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VERTICAL DISTRIBUTIONS OF TEMPERATURE AND HUMIDITY OVER THE OCEAN BETWEEN NANTUCKET AND NEW JERSEY

BY

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PREFACE

This paper is concerned with the results of a series of airplane psychrometer soundings that were made over the ocean up to a height of 1500 ft during June, 1945. These soundings and previous soundings already described in *Papers in Physical Oceanography and Meteorology* (Vol. X, No. 1) form a new fund of scientifically interesting and valuable information. The vertical distributions of temperature and humidity revealed by these observations in a part of the atmosphere previously subjected to but little detailed study are very different from what was expected; as frequently happens, the unexplored proved more intricate than was anticipated. It has been possible, nevertheless, to put forth a preliminary qualitative explanation of the physical phenomena after they were observed. These measurements contribute to the broad subject, important to meteorologists and oceanographers alike, of the interaction between atmosphere and ocean and the mutually dependent distributions of temperature and other properties on both sides of the interface. The nature of the present results indicates the desirability of further observations of the same type under different conditions and in different places.

The soundings, which were obtained for the immediate purpose of furthering an investigation of the meteorological conditions affecting the propagation of ultra-short radio waves, were executed by members of Group 42 of the Radiation Laboratory of the Massachusetts Institute of Technology, in collaboration with the Navy Department. All necessary facilities for the program were made available at the Naval Air Station, Quonset Point, Rhode Island. There, a PBY-6 amphibian, manufactured by the Consolidated Aircraft Corporation, was placed at the disposal of Radiation Laboratory Group 42. (This airplane is similar to the Catalina flying boat.) In addition, the Navy Department assigned a 105-ft submarine chaser to the task of collecting auxiliary meteorological observations. Actually three different vessels, the SC705, the SC642, and the SC1473, took turns in performing this observational duty.

At the Naval Air Station a "Quonset hut," adjacent to the hangar, was turned over to the members of Radiation Laboratory Group 42 for use as a headquarters. A room in the station's aerological office was provided for the group's convenience in the assembly and study of all weather information pertinent to the conduct of the program. Living accommodations were provided on the base.

Primary responsibility for the creation of the project rested with Dr. J. E. Freehafer and Dr. E. M. Purcell of the Radiation Laboratory. All details of the measuring program were planned by Dr. R. B. Montgomery and were carried out under the supervision of Mr. Isadore Katz. The actual measurements were made by Mr. D. G. Wilson and Mr. F. D. Parker, assisted by Mr. R. H. Burgoyne, 1st Lt. R. A. Craig, A. C., Mr. W. T. Fishback, T/Sgt. P. J. Harney, A. C., Mr. J. R. Magee, Mr. K. G. McCasland, and Mr. W. A. Remick. The airplane was piloted by Lt. (j.g.) R. A. Hilbert, USNR, and Lt. (j.g.) J. A. Pariseau, USNR.

Analysis of the soundings was begun by Dr. Montgomery, Lt. Craig, and Mr. Katz during June, 1945, but the termination of the wartime research activities of the Radiation Laboratory a short time later resulted in the suspension of this undertaking. In January, 1946, however, arrangements were effected by Mr. Donald E. Kerr, leader of Group 42, for transfer of the material to the Woods Hole Oceanographic Institution. There the writer was invited to complete the analyses.

The preparation of the material for publication has been carried out as a contribution to the research programs covered by Contract NObs-2083 with the Bureau of Ships, Navy Department, and Contract N6onr-277 with the Office of Naval Research. The author wishes to express his appreciation of the helpful criticisms and suggestions offered by Dr. Montgomery during the course of the work.

I. INTRODUCTION

In connection with wartime studies of the meteorological phenomena involved in the propagation of very short radio waves, detailed observations of temperature and humidity in the lowest few hundred feet of air over the sea were secured by various investigators. In particular, during the summer and autumn of 1944 nearly 500 low-level airplane soundings of temperature and humidity were obtained over Massachusetts Bay by the Radiation Laboratory of the Massachusetts Institute of Technology. The results of approximately 50 soundings in this series have been presented by Craig (1946).[1] Another collection of low-level measurements, obtained over Cardigan Bay (Wales) by the British Naval Meteorological Service during 1945 and 1946, has been discussed by Sheppard (1946).

The Massachusetts Bay soundings furnished considerable information about the manner in which relatively warm air leaving the coast is modified during the first 50 miles of its passage over colder water. The results were sufficiently important to justify further study of the modification problem, so the Radiation Laboratory laid plans for a series of similar measurements to be made, during the following spring, in air that had travelled 50–200 miles over relatively cool water. This second set of measurements forms the subject of the present report.

Because of the greater length of over-water travel involved, it was desirable that the soundings planned for 1945 be made in a region that afforded both sufficiently long over-water trajectories for westerly winds and uniform sea temperature in the west-east direction. The part of the North Atlantic Ocean between Nantucket and New Jersey satisfied these two requirements, since there the average isotherms of sea-surface temperature for the months of April, May, and June are oriented approximately west-east (see Fuglister, 1947). Consequently, this area was considered to be a suitable one, and within it five points, designated A, B, C, D, and E, were selected as desirable positions at which to make soundings. (A, B, and C were particularly favored because they were marked by buoys.) Their locations are shown on the chart in Figure 1. Since the Naval Air Station at Quonset Point was conveniently near the area, arrangements were made to conduct the program of observations from that place.

During the course of the project 32 soundings, consisting of wet- and dry-bulb measurements made at comparatively small height intervals up to an altitude of 1500 ft, were obtained. In addition, certain auxiliary meteorological observations, which were considered essential to a correct interpretation of the psychrometric data, were secured. Some of these observations were made from the airplane engaged in taking the soundings, while others (notably measurements of sea-surface temperature) were obtained by the three naval vessels that were assigned to special meteorological duty in the area between Nantucket and New Jersey during the period covered by the investigation.

The object of this report is to present in graphical form the results of the entire series of observations and to give an analysis and interpretation of each sounding in terms of the vertical distributions of temperature, moisture, and refractive index of air

[1] A few additional soundings belonging to the Massachusetts Bay series have been published by Montgomery (1947), Gerhardt and Gordon (1947), and Craig (1947). Examples of low-level observations of temperature and humidity obtained in British West Indian waters have been presented by Katzin, Bauchman, and Binnian (1947).

for radio frequencies. In order that due appreciation of the scope and reliability of the observational material, as well as an understanding of the discussion, may be facilitated, a full description of the measuring program and a statement of the methods of treatment of the data are given in the sections immediately following.

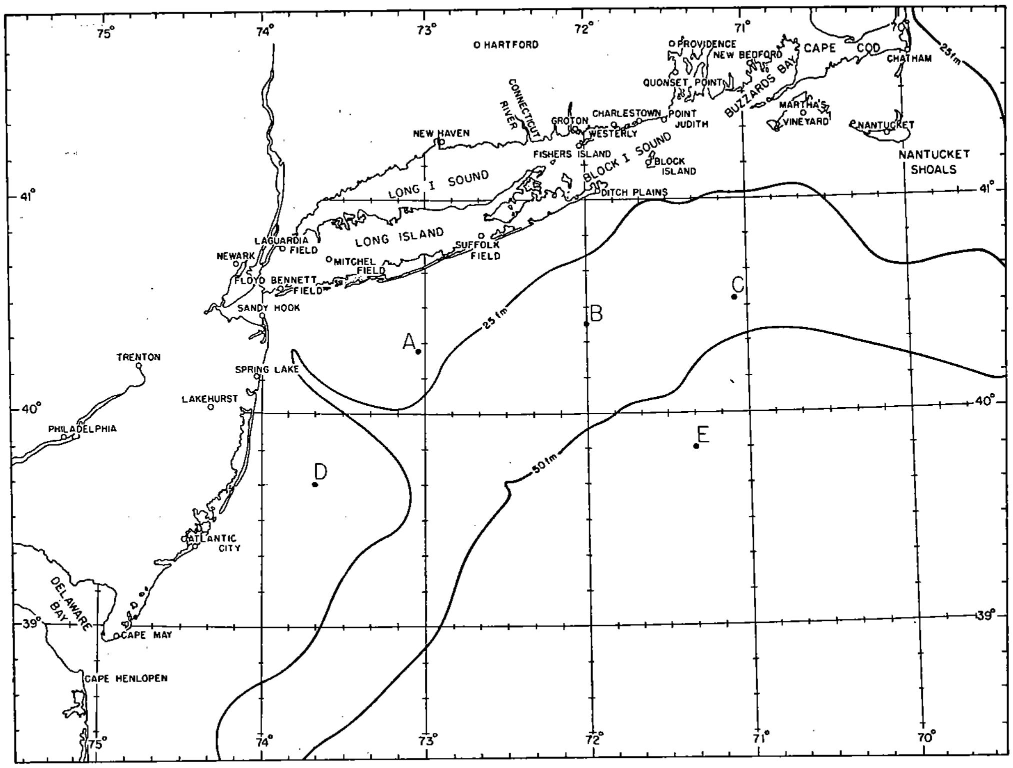

FIG. 1. Map of the coastal area between Nantucket and New Jersey, showing the locations of points A, B, C, D, and E, near or at which the majority of the soundings were made. The positions of weather stations mentioned in the text are indicated by circles. The scale of the map is 1:4,000,000.

The observations themselves constitute such a unique set of measurements of the structure of the atmosphere close to the sea surface that they are discussed at considerable length. Each analysis comprises a determination of the extent to which the air in the individual sounding has been modified by the water and an explanation of the vertical distributions of temperature and humidity in terms of the various contributing factors, such as the state of the air prior to leaving land, length of the over-water trajectory, and the temperature difference between the air and the sea. It is not anticipated that the reader will care to indulge in a complete review of all the observations. In order that the essential information may be easily gleaned, the legend for each sounding includes a statement of the outstanding features of the observed vertical distributions. It is suggested that the figures first be examined. Reference to the text may be made subsequently, if there is interest in the interpretation of other details.

II. OBSERVATIONAL TECHNIQUE

General Plan of Operations

In order to study simple conditions and to avoid the complications involved when the air being modified by contact with colder water was initially inhomogeneous, the soundings were planned to be made in air which had been homogeneous up to at least 1500 ft when it left land. So that the air leaving land should be free of nocturnal inversions, its departure time had to be between about 11^h and 17^h Eastern war time (10^h and 16^h local standard time). Consideration of the comparatively small wind speeds that normally prevail in summer shows that such air would not arrive at points 50 miles or more from shore before mid-afternoon. Therefore, the basic procedure was to have the airplane take off from Quonset Point in mid-afternoon daily (except Sundays and except in bad weather) and make three soundings along a west-east line at distances of approximately 50, 100, and 150 miles from the New Jersey coast. This flight plan was designed to take best advantage of the prevailing west and southwest winds by making possible the sampling of air that had been heated over land earlier in the day. On days when the wind direction was other than west or southwest the plan was altered to comply as nearly as possible in the particular circumstances with the main objective of the program.

The ship operations were conducted in such a way that a rendezvous with the airplane at one of the points A, B, or C could be effected on a maximum number of occasions. The time and place of each rendezvous had to be agreed upon several days in advance. During the cruises, which varied in length from one to four days, continuous observations were made in as much of the oceanic region between Nantucket Shoals and New Jersey as could be covered in the allotted time. The track of each cruise was distinct and consisted of three or more legs which were laid out to intersect each other at one or more points, as well as to traverse the path followed on the previous cruise.

Airplane Equipment and Procedure

The principal piece of meteorological equipment carried on the airplane was a special psychrograph, the design and construction of which are described in detail by Katz (1947). The wet- and dry-bulb elements of the psychrograph, consisting basically of two electrical resistors, were mounted in a housing on a 5-ft metal strut that projected forward and upward from the nose of the airplane (see Fig. 2), and thus were exposed in an undisturbed air flow. They were connected to an Esterline-Angus recorder inside the cabin through an amplifier circuit.

The greatest possible precautions were taken to obtain accurate soundings. The amplifier was calibrated before and after each flight. The resistors were checked about twice each week to ascertain whether any change in the temperature calibration had occurred. Tests for leakage were conducted frequently. The lag coefficients of the elements and the corrections to be applied for dynamic heating were determined by careful experiment. Additional tests for accuracy were regularly made during the course of a flight by comparing the readings of the psychrograph with those of an Army Signal Corps ML-313 psychrometer (wet- and dry-bulb mercurial thermometers in a housing designed especially for use on aircraft), which was mounted beside the base of the strut supporting the psychrograph. This procedure resulted in the attainment of an estimated overall accuracy of ± 0.2F in the readings.

Prior to the start of each sounding mission, the observation points for the particular days were selected on the basis of the conditions of wind and weather prevailing up

FIG. 2. The psychrograph in position above the nose of the PBY-6 amphibian.

to about 13^h00^m (60th meridian time). The flight schedule was then calculated so as to achieve a rendezvous between the airplane and the ship. The time of take-off was usually around 15^h00^m.

During the flight to the first sounding point the amplifier unit of the psychrograph was turned on and allowed to warm up. Approximately five minutes prior to the calculated time of arrival at the first sounding position an amplifier calibration was made. As soon as navigational computations indicated that this position had been reached, a smoke pot was dropped on the ocean. The airplane then circled the spot so marked until a loran fix, giving the geographical position, had been obtained. Subsequently it descended to an altitude of about 40 ft above the sea surface and made a straight and level run upwind directly over the line of smoke given off by the pot. A compass reading during this run defined the surface wind direction. Simultaneously the wind force, in Beaufort units, was estimated from the appearance of the sea surface.

After the surface wind had been determined, the psychrograph operator signaled the pilot to start a spiral ascent around the smoke pot. During the course of the ascent, which was performed at an indicated air speed of 100 knots and a rate of climb of 100 ft per minute, the operator marked the record of wet- and dry-bulb temperatures with indications of the altitude in steps of 50 ft, except below the 100-ft level, where marks indicating the altitude of the straight and level run and the heights of selected points between 40 ft and 100 ft were entered.

The system of determining the various altitudes involved the use of a radio altimeter, as well as the standard barometric altimeter. The radio altimeter was used to measure heights up to 300 ft, a remote-indicating meter having been installed beside the psychrograph operator. The barometric altimeter, which occupied a position near by, was set to correspond with the readings of the radio altimeter at low elevations and then employed at altitudes greater than 300 ft. This procedure was necessary because the scale of the radio altimeter was more compressed than that of the sensitive barometric altimeter; hence, the latter was the more useful instrument at altitudes over 300 ft.

The ascent was usually terminated at 1500 ft, but if an unusual temperature inversion or a rapid decrease of moisture was observed near this altitude, the operator requested the pilot to continue the sounding to a greater height. Following the completion of the ascent the airplane descended to an elevation of 40 ft and repeated the sounding to a height of 1000 ft.[2] After the execution of the second part of the sounding, a double-drift determination of the wind at the 1000-ft level was made, visibility permitting. This involved flying on some given course, course plus 60 degrees, course minus 60 degrees, and again on course. The air speed and the angle of drift on each heading served as data for the computation of the wind vector at 1000 ft. This observation having been completed, the airplane flew to the next assigned position and the procedure was repeated. Usually three, sometimes only one or two, soundings were obtained on each day a flight was made. Immediately after the last sounding a second calibration of the amplifier was performed for the purpose of checking the calibration made before the first sounding. It may be remarked that no significant changes in calibration occurred during the course of any of the sounding missions.

Ship Equipment and Procedure

Seven cruises were made between 28 May and 23 June, 1945, by the SC705, SC642, and SC1473. The meteorological instrumental equipment carried on each cruise consisted of a standard sling psychrometer, a portable anemometer, and a thermometer for measuring sea-surface temperatures. The observational program included measurements of surface water temperature and of wet- and dry-bulb air temperatures, as well as visual determinations of the wind direction and force and the state of weather. The sea temperature was measured regularly at 15-minute intervals, but the other observations were made only hourly, except during a rendezvous with the airplane, when all observations mentioned above, with the addition of anemometer readings, were made at 15-minute intervals.

All temperature measurements were obtained with mercurial thermometers which had been calibrated against a standard thermometer. The sea thermometer was enclosed

[2] In the cases of soundings 25 and 26 (made on 19 June) the visibility near sea level was so poor, owing to fog, that the initial approach to the sea surface for the purpose of determining the surface wind direction was abandoned. Upon reaching the designated position, the aircraft commenced the sounding immediately by making first a spiral descent from 1000 ft to 50 ft and then a spiral ascent to 1500 ft.

in a bakelite shock-proof case, to which was attached a cup, 2″ in diameter and 3″ deep, that fitted around the thermometer bulb. This instrument was fastened to a light rope and, at time of observation, was towed along the surface at a distance of several feet from the side of the moving ship for a period of about 30 seconds. It was then quickly hauled in, with the cup as nearly full of water as possible, and read immediately. The measurements of air and wet-bulb temperatures were made in standard fashion with the sling psychrometer, which was exposed at a height of 20 ft above the sea surface, except on the first cruise, when the height was 12 ft, and the third cruise, when the height was 16 ft. A few special psychrometric observations were taken at a height of 30 ft on the ship's mast during rendezvous with the airplane.

The frequency and the high degree of precision of the meteorological observations required that the ship's position be known with a maximum of accuracy at all times. In this connection it may be mentioned that navigational equipment on board the three ships included gyrocompass, depth recorder, radio direction finder, and radar. The SC705 made use of all these aids, the SC642 lacked only the gyrocompass, while the SC1473 was equipped only with a radio direction finder. Although not all facilities were used constantly, it is believed that errors of position never exceeded one nautical mile.

III. METHOD OF ANALYSIS OF SOUNDINGS

The nature and extent of the modification in air that has moved over cooler water are governed by several variables, notably the length of time the air has been over the water, the wind speed, the temperature difference between the air and the water, and the humidity deficit (defined as the vapor pressure at the water surface minus the potential vapor pressure in the homogeneous air aloft). The aim of the analysis is, therefore, to determine the values of these variables for each sounding and to show their bearing on the observed structure of the air.

The over-water trajectory of the air is estimated from wind observations. Determination of the values of the temperature difference between air and water and the humidity deficit requires a knowledge of the vertical distributions of temperature and humidity in the air at the time it left land and, also, a knowledge of the distribution of water temperature. Accordingly, the principal sets of data which have been used in the analyses of the individual soundings are the following:

(a) The standard 6-hourly surface weather maps. These charts show the general character of the wind field in the area where the soundings were made, the type of air mass in which each sounding was secured, and the positions of any fronts that may require consideration in the interpretation of the psychrometric observations.

(b) The regular 6-hourly upper-wind observations at land stations, as well as the special observations of wind at the 1000-ft level and at sea level taken by the airplane and the ship. With the aid of these data the time and place at which the air in a given sounding left land and the length of its path over the sea can be estimated.

(c) The regular 12-hourly radiosonde ascents at land stations. These observations give information about the vertical distributions of temperature and humidity in the air at the time it was over land; they are useful to the determination of the difference between air and water temperatures and the humidity deficit.

(d) The regular hourly reports from airways weather stations.[3] These give surface values of temperature and dew point and, also, some indication of the degree of homogeneity of the air over land (see below). Hence, they are used for the same purpose as the radiosonde observations, and more extensively, since it is seldom that the latter happen to be favorably placed with respect to time and point of departure of the air from land.

(e) The water temperatures measured from shipboard. These data complement the radiosonde observations and hourly airways reports by providing the information necessary for determination of the air-sea temperature difference and the humidity deficit.

The first step in the analysis of the data is the determination of the trajectory of the air. Since the soundings generally reached a height of 1500 ft or more, it is preferable in this connection to use observations of upper winds rather than surface winds. The pilot-balloon reports give the wind at intervals of 1000 ft, so it is convenient to use the values of the wind at the 1000-ft level as a measure of the motion of the air column as a whole. (This is the reason why the airplane regularly made a double-drift determination of the wind at that particular altitude.) In the discussion of the individual soundings, frequent reference will be made to the "1000-ft trajectory". This quantity

[3] The locations of most of the stations that are referred to in the discussion of individual soundings are shown in Fig. 1.

is defined as the over-water path followed by the air under the assumption of purely horizontal motion. It is expressed in terms of distance, travel time, and point and hour of departure of the air from land. Because of the existence of considerable wind shear in a large percentage of occasions, the 1000-ft trajectory often is not valid for the air strata in the lowest few hundred feet. Under such circumstances a qualitative estimate of the history of the air strata at other levels has to be made through a comparison of the surface wind with the air motion at 1000 ft.

After the 1000-ft trajectory has been computed from the upper-wind observations, an attempt is made to ascertain in precise fashion the original state of the air. Occasionally a radiosonde observation corresponding in time and place to the departure of the air from land is available, in which case the initial vertical distributions of temperature and moisture are known in fairly good detail. Often, however, dependence for this information has to be placed on the hourly airways weather reports, from which the degree of homogeneity of the air when it was over land can be estimated qualitatively with the aid of visibility and cloud observations. For example, the reported presence of cumulus clouds is a reliable indication that the air was homogeneous up to 2000 ft or higher.

Once the initial state of the air has been determined, it is possible to estimate the height and amount of the over-water modification by comparing the initial state with the conditions revealed in the sounding. Frequently the height of modification is not clearly defined when temperature and moisture are represented separately as functions of altitude. In order to facilitate a correct analysis of the sounding, it is helpful to make use of a characteristic diagram which has temperature and vapor pressure as its coordinates.[4] If one enters this diagram with *potential* values of these two variables, a column of homogeneous air is represented by a point. Furthermore, conditions at a water surface are represented by a point that corresponds to the temperature of the water and the saturation vapor pressure at that temperature. The advantage of this fact for the analysis is that, if initially homogeneous air is modified by passage over a water surface of constant temperature, the modified air will be represented by a chain of points which lie on the straight line joining the point corresponding to conditions at the water surface and the point which represents the original homogeneous state of the air. Since points in the upper, unmodified part of an air column generally assume a different alignment, the upper limit of modification normally is marked by a pronounced bend in the characteristic curve of the sounding. This circumstance helps to determine the height of the over-water modification.

Another advantage accruing from the use of the Taylor diagram is the indirect determination of the water temperature whenever direct measurements of this quantity are not available. A curve showing saturation vapor pressure as a function of temperature can be constructed in the diagram. The straight line joining points in the modified air can be extended so as to intersect this curve; the temperature indicated at the point of intersection is the derived water temperature.

[4] Such a diagram was first employed by G. I. Taylor (1917); its uses in the study of over-water modification have recently been discussed and illustrated by Craig (1946) and Montgomery (1947).

IV. FORM OF PRESENTATION OF OBSERVATIONS

Accompanying the discussion of the individual soundings are approximately fifty figures. These include the following: small maps, on which the 1000-ft over-water trajectories are drawn; diagrams showing the vertical distributions of temperature, dew point,[5] and potential refractive index observed in each sounding; and, as inset graphs, Taylor diagrams containing characteristic curves for each sounding. Whenever possible, the various curves of a sounding are included in one figure. In some instances, however, space limitations necessitate the use of two figures.

The 1000-ft trajectories of all soundings made on a given day are drawn on a single map. A path indicated by a broken line denotes an uncertain trajectory. The scale of the charts is 1:7,500,000.

On the diagrams showing vertical distributions, the units in the scale for the potential index represent values of the expression $(n_P - 1)10^6$, where n_P is the potential refractive index computed from the formula used by Craig (1946, p. 13). Measurements obtained during the first ascent of the airplane are represented by circles. The values for the second ascent are shown by dots.[6] Dashed lines indicate the lapse rates of temperature, dew point, and potential index that would prevail in homogeneous air. These are included for purposes of comparison with the observed lapse rates. The arrows at the base of the diagram point to the inferred values at the sea surface.

The coordinates of the Taylor diagram are potential temperature and potential vapor pressure, referred to sea-level pressure rather than 1000 mb. (The reason for using sea-level pressure as standard pressure is that the potential values so defined can be compared directly with the temperature and vapor pressure at the sea surface.) The sloping line in the lower right-hand corner of the diagram is the vapor-pressure curve for sea water of salinity 35 per mille. Measurements from both ascents are indicated by dots. Psychrometric observations made on the mast of the cooperating ship supplement some of the soundings; these observations are represented by circles. The curve of best fit through the chain of points, i.e., the characteristic curve of the sounding, is extrapolated to the salt-water curve. The resulting intersection defines the water temperature. A number indicating the height (in feet) of the over-water modification is entered beside the appropriate point on the characteristic curve. In cases where the modification is complex, due to passage of the air over water of changing temperature, two numbers appear. The larger number indicates the upper limit of over-water modification, while the smaller one shows the vertical extent of the influence of water of temperature equal to that at the position of the sounding. A broken line, which is an extrapolation of the segment of the characteristic curve that represents the earlier modification, is drawn in order to show the water temperature along the first part of the trajectory. An arrow points to the water temperature at the position of the sounding.

The legend for each figure gives the number of the sounding, the date on which it

[5] In every case where the "dew point" is less than 32F the plotted value is really the value of the *frost point*. This procedure conforms with U. S. Weather Bureau practice in respect to the computation of the temperature of saturation.

[6] In a few instances the first and second ascents differ appreciably in respect to the vertical distributions of temperature and dew point, so that a single curve cannot be fitted to both sets of points. In such cases the two ascents are plotted separately.

was made, its geographical position, and the times at which it began and ended. The supplementary meteorological observations are contained in the text.

Wherever the time of day is precisely stated in the text, the value refers to Eastern war time (local mean time at longitude 60°W). Horizontal distances are expressed in statute miles.

Charts containing the meteorological observations taken on board the submarine chasers during their cruises will be found at the end of this report.

V. ANALYSES AND INTERPRETATIONS OF INDIVIDUAL SOUNDINGS

1 June 1945 (Soundings 1, 2, 3)

Weather Summary. — The area between Nantucket and New Jersey was overspread by a flow of continental polar air emanating from northern Canada. A well-developed, stationary cyclone was situated over the Gulf of St. Lawrence, while a ridge of relatively high pressure extended from Hudson Bay south-southeastward to the vicinity of Cape Hatteras. In accordance with this distribution of sea-level pressure, the geostrophic wind over the region where soundings were made was approximately 340°, 30–35 mph, throughout the day. However, the wind direction at 1000 ft, as measured by pilot balloons, was 290°–300°. Surface wind speeds averaged about 20 mph in Connecticut, Rhode Island, and Long Island.

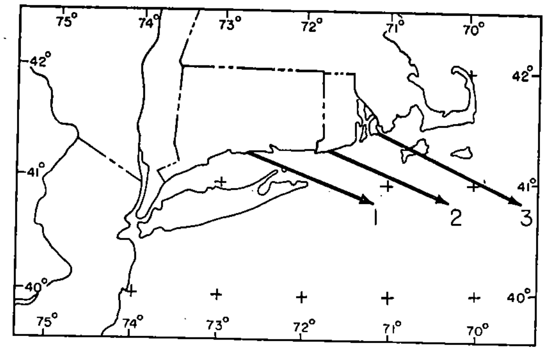

Fig. 3. Trajectories at 1000 ft for soundings made on 1 June 1945.

High clouds, associated with an active warm front over the central United States, appeared in the area during the early morning, and by late forenoon the sky had become overcast. Some light rain showers fell in New Jersey, Pennsylvania, and Long Island during the afternoon.

Surface temperatures over land were 40–50F in the early morning and rose to 60–65F in the afternoon. The dew points mostly were about 30F, dropping occasionally to near 20F in Connecticut, Rhode Island, and Long Island.

Sounding 1. — The conditions at the time and place of this sounding were quite variable, and appreciable differences between the first and second ascents are noticeable. For this reason the respective sets of data have been plotted on separate diagrams. Supplementary observations taken by the airplane and by the ship, which rendezvoused at the position of the sounding, are tabulated below.

		Surface Wind		1000-ft Wind		
By airplane		270° (force not est.)		not measured		

	Time	Surface Wind	Low Clouds	Air Temp.	Dew Point	Sea Temp.
By ship	14^h37^m	270°, 16 mph	none	51.5F	39.2F	51.6F
	14^h49^m	280°, 4 Beaufort	none	52.8	38.4	51.4
	15^h03^m	280°, 4 Beaufort	none	54.0	41.2	51.6
	15^h15^m	280°, 4 Beaufort	none	—	—	51.5

Since the wind at 1000 ft was not measured from the plane, the trajectory of the air has to be estimated from the 1000-ft winds observed at those pilot-balloon stations that were nearest to the position of the sounding, namely, Hartford, Fishers Island, Point Judith, and Quonset. The reports from these places show unusual agreement and yield the following approximate averages at the indicated times:

12^h	290°	22 mph
18^h	300°	20

Surface wind directions were consistent with the 1000-ft winds, except after about 13^h, and it is therefore estimated that the air left the mainland near New Haven, at a distance of 80–100 miles from the position of the sounding, as shown in Figure 3. The time of

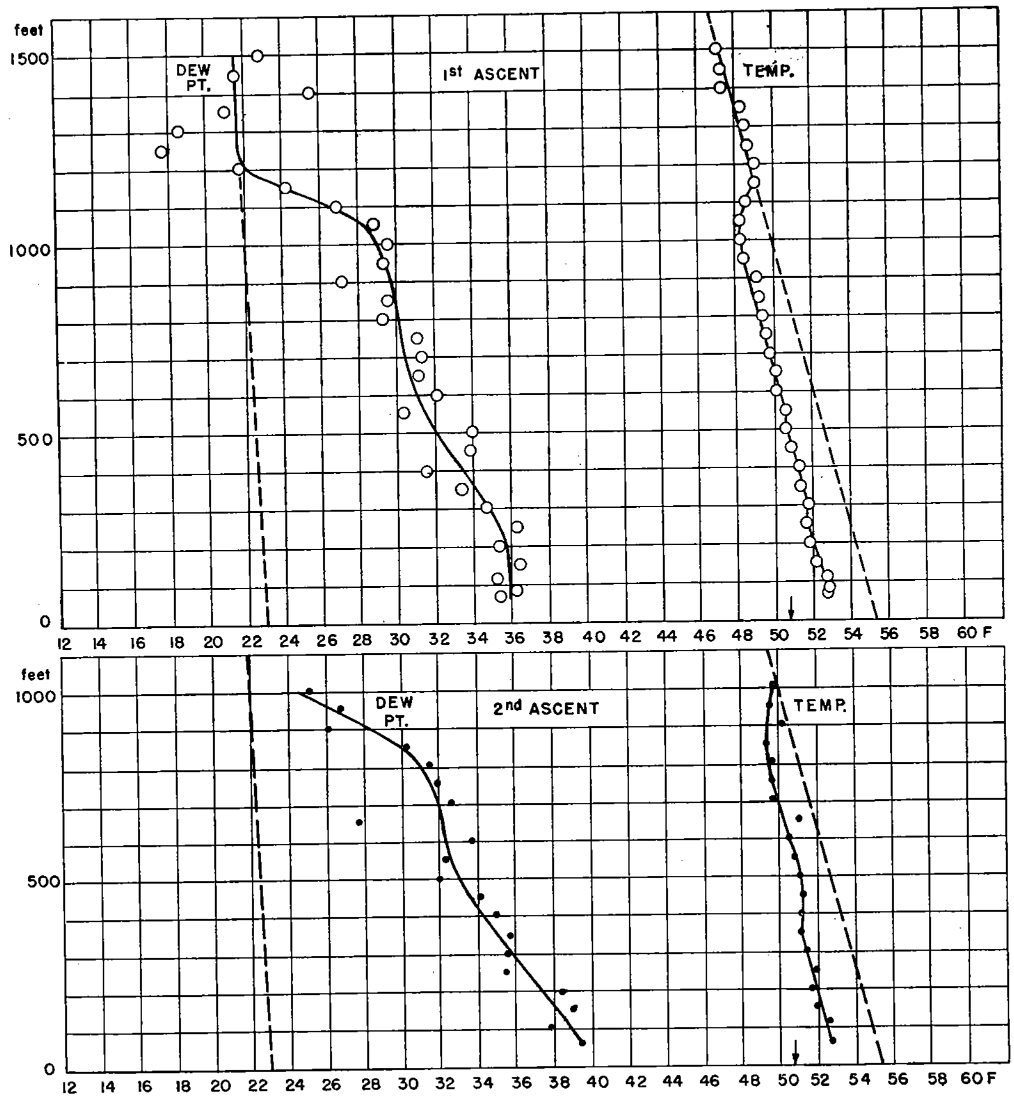

FIG. 4. Sounding 1; 40°51′N, 71°11′W; 1 June 1945; o ascent 14^{h}38^m–14^{h}59^m, • ascent 15^{h}04^m–15^{h}15^m. Modification by the water extends definitely to 800 ft and probably to 1100 ft. The explanation of the comparatively large depth of the modified layer is found in the small temperature difference between air and water in combination with relatively strong winds.

departure was between 10^{h}30^m and 11^{h}30^m; the air subsequently passed over or very near the eastern extremities of Long Island.

The temperature and dew point at New Haven were 54F and 26F at 10^{h}30^m and 55F and 26F at 11^{h}30^m. These air temperatures are higher than the potential temperatures observed up to 3500 ft either in the Quonset airplane ascent made at about 08^h

or in the Albany radiosonde ascent made at 11^h. This is good evidence that the air leaving land was homogeneous up to several thousand feet. In the Quonset ascent the dew points at the surface, 2000 ft, and 3500 ft were 27F, 22F, and 17F, respectively. Accordingly, the preferred interpretation is that the air in the sounding left land in an essentially homogeneous condition with potential temperature and dew point of about 55F and 22F.[7]

On the basis of these adopted initial values, it appears that the cooling and moistening influence of the water has extended up to 1100 ft in the first ascent (see Fig. 4); the potential temperatures below that level do not exceed 54F and are associated with potential dew points ranging from 29–38F, or 7–16F higher than the characteristic value over land. Between 1050 ft and 1150 ft there is a transitional layer characterized by an inversion of temperature and an abrupt lapse of moisture. The air between 1200 ft and the top of the sounding has an average potential dew point of about 22F, which agrees well with the value adopted as typical of the homogeneous air over land.

It is of interest to note the irregular distributions of the values of temperature and dew point. The irregularities, which are negatively correlated, probably are due to horizontal variations resulting from vertical oscillations of air parcels. In this case successive psychrometric readings can give a false picture of the real vertical structure, since the rate of climb of the airplane was very small in comparison with its forward speed. An especially striking irregularity is the air at 1400 ft, which is both more moist and potentially colder than the air immediately above or below it, but which is similar to the air at 1100 ft. Apparently, the airplane, as it ascended in a spiral, flew through an upward bulge of the inversion.

In the second ascent, which reached an elevation of only 1000 ft, the base of the inversion appears to be located at 850 ft. Between 900 ft and 1000 ft, the air has a potential temperature comparable to the mean of the values measured above 1100 ft in the first ascent, while the average dew point in this layer is relatively low. These facts suggest that the height and distinctness of the inversion were subject to pronounced fluctuations in space and time.

On the Taylor diagram the characteristic curve of each ascent (see Fig. 5) is characterized by a line segment that fits all points below the inversion.[8] The bend in the characteristic curve of the first ascent indicates that the air in the upper part of the sounding was overrunning the moister air below, probably as a consequence of the formation of a turbulence inversion at the top of the modified layer. The presence of the inversion would have permitted the air aloft to move more rapidly, and in this way the air in the upper part of the sounding could have left land later and belonged to a homogeneous column with a higher potential temperature than the air at the base of the inversion.

For each ascent the intersection of the characteristic curve with the salt-water curve occurs at a temperature of 50.5–51.0F, nearly 1.0F lower than the measured water temperature at the time and place of the sounding. Since temperatures around 53F

[7] Although the surface dew points in the coastal area mostly were somewhat higher than 22F, it is to be expected that a lapse of dew point existed within 50 ft of the ground, which presumably was still moist from the rains of two and three days before. Furthermore, there were scattered instances of surface values even lower than 22F; for example, at Charlestown at 10^h30^m and at Providence at 11^h30^m.

