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DISTRIBUTION OF SOLAR RADIATION WITHIN A DECIDUOUS FOREST

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Distribution of Solar Radiation Within a Deciduous Forest

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<KEYWORDS> Solar radiation, Deciduous forest

<ABSTRACT> Measurements of solar radiation during June 1972 have been reduced and plotted as time distributions of flux densities. The distributions are near normal and skewness of the distributions increase with elevation in the forest. Major changes in sky conditions (complete overcast to very clear) have minimal effects upon the distribution curves. Increasing cloudiness decreases skewness and narrows the distribution curve. Modal intensities are unchanged.

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Abstract:

It has long been recognized that the time distribution of radiative flux densities within vegetative stands depart from Gaussian. As early as 1911, Ramaan noted that time averages of radiation in a spruce forest were meaningless owing to the non-normality of the distribution of radiation values. In general, time distributions reported in the literature are unimodal and skewed to higher flux densities. However most of these studies deal only with radiation reaching the forest floor.

As part of the U.S.I.B.P. Eastern Deciduous Forest Biome effort at Oak Ridge, we are studying the distribution of solar radiation in a Liriodendron tulipifera forest in vertical and horizontal space and the temporal changes in this distribution. Results of this study indicate that time distributions of flux densities in this forest are non-normal. Further, the amount of skewness increases with elevation in this forest. Time distributions of flux densities are compared for days having complete overcast, for clear days, and for days of varying cloud cover and type. We find that, within the forest, the distributions of flux densities are similar on all days and that increasing cloudiness only narrows the distribution curve and decreases the amount of skewness.

Introduction

The distribution of solar radiation in vegetative stands has received considerable attention in the past and continues to intrique agronomists, ecologists, micrometeorologists, and others. As part of the Eastern Deciduous Forest Biome, U.S.I.B.P. effort at the Oak Ridge site, we are studying the distribution of solar radiation within a deciduous forest composed predominantly of tulip poplar (*Liriodendron tulipifera*). A major objective of this study is to relate this distribution of solar energy to forest structure.

As early as 1911, Ramaan realized that the simple determination of mean radiation in a spruce forest was not particularly meaningful because of the non-normal distributions of flux densities. Impens, Lemeur, and Moermans (1970) report bimodal frequency distributions of net radiation values in the upper portion of crop canopies. Lower in the canopy, the bimodality disappears and unimodal distributions skewed to high net radiation values are found. Similarly, Ovington and Madgwick (1955) report skewed, unimodal frequency distributions of flux densities reaching the floors of both spruce and oak stands.

Because of the non-Gaussian time distributions of radiant energy within vegetative stands, Alekseev (1963) concluded that measures of skewness and of kurtosis of the radiation distributions are needed beyond the usually cited statistical parameters of mean and standard deviation in order to characterize the radiation climates of plant communities in a meaningful way.

In a preliminary study that I conducted in this same forest during the spring-summer transition of 1969, measurements were made on clear days only. As the forest became fully leafed, I found that the time distributions of direct beam flux densities departed strongly from Gaussian (Hutchison, 1971). I also found that the distributions varied as to elevation within this forest. Between the projecting tips of the tulip tree crowns (≈ 20 m. elevation), bimodal distributions were found as shown in Figure 1. Just above the secondary canopy of redbud (*Cercis canadensis*) and flowering dogwood (*Cornus florida*), the distributions were unimodal but skewed to higher flux densities (Figure 2). On the forest floor, distribution curves were again unimodal but with modal flux densities around half of those observed at 9 m elevation. Again, the distributions are somewhat skewed (Figure 3).

During the past year, we have measured the time distribution of total solar radiation in this forest more intensively. Data are now collected under all meteorological conditions rather than just clear days. The number of replications of measurements in the forest canopy has also been increased.

Methods:

Radiant flux densities are measured using Lintronic Dome Solarimeters which sense radiation in the spectral band from 0.3 to 3 microns. The sensors are randomly located in horizontal space at 3 levels within the forest. At the base of the overstory canopy, about 15 meters above the ground, measurements are replicated 11 times. At the base of the secondary canopy, about 3 meters above the ground, and on the forest floor, measurements of total radiant flux densities are replicated 12 times. Solar radiation incident upon the top of the forest is measured with a single solarimeter situated 30 meters above the ground, some 1 to 2 meters above the tops of the tallest trees.

Output signals from all sensors are transmitted to a data logging system, converted to digital form, and recorded on punch paper tape. Because of the limited tape capacity, number of channels recorded, and limited access to the site, scan intervals used are 10 minute on workdays and 30 minute on weekends and holidays.

Site Description:

The forest under study is located on the AEC reservation some 10 km south of the town of Oak Ridge. This forest is situated in a moist limestone sink and is vegetatively similar to other cove hardwood stands of the Appalachian region. Because of the mesic nature of this site however, this forest is not at all typical of the predominant oak-hickory forests of this region. Density and diversity of this stand is considerably higher than that of the forest on the drier slopes above this sink. Also the secondary canopy of redbud and flowering dogwood is absent outside the area of the sink. The overstory canopy is nearly pure tulip poplar although numerous other species are present in low numbers. The pertinent mensurational data for this site are summarized in Table 1. The overall basal area for this site is about 20 m^2 $hectare^{-1}$ while stem density exceed 5500 stems $hectare^{-1}$. The maximum leaf area index of this forest approaches 6 $m^2 m^{-2}$ (Dinger, Richardson, & McConathy, 1972b). Figure 4 shows an aerial view of this site taken in November, 1972.

Results:

In most years this forest attains full leaf around June 1. To investigate the distribution of radiation in this forest during the growing season we have selected data from June 20, 1972, a completely overcast day, from June 24, 1972, a very clear day, and from June 14, 18 and 19, 1972, days of varying cloud conditions. Since all of these dates occur after the forest becomes fully leafed, these data should be fairly representative of the entire growing season.

On June 20, overcast conditions prevailed throughout the entire day as is evident from Figure 5, a plot of the incident flux densities recorded above the forest canopy. Figure 6 shows the distribution of total flux density on this day for the 3 levels within the forest and the above canopy level as well. The class interval of flux density used to generate these plots is 50 mly min^{-1}. As can be seen on this figure, modal intensities at all levels within the forest lie somewhere in the 0 to 50 mly min^{-1} class. Only at the 15 m level is there any contribution to total flux densities by flux densities greater than 50 mly min^{-1}.

Figure 7 shows the daily course of incident flux densities for June 24, 1972, obviously a very clear day. Despite the much greater amounts of radiation received above the canopy on this day, modal flux

Table 1: Mensurational Data and Diversity of the Cesium Tagged *Liriodendron* Forest at the Oak Ridge Site

Canopy Level	Height (meters)	Average DBH (cm)	Basal Area (m^2 hectare^{-1})	Density (stems hectare^{-1})	Species Diversity Index
Upper	15-25	23.8	24.0	518.1	1.11
Mid	9-15	8.6	1.7	286.9	1.42
Forest floor	1.5-9	2.3	3.0	4766.9	1.78
Overall	1.5-25	-	28.7	5571.9	2.06

densities within the canopy remain unchanged as shown on Figure 8. The increased amounts of incident radiation do however effect a broadening of the distribution curves at all levels and the frequency of the modal intensity class is reduced. At the 15 m level, radiant flux densities are present as high as 500 to 550 mly min^{-1}. Although the frequency of such flux density classes are individually very low, flux densities exceeding 200 mly min^{-1} were experienced at this level some 15 percent of the time on this day.

On days of varying cloud conditions, the flux density distributions are not much different from those on very clear days. For example, Figure 9 shows the course of incident radiation for June 14, a clear day with some cloudiness present in the early afternoon. The distribution of flux densities on this day are shown in Figure 10. Again modal intensities at all levels fall in the 0 to 50 mly min^{-1} class as on both very cloudy and very clear days. The tails of these curves drop off to zero frequency a little faster than on the clear day of June 24 (Figure 8).

On June 18, the early morning and late afternoon were quite cloudy while partly cloudy conditions prevailed through much of the rest of the day (Figure 11). As shown on Figure 12, the distribution curves are only slightly changed from those of the very clear and the mostly clear days shown in Figure 8 and 10. Modal frequencies are somewhat higher and the curves are somewhat narrower for within forest levels.

The final day that we will consider here is June 19, a day which began clear, became partly cloudy around mid-morning and completely overcast around local noon (Figure 13). The curves of frequency distribution shown on Figure 14 approach those of the overcast day of June 20 in Figure 6 but because of the clear or partly cloudy skies early in this day, the curves are slightly broader than those of the overcast day.

