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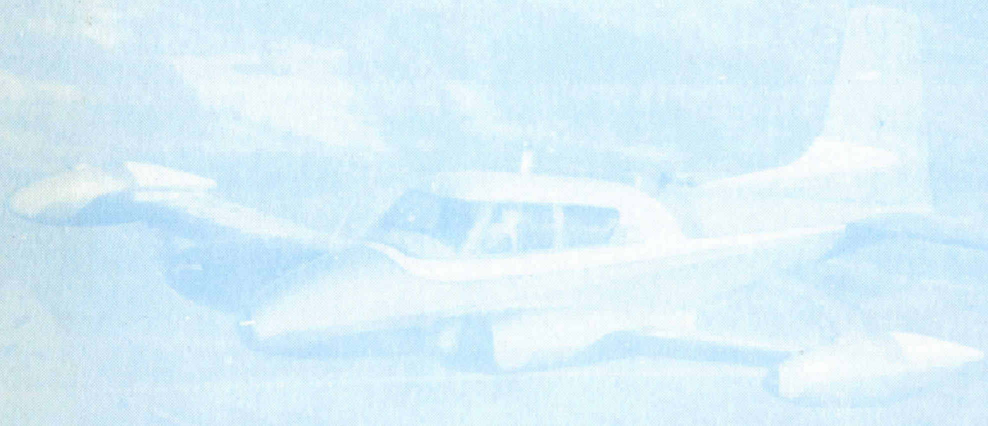
FLIGHT INVESTIGATIONS OF SURFACE ALBEDO

Kenneth G. Bauer
John A. Dutton



Department of Meteorology
The University of Wisconsin
September 1960

FLIGHT INVESTIGATIONS OF SURFACE ALBEDO

A Regional Study of South Central Wisconsin 1959-1960

by

Kenneth G. Bauer

John A. Dutton

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SYMBOLS

A --- Albedo of a surface.

I_o --- Short wave insolation incident on a horizontal surface.

I_r --- Short wave insolation reflected from a horizontal surface.

I_z --- Short wave insolation incident on a horizontal surface at height z.

I_{rv} --- Short wave insolation reflected vertically from a horizontal surface.

I_{rh} --- Short wave insolation reflected from a horizontal surface in all directions.

E_t --- Short wave radiation measured by the top Eppley.

E_b --- Short wave radiation measured by the bottom Eppley.

K_b --- Short wave radiation measured by the Kipp and Zonen.

A_B --- Beam Albedo.

A_H --- Hemisphere Albedo.

1. Introduction

For many years there has been an interest in the absorptive and reflective properties of the materials that make up the surface of the earth. Today it is known that the different amounts of sunlight absorbed by the widely varied surfaces of the earth have a significant effect on the behavior of the atmosphere. In determining the sunlight absorbed, it has been found convenient to evaluate both the incoming sunlight and that reflected--the difference being the amount absorbed. A measure of the incoming and reflected sunlight, and thus of that absorbed, is the albedo of a surface--various aspects of which will be considered in this paper.

The albedo, A, of a surface may be defined as the ratio of solar energy which the surface reflects, I_r, to the solar energy incident upon such a surface, I_o, or

$$A = I_r/I_o.$$

The albedo is an important consideration in any discussion of the heat budget of the atmosphere since it determines the fraction of the incoming solar energy available for differential heating of the surface layer. Historically, measurements of micrometeorological parameters have been conducted over relatively uniform terrain and surface conditions by means of stationary instrument complexes (masts, shelters, etc.). These experiments reduce to a study of the fluctuations of parameters with time in the vertical with the horizontal variations of the parameters usually being ignored. It is, however, to be expected that the wide variety of surface features occurring in nature will bring about significant variations in the horizontal structure of the boundary layer. As it would be unwieldy, as well as uneconomical, to place stationary instrument complexes on each type of surface occurring in a region, a new means of evaluating horizontal variations, and vertical variations above the practical limit of towers, must be considered. The instrumented light airplane seems to be a suitably versatile micrometeorological probe.

The advantages of an instrumented airplane are many. It has almost complete three-dimensional mobility which permits the investigation of micrometeorological parameters at specific locations and altitudes as desired. Its speed and range allow measurements to be made over large areas, approaching a synoptic scale, in a relatively short period of time. It provides a stable instrument platform. Being mobile and self-contained, an airplane is capable of operating over regions inaccessible to conventional micrometeorology stations. The inherent problems that arise in ground observational systems are also present in airborne probes, along with many additional problems, all of which must be considered. Among the more prominent airborne problems peculiar to measurements from airplanes are those of scale and "seeing." The responses of airborne sensors to the variations in surface parameters and the observational probability of measuring features of various size and number over a given flight path are discussed in detail by Dutton (1959).

The albedo of the ground is one important micrometeorological element which can be readily measured from aloft. Quantitative airplane measurements of surface albedo were obtained, among others, by Fritz (1948) and Kuhn and Suomi (1958). Some results of surface albedo measurements made over the sub-arctic, using a helicopter, are given by Jackson (1959). Jackson found that one great disadvantage of helicopter albedo measurements was the excessive vibration inherent in rotary-wing aircraft.

As a supplement to the total albedo, the spectral reflectance of natural surfaces can be measured from low-flying airplanes. Interesting results of several such studies have been summarized by Condion and Toolin (1957).

The purpose of this paper is to present the results of surface albedo measurements obtained by the use of an instrumented airplane operating at low level over south central Wisconsin. Although various other micrometeorological parameters were also measured during the course of these flights, the main consideration here will be given to the study of surface albedo.

In Section 2 the micrometeorological instrumentation of the airplane and methods of data evaluation are presented.

Some relationships between the measured parameters are considered.

The variation of albedo with the seasons is discussed in Section 3. Tables of average albedo values observed over various surface types are included in the appendix. Diurnal variations of albedo are considered in Section 4 and the vertical variations of measured albedo in Section 5.

In Section 6 some interesting case studies of observations taken during the flights are presented. Special consideration is given to flights that involve the effects of clouds on the measurement of albedo. Section 7 will contain some conclusions drawn from the results presented in the paper.

2. Instrumentation and Data Evaluation

2.1 Instrumented Airplane. A Cessna 310 is used as the research airplane in this project. Its operational capabilities are very well suited to a project of this type. The speed and endurance it provides allow surveys of large areas to be made in relatively short periods of time. The margin of safety provided by its twin engines permits unrestricted low level operation or flights over extended water or wilderness areas not feasible in a single engine light airplane. It can operate from airstrips not accessible to larger airplanes and still provide adequate space for crew, instrument installations, and supplies. The uninterrupted airframe construction allows all sensors to be mounted with little or no obstruction to their fields of view so that the shading effect of the airplane on the instruments may be considered negligible.

The micrometeorological instrument complex installed on the University of Wisconsin airplane at this time may be said to consist of three groups of sensing devices:

(1) Two Eppley pyrheliometers mounted on the top and bottom of the airplane to measure short wave radiation. In addition, a downward-facing Kipp and Zonen solarimeter was added midway in the program to provide additional short wave radiation measurements;

(2) Two black-coated "economical" radiometers (Suomi and Kuhn, 1958) to measure upward and downward total radiation

flux and net radiation. Later installation of a white-coated downward-facing radiometer allows computation of the long wave radiation impressed upon the bottom sensors. In addition to the radiometers, thermocouple air temperature measurements are taken at the top and bottom of the airplane;

(3) An aerial camera which records the surface over which the measurements are made. The recent installation of a radio altimeter on the airplane adds the capability of accurate determination of sensor height over any terrain and a means of determining actual terrain height variations along the observation path. Additional comments and photographs of the airplane instrument complex are given by Dutton (1959).

2.2 Albedo (Beam and Hemisphere). Only the results of measurements obtained from the sensing devices in the first group will be presented in this paper. These instruments are enclosed in glass and thus are sensitive only to short wave solar energy.

The characteristics of the Eppley pyrheliometer have been discussed in the literature by MacDonald (1951) and others. One ten-junction Eppley is mounted on the top of the airplane so that it is horizontal in straight and level flight. The top Eppley, E_t, provides a continuous measure of the incoming radiation, I_z, received by the airplane at height z.

A second ten-junction Eppley is mounted upright in a downward-facing beam reflector of narrow beam width (four degrees) on the bottom of the airplane. The installation is essentially identical with that described by Kuhn and Suomi (1958). The bottom Eppley, E_b, measures the short wave radiation reflected vertically from the surface, I_{rv}, as received at the airplane. With a beam width of four degrees for the parabolic reflector, it may be calculated that at an altitude of 500 feet above the surface the reflector is sampling a roughly circular area with a diameter of approximately 35 feet, and at an altitude of 1000 feet an area 70 feet in diameter. Thus at low altitudes we assume the beam reflector provides a "point" sampling or that the measurement would normally correspond to that of a small homogeneous area.

For the purpose of the study we will make the following assumptions for low level flights:

(1) The short wave radiation incident on the surface, I_o, equals that measured by the airplane, E_t.

(2) The short wave radiation reflected from the surface and measured by the reflector-mounted Eppley, E_b, equals that reflected vertically from the surface, I_{rv}. The validity of these assumptions will be discussed in Section 5.

Using the above assumptions we can make the following statement. The ratio of short wave radiation reflected from the surface, as measured with the beam reflector, E_b, to the measured incoming short wave radiation, E_t, is defined as the beam albedo, A_B, of a surface.

$$\frac{E_b \times 100}{E_t} = A_B \text{ (per cent)}$$

The Kipp and Zonen solarimeter on the bottom of the airplane, K_b, consists essentially of two concentric glass domes through which short wave radiation is received on a blackened thermopile. The radiation is converted into a voltage potential which is a measure of the radiation received on the sensor, much in the manner of the Eppley pyrheliometer. In contrast to the bottom Eppley with the beam reflector, the Kipp and Zonen measures the short wave radiation received over a solid angle of approximately 2π steradians.

As before, we will assume that I_o equals E_t, and also that the short wave radiation reflected from the surface and measured by the hemisphere-seeing Kipp and Zonen, K_b, equals that reflected from the surface in all directions, I_{rh}. The ratio of K_b to E_t is defined as the hemisphere albedo, A_H.

$$\frac{K_b \times 100}{E_t} = A_H \text{ (per cent)}$$

For comparison purposes, values of both the beam albedo and hemisphere albedo are presented--by graphs in Section 3.4 and by tabular form in the appendix. As may be seen by inspection, the beam albedo is consistently lower in value than the hemisphere albedo. Representative values from the tables show that over a uniform snow surface the beam albedo is 23% lower, over spring farmland 22% lower, over forest land in spring 19% lower, and over rippled water surfaces 60% lower. The percentage difference between the two values is quite variable--depending upon the type of surface for which it is computed. Smoother surfaces in general show the greatest differences.

The difference between beam and hemisphere albedo is caused mainly by the different fields of view of the two instruments. The Kipp and Zonen has a field of view of approximately 2π steradians and thus is sensitive not only to radiation being reflected from the surface directly beneath but to radiation from other sources as well. These may consist of (1) reflections from surfaces located outside the area of interest, (2) scattered or reflected radiation from air molecules and from regions of particulate matter suspended in the atmosphere at or below flight level, and (3) short wave radiation in the form of skylight if the level of observation is increased to a point that permits the instrument to see above the horizon. At very low sun angles there is also the possibility of receiving direct sunlight on the instrument.

In contrast, the bottom Eppley with the beam reflector receives only the reflected radiation contained within the effective beam width of the instrument. This essentially eliminates the effects of radiation reflected from surfaces outside the area of interest and the effect of skylight. It does not completely eliminate the effect of air molecules and of suspended particles but reduces it to a small value compared to the radiation reflected from the surface.

The hemisphere albedo is a weighted mean albedo of a large area of the surface but may be influenced by the other effects mentioned previously. The beam albedo is a measure of the radiation being returned almost vertically from a small area on the surface and thus would appear to better approximate the true albedo of a particular surface if the true values are not stationary and if the reflected radiation is isotropic. Further investigations will be required to determine the exact relationships between the two measurements of albedo and their applications to the heat budget of the surface of the earth. It is the opinion of the author that the best evaluation of the heat absorbed by a surface can be made by using a value of albedo located between the measured values with somewhat more weight being given to the value of the beam albedo.

2.3 Data Recording. To permit a simultaneous recording of the signals produced by the several sensors on the airplane, a multi-channel oscillograph recorder was installed. It utilizes an ultra-violet sensitive paper chart strip upon which a thin continuous trace is made of each signal being recorded. This trace is produced by a beam of ultra-violet light reflected by a mirror attached to a very sensitive galvanometer. The galvanometer gives a linear response to signal variations from the sensor. The recording chart strip may be exposed at rates up to 25 inches per minute with a rate of 5 inches per minute being chosen as the most suitable for the project. The exposed recorder chart strip is developed and evaluated under incandescent or fluorescent light with care being taken to prevent sunlight reaching the record at any time.

To aid in the identification of the signal produced by each sensor, each trace is periodically and automatically interrupted by the recorder in a constant sequence. In addition, a timing and counting circuit places an identification trace on the record in conjunction with a visual counting device. This permits a number obtained from the counter, at a known time and location, to be entered in the flight log for future identification. Special events are noted on the record by manually displacing a selected trace by use of a sensitivity switch. Variable sensitivities are provided for those sensors observing values that vary over a large range, usually with the season, to permit the most effective use of the recorder.

2.4 Record Evaluation. In theory it would be possible to obtain an almost infinite number of readings for a sensor from the continuous trace available. In practice, the sampling rate must be adjusted to be in accordance with the capabilities and requirements of the study. These might include the variability of the surface observed, sensitivity of the instruments, detail desired, data processing facilities, and many more.

The sampling criteria used in this project are described in the following steps:

(1) The airspeed of the airplane while observations are being made is approximately 180 miles per hour which gives a ground speed of three miles a minute under calm conditions. With a recorder speed of five inches of record per minute, there is one inch of record for each three-fifths of a mile of surface observed. As will be discussed in Section 3, the selected surfaces over which the average albedo is desired are from two to nine miles in length. To provide a sufficient number of samples to be averaged, an arbitrary sampling interval of twelve seconds, or every inch of record, was selected.

(2) In order to eliminate as much error as possible, the values to be averaged are sampled from the record only when the airplane is in straight and level flight. In addition, following turns, abrupt changes of terrain and/or surface, or other factors affecting the stability of the sensors, the instruments are allowed to stabilize again before sampling the record. Such variations are noted in the flight log as special events to prevent their inclusion in the samples. It has been found that representative values can be obtained for uniform surfaces (water, snow, large fields, etc.) by the use of single or "spot" samplings of the record.

2.5 Data Processing. After the portions of the record to be sampled are determined, values of all the sensors are read for the same instant in time. This permits a direct comparison and evaluation of the values recorded from each instrument. Each value is manually read from the strip chart as the number of chart divisions the trace is removed from the zero point of the instrument. The number of divisions in turn is multiplied by a calibration constant computed for each sensor. In the case of the short wave instruments, this gives a final measured radiation quantity in langleys per minute. From these values we compute the albedo of the surface.

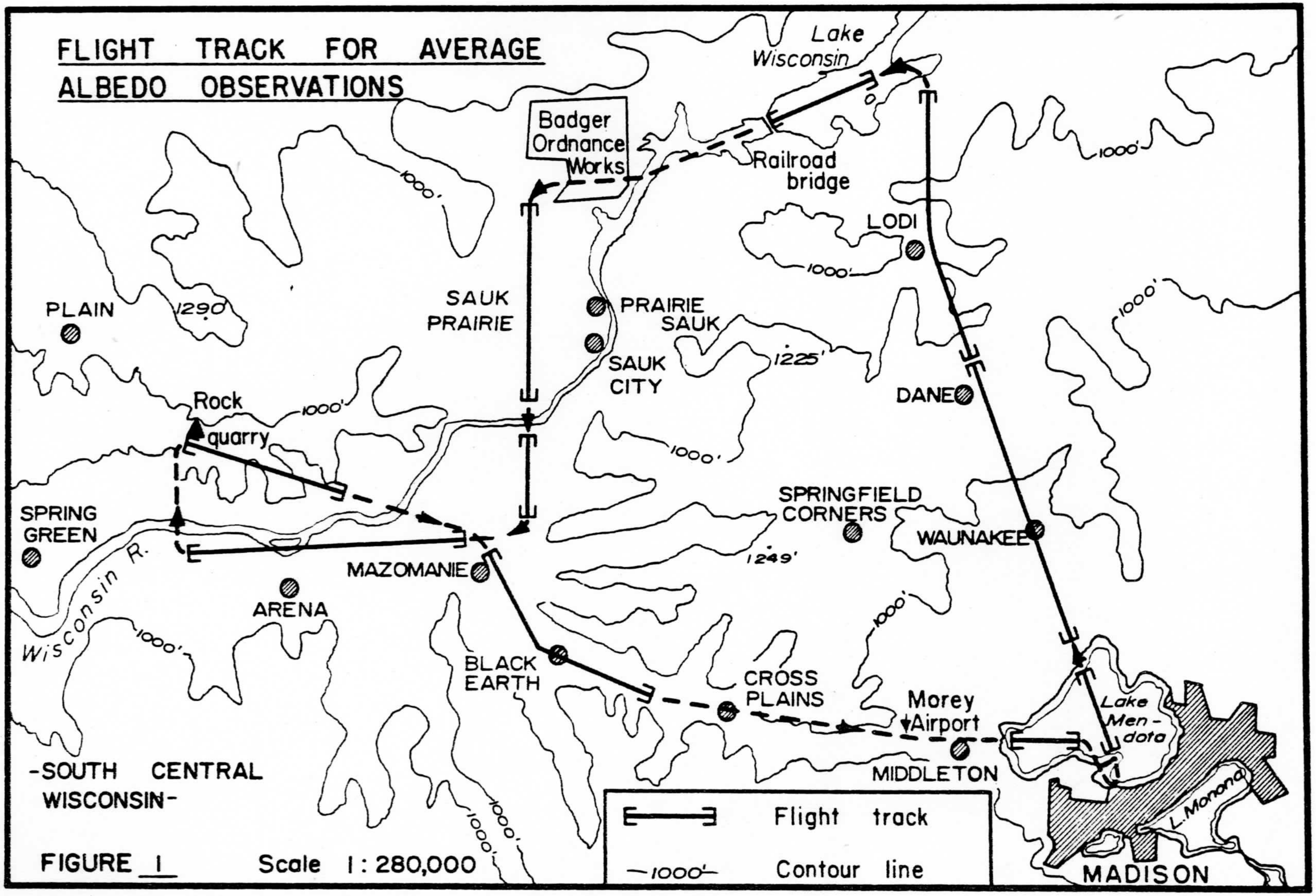
The first values of radiation and albedo were calculated by means of a standard desk calculator. Later computations are being carried out by an IBM 650 electronic computer. The computer is programed to complete all steps of the operation during one run of the raw data. It was necessary to adapt operations to the IBM computer program in order to process the large amount of raw data made available by a project of this scale.

