is the almost negligible change in air temperature with height above the 7.5 cm level in the forest, and above the 100 cm level in the open. Vertical differences amount to only 1 F deg. to 3 F deg. on both June 15 (sunny day) and June 21 (cloudy and rainy day), as shown in Figures 15 and 16. In the clearing, the effects of insolation and nocturnal (radiative) cooling may be seen from -2.5 cm to 100 cm.

The increase in temperature of 2 F deg. from -2.5 cm to 0 cm, and decrease of 5 F deg. from 0 cm to 7.5 cm at 0100 at the OPEN station on June 15 is intriguing. This increase was not confined to the one day, for it also appears in the June average, Figure 17. Normally, the surface would be expected to cool more rapidly than the ground beneath or the air above. This condition may have been caused by the partial shielding

VERTICAL TEMPERATURE DISTRIBUTION AT SELECTED HOURS ON A SUNNY DAY, JUNE 15, 1956 WOODS AND OPEN MICROCLIMATIC STATIONS BIG DELTA, ALASKA

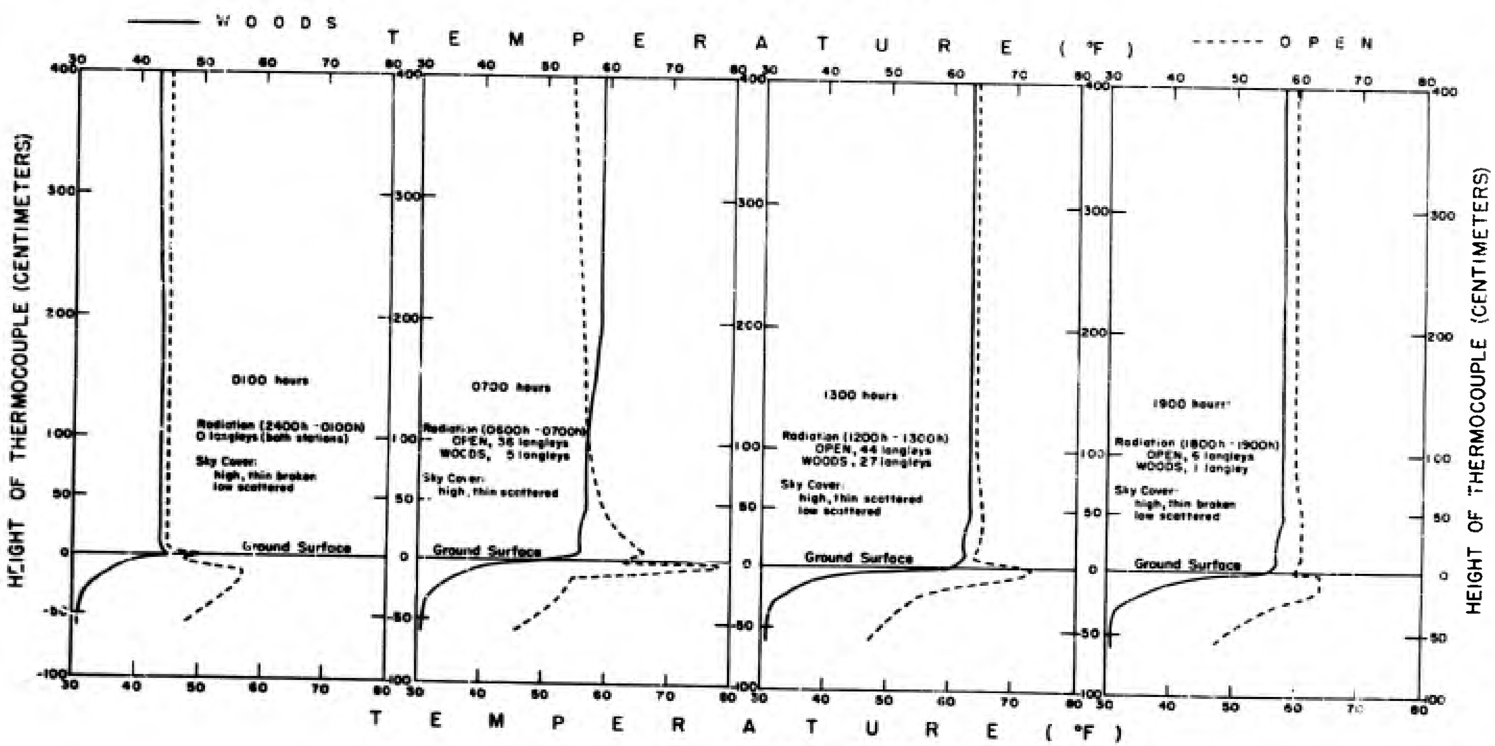


FIGURE 15

VERTICAL TEMPERATURE DISTRIBUTION AT SELECTED HOURS ON A CLOUDY DAY WITH RAIN, JUNE 21, 1956 WOODS AND OPEN MICROCLIMATIC STATIONS BIG DELTA, ALASKA

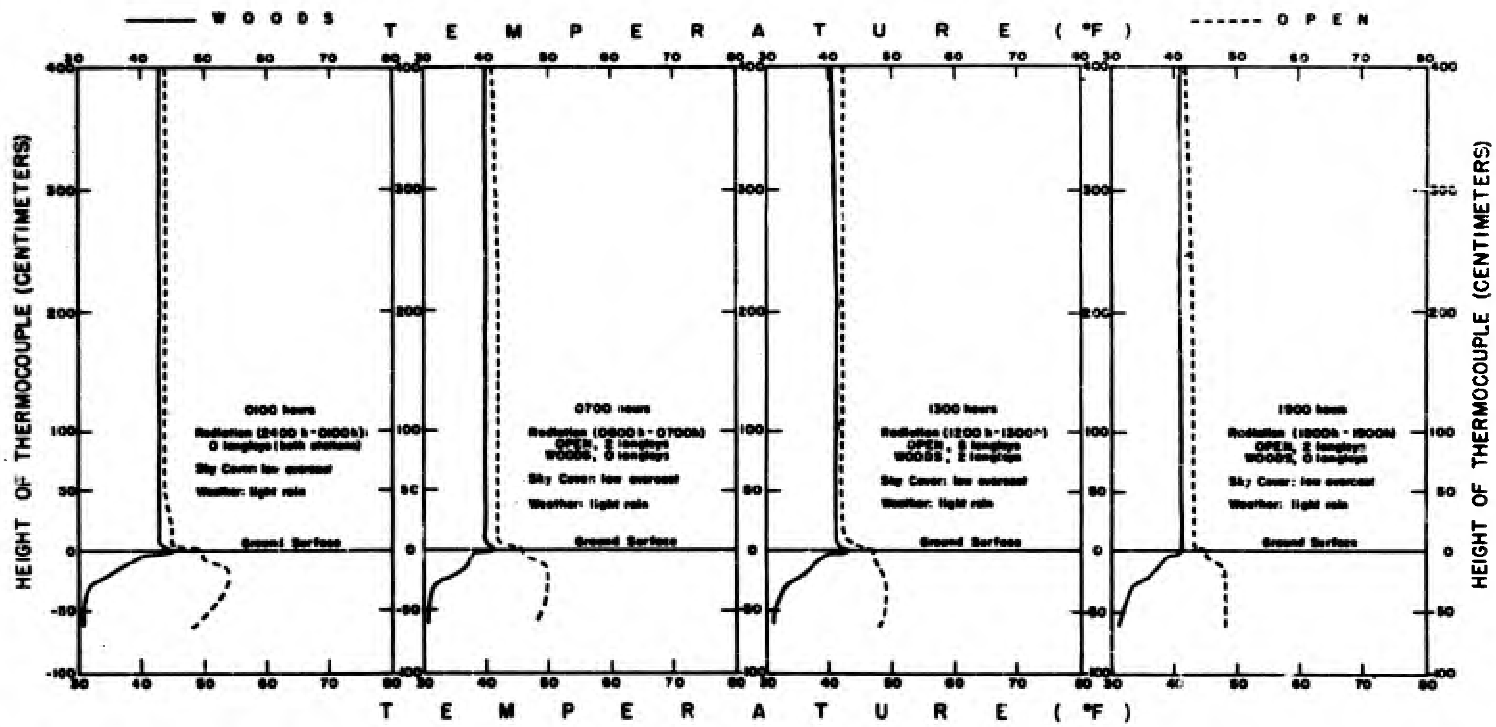


FIGURE 16

of the soil surface (0 cm) thermocouple by closely adjacent weeds or grasses. Radiation emitted by the ground surface was intercepted, in part at least, by the leaves and other parts of the plants. The leaves, in turn, re-radiated some of this absorbed radiation back toward the ground and some toward the sky. In this manner, all radiation from the ground did not escape directly to the sky, the net radiation loss from the ground was reduced, and surface cooling did not progress at its most efficient and rapid rate.

On June 21 (Fig. 16), rain and clouds exerted a moderating influence on air and surface temperatures, particularly at the OPEN station, where the highest temperatures occurred in the soil and the lowest in the air. In the forest, the temperatures were highest at the surface, except at 1900 when they were isothermal between 0 cm and 400 cm; on the ground, the temperature decreased rapidly with depth.

Brunt (1946), who studied the distribution of temperature in a forest with a thick canopy, such as that in which the WOODS station was located, found that during a clear day there is a general inversion below the canopy with cool air near the surface. The increase in temperature from surface to canopy is not regular. The base of an inversion occurs near the base of the canopy; below this there is an increase in temperature about one-half way to the ground followed by another inversion that extends to the ground. Brunt ascribes the intermediate maximum of temperature (about 400 cm at Big Delta) to the penetration of solar radiation through the canopy and absorption by tree trunks. Results at Big Delta only partially support Brunt's conclusions, and where in agreement, are not nearly so pronounced. Measurements were not made to the base of the canopy (about 600 to 700 cm) at Big Delta, and bad weather decreased the full effects of both solar and nocturnal radiation.

Brunt (1946) also found that on a clear night the top of the forest canopy is cooled by radiation to the sky. The ambient air, cooled by contact, sinks to the surface and an inversion builds up from the surface to the canopy. This condition was not observed at Big Delta, primarily due to cloudiness and the very short nights, which neither provided proper conditions nor allowed sufficient time for much nocturnal cooling.

Temperature distribution in the open conformed generally to the day-time (incoming radiation or insolation type) and nocturnal (outgoing radiation type) temperature distributions discussed by Geiger (1957, pp. 6-9, 62-79) and Bliss (1956). Cloudy or wet weather was again chiefly instrumental in limiting the effects of insolation and nocturnal radiation, and the extremes noted by Geiger and Bliss were not approached at Big Delta during June.

The very rapid decrease of temperatures with depth, shown in Figure 17, is similar to the illustration presented by Geiger (1957, p. 34), and is

VERTICAL DISTRIBUTION OF MEAN TEMPERATURES
AT VARIOUS LEVELS FOR SELECTED HOURS
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

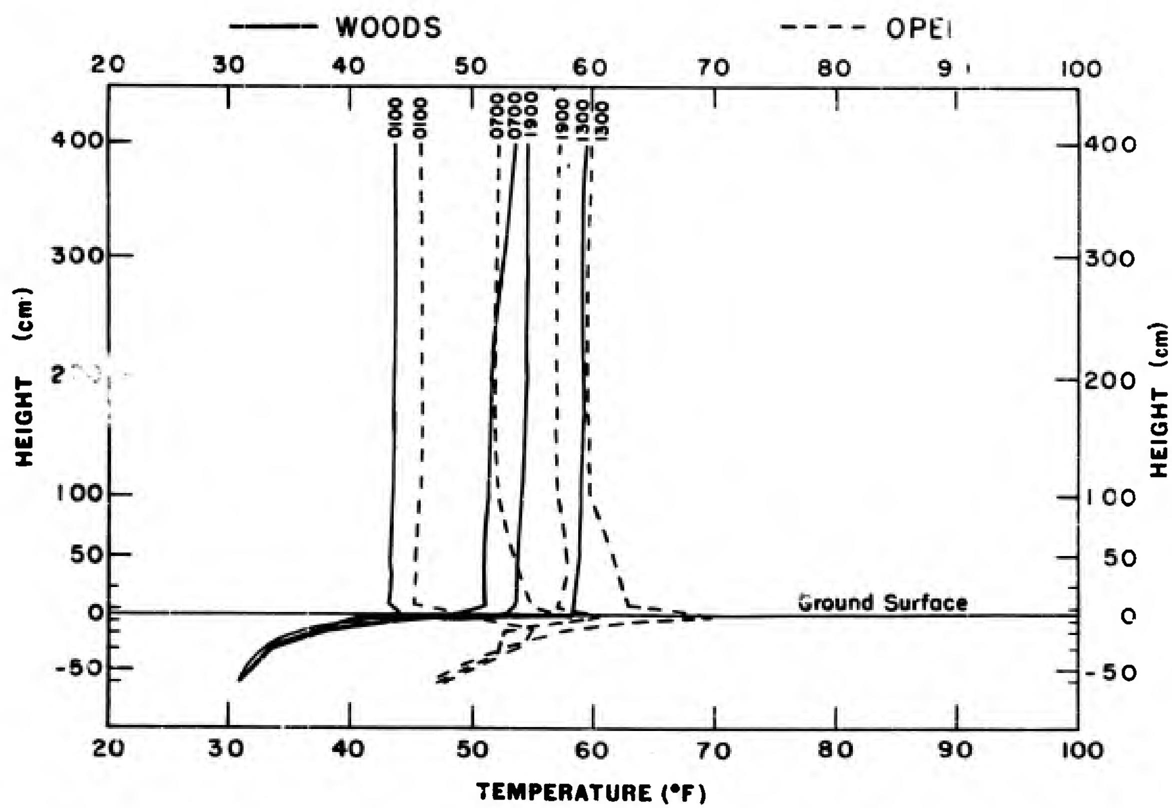


FIGURE 17

in agreement with results obtained by Bliss in his investigations (1956). Results obtained at Big Delta were also similar to the findings of Baum (1949b), the daily range of temperature increasing near and at the ground surface.

At the OPEN station, the ranges of temperature at 0 cm and -2.5 cm on June 15 were 21 F deg. and 30 F deg., respectively (Fig. 15). In contrast, the temperature range at these same levels on June 21 was only 5 F deg. (Fig. 16). The mean daily range was about 18 F deg. at 0 cm and 20 F deg. at -2.5 cm (Fig. 17). These values are small when compared with those observed in other regions, but in a subarctic summer environment, long hours of sunlight, low elevation of the sun with resulting low intensity of insolation, vegetation, and usually wet ground prevent the occurrence of large diurnal ranges in temperature, even at levels close to and at the ground surface.

(4) Daily mean temperatures

Daily mean temperatures are shown in Figure 18 and in Table A-3 (Appendix). Differences in daily mean temperatures at the same levels between the two stations, and between consecutive levels at each station, are presented in Figure 19.

Hide (1943) states that temperature is probably the most variable property of surface soil. He points out that numerous papers dealing with soil temperatures are available, but that daily fluctuations usually have not been emphasized nor has the relationship between temperatures at different depths of soil and those of the air been clearly defined. Figure 18 shows the day-by-day courses of soil and air temperatures. Figure 10, showing total daily global solar radiation and the daily mean cloudiness (sky cover), shows the dominant influence of insolation and clouds.

(5) Differences in daily mean temperatures

(a) OPEN compared to WOODS

Differences in daily mean temperatures at the same level between the two stations are shown in Figure 19A. These curves correspond closely to those for mean hourly temperatures, in that the largest differences, 4 to 24 F deg., occurred in the ground. Differences in the air were only 0.5 to 6 F deg. Clouds and rain were again responsible for reducing differences greatly on some days, especially June 21 and 22.

Soil temperature differences (at -2.5 cm and below) were greater than 10 F deg. and frequently more than 15 F deg., except at -2.5 cm on cloudy or rainy days. The largest difference between stations, 23.7 F deg., was at the -30 cm depth on June 16. On this day, the temperature at -30 cm in the forest was only 32.3 F while that at the OPEN station was 56.0 F, displaying the effect of insolation.

DAILY MEAN GROUND AND AIR TEMPERATURES
AND STANDARD DEVIATIONS
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

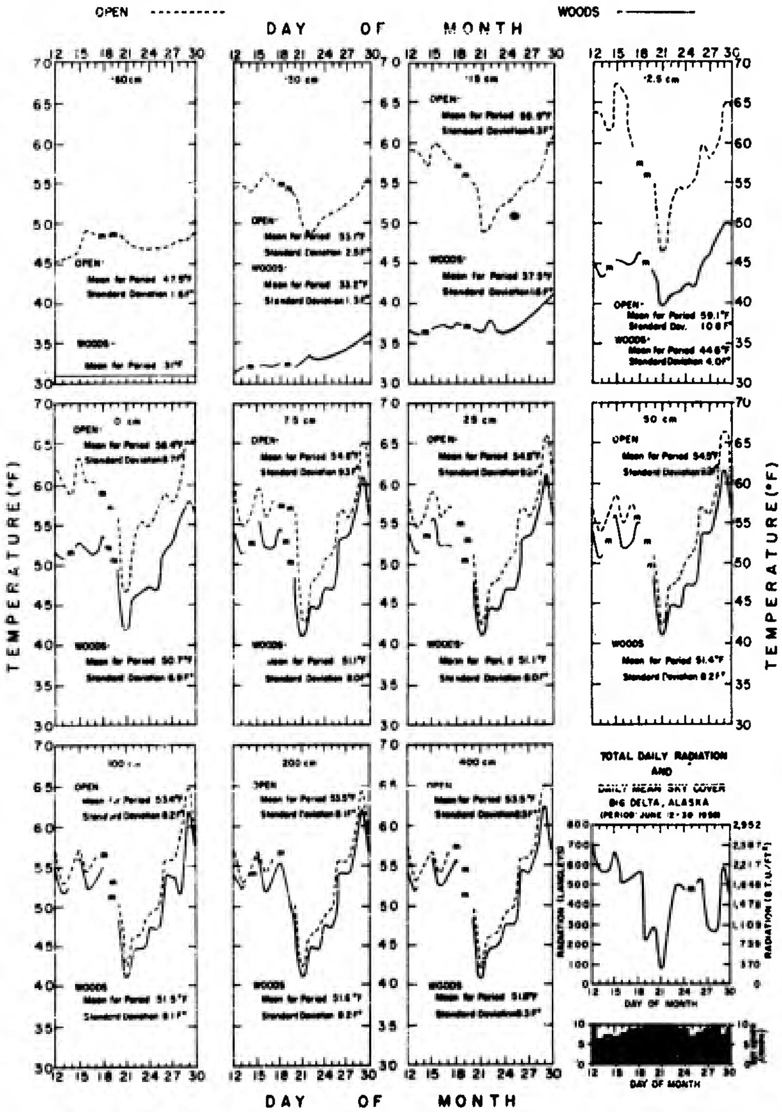


FIGURE 18

DIURNAL COURSE OF DIFFERENCES (F°) BETWEEN SIMULTANEOUS DAILY MEAN TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA
JUNE 12 - 30, 1956

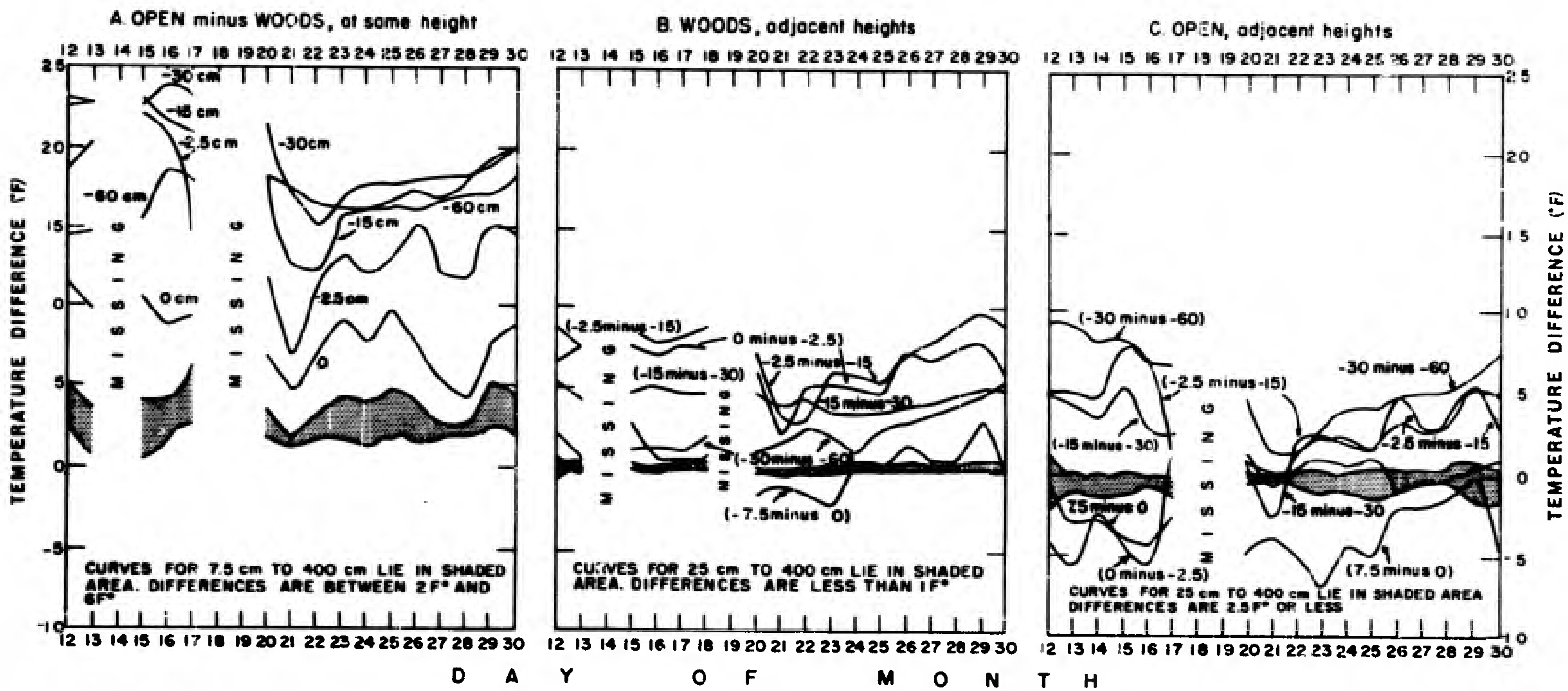


FIGURE 19

(b) Vertical gradients

The rapid decrease of ground temperature with depth shows in the large temperature differences between -2.5 cm and -15 cm, and between 0 cm and -2.5 cm (Fig. 19b). Differences in daily mean air temperatures were less than 2 F deg. between consecutive (adjacent) levels. Differences in daily mean temperatures were similar to those of mean hourly temperatures. For mean hourly temperatures, however, difference between 0 cm and -2.5 cm were greater than those between -2.5 cm and -15 cm during hours of greatest insolation, 0600 to 1300. This was not true for daily mean temperatures, for the hours of surface heating each day, reduced as they were by the trees and the cloudy, wet weather, were insufficient to make the differences between 0 cm and -2.5 cm as great as the large and continuous differences between -2.5 cm and -15 cm caused by the frozen layer at -30 cm and deeper. The temperature difference between 0 cm and -30 cm at midday was always larger than 12 F deg. and was frequently larger than 25 F deg.

Large temperature differences also occurred in the soil at the open station but were not nearly so marked as those in the forest. In the open, the warming of the soil had progressed considerably during May and early June (surface and soil temperatures were never less than 45 F) and diurnal fluctuations were apparent to -60 cm. Variations in soil temperatures were directly related to day-by-day variations in radiation (cloudiness) and precipitation.

A distinctive feature in the open was the difference in temperature between 0 cm and -2.5 cm and between 7.5 cm and 0 cm. Daily mean temperatures at -2.5 cm were often higher than those at the surface (0 cm), especially during the first few days of the period, June 12 to 16, when there were fewer clouds and less rain, than during the middle and end of the period. Surface temperatures, as expected, were higher than those at 7.5 cm. It must be surmised that the lower temperatures at 0 cm than at -2.5 cm were caused by either evaporative cooling or by shielding (shading, during the day), or a combination thereof.

When showers occurred during the middle or end of the day, after the soil had been heated at 0 cm and -2.5 cm, then it was possible for the surface to be cooled, through evaporation, while at -2.5 cm heat was still retained and temperatures did not decrease as rapidly. During the first several days of the period, and the last few, the ground surface was frequently wet due to intermittent showers, and there was both a low enough atmospheric vapor pressure and wind to favor strong evaporation.

Standard deviations computed for daily mean temperatures are given in Table III. Due to the few data available for performing calculations, the reliability of the values listed is limited. They are presented only as a means of rough comparison of the relative variabilities at the several heights and depths at the two stations.

TABLE III
MEAN DAILY TEMPERATURES, T (°F) AND STANDARD DEVIATIONS, S.D. (F°)
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

STATION	THERMOCOUPLE HEIGHT (CM)										
	-60	-30	-15	-2.5	0	7.5	25	50	100	200	400
OPEN											
T	47.5	53.1	55.9	59.1	58.4	54.8	54.5	54.5	53.4	53.3	53.5
S.D.	1.6	2.5	4.3	10.8	8.7	9.3	9.2	9.3	8.2	8.1	8.5
WOODS											
T	31.0	33.2	37.5	44.5	50.7	51.1	51.1	51.4	51.5	51.6	51.8
S.D.	0.0	1.3	1.6	4.0	6.9	8.0	8.0	8.2	8.1	8.2	8.3

In general, standard deviations increase with increases in mean temperatures, the largest deviation, 10.8 F deg., being at -2.5 cm at the OPEN station. The smallest value, 0.0 F deg. (no deviation), was at -60 cm in the forest, where the temperature remained constant (31.0 F) during the period. It is interesting to note that the highest daily mean temperature (59.1 F), highest absolute maximum temperature (100 F) and the greatest temperature range (59 F deg.) all occurred at -2.5 cm at the OPEN station.

Values included in Table III show a similarity in air temperatures at the two stations. The largest difference in daily mean air temperature was 3.7 F deg. at 7.5 cm, and differences in standard deviations ranged only from 0.1 F deg. at 100 cm and 200 cm to 1.3 F deg. at 7.5 cm.

(6) Temperature frequencies and durations

Relative and cumulative frequencies of temperatures, computed from hourly values, are shown in Figures 20 and 21. The greatest number of consecutive hours at or below selected temperatures, and the number of consecutive days with minimum temperatures at or below specified temperatures are given in Table IV and V, respectively.

Figure 20 shows the large contrasts between soil temperatures at the two stations and the similarity of air temperatures. The damping effect on temperature fluctuation with increased depth is also apparent. In the forest, where the concordant effects of vegetation and frozen ground are controlling influences there was no variation at -60 cm. The range of temperature at the WOODS station was usually one-half or less of that at the OPEN station for identical depths. Ranges varied

RELATIVE FREQUENCIES OF HOURLY GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

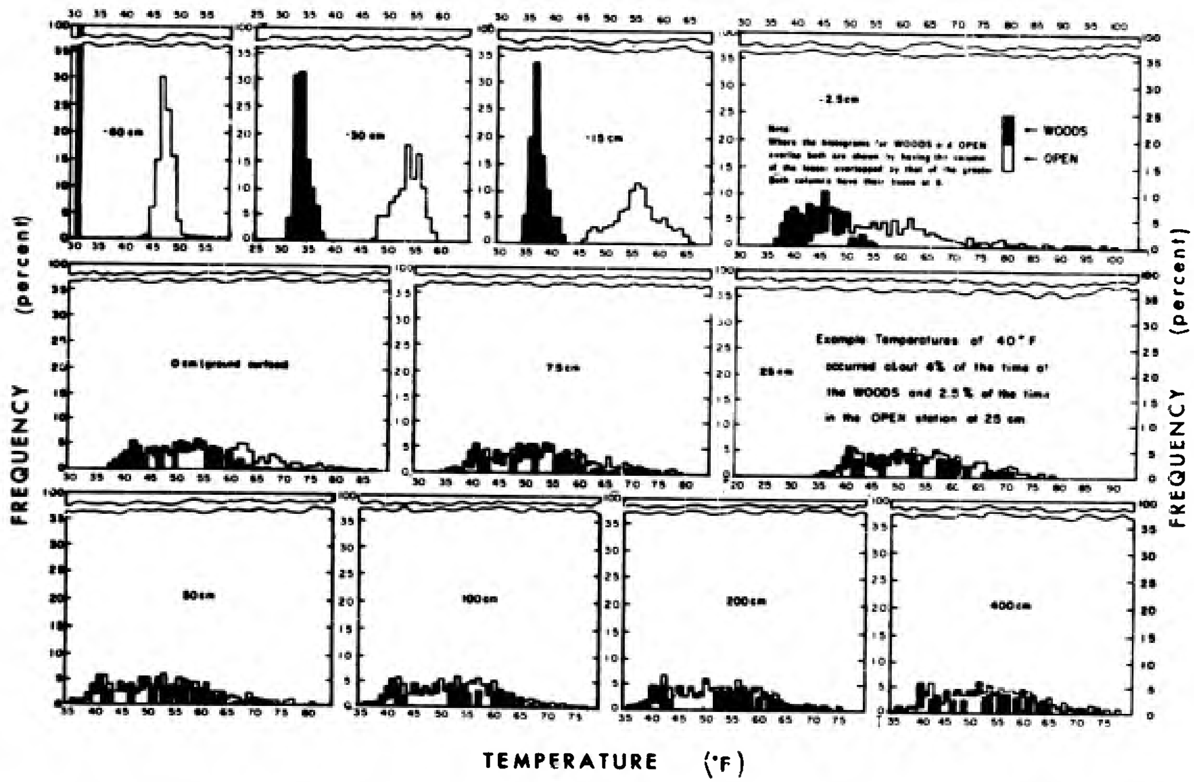


FIGURE 20

from 0 F deg. (-60 cm) to 19 F deg. (-2.5 cm) at the WOODS and from 6 F deg. (-60 cm) to 59 F deg. (-2.5 cm) at the OPEN station. The histograms of temperatures at 0 cm overlap considerably, but temperatures below 43 F did not occur at the OPEN station and values above 74 F were not recorded at the WOODS.

In the air (7.5 cm and above) there are few frequencies of five percent or greater, and all frequencies are less than seven percent. The similarity of air temperatures, caused primarily by the predominantly cloudy, rainy weather, is quite apparent. There is no sharp differentiation of temperatures between the stations, but only a slight tendency for lower temperatures to be more frequent in the forest and for higher temperatures to occur more often in the opening.

Cumulative frequencies of hourly temperatures, presented in Figure 21, provide an additional means of noting differences and similarities in soil and air temperatures at the two stations. The most distinctive features of this graph are the small range in soil temperatures at each station, the large contrasts in soil temperatures, and similarity of air temperatures between the stations.

It is often necessary to know how long certain temperatures may persist as well as knowing how often they occur. Extreme temperatures, lasting only a few hours, may not be as critical as more moderate temperatures which last a day or several days. Also, sudden changes may be more damaging than low or high temperatures. Preliminary investigations performed on Ladino clover stolons by Biel, Havens and Sprague (1955) indicate that with slow cooling (2 F deg. per hour) these plants will survive temperatures as low as 10 F, but that killing occurs with a more rapid change (10 F deg. per hour). A knowledge of the duration of temperatue is essential to a full understanding of stresses imposed upon flora and fauna. It is important for determining clothing requirements for men (Lee and Lemons, 1949), and for establishing practical design criteria for materiel (Hay, 1945; Sissenwine and Court, 1951).

Durations of temperatures above and below the following thresholds, after Conrad and Pollak (1950, pp. 164-68), are given in Tables IV and V: 32 F (frost days), 43 F (vegetative period or growing season), and 77 F (summer days). Except for 43 F, these and temperatures of 50 F and 68 F also are important for determining clothing requirements for soldiers in the field.

An interesting feature in Table IV is the very sudden decrease in duration of temperatures of 43 F and 50 F from -15 cm to -2.5 cm at the WOODS station. This is caused by the rapid increase in temperature toward the surface, due to the stronger influences of insolation and percolation of warmer rainwater at 0 cm and -2.5 cm. The duration of soil temperatures at 50 F and below is much greater at this station than at the OPEN.

CUMULATIVE FREQUENCIES OF HOURLY GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12-30, 1956

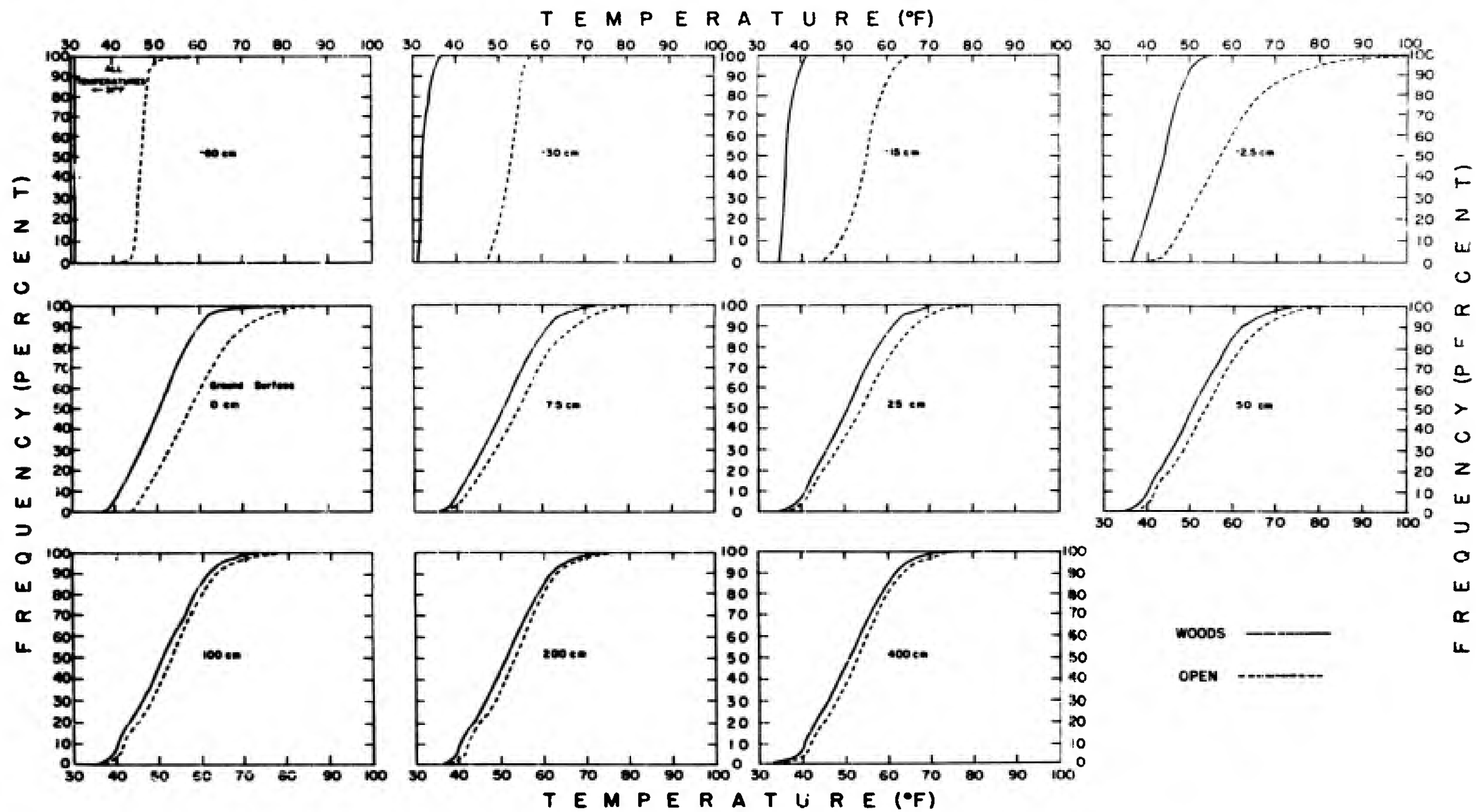


FIGURE 21

TABLE IV
GREATEST NUMBER OF CONSECTUVE HOURS AT OR BELOW SELECTED TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

THERMOCOUPLE HEIGHT (CM)	TEMPERATURE (°F) 32 WOODS	32 OPEN	43 WOODS	43 OPEN	50 WOODS	50 OPEN	68 WOODS	68 OPEN	77 WOODS	77 OPEN
-60	456	0	456	0	456	269	456	456	456	456
-30	92	0	456	0	456	59	456	456	456	456
-15	0	0	456	0	456	31	456	456	456	456
-2.5	0	0	40	0	289	32	456	148	456	310
SURFACE	0	0	29	0	39	20	456	102	456	311
7.5	0	0	31	17	41	37	309	242	456	312
25	0	0	31	28	37	37	309	242	456	420
50	0	0	31	27	41	37	309	242	456	421
100	0	0	31	28	41	38	309	244	456	456
200	0	0	31	28	41	37	309	244	456	456
400	0	0	32	28	40	37	309	244	456	456

TABLE V
NUMBER OF CONSECUTIVE DAYS WITH MINIMUM TEMPERATURES
AT OR BELOW SELECTED TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

THERMOCOUPLE HEIGHT (CM)	TEMPERATURE (°F) 32 WOODS	32 OPEN	43 WOODS	43 OPEN	50 WOODS	50 OPEN	68 WOODS	68 OPEN	77 WOODS	77 OPEN
-60	19	0	19	0	19	19	19	19	19	19
-30	6	0	19	0	19	3	19	19	19	19
-15	0	0	19	0	19	5	19	19	19	19
-2.5	0	0	16	0	19	7,7	19	19	19	19
SURFACE	0	0	7 (6)	0	18	8 (6)	19	19	19	19
7.5	0	0	13	5 (4)	19	9 (6)	19	19	19	19
25	0	0	6,6	5,5	19	9 (6)	19	19	19	19
50	0	0	7 (6)	6 (5)	19	9 (6)	19	19	19	19
100	0	0	7 (6)	6 (5)	19	9 (6)	19	19	19	19
200	0	0	7 (6)	6 (5)	19	9 (6)	19	19	19	19
400	0	0	7 (6)	6 (5)	19	9 (6)	19	19	19	19

WHERE TWO PERIODS OF NEARLY EQUAL LENGTH OCCUR THE SHORTER PERIOD IS GIVEN IN PARENTHESES.

Durations of air temperatures at the stations are similar, and in some instances, identical. The largest differences occur at and under temperatures of 68 F and 77 F at 50 cm, 25 cm, and 7.5 cm.

The longest durations of low air temperatures occurred from June 20 through June 23, days having the highest percentage of clouds, the greatest amounts of rain, and the least insolation.

In Table V there are large differences between the longest continuous runs of consecutive minima ≤ 50 F at WOODS and OPEN. This is because minima in the opening vary above and below 50 F while in the sheltered forest they are always 50 F or below. The total number of days with air temperatures ≤ 50 F at the OPEN, however, was only four less than at the WOODS. It is surmised that these differences might have been even less had not nighttime cloudiness kept minimum temperatures in the opening from falling to 50 F or below on several days.

Perhaps of greater interest are the variations in soil temperatures at the OPEN station. Minimum temperatures of 50 F or less were recorded on all 19 days at -60 cm, but only on three consecutive days at -30 cm and 7 and 8 consecutive days at -2.5 cm and 0 cm, respectively. At -60 cm, temperatures were continuously controlled by the colder ground below, whereas at 0 cm and -2.5 cm temperatures were lowered through contact with colder air, evaporation, rainfall, and, to a lesser extent, through radiational cooling. The -15 cm and -30 cm levels, lying between cooler layers above and below, retained much of the heat received during periods of insolation, were not cooled to the extent of the other levels and, consequently, minimum temperatures remained higher.

(7) Cumulated temperatures

Cumulated daily mean temperatures, Table VI, were computed for excesses above threshold values of 32 F and 43 F.

In lieu of satisfactory frost data, 32 F was used to determine the occurrence of killing frosts. Conrad and Pollak (1950, p. 167) quote a definition provided by C. F. Brooks as follows:

"A killing frost is one which kills the general vegetation at a place. There is no specific meteorological definition. Where the vegetation is succulent and easily damaged by frost, a killing frost will occur at a higher temperature than where the vegetation is hardy. In the absence of killable vegetation, a temperature of 32 F in a thermometer shelter is taken as a killing frost. Generally, however, the killing frost, first in fall and last in spring, occurs with a minimum shelter temperature higher than 32 F, sometimes as high as 40 F."

These authors conclude, therefore, that killing frost and growing season are usually defined biologically.

TABLE VI
CUMULATED DAILY MEAN TEMPERATURES (F°) ABOVE 32°F AND 43°F
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956*

STATION	THERMOCOUPLE HEIGHT (CM)										
	-60	-30	-15	-2.5	0	7.5	25	50	100	200	400
					ABOVE 32°F						
WOODS	0.0	2.8	95.3	215.0	320.5	327.0	352.1	332.3	333.8	335.4	349.0
OPEN	262.9	356.5	406.2	462.2	451.5	388.7	384.6	383.2	365.0	362.4	391.2
					ABOVE 43°F						
WOODS	0.0	0.0	0.0	36.6	134.5	141.9	142.4	147.2	148.7	150.3	154.1
OPEN	75.9	169.5	219.2	275.1	264.5	202.0	198.1	196.8	178.6	176.0	181.2

*TWO DAYS MISSING.

CUMULATED TEMPERATURE IS AN INDEX TO BOTH THE AMOUNT AND DURATION OF AN EXCESS OR DEFICIENCY OF AIR TEMPERATURE ABOVE OR BELOW A BASE TEMPERATURE. IN USING CUMULATED TEMPERATURES, HOWEVER, THE RELIABILITY OF DAILY MEAN TEMPERATURE MUST BE KEPT IN MIND. WHERE THE DIURNAL RANGE IS LARGE, THE TEMPERATURE MAY AT NIGHT DIP TO "LETHAL" LEVELS EVEN WHEN THE MEAN IS 43 F OR HIGHER. DATA PRESENTED IN TABLE VI SHOW THAT DIFFERENCES IN AIR TEMPERATURES WERE COMPARATIVELY SMALL, BEING LARGEST AT THE SURFACE AND 7.5 CM.

SOIL WARMING IN THE SPRING IS OBVIOUSLY CRITICALLY IMPORTANT IN THE SUBARCTIC WHERE THE GROWING SEASON IS VERY SHORT. SCIENTISTS OF THE UNIVERSITY OF ALASKA AND THE DEPARTMENT OF AGRICULTURE EXPERIMENT STATION, PALMER, ALASKA HAVE INCREASED THE RATE OF SNOW MELTING AND SOIL WARMING IN THE SPRING BY SPRINKLING COAL DUST OVER THE FIELDS. THIS ARTIFICIAL MEANS OF EXPEDITING THE HEATING OF THE SOIL IN THE SPRING CAN BE ACCOMPLISHED ONLY OVER SMALL AREAS, HOWEVER, SUCH AS GARDENS OR TRUCK FARMS.

