INLAND WATERS BRANCH

Airborne Techniques in Climatology: Oasis Effects above Prairie Surface Features

R. M. Holmes

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Preface

This paper describes a pilot study of oasis effects in southern Alberta using an instrumented aircraft and a mobile ground-based station. Observations were taken over and near two large, irregular, prairie lakes, an irrigated project, and a complex agricultural area to test the hypothesis that important climatic modifications measurable only from an airborne platform, occur in the vicinity of such surface features. The data obtained in this study are insufficient to apply boundary layer theory and no attempt is made to explain the disposition of energy in the region studied. The intent is to present a 3-dimensional picture of observed phenomena near and above prairie oases. Lenschow (10) discussed the advantages of using aircraft in studies of this nature and presented a detailed review of boundary layer theory as applied to aircraft observations.

Abstract

A light, single-engine aircraft instrumented to measure air temperature and radiation temperatures of the earth's surface was used successfully to identify several prairie oases. Climatic discontinuities produced by irrigation, agriculture, and prairie lakes were observed. Surface-radiation temperature differences between dry and moist areas were large, and temperature differences of air cooled by passage over these areas were measurable. Under the most extreme conditions measured, air cooling of 3°C was noted up to 120 m above Lake Pakowki in southeast Alberta and this cooled air often persisted as far as 10 km down wind from the lee edge of the lake. Surface temperatures of the surrounding land varied greatly and occassionally were 28°C warmer than the lake surface. Air temperature profiles obtained near an agriculturally complex area showed the heating and cooling of the atmospheric boundary layer due to surface heating and cooling. Up to 2.0°C of heating and 3.0°C of cooling of air near the surface was measured as a result of surface characteristics of agricultural and non-agricultural land.

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INTRODUCTION

The effect on the climate of large surface features such as islands, mountains, lakes, or wooded hills has been investigated using surface observations (2, 3, 7). The available data show that air passing over the earth is in a dynamic state and has properties that are continually changing to reach equilibrium with the surface. The effects of some surface features are often noted at great heights and over wide geographic areas. The effects of many of these features on the climate can be difficult to characterize because of the size or nature of the areas involved. As a surface feature becomes smaller in extent, its effect on the atmosphere becomes less noticeable and is more obscured by the proximity of other features. Nevertheless, it is possible to describe atmospheric processes in and near the boundary layer on a continually reducing space and time scale.

The term "oasis effect" describes the occasional, abnormally high, evaporation rates which occur from areas with soil moisture contents higher than that of the surrounding terrain. The oases first reported were either irrigated experimental plots or areas in and near irrigated lysimeters which were entirely surrounded by hotter and drier agricultural land. In each case the surrounding terrain was a source of large amounts of advectable heat. In the light of present usage of the term "oasis", other situations which are larger on the space and time scale might also be considered. Examples are lakes surrounded by dry prairie, irrigated projects surrounded by non-irrigated land, forested tracts of land with increased relief encompassed by lower and drier areas, and large fields of green, growing plants surrounded by drier summer fallow.

In all of the published cases, oases resulted from discontinuities in the moisture characteristics of the earth-air interface. One might also refer to a "reverse oasis" where dry land is surrounded by moist areas such as an island (7, 15). In its broadest sense an "oasis effect" can be considered as the climatic result (e.g. modification of air temperature, atmospheric moisture, diffusion) of many types of discontinuities in surface moisture. The work reported here assumes this definition.

Most studies of the climatic effects of meso scale oases and other surface features have been carried out entirely on the basis of surface observations. However, the effect on the atmosphere of these features often reaches a considerable height above the ground and continues down wind from the area (4, 7, 10, 15). If a complete study of an oasis or other feature and the atmosphere is to be made, an airborne observational platform should be used. Using an instrumented aircraft, observations can be made which will permit a complete spatial characterization of the relationship between the surface and the atmosphere. The total 3-dimensional effect on the climatology and hydrology of areas of terrain can then be described using only a few ground stations to provide the observational transition from the ground to the lowest air layers. The aircraft can provide the observational continuity to the atmosphere in the horizontal and vertical directions. The work of Dutton and Lenschow (5), Lenschow (10), Malkus (13, 14, 15) and others quoted by Lenschow (10) suggests this point of view.

INSTRUMENTATION

Instrumented aircraft have been used for many years to carry out research in cloud physics and weather modification (4, 13, 14, 15, 19, 20). Published accounts of aircraft use in climatology are also available but are less frequent (1, 5, 9, 10, 16, 18). In the research described in this paper two light, single-engine aircraft were used; a Cherokee "140" and a Cherokee "6".

Two sets of instruments were used to measure air temperature in each aircraft.

The Cherokee "140" instrumentation consisted of an electrical resis-

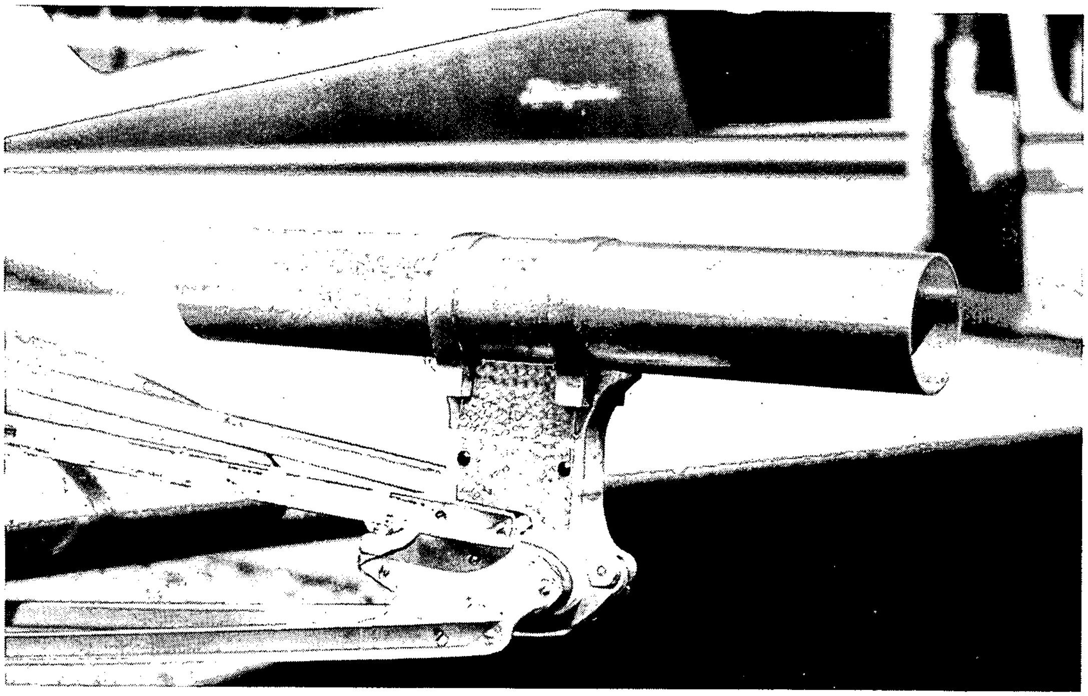

Figure 1. Air temperature sensor, housing and mounting, used on a Cherokee "140" near the wing tip. Aluminum tube is standard 2 in. ID, 40 cm. long and contains the electrical resistance elements. The vertical section below the tube contains electrical connectors.

tance element and a 5-junction, copper-constantan thermopile. The electrical resistance element was calibrated in a water bath to an accuracy of ±0.1°C. Initially, readings were taken by a technician using a milliammeter but in later stages of the observations, a strip chart recorder was used. The recorder was powered by an invertor driven by the aircraft's 12-volt dc supply. Figure 1 shows the installation of the electrical resistance element on the Cherokee "140". One end of the 5-junction, copper-constantan thermopile was potted in oil within a frigistor maintained at 0°C ± 0.01°C. The elements, housings and aircraft mountings for the thermopile, were designed in-house to ensure that radiation and dynamic heating effects were negligible. At 120 knots air speed, the thermopile time constant was approximately 0.5 second.

A radiation thermometer (Barnes IT-3) was mounted in the cabin so that the sensing head "looked" through a hole in the floor of the aircraft. A streamlined faring was placed around the hole on the underside of the fuselage to reduce turbulence around the sensing head and produced a steady flow of cabin air around the sensing head to the aircraft exterior. This mounting was made on the basis of recommendations made by Richards and Massey (18). The IT-3 radiation thermometer was powered from the invertor in the cabin.

The Cherokee "6" instrumentation, sensors, sensor mountings, data acquisition system, and power supplies will be described in detail in a subsequent publication but are briefly described by Holmes (9).

The general observational procedure required that the aircraft be flown at a height of 15 and 45 m above the surface. Ground surface and air temperatures were associated with ground fixes for position reference. Transections across the area of interest were flown at various horizontal intervals along north-south lines. Horizontal intervals flown varied depending on the wind speed. With this technique, measurements were taken at one level from north to south, then the altitude was increased to the next observational level and measurements were taken from south to north over the same ground track. Following this, the ground track was horizontally displaced by an appropriate amount and measurements were made at the higher altitude, with observations being made at the lower altitude on the return transect. During 1968, height above ground was maintained by use of a radar altimeter.

The ground tracks for the surface IR temperature measurements were chosen for each situation to cover representative surfaces around and on the feature being studied. In all cases, correction was applied for surface emissivity in a manner described by Holmes (9). Measurements of surface emissivity by Holmes over agricultural and non-agricultural land suggest that the IR measurements are accurate to ±1.0°C and temperature differences are accurate to ±0.2°C when observations are taken at heights less than 300 m. At this level and in this study area, atmospheric moisture effects were found to be negligible.

Air temperature at 2 m was measured using a sensor and indicator/recorder arrangement identical to that used in the aircraft but mounted on a car. The sensor was supported on a 2 inch O.D. aluminum-pipe boom held about 12 feet in front of the car. The pipe was strapped to the roof rack. Observational procedures involved driving the car to predetermined observation points that coincided as closely as possible to the airborne observation points. Measurements were made while the car was in motion.