[8] The deck-level observations by sling psychrometer are widely scattered on the diagram, which is not surprising in view of the difficulties of measurement on shipboard. The average of the points is, however, in good agreement with the sounding.

were measured by the ship shortly after it left the rendezvous on its way north, there is little possibility that the air could have been over water colder than 51F. Hence, there seems to be a real, if slight, discrepancy between the actual surface-water temper-

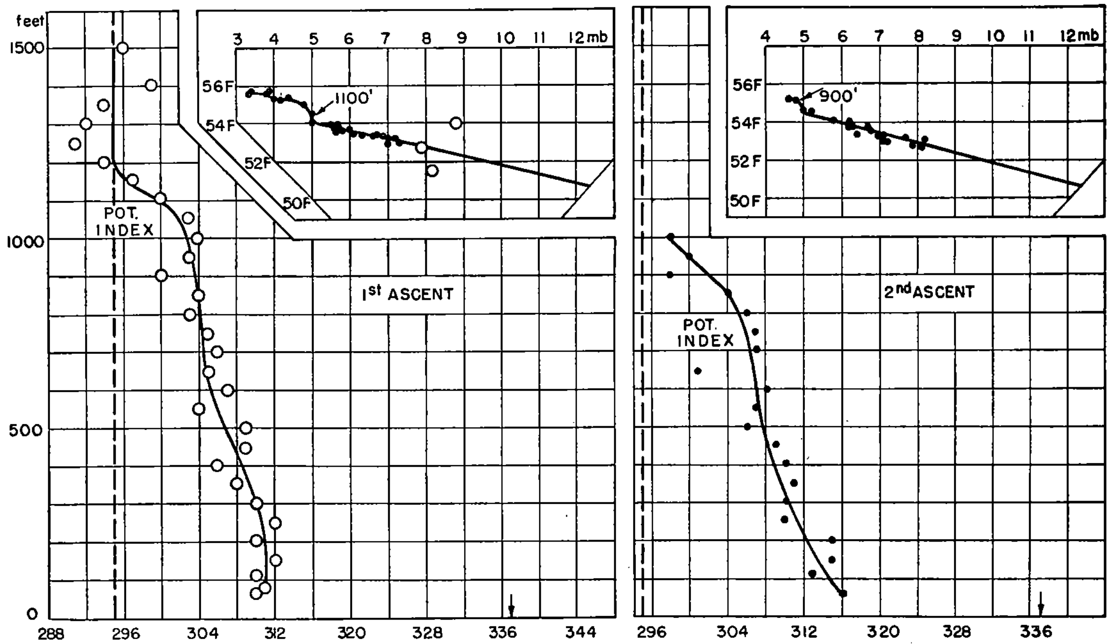

FIG. 5. Sounding 1. The entire modified layer is superstandard with respect to the propagation of radio waves. This condition is due to the large lapse of dew point.

ature and the one indicated by the characteristic curves; it is in the right direction to be the result of contact with spray cooled by evaporation. A wind force of 4 Beaufort and the presence of relatively dry air on this day would markedly favor such an effect. However, the distribution of actual water temperature is not known completely enough to warrant a definite conclusion.

Another interpretation, which seems less likely, is that the modification does not extend beyond about 800 ft. In support of this interpretation, it may be pointed out that the average potential dew point between 850 ft and 1100 ft in the first ascent agrees well with surface measurements made during the late forenoon at several stations on the southern New England coast.

In either case the modification extends higher than on subsequent days, and, despite the fact that the sea is cooler than the air, the lapse rate is nearly adiabatic through the modified layer as a whole. Both of these circumstances are due to the rather small temperature difference between air and water and to the fresh wind. This combination of conditions is favorable to a relatively large amount of mechanical mixing.

Owing to the large lapse of dew point, the potential index decreases with height from sea level to near the top of the sounding and makes the entire layer superstandard with respect to the propagation of radio waves.[9] Similar conditions occur in soundings 2 and 3.

[9] For an explanation of the relation of the vertical distribution of refractive index to the propagation of very short radio waves, see Appleton (1946) or Montgomery (1947).

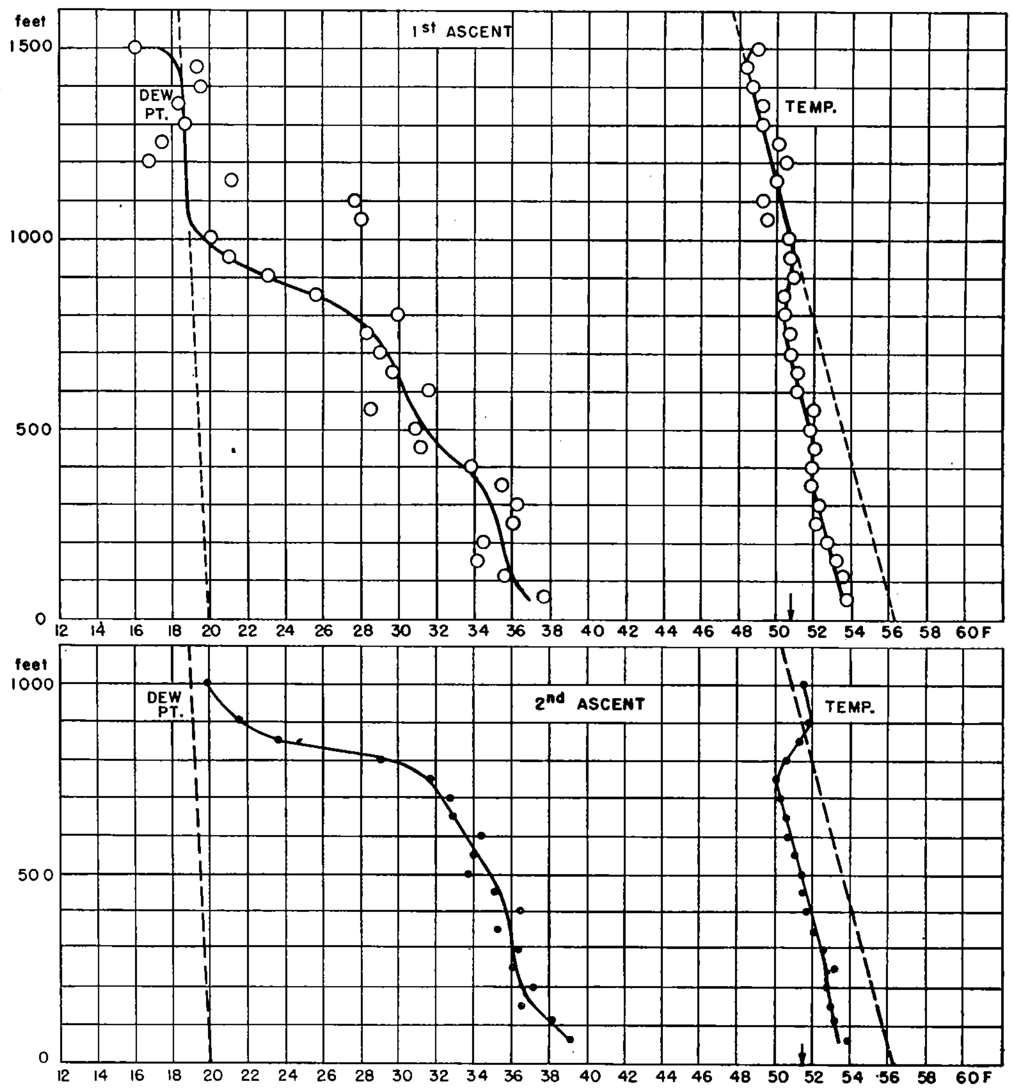

FIG. 6. Sounding 2; 40°51′N, 70°18′W; 1 June 1945; o ascent 15^h51^m–16^h12^m, • ascent 16^h17^m–16^h29^m. Modification by the water extends to 800 ft or slightly higher. The characteristics of this sounding are similar to those of sounding 1.

Sounding 2. — No supplementary observations were made at the position of this sounding. Pertinent observations from the nearest land stations were as follows:

Station	Time	Wind	Low Clouds	Air Temp.	Dew Point
Nantucket.............	15^h30^m	W, 17 mph	none	61F	34F
Nantucket.............	16^h30^m	WSW, 16	none	60	35
Martha's Vineyard......	15^h30^m	W, 18	none	62	29
Martha's Vineyard......	16^h30^m	W, 16	none	61	33

In addition, the cooperating ship, which was located 40–50 miles WNW of the position of the sounding, recorded the surface wind as 280°, 4 Beaufort, at 15^{h}30^m, and 270°, 4 Beaufort, at 16^{h}30^m. Water temperatures of 48–50F were measured 15 miles south eight hours earlier.

On the basis of the pilot-balloon observations of the 1000-ft wind which were cited in the discussion of sounding 1, the length of the over-water trajectory is about 90 miles, the air having left the coast between Groton and Point Judith at about 12^h (see Fig. 3). However, the surface-wind direction at sounding 1 was 270°–280°. Furthermore, the ship observed W winds later in the day at various positions east of Block Island, while reports from the Weather Bureau station on Block Island indicate that the wind there backed from WNW to W at about 13^h and held the latter direction throughout the

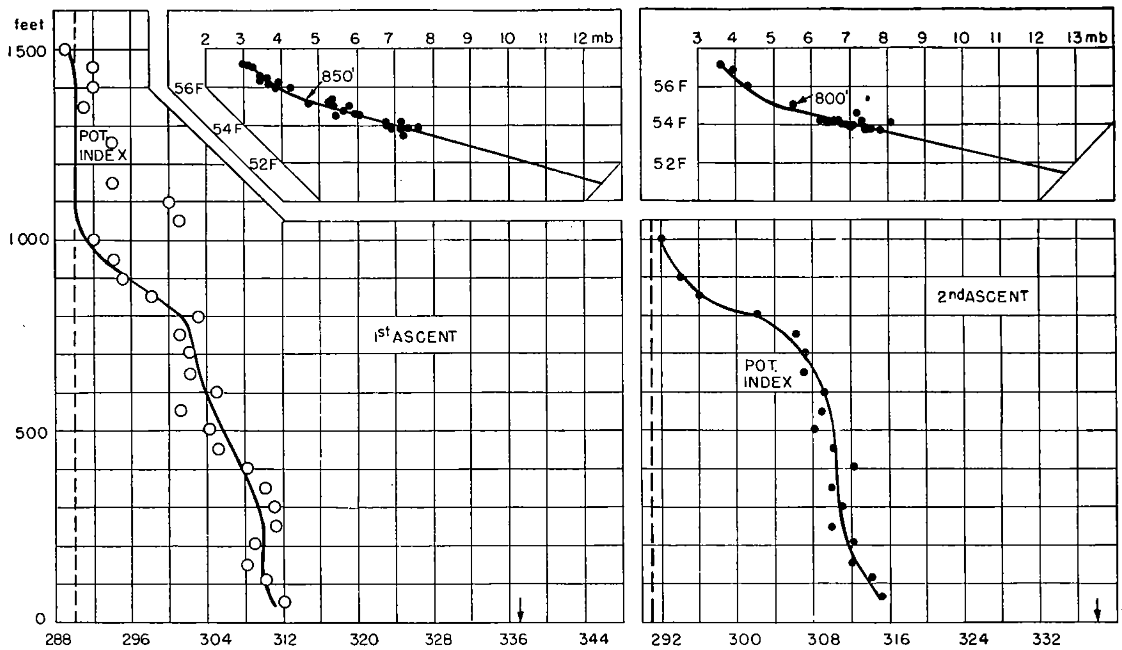

FIG. 7. Sounding 2. The distribution of refractive index is similar to that in sounding 1.

afternoon. If these facts are taken into account, the trajectory of the air close to the sea surface can be traced back to an area around the mouth of the Connecticut River, the length being about 110 miles and the departure time being about 10^{h}30^m.

The surface temperatures along the shore of Connecticut and Rhode Island were close to 53F at 10^{h}30^m; they increased to 54–55F by 11^{h}30^m and to 57–58F by 12^{h}30^m. The dew points reported at these times mostly had values between 25F and 30F, but it is reasonable to assume that the representative dew point in the air leaving land was less than 25F and that the higher values observed close to the ground were maintained by evaporation. Accordingly, it can be stated that the influence of the water extends at least to 800 ft and that there is evidence of maritime modification at higher levels (see Fig. 6). This interpretation is substantiated by the temperature inversion and the abrupt moisture lapse that appear between 800 ft and 900 ft. The inversion is probably a turbulence inversion, but the characteristic curves of the two ascents (Fig. 7) agree in showing a slight upward bend in that region. Therefore, the air in the upper part of the sounding left land somewhat later than that in the lower part, as noted in the case of sounding 1.

The conditions observed at 1050 ft and 1100 ft in the first ascent are interesting. The air at each of these levels is potentially cooler and moister than its surroundings and is similar to the air at 800 ft. Probably the topography of the inversion was so uneven that the airplane intercepted a dome or crest on the upper surface of the water-modified layer.

The indicated values of the water temperature are 50.9F and 51.4F. These appear to be quite reliable, since they are consistent with the measurements that were discussed in connection with sounding 1.

Sounding 3. — No supplementary observations were made at the position of the sounding. Pertinent observations from the nearest land station, namely Nantucket, which was 35 miles away, were as follows:

Time	Wind	Low Clouds	Air Temp.	Dew Point
16^h30^m	WSW, 16 mph	none	60F	35F
17^h30^m	WSW, 22	none	59	39

A trajectory based on the 1000-ft and 2000-ft winds measured by pilot-balloon observations at 12^h and 18^h can be traced west-northwestward from the position of the sounding to a point about 5 miles from the southwest shore of Nantucket, thence across Martha's Vineyard at 13^h30^m, and thence to the mainland between Quonset Point and New Bedford at about 12^h30^m (see Fig. 3). However, it is likely that the air near the sea surface followed an appreciably different trajectory. As noted above, the reported wind at Nantucket was WSW at the time of the sounding. Furthermore, the observed surface wind at sounding 1 was 270°–280°, while outlying stations such as Point Judith, Block Island, and Martha's Vineyard reported W winds from 13^h30^m through most of the afternoon. Hence, at 13^h30^m the surface air is estimated to have been located 60 to 80 miles W, or W by N, of the position of sounding 3. From there its course is traced west-northwestward to agree with the surface wind direction that prevailed early in the day. The trajectory as a whole is rather complicated, and there is a wide range of uncertainty in its determination. Thus, it is possible only to state that the surface air probably left land between Point Judith and the Connecticut River in the late forenoon.

The vertical structure of the air differs from soundings 1 and 2 in that there are two distinct inversions, which are readily seen in the temperature-height curve of the first ascent (Fig. 8).[10] The cooling and moistening influence of the sea definitely extends to 500 ft (in both ascents), probably to approximately 1000 ft, for, although there is an increase of temperature and a marked lapse of moisture between 500 ft and 600 ft, the layer from 700 ft to 900 ft has an average potential dew point of about 29F, which is a considerably higher value than the representative dew point of the surface air over land on this day. Therefore, a turbulence inversion appears to have been formed between 500 ft and 600 ft in the modified air by mechanical mixing. Such an interpretation is supported by the characteristic curves of each ascent (Fig. 9); if the inversion were the boundary between two air streams with slightly different histories, it would be a mere coincidence that the curves are straight lines through the inversion.

[10] The second ascent does not reflect this feature clearly because of its shorter vertical range.

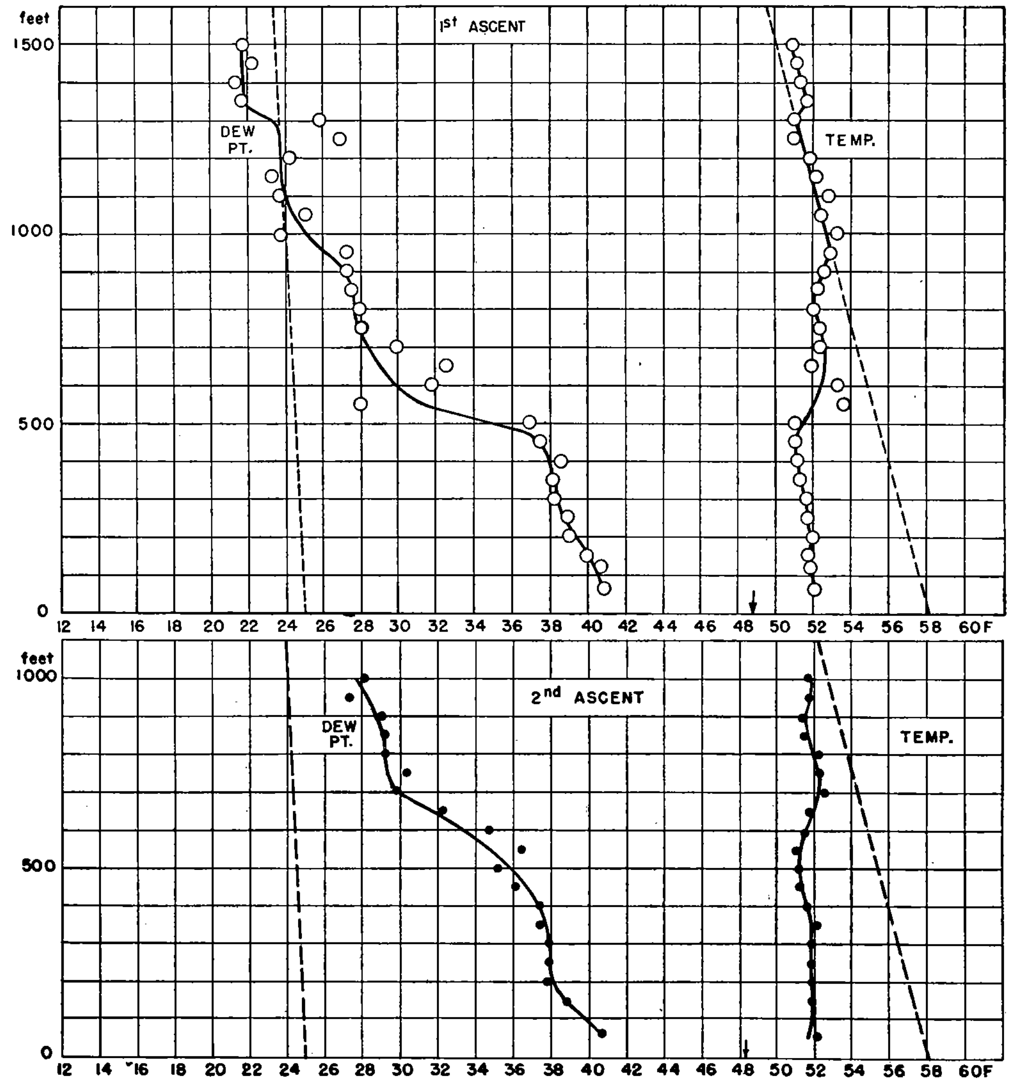

FIG. 8. Sounding 3; 40°51'N, 69°24'W; 1 June 1945; o ascent 16^h50^m–17^h09^m, • ascent 17^h12^m–17^h25^m. Modification by the water apparently extends to approximately 1000 ft. There is a temperature inversion in the middle, as well as at the top, of the modified layer.

The air between 1000 ft and 1500 ft is potentially warmer and drier than the homogeneous layer just beneath. With two or three exceptions it is characterized by potential temperatures and dew points of 59F and 24F, respectively.[11] The temperature coincides exactly with the 12^h30^m temperature at Quonset Point, but the dew point is somewhat higher than the previously adopted value (20F) of the representative dew point in the convectively mixed air over land. It seems probable that convection was more active

[11] Somewhat lower potential temperatures and somewhat higher dew points were measured at 1250 ft and 1300 ft. In particular, the air at 1250 ft has almost exactly the same characteristics as that at 950 ft, suggesting that the spirally ascending airplane traversed an upward bulge of the inversion.

at the relatively late hour at which the air in the top of this sounding left land and was more effectively distributing the moisture provided by evaporation from the ground. (This explanation is substantiated by the observed tendency of the surface dew points

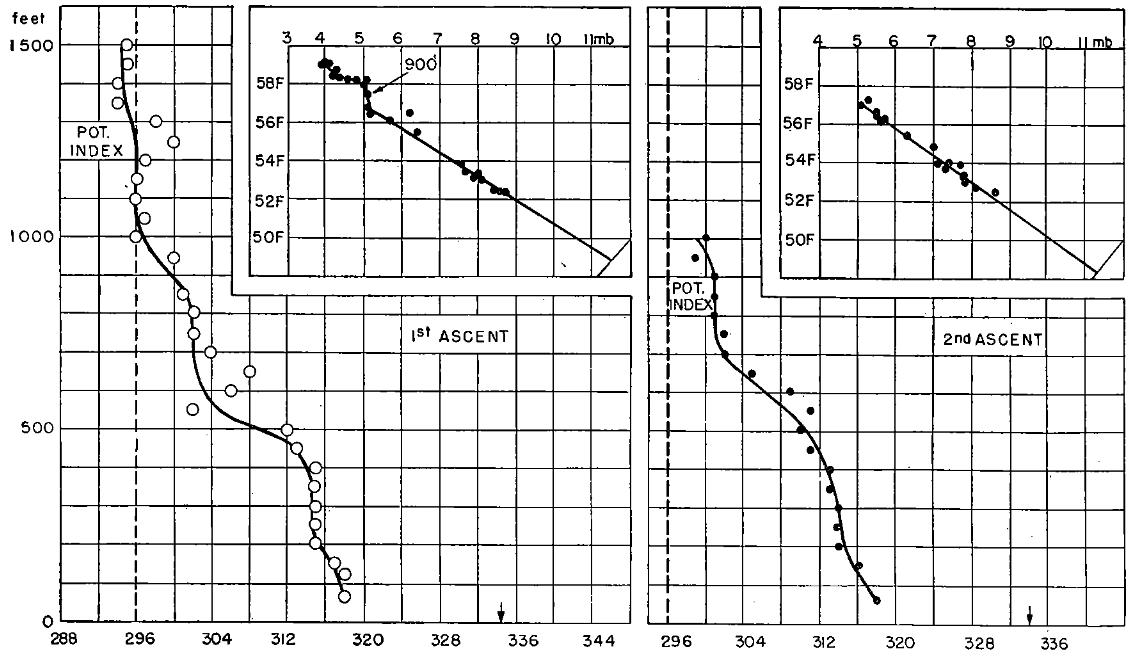

FIG 9. Sounding 3. The distribution of refractive index is similar to that in soundings 1 and 2.

on land to decrease from morning to early afternoon.) On the Taylor diagram for the first ascent the points corresponding to measurements made at heights from 900 ft to 1500 ft are not in alignment with those representing observations taken below the 900-ft level. The upper inversion must, therefore, separate air strata that had different trajectories.

The values of water temperature indicated by the characteristic curves of the two ascents are 48.8F and 48.4F. The actual surface-water temperature may have been slightly higher than this, say 50F. In any event, the water at the position of sounding 3 must have been colder than at sounding 1 and sounding 2, in accordance with the prevailing condition of low surface-water temperature in the strong tidal currents over Nantucket Shoals.

It is worth while to note the contrast presented by the sharp temperature inversion which must have existed between 50 ft and the sea surface (assuming that the actual water temperature was approximately equal to the indicated value) and the lapse rate between 50 ft and 150 ft, which has the normal sign. This is an effect of the fresh wind, which was keeping the air well stirred. In a very light wind the temperature would be expected to increase regularly with height from a value of about 49F at sea level to 51F at 500 ft.

4 June 1945 (Sounding 4)

Weather Summary. — A trough of relatively low pressure containing a quasi-stationary front extended east-northeastward over the Atlantic Ocean from the vicinity of Cape Hatteras, while pressure was relatively high in all of eastern Canada. In accordance with this distribution, moderate northeasterly surface winds prevailed over the coastal waters of New Jersey, New York, New England, and Nova Scotia from noon of 3 June to the afternoon of 4 June. Low clouds and intermittent light rain and drizzle occurred in this area on 4 June, and temperatures were below normal for the date.

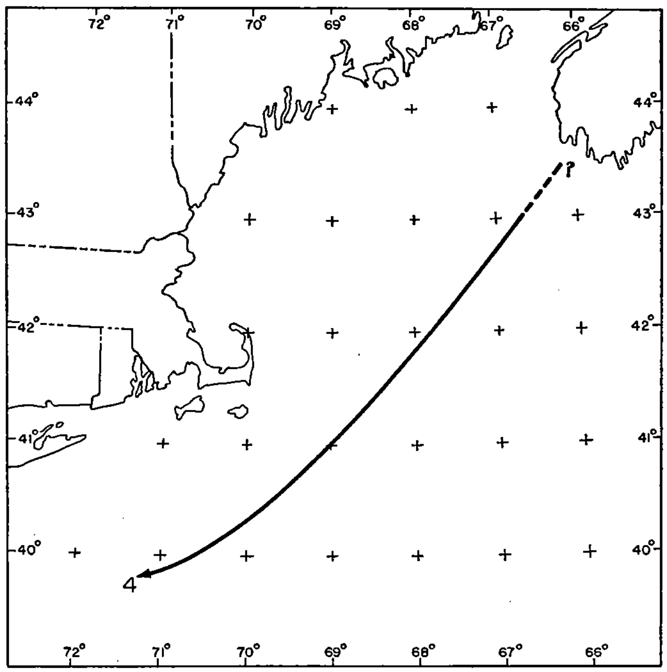

Fig. 10. Trajectory at 1000 ft for sounding made on 4 June 1945.

Sounding 4. — According to the estimate of the pilot of the airplane, the surface wind at the time and place of this sounding was 30°, 15 knots. Measurement of the wind at 1000 ft was prevented by the presence of low clouds, the bases of which were between 900 ft and 1000 ft.

The actual water temperature at this position (point E) is not definitely known, but readings of 51–56F were obtained in the vicinity 5½ days earlier. On 8 June the water temperature 15 miles northwest of point E was about 56F. The air sampled by this sounding had a long over-water trajectory. Twenty-four hours earlier it was in the vicinity of southwestern Nova Scotia, or about 300 miles northeast of point E (see Fig. 10). Its previous history and, consequently, the condition in which it left land are uncertain. Quite possibly this air arrived off Nova Scotia from the east or south and already had been over the ocean for two or three days. In any case, as it moved from the vicinity of Nova Scotia toward point E, it came over progressively warmer water.

The temperature at 50 ft above the sea was approximately 51F, in contrast to a reading of 49F at Nantucket at the time the air is estimated to have been about 35 miles southeast of that station. As a consequence of the heating from below the air column from 50 ft to 1000 ft is practically homogeneous (see Fig. 11). It is also very moist, with

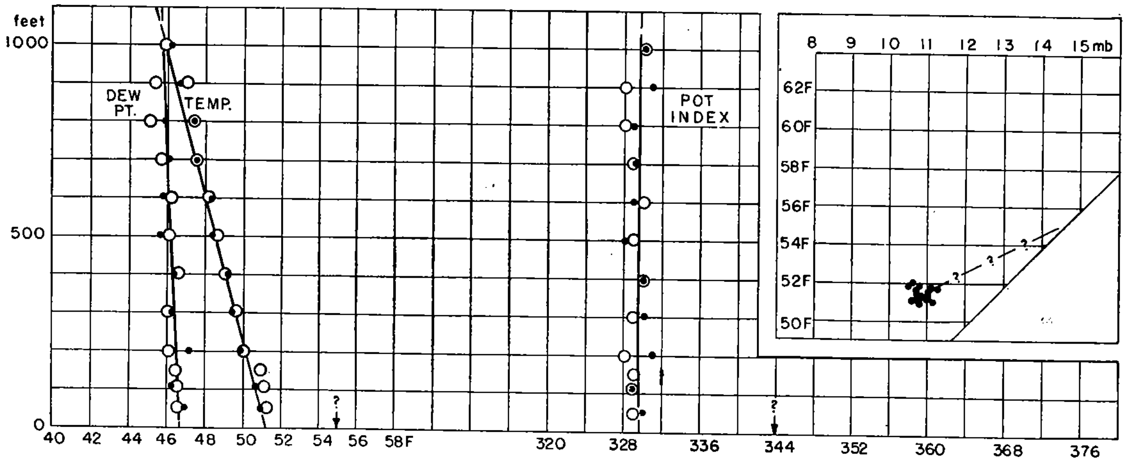

FIG. 11. Sounding 4; 39°50'N, 71°20'W; 4 June 1945; o ascent 16^h41^m–16^h56^m, • ascent 16^h59^m–17^h10^m. The air above 50 ft in this sounding is homogeneous as a result of travel over progressively warmer water. Note the cluster of points on the Taylor diagram (inset). The distribution of refractive index is standard (except near the surface).

vapor pressures corresponding to saturation values at the top.[12] The high degree of homogeneity is demonstrated by the agreement between the observed points and the lines for perfectly homogeneous air, with lapse rates of 1.0F and 5.4F per thousand feet for dew point and temperature.

On the Taylor diagram (Fig. 11) the sounding forms a cluster of points centered approximately at the spot corresponding to potential temperature 51.5F and potential vapor pressure 10.8 mb. Thus, the water temperatures measured several days before and after are sufficiently high, about 55F, to be entirely consistent with the sounding, which requires only a value greater than about 52F to account for the heating. The observed distribution of refractive index above 50 ft is close to standard, but, assuming that the water temperature is 55F, there is a lapse of potential index of magnitude about 14 in a shallow layer near the surface. The depth of this layer is probably about 20 ft.

6 June 1945 (Soundings 5, 6, 7)

Weather Summary. — A large anticyclone, centered over Hudson Bay, was the dominating control of the weather over eastern North America on 6 June. The region between Nantucket and Delaware Bay was covered by air of fairly recent polar origin. Throughout the day the geostrophic wind in that area had a northerly direction, although it backed from 10° at 02^h30^m to 330° at 18^h30^m. Actual surface winds were westerly, with sea breezes occurring at various stations on the shores of Long Island, Rhode

[12] At the two uppermost points of the second ascent the corrected dry-bulb temperature is 0.2F and 0.3F lower than the corrected wet-bulb temperature. For these two points, at 900 ft and 1000 ft, only the corrected wet-bulb temperature has been plotted.

Island, and Connecticut from mid-forenoon through the afternoon. Skies in the area were mostly clear at sunrise, but cumulus clouds began to develop as early as 08^h30^m and were widespread by 11^h30^m. Scattered showers occurred on land in the afternoon. Surface temperatures in Connecticut, southeastern New York, and northern New Jersey were about 45F at sunrise but became equal to the coastal water temperature of about 55F between 08^h30^m and 09^h30^m and reached maxima of 65–70F in the late afternoon. Surface dew points ranged from 40–50F.

Sounding 5. — Observations supplementing this sounding, which was made at point A (see Fig. 12), were as follows: Surface wind, 235°, 3 Beaufort; 1000-ft wind, 236°, 15 knots; there were no clouds; water temperatures in the vicinity of point A were 54–56F around noon of the preceding day; thirty-four hours after the sounding water temperatures of 55–56F were measured 3–10 miles northeast of point A.

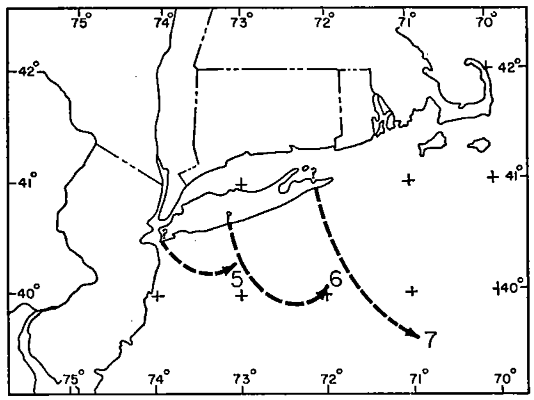

FIG. 12. Trajectories at 1000 ft for soundings made on 6 June 1945.

The trajectories of the air at various levels are difficult to determine, because the wind direction recorded both at the surface and aloft at point A was markedly different from conditions prevailing on shore. Pilot-balloon observations made in western Long Island and New Jersey at 12^h and 17^h gave winds at the 1000-ft and 2000-ft levels that varied between WNW and N in direction and between 3 and 19 mph in speed. From the available data one can conclude with certainty only that the air at 1000 ft and higher crossed the coast over western Long Island or northern New Jersey (see Fig. 12) some time between 11^h00^m and 15^h00^m.

At Sandy Hook the surface wind direction throughout the day was prevailingly W and the average speed was 11 mph. Since the distance that the air travelled over water could not have exceeded 80 miles, even if the remote possibility of an over-water trajectory directed toward point A from 235° is taken into account, it appears certain that none of the air below 1000 ft left shore before 10^h00^m. In that case homogeneity must have prevailed initially up to 2000 ft at least, for cumulus clouds had begun to appear over land as early as 08^h30^m; furthermore, the Lakehurst radiosonde ascent (made at 11^h) went through homogeneous air from the ground to 3000 ft.

The sounding (Fig. 13) shows a markedly stable layer extending from the sea up to 250 ft and overlain by a thin inversion. The characteristic curve consists of two distinct line segments, one of which is the best fit for points in the aforementioned stable layer and intersects the salt-water curve at about 55F, while the other is the best fit for points above 250 ft and can be extrapolated to intersect the salt-water curve at 51F. Since the water temperature between point A and the New Jersey coast about 36 hours earlier was 55–56F, it is safe to assume that the air could not have passed over water colder than 54F for any considerable distance. Therefore, the bend in the characteristic curve between 250 ft and 300 ft cannot be the effect of varying water temperature on a single homogeneous column of air. It must mark the upper limit of over-water modification, even though the influence of the water might appear to extend several

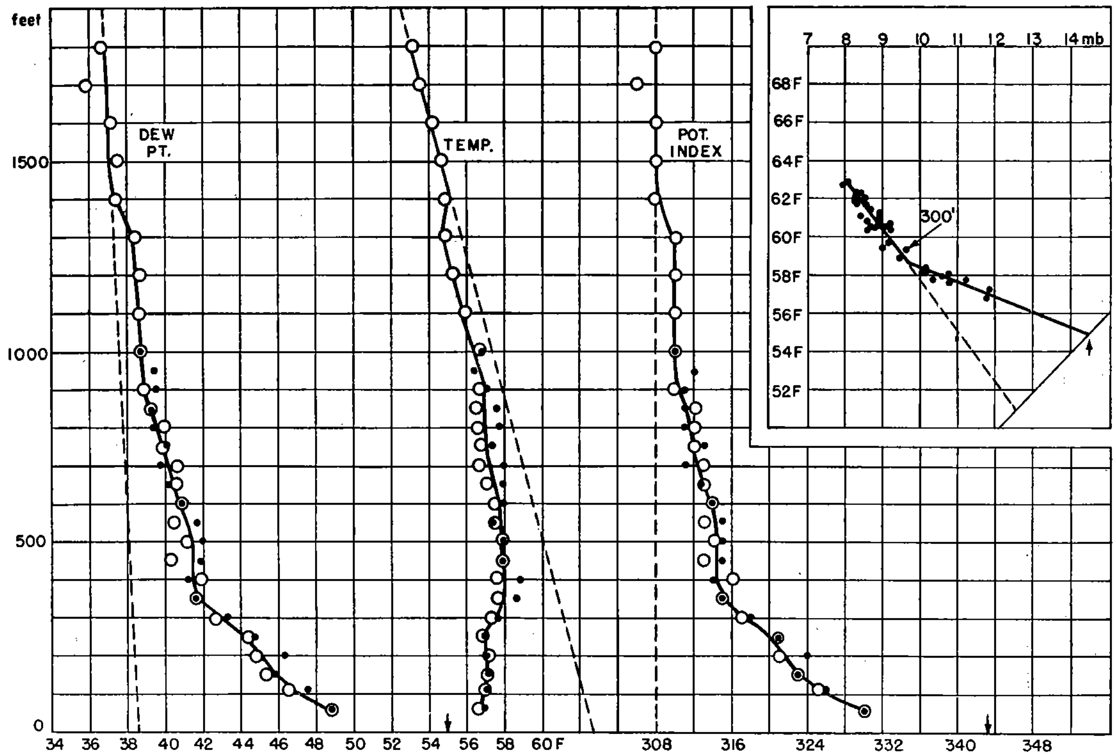

FIG. 13. Sounding 5; 40°18′N, 73°02′W; 6 June 1945; o ascent 16^h44^m–17^h05^m, • ascent 17^h08^m–17^h21^m. The air has been cooled and moistened only to a height of 250 ft by passage over the ocean. The stable region between 250 ft and 900 ft is the result of shearing stratification.

hundred feet higher on the basis of the vertical distributions of temperature and dew point.