Discussion:

While a 50 mly min^{-1} class interval seems sufficiently small to show significant physical differences in the distribution of radiant energy within a plant community, our results indicate that at this level of resolution, the distributions change only slightly from completely overcast days to completely clear days. The structure of this forest is apparently such that gross changes in incident levels radiation are smoothed out within the forest resulting in similar distribution curves on all days during the growing season. This is not too surprising since a major portion of the incident radiation on clear and partly cloudy days is made up of direct beam radiation. This direct beam radiation is more effectively absorbed by the forest canopy than the diffuse. Hence the radiation climate within the forest changes only slightly from day to day.

The results presented here also show that the flux density frequency distributions depart from Gaussian on cloudy and partly cloudy days as well as on clear days and that the departure from normality increases with elevation in the forest. This can be seen on Figure 15 which is a plot of the distribution of flux densities for all days in June, 1972 for which we have complete sunrise to sunset records. As would be expected from the similarity of distribution curves on the individual days presented, the curves exhibited by this combined plot are very similar to the curves for individual days.

In studies of CO_2 uptake in this forest conducted by Dr. B. E. Dinger, (1972a,b) he has found that light saturation occurs in tulip poplar at flux densities of about 400 mly min^{-1}. In flowering dogwood, a major understory species, light saturation occurs at flux densities around 200 mly min^{-1}. Further, Dr. Dinger has found that of the species studied from this forest, all have light compensation points near flux densities of 15 mly min^{-1}. Thus it appears that despite the severe reduction in the flux density of radiation effected by this forest, sufficient energy penetrates to all levels to exceed the light compensation point of the members of this community throughout much of each day. Since we have not studied the spectral distribution of this radiation, we do not know whether this light is of the proper quality to allow photosynthesis however.

Dr. Dinger's results also indicate that although we feel that levels of resolution reported here are sufficient to illustrate gross physical characteristics of radiation distribution, they are not really adequate to characterize possible biologic effects. Thus we plan to recompute these flux density distributions using smaller flux density class intervals to further clarify the biologic significance of these results.

Future Work:

Our analyses of forest and canopy structure are continuing in order to provide the information needed to relate these radiant energy distributions to forest structure. A word of caution is in order too regarding these data just presented. All flux densities were calculated using calibration coefficients derived from comparing our solarimeters with a standard pyrheliometer. Recently we have investigated the linearity of the response of these solarimeters over the entire range of flux densities to which they are exposed in the field. We have found that the response is strongly nonlinear at flux densities below 200 mly min^{-1} and we are presently deriving curvilinear calibration functions which will be used to recompute all of our radiometric data. Because of the nonlinear response of these sensors, indicated flux densities below 100 mly min^{-1} may be as much as 200 percent too high.

Conclusions:

At the level of resolution with which we are presently working, we conclude that radiation distributions within this forest during the growing season depart from normal and the departure apparently increases with height in the forest. Furthermore, the forest structure has evolved in such a way that the distribution of radiation within the forest changes only slightly as great changes in incident radiation occur. Finally, although our level of resolution is too coarse to allow definitive analysis of the biologic significance of these results, it appears that sufficient energy penetrates to all levels to satisfy the light requirements of the component species of this forest most of the time. The question of quality of radiation in the forest remains unresolved.

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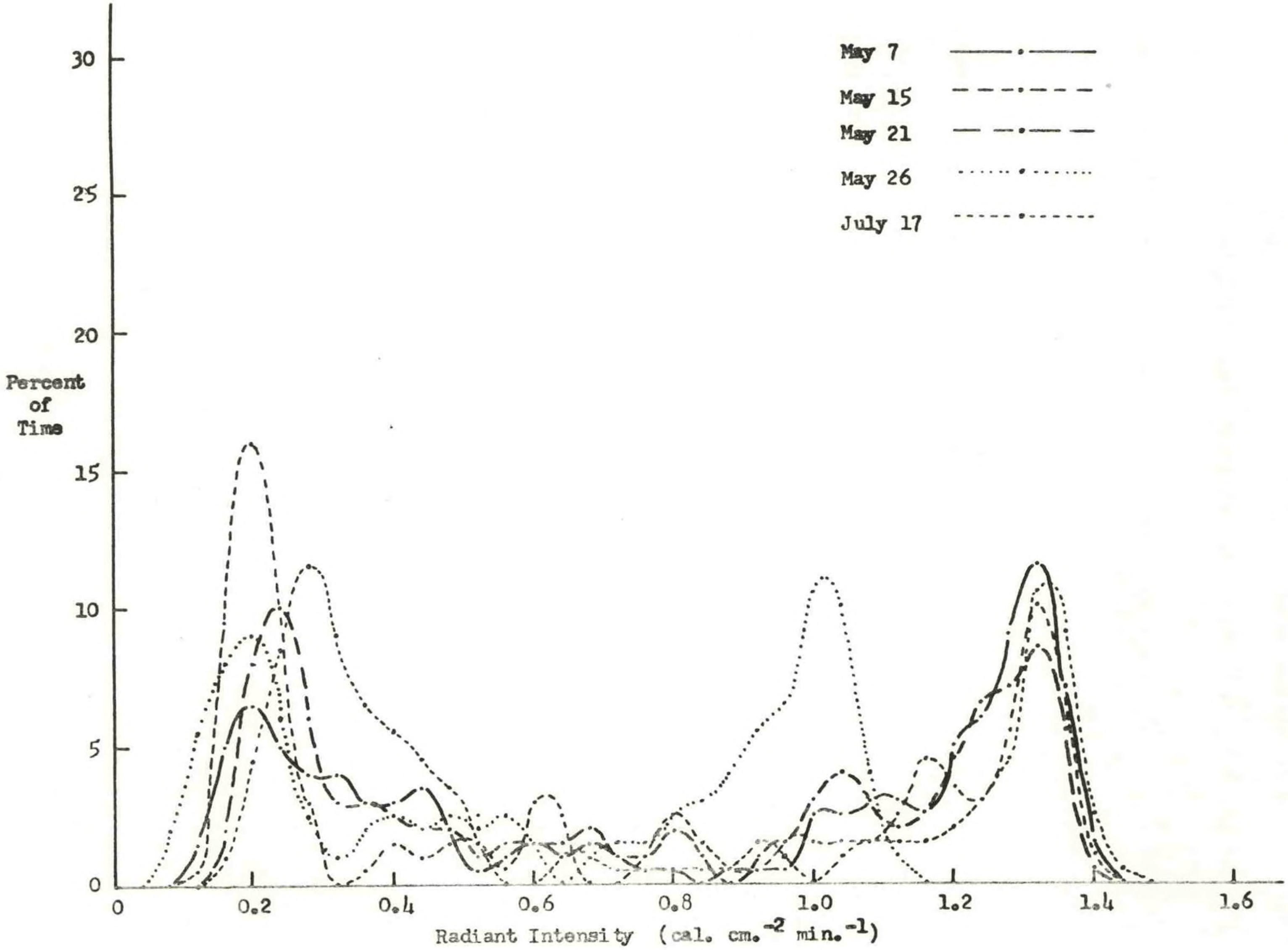
List of Figures:

Figure 1 : Distribution of Direct Beam Radiant Intensity at Upper Canopy for Period Solar Noon ± 3 Hours



