NAVAL RESEARCH LABORATORY REPORT

FR - 1370

28 May 1937

STATIC DIRECTION FINDER RESEARCH

By
W. M. Lockhart
Comdr, U.S.N.

Report No. R-1370

NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

28 May 1937.

NRL Report No.R-1370
BuEng. Prob. No.D3-1

NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

Static Direction Finder Research

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

Number of Pages: Text - 19 Plates - 6

Authorization: BuEng. ltr. S67(1-4-36) of 5 January 1934.

Date of Test: August 1936 to May 1937, inc.

Prepared by: W. M. Lockhart, Lieut. Comdr., U.S.N.

Approved by: H. M. Cooley, Captain, U.S.N.

Distribution:
BuEng. (5)

bmb Copy to BuAero

TABLE OF CONTENTS

APPENDICES

AUTHORIZATION.

1. This problem was authorized by reference (a).

Reference: (a) BuEng. ltr. S67(1-4-36) of 5 January 1934.

OBJECT OF TEST.

2. The object as outlined in reference (a) was "To produce a complete system whereby synchronized bearings of individual static discharges can be obtained at and correlated by two or more widely separated stations, thus fixing the location of disturbances."

3. Insofar as the development of such a system is concerned, this object was accomplished in 1935 when two static direction finders at Winter Harbor, Maine, and at the Naval Research Laboratory, Bellevue, D.C., were placed in commission and static observations have been taken daily since that time.

4. The object of the static investigation conducted between August 1936 and April 1937 by the writer of this report was "To determine the relation between static and weather phenomena."

ABSTRACT OF TEST.

5. The following meteorological phenomena were investigated as regards static indications:

(a) Thunderstorms.
(b) Static in relation to Extratropical Cyclones or "Lows."
(c) Static in relation to Extratropical Anticyclones or "Highs."
(d) Static in relation to Hurricanes.

CONCLUSIONS.

(a) As regards the static direction finder equipment as developed by the Naval Research Laboratory, it can be operated fairly reliably by regular enlisted personnel, but an expert radio technician will always be required to make necessary adjustments and repairs at regular intervals.

(b) The equipment will record crashes of static from considerable distances and these crashes can be located geographically with a satisfactory degree of accuracy by simultaneous bearings from two or more stations.

(c) In many cases it was possible to locate and track thundershowers and showers which were emitting static.

(d) Although most sources of static, such as showers and thundershowers, around an extratropical cyclone or "low" may be located and tracked, such sources do not give positive evidence of the position and movement of the cyclone itself, of its stage of development, or of the various weather elements (except such showers and thundershowers) surrounding such a cyclone. Thus, it appears impossible to track such cyclones by means of static.

(e) Extratropical anticyclones or "highs" are relatively free from static indications, except in their south and southeast sectors where showers and thundershowers may exist. But, in view of the large number of cyclones in northern latitudes that also lack static, this absence of static would be of doubtful forecasting value.

(f) The behavior of static recorded during the hurricanes or tropical cyclones during 1936 leads to the belief (lacking other more definite means of detection of such storms, such as a daily weather map over the oceans, and a better understanding of meteorological conditions surrounding such a storm, especially as regards the sources of static) - that it is not feasible either to locate or track tropical storms or hurricanes by means of the static recorders at present in use.

(g) This study has indicated that the static indications with relation to actual weather are not as simple as various radio investigators have led us to believe. In practically all the previous investigations, it is believed that only weather situations prolific in static indications have been studied and not a day to day analysis over a long period of time. Such studies have resulted in many erroneous conclusions regarding the correlation of static and weather which upon closer and prolonged investigation have been found very doubtful.

(h) The subject investigation has served to indicate that the actual application of radio work with static to meteorology or aviation is still doubtful. It thus appears that to obtain practical results, any investigation of static with regard to weather will have to be prolonged over a long period of years with close cooperation between the radio Physicist and the practical meteorologist.

RECOMMENDATIONS.

(a) In view of the above conclusions, it is recommended that further work on this problem be held in abeyance and that the problem be closed insofar as this Laboratory is concerned, unless interested parties desire that a meteorological section be established at the Naval Research Laboratory.

(b) In view of the partial deviation curve that has been obtained and the long period which will be required fully to calibrate these direction finders, it is recommended that the establishment of the third station, for which the equipment is now available, be deferred until a definite decision has been reached on recommendation (a).

DESCRIPTION OF MATERIAL.

6. The equipment employed for the determination of the source of static emanations consisted essentially of a radio direction finder with a cathode ray tube indicator and means for photographically recording the screen images. The direction finder employs two stationary loop collectors so positioned that the maximum pick-up of one is 90 degrees from that of the other. Each loop feeds a tuned radio frequency amplifier the output of which is fed to two opposite plates of the cathode ray tube. A third and similar amplifier is fed from an antenna pick up and its output is employed to control the cathode ray spot, extinguishing it while there is no static disturbance, and turning it on for each static impulse. This spot control amplifier is equipped with a rectifier system which also provides a means for reducing the intensity of, or extinguishing the spot completely for one-half of its cycle of swing, to give a unilateral indication. For ordinary bilateral operation, the voltages picked up by the two loops, after being amplified, are fed to the plates of the cathode ray tube, one pair influencing the spot's travel in one direction and the other pair at 90 degrees thereto; thus when both pairs of plates are excited at a 12 kilo-cycle rate, the spot is affected by the vector sum of the two voltages giving a movement of the electron beam in a direction corresponding to the direction of propagation as referred to an azimuth scale surrounding the fluorescent screen upon which the image appears.

7. A special camera is provided for making photographic records. This camera uses 16 millimeter moving picture film and means are provided to feed the film either at a constant speed of 5 feet per minute or in frames as in ordinary moving picture practice but of durations of 1/4, 1/2, 1, 2, or 4 minutes exposure per frame as desired. Arrangement is provided for recording tenth second timing dots on the edge of the film for time identification on the moving film runs, the timing signals being transmitted by radio from the control station. Time identification for the frame recordings, referred to in this report as composites, is made by photographing the face of an electric clock together with date numerals and station identification, at regular intervals on the film edge.

8. The static source bearings were determined from the film by use of a projector and a screen fitted with a rotatable index which refers to an azimuth scale. The timing marks on the moving film runs, together with the frequent appearance of characteristic groups, made it possible to identify the individual static impulses from the records of two or more stations. The individual bearings thus obtained were applied to a special chart corrected for great circle azimuth, prepared for this purpose, and the source was located by triangulation means.

9. Plate 6 shows specimens of various types of records employed in this investigation. These records were of afternoon runs made in the month of May at a sensitivity which should cover at least a 2500 mile radius. Records A to D' are in pairs showing simultaneous recordings for two stations. The recordings were made consecutively except for a few minutes' interruption between runs, in order that the effect of grouping as shown by the composites may be referred to the moving film run during a period of similar activity. A - A' and B - B' show the typical moving film records, the latter pair having been made at twice the sensitivity of the former. C - C' show 15 second

composites while D - D' show 4 minute composites recorded at a little less than half the sensitivity of the former. E was made on another day when the activity was greater and shows around 140 impulses per second for a short period of time. Records A, B, and E were made with half of the impulse image reduced in intensity to give a unilateral indication without reduction of the line length. Records C and D are full unilateral, only one half of the beam swing being effective. Records A', B', C' and D' are bilateral and may have 180 degree ambiguity.

METHOD OF TEST.

10. In attacking the problem, it was found necessary to experiment considerably with the static direction finder equipment in order to determine the type of record which could best be used for the purpose. The equipment can be used to record composite static, that is, static over certain periods of time varying from 15 seconds to hours, or to give a continuous record of static using moving film, that is, as high as 150 to 200 flashes of static per second may be easily discernible. The static as recorded by this equipment is the 12 kcs. component of the wave as selected by tuned radio frequency circuits.

11. Considerable difficulty was encountered, due to the fact that one set of equipment was unilateral in direction while the other was bilateral, in obtaining any reliable results from using composite static. This was especially true for composites over a considerable time interval, such as four minutes. In addition, on many days when static activity was very high, such records were practically undecipherable due to the smudging of the film by heavy static.

12. Eventually, the operation of the static direction finders at the two stations consisted of obtaining:

(a) Two one minute synchronized continuous runs using moving film at approximately 1000 and 1400 (zone plus 5 time) daily. One of these runs was made using high sensitivity and the other using low sensitivity.