Although two distinct homogeneous layers are evident in the upper half of the sounding, the air column from 250 ft to 900 ft is inhomogeneous. Since this condition cannot be ascribed to over-water modification, one must conclude that the ascent went through several strata of air, which left land at different times or places and in such fashion that the uppermost stratum departed latest and with the highest potential temperature. Such stabilizing action of the vertical variation of wind has been termed "shearing stratification" by Craig (1946, p. 11).

Sounding 6. — Supplementary observations made by the airplane were as follows: Surface wind, 255°, 3 Beaufort; 1000-ft wind, 254°, 15 knots; sky, clear. Measurements of water temperature obtained in the vicinity on 5 and 8 June are tabulated below.

Position	Time	Water Temp.
23 miles to north	18^h00^m, 5 June	52–54F
23 miles to north	00^h00^m, 8 June	53–56
16 miles to northeast	13^h00^m, 8 June	55–56

The trajectory of the air in sounding 6 is even more uncertain than that in sounding 5. The nearest land, eastern Long Island, is about 60 miles away. A rough estimate, based on the pilot-balloon observations mentioned in the discussion of sounding 5, is that the air at 1000 ft came from Long Island (see Fig. 12) and that it crossed the coast certainly not later than 13^h00^m. Air near the surface probably came from central New Jersey and left land several hours earlier.

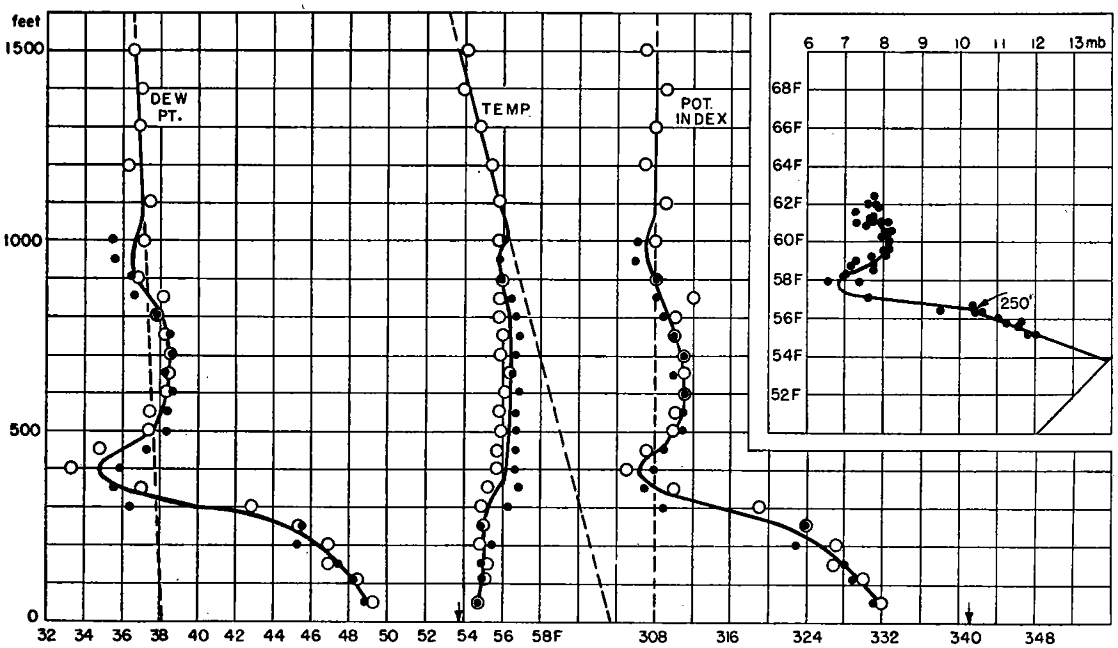

FIG. 14. Sounding 6; 40°02′N, 72°00′W; 6 June 1945; o ascent 17^h53^m–18^h08^m, • ascent 18^h11^m–18^h21^m. Modification by the water clearly does not extend above 400 ft. The characteristic curve (inset) indicates an upper limit of 250 ft. The vertical distribution of refractive index shows the presence of a type-2 superstandard layer from sea level to 400 ft.

Despite the uncertainty attached to its trajectory the air within the height range of the sounding (Fig. 14) is believed to have been homogeneous when it left land, in accordance with the reasoning which follows. The potential temperature at 200 ft is 56F and increases to 62F at 1500 ft. These values are higher than the ones recorded at corresponding elevations in the 23^h (5 June) Lakehurst radiosonde ascent and the 08^h (6 June) Quonset airplane ascent. Therefore, the air sampled by sounding 6 must have been warmed in the morning before leaving land. The surface temperature on land reached 56F at about 09^h30^m and 62F at 11^h30^m or 12^h30^m. It appears, therefore, that the lowest layer of air left land at about 09^h30^m and that successively higher strata left within the following two or three hours.[13]

This analysis implies that all the air leaving land was homogeneous and that the structure of the sounding results from shearing stratification. The minimum of dew point at 400 ft is not incompatible with this interpretation, since scattered surface values as low as 35F occurred in the convectively mixed air on land.

The characteristic curve is quite irregular. The first bend, which occurs at the point corresponding to 250 ft, probably represents the upper limit of over-water modification.

[13] The air within the height range 300–1000 ft is everywhere cooler in this sounding than in the preceding sounding. This fact is another indication of an earlier departure from land.

The minimum in dew point makes it certain that the influence of the water has not extended above 400 ft. The vertical distribution of refractive index shows the presence of a type-2 superstandard layer (see Montgomery, 1947) from sea level to 400 ft.

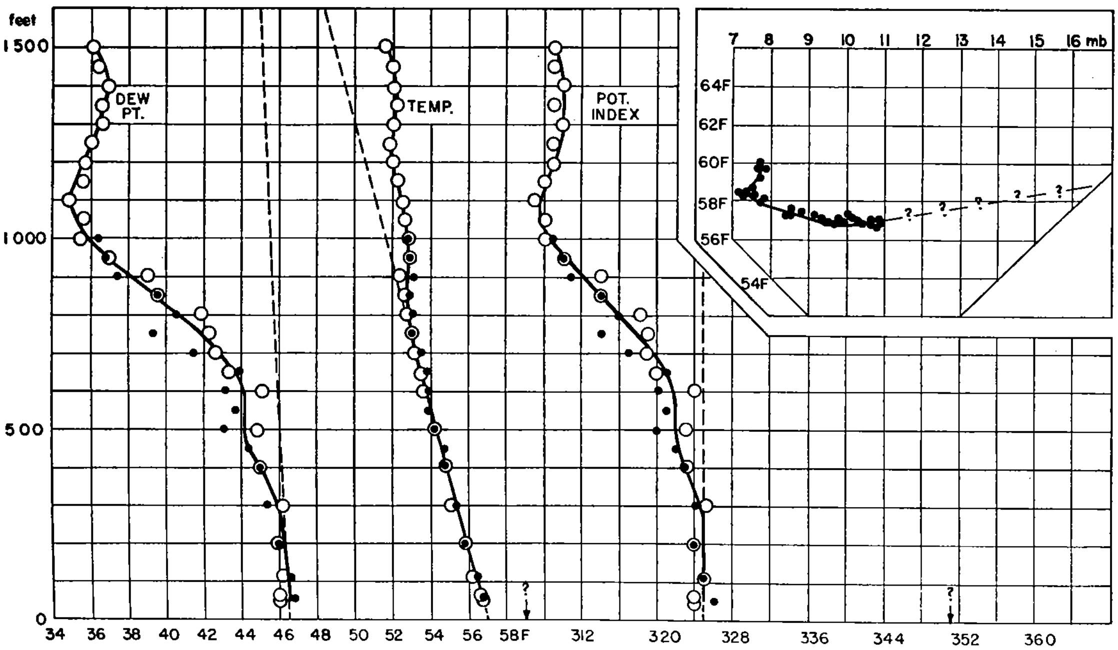

FIG. 15. Sounding 7; 39°35′N, 70°57′W; 6 June 1945; o ascent 18^h49^m–19^h06^m, • ascent 19^h10^m–19^h20^m. The air is homogeneous up to 800 ft as a result of passage over warmer water. The vertical distribution of refractive index is typical of a layer of air colder than the water. There is a superstandard condition in the middle part of the sounding, in this case giving constant modified index through a layer about 200 ft thick.

Sounding 7. — Supplementary observations made by the airplane were as follows: Surface wind, 264°, 3 Beaufort; 1000-ft wind, 305°, 11 knots; sky, clear. Available measurements of water temperature in the surrounding area are tabulated below.

Position	Date	Water Temp.
20 miles to north	30 May	53–56F
70 miles to west	30 May	54
90 miles to southwest	30 May	58
15 miles to northwest	12 June	57–63

This sounding was made more than 100 miles from the nearest land. The trajectory is doubtful because of the variations in the winds during the day. However, it is certain that the air at 1000 ft did not leave the mainland until after midnight, so its path over water could hardly have been longer than 150 miles. Its probable track is shown in Figure 12. The surface air evidently followed a cyclonically curved path and might have travelled over water for a distance of nearly 200 miles. In any case all parts of the column left land earlier in the day than any of the air in sounding 5 or sounding 6.

The vertical distributions of temperature and dew point shown in Figure 15 indicate that the air in sounding 7 was heated and moistened over relatively warm water. The resulting convection produced a nearly homogeneous layer up to 800 ft. The characteristic curve can be extrapolated to intersect the salt-water curve at about 57F. The actual water temperature must have been somewhat higher, say 59F, since the lapse rate between 50 ft and 300 ft is slightly superadiabatic and indicates the probable existence of a still larger lapse rate between the sea surface and 50 ft.

Despite the warming by the water, the temperature at all levels from 400 ft upward is lower than at corresponding heights in soundings 5 and 6. For instance, the 500-ft level, which experienced warming by the sea in sounding 7 but was above the upper limit of water modification in soundings 5 and 6, has a temperature of about 54F in sounding 7, 56F in sounding 6, and 58F in sounding 5. Hence, the air in sounding 7 almost certainly left land earlier than the columns in 5 and 6. The fact that sounding 7 shows pronounced stability above 1000 ft, whereas 5 and 6 do not, may be taken as an indication that daytime convection had not reached that level at the time of departure from land, which accordingly could hardly have been later than about two hours after sunrise.

The vertical distribution of refractive index is typical of a layer of air colder than the water. Just below the 1000-ft level there is a superstandard condition, in this case giving constant modified index of refraction (see Montgomery, 1947, p. 3) through a layer about 200 feet thick. Between the surface and 50 ft there is an unusually large lapse of potential index; this lapse results from the large gradients of temperature and humidity close to the water.

7 June 1945 (Soundings 8, 9, 10)

Weather Summary. — Air of polar origin was again present on this day, there having been no important changes in the wind field over the northeastern United States during the preceding 24 hours. The geostrophic wind was northwesterly and had a speed of about 20 mph. Clear skies in the early morning permitted strong solar heating of the ground, and cumulus clouds appeared over land as early as 10^h30^m at some stations and by 11^h30^m at all stations. Surface temperatures over land ranged from 40F to 50F at sunrise and increased to a maximum of about 70F by early afternoon. Dew points throughout the day were mostly 40–45F, although a few readings of 35–40F were reported. Fog occurred at some stations in the area during the early morning. Southwesterly sea breezes became established along the south shore of Long Island and the coast of Rhode Island after 10^h30^m.

Sounding 8. — Supplementary observations made by the airplane were as follows: Surface wind, 325°, 2 Beaufort; 1000-ft wind, 307°, 13 knots; sky, clear; visibility, unlimited. Measurements of water temperature made 7 days before at a position 50 miles west of sounding 8 gave readings of 53–59F.

The 1000-ft trajectory can be determined quite reliably from the airplane measurement of the wind aloft in conjunction with pilot-balloon measurements at La Guardia Field, Mitchel Field, Philadelphia, and Cape May. These observations show that the 1000-ft wind maintained a constant direction from approximately NNW between 05^h and 11^h but backed from NNW to approximately WNW between 11^h and 17^h. The average speed was about 15 mph. Evidently the air at 1000 ft travelled approximately 150 miles along a cyclonically curved path over the ocean (see Fig. 16). It left Long Island about 07^h. The air next the surface probably left land at a point somewhat to the west of the air at 1000 ft and made a slightly longer journey over water in respect to both time and distance. However, the trajectories differ less in this case than in earlier ones.

Temperatures on Long Island at 07^h were 50–55F. Since the sounding (Fig. 17) shows a temperature of 57F at 50 ft, it is obvious that the surface air must have been 2–7F warmer than when it left Long Island. The very high degree of homogeneity in the first 800 ft is good evidence that the air in the lower half of the sounding definitely was heated by passage over relatively warm water. Sea-surface temperatures measured within 25 miles of the central Long Island shore from 7 to 18 hours after the sounding were 54–56F. Hence, if departure from land not later than 07^h00^m is assumed, the air was over water of higher temperature at all times after leaving Long Island, the water having become progressively warmer along the trajectory. The distribution of points on the Taylor diagram indicates that the water temperature at the position of the sounding was certainly greater than 57F and was probably about 59F.

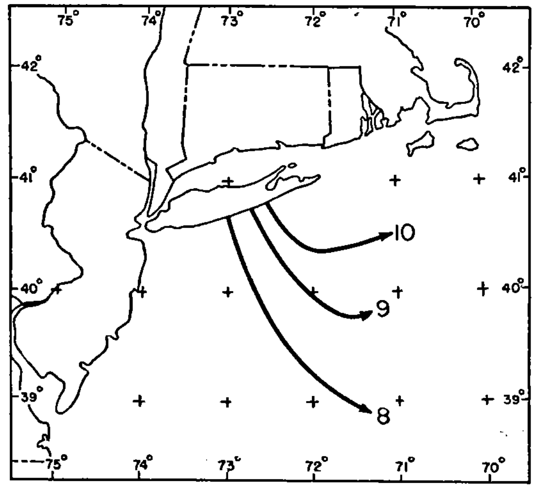

FIG. 16. Trajectories at 1000 ft for soundings made on 7 June 1945.

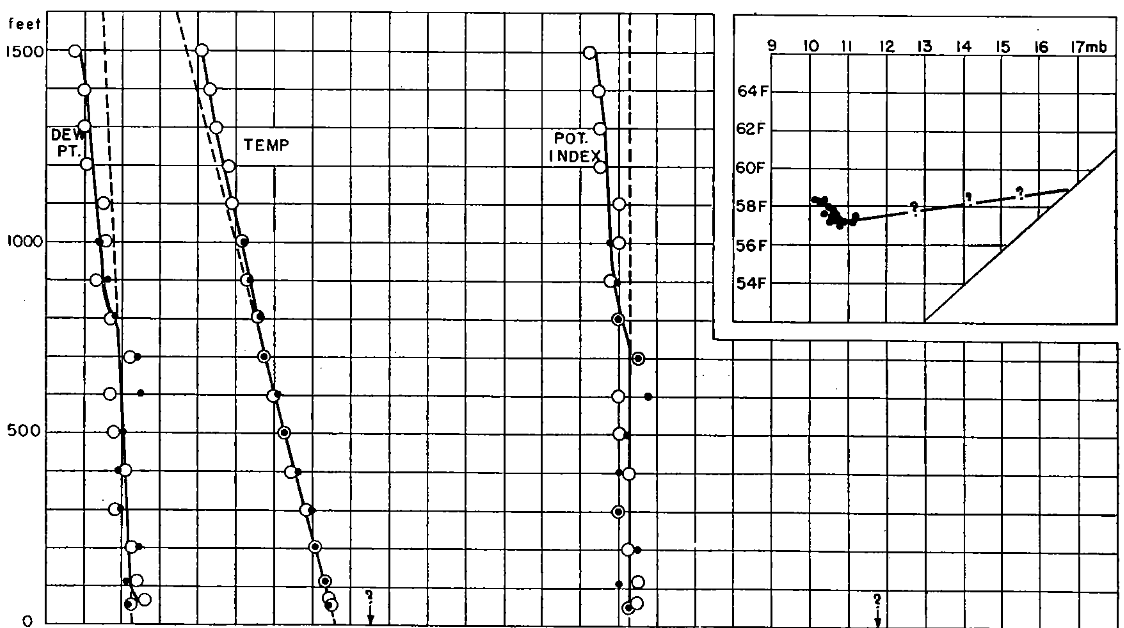

FIG. 17. Sounding 8; 38°56'N, 71°22'W; 7 June 1945; o ascent 16^h21^m–16^h39^m, • ascent 16^h43^m–16^h55^m. Heating over warmer water has produced homogeneous air up to 800 ft. The water temperature cannot be estimated satisfactorily, because the points on the Taylor diagram (inset) lie in a cluster. The markedly superstandard condition near the surface is the result of the large lapses of temperature and moisture over the relatively warm water.

The upper part of the sounding is nearly homogeneous and has properties only slightly different from those characterizing the lowest 800 ft. It is significant that the dew points in the upper part are considerably higher than those observed in the corresponding height range of soundings 5, 6, and 7 during the preceding day, despite the absence of any appreciable change in the general weather conditions. Furthermore, soundings 9 and 10, which were made later in the afternoon of 7 June, have dew points nearly 10F lower than sounding 8 above the 500-ft level. These facts strongly suggest that the heating and moistening influence of the water extends to or beyond 1500 ft in sounding 8. The trajectory is certainly long enough to admit of such an interpretation.

Another possibility is that the modification stops at 800 ft. In this connection reference may be made to the Albany radiosonde ascent at 23^h on 6 June, since the air was near Albany at that hour. The reported values of potential temperature and dew point were 56F and 46F at 600 ft and 62F and 42F at 1800 ft. The good agreement with conditions in the upper 600 ft of sounding 8 favors the interpretation that the air at those levels did not undergo any noticeable change during the night. However, doubts as to the validity of this reasoning are cast by the marked difference between the dew points recorded in the Albany observation and those measured in the synchronous radiosonde ascent at Lakehurst. The measurements at Lakehurst are mostly in agreement with conditions prevailing in the upper portions of soundings 5, 6, 7, 9, and 10, so that the representativeness of the dew points at Albany is questionable.

The vertical distribution of refractive index is close to standard except near the surface, where large lapses of temperature and moisture just above the relatively warm water produce markedly superstandard conditions.

Sounding 9. — Supplementary observations made by the airplane were as follows: Surface wind, 260°, 2 Beaufort; 1000-ft wind, 222°, 7 knots; sky, clear; visibility, unlimited. Observations of water temperature made 21 hours later at a position 15 miles northwest of sounding 9 gave readings of 55–56F.

The 1000-ft wind recorded by the airplane deviates considerably from the geostrophic direction and from pilot-balloon observations on land, so the path followed by the air is somewhat uncertain. The most reasonable 1000-ft trajectory is one that leaves central Long Island as a wind from about NNW, then curves cyclonically to arrive at point E[14] from about WSW (see Fig. 16). The length of this trajectory is approximately 120 miles; the time required, 8–10 hours. Hence, the air is estimated to have left land between 07^h30^m and 09^h30^m.

Surface-air temperatures on Long Island during the interval in which the air is supposed to have left land varied from 55F to 61F. Dew points mostly ranged from 44F to 48F, although a reading of 39F was obtained at Suffolk Field at 09^h30^m. An airplane ascent made at Quonset Point about 08^h showed stable conditions, the potential temperature and dew point changing from 56F and 42F at the ground to 64F and 39F at 2800 ft.

It is not possible to state definitely how much, if any, of the air in sounding 9 was in a homogeneous condition when leaving land, because the estimated time of departure is too uncertain. The upper half of the sounding (Fig. 18), with potential temperature and dew point increasing from 59F and 33F at 700 ft to 61F and 34F at 1500 ft, is drier

[14] The position of sounding 9.

than air of the same potential temperature in the Quonset airplane ascent and about 3F warmer than the upper part of sounding 8. This comparison affords fairly good evidence that the air left land after being convectively mixed and that it subsequently became slightly stable by shearing stratification.[15]

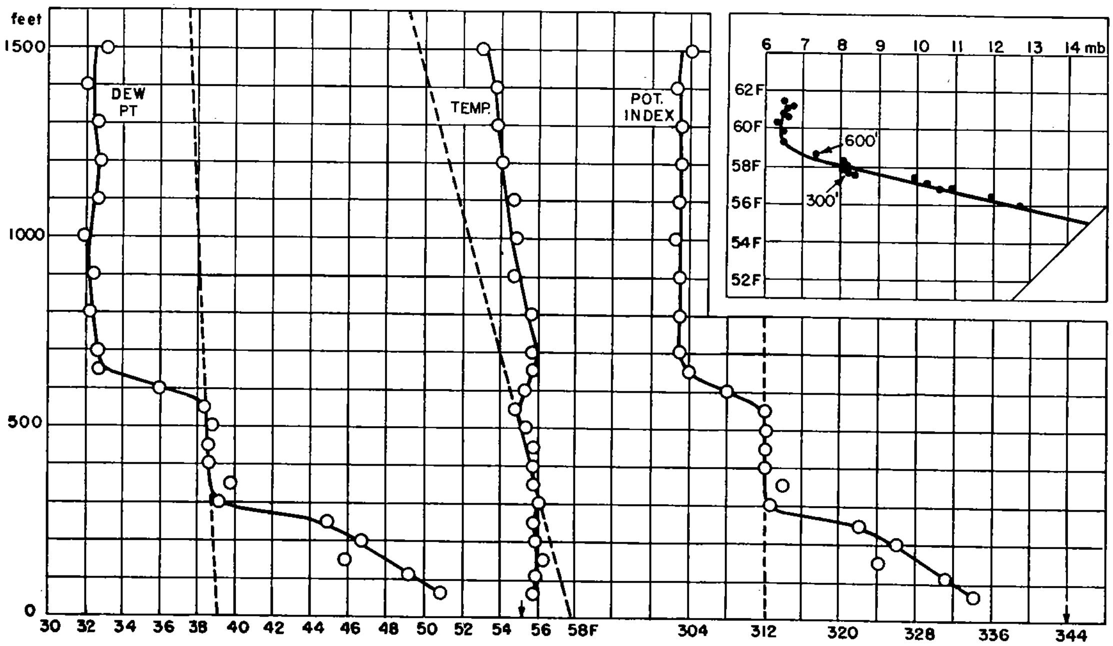

FIG. 18. Sounding 9; 39°50′N, 71°20′W; 7 June 1945; o ascent 17^h32^m–17^h53^m. Modification by the water extends only to 300 ft. The inversion between 550 ft and 700 ft is the result of shearing stratification. The water temperature indicated by the characteristic curve (inset) agrees well with measurements made in the vicinity. Note the marked type-2 superstandard layer produced by the large lapse of moisture between the surface and 300 ft.

Modification by the water definitely extends to 300 ft, but the homogeneous layer between 300 ft and 550 ft appears to be unaffected by the sea. The potential temperature and dew point of 58F and 39F suggest that the layer could have left central Long Island in a well-mixed condition at about 09^h and subsequently have remained homogeneous. However, there is cause to question this interpretation on the ground that the modification would be expected to extend higher than 300 ft with such a small temperature difference between air and water[16] and such a long sea journey. An alternative interpretation of the homogeneous layer is that it was formed by convection due to the air passing over a band of water warmer than 58F, the proximity of such water being known from the study of sounding 8. However, this explanation fails to account for either the rather low potential dew point (39F) in the layer or the large humidity lapse with small temperature inversion just below 300 ft.

When an air column is compounded of slowly moving currents having different directions, shearing stratification is especially effective, and a completely satisfactory

[15] The potential temperature of 61F at 1500 ft coincides with the 09^h30^m surface temperature at Suffolk Field; hence, the air at that level presumably left land shortly after 09^h30^m.

[16] The characteristic curve shows definitely that the water temperature was about 55F, in agreement with the measurements near point E.

explanation of all details becomes quite impossible. Sounding 9 should perhaps be placed in this category.

Sounding 10. — Due to the circumstance that the ship and the airplane rendezvoused at the position of this sounding, a detailed set of observations is available for study and is presented in the following table.

Time	Surface Wind	Low Clouds	Air Temp.	Dew Point	Water Temp.
17^h30^m	240°, 2 Beaufort	none	55.1F	47.8F	52.4F
17^h45^m					52.3
18^h00^m					52.2
18^h15^m					52.1
18^h30^m	240°, 12 mph	none	54.2	49.9	51.6
18^h45^m	240°, 12 mph	none	54.1	50.0	51.7
19^h00^m	240°, 14 mph	none	53.7	49.8	51.2

The wind at 1000 ft, as reported by the airplane, was 276°, 8½ knots.[17] Scattered high clouds were present.

The 1000-ft trajectory is estimated from winds observed by the ship and from pilot-balloon observations on land. Point C, the spot where this sounding was made, evidently was far enough north to have been affected by the sea breeze, which developed along the Rhode Island coast between 11^h30^m and 12^h30^m and which appeared as a WSW wind in the pilot-balloon observation made at Fishers Island at about 13^h. The sea breeze began somewhat later along the south shore of Long Island; at Suffolk Field its effects were not felt until shortly before 13^h30^m. On the basis of these considerations the trajectory starts from central Long Island and curves sharply toward point C (see Fig. 16). The over-water length is about 110 miles. If an average wind speed of 12–15 mph is assumed, the travel time is 7½–9 hours. Hence, it is concluded that the air left land between 09^h30^m and 11^h00^m. In that case all the air in the sounding probably departed late enough to have been convectively mixed, for cumulus clouds had appeared at some stations by 10^h30^m.[18]

From measurements made south of Long Island 2 days before and on the day following the sounding it is estimated that the air first passed over water of temperature ranging from 54F to 56F. Finally it came to cooler water of about 52F, as determined by the observations at point C. This history evidently was associated with cooling and moistening of the lower layers. The two ascents are reproduced separately in Figure 19, as there is an appreciable variation in the vertical distribution of dew point. In agreement with the distribution of water temperature along the trajectory, the characteristic curves indicate that at first the air was modified up to a height varying from 350 ft to 450 ft by water of temperature about 54F and that, subsequently, further cooling and moistening of the lowest 200 ft took place over water of about 52F.

With the exception of a nearly homogeneous layer, which appears in the first ascent (but not in the second) between 600 and 900 ft, the air above the upper limit of over-water modification is stable. The inhomogeneity must be due to the action of shearing stratification after the air left land. In the first ascent the potential temperatures at

[17] This value does not appear to be reliable, for the true wind speed at 1000 ft could hardly have been appreciably less than the surface speed.

[18] The 10^h30^m report from La Guardia Field placed the bases of the cumuli at 4500 ft.

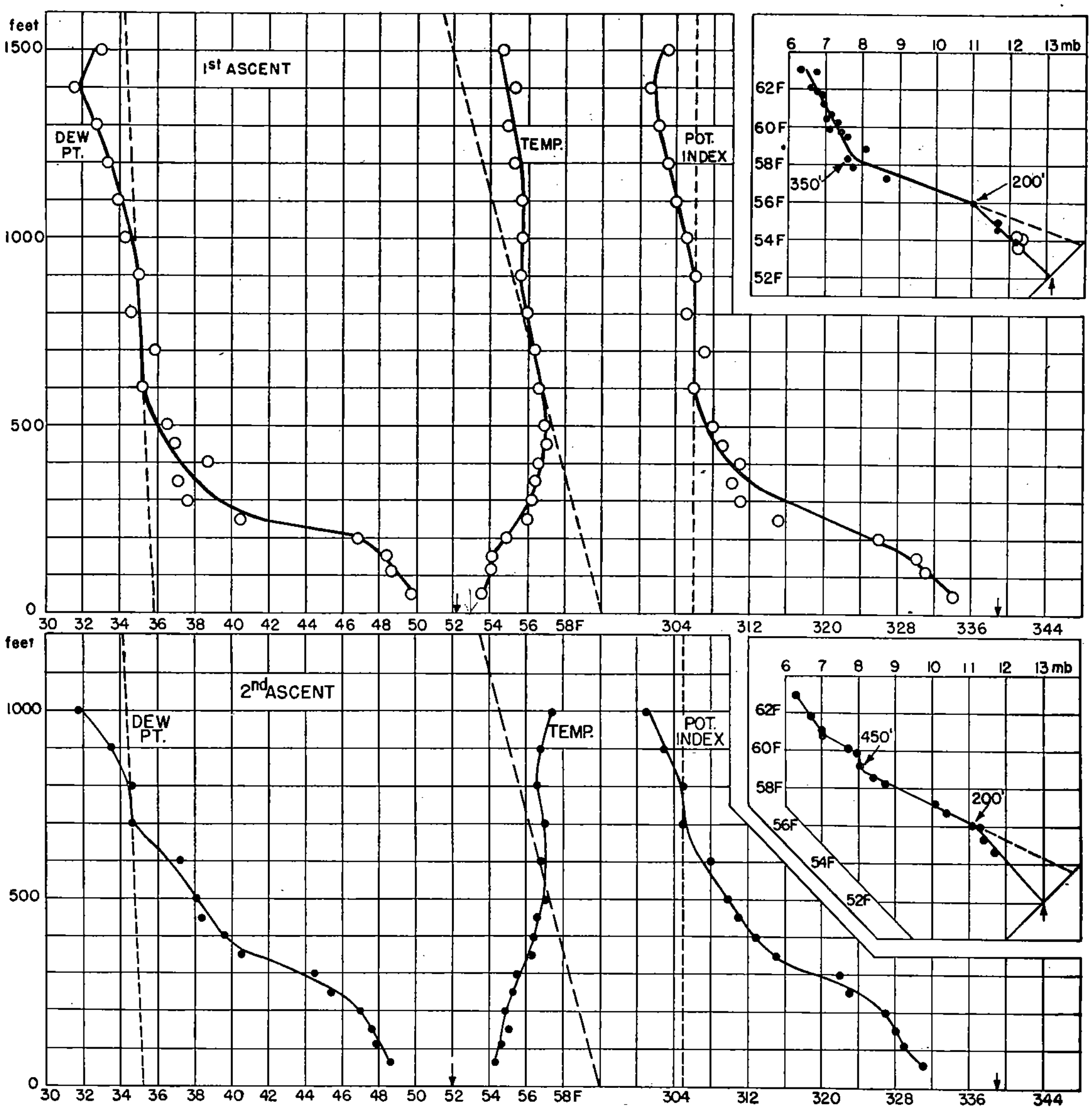

FIG. 19. Sounding 10; 40°31′N, 71°04′W; 7 June 1945; o ascent 18^h26^m–18^h44^m, • ascent 18^h50^m–19^h01^m. The modification is somewhat complex, owing to variations in water temperature along the trajectory. The upper limit of modification is at 350–450 ft, as shown by the characteristic curves. Shearing stratification accounts for the stable character of the upper part of the sounding. An especially deep superstandard layer exists at low levels.

500 ft and 1500 ft indicate that the air strata at those levels left land at about 10^h and 11^h, respectively.

8 June 1945 (Soundings 11 and 12)

Weather Summary. — The geostrophic wind between Nantucket and Delaware Bay was NW in the morning. Its speed decreased from about 18 mph at 02^h30^m to about 10 mph at 08^h30^m. During the afternoon it was indefinite, as the area was then occupied by a wedge of high pressure. However, well-developed sea breezes became established along the coast.

Early-morning minimum temperatures on land were 50–55F. The temperature rose rapidly, reaching maximum values of 75–78F in the afternoon, except on the coast, where the onset of the sea breeze checked the increase. Dew points mostly were 40–50F, but values of 35–40F occasionally were reported during the period of active convective mixing.

Cumulus clouds formed over land during the morning, and scattered showers and thunderstorms occurred in the afternoon. Over the ocean there were scattered high and middle clouds all day.

Sounding 11. — Supplementary observations obtained by the airplane during the course of this sounding were as follows: Surface wind, 200°, 2 Beaufort; 1000-ft wind, 238°, 9 knots; clouds, 0.7–0.8 cirrus and altocumulus; visibility, unlimited. In addition, smoke from ships was observed to rise to an estimated height of 600 ft. The water temperature measured at this position about 13 hours earlier was 55.5F.

At the time of the sounding the air over southwestern Long Island and the adjacent ocean was moving from SSW–SW, as indicated by the airplane's observations and by a pilot-balloon measurement of the 1000-ft wind over Mitchel Field at 18^h. However, upper-wind observations made at Mitchel Field, La Guardia Field, and Spring Lake during the forenoon show that the 1000-ft wind over the area was then blowing from NNW at a speed of about 11 mph. The exact time at which it shifted from NNW to SW is not directly known, but the regular hourly surface reports indicate that the sea breeze set in along the south shore of Long Island at about 12^h. Consequently, the 1000-ft trajectory is estimated to start from the coast somewhere between Spring Lake and Mitchel Field (see Fig. 20). The length is 60–80 miles; the time of departure from land was between 09^h30^m and 11^h00^m.

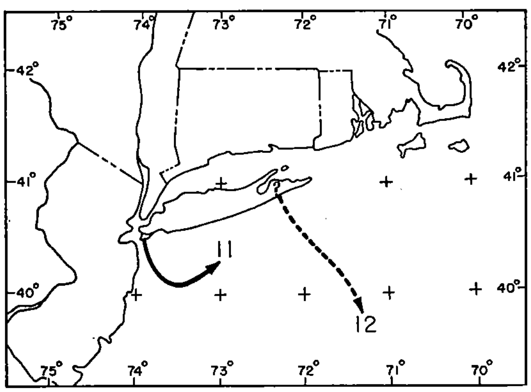

FIG. 20. Trajectories at 1000 ft for soundings made on 8 June 1945.

A trajectory computed by means of surface winds is still more uncertain, but it is safe to say that the several parts of the air column left western Long Island or northern New Jersey at various times between sunrise and noon.

The two ascents constituting this sound have been reproduced separately (see Fig. 21), because they differ slightly. The upper limit of modification by the water appears to be defined by the height at which the large lapse of dew point abruptly ceases. In the first ascent the reversal of trend occurs at 500 ft; in the second ascent, at 350 ft. The forms of the characteristic curves (Fig. 22) bear out this interpretation. The observed variation in the elevation of the top of the water-modified layer is an indication that the upper surface of the layer was characterized by undulations of rather large amplitude.

