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HYDROMETEOROLOGICAL REPORT NO. 26

Analysis of Winds Over Lake Okeechobee During Tropical Storm of August 26-27, 1949

Washington
January 1951

HYDROMETEOROLOGICAL REPORTS

(Nos. 6–22 Numbered Retroactively)

No. 1. Maximum possible precipitation over the Ompompanoosuc Basin above Union Village, Vt. 1943.
No. 2. Maximum possible precipitation over the Ohio River Basin above Pittsburgh, Pa. 1942.
No. 3. Maximum possible precipitation over the Sacramento Basin of California. 1943.
No. 4. Maximum possible precipitation over the Panama Canal Basin. 1943.
No. 5. Thunderstorm rainfall. 1947.
No. 6. A preliminary report on the probable occurrence of excessive precipitation over Fort Supply Basin, Okla. 1938.*
No. 7. Worst probable meteorological condition on Mill Creek, Butler, and Hamilton Counties, Ohio. 1937. (Unpublished.) Supplement, 1938.*
No. 8. A hydrometeorological analysis of possible maximum precipitation over St. Francis River Basin above Wappapello, Mo. 1938.*
No. 9. A report on the possible occurrence of maximum precipitation over White River Basin above Mud Mountain Dam site, Wash. 1939.*
No. 10. Maximum possible rainfall over the Arkansas River Basin above Caddoa, Colo. 1939.* Supplement, 1939.*
No. 11. A preliminary report on the maximum possible precipitation over the Dorena, Cottage Grove, and Fern Ridge Basins in the Willamette Basin, Oreg. 1939.*
No. 12. Maximum possible precipitation over the Red River Basin above Denison, Tex. 1939.*
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No. 14. The frequency of flood producing rainfall over the Pajaro River Basin in California. 1940.*
No. 15. A report on depth-frequency relations of thunderstorm rainfall on the Sevier Basin, Utah. 1941.*
No. 16. A preliminary report on the maximum possible precipitation over the Potomac and Rappahannock River Basins. 1943.*
No. 17. Maximum possible precipitation over the Pecos Basin of New Mexico. 1944. (Unpublished.)
No. 18. Tentative estimates of maximum possible flood-producing meteorological conditions in the Columbia River Basin. 1945.
No. 19. Preliminary report on depth-duration-frequency characteristics of precipitation over the Muskingum Basin for 1- to 9-week periods. 1945.*
No. 20. An estimate of maximum possible flood-producing meteorological conditions in the Missouri River Basin above Garrison Dam site. 1945.
No. 21. A hydrometeorological study of the Los Angeles area. 1939.*
No. 21A. Preliminary report on maximum possible precipitation, Los Angeles area, California. 1944.*
No. 21B. Revised report on maximum possible precipitation, Los Angeles area, California. 1945.
No. 22. An estimate of maximum possible flood-producing meteorological conditions in the Missouri River Basin between Garrison and Fort Randall. 1946.
No. 23. Generalized estimates of maximum possible precipitation over the United States east of the 105th meridian, for areas of 10, 200, and 500 square miles. 1947.
No. 24. Maximum possible precipitation over the San Joaquin Basin, Calif. 1947.
No. 25. Representative 12-hour dewpoints in major United States storms east of the Continental Divide. 1947.*
No. 25A. Representative 12-hour dewpoints in major United States storms east of the Continental Divide. 2d edition. 1949.

*Out of print.

U.S. Department of Commerce
Weather Bureau

U.S. Department of the Army
Corps of Engineers

Hydrometeorological Report No. 26

ANALYSIS OF WINDS OVER LAKE OKEECHOBEE DURING TROPICAL STORM OF AUGUST 26-27, 1949

Prepared by
The Hydrometeorological Section
Division of Climatological and Hydrologic Services
U.S. Weather Bureau

Washington
January 1951

ACKNOWLEDGEMENTS

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Particular thanks are due to Dr. I. M. Cline who kindly made available to the Section the originals of the drawings appearing in his book, "Tropical Cyclones". During the early part of the work these data provided techniques and guides which were adapted to the present study.

This study represents partial completion of an assignment by the Corps of Engineers, U.S. Army, but special credit is due their foresight in the establishment of a network of observing stations around and on Lake Okeechobee, which resulted in a wealth of observations unequalled in areas visited by tropical storms.

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Introduction

For a number of years, the Corps of Engineers, Department of the Army, has maintained meteorological observation stations at seven hurricane gates on the shore of Lake Okeechobee, Florida (see frontispiece). Intensifying a program for better comprehension of wind and tide relations, the Corps of Engineers, during the spring and summer of 1949, established three additional wind recording locations on steel-girder pylons within the Lake.

On August 23, 1949, the Miami Weather Bureau Office discovered evidence of a tropical disturbance in the formative stage near latitude 19° N, 61° W - east of the Virgin Islands - and its position was carefully tracked thereafter. The disturbance soon developed into a hurricane whose center entered Florida near West Palm Beach between 1830 EST and 1930 EST of the 26th. Advancing west-northwestward, the hurricane center crossed northern Lake Okeechobee shortly before midnight of the same day. Hurricane winds (speeds above 75 mph) were experienced at the newly-established Lake Stations and at most of the gates and other stations in the storm path across Florida. The general path of the storm and some notable features of wind and pressure are shown on figure 1 which is a reproduction of a chart prepared by the Weather Bureau Office at Miami. Occurrence of the storm and its movement across Lake Okeechobee provided what is probably the best coverage on record of surface winds within 100 miles of a hurricane's center. Simultaneous measurement of water level and wave height during the course of the storm furnished an unequaled set of data for investigation of relations between the meteorological and oceanographical elements on a shallow inland body of water during a period of strong winds.

At the request of the Corps of Engineers, the Hydrometeorological Section prepared, in November 1949, a preliminary report entitled, "Surface Winds over Lake Okeechobee, August 26-27, 1949". The report contained tabulations of ten-minute-average wind speeds and directions for all Lake and hurricane-gate stations at ten minute intervals, through the period 1300 EST of the 26th to 1000 EST of the 27th. The report also contained a set of successive maps illustrating the fields of isotachs (lines of constant 10-minute-average wind speeds) and streamlines (10-minute-average wind directions) for the same period. Since issuance of the preliminary report further studies have been made of the August 1949 data. The current report is intended to present to the meteorological field pertinent extracts from the preliminary report and the intermediate studies, with the hope that they may be of assistance in establishing a firmer understanding of the dynamics of a hurricane.

Wind and pressure data

Esterline-Angus multiple-pen recorder traces were available for the wind observations of the 3 Lake stations. For wind speed, one pen recorded the passage of each 1/10 mile of wind and a second recorded the passage of each 10 miles of wind. As long as the 1/10 mile marks were distinct, the 10-minute averages were determined directly. At the higher speeds the individual strokes of the 1/10-mile pen became indistinguishable, and the strokes of the 10-mile pen had to be used. For the high speeds (above about 35 mph) the duration for passage of each 10 miles of wind was determined, and a smooth curve of wind speed vs. time was plotted for each station. From these curves, then, the 10-minute-average wind speeds were extracted. Wind direction data were recorded by an 8-pen system. A smooth curve of direction vs. time was drawn for each station, and 10-minute-average directions were taken from the curves.

For Lake Station No. 2, the 10-mile wind speed pen failed to operate during the course of the storm. Use of the 1/10-mile record provided data close to and at some distance away from the storm center, but wind speeds in excess of 35 mph could not be determined with an acceptable degree of reliability. The record of wind direction for this station was satisfactory, however.

Continuous traces of wind speeds and directions were available for the Dines anemometers installed at 6 of the hurricane gates. At Hurricane Gate No. 3 only wind speeds were available. For each station the wind speed trace was divided into 10-minute segments. The 10-minute-average speed was defined as that value determined by a horizontal line bisecting the darkened area of the trace. The same process was used for determination of the 10-minute-average wind directions. This method of averaging was found to be accurate and most rapid when it was tested by comparison with other methods.

Also at the Section's disposal were pressure and wind data from 27 Weather Bureau, Coast Guard, Engineer and private observing stations. None of these data, available at the time of preparation of the preliminary report, were of the recorder type, and some were estimates of wind velocity, but all were used to a greater or lesser degree after qualitative evaluation of the observations.

<u>The pressure and wind fields</u>

After collecting and organizing the basic data, the Section drew half-hourly surface weather map analyses for the Southern half of Florida for the period of the hurricane. With these larger maps as guides, detailed analyses of pressure and wind over the Lake Okeechobee area were made on two separate sets of charts. Figures 2-10 portray the pressure patterns over the Lake at half-hourly intervals during the period of storm passage. Figures 11-61 portray the successive patterns of 10-minute-average wind speed and direction over the same area. The wind charts are for 10-minute intervals during the critical period of 2000 EST of the 26th to 0200 EST of the 27th, and for hourly intervals for several hours on either side of the critical period. The wind values are averaged over the 10-minute period from 5 minutes before to 5 minutes after the time indicated on each chart.

The wind charts illustrate the tremendous importance of surface friction on wind speeds measured near ground or water surfaces, and the observations suggest possible explanations of peculiarities often noted in the pressure and wind patterns of a hurricane. For instance, the "longitudinal" divergence (in the direction of the undistorted hurricane wind field) which exists with an offshore wind, appears at least partially to be compensated by a "transverse" convergence (across the undistorted streamlines). The opposite effect is noticeable with winds directed onshore. Such features of the wind, particularly noticeable on figures 36 and 37 , must play an important role in producing distortions in isobars passing over a coastline, as in figures 7 and 8 . Similar circumstances, noted in studies of other hurricanes, have given rise to considerable difficulty in tracing the paths of hurricanes crossing the Florida coastline.

In addition to gustiness of varying periodicity, the anemograph records show longer-period (20-30 minute) rises and falls in wind speed during passage of the storm. Many of these fluctuations must be associated with the spiral bands of turbulence and squally weather observed in airplane flights through tropical storms and shown remarkably well on radar PPI-scope photographs of recent hurricanes. An example of such a photograph for the hurricane of August 1949, however, is shown in figure 62, furnished by the Engineering and Industrial Experiment Station, Electronics Research Laboratory, University of Florida.

Although the wind charts are drawn to suggest a rather uniform acceleration of the surface wind upon leaving land, and of deceleration upon approaching the shore, the precise nature of the acceleration remains much in doubt. Addition of one or more judiciously placed Lake stations would materially aid in clarification of the problem as to how rapidly the wind speeds up or slows down upon crossing a coastline.