(b) Two five minute synchronized periods, spaced between the two continuous runs, were utilized to obtain 15 second composites of static.

(c) A continuous twenty-four hour record of static, except during the periods outlined above, was then obtained utilizing four minute composites.

(d) During the hurricane season and when a hurricane was in evidence on the daily weather maps, the above schedules were varied so that continuous runs of synchronized static were obtained three or four times a day instead of only twice.

13. In outlining a procedure for keeping abreast of the weather changes, it appeared more feasible to carry out a day to day analysis of the weather occurring during the period of the investigation and to study the static in relation to these changes, in preference to selecting certain

type weather situations, either present or past, and attempting to obtain weather information to cover such periods. Thus it was decided to obtain the twice daily weather broadcasts which were available at the Naval Air Station, Anacostia, D. C. These reports were then analyzed and a daily weather map, covering the United States, Canada and the adjacent Atlantic Ocean and Caribbean Sea was prepared. The methods of map analysis followed were those commonly known as the Norwegian or Polar Front Methods. This analysis permitted an insight into the dynamical and thermodynamical processes taking place in the various phases of the weather and gave an excellent basis upon which to draw conclusions as to the relations existing between static and actual weather. In addition, the teletypewriter records from all Airways Stations were examined daily for information as to the times and occurrence of thunderstorms during the preceding twenty-four hours over the continental United States.

14. The film analysis procedure was as follows:

(a) Films obtained from the two stations were synchronized in the projecting cameras.

(b) Synchronous bearings and intensities of static obtained on the continuous runs were measured and recorded.

(c) Composite static bearings, obtained from the 15 second composites, were then recorded.

(d) All bearings so obtained were then plotted on tracing paper which was placed over a weather chart on which great circle bearings from the two stations had been carefully drawn.

(e) Tracing paper records of static were then carefully fitted and attached to the daily weather map for the day in question.

15. The weather maps, together with the static plots and information as to the location of thunderstorms, were then carefully examined by the aerologist with a view to linking the static activity with the known weather.

16. The above procedure was considered adequate for the purposes of this investigation but if static records are to be of any direct value for daily use it will be necessary to speed up the static analysis. Visual observation of static was attempted between the Maine and Laboratory stations but experience showed that for stations widely separated, such observations do not give reliable results.

17. The most logical procedure appears to be to:

(a) Equip all stations with projector and graduated screen so they may analyze their own records.

(b) Have each static station develop their film immediately after each continuous film run.

(c) Have each station examine their film noting times and bearings of static flashes, number and intensities.

(d) Have one key station, such as the Laboratory where an aerologist may be stationed, study the film obtained at that station, then ask other stations for static indications at certain instants of time.

DATA ON DEVIATION.

18. With the cooperation of the stations at the University of Florida at Gainesville, Florida, and the University of Puerto Rico, San Juan, P.R., static records from four stations were synchronized and some data on deviations for the Winter Harbor and Laboratory static direction finders were obtained. The partial curves are appended for the Winter Harbor and Laboratory Stations, Plate 1.

19. Due to the very low static activity encountered during the months that these records were available and the difficulty in obtaining time records at all four stations so that the static could be synchronized, the curve was only obtained over a portion of the compass rose. But, the sectors in which these deviations were obtained were those which were of the greatest value as they happened to be in the sectors in which most of the hurricane activity of the previous summer occurred.

20. As may be seen from the curves attached, the deviations are small in amount and in no way affected or changed the original results or conclusions that had previously been drawn concerning the static accompanying the hurricanes which were studied.

21. Judging from the results obtained over a period of about four months, it is believed that a considerable period of time will be required in order to obtain a reliable deviation curve for all points of the compass by means of simultaneous bearings and intersections of static from three or more stations.

OPERATION OF EQUIPMENT.

22. In general, the two sets of equipment operated quite continuously, during the period of the investigation. But there were periods during which either one or the other of the stations were out of commission or the equipment gave undecipherable records.

23. This has led to the conclusion that, although the equipment can be operated reasonably reliably by enlisted personnel, an expert technician will always be required to insure proper operation at all times, and to make necessary adjustments and repairs as necessary.

RELATION BETWEEN SOURCES OF ATMOSPHERICS AND METEOROLOGICAL CONDITIONS ACCOMPANYING AN EXTRATROPICAL CYCLONE.

24. Numerous investigators of static have studied and located individual atmospherics and have come to various conclusions as to where such atmospherics originate. British workers, notably Watson-Watt, have concluded that all atmospherics arise in thunderstorms and that it has been found possible to trace cold fronts of cyclones by following the movement of thunderstorms across Europe. In France, Bureau has stated that he believes that "frontal" atmospherics are caused by thunderstorms set up

along a front and suggested that by locating such sources of atmospherics the position of a cold front could be more accurately located than by meteorological meth^ls. A few Americans, notably Dean and Harper, have stated that atmospherics are associated with moving cyclones. Recently, Australian workers have come to the conclusion that (a) all atmospherics are found in thunderstorms and (b) that these thunderstorms are often associated with barometric depressions.

25. Early in the study conducted at the Laboratory, it became evident that practically all the recorded static appeared to come from thunderstorms, insofar as it was possible to ascertain. With the network of airway station reports on thunderstorms, it was found possible to locate fairly definitely such thunderstorms over the continental United States. An attempt was then made to link the thunderstorms actually occurring and static records and, at the same time, to study the structure of the cyclones themselves and see if it was possible to track certain types of weather or the cyclones themselves across the country by means of static.

26. In attempting an explanation of the static records in relation to cyclones or weather connected with these cyclones, it appears necessary to diverge and give a short synopsis of the present day theories of extratropical cyclones. According to the commonly accepted Norwegian theory extratropical cyclones form along a surface boundary or "front" which separates the cooler air lying to the north in the northern hemisphere and the warmer air to the south. Along such a front, small waves are developed due to various dissimilarities between the currents in these two extensive air masses. These waves may, if the dissimilarities are small, travel along the front as an undulation or wave on the front itself, that is, similar to the ocean swell, until they finally disappear or dissipate; or, if the dissimilarities are great, these waves may develop into large scale perturbations of the general circulation, known as extratropical cyclones or whirls which pass through a series of progressive steps, that is a definite life history, before they finally dissipate and disappear.

27. The various steps involved in the formation, development and decay of a cyclone may be made reasonably clear by referring to Plate 2. In Sketch 1, a polar front is shown with a slight wave first appearing. Sketch 2 shows the warm air gradually pushing into the cold air on the front side at the surface and moving up and over this cold air aloft to form a cloud sheet and eventually a rain area on the front side of the wave, and the cold air on the rear side closing in behind to form a belt of showers or thundershowers along its boundary. Sketch 3 indicates the stage where the cold air on the rear side has traveled far enough around the rear side of the cyclone so that it begins to cut off the warm air in front and to meet the cold air on the front side; together with an extensive rain and cloud area which has developed in advance of the warm air at the surface which is commonly called the warm front rain area.

28. From this stage on, two phases of development of the cyclone may take place, dependent upon whether the cold air flowing around the rear side of the cyclone is colder or warmer than the cold air which lies on the front side. If the cold air to the rear is warmer than that to the front, then we have a series of steps as outlined in sketches 4, 5 and 6, in which the designation of the cold air to the rear has been changed to cool. In this case, the cool air continues the process of cutting off the warm air

supply farther and farther away from the center until finally the two currents are widely separated from the original cyclone. After this takes place, the cyclone itself and the closely linked cloud and rain areas gradually dissipate and the cyclone eventually fills in and disappears. At the same time, the cool air from the rear and closer to the cyclone center progressively climbs higher and higher over the cold air in front, as indicated by the dotted front to the north and northeast of the cyclone center, until finally cold air of more or less the same temperature and density completely surrounds the cyclone, as indicated in Sketch 7.

29. In Sketches 4a, 5a and 6a, are shown the orientation and evolution of the fronts when the cold air to the rear is colder than that lying in front of the cyclone. In this case, the cold air cuts off the warm air feeding the cyclone in the same manner as in the previous explanation, but the meteorological phenomena along that portion of the front where the cold air to the rear meets the cool air on the front side are somewhat different. Here again though, a stage is finally reached where the two cold air masses around the cyclone reach the same density and temperature and the cyclone gradually fills in and disappears together with its cloud sheet and rain area.