3. Variation of Albedo with the Seasons

3.1 Observation Program.

A program of regular observation flights began in October 1959 over a previously selected flight path. The purpose of these flights is to measure the change in albedo as surface characteristics are modified by seasonal variations of the weather. This will aid in understanding how solar energy received at the surface of the earth is utilized in differential heating from season to season. Observations are made at intervals of two to four days when possible. Periods of poor weather, modifications of the micrometeorological instrument complex, and periodic airplane inspections and maintenance have at times produced longer intervals between observation flights.

Prior to the beginning of the regular series of flights, a survey was made of the surrounding area to determine what flight path would give the best selection of representative surface types and terrain features. It is desirable to have relatively homogeneous areas representative of the various surface types found in south central Wisconsin and of sufficient extent to permit several observations to be obtained for each area. In the final selection, an integrated series of ten sections was chosen for observation. The standard track flown in conjunction with this portion of the project is presented in Figure 1. The sections under observation are enclosed by brackets. The track is flown in a counter-clockwise direction, beginning and terminating over



FLIGHT TRACK FOR AVERAGE ALBEDO OBSERVATIONS

FIGURE 1 Scale 1 : 280,000

Lake Mendota.

3.2 Representative Surfaces. To aid in the interpretation of the results of this program, with regard to the type of surfaces selected and observed, written descriptions and aerial photographs of each section are presented. The aerial photographs shown in Figure 2 through 9 display the standard flight track as a dashed line with the observation sections enclosed by brackets. Each section has been given a descriptive title for ease in identification and will be listed in the order in which they are observed during an actual flight to preserve continuity.

Mendota West, Figure 2. Lake Mendota is a natural lake with an area of 15.2 square miles and a mean depth of 39 feet. The observations are made over the western section of the lake on a 2 mile leg to the east terminating over the water abeam Second Point. An average of three values is used to compute the mean albedo of this portion of the lake.

Mendota North, Figure 2. A second section of Lake Mendota was chosen for comparison purposes. The observations are made over the northern section of the lake on a 2.3 mile leg to the NNW terminating at the northwest shore of the lake. An average of four values is used to compute the mean albedo of this section.

Waunakee--Dane, Figure 3. Observations of this section are made over a 9 mile track beginning at a point 3.5 miles SSE of Waunakee and ending 1.5 miles north of Dane. Rich, slightly rolling farmland comprises this section in a checkered pattern of varied field crops and pasture. An average of fifteen values is used to compute the mean albedo of this typical farmland.

Lodi, Figure 4. This section is observed for a distance of 9 miles beginning at a point 1.5 miles north of Dane and ending 1 mile south of the east end of Lake Wisconsin. Most of the track is made up of rolling farmland with varied crops and an increase in pasture from the previous section. Wooded hillsides are scattered along the track. The northern 10% of the track is upland forest. A wind-eroded, tree-spotted, sandy area located south of the forest makes up another 10% of the track. An average of fifteen values is used to compute the mean albedo of this varied section.

Lake Wisconsin, Figure 5. Lake Wisconsin is a shallow, artificial lake formed behind a hydroelectric dam built on the Wisconsin River. Observations are made over the eastern half of the lake on a 3.4 mile leg from 0.5 miles north of the small island to the railroad bridge which bisects the lake. An average of five values is used to compute the mean albedo of this lake.

Sauk Prairie, Figure 6. Flat, rich farmland for a distance of 5 miles makes up this section. It begins 2 miles west of the Badger Ordnance Works and ends at the beginning of the swamp and trees 1 mile north of the large bend in the Wisconsin River. The fields are checkered with varied crops.

A small, dense pine plantation stands midway on the track. An average of eight values is used to compute the mean albedo of this plain.

River Floodplain, Figure 7. Checkered fields of rich dark soil make up this 2.7 miles of level river bottom cropland. It begins 0.5 miles south of the Wisconsin River and ends at a point 1.5 miles NE of Mazomanie. In the spring, this area is partially flooded, and it is moist most of the time. An average of five values is used to compute the mean albedo of this section.

Mazomanie West, Figure 8. A variety of surfaces make up the 8.3 miles of this leg of the route located just south of the Wisconsin River. It begins with level farmland and scattered groves of trees at a point 1.3 miles NW of Mazomanie. This amounts to 20% of the route. We then have a brushy marsh--20%, a typical Wisconsin bog--10%, river bottom forest--10%, and the remainder consisting of level grassland or pasture with small areas of sand and scrub pine. It terminates 4.5 miles due east of Spring Green. An average of fourteen values is used to compute the mean albedo of this composite section.

Wooded Hills, Figure 8. The hills north of the Wisconsin River are typical of the southern Wisconsin dry upland forest with small farmed areas in the valleys. The 4.3 miles of this leg begin at a rock quarry 2 miles north of the river and extend eastward to the edge of the river plain. An average of eight values is used to compute the mean albedo of the forested hills.

Black Earth, Figure 9. This section is made up of 6.8 miles of rich, narrow, flat, farmed creek valley. It begins at Mazomanie and ends at a point 2 miles west of Cross Plains. An average of eleven values is used to compute the mean albedo of this valley.

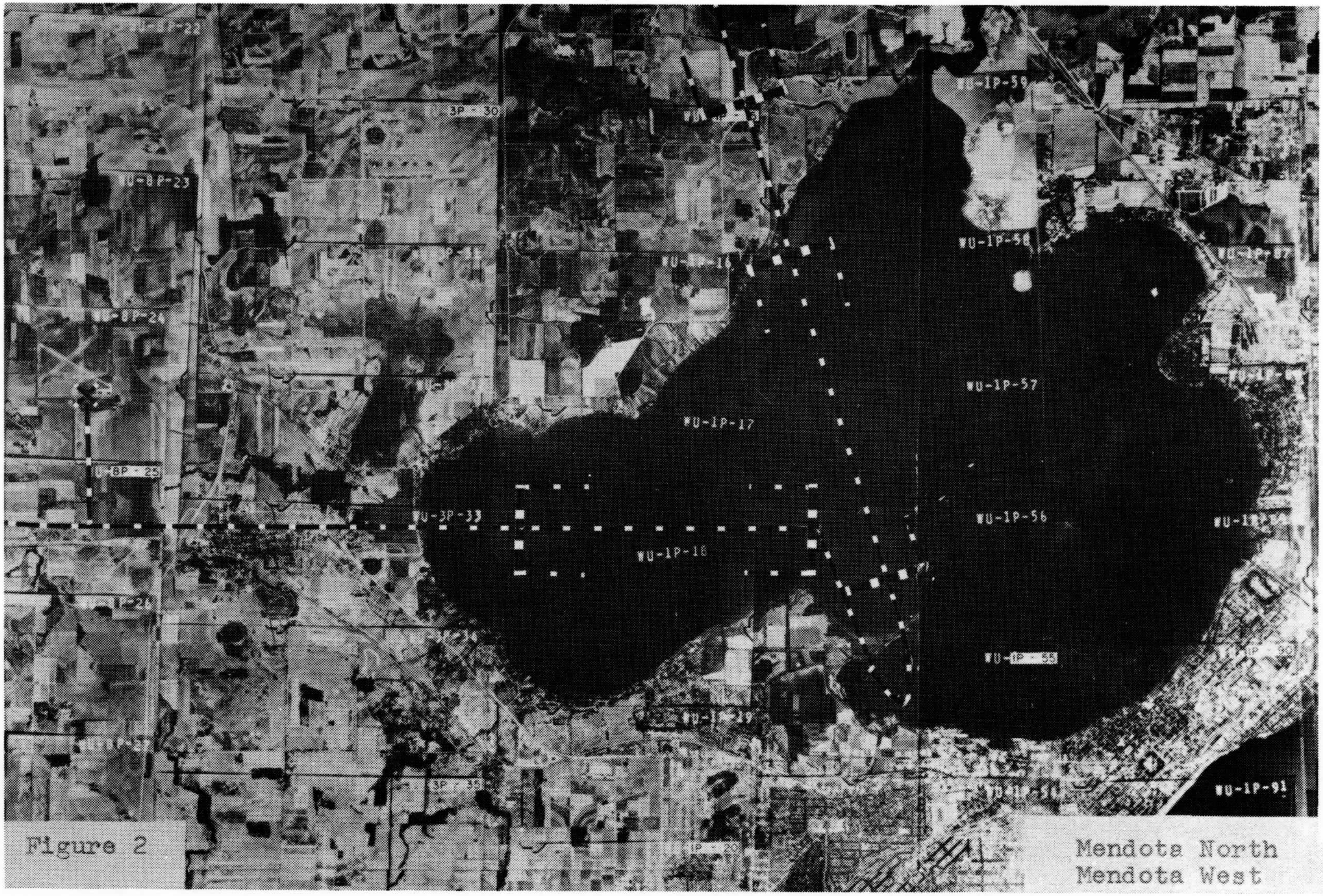


Figure 2

Mendota North
Mendota West

Figure 3 Waunakee-Dane

Figure 4 Lodi

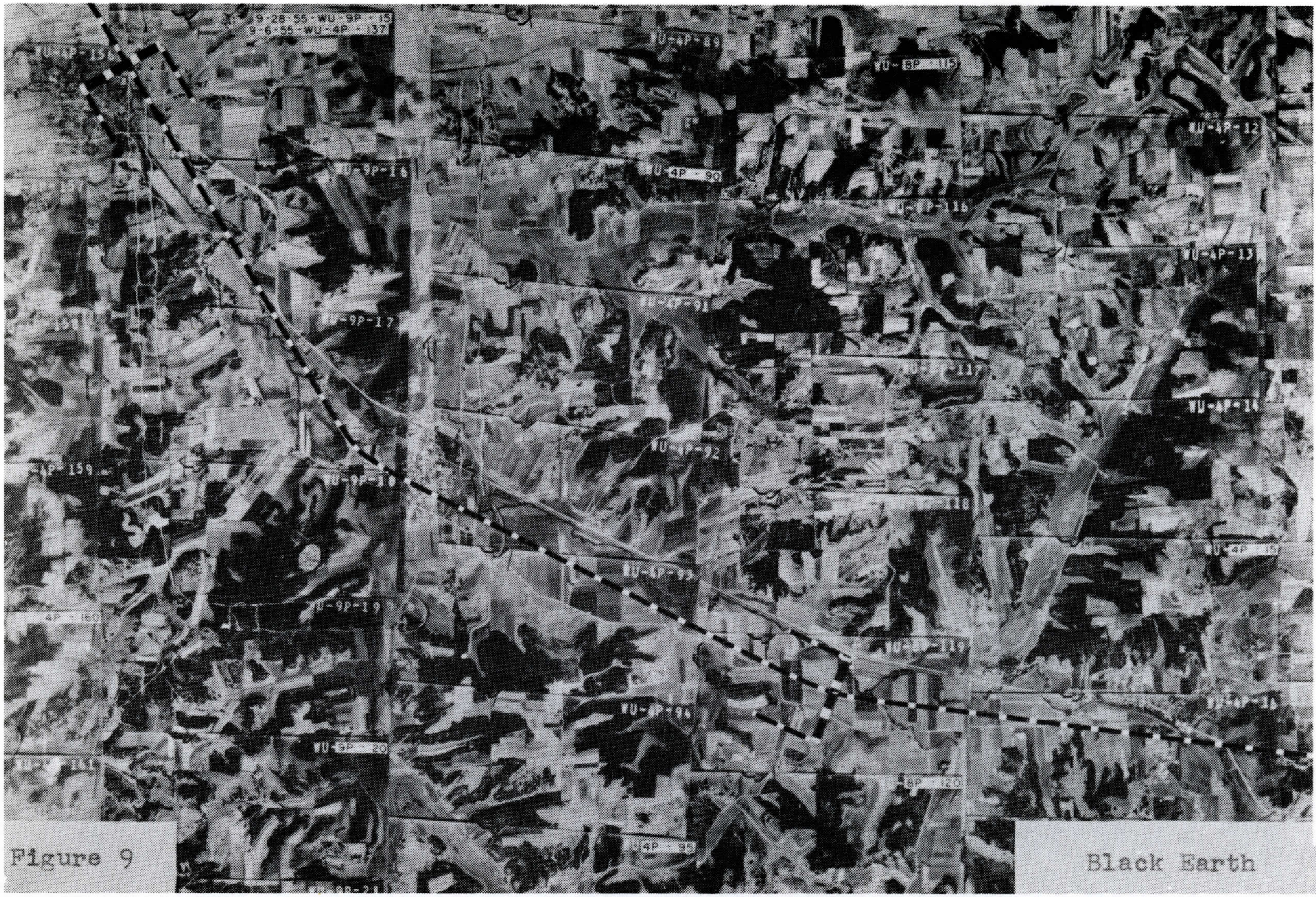
Figure 5 Lake Wisconsin

Figure 6 Sauk Prairie

Figure 7 River Floodplain

Figure 8

Wooded Hills
Mazomanie West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WU-4P-92
WU-9P-18
WU-4P-93
WU-9P-19
WU-4P-94
WU-9P-20
Black Earth

Figure 9

3.3 Observed Seasonal Albedo. Average albedo values observed over south central Wisconsin with the change of the seasons are presented in Table 1 of the appendix. All parts of Table 1 give the date of the observation in the left-hand column. Part I of the table gives the average albedo as observed over three sections: Waunakee-Dane, Lodi, and Sauk Prairie. The observations for each section are given in the following form:

$$T/H = \frac{\text{Time of Observations (CST)}}{\text{Height (hundreds of feet) of the airplane above the terrain}}$$

A_B = Beam Albedo (per cent)

A_H = Hemisphere Albedo (per cent)

Part II gives the data for the three following sections: River Floodplain, Mazomanie West, and the Wooded Hills in the same format as Part I. Part III gives the data for the Black Earth Section. In addition, Part III gives the sky and surface conditions experienced during the period of the flight. Variations in sky conditions over any section are indicated by (*) while changes in the surface condition are indicated by (+).

Average albedo values observed over Lake Mendota and Lake Wisconsin are presented in Table 2 of the appendix. Part I of the table gives the average albedo values for Mendota West and Mendota North with the state of the lake surface of each. Part II gives the average albedo values for Lake Wisconsin and the state of the lake surface. In addition, the sky condition experienced over both lakes is given in the third column. The format for the observations in Table 2 is the same as that for Table 1.

3.4 Discussion of Albedo Variations. To better illustrate the seasonal changes of the surface albedo, graphs of observed albedo, standard deviation, and relative variation versus time are presented for each section in Figures 10 through 17. Figure 18 gives only the albedo values for both Mendota West and Mendota North for direct comparison. The plotted points have been linked by solid or dotted lines as an aid to following trends and do not infer the nature of variations between observations. Days on which several flights were made have the different values observed connected by solid vertical lines.

The average albedo values are plotted using one of two symbols: (1) An open circle (o) is used for sky conditions of clear, scattered, or broken or overcast thin cirrus clouds. (2) A solid dot (•) is used for sky conditions of broken or overcast clouds which obscure the sun most or all of the time.

As a measure of the degree of variability or dispersion of the observed albedo values, the root mean square departure from the mean (standard deviation) has been computed for all observation sets containing more than three values. The standard deviation is plotted as the number of albedo units equal to one standard deviation versus the days of the year.

The ratio of the variation of albedo, as measured by the standard deviation, to the mean value of the albedo is a measure of the relative variation of the observed albedo. The relative variation is expressed as a percentage and is plotted versus the days of the year.

As may be seen from the plots of standard deviation and relative variation (Figures 10 to 18), there are noticeable variations of both parameters from day to day within the sections as well as from section to section. This is not unexpected as each section is not completely homogeneous within itself and thus each is affected in different ways by changes in the weather and surface conditions.

In general it may be said that the size of the standard deviation is directly related to the magnitude of the albedo values but this varies greatly from section to section--depending upon the type of surfaces included in the observations. The largest values of the standard deviation were found over areas in which there were large variations in the snow cover due to differences in snowfall, selective melting of certain areas, or patches of evergreen trees. When there was no snow on the surface, the standard deviations become lower and more uniform in each section but still show variations due to changes in surface vegetation, soil, or water conditions. Many times with cloudy conditions the standard deviation of the albedo experiences large variations due to the changes in intensity of the incoming radiation passing through non-uniform cloud covers.

The relative variation has been computed to determine if the standard deviation is largely a function of the magnitude of the albedo of an area or if it is also an indication of the variability of the surface within the area. A comparison of the relative variation from one section to another shows that it is relatively steady over the more homogeneous sections but exhibits large variations in those sections having pronounced variations in surface conditions. This is best seen in the values for the River Floodplain and the Mazomanie West sections. It is especially noticeable during the period of partial flooding of these areas. The results indicate that the relative variation of albedo is an indication of the variability of the area being measured and may be used to compare variations in surface features between areas.

The periods with snow on the surface show the largest variations in albedo from one surface to another. The highest values were measured over the frozen lakes with a uniform snow cover while progressively lower values are observed as the percentage of trees and other dark surfaces increases. The lowest average values were obtained over the Wooded Hills section where the albedo averaged almost 40% lower than over the snow-covered lakes--probably due in part to the winter-time shadows in the valleys. As the snow melts, all the land areas covered with vegetation turn an almost uniform brown color and show very little variation of the average albedo from one to another. As the fields and forests become green with the coming of spring and summer there is little change in the average albedo from the period of brown vegetation. The lowest average values are found over the areas of dark and moist soil (River Floodplain) with the highest average values observed over the areas of relatively smooth and homogeneous surfaces (Waunakee-Dane and Black Earth sections). The lake surfaces exhibit uniformly high albedo values when snow-covered and vary according to the surface condition of the water at other times. The variations of average albedo between sections are much less than would be found in comparing single values of each individual type of surface. The average values tend to mask the extreme variations that may be present.

The seasonal changes in average albedo of the various sections are well-illustrated by Figures 10 through 18. On a large scale there are two distinct levels of albedo that stand out and are separated by brief periods of transition. During the period of snow cover there are high albedo values over all areas. With the melting of the snow the albedo values drop to a much lower level and remain relatively constant until snow covers the surface again.

