A NUMERICAL DESCRIPTION OF NEW ENGLAND SQUALL LINES

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ABSTRACT

An investigation of the small-scale structure and changes in intensity of New England squall lines has been made. Digitalized rainfall rates obtained from range-corrected signal intensity contours displayed by radar have been used.

Results indicate two types of pre-cold frontal squall lines which do not appear to be detectable by previous synoptic conditions. The two types differ in narrowness of the line and development of showers along the southern extension of the line once it has moved into New England.

The upper air flow displays a marked consistency during the time of squall line activity.

Thesis Supervisor: James M. Austin
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I. INTRODUCTION

This study has as its aim the quantitative description of the distribution and development of precipitation in New England squall lines. Range-corrected signal intensity contours of radar echoes as displayed on P P I provide a convenient measure of instantaneous rainfall rate (see Kodaira, 1957). By use of a suitable moving grid system, rainfall patterns which vary over the life of a squall line can be investigated, while effects produced by the motion of the line as a whole are eliminated.

Noel and Fleisher (1960) made a study of patterns and their predictability in continuous precipitation by reducing semi-quantitative radar data to digitalized form in a grid system, but in their investigation the grid was stationary.

Studies of the motion and development of squall lines based on radar data have been made by Boucher and Wexler (1960), Boucher (1958) and by Swisher (1959). Boucher and Wexler investigated the motion and duration of the squall line as an entity based on normal P P I radar data. Boucher used normal P P I radar displays as a means of locating the squall lines under investigation without attempting to investigate the smaller structure of the line.

Swisher investigated development by use of radar signal intensity contours and rainfall data of the U. S. Weather Bureau raingauge network. Swisher located geographical areas of maximum precipitation and found that squall lines moving into New England increased in intensity in the region from the Berkshires to the Connecticut River valley. Regions of decrease were noted along the Maine and Massachusetts coasts. Swisher also found an average of three hours between the time when a line was first identified and maximum intensity was reached.

This study is an extension of the work by Swisher in that the internal structure of nine New England squall lines is investigated through digitalization of precipitation intensity data obtained from signal intensity contours.

II. DATA AND METHODS OF ANALYSIS

A. Squall Lines

In this study, a squall line is defined as a narrow band of precipitation parallel to and associated with a surface cold front which is advancing into New England from the northwest or west. The nine squall lines chosen were selected on the basis of radar records available at Weather Radar Research at M. I. T. Radar records for each line were in the form of range-corrected signal intensity contours on S C R 615-B 10-centimeter radar.

The synoptic weather aspects of the various storms were as follows:

1. 19 May 1958. A surface cold front moved into New England in the afternoon. Flow aloft was from the westsouthwest at both 700 and 500 millibars, and no change in direction occurred during the period of observation.

2. 26 June 1958. A northeast - southwest cold front advanced into New England during the day. Two short squall lines of differing orientation were observed by radar, the most southern of the two lines being considered the primary line. Upper air flow was from the southwest.

3. 08 July 1958. Two cold fronts were identified at 1300 E S T, the two merging along the western New England border prior to squall line formation. Flow aloft was westsouthwest during the time of squall line activity.

4. 11 July 1958. A northeast - southwest cold front with an extensive squall line moved into New England during the afternoon. Upper air flow was southwest at 0700 E S T and veered to west by 1900 E S T. The squall line was observed from 1315 E S T to 1845 E S T, the longest period of observation of a line in this study.

5. 12 July 1958. The cold front of the previous day became stationary through Massachusetts on this date, while a new cold front moved into New England from the northwest causing a short squall line in the afternoon. Flow aloft was southwesterly throughout the day.

6. 10 September 1958. The cold front moved into New England during the day and produced a weak squall line. Westsouthwest winds at 700 and 500 millibars at 0700 E S T veered to the west by 1900 E S T. Radar coverage midway through this storm was not available for a period of about one hour.

7. 13 June 1959. A cold front with a north - south orientation entered New England in the late morning, and the associated squall line moved ahead of the front in the early afternoon. Considerable precipitation occurred in the warm moist air throughout the day. Winds aloft were westsouthwest during the day, but the winds along the New England coast backed to south southwest by 1900 E S T.

8. 24 June 1960. A weak cold front advanced into New England in the late afternoon. The squall line developed about 1900 E S T. Upper air flow was westsouthwest at 700 millibars and westerly at 500 millibars.

9. 30 June 1960. The cold front and associated squall line entered New England at noon and progressed eastward rapidly. Flow aloft was westerly throughout the day.

B. Radar Data

The radar data are in the form of range - corrected signal intensity contours obtained from circuitry described by Kodaira, photographed on 35 mm film and then traced on a map of New England. In this type of display, the squall line becomes evident as a line of concentrated echoes (see Figure I). The interval between contour levels is some 5 db, and this interval corresponds approximately to a factor of two in rainfall rate. Thus, each contour represents a rainfall rate about twice as great as its predecessor. Because this is an experimental arrangement, certain inaccuracies in range correction appear. These inaccuracies are corrected by calibration of the circuit immediately after each storm. An inaccuracy occurs in the use of single values for each contour because the precipitation rate between two levels may have any value from the rate of the lower contour to that of the higher one.

C. Grid System

A moving grid system was used in order to eliminate the effects of the motion of the line as a whole and to reduce the number of points with no precipitation. Since it has been observed that new cells often form near the southern end of the squall line following its appearance in New England, the origin of the grid was placed on the southern most cell at the time when a line was first observed on S C R 615-B radar (maximum range 120 miles). When the origin cell dissipated the translation of the origin was continued by moving it parallel to the apparent velocity of some other strong cell which was observed as having the same motion as the origin cell when the latter was still present.

The grid was oriented so that one axis was along the line, the position of the line being determined by eye. This axis was subsequently maintained on the line even if it was necessary to rotate as well as translate the grid.

With this method of choosing the origin and orientation of the grid, the precipitation will be concentrated north of the origin in the early part of the observing period. If more cells are present south of the origin but out of range when the line is first identified, the subsequent advance of the line into New England will bring these cells into range, and precipitation south of the origin will appear in the grid. The same effect will be caused by cells building up within range but southeast of the line.

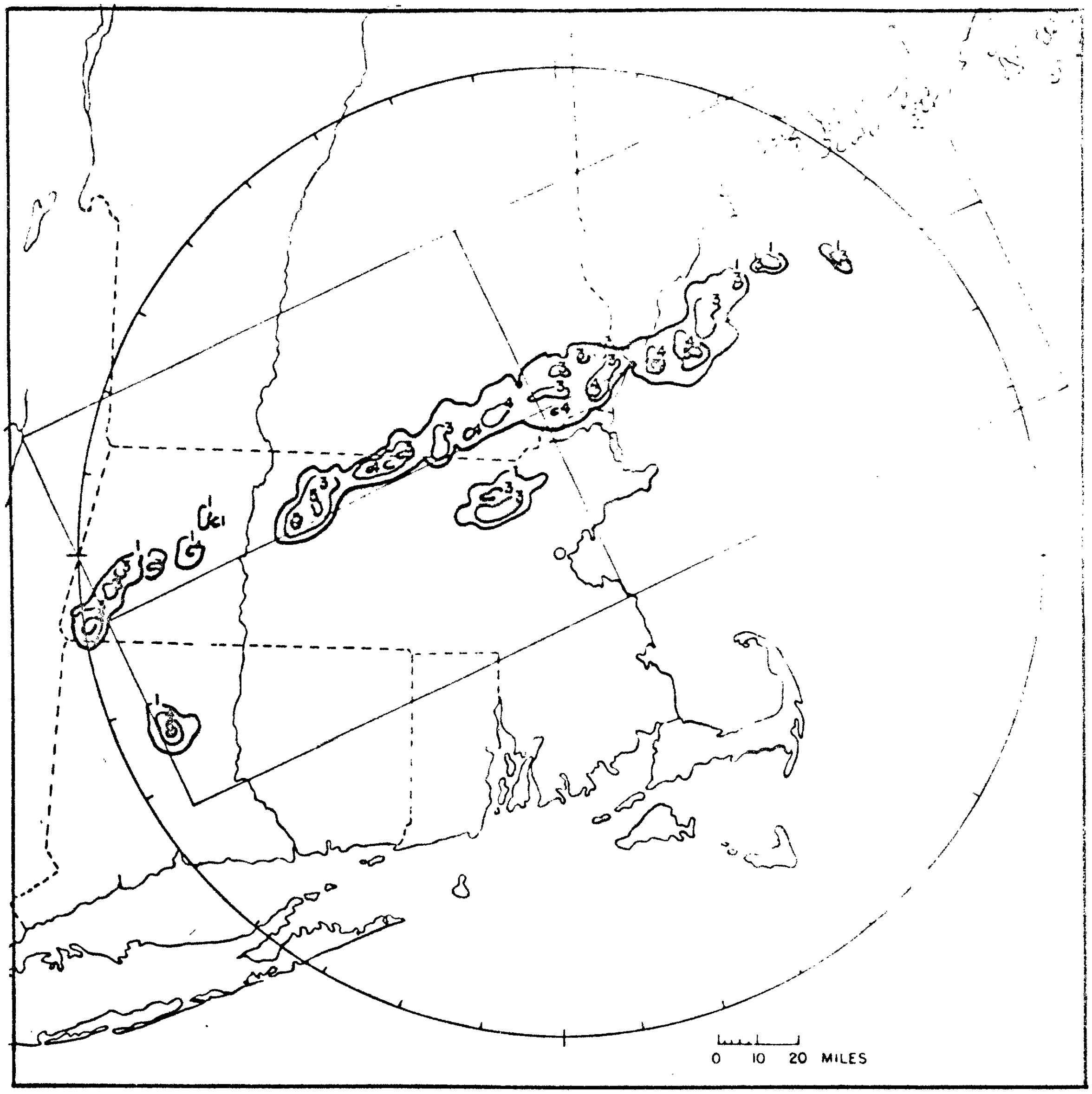

FIG. I Typical Squall Line With Contours and Grid Outline 11 July 1958 1544 EST

The spacing of grid points was made five miles in order to facilitate analysis. It was found that such a spacing permitted easy breakdown of the radar data into digitalized form. Even with the small spacing of the grid, interpolation of the average contour for each grid square (25 square miles in area) was necessary. Since each contour represents approximately twice as much rainfall as the next lower contour, greatest weight was given to the highest contour in the grid area. Conversion from contour value to rainfall rate was made by use of calibration charts prepared from data derived shortly after each storm.

The rainfall data were obtained at approximately 13 minute intervals for the 1958 storms and 10 minute intervals for the 1959 and 1960 storms, whenever radar coverage permitted.

In the following discussion, the grid is usually referred to as having a northern and southern sector, the dividing line being the axis running through the origin cell perpendicular to the line. Thus, no reference is made to geographical north and south, but rather to grid north and south.

Contour values recorded for each grid point were then converted to precipitation rate and recorded for analysis purposes (Figure 2).

D. Charts and Analyses

1. The total rainfall intensity for each time was obtained by simple addition of all precipitation rates regardless of the number of grid points involved. A spot check disclosed that the area of precipitation did not vary appreciably from map to map, so no reduction to rainfall rate per unit area was necessary.

The total rainfall intensity was plotted as a function of time for each storm. Figures 3, 6, 9, 12, 15, 18, 22, 25, and 28, are the result of this work. It will be noted that the precipitation rate scale varies from storm to storm. This was done because the total intensity differed considerably in each storm.

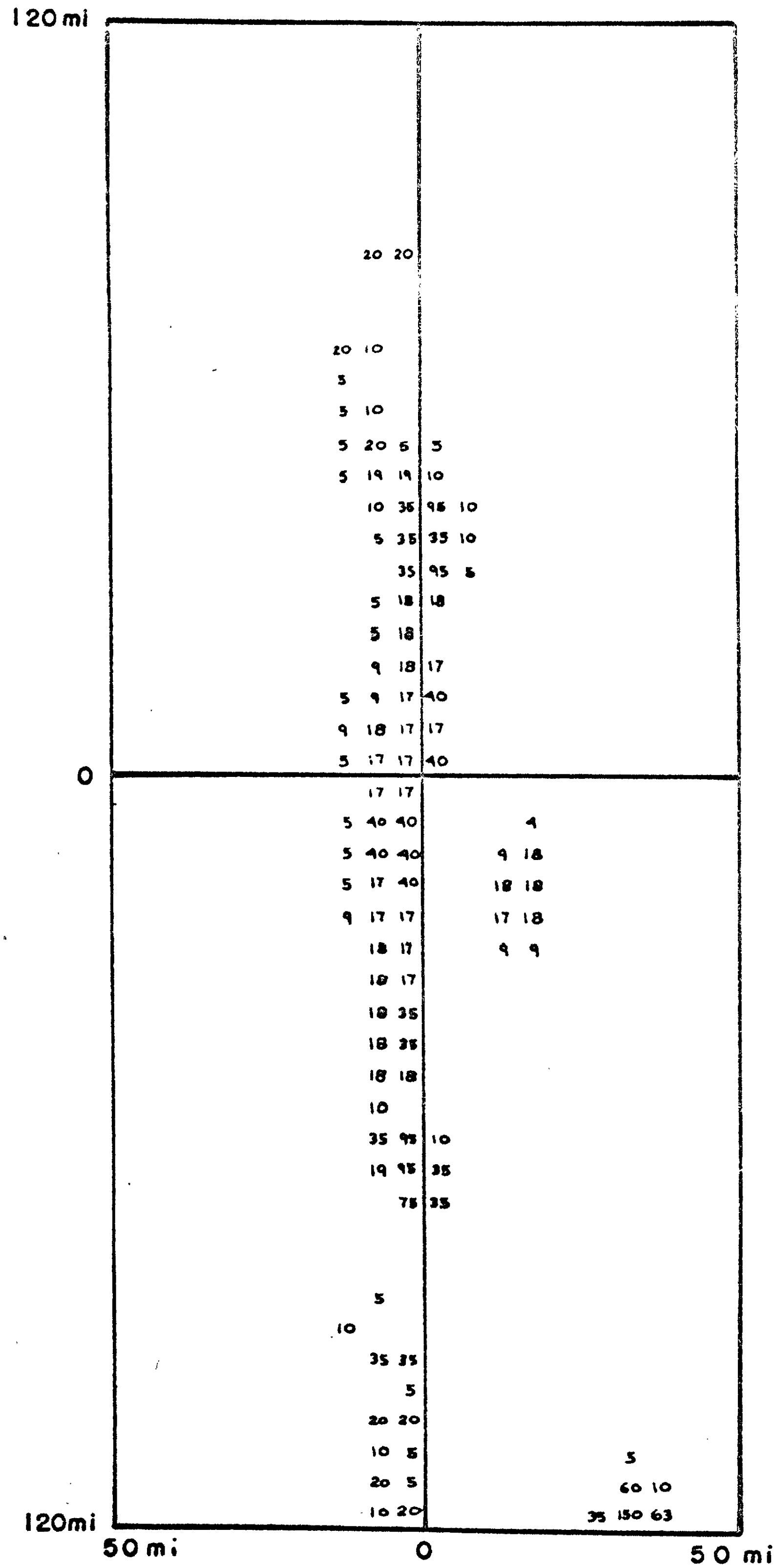

FIG. 2 Rainfall Intensity in mm/hr for Squall Line of FIG. 1

2. If the rainfall rates in each of the grid points are added for each point separately, a space composite chart for the squall line is obtained. The space composite shows the relative intensity of a cell or group of cells, the amount of scatter or organization of precipitation along the line, and the area of cell groups and the entire line. Another feature of the space composite is that of determining the spacing between maxima of precipitation. For ease of comparison, all space composite charts are of the same dimensions, namely 240 miles along the line and 100 miles wide. The line and origin cell are indicated by the vertical axis and intersection of the axes, respectively. The space composite charts for the nine storms are displayed in Figures 4, 7, 10, 13, 16, 19, 20, 23, 26, and 29.

3. A time - space composite for each squall line was obtained by adding the rainfall rates in each row of grid points perpendicular to the squall line (that is, in a grid east - west orientation) for each time of observation. The time composite chart is plotted with time along the horizontal scale and distance along the line along the vertical scale. The time-space composite charts are Figures 5, 8, 11, 14, 17, 21, 24, 27, and 30. The row addition provides a means of utilizing the entire precipitation in the grid without obscuring the maximum precipitation at the line.

An analysis of this chart for each squall line indicates the variation in time of the intensity of a cell or group of cells such as the origin cell, the time of growth and decay of cells, and the motion of cells relative to the origin.

4. The geographical movement of the origin cell was found by plotting the successive positions, as found by radar, on a base map. The average direction and speed of this cell was compared with the upper air winds, and a vector mean of the cell motions and winds were found along with their vector differences (Table I).

E. Sources of Error

There is a certain amount of subjectiveness in the estimate of the average contour value for each grid point. In this study, the estimates were performed by one investigator primarily, but another individual reworked three storms as an independent check, and no large or consistent discrepancies were found.

The transfer of the radar pictures from film to tracing paper permits a possible error in geographical position, but this will not affect the grid position. The trajectories of the origin cells were first checked for consistency of motion before conversion into grid data was accomplished, thus eliminating the geographical error in this case.

III. RESULTS

A. Individual Storm Analyses

1. 19 May 1958.