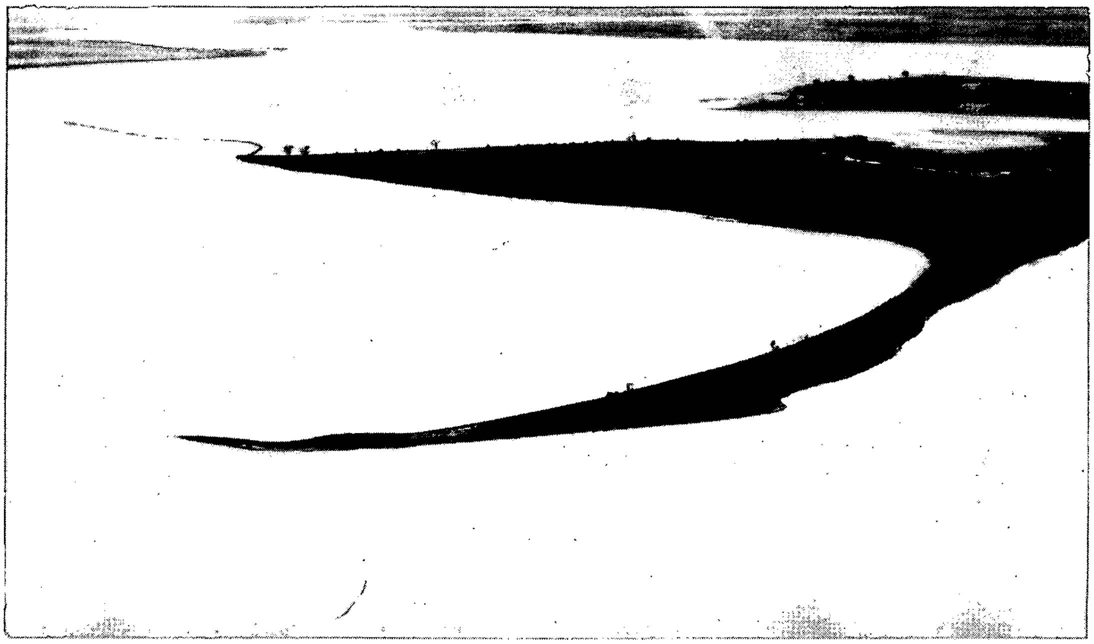

Figure 2. Lake Pakowki, Alberta, looking south. The body of land and curved spit are part of the centre island. Strong surface heating was noted over the islands in the lake and inland from the western shore. A strong oasis developed over the lake on many observational days.

PRAIRIE-LAKE OASES

Lake Pakowki is the remnant of a large Pleistocene glacial lake situated in southeast Alberta. It is shallow (average depth approximately 3 m), nearly always turbid, high in alkali salts, and has a widely fluctuating, annual water level. The surrounding terrain is composed of dry land farms and range land extending to the western edge of the Cypress Hills. One small area of irrigated forage is situated on the southeast side of the lake but, in general, the surrounding ground surface is flat and dry for most of the summer (spring and summer rainfall comes mostly from convection storms and averages about 5 cm). Figure 2 illustrates some essential features of the lake, and Figures 4, 5 and 6 show its size and shape during late July and early August of both 1966 and 1967.

The data obtained over and near Lake Pakowki are presented in Figures 3, 4, 5 and 6. Figure 3 shows the surface radiation temperatures determined by remote IR sensing over the ground track ABCD in Figures 4, 5 and 6. Observations were made at a height of 75 m. Large variations in surface temperature are noted, with the lake surface temperatures in sharp contrast with the agricultural land. Near A, unusual surface moisture conditions exist. Sand dunes sparsely covered by grass are prominent. A large community of phreatophytic bush grows about two-thirds of the distance between A and the lake shore. A drop in surface temperature of approximately 8°C was also noted at that point. Later, a field examination disclosed that the water table was 20 - 25 cm below the surface, whereas the water table was 1.2 to 1.5 m below the surface elsewhere on this part of the track. The highest surface temperatures were experienced between B and D with 50°C being

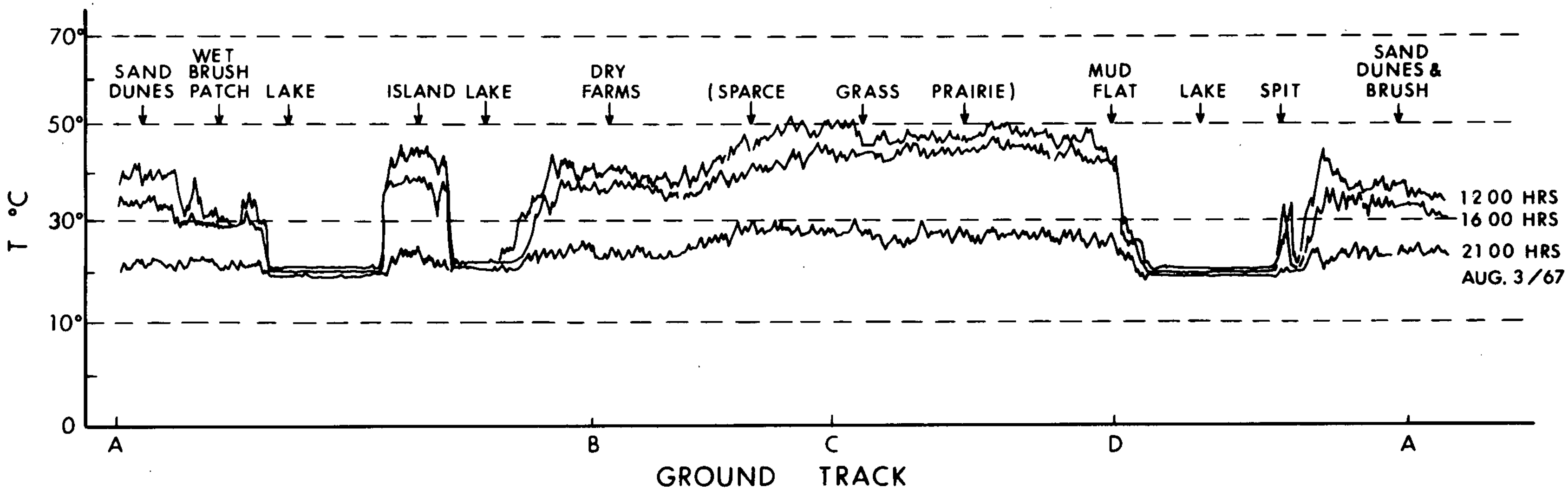

Figure 3. Surface radiation temperature (°C) at three intervals over ground track A, B, C, D, of Lake Pakowki shown in Figures 5 and 6.

exceeded at several points (temperatures of fallow dry-land 3 miles upwind averaged 34° to 39°C at this time of day). The surface over this part of the track is slightly elevated with very sparse growth of prairie grass. Salt accumulation at the surface was noted in several places with frequent wind-blown depressions. The ground track from D to A returns to the lake, the phreatophytic bush and dune formations, and the lower surface temperatures.

The reproduced traces of surface radiation temperature in Figure 3 show temperature variation with time of day. Observations were discontinued at 2100 hours because darkness obscured the ground track. The rapid cooling of the soil surface compared with the lake was evident as the day progressed. The area of land over the track BCD which had the highest surface radiation temperatures during the day also showed highest temperatures during the evening.

Figure 4 presents the results of the surface air temperature (2 m) observations. The isotherms are actual temperature measurements; the small "zeros" are observation points which coincide closely with the ground position of the airborne observation. The isotherms have the disadvantage of being drawn from single observations at the points indicated. During the observation period it was possible to cover the rather extensive ground track only once by car in the allotted time (1200 to 1500 hrs) by driving at maximum speeds on country roads. It is to be noted that the highest air temperatures at 2 m coincide with the highest surface temperatures observed by remote IR sensing. On the lee of the lake, rather restricted regions of air cooled by the lake are noted. Elsewhere, air temperatures are relatively constant at 26°C and appear to be relatively unaffected by surface variations. It is to be noted at this point that the areas where air temperatures at 2 m are influenced by known ground conditions, are almost completely restricted to those areas.

Ten airborne transections were made in the north-south direction at heights of 15 and 45 m. The horizontal extent of air temperature measurements covered the area shown in Figures 5 and 6. The data presented are the average of 3 hours of observations between 1200 and 1500 hours, August 3, 1967. The isotherms and temperature grid represent temperature differences in °C between the indicated position and the ambient prairie air 14-16 km upwind at the same elevation above the surface. Wind speed and direction were measured at 15 m height, 15 km upwind. Each set of temperatures measured at 15 and 45 m above the lake was followed by measurement of upwind air temperature at 15 and 45 m above the ground. Generally, it was found that ambient prairie air temperature varied very little with time. A super adiabatic (unstable) lapse existed at all times over the area and during the time indicated. At the upwind measuring point, the air temperature near the surface (2 m) was 31.5°C to 33.5°C during the study period. On the day shown, the variation with time was 24.7°C to 23.6°C from 1200 to 1500 hrs at 15 m, and 23.6°C to 22.9°C during the same period at 45 m altitude. The Student's "t" test was used to determine the significance of the temperature differences shown in the figures. These values are significant only at the 1 percent level. Where the value is not significant at the 5 percent level, a small "zero" is placed on Figures 5 and 6 at the position where the measurement was taken.

The effect of the lake on the temperature of the air passing over it was noted at both levels, with maximum cooling of 3°C at a height of 15 m (Figure 5) and 2°C at 45 m (Figure 6). The isotherms and temperature grid in Figures 5 and 6 show the average position of the cold and warm air

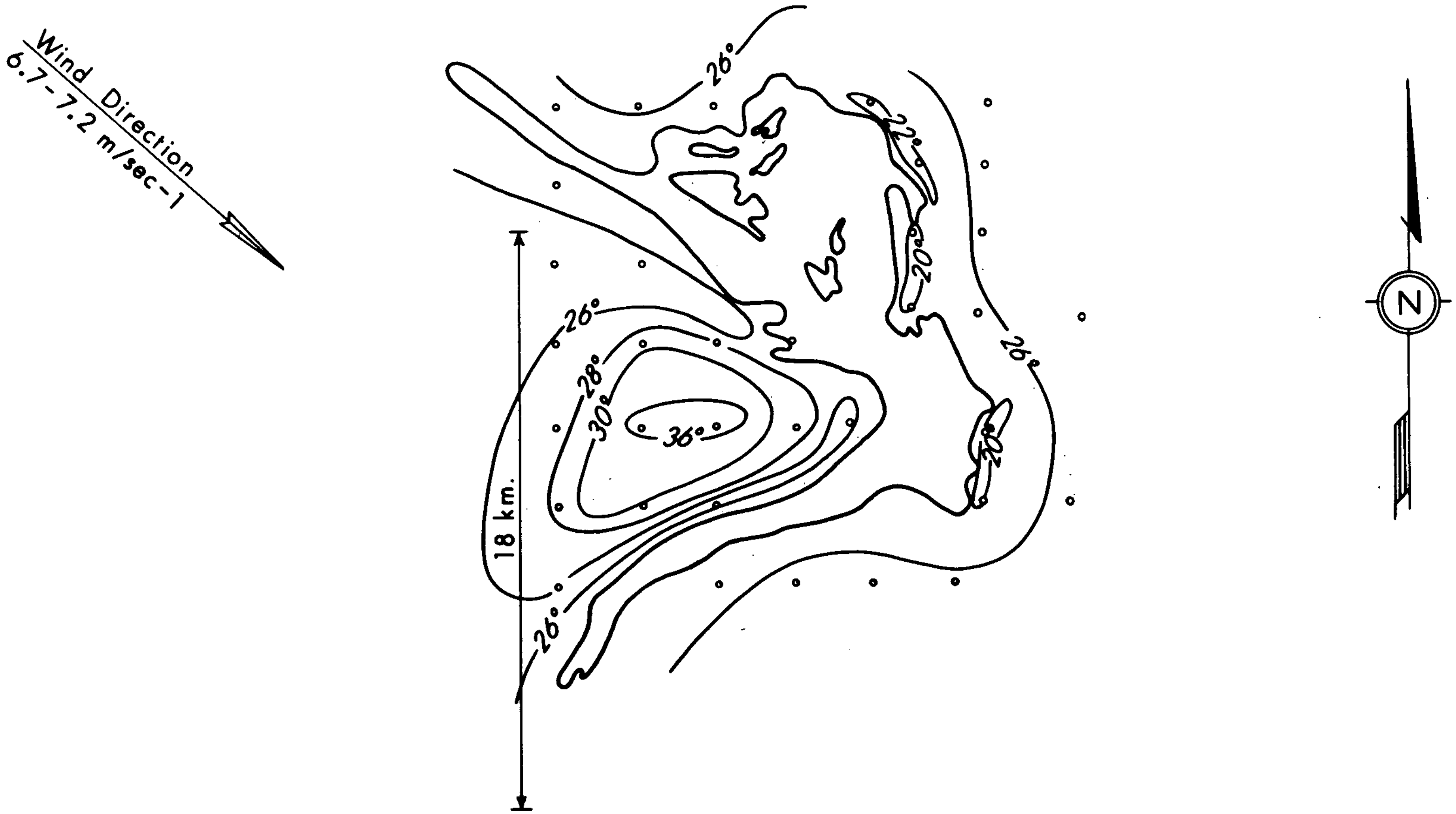

Figure 4. Isotherms of air temperature and observation grid at 2 m above surface near Lake Pakowki on August 3, 1967 (Lat. 49° 20' N, Long. 110° 50' W).