SMITH (1932) STATES THAT OPTIMUM SOIL TEMPERATURE FOR ROOT GROWTH OF CULTIVATED PLANTS IS BETWEEN 65 F AND 70 F. DAILY MEAN SOIL TEMPERATURES AT BIG DELTA DURING THE PERIOD SHOW THAT SOIL WARMING HAD NOT PROGRESSED SUFFICIENTLY TO MEET THIS REQUIREMENT. ONLY AT -2.5 CM AND 0 CM AT THE OPEN STATION WERE TEMPERATURES HIGH ENOUGH TO SHOW SMALL ACCUMULATIONS OF

3.3 F deg. and 0.6 F deg., respectively. Because of low soil temperatures in spring and early summer, many of the cultivated plants in the Subarctic must be started under cold frames or in hothouses and later transplanted. A few hardier varieties, such as potatoes and turnips, may be planted directly as soon as the ground has thawed sufficiently to be worked, generally late May or early June at Big Delta.

(8) Degree days

Degree days are the generally accepted means for determining heating requirements, and are computed using daily mean temperatures and a base of 65 F. One degree-day unit is a departure of 1 F deg. of the daily mean temperature below 65 F.

In summer, heating requirements in the Subarctic are minor. Nevertheless, degree days may be used as a further means of comparing the microclimates of the two stations. Table VII lists degree days for the WOODS and OPEN stations based on daily mean air temperatures at the several heights. There was a small, but steady, decrease of degree days with height in the forest, but the reverse occurred in the OPEN. At the same thermocouple heights, the OPEN station was warmer (fewer degree days) than the WOODS.

In the forest, owing to a minimum of surface heating, there was only a small decrease (12 degree days) from 7.5 cm to 400 cm. At the OPEN station, due to surface heating, highest temperatures and, therefore, the least number of degree days occurred near the surface, and there was an increase of 21.5 degree days from 7.5 cm to 400 cm.

TABLE VII
DEGREE DAYS (65°F BASE)
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
June 12 - 30, 1956*

Station	Thermocouple height (cm)					
	7.5	25	50	100	200	400
OPEN	172.3	177.3	178.8	196.0	198.6	193.8
WOODS	234.0	233.4	228.7	227.2	225.6	222.0
Difference WOODS-OPEN	61.7	56.1	49.9	31.2	27.0	28.2

*Two days missing.

The greatest difference between the stations, 61.7, occurred at the 7.5 cm level. Above this level, differences slowly decreased to 28.2 at 400 cm. These relative differences accord with those in mean temperature.

(9) Effects of weather

The pronounced influences of clouds and precipitation on radiation and temperature were discussed above. Summer is the season of maximum precipitation and clouds, and these tend to minimize extreme conditions, as does vegetation. Because almost all days were cloudy and/or rainy during the period, it was often difficult to distinguish between the effects of weather and those of the vegetation at the WOODS station, or to determine the magnitude of either. Figure 22 shows mean hourly radiation and Figure 23 shows the daily course of temperature for each level at each station on a radiation day (Geiger, 1957, p. 34), a cloudy (overcast) day, and on a cloudy day with rain.

June 15 was selected to illustrate the temperature course on a radiation day, or day with strong insolation (Fig. 23A). This day had the second greatest total daily radiation, 661 ly, despite a mean sky cover of 66 percent (compared with a mean of 83 percent for the period). Under these conditions, the greatest contrast between the forest and open areas during the period could reasonably be expected. Li (1926, p. 42) noted that forests lower mean daily maximum air temperatures and also diminish the daily range in air temperatures. Both these effects are shown in Figure 23A. The range of temperatures is not only greater and maximum temperatures higher at each level at the OPEN station, but significant temperature differences are observed between consecutive levels which do not appear in the forest. This can be attributed to the quick response of the comparatively bare soil, and adjacent air layers, to heating by solar radiation. This is shown by the high temperature, 92 F at 0900 at -2.5 cm, which occurred nearly simultaneously with hours of minimum cloudiness (1000, 0.3 sky cover) and maximum solar radiation (1000, 68 ly) of the day. The increase of daily air temperature range at levels close to the ground surface is not nearly so pronounced as that discussed by Baum (1949b). Only the -2.5 cm depth at the OPEN station exhibits a temperature range substantially greater than that at the other depths and one that approaches daily temperature ranges observed at and near the surface in middle latitudes.

Figure 23B shows the course of temperature on June 27, a cloudy day (0.88 sky cover) having only a moderate amount of solar radiation (294 ly). At each station air temperature curves at all levels were similar, amplitudes being curtailed considerably, and differences between air and soil temperatures were sharply reduced, as were differences between the same levels at the two stations.

Highest temperatures still occurred at -2.5 cm at the OPEN station, but differences between -2.5 cm and 0 cm were negligible in most instances.

MEAN HOURLY GLOBAL SOLAR RADIATION ON A SUNNY DAY. CLOUDY DAY WITH RAIN, AND CLOUDY DAY WOODS AND OPEN MICROCLIMATIC STATIONS BIG DELTA, ALASKA
JUNE 1956

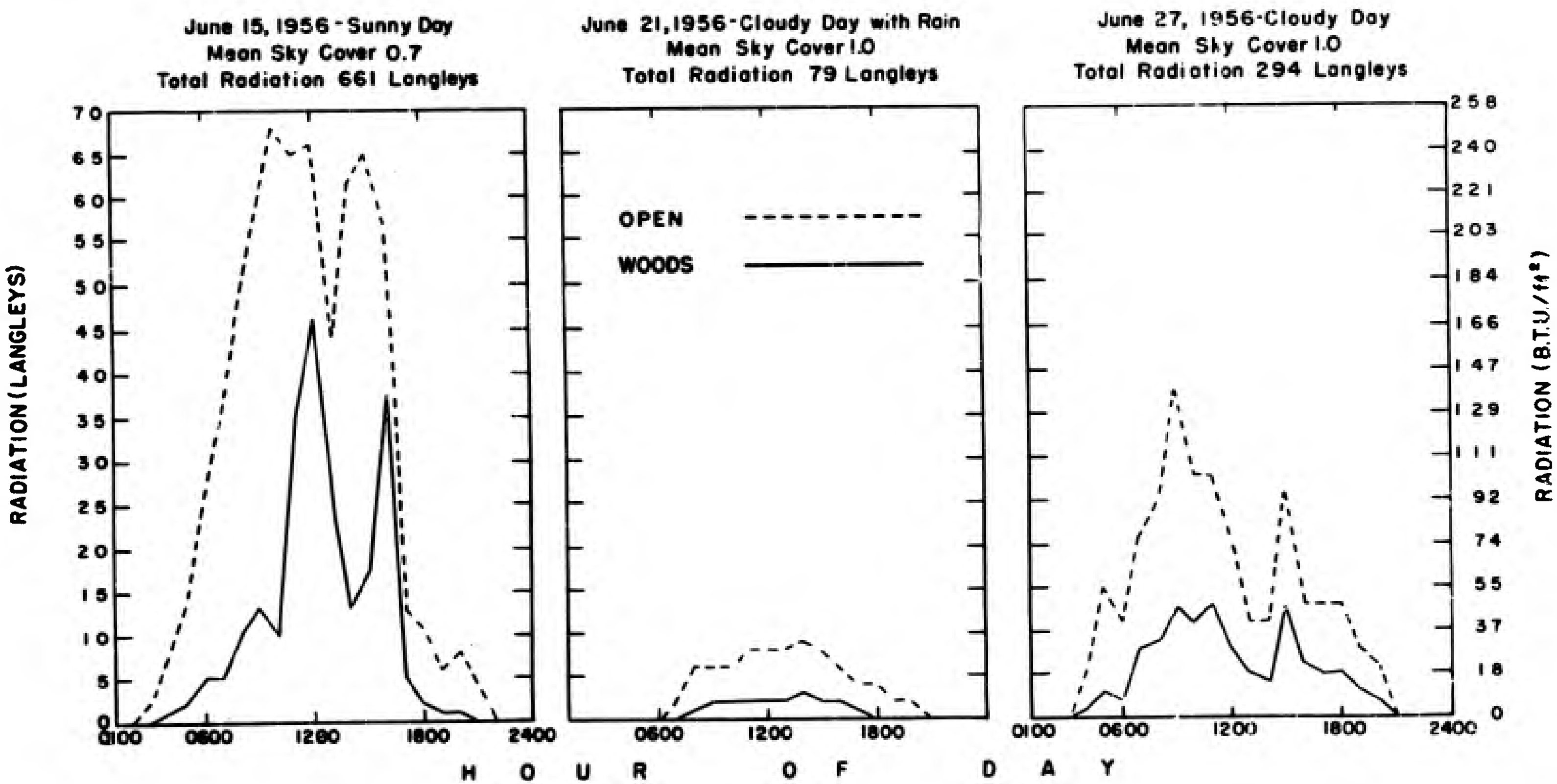


FIGURE 22

DIURNAL COURSE OF TEMPERATURE ON A SUNNY DAY, ON A CLOUDY DAY, AND ON A CLOUDY DAY WITH RAIN IN JUNE, 1956
WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA

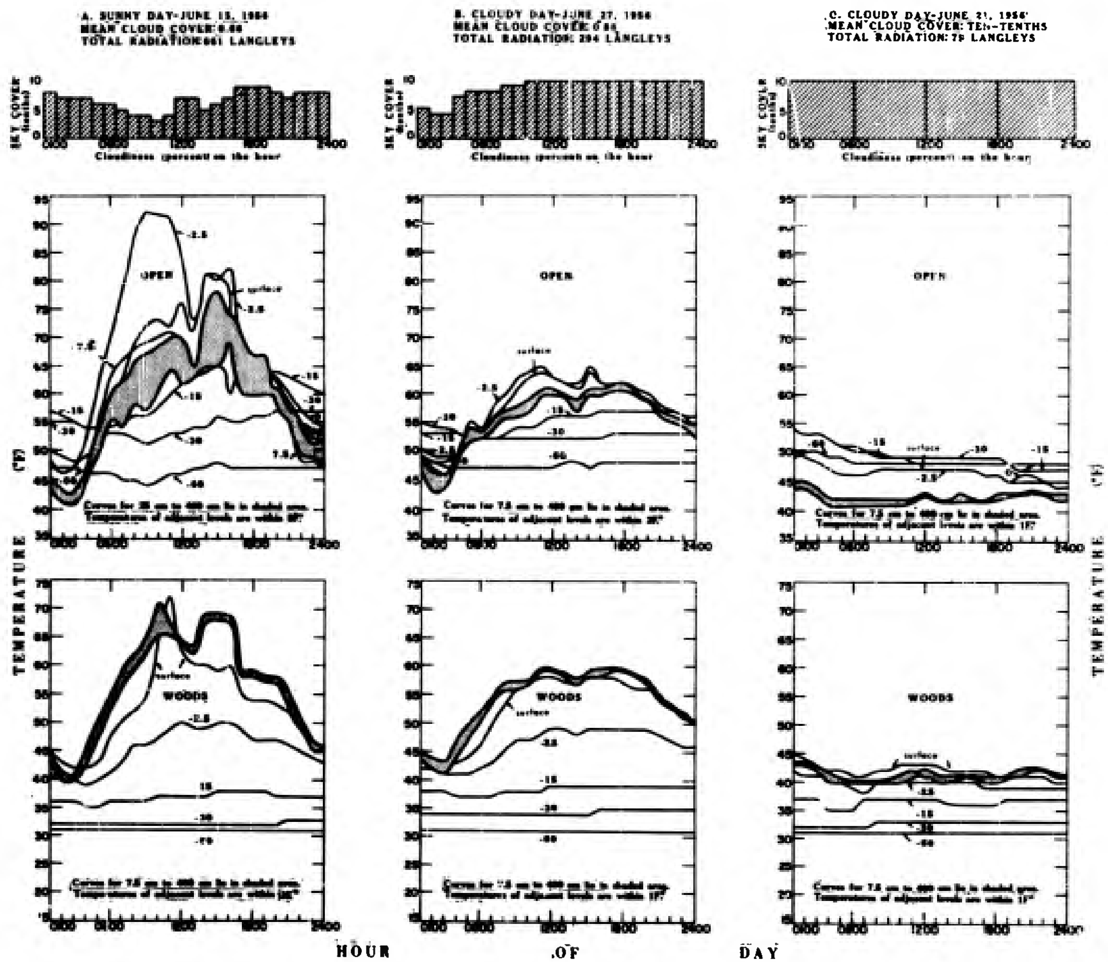


FIGURE 23

At night, at the OPEN station, minimum air temperatures were lower than minimum soil temperatures, occurring about 0200, just before sunrise. This same condition occurred on June 15, a relatively clear day, but it should be noted that during the early morning hours of June 27 the sky cover was actually less than on June 15, and the similarity in temperature is, thus, readily understandable. In the forest, the low temperature at -15 cm and deeper was evidently responsible for keeping soil temperatures at lesser depths at or below air temperatures most of the time.

Li (1926, p. 46) states that the effect of increased soil moisture (precipitation) is to lower maximum soil temperatures, lower mean soil temperatures, raise minimum soil temperatures, and greatly decrease the amplitudes of soil temperatures. Franklin (1919) points out that percolating rain is most important in producing minor (diurnal) fluctuations in soil temperature. Franklin also emphasizes that rain is a great equalizer of temperature between the surface and underground, and that the first rise in temperature underground (in England) is due to warm, spring rains. Gloyne (1950) supports this statement, noting that rain and/or lack of sunshine reduces the magnitude and regularity of diurnal oscillations of soil temperatures. Figure 23C, which shows the course of temperature on a cloudy and rainy day (June 21), illustrates some of these same conditions. June 21 was a cloudy (completely overcast) day with almost continuous rain and very little solar radiation (79 ly). The most distinctive feature of this graph is that air temperatures were lower than soil temperatures at the OPEN station. This was caused by the advection of fresh, cool, moist air from the Bering Sea in the west, and associated rain, which lowered air temperatures. In this case, rainwater did not significantly affect temperatures in the soil, except at 0 cm and -2.5 cm in the open. Temperatures at these two levels were nearly identical, and responsibility for this equalizing effect must be shared by both clouds and rain.

(10) Globe thermometer temperatures

The above discussion provides a means of comparing conditions at the stations on the basis of solar radiation and temperature. In addition to these two elements, however, the effects of wind also must be considered for a fuller understanding and appreciation of the thermal environment.

The instrument commonly used to measure the simultaneous effects of temperature, wind, and radiation is the globe thermometer. Globe-thermometer temperatures were measured at Big Delta to determine differences in the degree of warmness or coolness between the stations. Vernon (1932) describes the globe thermometer as an instrument used to record in a single measure the summated effect of diverse radiations from all sources, negative and positive, as well as the influence of convection and conduction. Bedford and Warner (1934) credit Vernon with introducing the globe thermometer as a means of indicating the combined effects of radiation and convection as they affect the human body. The instrument (shown in Fig. 4) consists of a hollow 6-inch diameter thin-walled copper sphere painted dull black into which a thermometer (or thermocouple) is inserted with the bulb at the center. The radiant energy exchange between the globe thermometer and its surroundings gives a crude approximation of that of a nude human body.

At the microclimatic stations, during summer, thermocouples were inserted into the globes and continuous measurements made. Mean hourly temperatures between the stations and between globe and air temperatures at each, and daily mean temperatures, relative and cumulative frequencies of hourly temperatures, and the differences are presented in Figures 24 through 26.

Mean hourly and daily mean globe temperatures closely follow the curves for solar radiation (Fig. 9), reflecting the changes of solar radiation at 1000, 1100, and 1400. Owing to the shading effects of the trees, mean hourly globe temperatures in the forest were lower by 5 F deg. to 10 F deg., and daily mean globe temperatures were lower by 6 F deg. at the WOODS than at the OPEN station.

The effects of cloudiness (lack of insolation) are strikingly shown by the curves for daily mean globe temperatures. From June 20 through 22, days with overcast sky and rain, differences in globe temperatures between the stations were at a minimum, and a difference of only 1 F deg. was measured on June 21, a day with almost continuous rain.

In addition to cloudiness, wind lowers globe temperatures. Wind speeds at 200 cm (the height of the globe thermometer) were 1 to 3 mph greater in the open than those at the same height in the forest. The effect, therefore, was larger at the OPEN station, and so offset the heating by insolation to some extent, thereby preventing the development of great differences between the stations.

Temperature, although a widely accepted means of indicating the degree of warmness or coldness, is not an adequate measure for determining human comfort. In cold regions especially, the globe thermometer, incorporating convection and radiation as well as air temperature, provides a more reliable method of determining the total thermal effects of the climatic environment. A comparison is presented between globe temperatures and temperatures at 200 cm in Figures 24 and 25.

In the forest, mean hourly globe temperatures were 2.8 F deg. to 8.8 F deg. higher than air temperatures during hours of greatest insola-

DIURNAL COURSE OF MEAN HOURLY GLOBE TEMPERATURES AND DIFFERENCES, GLOBE AND AIR TEMPERATURES AT 200 CM WOODS AND OPEN MICROCLIMATIC STATIONS BIG DELTA, ALASKA JUNE 12 - 30, 1956

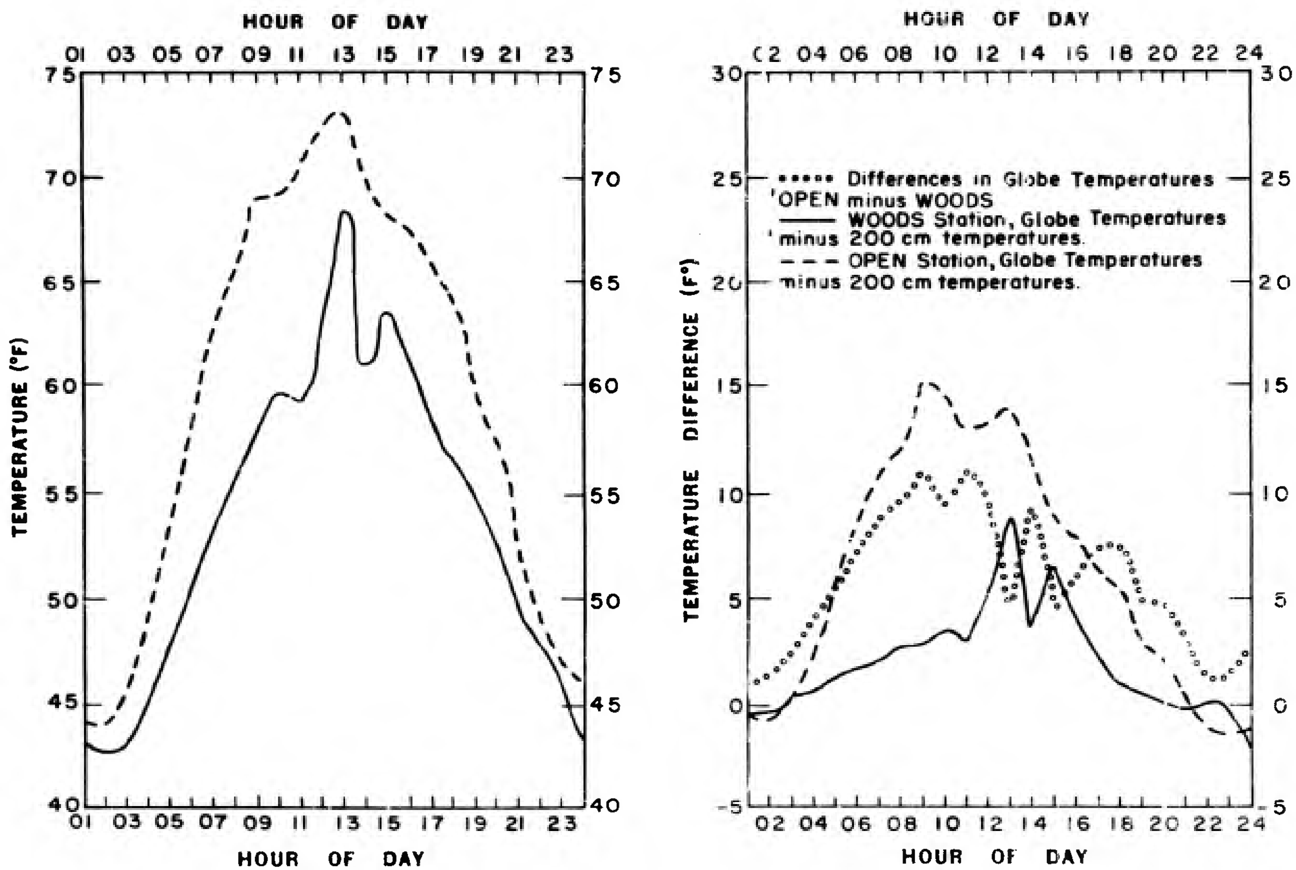


FIGURE 24

DAILY MEAN GLOBE TEMPERATURES AND DIFFERENCES
GLOBE VS. AIR AT 200 CM
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

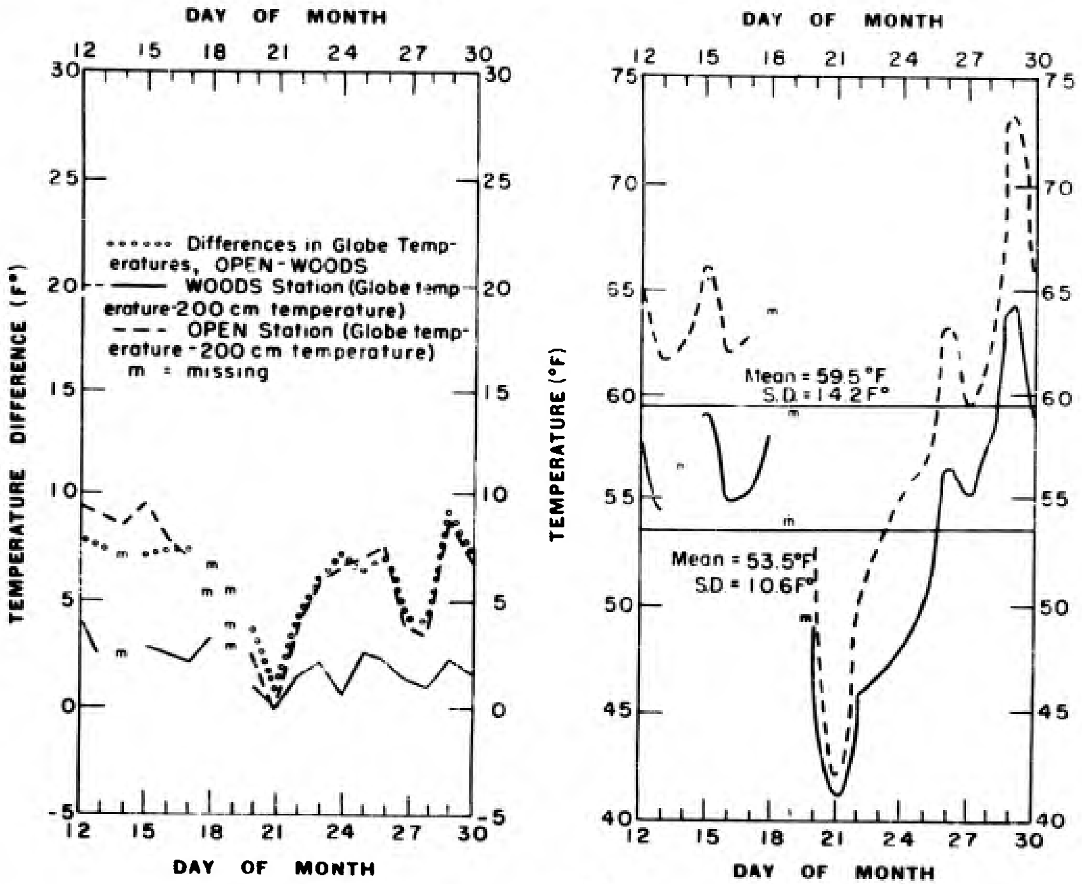


FIGURE 25

tion (usually 0900 to 1600). At night (2100 to 0230), globe temperatures were usually slightly lower, 0.2 F deg. to 1.8 F deg., than air temperatures. Radiational cooling of the globe thermometer at night, minimized by cloudy and rainy weather and short hours of darkness at both stations, was further limited at the WOODS station by the spruce trees which absorbed and radiated back much of the outgoing long-wave terrestrial radiation, thus preventing maximum cooling of the globe.

At the OPEN station, daytime differences between globe and air temperatures at 200 cm were larger (maximum, 15.2 F deg.) than those in the forest. At this station, the globe was fully exposed to both direct and indirect (sky) solar radiation, and the increased insolation was more than sufficient to offset the cooling effects of stronger winds. During the night, particularly when there was little sky cover, the globe cooled by radiation, and, as was true for the forest, its temperatures were slightly lower than those of the air at 200 cm. The moderating influences of weather, short nights and at the forest station, vegetation, were mainly responsible for keeping globe temperatures well above minima ordinarily anticipated under more normal circumstances.

Daily mean globe temperatures at both stations show the dominating effect of radiation (clouds): temperature curves are nearly identical with those for daily mean radiation, and the influence of vegetation is apparent at the WOODS station. A maximum difference of 9.5 F deg. was measured between the globe and air temperatures at 200 cm at the OPEN station, but the maximum difference was only 4.3 F deg. at the WOODS station.

The low globe temperatures measured at the stations on June 21 are quite distinctinve, especially those for the open. On this day alone was the daily mean globe temperature at the OPEN station less than the air temperature at 200 cm. This was caused apparently by evaporative cooling from the surface of the instrument, which was kept wet by the almost constant rain throughout the day. This cooling was increased by the wind. In the forest, the globe was protected by the trees from rain and wind, and globe and air temperatues at 200 cm were nearly identical, the globe temperature being only 0.1 F deg. higher.

Globe-thermometer measurements are important not only when one is studying human and animal physiological responses, but also when one is seeking clues to nature's workings in the plant world. It is known that certain arctic and subarctic plants flower when air temperatures are still below freezing. Krog (1955) found that at air temperatures of about 32 F the catkins of <u>Salix</u> became 27 F deg. to 45 F deg. warmer than the air. This same feature is found in other arctic and subarctic plants. <u>Eriophorum</u> (cotton grass) also has a dark-colored spikelet with shiny bracts, and at Anaktuvak Pass, Krog observed spikelets of this plant yellow with pollen on the side toward the sun, while the opposite side was black and undeveloped. Air temperatures were less than 32 F at the time. Although of interest, these observations of Krog must be supported by additional investigations.

Figure 26 shows the relative and cumulative frequencies of hourly temperatures measured by the globe thermometers. High temperatures were not as frequent at the WOODS station as would be expected, owing to the shading by the trees, and differences were not large, owing to the weather during the period. The range of globe temperatures was nearly identical at both stations. The fact that a large difference did not occur can also be attributed partially to the fact that in high latitudes much of the total solar radiation, even in summer, is diffuse. Since diffuse or scattered radiation comes from all directions, a larger proportion penetrates the forest canopy than does direct solar radiation. In this manner, differences in the amounts of solar radiation received at the stations were reduced. Consequently, the differences in globe temperatures were also reduced; nevertheless, the shadowing effect of the trees with respect to both direct and diffuse radiation at the WOODS station was considerable.

c. Wind

Wind is one of the more important of the environmental factors to be considered in the Subarctic and Arctic. It is most critical in winter. In summer, winds increase evaporation and, where soil drainage is good and rainfall small or variable, it may be detrimental to the growth of plants. In both summer and winter, blowing dust or snow reduce visibility and restrict outdoor operations, and, in addition, the dust and snow penetrate even the smallest cracks in mechanical (e.g., cameras) or electrical (e.g., field telephones) equipment, causing stoppage or damage.

The modifying influence of forests on wind, particularly on wind speeds, is very pronounced. Extreme wind speeds occurred at Big Delta in August 1955. At the time of these excessive speeds, the author was working in the spruce forest close to the site finally selected for the WOODS microclimatic station. In the open, gusts reached speeds of 40 to 50 mph, but about 150 yards in the forest only a light breeze was felt and the lower branches of trees barely moved. This protection afforded by forests against strong winds is of vital concern to man, animals, and plants.

(1) Mean hourly wind speeds

Mean hourly wind speeds are shown in Figure 27. Speeds recorded at the WOODS station were substantially less than those measured at the OPEN station. Both heights, 30 cm and 200 cm, at the two stations show a diurnal variation, the strongest winds occurring near midday, as usual. This variation was, naturally, greater at the OPEN than at the WOODS station. Unfortunately, no strong winds were recorded during the

RELATIVE AND CUMULATIVE FREQUENCIES OF HOURLY GLOBE TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

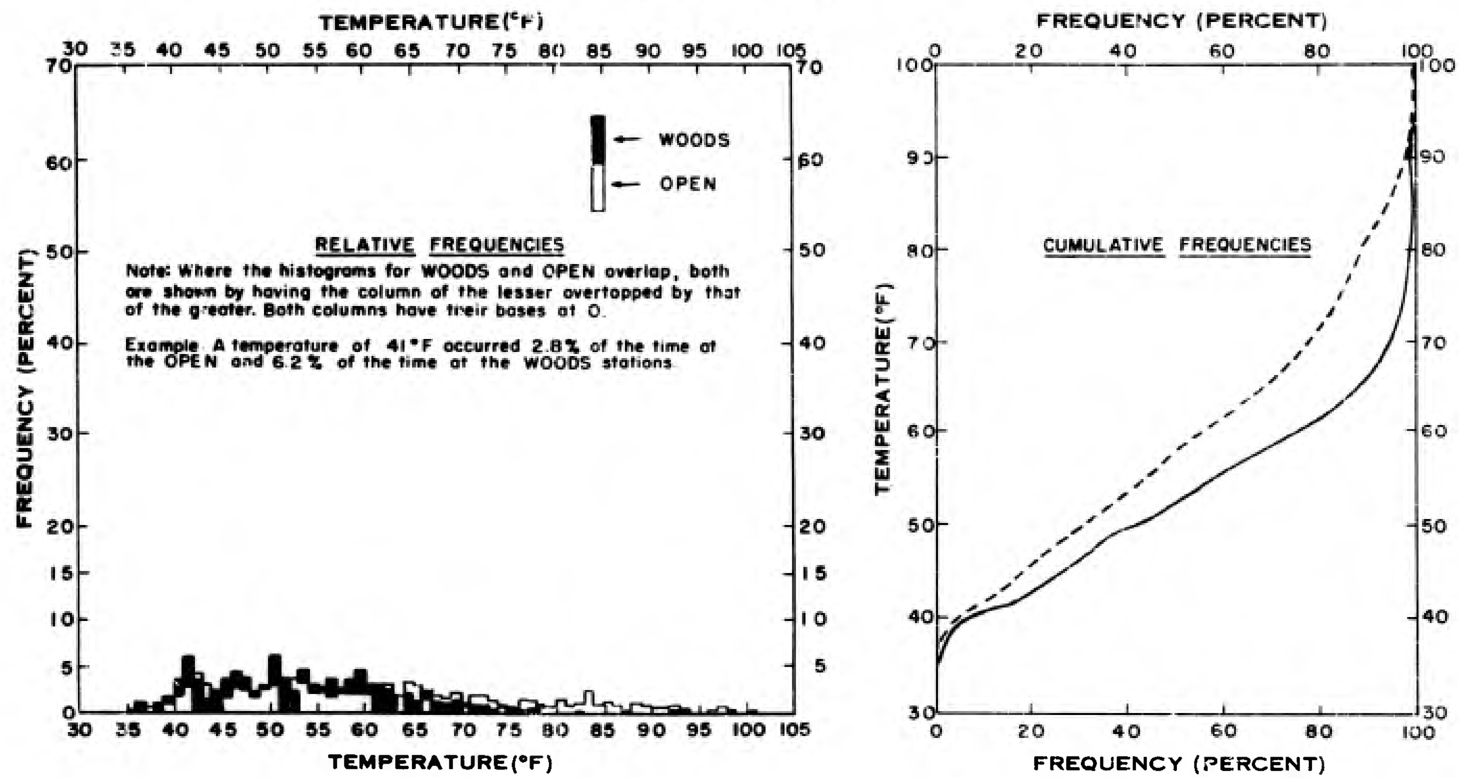


FIGURE 26

TABLE VIII
WIND SPEEDS OCCURRING SIMULTANEOUSLY WITH MAXIMUM WIND SPEED (MPH) RECORDED AT 200 CM AT THE OPEN MICROCLIMATIC STATION, BIG DELTA, ALASKA

Station and Height	June 15, 1956 1700 Speed	Direction	June 21, 1956 1700 Speed	Direction	1800 Speed	Direction
Open						
200 cm	11	N	11	NE	11	NE
30 cm	6	N	4	NE	6	NE
Woods						
200 cm	2	SE	Calm	-	Calm	-
30 cm	3	E	1	SW	1	SW

period, and the exact extent of the forest in reducing strong winds was not ascertained.

A maximum wind speed of 11 mph (three times) was measured at the OPEN station at 200 cm. This level also had the strongest winds on the average. Simultaneous speeds at the other levels in both forest and open areas are given in Table VIII. These values show only to a limited degree the influence of vegetation on wind speeds and directions.

In the open, mean hourly wind speeds at 30 cm were less than those at 200 cm, on the whole being only 75 percent as great. An exceptional feature is shown in Figure 27, namely, that mean hourly wind speeds at 30 cm in the woods were stronger during the daytime, 0700 to 1800, than those at 200 cm.

Thornthwaite (1949, p. 2) discusses the difficulty of obtaining several anemometers whose starting, stopping, and running speeds are identical. Although the anemometers used at Big Delta were not matched for uniform starting speeds, they were calibrated prior to being used and had threshold values of one-half mile per hour. Wind speed data are considered accurate, therefore, and differences noted between 30 cm and 200 cm in the forest are believed to have occurred.

The following explanation is offered for the higher speeds at the lower levels at the WOODS station. In the forests of this area, trees grow close together. This frequently results in the death of most of the lower branches up to heights of 10 or 15 feet. Animals, both large and small, pass through the woods, breaking off many of the branches at the

MEAN HOURLY AND DAILY MEAN WIND SPEEDS
30 CM AND 200 CM LEVELS
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

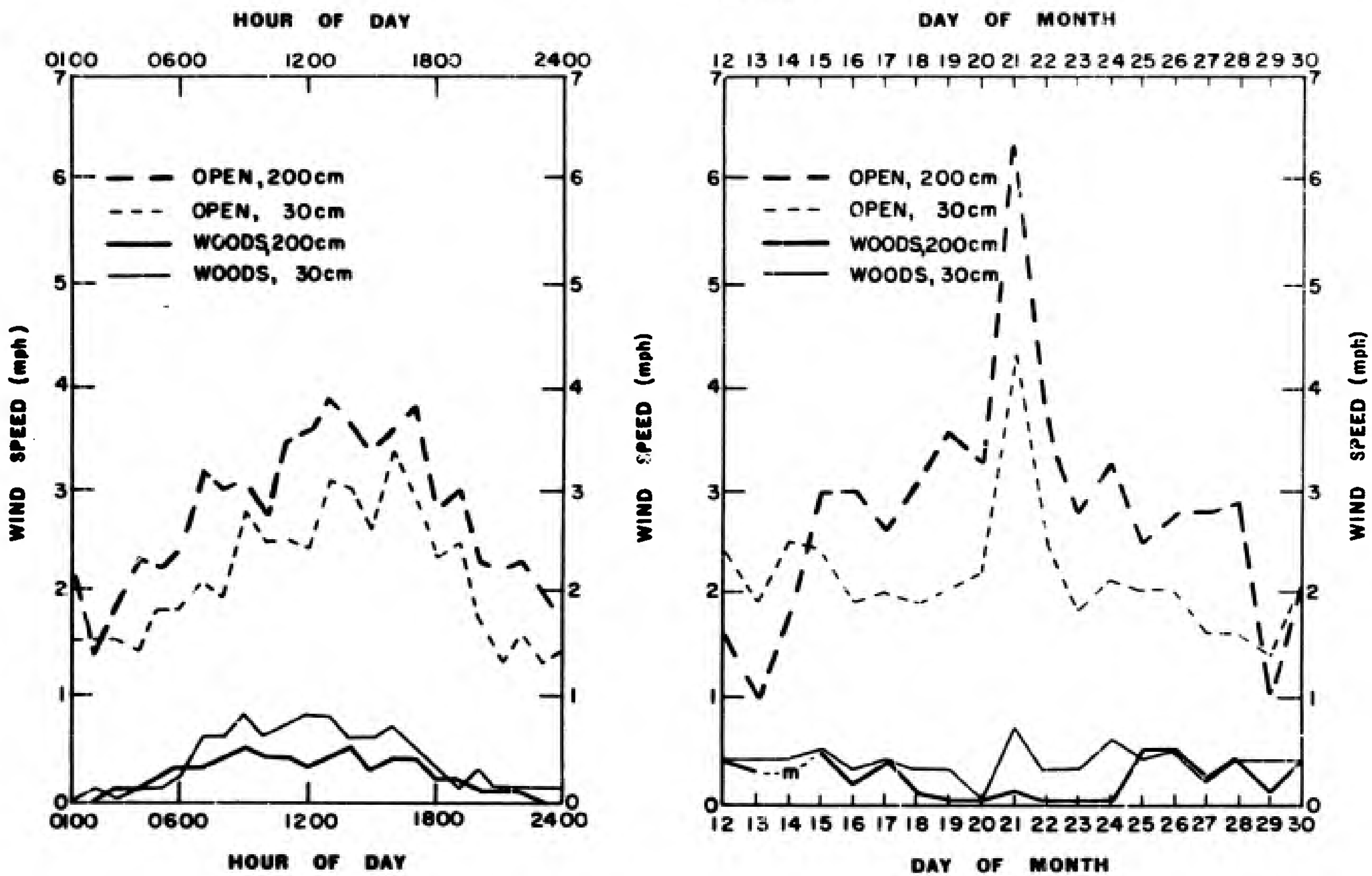


FIGURE 27

VERY LOWEST LEVELS, FROM THE SURFACE TO PERHAPS 2 OR 3 FEET. IN ADDITION, THESE ANIMALS FORM WELL-USED TRAILS THAT CRISS-CROSS THE FORESTS. THESE TRAILS AT THE SURFACE AND THE FEWER BRANCHES AT LEVELS CLOSEST TO THE GROUND PERMIT EASIER PENETRATION OF THE WIND AND FREER CIRCULATION OF AIR NEAR THE GROUND THAN HIGHER UP WHERE BRANCHES AND FOLIAGE ARE DENSER.

THE CONSIDERABLE VARIATION OF AVERAGE SPEED FROM ONE HOUR TO THE NEXT IS ATTRIBUTED BOTH TO THE SHORTNESS OF THE RECORD AND, PARTICULARLY, TO THE LARGE NUMBER OF CALMS DURING THE PERIOD. THE DIFFERENCES BETWEEN THE STATIONS AND LEVELS, HOWEVER, APPRECIABLY EXCEED THE INTER-HOURLY IRREGULARITIES.

(2) DAILY MEAN WIND SPEEDS

FIGURE 27 SHOWS DAILY MEAN WIND SPEEDS FOR THE PERIOD. AS WITH MEAN HOURLY VALUES, THE STRONGER WINDS WERE AT 30 CM IN THE FOREST RATHER THAN AT 200 CM. ON NINE OF THE 10 DAYS WITH RECORDS AT BOTH LEVELS, THE WIND AT 30 CM WAS THE STRONGER; ON ONLY ONE WAS IT THE WEAKER.

THE STRONGEST WINDS WERE RECORDED DURING TIMES OF BAD WEATHER, FOR EXAMPLE FROM JUNE 20 TO JUNE 23, AND WERE USUALLY ASSOCIATED WITH LOW PRESSURE AND FRONTAL SYSTEMS MOVING FROM THE BERING SEA. ON BRIGHT (RADIATION) DAYS, SUCH AS JUNE 12 AND JUNE 13, WHEN THERE WERE FEWER CLOUDS, NO "WEATHER", AND GREATER INSOLATION, WIND SPEEDS AT 30 CM SLIGHTLY EXCEEDED THOSE AT 200 CM AT THE OPEN STATION.

MEAN HOURLY AND DAILY MEAN WIND SPEEDS IN THE FOREST DEPENDED TO A CONSIDERABLE EXTENT ON THE DIRECTION FROM WHICH THE WIND BLEW, SINCE OPENINGS, TRAILS, ETC., DID NOT ALLOW EQUAL ACCESS FROM ALL DIRECTIONS. A SATISFACTORY DETERMINATION OF THE CORRELATION BETWEEN PREVAILING WIND DIRECTION AND WIND SPEEDS AT THE WOODS STATION, HOWEVER, REQUIRES THE COMPILATION OF A GREATER QUANTITY OF DATA THAN IS NOW AVAILABLE.

(3) FREQUENCIES OF WIND SPEEDS

RELATIVE AND CUMULATIVE FREQUENCIES OF HOURLY WIND SPEEDS ARE PRESENTED GRAPHICALLY IN FIGURE 28. DIFFERENCES IN WIND SPEEDS BETWEEN THE TWO STATIONS, AND ALSO BETWEEN THE 30 CM AND 200 CM LEVELS, ARE ILLUSTRATED BY THESE GRAPHS.

THE WEAKER WINDS AT 200 CM IN THE FOREST ARE PARTICULARLY WELL SHOWN, FOR IT CAN BE SEEN THAT CALMS OCCURRED 16.3 PERCENT MORE FREQUENTLY AT THIS LEVEL THAN AT 30 CM. CALMS ALSO OCCURRED MORE OFTEN AT 200 CM AT THE OPEN STATION, ALTHOUGH WINDS WERE GENERALLY STRONGER AT THIS LEVEL THAN AT 30 CM. ALTHOUGH THERE WERE FEWER CALMS AT 30 CM THAN AT 200 CM, THE FREQUENCY OF LOW WIND SPEEDS, ONLY 1 TO 2 MPH, WAS GREATER. STRONGER WINDS, 5 MPH OR GREATER, WERE SUBSTANTIALLY MORE FREQUENT AT 200 CM, AS WOULD BE EXPECTED FROM THE GREATER FRICTIONAL DRAG NEAR THE GROUND.