The total rainfall intensity chart contains two major maxima, at 1410 E S T and 1516 E S T. There is a moderate level of precipitation between these maxima, while the small rainfall intensity totals on either side indicate the entire life cycle of the squall line was included in the period between 1258 E S T and 1543 E S T. The strong increase between 1401 and 1410 E S T indicates that the line became more organized, as the signal intensity contours show. Prior to 1410, the line consists of isolated cells, but at this time individual cells are connected by areas of light er precipitation. This effect is not one of a decrease in range as the line in this short time interval does not move more than a few miles and is still some 50 miles distant. The decrease from 1430 to 1507 is primarily due to the decay of the strongest cell, while the subsequent increase at 1516 appears to be a combination of the growth of several cells and the shorter range which permits detection of lighter precipitation over a larger area. Subsequent decreases are plainly the decay of the line as a whole.

The space composite chart shows a well-organized line north of the origin with some dispersion south of the origin. The strongest precipitation is located at the origin, and two strong cells are located at 50 and 60 miles south of the origin. One fairly strong cell is located 65 miles north of the origin.

The three most pertinent features of the time - space composite are: a.) the continuity of the origin cell with four periods of maximum intensity of nearly equal spacing, this spacing being about 25 minutes. The next 25 - minute spacing after the last maximum shows a zero rainfall rate, and the 25 - minute spacing preceeding the first maximum occurs before data were available. It is possible that this

25 - minute period is indicative of the time between the decay of one cell and growth of its successor in the same group. b.) the light and discontinuous nature of the precipitation north of the origin cell, only one area of rainfall rate of 50 mm/hour or more being discernible. c.) the strong continuous rainfall south of the origin after 1330 E S T. A very strong intense group of cells occurs after 1500 E S T but does not persist for more than 30 minutes.

2. 26 June 1958.

Because of the short duration of radar coverage of this storm, very little can be deduced about its patterns.

The total rainfall intensity chart shows a single strong maximum at the beginning of the radar coverage, indicating that the storm had begun and progressed through part of its life cycle before coming into detectible range. The decrease after 1417 E S T is caused by decay of the principal cells with no appreciable change in total area of the squall lines.

The space composite chart shows that the southermost of the two lines contributes the most to the total rainfall, and the origin cell is the most southern cell in this line although not the strongest cell. This again suggests that the squall lines began some time before coming into radar range. The two strongest cells are located 40 and 45 miles north of the origin, the former being some 25% stronger then the latter. The lines showed good organization with some precipitation occurring ahead of the lines.

Three bands of precipitation maxima are evident on the time - space composite. The origin cell endures throughout the life of the lines, but it is never very strong. The strongest maximum occurs some 30 miles north of the origin at the beginning and moves northeastward to about 55 miles north of the origin by the end of the storm. This maximum band contains three maxima which are irregularly spaced in time. The third precipitation maximum band is nearly as weak as that of the origin, but a strong cell occurs at 1415 E S T and then decays rapidly.

3. 08 July 1958.

The total rainfall intensity chart shows a regular pattern with one pronounced maximum at 1707 E S T. The moderate rainfall at the beginning suggests that the squall line originated beyond the range of the radar but that most of the life cycle took place after the line moved into range. The low total after 1800 E S T is caused by the decay of cells and dissipation of the line.

The space composite shows an organized but spread pattern with the largest amounts north of the origin. There are few strong cells, the strongest being the one picked as the origin. The second strongest occurrence is located 10 miles north of the origin. Other maxima are more broad in character, suggesting that several cells contributed to their total.

The time - space composite shows a conflicting pattern of motion of the maxima in the northern sector. The general pattern' indicates a northward trend with time of all maxima except the origin cell, but this trend is by no means continuous. Those maxima north of the origin appear to grow and progress northward for about 45 minutes and then simultaneously decrease and turn eastward. The development of cells south of the origin occurs late in the period of coverage, and only two rather weak maxima appear. These maxima also track northward for 45 minutes and then decay. By the time that these southern cells appear, northern activity has nearly ceased, and the comparative weakness of the southern sector cells is a further indication of the decreasing intensity of the storm.

4. 11 July 1958.

This storm exhibited similar characteristics to that of 08 July 1958. The length of record is quite long, covering over five hours.

The total rainfall intensity chart shows a single maximum which is reached abruptly but decreases slowly. This increase can be attributed to the appearance of several new cells plus the growth of others. Some of the new cells appear at 1544 E S T at the extreme range, suggesting that they originated over the Hudson River valley and then moved into range. The gradual decrease after 1544 is caused by normal decay and dissipation along the line.

The space composite shows a number of strong cells, the strongest being located some 60 miles south of the origin. Other maxima are located 85, 105 and 120 miles south of the origin, while another maximum is also at 120 miles south but ahead of the line. The strongest cell north of the origin is some 40 to 45 miles north, and a moderate cell is at 85 miles north of the origin. Another moderate maximum is 90 miles north and ahead of the line. The line is organized, but light precipitation extends ahead of and behind the line by as much as 40 miles.

The time - space composite reveals that the origin cell goes through three cycles of increase and decrease before finally ceasing to exist. This cell is the strongest at the beginning and remains so throughout its life. The line is composed of individual cells or groups of cells while the origin cell exists. Coincident with the decay of the origin cell activity in the southern sector appears and increases rapidly. This sector shows greater overall intensity than the northern sector with a resulting connection of precipitation between intense cells. After 1530 E S T, the line shows marked organization with several intense cells. There is a strong maximum at about 40 to 50 miles north of the origin, and two maxima are located at 70 and 120 miles south of the origin. The strongest southern maximum is caused by several cells as a new group becomes predominant at 1630 E S T about 80 miles south of the origin. At this time, the entire northern sector begins to decay, and within one hour it has disappeared entirely. After 1700 E S T, the southern sector begins to break up, and very little activity appears after 1830 E S T. By this time, it is no longer possible to identify a line on the P P I display.

5. 12 July 1958.

The total rainfall intensity chart shows no pronounced maximum comparable to those of the two preceeding storms, but the relatively light precipitation throughout the storm may account for this. There is a rapid rise shortly after the line was first detected, mainly because of an increase in number and intensity of the cells along the line. A secondary line south and east of the main squall line remains at a constant intensity, so the increase can be attributed to the activity in the squall line. There is little total change in intensity after the maximum has been reached, but during this period the secondary line is decreasing, thus the main line is increasing in intensity. The peak intensity of the main line actually occurs about 1655 E S T. The line then decreases slowly and begins to break up after 1800 E S T.

The space composite clearly shows the narrow, organized character of the main line with five maxima, the strongest being found at the origin. The secondary line appears as a disjointed group of cells on the eastern edge of the grid.

The positions of the maxima in the main line are 40 and 55 miles north and 25 and 65 miles south of the origin. The origin cell apparently is a group of cells which cause a flat maximum covering some 400 square miles of the grid.

The time - space composite displays a very flat pattern with no coherent tracks of maxima. The origin cell contributes at a low and varying rate, and most of the other cells show no great intensity. The strongest area is located just south of the origin, commencing at 1605 E S T and continuing until 1715 E S T. Other isolated maxima are distributed, apparently at random, throughout the pattern. The increase of the southern sector and simultaneous decay of the northern sector starts at about 1700 E S T and continues to the end of the observing period (1937 E S T).

6. 10 September 1958.

Very little can be said about this storm because the radar data are missing for more than one hour in the middle of the storm. The total rainfall intensity shows no significant trends, and precipitation is very light during the two short periods of observation.

Two space composites were drawn for this storm to accommodate the separation of data. The first, covering the period from 1347 E S T to 1504 E S T, shows a small, compact line with three maxima; the origin, 30 miles north, and 50 miles north. The second, from 1617 E S T to 1730 E S T, shows a slightly longer but still compact line with two maxima; the origin and a small maximum at 35 miles south.

The time - space composite reveals little organization in the early portion, but the later time gives an indication of increase to the south of the origin coupled with decay in the northern sector. There is a suggestion of a trend to the south of cells from 1430 E S T to 1500 E S T, and a northward trend prior to this, but precipitation rates are too low to yield a definitive answer. No trends are obvious in the second period.

7. 13 June 1959.

This storm exhibits a single strong maximum on the total rainfall intensity chart. The rainfall at the beginning of observation is already moderate, indicating that the line was well established by this time. The maximum was reached shortly before the squall line passed over the station, thus the actual value of the total rainfall may have been larger than indicated since saturation and ground clutter effects would reduce the apparent intensity. Some of the contributing precipitation is occurring in a secondary line east of the main line, and after 1800 E S T a third line, west of the main line, appears, thus causing the rise in total rainfall intensity at the end of the observation period.

Because of the large amount of precipitation east of the main line, the grid has been expanded to include most of this, and thus a rather chaotic space composite results. The origin cell is not the strongest, other maxima along the line appearing 45, 75 and 115 miles north. A great deal of the precipitation fell outside the squall line, but the maximum amounts are still found in the line.

The time - space composite reflects the chaotic nature of the precipitation, but here a northward trend of a maximum in the northern sector is noticeable. Similar trends elsewhere are not apparent, and the origin cell itself shows no great stability, probably because of the proximity of another cell which appeared to split off from the original cell.

8. 24 June 1960.

The total rainfall intensity chart indicates that the storm had just reached its peak intensity when the radar data stopped.

The space composite shows two centers of high intensity, one associated with the origin cell, and the second and stronger of the two located at 50 to 60 miles north of the origin, this maximum being caused by several cells. The line as a whole is strong and well orgainzed but not as narrow as some of the 1958 storms.

The time - space composite shows the motion of the maxima to be parallel to the origin from 1910 E S T to about 1945 E S T and then northward, suggesting a change in the flow patterns associated with the squall line. The upper air flow for this period is not available, so no confirmation can be made at this time.

9. 30 June 1960.

As in the 10 September 1958 storm, considerable time was lost in the middle of this storm because of radar failures. Also, during the second portion, from 1506 E S T to 1632 E S T, the data were depleted by saturation and ground clutter near the radar site. Therefore, a large portion of the three charts is unrepresentative.

The early period, from 1223 E S T to 1319 E S T, shows three sharp maxima on the total rainfall intensity chart. The rapid decrease from the first maximum at 1254 E S T to the minimum just eight minutes later is attributed to the decay of some six major precipitation areas, while the subsequent growth and decay of new cells account for variations in total rainfall intensity. The total rainfall intensity during the second period of coverage is not very clear because of the data problem mentioned above, but there does appear to be a general decrease after 1525 E S T.

While a space composite for the entire period of radar coverage cannot be considered reliable, the space composite for 1223 E S T to 1349 E S T does show an interesting pattern. Six very strong precipitation areas are prominent, the two strongest being located at the origin and some 90 miles north of the origin on the leading edge of the squall line. The other four strong areas are located west of the line as are four moderate centers of precipitation; and one moderate area is located about 20 miles east of the line. This line is significant in that the cells west of the line cause a second maximum of precipitation. The line as a whole shows considerable scatter with light precipitation ahead of the line.

The time - space composite is most useful in the early period of observation. The origin cell, while fluctuating in intensity, maintains its identity throughout this early period and through most of the later period. Other strong cells indicate a parallel motion with the origin cell until after 1330 E S T, when the southern cell begins to show a northward movement. The cells in the northern sector maintain parallel motion with the origin cell until late in the later period, but the motion that ensued from 1400 E S T to 1500 E S T is not known.

B. Group Storm Analyses

An examination of the various charts for the nine storms suggests the following classification:

Group A: four storms in which there are no subsequent cells south of the origin, or at most very little southern development as shown on the space and time - space composites. The four storms are: 26 June 1958, 08 July 1958, 13 June 1959 and 30 June 1960.

Group B: four storms which do have subsequent development of cells in their southern sectors. The four storms are: 19 May 1958, 11 July 1958, 12 July 1958, and 24 June 1960.

The storm of 10 September 1958 does not contain enough data to make classification possible.

Group A storms also exhibit similar characteristics in their total rainfall intensity charts in that three of the four storms have one single maximum. The one exception, 30 June 1960, may contain a strong maximum, but missing data precludes confirmation or denial of this.

The group A space composites also show an organized pattern along the line and similar distribution of intensity maxima along the line. The distributions show connecting moderate precipitation between maxima on the space composite. The time - space composite shows an erratic character of maxima.

These points mentioned above would be expected on the basis of groups of strong cells imbedded in a squall line which contains few if any breaks. The single maximum of total rainfall intensity indicates that the majority of strong cells occurred at the same time. The space distribution suggests that groups of cells moved with a different motion than that of the origin cell, and these groups were large in comparison with the grid spacing. This would also account for the erratic behavior of the maxima on the time - space composite.

Group B storms differ from Group A storms in that no single maximum is present on the total rainfall intensity charts, but rather several maxima or a broad plateau are present. The space composites show considerably more scatter of light precipitation and the predominance of cells in the southern sector. Time - space composites exhibit more regular movement of maxima and more areas of little or no precipitation than those of Group A.

The development of cells in the southern sector after the northern sector has reached its maximum would account for the presence of more than one maximum, and the existence of gaps between maxima would explain the less orderly space composite and the lack of erratic motion of the maxima on the time - space composites. In only one instance, 24 June 1960, the development in the southern sector could be attributed to cells south of the origin coming into range. During this period, cells already in range also increased slightly.

No consistent differences can be noted in the geographical motion of the origin cell, the flow aloft or the orientation of the squall line with respect to the two groups.

The motion of the origin cells has a mean direction of 261 degrees and mean speed of 17 1/2 knots. The mean upper air flow is from 248 degrees and 35 knots at 700 millibars, and 248 degrees and 48 knots at 500 millibars. The average orientation of the squall line is 230 degrees. The consistent direction of the flow aloft is to be expected from the synoptic situation. It can be seen that the flow is between the angle of orientation of the squall lines and the direction of motion of the origin cell and that the speed of the origin cell is 1/2 that of the 700 - millibar wind. The explanation of these facts is not clear from an analysis of this type.

TABLE I

TRAJECTORY DATA

Date/ Time	Motion of Origin	700-mb Wind	500-mb Wind	Orientation Of Line
19 May 1958				
0700 EST	252/20	240/40	240/45	044°-224°
1900 EST		240/40	240/45	
26 June 1958				
0700 EST	251/13 1/2	240/30	240/50	039°-219°
1900 EST		250/40	240/60	
08 July 1958				
0700 EST	266/14	250/35	250/40	048°-228°
1900 EST		240/40	240/50	
11 July 1958				
0700 EST	273/16	260/35	260/40	066°-246°
1900 EST		260/30	270/35	
12 July 1958				
0700 EST	262/18	240/30	240/40	046°-226°
1900 EST		240/30	250/45	
10 Sept. 1958				
0700 EST	267/13	250/50	240/70	051°-231°
1900 EST		270/35	270/70	
13 June 1959				
0700 EST	245/18	240/35	240/40	050°-230°
1900 EST		250/35	230/50	
24 June 1960				
0700 EST	251/28	240/25	270/40	053°-233°
30 June 1960				
0700 EST	288/19	260/30	260/30	055°-235°

Vector Means

Origin: 261/17 1/2

0700 EST: 700-mb 247/34 500-mb 248/47

1900 EST: 700-mb 249/35 500-mb 248/50

IV. CONCLUSION

The use of a moving grid system as a means of digitalizing precipitation data for New England squall lines produces a quantitative picture of the distribution and development within these lines. The method involves a certain amount of work, but the results justify the effort.

The analyses of total rainfall intensity, space variations and time and space variations permit the classification of a given squall line into one of two groups without ambiguity. The two groups do not appear to differ in synoptic aspects.

Future research into the possibility of more detailed synoptic analysis of the squall line situations presented here could conceivably find a significant difference between the two groups.

Several modifications of the present work can be made;the most advantageous being that of expansion of the grid along the squall line axis and reduction in the width of the grid so that those cells which are a considerable distance north or south of the origin cell can be included in the grid while the areas of no precipitation east and west of the line would be reduced.

A shorter time interval of about three minutes would increase the information on both the total rainfall intensity and the time - space composite charts. The three minute interval would permit more complete examination into the nature and motion of the cells during their growth and decay, and the apparent simultaneous variation of the strong cells could be examined more closely.

Correlations of the various grid points in time and space could be programmed for a computer to look for possible relationships which would ultimately lead to a forecasting tool. This work is being planned for implementation in the near future.

Finally, with the improved stability of signal intensity contours now available at M I T, the work of digitalizing squall line data could be made routine once the origin cell was ascertained. This would expedite future work with this data to a great degree and also free the work of observer error.

ACKNOWLEDGEMENT

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Marty Haurwitz performed an inestimable service by checking and converting data, and Mister Steven Ricci provided the lettering for all drawings. Data were supplied by Weather Radar Research.