30. Taking up the rain and precipitation zones, the area of clouds and rain lying north and northeast of the warm air, shown in Sketches 2 to 4 inclusive, is formed by warm air gradually flowing up a wedge of cold air. This gradual lifting results in a widespread area of clouds and precipitation but little turbulence. Meteorologically, this warm air by being forced up this wedge becomes more and more stable and structurally will not permit of ascentional rates sufficient to give thunderstorms. Thus with a true warm front type of precipitation, thunderstorms and thus static appear to be out of the question and seldom if ever should be recorded.

31. Along the cold fronts of Sketches 2 to 7 inclusive where the cold air is moving rapidly in behind the cyclone and impinging upon the warm air in front, the air is extremely turbulent and showers and thundershowers are nearly always encountered. Thus, the cold front should, meteorologically speaking, be the region where static should be recorded. This will continue until the cold air finally warms up to a point where it is practically as warm as the warm air already in the region.

32. Also, on the rear side of the cyclone, the cold air is practically always structurally conducive to convection; that is, its structure is such that heating from below will carry upward to great heights and showers and thundershowers may form in this cold air mass. This usually results in a general area of one to two hundred miles in extent in the rear of the cold front where showers may fall, and this area will be prolific in static.

33. In the later stages of development or decay of a cyclone, as indicated in Sketches 5 to 6, the cool air to the rear and close to the cyclone center will flow over the cold air on the front side and will give a showery type of precipitation, sometimes with thunderstorms, to the north and northeast of the center which indicates considerable turbulence and instability. Thus this area is at times a source of static but it does not persist over long periods of time and gradually moves farther and farther from the center of the cyclone and eventually disappears.

34. Utilizing the preceding explanation of the meteorological conditions surrounding an extratropical cyclone and the sources of static in such a cyclone, it is possible to draw the following conclusions regarding static:

(a) During the early stages of the formation of a cyclone, static indications are few and it appears impossible to accurately predict the formation of a cyclone by means of static.

(b) No static accompanies true warm front precipitation.

(c) During the intermediate stages of development of a cyclone, illustrated by Sketches 2 to 6, static is recorded with the cold fronts which have a band of showers or thundershowers accompanying these fronts. When such showers and static are present, it is possible, within limits, to track such showers and thus to delimit the cold front by means of the static records.

Numerous cases were found, especially during autumn and winter months, where the cold fronts did not have a well defined band of showers or thundershowers and no static was recorded. This indicates that not every cyclone has a cold front that is active statically and thus it would be impossible to follow such cold fronts.

(d) Static is recorded over a considerable area to the rear of cold fronts at the surface when the cold air to the rear is unstable and showers are forming. This is especially true when cold air flows southward between Bermuda and the eastern United States and over Cuba and the Caribbean Sea.

In such cases, individual thunderstorms and showers may give as much or more static than those lying close to the cold front itself rendering it practically impossible to accurately delimit or track the cold front.

(e) Static is oftentimes recorded in the rain and precipitation area to the north and northeast of the cyclone center at certain stages of development of a cyclone. This area is that previously occupied by the warm front rain area preceding the cyclone and is often confused with it. This will occur as shown in Sketches 4 to 6, Plate 3.

This static is due to thunderstorms which originally set in close to the center of the cyclone and then progressively move farther and farther away from the center until they finally dissipate entirely. It has been found impossible to track the cyclone center successfully by utilizing the static indications from such thunderstorms. In addition, many cyclones fail to have thunderstorms or showers in these sectors, even though meteorologically the same process has taken place as illustrated; in other words, the air masses involved do not always appear to be structurally constituted so as to give adequate instability and turbulence for the generation of showers or thundershowers with resultant sources of static. This fact was very evident during the autumn and winter weather situations when few cyclones, even though extremely deep, had recordable static connected with them.

(f) The most active point or area connected with a cyclone, insofar as static is concerned and at the same time insofar as reports are available on thunderstorm areas, appears to be the "V" where the cold air from the rear, the cold air on the front side, and the warm air feeding the cyclone meet. This area is indicated by a "V" in Sketches 1b to 7b, Plate 3.

In the studies conducted, it was soon apparent that this area was very predominant as a source of static and it could be followed from day to day by means of this static. This held true for all cyclones in which thunderstorms or showers were connected with them. In analyzing the paths and tracks of this area from day to day, it was found that it moved eastward or southeastward away from the center of the cyclone itself. In order to illustrate this, Plate 4 gives a composite picture showing the path of the center of the cyclone, the normal evolution of the fronts connected to the cyclone, and the path of the heaviest static.

An attempt was made to draw up a relation between the angle subtended between the path of the cyclone and the path of the heaviest static but it was soon found that no two cyclones behaved according to any hard and fast rule but their rates of development and rates of travel were subject to great fluctuations, rendering it impossible to draw any conclusions.

Thus it appears that insofar as tracking the center of a cyclone is concerned, this source of static when present cannot be used.

(g) As a rule, most cyclones in their later stages of life history with their fronts diffuse or dissipating, as illustrated in Plate 3, Sketch 7, have little or no recordable static connected with them. Thus it was found that:

(1) All cyclones north of 50° N. latitude in summer had no recordable static connected with them.

(2) Practically all cyclones north of 45° N. latitude in autumn and winter had no recordable static accompanying them, even though precipitation sometimes was falling over wide areas.

(3) Most cyclones moving eastward to the continental United States from the Pacific Ocean had no recordable static accompanying them.

35. Other general observations were made, during the investigation, such as:

(a) Static over the continental United States was at a maximum value during the summer months, especially when thunderstorms were most prevalent.

(b) Static over the continental United States decreased greatly during the late autumn and winter months when thunderstorms were at a minimum. During many days, no static at all occurred even though considerable weather, such as winds, clouds, precipitation, was occurring over wide areas.

(c) Static from over the Caribbean Sea, Central America and the adjacent Tropics was practically always prevalent both summer and winter. This static appeared to increase with a strengthening of the Northeast or Trade winds over this area and practically always with a fresh outflow of cooler air into the Trade Wind Circulation.

(d) During most months of the year, the static recorded over portions of the Caribbean Sea and western Atlantic Ocean was so persistent and intense that it equalled or surpassed that recorded during the progress of hurricanes through that area. Without reference to other observations, such as a weather map for the region, this was so marked that it is deemed possible that many wrong conclusions concerning weather in that area might be drawn by only examining the static records.

(e) Conclusions.

(1) In many cases, it was possible to locate and track thundershowers and showers which were emitting static.

(2) Although most sources of static, such as showers and thundershowers, around an extratropical cyclone or "Low" may be located and tracked, such sources do not give positive evidence of the position and movement of the cyclone itself, of its stage of development, or of the various weather elements (except such showers and thundershowers) surrounding the cyclone. Thus, it appears impossible to track such cyclones by means of static.

<u>RELATION BETWEEN SOURCES OF ATMOSPHERICS AND METEOROLOGICAL CONDITIONS ACCOMPANYING AN EXTRATROPICAL ANTICYCLONE.</u>

36. Static is seldom recorded over an area covered by an extensive Anticyclone or High.

37. In those cases where static did accompany high pressure, it was found that:

(a) Most of it occurs in the south and southeast sectors of such an anticyclone where cold air is flowing southward over warmer ground or water surface. In such cases, showers and thundershowers are recorded and can be located and followed by means of static.

<u>HURRICANES.</u>

(a) Theories Regarding.

38. The commonly accepted theory of the formation of hurricanes or tropical storms is the convectional theory. Briefly, this presupposes vigorous convection in stagnant, overheated, moisture laden air, which gradually increases and extends over an ever widening area with consequent condensation of water vapor into clouds and rain. If this occurs, then the atmospheric pressure is gradually lowered over such an area and more and more moist warm air is imported. Due to the earth's rotation on moving air, this new air is deflected as it approaches this region of lower pressure in a counterclockwise turning spiral and a cyclonic circulation is finally established. The ever increasing amount of heat from the condensation of water vapor in such a circulation will then continue to decrease the pressure and eventually an extensive storm is generated. Such a storm gradually moves westward along the boundary of the Trade Wind Circulation until it finally dissolves or is carried northward into the temperate zone circulation.