Between 500 ft and 1500 ft the potential temperature increases from 67F to 69F, and the potential dew point varies between 26F and 37F. These values may be com-

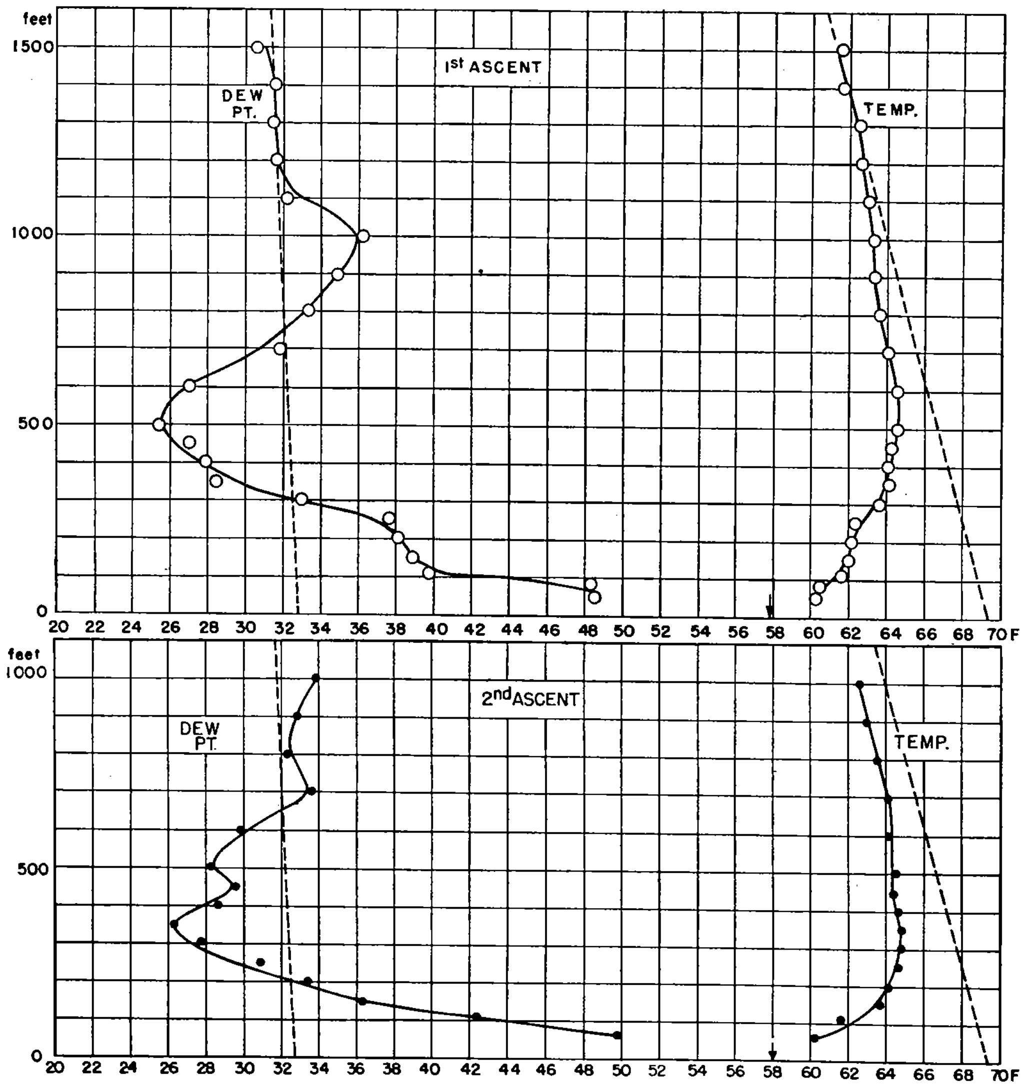

FIG. 21. Sounding 11; 40°18′N, 73°01′W; 8 June 1945; ○ ascent 16^h37^m–16^h53^m, • ascent 16^h54^m–17^h05^m. Modification by the water extends to 500 ft in the first ascent and to 350 ft in the second. The upper surface of the modified layer apparently is characterized by undulations of rather large amplitude.

pared with previous radiosonde ascents. At Albany at 23^h on 7 June the potential temperature and dew point were 61F and 46F at the ground and 66F and 38F at 2500 ft. At Lakehurst at 23^h on 7 June the conditions were 65F and 54F at 400 ft and 68F and 30F at 2400 ft. At Lakehurst at 11^h on 8 June there was a superadiabatic layer from the ground to 800 ft, above which the potential temperature and dew point were 66F and 35F, changing gradually to 73F and 32F at 7000 ft.

Since values nearly the same as in the sounding were observed at Lakehurst both late in the morning and in the preceding night, it is not possible to determine directly how much of the air left land in a stratified condition in the early morning and how

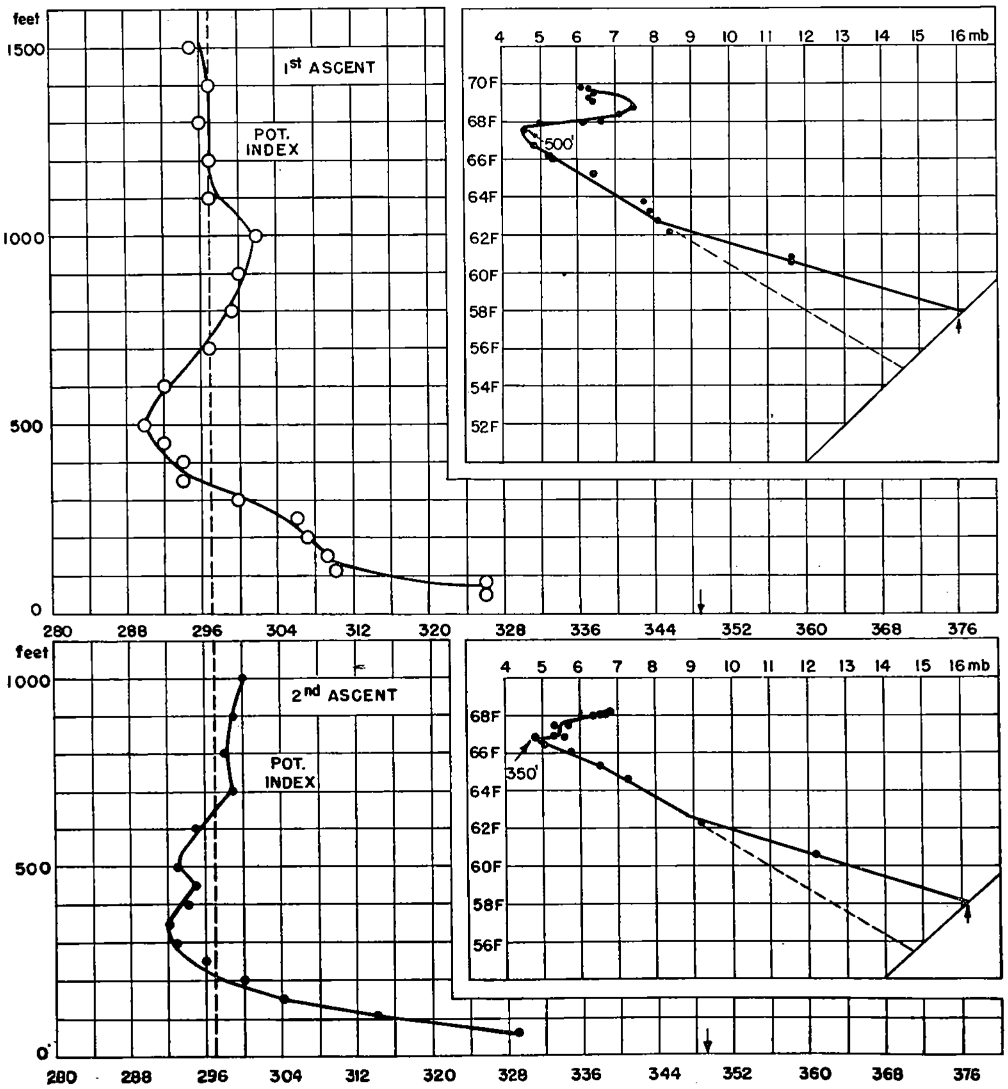

FIG. 22. Sounding 11. The characteristic curves of both ascents indicate that the air has travelled over water of varying temperature. The thick type-2 superstandard layer near the surface is chiefly a result of the large lapse of dew point between sea level and 300 ft.

much left later in the day after having been convectively mixed. However, it will be noted that the air from 600 ft to 1500 ft has higher dew points than that between 400 ft and 600 ft. This circumstance is probably due to an increase of moisture aloft by convective mixing with the damp surface air that lay over the ground during the night. It may be assumed that the air in the region where the dew points are minimum left land too early to have been subject to such mixing.

Subsequently this air was overtaken and overrun by mixed air that left land later but moved at a greater speed. The homogeneous layer between 1200 ft and 1500 ft has a potential temperature of 69F. A comparison of this value with the surface temperatures listed in the following table indicates that the air probably left land at about 11^h30^m, at which time scattered cumulus clouds were being reported at most stations.

	Mitchel Field	La Guardia Field	Floyd Bennett Field	Newark	Lakehurst
10^h30^m	67F	68F	68F	66F	67F
11^h30^m	69	71	71	69	70

An interesting feature displayed by this sounding is the extreme dryness of the layer between, roughly, 400 ft and 600 ft. In this connection mention should be made of the observations taken at the downtown office of the U. S. Weather Bureau in New York City, which lies very near the estimated 1000-ft trajectory. The Weather Bureau office, which is situated atop the Whitehall Building and at an elevation of 415 ft above sea level, recorded an early-morning minimum dew point of 34F just prior to the start of convection. This value was 10F or more lower than simultaneous readings at near-by airport stations close to sea level. The inference is that the large moisture lapse in the lowest few hundred feet and the exceptionally low dew points in the vicinity of the 500-ft level are due to subsidence. This explanation is supported by the Lakehurst radiosonde ascent made during the preceding evening. The Lakehurst values at 2400 ft are in quite good agreement with conditions in the dry layer of the sounding.

The characteristic curves of both ascents (Fig. 22) indicate a water temperature of about 58F in the vicinity of the sounding, but they contain evidence of an earlier contact with water of temperature about 55F. Since the wind was light and there were only scattered clouds, the surface water must have warmed during the day. Hence, the indicated values seem consistent with the temperature of 55.5F measured in the previous night.

The combination of the temperature inversion and the large lapse of dew point in the lowest 300 ft cause the lapse rate of potential index to exceed the critical value of 4.0×10^{-6} per hundred feet, so that radio rays directed horizontally in this layer are refracted downward to the sea surface.

Sounding 12. — Weather conditions accompanying this sounding were as follows: Surface wind, variable direction (250°–280°), 2 Beaufort; 1000-ft wind, 350°, 2 knots; clouds, scattered cirrus and altocumulus; visibility, restricted by surface haze. Smoke from ships was observed to rise to an estimated height of 400 ft. The measured water temperature at a position 15 miles northwest of the sounding was about 56F at 14^h30^m on this day.

The winds aloft were so light and variable (see discussion of sounding 11) and the position of sounding 12 was so far from shore that the trajectory can be described only in the most general way. All that can be said with certainty is that the air at 1000 ft left the coast of Rhode Island, Long Island, or New Jersey between midnight and noon and travelled 100–175 miles over water (see Fig. 20). The surface layer may have been moving over the water for more than 24 hours and may have had quite a different sea track.

The two ascents composing this sounding have been reproduced separately, because they exhibit rather marked differences, as in the case of sounding 11. In the first ascent the upper limit of over-water modification, as defined by both the vertical distribution of dew point (Fig. 23) and the characteristic curve (Fig. 24), is at 400 ft, while in the second ascent it is at 500 ft. Next the sea surface there is a nearly homogeneous layer,

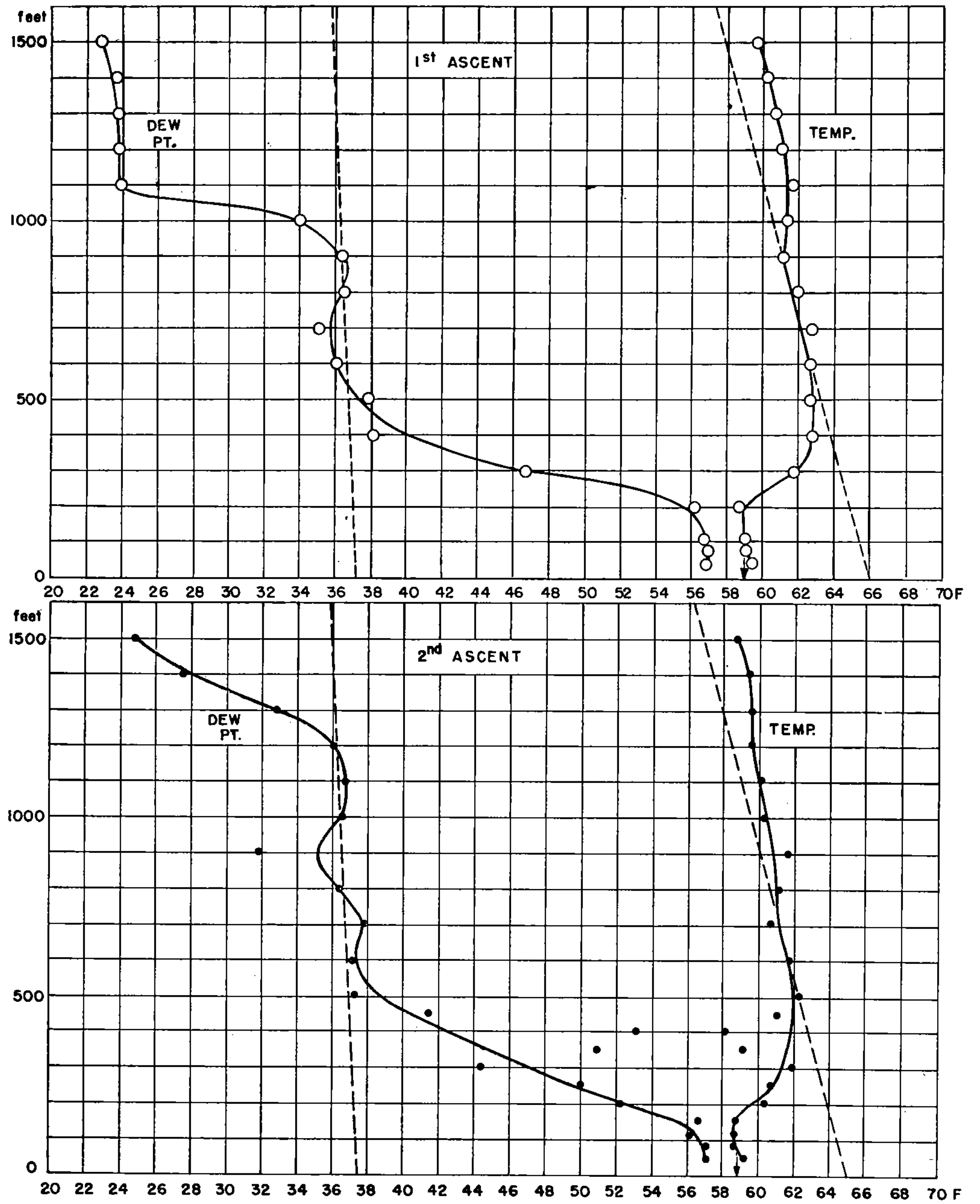

FIG. 23. Sounding 12; 39°50′N, 71°20′W; 8 June 1945; o ascent 18^h00^m–18^h15^m, • ascent 18^h20^m–18^h34^m. The height of over-water modification varies from 400 ft in the first ascent to 500 ft in the second, apparently as a result of undulations at the top of the moist layer.

which extends to the 200-ft level in the first ascent but only to the 150-ft level in the second. In both cases a superadiabatic lapse rate exists between 45 ft and 80 ft. These facts may be interpreted to mean that the air last travelled over water somewhat warmer

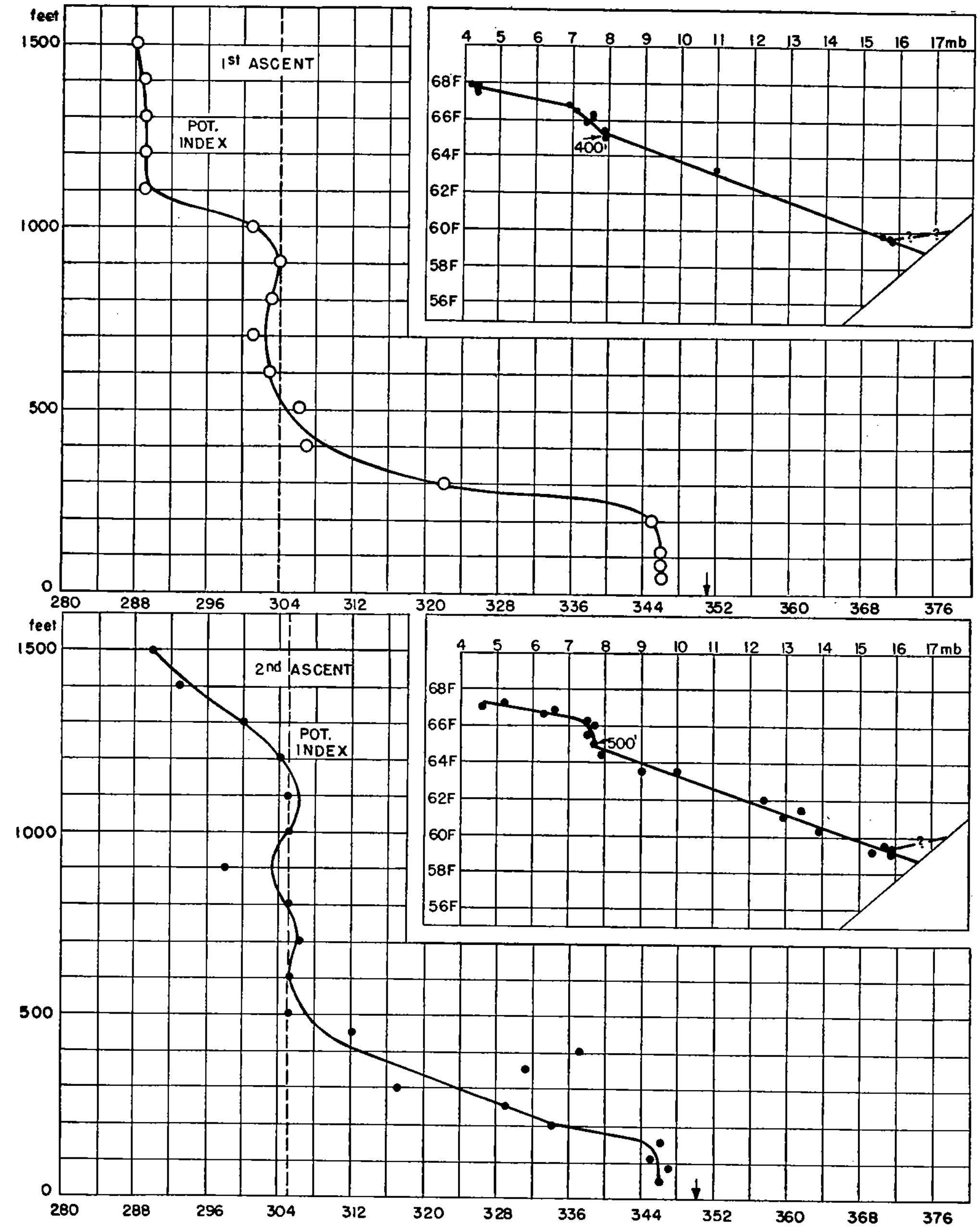

FIG. 24. Sounding 12. The indicated water temperature is not less than 59F and, accordingly, is 4–5F higher than values measured at this position during the preceding day. The rapid warming is a result of light winds and uninterrupted sunshine on 8 June. Note the variation between ascents of the height of the type-2 superstandard layer in the upper part of the sounding.

than 59.5F. On the other hand, the characteristic curve of the first ascent intersects the salt-water curve at 59.0F. For the second ascent the analogous value is 58.8F. If 59F is considered to approximate the true water temperature, the homogeneous layer could have been created only by mechanical mixing. However, a straight-line extrapolation from the cluster of points corresponding to measurements in the mixed layer is not mandatory. Under the circumstances the characteristic curve in each case could justifiably be extended in the fashion shown by the broken line-segment. In any event, a water temperature of 59.5F ± 1.0F is appreciably higher than the value of 55F indicated at this location on the previous day (see discussion of sounding 8), but 59.5F is not unreasonable, in view of the heating of the sea surface that undoubtedly took place during this day of light winds and sunshine.

The structure of the upper part of the air column is rather unusual. The extreme dryness at the top of the sounding makes it appear certain that convection had not yet reached the 1500-ft level when the air left land. In the Lakehurst radiosonde ascent made at 23^h on 7 June a comparable value of potential dew point was recorded at about 5000 ft. The potential temperature at that height was 70F, which is nearly the same as the value at the top of the sounding. The possibility that there was active subsidence during the preceding 20 hours is suggested.

From 600 ft to 900 ft in the first ascent (600 ft to 1200 ft in the second ascent) the potential temperature is essentially constant. The average potential dew point in the layer agrees with conditions observed between 800 ft and 3800 ft over Lakehurst at 11^h. Since convection on shore had become well established at this hour, as indicated by the presence of cumulus clouds, it may be concluded that the layer in question definitely contains air that was mixed over land. A comparison of the potential temperature (66F) with surface temperatures on shore during the morning indicates that the air left land at about 10^h30^m.

The large differences between the first and second ascents in respect to the measured values of temperature and dew point at certain levels quite definitely result from variations in time and space of the heights and thicknesses of the several strata, for the characteristic curves are quite similar. In the second ascent the apparent decrease of temperature with height between 300 ft and 400 ft corresponds to a lapse rate of approximately 6.5C per 100 m. At this distance from the earth's surface such a condition along a vertical is impossible. Furthermore, it may be noted that the potential temperature and dew point at 400 ft are intermediate between the conditions at 150 ft and at 200 ft. As in similar cases already noted, the explanation must be that the ascending airplane encountered a steep wave on the upper surface of the moist layer and passed from the top to the base of the inversion while climbing gradually from 300 ft to 400 ft.

11 June 1945 (Soundings 13 and 14)

Weather Summary. — The continental polar air mass that covered the area between Nantucket and New Jersey on 8 June was replaced during the succeeding 72 hours by a moist southwesterly current from subtropical latitudes. Consequently, this period was marked by an upward trend of temperature and dew point. As a result, surface temperatures on land in the early morning of 11 June were mostly no lower than about 65F. By late afternoon they had risen to 85–90F. Dew points remained between 60F and 70F throughout the day.

Stratus clouds and fog were present in the early morning and persisted until midday over the entire coastal area. Scattered showers occurred in New Jersey during the afternoon.

Sounding 13. — Supplementary observations taken during the course of this sounding were as follows: Surface wind, 186°, 2 Beaufort; 1000-ft wind, 232°, 16 knots; sky, clear; visibility, 1–2 miles (restricted by haze). Measurements of water temperature were obtained at the position of the sounding 3½ days earlier and 4 days later. The values recorded were 55–56F and 64–65F, respectively.

The air in the sounding had a fairly long journey over the ocean. Reports from pilot-balloon stations, as well as the observations made by the airplane, show that the average direction and speed of the wind at 1000 ft was 230°, 20 mph, throughout the day over New Jersey and adjacent waters. This gives a trajectory more or less parallel to the coast of southern New Jersey (see Fig. 25). The over-water distance is about 100 miles, so that the air at 1000 ft is estimated to have left land between 11^h00^m and 12^h00^m.

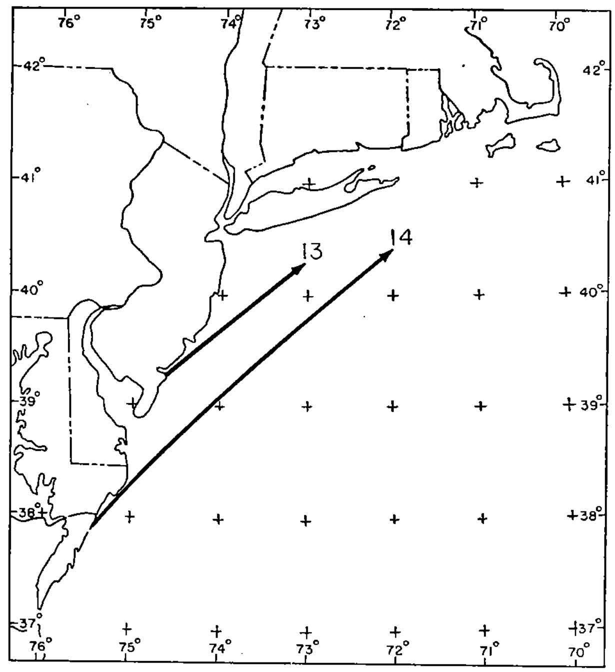

FIG. 25. Trajectories at 1000 ft for soundings made on 11 June 1945.

The upper half of the sounding almost certainly consists of air that was convectively mixed over land several hours earlier, because a homogeneous layer is present between 800 ft and 1200 ft (see Fig. 26). The potential temperature and dew point in this layer may be compared with surface values observed at Lakehurst[19] during the forenoon (77F and 68F at 10^h30^m and 82F and 72F at 11^h30^m). The results of the radiosonde ascent made at Lakehurst at about 11^h show that the air between the ground and 2000 ft was partially stirred; the potential temperature and dew point varied from 79F to 81F and 68F to 63F, respectively. These observations indicate that the air between the 800-ft and 1200-ft levels left land shortly after 11^h00^m; hence, they are consistent with the estimate based on the trajectory. The warmer air in the uppermost 300 ft must have left land a little later.

The characteristic curve shows quite clearly that the air in the lowest 350 ft lost both heat and moisture as a result of passage over water of temperature less than 62F. The indicated value of the water temperature is 59.5F, but this, by itself, must not be considered completely reliable, because of the fact that the lower portion of the characteristic curve is nearly parallel to the salt-water curve. However, 59.5F lies between the values of water temperature measured 3 days earlier and 4 days later and, therefore, is certainly reasonable.

The air between 400 ft and 600 ft was cooled but did not lose any moisture. It cannot be said definitely whether the loss of heat was due to radiational cooling on land

[19] In this comparison Lakehurst has been used in preference to stations closer to the estimated trajectory (e.g., Atlantic City and Cape May) because of sea-breeze effects at those places.

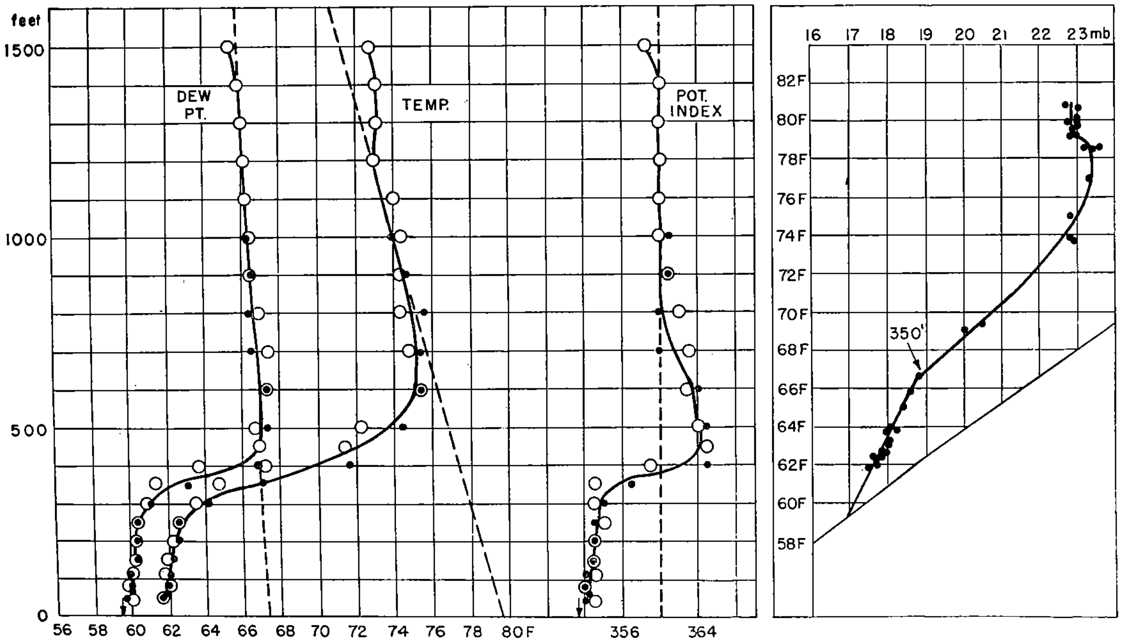

FIG. 26. Sounding 13; 40°18′N, 73°02′W; 11 June 1945; o ascent 16^h30^m–16^h46^m, • ascent 16^h49^m–17^h00^m. Modification by the water apparently does not extend beyond 350 ft. The pronounced temperature inversion between 350 ft and 600 ft is probably the result of cooling over land during the preceding night. The low-level inversions of temperature and moisture produce substandard conditions in the modified layer.

during the preceding night (assuming the air left shore in the early morning before convection started) or to passage over a stretch of water having a temperature of 67F. The latter circumstance is not impossible, since the layer in question could have followed a more southerly trajectory than the air at 1000 ft and so could have come from the relatively warm coastal waters of Virginia and North Carolina. However, it would be an unusual coincidence if the air, on leaving land, encountered water having a temperature equal to the initial dew point.

Sounding 14. — Supplementary observations obtained by the airplane during the course of this sounding were as follows: Surface wind, 195°, 3 Beaufort; 1000-ft wind, 197°, 16 knots; sky, clear; visibility, approximately 2 miles. The water temperature in the vicinity, as measured 24 hours later, was 60–64F. Three days earlier it had been 54–55F.

The trajectory of the air at 1000 ft in this sounding is estimated from the wind values adopted in the analysis of sounding 13. The result obtained is that the over-water path is 220–260 miles in length and runs back to the coast of Maryland and northeastern Virginia (see Fig. 25). The air could not have left land more than about one hour after sunrise; probably it left prior to 06^h00^m. The surface layers, in which the wind was southerly, had been travelling over the ocean for a greater distance and longer time.

Figure 27 shows that the influence of cooling from below extends at least up to 1000 ft. However, the humidity inversion extends only to the 600-ft level, which is the upper limit of modification by water cooler than 66F. Between 600 ft and 1200 ft the potential dew point is practically constant. Its value (66F) is within 1F of the surface dew point measured in the early morning at Chincoteague in northeastern Virginia. It may be inferred, therefore, that at the start of the trajectory the potential dew point was essentially constant up to 1000 ft or more as a result of convective mixing inland during the previous day. Hence, it is virtually certain that the temperature inversion between 600 ft and 1200 ft was produced by nocturnal cooling over land.

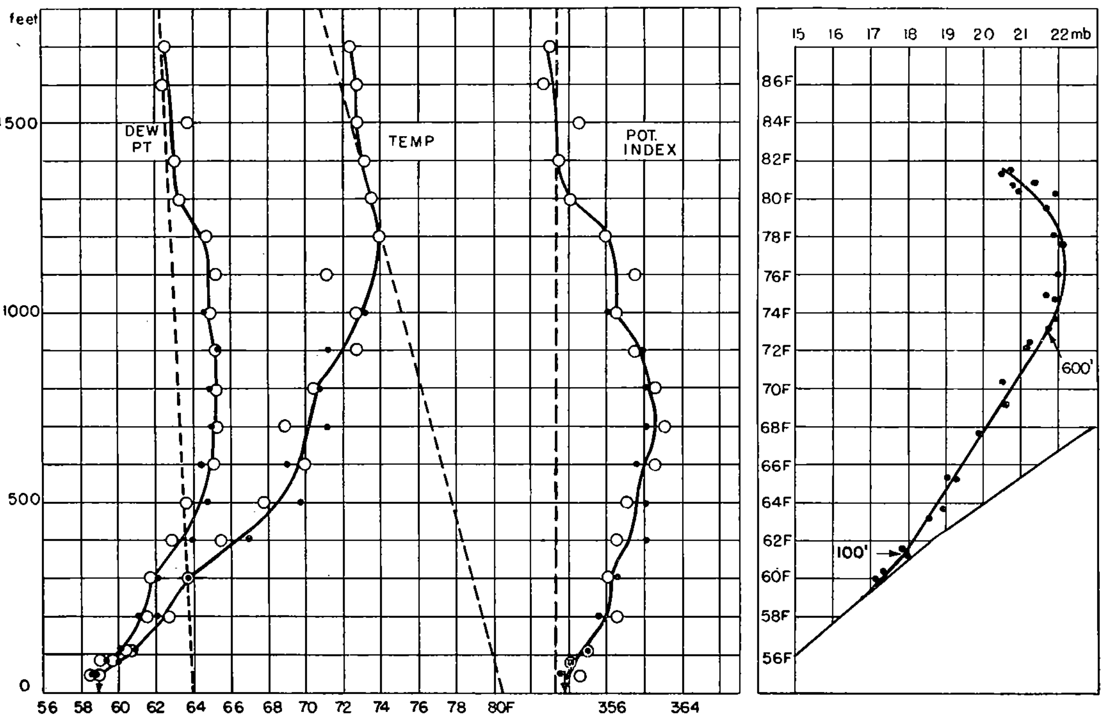

FIG. 27. Sounding 14; 40°25'N, 72°00'W; 11 June 1945; o ascent 17^h40^m–17^h58^m, • ascent 18^h00^m–18^h10^m. Modification by the water extends to 600 ft, as shown by the height of the humidity inversion and the distribution of points on the Taylor diagram. The temperature inversion above 600 ft is the result of cooling over land during the preceding night. The substandard layer produced by the influence of the cool water is especially deep.

The homogeneous layer that is present at 1300–1400 ft could not have been created by convection over land during this day, since a trajectory which could account for the departure of the air from land after the surface temperature reached 80F (i.e., at about 11^h30^m) would be completely inconsistent with all available observations of the wind at 1000 ft and 2000 ft. Therefore, the upper part of the sounding is interpreted to be representative of conditions prevailing over eastern Maryland early in the morning. The air above 1200 ft presumably reflects the persistence of a homogeneous state acquired during the preceding day. The midnight radiosonde ascent at Norfolk, near which place the air was located a few hours before it left land, recorded potential temperatures of 84F at 500 ft and 88F at 3400 ft. Thus, it is entirely reasonable to associate the comparatively high temperatures in the upper part of the sounding with overland heating on 10 June.

The distribution of points on the Taylor diagram (Fig. 27) bears out the statement based on an inspection of the dew point-height curve that the modification by the water extends only to 600 ft. The air in this lower layer not only was cooled but lost moisture by condensation on the sea surface, as shown by the slope of the characteristic curve. Evidently, modification over water of temperature 61F was followed by additional modification up to about 100 ft by water of temperature 59F in the immediate vicinity of the sounding. The indicated value is consistent with the results of measurements made on 8 June and 12 June.

An interesting phenomenon was the absence of fog, despite the existence of a saturated state at the 45-ft level. During the return flight to Quonset Point no well-defined fog layer was encountered until the airplane had flown about 40 miles downwind from the position of the sounding.

12 June 1945 (Soundings 15, 16, 17)

Weather Summary. — A weak cold front, accompanied by rain showers, crossed the coastal area between New Jersey and Nantucket during the forenoon hours. The front was followed by clearing weather and a weak northwesterly wind. The latter gave way by afternoon to a southwesterly sea breeze along the coast between western Long Island and Cape Cod. Over the ocean the surface wind remained very light W–SW all day.

The new air mass that moved into the area behind the front was only a little cooler and drier than the tropical air of the preceding day. On land the temperatures rose from morning minima of about 65F to afternoon maxima of 80–85F. Dew points did not change appreciably after the passage of the front.

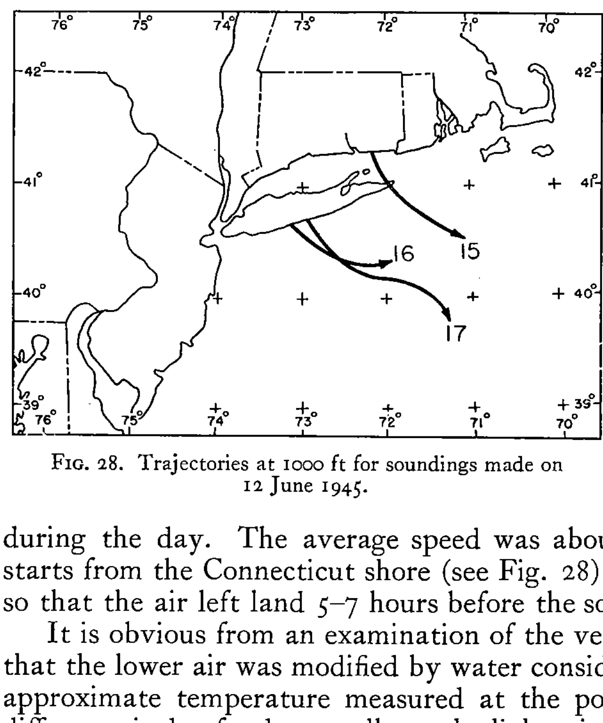

Fig. 28. Trajectories at 1000 ft for soundings made on 12 June 1945.