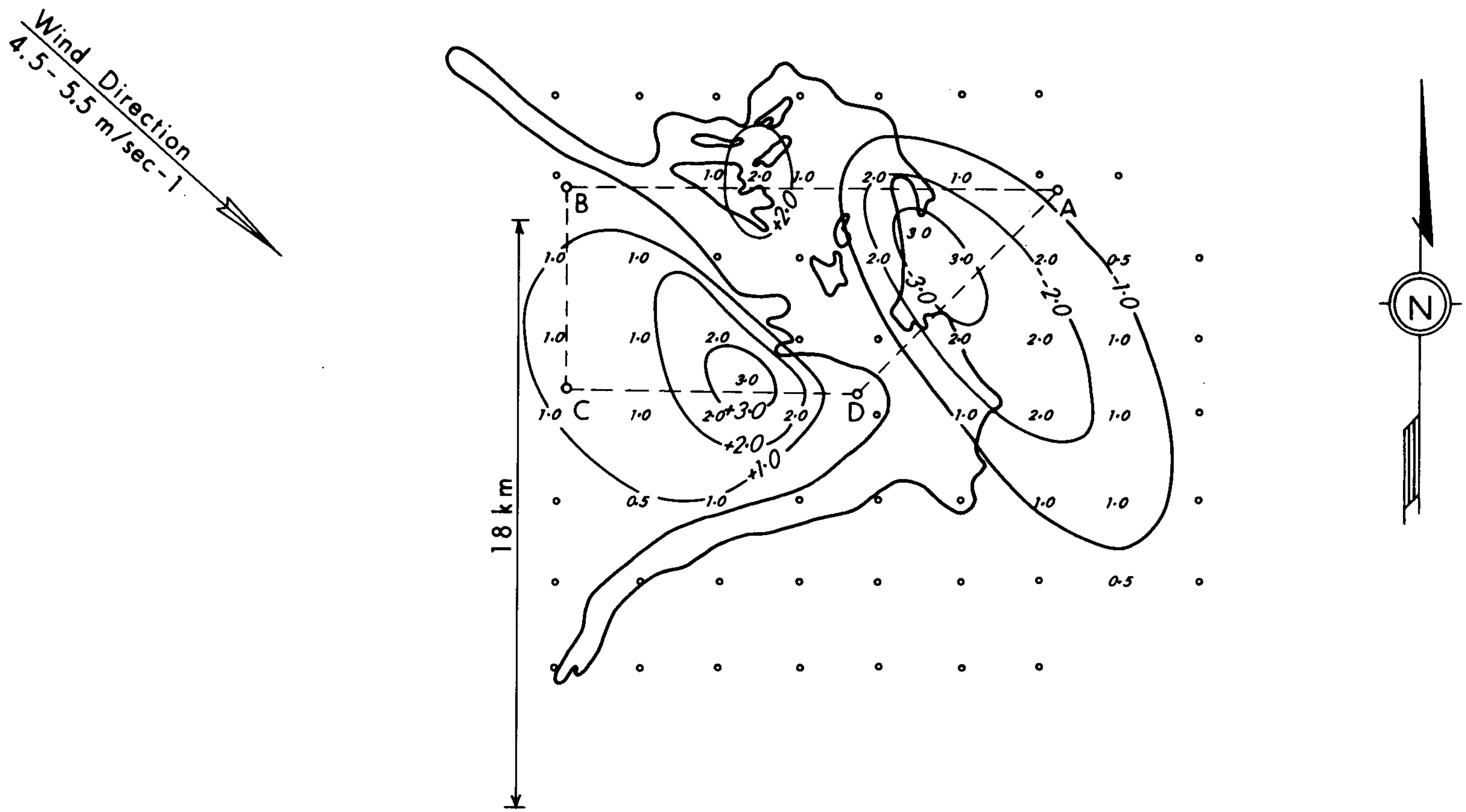

Figure 5. Isotherms and temperature grid of average air temperature difference (°C) at 15 m above surface near Lake Pakowki between positions indicated and ambient prairie air 14-16 km upwind on August 3, 1967.

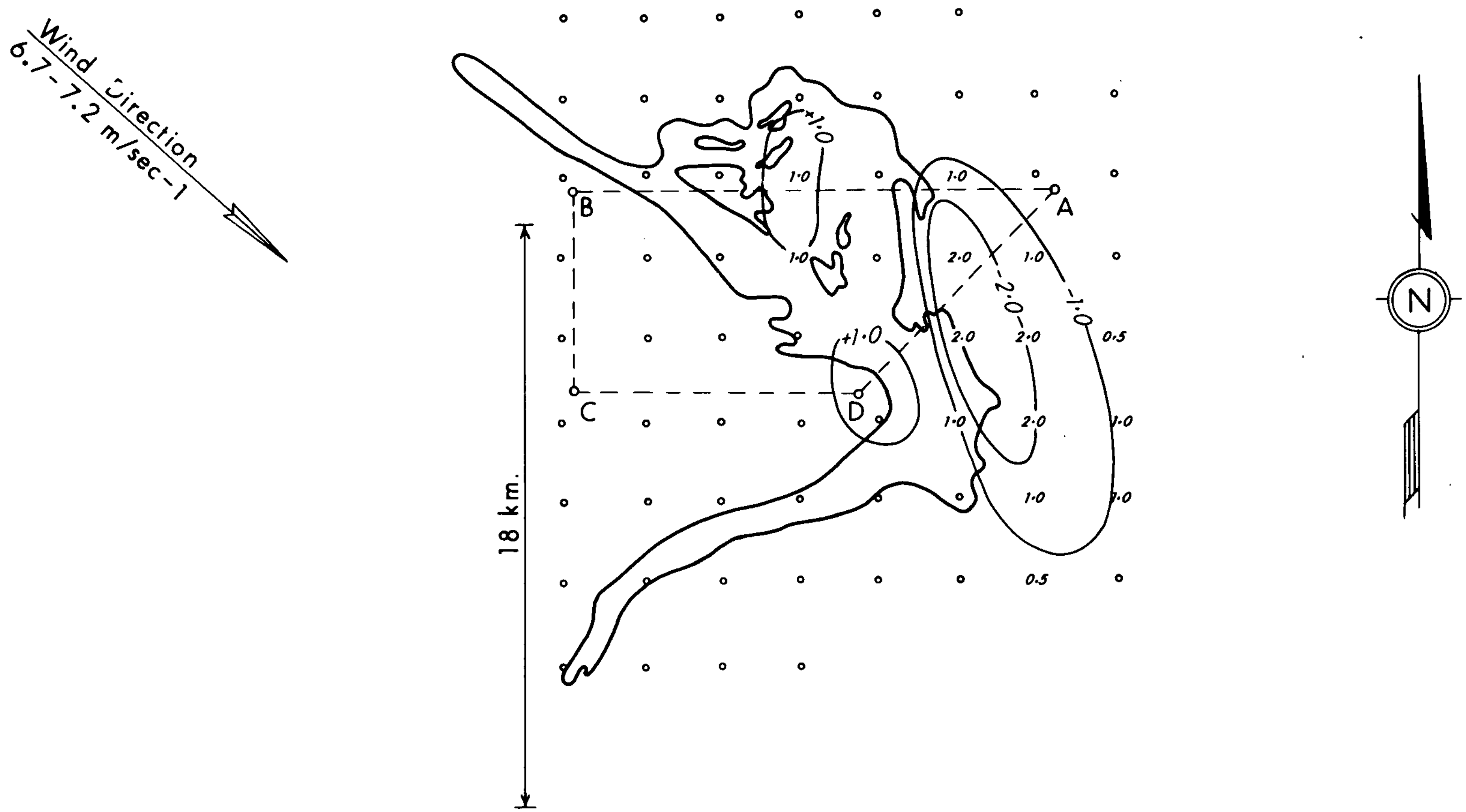

Figure 6. Isotherms and temperature grid of average air temperature difference (°C) at 45 m above surface near Lake Pakowki between positions indicated and ambient prairie air 14-16 km upwind on August 3, 1967.

"parcels" for the 3-hour period. While at 75 m there was no measurable effect on this particular day, on a calmer day a 3°C cooling was noted up to 120 m, but the effect was restricted more horizontally. The radiation temperature traces and air temperatures at 2 m indicate that warm air rises from the island and from the area between the two westerly arms of the lake, and there is ample reason to believe that momentum conserved downwind and above the oasis may carry aloft air parcels cooled by evaporation.

It is somewhat surprising that the regions of cool temperatures at 15 and 45 m are almost entirely displaced from the lake, even the region of coolest temperature on the lee shore does not extend over the shore exposed to the largest fetch. Doubtless, lateral mixing from the heated shoreline over this narrow water fetch would tend to place the coolest air to the north of the longest fetch. During the study period and also during August of 1966 and 1967 when transects were flown over the lake, it was discovered that the shape and position of the cooled and heated air was highly variable and largely a function of daytime heating, wind speed and direction. The data presented show the *average* position of the heated and cooled air during the study period. The reason for the position of the cooled air being displaced to the lee as much as shown is not immediately obvious. At no time was cooling noted at altitudes of more than 120 m above the terrain, and at no time was cooling measurable farther than 11 km from the lee edge of the lake. There were many days when no air cooling was measurable regardless of height or position.

The airborne observations are in contrast to those at 2 m. It was noted that at ground level the areas of markedly heated air coincided closely with the soil surfaces that provided the energy, with very little tendency to locate down wind near the surface. This "local effect" at ground level was offset by the marked displacement of thermally altered air at higher elevations. Obviously, however, warm air is advected at the surface, since the temperature of the air over the irrigated area to the east of the lake, for example, decreases with fetch.