The Hydrometeorological Section is continuing to study deviations, such as the above, from symmetrical wind and pressure fields with the aim of developing quantitative methods of introducing them into a generalized wind model. In its present state, the model consists of an empirical description of a symmetrical hurricane surface-wind pattern upon which are superimposed local adjustments to account for effects, on surface wind speed, of a friction factor which varies with the type of surface traversed by the wind. The current model may thus be considered as a first approximation for determining interrelations of wind speed, direction, and duration, and such oceanographical parameters as fetch, wind tide, and wave height. Derivation of the model as it applies to the hurricane of August 1949 is given in the following paragraphs.

Determination of the storm path

General forecasting techniques do not require extremely accurate pin-

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pointing of the exact "center" of a hurricane, nor is there a particular need for giving a definition of "center". For some time the Hydrometeorological Section has been attempting to develop a general theoretical representation of tropical storms for the Lake Okeechobee area, and has experienced considerable difficulty reproducing winds near the "center" of such storms through use of cyclostrophic or gradient wind equations. The reason for much of the difficulty is that the wind center and center of minimum pressure are not always coincident. In order to be consistent in location of "center" and yet avoid depending completely upon the pressures at one or two stations near the "center" for location, the Section decided to use a "center of pressure symmetry" to define successive positions along the path. The center of pressure symmetry at any time is defined as that location which produces the best fit of all simultaneous pressure readings to a smooth mean pressure profile for the total storm period over the Lake. Figure 63 shows the path of pressure symmetry determined for the 1949 storm. For comparison, figure 64 shows the path of minimum pressure determined by means of isochrones of minimum pressure and isobars of minimum pressure. It is interesting to note that whereas the center of pressure symmetry passed to the north of Port Mayaca, the center of minimum pressure passed south of it. Due to storm movement, the path of the center of wind rotation is not coincident with either of the above paths.

The wind direction pattern

Assumption of gradient wind conditions with flow parallel to the isobars would result in considerable error in wind direction, particularly near the center. This is illustrated by the fact that the center of minimum pressure passed south of Port Mayaca, and yet the winds backed at that station as the hurricane moved westward across the Lake. The implication from the observed data, then, is that a "wind center" passed north of Port Mayaca. Therefore, it was necessary to devise a practical means of showing instantaneous wind directions. With a transparent sheet always aligned north and south and always centered at the center of pressure symmetry, wind directions were plotted at ten-minute intervals (figure 65). On this chart the suspected distinct center of wind rotation became evident. The bearing and distance of the wind center from the center of pressure symmetry were determined and this constant vector adjustment was applied to all positions along the path of pressure symmetry to obtain a path of wind rotation. All subsequent measures of distance and references to path are based upon the position of the wind center.

Figure 66A shows the mean deflection of the observed wind direction from a perpendicular to a radius (drawn from the center of wind pattern) as a function of distance from the wind center. There are indications that there may be relationship between rate of change of deflection angle and position of the station relative to the path of the storm center. However, as a first approximation used in this report, it appeared suitable to attribute the deviations from a symmetrical pattern to local station exposure characteristics. Assuming, then, that deviations from a symmetrical pattern are due to local characteristics, and in order to facilitate drawing of a sequence of charts, the mean deflection angles were converted into a spiral as shown in figure 66B. Centering the curve at successive positions of the storm center permits quick reproduction of the mean instantaneous wind directions within the field of the hurricane. Figure 66A suggests that the deflection angle becomes negative for distances less than five miles from the center of the storm. Actually, two observations within five miles of the center do show such deflection angles. It is interesting to note that the observations suggest outflow from the center which is in agreement with the mechanics necessary to produce dissipation of clouds and the resultant "eye" of the storm.

The wind speed field

In order to establish a general wind-speed field, it was necessary to fix a standard of wind with nearly constant frictional effects. Since there were three stations operating on the Lake, it was decided to use as a base an "over-water" wind as defined by the observations recorded on Lake Okeechobee. Figure 67 is an envelopment of all 10-minute average speeds recorded at the Lake stations. For convenience in use for design procedures, envelopments are the most suitable values to use. It should be pointed out that the wind field represents conditions in the vicinity of Lake Okeechobee, and not throughout the life of the storm, and further, the velocities represented are 10-minute averages obtained by procedures previously described.

In order to establish adjustment factors for site and exposure of anemometers at the stations along the shores of Lake Okeechobee, the winds at each station were separated into two categories - off-land, and off-water. For each station a mean percentage of over-water wind was determined for each of the two categories. Table I expresses the relation of off-water and off-land winds at each station as a percentage of the over-water wind.

Table I
Percent over-water wind

Station	Off water	Off land
Hurricane Gate No. 1	55	55
" " " 2	73	58
" " " 3	81	64
" " " 4	80	66
" " " 5	89	56
" " " 6	87	57
Port Mayaca	89	64

The low value of off-water wind for Hurricane Gate No. 1 is probably due to the fact that there is a considerable stretch of marshland on the water side of the station, so that for practical purposes this station may be considered as not having a true off-water exposure.

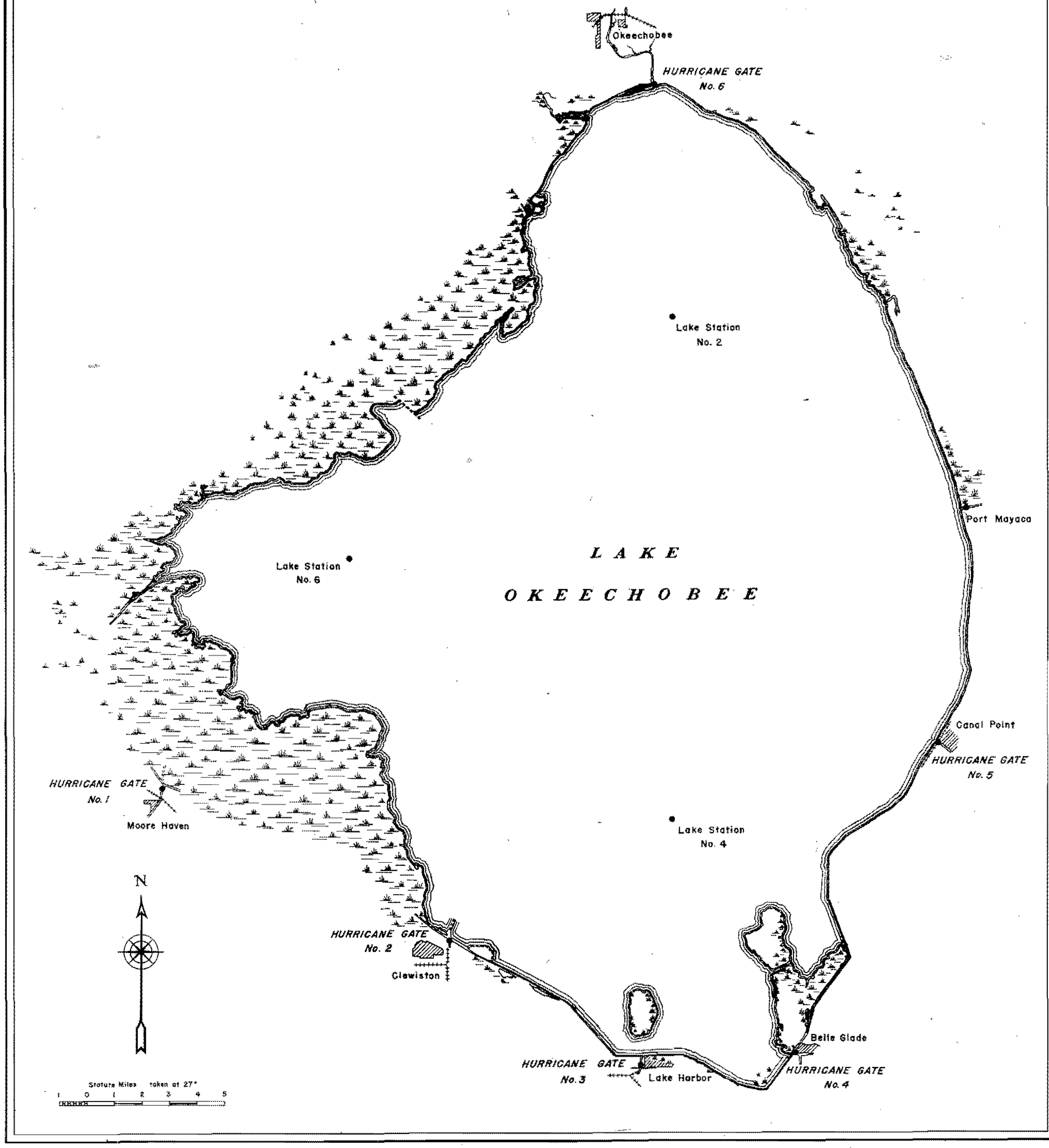
Off-water winds at the remaining stations indicate the effects of deceleration as wind approaches the shore, since with onshore winds, one would otherwise expect well-exposed anemometers to show velocities equal to the over-water velocities. The cumulative effect of increased friction over land and consequent convergence at the shore apparently produces a slowdown of the wind before reaching the shoreline. An item of added interest in this connection requiring further study is an apparent curvature of the path of a hurricane when crossing a shoreline. On approaching a shoreline from water there appears to be an excess of pressure, or mass accumulation, to the right of the path, and a deficit of pressure to the left of the path. Immediately upon crossing the shoreline and passing onto a surface of uniform frictional effects, then, the apparent path shifts when the pressures to right and left approach symmetry.