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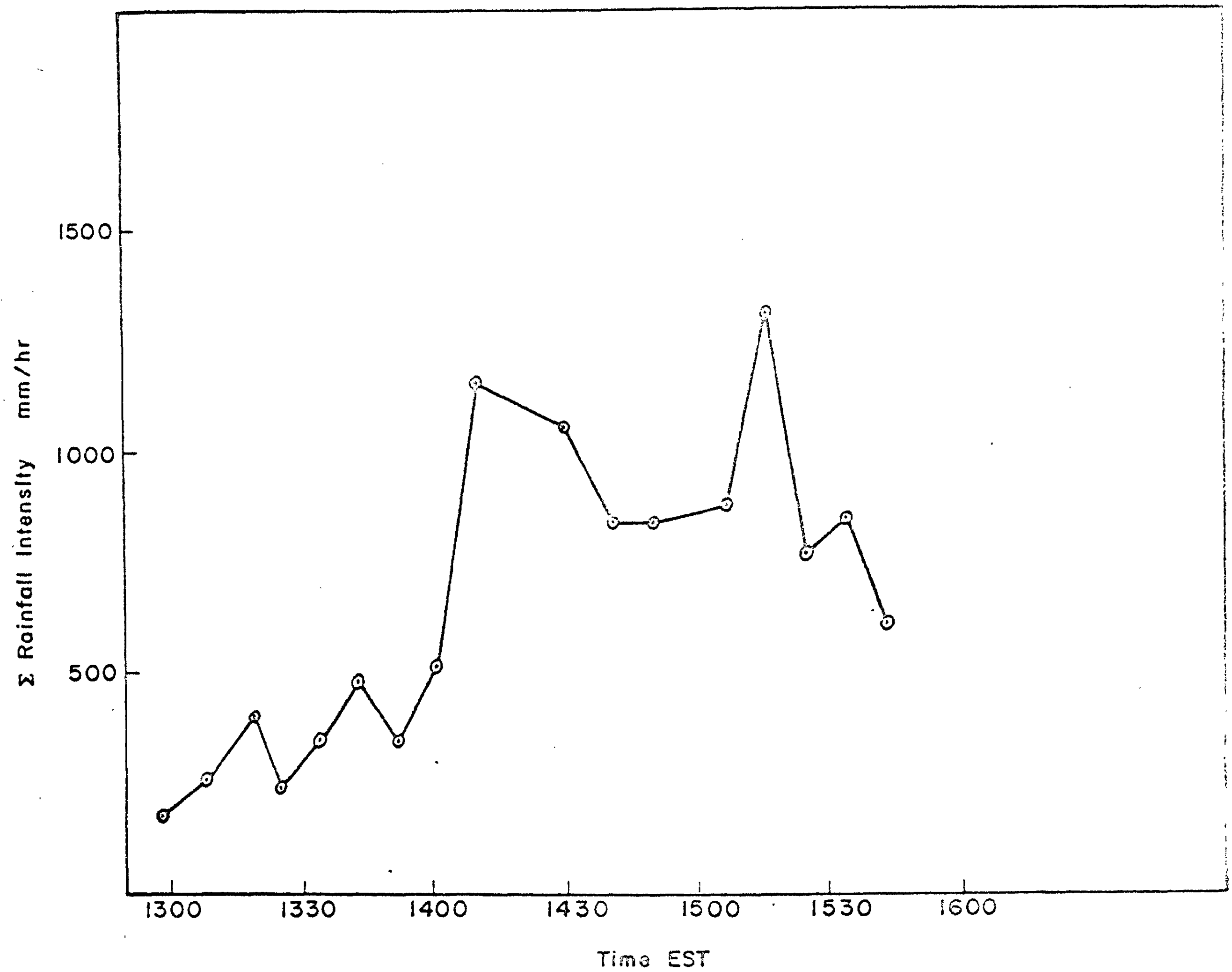