A second lake was studied on August 20, 1967, for a possible oasis effect. Lake Murray and surrounding terrain, in southern Alberta, are illustrated in Figure 7. Much of this area is given over to dry land farming. On the south shore there is a sharp topographic rise of approximately 12 m. South of this rise the terrain is essentially flat prairie with occasional wet land patches. Aircraft transects were flown at 15 and 45 m above the surface and air temperature was observed in a manner similar to that used over Lake Pakowki. The measurements indicated an exceedingly complex situation and it was not possible to relate the position of cooled air parcels to the amount of cooling. Cooling was noted over most of the lake below a height of 60 m altitude. But most occurrences of cooled air parcels were over the lee edge of the lake. At no time was cooled air measurable over the land at 15 or 45 m. Air temperature was not measured at 2 m near Lake Murray due to the lack of suitable roads near the lake shore.

Lake Murray is somewhat smaller than Lake Pakowki and the lack of larger, definable regions of cooled air over Lake Murray can be partially explained on this basis. Because of the smaller size, warm air advected from the surrounding land would likely invade the cooled air of the Lake area and persist as parcels. This could create the complex situation noted above. Over larger lakes there would be less opportunity for warm air to persist because air cooled by the Lake is more likely to exist as a larger mass.

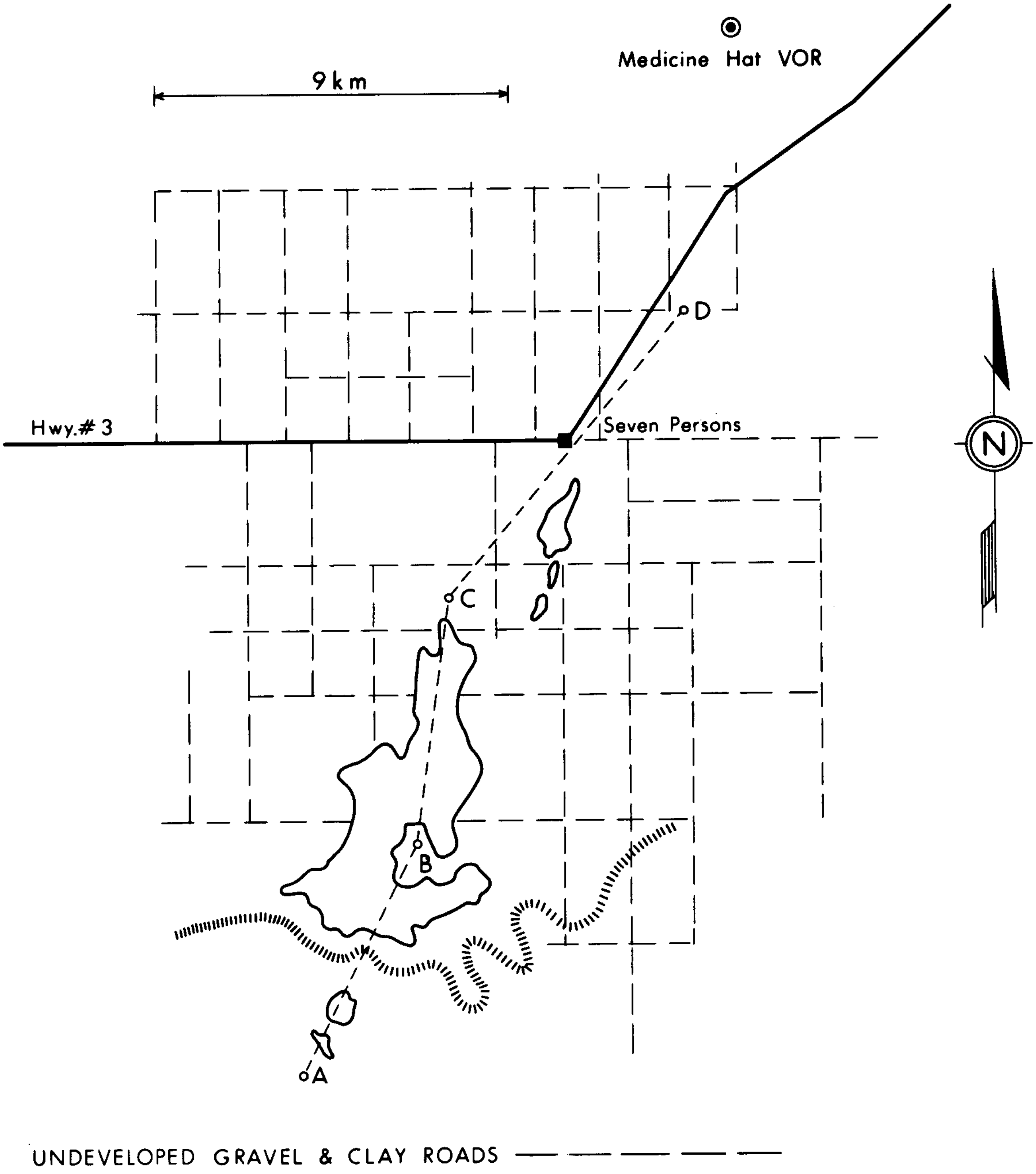

Figure 7. Lake Murray, Alberta, and surrounding terrain (Lat. 49° 47' N; Long. 110° 57' W).

Other transects were flown on August 20 and 21, 1967, at a constant altitude of 240 m above the lake surface to measure surface radiation temperature throughout one day and night. The ground track was maintained through the dark hours by using the Medicine Hat VOR Radio Station. These data are shown in Figure 8 and the ground track is ABCD (Figure 7).

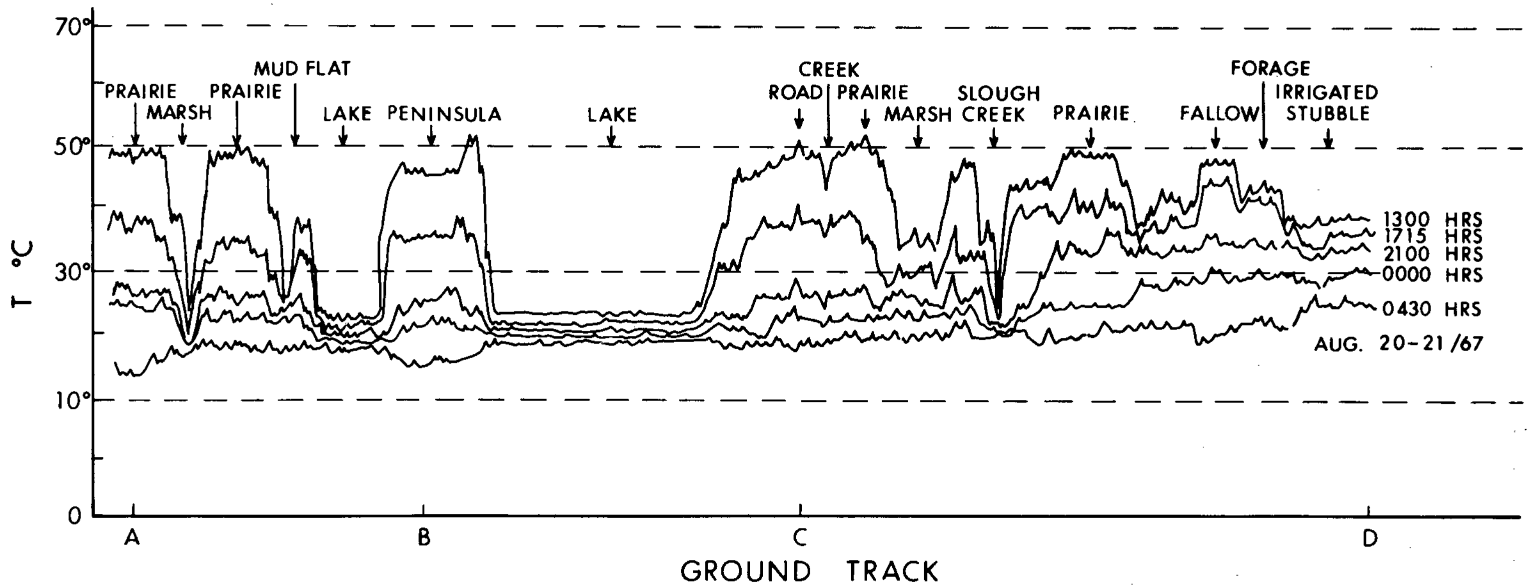

Figure 8. Surface radiation temperature (°C) at various intervals over ground track A, B, C, D, of Lake Murray shown in Figure 7.

As with the Lake Pakowki readings, these observations show marked surface-temperature discontinuities and a difference in rate of cooling between the lake and soil surface with surface temperatures exceeding 50°C at several points. At 0430 hours there is little difference between the average lake and soil surface temperature. The peninsula at ground track position B (Figure 7) was cooler by approximately 4°C than the lake at 0430 hours. It is interesting to note that the water surface-radiation temperature trace for Lake Murray is less steady and cools to a greater degree than that for Lake Pakowki. Because Lake Murray is less saline, there are quantities of floating marsh weeds and algae which may cause the surface-temperature fluctuations. Of further interest are the fields of fallow, forage, and irrigated stubble near ground track position D (Figure 6). The fallow was approximately 47°C, and warmer by approximately 6°C during the day than the forage, which in turn was approximately 5°C warmer than irrigated stubble. As nocturnal cooling proceeded, the fallow temperature was reduced to approximately 17°C, the forage was warmer at approximately 20°C and the irrigated stubble was still warmer at about 25°C. This order did not always hold, however. On another night (2 days previous and with overcast conditions) the forage became cooler than the fallow by 2°C. On the date of the observations shown in Figure 7, the farmer had irrigated the adjacent stubble field so comparisons with data from other nights are not available.

IRRIGATION OASIS

A small irrigation project of about 12 square km situated at the confluence of the Bow and Oldman Rivers, Alberta, was studied using techniques similar to those used at Lake Pakowki. A photograph of the western edge of the district is shown in Figure 9 and the results of air and surface-radiation temperature measurements are shown in Figures 10, 11, 12 and 13, with observational altitudes of 15 and 45 m above average ground surface. Data were taken in a manner similar to that used over Lake Pakowki, except airborne transects were displaced horizontally to cover the area as indicated. The prairie surrounding the irrigated project is very flat and homogeneous as regards vegetation and surface characteristics for 40 km upwind.

Figure 10 presents the surface temperatures determined by remote IR sensing over ground track ABCD on August 2, 1966, shown in Figures 11, 12 and 13. The surface-temperature discontinuity produced by irrigation is clearly shown with sharp changes indicated for ditches and ponds. A general decrease of 11°C occurred in surface temperature because of irrigation.

Air temperatures measured at 2 m with the mobile station are shown in Figure 11. The absence of suitable roads outside the irrigated project made it possible to make only spot measurements in this area. Because of the large amount of time necessary to cover the planned route by car compared to the aircraft, the data in Figure 11 represent only one measurement at the points indicated. These surface observation points coincided as closely as possible to the ground positions of the airborne measurements. A maximum of 6°C of cooling was noted in the southeast portion of the area. The temperature of 20°C was noted at only 2 points so this temperature may be a very local effect and not represent the effect of the general irrigation. Other temperatures of 22° and 24°C were found to be more the rule in the positions indicated in Figure 11. The effect of irrigation in positioning the cool air was restricted to the area irrigated.