Applications of the analysis

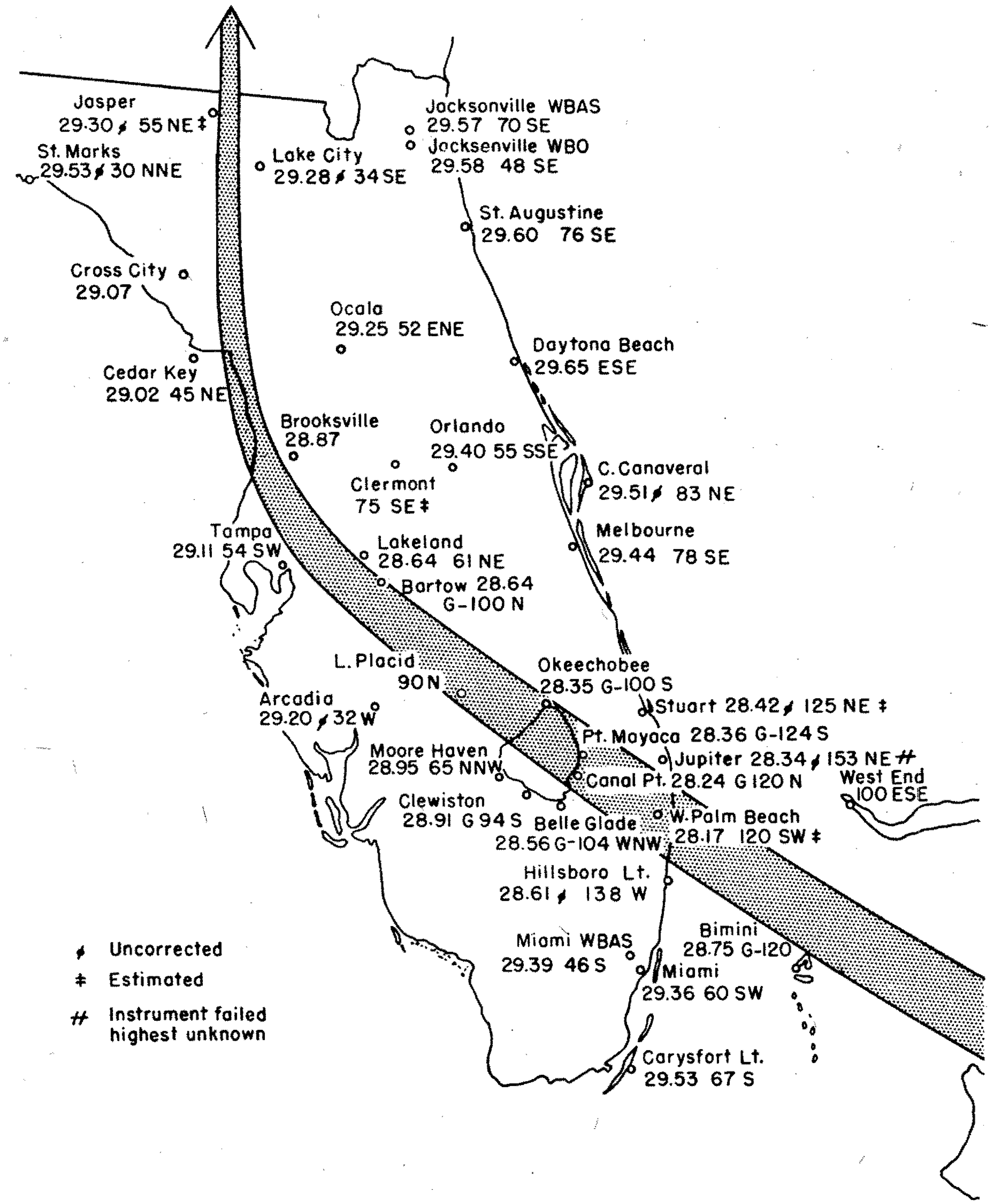
Reliability of the procedures was tested qualitatively by an attempt to reproduce observed wind directions and speeds for the storm of August 26-27, 1949. Since the whole procedure is based upon an averaging of the observed conditions in the storm, it can be expected that there should be a fairly close agreement. Figure 68 is a typical reproduction of the wind direction and speed as outlined by the above procedures. The agreement with observed values plotted at the individual stations indicates that the concurrence is of sufficient accuracy for use in determination of wind-tide and waves for design purposes.

It is believed that the effective hurricane history can be increased over areas commonly visited by such storms by the technique of transposition. In order to assist in the estimation of the maximum possible rainfall over river basins, the Hydrometeorological Section has been applying such techniques to storm rainfall for some years, with considerable satisfaction. At the present time the Section is applying the procedure of wind analysis described, to other tropical storms in Florida for which sufficient data are available to provide a fairly reliable analysis. Within reasonable meteorological limits each of these storms will be transposed in such fashion as to produce a critical sequence of winds at a particular levee or flood control structure. Thus, after the completed transpositions, oceanographers, familiar with the relationships between winds and tides or waves, will be able to estimate the needs of a design structure adequate to cope with a situation arising from critical passage of a tropical storm of magnitude comparable to any which has been experienced in Florida.

This report has deliberately been confined to discussion of the empirical analysis of the 1949 hurricane, based upon the excellent set of observations obtained during the storm. Other tropical storms are being subjected to similar analyses and transpositions by the Hydrometeorological Section. The theoretical aspects of hurricane mechanisms have not been neglected, however, since the problem of estimating maximum possible hurricane winds will require a thorough investigation of all the possible variables. These and other theoretical considerations are a continuing phase of the overall investigation of hurricane winds.



METEOROLOGICAL INSTALLATIONS ON LAKE OKEECHOBEE, FLORIDA



EXTREMES OF WIND AND BAROMETRIC PRESSURE, DURING HURRICANE OF 26-27 AUGUST 1949 IN FLORIDA

AFTER WBO MIAMI

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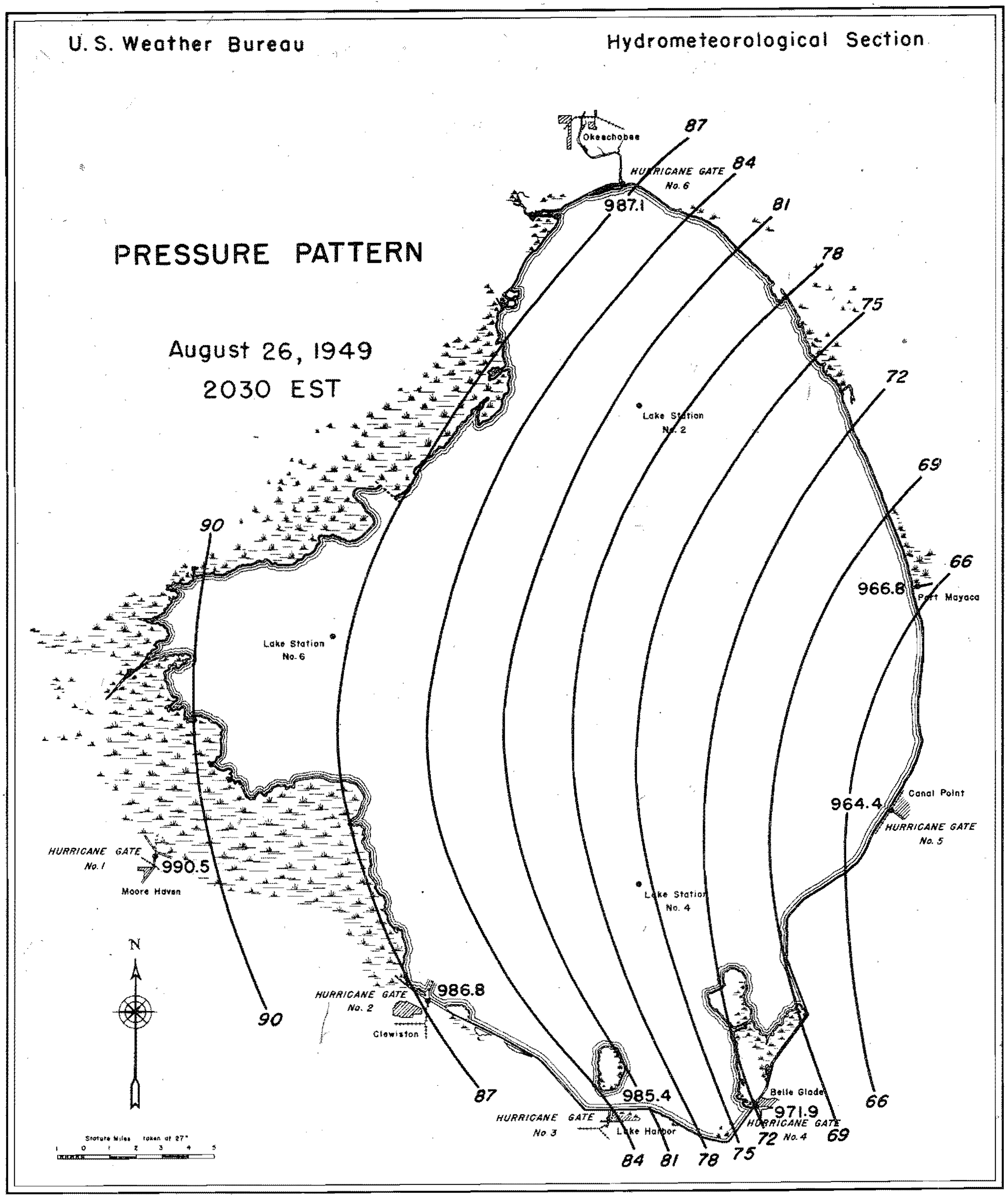