Sounding 15. — Supplementary observations obtained during the course of the sounding were as follows: Surface wind, 235°, 1 Beaufort; 1000-ft wind, 292°, 8 knots; sky, cloudy; visibility, approximately 2 miles. The water temperature at this position at 09^h30^m on 12 June was 54–55F.

The trajectory of the air in the upper half of the sounding can be determined quite reliably. Pilot-balloon observations made at La Guardia Field, Hartford, Fishers Island, Point Judith, and Quonset Point at various hours show that the wind direction at 1000 ft varied from 320° to 290° during the day. The average speed was about 12 mph. Accordingly, the trajectory starts from the Connecticut shore (see Fig. 28). The length over water is 60–85 miles, so that the air left land 5–7 hours before the sounding, i.e., between 09^h30^m and 11^h30^m.

It is obvious from an examination of the vertical distribution of dew point (Fig. 29) that the lower air was modified by water considerably warmer than 55F, which was the approximate temperature measured at the position of the sounding at 09^h30^m. The difference is due fundamentally to the light winds (1–2 Beaufort) that prevailed all day. The relatively calm state of the sea allowed the daily quota of solar heat to accumulate

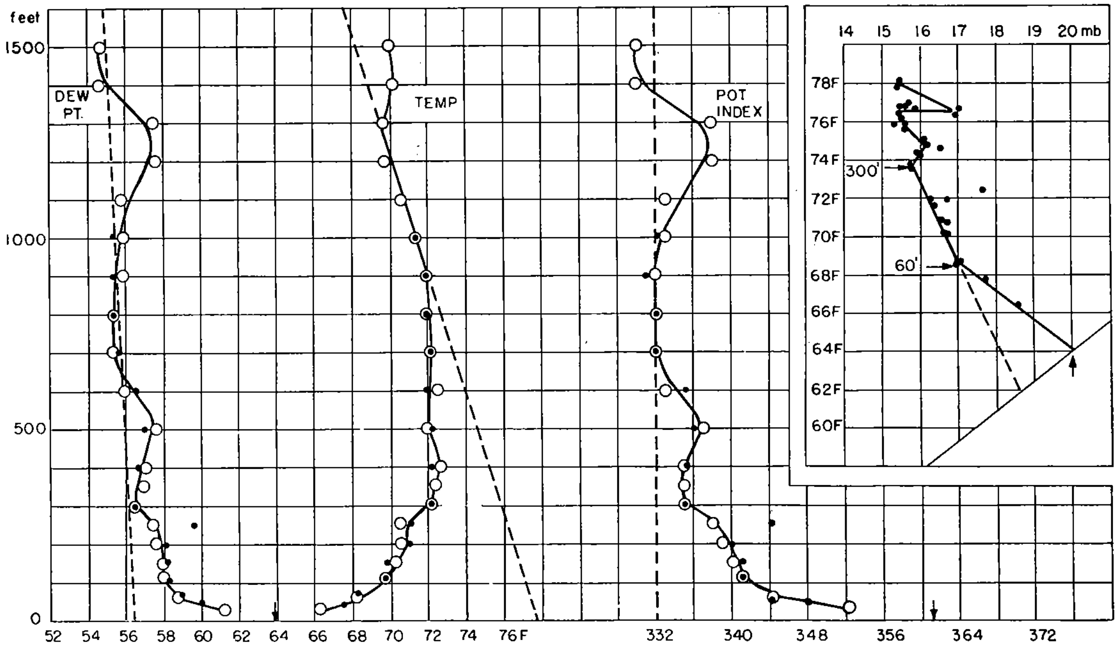

FIG. 29. Sounding 15; 40°32′N, 71°05′W; 12 June 1945; o ascent 16^h20^m–16^h40^m, • ascent 16^h43^m–16^h56^m. Modification by relatively cool water extends to 300 ft. The characteristic curve shows that the air first moved over water of temperature 62F but later came over water of temperature 64F in the vicinity of the sounding. The temperature inversion and the large dew-point lapse in the lowest 100 ft cause downward refraction of horizontally directed radio rays.

in the topmost stratum of water, so that the surface temperature increased considerably from morning to late afternoon. This fact is shown quite clearly by the sequence of water temperatures measured by the ship on that day (see Chart 4).

The characteristic curve (Fig. 29) shows that at first the air was modified up to 300 ft by water of temperature about 62F. The upper limit of modification is made evident also by the fact that the potential dew point varies only slightly above the 300-ft level. The water temperature at the position of the sounding was about 64F. The characteristic curve indicates, however, that the influence of water of that temperature was restricted to the lowest 60 ft.

The stable condition between 300 ft and 900 ft is not easily interpreted, because the previous history of the air in this layer is uncertain. Probably the air was unmixed when it left land. Subsequently it became increasingly inhomogeneous through shearing stratification, as suggested by the large amount of veer of the wind between sea level and 1000 ft.

An adiabatic lapse rate of temperature between 900 ft and 1300 ft is evidence that the air at these levels was convectively mixed and essentially homogeneous before starting on its journey over the ocean. The variation of potential dew point in this layer is probably due to the presence of relatively moist air at the ground and a large moisture lapse when convection commenced. The potential temperature may be compared with the surface temperatures at Groton and Suffolk Field during the forenoon. Both stations reported 76F at 10^h30^m and 78F at 11^h30^m. Hence, the air between 900 ft and 1300 ft is presumed to have left land at about 11^h30^m.

The dew points throughout most of the sounding are lower than the surface values recorded on land during the forenoon. This difference is attributable to a large humidity lapse at the ground, such lapse having been the result of the rain showers that occurred in the early morning.[20] Later on, in the afternoon, the dew points at inland stations beyond the influence of the sea breeze decreased to 55–60F, that is, to values comparable with those measured in the sounding.

The temperature inversion and the large lapse of dew point in the lowest 100 ft cause propagation phenomena like those noted in sounding 9. Radio rays directed horizontally in this layer are refracted downward to the surface.

Sounding 16. — The airplane and the cooperating ship established a rendezvous at the position of this sounding, so that a number of supplementary observations are available (see table below).

	Surface Wind[21]	1000-ft Wind
By airplane	250°, 1 Beaufort	265°, 15 knots

	Time	Surface Wind[21]	Air Temp.	Dew Point	Sea Temp.
By ship	17^h45^m	190°, 5 mph	68.1F	64.0F	60.0F
	18^h00^m	190°, 6	67.8	63.7	62.0

A measurement at the top of the ship's mast (elevation about 30 ft) gave temperature and dew point of 69.2F and 63.8F. Other observations were as follows: Sky, clear, except for a few altocumulus clouds; visibility, 1–2 miles.

Although the 1000-ft wind at the position of the sounding was slightly south of west, pilot-balloon observations made at about this time gave directions between west and north over land. About an hour earlier the airplane recorded the 1000-ft wind direction over point C (about 50 miles east of sounding 16) as 292°. Therefore, it seems reasonable to conclude that the air in the upper part of the sounding had been travelling from south of west for a comparatively short time and that it crossed the coast as a northwesterly wind (see Fig. 28). The estimated length of the over-water trajectory is about 80 miles, and, if an average speed of 12 mph is assumed, the travel time is 6–7 hours. Hence, the air at the 1000-ft level left land at about 11^h. Furthermore, it is presumed that convective mixing extended at least to 1500 ft at that hour, for the airways weather reports indicate that between 10^h30^m and 11^h30^m cumulus clouds began to form over western and central Long Island at estimated elevations ranging from 2000 ft to 3500 ft.

A comparison of Figures 29 and 30 shows that sounding 16 has essentially the same characteristics as sounding 15. The potential temperature in the homogeneous layer between 1200 ft and 1500 ft (see Fig. 30) is consistent with the estimate of the 1000-ft trajectory, for surface temperatures in western and central Long Island were mostly 76F at 10^h30^m and 80F at 11^h30^m. The air below 1200 ft probably left land somewhat earlier than the air in the homogeneous layer; shearing stratification rendered it quite stable.

Modification by the water extends to about 200 ft, as the Taylor diagram (Fig. 30) clearly shows. The relatively moist stratum between 400 ft and 600 ft displays an adiabatic lapse rate of temperature and appears to be the product of an early stage of convection, in which some of the high moisture content of the air at the ground was

[20] Both the Albany and Lakehurst radiosonde observations at 11^h showed a rapid decrease of specific humidity upward in the lowest few hundred feet.

[21] Both observations of surface wind direction were obtained by visual observation of the ripples on the ocean surface. (The airplane did not employ a smoke bomb on this occasion.) Of the two, that made by the ship is probably the more reliable.

transported up to these elevations but was not mixed through a sufficiently deep layer to be completely dispersed. The drier air beneath (200–400 ft) presumably left land before the start of convection.

The water temperature indicated by the characteristic curve is more than 3F higher than the value measured by the ship. The discrepancy is unquestionably a result of

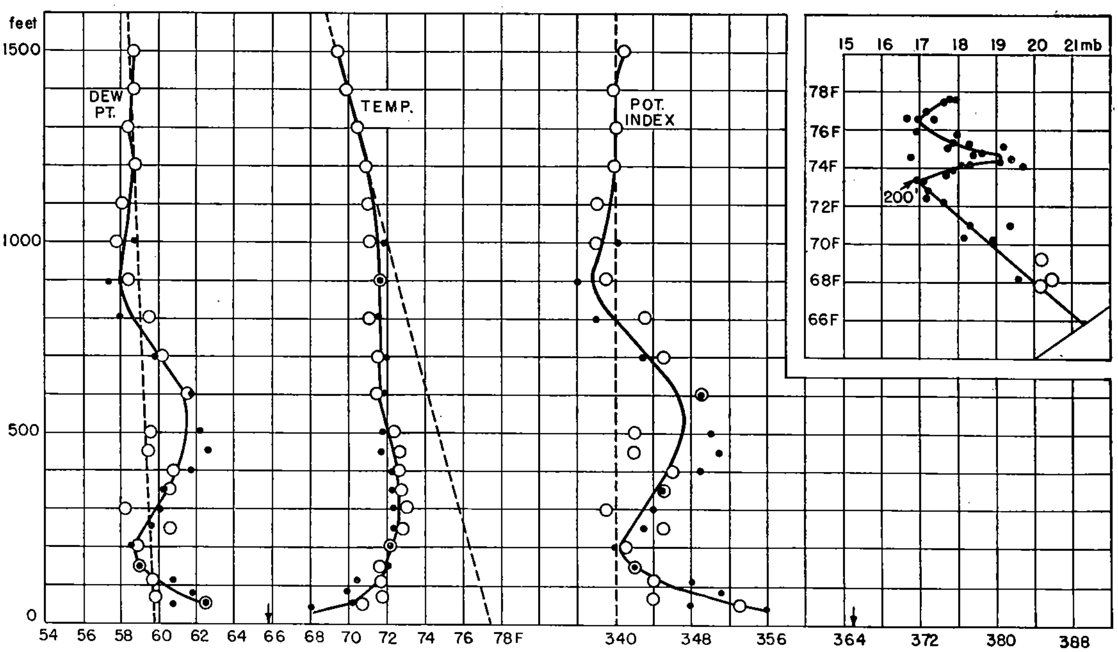

FIG. 30. Sounding 16; 40°20′N, 71°57′W; 12 June 1945; o ascent 17^h38^m–17^h50^m, • ascent 17^h53^m–18^h08^m. Modification by relatively cool water extends to 200 ft. Stable layers above this level are the result of shearing stratification. The relatively moist layer between 400 ft and 600 ft probably is composed of air that left land at the beginning of daytime convection.

the large vertical temperature gradient that must have existed just beneath the sea surface on this day. Since the sea-water thermometer measures the temperature of the water that lies two or three inches below the surface, and since some of this water may, on account of turbulence created by the moving ship, have been brought up from a depth of several feet, it is not surprising to find a difference of the magnitude observed.

Sounding 17. — Supplementary observations taken during the course of the sounding were as follows: Surface wind, 230°, 2 Beaufort; 1000-ft wind, 343°, 20 knots; sky, few altocumulus clouds; sharp haze line visible from airplane. The water temperature 5–10 miles away was measured as 59–63F five hours earlier.

The trajectory, as constructed from the 1000-ft winds measured by the airplane and by pilot-balloon observations, describes a comparatively complicated path (see Fig. 28). The length of the path is 100–125 miles. The air is estimated to have left land within the interval 08^h30^m–10^h30^m. During this period there was a considerable amount of middle clouds over Long Island, and horizontal visibility at the ground was restricted by haze and smoke. These facts suggest that convection could not have become well established before 10^h30^m, so that the air column as a whole must have lacked homogeneity at the time of its departure from land.

In accordance with expectations based on the trajectory analysis, there is no well-defined homogeneous layer in sounding 17 (Fig. 31). The air between 200 ft and 1100 ft is decidedly heterogeneous. Its history is difficult to reconstruct, but one can be

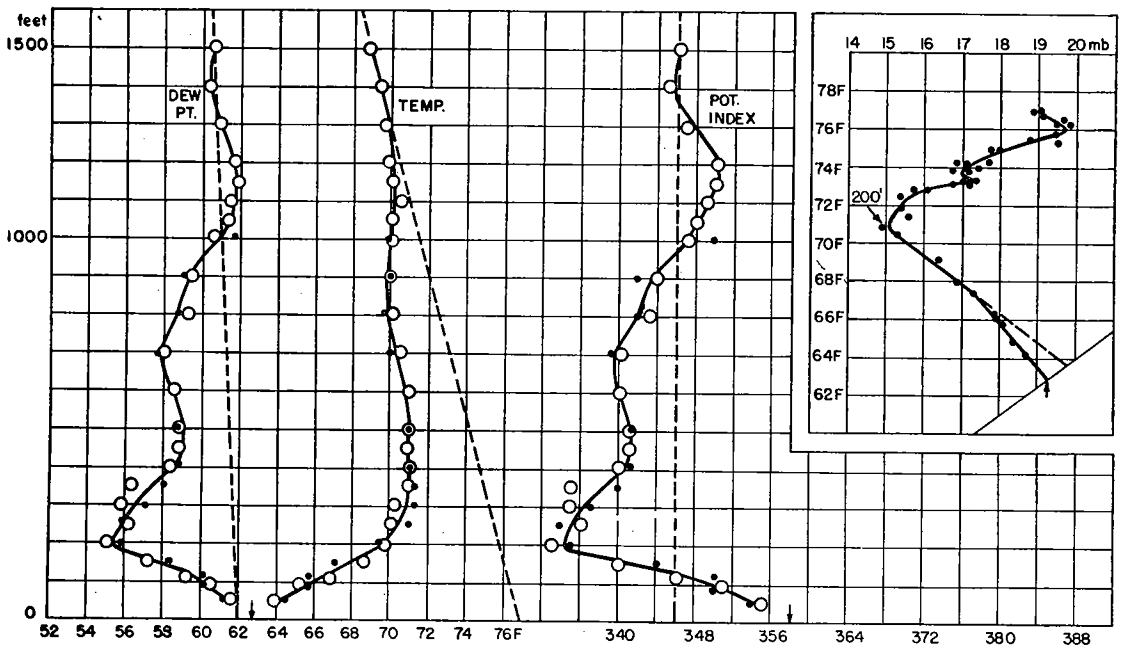

FIG. 31. Sounding 17; 39°48'N, 71°18'W; 12 June 1945; o ascent 18^h41^m–18^h57^m, • ascent 19^h00^m–19^h10^m. Modification by relatively cool water extends to 200 ft, as in the case of sounding 16. The relatively high dew points near the top of the first ascent suggest that convection transported moisture upward from the ground after the air in the lower part of the sounding left land. Superstandard conditions similar to those in soundings 9, 15, and 16 prevail between sea level and 200 ft. Humidity inversions produce substandard conditions at 200–500 ft and at 700–1200 ft.

fairly certain that it left land before the start of active convection. On the other hand, the air between 1200 ft and 1500 ft may have been convectively mixed, for its condition approaches homogeneity. If so, the potential temperature (76–77F) in this layer indicates departure from land at about 11^h. The fact that the potential dew point is higher than in the air below suggests the possibility that moisture was introduced in the upper part of the sounding by convection from a humid source next the ground,[22] while the middle and lower portions, by reason of their earlier departure from land, escaped this effect. In any case, it is probable that the air column consists of several layers having different trajectories, as a result of the light variable winds and the relatively large distance from shore.

The distribution of points on the Taylor diagram (Fig. 31) shows that cooling by the water was effective up to 200 ft. The indicated sea-surface temperature (62.8F) is close to the highest value measured in the vicinity 5 hours earlier. It is apparent from the characteristic curve that the air at one time was over water of temperature 63–64F.

[22] Surface dew points on Long Island during the forenoon were 62–65F.

The somewhat lower value at the position of the sounding can be explained by the marked diurnal variation of the surface-water temperature previously noted on this day; the temperature in the area may well have been slightly higher in mid-afternoon. Furthermore, there is a possibility that an increase in wind speed occurred in the late afternoon.[23] Such an increase would have accelerated mixing of the warmed surface film with the cooler water underneath.

A large lapse of potential index, giving superstandard conditions similar to those noted in soundings 9, 15, and 16, occurs in a rather shallow stratum next the surface. However, humidity inversions produce substandard distributions of refractive index between 200 ft and 500 ft and between 700 ft and 1200 ft.

15 June 1945 (Soundings 18, 19, 20)

Weather Summary. — The entire region from Nantucket to Cape Hatteras was occupied by moist tropical air, for the geostrophic wind along the Middle Atlantic coast had maintained a southwesterly direction since 13 June. Fog prevailed at nearly all stations at sunrise but disappeared during the forenoon. Thunderstorms developed in the afternoon, and fog reappeared at Point Judith and Nantucket in the early evening.

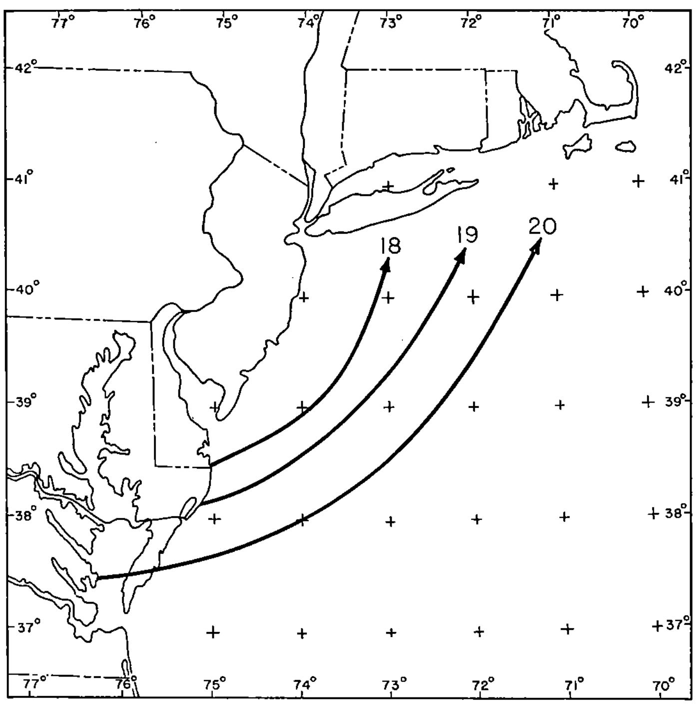

Fig. 32. Trajectories at 1000 ft for soundings made on 15 June 1945.

This was one of a series of hot days. Temperatures in New Jersey, Delaware, and Maryland were 70F or higher in the early morning; by 09^h30^m they were mostly above 80F. Afternoon temperatures exceeded 90F except in coastal areas exposed to onshore

[23] The wind force was 1 Beaufort at soundings 15 and 16, whereas it was 2 Beaufort at sounding 17.

winds. Dew points in the entire region varied between 60F and 76F, the lowest readings having been observed at cool coastal locations.

Sounding 18. — Supplementary observations taken during the course of the sounding were as follows: Surface wind, 190°–200°, 3 Beaufort; 1000-ft wind, 194°, 31 knots; sky, clear; visibility at sea level restricted by haze. A measurement of water temperature made at the position of the sounding in the morning of the following day gave a reading of approximately 64F.

The 1000-ft wind measured by the airplane is in good agreement with pilot-balloon observations at La Guardia Field and Mitchel Field. The winds evidently backed and increased during the afternoon, as shown by a comparison of the pilot-balloon observations made in the late forenoon with those made at about 18^h. Accordingly, the 1000-ft trajectory is cyclonically curved, as shown in Fig. 32, and is 160–180 miles in length. The air is estimated to have left land between 07^h00^m and 08^h00^m.

These calculations are substantiated by the sounding itself (Fig. 33). The air column is stable throughout, as would be expected if it left land within the estimated interval. Furthermore, with the exception of the lowest few hundred feet, the sounding agrees

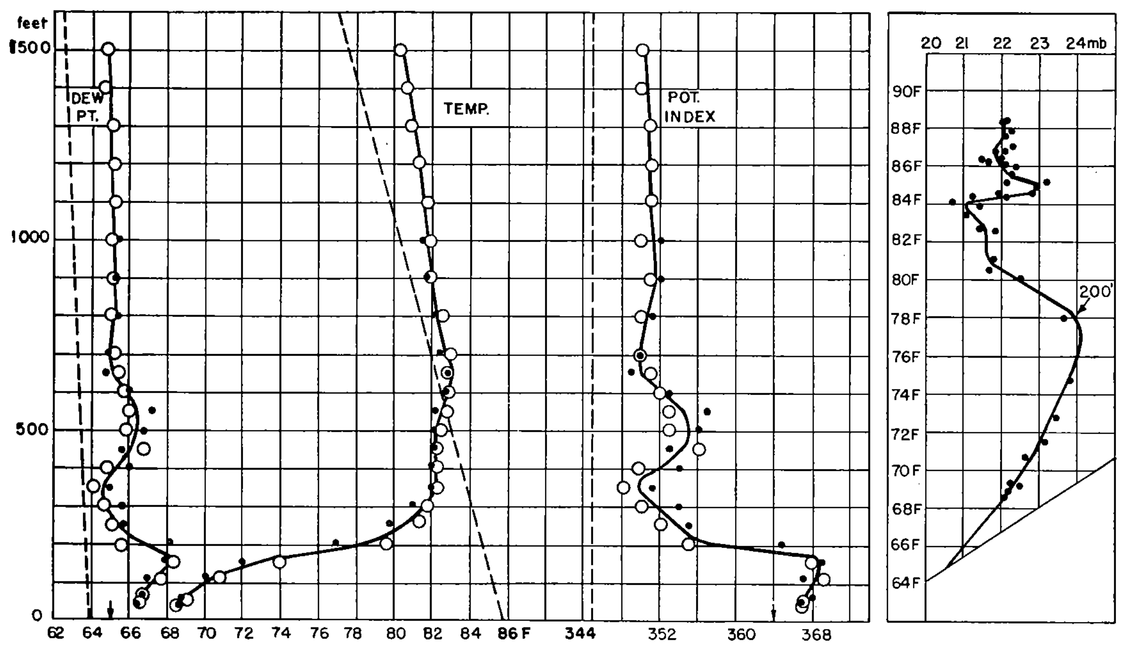

FIG. 33. Sounding 18; 40°22′N, 72°59′W; 15 June 1945; ○ ascent 17^h02^m–17^h17^m, • ascent 17^h20^m–17^h29^m. The air in this sounding left land shortly after sunrise, so that stability prevails at all levels. The characteristic curve indicates that modification by the ocean has not extended beyond a height of 200 ft. The humidity inversion between sea level and 150 ft produces substandard conditions near the surface. Between 150 ft and 350 ft the combination of moisture lapse and large inversion of temperature gives a superstandard layer.

closely with conditions over Norfolk, Virginia, at 23^h in the preceding night.[24] At 150–200 ft, where the dew point is maximum, the air is very similar to surface conditions near the place where the trajectory starts from shore. For example, Cedar Point,

[24] The Norfolk radiosonde ascent showed temperature and dew point of 81F and 67F at 1200 ft.

Maryland, (38°17′N, 76°25′W), reported temperature and dew point of 76F and 70F at 07^h30^m. It therefore appears probable that the air from 200 ft upward was not affected by the ocean, despite the relatively long over-water trajectory.

However, the possibility that the air in the upper part of the sounding left land late enough the same day to have been convectively mixed should be considered. (In that event the stability and the irregular distribution of dew point can be explained as due to shearing stratification.) The potential temperature at the top of the sounding has approximately the same value as the surface-air temperature measured at Atlantic City at 10^h30^m. If the air at 1500 ft actually left land at that time and place, the over-water trajectory was about 115 miles and 7 hours. Such a trajectory would have required a resultant wind direction of 230°, which is hardly possible in the light of observations.

The location of the pronounced bend in the characteristic curve (Fig. 33) clearly shows that modification by the water does not extend above 200 ft, despite the rather long journey over the sea. The indicated water temperature (65F) at the position of the sounding agrees well with the measurement already mentioned. The characteristic curve also indicates that the initial modification of the air was by water of temperature 67–68F. This result is entirely reasonable, since the air in the lowest 200 ft may have had a more southerly trajectory than that in the upper part of the sounding.

Sounding 19. — The cooperating ship established a rendezvous with the airplane at the position of this sounding, so that a comparatively large number of supplementary observations of temperatures and wind were obtained. These are presented in the following table.

		Surface Wind		1000-ft Wind	
By airplane		195°, 3 Beaufort		213°, 30 knots	
	Time	Surface Wind	Air Temp.	Dew Point	Sea Temp.
By ship	18^h00^m	200°, 12 mph	67.4F	65.0F	62.0F
	18^h15^m	200°, 10	67.1	65.0	60.8
	18^h30^m	200°, 10	67.3	65.5	62.6

Other pertinent observations were as follows: Sky, clear; visibility at sea level restricted by haze; sea temperatures measured by the ship as it approached the rendezvous from the south during the preceding 1½ hours were 62.2–64.3F.

The 1000-ft trajectory is similar to that for sounding 18. It starts from shore near the boundary between Virginia and Maryland (see Fig. 32) and has a length of 230–260 miles. The time at which the air left land was about 06^h.

As in the preceding sounding, there is a maximum of dew point not far above the surface (Fig. 34), the height in this case being 250 ft. The temperature and dew point at 250 ft agree well with early-morning surface observations on shore. The air column is stable except between 1200 ft and 1500 ft, where the potential temperature is constant. This essentially homogeneous layer (the potential dew point is nearly constant) cannot be the result of convection over land on 15 June. Alternatively, it must have been formed on the previous day and must not have been affected by nocturnal cooling from below prior to departure from land. This interpretation is supported by a radiosonde ascent at Norfolk, Virginia, at 23^h on 14 June. The ascent revealed the presence of a nearly homogeneous layer between 1400 ft and 3600 ft, in which the potential temperature varied from 88F to 90F and the potential dew point decreased from 68F to 65F.

The lowest layer of the air column shows loss of heat and moisture to the water. In this case the influence extends to 250 ft, as shown by the location of the prominent bend in the characteristic curve. Although the indicated water temperature (63.5F) is somewhat higher than the values measured at the position of the sounding, it is consistent with the observations made less than 10 miles to windward. The portion of the charac-

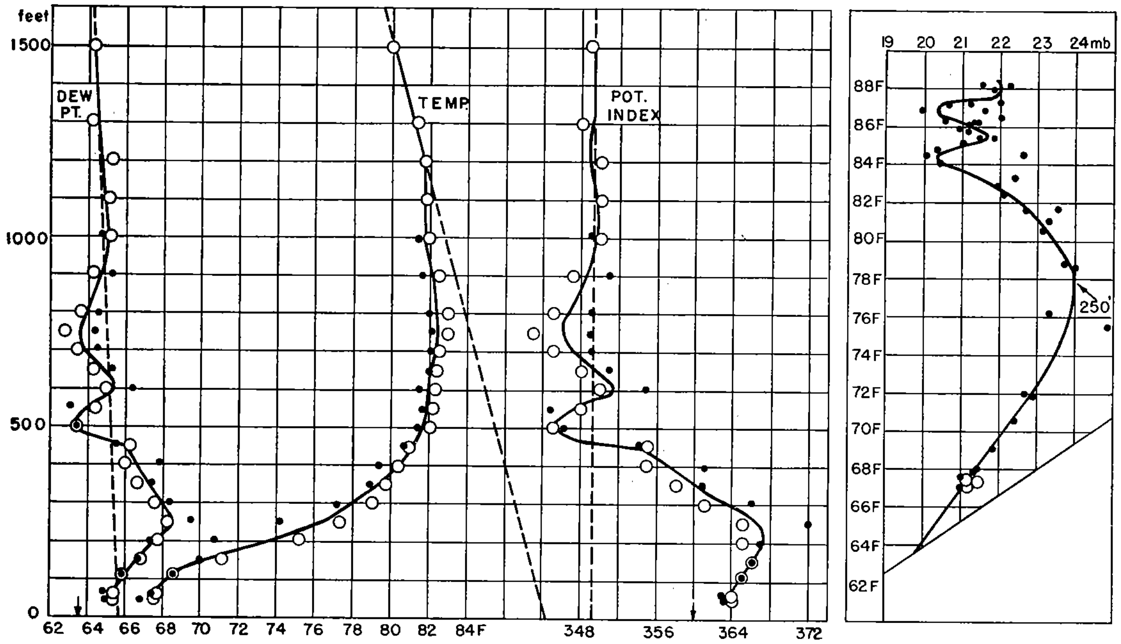

FIG. 34. Sounding 19; 40°26′N, 72°03′W; 15 June 1945; o ascent 18^h07^m–18^h22^m, • ascent 18^h24^m–18^h34^m. Modification by the ocean extends only to 250 ft despite the long over-water trajectory. The vertical distributions of temperature and humidity are much like those of sounding 18 and bring about a similar distribution of refractive index.

teristic curve that fits points below 250 ft is not a straight line and shows definitely the effect of gradually decreasing sea-surface temperature along the trajectory. The initial modification was by water of temperature close to 68F.

The humidity inversion between sea level and 250 ft produces a substandard layer next the surface. Marked superstandard conditions prevail between 250 ft and 500 ft, due to the large lapse of dew point and strong temperature inversion in that region.

Sounding 20. — Supplementary observations made by the airplane during the course of this sounding were as follows: Surface wind, 200°, 3 Beaufort; 1000-ft wind, 210°, 24 knots; sky, clear; visibility, approximately 6 miles. During the preceding night the water temperature along a line running southward through the position of the sounding was 59–62F.

The 1000-ft trajectory of the air in this sounding starts from the coast of northeastern Virginia and is 300–350 miles in length (see Fig. 32). The air is estimated to have begun its offshore journey at about 03^h or 04^h and to have been over Chesapeake Bay earlier in the night.

One important respect in which this sounding (Fig. 35) differs from the two preceding ones is the presence of a marked humidity lapse at its top. During the preceding night variability between radiosonde ascents was evident within the same air mass. For example, the large humidity lapse began at 3600 ft over Norfolk, at 1300 ft over Washington, and at 600 ft over Cape Hatteras.

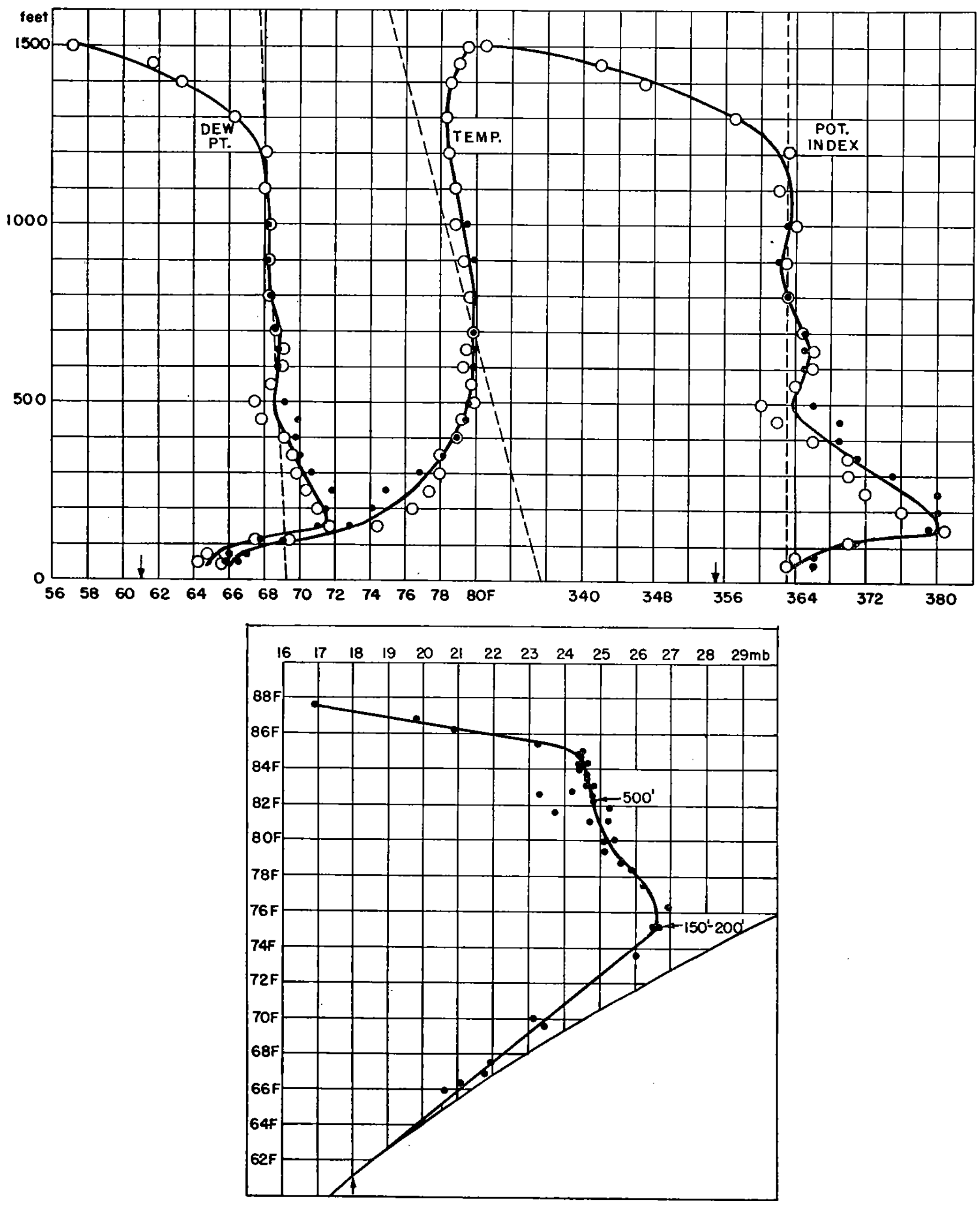

FIG. 35. Sounding 20; 40°32′N, 71°05′W; 15 June 1945; o ascent 19^h13^m–19^h28^m, • ascent 19^h31^m–19^h47^m. Modification by water of temperature less than 70F is restricted to the lowest 200 ft. The humidity maximum at the 200-ft level and the lapse of moisture between 200 ft and 400 ft indicate that the air has previously been over water of temperature somewhat greater than 72F. The marked type-2 superstandard layer at the top of the sounding results from the combination of moisture lapse and temperature inversion between 1300 ft and 1500 ft.

Throughout the greater part of sounding 20 the dew points average about 4F higher than the values at corresponding levels in soundings 18 and 19. This fact is consistent with the more southerly origin of the air in sounding 20. The layer from 800 ft to 1200 ft has constant potential dew point and evidently was at one time homogeneous. (It will be recalled that similar conditions were found between 1200 ft and 1500 ft in sounding 19.) The occurrence of this condition in a very moist layer with a well-defined top suggests that a homogeneous state, acquired over land the day before, was maintained throughout the night by radiational cooling of the upper boundary.