39. Such a theory presupposes an area of very active turbulence and consequent thunderstorms for a period of from one to seven days over the area in which a tropical storm is brewing as the vigorous convection called for by this theory will result in extensive vertical turbulence. This appears to be true in those cases where surface observations are available close to the region in which certain of these storms have formed. The general regions for the formation of tropical storms which reach North America, that is, hurricanes, lie near the Cape Verde Islands, the western Caribbean Sea and the eastern North Pacific Ocean off the coast of Central America, all of which are theoretically within range of the present static recorders. Thus, if the above theory is correct and extreme thunderstorm activity is present over an area where such a storm is forming, it should be possible to pick up and record the static which should accompany the formation of such a storm.

40. After a tropical storm is well developed and during the latter stages of development, the literature fails to disclose much accurate information on whether thunder and lightning are always present or accompany the storm. Theoretically with the extreme turbulence and precipitation that accompany such a storm, one would expect static and probably thunderstorms but, as a rule, wind and cloud conditions are such that thunder might not be heard or lightning observed. Some reliable observers have reported intense thunderstorms accompanying some hurricanes but, in a majority of cases, no such reports have been made. In general, in those storms in which thunderstorms were observed, they have generally been in the southeast sector of the main storm and at a considerable distance from the center.

41. The newer theory which is rapidly gaining in popularity although still lacking in observational and physical proof is that which has recently been advanced by Norwegian meteorologists. This theory advances the idea that a tropical storm forms as a wave disturbance on the equatorial front (by front is meant the boundary at the surface between the northeast trades of the Northern Hemisphere and the southeast trades of the Southern Hemisphere similar to the formation of extratropical cyclones on the polar front). It is known that the air masses from the different hemispheres differ radically in temperature and water vapor content. If such a wave were formed due to differences in wind direction or force, and if the surrounding meteorological conditions are favorable, it will develop into a disturbance in the same manner as the usual extratropical cyclone of temperate latitudes and will go through a similar life history or evolution. In such a case, the warm air moving northward from the Southern Hemisphere will actually act as cool air

when brought into contact with the warmer air flowing southward from the northern hemisphere. We will then, in the initial stages of development, ha a cyclone in which the fronts are reversed from those normally encountered in the extratropical cyclone. At the same time, if the cyclone develops, the cool air will tend to progressively cut off the warm air and the cyclone will go through a definite stage of development until it reaches a peak and will then begin to fill in and dissipate.

42. If this theory of the formation and development of a tropical cyclone is true, then one would expect to find certain definite regions in which thunderstorms and static would be encountered and some definite evolution of these thunderstorm areas. In general, it would be expected that during the early stages, thunderstorms would be reasonably close to the center of the disturbance, as the cool air flows inward and tends to cut off the warmer air. After the disturbance has formed and, as the process of evolution continues, one would expect the area of thunderstorms to leave the center and progress outward from the center, that is, it will tend to follow the region in which the cool air is progressively cutting off the warm air. Eventually one would expect all thunderstorm activity to be far separated from the center of the disturbance itself and finally to disappear altogether probably when the cyclone has passed its peak of development. Also, considering this theory as accurate, then it would be possible that the thunderstorm activity would not of necessity be prolonged enough, intense enough, or cover enough of an area, to be detected by the present static direction finders, especially if there were other static activity that might overshadow it.

43. After such a cyclone has been formed in the tropical regions and has passed through its various stages of development, it would then move westward along the equatorial front or along the boundary of the northeast trades. At any time, during its life history, it would be possible for this cyclone to redevelop over a different part of the ocean, if meteorological conditions are favorable. In such a case, new air masses would be brought into play and a new set of conditions would be set up which might again tend to deepen the cyclone and increase the thunderstorm activity. Thus, for example, if a small cyclone moves westward across the tropics to the vicinity of the continent, cold air from higher latitudes may be drawn into the circulation around the cyclone. This cold air will then interact with the warm air surrounding the cyclone and will tend to progressively cut off this warm air. A deepening of the original cyclone will then occur and, as a rule, exceptional turbulence and thunderstorms would then be expected near the point where these two currents were meeting. There would then, if such were the case, be an increase in the static conditions near or in the vicinity of the center which, once again, would progress outward away from the center as previously described during the inception of the cyclone. In general, this static would be expected to gradually move farther and farther from the actual center and finally disappear entirely.

(b) Hurricanes or Tropical Storms, Season of 1936.

44. During the past season, seventeen tropical storms were located and tracked by the U. S. Weather Bureau over the Caribbean Sea and western Atlantic Ocean, together with four over the eastern North Pacific Ocean. Of these seven were classed as hurricanes while the remainder were merely classed as tropical storms as the wind velocities recorded did not attain hurricane strength.

(c) Tropical Storms analyzed by the Research Laboratory.

45. Due to various operating difficulties, the equipment was not in operation during all the above storms. Plate 5 indicates the paths of these storms as plotted by the U. S. Weather Bureau. The following list indicates those in which static records were available from both the Winter Harbor and Laboratory static direction finders.

(1) July 27 to August 1 - Hurricane.
(2) August 15 to August 19 -Hurricane.
(3) August 17 to August 19 -Hurricane.
(4) September 10 to September 26 - Hurricane.
(5) September 19 to September 24 - Hurricane.
(6) October 27 to October 29 - Hurricane.
(7) October 7 to October 8 - Not of hurricane intensity.

During the three hurricanes listed above under (2), (4) and (5), continuous static records were obtained three to four times each day, in addition to the composites. In all the others, two periods each day were devoted to obtaining a continuous record of static.

(d) Brief Synopsis of Static Analysis during period of Tropical Storms.

(1) <u>July 27 to August 1.</u>

46. This hurricane was first located at 0800 on 27 July about two hundred miles north of Guantanamo, Cuba, as a shallow disturbance with an approximate pressure of 29.90" at its center. Weak static was plotted in the general area between Yucatan and Jamaica--all of which lay some three to five hundred miles southwest of the center. This static was in no way exceptional in quantity or intensity for the general area in which it lay, considering the time of year, and it is very unlikely that it would have attracted any attention, unless it was known by some other methods that a hurricane was located in the general area.

47. During the period between 27 and 31 July, this hurricane crossed the lower tip of Florida, still small in area and of no great intensity, then curved northwestward and reached the northwestern coast of Florida on the 31st. By that time, it had deepened to about 29.40" and winds of hurricane force covered a considerable area near its center. For twenty-four hours, between the 27th and 28th, the static activity, which still plotted between Yucatan and Jamaica well southward of the storm center, increased to a very high value, both in intensity and amount. It first appeared centered near Yucatan and then extended eastward during the succeeding twelve hours a distance which was approximately twice that which the storm itself moved westward. During the 28th and 29th, this area of static gradually extended farther eastward over the region to the south and southeast of the center and at the same time dissipated to a great extent and spread out. By the 30th, it had continued to dissipate further and move generally southward. On the 31st, the static had again increased over Yucatan, Cuba and eastern Florida, but remained well to the south and southeast of the storm center itself.

48. During most of this period, in addition to the static over the western Caribbean, active thunderstorms occurred over the upper Ohio valley

and West Virginia on the 27th and 28th and this thunderstorm area moved southeastward over Virginia and North Carolina and then seaward between then and the 30th. These thunderstorms gave considerable static in a general direction, that is to the southward from the Maine and Washington stations, of the hurricane itself and served to complicate the analysis. This was especially true of the composite pictures of static and it was impossible to distinguish between the thunderstorm static and the hurricane static during the days in question.

49. In this same connection, the records which were published by the Engineering Experiment Station, University of Florida, Bulletin No. 3 dealing with "The Locating of Tropical Storms by Means of Associated Static", were examined in connection with the records obtained at the Laboratory and Maine. This analysis indicated that there is considerable doubt as to whether the static which this bulletin ascribed to the hurricane itself was not due partially to the thunderstorm area which lay originally to the north of the Florida station and then progressively to the northeast and east on the succeeding days.

50. The general conclusion drawn from the analysis of this static was that it would have been impossible to track this hurricane by means of static.

(2) <u>August 15 to August 19.</u>

51. This hurricane developed just to the North of the Yucatan peninsula on or about the 15th of August, then moved westward and westsouthwestward passing near Tampico, Mexico, on the 19th.

52. Records of continuous static were only available for the period between the 17th and 19th. These records showed that only weak static was present on the 17th. This plotted to the southeast of the Yucatan peninsula, some 500 miles from the storm center on that day. On the 18th, this static moved eastward to a point between Yucatan and Cuba while the storm center itself moved westward. On the 19th, the static increased over the general area between Yucatan and Jamaica but in general this area lay some 700 to 900 miles east of the hurricane. On this day, some weak static was in evidence on the same bearing from Washington as the hurricane center but it was completely overshadowed by the other more intense static to the eastward and that connected with active thunderstorms over the central United States.