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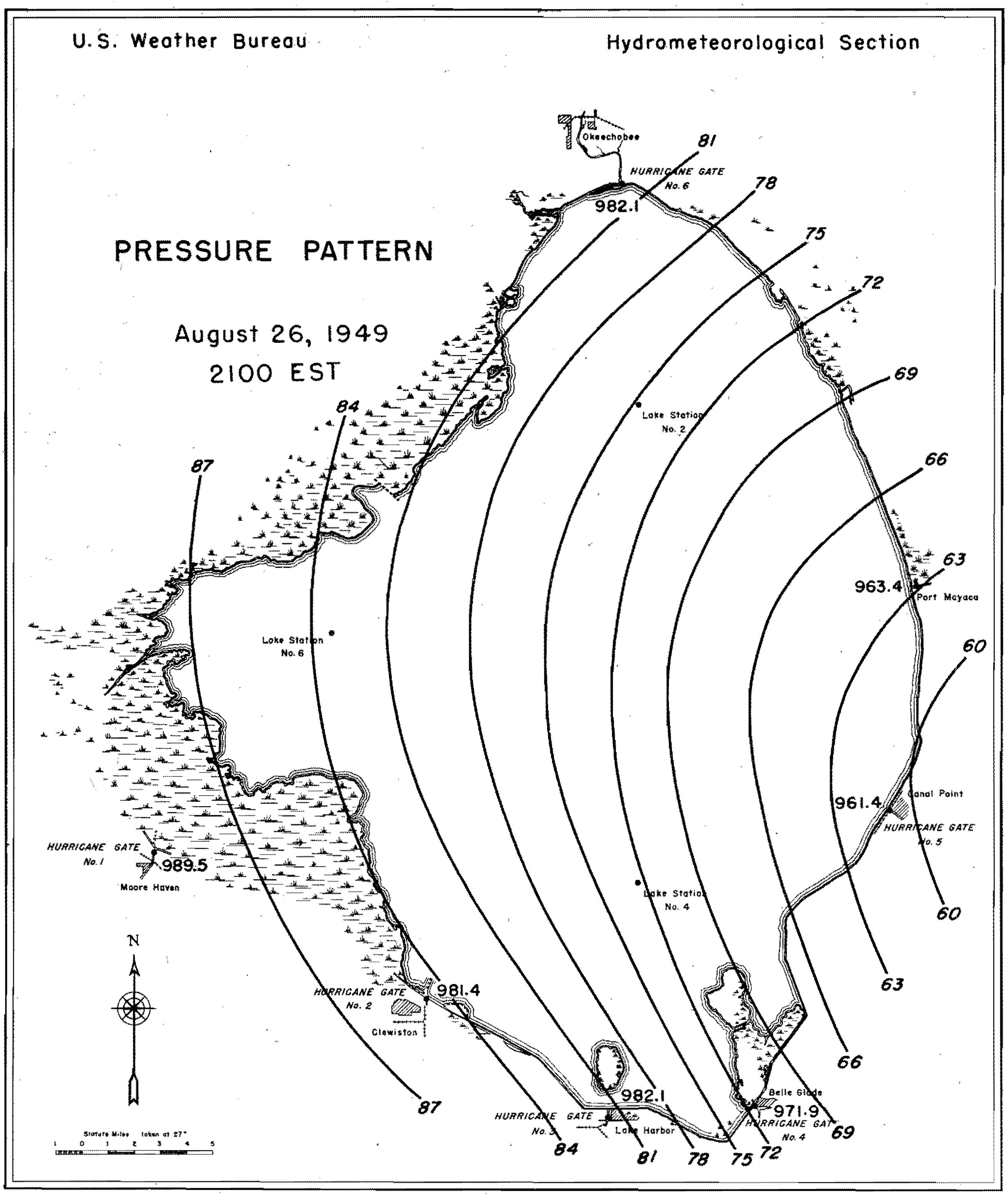
Figure 2



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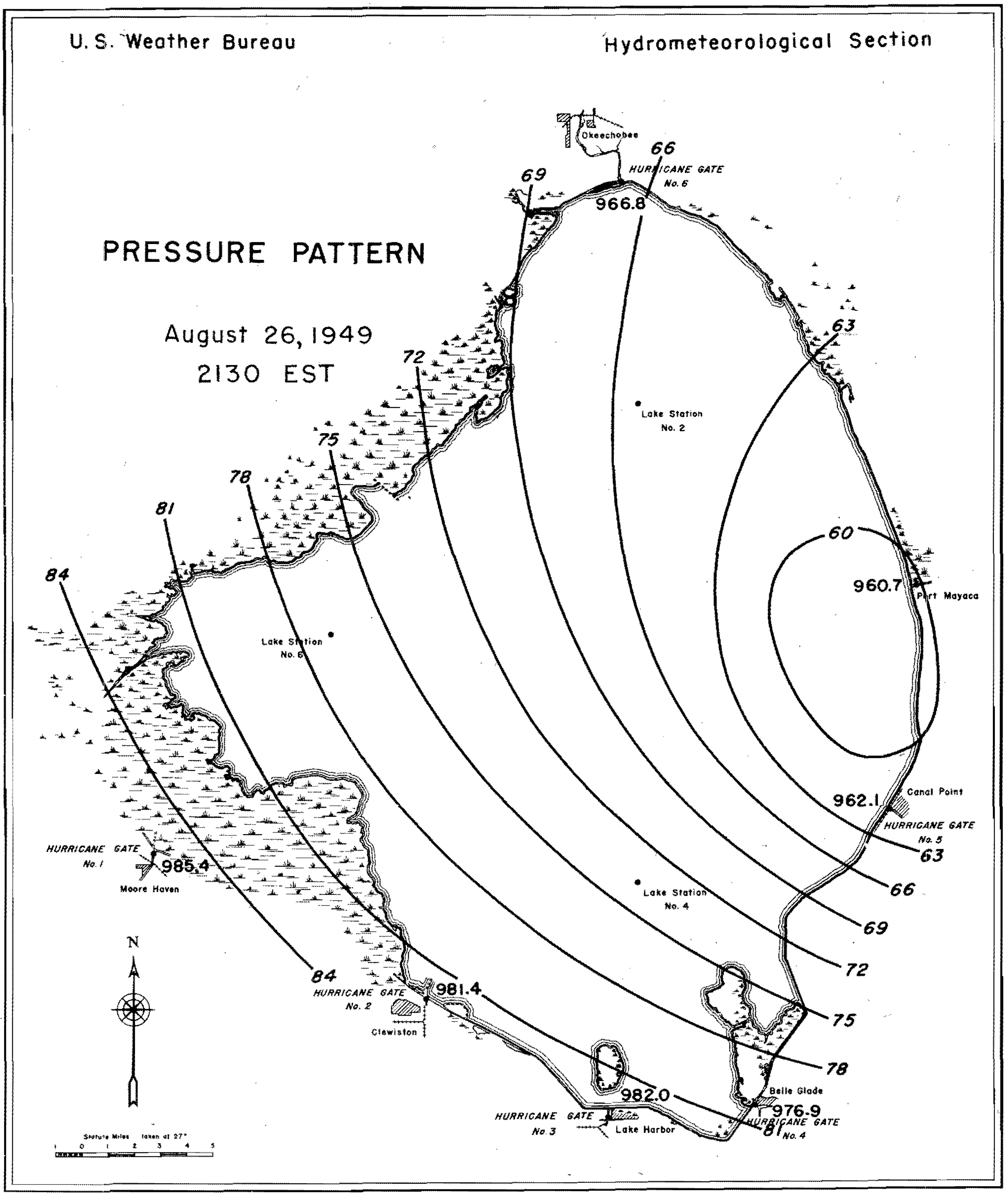

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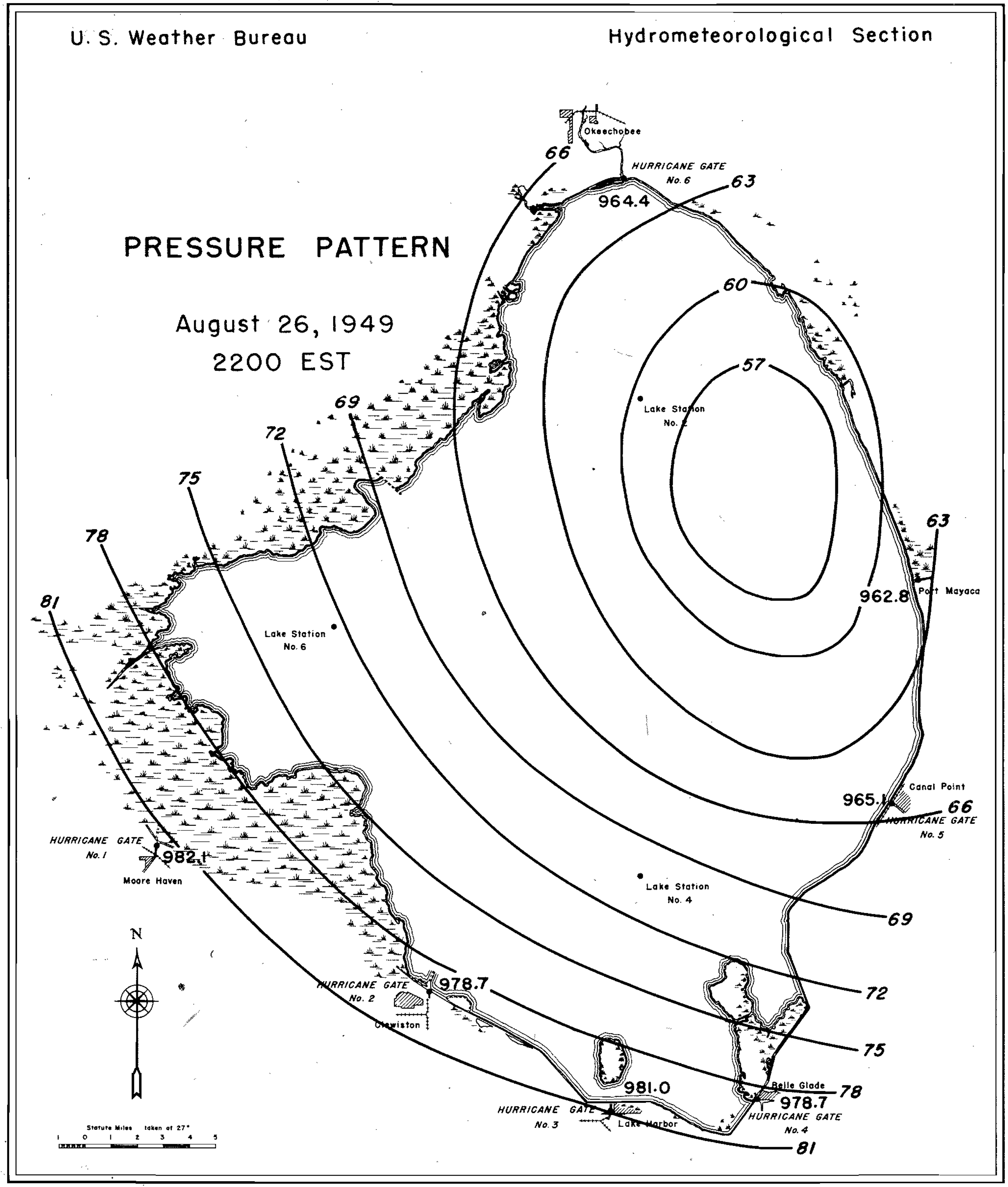