RELATIVE AND CUMULATIVE FREQUENCIES OF HOURLY WIND SPEEDS
30 CM AND 200 CM LEVELS
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

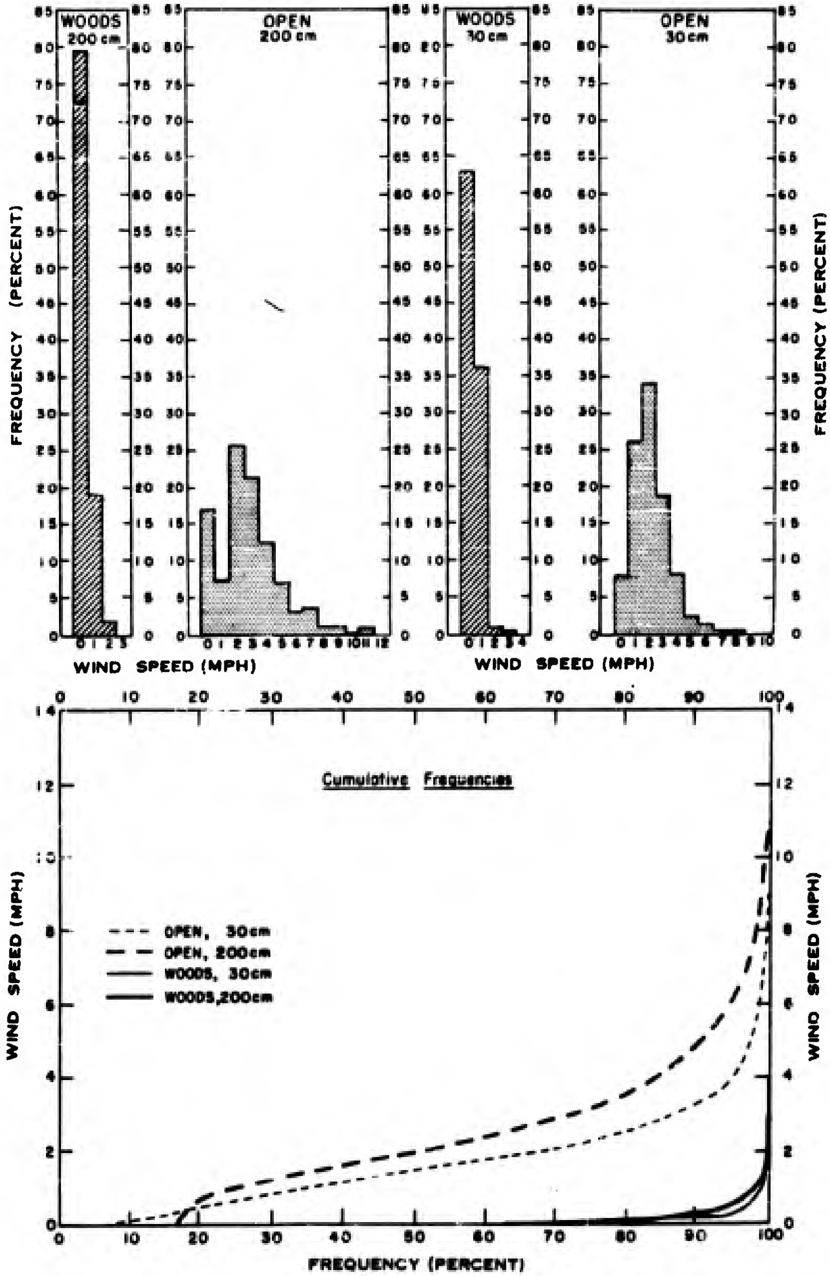


FIGURE 28

Wind speeds 2 mph or greater were measured only 0.9 percent of the time at 30 cm in the forest and only slightly more, 1.8 percent, at 200 cm. At the OPEN station, frequencies of winds 2 mph or greater were 37.8 and 49.9 percent, respectively, at 30 cm and 200 cm.

(4) Frequencies of wind directions and average speeds for each direction

Figure 29 shows the frequencies of wind directions to eight points and the average speed for each direction at 30 cm and 200 cm for each station.

At 200 cm, winds from the northeast were most frequent (31.5 percent) in the open, but the opposite direction, southwest, was most frequent (35.4 percent) in the forest. At both stations the least frequent wind direction was from a direction opposite to that of the most frequent direction, that is, southwest (5.1 percent) and west (4.8 percent) at the OPEN station, and northeast (3.2 percent) at the WOODS station.

Another feature of these graphs is the shift of the most frequent wind direction from northeast at 200 cm to south at 30 cm at the OPEN station. At the WOODS station, southwest winds were most frequent at both 30 cm and 200 cm. The change of wind direction from northeast to south between 200 cm and 30 cm in the open may be due to the fact that winds were weaker at 30 cm and increased variability resulting in changes in direction occurs more easily at low speeds.

The strongest average winds were recorded at 200 cm at the OPEN station. They ranged from 2.6 mph (east) to 3.6 mph (northeast and south). The next strongest were at 30 cm in the open, 1.6 mph (east) to 2.6 mph (northeast). At the WOODS station, average wind speeds were, for the most part, only 1 mph. Higher values, 1.7 mph from the northeast and 1.4 mph from the east, were measured at 200 cm. This appears contradictory to a previous statement that higher mean wind speeds occurred at 30 cm. The values shown in Figure 29, however, include only those hours during which the wind was blowing, thereby excluding calms. Average wind speeds for the period include the calms as 0's, and these were enough more frequent at 200 cm to reduce the average to less than that at 30 cm.

Contrary to the usual relation, the strongest mean winds in the forest did not blow from the direction of greatest frequency. Actually, the reverse was true: largest speed values occurred with the least frequent directions. It is generally found that strongest winds blow from the direction of the prevailing wind (direction of greatest frequency), and this is true for the OPEN station. Hawke (1955) has shown, however, that this premise is not always reliable, for the strongest winds along the North Sea coast of England blow in a direction opposite to that of the

FREQUENCIES, AVERAGE SPEEDS, AND RUN OF THE WIND
FOR EIGHT DIRECTIONS, 200 CM AND 30 CM LEVELS
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

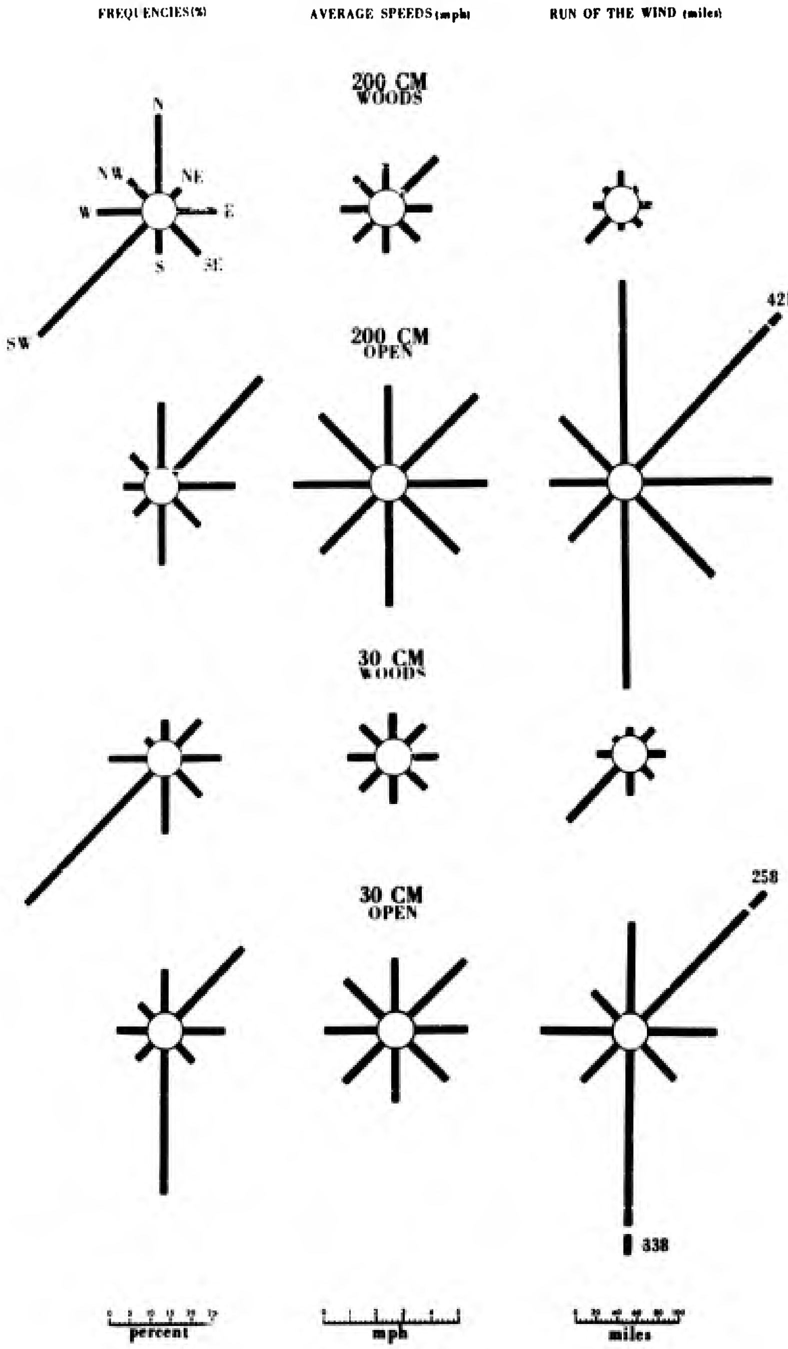


FIGURE 29

dominant (prevailing) winds. Locally, therefore, topography and vegetation play important roles in determining both wind speeds and directions.

The distribution of the trees about the WOODS station apparently determined the direction from which the stronger winds blew as well as the direction of greatest frequency. If, for example, winds from the northeast are most frequent and are also strongest, and there is a well-established trail in the forest running southeast-northwest, then it is believed that the wind will follow the path of least resistance, perhaps blowing from the southeast rather than from the northeast.

(5) Run of the wind

The run of the wind, also shown in Figure 29, is the total mileage of wind from each of the eight directions registered by each anemometer in the course of the month.

The miles of wind passing the OPEN station at both levels was, naturally, much larger than at the WOODS station. The greatest mileage at 200 cm from any direction was 421.2 (northeast) in the open, but no more than 33.0 (southwest) in the woods. Differences between the stations at 30 cm were also significant, the largest values being 338 (south) in the open, and only 74 (southwest) in the forest.

At the OPEN station, the run of the wind was larger at 200 cm than at 30 cm for 6 of the 8 directions. South and west winds at 30 cm were enough more frequent than at 200 cm, however, to make their mileages the greater at 30 cm. At the WOODS station, the run of the wind was the greater at 30 cm for all directions except north and northwest, which were most frequent at 200 cm. Differences between the two levels in the forest were quite small compared with those in the open. The generally larger runs of the wind at 30 cm at the WOODS station is another expression of the previous finding that average wind speeds, disregarding direction, were the greater at 30 cm.

(6) Resultant run of the wind and the steadiness ratio

The resultant run of the wind, computed by using Lambert's Formula (Conrad and Pollak, 1950, pp. 179-84), is the vectorial average of all wind directions and speeds at a given station for a certain period, in this case, June 12 to 30. Values of the resultant run of the wind for 30 cm and 200 cm at each station, and also for the steadiness ratio, are given in Table IX.

The resultant run of the wind synthesizes speed and direction, giving the net movement of air past each station. Large values, for example that for 200 cm at the OPEN station, result from a steady wind direction or a strong prevalence from one quarter, high average wind speeds from one direction, or a combination thereof. Essentially, a large value indicates that far greater amounts of wind,

TABLE IX
RESULTANT RUN OF THE WIND AND THE STEADINESS RATIO AT
200 CM AND 30 CM ABOVE THE SURFACE
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
JUNE 12 - 30, 1956

HEIGHT/STATION	RESUL. RUN OF WIND (MILES)	STEADINESS RATIO (%)
200 CM		
OPEN	427.9	34.7
WOODS	18.0	17.9
30 CM		
OPEN	188.5	19.5
WOODS	172.0	40.5

THAT IS, MORE MILES, PASS THE STATIONS FROM ONE DIRECTION THAN FROM THE OTHER DIRECTIONS. SMALL VALUES, SUCH AS THAT FOR 200 CM IN THE FOREST, INDICATE THAT THERE IS NO DOMINANT DIRECTION OR DIRECTION WITH PRONOUNCED WIND SPEEDS.

THE STEADINESS RATIO IS SIMPLY THE RATIO OF THE RESULTANT RUN OF THE WIND TO THE TOTAL RUN OF THE WIND (DISREGARDING DIRECTION) MULTIPLIED BY 100 TO MAKE IT PERCENT (CONRAD AND POLLAK, 1950, PP. 184-85). WIND FROM THE SAME DIRECTION AT ALL TIMES WOULD GIVE A STEADINESS RATIO OF 100 PERCENT. IF THERE WERE NO PREVAILING DIRECTION AND THE WIND BLEW WITH THE SAME FREQUENCIES AND SPEEDS FROM ALL DIRECTIONS, THE STEADINESS RATIO WOULD BE 0 PERCENT.

TABLE IX SHOWS THAT THE WIND IS STEADIEST AT 30 CM IN THE FOREST (40.5 PERCENT) AND AT 200 CM IN THE OPEN (34.7 PERCENT). THESE ARE THE WINDIER SITES AT THE MICROCLIMATIC STATIONS. FOR COMPARISON, CONRAD AND POLLAK (1950, P. 185) CONSIDER THE STEADINESS RATIO FOR JANUARY AT BOSTON, 54 PERCENT, AS RATHER HIGH, ALTHOUGH IN THE TROPICS VALUES EXCEEDING 90 PERCENT OCCUR DURING MONTHS WITH WELL-DEVELOPED TRADE WINDS. THE LOWER VALUES SHOWN IN THE TABLE, FOR THE OPEN AT 30 CM AND THE WOODS AT 200 CM, IMPLY GREATER VARIABILITY, BUT THE RELATIVELY FEW RECORDS AVAILABLE CAST SOME DOUBT ON THE RELIABILITY OF THE COMPARISONS.

D. PRECIPITATION

GEIGER (1957, P. 339) STATES THAT IT WAS EARLY RECOGNIZED THAT ONE CANNOT SAY OF A RAIN MEASUREMENT MERELY THAT IT WAS MADE "IN THE FOREST". MUCH DEPENDS UPON WHERE THE RAIN GAGE IS PLACED. THIS IS IMPORTANT WHEN CONSIDERING MEASUREMENTS MADE AT THE WOODS STATION

AT BIG DELTA. VALUES RECORDED ARE SIGNIFICANT ONLY FOR PROVIDING INFORMATION OF AMOUNTS RECEIVED AT THAT STATION, AND NOT OF THE FOREST IN TOTO. THESE DATA DO PROVIDE INFORMATION OF THE DIFFERENCES IN AMOUNTS RECEIVED AT THE TWO STATIONS, AND ARE VALUABLE WHEN USED IN CONJUNCTION WITH THE SOIL TEMPERATURE MEASUREMENTS.

(1) TOTAL PRECIPITATION

RAINFALL (NO SNOW WAS RECORDED) WAS HEAVY DURING THE MONTH OF JUNE 1956, AND ESPECIALLY DURING THE PERIOD OF STUDY. AMOUNTS RECEIVED WERE DISCUSSED PREVIOUSLY, BUT FOR CONVENIENCE ARE PRESENTED IN TABLE X.

MEASUREMENTS WERE MADE EVERY 24 HOURS AT 0900 AT THE MICROCLIMATIC STATIONS, BUT WERE NOT MADE ON HOLIDAYS OR WEEKENDS. AT THE CAA STATION, AMOUNTS ARE MEASURED EVERY SIX HOURS. FOR COMPARISON HERE, THE CAA DATA WERE TOTALED FOR THE 24-HOUR PERIOD ENDING AT 0830. IT MUST BE ASSUMED, IN THE ABSENCE OF A CONTINUOUS RECORD, THAT THE DIFFERENCE IN THE RAINFALL BETWEEN THE CAA AND THE MICROCLIMATIC STATION RECORDS DURING THE ONE-HALF HOUR 0830 TO 0900 WAS INCONSEQUENTIAL. THE DAILY RAINFALLS AT THE CAA AND THE MICROCLIMATIC STATIONS ARE GIVEN IN TABLE A-4 (APPENDIX).

GEIGER (1957, P. 339), CITING HOPPE, STATES THAT AN AVERAGE ERROR OF 25 TO 30 PERCENT IN REPRESENTING THE RAINFALL REACHING THE GROUND IN A FOREST MUST BE EXPECTED WHEN ONLY ONE GAGE IS USED, WHILE THE AVERAGE MAY AT TIMES EXCEED A SINGLE MEASUREMENT BY MORE THAN 100 PERCENT. IN ADDITION, ONE-FIFTH OF THE RAINFALL DOES NOT DRIP THROUGH AND REACH THE GROUND INSIDE OF THE FOREST (ALTHOUGH THE RAIN MAY RUN DOWN THE TRUNKS OF THE TREES), EVEN WITH THE HEAVIEST RAINFALL. DATA FROM BIG DELTA CONFORM TO THE LATTER OF THESE STATEMENTS. RAINFALL MEASURED IN THE FOREST WAS ALMOST ONE-FIFTH LESS THAN THAT RECEIVED IN THE OPEN. A SATISFACTORY EXPLANATION CANNOT BE GIVEN, HOWEVER, FOR THE DIFFERENCE IN AMOUNTS RECEIVED AT THE CAA AND OPEN STATIONS. THIS DIFFERENCE MAY HAVE RESULTED

TABLE X
TOTAL PRECIPITATION (INCHES) DURING JUNE 1956, FOR THE PERIOD JUNE 12 THROUGH 30, 1956, AND THE MEAN FOR JUNE
BIG DELTA, ALASKA

STATION	AV. JUNE	MAX. JUNE	JUNE 1956	JUNE 12 - 30, 1956
CAA	2.30	3.70	3.85	3.80
OPEN	--	--	5.08	4.65
WOODS	--	--	3.85	3.73

from the difference in location or exposure to wind, but gages were well exposed, wind speeds were small, and the procedure for making measurements is rather simple. The gage at the CAA station was located on the ground at the airfield and sufficiently far from the building so as not to be influenced. The location of the gage at the OPEN station may be seen in Figure 6.

An additional explanation may be offered for the large difference in precipitation between CAA and OPEN stations. Summer precipitation at Big Delta is usually associated with convection, occurring as scattered afternoon showers. Rain of this type sometimes occurs at one place and not at a nearby location. Although cyclonic activity accounted for the greater than average rain in June, the usual summer convective activity was also important, and was perhaps "triggered" by the frontal systems and lows. Thus, rainfall, though more widespread than usual, still fell in heavy showers locally, and this would partially explain the difference in amounts received by stations not far apart.

(2) Frequencies of precipitation amounts

At the CAA station, rain or drizzle (including traces) occurred during all but five of the 24-hour periods, but substantial amounts (over 0.25 inch) were measured on only five days. Six days had only a trace, and the heaviest 24-hour amount was 1.13 inches. At the OPEN station, 2.50 inches was measured between 0900 on June 21 and 0900, June 22, and 2.10 inches at the WOODS station. This heavy rain, split between two days at the CAA station, totaled 1.92 inches.

(3) Dry and wet spells

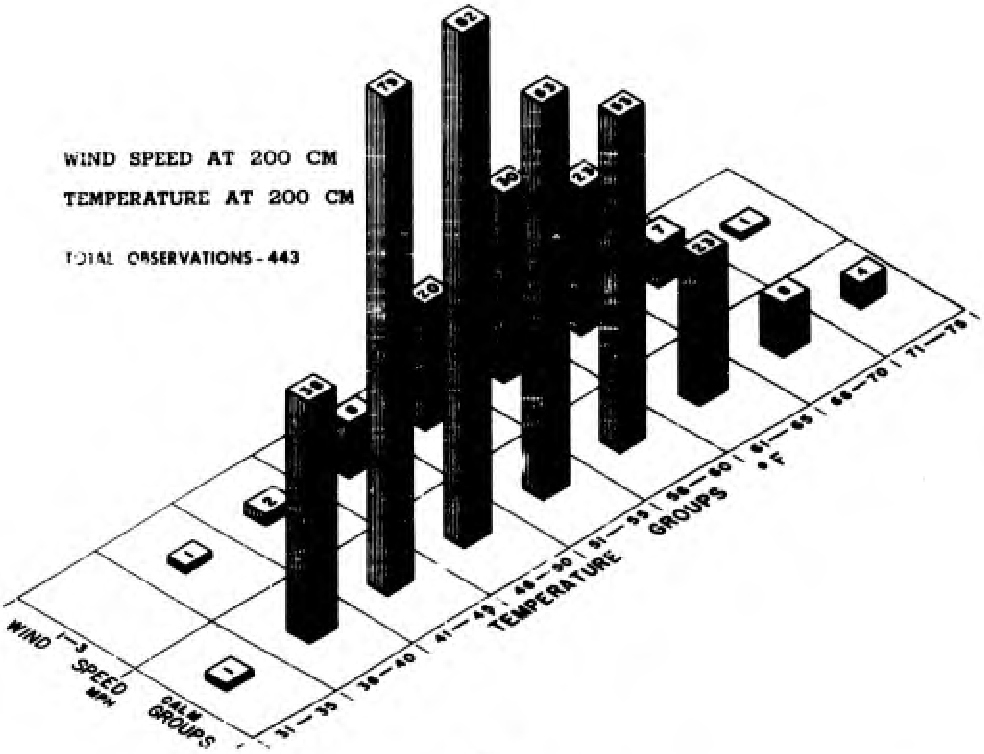
There were no dry spells (defined as five consecutive rainless days) during the period. Conversely, much of the period might be considered a wet spell (at least three consecutive days to each of which is credited 0.01 inch or more of precipitation), although "drier" conditions persisted from June 24 to 30.

E. Combined elements

The greatest stresses and limitations imposed on man, his equipment and activities, and upon animals and plants, frequently result from a combination of climatic elements acting together rather than from one element acting individually. In the Subarctic, climatic problems in summer are not as severe as those of winter. Temperatures are sufficiently low, however, to fall within the category of cold-wet (Meigs and de Percin, 1957, pp. 1-2) and, when combined with occasional moderate or strong winds, cause outdoor activity to be difficult, or at best, unpleasant. Hare (1955) points out the importance of knowing how weather elements

OCCURRENCES OF WIND SPEEDS AT VARIOUS TEMPERATURES, WOODS MICROCLIMATIC STATION, BIG DELTA, ALASKA

PERIOD: 12 - 30 JUNE 1956



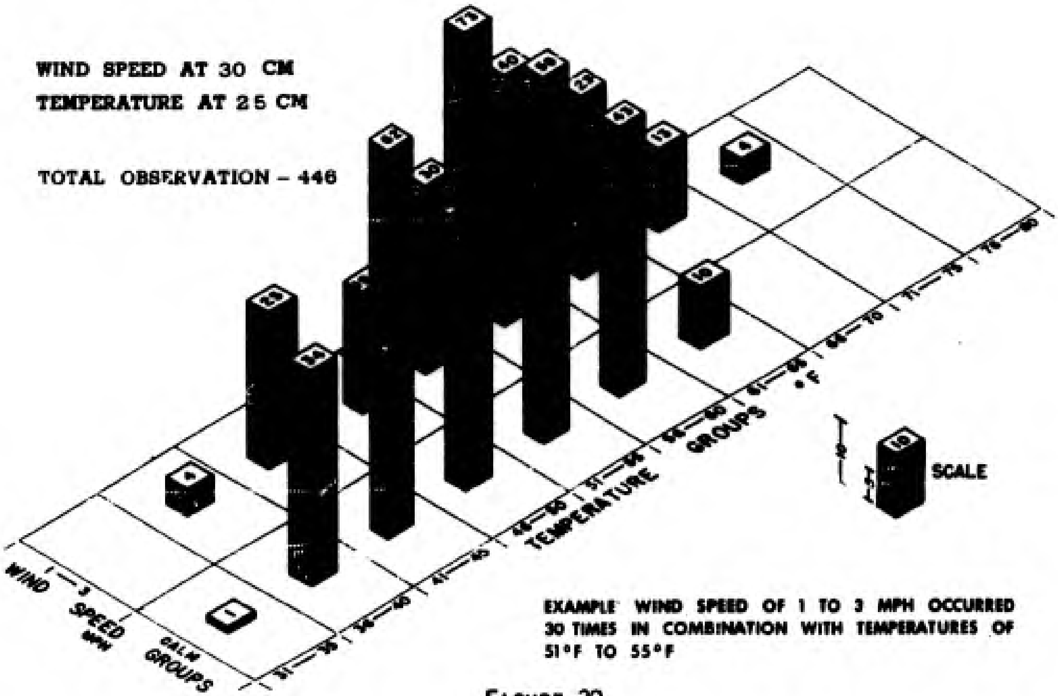


FIGURE 30

OCCURRENCES OF WIND SPEEDS AT VARIOUS TEMPERATURES, OPEN MICROCLIMATIC STATION, BIG DELTA, ALASKA

PERIOD 12 - 30 JUNE 1956

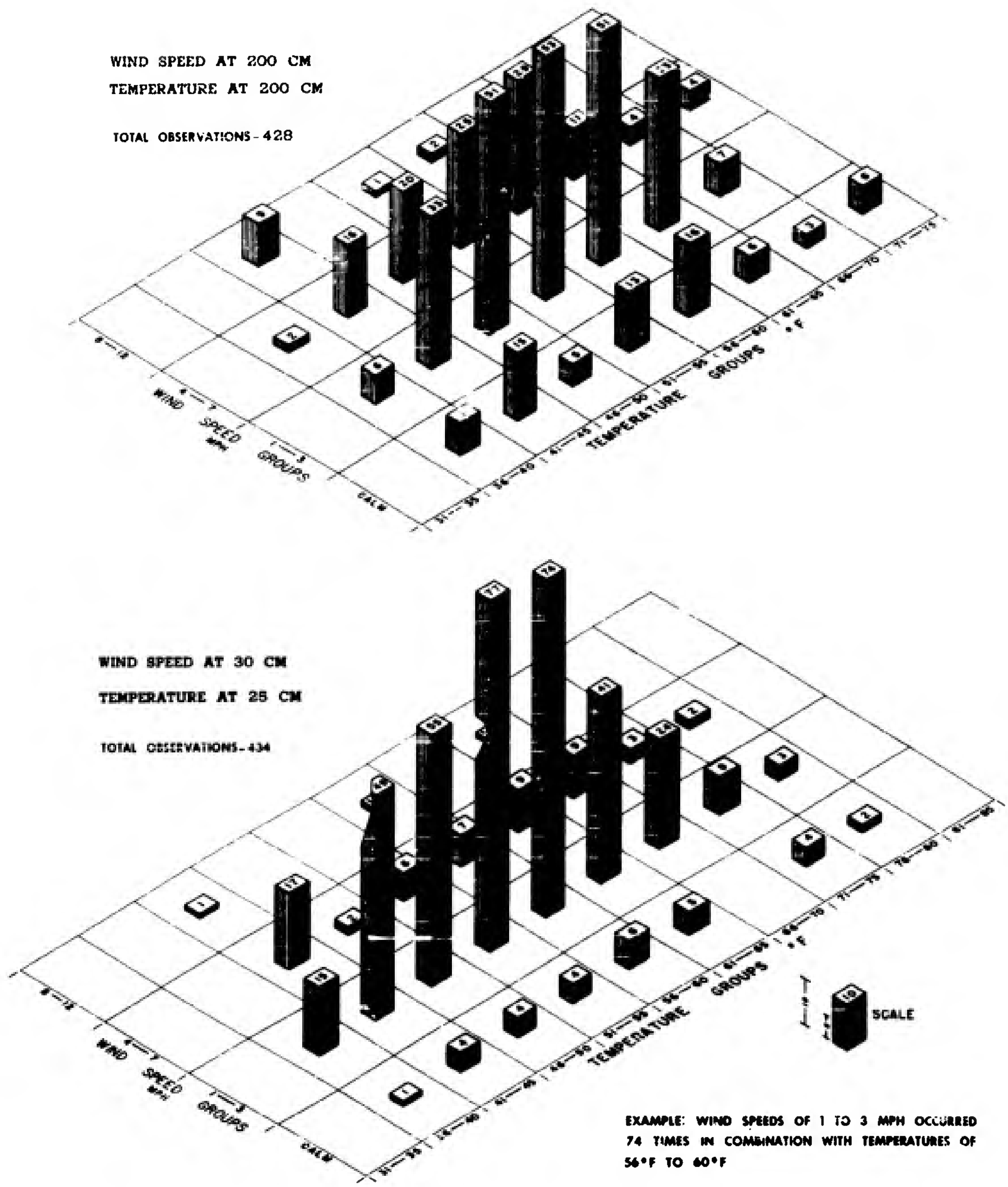


FIGURE 31

combine over large areas. This is of special significance to military operations, for the soldier and his equipment are fully exposed to, and under the influence of, the total environment, and man's activity and the efficient functioning of equipment is seldom controlled or limited by a single element.

Also during summer, insects plague men and animals, and their abundance and distribution are directly related to temperature and wind speed. In parts of the Subarctic, agriculture is limited by a lack, or uncertainty, of summer rainfall (Rauf, 1945b). A combination of moderately strong winds and relatively high temperatures (75 F to 90 F) may cause damage to crops by increasing evaporation.

(1) Wind speeds and temperatures

The combination of various wind speed groups (Beaufort scale) and temperature groups (5 F deg. intervals) are shown in Figures 30 and 31. These graphs clearly show the differences between stations and between different levels at the same station. The large frequency of calms at 200 cm in the forest is well illustrated. The lack of strong winds during the period eliminated the possibility of demonstrating the actual protection afforded by the forest.

(2) Dry cooling power and windchill

Temperatures were not low enough to cause dangerous windchill. During the period, the greatest windchill was approximately 925 kilogram calories per square meter per hour. This value, which lies near "cold" and "very cold" on the nomogram for dry-shade atmospheric cooling (Fig 51) was caused by the simultaneous occurrence of a wind speed of 12 mph and a temperature of 42 F, at 200 cm at the OPEN station. This windchill is not dangerous, but if combined with wet ground, frequent rain, and a high percentage of cloudiness (lack of solar radiation), it can adversely affect the operational efficiency of men working and living in the open.

3. Weather during December 1956

December has the longest nights and shortest days and, next to January, is also the coldest month at Big Delta. At the winter solstice, there are only 4 hours, 12 minutes of sunshine possible, although morning and evening twilight add about three more hours of light. This amount is reduced by cloudiness and also by the high mountains of the Alaska Range south of Big Delta.

As is typical of northern regions having a snow cover in winter, the days are often brighter than the low intensity of solar radiation would suggest. Conrad (1942, p. 2) points out that the high albedo of snow nearly doubles the light intensity just in the season when the altitudes of the sun are low and the diurnal arcs short. Rikhter (1950, p. 29) shows that when the height of the sun is between 0° and 5° above the horizon, a snow cover increases illumination from 220 percent (at 0°) to 48 percent (at 5°).

The greatest number of clear days occur during winter, and during December about 20 percent of the days may be expected to have no clouds. Skies were considerably clearer than average during December 1956, however, for 41 percent of the days were cloudless.

December 1956 was much colder than the average December, despite a thaw during the last four days of the month which raised temperatures to a maximum of 38 F on December 30. During an average December, about 23 days may be expected to have minimum temperatures at or below 0 F and eight days to have minimum temperatues at or below -25 F. During December 1956, at the CAA station, 27 days had minimum temperatures below 0 F and 17 had minima below -25 F. On four days the maxima did not get above -30 F and on seven days the minima were -40 F or colder.

Table XI shows the mean and extreme temperatures and the precipitation and snowfall, and departures, for the month, for the 10 years of record and for December 1956. The mean temperature of December 1956 was 14.8 F deg. below average. The precipitation and snowfall of December 1956 were about normal.

December 1956 was the fourth coldest month of the 14 years of record, and the month was much colder than the average December, January (usually

TABLE XI
TEMPERATURE AND PRECIPITATION IN DECEMBER AT CAA STATION
BIG DELTA, ALASKA

	Temperature (°F)						
	Abs. max.	Mean daily max.	Mean	Mean daily min.	Abs. min.	Precipitation (in.)	Snowfall (in.)
Dec. 1944-53	48	5.3	-1.8	-9.6	-62	0.35	3.8
Dec. 1956	38	-8.9	-16.6	-25.9	-47	0.41	4.3
Departure 1956	-10	-14.2	-14.8	-16.8	15	0.06	0.5

THE COLDEST MONTH), OR FEBRUARY. FEBRUARY 1950 WAS SIGNIFICANTLY COLDER, MEAN AND MEAN MINIMUM TEMPERATURES BEING 3 F DEG. TO 5 F DEG. LOWER. DECEMBER 1946 AND JANUARY 1947 WERE ALSO COLDER, BUT MEAN TEMPERATURES WERE LESS THAN 1 F DEG. LOWER THAN THOSE OF DECEMBER 1956.

4. MICROCLIMATIC MEASUREMENTS, DECEMBER 1956

MICROCLIMATIC MEASUREMENTS MADE DURING DECEMBER 1956 THUS PROVIDE AN EXCELLENT MEANS OF COMPARING THE CLIMATIC ENVIRONMENT AT THE STATIONS UNDER SEVERE SUBARCTIC CONDITIONS — MINIMUM SOLAR RADIATION, MAXIMUM TERRESTRIAL RADIATION, EXTREMELY LOW TEMPERATURES, STRONG WINDS, AND FAIRLY DEEP SNOW COVER.

DURING WINTER, THERMOCOUPLES WERE LEFT AT THE SAME HEIGHTS AS DURING THE SUMMER. THOSE AT THE LOWEST LEVELS (25 CM AND BELOW), THEREFORE, WERE COVERED WITH SNOW. NO ATTEMPT WAS MADE TO MAINTAIN CONSTANT HEIGHTS ABOVE THE SNOW SURFACE BECAUSE OF DIFFICULTIES INVOLVED IN ADJUSTING THE THERMOCOUPLE SHIELDS AND ARMS ON THE GRADIENT TOWERS. DURING TIMES OF EXTREME COLD THIS IS A VERY DIFFICULT TASK, AND COULD NOT HAVE BEEN ACCOMPLISHED WITHOUT SERIOUSLY DISTURBING THE NATURAL CONDITIONS, ESPECIALLY THE SNOW COVER. BELOTELKIN (1941) DISCUSSES THE EFFECTS ON SOIL AND SNOW TEMPERATURE MEASUREMENTS WHEN THE SNOW COVER IS DISTURBED BY TRAMPLING CLOSE TO WHERE MEASUREMENTS ARE BEING MADE. HE POINTS OUT THAT SERIOUS ERRORS MAY RESULT WHEN THE SNOW IS TRAMPLED EVEN A FEW FEET AWAY. IN THIS STUDY, EVERY EFFORT WAS MADE TO LEAVE THE SNOW COVER UNDISTURBED. BY LEAVING THE THERMOCOUPLES AT CONSTANT HEIGHTS, SOME INFORMATION WAS OBTAINED OF THE TEMPERATURE GRADIENT THROUGH THE SNOW AND OF THE PROTECTION AFFORDED THE GROUND BENEATH BY A SNOW COVER. IN ANALYZING THE TEMPERATURE DATA, CAREFUL CONSIDERATION WAS GIVEN TO THE DEPTH OF SNOW AT THE STATIONS.

DURING WINTER, THE THERMOCOUPLE USED TO MEASURE GLOBE TEMPERATURES IN SUMMER WAS USED TO MEASURE SNOW-SURFACE TEMPERATURES. THE THERMOCOUPLE WAS PAINTED WHITE AND AN ATTEMPT WAS MADE TO KEEP IT JUST BELOW THE SURFACE OF THE SNOW. DIFFICULTY WAS EXPERIENCED, HOWEVER, IN KEEPING THE THERMOCOUPLE JUST COVERED WITH SNOW AND NEAR THE SURFACE. THE SNOW WAS NOT DENSE AND THE WEIGHT OF THE THERMOCOUPLE AND LEAD WIRE WAS SUFFICIENT TO CAUSE BOTH TO SINK DEEP INTO THE SNOW. THIS WAS OVERCOME BY ATTACHING THE LEAD WIRE TO A FLAT, THIN PIECE OF WOOD ABOUT ONE FOOT SQUARE. THE LEAD WIRE AND THERMOCOUPLE EXTENDED 8 TO 10 INCHES BEYOND THE EDGE OF THE BOARD, WHICH WAS KEPT LEVEL WITH THE SNOW SURFACE.

THE THERMOCOUPLE OF EACH GLOBE THERMOMETER WAS REPLACED BY AN ALCOHOL THERMOMETER AND READINGS WERE MADE THREE TIMES DAILY: MORNING, NOON, AND LATE AFTERNOON. THESE INSTRUMENTS REMAINED AT A CONSTANT HEIGHT OF 200 CM ABOVE THE GROUND, BUT THE HEIGHTS ABOVE THE SNOW VARIED WITH CHANGES IN SNOW DEPTH WHICH AVERAGED ABOUT 22 CM IN THE OPEN AND 44 CM IN THE FOREST.

Wind instruments were maintained at constant levels of 30 cm and 200 cm above the snow surface. The instruments were attached to square wooden platforms (painted white) and were kept level with the ground surface at the snow surface. The platform used for the 30 cm instrument was about 10 inches square and that used for the 200 cm anemometer and wind vane was about 42 inches square. Two expected difficulties materialized, but were not troublesome. One was in keeping the axes of the instruments vertical, and the other was in keeping the small plastic cups of the anemometer free from frost and snow. The snow depth changed only slightly during the month and the only thaw that occurred came at the end of the month so that tilting of the instruments due to differential melting around the platforms was not a serious problem. A long-handled, soft-hair brush was used to remove snow and ice (frost) from the anemometer cups. Again conditions were helpful in keeping this problem at a minimum. Frost deposits on the cups were generally caused by ice fogs or hoar-frost, but when these occurred there was usually no wind. During times of strong winds there was no ice deposit and the whirling of the cups kept them mostly free of the very light, blowing snow. The snow was dry and was easily removed at times when it did accumulate, at low or moderate wind speeds. Removal of hoar-frost was much more difficult, and wind speed measurements were occasionally affected.

Precipitation measurements were made with standard 8-inch gages at each of the stations. These data are not considered accurate, however, for gages were not shielded against wind. Instead, precipitation amounts measured at the CAA station are used. Of greater significance are the depth-of-snow measurements made at least once each day, and during snowfall, three times daily at the microclimatic stations. During the month, the depth of snow cover ranged from 39.4 cm to 48.3 cm at the WOODS station, and from 17.8 cm to 25.4 cm at the OPEN station. Day-to-day changes were small, and were caused mainly by evaporation or drifting rather than by snowfall.

A. Solar Radiation and Cloudiness

Sky-cover data were obtained from the records of the CAA weather station and radiation data from continuous measurements at the microclimatic stations. In the forest, the Eppley was usually about 155 to 160 cm above the snow surface and in the open it was about 175 to 180 cm above the snow. As previously mentioned, precautions were taken to keep the glass bulb free from frost and snow. The radiation (and other) instruments were inspected at least three times each day, when the globe thermometer readings were made.

The pyrheliometer at the WOODS station was inspected and tested at the beginning and end of the month and was found to be in proper operating condition. The lack of insolation in the forest must be attributed to

THE COMBINED EFFECTS OF THE LOW INTENSITY OF SOLAR RADIATION AND SHIELDING BY THE SPRUCE TREES. TOGETHER, THESE REDUCED INSOLATION AMOUNTS SO THAT LESS WAS RECEIVED THAN REQUIRED (0.1 MILLIVOLT) TO ACTIVATE THE RECORDER.

THE SMALL NUMBER OF HOURS OF DAYLIGHT IN NORTHERN LATITUDES DURING WINTER IS IMPORTANT. CONSIDERATION MUST BE GIVEN NOT ONLY TO PHYSICAL AND PHYSIOLOGICAL EFFECTS, BUT ALSO TO PSYCHOLOGICAL PROBLEMS. THE LONG HOURS OF DARKNESS DURING THE ARCTIC WINTER HAVE A DEMORALIZING EFFECT ON INHABITANTS. THIS HAS BEEN OBSERVED EVEN AMONG RUSSIAN AND SCANDINAVIAN SCIENTISTS WHO WERE ACCUSTOMED TO THE SUBARCTIC AND ARCTIC. BOUGHNER AND THOMAS (1956) DERIVED A NUMERICAL MEANS OF ASSESSING THE INTEGRATED UNFAVORABLE ASPECTS OF CLIMATE AFFECTING THE WELL-BEING OF RESIDENTS IN THE CANADIAN NORTH. TO ACCOMPLISH THIS, THE ADVICE AND OPINIONS OF PERSONS WHO HAD LIVED FOR EXTENDED PERIODS IN THE CANADIAN ARCTIC WERE SOUGHT. RESULTS OF THIS SURVEY INDICATED THAT THE MOST TRYING ASPECTS OF LIVING IN HIGH LATITUDES WERE: 1) THE LENGTH OF THE DARK PERIOD, AND 2) THE LENGTH OF THE WINTER SEASON. SIR HUBERT WILKINS* (PERSONAL COMMUNICATION) LISTED DARKNESS AS FIRST IN IMPORTANCE AMONG THE CLIMATIC ELEMENTS. WEYER (1956) DISAGREES, ALTHOUGH READILY ADMITTING THAT THE "LONG DARKNESS OF WINTER" MORE THAN ANYTHING ELSE EXCEPT PERHAPS FEAR OF THE COLD, HAS PREVENTED PEOPLE FROM GOING TO THE ARCTIC. WEYER POINTS OUT THAT DUE TO REFRACTION AND TWILIGHT, THE PERIOD OF DARKNESS IS NOT NEARLY SO LONG AS ASSUMED. IN ADDITION, HE STATES THAT THE LACK OF DUST IN THE ATMOSPHERE AND THE REFLECTION FROM SNOW-COVERED LANDSCAPE MAKE MOONLIGHT ESPECIALLY BRIGHT, AND THAT THE MOON REMAINS ABOVE THE HORIZON CONTINUOUSLY FOR ABOUT TWO WEEKS EACH MONTH.

(1) FREQUENCIES OF VARIOUS AMOUNTS OF SKY COVER

THE FREQUENCIES OF SKY COVER DURING DECEMBER 1956 AS COMPARED WITH AN AVERAGE DECEMBER ARE PRESENTED IN TABLE XII. MORE DETAILED INFORMATION CONCERNING CLOUDINESS DURING DECEMBER 1956 IS SHOWN GRAPHICALLY IN FIGURES 32 AND 33.

DECEMBER 1956 WAS MUCH CLEARER THAN AVERAGE. CLEAR OR SCATTERED SKIES OCCURRED 63 PERCENT OF THE TIME, COMPARED WITH THE 37 PERCENT AVERAGE FOR DECEMBER. OVERCAST SKIES WERE ONLY ABOUT HALF AS FREQUENT AS AVERAGE (24 VS. 44 PERCENT).

MEAN HOURLY SKY COVER VARIED FROM 32 PERCENT (0400) TO 50 PERCENT (1000). DAILY MEAN AMOUNTS RANGED FROM CLEAR ON DECEMBER 14 TO OVERCAST

*THE LATE SIR HUBERT WILKINS, FORMERLY GEOGRAPHER, QUARTERMASTER RESEARCH & ENGINEERING COMMAND, NATICK, MASSACHUSETTS, TRAVELLED, STUDIED, AND LIVED IN THE ARCTIC AND ANTARCTIC FOR APPROXIMATELY 50 OF HIS 70 YEARS.