FIG. 3 Total Rainfall Intensity 19 May 1958

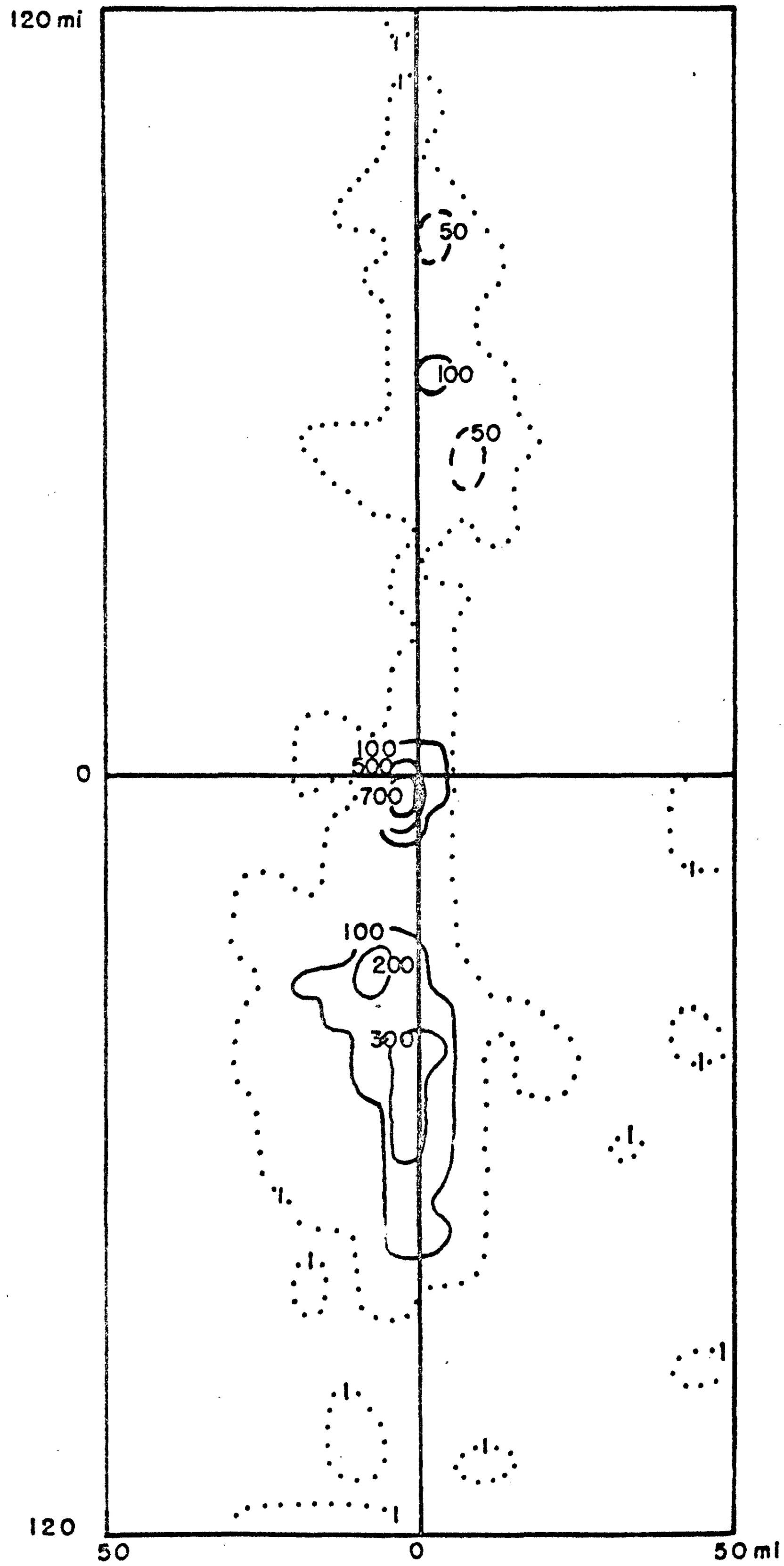

FIG. 4 Space Composite 19 May 1958

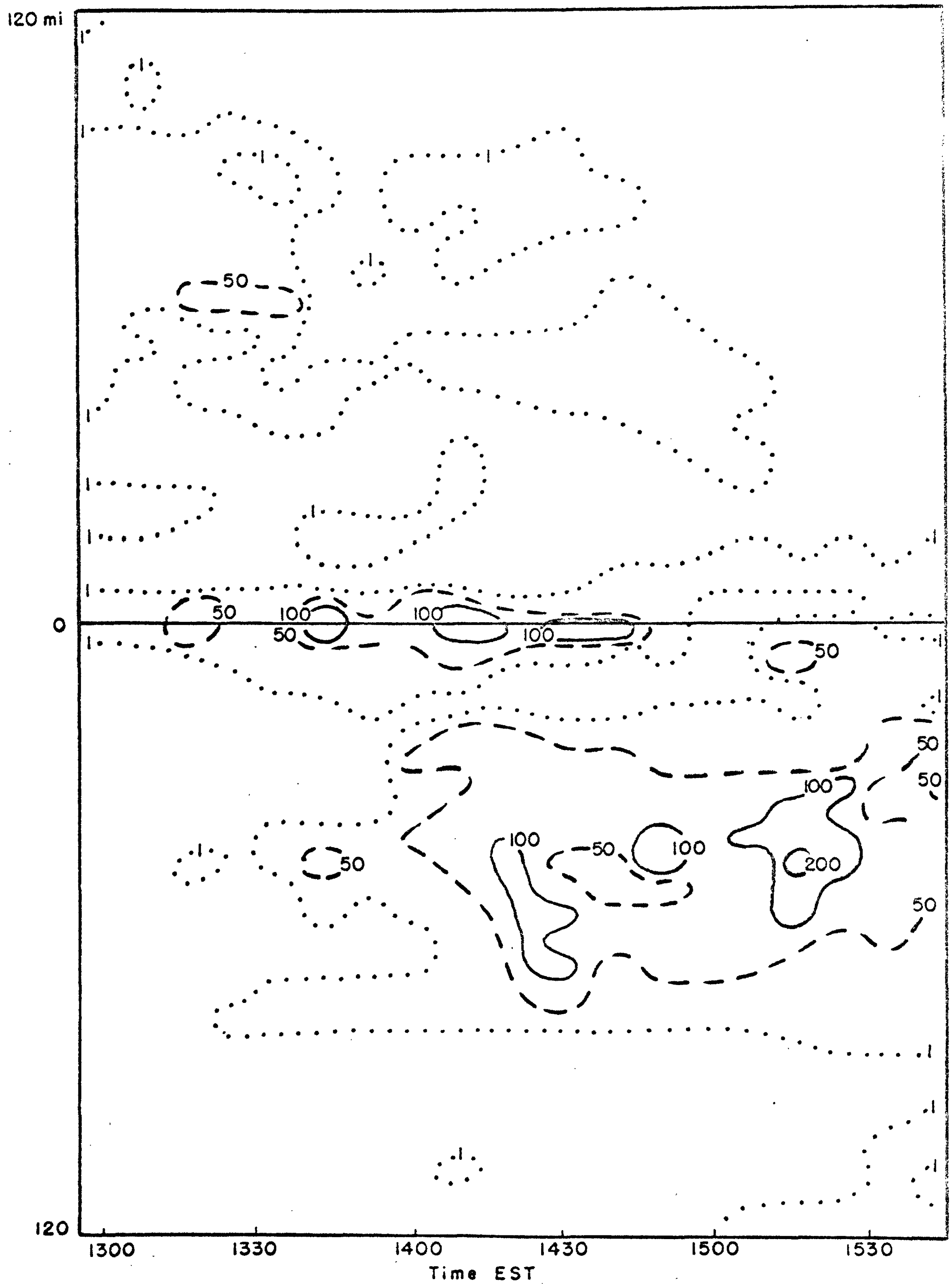

FIG. 5 Time - Space Composite 19 May 1958

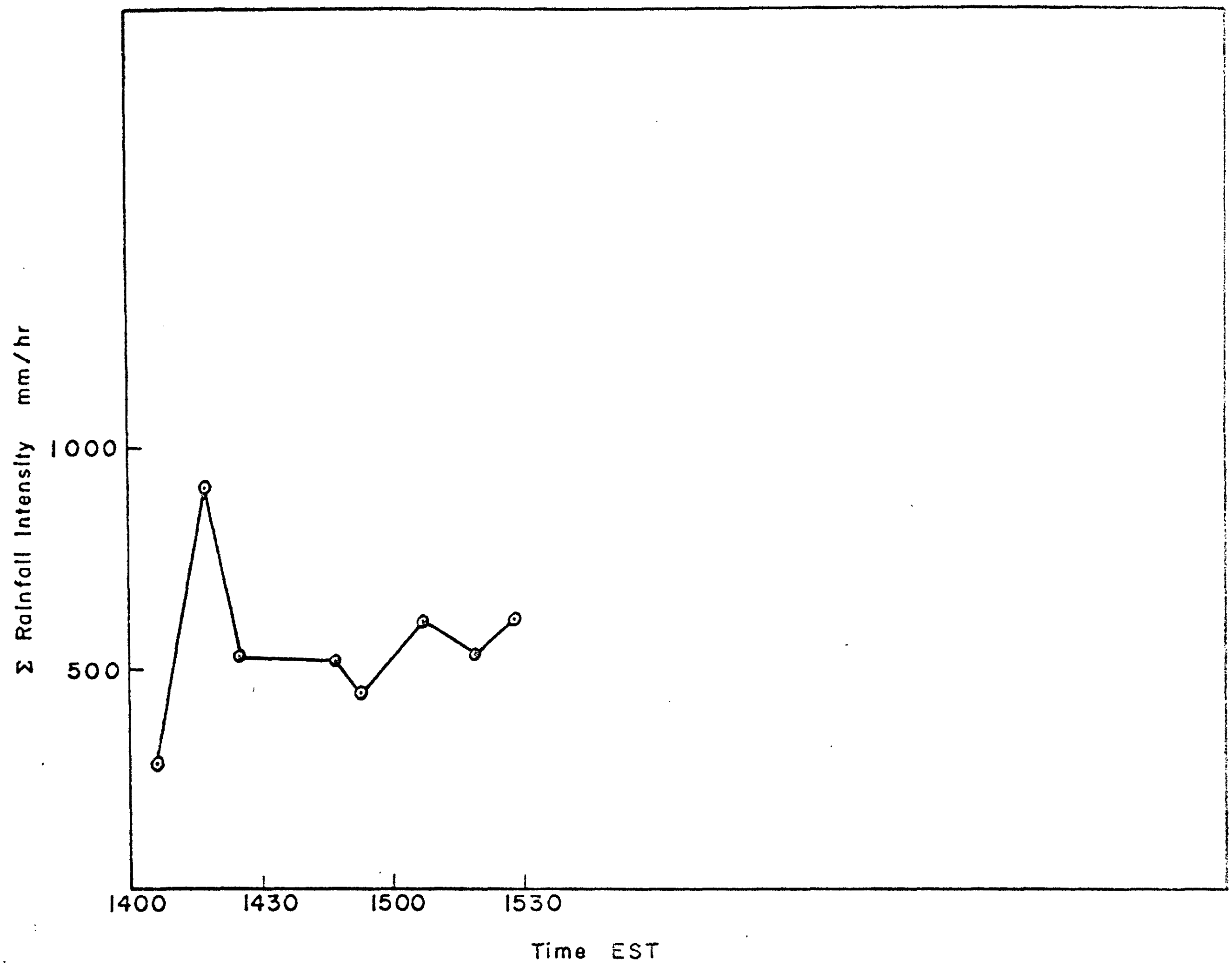

FIG. 6 Total Rainfall Intensity 26 June 1958

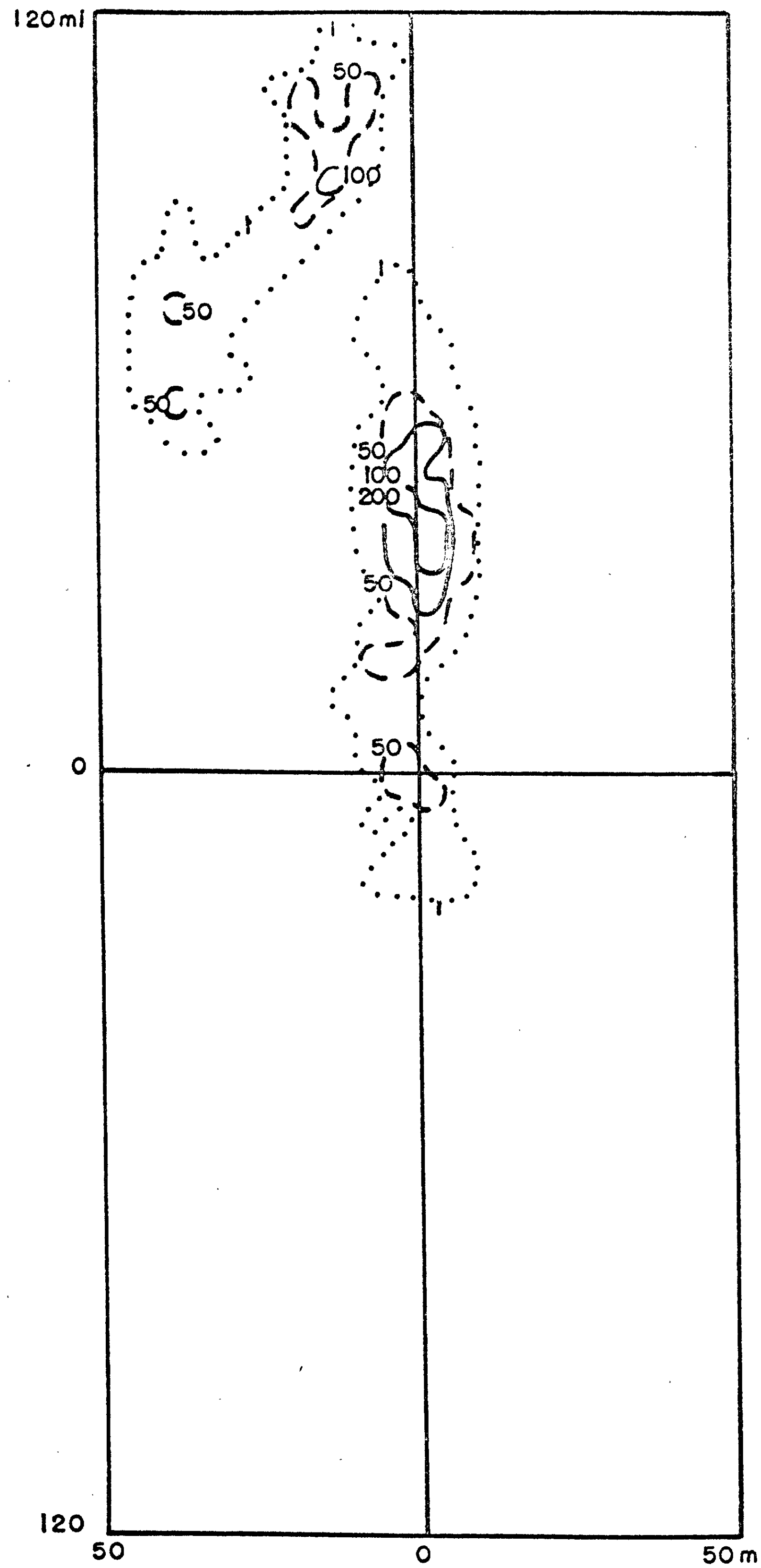

FIG. 7 Space Composite 26 June 1958

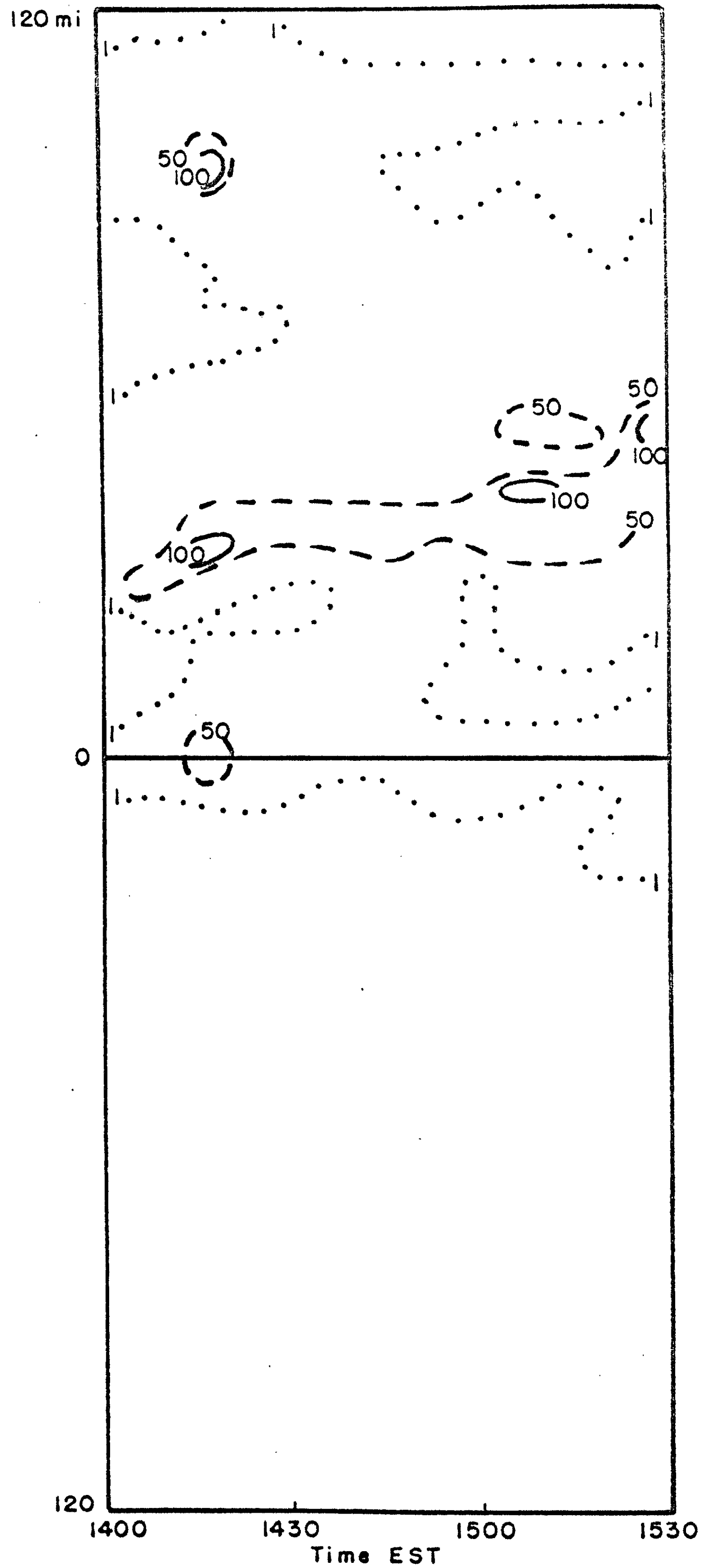

FIG. 8 Time - Space Composite 26 June 1958

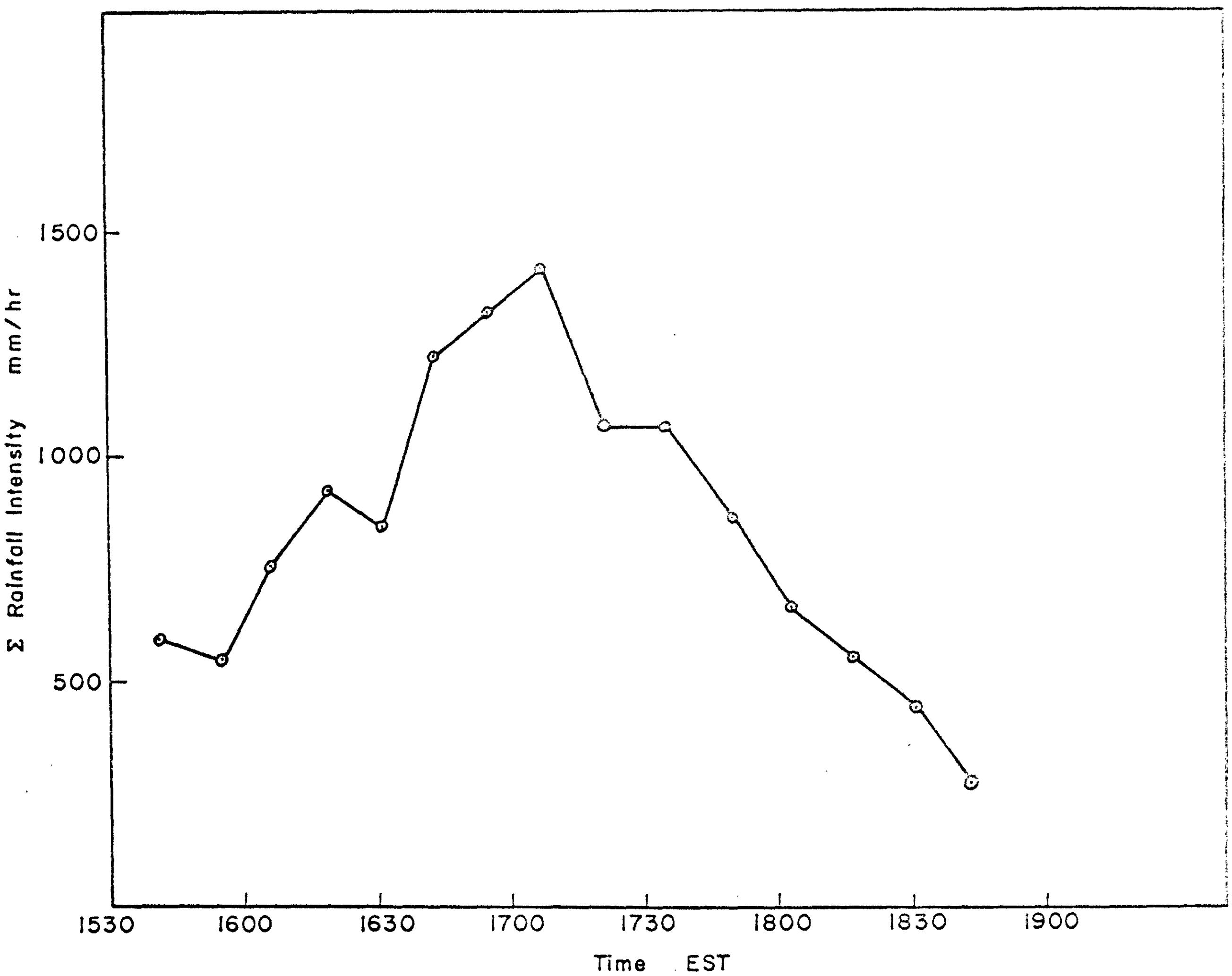