Of particular interest is the maximum of dew point at 200 ft. If this maximum were the result of modification over the ocean, the sea-surface temperature would have had to have been 73–74F along some part of the trajectory. Unfortunately, the distribution of water temperature is not completely known, although a few data are available. At about 13^h the ship, which was headed on a N by W course, crossed the 1000-ft trajectory at a point 80 miles to windward of the sounding. Water temperatures of 66–69F were measured in the vicinity. During its cruise of 14–16 June the ship nowhere encountered water warmer than 69F. However, south and east of Cape Hatteras the average sea-surface temperature in the month of June exceeds 75F (see Fuglister, 1947), so it is possible that the lowest 500 ft of the air column has passed over a stretch of ocean having a temperature of 73–74F.

The estimated trajectory of the air at 200 ft starts from the coastal region of Virginia and North Carolina. During the preceding night temperatures of 75–80F and dew points of 70–74F were observed in that area. Since these conditions are similar to those at the 200-ft level in the sounding, it is probable that the humidity maximum was formed over the numerous swamps and shallow, warm inland waterways which lie between Norfolk and Cape Hatteras. If this interpretation is correct, the effect of modification by relatively cool water extends only to 200 ft, in spite of the fact that the air travelled 300 miles over the ocean. Even if the humidity maximum were produced over ocean water of temperature 73–74F, one cannot avoid the conclusion that the subsequent modification by colder water began before the air had approached to within 150 miles of the position of the sounding. It is remarkable that this modification is restricted to such a shallow layer after such a long trajectory.

The water vapor in the modified layer is nearly saturated. In this connection it may be mentioned that the airplane encountered fog between soundings 19 and 20 and during the return flight to Quonset Point after the completion of sounding 20. The sea temperature indicated by the characteristic curve on the Taylor diagram is 61.0F ± 4.0F. (The uncertainty arises because the characteristic curve is very nearly parallel to the salt-water curve.) The range of values agrees well with the measurements made in the vicinity during the preceding night.

The comparatively cool water at the position of this sounding produced a humidity inversion like that in the previous sounding. Accordingly, the distribution of refractive index is again indicative of substandard conditions close to the sea surface.

16 June 1945 (Soundings 21, 22, 23)

Weather Summary. — As on the preceding day, the entire coastal region between Nantucket and Delaware Bay was occupied by maritime tropical air. The geostrophic wind was about 270°, 20 mph, in the early morning, but during the forenoon and early afternoon it backed over the eastern portion of the area, and by 14^h30^m its direction in the vicinity of Nantucket had changed to 230°. By evening a direction of 230° had become established over the western portion of the area as well.

Fog was reported at some stations before sunrise but it mostly disappeared by 08^h30^m. Despite the presence of scattered to broken high clouds, there was appreciable surface heating over land, and cumulus clouds had formed by 11^h30^m. Scattered showers and thunderstorms occurred during the afternoon.

Surface temperatures at inland stations were close to 70F in the early morning and rose rapidly to maxima of 90–95F in the early afternoon. Surface dew points ranged from 65F to 70F throughout the day.

Sounding 21. — Supplementary observations made by the airplane during the course of the sounding were as follows: Surface wind, 220°, 3 Beaufort; 1000-ft wind, 220°, 20 knots; sky, clear; visibility, 2½ miles in haze; depth of haze layer, at least 1500 ft. During the preceding 18 hours water temperatures of 63–65F were measured within a radius of 10 miles.

Prior to arrival at the position of the sounding the air had been following a cyclonically curved path. This fact is deduced from the late-forenoon pilot-balloon observations in New Jersey; at 11^h the 1000-ft wind over Spring Lake was 260°, 15 mph, and over Cape May it was 280°, 15 mph. On the assumption that the time variations in the direction and speed were linear, the trajectory is traced back approximately 70 miles to the New Jersey shore (see Fig. 36), so that the air must have left land shortly after 12^h00^m. At that time it was convectively mixed, for the radiosonde ascent made at Lakehurst at 11^h showed a superadiabatic lapse rate from the ground to 400 ft and an adiabatic lapse rate from 400 ft to 2000 ft. This interpretation is consistent with conditions in the upper half of the sounding. The potential temperature and dew point between 700 ft and 1500 ft are similar to the surface values (87F and 67F) at Lakehurst at 12^h30^m.

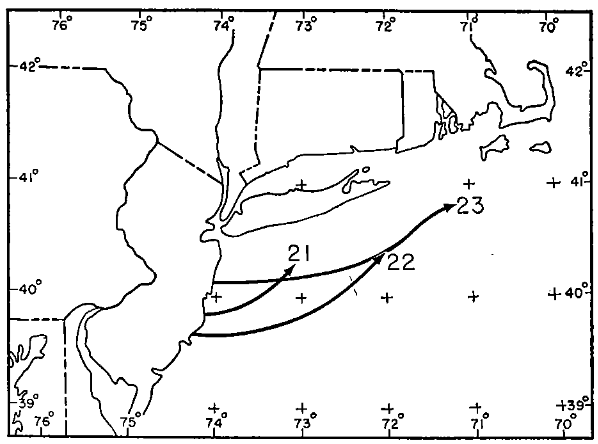

FIG. 36. Trajectories at 1000 ft for soundings made on 16 June 1945.

According to the Taylor diagram (Fig. 37), over-water modification extends to about 200 ft. The form of the characteristic curve indicates a varying water temperature. The layer between about 100 ft and 200 ft was modified by water of temperature 68–69F, while the air below 100 ft was influenced at the end by water of temperature 66F. The latter value is seen to agree well with the measurements made in the vicinity earlier in the day, if the likelihood of some diurnal heating is taken into consideration, but it is difficult to account for the modification by water of 68–69F. Measurements made by the ship within a few miles of the New Jersey coast in the early morning gave readings below 66F. One possibility is that the air between 125 ft and 200 ft was in contact with the earth's surface before reaching the coast and was affected by the comparatively warm waters of the inland bays that lie north-northeast of Atlantic City. Upon arrival at the outer beach, this layer could have ascended over a shallow stratum of cooler, maritime air and thus never have come in contact with the surface of the ocean. Favoring this explanation is the fact that the ship, while cruising within 25 miles of the New Jersey shore between 05^h00^m and 08^h00^m of this day, observed the wind as SSW, force 2, and

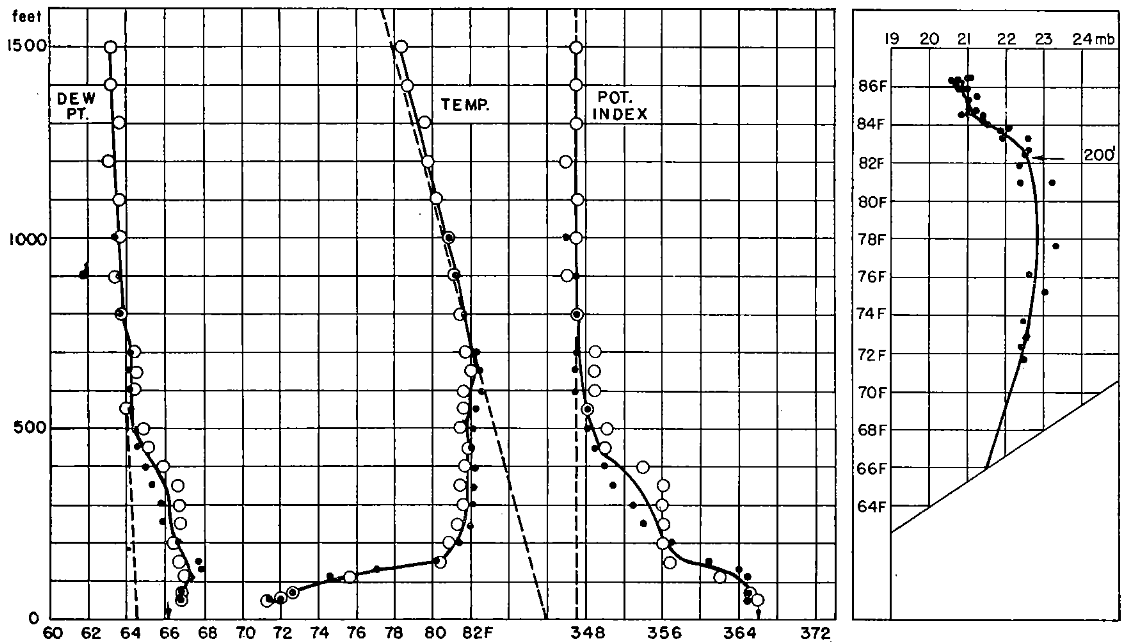

FIG. 37. Sounding 21; 40°18′N, 73°02′W; 16 June 1945; ○ ascent 16^h04^m–16^h20^m, • ascent 16^h27^m–16^h36^m. The air has been modified by the water to a height of 200 ft. The humidity inversion at the bottom of the sounding is due to the influence of water colder than that encountered by the air near the start of the trajectory. The isothermal layer between 200 ft and 700 ft is the result of shearing stratification.

the air temperature (at 20 ft) as 66–68F. Since the ship at no time between 04^h00^m and 11^h00^m observed a surface wind direction having a component from the New Jersey coast, it seems virtually certain that the air in the lowest 100 ft of the sounding had a much longer over-water trajectory than the layers above 200 ft.

It is to be expected that the air in the lower part of the unmodified portion of the sounding left land earlier than the air at the top, in accordance with the normal vertical variation of wind velocity. The air parcels between 200 ft and 700 ft evidently left land during the period of rapidly rising temperature in the early forenoon, with the result that shearing stratification was decidedly effective in the region from 200 ft to 700 ft. However, stability caused by shear was negligible above 700 ft, probably because the potential temperature in the convection layer over land increased very slowly after reaching a value of 86F.

Sounding 22. — Supplementary observations made during the course of this sounding were as follows: Surface wind, 210°, 3 Beaufort; 1000-ft wind, 220°, 20 knots; sky, clear; visibility, 4 miles in haze; depth of haze layer, 1450 ft. Twenty-four hours earlier the measured water temperature in the vicinity was 61–64F.

Computations based on the winds observed at 1000 ft indicate that the air in the upper half of the sounding left land at about 10^h30^m and had an over-water trajectory approximately 125 miles in length (see Fig. 36). It is probable that most of the air was convectively mixed prior to departure from land, for cumulus clouds had already begun to form at scattered points by 10^h30^m. This supposition is largely substantiated by the

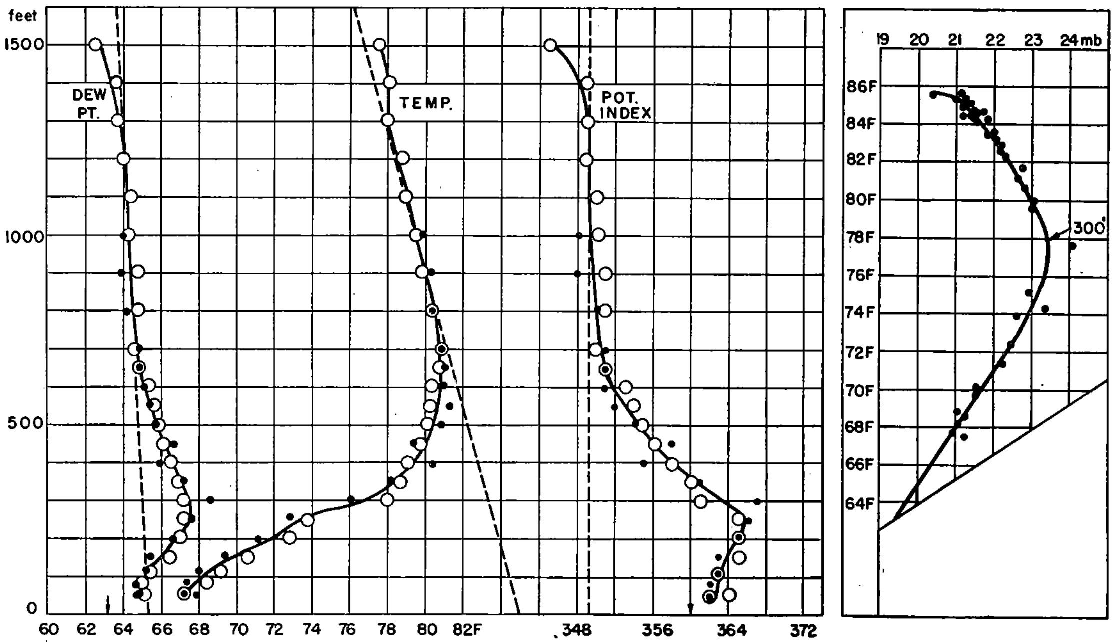

FIG. 38. Sounding 22; 40°25′N, 72°00′W; 16 June 1945; o ascent 17^h13^m–17^h27^m, • ascent 17^h30^m–17^h42^m. This sounding is similar in most respects to sounding 21. Modification by relatively cool water extends to about 300 ft and gives rise to substandard conditions in the layer affected.

essentially homogeneous layer between 800 ft and 1300 ft (see Fig. 38), which has the same potential temperature (85F) as the surface air at Atlantic City at 10^h30^m. The marked decrease in dew point at the top of the sounding is an indication that mixing had not extended above 1400 ft at the time the air left land.

The cooling and dehumidifying influence of the ocean extends to 250–300 ft. The exact height is quite clearly shown by the location of the maximum of dew point and by the characteristic curve. The indicated water temperature (63.0F ± 1.0F) is consistent with measurements made there in the preceding day.

The stability of the air between 300 ft and 800 ft may be due to shearing stratification, in which case each of the various strata originally belonged to a homogeneous column. Alternatively, the structure of the layer in question may be the result of nocturnal cooling, in which case it is assumed that all the air within this height range left land at least two hours earlier than the air at 1000 ft. The fact that the temperatures here are about 2F higher than at the corresponding levels in sounding 23, which, as will be seen, consists of air that definitely left land before the start of convection, suggests that the stability was produced by shearing stratification rather than nocturnal cooling.

Sounding 23. — Supplementary observations of temperatures and wind at the position of this sounding are given in the table below.

		Surface Wind		1000-ft Wind	
By airplane		210°, 3 Beaufort		267°, 10 knots	
	Time	Surface Wind	Air Temp.	Dew Point	Sea Temp.
By ship	18^h00^m	190°, 11 mph	64.4F	62.3F	60.2F
	18^h15^m	190°, 11	64.5	62.5	61.0
	18^h30^m	190°, 11	64.5	62.5	61.5

Other pertinent observations were as follows: Sky, clear; visibility, 2 miles in haze.

According to the trajectory constructed from available wind data for the 1000-ft level, the air in the upper part of the sounding left the coast of New Jersey between 07^h00^m and 08^h00^m and travelled 160–170 miles over the water (see Fig. 36). Judging from the wind directions reported by the ship in this general area during the preceding 24 hours, the air next the surface had a much longer maritime history. Hence, it is likely that none of the air in the sounding had been convectively mixed over land earlier in the day. The absence of any homogeneous layer in the sounding (see Fig. 39) supports this assumption.

The position of the bend in the characteristic curve indicates that the cooling and drying influence of the water extended to about 250 ft, which is approximately the height of over-water modification observed in soundings 21 and 22. It appears that nocturnal cooling produced the stable state above 250 ft. The vertical structure re-

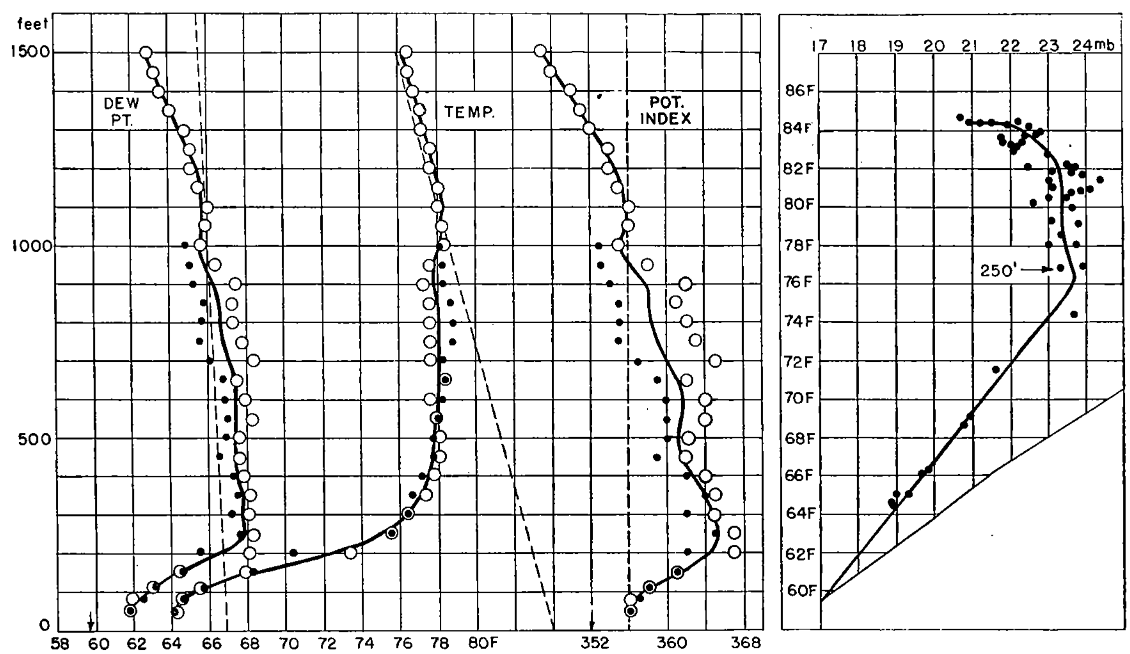

FIG. 39. Sounding 23; 40°49′N, 71°10′W; 16 June 1945; o ascent 18^h07^m–18^h22^m, • ascent 18^h25^m–18^h37^m. Modification by the water extends to approximately 250 ft. The air was inhomogeneous when it left land, so that the distribution of dew point is quite irregular. The humidity inversion in the modified layer produces markedly substandard conditions in the lowest 200 ft.

mained essentially unchanged after sunrise, because of the fact that the air was moving over the cool ocean all day. The irregular distribution of dew point indicates different trajectories at different altitudes. Direct evidence of diverse trajectories is furnished by pilot-balloon observations made at 05^h in the westerly flow over New Jersey. The veer of the wind between the surface and 2000 ft was about 45° at that time.

It is interesting to note that a substandard distribution of refractive index prevailed close to sea level again on this day at the same positions (points B and C) as on 15 June. This phenomenon is attributable to the persistence of a low-level humidity inversion, which was maintained by the continuation of the flow of maritime tropical air over the comparatively cool water at points B and C.

The water temperature inferred from the Taylor diagram is somewhat uncertain, because the lower portion of the characteristic curve is nearly parallel to the salt-water curve. However, the indicated value (approximately 60F) agrees quite well with the range of sea-surface temperatures measured by the ship.

The values of potential temperature and vapor pressure derived from the psychrometric observations made on board the ship are almost exactly equal to those recorded by the airplane at a height of 50 ft, and, in order to avoid congestion, they have not been plotted on the Taylor diagram.

19 June 1945 (Soundings 24, 25, 26)

Weather Summary. — The coastal states from Massachusetts to Delaware remained in a southwesterly flow of maritime tropical air in advance of a very slowly moving cold front, which, at 08^h30^m, extended from eastern Pennsylvania to northeastern Massachusetts. The sky was mostly cloudy all day. During the afternoon thunderstorms developed in the extreme west and north portions of the area. Fog was prevalent along the coastal sections of southern Rhode Island and southeastern Massachusetts during the morning and again in the evening. Surface temperatures at inland stations were 65–70F at sunrise and increased to 80–85F in the afternoon. Dew points remained between 65F and 70F throughout the day.

Sounding 24. — Supplementary observations made by the airplane during the course of the sounding were as follows: Surface wind, 210°, 3 Beaufort; 1000-ft wind, 200°, 20 knots; sky, scattered high clouds; visibility, 5 miles in haze; patches of fog present near the sea surface. The water temperature measured by the ship 1–2 hours later and 5 miles south of the position of the sounding was 68F.

This sounding reaches a higher elevation than any other in the series and displays a large number of complicated features. The occurrence of scattered, local showers in the region where the air in the upper part of the sounding was located during the preceding night, in combination with diverse trajectories at different levels, has produced unusually irregular distributions of temperature and dew point (see Fig. 41).

The trajectory of the air at 1000 ft, as calculated from pilot-balloon observations,[25] starts from the coast of Delaware and runs very close to Cape May (see Fig. 40). Whether the trajectory leaves shore south of Cape Henlopen and passes east of Cape May or originates over the western side of Delaware Bay and crosses the southern tip

[25] The 1000-ft wind reported by the airplane at the position of the sounding is disregarded because its direction not only seems inconsistent with the measured surface wind but does not agree with pilot-balloon observations at such points as Cape May, Fishers Island and Point Judith.

of New Jersey cannot be definitely determined. In the first instance, the air had an uninterrupted over-water journey of about 175 miles; in the second, it first had an over-water passage of about 15 miles across Delaware Bay, then an overland journey of about 20 miles, followed by over-water travel of about 115 miles. In either case the air at 1000 ft left the mainland several hours before noon.

The wind direction at 3000 ft was about 230°, so that the air at the top of the sounding probably left land about 20 miles north of Atlantic City between 13^h00^m and 14^h00^m.

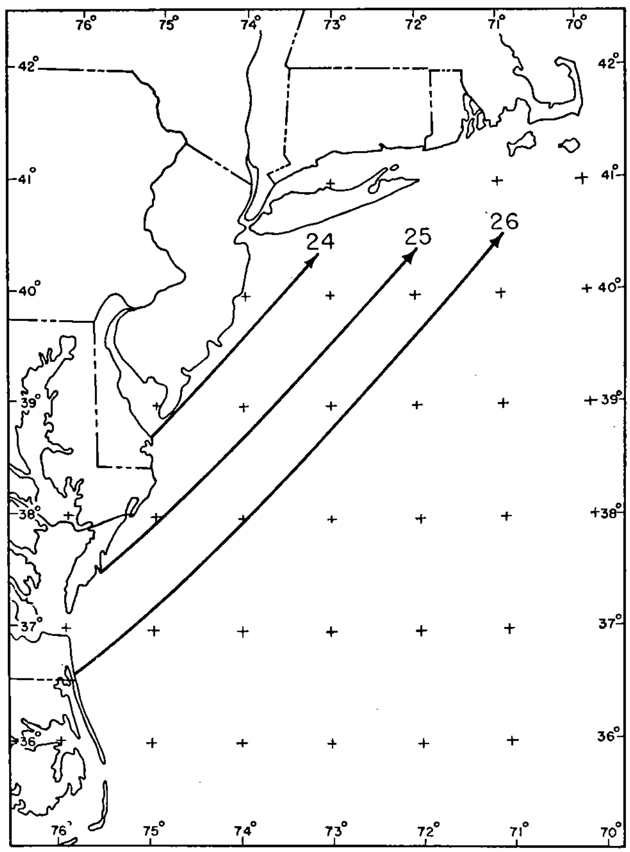

FIG. 40. Trajectories at 1000 ft for soundings made on 19 June 1945.

In contrast to this trajectory is that of the air close to the sea. This surface layer came from a south-southwesterly direction. Probably it left land somewhere between Norfolk and Cape Hatteras and travelled over the ocean for at least 24 hours.

The only portion of the sounding (Fig. 41) that contains essentially homogeneous air is that between 2350 ft and 2700 ft. On the basis of the computed trajectory this layer could have been formed over land around noon of this day. Furthermore, the potential temperature and dew point in the layer agree well with surface observations in New Jersey at the time the air in the upper third of the sounding is supposed to have left land.

The air in the lowest 300 ft of the sounding was moistened and cooled by passage over the ocean. There is a possibility that this air may have been over warmer water at the start of its trajectory, but such a supposition cannot be verified. The characteristic curve only indicates modification by progressively cooler water, the temperature at the

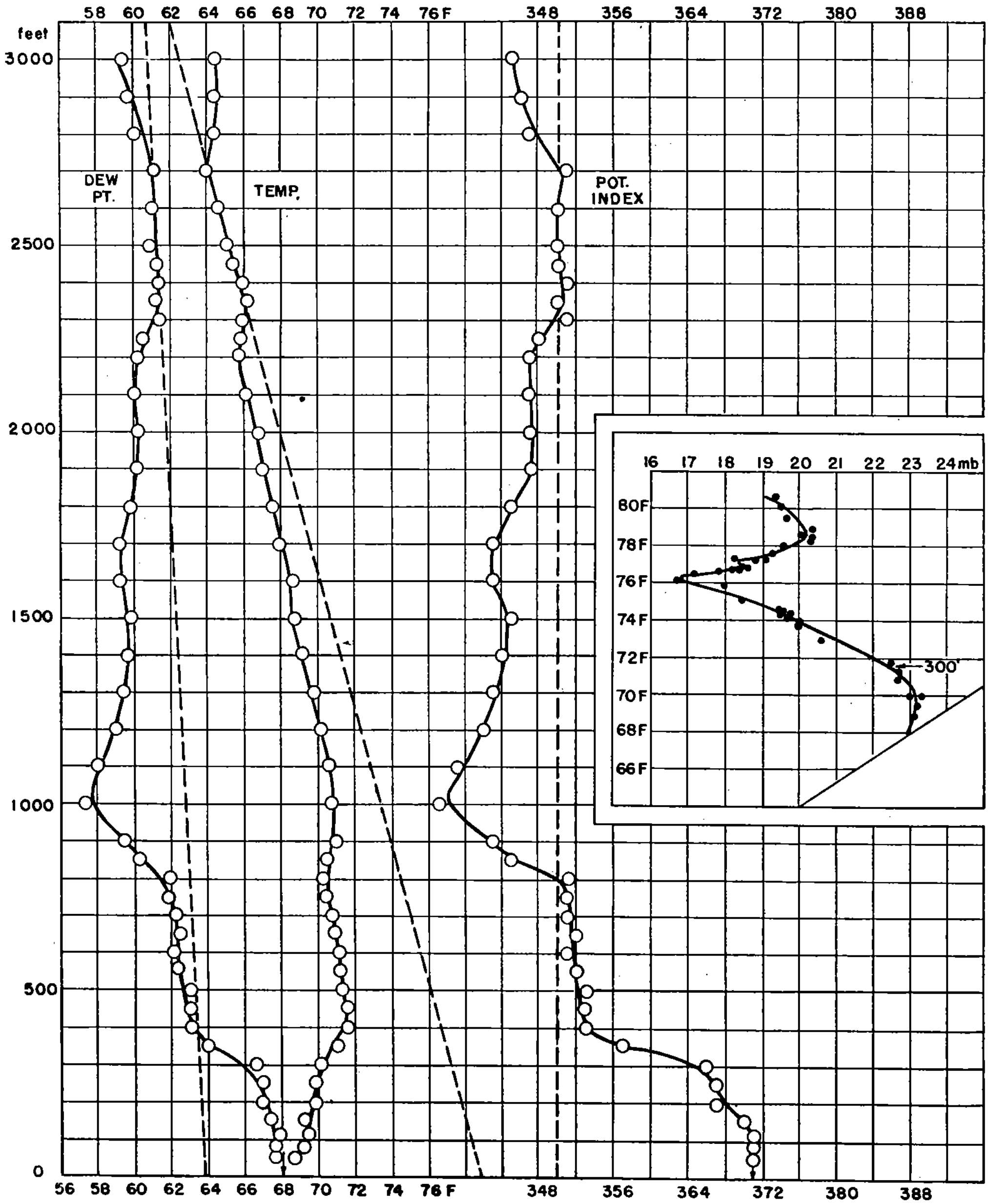

FIG. 41. Sounding 24; 40°23′N, 73°08′W; 19 June 1945; o ascent 17ʰ01ᵐ–17ʰ33ᵐ. This sounding presents a number of complications, and many of the structural details cannot be explained satisfactorily. Modification by the water extends only to 300 ft, despite the fact that the trajectory is more than 100 miles in length. Large lapses of dew point between 300 ft and 400 ft and between 800 ft and 1000 ft produce markedly superstandard conditions in those layers.

position of the sounding being 68F. This value agrees very well with measurements made a few miles away at about the same time.

Other details of the sounding cannot be explained satisfactorily. It is possible that the air between 400 ft and 800 ft traversed the southern tip of New Jersey between 10^h00^m and 11^h00^m and became partially mixed during the crossing, but this interpretation is not easily reconciled with the wind observations.

With the exception of markedly superstandard layers at 300–400 ft and 800–1000 ft, which are associated with large lapses of dew point, propagation conditions are close to standard through the entire vertical range of the sounding.

Sounding 25. — Observations of the wind at the position of this sounding were prevented by fog. Therefore, it is necessary in this case to deduce the trajectory with the aid of the observations made at sounding 24 and the pilot-balloon reports obtained from land stations. The only certain conclusion that can be drawn is that the air at 1000 ft left land somewhere between Delaware Bay and Norfolk (see Fig. 40) and travelled a distance of at least 200 miles over water prior to its arrival at the position of sounding 25. The time of departure from land probably was between midnight and

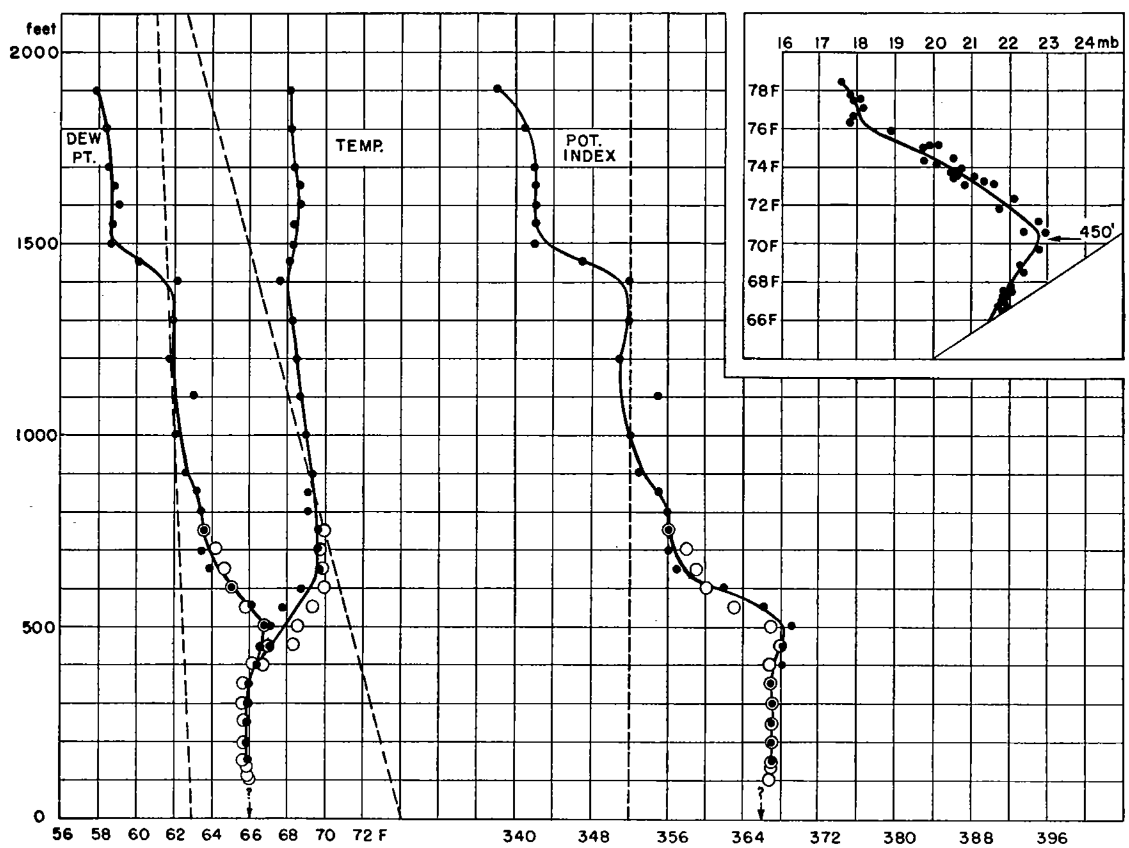

FIG. 42. Sounding 25; 40°25′N, 72°00′W; 19 June 1945; o descent 18^h03^m–18^h10^m, • ascent 18^h10^m–18^h25^m. Fog is present from sea level to an estimated height of 300 ft. Modification by the water extends to 450 ft. The marked degree of stability in the upper part of the sounding is accounted for by the fact that the air left land during the preceding night.

07^h00^m. During the relatively long passage over the ocean the modifying influence of water of temperature less than 68F extended to 450 ft, as shown by the location of the maximum of dew point and the shape of the characteristic curve (Fig. 42).

The presence of a temperature inversion between 450 ft and 650 ft may indicate that the air in this layer was modified by water of temperature of about 69F. In this connection it should be mentioned that the ship measured water temperatures of 69.0–69.5F approximately 50 miles east of Atlantic City about 7 hours after sounding 25 was made. This position lies very close to the 1000-ft trajectory. On the other hand, the layer in question may have acquired its characteristics over a moist land surface of temperature 69F during the night. In any case, the 450-ft level marks the upper limit of modification by water of temperature approximately equal to that of the sea surface in the vicinity of the sounding.

The air above 650 ft remains essentially as it was when it left land. The marked degree of stability is consistent with the results of the radiosonde ascent made at Norfolk at 23^h on 18 June. The large moisture lapse between 1400 ft and 1500 ft appears in the Norfolk ascent also, and the temperature and dew point at the top of the sounding are similar to Norfolk's values (69F and 55F) at the 1900-ft level.

The best fitting straight line on the Taylor diagram for points below 450 ft intersects the salt-water curve at 66F. However, this value cannot be considered a reliable indication of the actual water temperature, because no psychrometric measurements were made closer to sea level than 110 ft. About 6 hours earlier the ship, which at that time was located 3 miles north of sounding 25, measured the water temperature as 64.5F.

According to the airplane's report, the fog extended from sea level to an estimated height of 300 ft and had an undulated top.

Sounding 26. — Supplementary observations made during the course of this sounding were as follows: Surface wind, 3 Beaufort (direction not determined); 1000-ft wind, indeterminable; sky, scattered high clouds; thick fog from the sea surface up to 200 ft (the fog layer had an undulated top). Water temperatures measured within a 10-mile radius of this position on 18, 19 and 20 June ranged from 60F to 64F.

The air at 1000 ft left land during the preceding night at a point more than 300 miles southwest of the position of the sounding (see Fig. 40). The path of the air near the sea surface probably leads back to the region east of Cape Hatteras, so that the lower layers of the sounding had no immediate overland history.

The psychrometric measurements suggest that the depth of the saturated surface layer varied with time or space, or with both. Such variation was undoubtedly real, since the results are consistent with the observed undulated character of the top of the fog. Although very great stability prevails up to at least 1000 ft (see Fig. 43), it is unlikely that the modifying influence of relatively cool water penetrated to that elevation, because the maximum of dew point occurs at about 500 ft in both the ascending and descending runs of the airplane. Furthermore, in each characteristic curve the sharp bend that appears among points corresponding to measurements in the vicinity of the 600-ft level quite certainly marks the upper limit of cooling by the water.

The indicated value of the water temperature (approximately 64F) is consistent with the results of measurements made in the vicinity by the ship. The shape of the characteristic curves gives evidence that the air travelled over progressively cooler water. The effects of earlier modification by water of temperature as high as 68.5–69.0F are apparent.