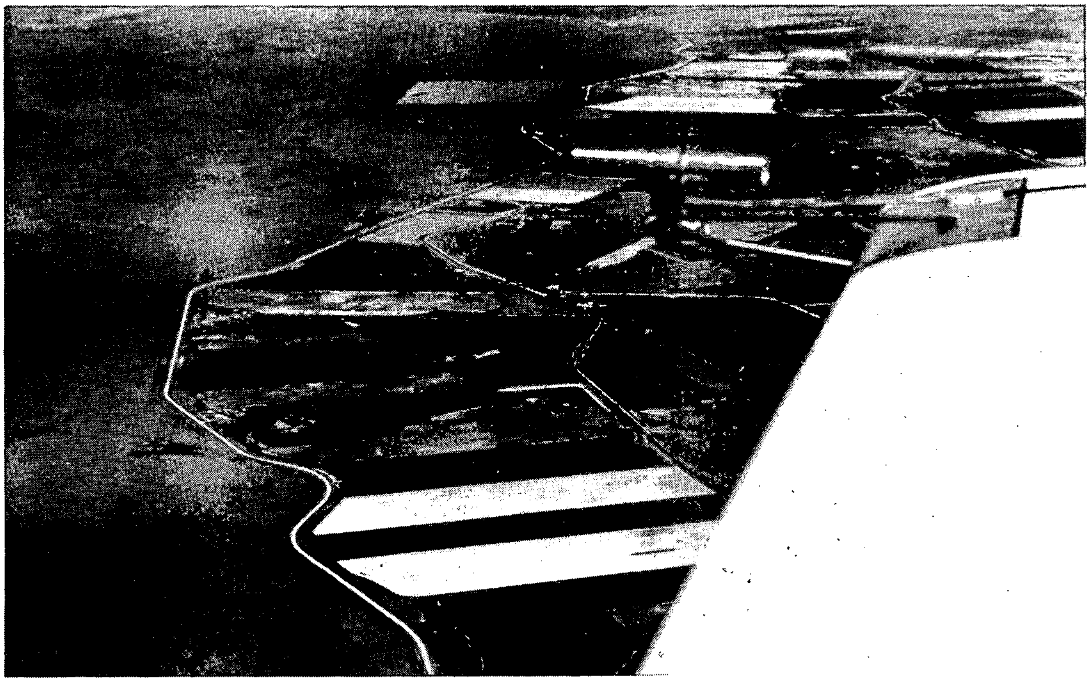

Figure 9. Western margin of a small irrigated project near the confluence of Bow and Oldman Rivers, in Alberta. This area caused a mild oasis effect on several days when measurements were taken. Also shown is the air temperature measuring sensor and housing on wing of aircraft.

The results of the airborne measurements are shown in Figure 12 and 13. The isotherms show temperature differences between the positions indicated and 9 km upwind at the same latitude. These measurements were taken between 1200 and 1500 hours on August 8, 1966, and show the average position of the cooled air for the three-hour interval. Wind speed and direction upwind was measured at 15 m.

It was not possible to measure the presence of cooled air over this area as often as over Lake Pakowki. The day selected was exceptional in that cooled air was detectable. However, at no time was cooled air noted at heights greater than 75 m or more than 4.5 km downwind from the project.

The information obtained from near and over the irrigated area shows that even though the effect of irrigation on air temperature is very local at the surface, at higher elevations the influence is detectable over a much greater areal extent.

The oasis effect of this area was highly dependent on surface heating upwind, wind speed, and wind direction. There are insufficient data at the present time to relate these factors quantitatively. On 60 percent of the days observations were taken, no effect was measurable. Some air cooling was noted over a small lake approximately 2 km northwest of the irrigated land. Cooling was also measurable over the junction of the rivers. It is somewhat surprising that this was possible over these two very small features, when it was not measurable over Lake Murray. Observations were not made over all these areas on the same days or in the same weather situation so it is not possible to completely explain positioning in one case and lack of it in the other.

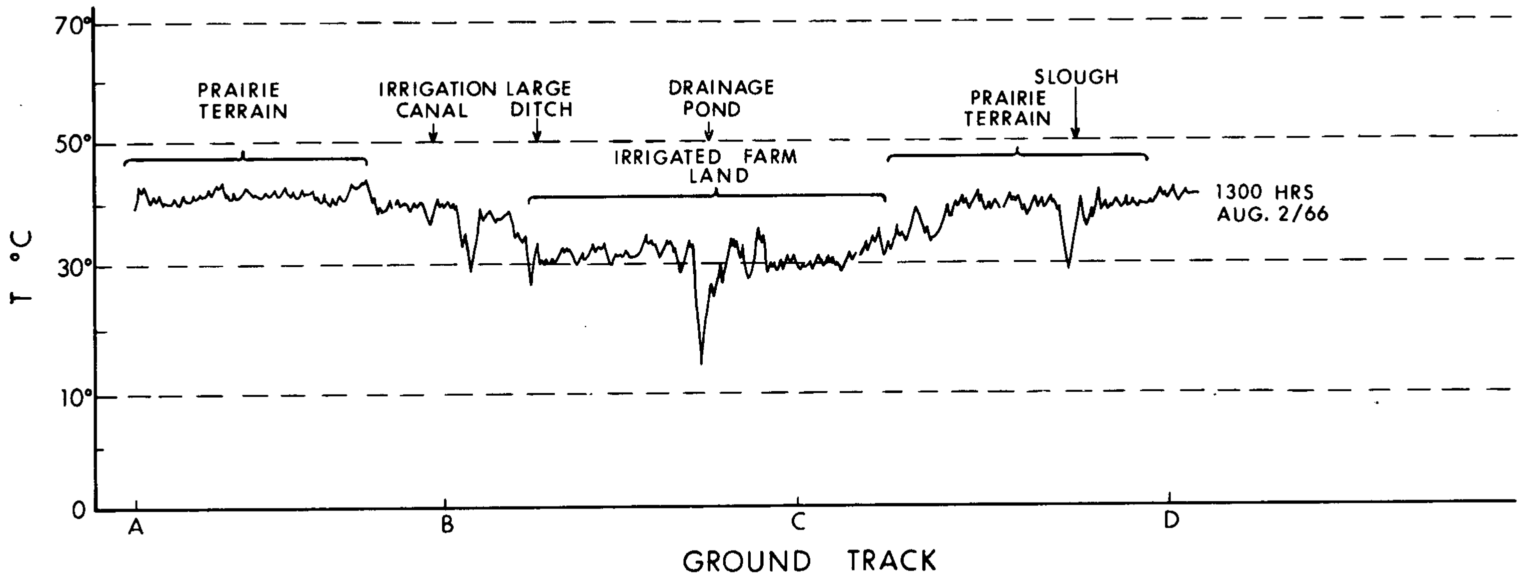

Figure 10. Surface radiation temperature (°C) at various intervals over ground track A, B, C, D, of irrigated area near Bow Island shown in Figures 12 and 13.

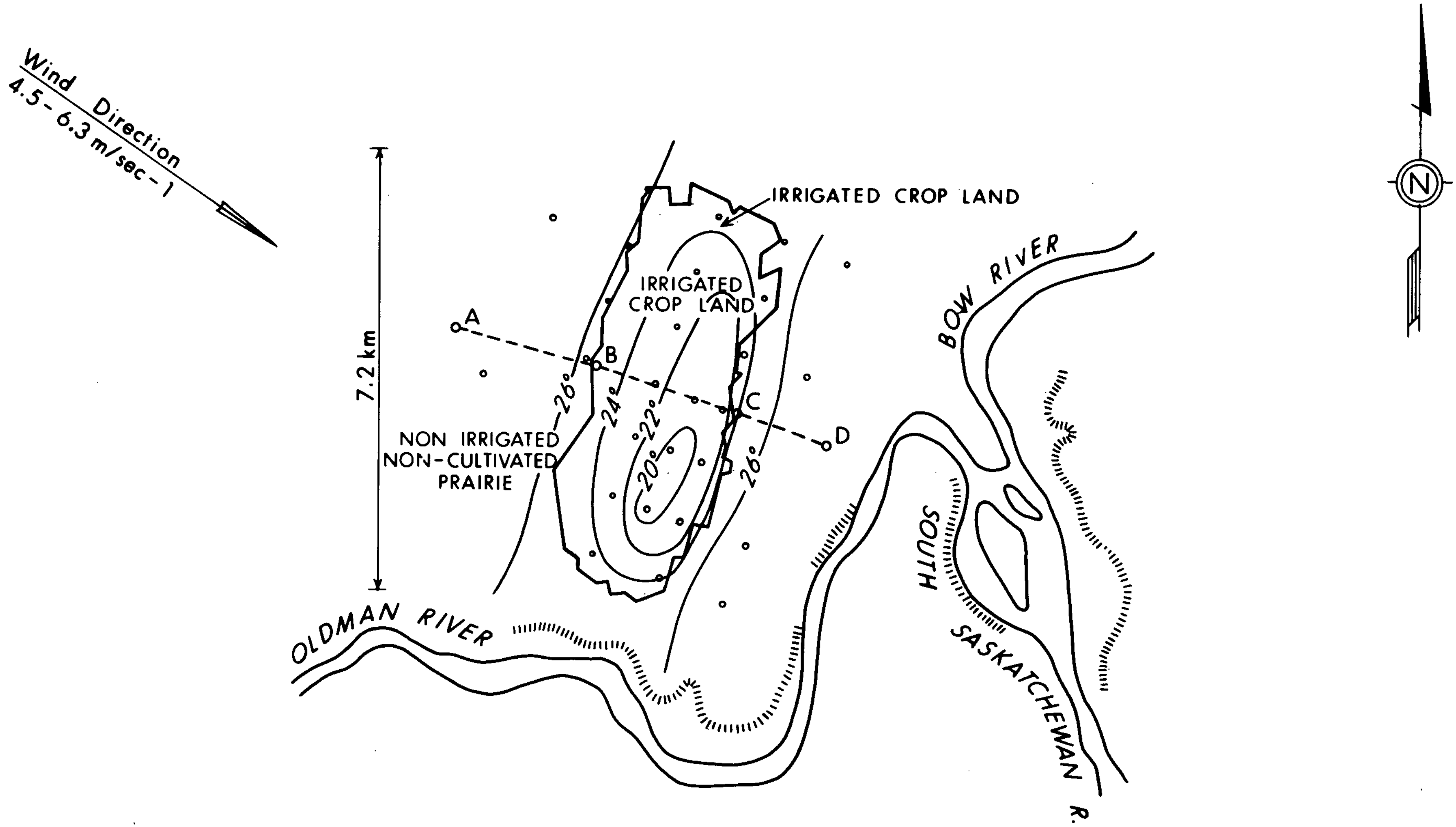

Figure 11. Isotherms of air temperature and observation grid at 2 m above surface of irrigation project near Bow Island on August 8, 1966 (Lat. 49° 30' N, Long. 110° 50' W).