Albedo exhibits only two seasons--snow or no snow. It does not show distinct seasonal variations with observable color changes of the fields and forests as they go through their spring--summer--fall cycle.

The distinct differences between the two main albedo levels and the rapid change from a period of little absorption to one of much greater absorption would seem to show quite well the radiation effects involved in the coming of spring to an area. While the snow cover is on the ground, there is little modification of air masses in the region, as only about 30% to 40% of the incoming short wave radiation is absorbed by the surface. This effect continues until a warm mass of air from a region free of snow cover moves over the area and removes the snow cover. Once the snow cover is gone, approximately 85% of the incoming sunlight is absorbed by the surface and much of this is available to warm the air over it. With the snow gone an air mass that previously remained cold while over the area is now rapidly modified by the heat available at the surface. For example, the Madison daily temperature curve shows a rather abrupt rise in the average daily temperature at this time. Once the cold air masses are not able to retain their identity over the region, temperatures are much more favorable for the beginning of new plant growth and spring makes its appearance (Bryson and Lahey, 1958).

The reverse of this procedure for air mass modification is apparently true with the coming of winter. It has been observed that the cold weather of winter does not persist in a region until the local area and that to the north have acquired a significant snow cover. It may be seen in Figures 10 through 18 that a persistent snow cover and associated high albedo can appear quite rapidly and once established persist for some time even though there are many periods of sunshine to provide radiant energy at the surface.

Only the more pronounced albedo variations have been mentioned in this section. Additional observation and study will be required to provide a more complete understanding of the prominent features and of the less apparent but no less important small scale features of albedo and its variations with the seasons.

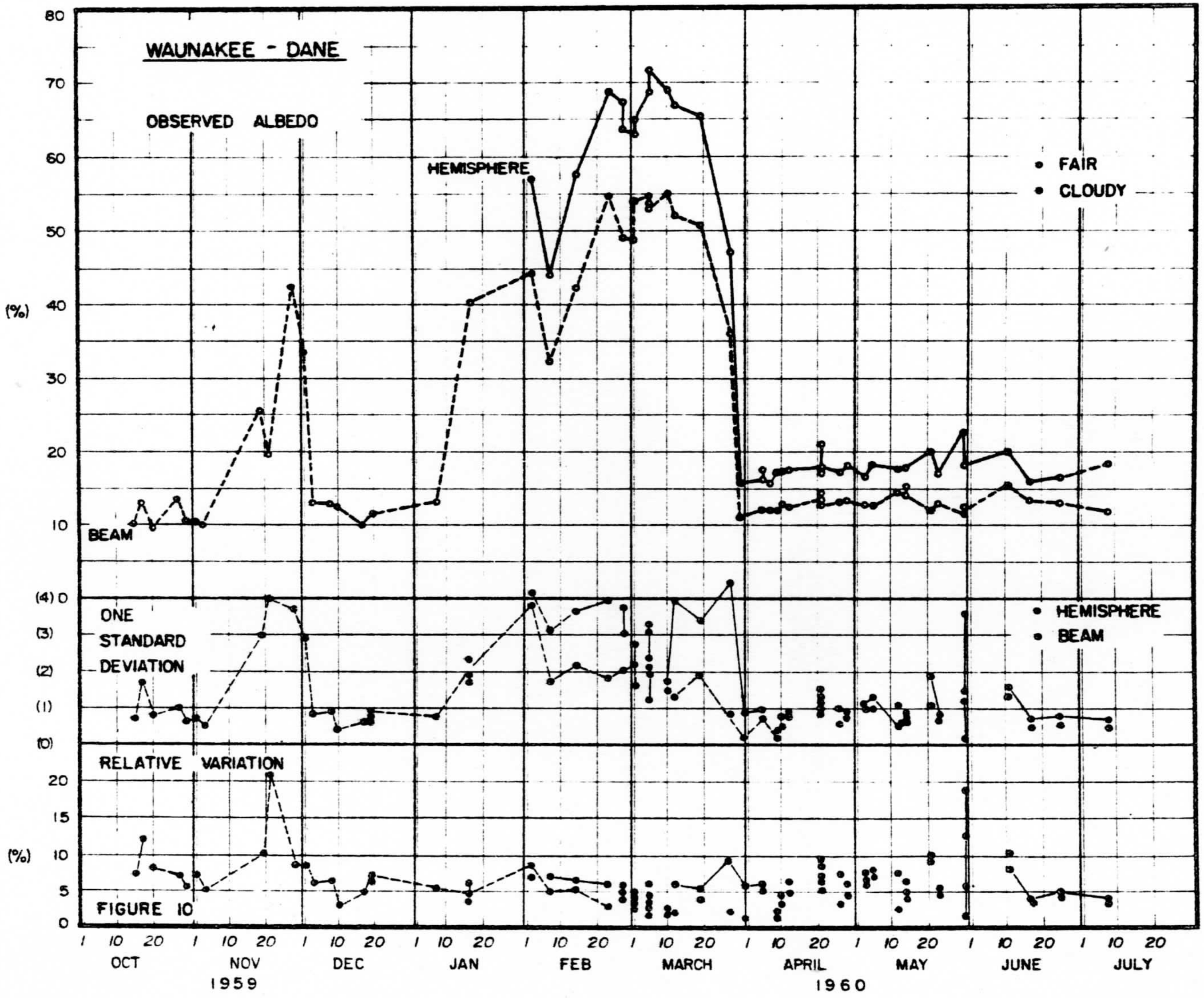

WAUNAKEE - DANE
OBSERVED ALBEDO
HEMISPHERE
BEAM
● FAIR
● CLOUDY
(%)
80
70
60
50
40
30
20
10
ONE STANDARD DEVIATION
● HEMISPHERE
● BEAM
(4) 0
(3)
(2)
(1)
(0)
RELATIVE VARIATION
(%)
20
15
10
5
0
1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
1959
1960

FIGURE 10

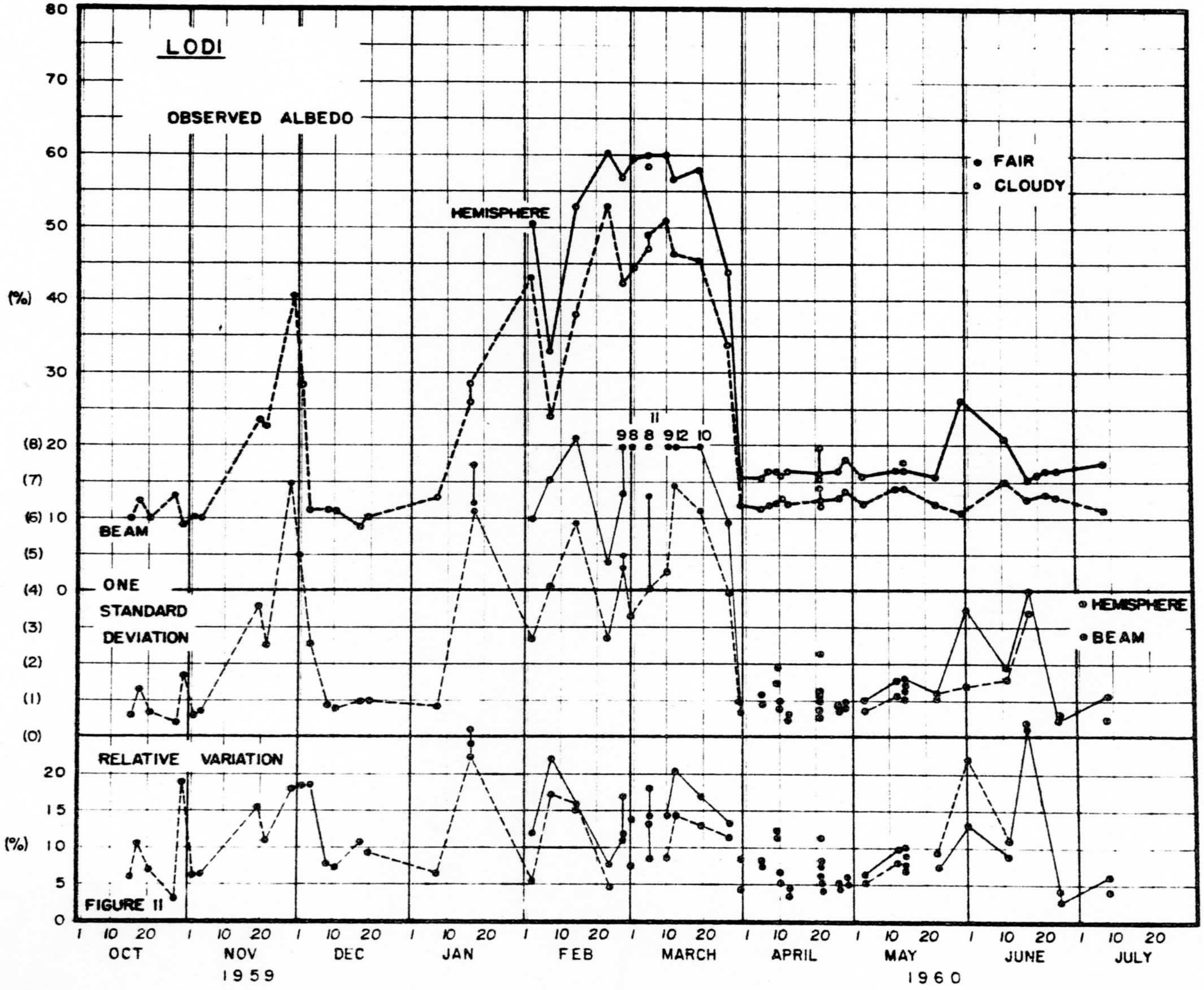

LODI
OBSERVED ALBEDO
HEMISPHERE
BEAM
• FAIR
• CLOUDY
ONE STANDARD DEVIATION
• HEMISPHERE
• BEAM
RELATIVE VARIATION
9 8 8 11 9 12 10
(%)
80
70
60
50
40
30
(8) 20
(7)
(6) 10
(5)
(4) 0
(3)
(2)
(1)
(0)
20
15
10
5
0
1 10 20 OCT
1 10 20 NOV
1 10 20 DEC
1 10 20 JAN
1 10 20 FEB
1 10 20 MARCH
1 10 20 APRIL
1 10 20 MAY
1 10 20 JUNE
1 10 20 JULY
1959
1960

FIGURE 11

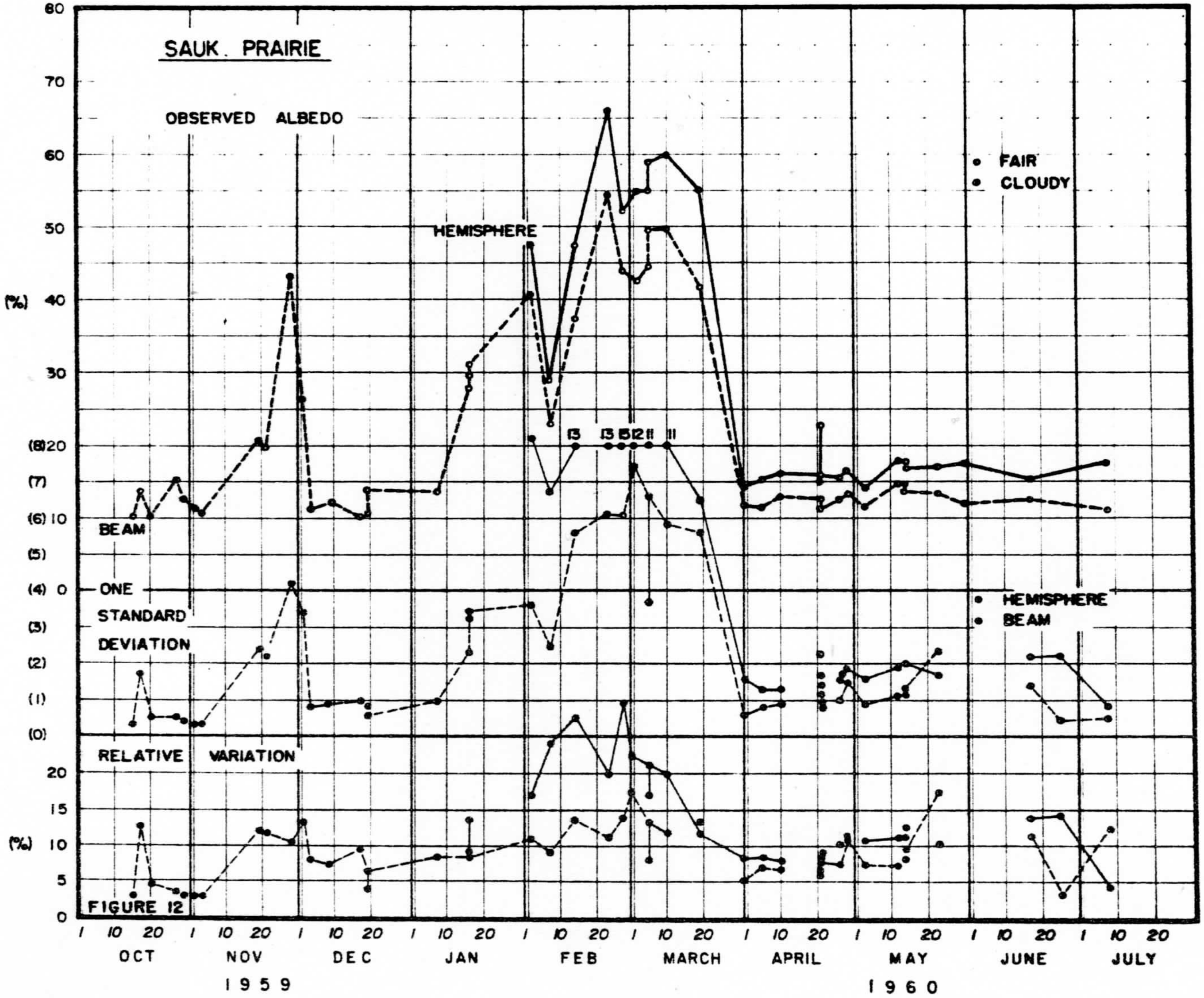

SAUK. PRAIRIE
OBSERVED ALBEDO
HEMISPHERE
BEAM
ONE STANDARD DEVIATION
RELATIVE VARIATION
○ FAIR
● CLOUDY
● HEMISPHERE
● BEAM
13
13 15 12 11
11
(%)
80
70
60
50
40
30
(8) 20
(7)
(6) 10
(5)
(4) 0
(3)
(2)
(1)
(0)
20
15
(%) 10
5
0
1 10 20
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
1 9 5 9
1 9 6 0

FIGURE 12

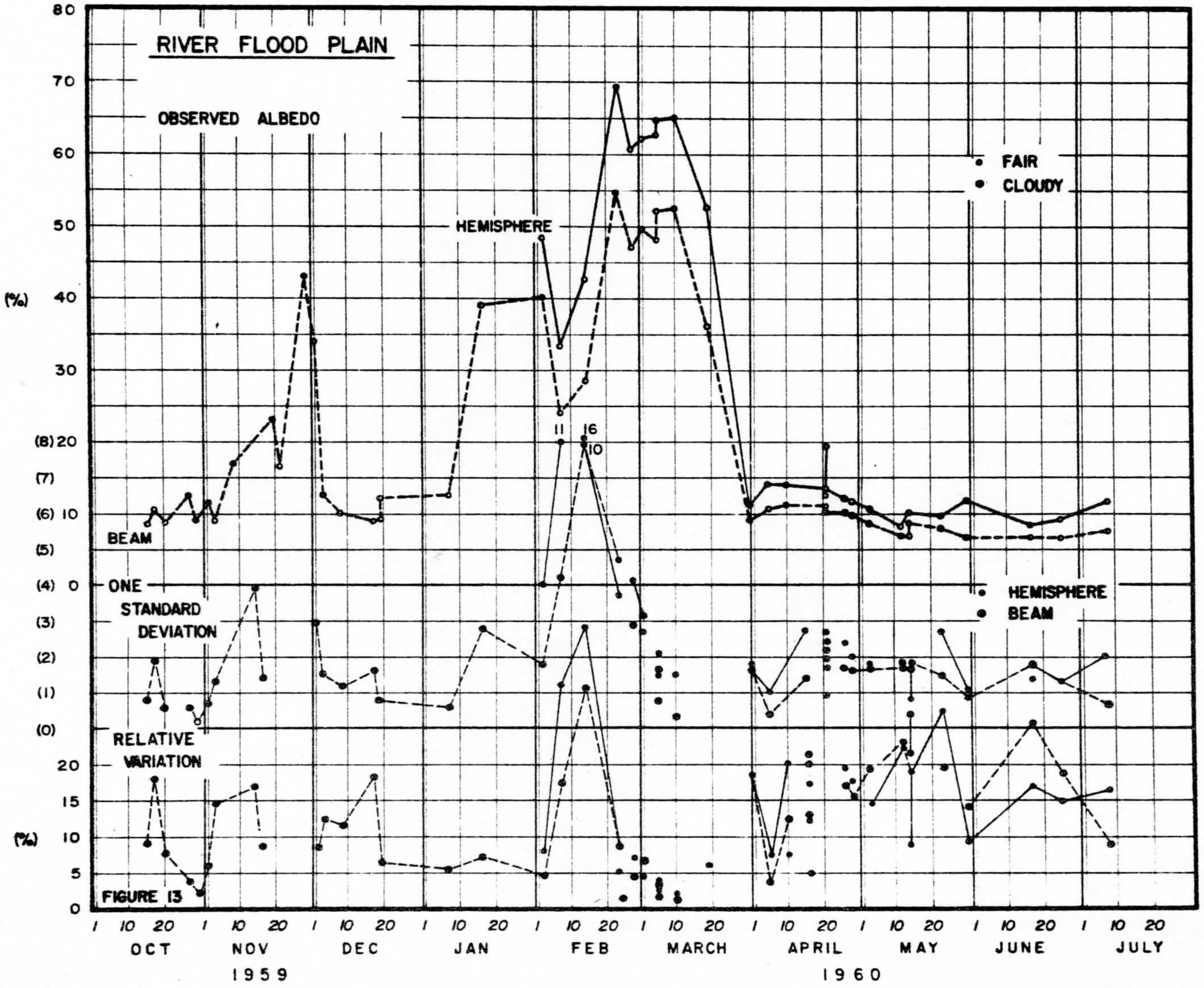


FIGURE 13
RIVER FLOOD PLAIN
OBSERVED ALBEDO
HEMISPHERE
BEAM
ONE STANDARD DEVIATION
RELATIVE VARIATION
FAIR
CLOUDY
HEMISPHERE
BEAM
11
16
10
(%)
80
70
60
50
40
30
(8) 20
(7)
(6) 10
(5)
(4) 0
(3)
(2)
(1)
(0)
20
15
10
5
0
1 10 20
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
1959
1960