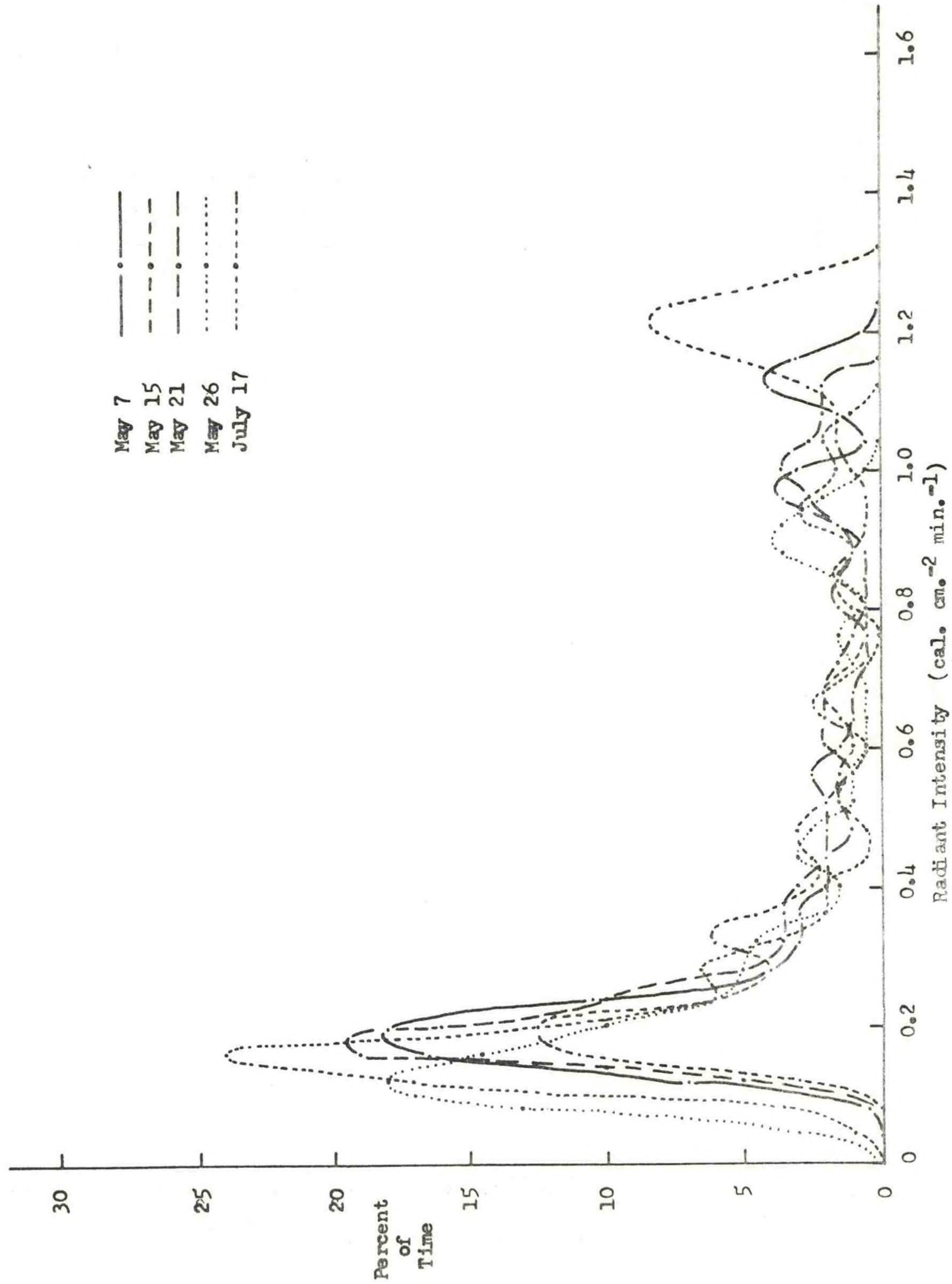


Figure 2 : Distribution of Direct Beam Radiant Intensity at Mid-canopy for Period Solar Noon ± 3 Hours

Figure 3 : Distribution of Direct Beam Radiant Intensity on Forest Floor for Period Solar Noon ±3 Hours

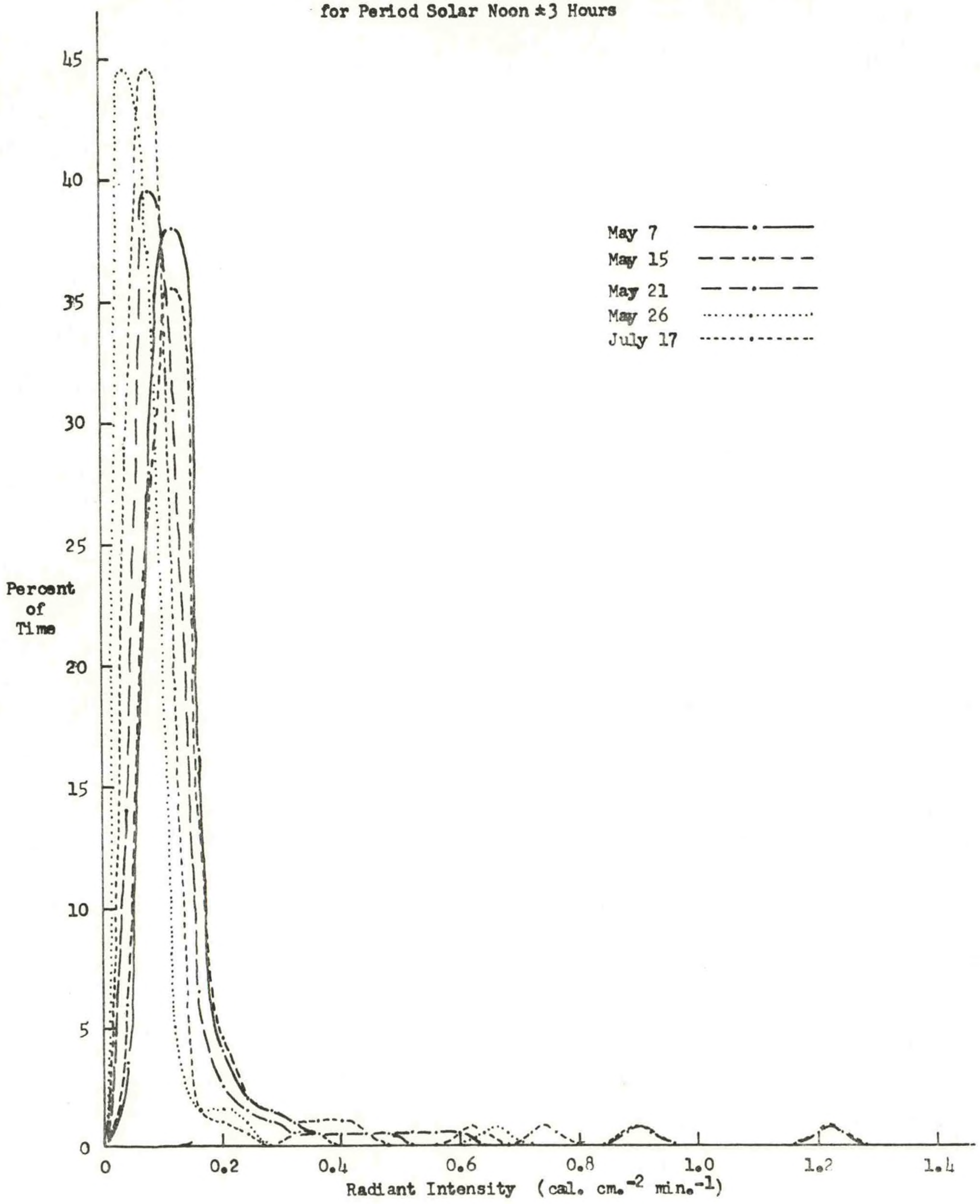


Figure 4: Aerial View of Liriodendron Forest Under Study (November, 1972). All measurements were made within the area outlined in the photograph.