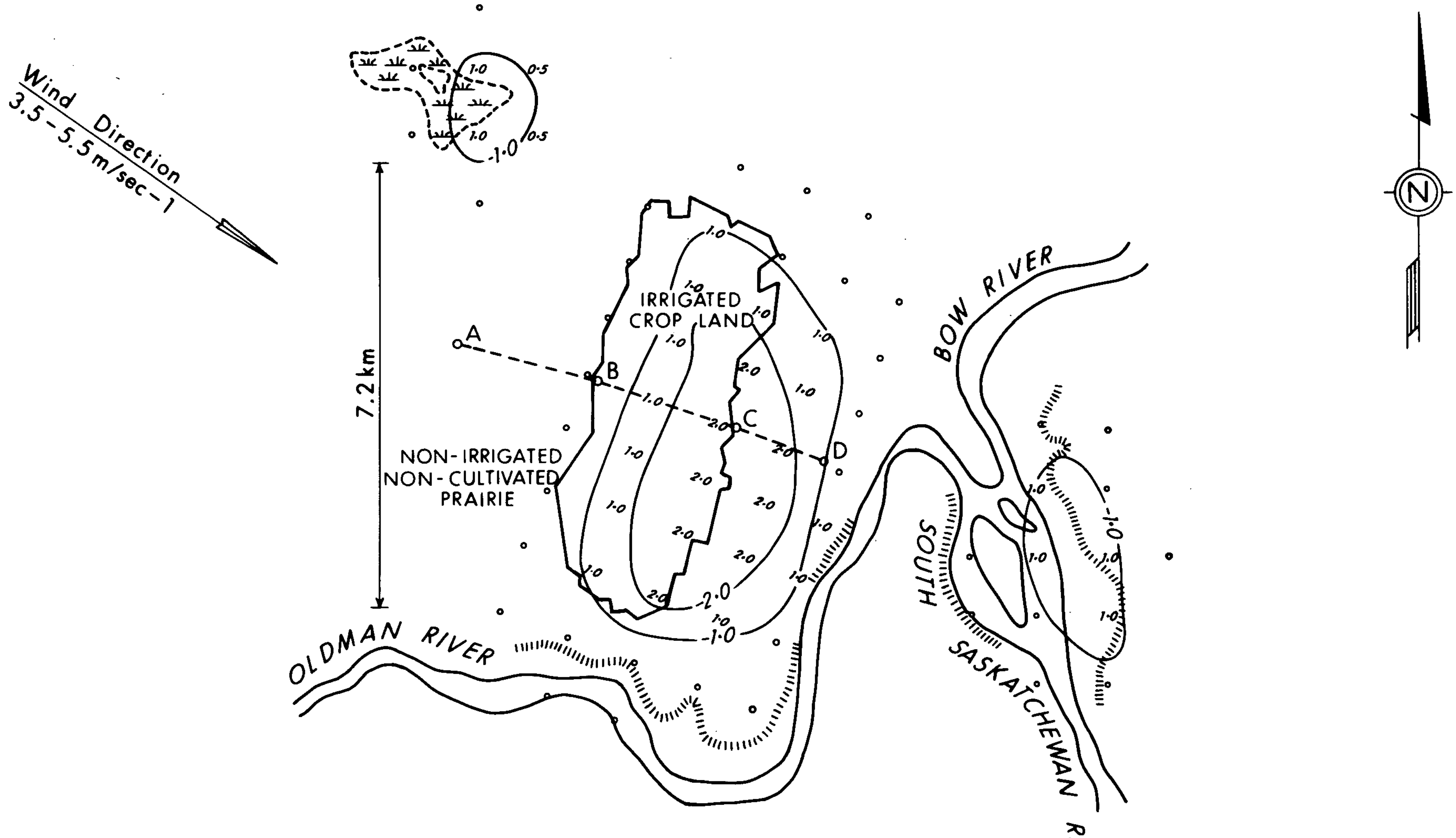

Figure 12. Isotherms and temperature grid of average air temperature difference (°C) at 15 m above surface between positions indicated and ambient prairie air 7 km upwind near irrigation project near Bow Island on August 8, 1966 (Lat. 49° 55' N, Long. 111° 45' W).

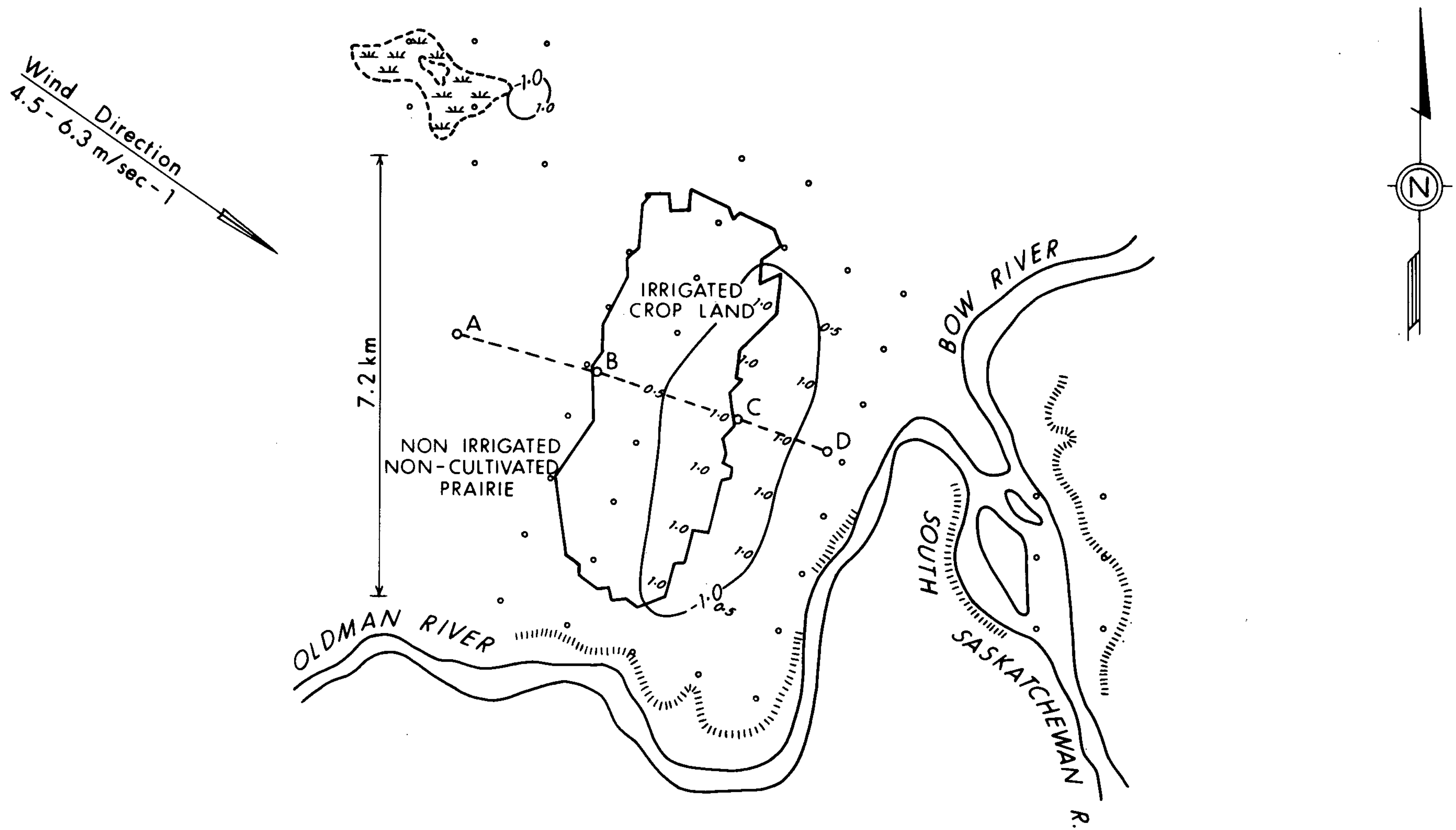

Figure 13. Isotherms and temperature grid of average air temperature difference (°C) at 45 m above surface between positions indicated and ambient prairie air 7 km upwind near irrigation project near Bow Island on August 8, 1966.

AIR TEMPERATURES OVER AND NEAR AN AGRICULTURALLY COMPLEX REGION

An area near Brooks, Alberta, with a diversified surface, was chosen for study, using the same methods as over the previously described regions. The essential features of the area are shown in Figures 14, 15, 16, 17 and 18. Newells Lake is to the east of an extensive area of dry land farms. To the east of the lake are two small regions and one large area of irrigation. Surfaces east of highway No. 1 and between the irrigated sections are mainly undulating, uncultivated virgin prairie. The positioning of the features in the figures was done from visual aerial examination of the region at the time of the study, because the amount of cultivated and irrigated land changes from year to year.

Figure 14 presents the surface temperatures as determined by remote IR sensing over the ground track ABCD on August 8, 1968, shown in Figures 15, 16 and 17. The general weather was bright sunshine with light and variable surface winds. The surface temperature of Lake Newell contrasted with the heated surrounding land between A and B. The lake has an average depth of 10 m and the surface temperature was uniform at 16°C. Following observation point B to C, the surface temperature exceeded 50°C and then dropped to near 30°C over the irrigated area. The flat prairie approaching D had a surface temperature of approximately 46°C. It should be pointed out that a certain amount of curve smoothing occurs in the process of applying the surface emissivity to the raw data as described elsewhere (9). However, the surface temperature detail which demonstrates the general temperature anomalies at the surface is preserved.

The study area was rather extensive and it was not possible to cover the region adequately by car in a single day to measure air temperature at 2 m during the period of maximum daytime heating (1200 to 1600 hrs). A portion of the dry farm land to the west and part of the large irrigated area to the east of the Lake were studied over a two-day period (August 6 and 7, 1968) when similar conditions prevailed. The data are shown in Figure 15, the small zeros indicating observation points. It can be seen that heated or cooled air is local to the particular surface, with cooler conditions over the irrigated land and warm air over the surfaces that are heated.

Airborne measurements of air temperature were made over a one-mile grid covering the entire area at heights of 20 and 40 m. The data were obtained and analyzed in a manner similar to that for Lake Pakowki. Figures 16 and 17 show the temperature difference of air at the positions indicated compared to air at the same altitude but 10 km upwind from Lake Newell. The Student's "t" test was used to determine the significance of the temperature differences and only those differences significant at the 5 percent level are shown.