TABLE XII
FREQUENCIES OF SKY COVER
IN DECEMBER, CAA STATION
BIG DELTA, ALASKA

Sky cover (tenths)	Frequency (percent) December 1956	December mean
Clear (≤0.1)	41	20
Scattered (0.1 - 0.5)	22	17
Broken (0.6 - 0.9)	13	19
Overcast (1.0)	24	44
Mean	40	55

on December 6, but only 10 days of the month had a sky cover of 50 percent or more.

The clear skies during the month provided optimum conditions for solar radiation during the day and nocturnal radiation during the long night.

(2) Hourly and daily total global solar radiation

Hourly and daily totals of global solar radiation during December 1956 are given in Table XIII, and daily totals are shown in Figure 33. Except for the first two days of the month, solar radiation was intense enough to be recorded only during the hours ending at 1100, 1200 and 1300 at the OPEN station. At the WOODS station the solar radiation was never intense enough to be recorded at any time during the month!

Table XIII shows that only 160 ly were received during the month, and the daily mean solar radiation amounted to only 5.1 ly. From the long-period record at Fairbanks it is estimated that the average daily total is about 10 ly and the average value for December is about 300 ly. Fairbanks, located at 64° N. lat., is less than a degree of latitude farther north than Big Delta and it might reasonably be expected that the radiation received at the two stations would be similar. During December 1956, however, Fairbanks recorded 235 ly and the mean daily amount was 8.1 ly compared with 160 ly and 5.1 ly for Big Delta. Mean cloudiness (sky cover) for the month at Fairbanks was 50 percent and at Big Delta, 40 percent. Since December 1956 had more than the usual number of clear days at Big Delta, and since differences between Big Delta and Fairbanks due to sky cover and latitude were small, and perhaps negligible, the differences in radiation values must be attributed to the shadowing effect of the mountains to the south of Big Delta. Without this effect, larger differences also might have resulted between

MEAN HOURLY, AND RELATIVE AND CUMULATIVE,
FREQUENCIES OF SKY COVER
BIG DELTA, ALASKA
DECEMBER 1956

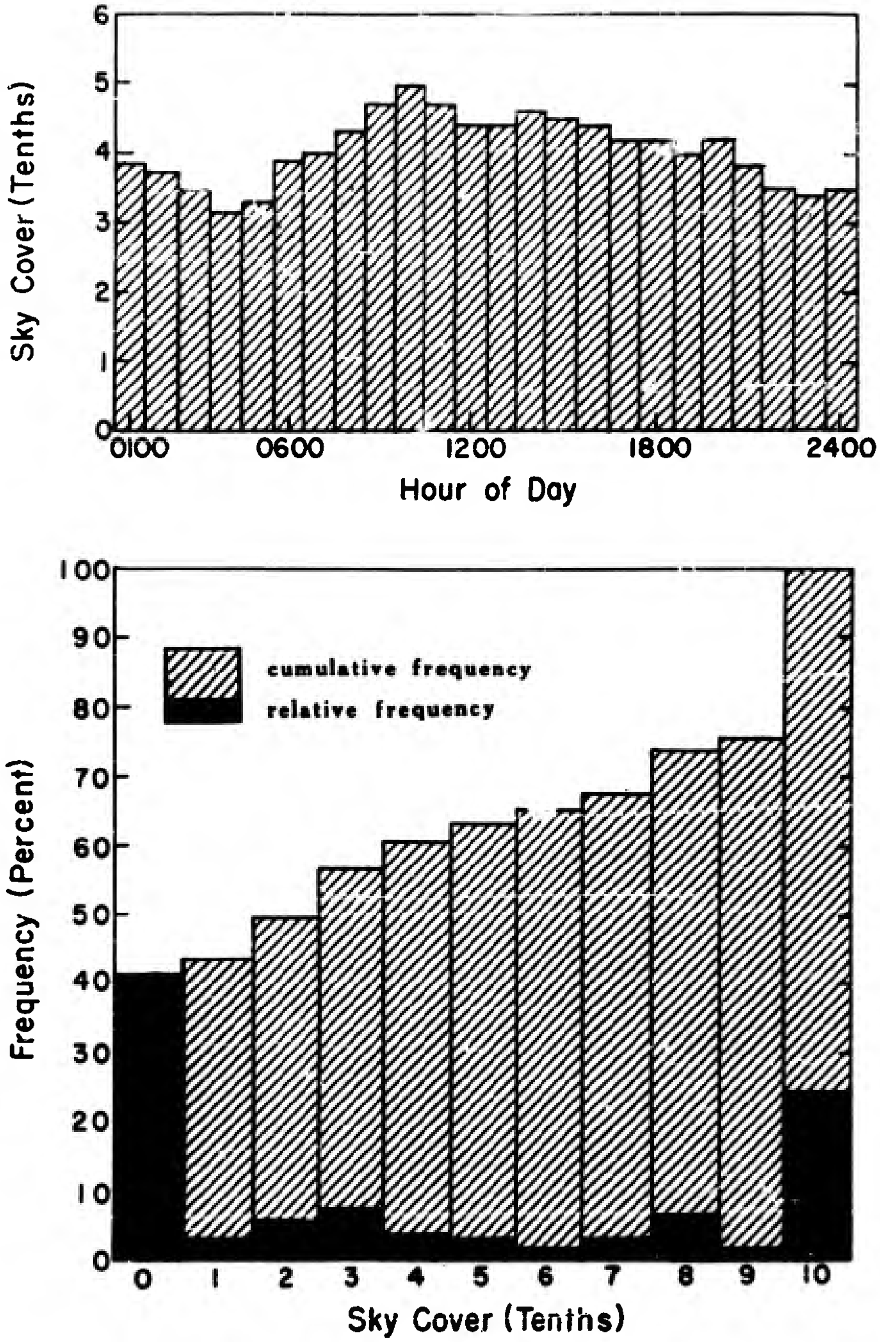
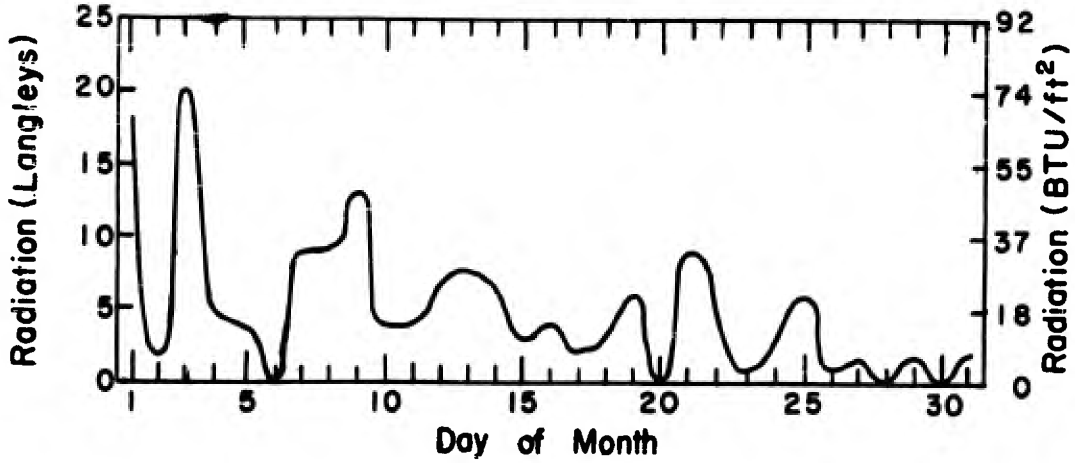


FIGURE 32

TOTAL DAILY GLOBAL SOLAR RADIATION AT OPEN MICROCLIMATIC STATIONS AND DAILY MEAN SKY COVER AT CAA STATION
BIG DELTA, ALASKA
DECEMBER 1956



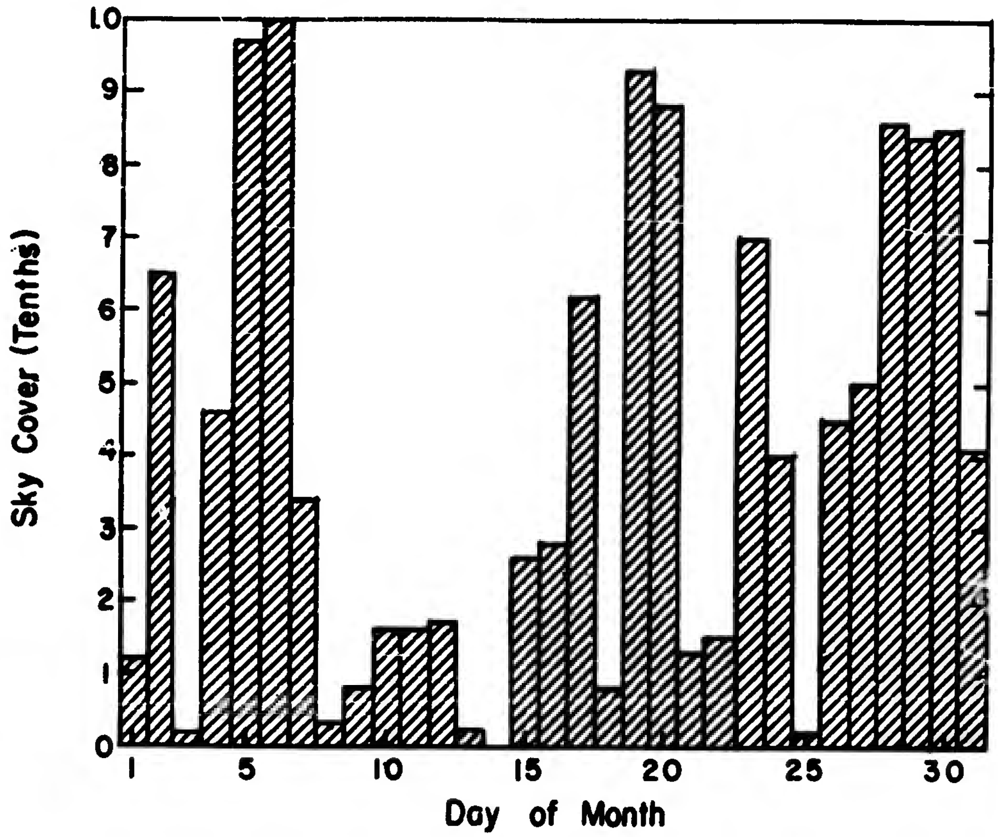


FIGURE 33

TABLE XIII
SOLAR RADIATION (LANGLEYS) DURING DECEMBER 1956
OPEN MICROCLIMATIC STATION
BIG DELTA, ALASKA

DAY	HOUR ENDING 1000	1100	1200	1300	1400	DAILY TOTAL	DAY	HOUR ENDING 1000	1100	1200	1300	1400	DAILY TOTAL
1	0	5	7	5	1	18	17	0	0	1	1	0	2
2	1	1	0	0	0	2	18	0	3	0	0	0	3
3	0	6	10	4	0	20	19	0	0	3	3	0	6
4	0	2	2	1	0	5	20	0	0	0	0	0	0
5	0	1	2	1	0	4	21	0	1	7	1	0	9
6	0	0	0	0	0	0	22	0	0	3	1	0	4
7	0	3	4	2	0	9	23	0	0	1	0	0	1
8	0	2	6	1	0	9	24	0	0	2	1	0	3
9	0	5	6	2	0	13	25	0	1	4	1	0	6
10	0	1	3	0	0	4	26	0	1	0	0	0	1
11	0	1	2	1	0	4	27	0	0	1	1	0	2
12	0	2	4	1	0	7	28	0	0	0	0	0	0
13	0	2	5	1	0	8	29	0	0	1	1	0	2
14	0	2	4	1	0	7	30	0	0	0	0	0	0
15	0	1	1	1	0	3	31	0	1	1	0	0	2
16	0	1	2	1	0	4							

TOTAL FOR MONTH: 160 LANGLEYS.
MEAN DAILY: 5.1 LANGLEYS.

THE MICROCLIMATIC STATIONS. AT THE OPEN STATION RADIATION WOULD PROBABLY HAVE BEEN MEASURED DURING OTHER HOURS OF THE DAY, ALTHOUGH INTENSITIES WOULD NOT NECESSARILY HAVE INCREASED SUBSTANTIALLY. THE GREATEST NUMBER OF LANGLEYS MEASURED DURING ANY ONE HOUR AT THE OPEN STATION WAS 10, BUT EVEN AT THIS TIME NO RADIATION WAS RECORDED AT THE WOODS STATION. THE PREPONDERANCE OF HOURLY VALUES WERE WITHIN THE RANGE 0 TO 3 LY, AND DAILY TOTALS RANGED FROM 0 TO 20.

IN ADDITON TO THE EFFECTS OF CLOUDINESS AND THE MOUNTAINS, ANOTHER ELEMENT OF THE CLIMATE, ICE FOG, WAS INSTRUMENTAL IN REDUCING SOLAR RADIATION RECEIVED. ICE FOGS ARE A WIDESPREAD AND COMMON PHENOMENA OF THE ARCTIC AND SUBARCTIC, FORMING NEAR CITIES, CAMPS, AND SETTLEMENTS WHICH DISCHARGE NUCLEI IN SMOKE AND MOISTURE INTO THE ATMOSPHERE THROUGH COMBUSTION. THESE FOGS OCCUR USUALLY ONLY DURING VERY LOW TEMPERATURES, MOSTLY AT -30 F OR BELOW, ALTHOUGH V. AND M. OLIVER (1949) FOUND FROM EXAMINATION OF THE RECORDS FOR FAIRBANKS, THAT ICE FOG HAS BEEN REPORTED AT TEMPERATURES RANGING FROM 0 F TO -66 F. THEY STATE, HOWEVER, THAT VERY FEW CASES WERE FOUND WITH TEMPERATURES HIGHER THAN -20 F.

Both water and ice fogs are included in these statistics, but no water fogs occurred at temperatures below -40 F. These authors also state that ice fog is not very probable with temperatures between -30 F and -40 F, but that with temperatures lower than -50 F ice fog is nearly inevitable. Observations made by the Olivers indicate that ice-fog particles form on smoke nuclei beginning at temperatures of -35 F to -40 F, and that where no smoke is present, no persistent ice fog is found. They point out, however, that most sources of smoke are also sources of moisture, and that the fog might be due entirely to the additional moisture which accompanies the smoke. The findings of V. and M. Oliver are supported by Robinson and Bell (1956), who found that ice fogs usually occurred at temperatures below -22 F (-30 C).

Ice fogs were definitely important in diminishing solar radiation received at the OPEN station during the month. These fogs usually were dissipated by solar radiation or wind after several hours in the early morning, but on very cold, calm days they were sometimes sufficiently intense to persist throughout the few hours during which insolation was received. Table XIV illustrates the effectiveness of ice fog in depleting solar radiation. On all four days, December 10, 11, 13, and 14, temperatures were low and skies were clear from 1000 to 1300, the hours of sunshine (with the exception of 1000 on December 11 and 1300 on December 13). On December 10 and 11, however, ice fogs lasted all day, and reduced solar radiation by about half.

Since ice fogs are common in the arctic and subarctic winter, measurements made at, and data available from, towns and cities do not provide an accurate measure of amounts of solar radiation received only short distances away under field conditions. During the month, ice fogs occurred on nine days at Big Delta. On six of these days the daily mean sky cover was less than 20 percent, and the air was calm at all times. Temperatures were between -35 F and -45 F, but on 3 of the 9 days ice fogs were reported when temperatures were between 0 F and -20 F. At these higher temperatures the fogs were most likely a combination of water and ice.

(3) Frequencies of hourly amounts of solar radiation

The solar radiations for each hour of December 1956 are given in Table XIV. Relative and cumulative frequencies of these values are presented in Table XV. Approximately 77 percent of the hours during which radiation was usually recorded (1000 through 1300) received two ly or less, and 31.2 percent had none. In about 91 percent of all the 744 hours of December there was no measureable radiation. At no time were more than 10 ly recorded in one hour.

Although only a few hours of the month received measureable amounts of insolation, total darkness did not exist at all other times. On solstice day, December 22 in 1956, a maximum of 4 hours and 12 minutes

TABLE XIV
COMPARISON OF SOLAR RADIATION RECEIVED ON CLEAR DAYS
AND DAYS WITH ICE FOGS
BIG DELTA, ALASKA

	Total daily solar radiation (langleys - all between 1000 and 1300)	Sky cover (percent) 1000	1100	1200	1300	Temperature (°F)* 1000	1100	1200	1300
Clear days									
Dec. 13	8	0	0	0	20	-36	-34	-35	-34
14	7	0	0	0	0	-32	-31	-31	-30
Ice fog days									
Dec. 10	4	0	0	0	0	-52	-44	-42	-43
11	4	30	0	0	0	-53	-50	-48	-49

*Temperature at 200 cm, open station.

TABLE XV
FREQUENCIES OF HOURLY SOLAR RADIATION AMOUNTS
BIG DELTA, ALASKA
December 1956

	Solar radiation (langleys) from 1000 to 1300 * 0	1	2	3	4	5	6	7	8	9	10
Rel. freq. (%)	31.2	33.3	12.8	6.5	5.4	4.3	3.2	2.2	0.0	0.0	1.1
Cum. freq. (%)	31.2	64.5	77.3	83.8	89.2	93.5	96.7	98.9	98.9	98.9	100.0

*Does not include one langley measured from 1300 - 1400, December 1, and one langley measured from 0900 - 1000, December 2.

of sunshine is possible, but one and one-half additional hours of twilight before sunrise and one and one-half more after sunset also occur. As previously mentioned, the snow cover and moonlight serve effectively to increase illumination at this time of year.

B. Precipitation

In winter, precipitation is most influential in the form of snow in determining the microclimate of the sites. Snow cover has a

PRONOUNCED EFFECT ON GROUND AND SURFACE TEMPERATURES AND ON THE QUANTITY OF SOLAR RADIATION ABSORBED AND REFLECTED AND LONG-WAVE RADIATION EMITTED. THE EXISTENCE OF A SNOW COVER DURING LONG HOURS OF DARKNESS, WITH CLEAR SKIES AND CALM OR NEAR-CALM AIR, PROVIDES OPTIMUM CONDITIONS FOR NOCTURNAL RADIATIONAL COOLING FROM THE SNOW SURFACE.

THE DIFFICULTIES ENCOUNTERED IN MAKING ACCURATE SNOWFALL AND SNOW PRECIPITATION MEASUREMENTS IN THE ARCTIC AND SUBARCTIC, AND THE PRECAUTIONS REQUIRED AND THE ERRORS INVOLVED, HAVE BEEN DISCUSSED IN DETAIL BY WARNICK (1953), BLACK (1954) AND RAE (1954). CONNAUGHTON'S (1935) INVESTIGATIONS REVEALED THAT FORESTS OF OPEN PONDEROSA PINE INTERCEPTED 25 TO 30 PERCENT OF THE SNOWFALL. AT THE WOODS STATION, DUE TO THE DENSENESS OF THE CONIFERS, THE AMOUNT INTERCEPTED MIGHT HAVE BEEN EVEN GREATER.

(1) DAILY AND MONTHLY SNOWFALL TOTALS

PRECIPITATION GAGES AT THE MICROCLIMATIC STATIONS WERE UNSHIELDED AND SO THE AMOUNTS RECORDED ARE NOT CONSIDERED ACCURATE. THE DATA GIVEN IN TABLE A-5 (APPENDIX) ARE OF VALUE ONLY IN PROVIDING APPROXIMATE AMOUNTS AND TIMES OF OCCURRENCE OF SNOWFALL AT THE TWO STATIONS. THEY DO NOT CONFORM WITH OBSERVATIONS MADE AT THE OFFICIAL CAA WEATHER STATION, FOR WHICH 24-HOUR PRECIPITATION VALUES ARE ALSO INCLUDED IN TABLE A-5.

(2) SNOW COVER

THE FORMATION, DURATION, AND DEPTH OF SNOW COVER AT THE TWO STATIONS ARE IMPORTANT IN THE INTERPRETATION OF THE TEMPERATURE RECORDS. THE THERMOCOUPLES REMAINED AT CONSTANT HEIGHTS, AND SO THOSE CLOSEST TO THE GROUND BECAME COVERED BY THE SNOW. SNOW DEPTHS ARE SHOWN IN TABLE XVI. DIFFERENCES BETWEEN SNOW DEPTHS MEASURED AT THE CAA AND OPEN STATIONS WERE CAUSED BY DIFFERENCES IN EXPOSURE WHICH RESULTED IN THE ACCUMULATION OR DEPLETION OF SNOW BY WIND ACTION, AND PROBABLY ALSO BY DIFFERENCES BETWEEN THE OBSERVERS' PRACTICE IN MAKING THE MEASUREMENTS. HOWEVER, SINCE THE SAME OBSERVER MADE THE MEASUREMENTS AT BOTH WOODS AND OPEN STATIONS, THESE DATA PROVIDE A BASIS FOR COMPARISONS.

DURING THE WINTER OF 1955-56 IT WAS FOUND THAT EXCESSIVE DRIFTING OCCURRED AT THE WOODS STATION. AS PREVIOUSLY MENTIONED, A SNOW FENCE WAS CONSTRUCTED IN THE SUMMER OF 1956 TO PREVENT THIS DRIFTING. FIGURE 34 SHOWS THIS FENCE, WHICH WAS ABOUT 5 FEET HIGH IN MIDWINTER 1956-57. AT TIMES THE SNOW COMPLETELY COVERED THE FENCE.

THE VALUES LISTED IN TABLE XVI SHOW THAT THE SNOW AT THE WOODS STATION WAS 17 TO 24 CM DEEPER THAN AT THE OPEN STATION. IN THE FOREST THE AVERAGE SNOW DEPTH FOR THE MONTH WAS 43 CM, SO THE THERMOCOUPLE LOCATED AT 25 CM ABOVE THE GROUND SURFACE WAS USUALLY COVERED WITH 18 CM OF SNOW. THE 25 CM THERMOCOUPLE WAS THE HIGHEST ABOVE THE GROUND SURFACE

TABLE XVI
WEEKLY SNOW DEPTHS
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

STATION	DEC. 3	DEC. 10	DEC. 17	DEC. 24	DEC. 31	MEAN
CAA						
INCHES	10.0	13.0	10.0	11.0	11.0	11.0
CENTIMETERS	25	33	25	28	28	28
OPEN						
INCHES	7.0	10.0	9.0	9.0	8.5	8.7
CENTIMETERS	18	25	23	23	22	22
WOODS						
INCHES	16.0	19.5	17.5	17.0	15.5	17.1
CENTIMETERS	41	49	44	43	39	43

FIGURE 34: SNOW FENCE AT EASTERN EDGE OF FOREST NEAR WOODS MICROCLIMATIC STATION SHOWING DEPTH OF SNOW, ABOUT 4 TO 5 FEET, DURING WINTER 1956-57. WIRES LEAD TO INSTRUMENTS AT THE STATION.

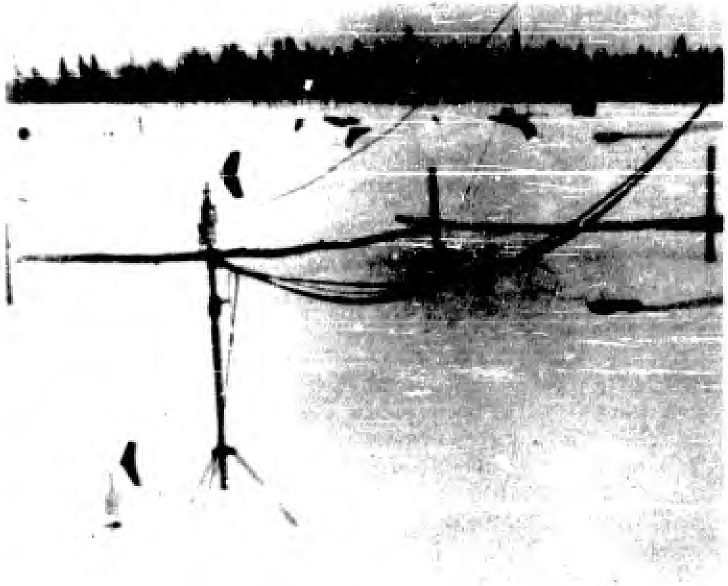


FIGURE 35, ABOVE, AND FIGURE 36, BELOW, SHOW THE OPEN AND WOODS MICROCLIMATIC STATIONS, RESPECTIVELY, SHORTLY AFTER A SNOWSTORM ACCOMPANIED BY STRONG WINDS. PHOTOGRAPHS WERE TAKEN DURING WINTER 1956-57.

FIGURE 36

to be covered by snow in the forest, the snow surface generally being 7 cm below the 50 cm thermocouple. At the OPEN station, the 7.5 cm thermocouple was the highest above the ground surface to be covered by snow, and was usually overlaid by about 14 to 15 cm of snow. Figures 35 and 36 show the stations immediately following a snowstorm.

The main properties of snow, as discussed by Voeikov (1889) are as follows: 1) strong radiation in the long wavelengths, 2) high albedo toward radiation of short wavelengths, 3) low thermal conductivity, and 4) heat required for change of physical state. D. H. Miller (1956b) discusses the influence of snow cover on local climate in Greenland, noting that Voeikov's four characteristic elements of snow are still of utmost importance. At Big Delta, in winter, snow was the most important single climatic factor determining the differences in temperature between the two stations, although, on occasions, wind also played a significant role.

Snow cover reflects much of the incoming solar radiation. This is especially true during winter when the sun is low and its rays strike the snow surface at a very low angle.

Rikhter (1950, p. 29) reports an albedo of 94 percent in the Russian Arctic in April 1935, and Geiger (1957, p. 164) mentions that albedos of 100 percent have been observed with freshly-fallen snow. Penndorf (1956) summarizes the luminous reflectance (visual albedo) of natural objects, including snow and coniferous forests, as determined by various investigators. He lists the albedo of freshly-fallen snow as varying from 70 to 86 percent as shown by the Smithsonian Tables and also lists a specific value of 77 percent as given by Krinov. For a coniferous forest in winter, Penndorf uses Krinov's value of 3 percent. Penndorf cautions that Kronov's computations should be considered an indication of the approximate value, and that departures of $\pm$ 25 percent from the value given might be a good guess of the actual variations of the albedo under natural conditions. He further mentions that, of the solar radiation not absorbed by the surface, some is specularly reflected and some is diffusely reflected, depending upon the nature of the surface. Polished surfaces reflect directly, matt surfaces reflect diffusely. Snow is generally regarded as reflecting solar radiation diffusely (Dunkle and Gier, 1953, p. 1), but Suga (1954, p. 2) found that granular snow does not offer a perfect diffusing medium, and that the strength of the reflected light tends to vary somewhat in intensity with the direction of the incident light.

Although most of the insolation is usually reflected by a snow surface, particularly freshly-fallen snow, Reuter (1948) states that the small amounts absorbed occur within a layer several meters thick. Measurements made by Rohsenow and Van Alstyne (1954, p. 16) revealed that solar radiation penetrates to a foot or more in a snow cover. Depth of penetration, and amounts received at various depths, are determined by the density of the snow. With 45 percent dense snow, 37 of 200 $cal/cm^2/day$ are received at -12 inches (-30 cm), but with 20 percent dense snow only 1 of 200 $cal/cm^2/day$ is received at that depth. Dunkle and Gier (1953, p. 9) consider the transmission of solar energy negligible for depths greater than 12 to 24 inches (30 to 60 cm), depending upon the type and nature of the snow. Liljequist (1954) found that the extinction coefficient for red and orange light is much greater than for the blue, and that blue light, therefore, penetrates the snow in larger amounts. The deep blue color of crevasses and pits below 1/2 to 1 meter may be attributed to the greater penetration of the blue component of sunshine. The temperature of objects (especially dark ones) in or under the snow, for example, the ground surface, may be raised considerably above that of the air above the snow surface through absorption of the small amounts of insolation that penetrates the snow.

One of the more significant characteristics of snow is that it acts as an insulating medium. When of sufficient depth, a snow cover protects the ground surface, including animals and vegetation, from extreme cold. Horn (1952, p. 2), in his review of soil temperature studies, credits R. F. Black with measuring the lowest soil surface temperature, -11.9 F, recorded under a snow cover. This temperature was measured at Point Barrow, Alaska, after eight days of air temperatures which ranged from -22.4 F to -34.6 F. Unfortunately, the snow depth is not given. Beckel (1957), however, states that soil surface temperatures of -25 C (-13 F) occurred in non-forested regions during studies conducted at Fort Churchill, Canada. Bay, Wunnecke and Hays (1952) found that a snow cover of 24 inches prevents freezing of the soil when air temperatures are as low as -21 F. Cherepanov (1933) reports a minimum soil surface temperature of -17.8 C (0.0 F) at Novosibirsk during winter 1932-33 when the snow cover was 30 to 40 cm deep and the snow surface temperature was -48 C (-54.4 F).

Thomson (1934) conducted soil temperature studies at Winnepeg, Canada for three years. He noted that a snow cover strongly reduced variations in soil temperatures, retarded frost formation in the soil, and limited the depth of penetration of frost in the soil. The insulation afforded by a snow cover is due to the notably poor heat conductivity of snow. A large quantity of air is trapped in minute units between and within the snow and ice crystals that form a snow cover, and soil heat passes through only with difficulty. Loose snow contains a larger amount of air between and within snowflakes than does dense snow, and is a much better insulator. The heat conductivity of snow, therefore, is directly related to the density of the snow and, according to Rikhter (1950, p. 26), the coefficient of heat conductivity of snow is approximately proportional to the square of its density.

Snow density measurements were made once each week by using a standard kit and instruments provided by the Snow, Ice and Permafrost Research

Establishment, Corps of Engineers, U.S. Army, and following instructions found in SIPRE Instruction Manual No. 1 (1954). These measurements showed that the density of snow at the microclimatic stations varied from 0.170 gm/cm^{-3} for freshly-fallen snow near the surface (usually at very low temperatures) to a maximum density of 0.260 gm/cm^{-3} for older snow at greater depths, -7.5 cm to -10 cm (and generally higher temperatures). These values may be compared with a very light, fluffy snow which has a density of 0.05 gm/cm^{-3} and that of a highly compressed snow whose density approaches that of solid ice, 0.917 gm/cm^{-3} (SIPRE Rpt. 10, 1953, pp. 5-6). It is evident, therefore, that the snow at the stations was not very dense, that it presumably had a low coefficient of heat conductivity, and served as an excellent insulating medium between the soil and air. With this knowledge, large differences could be expected in soil, snow, and air temperatures.

c. Temperature

To most people, the Arctic and Subarctic mean extreme cold. Low temperatures are usually considered one of the most serious climatic elements imposing stress and limitations on the effective, efficient operation and functioning of man and his equipment. During December 1956, optimum conditions occurred for studying the distribution of low temperatures in the microclimatic layer near the ground, and for noting differences caused by vegetation, depth of snow, wind, and insolation.

Snow-surface measurements are among the most difficult of climatic observations. Nechaev (1953, pp. 1-7) discusses methods of making instantaneous temperature observations at the snow surface. He particularly emphasizes the importance of carefully setting the thermometers upon an undisturbed snow cover 10 to 30 minutes before the reading time. Geiger (1957, p. 169) points out that, due to the cooling effect of evaporation on the surface of the snow, the temperature maximum does not occur immediately on the snow surface during insolation, but at a depth of about 1 cm. When air temperatures are less than 32 F, conduction also plays a role in cooling the snow surface. The method of making snow "surface" temperature measurements at Big Delta has been described. Every effort was made to keep the thermocouple just beneath the snow surface, at a depth of about half an inch, but during times of snowfall and especially blowing snow this was not possible. Therefore, these data must be considered, at best, an approximation to the actual temperatures at the snow surface. Nechaev (1953, pp. 1-4) points out, in his measurements using alcohol thermometers, that the temperature of the thermometers will differ from that of the snow because of differences between the absorption and radiation characteristics of the thermometer and snow. To reduce this source of error, thermocouples and lead wires were painted white. Error on account of solar radiation was small, owing both to its low value and to the low elevation of the sun and consequent strong reflection (albedo) from the

SNOW SURFACE. AT THE WOODS STATION, WHERE THE INSOLATION WAS VIRTUALLY NIL, THE THERMOCOUPLE COULD NOT BE AFFECTED BY SOLAR RADIATION.

(1) MEAN HOURLY TEMPERATURES

MEAN HOURLY TEMPERATURES FOR THE VARIOUS THERMOCOUPLE HEIGHTS ARE SHOWN IN FIGURE 37 AND LISTED IN TABLE A-6 (APPENDIX). THESE DATA SHOW THE EFFECTS OF SNOW AND TREES ON TEMPERATURES, BOTH AIR AND SOIL. THE DIFFERENCES IN THE DEPTH OF THE SNOW BETWEEN THE STATIONS IS IMPORTANT HERE.

THE MOST STRIKING THING SHOWN BY THE CURVES IN FIGURE 37 IS THE STEADINESS OF THE TEMPERATURES IN THE SOIL. EVEN NEAR THE SURFACE THERE WAS LITTLE OR NO FLUCTUATION DURING THE DAY, ILLUSTRATING THE MARKED INSULATING PROPERTIES OF THE SNOW. ANOTHER INTERESTING FEATURE IS THE LOWER SOIL TEMPERATURES AT THE WOODS STATION. THE PROTECTION AFFORDED BY A DEEPER SNOW COVER AND BY THE TREES SHOULD RESULT IN HIGHER SOIL TEMPERATURES AT THIS STATION THAN AT THE OPEN STATION. THIS DIFFERENCE, WHICH IS RETAINED UNTIL THE LAST FEW DAYS OF DECEMBER, MUST BE ATTRIBUTED TO THE FACT THAT SOIL TEMPERATURES REMAIN LOW THROUGHOUT THE WARM MONTHS. WITH THE START OF COLD WEATHER, SOIL TEMPERATURES IN THE FOREST ARE ALREADY MUCH COLDER (ABOUT 5 F DEG. AT -60 CM AND 8 F DEG. AT -2.5 CM IN NOVEMBER) THAN THOSE IN THE OPEN, AND REMAIN SO IN SPITE OF THE GREATER PROTECTION OF THE DEEPER SNOW THAT EVENTUALLY ACCUMULATES. TOWARD MIDWINTER, THE SOIL IN THE OPEN BECOMES COLDER THAN IN THE WOODS.

TEMPERATURES AT AND ABOVE THE GROUND SURFACE DISPLAY THE OPPOSITE TENDENCY, THOSE IN THE FOREST BEING HIGHER THAN THOSE IN THE OPEN. THE GREATER INSULATION PROVIDED BY DEEPER SNOW AT THE WOODS STATION IS LARGELY RESPONSIBLE FOR THESE HIGHER TEMPERATURES BUT THE SPRUCE TREES PLAY A DECISIVE ROLE BY REDUCING THE EXCESSIVE NET NOCTURNAL RADIATION FROM THE SNOW SURFACE.

(2) DIFFERENCES IN MEAN HOURLY TEMPERATURES

(A) OPEN COMPARED TO WOODS

DIFFERENCES IN MEAN HOURLY TEMPERATURES BETWEEN TWO STATIONS AT THE SAME THERMOCOUPLE LEVELS, AND BETWEEN CONSECUTIVE (ADJACENT) LEVELS AT THE SAME STATION, ARE PRESENTED GRAPHICALLY IN FIGURE 38.

FIGURE 38 ILLUSTRATES WELL THE DIFFERENCES IN TEMPERATURE BETWEEN THE STATIONS AT THE VARIOUS LEVELS. AT THE OPEN STATION, SOIL TEMPERATURES WERE 1 F DEG. TO 4 F DEG. HIGHER THAN THOSE IN THE FOREST. AS EXPLAINED ABOVE, THIS IS ATTRIBUTED TO THE LOWER TEMPERATURES IN THE SOIL IN THE FOREST AT THE START OF WINTER.

MEAN HOURLY GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

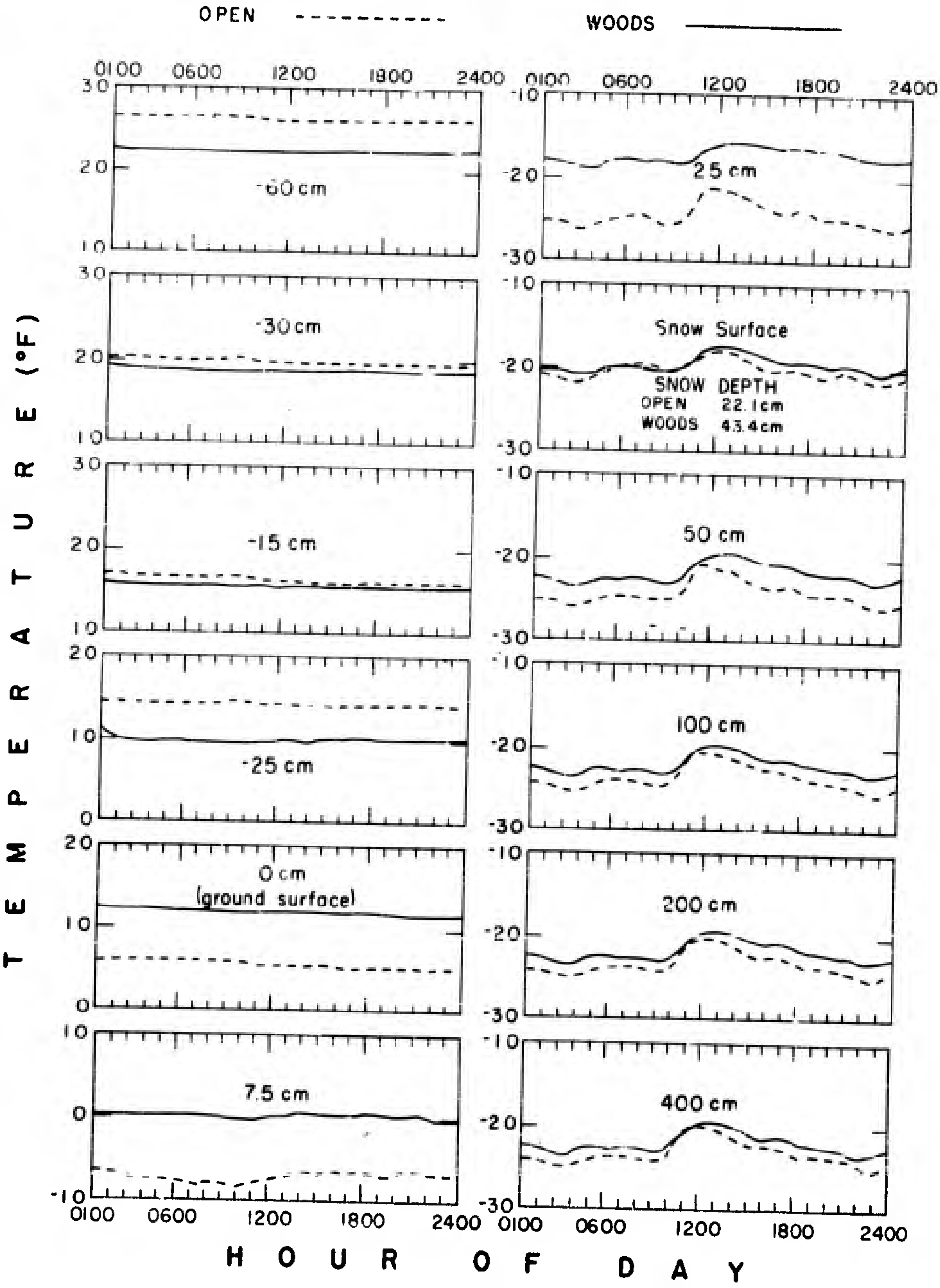


FIGURE 37

DIURNAL COURSE OF DIFFERENCES (F°) BETWEEN SIMULTANEOUS MEAN HOURLY TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA
DECEMBER 1956

SNOW DEPTH
WOODS: 43.4 CM
OPEN: 22.1 CM

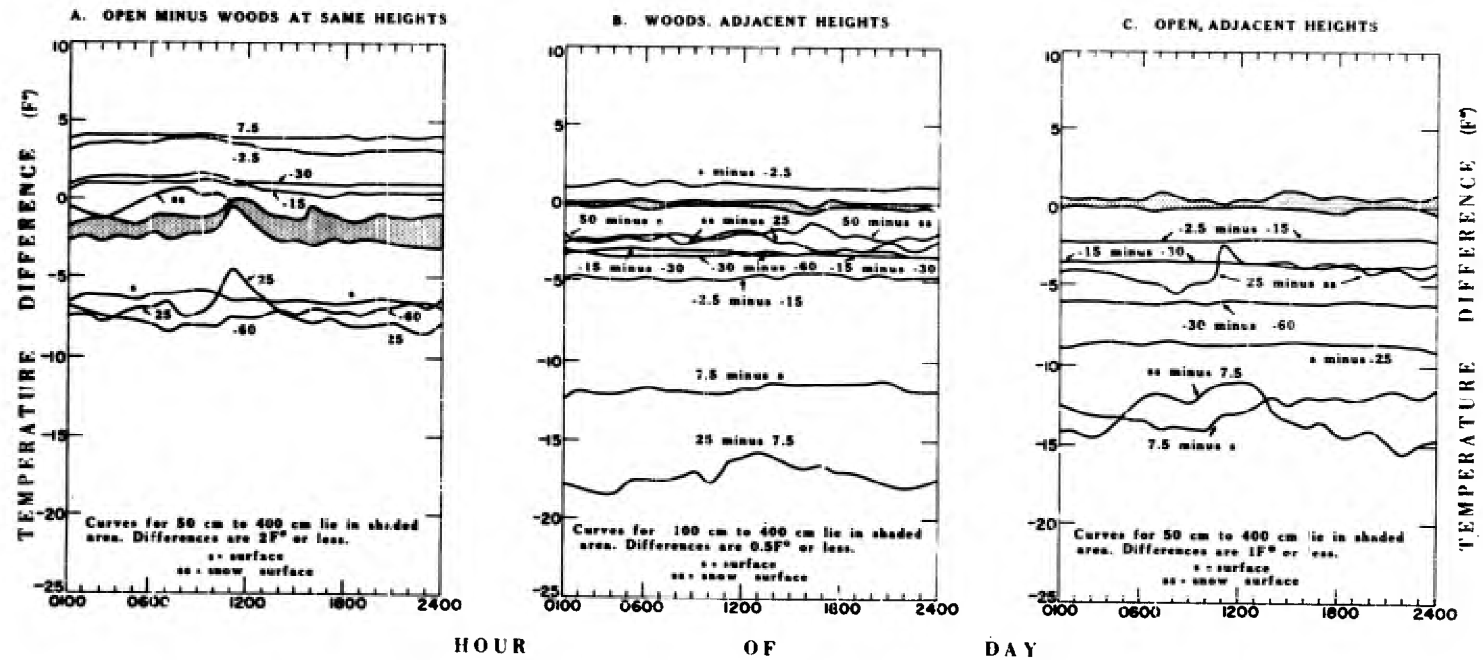


FIGURE 38

The protection by the snow is particularly evidenced in the temperatures at levels closest to the ground, 25 cm, 7.5 cm and 0 cm, where thermocouples were covered with snow (except at 25 cm at the OPEN station). At these levels temperatures in the forest were 5 F deg. to 8 F deg. higher than those in the open. This was primarily due to the thinner snow cover and to the greater loss of heat from the ground surface through radiational cooling from the snow surface on clear nights in the open.