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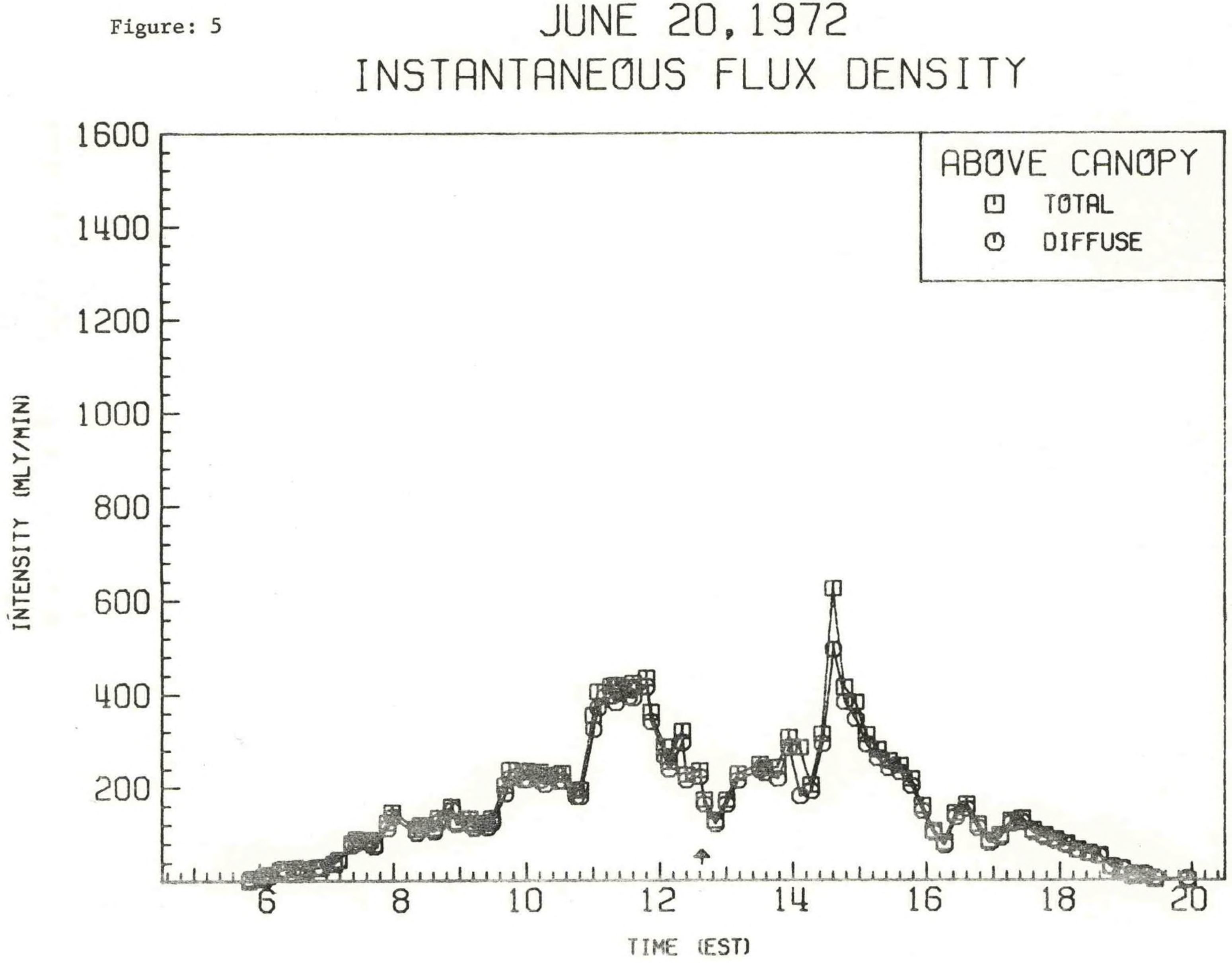
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DIFFUSE
INTENSITY (MLY/MIN)
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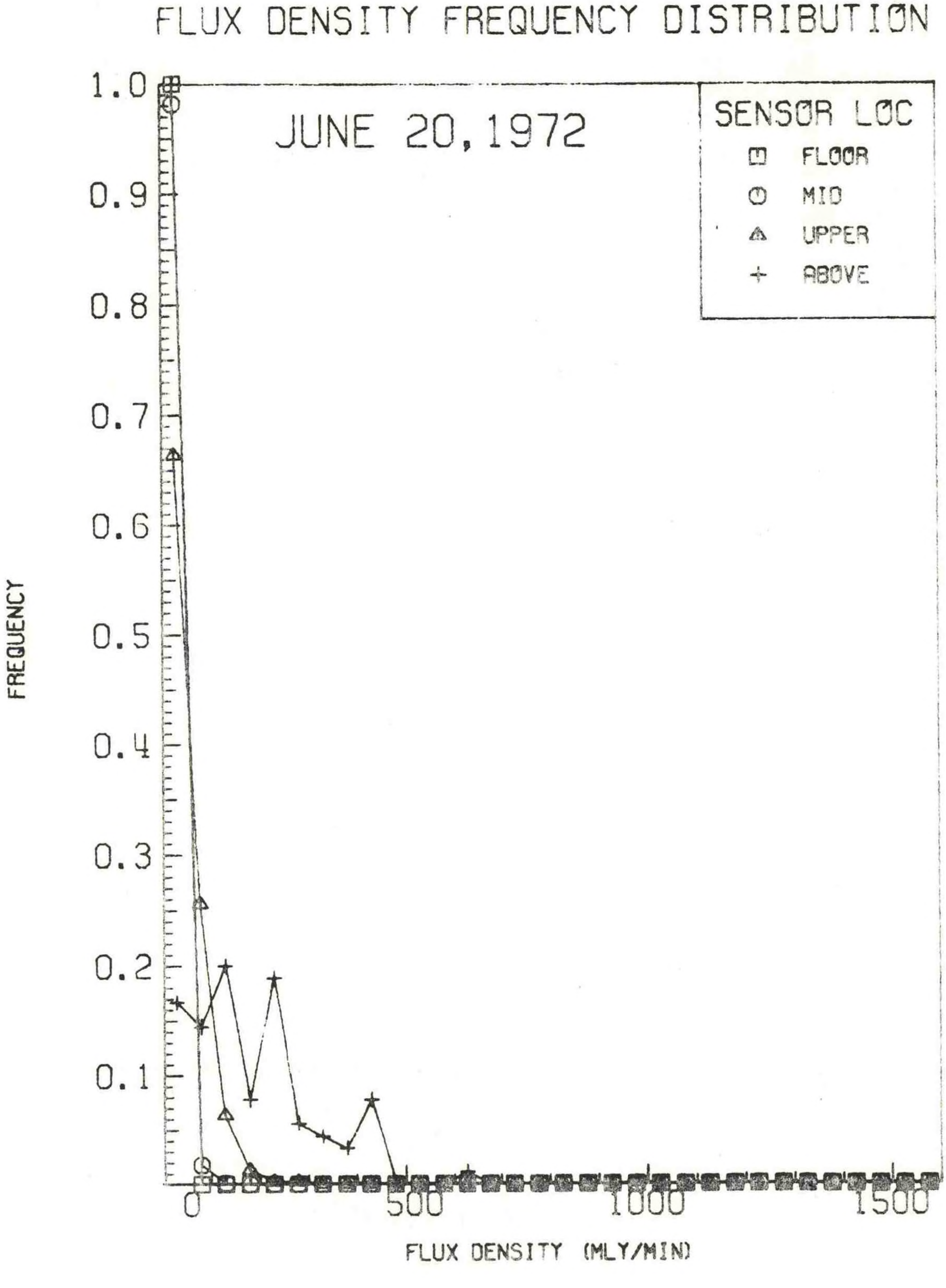
1200
1000
800
600
400
200
TIME (EST)
6
8
10
12
14
16
18
20