A complex temperature pattern was evident, with warm air over several dry, farm land, areas and cooled air over irrigated land and Lake Newell. At 20 m, the maximum significant heating noted was 2.0°C and maximum significant cooling was 3.0°C. Warmed air was measured down wind from the westerly, dry farm land and extended over the lake, while cooled air from the lake extended over the heated prairie to the east of the lake. Cooled air from the irrigated sections also extended over the heated uncultivated prairie. Heated and cooled air was noted at 40 m as shown in Figure 17, but was not present to the same degree as at 20 m. At 60 m on this day, the air was uniform in temperature over most of the area. The lapse rate was super adiabatic (unstable) to

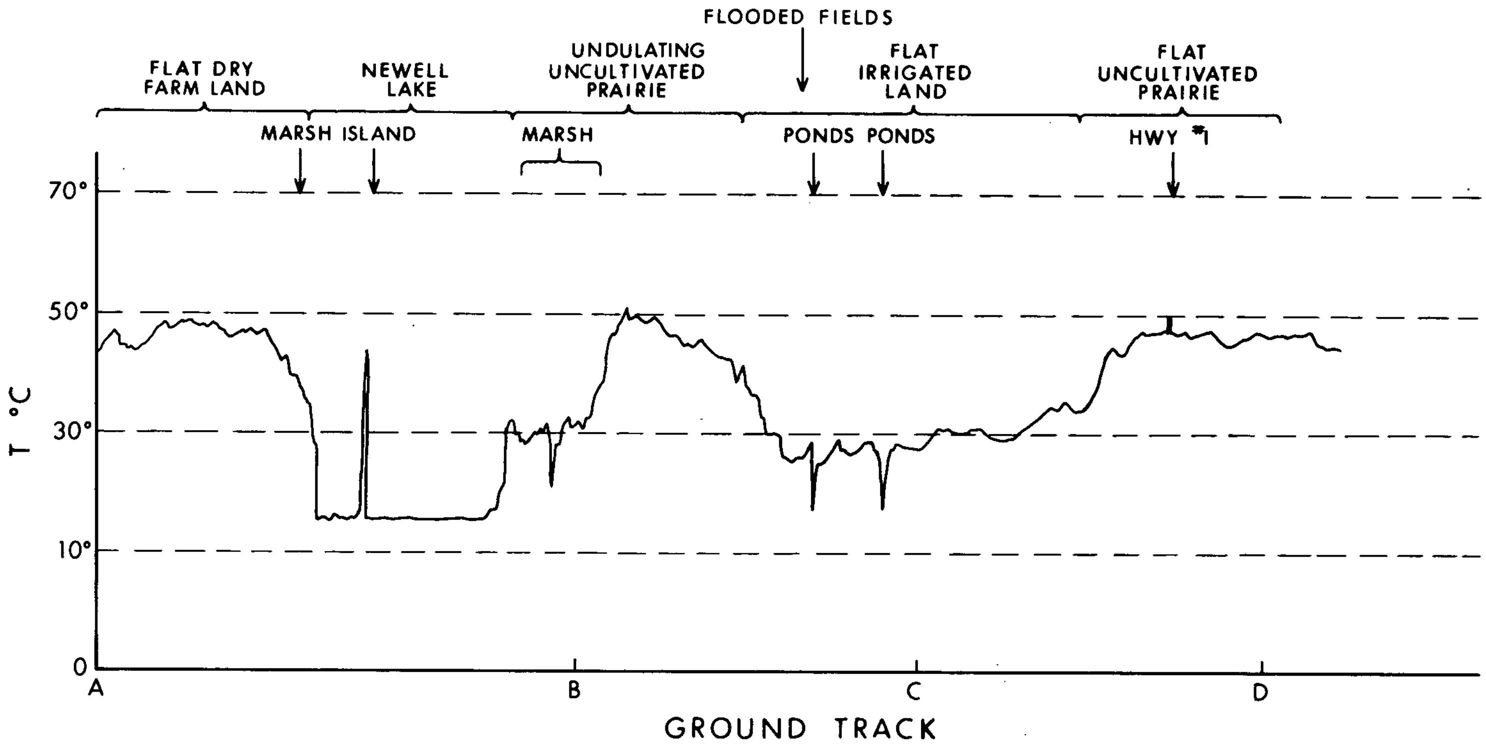

Figure 14. Surface radiation temperature (°C) over ground track A, B, C, D, of area near Brooks, Alberta, shown in Figures 16, 17 and 18 (Lat. 50° 25' N, Long. 111° 55' W).

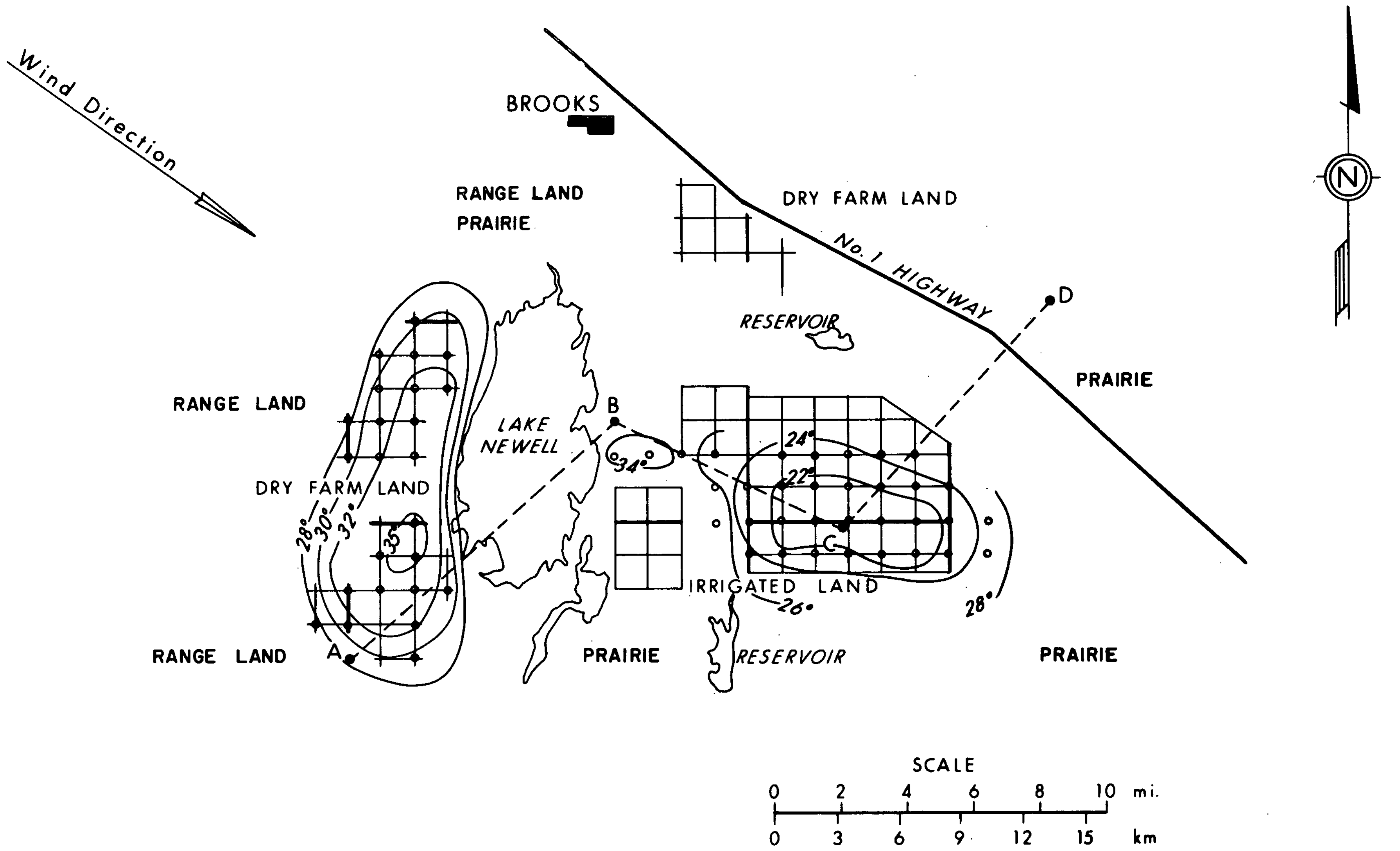

Figure 15. Isotherms of air temperature and observation grid at 2 m above surface of varied agricultural land near Brooks on August 6 and 7, 1968.

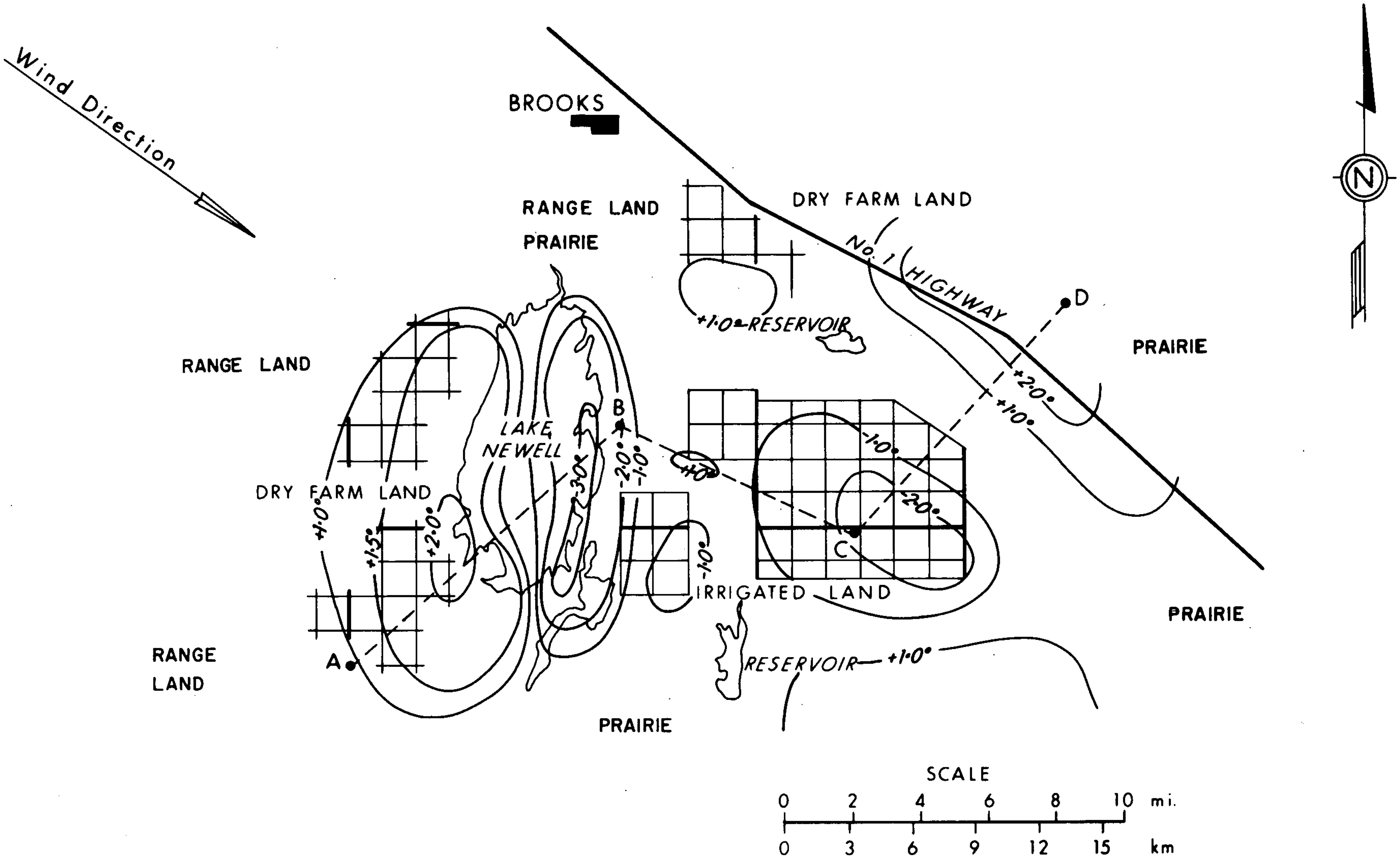

Figure 16. Isotherms of average air temperature difference (°C) at 20 m above surface between positions indicated and ambient prairie air 8 km upwind near Brooks on August 6, 1968.