53. No conclusions could be drawn from the records obtained during this hurricane.

(3) <u>August 17 to August 19.</u>

54. This hurricane formed somewhere off the west coast of Mexico and on the 17th, was centered off Cape San Lucas, Lower California, with a pressure of 28.82" and with winds of force 11 to 12 Beaufort.

55. Static observations showed some weak static on a line bearing approximately the same as the center itself from Washington and Maine but no intersections were obtained. The prevalence of active thunderstorms over the Ohio Valley and southern Appalachian Mountains rendered it impossible to

say whether this weak static was directly connected with the hurricane or with thunderstorm activity.

(4) September 10 to September 26.

56. Between September 10 and 14, this hurricane moved westward across the Atlantic to within 500 miles of Puerto Rico. During the first day, no static was plotted anywhere close to the storm, which at that time was quite small in extent and intensity. That which was plotted lay over the western Caribbean between Yucatan and Cuba, far distant from the center. By the 14th, this static had decreased greatly in intensity and amount and had progressed eastward to a point which plotted to within 300 miles of the hurricane center. Up until this time, the hurricane was small in area and no storms or hurricane winds were reported.

57. By the 15th, this small hurricane had commenced to deepen and increase in intensity and by the 18th had reached a depth of about 28.49" when it passed northward near the Carolina coast and gave hurricane winds over a wide area.

58. On the 15th, when only one static run was made, occasional static plotted over the northeast and south sectors of the storm, but these plots mostly lay some 300 miles from the plotted center of the storm. On the 16th, occasional static again plotted within 300 miles of the center but was now all concentrated in the northeast sector. At the same time, intense static was plotted over Florida, Cuba and the eastern Gulf of Mexico which far outweighed that nearer the hurricane center.

59. On the 17th, three daily runs were made to record continuous static. Plots and bearings of static on this day lay in the east, southeast and south sectors of the hurricane but at a distance of 600 to 1000 miles from the center. The static level this day was very high and reached a maximum value both in intensity and amount. By the 18th, when the hurricane had reached its maximum intensity, the static continued heavy and intense in the area south of the storm, being concentrated in the south and southeast sectors between 600 and 1500 miles distant from the center of the storm itself.

60. Before commenting on the static records during this storm, it should be pointed out that this hurricane was as perfectly located, for the purpose of analyzing the records obtained from Maine and the Laboratory static recorders, as it would be possible to hope for. On the 10th, the subtended angle between the two stations and the center amounted to 25° with the hurricane distant 1500 miles; on the 16th, this angle was 35° with the center 700 miles distant; while on the 18th, the angle was about 60° with the center about 150 miles from Washington.

61. During the early stages of the hurricane, that is, before it reached hurricane intensity, there appeared to be practically no evidence of its existence insofar as static observations were concerned. When it began to deepen and take on the characteristics of a hurricane, the static did appear to be concentrated in the general area covered by the storm but lay in the south, southeast and east sectors at a considerable distance from the center. In the later stages of the hurricane, this static became farther and farther separated from the center and appeared to recede southward and eastward away from the direction in which the center itself was moving. At no times was static plotted in the north or northwest sectors of the storm.

62. From the static records available, it can be definitely stated that, for this hurricane, it would have been impossible to locate it definitely at any stage of its development or to track it by means of static.

(5) September 19 to September 24.

63. This hurricane appeared to have formed east of Puerto Rico or at least was first located on the 20th about 300 miles north of Puerto Rico. At this time, it was rather shallow and small in area. Between the 20th and the 24th, it deepened considerably, reaching a depth of 28.94" and giving winds of hurricane force over a wide area, and moved nearly due north to the vicinity of Nova Scotia.

64. A few static plots on the 21st fell quite close to the center at that time, but the great preponderance of static lay some 500 to 700 miles to the southwest of the center. On the 22nd, occasional static plots were located near the center but again the preponderance of static lay far to the south and southwest of the center but with a general eastward movement discernible when compared to the preceding day's records. In addition, a striking increase in the amount and intensity of this static was noted which appeared to occur simultaneously with a deepening and extension of the storm area surrounding the hurricane center. By the 23rd, there still appeared some static within 250 miles of the center but this had decreased considerably in amount over the preceding day. At the same time, the static which lay to the south and southwest the previous day also decreased in intensity and amount and appeared to have shifted farther southward - a direction opposite to the storm's movement. By the 24th, some weak static was again in evidence some 500 to 700 miles south of the center.

65. Once again, the course of this hurricane was ideally situated with regard to the two stations recording static. On the 20th, the angle subtended by the two stations was about 30° with the hurricane distant about 1100 miles, while by the 24th, this angle had increased to 85° and the hurricane was distant about 500 miles from Washington. In addition, calibration data obtained during the past few months utilizing records from Florida and Puerto Rico together with Washington and Maine have indicated that deviation errors in the south and southeast quadrants are of the order of 2° which would not serve to shift the location of the static intersections any great amount in one direction or another.

66. It thus can be rather definitely stated that the static from this hurricane, similar to that obtained during the preceding hurricane, did not permit one to track it over any portion of its path.

(6) October 27 to October 29.

67. This hurricane formed off the west coast of Mexico and moved northwest into the Gulf of California during the period outlined.

68. No static was obtained from either station during the progress of this storm which plotted anywhere adjacent to the area covered by it.

(7) October 7 to October 8.

69. This hurricane formed somewhere to the southwest of Salina Cruz, Mexico in the Gulf of Tehuantepec and moved northward to the coast on the 8th. It was not of hurricane intensity.

70. Static records failed to indicate any static in that area.

(e) Results.

71. In the hurricanes which occurred during the 1936 season on which it was possible to obtain bearings of static from both the Laboratory and Winter Harbor static direction finders, the following results were obtained:

(1) Such a small amount of static, as compared to the normal amount which exists in the tropical regions year in and year out, was recorded during the early stages of a tropical cyclone that it is considered impossible to locate such an area where such a tropical cyclone may be forming.

(2) During the period that a tropical cyclone is small in extent and hurricane or strong winds are confined to a small area, the static indications are not sufficient to locate or track it.

(3) During the later stages of development of such a cyclone, that is, if a small tropical cyclone redevelops and becomes exceedingly deep and of wide extent (which sometimes seems to occur as it approaches a continent and begins to leave the tropical wind circulation and moves into higher latitudes) the static indications increase for a considerable period of time and static becomes extremely heavy both in amount and intensity. Such static at first appears to be concentrated over the southwest and northeast sectors of the cyclone, and then that in the southwest sector progressively moves eastward eventually joining with that in the northeast and east sectors. Such static, in the hurricanes examined, only appeared in the close vicinity of the center for a short period of time and then moved outward from the center in a direction away from the actual direction of movement of the hurricane itself.

This gradual increase and movement of static in the various sectors of a tropical cyclone seems to indicate that the Norwegian theory regarding their inception and development is probably correct and that the static is intimately related to the presence of "fronts" and their evolution, as has been explained under the theories concerning extratropical cyclones. Thus the tropical cyclone appears to go through a life cycle of development and decay somewhat similar to that described for extratropical cyclones, but of course the fronts would evolve somewhat differently.

(4) After the tropical cyclone had passed its peak of development, the static previously recorded began to decrease just as rapidly as it increased and finally disappeared over the area covered by the cyclone.

(f) Conclusion.

72. The behavior of static recorded during the hurricanes or tropical cyclones during 1936 leads to the belief, lacking other more definite means of detection of such storms, such as a daily weather map over the oceans, and

a better understanding of meteorological conditions surrounding such a storm especially as regards the sources of static, that it is not feasible to either locate or track tropical storms or hurricanes by means of the static recorders at present in use.

CONCLUSIONS.

73. As regards the static direction finder equipment as developed by the Naval Research Laboratory, it can be operated fairly reliably by regular enlisted personnel, but an expert radio technician will always be required to make necessary adjustments and repairs at regular intervals.

74. The equipment will record crashes of static from considerable distances and these crashes can be located geographically with a satisfactory degree of accuracy by simultaneous bearings from two or more stations.