Figure: 6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JUNE 20,1972
SENSØR LØC
FLOOR
MID
UPPER
ABOVE
FREQUENCY
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0.9
0.8
0.7
0.6
0.5
0.4
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0.1
0
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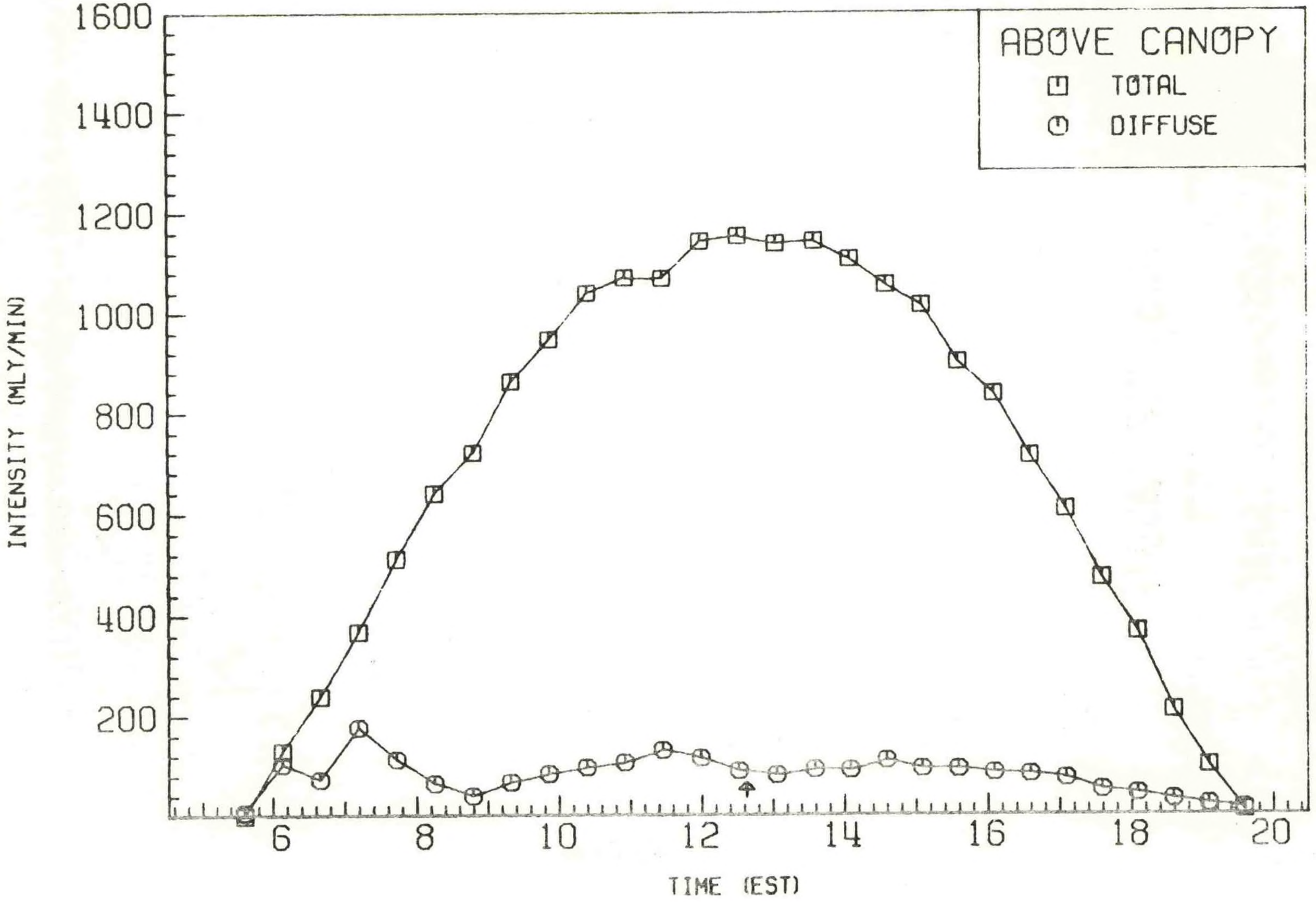
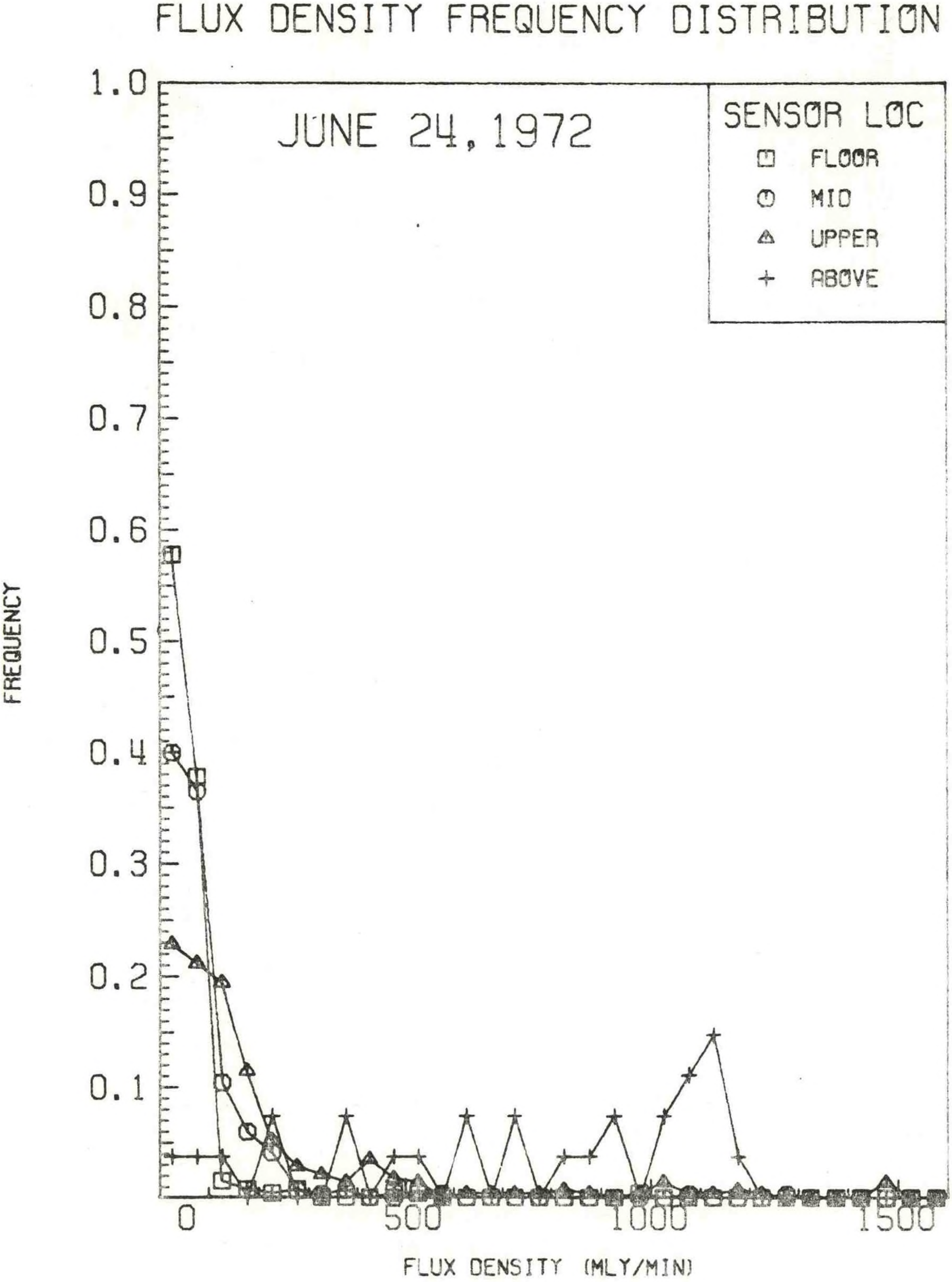
1000
1500
FLUX DENSITY (MLY/MIN)

Figure: 7



JUNE 24, 1972
INSTANTANEOUS FLUX DENSITY

Figure: 8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SENSOR LOC
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MID
UPPER
ABOVE
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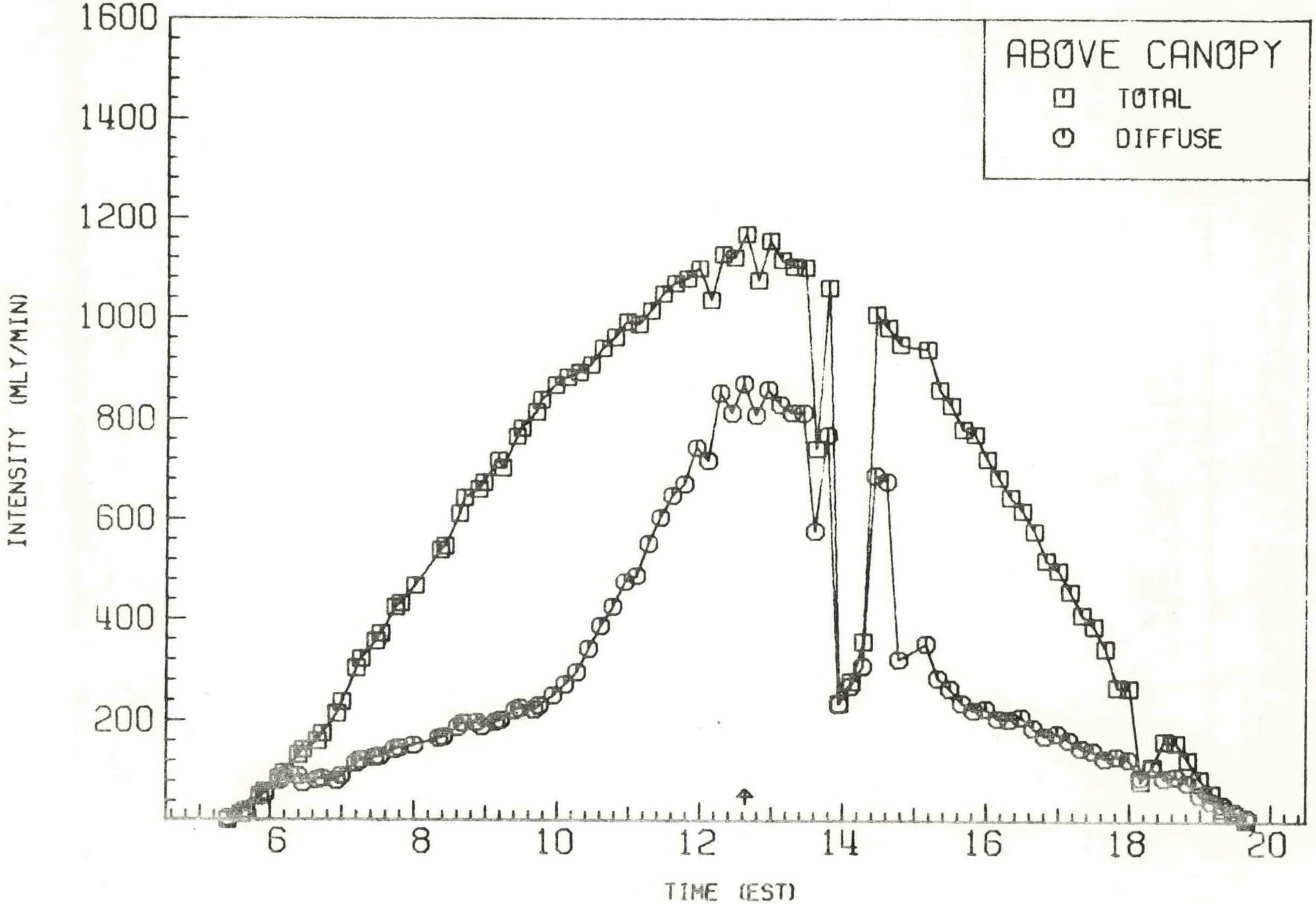
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
500
1000
1500
FLUX DENSITY (MLY/MIN)