Air temperatures did not differ greatly, generally being less than 2 F deg. lower at the OPEN station. The snow surface temperature was usually 1 F deg. to 2 F deg. lower at the OPEN station. This was caused by evaporation during the day, solar radiation and wind speed being greater; by loss of heat by radiation during the night; and by conduction when the air temperature was 32 F or lower. From about 0700 to 1100 the snow-surface temperature in the open was higher than in the woods. This was most likely caused by the increase in insolation at this time, although later in the day, at 1200 and 1300, when this heating had progressed and when insolation was most intense and wind speeds were strongest, the surface temperature in the open was lowered by evaporation and conduction, and was below that of the forest.

In the air above the snow, temperatures at the two stations were most similar during the daytime hours of **measurable** insolation, 1000 to 1400. On calm, clear nights, the snow surface and adjacent air layers cooled more rapidly and to lower temperatures in the open than in the forest where nocturnal radiational cooling was reduced by the spruce trees.

(b) Vertical gradients

At the WOODS station the greatest differences between temperatures at consecutive thermocouple levels occurred in the snow, between the snow surface (43 cm) and the ground surface (0 cm). The insulating properties of the snow are shown by the temperature distribution within the snow itself. The greatest temperature differences were between the 25 cm and 7.5 cm levels, the former being 16 F deg. to 18 F deg. colder. The 25 cm thermocouple was covered with approximately 18 cm of snow while that at 7.5 cm was covered with approximately 35 cm. The differences in temperatures between levels were due to the greater amount of snow overlying the 7.5 cm thermocouple. The next greatest temperature difference, 11 F deg. to 12.5 F deg., was between the 7.5 cm and 0 cm levels, the former being the colder. Again, the warmer temperatures closer to the ground were caused by the greater depth of the overlying snow, as well as by the conduction of heat from the warmer ground below.

The large temperature gradient in the snow is a striking feature. Between the ground surface and snow surface, a distance of 43 cm on the

AVERAGE (ABOUT 17 INCHES), PERSISTENT TEMPERATURE DIFFERENCES OF OVER 20 F DEG. OCCURRED. THIS AMOUNTS TO A DECREASE IN TEMPERATURE OF 2 F DEG. FOR EVERY 2 TO 2.5 CM, OR ABOUT 2 F DEG. PER INCH.

IN THE SOIL IN THE FOREST, THE HIGHEST TEMPERATURES WERE MEASURED AT THE DEEPEST LEVEL, -60 CM, AND TEMPERATURES GRADUALLY DECREASED UPWARD. A UNIQUE SITUATION OCCURRED AT THE GROUND SURFACE, THE 0 CM TEMPERATURE BEING WARMER BY ABOUT 2 F DEG. THAN THAT AT -2.5 CM. THE ONLY EXPLANATION FOR THIS IS THAT ONE OR BOTH OF THESE THERMOCOUPLES BECAME SLIGHTLY DISPLACED, BEING QUITE CLOSE TO THE SURFACE, SO THAT THE -2.5 CM THERMOCOUPLE WAS MORE EXPOSED THAN THE ONE AT 0 CM.

THERE WAS LITTLE VERTICAL GRADIENT OF AIR TEMPERATURE IN THE FOREST. AIR TEMPERATURES WERE USUALLY WITHIN 0.5 F DEG. OF ONE ANOTHER, WITH NO SIGNIFICANT DIFFERENCES. IT IS INTERESTING TO NOTE THAT THE TEMPERATURE AT 50 CM, ABOUT 6 OR 7 CM ABOVE THE SNOW SURFACE, WAS 1 F DEG. TO 2.5 F DEG. LOWER THAN AT THE SNOW SURFACE. DURING THE DAY, INSOLATION SLIGHTLY WARMED THE SNOW JUST BELOW THE SURFACE WHERE THE 0 CM THERMOCOUPLE WAS INSTALLED (EVAPORATION MOST LIKELY COOLED THE SURFACE). AT NIGHT, COOLING TOOK PLACE FROM THE SURFACE, AND THE THERMOCOUPLE, EMBEDDED JUST BELOW THE SURFACE, WAS SOMEWHAT PROTECTED, NOT COOLING AS RAPIDLY OR TO AS LOW A TEMPERATURE AS THE ACTUAL SURFACE AND ADJACENT AIR.

TEMPERATURE DIFFERENCES BETWEEN ADJACENT HEIGHTS IN THE OPEN WERE SIMILAR TO THOSE IN THE FOREST. THE SNOW COVER IN THE OPEN WAS NOT AS DEEP, HOWEVER, AND SO THE GROUND WAS INFLUENCED MORE BY THE COLD AIR ABOVE. THE GREATEST DIFFERENCES, 10 F DEG. TO 15 F DEG., WERE OBSERVED BETWEEN THE 7.5 CM AND 0 CM LEVELS AND BETWEEN THE SNOW SURFACE (22.1 CM) AND 7.5 CM. IN CONTRAST TO THE WOODS STATION, THE GROUND SURFACE (0 CM) AT THE OPEN STATION WAS MUCH COLDER (8 F DEG. TO 9 F DEG.) THAN THE -2.5 CM LEVEL. AT THIS STATION, THE GROUND BENEATH, ALTHOUGH COLD BY NORMAL STANDARDS, ACTED AS A HEAT SOURCE TO THE STILL COLDER SURFACE ABOVE.

(3) <u>VERTICAL TEMPERATURE DISTRIBUTION ON SELECTED HOURS AND DAYS</u>

THE EFFECTS OF CLOUDS AND WIND ARE ILLUSTRATED BY FIGURE 39 WHICH SHOWS THE VERTICAL TEMPERATURE DISTRIBUTION ON SELECTED DAYS OF THE MONTH (DECEMBER 21 AND 28) AT FOUR DIFFERENT HOURS ON EACH DAY (0100, 0700, 1300, AND 1900).

DECEMBER 21 WAS EXTREMELY COLD; TEMPERATURES AT THE CAA STATION RANGED FROM -29 F TO -44 F. EXCEPT FOR LIGHT WINDS VERY EARLY IN THE MORNING, CALM PERSISTED THROUGHOUT THE DAY. ALTHOUGH THERE WERE NO CLOUDS REPORTED, NEARLY HALF THE DAY THE SKY WAS COVERED BY ICE FOG WHICH REDUCED HORIZONTAL VISIBILITY TO LESS THAN A MILE. SOLAR RADIATION AT THE OPEN STATION TOTALED 9 LY. IN CONTRAST, DECEMBER 28 WAS A WINDY,

VERTICAL DISTRIBUTION OF TEMPERATURE DECEMBER 21 AND 28, 1956
WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA

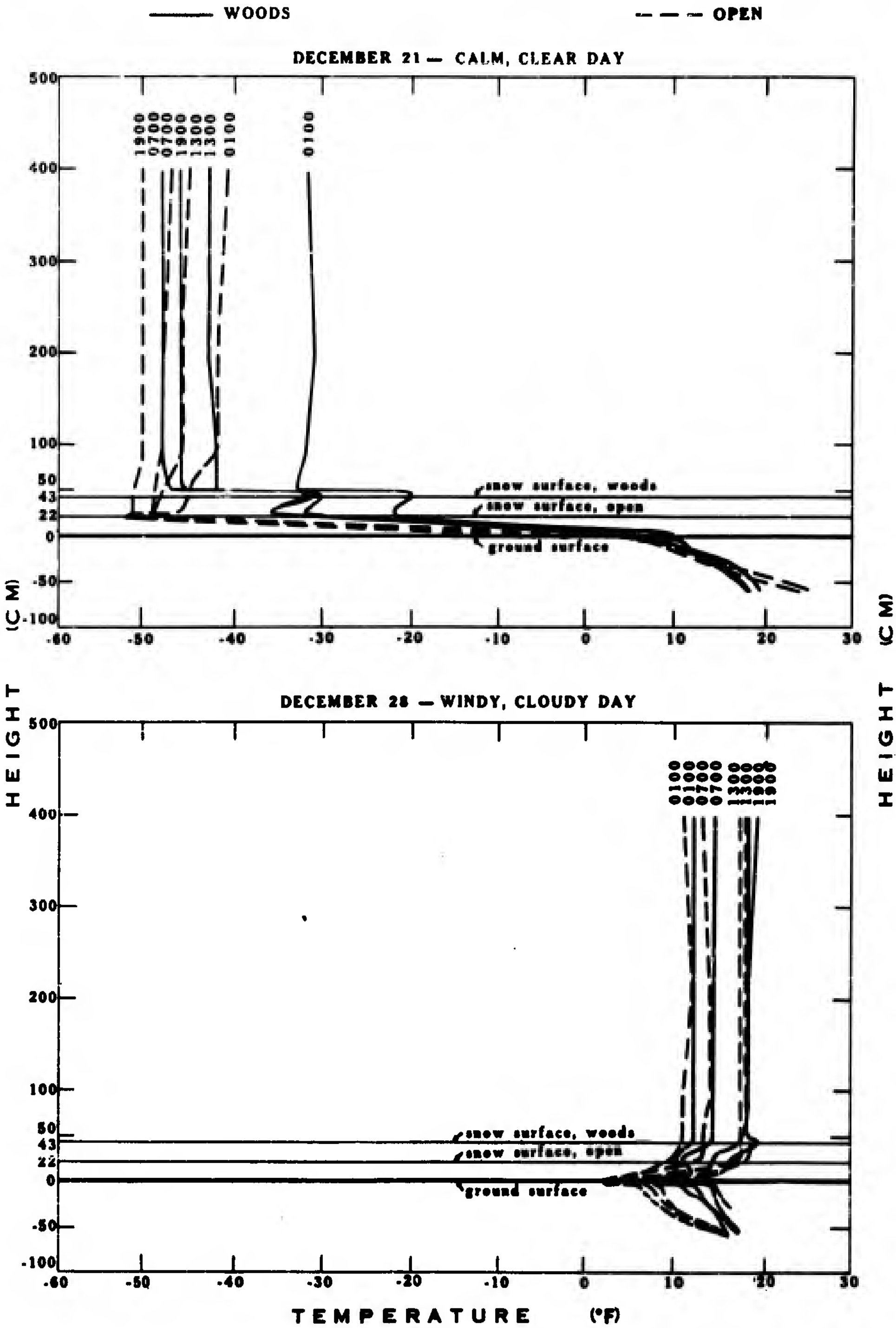


FIGURE 39

cloudy day. The wind blew steadily from the east or southeast, at 10 to 20 mph, with gusts to 27 mph (at the CAA station). Sky cover varied from 0.3 in the early morning to 1.0 (overcast) about 1000 and remained so for the rest of the day. Solar radiation was too weak to be recorded that day.

The differences between air and snow temperatures on these two days were surprising, amounting to approximately 60 F deg., although specific differences varied with time of day, station, and level. In the soil, well insulated from the air, differences were generally less than 10 F deg. at the OPEN station and less than 5 F deg. at the WOODS station.

Figure 40 shows the vertical distribution of mean temperatures during the month for the four selected hours used above.

This graph reveals: 1) that ground temperatures below the surface averaged warmer at the OPEN than at the WOODS station, while at and above the surface the OPEN station was the colder, 2) the strong insulating properties of the snow cover and the very steep temperature gradient through the snow from the ground to the snow surface, and 3) a very slight tendency toward an increase in temperature from 25 cm to 100 cm at the OPEN station, with an isothermal lapse-rate above 100 cm, and an isothermal lapse-rate from 50 cm, just above the snow surface, to 400 cm at the WOODS station.

Although soil temperatures in the open were as low as or lower than, those in the forest toward the end of the month, the soil averaged warmer at the OPEN station during the month, the largest difference occurring at -60 cm. In the snow and the air, however, temperatures at the OPEN station were lower than those of the WOODS.

The strong insulating properties of the snow are reflected in the rapid decrease in temperatues from the ground to the snow surface. This decrease was greater at the OPEN station, amounting to 25 F deg. in the 22.1 cm mean depth, while in the forest it was about 32 F deg. in 43.4 cm.

Air temperature differences between the stations were very small, being 2 F deg. or less most of the time. At the OPEN station, there was only a 1 F deg. increase in mean temperature between the 25 cm level (just above the snow surface) and the 100 cm level, above which the lapse-rate was isothermal. At the WOODS station the lapse-rate was isothermal from 50 cm (just above the snow surface) to 400 cm.

(4) <u>Daily mean temperatures</u>

Daily mean temperatures are shown on Figure 41 and listed in Table A-7 (Appendix).

VERTICAL DISTRIBUTION OF MEAN TEMPERATURES AT VARIOUS LEVELS FOR SELECTED HOURS
WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA
DECEMBER 1956

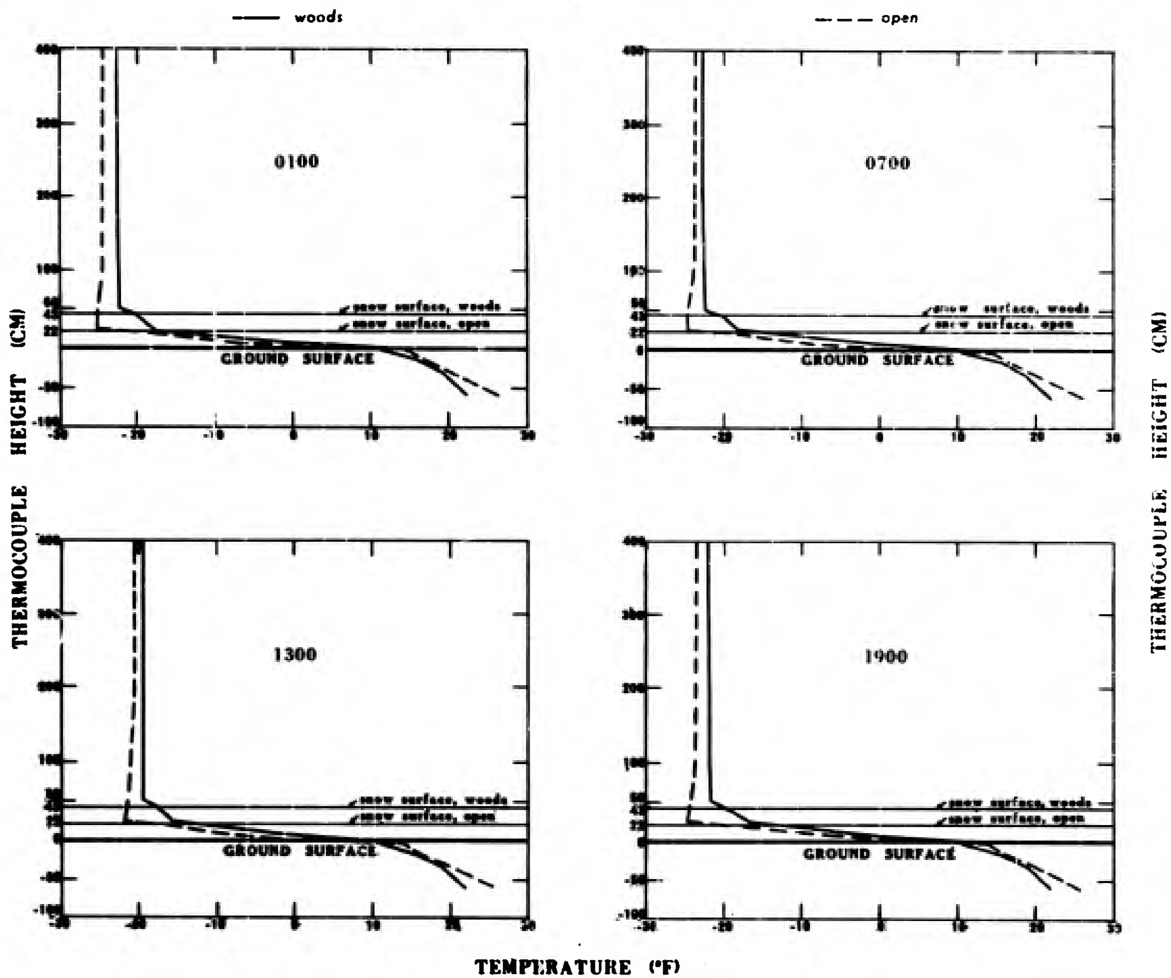


FIGURE 40

DAILY MEAN GROUND AND AIR TEMPERATURES AND STANDARD DEVIATIONS WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA DECEMBER 1956

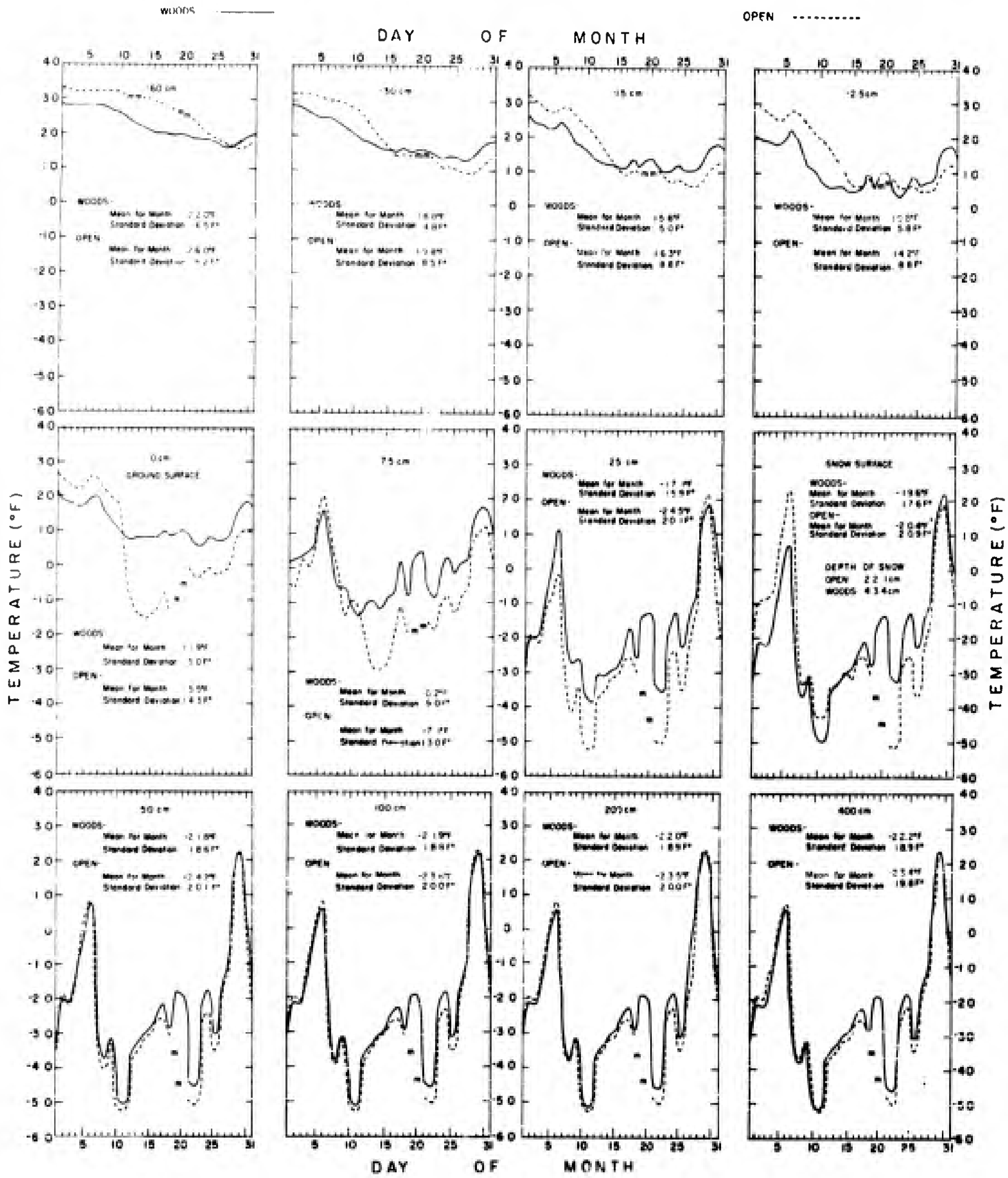


FIGURE 41

Daily mean temperatures show significant interdiurnal variability. The most interesting features of this graph are: 1) the small variability in temperatures at greater depths in the soil (less in the forest than in the open), 2) the lag in soil temperatures behind air temperatures, 3) the increase in variability near the surface of the ground, in the snow, and in the air, 4) the more pronounced insulating effects of the deeper snow in the forest, and 5) the similarity in air temperatures at the stations.

Many investigators have noted the effects of snow cover on soil and air temperatures. Among these, Bouyoucos (1916, p. 132), Harrington (1928), Thomson (1934), Anderson (1947), and Bay et al. (1952) have made detailed studies. Geiger (1957, pp. 164-74) discusses the air layer near the snow and the influence of snow cover on soil temperatures, mentioning the works of many authors, and Horn (1952) summarizes information on soil temperatures including results obtained in various studies on the effects of snow on these temperatures. More recently, Chang (1957) has completed a very detailed and comprehensive study of ground temperatures.

During the cold period extending from December 6 to 26, daily mean air temperatures were below -20 F and on about half the days they were below -30 F. The intense cold was reflected in fluctuations of temperature even deep in the soil (with increasing lag at greater depths, -30 cm and -60 cm), in spite of the insulating effects of the snow. The protection provided by deeper snow (and duff) in the woods (and by the forest itself by reducing loss of heat by out-going radiation and by Austausch) is obvious when a comparison is made of soil temperatures at the two stations. At the beginning of the month, temperatures at all depths were higher in the open. Although a more or less steady decrease in soil temperatures could usually be expected, during the extreme cold period the decrease in soil temperatures was sharply accentuated at both stations, with increasing time-lag required for it to begin, the greater the depth beneath the snow and soil surfaces.

The decrease in soil temperatures was by far the more rapid at the OPEN station, however, and eventually, toward the end of the month (December 28), soil temperatures at the OPEN station were as low as, or lower than, those at the WOODS station for the first time during the winter. The cross-over point, where soil temperatures in the open became lower than those in the forest, occurred earlier in the month (December 10) at levels closer to the ground surface.

Fluctuations of soil temperatures were far more pronounced in the open than in the forest. This illustrates the damping effects of deeper snow. Harrington (1928) found that at depths of 1 and 2 feet (30 and 60 cm) in the soil, scarcely any immediate response could be detected to the most decided fluctuations in the temperature of the air. He considered this as most striking evidence of the marked insulating property of snow. In Saskatchewan, where Harrington's studies were conducted, air temperatures as low as those experienced at Big Delta were seldom observed during the period on which his study was based. Daily mean air temperatures were generally between 0 F and -10 F and were only infrequently as low as -20 F or -30 F. Unfortunately, Harrington did not give the extent or depth of the snow cover during his winter measurements.

At Big Delta the lower temperatures and perhaps thinner snow cover were responsible for the temperature fluctuations that occurred to depths of -60 cm. It is surmised that temperatures near the ground surface in the open might have been influenced, if only slightly, by insolation which penetrated the snow.

As was true for mean hourly temperatures, daily mean temperatures at various levels between the ground surface and the snow surface strikingly illustrate the insulating properties of snow. In the forest, at 0 cm, the range of daily mean temperature was 17 F deg. during the month, and the lowest daily mean temperature was 5.5 F. In the open, at 0 cm, the range of daily mean temperature was 43 F deg., and a temperature change of 41 F deg. occurred in only eight days (December 6 to 14). The lowest daily mean temperature was -15.4 F, which was recorded on the 14th, three days after the month's lowest daily mean air temperature, -52.3 F. In the forest, the daily mean temperature at 0 cm on December 14 was 8.0 F, or 23 F deg. higher than in the open. Closer to the snow surface, the daily fluctuations of temperature were accentuated and more closely followed those of the air.

Air temperatures at the stations were usually within 1 or 2 F deg. of each other, following the same patterns in their day-to-day variations.

(5) Differences in daily mean temperatures

Differences in daily mean temperatures at the same thermocouple levels between the two stations, and between consecutive levels at each station, are shown in Figure 42.

(a) OPEN compared to WOODS

As might be expected, differences in daily mean temperatures between the stations were very much larger than differences in mean hourly temperatures. This was especially true of temperatures near the ground surface and in the snow during times of extreme cold. When temperatures were moderately low — at or below -20 F or -25 F — and when days were clear, it is surmised that some solar radiation penetrated the thin snow cover at the OPEN station, warming the ground. At these times, for example, during the first week of the month, temperatures of the ground surface, in the snow, and on the snow surface were 5 F deg. to 10 F deg. higher at the OPEN station.

DIURNAL COURSE OF DIFFERENCES (F°) BETWEEN SIMULTANEOUS DAILY MEAN TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA
DECEMBER 1956

SNOW DEPTH

WOODS: 43.4 CM
OPEN: 22.1 CM

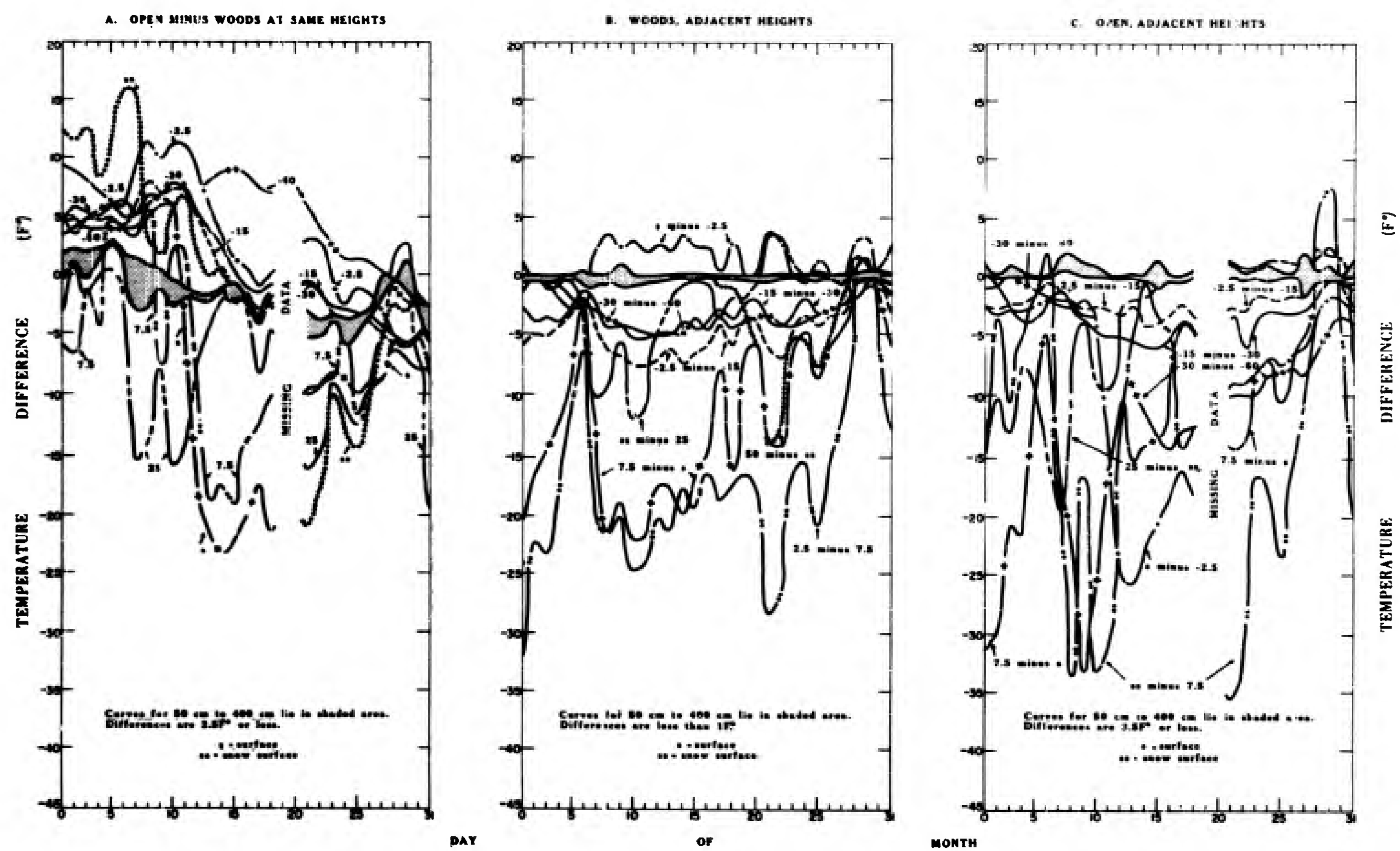


FIGURE 42

When air temperatures were very low, as during the middle of the month, the heat loss from the ground surface was greater (because of the thinner snow cover) at the OPEN station and, despite the warming effects of insolation (which was at a minimum at this time), the ground surface and snow temperatures were much lower than those at the WOODS station. At night, the spruce trees reduced heat loss through radiational cooling from the snow surface at the WOODS station. The 23.4 F deg. difference at the ground surface (0 cm) between the two stations, recorded on December 14, was the month's maximum temperature difference at any observing level between the stations.

The differences between the stations were usually less than 8 F deg. with respect to both soil and air temperatures. In periods of moderately cold weather early in the month and later, air and soil temperatures at the OPEN station were higher than those at the WOODS station, but during times of deep cold the reverse was true.

(b) Vertical gradients

The largest differences between temperatures at consecutive thermocouple levels at the stations occurred from the ground to snow surface, and in the snow. In the forest, maximum temperature differences of 27.1 F deg. to 32.5 F deg. were measured between 25 cm and 7.5 cm, the former being colder. The next greatest differences were observed between the 7.5 cm and 0 cm levels, with the higher level again colder. Substantial differences were also noted between the snow surface (43.4 cm) and 25 cm, and between 50 cm and the snow surface.

In the open, the largest differences were also between the ground surface (0 cm) and the snow surface (22.1 cm) and in the air layers immediately above. The greatest difference, 35.8 F deg., was between the snow surface and 7.5 cm, but, as was found to be true in the forest, significant differences also were noted between 7.5 cm and 0 cm.

Differences of more than 10 F deg. were measured between 25 cm and and the snow surface and between 0 cm and -2.5 cm. No difference was detected between 0 cm and -2.5 cm at the WOODS station, because of the better insulation by the deeper snow.

Soil-temperature differences between consecutive levels at the stations were considerably smaller, usually being less than 5 F deg. In the open, however, a maximum soil temperature difference of 14.3 F deg. occurred between -30 cm and -60 cm on December 14. Intense cooling of the ground was already in progress to a depth of at least -30 cm but had not yet begun at a depth of -60 cm.

Air-temperature differences between consecutive levels were insignificant at both stations, amounting to less than 1 F deg. most of the

TIME, AND LAPSE-RATES WERE NEARLY ISOTHERMAL FROM THE 25 CM (WOODS) OR 50 CM (OPEN) LEVELS TO 400 CM.

A KNOWLEDGE OF THE INFLUENCE OF SNOW AND VEGETATION ON SOIL TEMPERATURES IS IMPORTANT IN THE FIELDS OF AGRICULTURE, BIOLOGY, AND ENGINEERING. BELOTELKIN (1941) AND BAY ET AL. (1952) FOUND THAT SNOW AND DENSE VEGETATION (SUCH AS FOUND AT BIG DELTA) INSULATED THE SOIL AND REDUCED THE RATE OF SOIL FREEZING. SOIL TEMPERATURE DATA OBTAINED FROM THE PRESENT STUDY WERE USED BY ENGINEERS AT BIG DELTA IN DETERMINING THE DEPTH TO WHICH STEAM AND WATER PIPES SHOULD BE LAID WHEN EXTENDED FROM THE POWER PLANT TO BUILDINGS. PRUITT (1957), AND JOHNSON (1957) AND HIS CO-WORKERS, AT FAIRBANKS, ALASKA, SHOWED THAT TEMPERATURES AT THE GROUND SURFACE AND IN SNOW WERE IMPORTANT IN DETERMINING THE DISTRIBUTION AND LIFE HABITS OF SMALL ANIMALS. MAMMALS USUALLY KILLED AT TEMPERATURES OF -40 F HAVE SURVIVED IN AIR TEMPERATURES AS LOW AS -70 F WHEN PROTECTED BY SNOW. JOHNSON ALSO FOUND THAT TEMPERATURES AT THE BASE OF A SNOW COVER TWO FEET (60 CM) DEEP WERE 15 F TO 25 F WHEN AIR TEMPERATURES WERE -40 F TO -50 F OR LESS. VALUES OBTAINED AT BIG DELTA AGREE WITH THESE FINDINGS. JOHNSON FURTHER OBSERVED THAT TEMPERATURES IN THE SNOW NEAR THE GROUND SURFACE REMAINED CONSTANT WHEN THE SNOW COVER WAS AT LEAST TWO FEET DEEP. THIS WAS NOT OBSERVED AT BIG DELTA, WHERE THE SNOW WAS A MAXIMUM OF ABOUT 18 TO 20 INCHES DEEP AT THE WOODS STATION. THERE WAS CONSIDERABLY LESS VARIATION AT THE GROUND SURFACE IN THE FOREST, HOWEVER, WHERE THE SNOW WAS MUCH DEEPER, THAN IN THE OPEN, WHERE THE SNOW AVERAGED ONLY NINE INCHES DEEP.

BENSIN (1951, 1952) AND RAMDAS (1957) DISCUSS VARIOUS MEANS OF ARTIFICALLY MODIFYING THE MICROCLIMATE, BUT HARRINGTON (1928, P. 194) STATES THAT MAN CAN DO LITTLE TO ENCOURAGE AGRICULTURE AND PREVENT, OR AT LEAST REDUCE, SOIL FREEZING IN WINTER. AN EFFORT CAN BE MADE TO INCREASE THE DEPTH OF SNOW, TO DARKEN THE COLOR OF THE SOIL, ARRANGE FOR PROPER DRAINAGE, PROVIDE VEGETATION TO HOLD SNOW, AND COMPACT THE SURFACE OF THE SOIL AND THEREBY ACCELERATE WARMING IN THE SPRING, BUT THE TOTAL RESULTS WILL BE RELATIVELY SMALL. ON A SMALL SCALE, HOWEVER, MUCH CAN BE DONE TO STIMULATE AGRICULTURE BY INCREASING SNOW IN WINTER AND PROVIDING SOME MEANS FOR REMOVING IT QUICKLY IN SPRING.

GOOD USE CAN BE MADE OF THE INSULATING PROPERTY OF SNOW IN CONSTRUCTING SNOW SHELTERS OF VARIOUS SORTS. TEMPERATURES IN A SMALL SNOW HOUSE (HEIGHT 4 1/2 FEET, FLOOR DIAMETER 6 FEET) CONSTRUCTED BY PILING SNOW ON AN INFLATED WEATHER BALLOON, REMAINED ESSENTIALLY CONSTANT AT ABOUT 20 F DURING A 4-DAY PERIOD WHEN AIR TEMPERATURES VARIED FROM A MAXIMUM OF -12 F TO A MINIMUM OF -40 F. THE SHELTER WAS WARMED ONLY BY THE BODY HEAT OF ONE OR TWO OCCUPANTS OR, AT TIMES, BY A SINGLE CANDLE (ELSNER AND PRUITT, 1959).

<u>STANDARD DEVIATIONS</u> OF DAILY MEAN TEMPERATURES ARE GIVEN IN TABLE XVII. THESE DATA ARE OF LIMITED VALUE, AS WERE THOSE FOR JUNE 1956, DUE TO THE

TABLE XVII
MONTHLY MEAN TEMPERATURES (°F) AND STANDARD DEVIATIONS
OF DAILY MEAN TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

STATION	THERMOCOUPLE HEIGHT (CM)*											
	-60	-30	-15	-2.5	0	7.5	25	SS	50	100	200	400
WOODS												
TEMP.	22.0	18.8	15.6	10.8	11.9	0.2	-17.1	-19.6	-21.8	-21.9	-22.0	-22.2
S. D.	6.5	4.8	5.0	5.8	5.0	9.0	15.9	17.6	18.6	18.8	18.9	18.9
							SS	25				
OPEN												
TEMP.	26.0	19.8	16.3	14.2	5.5	-7.1	-20.4	-24.5	-24.2	-23.6	-23.5	-23.4
S. D.	6.5	8.5	8.8	8.8	14.3	13.0	20.9	20.1	20.1	20.0	20.0	19.8

*AT THE WOODS STATION THE 7.5 AND 25 CM THERMOCOUPLES WERE COVERED WITH SNOW, WHICH AVERAGED 43.4 CM DEEP. AT THE OPEN STATION ONLY THE 7.5 CM THERMOCOUPLE WAS COVERED WITH SNOW, WHICH AVERAGED 22.1 CM DEEP.

LIMITED NUMBER OF CASES. THEY DO OFFER, HOWEVER, SOME MEANS OF COMPARING THE TEMPERATURE VARIABILITY AT THE STATIONS.

STANDARD DEVIATIONS ARE SMALLEST FOR TEMPERATURES OF THE SOIL AND SNOW (WHERE TEMPERATURE FLUCTUATIONS AND RANGES ARE SMALLEST), THOSE FOR THE SNOW SURFACE AND AIR BEING 2 OR 3 TIMES AS LARGE. AT THE WOODS STATION, STANDARD DEVIATIONS RANGED FROM 4.8 F DEG. (THE SMALLEST VALUE FOR EITHER STATION) AT -30 CM TO 5.0 F DEG. AT 0 CM. AT THE OPEN STATION, VALUES VARIED FROM 6.5 F DEG. AT -60 CM TO 14.3 F DEG. AT 0 CM. THE SUDDEN INCREASE IN STANDARD DEVIATIONS FROM -2.5 CM TO 0 CM IN THE OPEN BUT NOT IN THE FOREST, MAY BE ATTRIBUTED TO THE LESSER DEPTH OF SNOW AT THE OPEN STATION. AT THE WOODS STATION, THE TREES, THE DEEP SNOW, AND THE DUFF REDUCED TO A MINIMUM THE RESPONSE OF THE SOIL TO FLUCTUATIONS OF AIR TEMPERATURES.

THE STANDARD DEVIATIONS OF AIR TEMPERATURES (50 CM AND ABOVE IN THE FOREST, 25 CM AND ABOVE IN THE OPEN) ARE QUITE LARGE: BETWEEN 18 F DEG. AND 19 F DEG. AT THE WOODS STATION AND FROM 19.8 F DEG. TO 20.9 F DEG. (THE LARGEST VALUE) AT THE SNOW SURFACE AT THE OPEN STATION. IN THE FOREST, THE LOWEST MEAN MONTHLY TEMPERATURES AND GREATEST STANDARD DEVIATIONS OCCURRED AT 200 CM AND 400 CM. IN CONTRAST, IN THE OPEN, THE LARGEST

STANDARD DEVIATIONS OCCURRED AT THE SNOW SURFACE, ALTHOUGH LOWEST TEMPERATURE WAS THAT OF THE AIR 3 CM ABOVE.

THIS DIFFERENCE BETWEEN WOODS AND OPEN STATIONS WAS CAUSED BY THE DAYTIME INSOLATION AND THE LARGER NOCTURNAL RADIATION IN THE OPEN, WHICH WERE RESPONSIBLE FOR GREAT DIURNAL RANGES AS WELL AS LARGE INTERDIURNAL VARIABILITY OF TEMPERATURE AT THE SNOW SURFACE. AT THE WOODS STATION, THE SPRUCE TREES CUT SOLAR RADIATION TO VALUES TOO SMALL TO MEASURE AND SUBSTANTIALLY REDUCED NET, OUTGOING NOCTURNAL RADIATION FROM THE SNOW. ACCORDING TO BRUNT (1946), THE LOCUS OF EFFECTIVE ABSORPTION OF INSOLATION AND EMISSION OF RADIATION, IS NOT A SURFACE BUT IN GENERAL IS A LAYER OF DEPTH NEAR THE CROWNS OF THE TREES OF A FOREST, AND, THEREFORE, THE LOWEST TEMPERATURES AND LARGEST VARIATIONS IN TEMPERATURE SHOULD BE EXPECTED AND, INDEED, ARE FOUND, AT THE HIGHER LEVELS (200 CM AND 400 CM) AT THE WOODS STATION.

(6) TEMPERATURE FREQUENCIES AND DURATIONS

RELATIVE AND CUMULATIVE FREQUENCIES OF HOURLY TEMPERATURES ARE SHOWN IN FIGURES 43 AND 44.

THE SAME FEATURES ARE ILLUSTRATED BY FIGURES 43 AND 44 AS WERE REVEALED BY MEAN TEMPERATURE DATA. THE GREATEST DIFFERENCES BETWEEN THE STATIONS OCCURRED IN THE SNOW COVER. THE NEXT LARGEST DIFFERENCES WERE IN THE SOIL, AND SMALLEST WERE IN THE AIR.

DURATIONS OF TEMPERATURES AT OR BELOW CERTAIN THRESHOLDS (32 F, 0 F, -25 F AND -40 F) ARE GIVEN IN TABLES XVIII AND XIX, AND THE NUMBER OF DAYS AND NUMBER OF CONSECUTIVE DAYS WITH MAXIMUM OR MINIMUM TEMPERATURES ABOVE OR BELOW THESE THRESHOLDS ARE GIVEN IN TABLES XX AND XXI.

IT HAS ALREADY BEEN SHOWN THAT TEMPERATURES AT AND NEAR THE GROUND SURFACE WERE MUCH COLDER IN THE OPEN THAN IN THE FOREST DURING PERIODS OF EXTREMELY LOW TEMPERATURES (-25 F AND -40 F). FROM THE DATA INCLUDED IN THESE TABLES, IT IS READILY SEEN THAT THE 25 CM, 7.5 CM AND 0 CM LEVELS WERE MUCH COLDER AT THE OPEN STATION THAN AT THE WOODS STATION. IN STUDYING THESE DATA THE DIFFERENCES IN NUMBER OF TOTAL OBSERVATIONS (WOODS, 739; OPEN, 718 [655 AT -60 CM]) MUST BE CONSIDERED. THE MISSING DATA FOR THE -60 CM LEVEL AT THE OPEN STATION WERE NOT A SERIOUS LOSS, SINCE EXAMINATION OF HOURLY VALUES REVEALS THAT TEMPERATURES AT THIS DEPTH MUST HAVE BEEN HIGHER THAN 0 F AND LOWER THAN 32 F DURING THE MISSING HOURS AT BOTH STATIONS. AT THE OTHER LEVELS, THE MISSING HOURS OF DATA WERE FOR THE PERIODS 2100, DECEMBER 20, THROUGH 0100, DECEMBER 21, AT THE WOODS STATION, AND 0900, DECEMBER 19, THROUGH 1000, DECEMBER 20, AT THE OPEN STATION.