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Figure 5

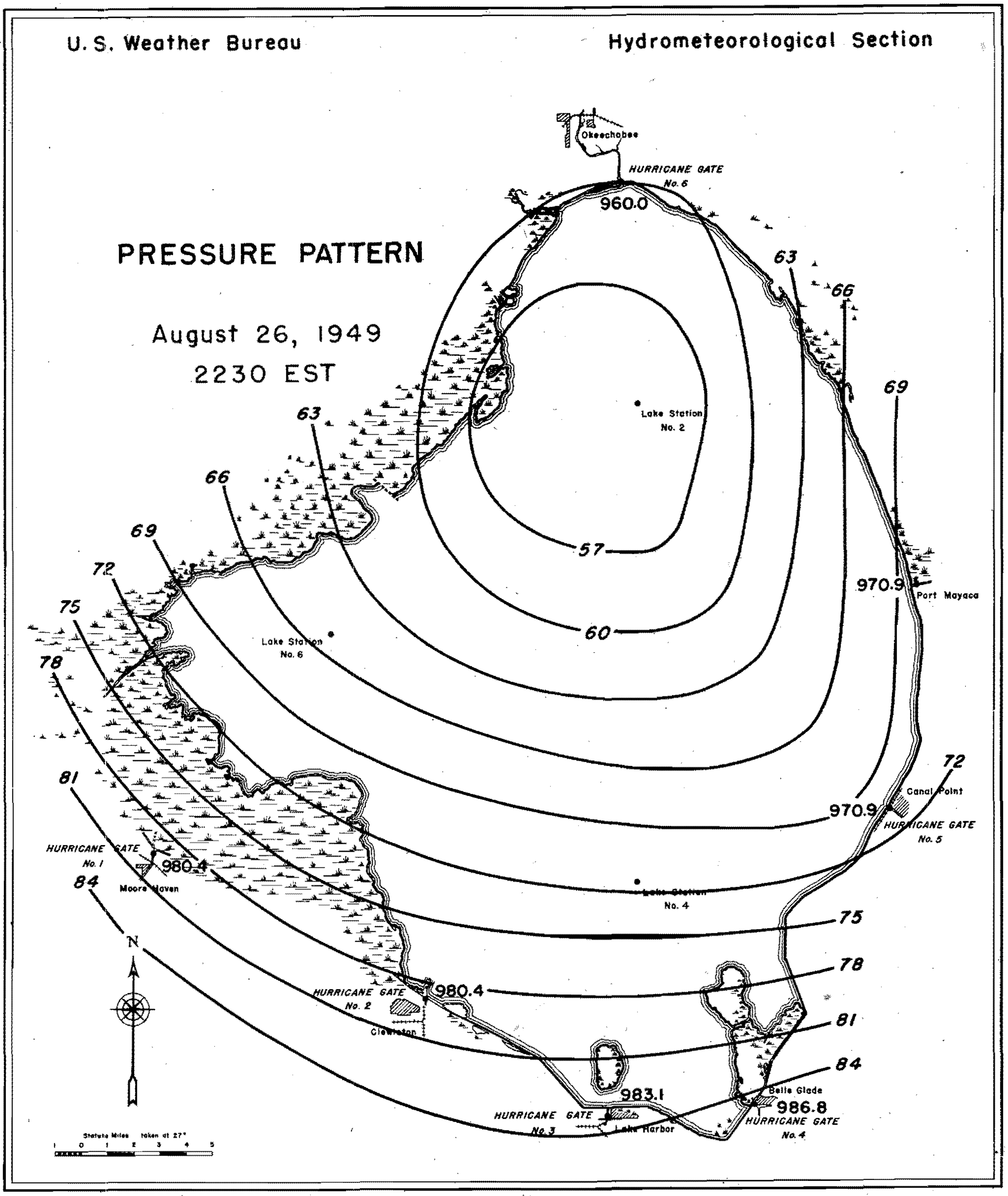

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Figure 6

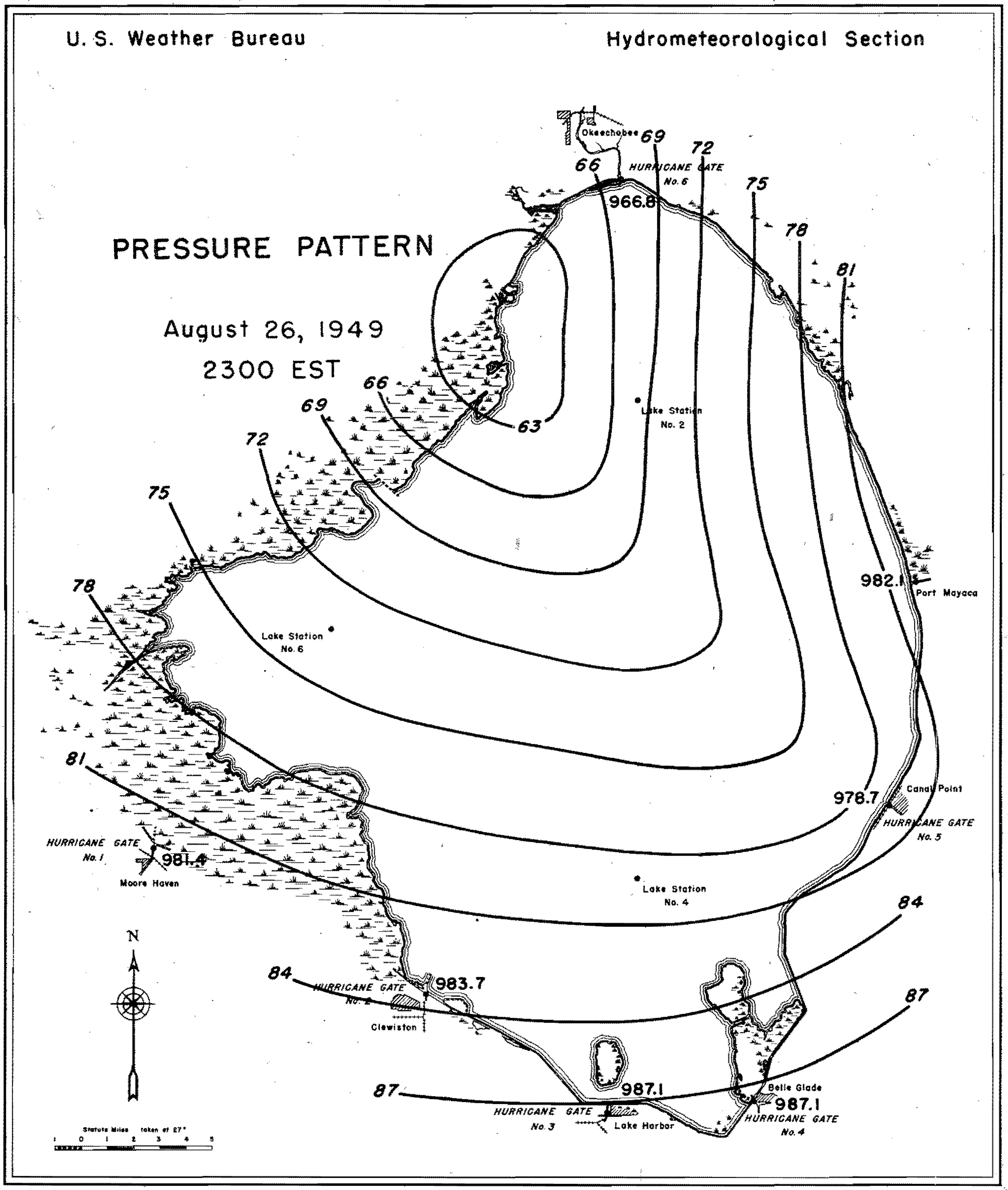

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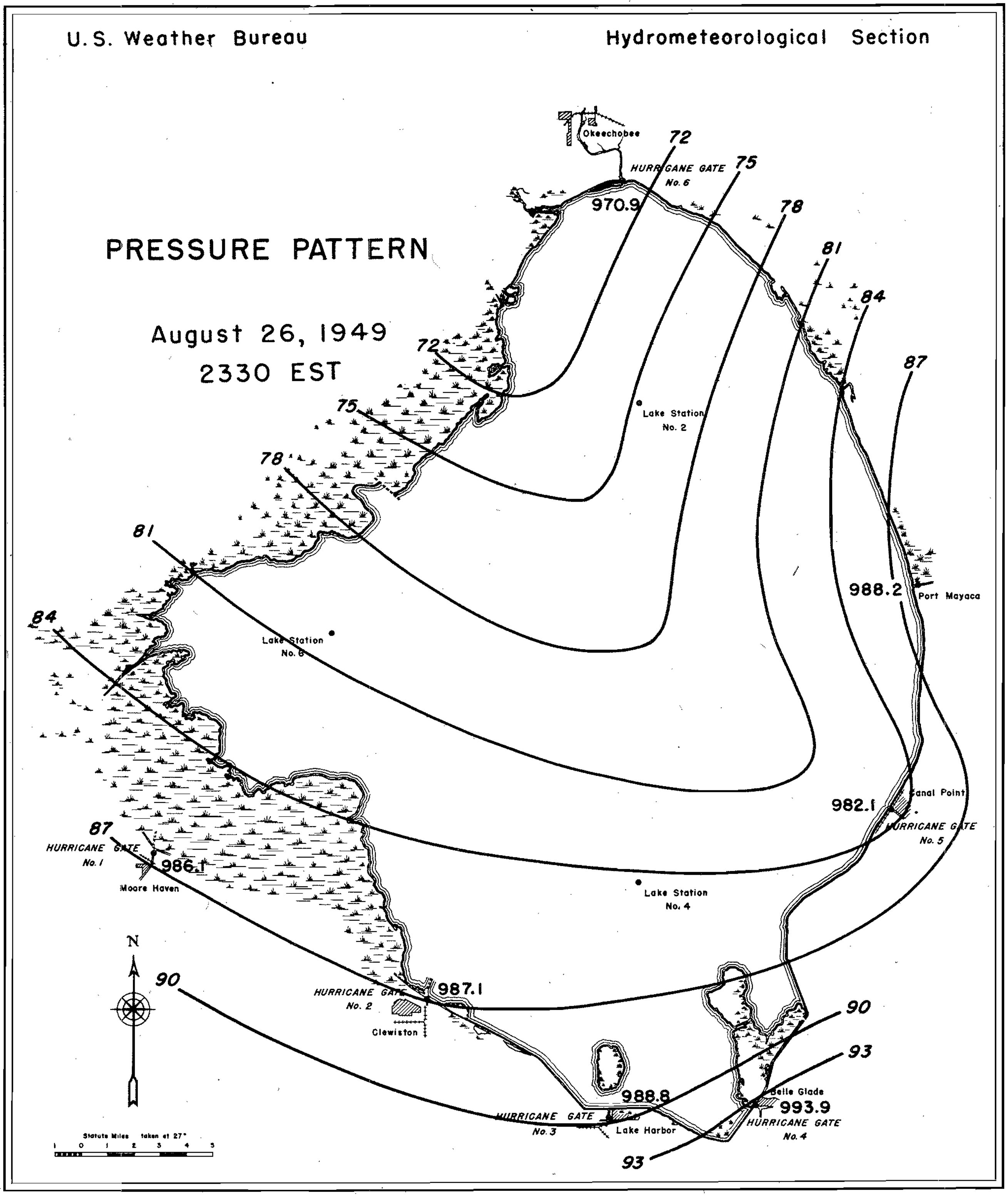
Figure 7