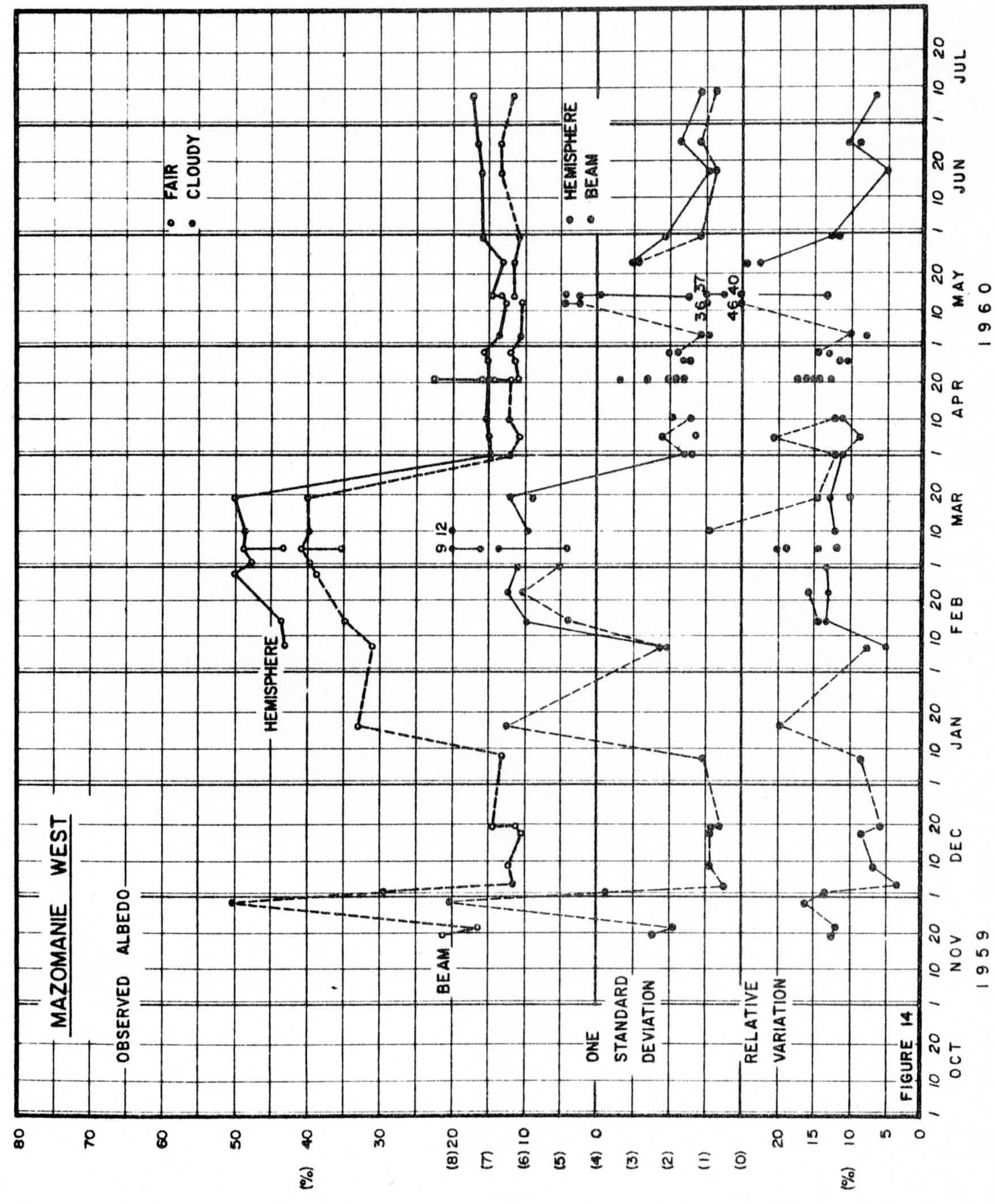


FIGURE 14

MAZOMANIE WEST
OBSERVED ALBEDO
HEMISPHERE
BEAM
ONE STANDARD DEVIATION
RELATIVE VARIATION
○ FAIR
● CLOUDY
○ HEMISPHERE
● BEAM
9 12
36 37
46 40
80
70
60
50
(%) 40
30
(8) 20
(7)
(6) 10
(5)
(4) 0
(3)
(2)
(1)
(0)
20
15
(%) 10
5
0
1 10 20 OCT
1 10 20 NOV
1959
1 10 20 DEC
1 10 20 JAN
1 10 20 FEB
1 10 20 MAR
1 10 20 APR
1 10 20 MAY
1960
1 10 20 JUN
1 10 20 JUL

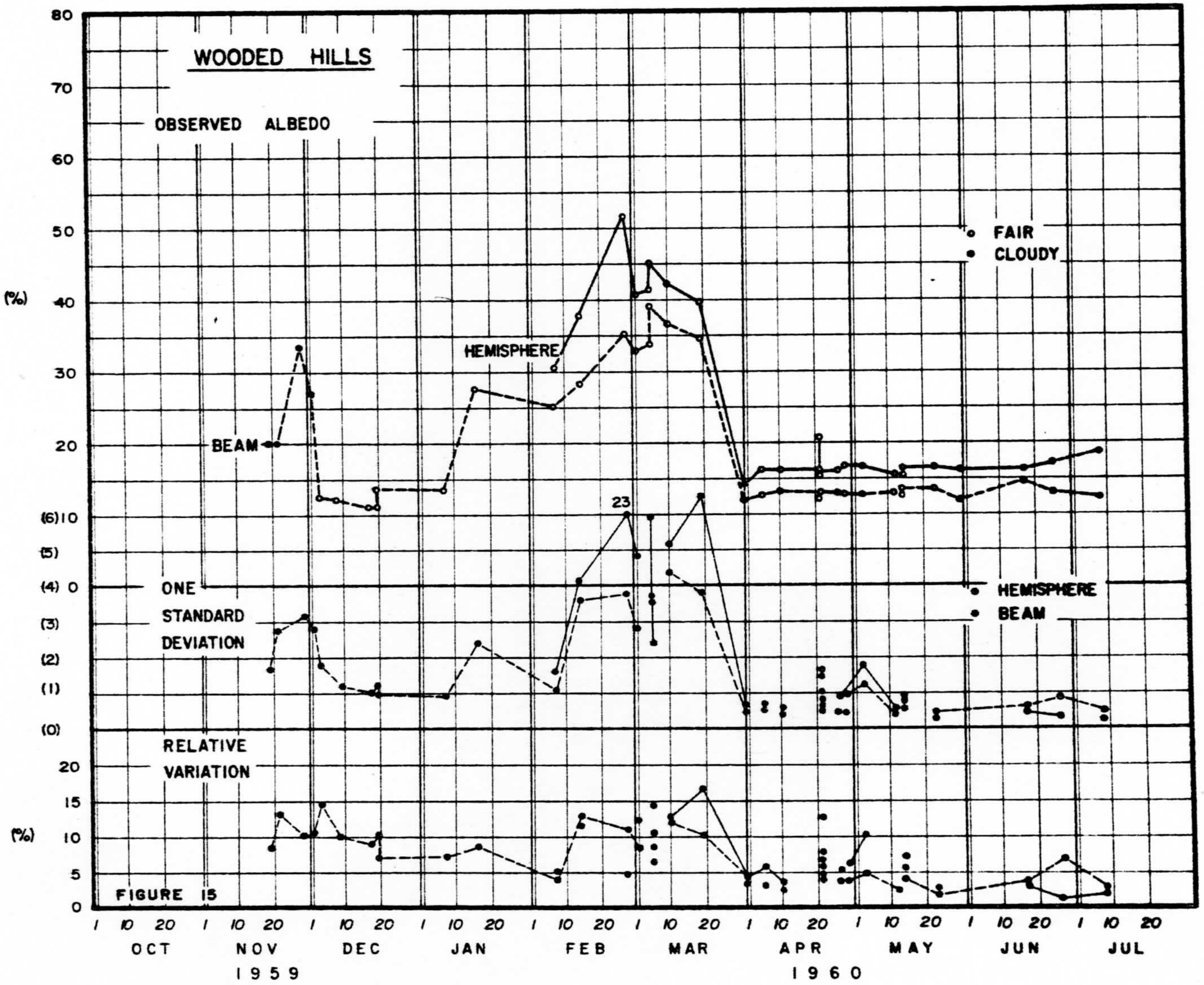


FIGURE 15

WOODED HILLS

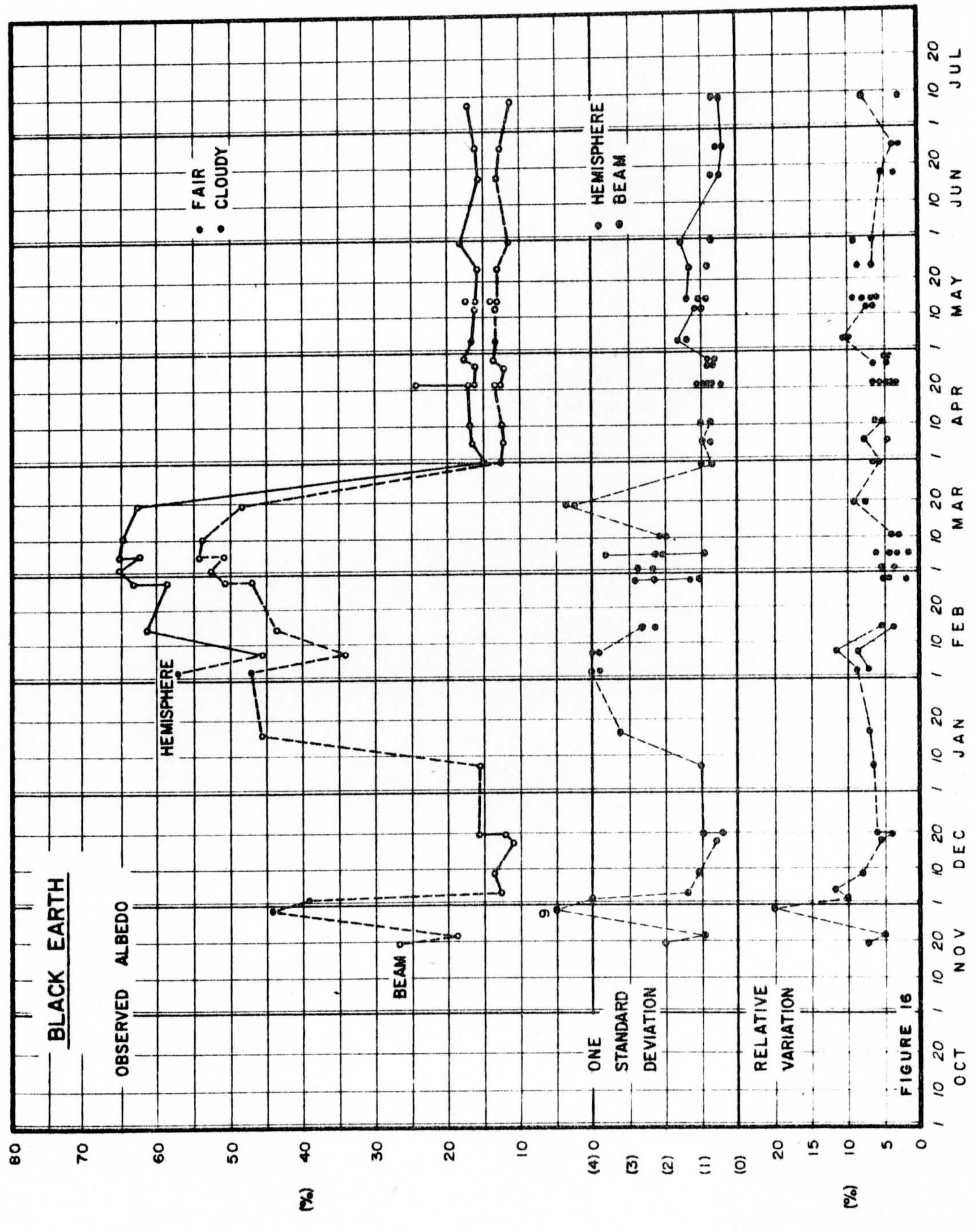


FIGURE 16

BLACK EARTH
OBSERVED ALBEDO
HEMISPHERE
BEAM
● FAIR
● CLOUDY
ONE STANDARD DEVIATION
● HEMISPHERE
● BEAM
RELATIVE VARIATION
(%)
80
70
60
50
40
30
20
10
(4) 0
(3)
(2)
(1)
(0)
20
15
10
5
0
(%)
9
1 10 20 OCT
1 10 20 NOV
1 10 20 DEC
1 10 20 JAN
1 10 20 FEB
1 10 20 MAR
1 10 20 APR
1 10 20 MAY
1 10 20 JUN
1 10 20 JUL
1959
1960

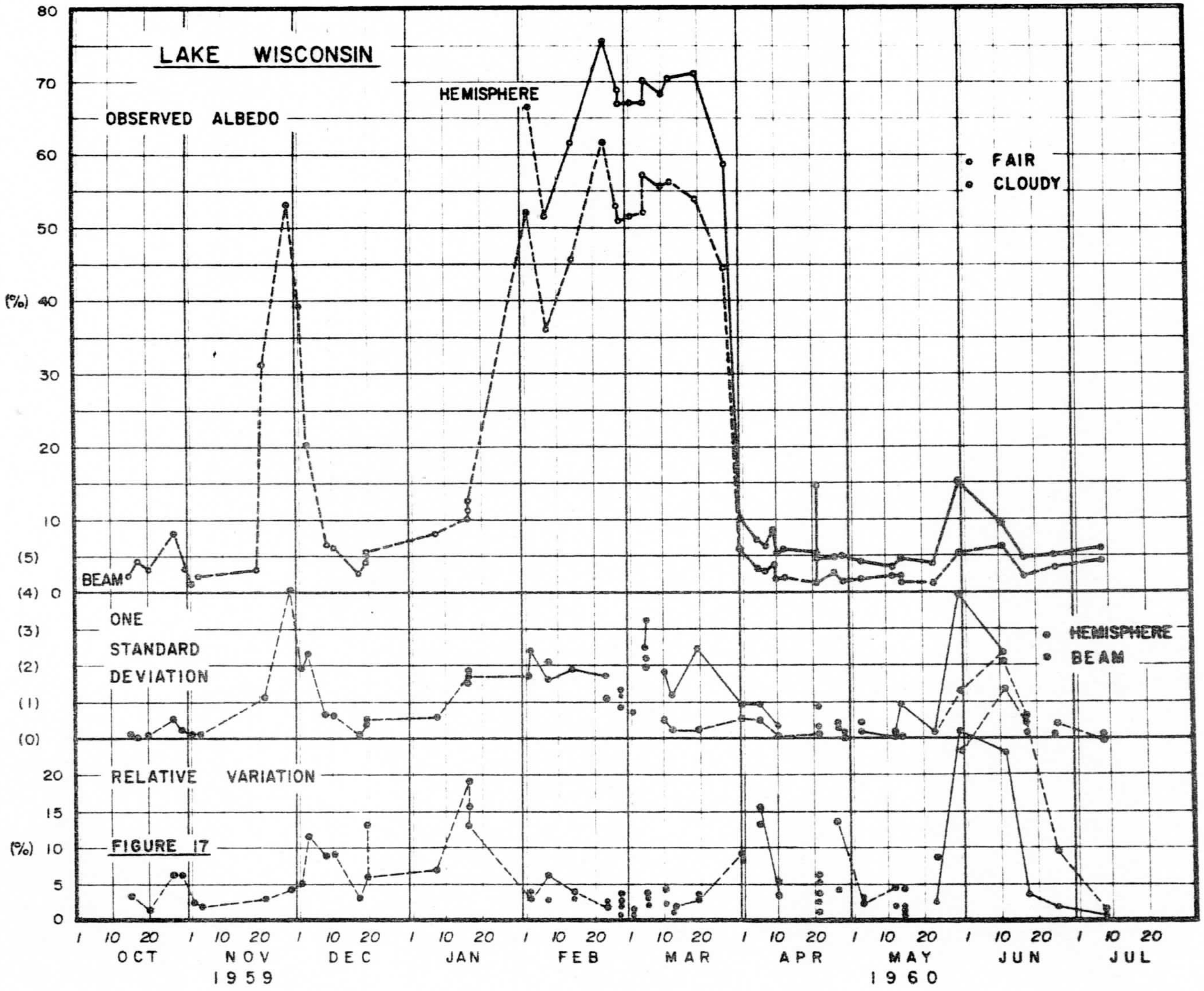

LAKE WISCONSIN
OBSERVED ALBEDO
HEMISPHERE
BEAM
• FAIR
• CLOUDY
ONE STANDARD DEVIATION
• HEMISPHERE
• BEAM
RELATIVE VARIATION
80
70
60
50
(%) 40
30
20
10
(5)
(4) 0
(3)
(2)
(1)
(0)
20
15
(%) 10
5
0
1 10 20
OCT
NOV
1959
DEC
JAN
FEB
MAR
APR
MAY
1960
JUN
JUL