A STUDY OF THE TEMPERATURE DATA FOR THE CAA STATION FOR THE MISSING HOURS AT THE OPEN STATION SHOWED THAT THERE WAS PRACTICALLY NO FLUCTUATION,

RELATIVE FREQUENCIES OF HOURLY GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

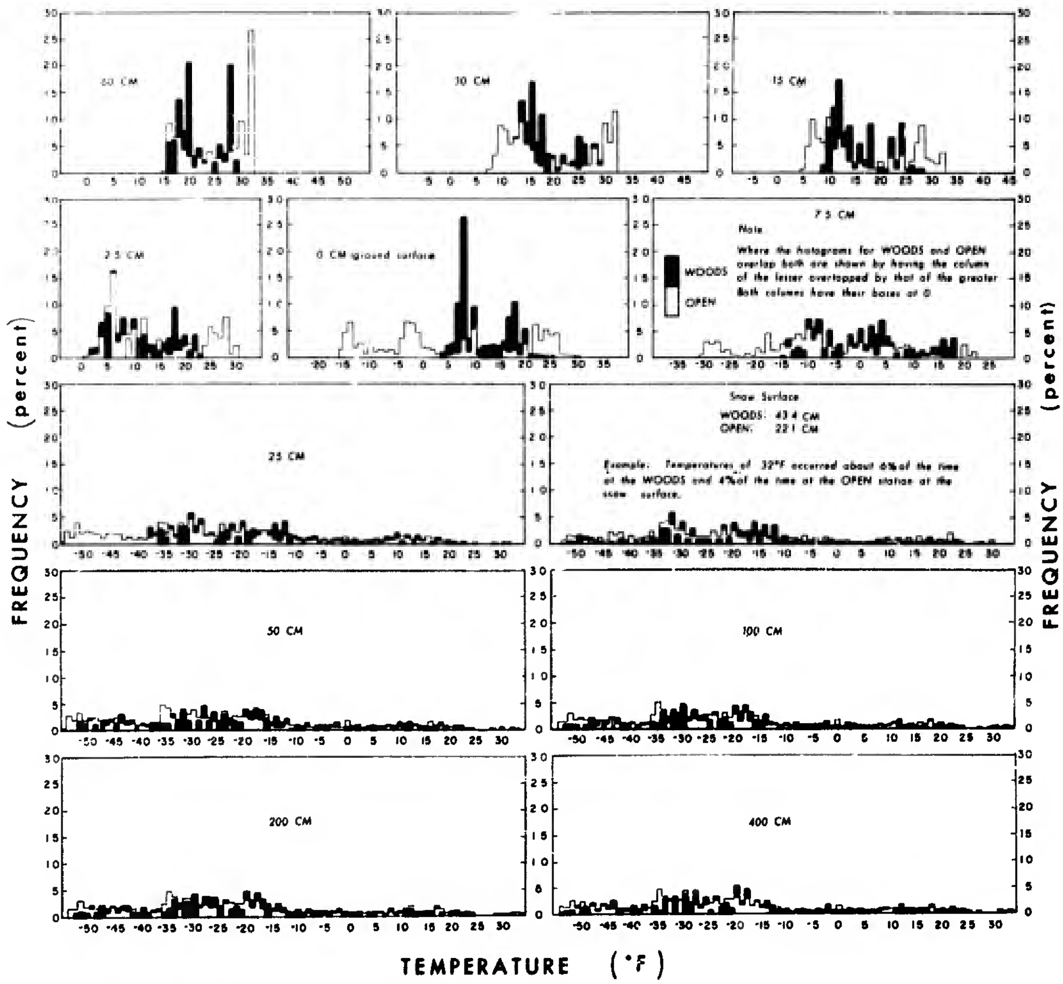


FIGURE 43

CUMULATIVE FREQUENCIES OF HOURLY GROUND AND AIR TEMPERATURES WOODS AND OPEN MICROCLIMATIC STATIONS, BIG DELTA, ALASKA DECEMBER 1956

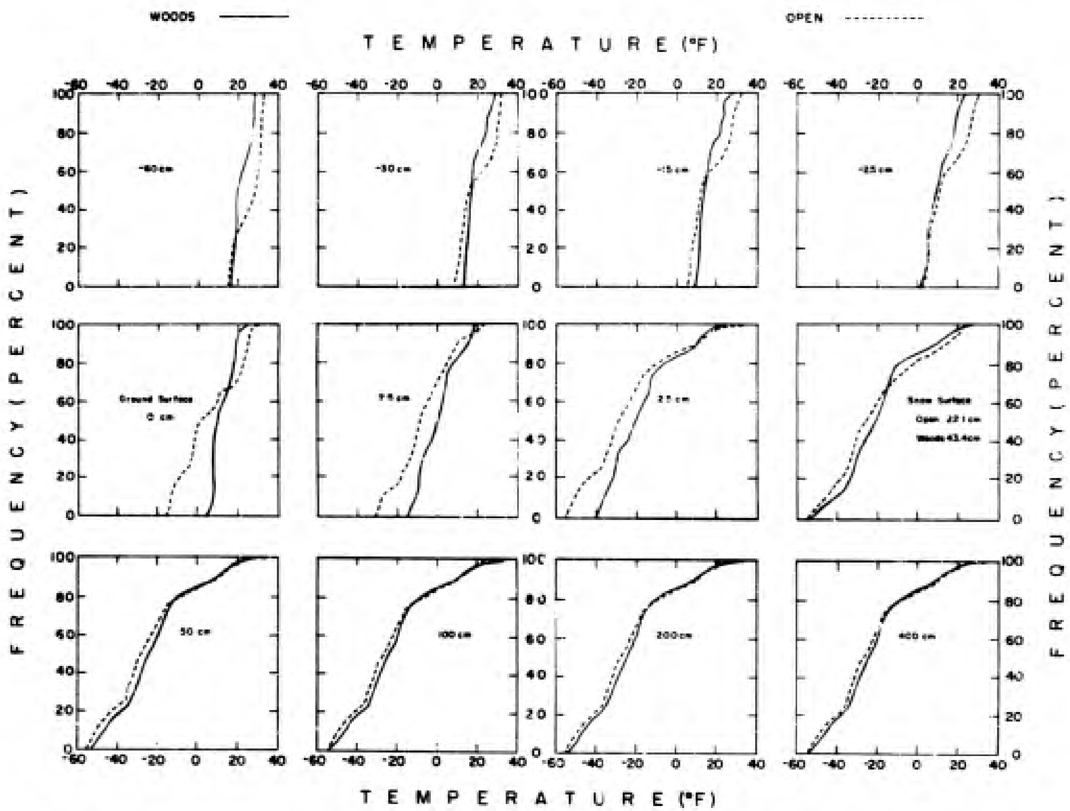


FIGURE 44

TABLE XVIII
NUMBER OF HOURS AT OR BELOW SELECTED TEMPERATURES*
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

STATION	-60	-30	-15	-2.5	0	7.5	22.1**	25	43.4***	50	100	200	400
							THERMOCOUPLE HEIGHT (CM)						
							32 F OR COLDER						
WOODS	739	739	739	739	739	739		739	739	739	739	739	739
OPEN	645	718	718	718	718	718	718	718		717	714	713	715
							0 F OR COLDER						
WOODS	0	0	0	0	0	386		614	633	632	633	633	633
OPEN	0	0	0	0	348	516	585	615		613	612	611	614
							-25 F OR COLDER						
WOODS	0	0	0	0	0	0		285	308	364	365	365	367
OPEN	0	0	0	0	0	90	359	406		405	393	390	386
							-40 F OR COLDER						
WOODS	0	0	0	0	0	0		0	80	134	135	135	139
OPEN	0	0	0	0	0	0	126	162		157	152	149	145

*TOTAL OBSERVATIONS: WOODS STATION, 739; OPEN STATION, 718 (-60 CM, 655). AT BOTH STATIONS MISSING DATA ARE FOR DECEMBER 19TH AND 20TH (ALSO DECMEBER 11TH AND 12TH AT -60 CM AT THE OPEN STATION).

**SNOW DEPTH, OPEN STATION.

***SNOW DEPTH, WOODS STATION.

TABLE XIX

GREATEST NUMBER OF CONSECUTIVE HOURS AT OR BELOW SELECTED TEMPERATURES*

WOODS AND OPEN MICROCLIMATIC STATIONS

BIG DELTA, ALASKA

DECEMBER 1956

STATION	THERMOCOUPLE HEIGHT (CM)												
	-60	-30	-15	-2.5	0	7.5	22.1**	25	43.4***	50	100	200	400
						32 F OR COLDER							
WOODS	739	739	739	739	739	739		739	739	739	739	739	739
OPEN	645	718	718	718	718	718	718	718		656	655	655	656
						0 F OR COLDER							
WOODS	0	0	0	0	0	227		487	496	496	496	496	496
OPEN	0	0	0	0	287	444	460	475		475	474	473	475
						-25 F OR COLDER							
WOODS	0	0	0	0	0	0		165	169	170	169	169	170
OPEN	0	0	0	0	0	61	98	149		173	173	173	173
						-40 F OR COLDER							
WOODS	0	0	0	0	0	0		0	62	61	60	60	61
OPEN	0	0	0	0	0	0	55	63		63	62	62	62

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*TOTAL OBSERVATIONS: WOODS STATION, 739; OPEN STATION, 718 (-60 CM, 655). AT BOTH STATIONS MISSING DATA ARE FOR DECEMBER 19TH AND 20TH (ALSO DECEMBER 11TH AND 12TH AT -60 CM AT THE OPEN STATION).

**SNOW DEPTH, OPEN STATION.

***SNOW DEPTH, WOODS STATION.

TABLE XX

NUMBER OF DAYS WITH MAXIMUM TEMPERATURES AT OR BELOW AND MINIMUM TEMPERATURES AT OR ABOVE SELECTED VALUES*

WOODS AND OPEN MICROCLIMATIC STATIONS

BIG DELTA, ALASKA

DECEMBER 1956

STATION	THERMOCOUPLE HEIGHT (CM)												
	-60	-30	-15	-2.5	0	7.5	22.1**	25	43.4***	50	100	200	400
							32 F						
WOODS													
TMAX	31	31	31	31	31	31		31	31	31	31	31	31
TMIN	0	0	0	0	0	0		0	0	0	0	0	0
OPEN													
TMAX	29	31	31	31	31	31	31	31		30	30	29	29
TMIN	9	3	1	0	0	0	0	0		0	0	0	0
							0 F						
WOODS													
TMAX	0	0	0	0	0	11		23	24	24	24	24	24
TMIN	31	31	31	31	31	11		4	2	2	2	2	2
OPEN													
TMAX	0	0	0	0	13	18	23	25		24	24	24	24
TMIN	31	31	31	31	15	6	4	2		2	2	2	2
							-25 F						
WOODS													
TMAX	0	0	0	0	0	0		8	10	11	10	10	10
TMIN	31	31	31	31	31	31		13	14	10	9	9	8
OPEN													
TMAX	0	0	0	0	0	1	9	11		11	10	10	10
TMIN	31	31	31	31	31	26	9	8		8	8	8	8
							-40 F						
WOODS													
TMAX	0	0	0	0	0	0		0	2	3	3	3	3
TMIN	31	31	31	31	31	31		31	25	21	21	21	21
OPEN													
TMAX	0	0	0	0	0	0	3	4		4	3	3	3
TMIN	31	31	31	31	31	31	21	19		19	19	20	21

*TOTAL FULL DAYS' OBSERVATIONS: WOODS STATION, 30; OPEN STATION, 29 (27 FOR -60 CM).

**SNOW DEPTH, OPEN STATION.

***SNOW DEPTH, WOODS STATION.

TABLE XXI

GREATEST NUMBER OF CONSECUTIVE DAYS WITH MAXIMUM TEMPERATURES AT OR BELOW AND MINIMUM TEMPERATURES AT OR ABOVE SELECTED VALUES*

WOODS AND OPEN MICROCLIMATIC STATIONS

BIG DELTA, ALASKA

DECEMBER 1956

STATION	THERMOCOUPLE HEIGHT (CM)												
	-60	-30	-15	-2.5	0	7.5	22.1**	25	43.4***	50	100	200	400
							32 F						
WOODS													
TMAX	31	31	31	31	31	31		31	31	31	31	31	31
TMIN	0	0	0	0	0	0		0	0	0	0	0	0
OPEN													
TMAX	29	31	31	31	31	31	31	31		29	29	29	29
TMIN	9	3	1	0	0	0	0	0		0	0	0	0
							0 F						
WOODS													
TMAX	0	0	0	0	0	9		19	20	20	20	20	20
TMIN	31	31	31	31	31	5		3	2	2	2	2	2
OPEN													
TMAX	0	0	0	0	8	18	19	20		20	20	20	20
TMIN	31	31	31	31	10	3	3	2		2	2	2	2
							-25 F						
WOODS													
TMAX	0	0	0	0	0	0		6	6	6	6	6	6
TMIN	31	31	31	31	31	31		8	8	4	4	4	4
OPEN													
TMAX	0	0	0	0	0	1	4	6		6	6	6	6
TMIN	31	31	31	31	31	15	5	4		4	4	4	4
							-40 F						
WOODS													
TMAX	0	0	0	0	0	0		0	2	2	2	2	2
TMIN	31	31	31	31	31	31		31	13	8	8	8	8
OPEN													
TMAX	0	0	0	0	0	0	2	2		2	2	2	2
TMIN	31	31	31	31	31	31	8	8		8	8	8	8

*TOTAL FULL DAYS' OBSERVATIONS: WOODS STATION, 30; OPEN STATION, 29 (27 FOR -60 CM).

**SNOW DEPTH, OPEN STATION.

***SNOW DEPTH, WOODS STATION.

temperatures remaining almost constant, the highest being -14 F and the lowest, -17 F. Examination of the data for the microclimatic stations shows a similar lack of variation, and, further, temperatures, except for 0 cm in the open, were not close to the selected threshold values at any level. At 0 cm, at the OPEN station, temperatures rose from -6 F (at 0800, December 19) to 1 F (1100, December 20) and it was necessary to estimate the hour (0900, December 20) when the temperature rose above 0 F, to 1 F. It is believed, therefore, that data for all other levels can be used with a high degree of confidence, and at 0 cm in the open, the error for the 0 F value is probably not more than 2 or 3 hours.

An interesting feature occurred at the snow surface. The number of hours with temperatures at or below -25 F and -40 F was greater at the OPEN station than at the WOODS station. This would be expected from the previous comparisons of temperature. The number of consecutive hours with temperatures at or below these values, however, was larger at the WOODS station. This may be explained by solar radiation, which, striking the snow surface directly at the OPEN station (on the 0 cm thermocouple) heated this surface during the day, in spite of the greater rate of cooling by evaporation, conduction, and longwave radiation in the open, thereby decreasing the number of consecutive hours having low temperatures.

(7) Cumulated temperatures

Cumulated temperatures computed by using daily mean temperatures and the threshold values discussed above are shown in Table XXII. These data show cumulations at the OPEN station generally lower than those of the WOODS station, especially for the -25 F and -40 F thresholds in the snow and air. Exceptions occurred, however, as in the cumulated temperatures for the 0 F threshold value at the snow surface. For the forest, this figure is 52 F deg. and for the open, 71 F deg. The higher cumulations at the OPEN station is due to surface heating during hours of insolation.

(8) Degree days

Degree days are a measure of coldness, and, together with temperature frequencies and durations, and cumulated temperatures, they provide another basis of comparison of temperature conditions at the microclimatic stations. The values shown in Table XXIII were computed by using daily mean temperatures and the commonly accepted base of 65 F. Degree days are used to determine heating requirements even though their computation is based on the air temperature alone, despite the effects of several other factors. Degree days were computed for the 50 cm, 100 cm, 200 cm and 400 cm levels in the air.

TABLE XXII
CUMULATED TEMPERATURES (F°) ABOVE 32 F, 0 F, -25 F AND -40 F BASES*
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

STATION	THERMOCOUPLE HEIGHT (CM) -60	-30	-15	-2.5	0	7.5	22.1**	25	43.4***	50	100	200	400
32 F													
WOODS	0	0	0	0	0	0		0	0	0	0	0	0
OPEN	2	0	0	0	0	0	0	0		0	0	0	0
0 F													
WOODS	700	580	482	335	369	116		53	52	52	52	52	53
OPEN	699	581	479	416	267	86	71	50		51	53	53	52
-25 F													
WOODS	1457	1356	1258	1110	1113	782		315	311	251	247	248	245
OPEN	1416	1306	1204	1141	890	530	285	214		215	224	224	262
-40 F													
WOODS	1666	1820	1722	1575	1609	1246		708	639	593	587	574	583
OPEN	1780	1741	1639	1576	1325	955	597	496		530	518	519	520

* COMPUTATIONS BASED ON DAILY MEAN VALUES. ALL VALUES ROUNDED TO WHOLE NUMBERS.
** SNOW DEPTH, OPEN STATION.
*** SNOW DEPTH, WOODS STATION.

TABLE XXIII
DEGREE DAYS (65 F BASE)
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

STATION	THERMOCOUPLE HEIGHT (CM) 50	100	200	400
WOODS (DEC. 1-31)	2,690.6	2,611.8	2,696.6	2,703.9
WOODS (DEC. 1-18, 21-31)	2,523.3	2,443.9	2,528.7	2,535.4
OPEN (DEC. 1-18, 21-31)	2,604.4	2,569.2	2,566.6	2,565.0

Values given in Table XXIII show that differences between the stations, at comparable levels, were quite small. This is especially true when the two missing days at the OPEN station are taken into consideration. These two days, December 19 and 20, occurred during the coldest time of the month. When the degree day values for December 19 and 20 are omitted for the WOODS station in the totals for the month, the OPEN station is then somewhat colder, conforming with results shown by other computations.

(9) Effects of weather

In winter, the wind, clouds, and precipitation raise temperatures. A cloud cover reduces net nocturnal radiation. This reduction is, however, offset by the loss of most of the insolation, but since this is weak and of short duration (days short) the net effect is a rise in temperature. Wind is of equal, and perhaps greater, importance in causing high temperatures at Big Delta. When from the south, winds are forced to rise over and then descend the high mountains of the Alaska Range. These winds are föhns and, therefore, upon reaching Big Delta they cause rapid and large increases in temperatures.

Winds from the east and southeast blow when there is a high pressure to the east and, therefore, a westward pressure gradient in the Tanana Valley. A wind-channeling effect near Big Delta makes these winds very strong (Mitchell, 1955; Evans, 1957). They, and the föhns from the south, which are also quite strong, as well as being warm and dry, destroy the winter inversion in the area and frequently raise the surface temperatures to above freezing. These winds are responsible for temperatures at Big Delta being substantially higher than those at Fairbanks, which is at almost the same latitude but farther west and is not influenced by the winds reaching the Big Delta area.

Data for December 27 may be used to illustrate the effects of wind. At 1400 the air temperature at the OPEN station was -22 F and the air was calm. At 1700, the wind was southeast, 7 mph, and the temperature, 5 F, a rise of 27 F deg. At 1900, the wind had increased to 13 mph and the temperature had risen to 10 F. In the short interval of five hours, therefore, there was an increase in temperature of 32 F deg. In the forest, in the same five hours, the wind reached 5 mph and the temperature rose 30 F deg., from -19 F to 11 F. The increase in wind and temperature was accompanied by an increase in sky cover. There were no clouds during the morning of December 27, but a high overcast developed by 1400 and the ceiling lowered to 6,000 feet by 1900. There was no precipitation.

(10) Globe thermometer temperatures

Continuous measurements of temperatures of a black globe were not made during winter because the thermocouple used for making

THESE MEASUREMENTS IN SUMMER WAS PLACED, INSTEAD, AT THE SNOW SURFACE. READINGS OF A STANDARD ALCOHOL THERMOMETER WERE MADE DAILY AT 0815, 1315, AND 1630, EXCEPT ON WEEKENDS AND HOLIDAYS. THE DAILY MEANS OF THE THREE OBSERVATIONS AT THE WOODS AND OPEN STATIONS FOR 20 DAYS OF DECEMBER ARE SHOWN IN FIGURE 45.

DIFFERENCES BETWEEN THE GLOBE TEMPERATURES AT THE STATIONS WERE SMALL COMPARED WITH THOSE IN JUNE. IN WINTER, SOLAR RADIATION IS WEAK AND OF SHORT DURATION AND THE STRONGER WINDS AT THE OPEN STATION MINIMIZED THE EFFECTIVENESS OF THE HEATING. TABLE XXIV SHOWS MONTHLY MEAN TEMPERATURES FOR EACH OF THE THREE HOURS OF OBSERVATION AND ALSO MONTHLY MEAN VALUES OF ALL THREE TOGETHER. IN ALL INSTANCES, THE DIFFERENCES BETWEEN STATIONS ARE LESS THAN 1 F DEG. GLOBE TEMPERATURES AT THE OPEN STATION WERE SLIGHTLY HIGHER THAN THOSE AT THE WOODS STATION, APPARENTLY DUE TO A SLIGHT NET SOLAR HEATING IN THE OPEN AS AGAINST NONE (NO MEASURABLE RADIATION) IN THE FOREST.

THE DIFFERENCES BETWEEN GLOBE TEMPERATURES AND AIR TEMPERATURES AT EACH OF THE STATIONS ARE GREATER THAN THE DIFFERENCES BETWEEN GLOBE

TABLE XXIV
MEAN HOURLY AND MEAN MONTHLY GLOBE AND AIR TEMPERATURES (°F) AT 200 CM*
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

STATION	HOUR OF THE DAY			MEAN MONTHLY
	0815	1315	1630	
WOODS				
G.T.	-17.6	-14.6	-17.3	-16.5
TAIR	-22.7	-20.1	-21.6	-21.5
OPEN				
G.T.	-17.4	-13.9	-16.8	-16.0
TAIR	-23.5	-21.2	-22.3	-22.3

*VALUES BASED ON 20 DAYS' OBSERVATIONS, THREE OBSERVATIONS EACH DAY. GLOBE THERMOMETER AND THERMOCOUPLE 200 CM ABOVE GROUND SURFACE, ABOUT 157 CM ABOVE SNOW SURFACE AT WOODS STATION AND ABOUT 178 CM ABOVE SNOW SURFACE AT OPEN STATION.

DAILY MEAN GLOBE AND 200 CM AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER 1956

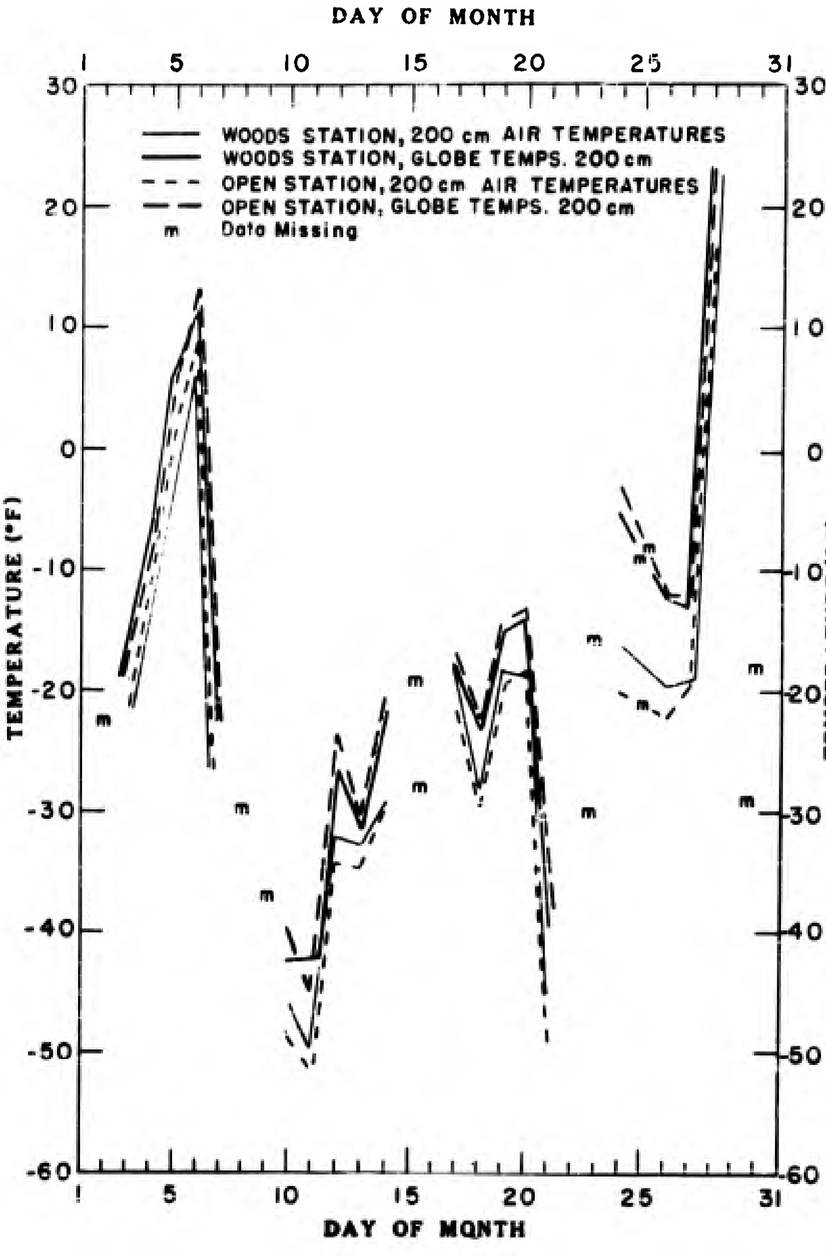


FIGURE 45

temperatures of the two stations. Table XXIV shows that mean hourly globe temperatures for the three hours were about 5 F deg. higher than air temperatures at the WOODS station and about 6 F deg. or 7 F deg. higher at the OPEN station.

From Figure 45 the differences between the daily mean globe and air temperatures may be obtained. In general, these differences were least at the WOODS station, ranging from a minimum of less than 1 F deg. to a maximum of 11 F deg., and greatest at the OPEN station, ranging from less than 1 F deg. to 17 F deg. In addition, it should be noted that air temperatures in the open were about 1 F deg. lower than in the forest, so that it must be assumed that the greater solar radiation received at the OPEN station resulted in a greater heating of the globe in spite of the lower air temperatures and stronger average winds.

D. Wind

In the Subarctic in winter, wind plays an extremely important, and often critical, role. The combination of wind and low temperature chills the body faster than heat can be produced within the body (Roberts, 1953, p. 4). When temperatures are frequently very low this chilling effect, more commonly called windchill, can be extremely dangerous. Windchill (Court, 1948a) or dry atmospheric cooling (Siple and Passel, 1945; Falkowski and Hastings, 1958) applies, in a sense, not only to warmblooded animals, but also to any relatively warm object. Sissenwine (1951, pp. 1-4) discusses the effects of wind speed on heating requirements in the Arctic, and Urdahl (1949) states:

"Since wind velocity is a factor very definitely influencing the heat loss of a structure, fuel consumption curves may well follow wind velocity curves with a greater degree of accuracy than they do the dry bulb temperature."

This statement is accurate only when temperatures are less than 65 F.

Wind must also be considered in the design of equipment. Strong winds may tear and damage tents, and the combined effects of wind speed and snow loads strongly influence the design and construction of temporary shelters other than tents (Sissenwine and Court, 1950). Moderately strong to strong winds will adversely affect outdoor activities and operations through blowing snow, by reducing visibilities, increasing cooling power (for exposed skin), and affecting breathing.

Walsh (1954, p. 2), from investigations conducted on the Greenland Icecap, found that most cases of blowing snow occurred when wind speeds were 20 mph or greater. He found that on the Icecap blowing snow occurred at least 85 percent of the time when the wind speed was greater than 20 mph, 50 percent of the time when the wind speed was between 15 and 20 mph, and only 15 percent of the time when the wind speed was less than 15 mph. Blowing snow not only restricts visibility, but also forms drifts which impede travel, and the snow filters through small openings in instruments and equipment, clogging mechanical parts and causing short circuits in electrical apparatus.

Wind, therefore, is most critical to human activities, in relation to other climatic elements, during the subarctic and arctic winter. Its importance is compounded when the extreme cold is also considered. In assessing the unfavorable aspects of the Canadian climate, Boughner and Thomas (1956, p. 4) consider January windchill and the darkness as the most important factors. It is necessary to know, therefore, the differences between wind speeds measured at official weather stations, usually located in open, exposed areas (where anemometers are exposed some distance above the ground*, often on the tops of buildings), and those recorded in the microclimatic layer close to the ground or in sheltered areas, such as the coniferous forests of the northern regions. This knowledge can be used to select optimum locations for buildings, and can also be used by persons living and working outdoors, to reduce stress imposed by windchill.

(1) Mean hourly and daily mean wind speeds

Mean hourly and daily mean wind speeds are shown in Figure 46.

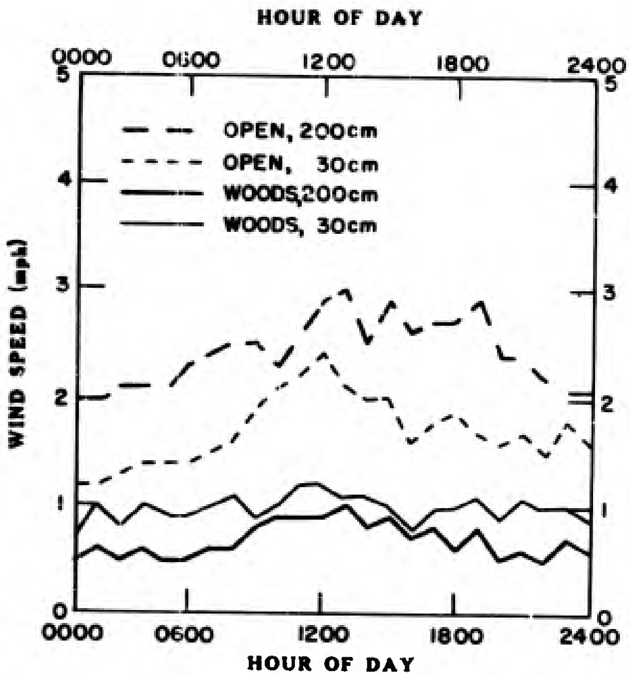
Figure 46 shows that in the open strongest winds occurred at 200 cm but in the forest, as during summer, mean hourly, and in most instances, daily mean, wind speeds were greater at 30 cm rather than at 200 cm. A diurnal variation is noted, with strongest winds occurring near and after noon being the usual convective type. This variation is, naturally, less pronounced in the forest than in the open.

Mean hourly wind speeds at 200 cm ranged from 1/2 to 1 mph at the WOODS station to 2 to 3 mph at the OPEN station. At 30 cm, mean hourly wind speeds ranged from 0.7 to 1.1 mph at the WOODS station and from 1.2 to 2.4 mph at the OPEN. Daily mean wind speeds changed greatly from day to day. On the windiest days, speeds at 200 cm in the open were about 8 mph while those in the forest were only 3 1/2 mph.

Winds were stronger during December than in June, and the effects of the forest in reducing wind speeds was more apparent. To illustrate the influence of the dense spruce woods of the north, data are given in

*Standard height is 10 meters.

MEAN HOURLY AND DAILY MEAN WIND SPEEDS
30 CM AND 200 CM ABOVE SNOW SURFACE
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER, 1956



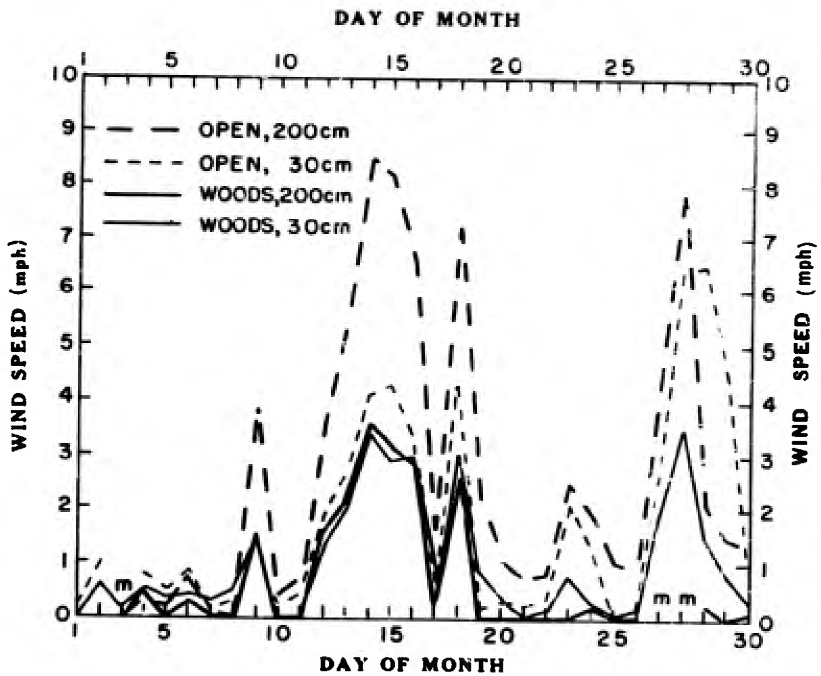


Figure 46

Table XXV which show wind speeds on December 28, one of the windiest days, at the microclimatic stations and, for comparison, at the CAA station. The anemometer at the CAA station is significantly higher (about 10 feet) above the ground surface, and is more openly exposed, than were the anemometers at the microclimatic stations. This explains the recording of stronger winds at the CAA station.

Table XXV shows that winds were usually only half as fast, and at times, only one-fifth as fast, in the forest as winds at the same level in the open. The prevailing direction during the day at all three stations, and at all levels, was easterly, either east or southeast; this is typical of most strong winds that blow in the area. The WOODS station was nearest the eastern edge of the forest and would be more influenced by winds from the east than from any other direction.

(2) Frequencies of wind speeds

The relative and cumulative frequencies of wind speeds measured at the stations are shown graphically in Figure 47.

Figure 47 shows clearly the great differences in wind speeds between the forest and open. At 200 cm especially, the percentage of hours with

TABLE XXV
WIND SPEEDS (MPH) ON DECEMBER 28, 1956
CAA WEATHER STATION, AND WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA

Station	Hour of the day												Prev. dir.
	01	03	05	07	09	11	13	15	17	19	21	23	
CAA													
5 m.	18	19	20	20	16	20	18	15	8	10	12	13	E, SE
WOODS													
200 cm	M	M	M	M	5	4	3	C	1	2	C	2	SE
30 cm	5	6	5	5	4	3	3	1	2	4	1	3	E
OPEN													
200 cm	11	10	8	12	9	10	8	6	5	10	3	6	E, SE
30 cm	5	3	6	7	8	8	9	6	7	6	6	7	E, SE

C = calm.
M = data missing.

RELATIVE AND CUMULATIVE FREQUENCIES OF WIND SPEEDS
30 CM AND 200 CM ABOVE THE SNOW SURFACE
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA

DECEMBER 1956

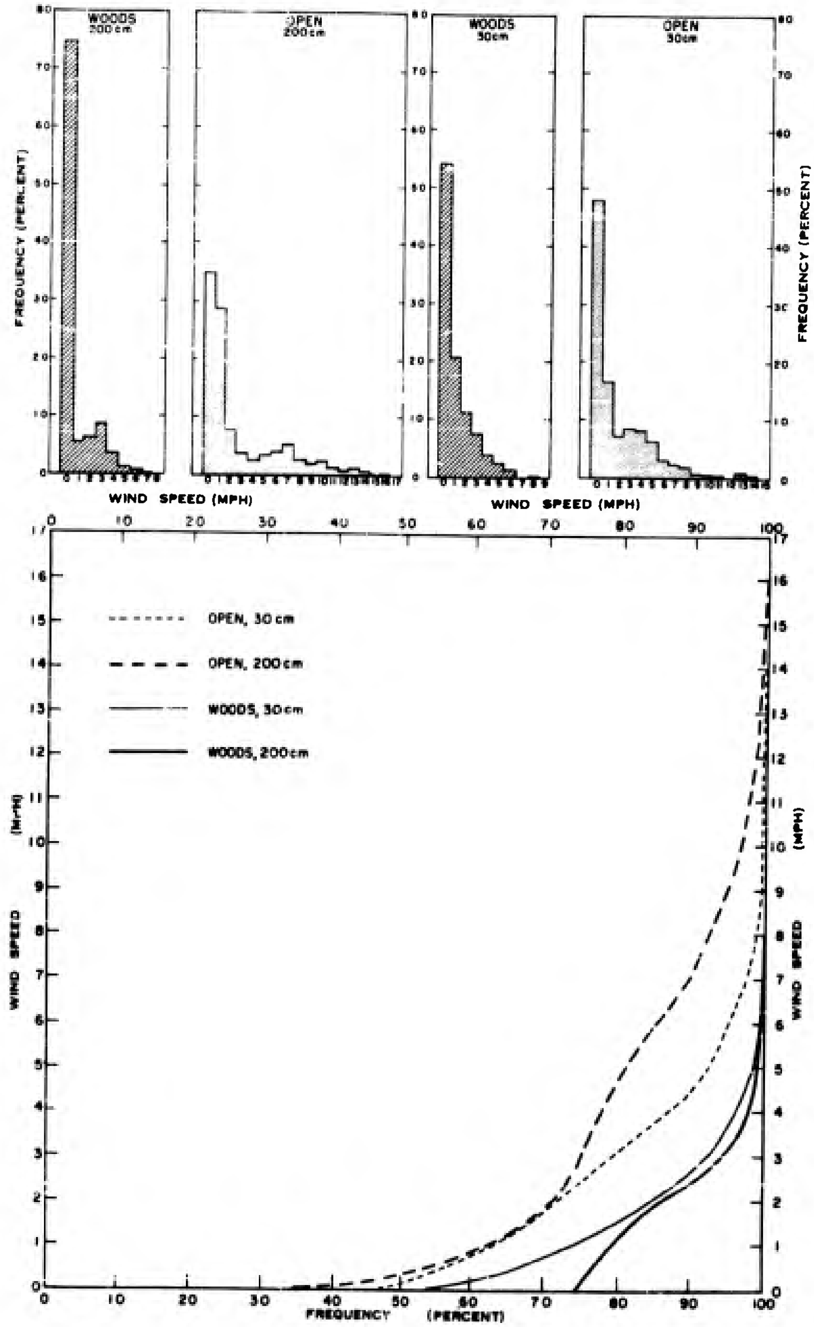


FIGURE 17

calms at the WOODS station was more than double that at the OPEN station (74.5 percent vs. 35.0 percent). At 30 cm, calms were more frequent in the forest, but by only a small percentage, 6 percent. The greater frequency of stronger winds at the OPEN station is clearly shown. There were no speeds above 8 mph in the forest, but speeds as great as 14 mph (at 30 cm) and 16 mph (at 200 cm) occurred in the open.

These histograms and curves illustrate the protection provided by forests in northern regions. At very low temperatures, small increases in wind speeds will effectively increase the stress imposed upon men. The great frequency of calms and for the rest of the time the very low wind speeds in the forest, combined with the reduced net nocturnal radiation, make a wooded area a considerably less severe location than the open for men, equipment, and instruments.

(3) Frequencies of wind directions and average speeds for each direction

Figure 48 shows the frequencies of wind directions to eight points of the compass and the average speed for each direction.

Winds blew predominantly from an easterly direction, generally between east and south, and the strongest speeds also were from these directions. In the forest, at 200 cm, winds blew from the southeast more than 90 percent of the time, and winds from the east and southeast blew for at least 30 percent of the time at both 200 cm and 30 cm levels at each station. Mean wind speeds were also largest for winds from the east and southeast. At 200 cm at the OPEN station, mean speeds from these two directions (5.4 mph and 6.9 mph, respectively) were several times those of the direction having the next strongest winds (1.8 mph, northeast). Indeed, all strong winds during the month blew from either the east or southeast. Since the WOODS station was located close to the eastern edge of the forest, the direction from which the strong winds came, it might reasonably be expected that if the station had been located deeper in the forest, or if the strongest winds had come from the west, the differences noted between the stations might have been even larger.

(4) Run of the wind

The run of the wind, the mileage from each direction, is also shown in Figure 48. The runs provide further evidence of the effects of the forest. Differences at 200 cm between the stations are very large. During the month, less than 500 miles of wind passed at this level in the forest (461 miles from the southeast), but in the open more than 1,800 miles of wind passed the station (652 miles from the east and 833 miles from the southeast), nearly four times the run in the forest.