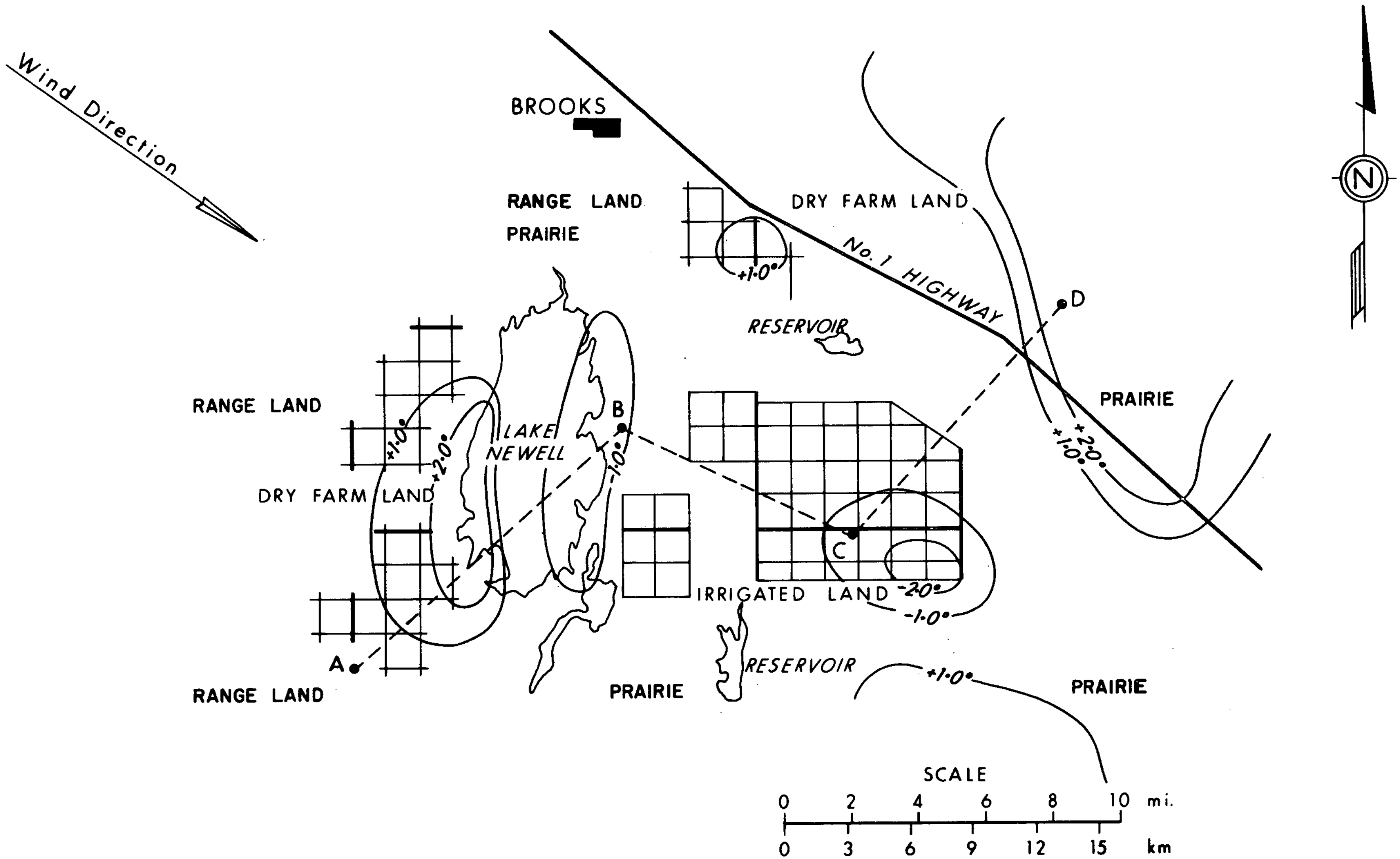

Figure 17. Isotherms of average air temperature difference (°C) at 40 m above surface between positions indicated and ambient prairie air at 8 km upwind near Brooks on August 6, 1968.

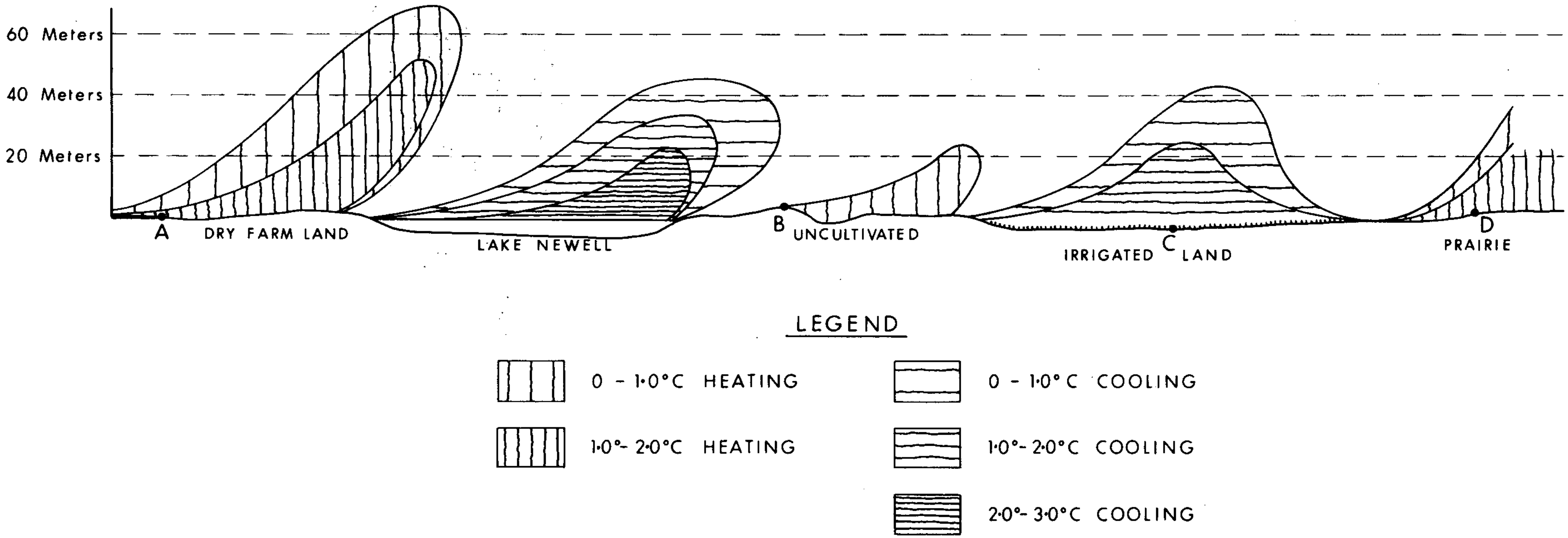

Figure 18. Temperature profile of air temperature over ground track A, B, C, D, over area near Brooks, shown in Figures 15, 16 and 17, on August 6, 1968.

a height of 700 m. Observations were discontinued at this altitude. It must be remembered that the figures show the *average* position of heated and cooled air over a three-hour period. Therefore, the true situation at any single moment may be considerably different and much more complex, since the technique used to determine significance of temperature difference is also a "smoothing" process.

An attempt was made to present the data in a vertical transect and this is shown in Figure 18. The shapes of the heated and cooled air parcels were deduced using the information obtained at the surface and at heights of 2 m, 20 m, 40 m, and 60 m above ground on three consecutive days. The ground track is shown in Figures 16 and 17 (ABCD). The heated and cooled air rises above and extends over adjacent land. For example, warm air from near A extends somewhat above and over the lake, and cooled air extends above and over the heated prairie near B. The frequency and positions of observance of heated and cooled air over the three days suggest that the shapes of the air parcels are qualitative as indicated. Cooled air remains slightly above but closer to the surface, is more uniform in shape and is shorter-lived than heated air. The heated air rises and seems to break off in parcels which persist to greater heights. The temperature structure of air over this area varied considerably from day to day, and was markedly affected by surface heating (radiation) and wind speed and direction.

The effect of advection of warm air on evaporation and evapotranspiration has been studied and is known to greatly increase water losses. The density of measurements in the author's study did not permit a close examination of this phenomenon near the ground where both warm and cold air is seen to advect. The temperature of air at 20 m over the lake decreases with fetch and indicates that warm air from the dry farm land is advecting and slowly cooling with fetch. Similarly, air at 2 m over the irrigated land at C cools with fetch and approaches a minimum temperature down-wind, suggesting pronounced advection of heat at the surface from up-wind areas. One should also note that the lake produces a much stronger oasis and more pronounced advection than the irrigated land.

DISCUSSION AND SUMMARY

The data presented show that it is possible to measure the influence of small prairie oases of agricultural and non-agricultural areas on the temperature of the lowest air layers. However, the position and magnitude of cooling or heating of the air by passage over cool lakes or heated agricultural areas is highly variable and not always measurable. It seems particularly remarkable that under some conditions cooled air should persist for extended periods, especially since the air was very unstable during all of the observational periods. The factors which contribute most to the presence and position of the cooled air are only suggested. Observations indicate that if the effect was measurable at various observational heights over one oasis, then it was measurable over a nearby oasis during the same period; conversely, if the effect was absent from one, it was usually absent from the other during the same time period. This suggests a common factor, or factors, operating at the same time over the entire area under study. These factors are radiational heating of the surface (stability), wind speed and wind direction. The radiation temperature of the surface around and over each area showed that sharp contrasts are possible from one section to another and from one period of the day to another. Others have noted similar differences (8, 9, 17).

It has been previously observed that at the surface the cooling or heating effect on the air of various agricultural surfaces is short-lived and restricted to near the particular surface (6) (9). The data presented here support this view. However, the data also indicate that at elevations well above the surface, heated and cooled air may persist and be advected down wind for considerable distances and completely out of range of surface stations. The variability of this phenomenon is emphasized. Pronounced advection very near the surface is also suggested.

The diurnal fluctuations of the physical characteristics of the earth-air interface and, in particular, surface moisture and temperature, produce an ever-changing "oasis-intensity", with maximum effect when contrasts are greatest. When one investigates the surface of the earth in relation to the lowest air layers, one examines, in effect, the results of a continuum of oases, some of which may be widely spaced and some of which may be overlapping. Therefore, there is a climatic pattern overlaying the irregularities of the earth's surface. This climatic mosaic is not a direct pattern superimposable over the earth, because it is much different in shape due to various "distorting" forces that exist near the surface.

This present work points to some of the surface-air relationships that exist on a meso space and time scale. Further, although the data are not extensive and are insufficient to apply to known theory, the results substantiate the view that important information can be obtained about these relationships by using instrumented aircraft in support of surface observations. It is envisaged that with the support of ground observations, the complete energy budget of meso scale areas of the earth can be determined.

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