FIGURE 17

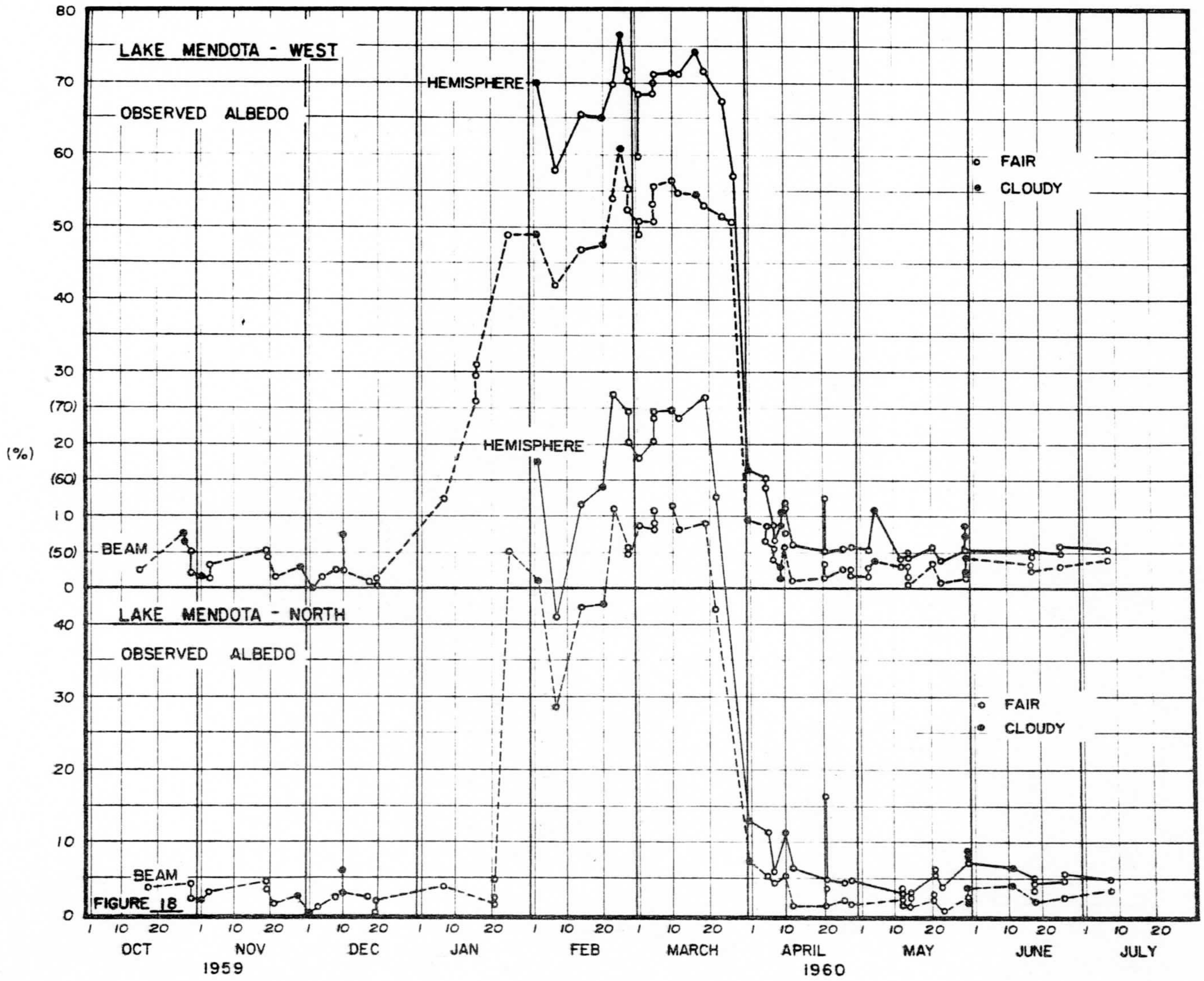

LAKE MENDOTA - WEST
OBSERVED ALBEDO
HEMISPHERE
BEAM
FAIR
CLOUDY
HEMISPHERE
LAKE MENDOTA - NORTH
OBSERVED ALBEDO
BEAM
FAIR
CLOUDY
(%)
80
70
60
50
40
30
(70)
20
(60)
10
(50)
0
40
30
20
10
0
1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20 1 10 20
OCT
NOV
1959
DEC
JAN
FEB
MARCH
APRIL
1960
MAY
JUNE
JULY

FIGURE 18

4. Diurnal Variation of Albedo

The variation of short wave radiation reflected from a surface shows a relationship to the diurnal variation of the elevation angle of the sun. This is especially true during the early morning and late evening when the sun is close to the horizon. This has an influence on the daily heat budget of the earth and can also be applied to the annual heat budget. Not only does the total amount of radiation falling on an area diminish as the sun angle decreases but the percentage reflected increases in comparison to the mid-day values. The increase in the reflectivity of a surface with a decrease in sun angle is illustrated in the following table. The observations presented were made under clear skies on the 21st of April, 1960. Sunset on this date was at 1846 CST.

Table 4.1 - Variation of Albedo with Local Time

Mendota West			Waunakee-Dane			Black Earth		
Time	A_B	A_H	Time	A_B	A_H	Time	A_B	A_H
1023	1.5	5.5	1027	13.0	17.6	1051	12.4	16.2
1057	2.0	4.5						
1327	1.7	5.3	1330	13.3	17.6	1353	12.9	16.7
1359	2.1	5.3						
1710	3.6	12.5	1718	14.4	21.2	1740	16.7	24.0
1746	15.7	20.9						

During the mid-portion of the day there are only small variations present in each section indicating that the higher angles of the sun found during this period have little effect on albedo measurements. This allows direct comparison of observations made during this period from one area with those made in another area. This is not the case as the sun approaches the horizon as both the beam and hemisphere albedo values begin to show increasingly rapid increases. The increase is much more pronounced over the smooth water surface than over the land areas indicating a relationship between the surface roughness and the measured reflectivity at low sun angles. This effect could be applied to heat budget studies of the northern latitudes where the sun is low on the horizon much of the year.

As might be expected from the construction of the instruments, the effect of low sun angle is more apparent in the hemisphere albedo measurements than in the beam albedo measurements, but both are strongly affected when the sun angle becomes quite small. Additional investigation is needed to determine what amount of the increase in albedo is due to the change in reflective properties of the surfaces, what part is due to the effect of airlight, and what part is due to the characteristics of the instrument. It is apparent that even allowing for changes due to instrument characteristics there is a much greater percentage increase in the albedo of a water surface than in the surrounding land surfaces. This indicates a dependency of reflection and absorption at low sun angles on the characteristics of the surface.

5. Vertical Variation of Measured Albedo

Short wave radiation passing through the atmosphere of the earth suffers a certain amount of depletion depending upon the concentration of scattering and absorbing matter encountered. Since the albedo of a surface is determined from two fluxes of short wave radiation, both which must pass through varying portions of the atmosphere, the problem of depletion must be considered in determining the true amount of radiation that is reflected from a surface.

When the albedo measurements are made within a few feet of the surface, the effect of depletion of the radiation by the atmosphere can be neglected since there is very little difference in the incoming radiation that is measured at the instrument level and that falling on the surface a few feet below. Also, the amount of radiation reflected from the surface does not vary from the surface to the instrument level.

In contrast to the measurements made at the surface, which have no effects of depletion, we find that as we go farther away from the surface the effect of depletion by the atmosphere becomes more pronounced in the measurements. The higher in the atmosphere we go, the less depletion is experienced by the incoming radiation while the radiation that passes to the surface of the earth and is reflected back to the level of measurement has experienced much more scattering and absorption by the atmosphere. This has a significant effect on the measurement of albedo since the value of incoming radiation measured at a level above the surface will not be the same as that striking the surface beneath and the return radiation received at the level of measurement will not be the same as was reflected from the surface. Since the albedo is the ratio of the two measured radiations it will not be a true measure of the reflectivity of the surface but of both the surface and the intervening atmosphere. Efforts to evaluate this effect were made by Fritz (1948) from altitudes of 7,000 and 10,000 feet.

As we are concerned with the amount of energy available for differential heating of the surface of the earth, we must either determine the effects of the intervening atmosphere or make our measurements at a level that will provide a good approximation of measurements made at the surface. The amounts of scattering and absorbing matter in the atmosphere are quite variable with time and location so it is more meaningful to work at a level that will approximate surface values directly. The best procedure would be to always work within a few feet of the surface but natural terrain features and a necessary margin of safety preclude airplane operations at a very low level.

To determine the actual variations with altitude of the incoming and reflected short wave radiation, a vertical sounding of these parameters was made over an extensive homogeneous surface--snow-covered Lake Mendota. The sounding began at 1000 CST on the 12th of March and was completed at

1045 CST. The weather was clear and the wind calm. To eliminate any directional effects present in the instruments, separate observations were made on opposite headings at each level over the same flight path. To compensate for the increased incoming solar radiation as the sun rose in the sky, observations were made at each level during both the climb and descent with the results being averaged together to give a representative value for each level. The results of this sounding are given in Figure 19.

As would be expected with the decrease in the amount of intervening atmosphere, the top Eppley shows an increase of incoming radiation with the increase in elevation. It is interesting to note the secondary maximum of radiation found at the 650 foot level. A comparison of this maximum with the inversion illustrated by the air temperature trace made at the same time indicates that this level was near the top of the low level inversion and may have contained a greater concentration of scattering particles. This effect is not as evident on the bottom Eppley and Kipp and Zonen--both of which show a decrease in measured radiation with altitude. The percentage change of the instruments and measured albedo with altitude is given by Table 5.1. The 50-foot level is assumed to represent the surface value.

Table 5.1--Measured Radiation and Albedo change with Altitude

Per cent change from:	50' to 1150'	50' to 2150'
Top Eppley	+ 1.5	+ 2.5
Bottom Eppley	- 0.9	- 1.3
Kipp and Zonen	- 2.1	- 3.4
Beam Albedo	- 2.7	- 3.4
Hemisphere Albedo	- 3.4	- 5.4

The observations given in the table show that as the altitude increases, the measured beam and hemisphere albedo decreases by 2.7% and 3.4% at 1150 feet and by 3.4% and 5.4% at 2150 feet. These results indicate that albedo measurements made at altitudes up to 1000 feet above the surface may be assumed to approximate the surface albedo within the error of the instruments and that those made up to 2000 feet are also good approximations of the surface albedo. From this and similar soundings the assumption was made in Section 2.2 to consider the short wave radiation and albedo measurements used in this report as representative of the surface values.

These results also demonstrate the feasibility of investigating the scattering and absorption of short wave energy by the atmosphere using the vertical sounding technique to these and higher levels. The measurement of the low level temperature inversion illustrated the versatility of an airplane for measuring other low level parameters. The inversion shown was even more well-defined before the averaging process for the low level temperature warmed by more than a degree during the period of the sounding.

VERTICAL VARIATION OF MEASURED ALBEDO

DATE : March 12, 1960 WEATHER : Clear, calm SURFACE : Snow covered
(10:00 - 10 45: CST) LAKE MENDOTA

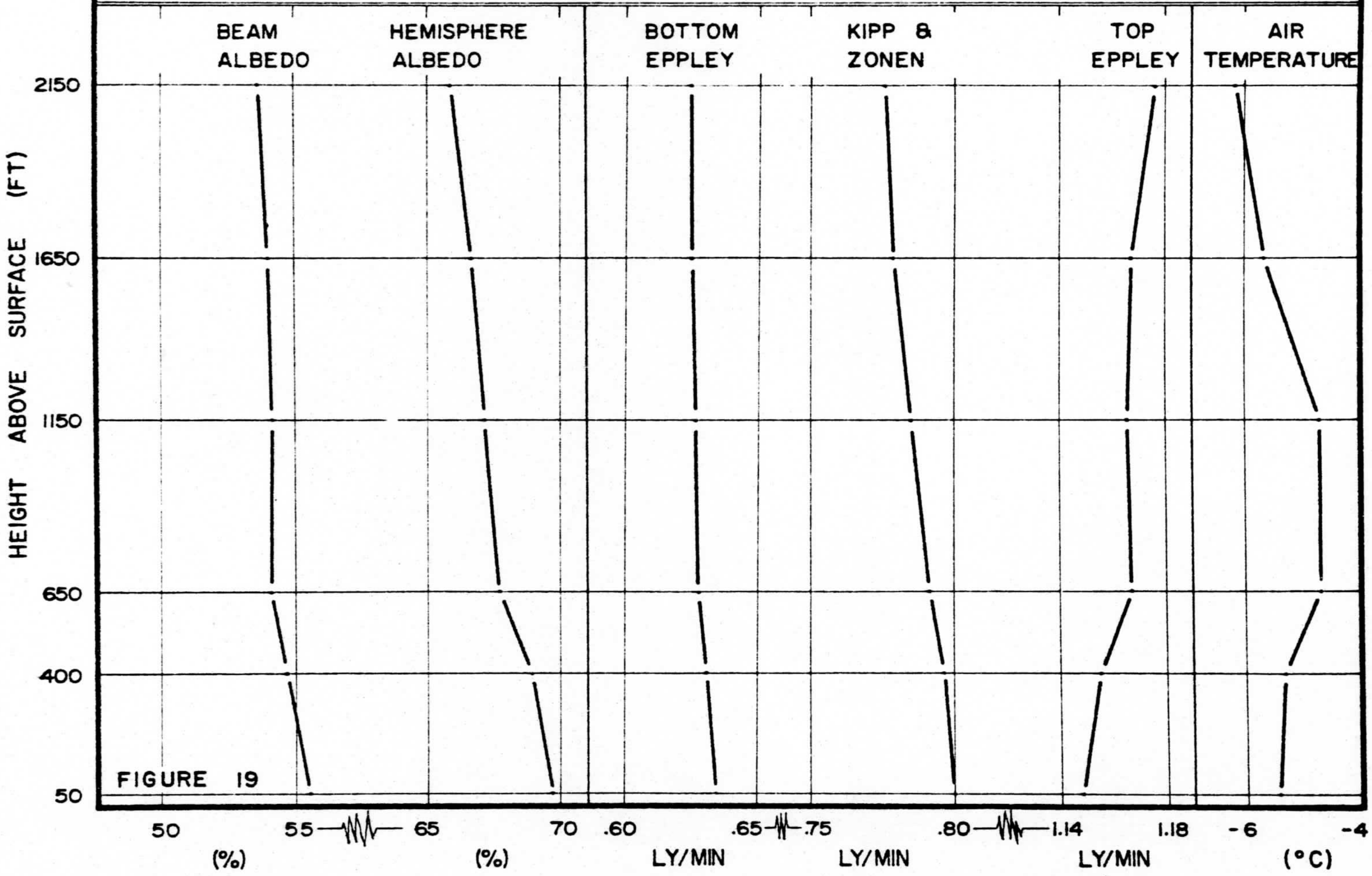


FIGURE 19

6. Case Studies

Many interesting observations have been made during the course of this project in addition to those taken on a routine basis. Studies of several individual cases are presented with particular attention being given to the effects of clouds on the measurement of short wave radiation and albedo.

6.1 Short Wave Radiation under the Edge of a Cloud Deck.

Numerous factors must be considered when obtaining a true measure of the albedo of a surface. One important point that may lead to sizeable error is a marked difference between radiation falling on the airplane and that falling on the observed surface beneath. Figure 20 illustrates the effect of clouds in bringing about this difference.

The diagram presents the results of a regular observation flight to the north on the Waunakee-Dane track. The weather at takeoff was clear with a high altocumulus cloud deck showing a well-defined edge visible to the north. As the edge of the cloud deck is approached (A), the radiation values measured by the top and bottom Eppleys are quite steady. At point B the top Eppley begins to rise and reaches a maximum at point C--an increase of 22.5%. This rise is due to the increasing amount of sunlight being reflected and scattered downward from the leading edge of the cloud as the airplane approaches, the maximum being reached just before the airplane enters the cloud shadow. At this point

(C) a combination of direct sunlight, the maximum of reflected and scattered sunlight, and the diffuse sunlight passing through the clouds are all impinging on the top Eppley. As the airplane passes into the cloud shadow, the top Eppley displays a rapid decline and reaches a new steady value at point E--this value being 57% lower than the mean albedo value of point A.

As would be expected with the increasing sunlight from the cloud edge, the radiation on the bottom Eppley also begins to rise (total increase 27.5%), but at a later time than did the top Eppley. This lag between the two Eppleys is maintained until the cloud shadow is reached--the top Eppley reaching its maximum at point C while the bottom Eppley continues to rise until point D, approximately twenty seconds later. This is shown in the diagram. At point C the airplane enters the cloud shadow but the bottom Eppley sees the sunlit surface until point D. Here the cloud shadow begins on the surface causing the bottom Eppley to fall rapidly, as did the top Eppley, to a new steady value at point E.

The effect of the time lag on the measured albedo is illustrated by the beam albedo trace. As the top Eppley begins to rise (B) there is a decrease in the albedo because the bottom Eppley has not yet begun to see the increasing radiation. Even after the bottom Eppley begins to increase, the albedo continues to decrease. When the top Eppley is shadowed (C), the albedo begins a sharp rise that peaks at point D--the point where the bottom Eppley sees the maximum radiation reflected from the surface. From here the albedo decreases irregularly to a stable value at point E.

The slow decrease and rapid increase of the measured albedo over a relatively homogeneous surface illustrates the inaccuracies that appear during partly cloudy weather. The condition described here has been observed many times, especially in the vicinity of cumulus clouds where both the airplane and the surface are intermittently in shadow.

For convenience and better presentation, the vertical scale of the flight cross-section has been distorted. At the time of these observations the elevation angle of the sun was approximately 25 degrees. This gives a much smaller actual reflection angle for the sunlight at the edge of the cloud than is pictured. It is interesting to note that over relatively homogeneous surfaces there is a 22.5% decrease in the measured beam albedo from the clear portion (A) to the overcast portion (E). One possible explanation of this might be that the diffuse radiation found below an overcast is more effectively absorbed at the surface than the direct rays of the sun, at least as observed by the bottom Eppley.