Figure: 9

JUNE 14,1972
INSTANTANEOUS FLUX DENSITY



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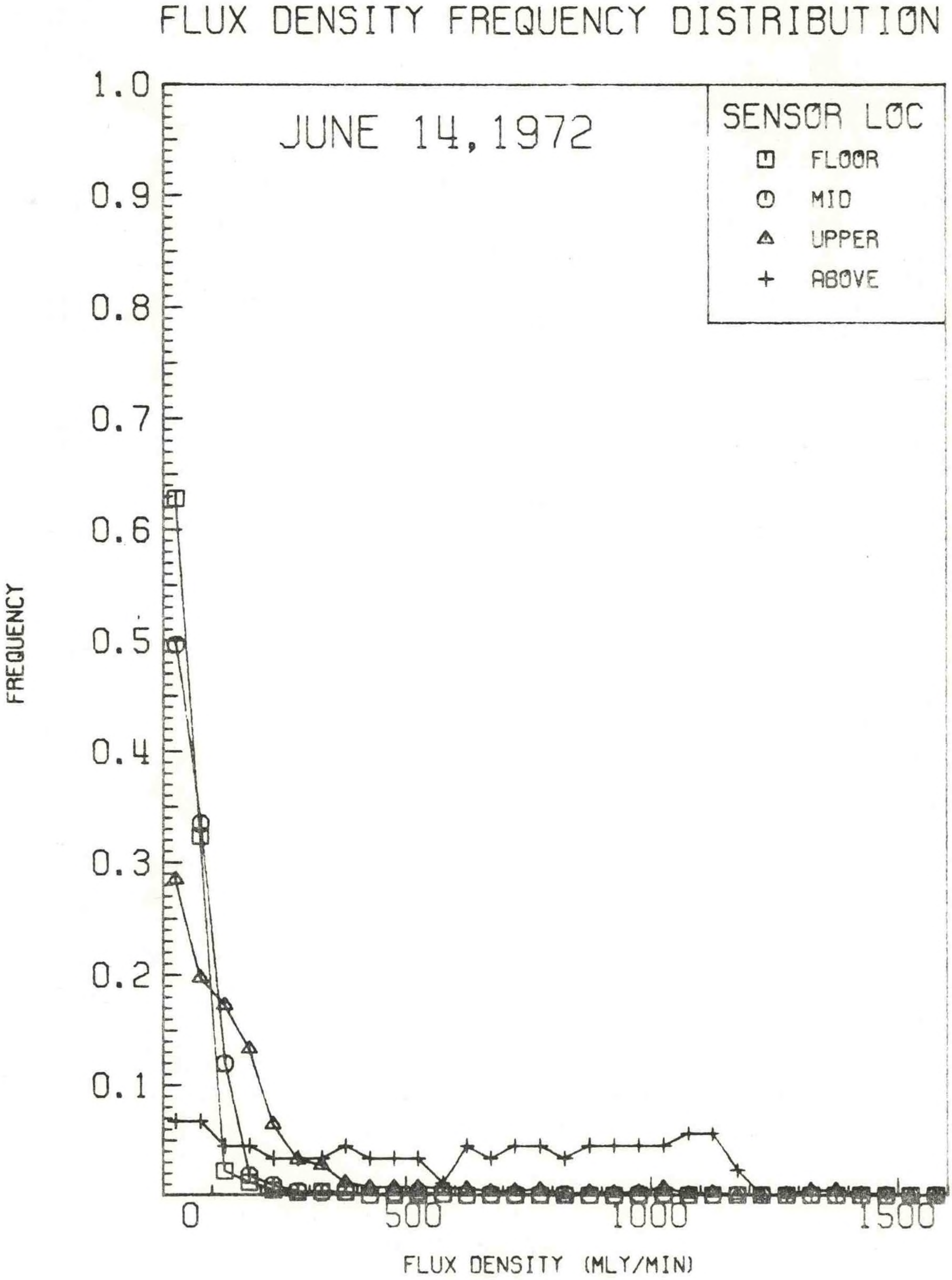
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0.1
FREQUENCY
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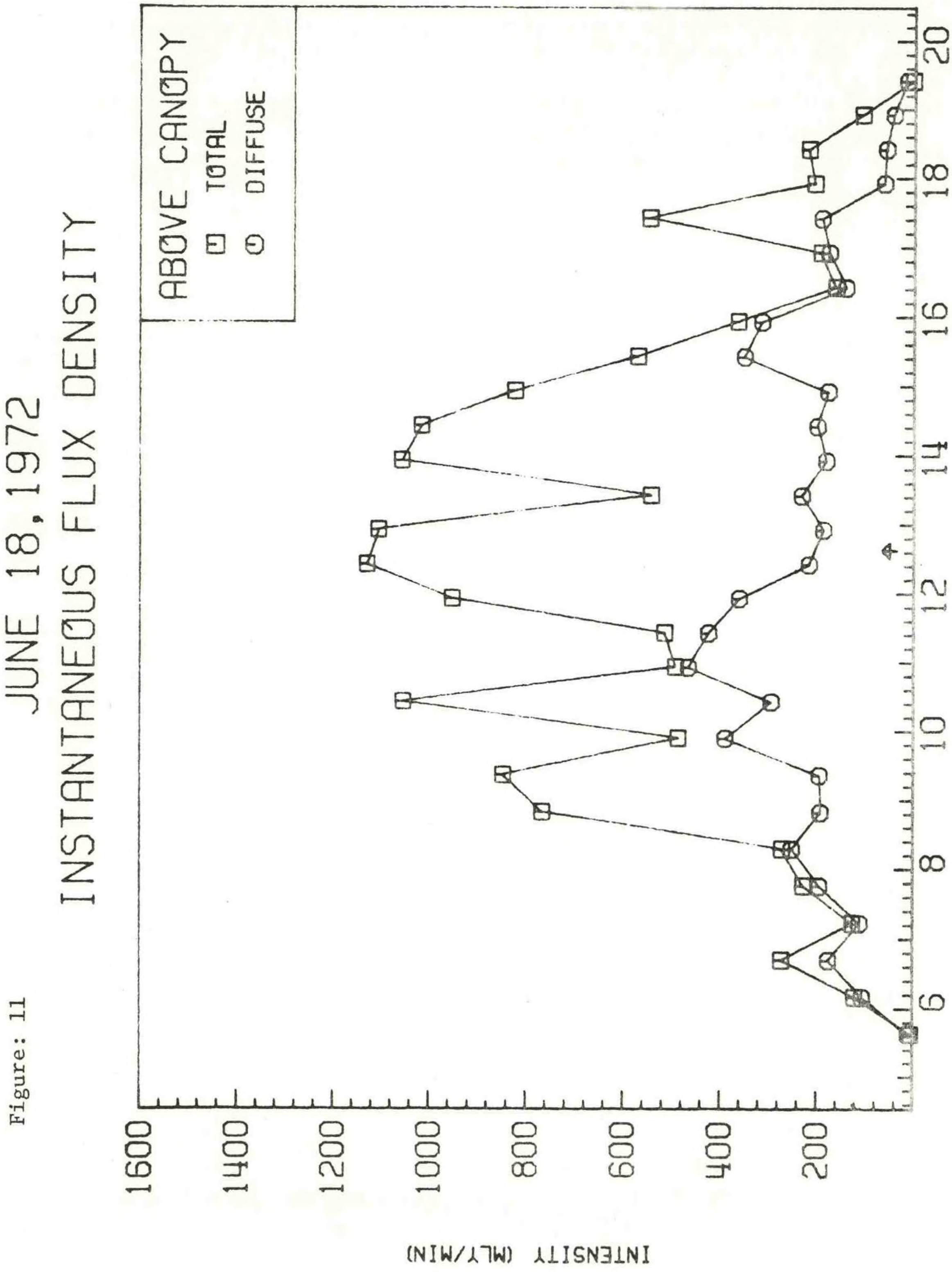
500
1000
1500
FLUX DENSITY (MLY/MIN)