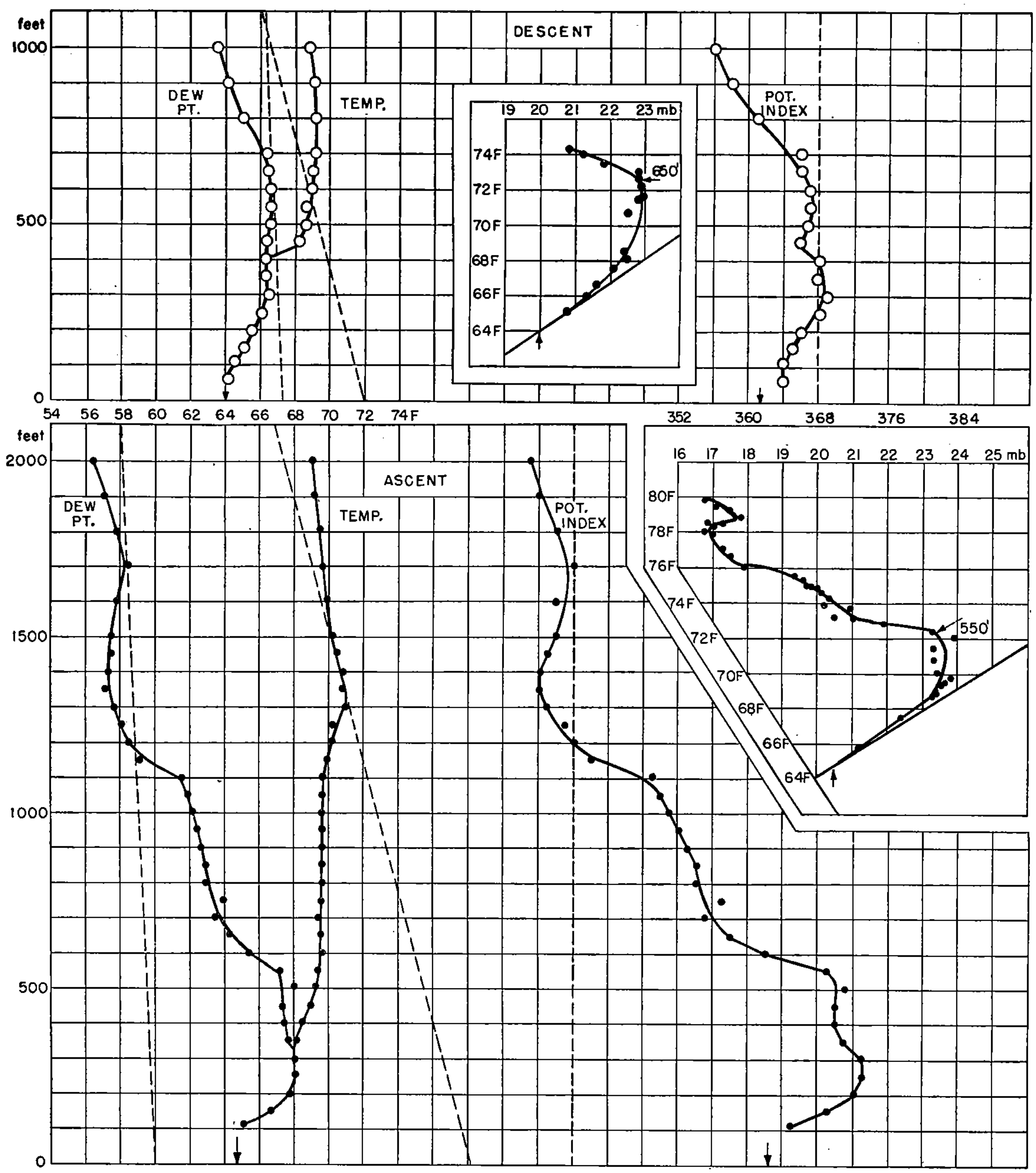

FIG. 43. Sounding 26; 40°32′N, 70°58′W; 19 June 1945; o descent 18^h53^m–18^h59^m, • ascent 18^h59^m–19^h15^m. Fog is present from sea level to an estimated height of 200 ft. Modification by water of varying temperature extends to about 600 ft. The humidity inversion in the lowest 200 ft produces substandard conditions in the fog layer.

In the light of available information regarding the distribution of sea temperature off the middle Atlantic coast at this time, it is probable that the distinguishable modification of the lowest 500–600 ft of air took place entirely within the last 150 miles of the trajectory.

Whereas propagation conditions next the sea surface were close to standard in sounding 25, the distribution of refractive index in the fog layer of sounding 26 is substandard. The difference is due to the humidity inversion that is present between sea level and 200 ft in sounding 26.

20 June 1945 (Soundings 27, 28, 29)

Weather Summary. — The cold front which extended from eastern Massachusetts to eastern Pennsylvania on the morning of 19 June was subject to short advances and retreats until the early morning of 20 June. Then the front began to advance steadily southeastward. Oriented approximately NE–SW, it passed Mitchel Field at about 09^h, Suffolk Field at about 11^h, Point Judith at about 13^h, and Nantucket at 17^h30^m.

Rain, ceilings less than 1000 ft, and fog were prevalent a short distance in advance of the front. Rapid clearing followed its passage, as continental air moved across the area from a northwesterly direction. Temperatures on land rose to 80–85F in the afternoon. Dew points dropped to about 60F.

Sounding 27. — Supplementary observations made during the course of the sounding were as follows: Surface wind, 265°, 3 Beaufort; 1000-ft wind, 291°, 11 knots; sky, clear; visibility, good. Water temperatures in the vicinity were measured as 65–67F a few hours before and after the sounding.

At 17^h the 1000-ft winds at La Guardia Field, Mitchel Field, Fishers Island, and Point Judith had directions between 310° and 360° and speeds between 5 mph and 25 mph. Although the 1000-ft wind direction measured by the airplane was westerly, it is evident from the character of the weather that the front had moved to the east of the position of the sounding. Therefore, it seems certain that the air at 1000 ft left land as a NW or NNW wind and arrived at the position of the sounding as a WNW wind (see Fig. 44). The distance travelled over water was 55–65 miles. The time was 4–4½ hours.

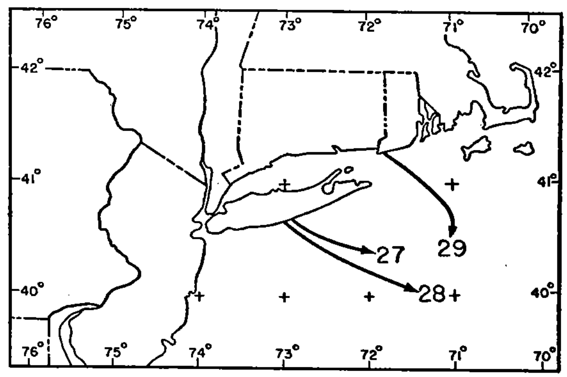

Fig. 44. Trajectories at 1000 ft for soundings made on 20 June 1945.

The surface wind direction at the sounding was 265°. However, the air near sea level, which is clearly a part of the new continental air mass, could not have followed a straight path from that direction and simultaneously maintained positions to the rear of the front during the early morning. Therefore, the surface air must have moved along a cyclonically curved path prior to its arrival at the position of the sounding.

The modifying influence of the ocean is apparent up to about 250 ft (Fig. 45). According to the characteristic curve, the air originally was cooled by passage over water of temperature about 65F but subsequently was subject to warming by water of about 67F.[26] This interpretation is consistent with actual measurements. Between 09^h15^m and 12^h00^m on this day the ship steamed toward the position of the sounding on a SE course from a point about 30 miles east of the place where the air at 1000 ft is supposed

[26] This later modification extends only to 125 ft.

to have left land. The water temperature was observed to increase from 62F near Long Island to 67F near the sounding (see Chart 7).

With the exception of a homogeneous layer between 400 ft and 600 ft, the portion of the sounding above 250 ft exhibits a stable stratification. This circumstance could be an indication that convective mixing had not become active at the time the air left

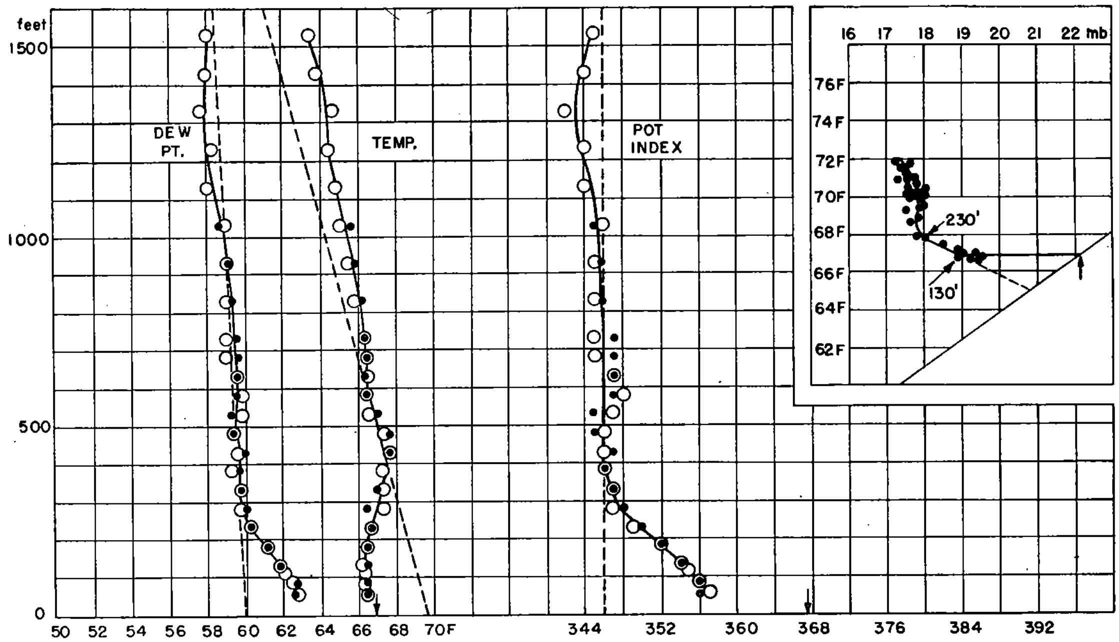

FIG. 45. Sounding 27; 40°23′N, 71°56′W; 20 June 1945; o ascent 16^h00^m–16^h16^m, • ascent 16^h19^m–16^h30^m. This sounding exhibits complex modification. At first the air passed over relatively cool water. The most recent influence has been a warming of the lowest 125 ft by water of temperature about 67F.

land (about 12^h), because of the cloudy weather that prevailed during the first part of the forenoon. On the other hand, the following observations indicate that convection was well established when the air left land: (1) At 11^h30^m Mitchel Field reported scattered cumulus clouds of fine weather at 2000 ft, (2) at 12^h30^m Suffolk Field reported scattered clouds (form not specified) at 2000 ft, (3) the only other clouds present over these stations at the stated times were scattered high clouds. Therefore, the air must have acquired its stability while moving over the water. In that case the stratification is due to vertical wind shear, the air parcels at successively higher levels having left land at progressively later times in the day.

The superstandard condition in the layer between sea level and 200 ft is, as in previous cases, chiefly the result of a relatively large lapse of dew point next the sea surface.

Sounding 28. — Supplementary observations made during the course of this sounding were as follows: Surface wind, 285°, 3 Beaufort; 1000-ft wind, 290°, 6 knots; sky, clear overhead, rear edge of frontal cloud system 3½–5 miles east; visibility, good. Water temperatures measured in the vicinity 2–3 hours earlier were as follows: 4 miles SW, 61.1F; 6 miles SE, 61.7F; 8 miles NE, 60.2F.

As in the case of the preceding sounding, the air at 1000 ft came from Long Island

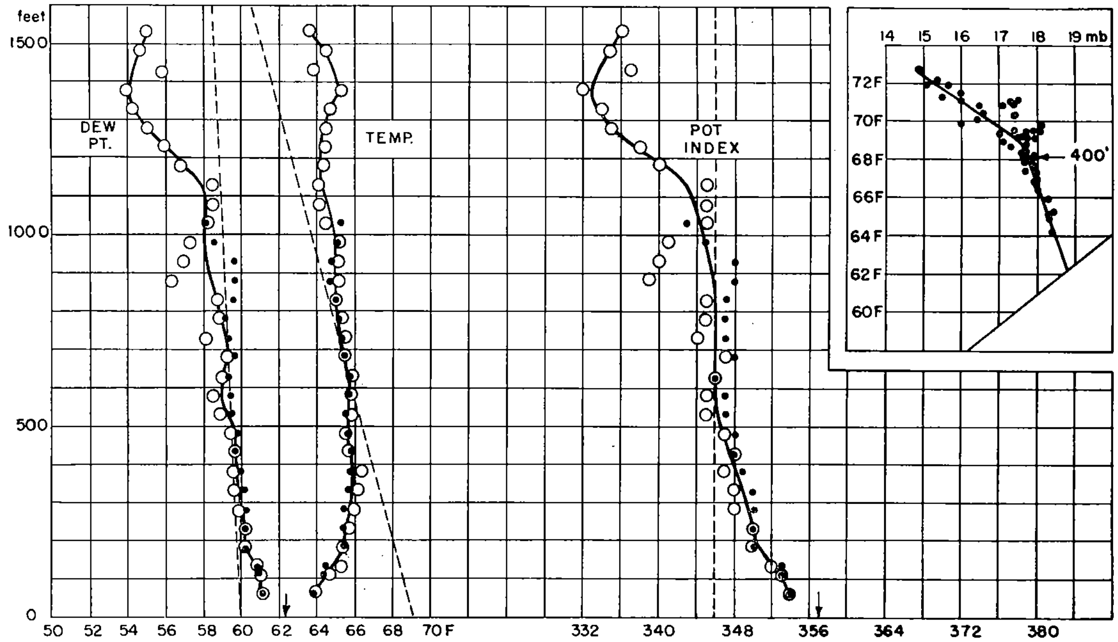

FIG. 46. Sounding 28; 40°02'N, 71°27'W; 20 June 1945; o ascent 16^h58^m–17^h14^m, • ascent 17^h16^m–17^h28^m. The vertical distributions of temperature and humidity are unusually irregular, as the sounding was made closely behind a cold front. The air has been cooled and moistened by the ocean to a height of 400 ft.

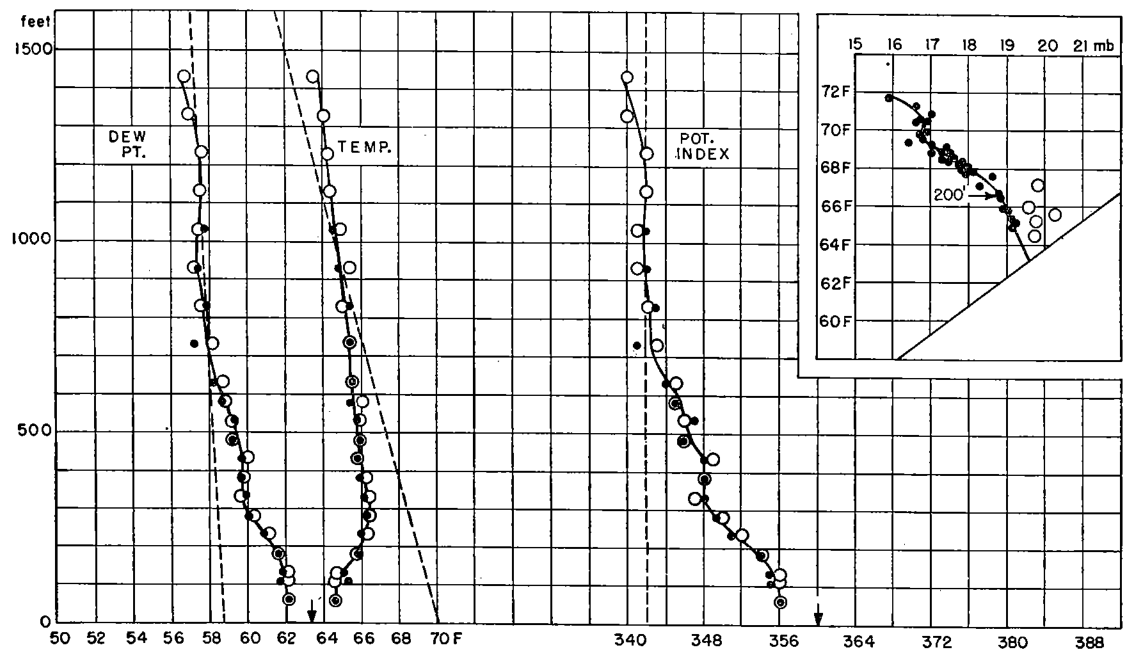

FIG. 47. Sounding 29; 40°32'N, 71°05'W; 20 June 1945; o ascent 17^h59^m–18^h15^m, • ascent 18^h18^m–18^h34^m. The characteristic curve indicates that modification by the water does not extend above 200 ft. The air was convectively mixed at the time it left land, but, as a result of shearing stratification, stability subsequently developed at all levels.

(see Fig. 44). The length of the over-water trajectory is about 100 miles. Along this path the average speed of the wind is assumed to have been the same as that of the cold front, namely, 15 mph, so that the air left land about 6½ hours prior to the time of observation, or at about 10^h30^m.

The sounding (Fig. 46) does not contain any well-defined homogeneous layer, probably because the air followed the cold-front cloud system so closely that the land over which it passed during the morning had no previous opportunity to become well warmed by solar radiation. On this account, and also because vertical motion becomes a disturbing factor in the vicinity of a front, the distributions of temperature and humidity are more unsystematic than usual. As a result, the characteristics of individual layers in the upper part of this sounding cannot be explained in terms of trajectories.

The cooling and moistening influence of the water extends to about 400 ft. The characteristic curve indicates that the temperature of the sea in the vicinity of the sounding was about 62F. This value agrees with a series of water-temperature measurements made by the ship during the early afternoon. Near the estimated 1000-ft trajectory the temperature of the sea surface decreased in the downwind direction from about 66F at point B to 61F near the position of sounding 28.

Sounding 29. — The airplane and the cooperating ship established a rendezvous at the position of this sounding and obtained the following wind and temperature measurements:

		Surface Wind[27]		1000-ft Wind	
By airplane		265°–270°, 2 Beaufort		23°, 14 knots	
	Time	Surface Wind[27]	Air Temp.	Dew Point	Sea Temp.
By ship	18^h00^m	235°, 9 mph	64.5F	63.0F	63.2F
	18^h15^m	235°, 9	65.2	63.1	63.6
	18^h30^m	235°, 9	67.1	63.2	63.4

Additional supplementary observations were as follows: Sky, clear, except for frontal cloud system near horizon to the south; visibility, good.

Although the airplane reported a NNE wind at the 1000-ft level, pilot-balloon observations made at about 17^h at the nearest land stations showed northwesterly directions. Earlier in the day the 1000-ft winds behind the cold front had been NW–N, so that the wind direction observed by the airplane probably had not been maintained for long. Therefore, it is assumed that the air followed an almost straight path from about NW until 17^h, at which time the direction changed toward the right. On this basis, the 1000-ft trajectory starts from southwestern Rhode Island or southeastern Connecticut (see Fig. 44). The distance over water is 75–80 miles; the time, about 4½ hours. Thus, the air left land at about 13^h30^m, i.e., 1–2 hours after the time of front passage at the estimated point of departure.

The sounding (Fig. 47) is characterized by stability at practically all levels. Although this condition may be an indication that all of the air left land too soon after the front passage to have been stirred by convection, the available evidence is to the contrary. For instance, stratocumulus and heavy swelling cumulus clouds were reported over southern Rhode Island and southeastern Connecticut at the time the air left land.

[27] The surface wind direction reported by the ship disagrees sharply with that obtained by the airplane. The airplane's observation is believed to be more nearly correct, since it is consistent with the surface winds observed during the course of soundings 27 and 28.

Accordingly, the preferred interpretation is that the observed structure was developed by the action of shearing motion during the journey over the water.

The influence of the sea apparently extends no higher than about 200 ft. The water temperature indicated by the characteristic curve is in excellent agreement with the values measured by the ship.

Unfortunately the temperatures and dew points measured on shipboard by means of the sling psychrometer are out of line with the values recorded by the psychrograph and with the water-temperature measurements. In every case they are too high. Since the other measurements are mutually consistent, it can only be concluded that the readings of the sling psychrometer are in error, probably because they were affected by heat from the ship.

22 JUNE 1945 (SOUNDINGS 30, 31, 32)

Weather Summary. — A weak cold front extended south-southwestward from eastern Long Island at 08^h30^m. It moved slowly southeastward during the day and reached latitude 40°N, longitude 70°W, by late afternoon, so that all soundings on 22 June were made in a new continental polar air mass. The geostrophic wind direction was northerly in the rear of the front.

Considerable cloudiness prevailed during most of the day at all land stations. The air mass became quite unstable over land in the afternoon, and scattered rain showers developed. Temperatures on land were 60–65F in the early morning and rose to about 80F by late afternoon. Dew points were 60–65F all day.

Sounding 30. — Supplementary observations made during the course of the sounding were as follows: Surface wind, 325°–330°, 2 Beaufort; 1000-ft wind, 255°, 8 knots; sky, clear; visibility, 5 miles in haze. About 2½ days earlier water temperatures of 68.5–69.5F were measured 5–10 miles west of the position of the sounding.

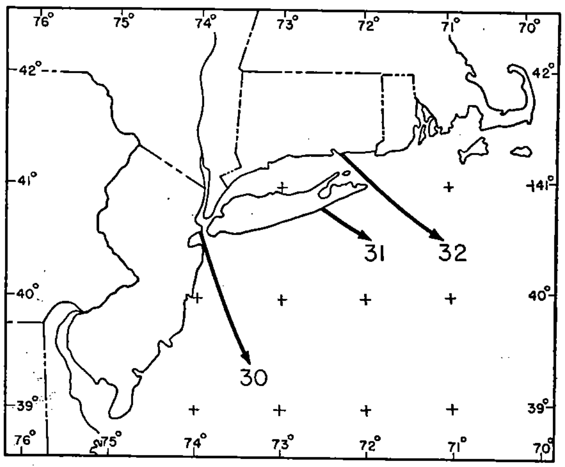

FIG. 48. Trajectories at 1000 ft for soundings made on 22 June 1945.

During the day the prevailing direction and speed of movement of the air at 1000 ft was, according to pilot-balloon observations, approximately NNW, 17 mph,[28] so that the air at 1000 ft must have left western Long Island or northeastern New Jersey between 12^h00^m and 13^h00^m (see Fig. 48). The distance travelled over water was 70–85 miles.

A radiosonde ascent made at Lakehurst at about 11^h showed the existence of a mixed layer between the ground and 2500 ft. (The potential temperature and dew point in this layer were 70F and 54F). At 11^h30^m heavy swelling cumulus clouds were reported by several stations near the starting point of the trajectory. Since the determination of

[28] The 1000-ft wind direction reported by the airplane is about 70° to the left of the surface wind. Shear of this kind would be observed only if there were pronounced horizontal advection of colder air in the lowest 1000 ft. Since the weather charts do not furnish any corroborating evidence of such a condition, the observation made by the airplane is considered to be in error. Presumably the sea surface was too smooth to permit an accurate double-drift determination.

the time of departure of the air from land is quite reliable in this case, there can be little doubt that all the air in the sounding was convectively mixed before commencement of the over-water journey and that the homogeneous layer between 600 ft and 1000 ft (see Fig. 49) left land at some time after 11^h00^m. (The warmer air above 1000 ft almost certainly left the coast at a later time and overran the air below.)

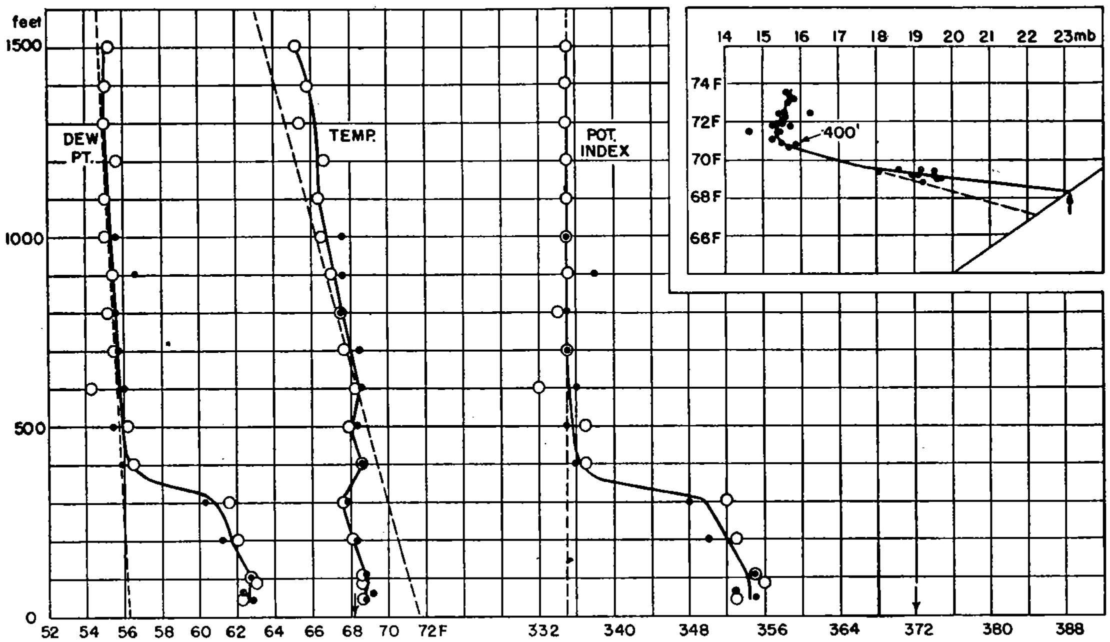

FIG. 49. Sounding 30; 39°25′N, 73°22′W; 22 June 1945; o ascent 16^h37^m–16^h53^m, • ascent 16^h57^m–17^h11^m. Modification by the ocean extends to 400 ft. The air has passed over water of varying temperature, as indicated by the character of the lapse rate in the modified layer. Strongly superstandard conditions are produced close to the surface by the rapid decrease of moisture between sea level and 50 ft.

Modification by the sea extends no higher than 400 ft. The temperature inversion between 500 ft and 600 ft could not have been formed by downward transport of heat to the water, since there is no corresponding influence on the distribution of dew point. As early as 10^h30^m coastal stations near the start of the trajectory generally reported surface temperatures slightly higher than the value measured at the 500-ft level. Therefore, the inversion must have been formed by vertical wind shear.

It is likely that during the first part of the trajectory the air in the modified layer was cooled from below, for the characteristic curve indicates that the inversion between 300 ft and 400 ft was formed over water of temperature about 67F. Subsequently, the air arrived over water somewhat warmer than 69F, as suggested by the character of the lapse rate between 100 ft and 300 ft. (This interpretation is consistent with the fact that 2½–3 days earlier water temperatures were 66–67F in an area 25–50 miles to windward of the position of the sounding and approximately 69F at a point about 5 miles to windward.) At the time of the sounding, however, the lowest 100 ft of the air column was being cooled slightly by water of temperature 68.0–68.5F.

The vertical distribution of temperature and humidity resulting from the cooling and moistening effects of the water give strongly superstandard conditions in a shallow layer next the sea surface and, also, between 300 ft and 400 ft.

Sounding 31. — Supplementary observations made during the course of this sounding were as follows: Surface wind, 290°, 3 Beaufort; 1000-ft wind, 235°, 7 knots; sky, partly cloudy (scattered cumulus clouds); visibility at sea level, good; visibility at 1000 ft, 5 miles in haze. Six hours earlier the water temperature at a point 3 miles east was 67.6F.

According to pilot-balloon observations made at La Guardia Field, Mitchel Field, Hartford, and Fishers Island, the 1000-ft wind in the vicinity of sounding 31 had been blowing from the northwest quadrant throughout the afternoon but had been weaker and closer to west in direction than in the case of sounding 30. Although the estimate of the 1000-ft trajectory is subject to some uncertainty, it is probable that the air in the upper part of the sounding left the coast at a point in eastern Long Island and travelled 35–40 miles over the ocean, as shown in Figure 48. The homogeneous layer between 900 ft and 1200 ft (Fig. 50) undoubtedly is the product of convective mixing

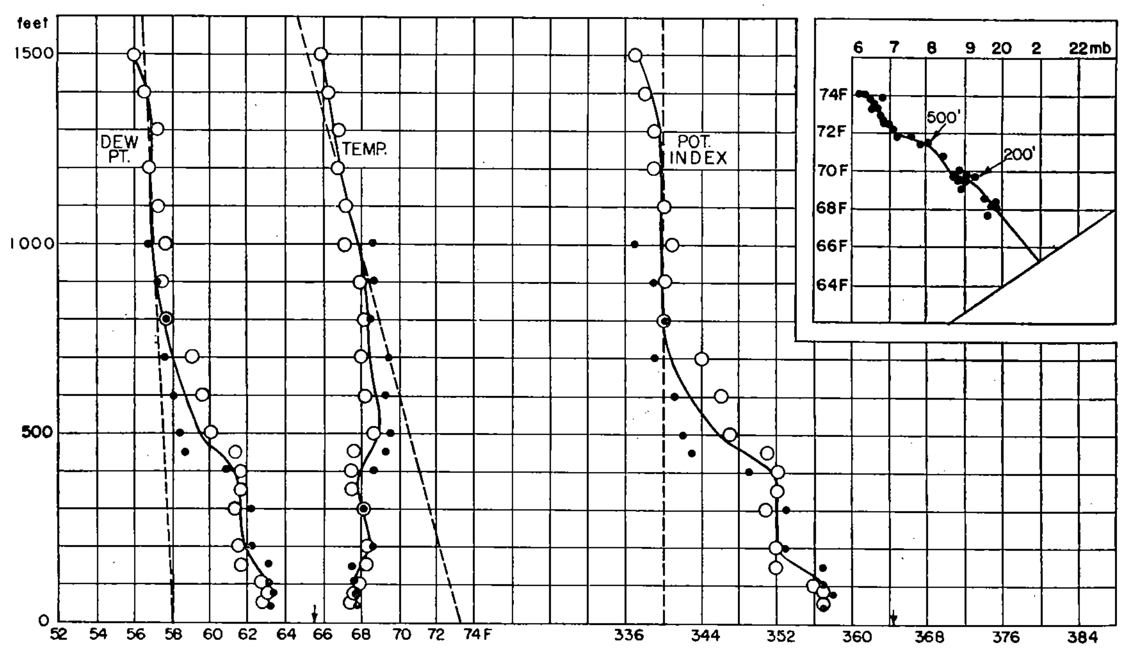

FIG. 50. Sounding 31; 40°33′N, 71°57′W; 22 June 1945; o ascent 18^h04^m–18^h18^m, • ascent 18^h22^m–18^h34^m. Modification by the ocean extends definitely to 200 ft, possibly to 500 ft. The homogeneous layer between 200 ft and 400 ft may have been formed over relatively warm water along the first part of the trajectory.

over land earlier in the day. Measurements of temperature and dew point at Suffolk Field at 12^h30^m, 13^h30^m, and 14^h30^m gave values of 72F and 61F, 75F and 61F, and 76F and 62F, respectively. (Heavy swelling cumulus clouds were observed there at 14^h30^m.) Thus, it appears that the air between 900 ft and 1200 ft left land at about 13^h30^m, i.e., 4½–5 hours prior to the time of the sounding.

The structure of the lowest 500 ft of the sounding is difficult to interpret. According to the characteristic curve, modification by water of temperature 65–66F definitely extends to 200 ft. The vertical distribution of dew point is such as to suggest that the influence of the sea may have penetrated to the 500-ft level. In that case the homogeneous layer between 200 ft and 400 ft would have to have been produced by heating over a considerable stretch of water of temperature at least 70F during the first part of the trajectory. On five of the cruises made earlier in the month by the ship, water temperatures were measured at various points on the estimated trajectory and no values higher than 68F were obtained. Thus, the available observations favor the argument that the layer between 200 ft and 400 ft was homogenized by heating over land and that over-water modification was restricted to the lowest 200 ft. On the other hand, water temperatures in the area just to the east of point B rose 2–4F between 19 and 22 June (see Charts 7 and 8), so it seems possible that temperatures of 67–68F measured along the trajectory on 19 June and 20 June might have increased to 70F by 22 June. The question apparently cannot be decided satisfactorily.

Sounding 32. — The airplane and the cooperating ship established a rendezvous at the position of this sounding and obtained the following wind and temperature measurements:

	Surface Wind	1000-ft Wind
By airplane	305°, 2 Beaufort	(undetermined)

	Time	Surface Wind	Air Temp. 20′	Air Temp. 30′	Dew Point 20′	Dew Point 30′	Sea Temp.
By ship	19^h15^m	300°, 2 Beaufort	66.5F	65.8F	64.0F	63.0F	66.4F
	19^h30^m	300°, 2	66.8	65.8	64.7	63.8	66.4
	19^h45^m	—	66.6	65.9	64.7	63.6	66.4

Additional supplementary observations were as follows: Sky, clear; visibility at sea level, good; visibility at 1000 ft, 5 miles in haze.

An analysis of pilot-balloon observations made in Connecticut and Rhode Island and of surface-wind reports on eastern Long Island and Block Island makes it fairly certain that the trajectory starts from southeastern Connecticut (see Fig. 48). The total length of the over-water path is about 80 miles. Since the wind is estimated to have maintained an average speed of approximately 10 mph, the air must have left the mainland at about 11^h.

An inspection of conditions between 600 ft and 800 ft in the sounding (Fig. 51) confirms the above analysis. The average potential temperature and dew point in this nearly homogeneous layer agree quite well with surface observations made at 10^h30^m and at 11^h30^m near the estimated starting point of the over-water trajectory. For example, at 10^h30^m the temperature and dew point were 70F and 63F at New Haven and 68F and 63F at Groton; at 11^h30^m the values were 73F and 62F at New Haven and 72F and 63F at Groton.

The structure of the air above 800 ft may represent a state that persisted over land until after 11^h00^m. On the other hand, the stability may be the result of shearing stratification. The second possibility seems to be more likely.

According to the characteristic curve, modification by the water extends to the 300-ft level. The layer between 200 ft and 300 ft shows the effect of cooling by water of temperature 64–65F. In accordance with the measurements of sea-surface temperature made by the ship between 18^h55^m and 19^h45^m, the air below 200 ft was warmed by water of temperature 66.4F.

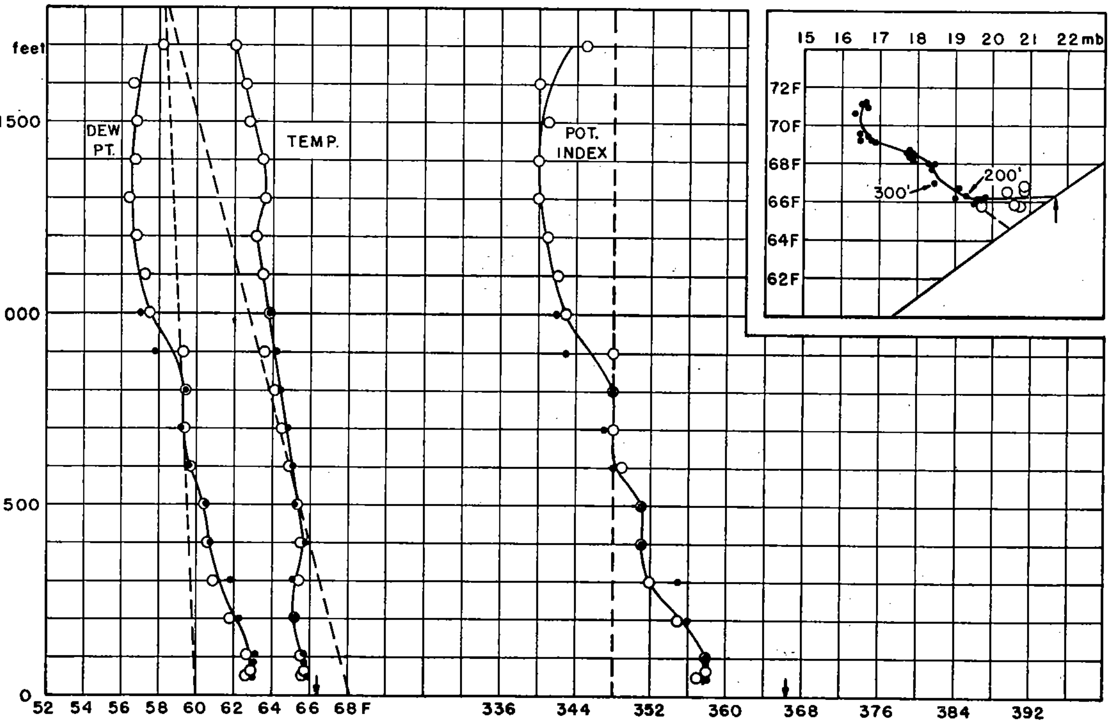

FIG. 51. Sounding 32; 40°32'N, 71°05'W; 22 June 1945; o ascent 19^h13^m–19^h31^m, • ascent 19^h34^m–19^h45^m. Modification by the ocean extends to 300 ft. The air at first was cooled from below. During the last part of the trajectory heating of the lowest 200 ft took place.