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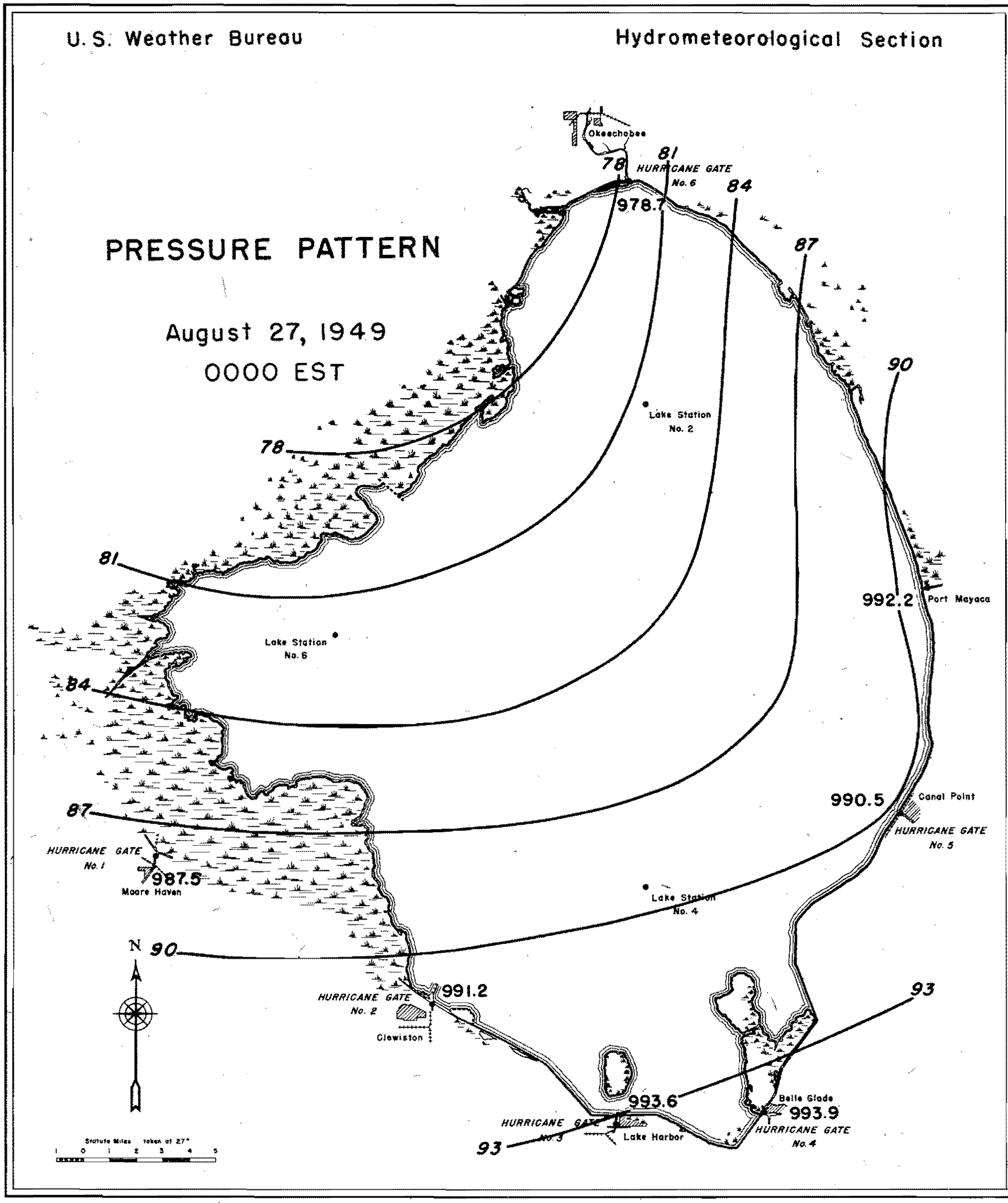

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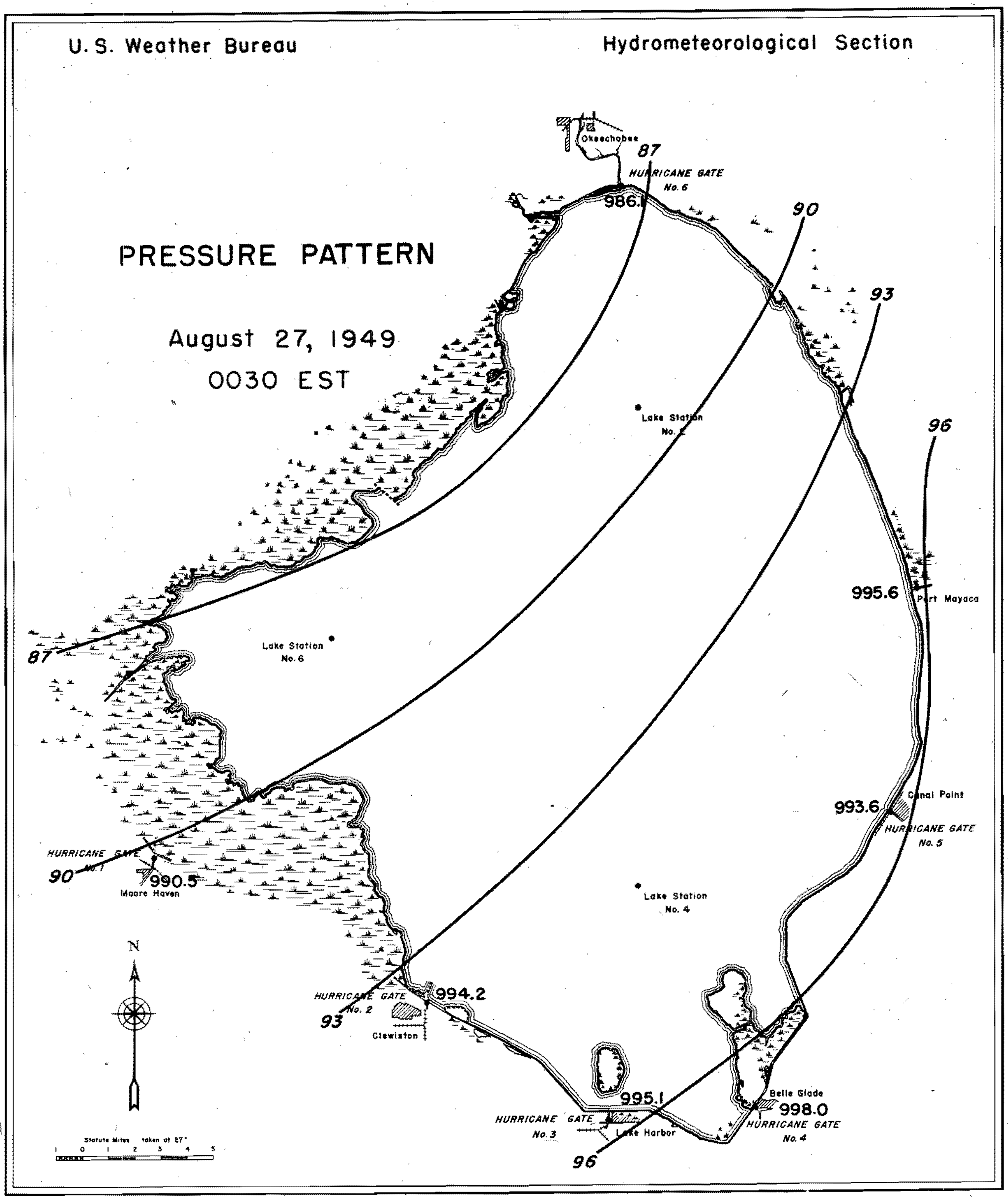

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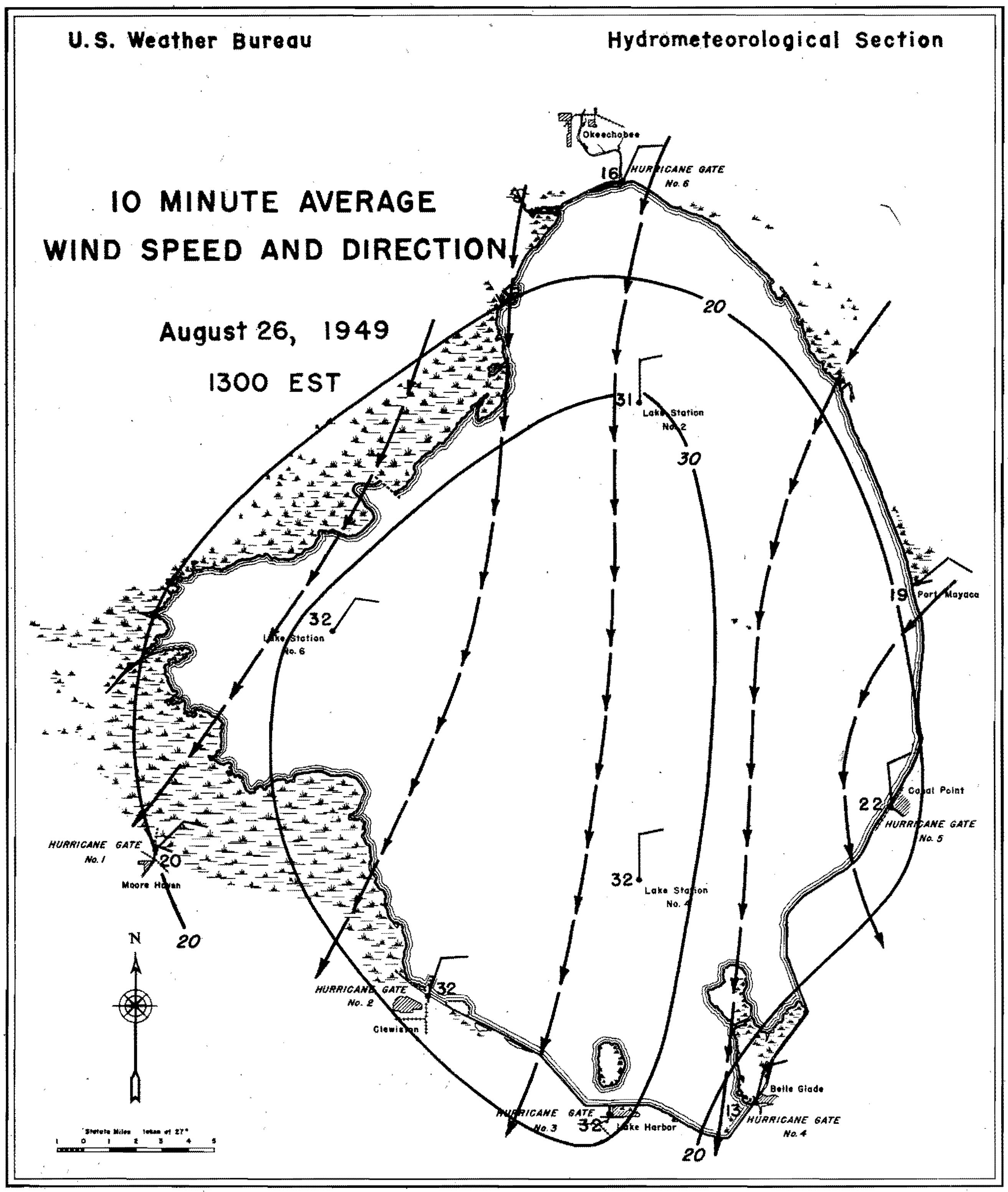