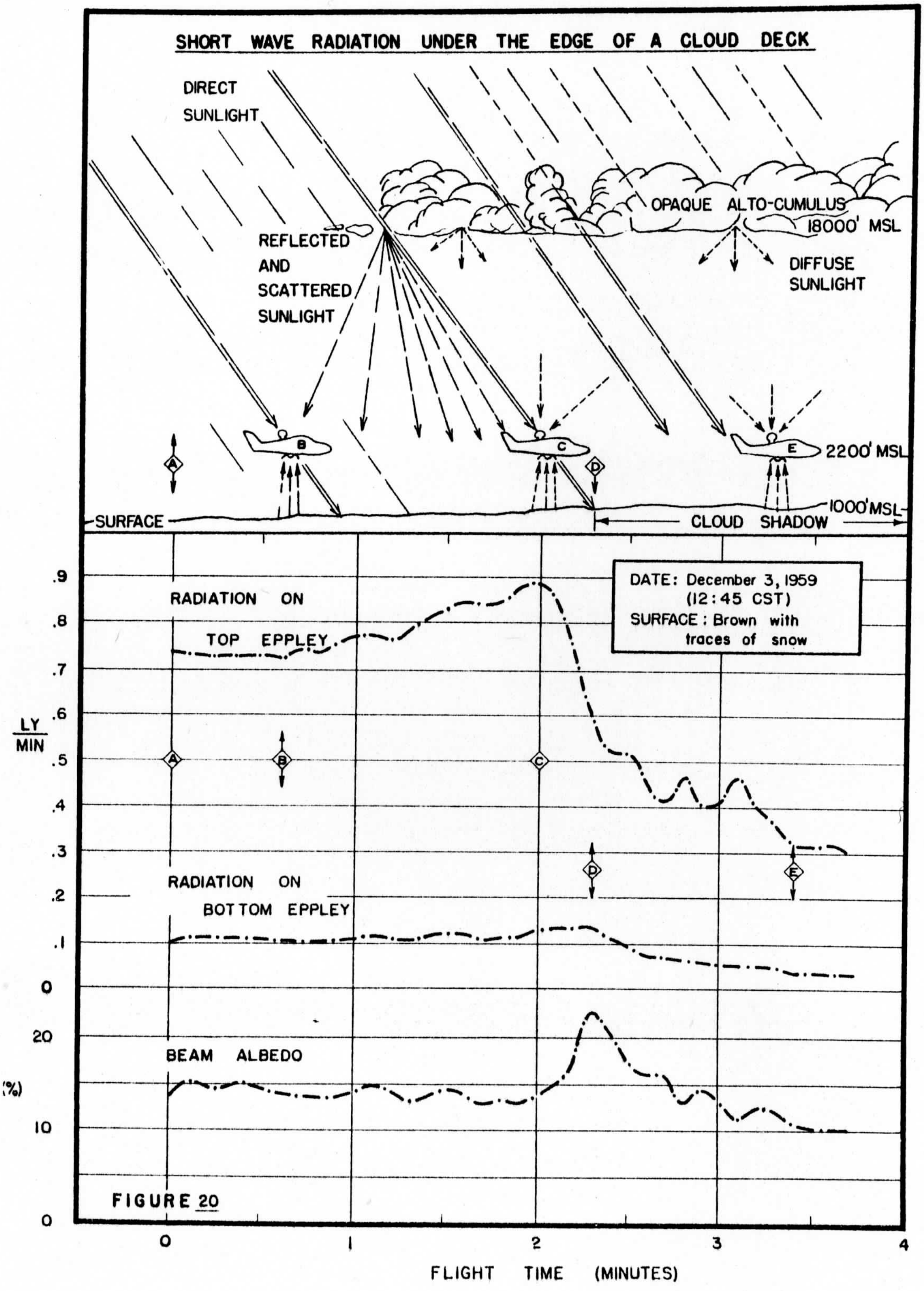

SHORT WAVE RADIATION UNDER THE EDGE OF A CLOUD DECK
DIRECT SUNLIGHT
REFLECTED AND SCATTERED SUNLIGHT
OPAQUE ALTO-CUMULUS
18000' MSL
DIFFUSE SUNLIGHT
A
B
C
D
E
2200' MSL
SURFACE
1000' MSL
CLOUD SHADOW
DATE: December 3, 1959
(12:45 CST)
SURFACE: Brown with traces of snow
RADIATION ON TOP EPPLEY
RADIATION ON BOTTOM EPPLEY
BEAM ALBEDO
LY/MIN
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
20
(%)
10
0
0
1
2
3
4
FLIGHT TIME (MINUTES)

FIGURE 20

6.2 Short Wave Radiation Variations under Clear and Overcast Conditions. Several noteworthy points are illustrated by the two flights presented in Figure 21. A continuous record of the radiation measured by the top and bottom Eppley is given to show the response of the instruments. The albedo values are given only for the periods of level flight as they have little meaning when the instruments are tilted. Both flights were made over the flight track shown in the upper left-hand portion of the figure.

A comparison of the two traces recorded by the top Eppley shows a significant variation from the clear to the overcast flight. This is particularly noticeable during the turns of the airplane over the lake. On the clear days it is immediately apparent, from the sharp increase in radiation (C), where the airplane turned to the south. The radiation almost doubled as the Eppley became more perpendicular to the rays of the sun during the turn--the elevation angle of the sun being approximately 25 degrees at this time. The turn to the north, away from the sun (D), is also very evident as the radiation falls to a very low value before recovering (E). In strong contrast to the clear conditions, it is difficult to determine when the airplane made the same turns during flight under the overcast. This small response to variations in airplane attitude under the uniform overcast was found to occur regularly under such conditions. The observations indicate a relatively uniform distribution of diffuse radiation beneath the overcast--at least to an angle of thirty degrees which is the bank of the airplane during turns. Further study of this phenomenon is needed to determine the effect of tilting the top Eppley toward the surface during the turn and thus receiving some influence in the observation from reflected radiation.

A phenomenon sometimes used in the arctic regions to locate open water--a dark patch on the bottom of the clouds--is illustrated by the top Eppley trace from the overcast flight. On this flight the albedo of the ground was high (38%), due to a snow cover, while the albedo of the water was almost zero. The overcast over the water looked quite dark compared to that over the land even though the clouds were thick and uniform. As the airplane approached the lake (A), the top Eppley value was high but then decreased by 39% over the water and remained low until the north shore was approached (F). The only increase noted was at point D where the track was close to the snow-covered shore. The radiation measured up to point A and beyond point F is the sum of the diffuse sunlight passing through the overcast and that experiencing multiple reflections between the snow and the bottom of the clouds. The lower value of radiation measured over the lake, under the darker appearing cloud area, more nearly approaches the actual amount passing through the overcast since the lake reflects no radiation back to the clouds. The effect of multiple reflections from the snow and clouds should be considered when making any comparison of incoming short wave radiation measurements made under overcast conditions over surfaces with different albedo.

Another point of interest is the large decrease in the albedo of the ground over the two-day period as the snow melted. The possibility of such a rapid variation in the absorptive properties of a surface should be considered in any heat budget study of a region or when considering the synoptic temperature modifications occurring in an air mass over such an area.

The change in albedo from farmland to a small city is demonstrated at point A for both flights. With either a snowy or bare surface there is a significant decrease in the albedo over the urban area. This has been observed with regard to other cities as well.

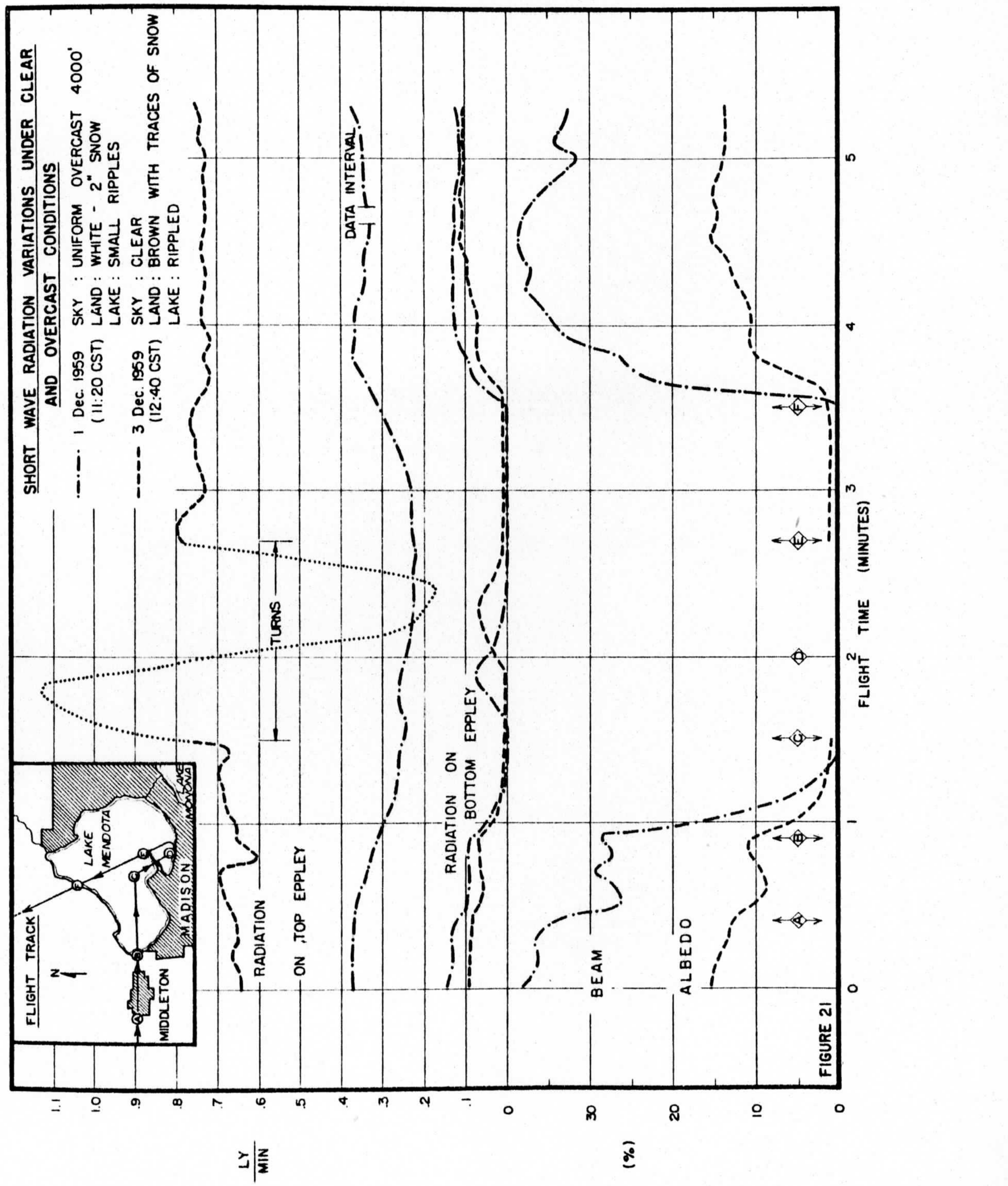

SHORT WAVE RADIATION VARIATIONS UNDER CLEAR AND OVERCAST CONDITIONS
1 Dec. 1959 (11:20 CST)
SKY : UNIFORM OVERCAST 4000'
LAND : WHITE - 2" SNOW
LAKE : SMALL RIPPLES
3 Dec. 1959 (12:40 CST)
SKY : CLEAR
LAND : BROWN WITH TRACES OF SNOW
LAKE : RIPPLED
FLIGHT TRACK
N
MIDDLETON
MADISON
LAKE MENDOTA
LAKE MONONA
A
B
C
D
E
F
RADIATION ON TOP EPPLEY
RADIATION ON BOTTOM EPPLEY
TURNS
DATA INTERVAL
BEAM
ALBEDO
LY/MIN
(%)
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
30
20
10
0
FLIGHT TIME (MINUTES)
1
2
3
4
5

FIGURE 21

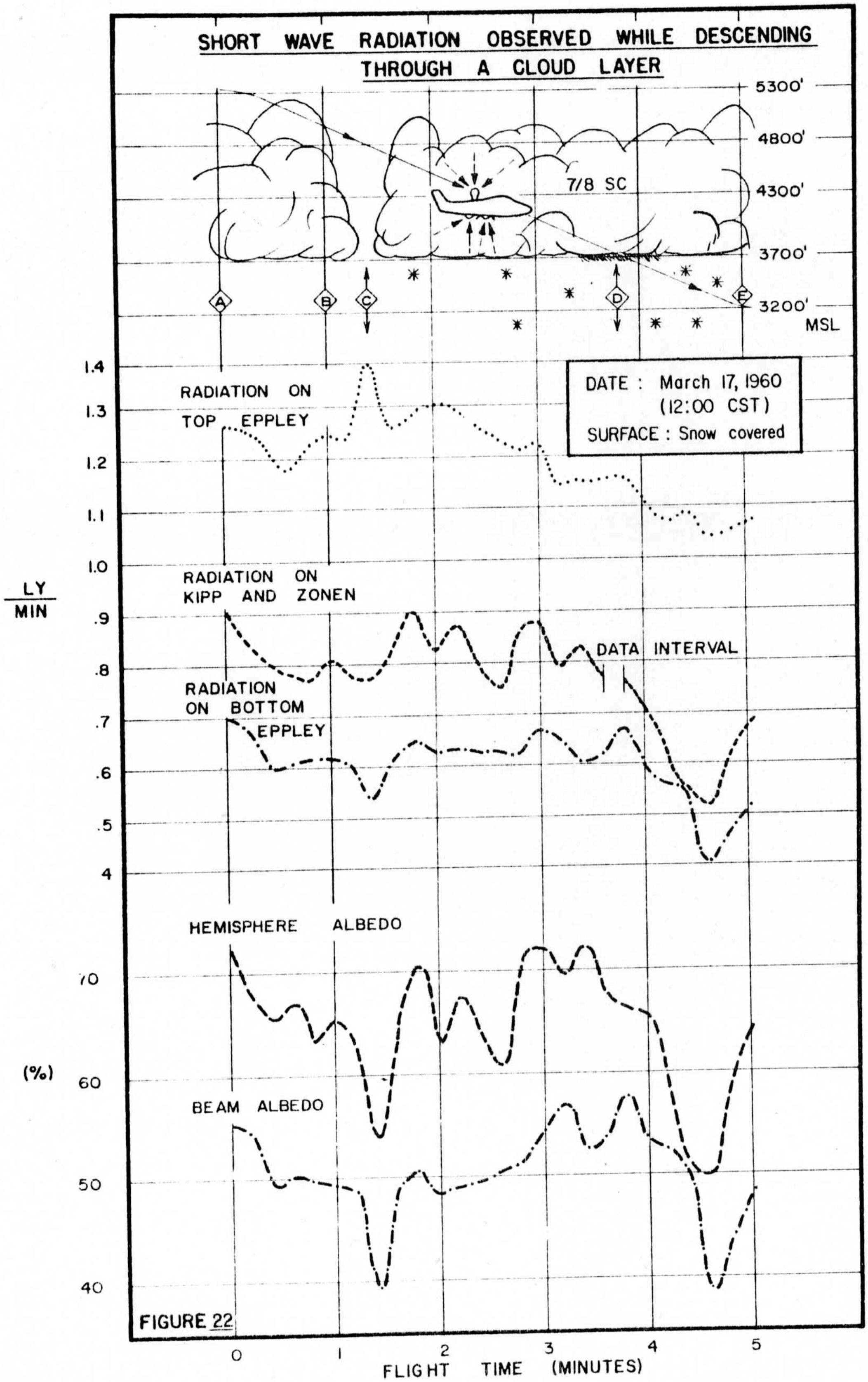
6.3 Short Wave Radiation Observed while Descending Through a Cloud Layer. The changes in radiation observed during a descent through a stratocumulus cloud layer are presented in Figure 22. The sky was clear above the cloud layer with a light snow falling beneath the clouds. Some small breaks were observed in the layer and are indicated in the diagram. The airplane was descending at the rate of 400 feet per minute while passing through the cloud layer.

At point A the airplane was in level flight above the cloud layer. The observed hemisphere albedo of the cloud layer was 72% compared to 55% for the beam albedo. These albedo values are representative of those observed during other portions of the flight. There was, however, a tendency for the albedo to be several percent lower over stratocumulus cloud areas with uniform tops and somewhat higher and more variable over areas of irregularly mounded cumulus cloud tops.

At the beginning of the descent the airplane was in the cloud layer for a short time and then entered a break in the overcast (B). At point C there was a rapid fall and rise in the observed albedo values before the airplane entered the cloud layer again. This was due to the bottom Eppley and Kipp and Zonen seeing a dark forest on the ground, and thus receiving a lower radiation value, while the top Eppley was receiving increased radiation due to the sunlight reflected from the edges of the clouds in the manner described in Section 6.1.

As the airplane continued to descend in the cloud layer the top Eppley had a general decline in radiation to point E. In the cloud the albedo values showed irregular variations but decreased rapidly as the airplane emerged from the cloud base (D) over a forested area. As the airplane leveled off beneath the clouds (E), it passed from an area of trees to a flat, snow-covered prairie which resulted in the albedo rising again at point E.

In contrast to the 57% decrease observed from the clear to overcast condition in Section 6.1, a comparison of the top Eppley values at points A and E shows only a 16.5% decrease in the short wave radiation as it passes through the cloud layer. The 16.5% decrease is also not consistent with the hemisphere albedo observed for the cloud tops (72%) which would allow only 28% of the short wave radiation to enter the top of the cloud in contrast to the 83.5% that is measured beneath the cloud layer. The small decrease in the top Eppley may be partly due to the multiple reflections of radiation from the snow and cloud layer discussed in Section 6.2, but would not appear to explain the large variations encountered. The lack of agreement between the various observations illustrates the inter-relationships between the short wave radiation, the cloud reflectivity and absorptivity, and the surface albedo that must be determined before there can be a complete understanding of the processes involved.



SHORT WAVE RADIATION OBSERVED WHILE DESCENDING THROUGH A CLOUD LAYER

FIGURE 22

6.4 Albedo of Lake Ice Preceding Breakup. A knowledge of what changes take place in the albedo of an ice-covered lake in spring as breakup time approaches is helpful in understanding the heat budget of the lake. Since energy must be supplied to the lake to melt the ice covering, an estimate of the rate and amount of heat being absorbed by the lake is important. This can in part be provided by albedo measurements of the ice since the albedo determines the amount of solar radiation absorbed by the lake--solar radiation being the main source of energy available for melting the ice cover. Measurements of the albedo of lake ice were made over Lake Mendota during the spring of 1960. The results of this study are presented in Figure 23.

During most of March the ice was covered by several inches of snow giving it a high albedo. The albedo slowly decreased during the last week of March as the snow cover became dirty and more compact. Following this initial decrease, the snow was subjected to the influences of a warm air mass and rain causing it to undergo changes in its structure and begin to disappear. By the last day of March the snow cover was essentially gone from the ice leaving it with a dark mottled-gray appearance and a low albedo. During this period the albedo decreased by approximately 80% from the high values observed over the snow cover of mid-March.

With the snow removed from the ice, the resulting lower albedo permitted much more radiation to be absorbed by the lake. Over a period of ten days the albedo of the lake gradually decreased still more and reached its lowest value on the 9th of April. During this ten day period the lake was absorbing 85% to 95% of the incident radiation with the ice becoming thinner and more porous.

On the 10th of April the albedo almost doubled from the low point of the day before. This is thought to have been brought about by the draining of water, previously trapped in the candled ice, leaving a light-colored, porous ice surface to reflect radiation. The porous ice persisted until the 12th of April when open water began to appear over most of the lake. The appearance of open water followed by a few hours the development of a moderate wind blowing over the lake leading to the assumption that the wind was a significant factor in initiating the final breakup of the ice.