75. In many cases it was possible to locate and track thundershowers and showers which were emitting static.

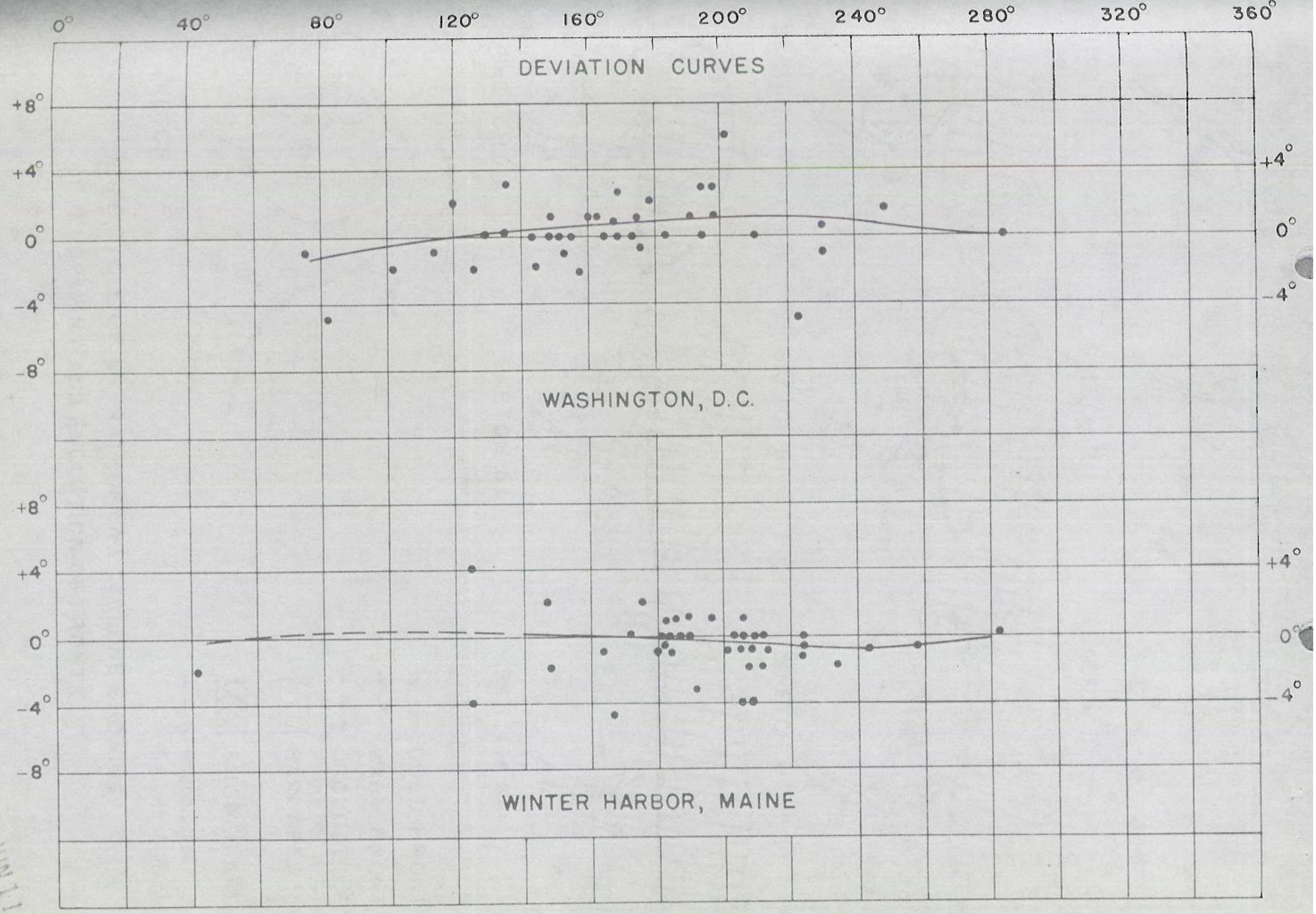
76. Although most sources of static, such as showers and thundershowers, around an extratropical cyclone or "low" may be located and tracked, such sources do not give positive evidence of the position and movement of the cyclone itself, of its stage of development, or of the various weather elements (except such showers and thundershowers) surrounding such a cyclone. Thus, it appears impossible to track such cyclones by means of static.

77. Extratropical anticyclones or "highs" are relatively free from static indications, except in their south and southeast sectors where showers and thundershowers may exist. But, in view of the large number of cyclones in northern latitudes that also lack static, this absence of static would be of doubtful forecasting value.

78. The behavior of static recorded during the hurricanes or tropical cyclones during 1936 leads to the belief (lacking other more definite means of detection of such storms, such as a daily weather map over the oceans, and a better understanding of meteorological conditions surrounding such a storm, especially as regards the sources of static) - that it is not feasible either to locate or track tropical storms or hurricanes by means of the static recorders at present in use.

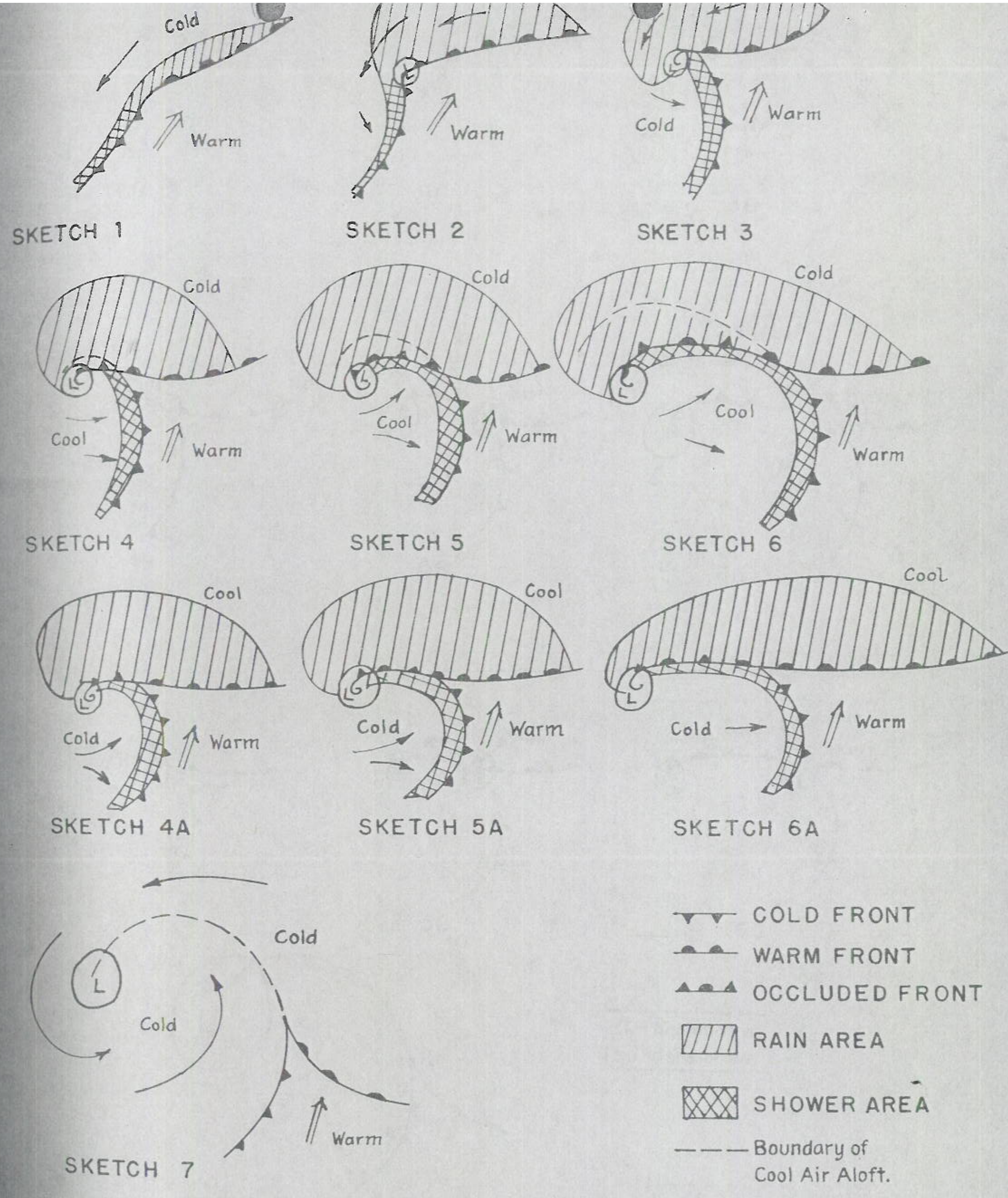
79. This study has indicated that the static indications with relation to actual weather are not as simple as various radio investigators have led us to believe. In practically all the previous investigations, it is believed that only weather situations prolific in static indications have been studied and not a day to day analysis over a long period of time. Such studies have resulted in many erroneous conclusions regarding the correlation of static and weather which upon closer and prolonged investigation have been found very doubtful.