FREQUENCIES, AVERAGE SPEEDS, AND RUN OF THE WIND
FOR EIGHT WIND DIRECTIONS, 200 CM AND 30 CM LEVELS
WOODS AND AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
DECEMBER, 1956

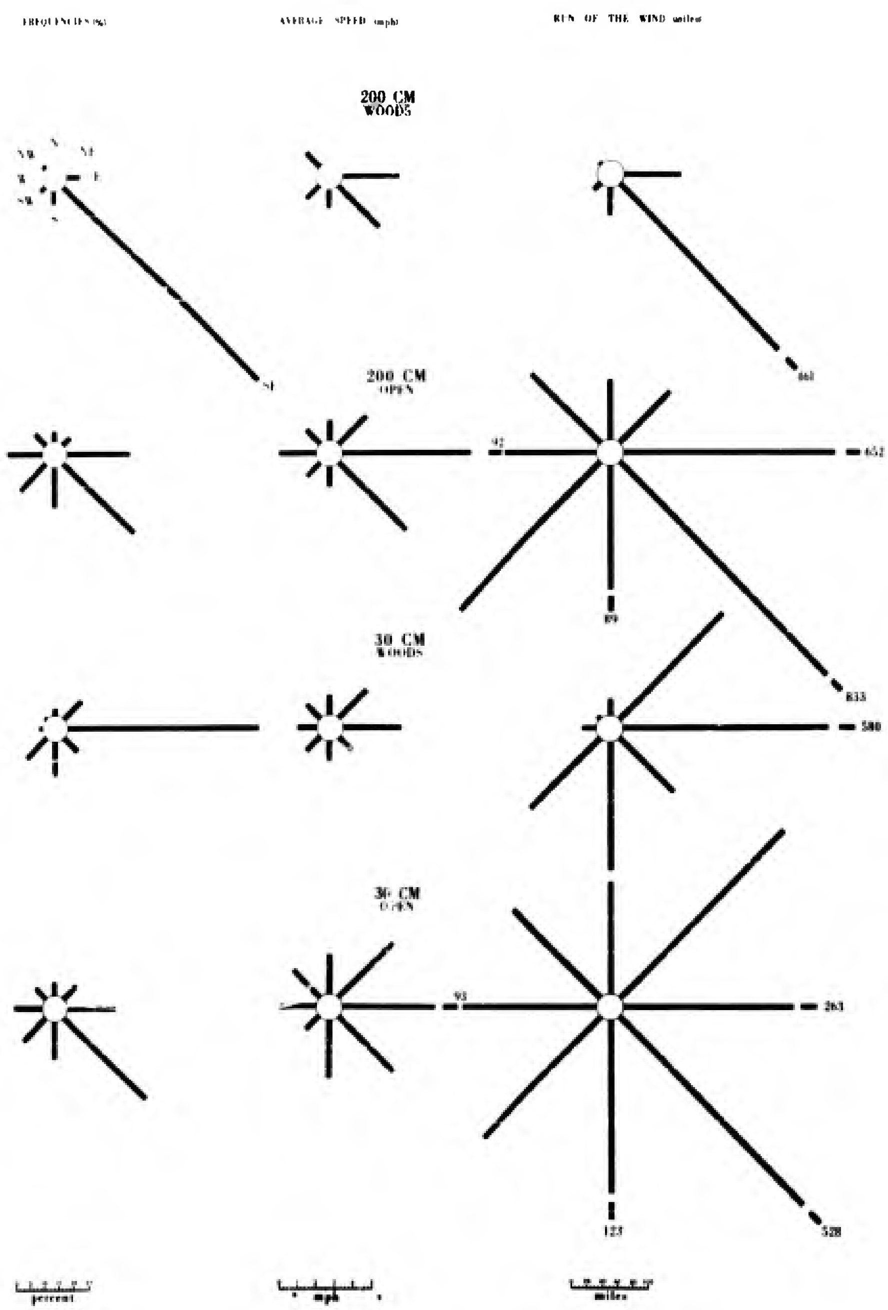


FIGURE 48

At the 30 cm levels, differences were not so striking, 739 miles in the forest (580 miles from the east) and 1,218 miles in the open (263 miles from the east, 528 miles from the southeast, and 123 miles from the south).

(5) Resultant run of the wind and the steadiness ratio

The resultant run of the wind and the steadiness ratio are listed in Table XXVI. In contrast to results obtained for June, when the winds were quite diverse, these values show that the winds were predominantly from 1 or 2 directions, and that strongest mean wind speed also occurred with the wind of the dominant direction. In reference to the example offered by Conrad and Pollak (1950, p. 185), who consider a steadiness ratio of 54 percent for January at Boston as being rather high, the steadiness ratios at the stations during December must be considered exceptionally large. This is especially true in the forest. The greatest variation occurred at 30 cm in the open, but the steadiness ratio, 54.8 percent, is equal to that given by Conrad and Pollak as a rather high value.

E. Combined elements

As indicated above in the discussion of wind, the most serious combination of climatic elements in the subarctic and arctic winter is low temperature and wind which combine to cause windchill. Windchill effectively limits outdoor activity much of the time, and may be particularly hazardous when a situation requires prolonged exposure.

TABLE XXVI
RESULTANT RUN OF THE WIND AND THE STEADINESS RATIO
200 CM AND 30 CM ABOVE THE SNOW SURFACE
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA

Height/station	Resultant run of the wind (miles)	Steadiness ratio (percent)
WOODS		
200 cm	474	96.3
30 cm	605	81.9
OPEN		
200 cm	1,275	70.5
30 cm	668	54.8

TO THESE TWO ELEMENTS MIGHT BE ADDED DARKNESS, ALTHOUGH DARKNESS PERHAPS PROPERLY CANNOT BE LISTED AS A CLIMATIC ELEMENT. THE LACK OF SOLAR RADIATION MOST OF THE 24 HOURS IN MIDWINTER, HOWEVER, WITH RESULTING CONSIDERABLE NET OUTGOING RADIATION, SERVES TO ACCENTUATE THE COLD AND THE STRESS IMPOSED ON MEN AND EQUIPMENT BY WINDCHILL.

(1) WIND SPEEDS AND TEMPERATURES

FIGURES 49 AND 50 SHOW THE COMBINATION OF WIND SPEED GROUPS (BEAUFORT SCALE) AND TEMPERATURE GROUPS (5 F DEG. INTERVALS).

WIND SPEEDS WERE MEASURED AT 200 CM AND 30 CM ABOVE THE SNOW SURFACE, BUT TEMPERATURE MEASUREMENTS (THERMOCOUPLES) REMAINED AT CONSTANT HEIGHTS ABOVE THE GROUND SURFACE. FOR THIS REASON, IT WAS NECESSARY TO SELECT FOR USE THE TEMPERATURES RECORDED BY THE THERMOCOUPLE NEAREST IN HEIGHT TO 200 CM AND 30 CM ABOVE THE SNOW SURFACE AT EACH OF THE STATIONS. AT THE OPEN STATION, THE 50 CM THERMOCOUPLE (28 CM ABOVE THE SNOW SURFACE) WAS USED WITH THE 30 CM WIND LEVEL, AND THE 200 CM THERMOCOUPLE (178 CM ABOVE THE SNOW SURFACE) WITH THE 200 CM WIND LEVEL. AT THE WOODS STATION, IT WAS NECESSARY TO USE THE 100 CM THERMOCOUPLE (57 CM ABOVE THE SNOW SURFACE) WITH THE 30 CM WIND LEVEL, AND THE 200 CM THERMOCOUPLE (157 CM ABOVE THE SNOW SURFACE) WITH THE 200 CM WIND LEVEL.

FIGURES 49 AND 50 SHOW THAT THIS MATCHING OF TEMPERATURE AND WIND LEVELS RESULTED IN NO SIGNIFICANT DIFFERENCES FROM WHAT MIGHT HAVE BEEN OBTAINED IF BOTH TEMPERATURE AND WIND INSTRUMENTS HAD BEEN AT IDENTICAL LEVELS. THESE COMBINATIONS PROVIDE A RELIABLE MEASURE OF TEMPERATURE-WIND COMBINATION. THE USE OF DIFFERENT TEMPERATURE LEVELS WAS ESSENTIAL, IN ORDER TO LEAVE THE TEMPERATURE STATIONS COMPLETELY UNDISTURBED. ADJUSTMENTS OF THE THERMOCOUPLES FOR HEIGHT ABOVE THE SNOW SURFACE WOULD HAVE RESULTED IN TRAMPLING OF THE SNOW, THUS AFFECTING SOIL AND SNOW TEMPERATURES.

FIGURES 49 AND 50 REVEAL THAT THE TEMPERATURE-WIND GROUPINGS AT 30 CM AT THE OPEN STATION, AND AT BOTH 200 CM AND 30 CM AT THE WOODS STATION, ACCORD WITH THE USUAL EXPERIENCE THAT WINDS ARE NEAR CALM OR CALM DURING TIMES OF VERY COLD WEATHER. AT 200 CM IN THE OPEN, HOWEVER, THIS IS NOT SO. AT TEMPERATURES RANGING FROM -20 F TO -54 F, WINDS OF 1 TO 3 MPH AND/OR 4 TO 7 MPH WERE AS FREQUENT AS, OR MORE FREQUENT THAN, CALMS. IN THE TEMPERATURE GROUP -30 F TO -34 F, FOR EXAMPLE, WINDS OF 8 TO 12 MPH OCCURRED MORE FREQUENTLY THAN DID CALMS, AND AT TEMPERATURES OF -50 F TO -54 F, WINDS WITH SPEEDS OF 1 TO 3 MPH WERE MORE NUMEROUS THAN CALMS. THIS SAME CONDITION WAS FOUND IN STUDIES AT FORT CHURCHILL, CANADA (DE PERCIN AND FALKOWSKI, 1956, PP. 21-25), AND IT MUST BE CONCLUDED THAT THE COMMONLY-ACCEPTED BELIEF THAT CALMS OCCUR SIMULTANEOUSLY WITH EXTREME LOW TEMPERATURES DOES NOT HOLD TRUE ON MANY OCCASIONS.

OCCURRENCES OF WIND SPEEDS AT VARIOUS TEMPERATURES, WOODS MICROCLIMATIC STATION, BIG DELTA, ALASKA

PERIOD: DECEMBER 1956

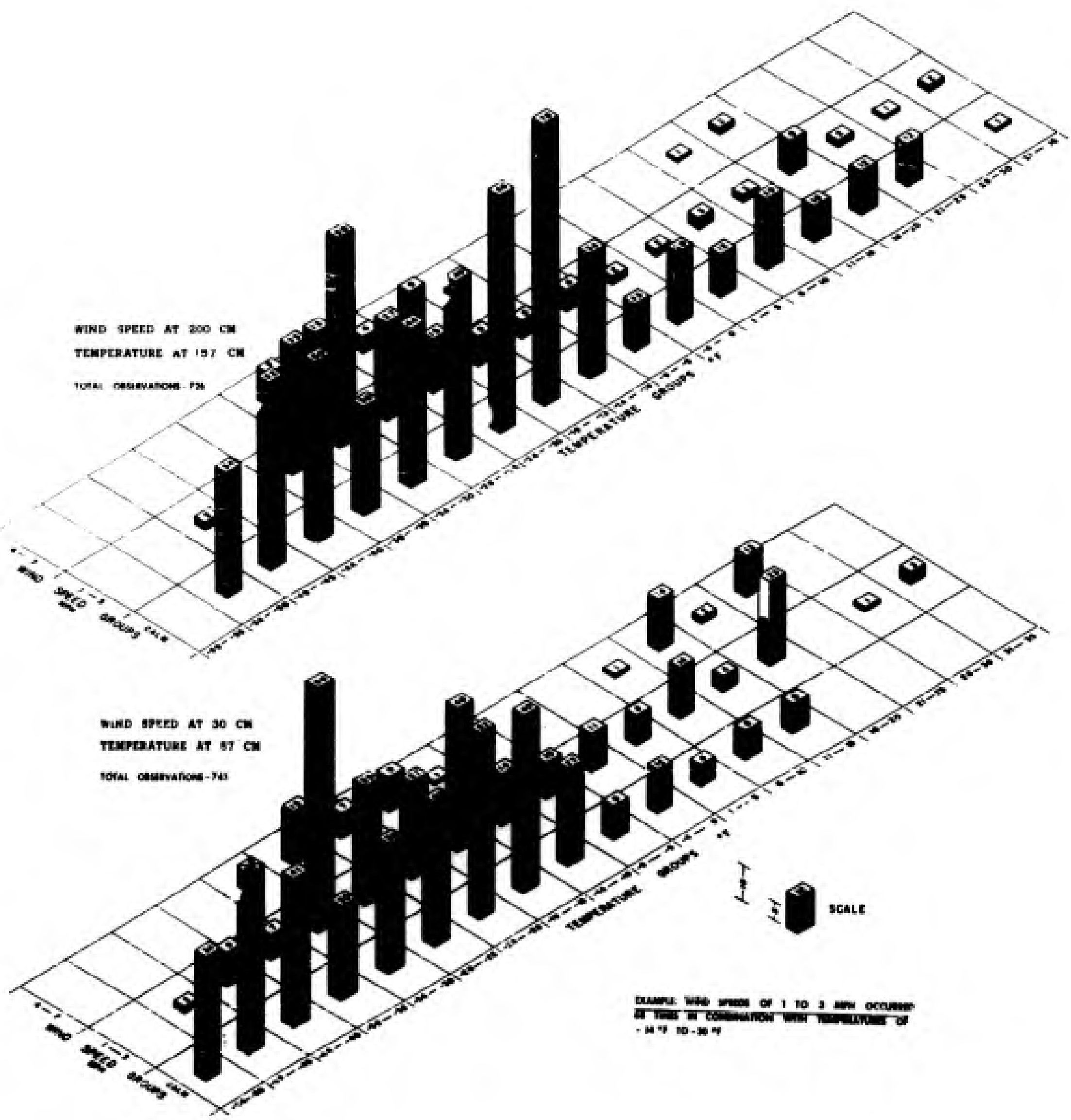


FIGURE 49

OCCURRENCES OF WIND SPEEDS AT VARIOUS TEMPERATURES, OPEN MICROCLIMATIC STATION, BIG DELTA, ALASKA

PERIOD DECEMBER 1956

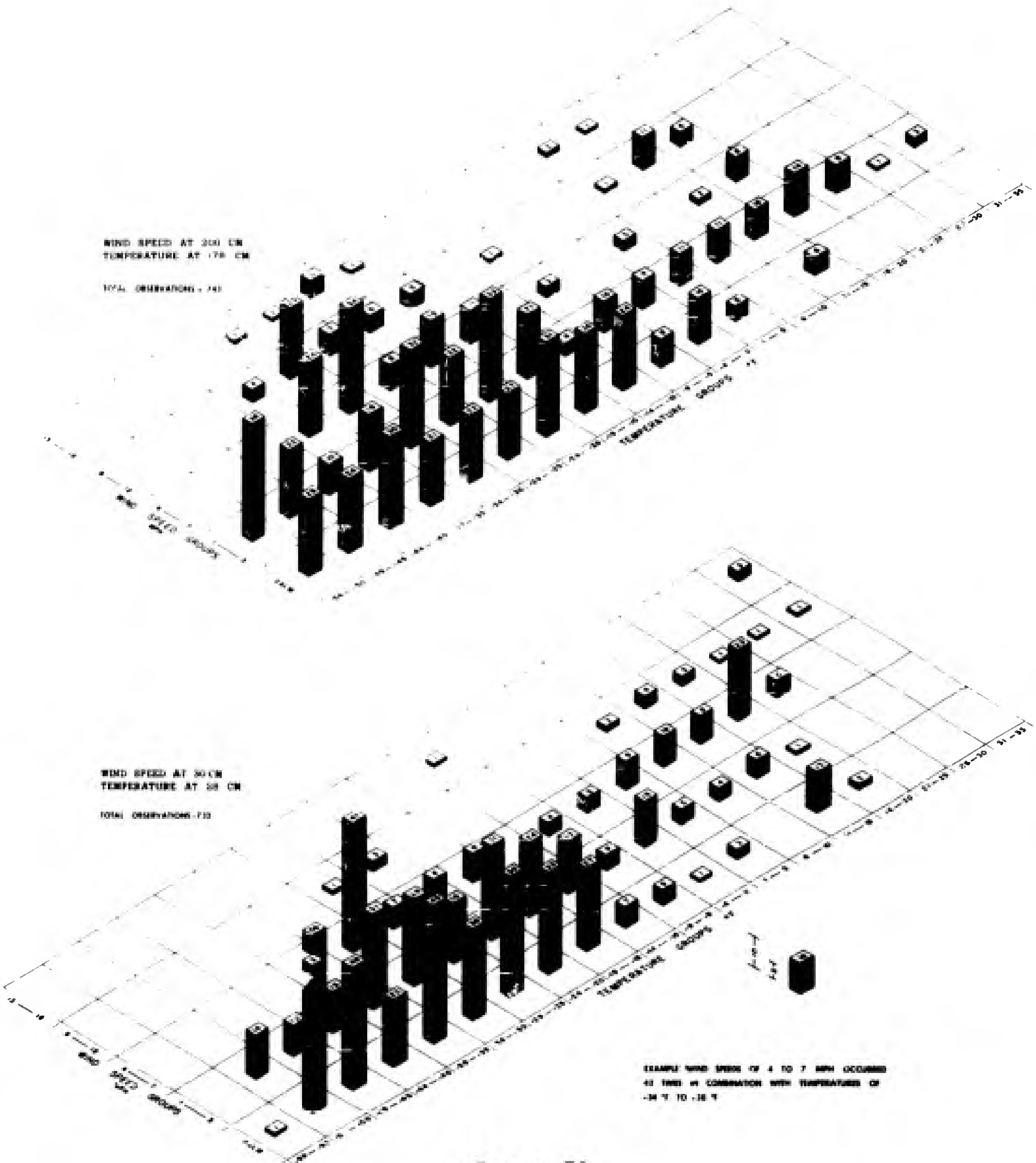


FIGURE 50

(2) WINDCHILL OR DRY ATMOSPHERIC COOLING

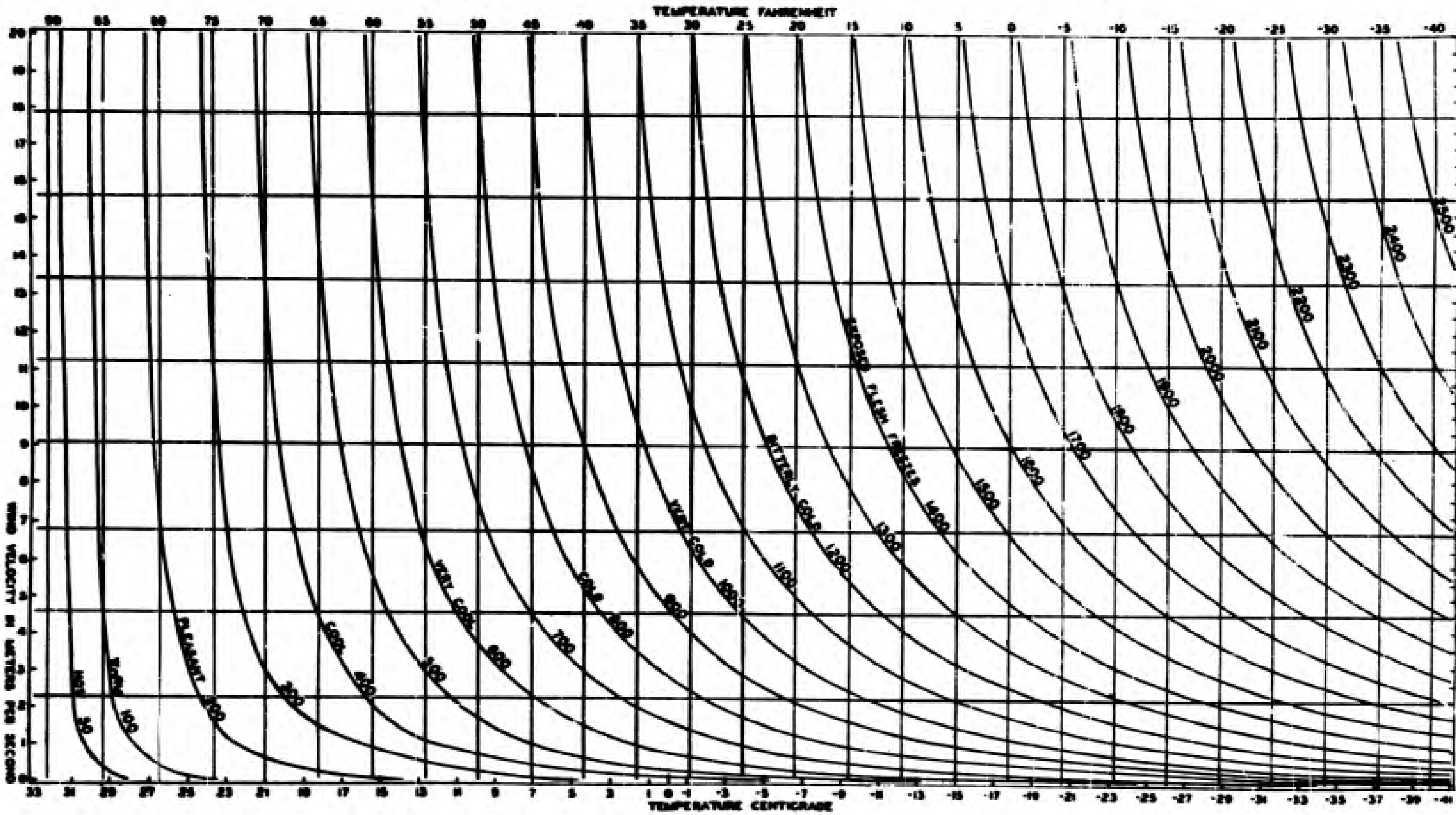
COURT (1948A) POINTS OUT THAT THE TERM "WINDCHILL" WAS FIRST USED BY SIPLE IN 1939, ALTHOUGH THE CONCEPT OF THE COOLING EFFECT OF AIR MOVEMENT AND LOW TEMPERATURE HAS LONG BEEN RECOGNIZED. SIPLE AND PASSEL (1945) PRESENT IN DETAIL THE METHOD EMPLOYED IN MAKING ATMOSPHERIC COOLING MEASUREMENTS AT LITTLE AMERICA, ANTARCTICA, IN 1941. FROM THEIR EXPERIMENTS AT LITTLE AMERICA, THE FORMULA WAS DEVELOPED UPON WHICH FIGURE 51 (NOMOGRAM OF DRY ATMOSPHERIC COOLING) AND THE WINDCHILL VALUES PRESENTED IN THIS STUDY ARE BASED. C. F. BROOKS (1925) IN DISCUSSING THE COOLING OF MAN UNDER VARIOUS WEATHER CONDITIONS, AND DORNO (1926) IN HIS CRITIQUE OF BROOKS' PAPER, MENTION THE IMPORTANCE OF SOLAR RADIATION IN COMPUTING WINDCHILL. INSOLATION IS IMPORTANT IN WARMING MEN AND COUNTERACTING, TO A CERTAIN EXTENT, THE EFFECTS OF WINDCHILL.

IN THE SUBARCTIC, HOWEVER, RADIATION MEASUREMENTS ARE GENERALLY LACKING, AND, ANYWAY, THE SHORT HOURS OF DAYLIGHT AND WEAKNESS OF THE INSOLATION BECAUSE OF LOW ANGLE AND CLOUDINESS TEND TO MINIMIZE THE EFFECTS OF SOLAR RADIATION. IN ADDITION, VEGETATION SUCH AS THAT AT THE WOODS STATION WILL FURTHER MINIMIZE THE EFFECTS OF INSOLATION. SOLAR RADIATION MUST NOT BE IGNORED COMPLETELY, HOWEVER, WHEN CONSIDERING WINDCHILL, FOR WHEN THE SUN SHINES SOME WARMTH IS GAINED EVEN THOUGH THE TEMPERATURES MAY BE LOW AND THE WIND BLOWING. THIS IS PARTICULARLY TRUE WHEN IT IS REALIZED THAT SOLAR RADIATION RECEIVED ON A VERTICAL SURFACE, SUCH AS STANDING OR EVEN SITTING MEN, IS OFTEN MUCH GREATER THAN THAT RECEIVED ON A HORIZONTAL SURFACE (SUCH AS THE PYRHELIOMETER). AT NIGHT, LONGWAVE OUTGOING RADIATION IS A DIRECT CAUSE OF CHILLING OF MEN.

FROM FIGURES 49 AND 50 THE FREQUENCIES OF VARIOUS WINDCHILL VALUES MAY BE ESTIMATED. AS AN EXAMPLE, AT 200 CM AT THE OPEN STATION TEMPERATURES OF -30 F TO -34 F WITH WIND SPEED OF 8 TO 12 MPH OCCURRED 23 TIMES, BUT DID NOT OCCUR AT 30 CM, OR AT 200 CM AND 30 CM AT THE WOODS STATION. USING THE MIDDLE VALUES OF BOTH WIND AND TEMPERATURE GROUPS (10 MPH AND -32 F) A WINDCHILL OF 1,850 KGCAL/M^2/HR IS OBTAINED FROM FIGURE 51. P. ROBERTS (1943, P. 4) LISTS WINDCHILL VALUES OF 1,000 TO 2,000 KGCAL/M^2/HR AS THE WORST POSSIBLE COMBINATION OF WIND AND LOW TEMPERATURE, AND AT THE OFFICIAL WEATHER STATION AT FORT CHURCHILL, MANITOBA, CANADA THE FOLLOWING SCALE IS GIVEN ON THE DAILY WEATHER OBSERVATION FORM:

WINDCHILL VALUE	DESCRIPTION
700 - 900	COLD
900 - 1,100	VERY COLD
1,100 - 1,400	BITTERLY COLD
1,400 - 1,900	FREEZINGLY COLD
1,900 - OVER	DANGEROUSLY COLD

NOMOGRAM OF DRY-SHADE ATMOSPHERIC COOLING



COOLING IS EXPRESSED IN KILOGRAM CALORIES PER SQUARE METER PER HOUR FOR VARIOUS TEMPERATURES AND WIND VELOCITIES. THE COOLING RATE IS BASED UPON A BODY AT A NEUTRAL SKIN TEMPERATURE OF 33 C. (91.4 F.). WHEN DRY COOLING RATE IS LESS THAN THE RATE OF BODY HEAT PRODUCTION, EXCESS HEAT IS REMOVED BY VAPORIZATION. UNDER CONDITIONS OF BRIGHT SUNSHINE COOLING IS REDUCED BY ABOUT 200 CALORIES. EXPRESSIONS OF RELATIVE COMFORT ARE BASED UPON AN INDIVIDUAL IN A STATE OF INACTIVITY.

FIGURE 51

FROM THE ABOVE SCALE IT IS SEEN THAT A WINDCHILL OF 1,850 KGCAL/M^2/HR IS FREEZINGLY COLD, AND THAT UNDER SUCH CONDITIONS PROLONGED EXPOSURE WOULD BE DIFFICULT, AND WITHOUT PROPER CLOTHING, SHELTER, AND FOOD IT WOULD BE DANGEROUS. THE PROTECTION AFFORDED BY THE FOREST, THEREFORE, CANNOT BE UNDERESTIMATED. DEEP SNOW OR DENSE VEGETATION CAN EFFECTIVELY PROTECT MEN FROM THE FULL EFFECTS OF WINDCHILL, AND CAN SUBSTANTIALLY REDUCE HEATING REQUIREMENTS FOR TEMPORARY OR PERMANENT SHELTERS.

PART III - SUMMARY OF RESULTS

The results obtained by this study show that very large differences in solar radiation, temperature, wind, and precipitation occurred between two microclimatic stations, one located in a relatively dense subarctic spruce forest (taiga), and the other located close by in an open, cleared area having little or no vegetation. These differences have important applications to many fields of science, including military, engineering, agriculture, biology, geology, climatology, and meteorology. They are especially significant when applied to military problems, for a knowledge of the microclimate is important, if not essential, in military planning and operations involving soldiers and equipment. Without this knowledge, a full understanding of the impact and stress of the climate on the efficient functioning of men and equipment is lacking.

The following summary gives some of the more important results obtained, and, in most instances, provides a brief explanation of the causes leading to these results.

1. Radiation

The spruce forest effectively decreased solar radiation received at or near the ground (or snow) surface during the day in both summer and winter, and, in winter especially, the trees reduced the net longwave radiational loss at night. In the forest, the effective locus of both absorption and radiation was no longer the surface of the ground (or snow), but was a layer of depth near the canopy. At the WOODS station, during the day, with the sun at a low angle all year, most of the direct solar radiation was intercepted at the upper parts of the spruce trees, and it is surmised that, of the radiation received in the forest, the large proportion was diffuse or scattered radiation from the sky. In winter, when temperatures were low (usually -30 F or below), ice fogs reduced the amounts of insolation received at the OPEN station.

The following results were noted from solar radiation measurements made in June and December 1956.

A. In June 1956, total daily solar radiation measured in the forest was only about a third of that measured in the open, the mean total daily radiation being 165 ly and 452 ly at the WOODS and OPEN stations, respectively. During the hours of most intense insolation, 0700 to 1800, mean hourly solar radiation was 15 to 32 ly greater in the open than in the forest.

B. In December 1956, absolute differences in solar radiation were not as great as during summer, due to the very short days and smaller

QUANTITIES MEASURED, BUT RELATIVE DIFFERENCES WERE LARGER. SOLAR RADIATION WAS RECORDED DURING ONLY THREE HOURS OF THE DAY (EXCEPT FOR THE FIRST TWO DAYS OF THE MONTH), 1000 THROUGH 1300, AT THE OPEN STATION. IN THE OPEN, THE MONTHLY TOTAL WAS 160 LY AND THE MEAN DAILY VALUE WAS 5.1 LY. IN THE FOREST, SOLAR RADIATION WAS NOT RECORDED AT ANY TIME DURING THE MONTH; THE AMOUNTS RECEIVED WERE NOT OF SUFFICIENT INTENSITY TO ACTIVATE THE INSTRUMENT, OFFERING AMPLE EVIDENCE OF THE INFLUENCE OF THE SPRUCE TREES IN REDUCING INSOLATION, PARTICULARLY DURING PERIODS WHEN THE ALTITUDE OF THE SUN IS LOW AND THE ANGLE OF INCIDENCE OF THE RAYS OF THE SUN IS LARGE.

C. DURING WINTER, ICE FOGS WERE INSTRUMENTAL IN REDUCING AMOUNTS OF INSOLATION MEASURED AT THE OPEN STATION.

D. THE FREQUENCIES OF SOLAR RADIATION AMOUNTS RECEIVED PROVIDE ADDITIONAL EVIDENCE OF THE DIFFERENCES BETWEEN THE MICROCLIMATIC STATIONS. IN JUNE, 50 PERCENT OF THE HOURS AT THE WOODS STATION HAD 4 LY OR LESS, WHILE AT THE OPEN STATION THIS FIGURE WAS 37 PERCENT. THIRTY LANGLEYS OR MORE WERE MEASURED DURING 4 PERCENT OF THE HOURS AT THE WOODS STATION, BUT AT THE OPEN STATION TWICE THAT NUMBER, 60 LY, OR MORE, WERE MEASURED DURING 7 PERCENT OF THE HOURS. IN DECEMBER, THE GREATEST AMOUNT OF INSOLATION MEASURED DURING ONE HOUR WAS 10 LY AT THE OPEN STATION, BUT DURING THIS SAME HOUR NO RADIATION WAS RECORDED AT THE WOODS STATION. AT THE OPEN STATION, HOWEVER, 90 PERCENT OF THE HOURS DURING WHICH SOLAR RADIATION WAS RECORDED IN DECEMBER HAD ONLY 4 LY OR LESS.

THE DIFFERENCES IN SOLAR RADIATION RECEIVED AT THE STATIONS ARE INDICATED BY THE VEGETATION COVER AT THE GROUND. IN THE FOREST, THE GROUND SURFACE WAS COVERED WITH MOSSES AND LICHENS, PLANTS TOLERANT TO A COOL, MOIST, SHADY ENVIRONMENT, BUT IN THE OPEN THE PREDOMINANT PLANTS WERE WEEDS AND GRASSES.

2. PRECIPITATION

PRECIPITATION, AS RAIN IN SUMMER AND AS SNOW IN WINTER, PLAYS A VERY SIGNIFICANT ROLE IN AFFECTING SOIL, SOIL-SURFACE, AND NEAR-SURFACE AIR TEMPERATURES. MEASUREMENTS MADE AT ONLY ONE LOCATION IN A FOREST ARE NOT INDICATIVE OF AMOUNTS RECEIVED THROUGHOUT THE FOREST, AND PRECIPITATION AMOUNTS RECORDED DURING JUNE AND DECEMBER IN THE WOODS ARE OF VALUE AND INTEREST ONLY FOR COMPARING AMOUNTS RECEIVED AT THE STATIONS AND FOR KNOWING HOW MUCH WAS RECEIVED AT THE GROUND NEAR THE SOIL THERMOCOUPLES. DURING WINTER, THE DEPTH OF THE SNOW COVER AT EACH STATION WAS OF GREATER SIGNIFICANCE THAN THE AMOUNT OF SNOWFALL.

A. IN JUNE 1956, PRECIPITATION MEASURED AT THE OPEN STATION (4.65 IN.) WAS ABOUT 20 PERCENT GREATER THAN THAT RECEIVED AT THE WOODS STATION (3.72 IN.), CONFORMING WITH RESULTS OBTAINED IN OTHER STUDIES.

b. In December, amounts of snowfall measured were not accurate because windshields were not placed on the precipitation gages. Observations of depth-of-snow revealed, however, that the snow cover in the forest was about twice as deep as that in the open. Snow cover varied in depth from 39 cm to 49 cm at the WOODS station, averaging 43.4 cm for the month, while at the OPEN station it varied from 18 cm to 25 cm, averaging 22.1 cm in depth for the month.

The deeper snow cover in the forest reduced the rate of the heat loss from the ground and this was reflected in the higher temperatures at the ground surface in the forest during times of extreme cold, and also in the greater lag of ground and soil temperatures in responding to large day-to-day fluctuations in air temperature. In the open, the heat loss from the ground was greater, due to the thinner snow cover, and ground surface temperatures responded more rapidly to changes in air temperature.

3. Temperature

The vegetation of the WOODS station was instrumental in causing very large differences in soil, ground surface, and near-surface temperatures between the stations, but air temperatures at 50 cm and above were not greatly affected. At these heights (50 cm to 400 cm), differences in temperatures between the stations were small.

In summer, the spruce trees considerably reduced the insolation received at the ground surface, and this, combined with the insulating property of the moss-lichen cover at the ground surface in the forest, caused ground surface and soil temperatures to be very much lower in the forest than in the open.

In winter, snow accumulated to greater depths in the woods, and due to the insulating property of the deeper snow cover, greater protection was afforded the ground beneath. Higher soil temperatures were not recorded at the WOODS station than at the OPEN until the end of the month (December), however, because the soil in the forest was much colder at the beginning of winter. In the open, where soil temperatures were relatively high compared with those in the forest because of heating during summer, soil temperatures became as low as, or lower than, those in the woods only toward the end of the month. At the OPEN station, the heat loss from the ground, and, therefore, the cooling of the soil, progressed more rapidly than in the forest where the deeper snow and vegetation reduced the amount of heat loss from the ground.

Some of the more important differences in temperatures observed in June 1956 are as follows:

a. The spruce trees and moss-lichen ground cover greatly retarded warming of the soil at the WOODS station. This resulted in large differences

IN SOIL TEMPERATURES BETWEEN THE STATIONS, AND BETWEEN THE SOIL AND AIR TEMPERATURES AT THE WOODS STATION ITSELF.

B. AT THE WOODS STATION, MAXIMUM SOIL TEMPERATURES LAGGED 24 TO 26 HOURS BEHIND MAXIMUM AIR TEMPERATURES AT -15 CM AND -30 CM. ISOTHERMAL CONDITIONS EXISTED AT -60 CM, THE TEMPERATURE REMAINING CONSTANT AT 31 F DURING THE PERIOD. AT THE OPEN STATION, MAXIMUM SOIL TEMPERATURES LAGGED 4 HOURS (AT -15 CM) TO 24 HOURS (AT -60 CM) BEHIND MAXIMUM AIR TEMPERATURES. THE TEMPERATURES OF THE SURFACE (0 CM) AND -2.5 CM FOLLOWED CLOSELY THE FLUCTUATIONS AND CHANGES IN AIR TEMPERATURES, SHOWING LITTLE LAG.

C. AT BOTH STATIONS, THERE WAS AN INCREASE IN THE LAG IN SOIL WARMING WITH INCREASING DEPTH. THIS LAG WAS GREATER IN THE FOREST THAN IN THE OPEN.

D. AT BOTH STATIONS THERE WAS A DECIDED DAMPING OF SOIL TEMPERATURE FLUCTUATIONS WITH INCREASING DEPTH. THIS DAMPING EFFECT WAS GREATER IN THE FOREST, REACHING A MAXIMUM AT -60 CM WHERE THE TEMPERATURE REMAINED CONSTANT.

E. IN THE FOREST, MINIMUM SOIL TEMPERATURES LAGGED BEHIND MINIMUM AIR TEMPERATURES 1 HOUR AT -2.5 CM, 2 TO 3 HOURS AT -15 CM, APPROXIMATELY 26 HOURS AT -30 CM, AND THERE WAS NO VARIATION AT -60 CM. IN THE OPEN, MINIMUM TEMPERATUES OCCURRED SIMULTANEOUSLY IN THE AIR, AT THE SURFACE (0 CM), AND AT -2.5 CM, BUT LAGGED 3 HOURS BEHIND AT -15 CM, 7 TO 8 HOURS AT -30 CM, AND ABOUT 30 HOURS AT -60 CM.

F. MEAN HOURLY SOIL TEMPERATURES IN THE FOREST WERE AT LEAST 7 F DEG., AND WERE GENERALLY 15 F DEG. TO 20 F DEG., LOWER THAN THOSE AT THE SAME DEPTHS IN THE OPEN, THE DIFFERENCES DEPENDING UPON THE DEPTH AND TIME OF DAY.

G. AT BOTH STATIONS, GREATEST VERTICAL DIFFERENCES IN MEAN HOURLY AND DAILY MEAN TEMPERATURES OCCURRED IN THE SOIL AND AT THE SOIL SURFACE. THESE DIFFERENCES RANGED FROM 5 F DEG. TO 15 F DEG., DEPENDING UPON THE STATION, TIME, AND DEPTH.

H. DAILY MEAN SOIL TEMPERATURES IN THE FOREST WERE USUALLY MORE THAN 10 F DEG., AND FREQUENTLY 15 F DEG. TO 20 F DEG. LOWER THAN THOSE AT THE SAME DEPTHS IN THE OPEN, EXCEPTIONS OCCURRING AT -2.5 CM ON CLOUDY AND RAINY DAYS.

I. HIGHEST SOIL TEMPERATURES AT THE WOODS STATION WERE MEASURED AT THE SURFACE (0 CM), WITH TEMPERATURES INCREASING FROM -60 CM TO 0 CM. AIR TEMPERATURES WERE NEARLY ALWAYS HIGHER THAN SOIL TEMPERATURES IN THE FOREST. AT THE OPEN STATION, HIGHEST SOIL TEMPERATURES WERE MEASURED AT

-2.5 cm rather than at 0 cm due to evaporative cooling from the surface or conduction from the surface to the colder air directly above. During most of the days, the 0 cm and -2.5 cm temperatures were as high as, or higher than, the air temperatures.

j. The range of soil temperatures in the forest was half or less than half, of the range of those at comparable depths in the open.

k. The frequency of low soil temperatures was much greater in the forest than in the open. Temperatures at or below 43 F, for example, were quite common in the forest, but did not occur in the open. Conversely, near-surface soil temperatures above 77 F were common in the open, but were not observed in the forest.

l. Durations of low soil temperatures, 50 F and below, were much larger in the forest than in the open. Above 50 F, at 68 F and 77 F, there were no differences at depths of -15 cm and below, but at -2.5 cm and 0 cm large differences occurred, the OPEN station being much warmer.

m. Cumulated temperatures (using bases of 32 F and 43 F), were far larger in the soil at the OPEN station than at the WOODS station.

n. The forest slightly lowered daily maximum and slightly raised daily minimum air temperatures.

o. The forest slightly lowered mean air temperatures for the period.

p. Mean hourly air temperatures (7.5 cm to 400 cm) in the forest were usually only 2 F deg. lower than those at identical levels in the open. They were never more than 5.5 F deg. lower and were infrequently the same. This is true even at levels close to the ground, that is, at 7.5 cm.

q. Daily mean air temperatures (7.5 cm to 400 cm) were generally only 2 F deg. to 4 F deg. lower, and were never more than 6 F deg. lower, in the forest when compared with the same heights in the open.

r. Largest variations in temperature occurred at levels having the highest mean daily temperatures, at -2.5 cm and 0 cm at the OPEN station, and in the air, from 7.5 cm to 400 cm, at the WOODS station.

s. Frequencies of hourly air temperatures revealed little differences between the stations. There was a very slight tendency toward a greater frequency of lower temperatures in the forest and of higher temperatures in the open.

t. Durations of air temperatures were similar, and in some instances, identical, at the stations.

u. The forest had a greater number of degree days than did the open. Differences varied from 62 degree days at 7.5 cm to 27 and 28 degree days at 200 cm and 400 cm, respectively.

v. The occurrence of clouds and rain had a pronounced effect in minimizing air, surface, and near-surface temperature differences between the stations, but did not affect temperatures deeper in the soil, that is, at -30 cm and -60 cm. Clouds and/or rain decreased the daily range of temperatures in a manner similar to that of the vegetation at the WOODS station. These effects of weather, however, were much more pronounced at the OPEN than at the WOODS station.

w. Large differences occurred in globe temperatures between the stations. Due to the shielding effects of the spruce trees, mean hourly globe temperatures were 5 F deg. to 10 F deg. lower, and daily mean globe temperatures were about 6 F deg. lower at the WOODS station than at the OPEN station.

x. It is surmised that the effects of stronger winds at 200 cm at the OPEN station tended to lower globe temperatures at that station, and, therefore, lessen the differences between the stations.

y. In the forest, mean hourly globe temperatures were 2.8 F deg. to 8.8 F deg. higher than 200 cm air temperatures during the hours of greatest insolation (0900 to 1600), and were usually slightly lower, 0.2 F deg. to 1.8 F deg., at night (2100 to 0230).

z. In the open, daytime differences between mean hourly globe and 200 cm air temperatures were from 9 F deg. to 15 F deg., while at night, as in the forest, the globe temperature was slightly less, 0.7 F deg. to 1.4 F deg., than air temperatures.

aa. Daily mean globe temperatures closely followed the curves for daily mean solar radiation at both stations. In the forest, a maximum difference of about 4 F deg. was observed between globe and 200 cm daily mean temperatures; in the open, the maximum difference was nearly 10 F deg.

bb. During times of precipitation, globe temperatures at the OPEN station were cooled below the air temperatures due to evaporative cooling, which, in turn, was increased by the stronger winds at that station. At the WOODS station, during rainy periods, the globe was protected from the rain by the trees, winds were not as strong, and globe temperatures and air temperatures were nearly identical, the former being only a little higher.

In winter (December), only small amounts of solar radiation were received and the snow cover played a dominant role in determining the temperatures at the stations.

A. MEAN HOURLY SOIL TEMPERATURES WERE 1 F DEG. TO 4 F DEG. LOWER IN THE FOREST, ALTHOUGH THE SNOW COVER WAS DEEPER, BECAUSE THE SOIL IN THE FOREST WAS MUCH COLDER AT THE START OF WINTER. DIFFERENCES IN MEAN HOURLY SOIL TEMPERATURES BETWEEN THE STATIONS DECREASED DURING THE MONTH, HOWEVER, BECAUSE THE LOSS OF HEAT FROM THE GROUND WAS GREATER IN THE OPEN AND COOLING PROGRESSED MORE RAPIDLY.

B. VARIATIONS IN MEAN HOURLY SOIL TEMPERATURES WERE SMALL AT THE STATIONS DUE TO THE INSULATING PROPERTY AND DAMPING EFFECTS OF THE SNOW COVER.

C. MEAN HOURLY TEMPERATURES OF THE GROUND SURFACE (0 CM) AND IN THE SNOW (7.5 CM AND 25 CM) WERE 5 F DEG. TO 8 F DEG. HIGHER IN THE WOODS, MAINLY DUE TO THE GREATER INSULATION PROVIDED BY THE DEEPER SNOW, BUT ALSO PARTLY DUE TO THE REDUCTION BY THE VEGETATION AT THE WOODS STATION OF THE NET NOCTURNAL RADIATIONAL LOSS.