Figure: 11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ABOVE CANOPY
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DIFFUSE
INTENSITY (MLY/MIN)
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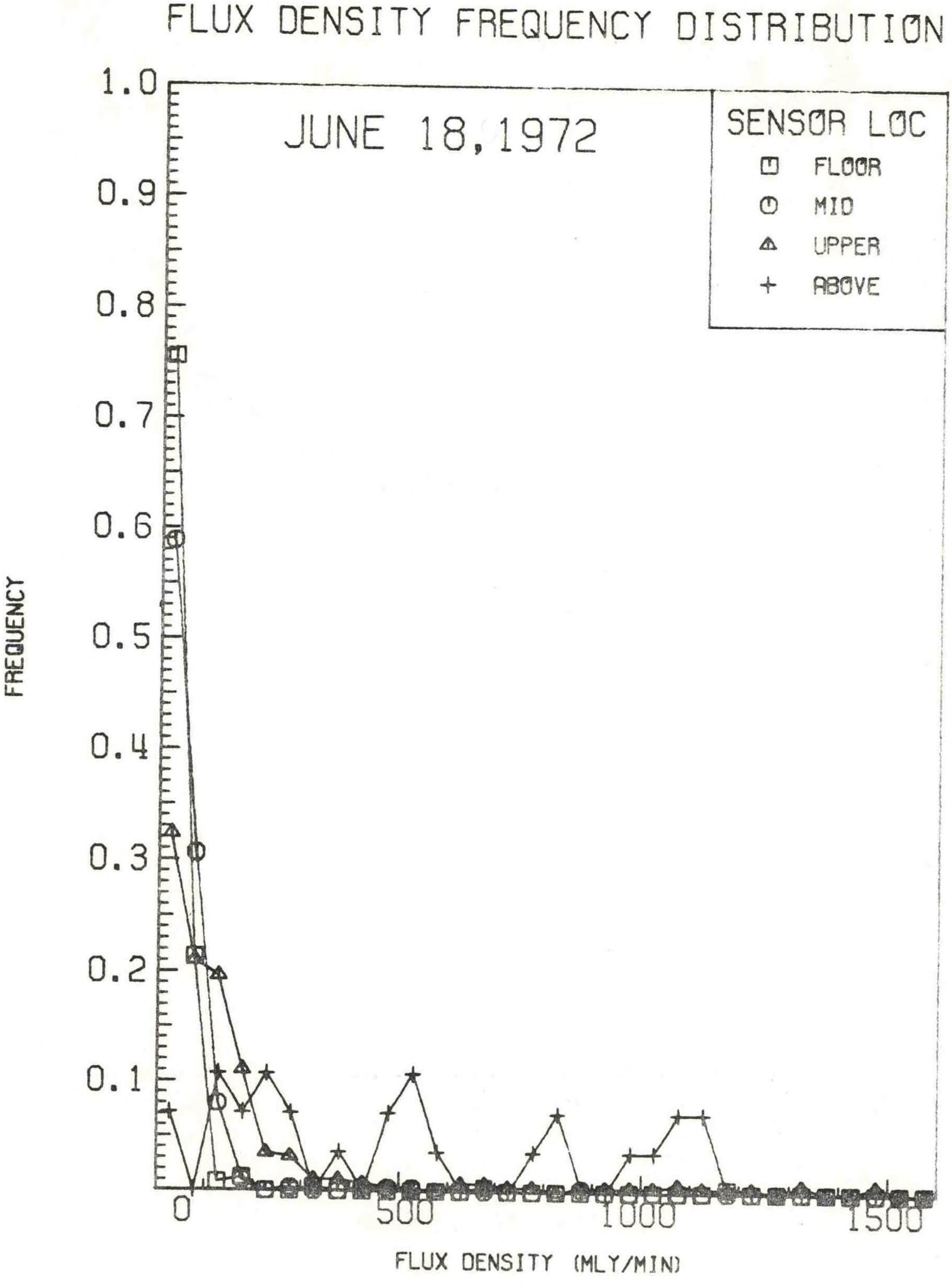
800
600
400
200
TIME (EST)
6
8
10
12
14
16
18
20

Figure: 12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FLUX DENSITY (MLY/MIN)