FIG. 9 Total Rainfall Intensity 08 July 1953

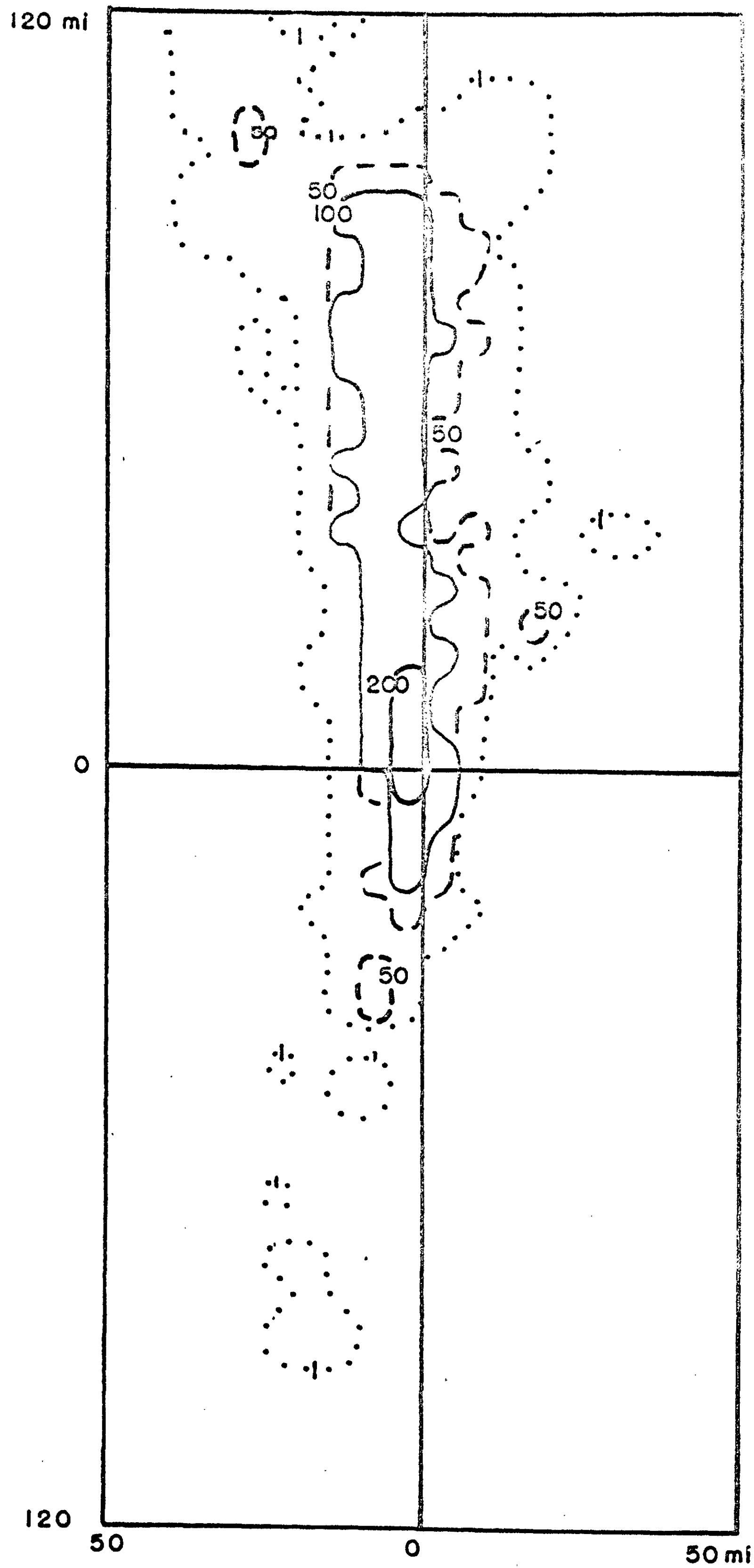

FIG. 10 Space Composite 08 July 1958

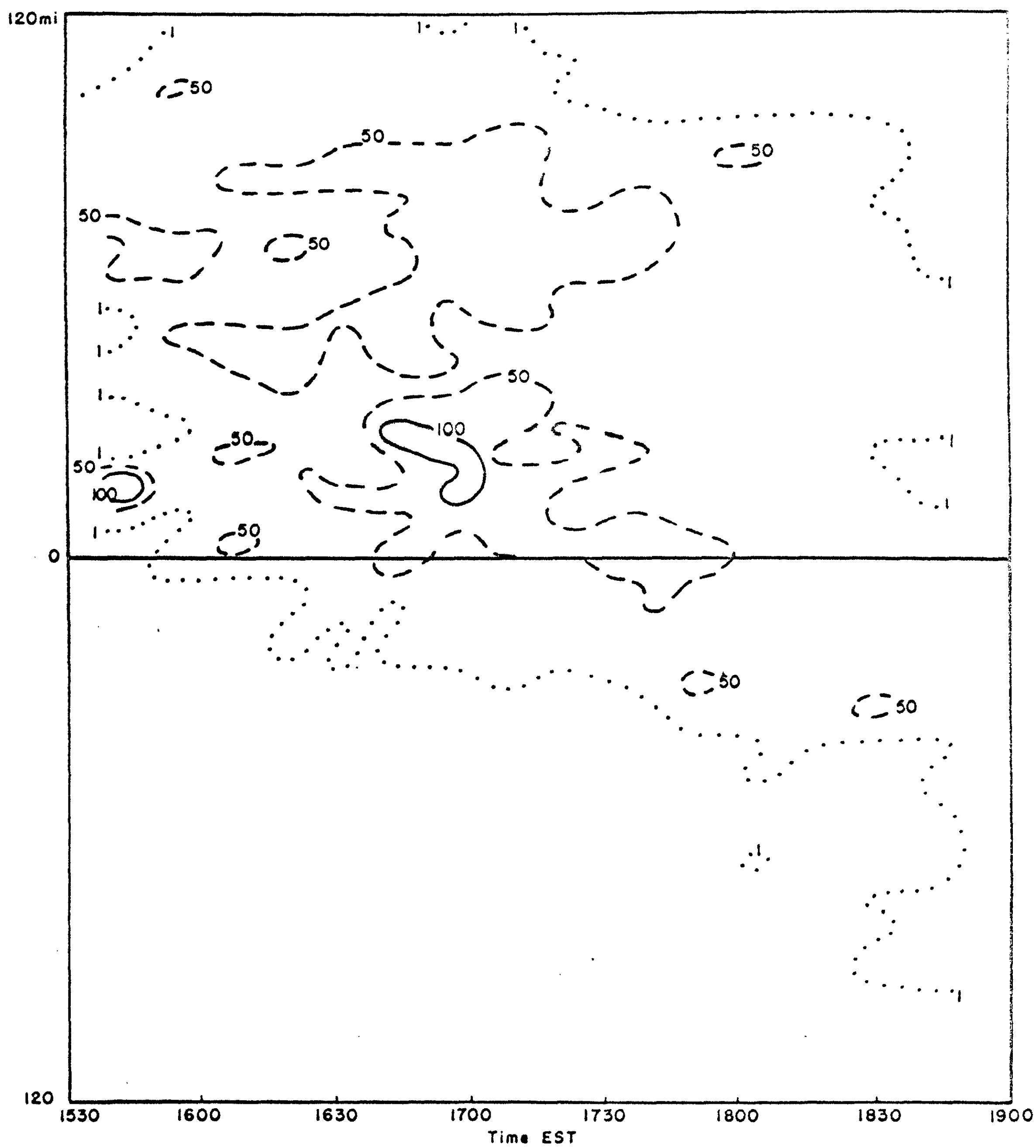

FIG. 11 Time-Space Composite 08 July 1958

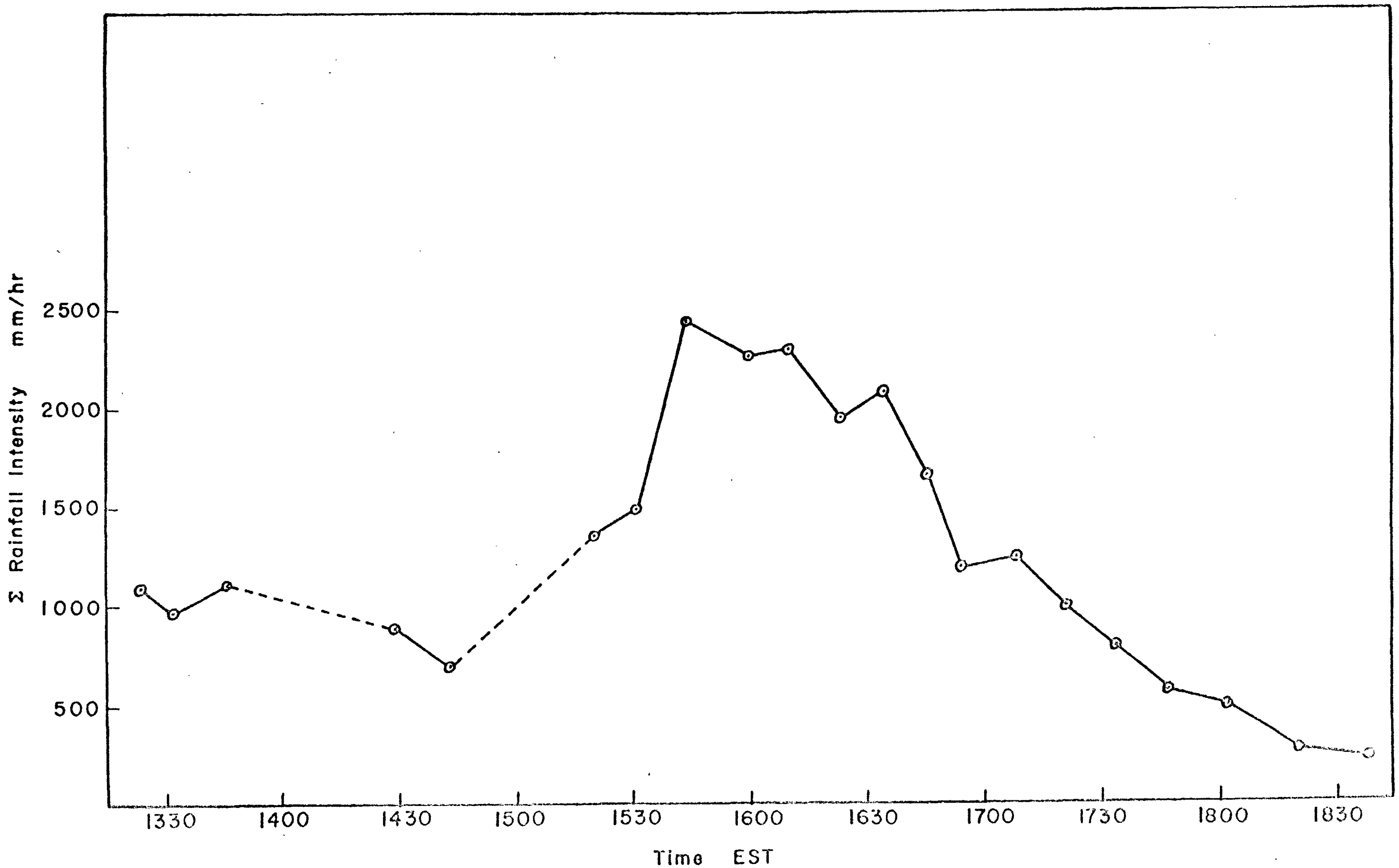

FIG. 12 Total Rainfall Intensity 11 July 1958

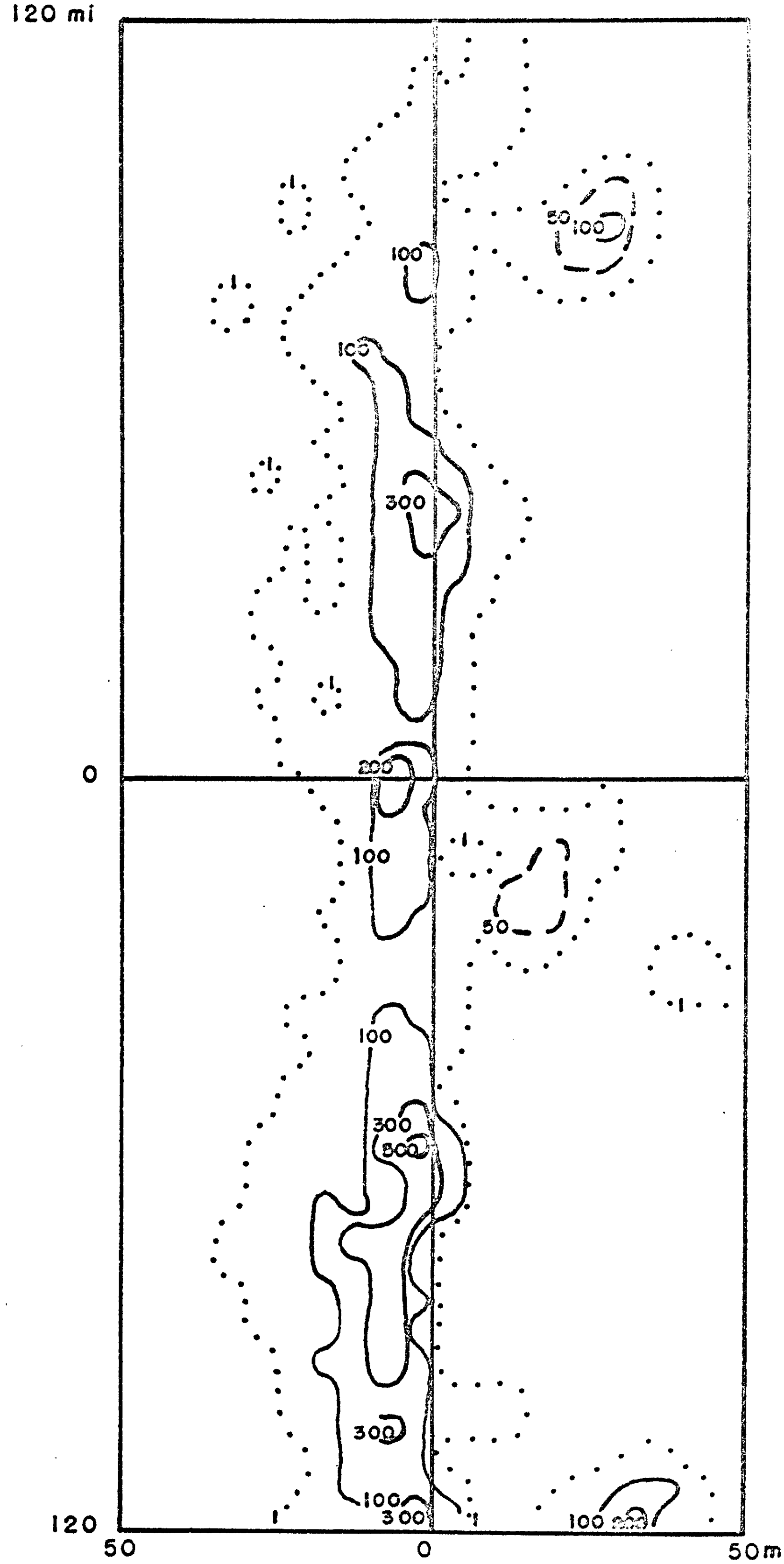

FIG. 13 Space Composite 11 July 1958

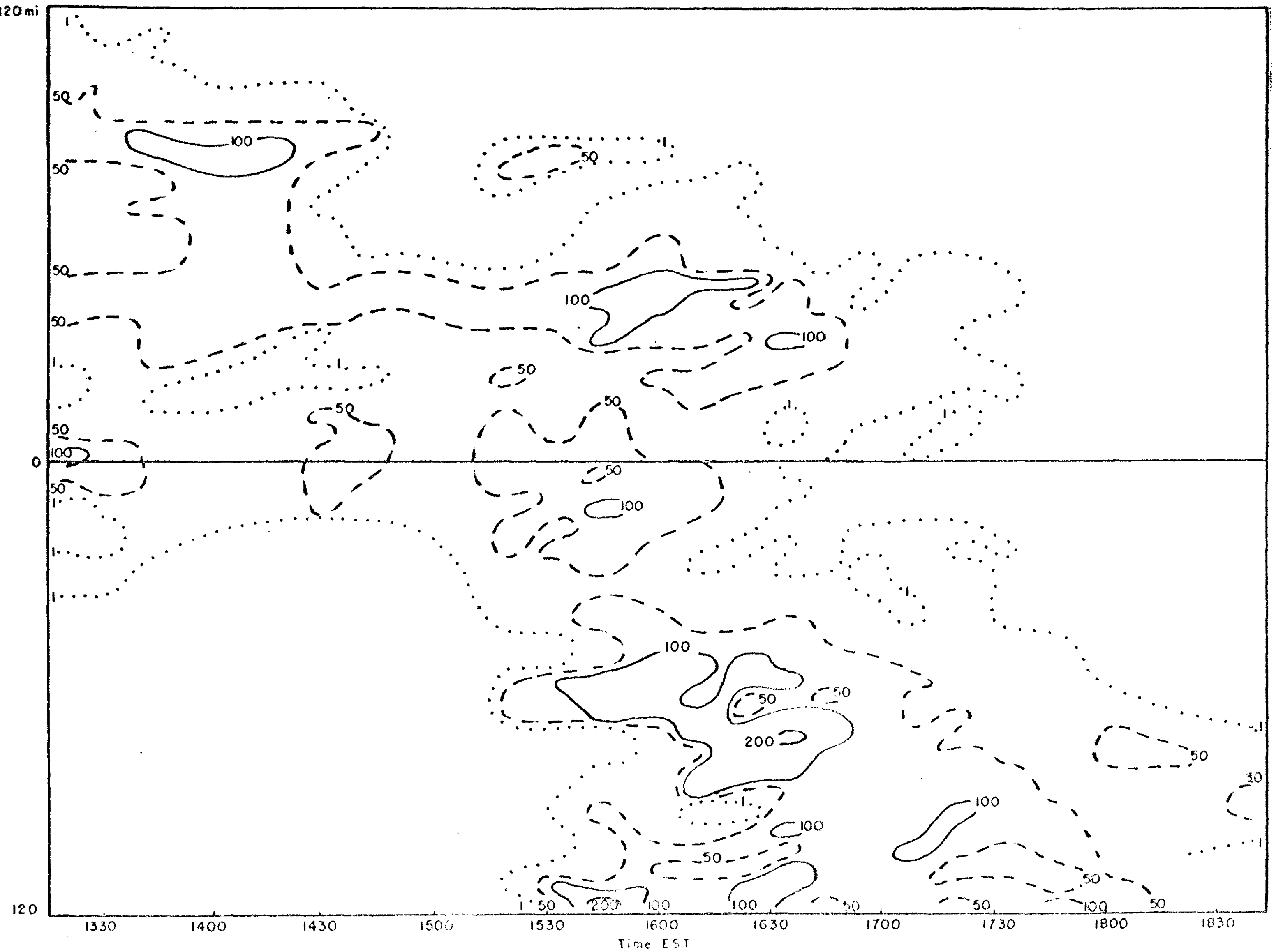

FIG 14 Time - Space Composite 11 July 19[illegible]