80. The subject investigation has served to indicate that the actual application of radio work with static to meteorology or aviation is still doubtful. It thus appears that to obtain practical results, any investigation of static with regard to weather will have to be prolonged over a long period of years with close cooperation between the radio physicist and the practical meteorologist.



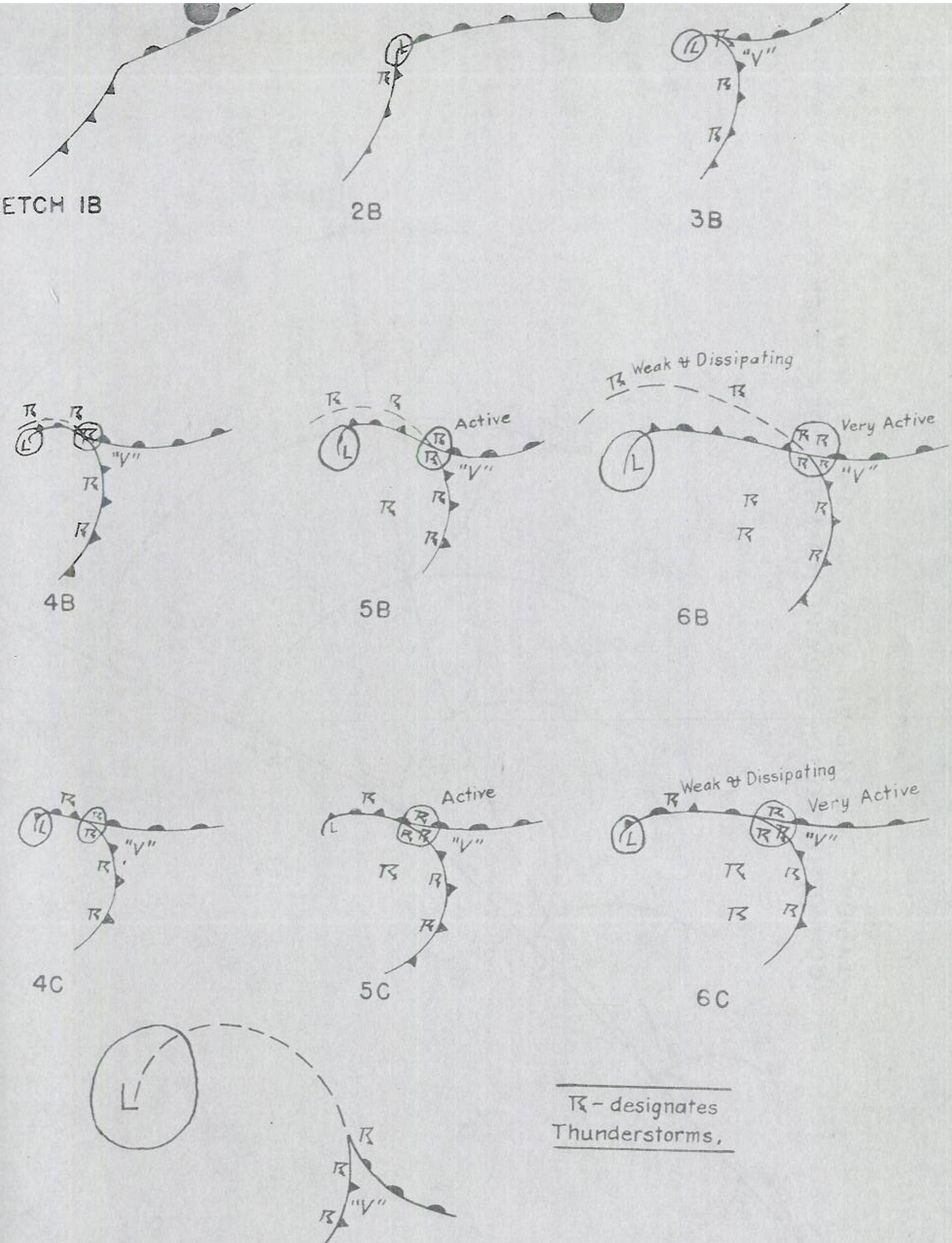
DEVIATION CURVES
WASHINGTON, D.C.
WINTER HARBOR, MAINE
0° 40° 80° 120° 160° 200° 240° 280° 320° 360°
+8° +4° 0° -4° -8°

PLATE I



LIFE CYCLE OF EXTRATROPICAL CYCLONE SHOWING DEVELOPMENT AND EVOLUTION OF FRONTS.