ALBEDO OF LAKE ICE PRECEDING BREAKUP

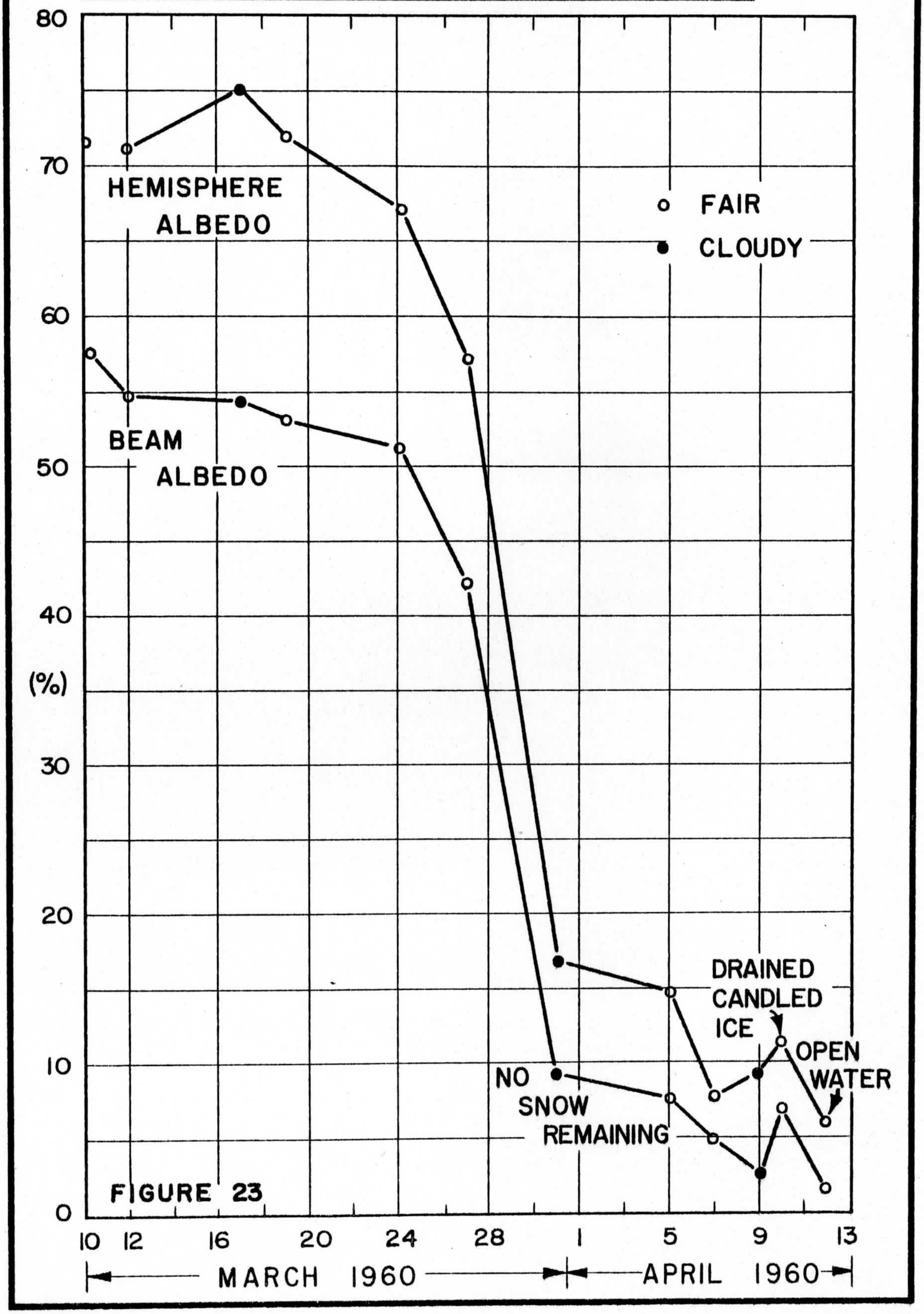


FIGURE 23

7. Conclusions

The suitability of a light airplane as a micrometeorological probe has been demonstrated by the results of the many flights made during the past year. In addition to the micrometeorological data obtained, valuable experience was gained in airplane and instrument operation, flight techniques for low level observations, the adaptation of meteorological sensors to airborne probing, and in many other related subjects. The advances made will provide the basis for more complete and comprehensive measurements in later phases of the project.

The effects of various weather elements on the measurement of albedo were evaluated. Attempts to obtain valid albedo measurements under partly cloudy conditions met with little success. This was due in part to the non-uniform reflection and scattering of radiation as previously illustrated in Section 6.1. The response time of the sensors was also a factor during these periods of rapidly varying radiation.

The effect of turbulence was also investigated. Some turbulence is almost always present in the lower levels of the atmosphere where the observation flights are made. Its effect on individual observations is noticeable, but the averaging process reduces its influence to a relatively low level.

The results of the average albedo measurements are very interesting. Only the large scale features of the surface albedo have as yet been examined, but many other avenues of investigation have been shown to be open to further airborne study.

The relationship between the albedo of the surface and the climatic changes of a region requires additional investigation, especially on a larger scale than before. Consideration should also be given to a further study of the diurnal and vertical variations of measured albedo as well as to the variation of albedo with surface type. Small scale studies similar to that presented in Section 6.4 offer promise. The study of cloud albedo and the absorption of radiation by clouds has been shown to be practical for airplane probing.

These are only a few of the possibilities to be considered for further airplane investigation. The results discussed in this paper indicate the feasibility of such work. The material presented is unique in itself but is even more useful as a foundation upon which to build future research in this field.

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APPENDIX

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part I

DATE 1959	Waunakee - Dane			Lodi			Sauk Prairie		
	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
15 Oct	1215 10	10.4	----	1220 11	10.0	----	1230 12	10.3	----
17 Oct	1010 10	12.9	----	1015 11	12.3	----	1020 12	13.6	----
20 Oct	1355 10	9.7	----	1400 11	10.0	----	1405 13	10.1	----
27 Oct	1330 11	13.8	----	1335 12	13.2	----	1340 14	14.8	----
29 Oct	1345 11	10.6	----	1350* 11	9.2	----	1355** 12	12.4	----
1 Nov	1205 10	10.3	----	1210 12	10.3	----	1215 17	11.5	----
3 Nov	1120 10	10.2	----	1125 11	9.8	----	1130 12	10.3	----
19 Nov	1340 11	25.6	----	1345 11	23.4	----	1348* 12	20.3	----
21 Nov	1350 10	19.8	----	1355 11	22.7	----	1400 12	19.4	----
28 Nov	1105 10	42.7	----	1110* 12	40.7	----	1115 13	43.1	----
1 Dec	1120 10	33.5	----	1125 11	28.1	----	1135 12	25.9	----
3 Dec	1240 11	13.8	----	1245* 13	11.4	----	1250* 13	11.0	----
8 Dec	1305 10	13.1	----	1310 11	11.3	----	1320 12	12.1	----
10 Dec	1105 10	12.6	----	1110 11	11.0	----			
17 Dec	1105 6	10.6	----	1110 7	8.9	----	1115 7	10.1	----

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part II

DATE 1959	River Floodplain			Mazomanie West			Wooded Hills		
	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
15 Oct	1235 13	8.3	----						
17 Oct	1022 13	10.7	----						
20 Oct	1410 14	8.8	----						
27 Oct	1345^{+} 14	12.7	----						
29 Oct	1400^{**+} 13	8.9	----						
1 Nov	1220^{+} 18	11.6	----						
3 Nov	1135 13	9.1	----						
19 Nov	1350^{*} 13	23.1	----	1355 14	21.0	----	1338 13	20.0	----
21 Nov	1402 13	16.8	----	1405 13	16.2	----	1410 10	20.2	----
28 Nov	1117 14	42.8	----	1120^{*} 15	50.2	----	1125 14	33.5	----
1 Dec	1135 13	34.1	----	1140 15	29.1	----	1143 11	27.1	----
3 Dec	1255^{*} 15	12.4	----	1300 15	11.4	----	1303 12	12.4	----
8 Dec	1322 13	10.2	----	1325 13	12.2	----	1330 11	12.0	----
10 Dec									
17 Dec	1117 10	8.8	----	1120 10	10.0	----	1125 7	10.8	----

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part III

DATE	Black Earth			Sky	Surface
1959	T/H	A_B	A_H	Condition	Condition
15 Oct				BRKN Thin Cirrus	Green - Moist
17 Oct				Clear	Green - Moist
20 Oct				OCNL Sc 4000	Late Fall Green and Brown
27 Oct				Uniform OVC 2000	Late Fall Green and Brown +Wet
29 Oct				SCTD Sc 3500 *Cloud Shadows **OVC Sc 3500	Late Fall Brown and Green +Wet
1 Nov				Uniform OVC 6000	Late Fall Brown +Wet
3 Nov				SCTD Thin Cirrus	Late Fall Brown
19 Nov	1400 12	26.6	----	SCTD Cirrus *BRKN Cirrus	2" Old Snow Crusted
21 Nov	1415 12	18.5	----	SCTD Thin Cirrus Haze	2" Old-Trace New Snow - Melting
28 Nov	1130* 16	44.2	----	OVC St 5000 *OCNL Sunlight	3" Two Day Snow White
1 Dec	1145 13	39.3	----	Uniform OVC 4000	2" Five Day Snow Melting
3 Dec	1305 12	12.4	----	SCTD Ac 18000 *OVC Ac 18000	Winter Brown Some Old Snow
8 Dec	1333 13	13.5	----	Clear	Winter Brown Trace Old Snow
10 Dec				SCTD Thin Cirrus	Winter Brown OCNL Trace Snow
17 Dec	1130 8	11.4	----	BRKN Thin Cirrus	Winter Brown

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part I-a

DATE	Waunakee - Dane			Lodi			Sauk Prairie		
1959	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
19 Dec	1050 10	11.3	----	1055 11	10.0	----	1100 12	11.6	----
	1410 10	11.8	----	1415 11	10.8	----	1420 12	13.8	----
1960 7 Jan	1433 10	12.9	----	1435 11	13.2	----	1445 12	13.6	----
16 Jan	1110 10	40.0	----	1113+ 11	26.0	----	1120 12	31.1	----
	1337 10	40.9	----	1340+ 11	26.0	----	1348 12	29.5	----
	1410 3	40.2	----	1413+ 4	28.6	----	1420 2	27.7	----
2 Feb	1017 7	44.2	57.6	1020 9	43.0	50.4	1026 5	40.0	47.6
7 Feb	1323 3	32.2	44.8	1325 6	23.8	32.9	1333 2	23.2	28.9
14 Feb	1200 2	42.0	58.3	1203 6	38.0	53.2	1212 3	37.3	47.3
23 Feb	1054 3	54.8	68.9	1058* 7	52.9	60.4	1104 4	54.6	66.1
27 Feb	1020 3	48.6	67.3	1023 5	42.7	57.8	1032 3	44.0	52.2
	1422 5	49.0	63.7	1425 6	42.6	57.3			
1 Mar	0947 4	48.6	65.6	0950 5	44.9	59.5	0958 3	42.6	55.0
	1155 6	54.1	63.8						
5 Mar	0800 6	52.9	71.4	0803 7	47.2	59.9	0815 4	44.4	54.9

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part II-a

DATE 1959	River Floodplain			Mazomanie West			Wooded Hills		
	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
19 Dec	1103 10	9.1	----	1106 11	11.2	----	1110 12	11.3	----
	1422 10	12.0	----	1425 11	13.8	----	1435 12	13.6	----
1960 7 Jan	1446 13	12.6	----	1450 13	13.0	----	1452 10	13.5	----
16 Jan									
	1348 13	39.3	----	1352 13	33.2	----	1357 10	27.6	----
2 Feb	1030* 8	40.3	48.6						
7 Feb	1336 6	24.2	33.5	1340 6	30.7	43.1	1343* 7	25.1	30.6
14 Feb	1214 4	28.6	42.6	1216 5	34.9	43.6	1218 7	28.2	37.6
23 Feb	1008 6	54.4	69.6						
27 Feb	1033 6	47.2	60.5	1035 6	38.7	49.9	1044 7	35.3	51.6
1 Mar	0958 6	49.2	62.1	1002 7	39.8	47.5	1006 8	32.9	40.3
5 Mar	0820 6	48.1	62.7	0822 7	35.3	43.3	0823 9	33.8	41.3

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part III-a

DATE 1959	Black Earth T/H	 A_B	 A_H	Sky Condition	Surface Condition
19 Dec	1115 12	12.2	----	Clear	Winter Brown
	1440 12	15.5	----	OVC Thin Cirrus	" "
1960 7 Jan	1455 12	15.5	----	Clear	1" Old Melting Snow - Brown
16 Jan				Clear	5" One Day Snow White +2" Snow
	1400 12	45.6	----	"	" "
				"	" "
2 Feb	1031 10	46.8	56.9	OVC St 1700 *Light Snow	3" Two Week Snow
7 Feb	1345 5	34.1	45.6	SCTD Thin Cirrus *SCTD Sc 3000	2" Old Crusted Snow +1" Snow
14 Feb	1224 6	48.4	61.5	OCNL Thin Cirrus	5" Four Day Snow White with Drift
23 Feb				BRKN Sc 1200 *OVC Sc 1200	7" One Day Snow White
27 Feb	1048 6	50.3	63.5	Clear	6" One Week Snow 1" One Day Snow
	1436 8	47.0	58.5	"	" "
1 Mar	1010 8	52.6	65.1	Clear	6" Nine Day Snow White
				"	" "
5 Mar	0828 8	50.7	62.0	Clear	8" Drifted Snow 2" One Day Old

Table 1. Average Albedo Values Observed Over South Central Wisconsin with the Change of the Seasons - Part I-b

DATE	Waunakee - Dane			Lodi			Sauk Prairie		
1960	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
5 Mar	1028 4	54.7	67.8	1030 5	49.1	58.4	1039 3	49.4	59.0
	1430 7	53.6	67.6						
10 Mar	1035 4	55.5	69.0	1039 7	51.0	60.3	1045 4	49.6	59.9
12 Mar	1407 3	52.3	66.9	1410 5	46.4	56.9			
19 Mar	1243 3	50.6	66.0	1245 4	45.8	58.0	1252 3	41.8	55.0
27 Mar	1028 7	36.1	47.7	1028 8	34.2	44.1			
31 Mar	1244 5	11.3	15.7	1246 8	11.7	15.5	1253 4	11.8	14.0
5 Apr	1003 5	12.0	16.9	1005 6	11.4	15.6	1013 5	11.6	15.3
7 Apr	0941 3	12.1	15.6	0944 5	11.7	16.6			
9 Apr	1033 5	11.9	17.9	1036 7	12.4	16.4			
10 Apr	1126 4	12.9	17.1	1130 7	12.5	16.4	1137 4	13.0	16.2
12 Apr	1020 5	12.5	17.4	1023 7	12.2	16.7			
21 Apr	1027 5	13.0	17.6	1030 6	12.2	16.2	1038 5	11.3	15.0
	1330 5	13.3	17.6	1333 6	12.6	15.9	1340 5	12.8	15.9
	1718 4	14.4	21.2	1720 5	14.4	20.0	1728 2	17.8	22.9

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - <u>Part II-b</u>

DATE 1960	River Floodplain			Mazomanie West			Wooded Hills		
	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
5 Mar	1041 6	52.0	64.4	1043 7	40.8	48.7	1047 8	39.2	45.2
10 Mar	1048 7	52.7	65.1	1050 9	39.7	48.8	1054^{+} 9	36.8	42.4
12 Mar									
19 Mar	1254 4	35.9	52.5	1257 6	40.0	49.9	1300^{+} 8	34.9	39.8
27 Mar									
31 Mar	1254 5	9.2	11.1	1258 7	12.3	14.8	1302 8	12.0	14.3
5 Apr	1015 9	10.6	13.9	1018 9	10.9	15.0	1021 9	12.5	16.0
7 Apr									
9 Apr									
10 Apr	1138 6	11.1	13.5	1140 8	12.1	15.5	1145 10	13.1	16.2
12 Apr									
21 Apr	1040 7	10.3	13.2	1042 10	11.1	14.5	1046 10	13.0	15.9
	1343 7	10.8	13.4	1345 10	11.9	15.3	1350 9	12.4	15.6
	1730 4	14.7	19.8	1732 9	14.8	22.7	1736 9	12.8	20.5

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part III-b

DATE 1960	Black Earth			Sky Condition	Surface Condition
	T/H	A_B	A_H		
5 Mar	1052 8	54.0	65.1	Clear	8" Drifted Snow 2" One Day Old
				SCTD Thin Cirrus	" "
10 Mar	1058 10	53.4	64.9	Clear	6" One Week Snow +South Side Bare
12 Mar				Clear	5" Drifted Snow 1" One Day Old
19 Mar	1305 7	48.2	62.8	BRKN Thin Cirrus	4" Four Day Snow + South Side Bare
27 Mar				SCTD Thin Cirrus	3" Two Day Snow Melting - Brown
31 Mar	1306 6	12.5	14.8	OVC Sc 1500	Spring Brown Trace Snow - Wet
5 Apr	1025 8	12.3	16.5	SCTD Sc 2000	Spring Brown Moist
7 Apr				SCTD Sc 5000	Spring Brown Moist
9 Apr				BRKN Sc 3000	Spring Brown
10 Apr	1150 8	12.5	16.7	Clear	Spring Brown
12 Apr				Clear	Spring Brown
21 Apr	1051 9	12.4	16.2	Clear	Spring Green and Brown - Moist
	1353 9	12.9	16.7	"	" "
	1740 8	16.7	24.0	"	" "

Table 1. Average Albedo Values Observed Over South Central Wisconsin with the Change of the Seasons - <u>Part I-c</u>

DATE 1960	Waunakee-Dane			Lodi			Sauk Prairie		
	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
26 Apr	1135 5	13.3	17.1	1138 7	13.1	16.5	1145 5	12.4	15.5
28 Apr	1214 4	13.4	18.0	1215 5	13.7	18.1	1222 4	13.4	16.9
3 May	0933 6	12.9	16.8	0936 5	12.3	15.8	0945* 5	11.5	14.2
5 May	1025 6	12.8	18.3						
12 May	1155 6	14.7	17.8	1158 7	14.0	16.5	1204 5	14.5	17.3
14 May	0920 5	14.1	18.1	0922 6	14.1	17.8	0928 5	13.9	17.5
	1143 5	15.2	18.0	1145 6	13.9	16.7	1153 5	14.6	17.0
21 May	1146 7	12.0	20.4						
23 May	1118 5	13.1	17.0	1120 6	12.0	15.9	1127 5	13.5	17.0
30 May	0958 6	11.6	22.8	1000 7	10.9	26.3	1009* 8	12.1	17.5
	1505 7	12.1	17.0						
11 Jun	1231 6	15.4	20.0	1233 7	15.0	20.8			
17 Jun	1143 7	13.5	16.1	1147 8	12.6	15.2	1154 7	12.6	15.3
25 Jun	1308 6	12.9	16.7	1311 7	13.1	16.5	1319 5	12.2	15.5
8 Jul	1051 7	12.0	18.6	1055 9	11.2	17.7	1103 8	11.2	17.4