Figure: 13

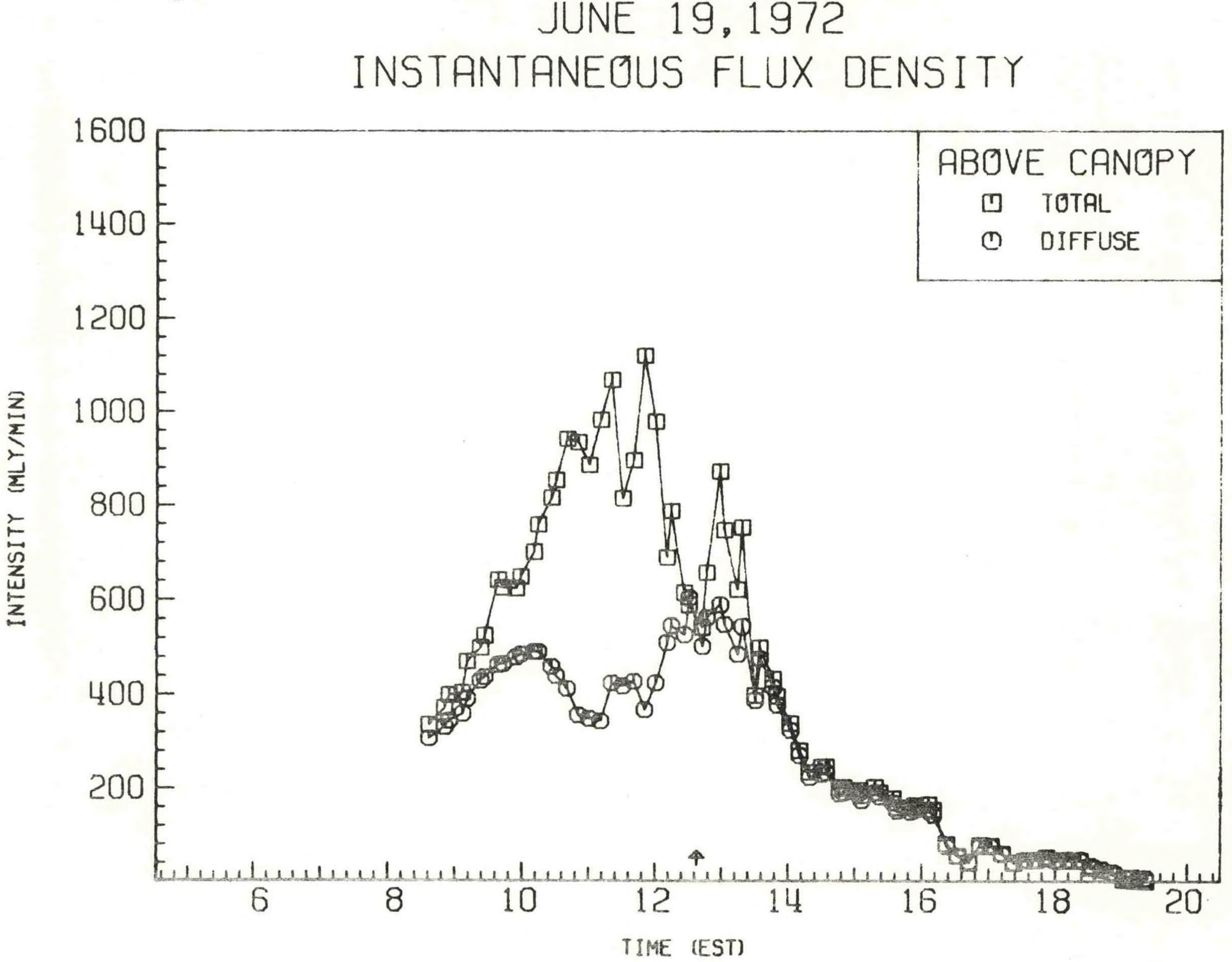
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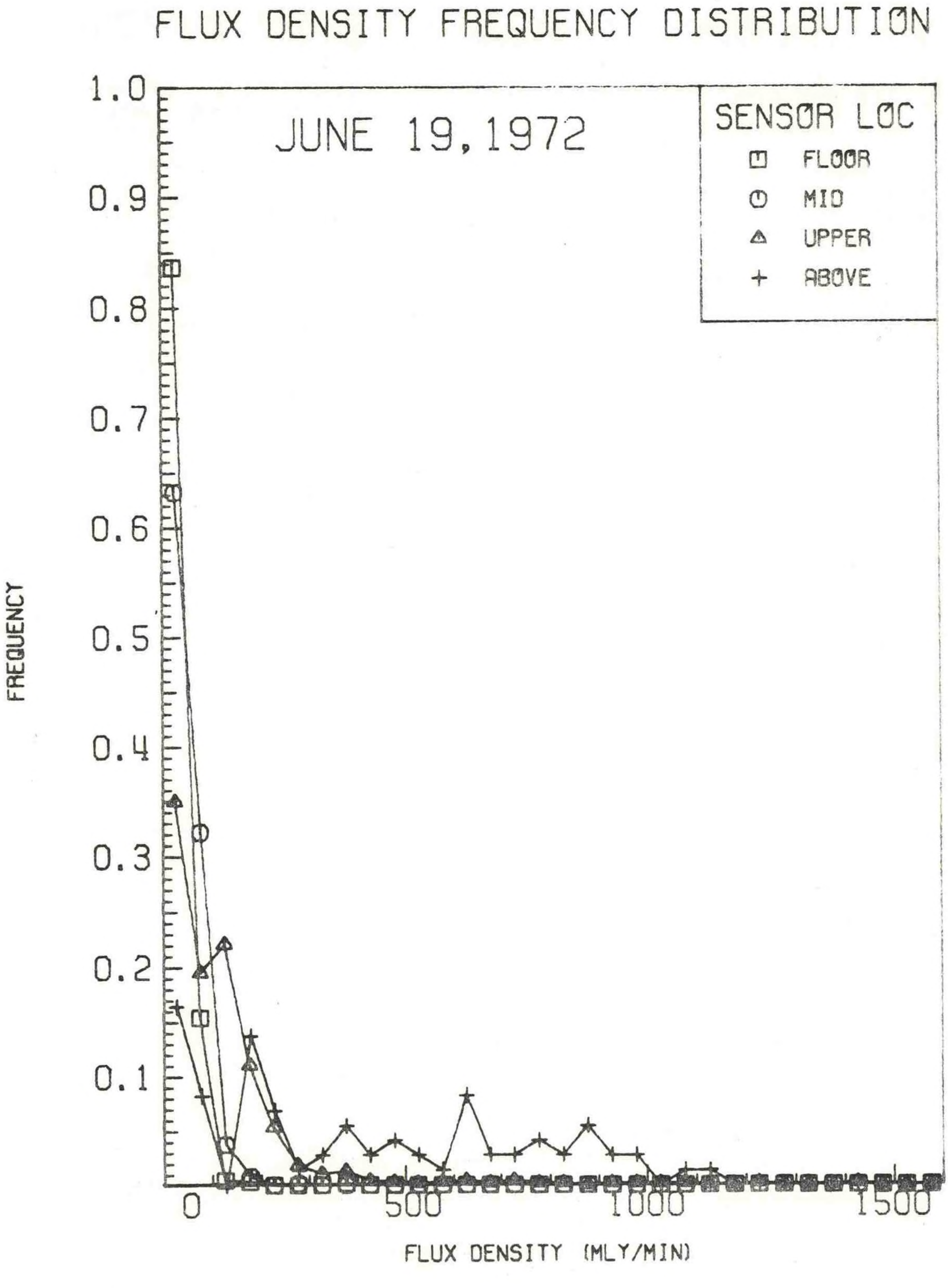
Figure: 14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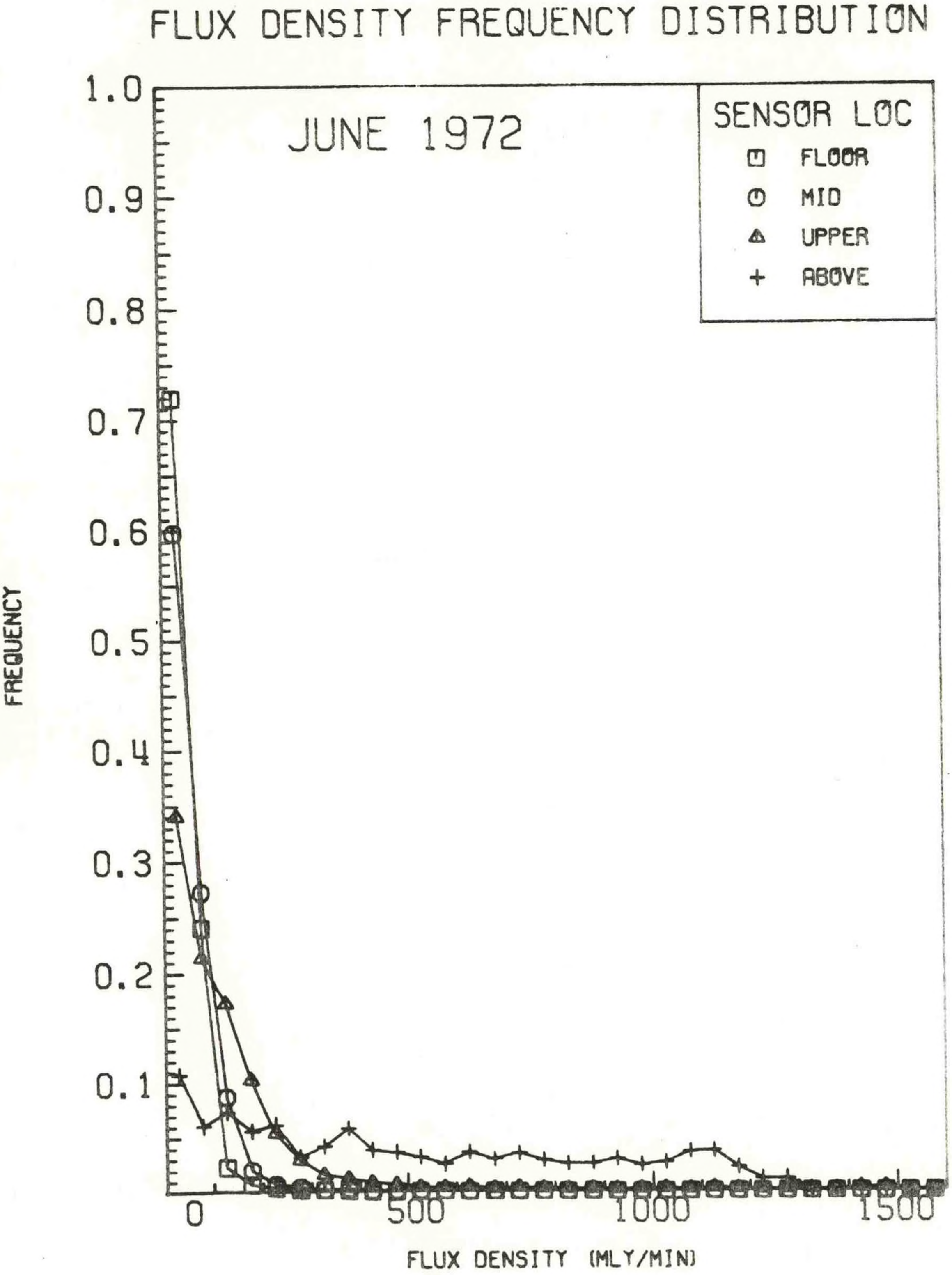
FLUX DENSITY (MLY/MIN)

Figure: 15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FLUX DENSITY (MLY/MIN)