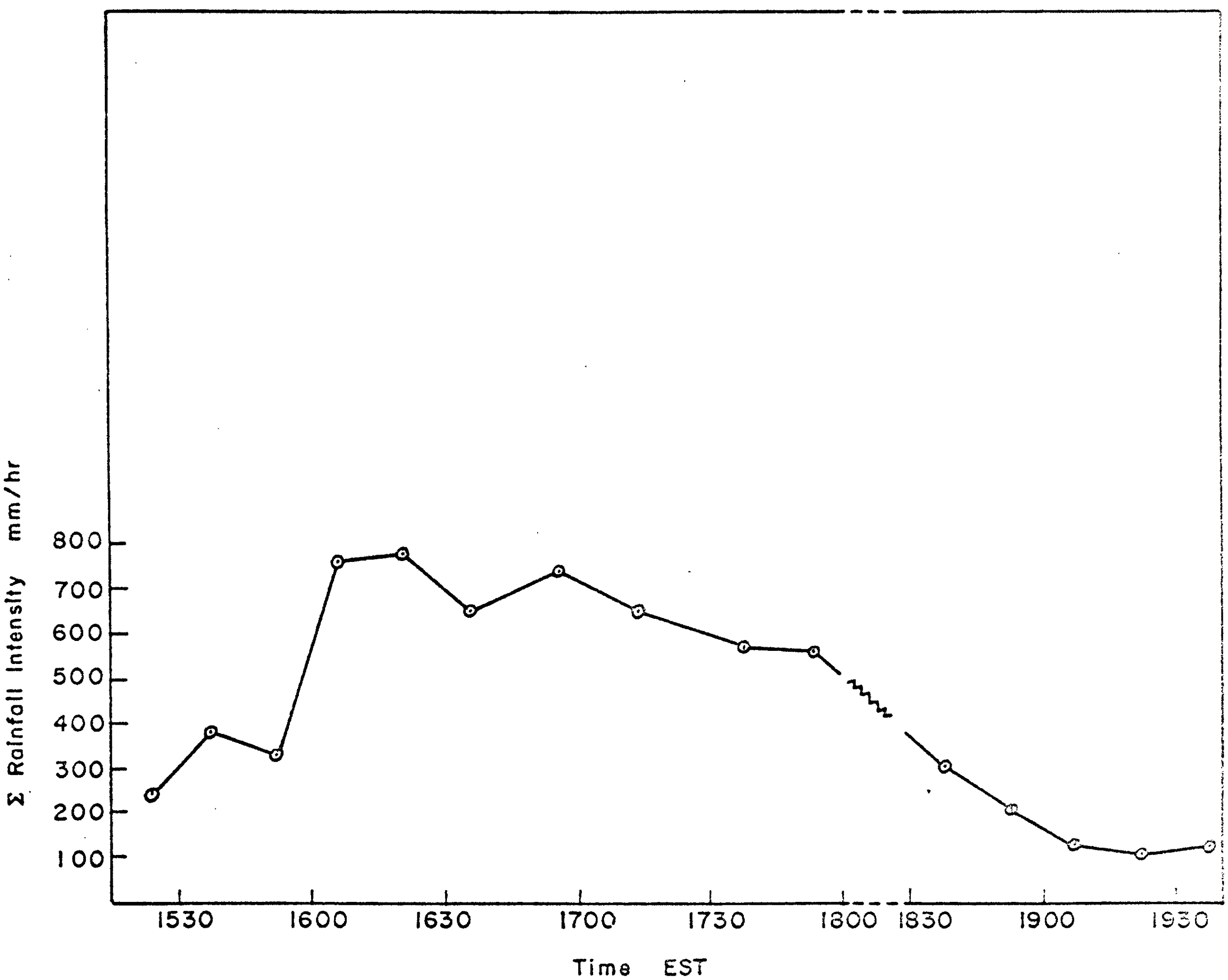

FIG. 15 Total Rainfall Intensity 12 July 1958

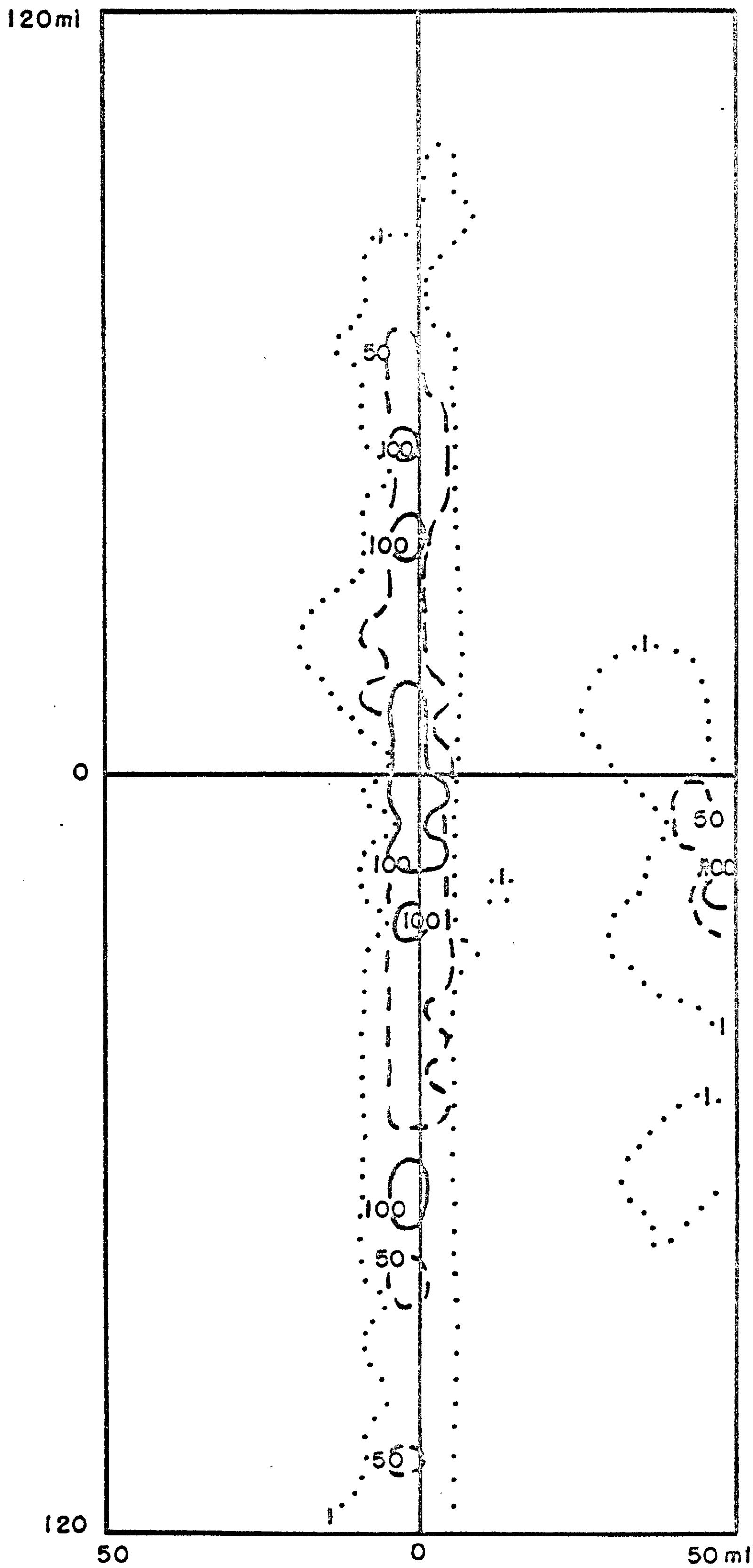

FIG. 16 Space Composite 12 July 1958

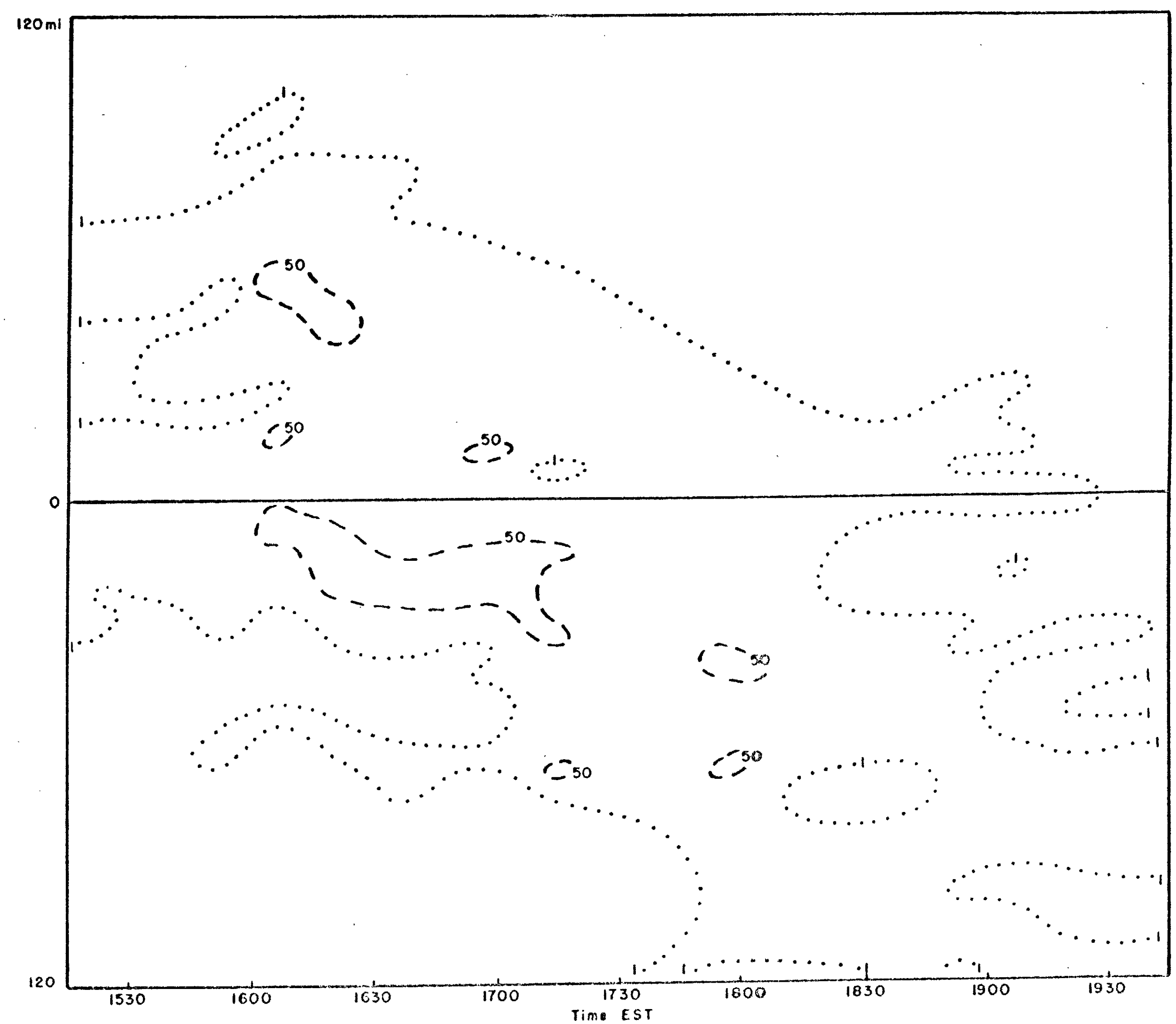

FIG. 17 Time-Space Composite 12 July 1958

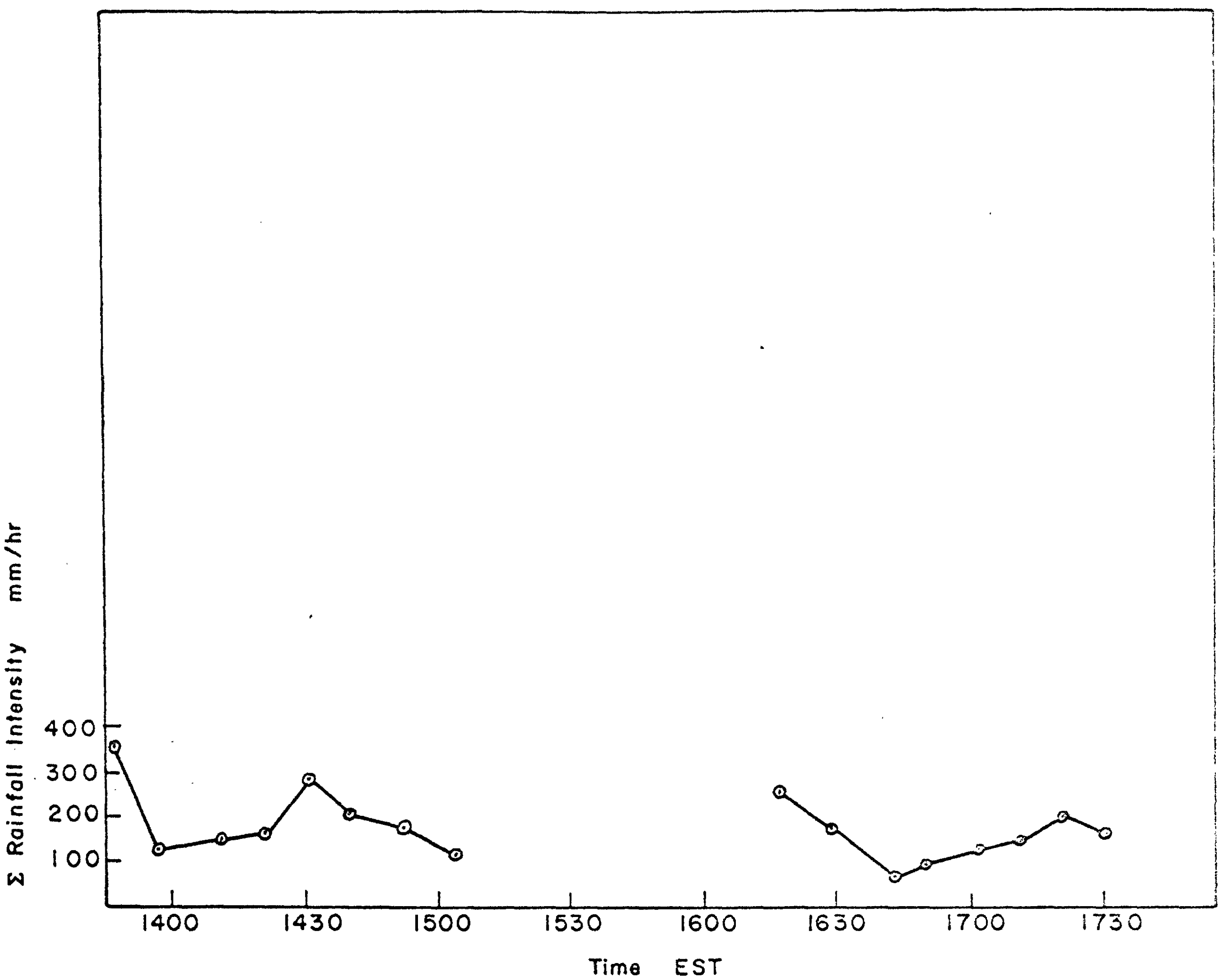

FIG. 18 Total Rainfall Intensity 10 Sept. 1958

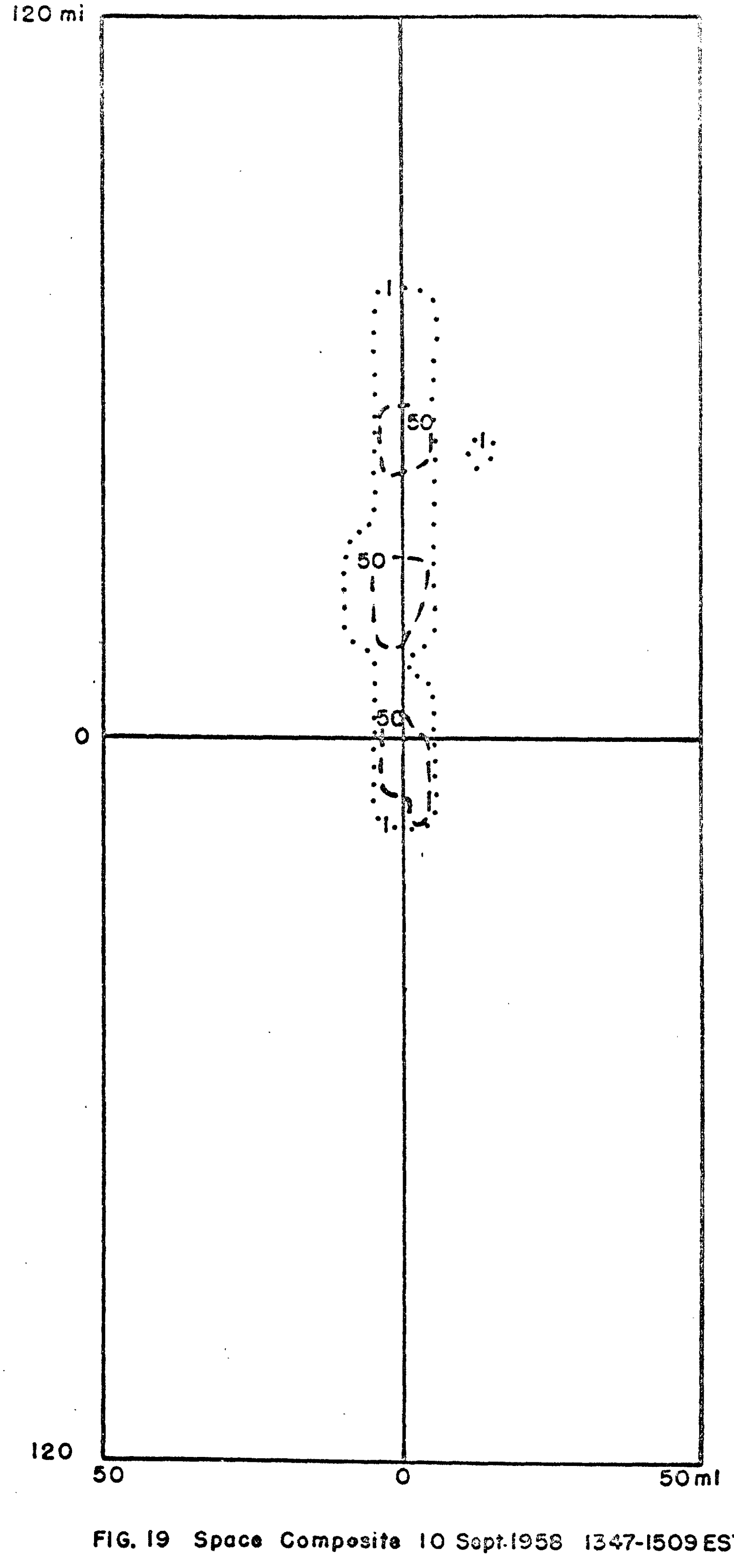

FIG. 19 Space Composite 10 Sept. 1958 1347-1509 EST

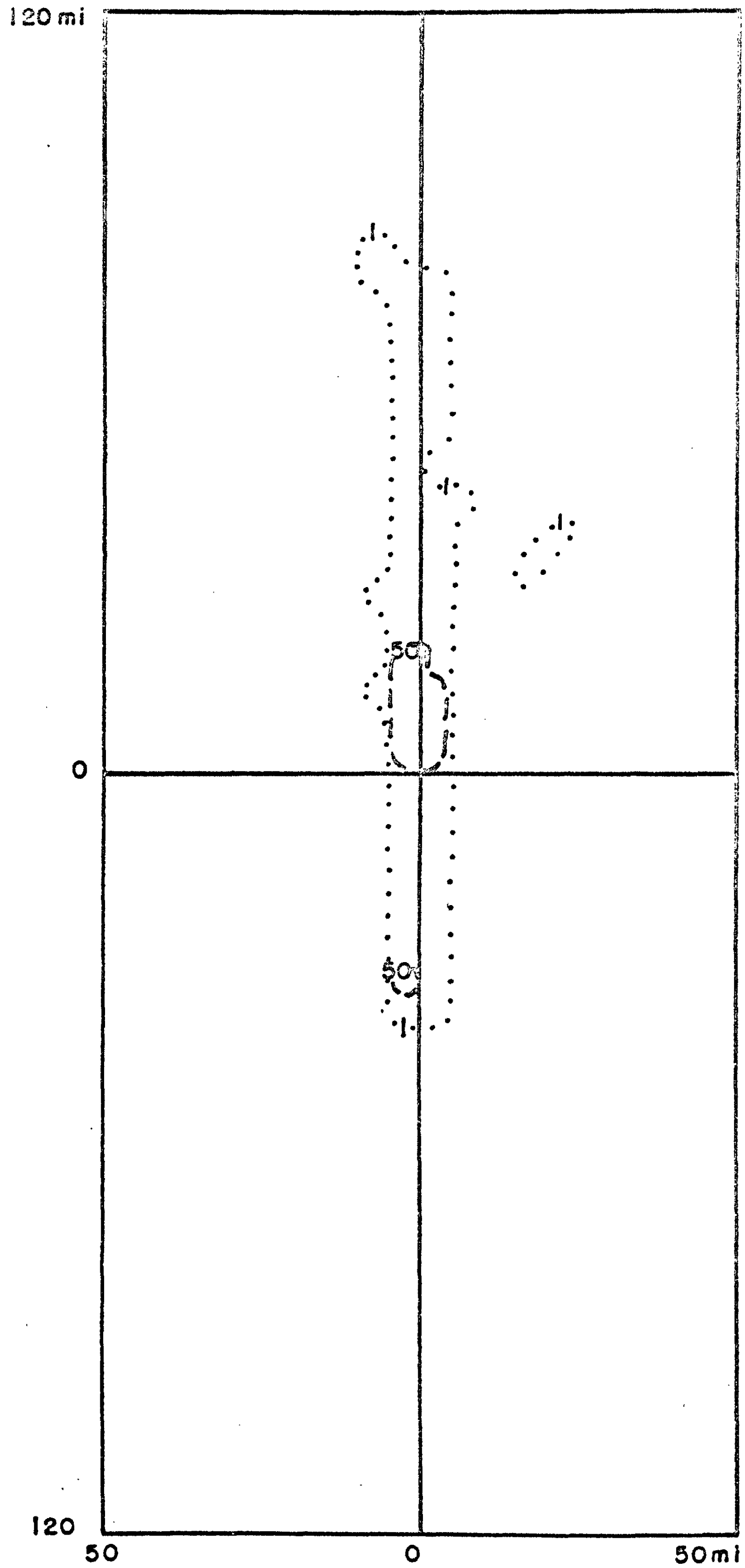