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part II-c

DATE 1960	River Floodplain			Mazomanie West			Wooded Hills		
	T/H	A_B	A_H	T/H	A_B	A_H	T/H	A_B	A_H
26 Apr	1148 7	10.1	12.1	1150 9	11.4	15.0	1154 10	13.2	15.9
28 Apr	1225 6	9.9	11.7	1227 6	12.1	15.7	1230 6	12.9	15.9
3 May	0947* 7	8.6	10.8	0950* 8	10.5	13.8	0954* 10	12.6	16.8
5 May									
12 May	1205^{+} 6	7.4	8.2	1209^{+} 10	10.4	12.8	1214 10	12.9	15.5
14 May	0932^{+} 6	6.7	9.9	0933^{*+} 7	11.5	14.5	0939* 8	12.8	16.3
	1155^{+} 7	8.5	9.1	1158^{+} 7	11.1	13.0	1201 8	13.3	15.6
21 May									
23 May	1129 6	8.2	9.6	1132^{+} 9	11.5	13.3	1135 8	13.5	16.4
30 May	1011* 7	6.3	11.9	1013* 9	10.8	16.0	1017* 8	11.9	16.1
11 Jun									
17 Jun	1156 8	6.7	8.1	1158 9	13.4	15.9	1202 8	14.9	16.9
25 Jun	1321 8	6.4	8.3	1324 9	13.3	16.5	1329 9	13.0	17.1
8 Jul	1105 10	7.7	11.8	1107 11	11.6	17.3	1112 8	12.0	17.9

Table 1. Average Albedo Values Observed over South Central Wisconsin with the Change of the Seasons - Part III-c

DATE 1960	Black Earth			Sky Condition	Surface Condition
	T/H	A_B	A_H		
26 Apr	1158 8	12.2	15.8	SCTD Thin Cirrus	Spring Green and Brown
28 Apr	1236 7	13.6	17.4	SCTD Ac 10000 OVC Thin Cirrus	Spring Green
3 May	1000 8	13.3	16.8	BRKN Thin Cirrus *BRKN Ac 14000	Green - Trees Showing Leaves
5 May				BRKN St 1000 OVC AS 7000-Rain	Green - Moist Trees Leafing
12 May	1217 9	13.2	16.2	Clear	Green - Unplowed Fields Brown +Parts Flooded
14 May	0940 8	13.2	17.0	Clear *SCTD Cirrus	Green - Unplowed Fields Brown Trees 60% Leafed +Parts Flooded
	1205 6	13.8	15.9	BRKN Thin Cirrus	
21 May				BRKN Cu 1500 OVC AC 7000-Rain	" " Trees 80% Leafed
23 May	1140 9	12.8	15.5	SCTD Sc 3000	" " +Parts Wet
30 May	1021* 8	11.4	18.1	OVC Sc 2500 *BRKN Sc	Green - Plowed Fields Brown Trees Leafed
				SCTD Cu 3000	" "
11 Jun				OVC St 1500	Green - Crop Fields Brown
17 Jun	1206 8	13.1	15.5	OCNL Sc 3000 SCTD Thin Cirrus	" "
25 Jun	1332 9	12.8	16.2	SCTD Sc 2500	Crops Showing Green in Fields
8 Jul	1115 9	11.1	17.0	Clear	Green

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part I

DATE 1959	Mendota West			Mendota North			State of Surface
	T/H	A_B	A_H	T/H	A_B	A_H	Mendota W and N
15 Oct	1214 2	2.4	----				Rippled
17 Oct				1005 11	3.5	----	Small Waves
20 Oct							
27 Oct	1328 11	7.3	----				Rippled
	1350 11	6.7	----				"
29 Oct	1343 3	1.9	----	1345 11	1.8	----	Rippled
	1405 11	4.7	----	1407 11	4.3		"
1 Nov	1158 6	1.4	----	1200 6	1.8	----	Rippled with Thin Foam Lines
3 Nov	1118 2	1.5	----				Rippled
	1140 11	3.2	----	1142 11	3.1	----	"
19 Nov	1335 2	4.5	----	1337 11	3.5	----	Rippled
	1405 11	4.9	----	1407 11	4.4	----	"
21 Nov	1345 11	1.3	----	1347 11	1.4	----	Rippled
28 Nov	1100 11	3.1	----	1103 11	2.4	----	Rippled Foam Lines
1 Dec	1120 11	0.1	----	1122 11	0.0	----	Small Ripples

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part II

DATE 1959	Lake Wisconsin T/H	A_B	A_H	State of Surface Lake Wisconsin	Sky Condition
15 Oct	1225 12	2.2	----		BRKN Thin Cirrus
17 Oct	1017 12	4.0	----	Small Waves	Clear
20 Oct	1403 12	2.9	----	Choppy with Foam Lines	OCNL Sc 4000
27 Oct	1338 13	8.3	----	Rippled	Uniform OVC 2000
					" "
29 Oct	1353* 12	2.9	----	Rippled	SCTD Sc 3500 *Haze
					" "
1 Nov	1212 15	1.1	----	Rippled	Uniform OVC 6000
3 Nov	1128 12	2.0	----	Rippled with Foam Lines	SCTD Thin Cirrus
					" "
19 Nov	1346* 12	3.2	----	Frozen - Black	SCTD Cirrus *BRKN Cirrus
					" "
21 Nov	1357 12	36.1	----	Snow Covered	SCTD Thin Cirrus Haze
28 Nov	1113* 12	53.0	----	Snow Covered Spots Bare Ice	OVC St 5000 *OCNL Sunlight
1 Dec	1128 12	39.1	----	Rippled Snow Small Dark Spots	Uniform OVC 4000

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part I-a

DATE	Mendota West			Mendota North			State of Surface
1959	T/H	A_B	A_H	T/H	A_B	A_H	Mendota W and N
3 Dec	1239 11	1.3	----	1240 11	1.1	----	Rippled with Thin Foam Lines
8 Dec	1303 11	2.6	----	1305 11	2.4	----	Rippled
10 Dec	1059 11	2.6	----	1101 11	2.9	----	Thin Coat of Ice Open Leads
	1500 6	7.4	----	1502 11	6.1	----	" "
17 Dec	1101 7	1.2	----	1103 9	2.4	----	Calm
19 Dec	1045 11	1.5	----	1047 11	2.3	----	Rippled
	1407 11	0.8	----	1408 11	0.3	----	Rippled
1960 7 Jan	1428 11	12.5	----	1430^{+} 11	4.1	----	Melting Snow +Open Water
16 Jan	1105 11	29.4	----	1106^{+} 11	2.6	----	Snow Covered +Open Water
	1334 11	26.1	----	1335^{+} 11	2.4	----	" "
	1406 3	31.4	----	1407^{+} 1	4.9	----	" "
25 Jan	1335 11	48.9	----	1348 3	49.9	----	5" One Week Snow Drifted
2 Feb	0958 6	48.9	69.7	1003 6	45.7	62.5	Snow Covered White
7 Feb	1315 6	41.6	58.4	1319^{+} 3	28.5	41.2	Snow Covered White +Gray Spot
14 Feb	1152 10	47.1	65.4	1158 2	42.3	56.7	5" Four Day Snow Trace Bare Ice

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons -Part II-a

DATE 1959	Lake Wisconsin T/H	 A_B	 A_H	State of Surface Lake Wisconsin	Sky Condition
3 Dec	1248* 13	19.9	----	Mottled Snow Patches on Ice	SCTD Ac 18000 *OVC Ac 18000
8 Dec	1315 12	6.8	----	Ice Black and White - Puddles	Clear
10 Dec	1108 12	6.2	----	Ice Black and White	SCTD Thin Cirrus
					Uniform OVC 9000
17 Dec	1112 8	2.6	----	Ice Black and Gray	BRKN Thin Cirrus
19 Dec	1057 12	4.1	----	Ice Dark	Clear
	1418 12	5.3	----	" "	OVC Thin Cirrus
1960 7 Jan	1438 12	7.9	----	Ice Black Trace of Snow	Clear
16 Jan	1118 12	10.1	----	Ice Black Patches of Snow	Clear
	1344 12	11.3	----	" "	"
	1416 2	12.6	----	" "	"
25 Jan					SCTD Thin Cirrus
2 Feb	1022 8	51.7	66.6	Two Week Snow Trace Bare Ice	OVC St 1700
7 Feb	1327 4	36.0	51.5	Old Snow OCNL Dark Areas	SCTD Thin Cirrus
14 Feb	1206 3	45.6	61.5	Drifted Snow	OCNL Thin Cirrus

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part I-b

DATE	Mendota West			Mendota North			State of Surface
1960	T/H	A_B	A_H	T/H	A_B	A_H	Mendota W and N
20 Feb	1501 2	47.7	65.1	1502^+ 6	42.8	59.1	4" Ten Day Snow $^+$Gray Ice, Snow
23 Feb	1038 6	54.1	69.7	1051 4	56.2	72.2	7" One Day Snow White
25 Feb	1029 2	60.9	76.8				7" Snow 1" One Day Snow
27 Feb	1015 4	52.5	70.6	1017 4	50.7	69.8	6" One Week Snow 1" One Day Snow
	1416 4	55.3	71.7	1418 4	50.3	65.4	" "
1 Mar	0943 2	49.1	68.4				6" Nine Day Snow Slight Drifts
	1148 2	50.8	59.8	1150 8	53.8	63.3	" "
5 Mar	0755 3	50.9	71.1	0756 4	53.4	65.3	8" Drifted Snow 2" One Day Snow
	1023 3	55.6	70.1	1025 4	55.8	69.5	" "
	1033 4	53.1	67.4	1030 5	53.6	68.7	" "
10 Mar	1032 4	56.6	71.3	1034 4	56.3	69.9	6" One Week Snow Drifted
12 Mar	1401 3	54.9	71.1	1404 4	53.2	68.5	5" Drifted Snow 1" One Day Snow
17 Mar	1013 11	54.6	74.4				4" Two Day Snow Drifted
19 Mar	1230 1	53.1	71.9	1240 4	54.3	71.6	3" Four Day Snow Drifted -Melting
24 Mar	1017 3	51.4	67.3				2" Crusted Snow Trace New Snow

Table 2. Average Albedo Values Observed Over Lake Mendota and Lake Wisconsin with the Change of the Seasons -Part II-b

DATE 1960	Lake Wisconsin			State of Surface Lake Wisconsin	Sky Condition
	T/H	A_B	A_H		
20 Feb					OVC As 7000
23 Feb	1100* 6	61.7	75.5	7" One Day Snow White	Clear *OVC Sc 1200
25 Feb					BRKN Sc 2000 OVC As 6000
27 Feb	1025 3	50.5	67.0	6" One Week Snow 1" One Day Snow	Clear
	1426 3	53.3	68.9	" "	"
1 Mar	0953 2	51.6	66.9	6" Nine Day Snow Slight Drifts	Clear
					"
5 Mar	0806 4	51.9	67.1	8" Drifted Snow 2" One Day Snow	Clear
	1034 4	57.1	70.4	" "	"
					"
10 Mar	1041 5	55.5	68.4	6" One Week Snow Drifted	Clear
12 Mar	1013 6	56.3	70.6	5" Drifted Snow 1" One Day Snow	Clear
17 Mar					OVC St 1500
19 Mar	1249 4	53.9	71.0	3" Four Day Snow Drifted -Melting	BRKN Thin Cirrus
24 Mar					SCTD Sc 3000

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part I-c

DATE	Mendota West			Mendota North			State of Surface
1960	T/H	A_B	A_H	T/H	A_B	A_H	Mendota N and W
27 Mar	1021 6	42.2	57.2	1022 6	42.4	57.8	3" Drifted Snow Dark Gray Spots
31 Mar	1239 6	9.4	16.6	1240 6	7.3	13.2	Mottled Dark Gray Ice
5 Apr	0957 6	6.6	15.3	1000 6	5.4	11.9	Ice Mottled Dark and Light Gray
	1030 10	8.7	14.1				" "
7 Apr	0937 4	4.2	8.7				Ice Dark Mottled Gray
	1050 7	5.5	6.5	1045 21	4.5	5.8	" "
9 Apr	1028 4	3.2	8.6				Ice Dark Mottled Gray
	1048 7	1.8	10.5				" "
10 Apr	1022 3	5.7	11.0	1024 5	5.6	11.5	Ice Dark Mottled Gray and Green
	1155 8	7.7	11.6				" "
12 Apr	1016 4	1.1	5.9	1018$^+$ 5	1.6	6.7	Rippled Water $^+$Dark Melting Ice
21 Apr	1023 6	1.5	5.5	1025 6	1.7	5.3	Trace of Ripples
	1057 6	2.0	4.5				" "
	1327 6	1.7	5.3	1328 6	1.4	4.9	Ripples
	1359 7	2.1	5.3				"

Table 2. Average Albedo Values Observed Over Lake Mendota and Lake Wisconsin with the Change of the Seasons -Part II-c

DATE	Lake Wisconsin			State of Surface	Sky
1960	T/H	A_B	A_H	Lake Wisconsin	Condition
27 Mar	1030 6	44.5	58.7	3" Drifted Snow Gray Spots	SCTD Thin Cirrus
31 Mar	1249 5	5.9	10.2	Ice Mottled Dark Gray	OVC St 1500
5 Apr	1009 5	3.2	7.0	Dark Gray Ice 1/3 Open Water	SCTD Sc 2000
					" "
7 Apr	0946 6	2.9	6.3	Open Water	SCTD Sc 5000
					" "
9 Apr	1040 8	3.6	8.6	Small Waves Foam Lines	BRKN Sc 3000
					" "
10 Apr	1132 5	1.6	5.0	Rippled - Some Foam Lines	Clear
					"
12 Apr	1025 8	2.1	5.8	Rippled	Clear
21 Apr	1033 8	1.4	5.1	Rippled	Clear
					"
	1336 7	1.5	4.6	Rippled	"
					"

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part I-d

DATE	Mendota West			Mendota North			State of Surface
1960	T/H	A_B	A_H	T/H	A_B	A_H	Mendota W and N
21 Apr	1710 6	3.6	12.5	1715 6	3.9	16.5	Rippled
	1746 6	15.7	20.9				"
26 Apr	1131 5	2.6	5.3	1132 5	2.1	4.8	Small Waves Some White Caps
28 Apr	1208 4	2.0	5.6	1210 5	1.8	5.2	Moderate Ripples
	1241 6	2.9	5.6				" "
3 May	0930 5	1.8	5.3				Waves - White Caps - Foam Line
	1008 8	3.0	5.1				" "
5 May	1013 7	4.2	11.0				Rippled
12 May	1150 6	3.7	3.7	1152 6	2.7	3.5	Waves - White Caps - Deep Blue
	1223 7	3.8	4.0	1225 7	3.0	3.7	" "
14 May	0914 4	0.7	5.0	0916 4	1.3	5.1	Small Ripples Glassy
	0948 5	1.7	4.1	0949 5	2.9	5.0	" "
	1138 5	1.8	4.2	1140 5	1.3	4.0	Small Ripples
	1211 6	3.4	5.0	1213 6	3.4	4.5	" "
21 May				1143 8	2.6	5.9	Small Waves OCNL White Caps

Table 2. Average Albedo Values Observed Over Lake Mendota and Lake Wisconsin with the Change of the Seasons -Part II-d

DATE 1960	Lake Wisconsin			State of Surface	Sky Condition
	T/H	A_B	A_H	Lake Wisconsin	
21 Apr	1723 4	5.9	14.8	Rippled	Clear
				"	"
26 Apr	1142 5	2.4	4.7	Waves - White Caps	SCTD Thin Cirrus
28 Apr	1218 4	1.5	5.0	Rippled	SCTD Ac 10000 OVC Thin Cirrus
					" "
3 May	0940 5	1.7	4.1	Small Waves OCNL Foam Lines	BRKN Thin Cirrus
					" "
5 May					BRKN St 1000 OVC As 7000
12 May	1200 6	2.2	3.6	Rippled Dirty Brown	Clear
					"
14 May	0925 5	1.4	4.5	Small Ripples	Clear
					"
	1148 5	2.2	4.6	" "	BRKN Thin Cirrus
					" "
21 May					BRKN Cu 1500 OVC Ac 7000

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons - Part I-e

DATE 1960	Mendota West			Mendota North			State of Surface Mendota W and N
	T/H	A_B	A_H	T/H	A_B	A_H	
21 May	1153 7	3.1	5.9	1152 7	3.4	6.0	Small Waves OCNL White Caps
23 May	1112 5	0.7	4.3	1113 5	0.8	4.2	Small Ripples Glassy
30 May	0953 6	2.5	8.4	0955 7	2.2	8.4	Waves - OCNL White Caps
	1025 7	4.3	7.3	1029 5	4.3	8.6	" "
	1455 7	1.7	5.1	1459 7	2.5	7.8	Waves - White Caps
11 Jun				1227 6	4.6	6.7	Small Waves OCNL White Caps
17 Jun	1138 6	2.7	5.2	1140 8	3.3	5.1	Calm - Areas of Small Ripples
	1212 6	3.9	4.5	1214 7	2.3	4.4	" "
25 Jun	1303 6	3.6	5.9	1305 6	2.7	5.6	Calm - Areas of Small Ripples
	1337 6	3.2	4.9	1340 6	2.7	5.0	" "
8 Jul	1046 8	3.8	5.5	1048 8	3.7	5.4	Rippled
	1120 8	4.1	5.2	1122 9	3.7	5.0	"

Table 2. Average Albedo Values Observed over Lake Mendota and Lake Wisconsin with the Change of the Seasons -Part II-e

DATE 1960	Lake Wisconsin T/H	Lake Wisconsin A_B	Lake Wisconsin A_H	State of Surface Lake Wisconsin	Sky Condition
21 May					BRKN Cu 1500 OVC Ac 7000
23 May	1122 6	1.2	3.9	Small Ripples	SCTD Sc 3000
30 May	1005* 6	5.5	15.1	Small Waves Foam Lines	OVC Sc 2500 *INTER Bright
					" "
					SCTD Cu 3000
11 Jun	1235* 8	6.6	9.5	Small Waves	OVC St 1500 *INTER Bright
17 Jun	1150 8	2.3	4.5	Calm - Areas of Small Ripples	OCNL Sc 3000 SCTD Thin Cirrus
					" "
25 Jun	1314 6	3.6	5.0	Calm - Areas of Small Ripples	SCTD Sc 2500
					" "
8 Jul	1058 8	4.3	6.1	Rippled	Clear
					"