D. MEAN HOURLY AIR TEMPERATURES WERE SIMILAR AT THE STATIONS, USUALLY BEING 1 F DEG. TO 2 F DEG. COLDER IN THE OPEN.

E. GREATEST TEMPERATURE DIFFERENCES BETWEEN ADJACENT THERMOCOUPLE HEIGHTS OCCURRED IN THE SNOW AT BOTH STATIONS:

(1) IN THE FOREST, WHERE THE SNOW WAS 43 CM DEEP, THE DECREASE IN TEMPERATURE FROM THE GROUND SURFACE TO THE SNOW SURFACE WAS GENERALLY GREATER THAN 20 F DEG.

(2) IN THE OPEN, THE SNOW WAS ONLY 22 CM DEEP, THE LOSS OF HEAT FROM THE GROUND SURFACE WAS GREATER, AND TEMPERATURE DIFFERENCES BETWEEN THE GROUND AND SNOW SURFACES WERE NOT AS LARGE AS THOSE IN THE FOREST, BEING APPROXIMATELY 10 F DEG. TO 15 F DEG.

F. FLUCTUATIONS OF DAILY MEAN TEMPERATURES AT -30 CM AND -60 CM WERE SMALL AT BOTH STATIONS, BUT WERE LESS IN THE FOREST THAN IN THE OPEN, DUE TO THE DEEPER SNOW.

G. FLUCTUATIONS OF NEAR-SURFACE SOIL TEMPERATURES (-15 CM, -2.5 CM AND 0 CM) WERE MORE PRONOUNCED IN THE OPEN THAN IN THE FOREST. IN THE OPEN, A TEMPERATURE CHANGE OF 40 F DEG. OCCURRED WITHIN EIGHT DAYS, BUT IN THE WOODS THE LARGEST TEMPERATURE RANGE DURING THE ENTIRE MONTH WAS ONLY 17 F DEG.

H. THE LOWEST DAILY MEAN TEMPERATURE MEASURED AT THE GROUND SURFACE AT THE OPEN STATION WAS -15.4 F, WHILE AT THE WOODS STATION IT WAS ONLY 5.5 F, REFLECTING THE PROTECTION GIVEN BY A DEEP SNOW COVER.

I. DAILY MEAN AIR TEMPERATURES AT THE STATIONS WERE WITHIN 1 F DEG.

to 2 F deg. most of the time, and followed the same fluctuations and patterns in their day-to-day variations.

j. Largest differences in daily mean temperatures between adjacent thermocouple heights at each station occurred in the snow. This was also true of mean hourly temperatures.

(1) In the forest, a maximum difference of 32.5 F deg. occurred between daily mean temperatures of the 25 cm and 7.5 cm heights, the higher thermocouple level being the colder.

(2) In the open, the maximum difference, 35.8 F deg., was observed between the snow surface (22.1 cm) and 7.5 cm, the higher level again being the colder.

k. Daily mean soil temperature differences between adjacent heights were quite small at each station, less than 5 F deg.

l. Daily mean air temperature differences between adjacent heights were insignificant at each station, being less than 1 F deg. the majority of the time.

m. Inversions in air temperatures were not apparent, even during ideal times of extreme cold, clear skies, calm winds, and long nights. During such periods, nighttime air temperatures in the open were generally 5 F deg. to 10 F deg. lower than those of the forest, probably due to the larger net nocturnal radiation loss in the open.

n. At both stations, greatest variability of daily mean temperatures occurred in the air, and the least variability occurred in the soil.

o. Low air and snow temperatures were more frequent at the OPEN station than at the WOODS station, due to the greater nocturnal radiative cooling, which produced a larger net radiational loss, and also due to the thinner snow cover in the open.

p. Cumulated temperatures at the snow surface were much larger at the OPEN station than at the WOODS station, but in the air and snow, cumulated temperatures were considerably less in the open than in the forest.

q. Differences in the number of degree days between the stations, at comparable thermocouple heights in the air, were insignificant.

r. In December, as in June, weather, such as strong winds, clouds, and precipitation, tended to reduce the differences in temperatures between the stations, particularly those of the air and snow. In contrast

TO SUMMER (JUNE), HOWEVER, THE OCCURRENCE OF THESE CLIMATIC ELEMENTS SERVED TO SUBSTANTIALLY RAISE TEMPERATURES RATHER THAN LOWER THEM.

S. DIFFERENCES IN GLOBE TEMPERATURES MEASURED AT THE STATIONS WERE INSIGNIFICANTLY SMALL, BEING LESS THAN 1 F DEG. IT IS ASSUMED THAT THE SOLAR RADIATION (INSOLATION) RECEIVED AT THE OPEN STATION, WHICH SERVED TO HEAT THE GLOBE AND RAISE THE TEMPERATURES, WAS COMPENSATED FOR BY THE COOLING EFFECT OF STRONGER WINDS AT THIS STATION.

T. MEAN HOURLY AND MEAN MONTHLY GLOBE TEMPERATURES, BASED ON OBSERVATIONS MADE AT 0815, 1315 AND 1630 AST, WERE ABOUT 5 F DEG. HIGHER THAN 200 CM AIR TEMPERATURES IN THE FOREST AND ABOUT 6 F DEG. TO 7 F DEG. HIGHER IN THE OPEN.

4. WIND

THE MODIFYING INFLUENCE OF THE FOREST (SPRUCE TREES) ON WIND, ESPECIALLY WIND SPEEDS, WAS QUITE PRONOUNCED. THE EFFECT OF THE SPRUCE TREES IN REDUCING WIND SPEEDS WAS PARTICULARLY NOTICEABLE DURING TIMES OF MODERATELY STRONG WINDS, FOR EXAMPLE, WHEN WIND SPEEDS WERE 15 TO 20 MPH.

IN SUMMER, AN INCREASE IN WIND SPEED MAY BE EXPECTED TO INCREASE EVAPORATION FROM THE GROUND SURFACE AND TO ALSO INCREASE TRANSPIRATION FROM PLANTS.

A. IN BOTH JUNE AND DECEMBER, MEAN HOURLY WIND SPEEDS AND DAILY MEAN WIND SPEEDS WERE SUBSTANTIALLY LESS IN THE FOREST THAN IN THE OPEN, USUALLY BEING ONLY A THIRD AS STRONG AS THOSE IN THE OPEN.

B. THE STRONGEST WINDS MEASURED IN THE FOREST WERE ONLY 7 TO 8 MPH, BUT IN THE OPEN, WIND SPEEDS OF 14 TO 16 MPH WERE RECORDED.

C. AT THE OPEN STATION, STRONGEST WINDS OCCURRED AT 200 CM, BUT AT THE WOODS STATION STRONGEST WINDS OCCURRED MOST FREQUENTLY AT 30 CM. THIS WAS CAUSED BY ANIMAL TRAILS AT THE GROUND SURFACE (IN WINTER, IN THE SNOW) AS WELL AS BY THE ABSENCE OF FOLIAGE AND FEWER BRANCHES NEAR THE GROUND, THUS ALLOWING FREER CIRCULATION OF AIR NEAR THE GROUND.

D. A DIURNAL VARIATION OF WIND SPEED WAS NOTED AT BOTH THE 200 CM AND 30 CM LEVELS AT BOTH STATIONS, MAXIMUM WIND SPEEDS GENERALLY OCCURRING NEAR MIDDAY. THIS VARIATION WAS BETTER DEVELOPED IN THE OPEN THAN IN THE FOREST, AND IN JUNE RATHER THAN IN DECEMBER.

E. ALTHOUGH A GREATER PERCENTAGE OF CALMS OCCURRED IN THE FOREST, DIFFERENCES BETWEEN THE STATIONS IN THE PERCENTAGE OF HOURS WITH CALMS WERE MUCH LARGER AT THE 200 CM LEVEL THAN AT THE 30 CM LEVEL. IN DECEMBER, FOR EXAMPLE, CALMS WERE MORE THAN TWICE AS FREQUENT AT 200 CM IN

THE FOREST (74 PERCENT COMPARED WITH 35 PERCENT) WHEN COMPARED WITH 200 CM IN THE OPEN. AT 30 CM, HOWEVER, CALMS OCCURRED ABOUT 54 PERCENT OF THE TIME IN THE FOREST COMPARED TO 48 PERCENT IN THE OPEN.

F. GREATEST DIFFERENCES BETWEEN THE STATIONS, AT BOTH THE 200 CM AND 30 CM LEVELS, OCCURRED DURING PERIODS OF STRONGER WINDS. FROM MEASUREMENTS MADE DURING THIS STUDY, DURING SIMILAR STUDIES AT FORT CHURCHILL, CANADA, AND FROM PERSONAL OBSERVATIONS, IT IS BELIEVED THAT WINDS STRONGER THAN 10 MPH WILL OCCUR VERY INFREQUENTLY IN THE SUBARCTIC TAIGA, ALTHOUGH WINDS AT EXPOSED LOCATIONS IN THE OPEN MAY REACH SPEEDS IN EXCESS OF 40 OR 50 MPH.

G. IN BOTH JUNE AND DECEMBER, THE RUN OF THE WIND AND RESULTANT RUN OF THE WIND, WERE SMALLER FOR THE WOODS STATION THAN FOR THE OPEN STATION AT BOTH 200 CM AND 30 CM, BUT THE DIFFERENCES BETWEEN THE 30 CM LEVELS WERE SMALL COMPARED WITH THOSE FOR THE 200 CM LEVELS.

H. THE STEADINESS RATIO WAS MUCH GREATER AT EACH LEVEL AT THE WOODS STATION (EXCEPT IN JUNE, AT 200 CM, WHEN CALMS WERE FREQUENT) THAN AT THE OPEN STATION. THE EXTREMELY HIGH VALUES FOR DECEMBER, PARTICULARLY AT THE WOODS STATION (96 PERCENT FOR 200 CM AND 82 PERCENT FOR 30 CM), WERE ESPECIALLY SIGNIFICANT.

5. <u>WIND AND TEMPERATURE</u>

A. IN JUNE, THE WIND-TEMPERATURE COMBINATION WAS NOT IMPORTANT, BUT IN DECEMBER, THE FOREST PROVIDED PROTECTION FROM THE COMBINED EFFECTS OF WIND AND LOW TEMPERATURES. IN THE OPEN, FOR EXAMPLE, WINDS OF 4 TO 7 MPH OCCURRED 34 TIMES AT 200 CM AND 42 TIMES AT 30 CM IN COMBINATION WITH TEMPERATURES OF -30 F TO -34 F, BUT IN THE FOREST THIS COMBINATION DID NOT OCCUR AT EITHER HEIGHT. INDEED, IN THE FOREST, WIND SPEEDS GREATER THAN 3 MPH OCCURRED ONLY 26 TIMES AT 200 CM AND 32 TIMES AT 30 CM DURING THE MONTH IN COMBINATION WITH TEMPERATURES OF -10 F, OR LOWER.

B. IN DECEMBER, WINDCHILL WAS MUCH GREATER, AT BOTH 200 CM AND 30 CM, IN THE OPEN WHEN COMPARED TO THE FOREST. THE FOREST, THEREFORE, WILL SERVE TO EFFECTIVELY REDUCE HEAT LOSS FROM ANY RELATIVELY WARM HEAT SOURCE DURING WINDY PERIODS WHEN TEMPERATURES ARE LOW.

C. IN DECEMBER, AT 200 CM AND 30 CM IN THE FOREST, AND AT 30 CM IN THE OPEN, WINDS WERE USUALLY CALM, OR NEAR-CALM, WHEN TEMPERATURES WERE BELOW -20 F. AT 200 CM IN THE OPEN, HOWEVER, WINDS OF 1 TO 7 MPH WERE AS FREQUENT AS, OR MORE FREQUENT THAN, CALMS DURING TIMES OF LOW TEMPERATURES.

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NATICK, MASSACHUSETTS
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APPENDIX

MICROCLIMATIC DATA FOR JUNE 1956 AND DECEMBER 1956

HOURLY TOTAL, MEAN HOURLY AND DAILY TOTAL GLOBAL SOLAR RADIATION (LANGLEYS)
AND DIFFERENCES BETWEEN WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
(June 12 - 30, 1956)

Hourly *

Hour	Mean		Difference	
	WOODS	OPEN	OPEN-WOODS	
01	0	0	0	0
02	0	0	0	0
03	0	0.4	0.4	0
04	0.5	3.4	2.9	15
05	1.7	6.9	5.2	25
06	3.9	14.3	10.4	27
07	5.9	21.5	15.6	27
08	8.9	27.9	19.0	32
09	10.7	35.7	25.0	30
10	12.1	40.8	28.7	30
11	19.6	38.8	19.2	50
12	26.7	45.2	18.5	59
13	23.4	43.7	20.3	54
14	12.0	44.3	32.3	27
15	10.8	35.4	24.6	31
16	15.4	31.8	16.4	48
17	6.4	24.2	17.8	26
18	3.6	19.5	15.9	18
19	2.2	11.1	8.9	20
20	0.9	6.3	5.4	14
21	0.1	2.1	2.0	5
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0

* 25th, 29th and 30th omitted.

Daily

Day	Total		Difference	
	WOODS	OPEN	OPEN-WOODS	
12	284	723	439	39
13	182	572	390	32
14	195	559	364	35
15	230	661	431	35
16	205	511	306	40
17	170	530	360	32
18	211	562	351	38
19	69	221	152	31
20	119	287	168	41
21	19	79	60	24
22	129	319	190	40
23	185	500	315	37
24	179	474	295	38
25	225	m	m	m
26	193	527	334	30
27	111	294	183	38
28	101	265	164	38
29	m	586	m	m
30	m	473	m	m

m = missing data.

TABLE A-1.

MEAN HOURLY GROUND, AIR AND GLOBE TEMPERATURES (°F)
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
June 12 - 30, 1956

HOUR OF THE DAY

Station and Height	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Mean for Period
WOODS, -60 cm	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
OPEN, -60 cm	47.6	47.7	47.6	47.4	47.3	47.2	47.0	47.0	46.6	46.7	46.9	47.2	47.5	48.0	48.4	48.2	48.1	47.9	47.8	47.7	47.8	47.9	47.8	47.9	47.5
WOODS, -30 cm	33.1	33.1	32.9	32.9	32.9	32.9	33.0	33.1	33.0	33.[illegible]	33.3	33.3	33.3	33.3	33.3	33.3	33.2	33.[illegible]	33.3	33.5	33.5	33.5	33.5	33.5	33.2
OPEN, -30 cm	53.8	53.6	53.4	53.2	52.8	52.6	52.2	52.2	51.8	[illegible]	52.2	52.2	52.5	52.7	53.1	53.3	53.3	53.6	53.7	53.9	54.1	54.1	54.1	54.1	53.1
WOODS, -15 cm	37.3	36.8	36.7	36.4	36.4	36.5	36.7	36.9	37.2	37.4	37.6	38.0	38.1	38.2	[illegible]	38.4	38.3	38.3	38.3	38.2	37.9	37.7	37.7	37.6	[illegible]
OPEN, -15 cm	55.0	54.2	53.7	53.0	52.7	52.7	52.8	53.5	53.9	54.6	55.7	56.5	57.4	58.1	58.4	58.7	59.1	58.[illegible]	58.6	58.0	57.8	57.1	56.4	55.6	55.9
WOODS, -2.5 cm	41.5	40.8	40.5	40.5	40.8	41.5	42.7	44.0	45.0	45.8	46.9	47.9	48.0	47.8	47.8	47.5	46.8	46.[illegible]	46.[illegible]	45.9	45.1	44.2	43.2	42.6	44.5
OPEN, -2.5 cm	48.7	48.2	48.4	49.9	52.6	56.5	60.6	63.6	67.5	68.1	69.6	71.4	69.6	66.4	65.1	64.8	62.1	60.[illegible]	58.3	56.6	54.4	52.6	51.3	50.1	59.1
WOODS, 0 cm	44.2	43.4	43.0	43.4	44.4	45.5	48.9	51.1	53.6	57.3	59.4	57.9	57.9	56.3	55.6	55.3	54.5	53.[illegible]	52.5	[illegible]	49.7	48.2	46.8	45.6	50.7
OPEN, 0 cm	50.1	49.3	49.2	49.8	51.1	53.6	56.6	59.3	61.9	60.9	64.7	68.3	68.6	68.2	66.8	66.2	63.4	61.[illegible]	59.9	57.7	55.1	54.3	52.9	51.7	56.4
WOODS, 7.5 cm	43.2	42.5	42.6	44.2	45.9	48.5	51.1	52.7	55.2	57.3	56.5	58.0	58.4	57.0	56.4	57.1	55.5	54.[illegible]	53.5	51.5	49.3	47.3	45.6	44.7	51.1
OPEN, 7.5 cm	45.2	44.6	45.3	47.2	49.6	52.4	55.1	56.8	59.1	60.2	61.5	63.0	62.7	61.8	61.5	61.9	60.2	59.[illegible]	57.1	54.9	51.5	49.3	47.9	46.7	54.8
WOODS, 25 cm	43.3	42.6	42.7	44.2	46.1	48.6	51.1	52.7	54.8	56.6	56.2	57.7	58.4	57.1	56.6	57.1	55.7	55.[illegible]	53.7	51.9	49.4	47.5	45.8	44.6	51.1
OPEN, 25 cm	45.3	44.8	45.1	47.2	49.2	51.8	54.3	56.2	58.1	59.1	60.8	62.1	62.3	61.3	61.1	61.3	60.3	59.[illegible]	57.5	55.2	51.7	49.8	48.2	46.6	54.5
WOODS, 50 cm	43.3	42.7	42.7	44.3	46.2	48.8	51.0	53.1	55.5	57.[illegible]	56.6	58.0	58.9	57.3	56.7	57.5	56.0	55.[illegible]	54.0	52.1	49.6	47.8	46.0	45.0	51.4
OPEN, 50 cm	45.2	44.6	45.2	47.1	48.9	51.5	53.6	55.3	57.5	58.3	60.2	62.2	61.7	61.6	61.3	61.9	60.7	60.[illegible]	57.8	55.5	52.1	49.9	48.3	46.7	54.5
WOODS, 100 cm	43.5	42.9	41.[illegible]	44.6	46.5	48.9	51.4	52.9	55.2	56.9	56.4	57.9	59.1	57.3	56.7	57.6	56.3	55.4	54.2	52.3	47.9	47.9	46.2	45.[illegible]	51.5
OPEN, 100 cm	45.6	44.9	45.3	47.1	48.5	50.5	52.2	53.7	54.9	56.0	57.8	59.3	59.7	59.6	59.6	59.9	59.1	58.[illegible]	57.1	55.0	52.0	50.1	48.6	46.9	53.4
WOODS, 200 cm	43.7	43.1	42.9	44.8	46.7	49.2	51.6	52.9	55.3	56.2	56.3	58.0	59.6	57.5	56.9	57.7	56.4	55.[illegible]	54.5	52.4	50.0	47.8	46.1	45.[illegible]	51.6
OPEN, 200 cm	45.5	44.9	45.2	46.9	48.3	50.4	51.8	53.3	54.8	55.6	57.4	59.1	59.4	58.6	59.4	59.5	59.4	58.[illegible]	56.9	55.3	52.2	50.1	48.6	47.0	53.3
WOODS, 400 cm	43.7	43.1	43.4	44.2	47.2	49.6	52.2	53.5	54.9	55.9	56.6	58.3	59.7	57.7	57.2	58.1	56.6	56.[illegible]	51.7	52.4	49.9	47.8	46.1	45.1	51.8
OPEN, 400 cm	45.7	44.8	45.2	46.7	48.3	50.6	52.2	53.6	55.3	56.[illegible]	58.2	60.1	59.8	59.6	59.5	60.4	59.2	58.5	57.[illegible]	55.[illegible]	52.6	50.2	48.3	47.1	53.5
WOODS, GT*	43.4	42.8	43.3	45.5	48.0	51.0	53.7	55.6	58.1	59.7	59.3	63.0	68.4	61.1	63.6	61.6	58.5	56.7	55.1	52.7	49.8	48.0	46.0	43.3	53.5
OPEN, GT	44.4	44.2	45.9	49.6	53.7	58.3	62.6	65.3	69.0	69.2	70.4	72.4	73.2	70.4	68.3	67.7	65.9	64.2	60.0	57.5	52.6	49.3	47.3	46.0	59.5

*GT = Globe thermometer

TABLE A-2

DAILY MEAN GROUND, AIR AND GLOBE TEMPERATURES (°F)
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
June 12 - 30, 1956

DAY OF MONTH

Station and Height	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
WOODS, -60 cm	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
OPEN, -60 cm	45.3	45.7	45.9	46.5	49.3	48.9	-	-	49.0	48.3	47.3	47.0	46.8	47.1	47.0	47.5	48.0	48.2	49.1
WOODS, -30 cm	31.3	31.9	-	32.2	32.3	32.2	33.0	-	32.2	32.7	33.5	33.1	33.2	33.5	33.8	34.4	35.0	35.5	36.3
OPEN, -30 cm	54.3	54.6	53.8	54.7	56.1	55.4	-	-	53.5	49.7	48.7	49.8	50.8	51.2	51.7	52.5	53.2	54.3	56.2
WOODS, -15 cm	36.6	36.1	-	36.8	37.3	36.9	37.6	-	36.8	36.5	37.8	36.5	36.6	36.9	37.6	38.4	39.5	40.3	41.1
OPEN, -15 cm	59.0	58.7	57.1	59.8	58.9	57.8	-	-	54.7	49.0	49.9	52.1	52.6	53.6	54.9	55.2	56.3	59.6	61.0
WOODS, -2.5 cm	45.3	43.4	-	45.3	45.0	44.9	46.3	-	43.9	39.8	40.8	41.3	42.3	42.2	44.5	46.1	48.1	50.0	49.8
OPEN, -2.5 cm	63.7	63.6	61.7	67.3	66.0	59.5	-	-	55.5	46.5	52.0	54.4	54.3	55.1	59.5	58.0	59.7	64.9	64.4
WOODS, 0 cm (surf)	51.8	50.8	-	52.8	51.8	51.4	53.7	-	49.7	42.0	45.8	46.5	47.3	46.8	51.5	52.7	55.4	57.8	56.7
OPEN, 0 cm (surf)	63.2	60.5	58.9	63.3	60.5	60.5	-	-	56.3	46.7	52.4	55.3	54.9	56.3	58.8	57.8	59.5	65.3	65.3
WOODS, 7.5 cm	53.9	51.4	-	55.6	52.3	52.0	54.3	-	48.2	41.1	44.5	44.4	46.8	46.8	53.0	53.4	56.0	60.8	56.5
OPEN, 7.5 cm	59.0	54.8	56.4	59.5	56.2	58.0	-	-	51.5	42.8	47.5	48.5	50.6	51.4	56.7	55.6	58.1	65.1	60.9
WOODS, 25 cm	53.8	51.3	-	55.6	52.2	52.3	54.3	-	48.2	41.2	44.4	44.3	46.8	46.8	53.2	53.5	56.2	61.0	56.5
OPEN, 25 cm	56.1	54.5	56.0	59.0	55.8	57.1	-	-	51.0	42.5	47.3	48.0	50.0	51.3	56.9	56.0	58.6	65.9	60.6
WOODS, 50 cm	54.2	51.7	-	56.0	52.4	52.4	55.0	-	48.2	41.1	44.6	44.4	47.2	47.1	53.6	53.6	56.4	61.5	56.9
OPEN, 50 cm	58.8	54.0	55.9	58.4	55.1	57.3	-	-	50.8	42.4	47.0	47.7	50.0	51.3	56.9	56.2	58.7	66.3	60.7
WOODS, 100 cm	54.2	51.7	-	56.0	52.2	53.0	55.0	-	48.3	41.1	44.6	44.6	47.3	37.2	53.8	53.7	[illegible]	61.7	56.9
OPEN, 100 cm	56.5	52.8	54.5	57.1	[illegible]	55.9	-	-	50.2	42.4	46.3	46.5	49.0	49.8	55.8	55.7	58.4	64.7	59.0
WOODS, 200 cm	53.7	52.1	-	56.2	[illegible]	53.2	55.3	-	48.2	41.1	44.6	44.5	47.5	47.3	54.1	53.8	56.5	62.0	57.0
OPEN, 200 cm	56.5	52.8	54.0	56.7	[illegible]	55.7	-	-	50.3	42.4	46.2	46.8	48.6	49.4	55.6	55.6	[illegible]	64.3	59.0
WOODS, 400 cm	54.5	52.0	-	56.2	52.5	53.5	55.7	-	48.4	40.9	44.6	44.8	47.5	47.8	54.4	54.2	56.6	62.5	57.3
OPEN, 400 cm	57.8	53.1	54.7	56.7	54.1	56.5	-	-	50.2	42.1	46.2	46.5	48.8	49.8	55.9	55.9	58.4	65.1	59.5
WOODS, GT, 200 cm*	58.0	54.4	-	59.1	54.9	55.4	58.6	-	49.2	41.2	45.9	46.7	48.2	49.9	56.4	55.2	57.6	64.3	58.8
OPEN, GT, 200 cm	65.9	61.8	62.5	66.2	68.2	62.8	-	-	52.8	42.2	50.1	52.7	55.3	56.4	63.3	59.6	61.8	73.3	66.2

*GT = globe thermometer

TABLE A-3

TWENTY-FOUR HOUR PRECIPITATION AMOUNTS (INCHES)*
CIVIL AERONAUTICS ADMINISTRATION WEATHER STATION AND WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA

June 12 - 30, 1956

Day of Month

	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
CAA STATION	--	T	0.05	—	—	0.38	T	0.11	0.91	1.13	0.79	0.35	T	T	—	—	T	T	0.08	3.80
WOODS MICROCLM STATION	—	—	—	—		0.93 (total for June 16–18)		—	0.30	—	2.10		0.40 (total for June 23–25)		—	—	T	—	m	4.65
OPEN MICROCLM STATION	—	—	—	—		0.90 (total for June 16–18)		—	0.75	—	2.50		0.50 (total for June 23–25)		—	—	T	—	m	3.72

* 24-hour period ending 0900 AST each day at microclimatic stations, and at 0830 hours AST at the CAA Station. Dash = no rain, m = data missing.

TABLE A-4

TWENTY-FOUR HOUR PRECIPITATION AMOUNTS (INCHES)*
CIVIL AERONAUTICS ADMINISTRATION WEATHER STATION AND WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
December 1956

Day of Month

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
CAA STATION	T	T			1.6	1.0	T												0.2	0.7										0.7	0.1	4.3
WOODS MICROCLIM STATION					T	T	T			4.0							T			T	T	T						T				4.0
OPEN MICROCLIM STATION					T	T	T			4.5							T			T	T	T						T				4.5

*24-hour period ending 0900 h AST each day at microclimatic stations, and at 0830 h AST at the CAA station. Measurements were not made on weekends or holidays at the microclimatic stations. [illegible] given are inches of snowfall. For water equivalent, approximately 12 inches of snow [illegible] inch of water.

TABLE A-5

MEAN HOURLY GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
December 1956

HOUR OF DAY

Station and Height	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Mean
WOODS, -60 cm	22.5	22.1	22.4	22.1	22.1	22.1	22.1	22.0	22.0	21.9	21.9	21.9	22.0	22.0	22.0	22.0	22.0	21.9	22.0	21.9	21.9	21.1	22.3	[illegible]	22.0
OPEN, -60 cm	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.2	26.3	26.0	25.7	25.8	25.8	25.8	25.8	25.8	25.9	25.8	25.8	25.9	25.9	25.9	25.9	25.9	26.0
WOODS, -30 cm	19.2	18.9	18.8	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.6	18.7	18.7	18.7	18.8	18.8	18.9	18.9	18.9	18.8	18.8	18.8	18.8	18.8	18.8
OPEN, -30 cm	20.3	20.2	20.2	20.1	20.1	20.0	20.0	20.1	20.2	20.1	19.8	19.8	19.8	19.7	19.7	19.7	19.7	19.7	19.8	19.7	19.7	19.7	19.6	19.7	19.8
WOODS, -15 cm	16.1	15.7	15.7	15.7	15.7	15.6	15.6	15.6	15.5	15.7	15.5	15.4	15.5	15.5	15.5	15.6	15.7	15.6	15.6	15.5	15.5	15.5	15.5	15.5	15.6
OPEN, -15 cm	16.7	16.7	16.4	16.6	16.5	16.6	16.6	16.5	16.7	16.6	16.3	16.2	16.1	16.3	15.9	15.9	15.8	16.0	15.9	15.9	15.9	15.9	15.9	16.0	16.3
WOODS, -2.5 cm	11.3	11.5	10.9	10.7	10.8	10.6	10.6	10.6	10.7	10.8	10.6	10.7	10.9	10.9	10.9	11.0	11.1	11.0	10.8	10.9	10.8	10.8	10.8	10.8	10.8
OPEN, -2.5 cm	14.5	14.5	14.4	14.4	14.4	14.4	14.4	14.4	14.6	14.4	14.3	14.2	14.1	14.0	13.9	13.9	13.9	13.9	13.9	14.0	14.0	14.0	14.0	13.9	14.2
WOODS, 0 cm (surf)	12.3	12.0	12.1	12.1	12.0	11.9	12.0	11.9	11.8	11.8	11.9	11.9	12.0	12.0	12.0	12.0	12.0	12.0	11.9	11.8	11.8	11.8	11.8	11.8	11.9
OPEN, 0 cm (surf)	5.7	5.8	5.8	5.8	5.8	5.7	5.8	5.9	5.9	5.7	5.4	5.5	5.5	5.4	5.5	5.4	5.3	5.3	5.3	5.4	5.3	5.2	5.2	4.9	5.5
WOODS, 7.5 cm	0.0	0.2	0.1	0.1	0.1	0.2	0.2	0.1	-0.1	-0.2	-0.2	0.2	0.3	0.6	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.1	0.1	0.3	0.2
OPEN, 7.5 cm	-6.8	-7.0	-7.4	-7.5	-7.6	-7.7	-8.2	-7.9	-8.1	-8.3	-7.7	-7.4	-7.1	-6.6	-6.9	-6.5	-6.7	-6.6	-6.9	-6.5	-6.3	-6.5	-6.8	-6.4	-7.1
WOODS, 25 cm	-17.7	-17.9	-18.3	-18.4	-17.9	-17.8	-17.5	-17.8	-18.0	-17.9	-16.6	-15.9	-15.4	-15.5	-16.0	-16.2	-16.1	-16.5	-16.6	-16.9	-17.3	-17.7	-17.7	-17.5	-17.1
OPEN, 25 cm	-25.1	-25.2	-26.1	-25.8	-25.0	-24.7	-24.5	-25.3	-25.3	-24.5	-21.2	-21.5	-21.8	-22.8	-23.6	-24.1	-23.7	-24.6	-24.7	-24.9	-25.1	-26.0	-26.2	-25.3	-24.5
WOODS, 50 cm	-22.4	-22.7	-23.2	-23.1	-22.4	-22.5	-22.2	-22.6	-22.8	-22.4	-20.5	-19.6	-19.7	-19.8	-20.4	-20.6	-20.8	-21.6	-21.8	-22.0	-22.1	-22.9	-22.9	-22.1	-21.8
OPEN, 50 cm	-25.1	-25.1	-25.9	-25.6	-25.0	-24.6	-24.8	-25.0	-25.1	-24.3	-21.0	-21.1	-21.4	-22.5	-23.3	-23.7	-23.3	-24.3	-24.4	-24.6	-24.9	-25.8	-26.0	-25.3	-24.2
WOODS, snow surf.	-20.3	-20.8	-20.7	-20.7	-20.1	-20.0	-20.0	-20.5	-20.5	-20.1	-18.4	-17.6	-17.4	-18.1	-18.5	-19.3	-19.3	-19.4	-19.7	-19.7	-19.8	-20.7	-20.6	-20.0	-19.6
OPEN, snow surf.	-20.9	-21.1	-21.9	-21.5	-20.6	-17.9	-19.6	-19.8	-20.4	-19.7	-18.8	-18.4	-18.3	-19.3	-20.2	-20.3	-20.2	-21.0	-21.2	-20.6	-21.2	-22.0	-21.7	-21.1	-20.4
WOODS, 100 cm	-22.5	-22.9	-23.4	-23.3	-22.6	-22.9	-22.5	-22.6	-22.9	-22.5	-20.7	-19.8	-19.5	-20.1	-20.8	-21.3	-21.2	-21.8	-22.0	-22.3	-22.4	-23.1	-23.0	-22.6	-21.9
OPEN, 100 cm	-24.5	-24.6	-25.3	-25.3	-24.5	-24.1	-23.9	-24.3	-24.7	-23.8	-20.9	-20.6	-21.0	-21.7	-22.2	-22.7	-22.8	-23.6	-23.7	-24.2	-24.4	-25.1	-25.4	-24.5	-23.6
WOODS, 200 cm	-22.8	-22.9	-23.4	-23.3	-22.5	-22.7	-22.7	-22.7	-23.1	-22.6	-20.7	-19.8	-19.4	-20.0	-20.7	-21.0	-21.0	-21.8	-22.0	-22.3	-22.4	-23.1	-23.0	-22.6	-22.0
OPEN, 200 cm	-24.4	-24.4	-25.4	-25.1	-24.5	-24.1	-23.9	-24.0	-24.4	-23.7	-20.7	-20.3	-20.5	-21.4	-22.3	-22.6	-22.6	-23.5	-23.8	-23.9	-24.2	-25.1	-25.2	-24.0	-23.5
WOODS, 400 cm	-22.7	-23.0	-23.7	-23.4	-22.6	-22.9	-22.7	-22.9	-23.1	-22.5	-20.7	-19.9	-19.4	-20.1	-20.9	-21.4	-21.2	-22.0	-22.2	-22.6	-22.8	-23.4	-23.3	-22.7	22.2
OPEN, 400 cm	-24.4	-24.4	-25.1	-25.0	-24.3	-24.0	-23.8	-24.1	-24.4	-23.6	-20.5	-20.1	-20.5	-21.4	-22.3	-22.6	-22.8	-23.8	-23.7	-23.9	-24.0	-24.9	-25.2	-24.3	-23.4

TABLE A-6

DAILY MEAN GROUND AND AIR TEMPERATURES
WOODS AND OPEN MICROCLIMATIC STATIONS
BIG DELTA, ALASKA
December, 1956

DAY OF MONTH

Station and Height	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
WOODS, -40 cm	28.7	28.0	28.0	28.0	28.0	28.0	27.8	27.0	26.0	25.5	24.0	23.1	22.0	21.3	20.3	20.0	20.0	19.8	19.3	19.6	18.5	18.3	18.0	18.4	17.1	16.3	16.0	17.0	18.3	15.5	22.0
OPEN, -40 cm	33.0	32.8	32.0	32.0	32.0	32.0	32.0	32.0	32.0	31.4	m	m	30.0	30.0	29.4	28.7	27.5	26.8	m	m	21.4	22.4	20.6	15.3	18.5	17.4	16.4	16.3	16.0	16.9	18.0
WOODS, -30 cm	28.7	28.0	27.3	26.0	25.0	25.3	24.8	23.1	21.8	20.1	18.5	18.0	17.1	15.1	16.0	15.3	16.4	15.2	11.8	15.9	15.1	14.1	13.5	14.0	13.7	13.2	13.5	14.8	17.3	14.5	18.3
OPEN, -30 cm	32.0	32.0	32.0	31.5	31.0	26.3	30.0	30.0	28.6	27.9	26.1	23.3	20.9	15.6	16.3	14.4	14.8	14.4	m	m	14.4	12.5	10.5	11.0	10.4	9.7	9.1	9.7	11.5	13.5	14.0
WOODS, -15 cm	28.6	24.1	23.6	22.0	22.3	24.0	22.3	18.6	17.5	15.5	13.5	12.9	12.1	11.0	11.3	11.3	13.5	11.5	13.3	13.8	11.3	9.8	10.3	12.0	10.4	10.4	10.9	14.3	16.9	18.0	16.5
OPEN, -15 cm	30.0	30.7	28.8	27.3	27.3	28.2	28.4	26.4	24.4	22.8	20.8	17.8	15.1	17.2	10.0	9.3	10.4	8.9	m	m	10.9	8.4	7.0	7.8	6.9	6.2	6.0	8.3	10.3	12.6	12.8
WOODS, -5 cm	20.2	19.1	18.4	17.8	19.1	22.0	17.9	12.2	10.8	9.0	5.8	5.8	5.9	4.5	4.6	5.3	9.3	5.4	9.4	9.9	5.0	2.7	5.6	8.6	6.1	6.9	7.5	13.3	16.9	17.5	13.6
OPEN, -5 cm	29.6	28.0	26.4	25.0	25.5	27.8	27.3	24.6	21.7	20.2	18.0	14.5	12.1	5.0	6.1	6.0	8.3	5.3	m	m	8.1	5.5	5.1	6.0	4.9	4.9	4.7	8.2	10.8	12.0	11.7
WOODS, 0 cm	22.8	18.8	18.0	17.0	17.1	19.4	19.7	15.8	13.1	11.0	8.0	7.3	8.0	5.0	8.0	7.8	9.6	8.3	9.3	10.0	8.7	5.9	5.6	7.9	7.4	7.0	7.5	11.3	14.2	18.0	16.5
OPEN, 0 cm	27.2	24.7	23.5	22.0	23.1	25.8	24.9	21.9	19.8	17.1	4.4	-10.6	-13.8	-15.4	-14.4	-12.5	-7.8	-13.1	m	m	-0.5	-3.8	-2.8	-4.9	-2.6	-2.1	-4.4	4.9	9.0	10.1	8.8
WOODS, 7.5 cm	1.5	8.3	3.7	4.8	9.7	16.6	5.2	-5.5	-5.8	-11.1	-13.9	-13.7	-9.5	-11.8	-9.0	-7.3	1.5	-7.9	2.5	4.3	-5.1	-8.3	-2.1	2.2	-1.3	1.0	2.4	12.9	17.1	16.9	10.5
OPEN, 7.5 cm	-4.4	-5.4	2.4	0.4	13.1	20.8	8.5	0.2	-13.5	-9.2	-11.8	-23.9	-28.4	-29.3	-28.0	-21.1	-11.8	-18.1	m	m	-15.2	-17.8	-11.0	-8.0	-13.0	-8.5	-6.5	7.3	10.9	11.6	1.6
WOODS, 25 cm	-30.9	-20.0	-19.6	-12.1	-0.8	10.1	-33.3	-27.0	-26.0	-35.9	-38.3	-33.6	-30.8	-29.5	-28.3	-23.7	-17.2	-25.4	-13.8	-12.7	-33.4	-35.4	-18.6	-17.6	-22.4	-14.9	-9.4	13.1	14.5	11.5	-6.7
OPEN, 25 cm	-34.7	-19.1	-21.3	-12.2	1.3	8.2	-28.8	-41.2	-34.0	-51.6	-52.5	-37.9	-35.3	-31.7	-31.0	-26.3	-25.6	-30.3	m	m	-49.6	-50.2	-26.5	-23.7	-35.0	-23.9	-14.9	14.8	21.3	4.7	-21.7
WOODS, 50 cm	-30.8	-20.3	-20.9	-12.8	-1.7	7.3	-24.0	-37.3	-31.9	-48.5	-50.4	-30.0	-33.0	-30.2	-28.6	-24.1	-21.8	-28.4	-18.3	-19.0	-44.1	-45.2	-22.0	-17.9	-30.3	-20.4	-12.3	15.5	21.9	7.5	-15.1
OPEN, 50 cm	-33.5	-19.1	-21.3	-11.9	1.1	8.2	-27.1	-40.3	-33.2	-51.3	-52.5	-30.1	-35.3	-31.8	-31.2	-26.5	-25.8	-30.3	m	m	-49.5	-50.5	-27.0	-21.2	-35.1	-24.4	-14.8	15.1	22.0	4.8	-20.9
WOODS, Snow surf.	-30.7	-20.3	-20.8	-12.8	-1.2	7.0	-23.5	-26.5	-31.7	-47.9	-49.8	-35.8	-33.1	-30.3	-28.8	-24.3	-20.9	-17.5	-15.7	-13.5	-30.0	-32.3	-17.5	-11.4	-22.1	-13.0	-10.2	15.7	21.9	7.1	-15.2
OPEN, Snow surf.	-20.0	-8.9	-8.3	-4.5	11.1	22.9	-4.8	-33.4	-30.0	-42.5	-43.0	-34.0	-33.3	-29.8	-31.3	-26.0	-25.2	-30.8	m	m	-51.0	-51.0	-27.5	-25.1	-36.5	-25.0	-15.9	13.2	18.7	5.4	-19.3
WOODS, 100 cm	-32.2	-20.9	-21.1	-12.8	-1.7	6.3	-25.0	-37.4	-31.0	-48.6	-51.0	-32.4	-33.3	-30.3	-29.0	-24.3	-22.1	-28.3	-18.7	-19.2	-44.3	-45.4	-23.0	-18.0	-30.5	-20.5	-12.7	16.4	22.5	7.2	-18.3
OPEN, 100 cm	-32.5	-19.0	-20.2	-11.3	1.1	8.2	-25.4	-38.3	-32.0	-50.3	-52.4	-32.3	-35.0	-31.4	-29.7	-26.5	-25.8	-30.3	m	m	-48.3	-50.0	-26.7	-22.3	-34.7	-23.8	-12.8	15.5	23.2	4.8	-19.3
WOODS, 200 cm	-33.1	-20.9	-21.0	-12.8	-1.4	6.3	-26.8	-37.4	-31.7	-48.6	-51.0	-32.5	-33.4	-30.3	-29.0	-24.3	-22.2	-28.6	-18.7	-19.7	-44.7	-45.4	-23.0	-18.0	-30.5	-20.6	-12.5	16.0	22.9	7.2	-15.1
OPEN, 200 cm	-32.2	-19.2	-19.8	-11.3	0.0	8.2	-26.4	-37.3	-31.7	-50.3	-52.3	-32.3	-35.0	-31.6	-30.9	-26.5	-25.8	-30.3	m	m	-48.2	-50.0	-26.6	-22.4	-34.4	-23.6	-14.5	15.6	24.5	4.9	-18.4
WOODS, 400 cm	-33.7	-21.2	-21.5	-13.1	-1.5	6.3	-25.3	-37.7	-32.1	-49.5	-51.4	-32.5	-33.4	-30.5	-29.1	-24.5	-22.3	-28.7	-15.0	-19.5	-44.7	-46.0	-23.0	-18.0	-30.5	-20.6	-12.6	16.1	23.2	7.2	-15.7
OPEN, 400 cm	-32.0	-19.0	-19.5	-11.3	1.2	8.0	-23.8	-36.9	-31.4	-50.0	-52.3	-32.3	-35.1	-31.9	-31.3	-26.5	-25.8	-30.3	m	m	-47.8	-50.0	-26.6	-21.5	-34.2	-23.4	-14.5	15.3	23.2	4.6	-18.4

m = data missing

TABLE A-7

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