FIG. 20 Space Composite 10 Sept. 1958 1617-1730 EST

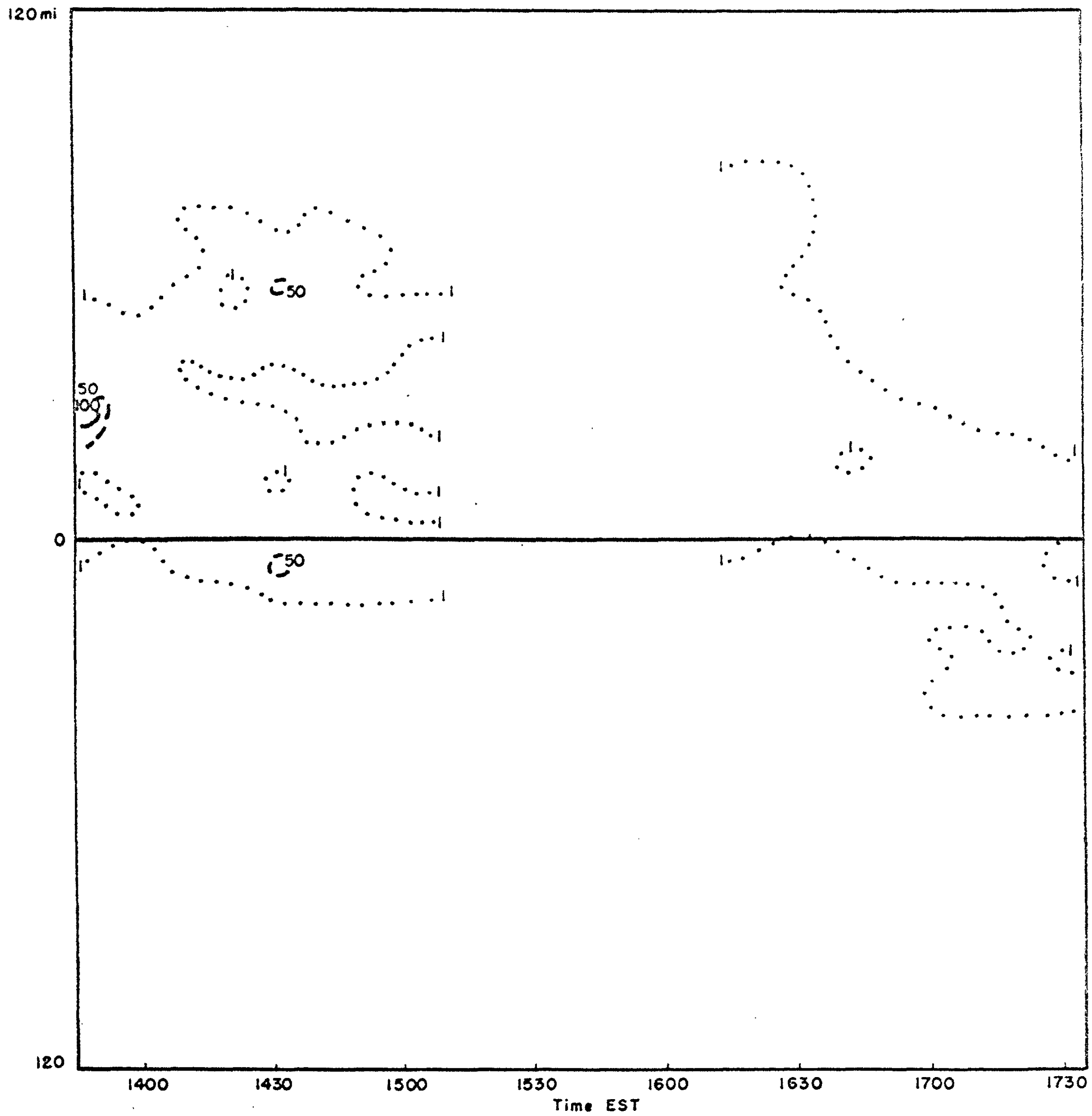

FIG. 21 Time-Space Composite 10 Sept. 1958

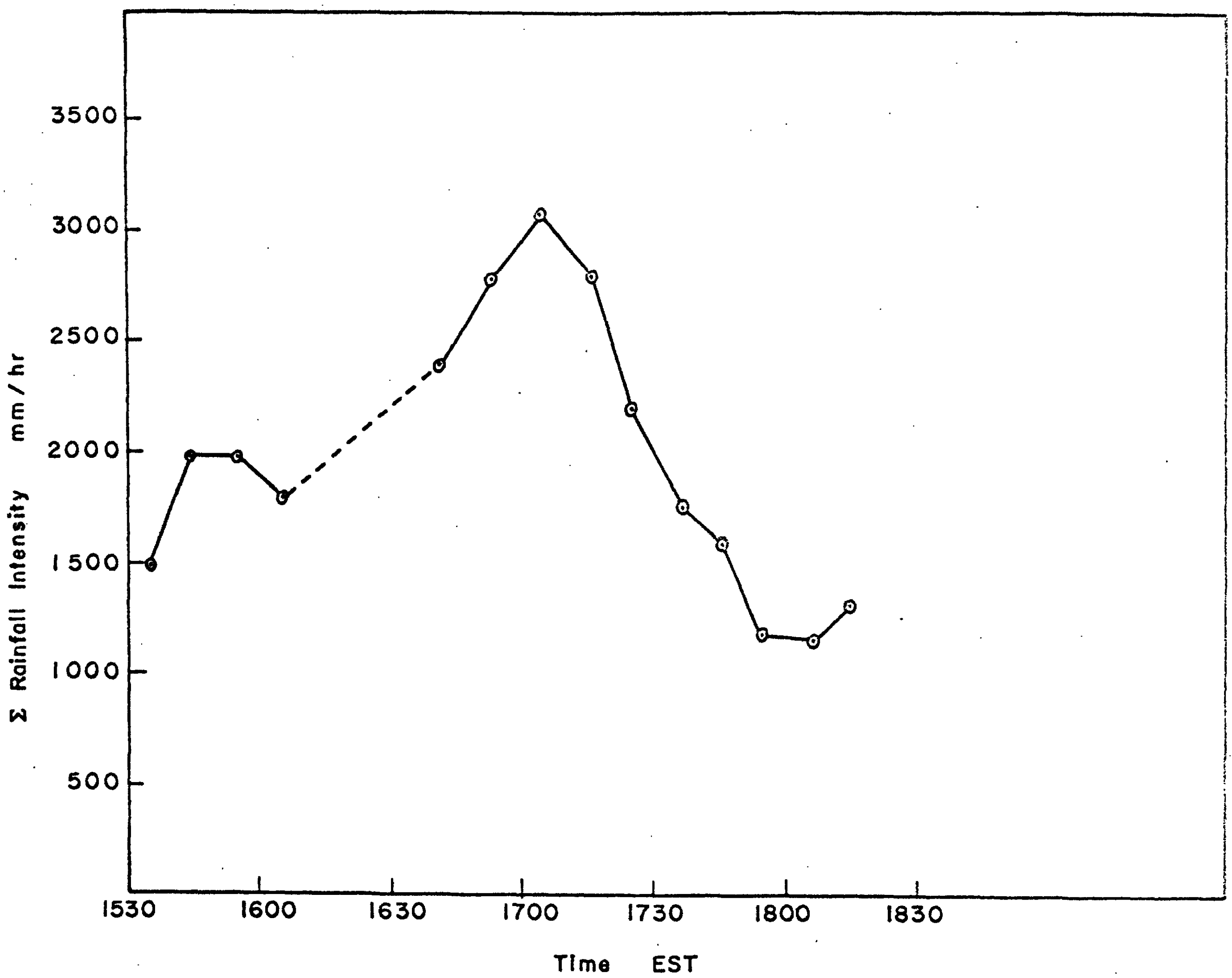

FIG. 22 Total Rainfall Intensity 13 June 1959

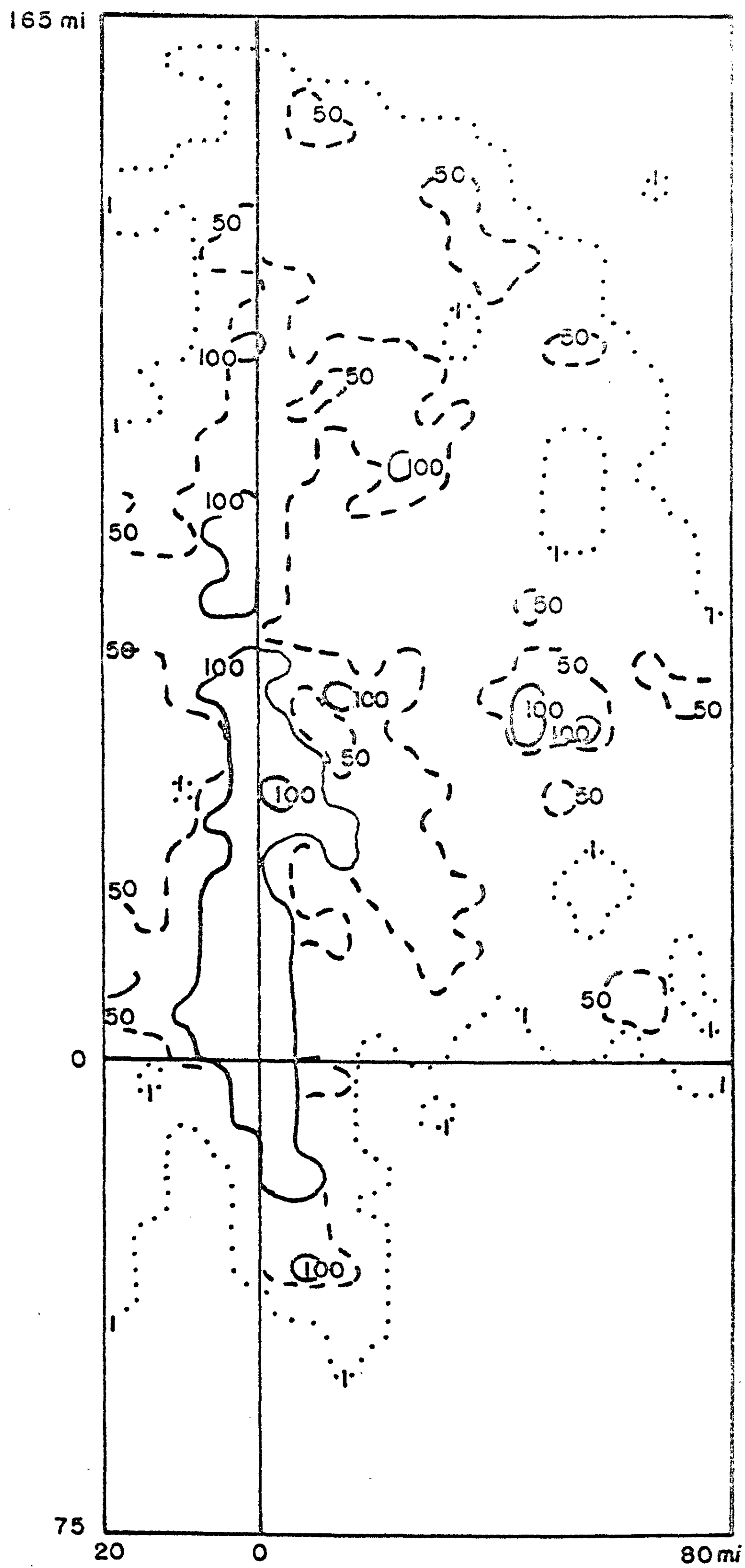

FIG. 23 Space Composite 13 June 1959

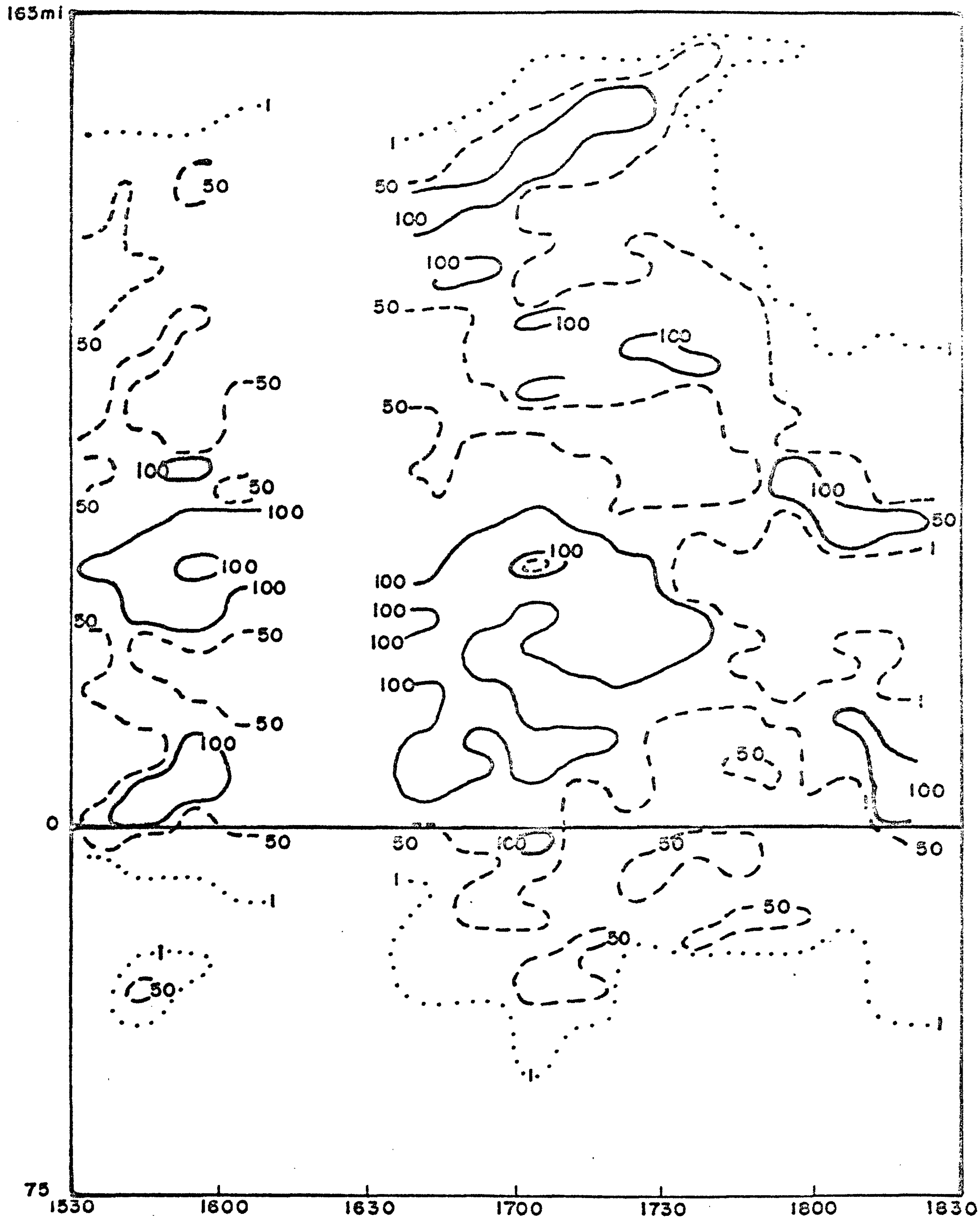

FIG. 24 Time-Space Composite 13 June 1959

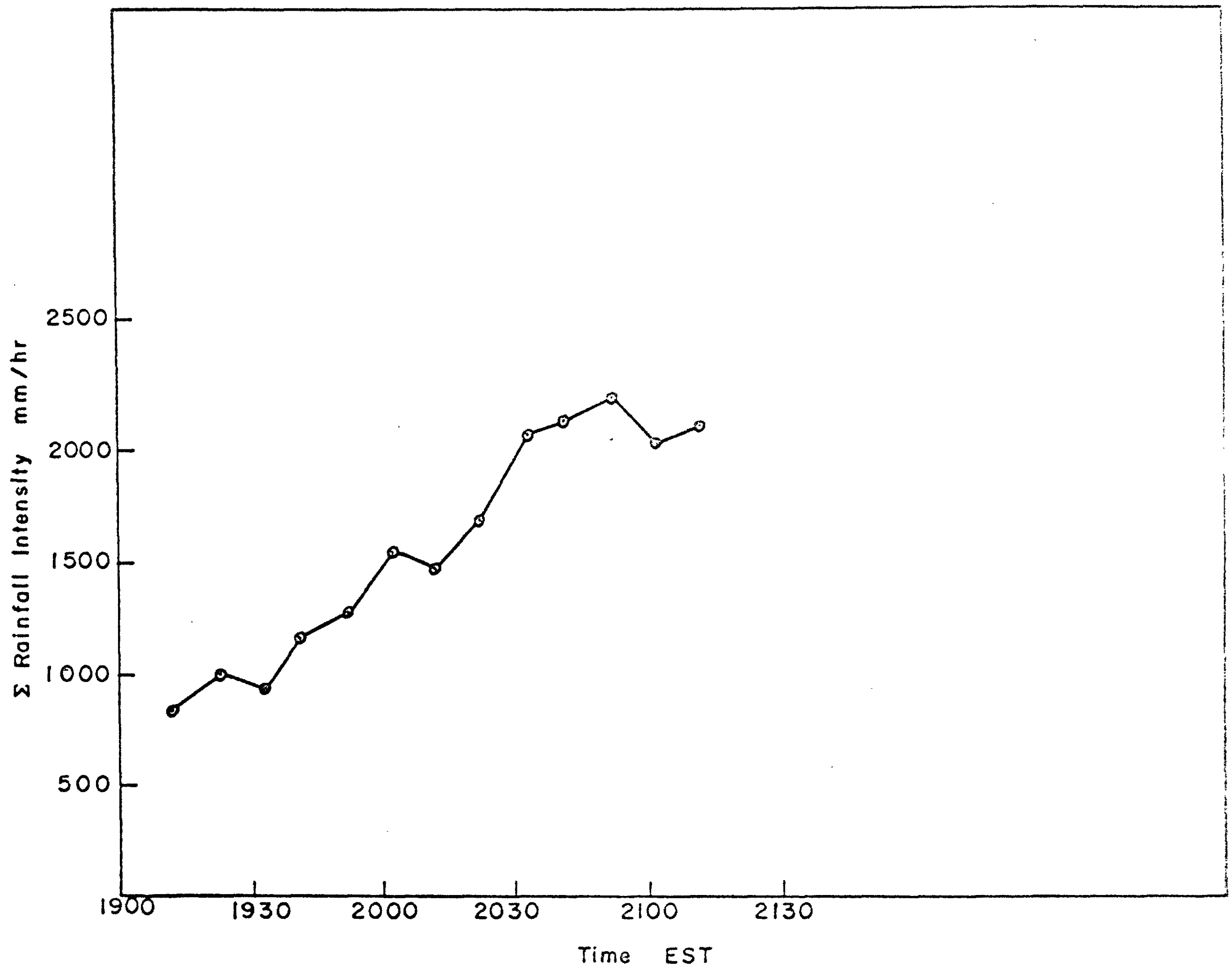