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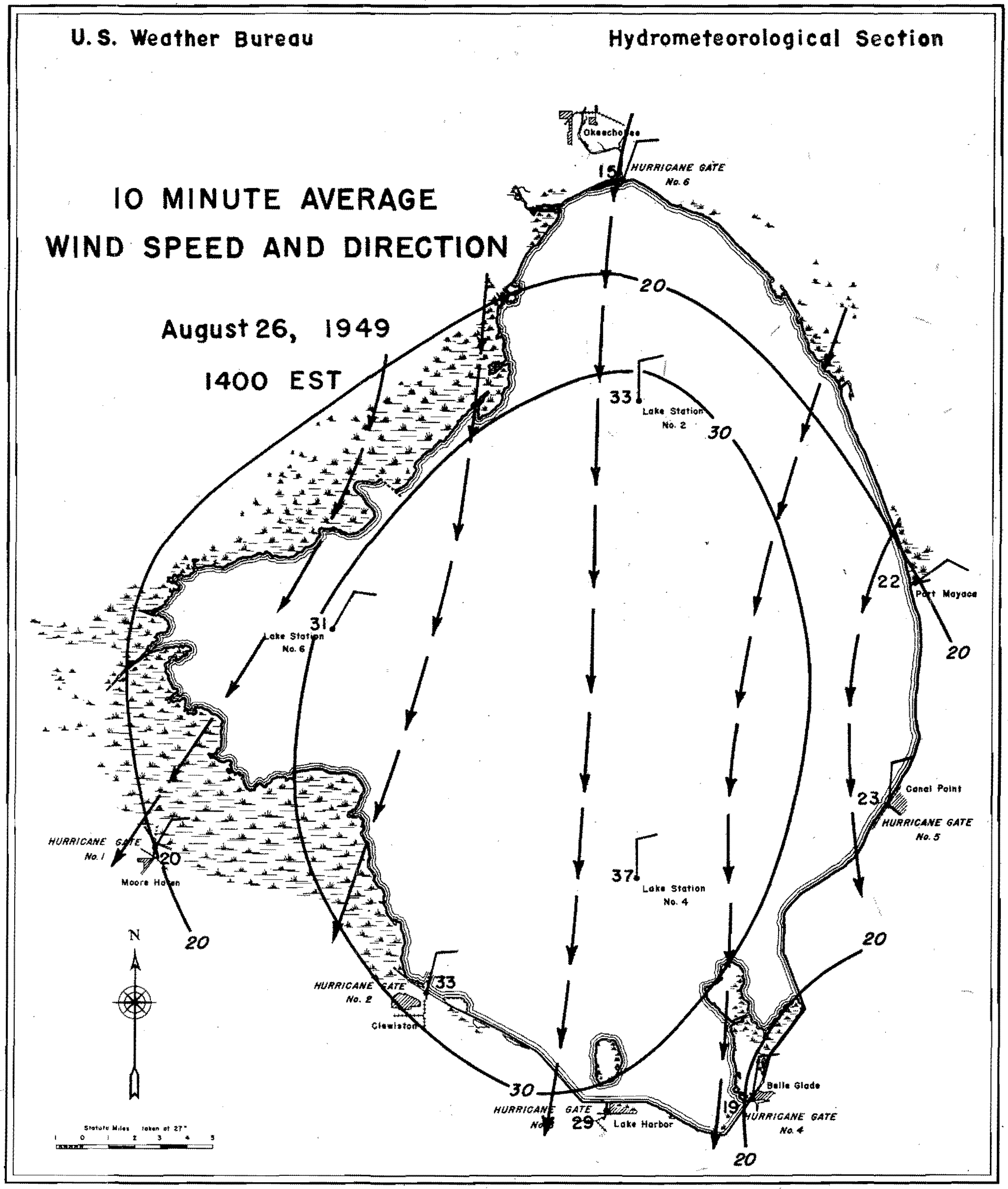

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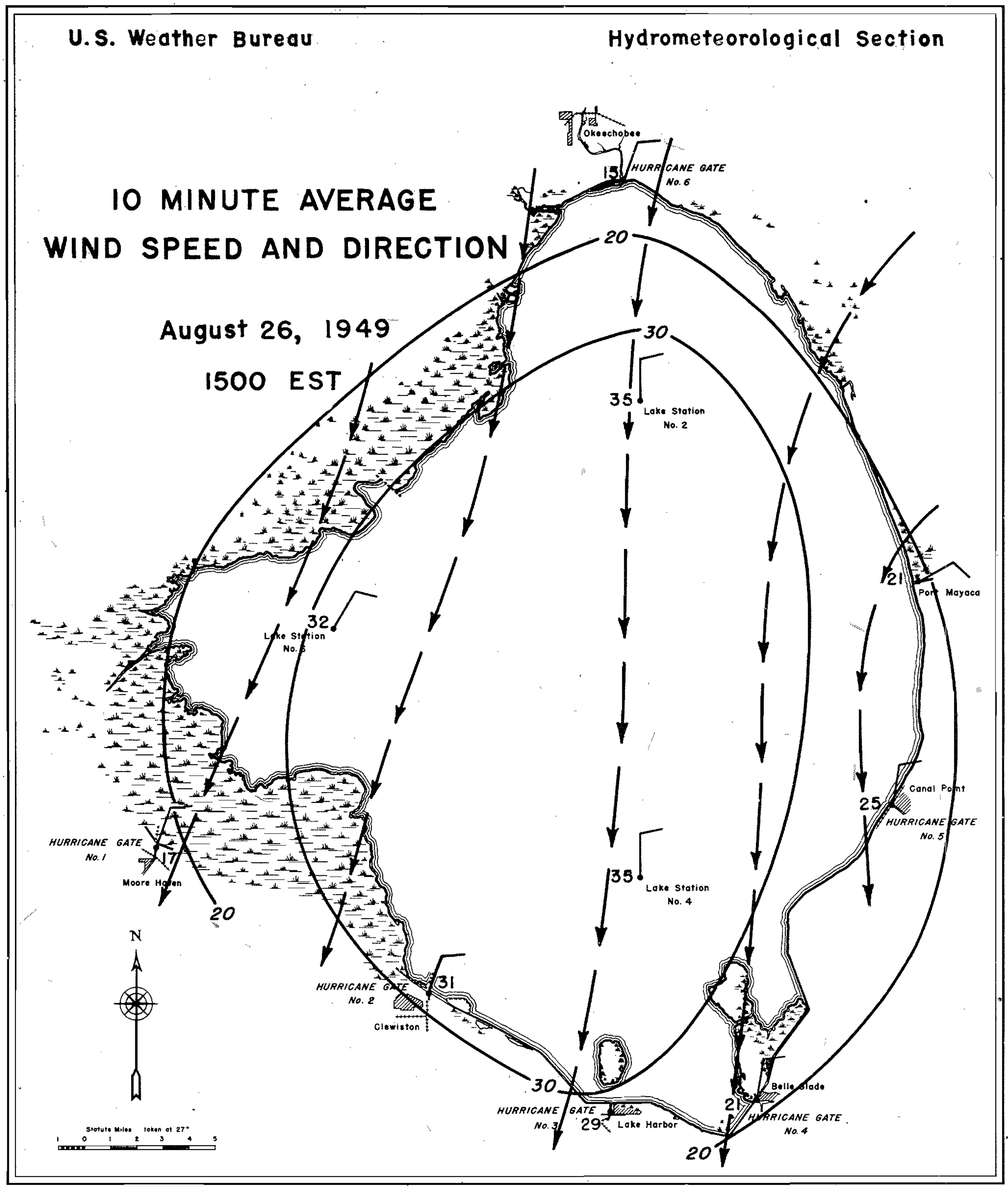