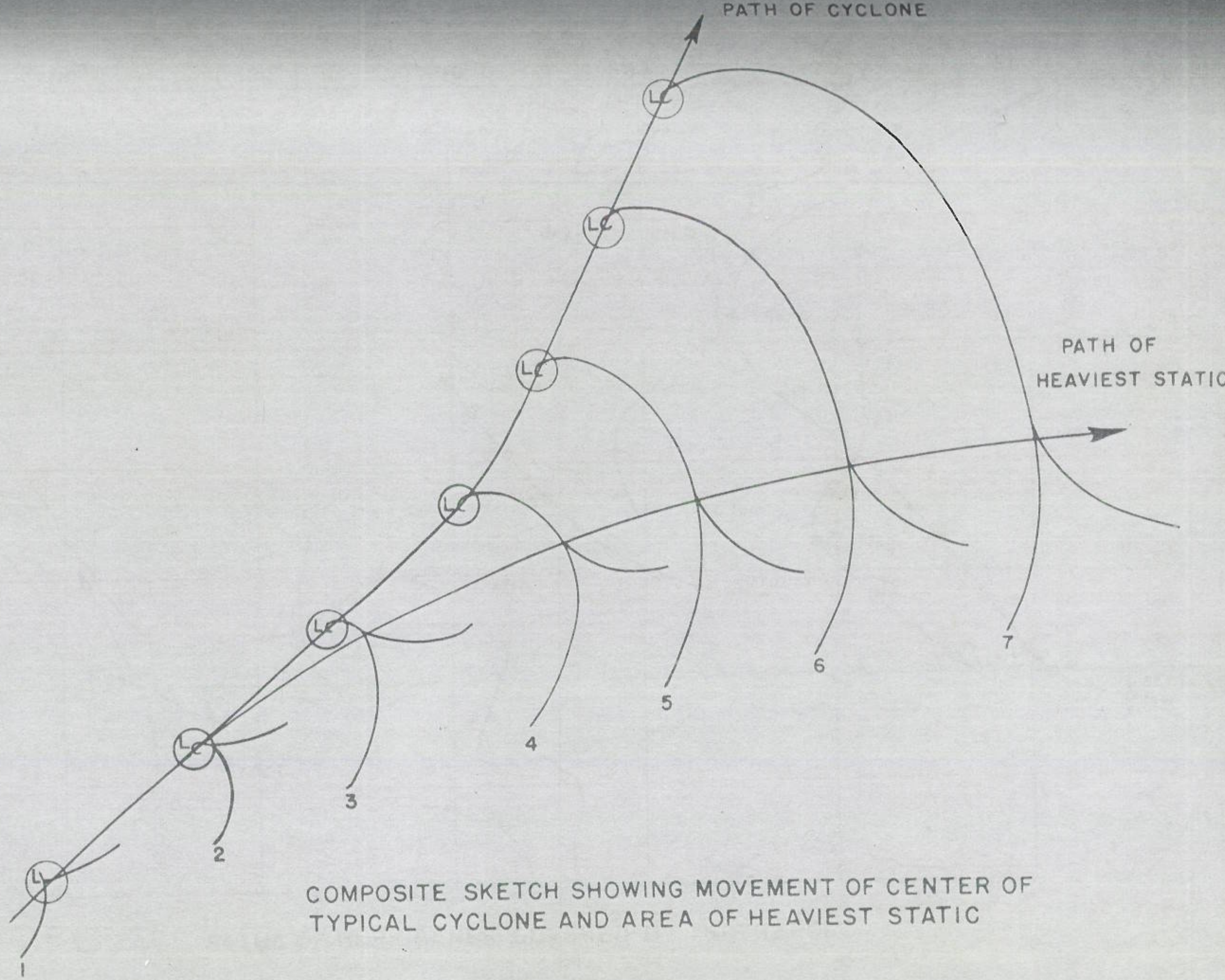
PLATE 2



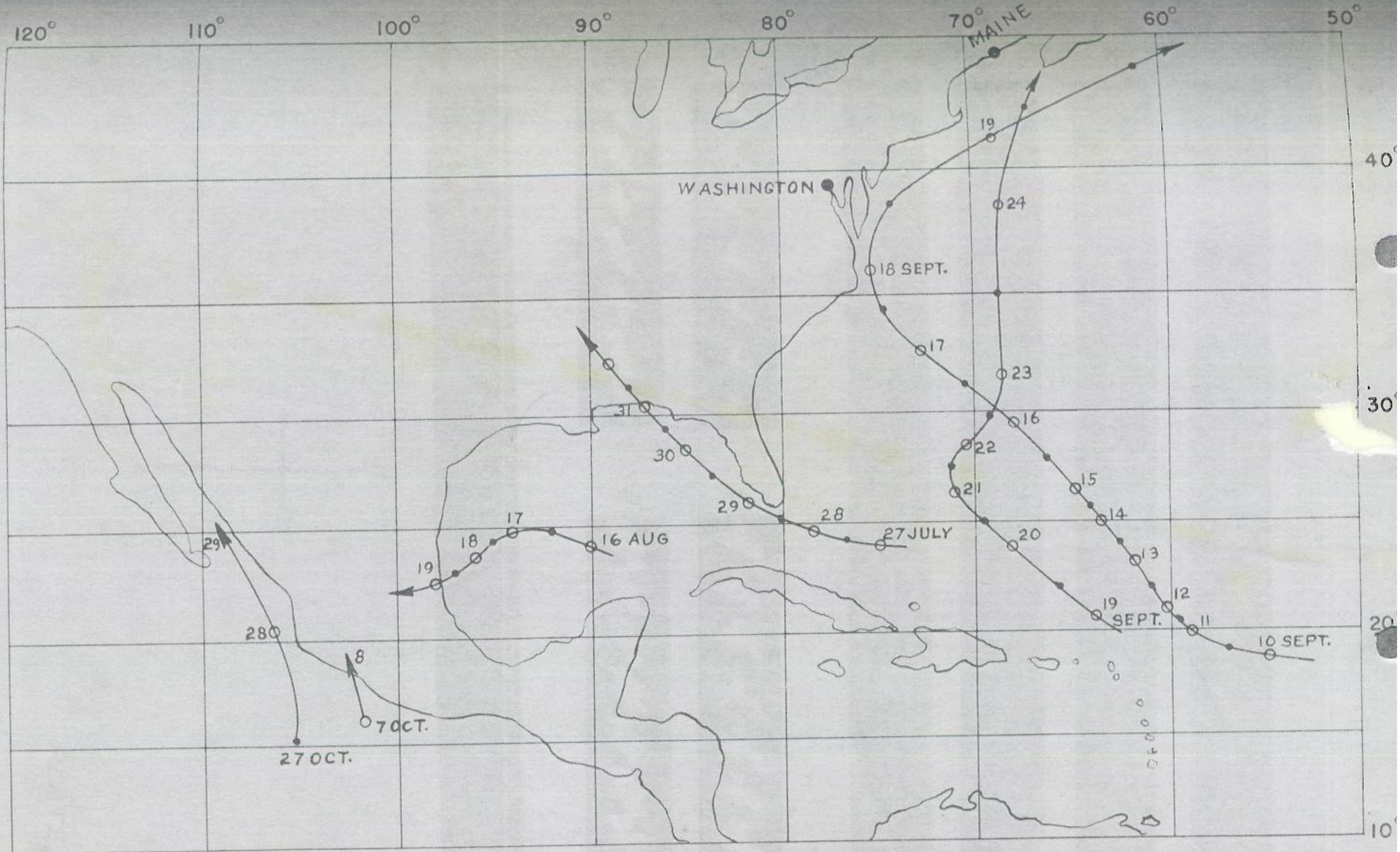
DISTRIBUTION OF THUNDERSTORMS DURING LIFE CYCLE OF EXTRATROPICAL CYCLONE.

PLATE 3

PLATE 4



COMPOSITE SKETCH SHOWING MOVEMENT OF CENTER OF
TYPICAL CYCLONE AND AREA OF HEAVIEST STATIC



PATHS OF HURRICANES COVERED BY THIS REPORT

PLATE 5

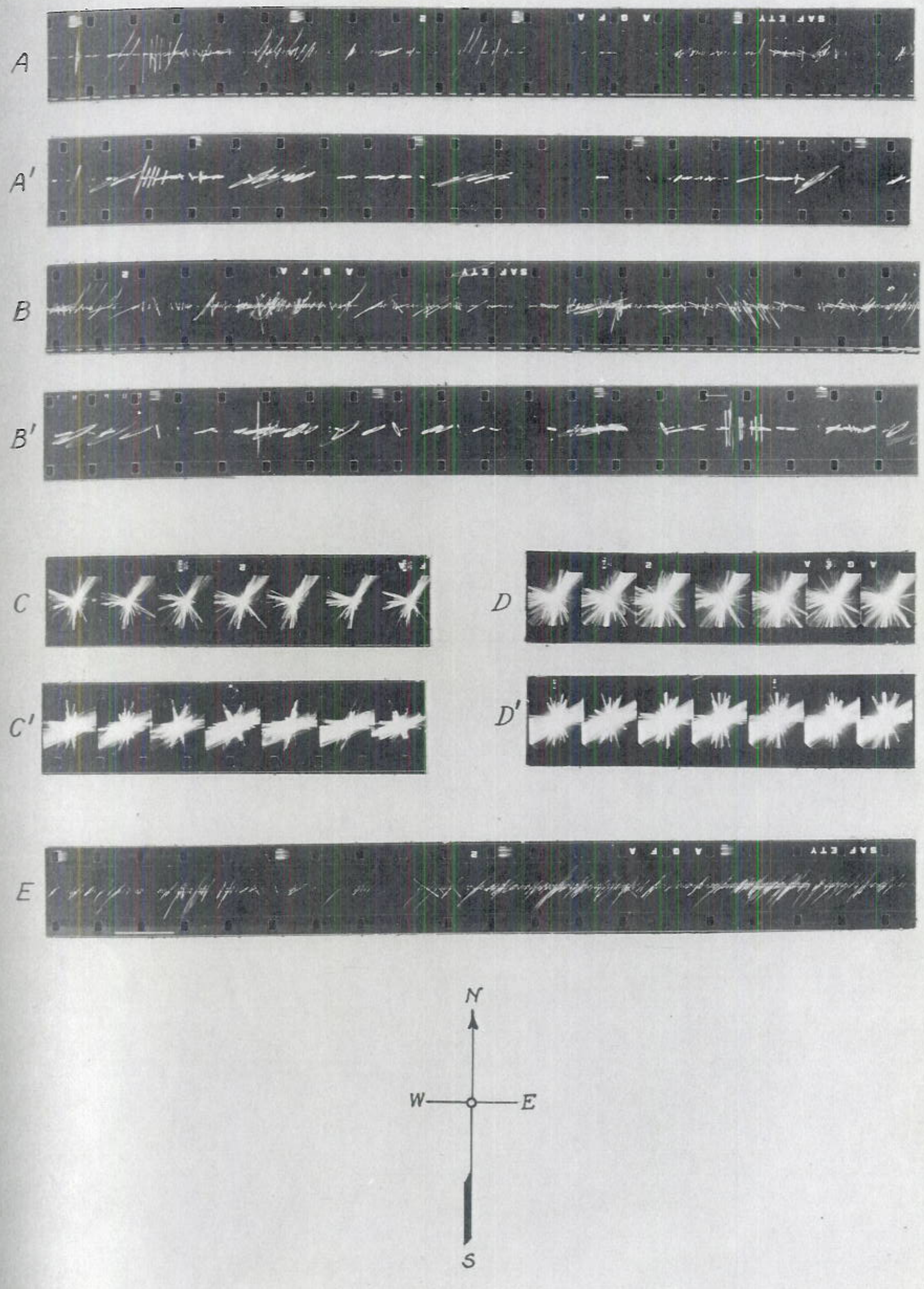


PLATE 6