Of the three sling psychrometer measurements made at the ship's masthead, one agrees well with the airplane's observations in the lowest 200 ft, while the other two have higher dew points. This circumstance indicates that at a height of 30 ft (i.e., masthead height) the dew point was beginning to increase rapidly from a value of about 63F, which prevailed between 50 and 100 ft, to 66.4F at the sea surface. At a height of 20 ft the dew points are about halfway between these values. However, the recorded temperatures at 20 ft (a few feet above deck level) are slightly higher than the water temperature. This discrepancy is probably due to radiation of heat from the hull of the ship.

VI. SUMMARY OF RESULTS

In the majority of the 32 soundings the air at 1000 ft travelled 100 statute miles or more over water. In not more than 13 cases was the over-water distance less than 100 miles and in only one case (sounding 31) was it apparently less than 50 miles. In 6 soundings the length of the oceanic trajectory was greater than 200 miles.

The water exerted a predominantly cooling influence on the air in 29 of the soundings. On 3 occasions the air had previously been moving over progressively warmer water; these cases are characterized by a homogeneous state extending from the surface to a height of at least 800 ft. Of the 29 soundings that display the effects of travel over relatively cool water, the 3 soundings made on 1 June show over-water modification up to 800–1100 ft, while the remaining 26 show that the modification extends only to 200–600 ft (the range in wind speed at 1000 ft being 2–31 knots). In 16 cases of cooling from below the modification apparently does not extend above 300 ft; for 8 soundings in this group the length of the over-water trajectory was less than 100 miles, for 1 (sounding 19) it was in excess of 200 miles.

In only 1 of the 29 soundings representing stable equilibrium does the vertical gradient of refractive index at the surface approximate standard conditions. Eight soundings show substandard conditions at the surface; in one case (sounding 14) the substandard layer extends from sea level to 700 ft. Seven are characterized by type-2 superstandard conditions (see Montgomery, 1947) from the surface to heights of less than 100 ft. In the remaining 13 soundings type-2 superstandard conditions prevail from the surface to heights greater than 100 ft but not exceeding 400 ft. Thus, the majority of occasions on which soundings were made were favorable to greater-than-normal ranges for ultra-short radio waves transmitted from a point near the sea surface. In addition, type-2 superstandard layers occurred at elevations greater than 500 ft in 7 soundings.

The results of the soundings indicate that the modifying influence of relatively cool water spreads upward comparatively rapidly during the first 50 miles of the trajectory. When the initial temperature difference between the air and the water is of the order of 10–20F and the surface wind speed is less than about 15 mph, the depth of the modified layer remains constant or increases only slowly to a value not exceeding about 600 ft in the next 250 miles, even when the wind speed at 1000 ft is as great as 35 mph. However, modification extends rapidly to levels higher than 600 ft if the wind is comparatively strong both at the surface and aloft and the air initially is less than 5F warmer than the water (e.g., soundings 1, 2, and 3).

The complexity of the relationship between the variables governing the height of over-water modification in cases of cooling from below is illustrated by a comparison of values for soundings 18 and 19 with corresponding quantities for soundings 11 and 30. The winds were appreciably stronger and the trajectories were at least 75 miles longer in the cases of soundings 18 and 19. However, the upper limit of modification is at least 100 ft lower than in soundings 11 and 30. This paradoxical result no doubt stems partly from the fact that the magnitude of the initial temperature difference between the air and the water was much greater in the cases of soundings 18 and 19 than in either sounding 11 or sounding 30. Furthermore, the wind speed measured at the position of a sounding may often be unrepresentative of previous over-water stages of the motion of the air.

Vertical variations of wind velocity, commonly referred to as "vertical wind shear," had a marked stabilizing influence on the structure of the upper parts of nearly all soundings in which cooling from below was involved. The principal reason for this influence is as follows: the normal increase of wind speed with height had the effect of superimposing air parcels in order of departure from land, and, since the times of departure usually occurred within the interval of diurnal warming, the potential temperature of any superimposed parcel was greater than that of the underlying parcels. A secondary stabilizing tendency of wind shear resulted from the orientation of the coast line in relation to the positions of the soundings; the normal veer of wind with height caused the air aloft to come more nearly from the direction of the closest part of the coast.

The lower parts of some of the soundings are complicated by the effects of initial inhomogeneity and of changing water temperature along the trajectory. Nevertheless, in the majority of cases the temperature and humidity measurements in the modified layer form a series of points that lie essentially along a straight line on the Taylor diagram. The almost invariably good agreement between the inferred water temperature, as given by the intersection of such a line with the salt-water curve, and actual measurements of sea-surface temperature confirms the expectation that the eddy diffusivity of heat and water vapor are identical.

This identity is important in connection with the explanation of the formation of so-called "advection fog." The vertical distributions of temperature and moisture in certain of the soundings show that cooling of warm, moist air through contact with a water surface having a temperature less than the dew point is accompanied by a proportionate loss of moisture by condensation on the water. Therefore, with respect to relatively warm, moist air which starts to move over colder water, it is incorrect to assume that fog will commence to form as soon as the temperature of the air is decreased to the value of the initial dew point.

Nine of the soundings (13, 14, 18, 19, 20, 22, 23, 25, and 26) were made on what may be described as occasions potentially favorable for fog formation. In each of these 9 cases the surface dew point at the time the air left land was considerably higher than the temperature of the water at the position of the sounding. However, thick fog was present in only two cases (soundings 25 and 26). The other 7 soundings show in striking fashion how the dew point, as well as the temperature, was decreased during passage over the water, with the result that saturation was not attained. The conclusion to be drawn is that ordinary sea fog cannot be formed as a result of heat loss to the water exclusively through the agencies of conduction and eddy diffusion (see Emmons and Montgomery, 1947). The additional increment of loss necessary to produce supersaturation must be effected by some other process, specifically, the removal of heat from the air by radiative transfer.[29]

Previous mention has been made of the conspicuous variations in temperature and dew point that occur between the first and second ascents in a few soundings. It was concluded that these irregularities are the result of vertical oscillations associated with wave motion on the upper surface of the modified layer. The variations at a given

[29] The radiative cooling of air over cold ground has been studied by Panofsky (1947).

level are particularly striking when the sounding is characterized by a pronounced temperature inversion or a large vertical gradient of moisture. Soundings in which no noticeable differences between ascents are evident mostly are characterized by small vertical gradients of temperature and moisture. The existence of wave motion may easily be masked in such cases, so it seems likely that the phenomenon occurs more frequently than is clearly indicated by the measurements. In this connection it may be pointed out that soundings 25 and 26, which have comparatively small vertical gradients of temperature and dew point in the modified layer, show no striking variations, yet the fog, which was present in both instances, was observed to have a wavy top.

The wave motion made evident by the soundings appears to be a manifestation of the well known shearing waves that form on a surface of discontinuity within a fluid.[30] In the atmosphere such waves can occur at a temperature inversion, which typically is a zone of marked wind shear. Under suitable conditions they give rise to the visible phenomenon of billow clouds. When strongly developed, they may create easily detectable fluctuations of atmospheric pressure at the ground (Haurwitz et al, 1935). With regard to the soundings discussed in this paper it is not possible to estimate the wave length, because the method of observation was not adapted to that purpose. However, the amplitude of the waves observed at the top of the water-modified layer in soundings 1, 2, 3, and 12 must have been at least 150 ft, for vertical displacements of twice that distance are indicated by a comparison of the measurements obtained in the first ascent of each of these soundings with those in the second. The possibility that shearing waves are important in problems of ultra-short-wave radio transmission is suggested by the variations in the vertical gradient of refractive index that took place during sounding 12; a type-2 superstandard layer occurs at 1000–1100 ft in the first ascent but appears between 1200 ft and 1500 ft in the second.

In general the results of the soundings demonstrate the potentialities afforded by psychrometric measurements of this type in the study of low-level meteorological phenomena both over land and over water. The solution of many practical problems in which the fine details of the vertical gradients of temperature and moisture are of primary importance can be greatly facilitated by the application of a similar observational technique.

[30] Regarding the theory of shearing waves see, for instance, Haurwitz (1941, pp. 282–288).

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APPENDIX: CHARTS OF SHIPS' CRUISES

Charts 1-8 cover different sections of the coastal region between Nantucket and New Jersey and show the temperature and weather conditions that prevailed at various places and times during the month of June, 1945, in the area where the airplane psychrometer measurements were made. The scale of these charts is 1:2,500,000. Isobaths for 25 and 50 fathoms have been included for the purpose of showing in a rough way the distribution of depth of water.

In order to avoid overcrowding of the data and to maintain a uniform scale the tracks of the longer cruises have been divided into two parts. Only the complete weather observations taken at intervals of one hour have been plotted, intermediate measurements of water temperature having been omitted for reasons of space. The data of each observation are grouped around a circle representing the ship's position at the time. The date and hour of observation are indicated by relatively large numerals, the two items being separated by a slanting line. Wind and state of weather are represented according to the conventional symbolic system. The pair of numbers to the left of each circle are the temperature (upper number) and the dew point (lower number). The water temperature is entered in slanted numerals to the right of the circle.

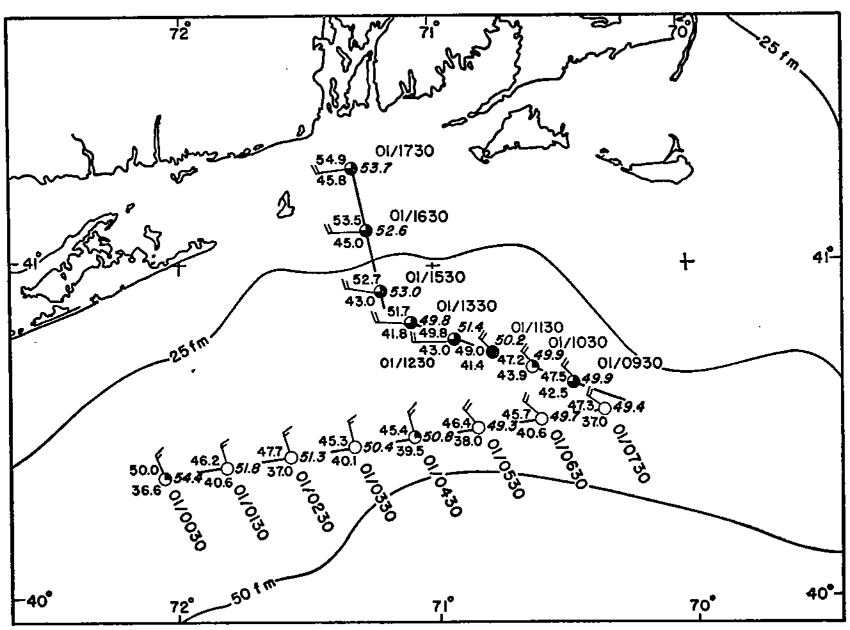

CHART 1. Cruise 1; 1 June 1945.

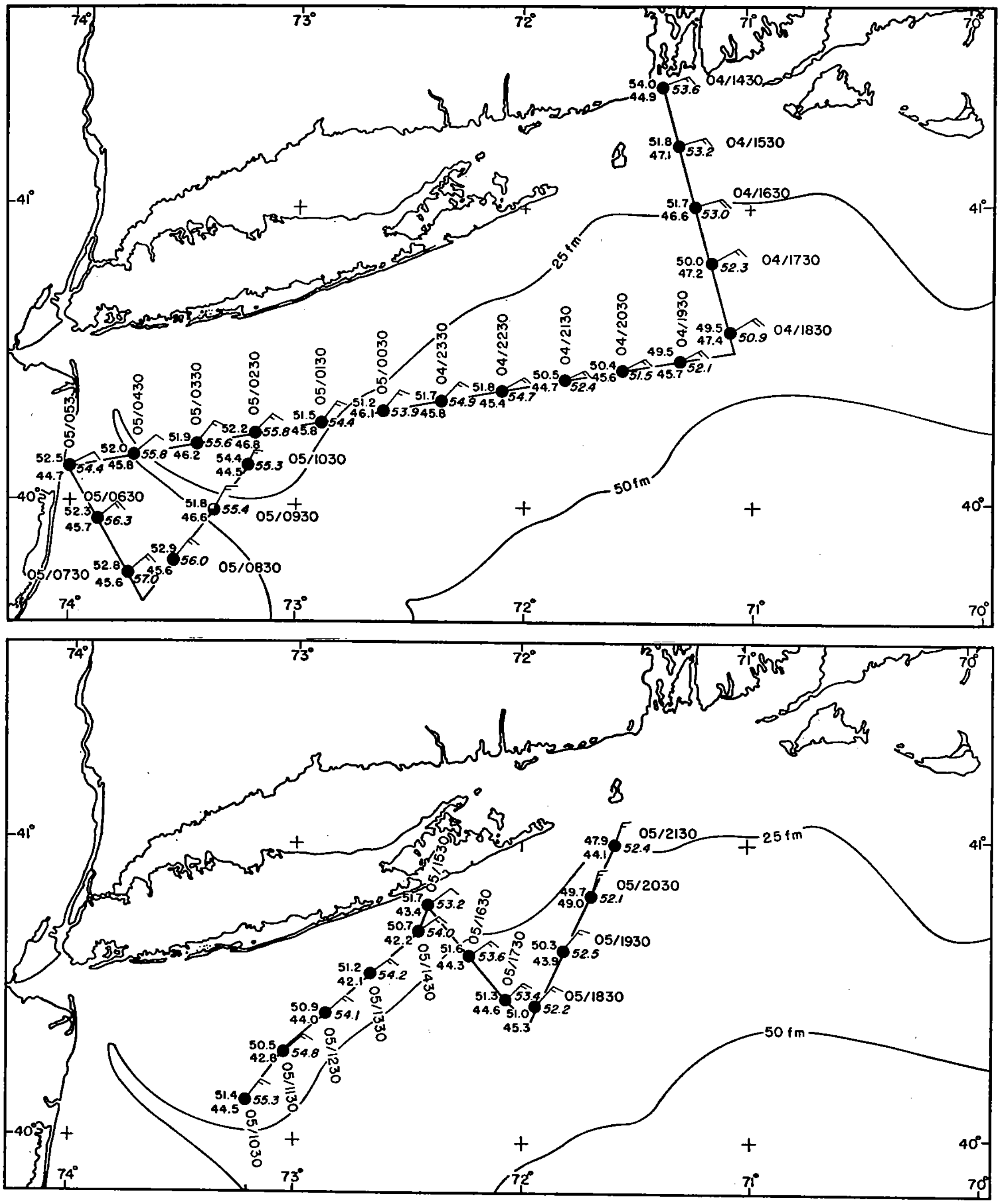

CHART 2. Cruise 2; 4–5 June 1945.

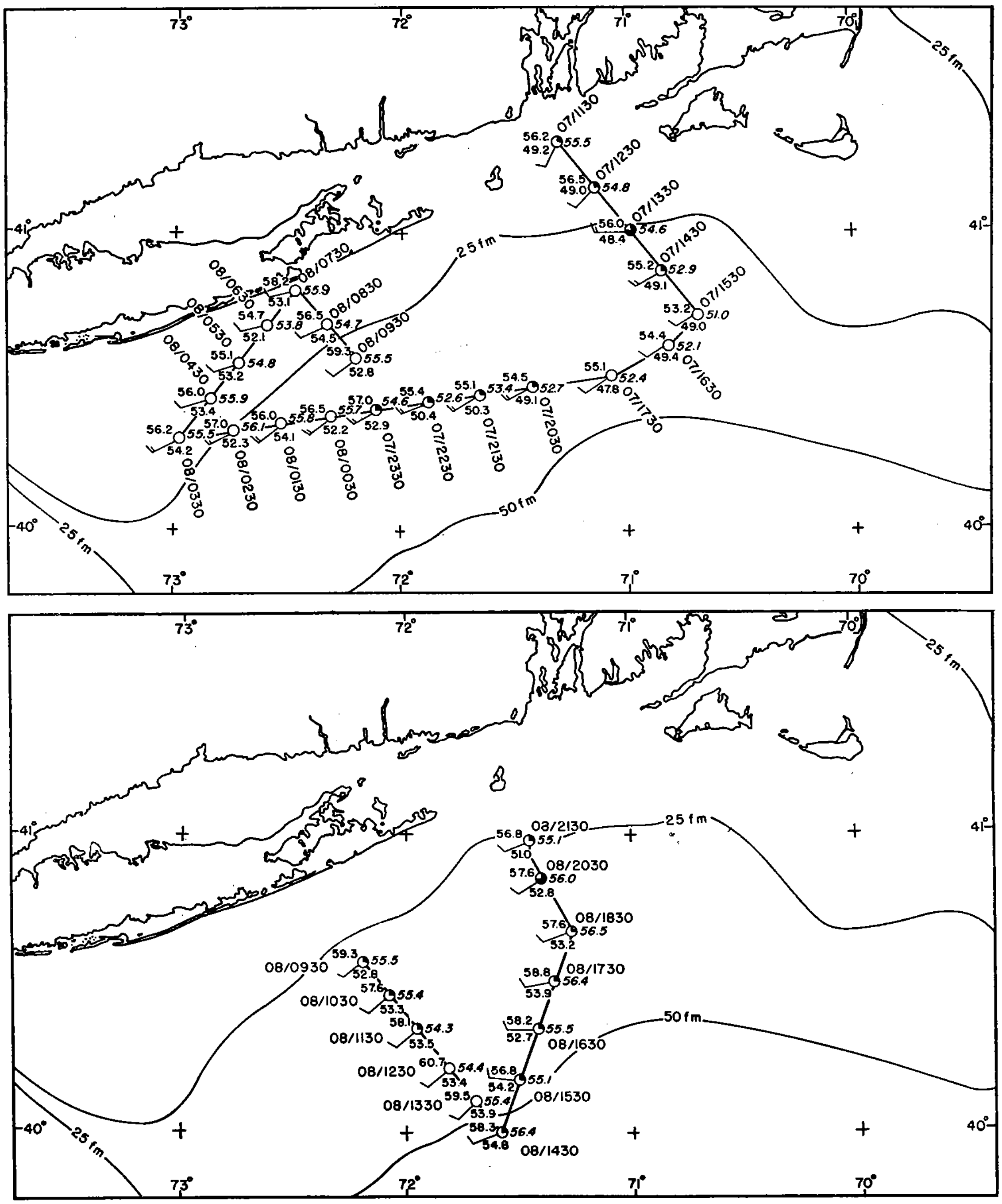

CHART 3. Cruise 3; 7–8 June 1945.

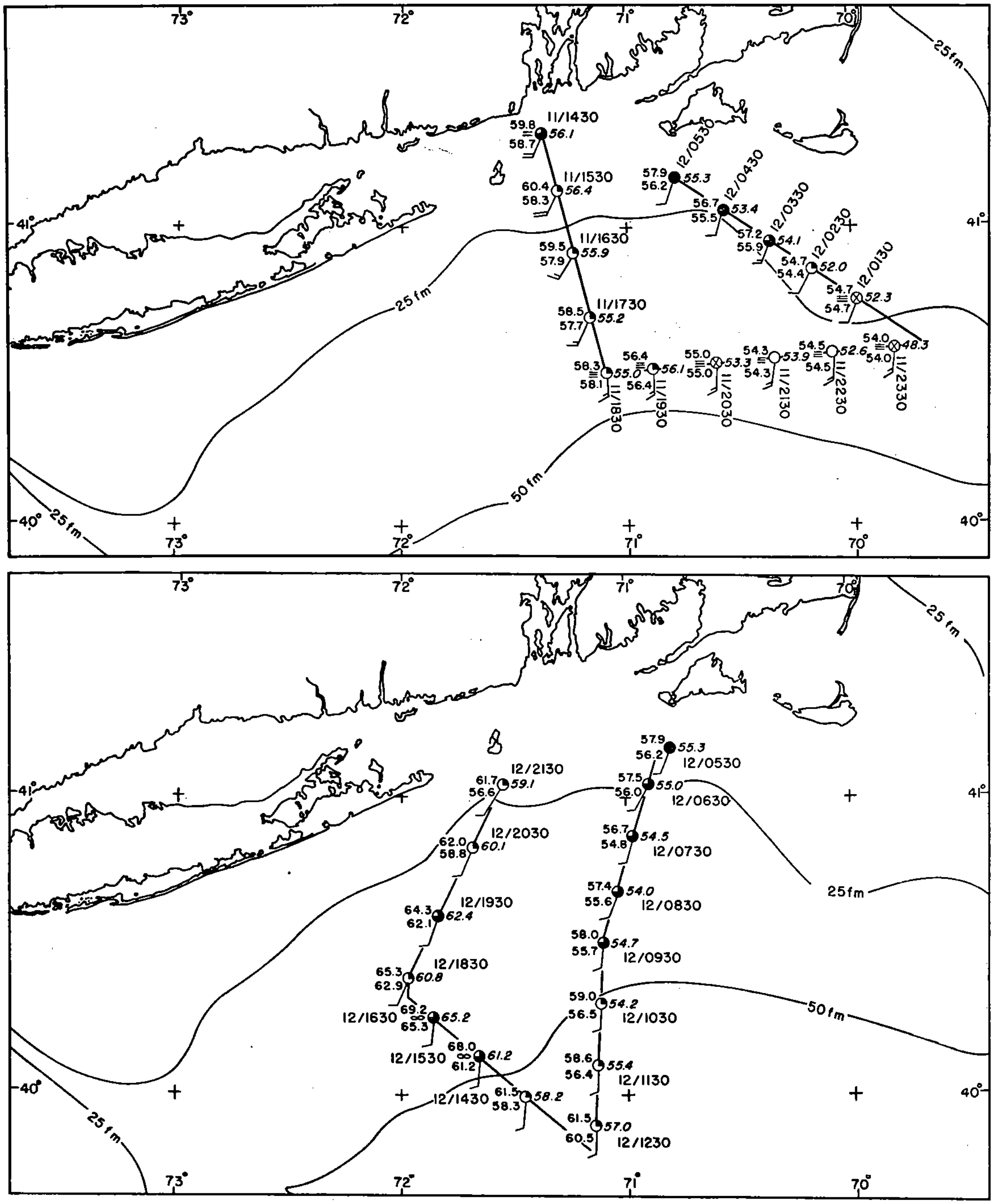

CHART 4. Cruise 4; 11–12 June 1945.

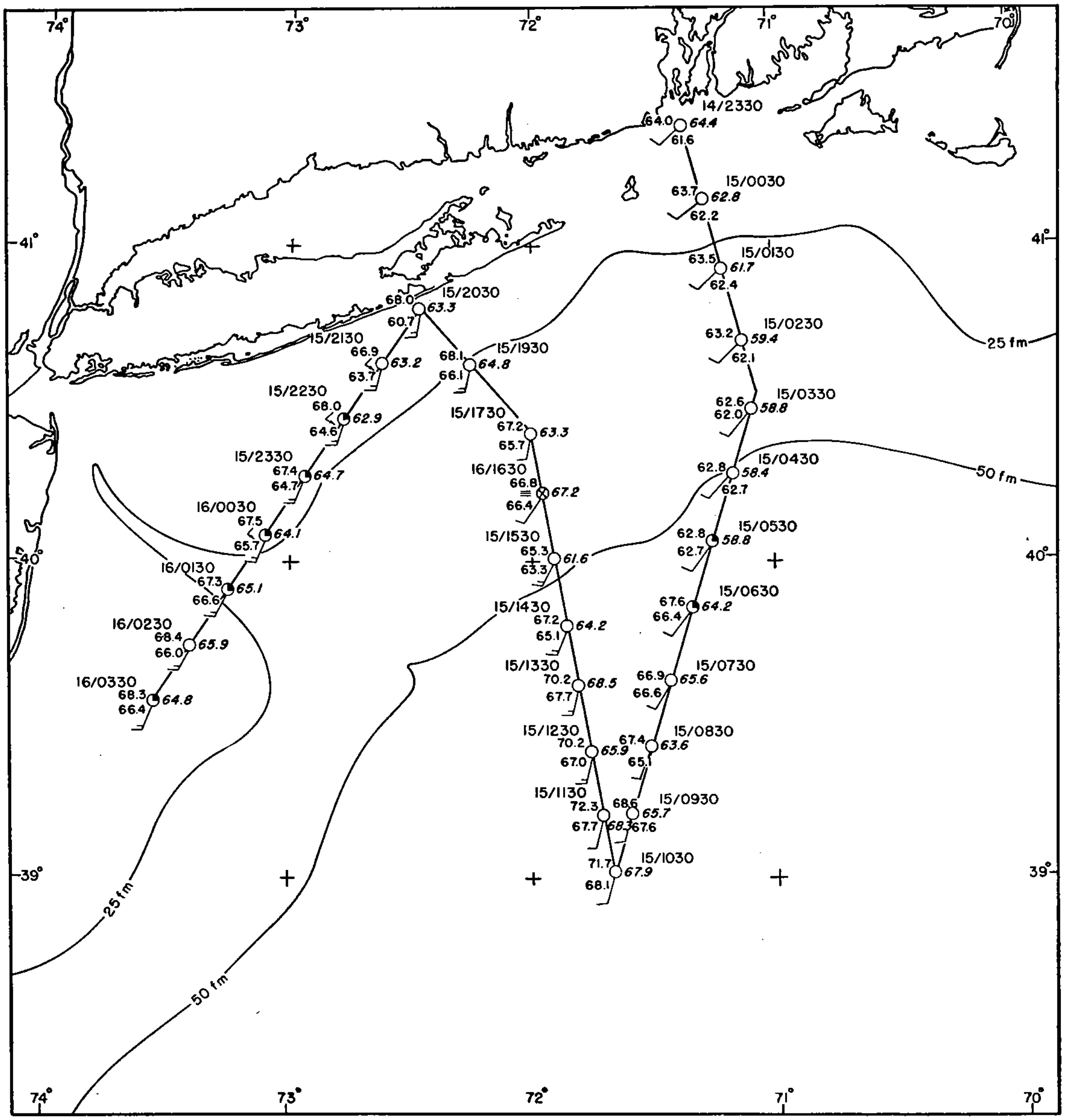

Chart 5. Cruise 5; outbound trip, 14–16 June 1945.

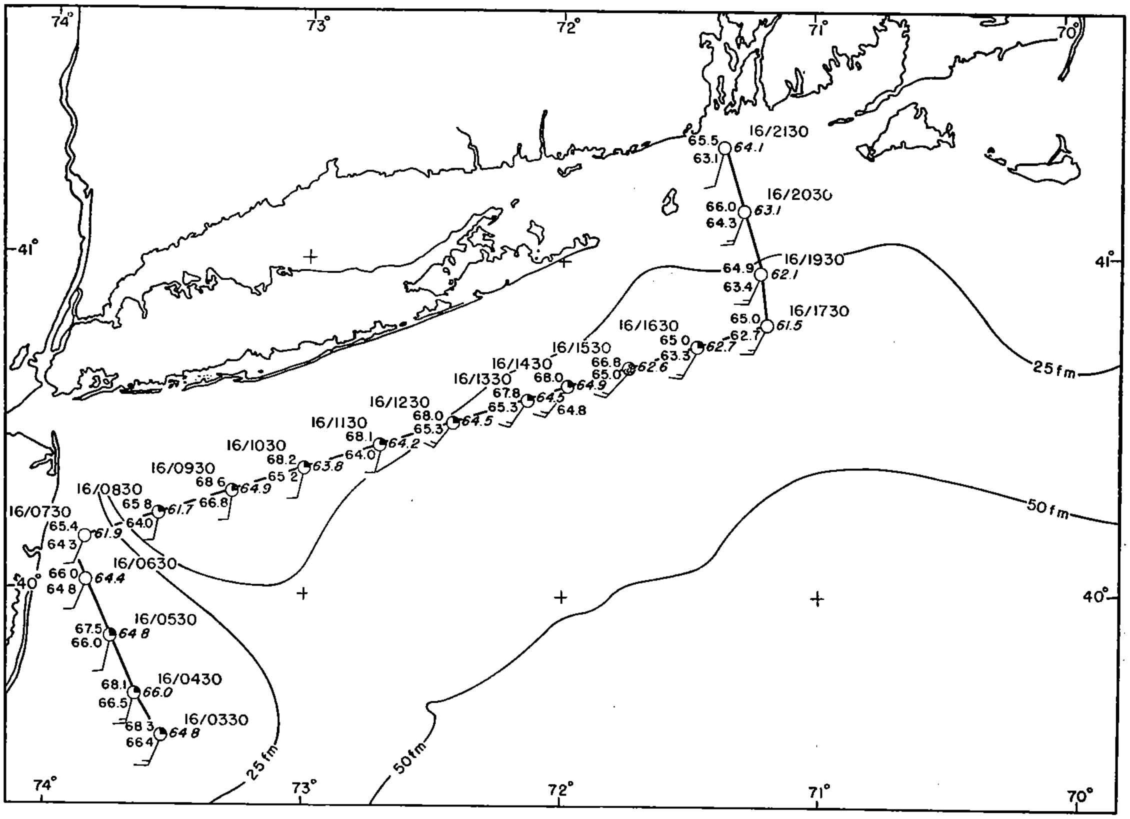

CHART 6. Cruise 5; inbound trip, 16 June 1945.

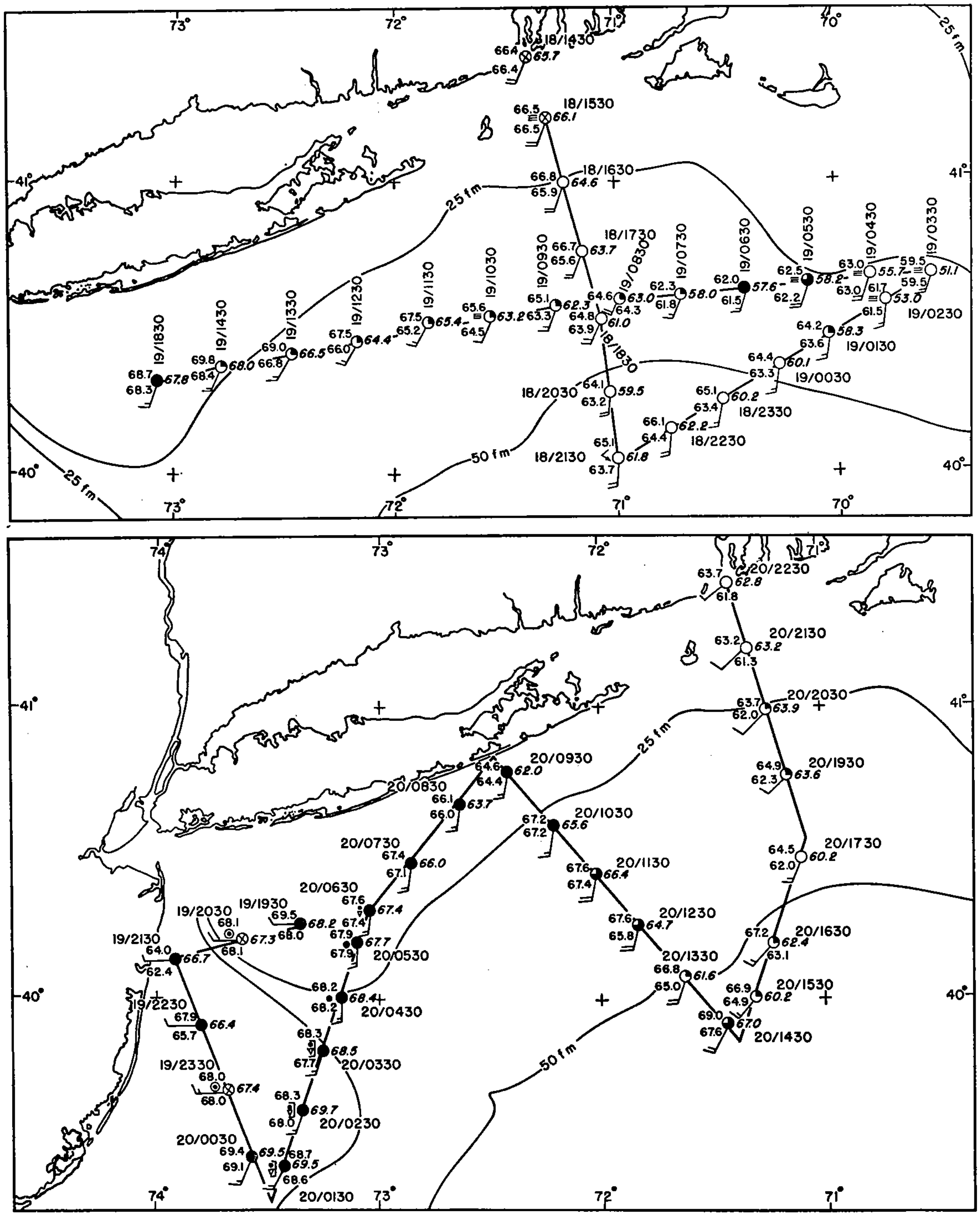

CHART 7. Cruise 6; 18–20 June 1945.

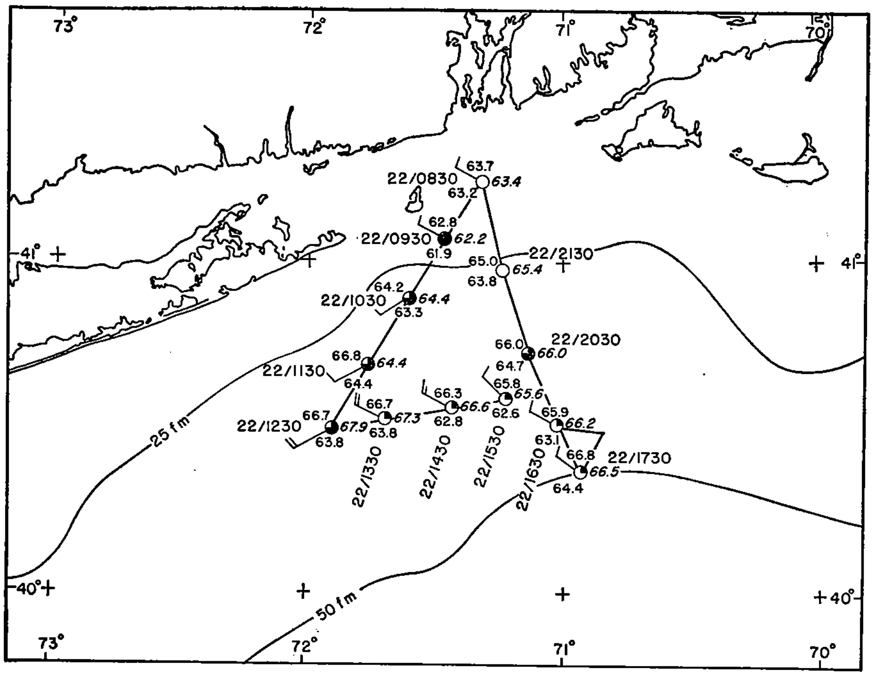

CHART 8. Cruise 7; 22 June 1945.