FIG. 25 Total Rainfall Intensity 24 June 1960

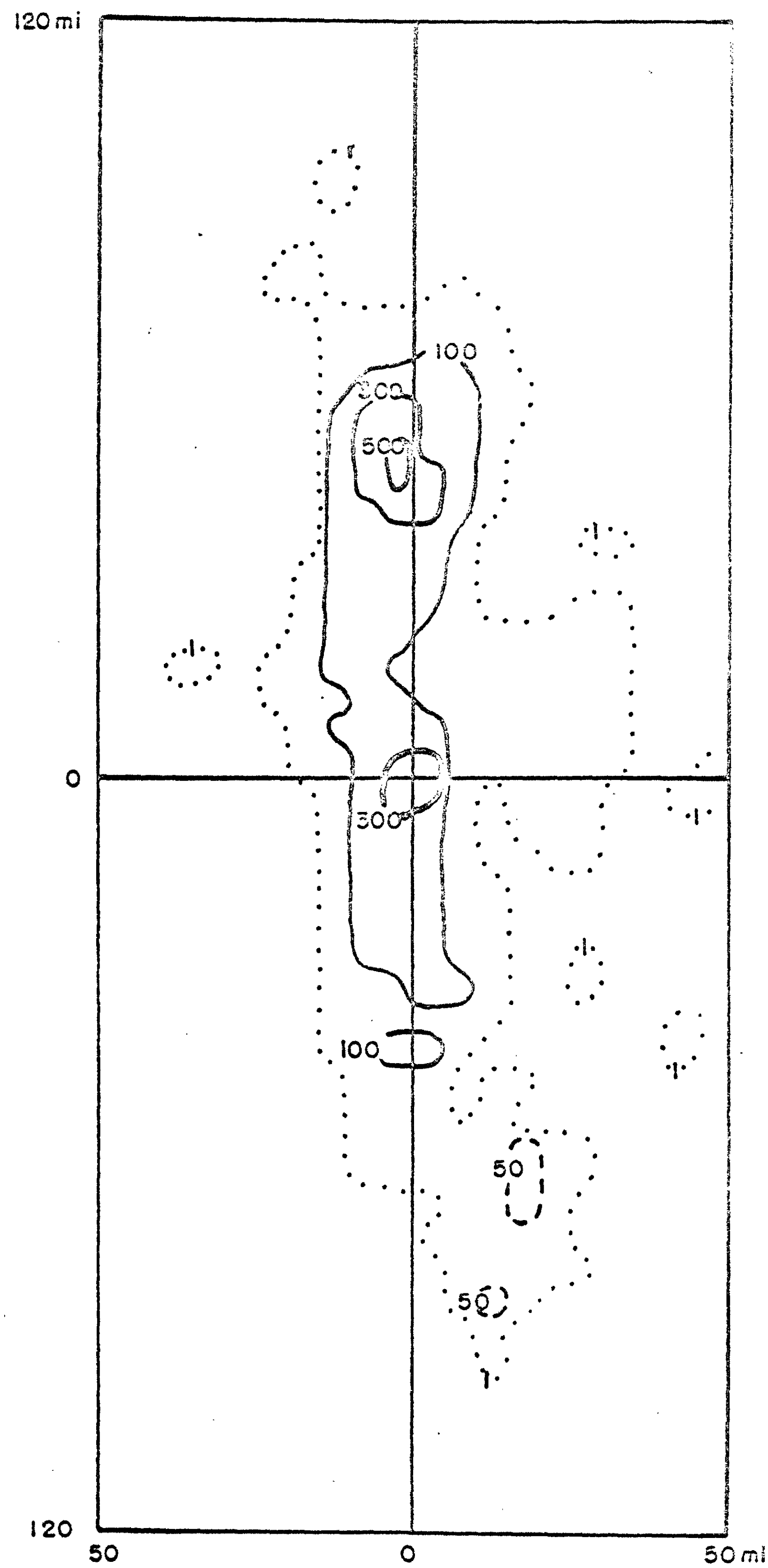

FIG. 26 Space Composite 24 June 1960

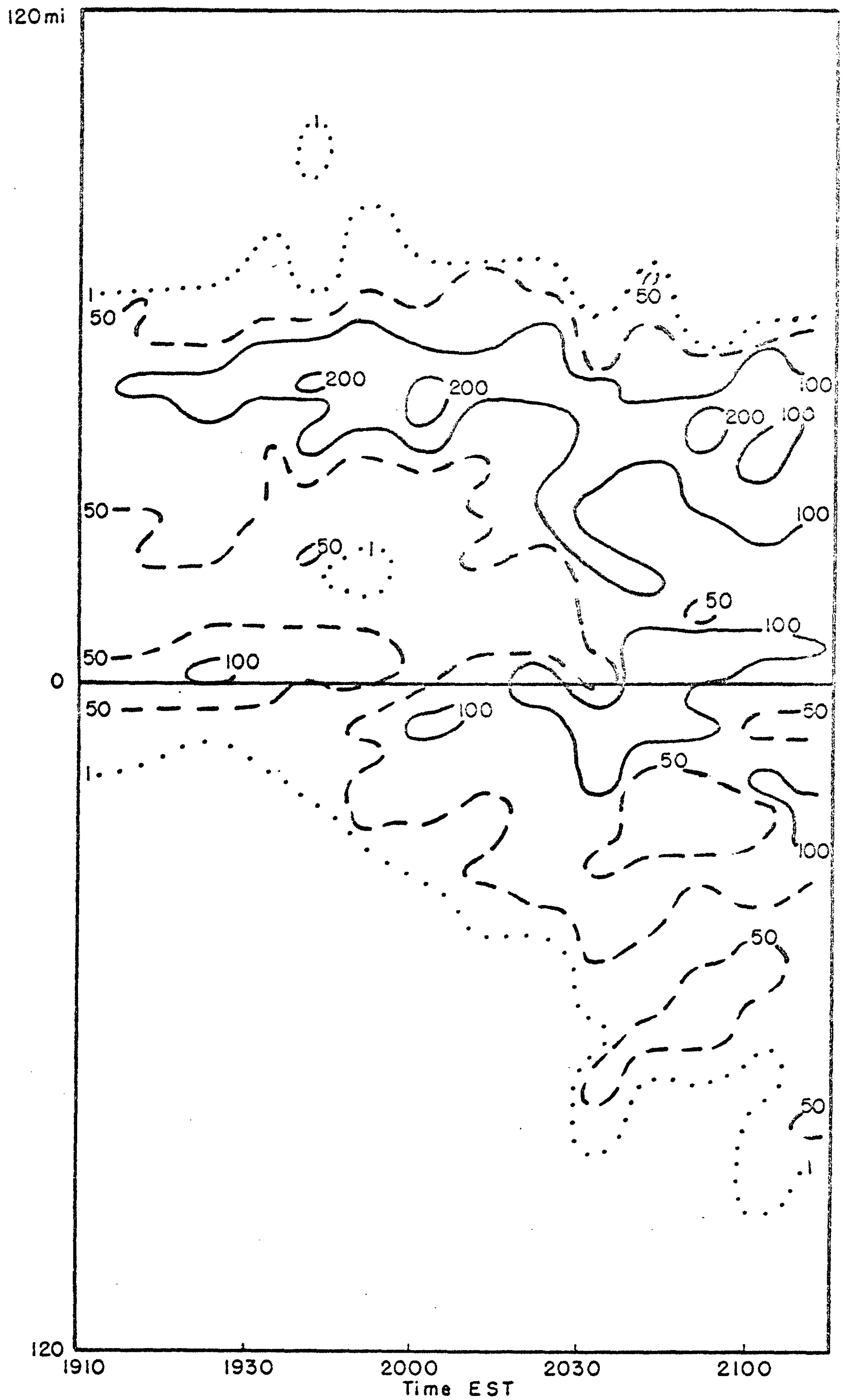

FIG. 27 Time-Space Composite 24 June 1960

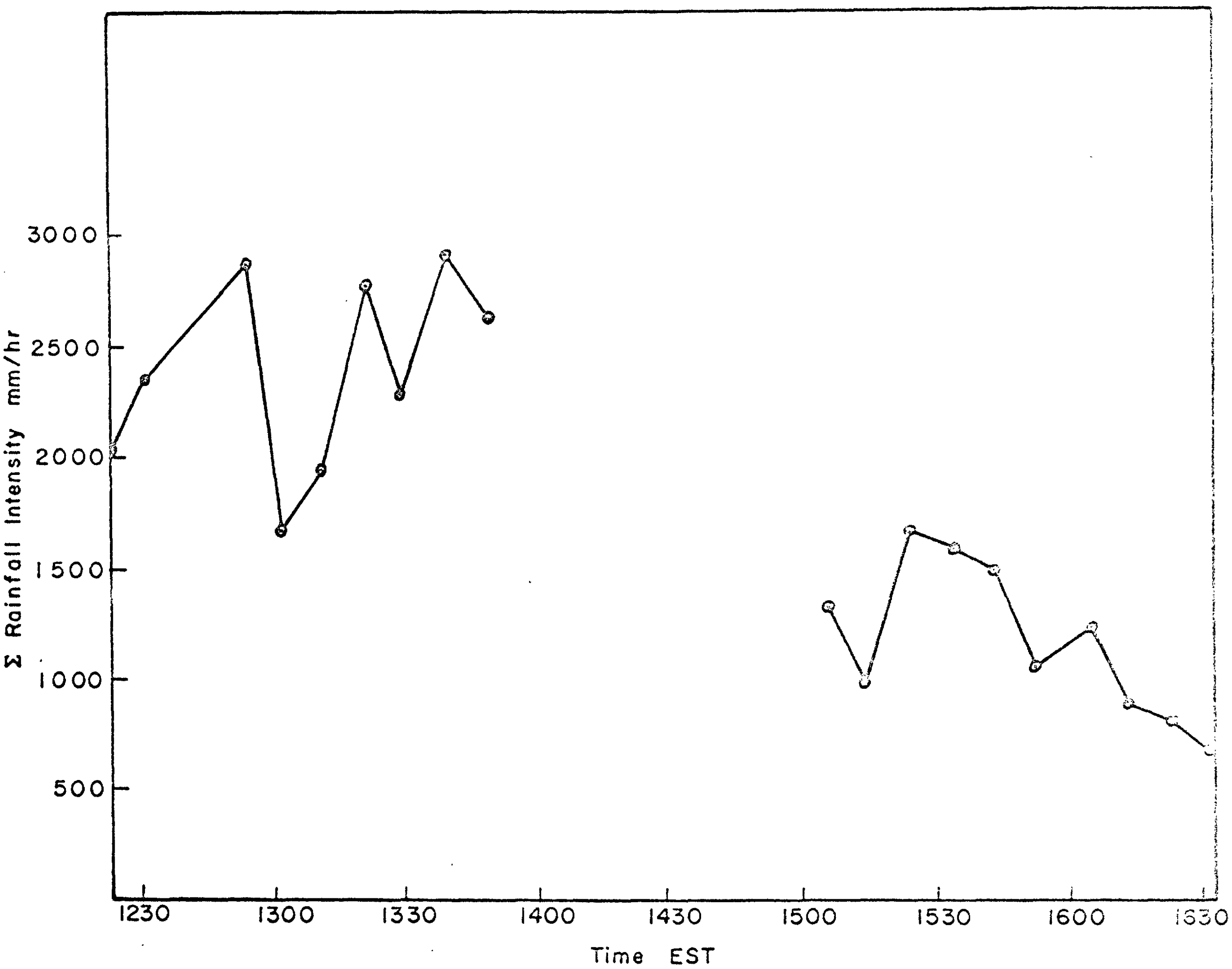

FIG. 28 Total Rainfall Intensity 30 June 1960

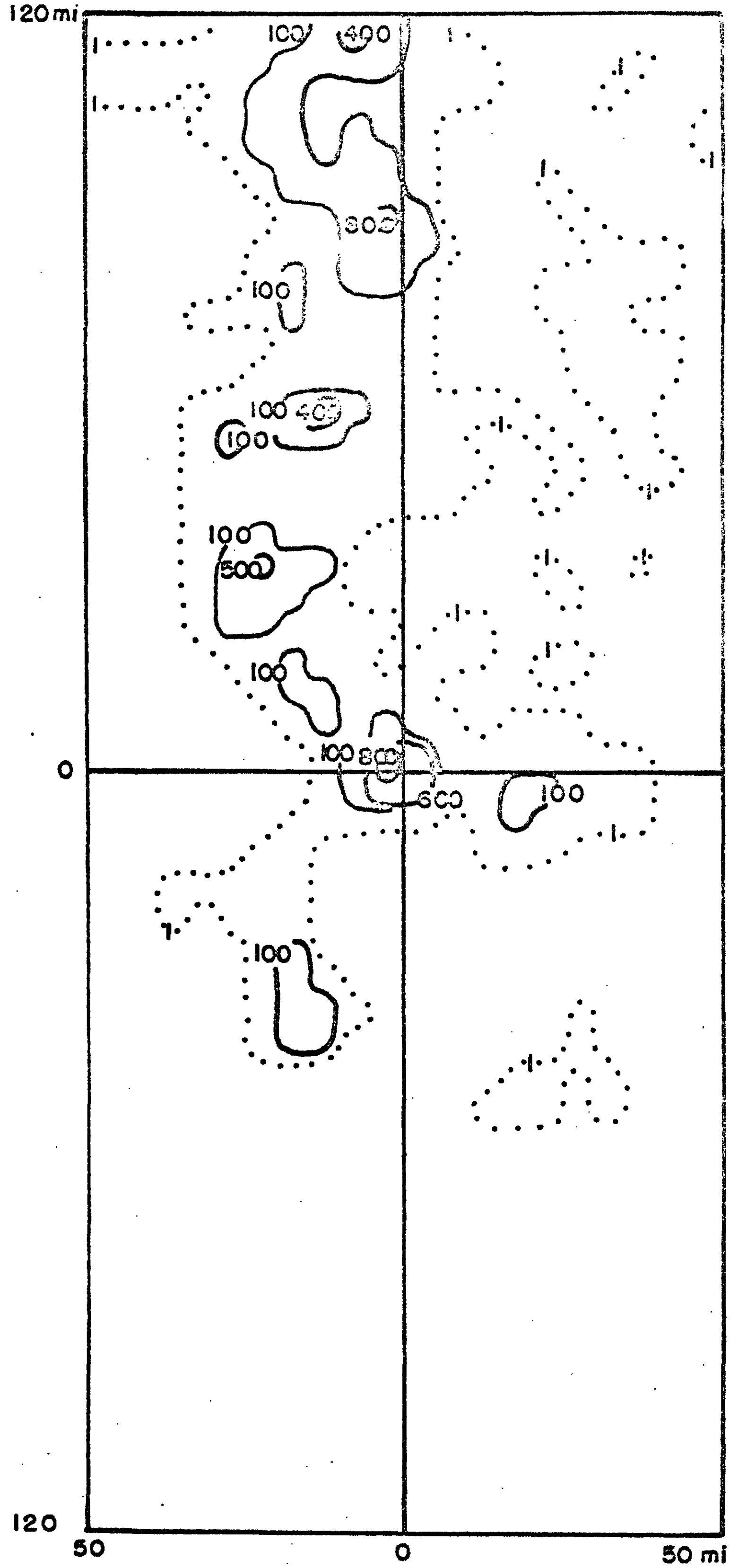

FIG. 29 Space Composite 30 June 1960 1223-1349 EST

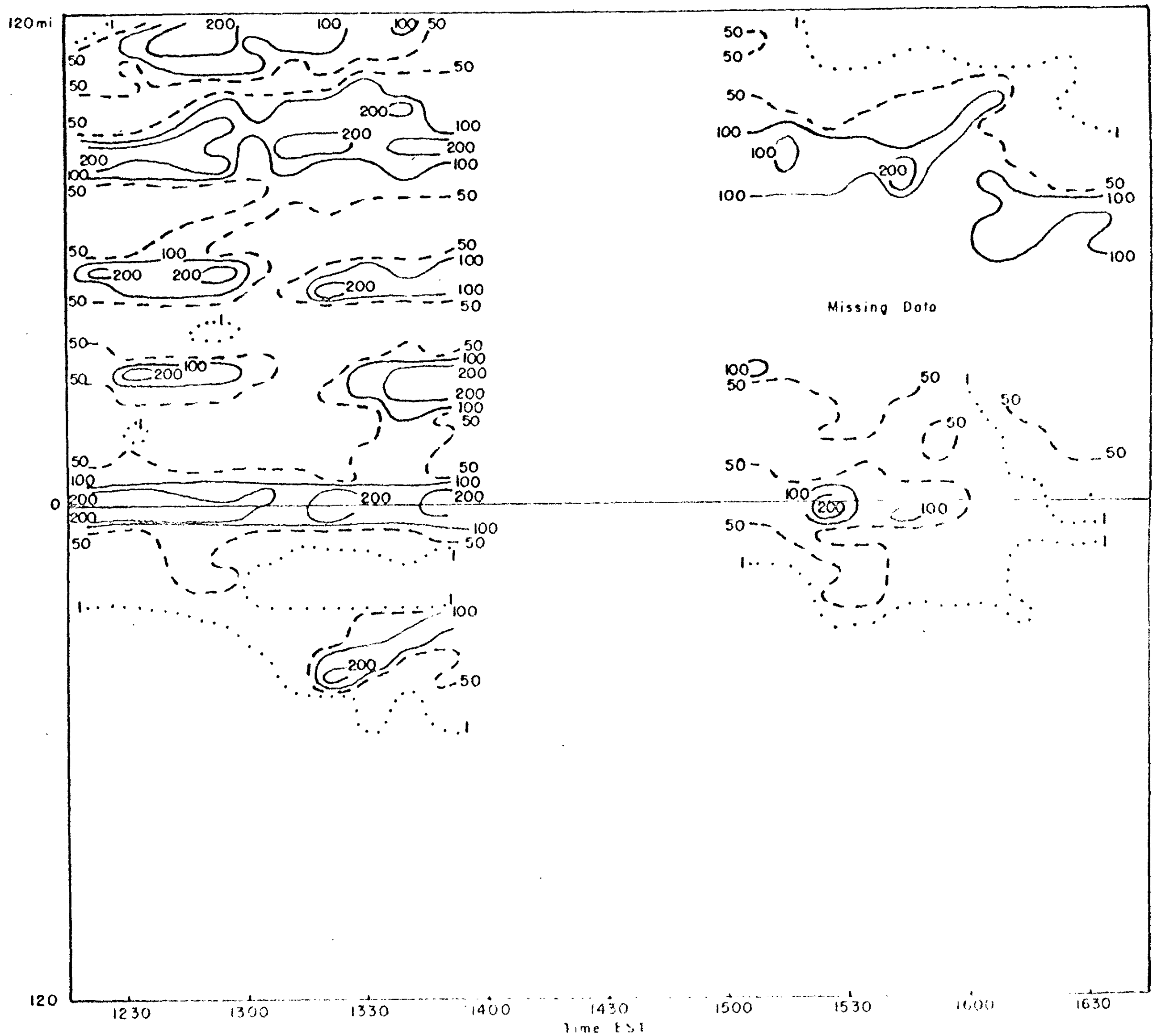

FIG 30 Time Space Composite 30 June 1960