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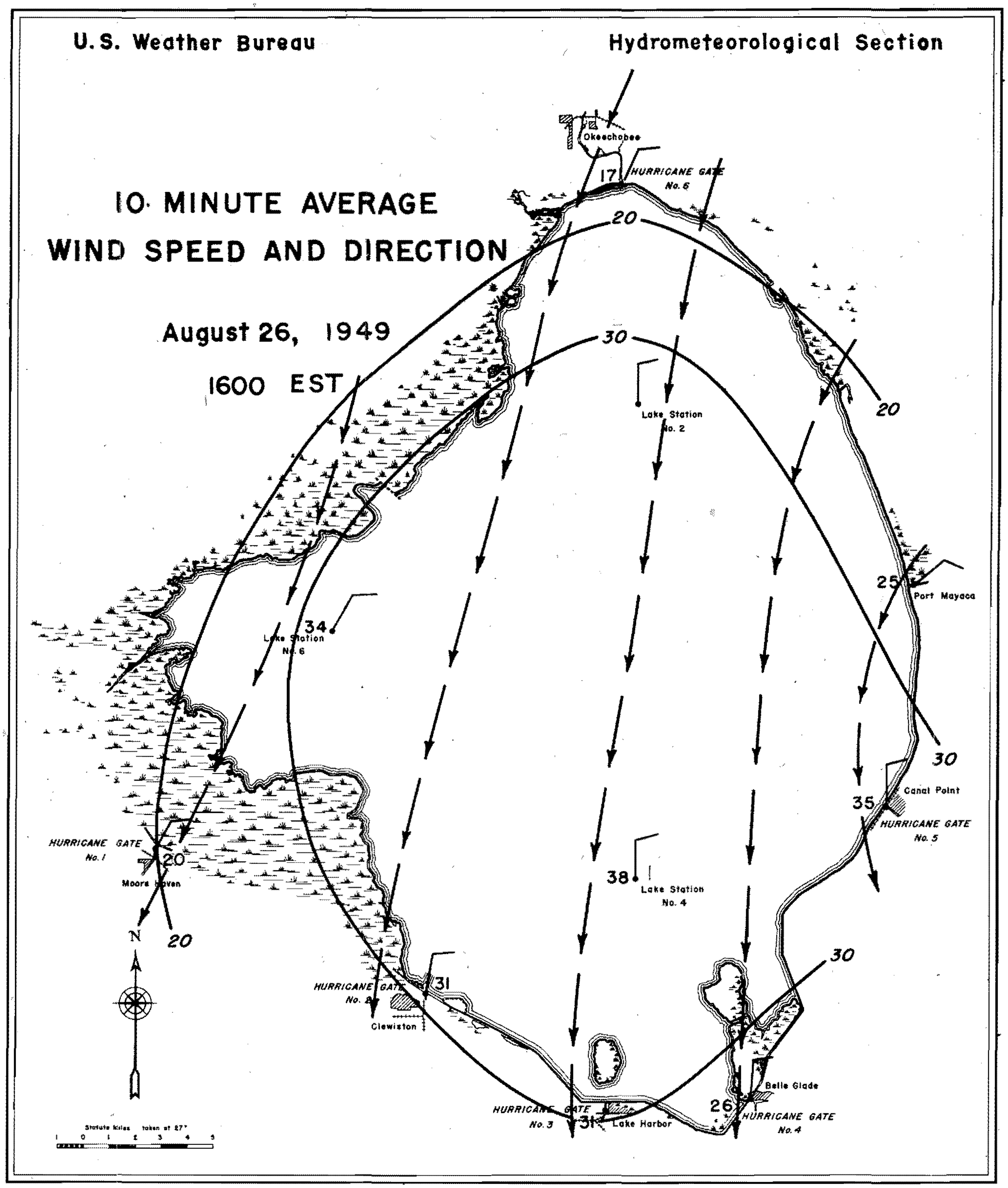

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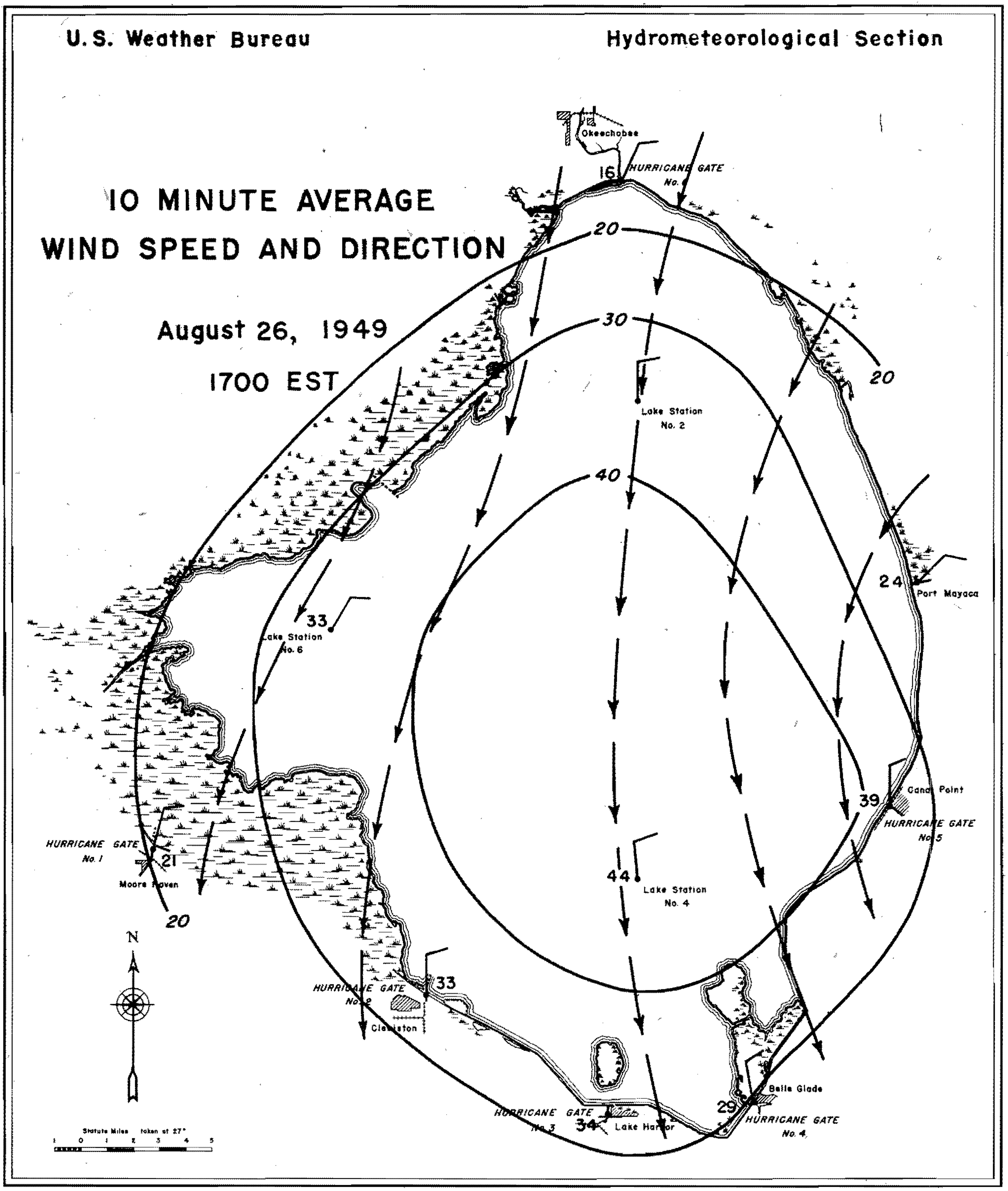

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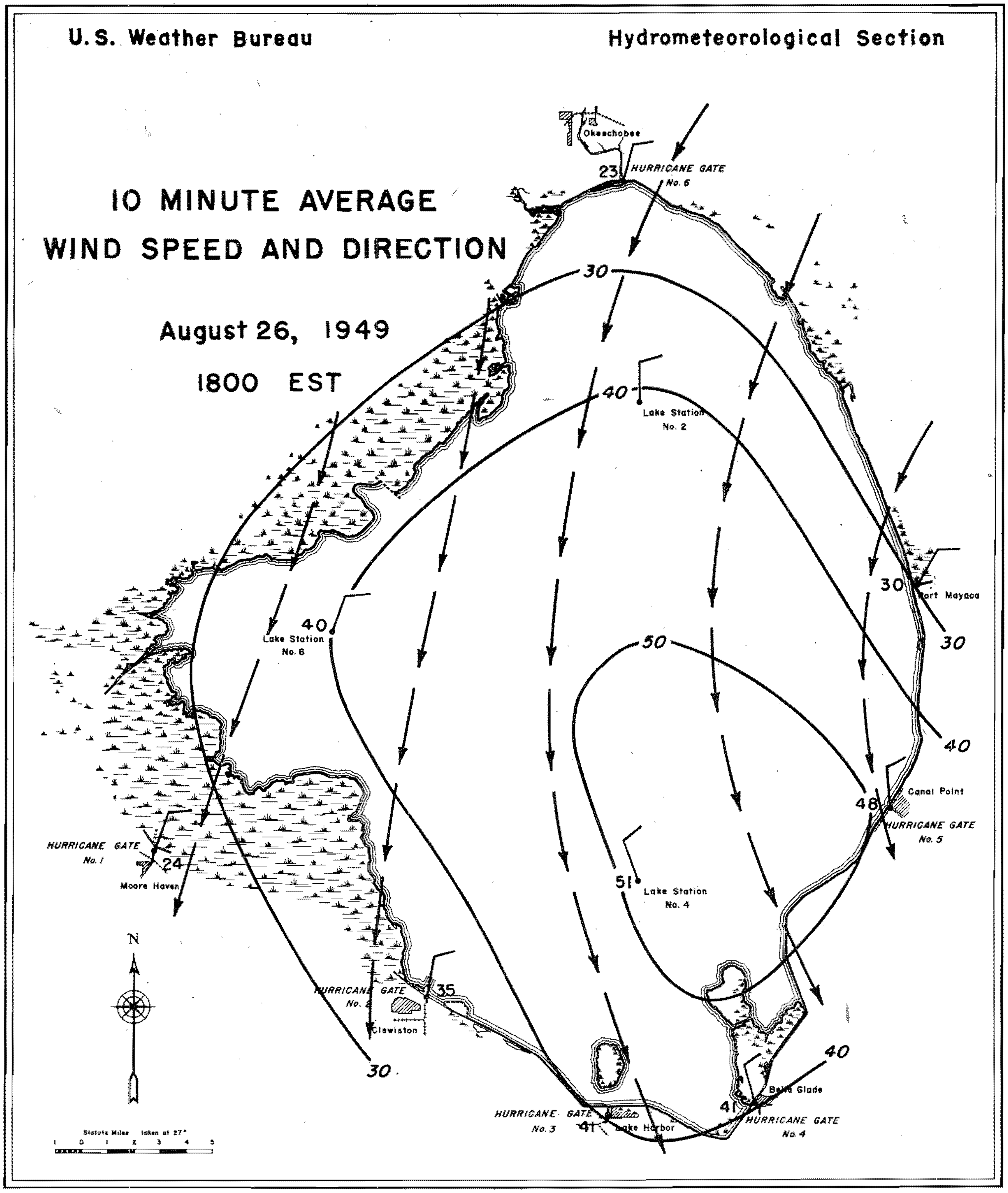

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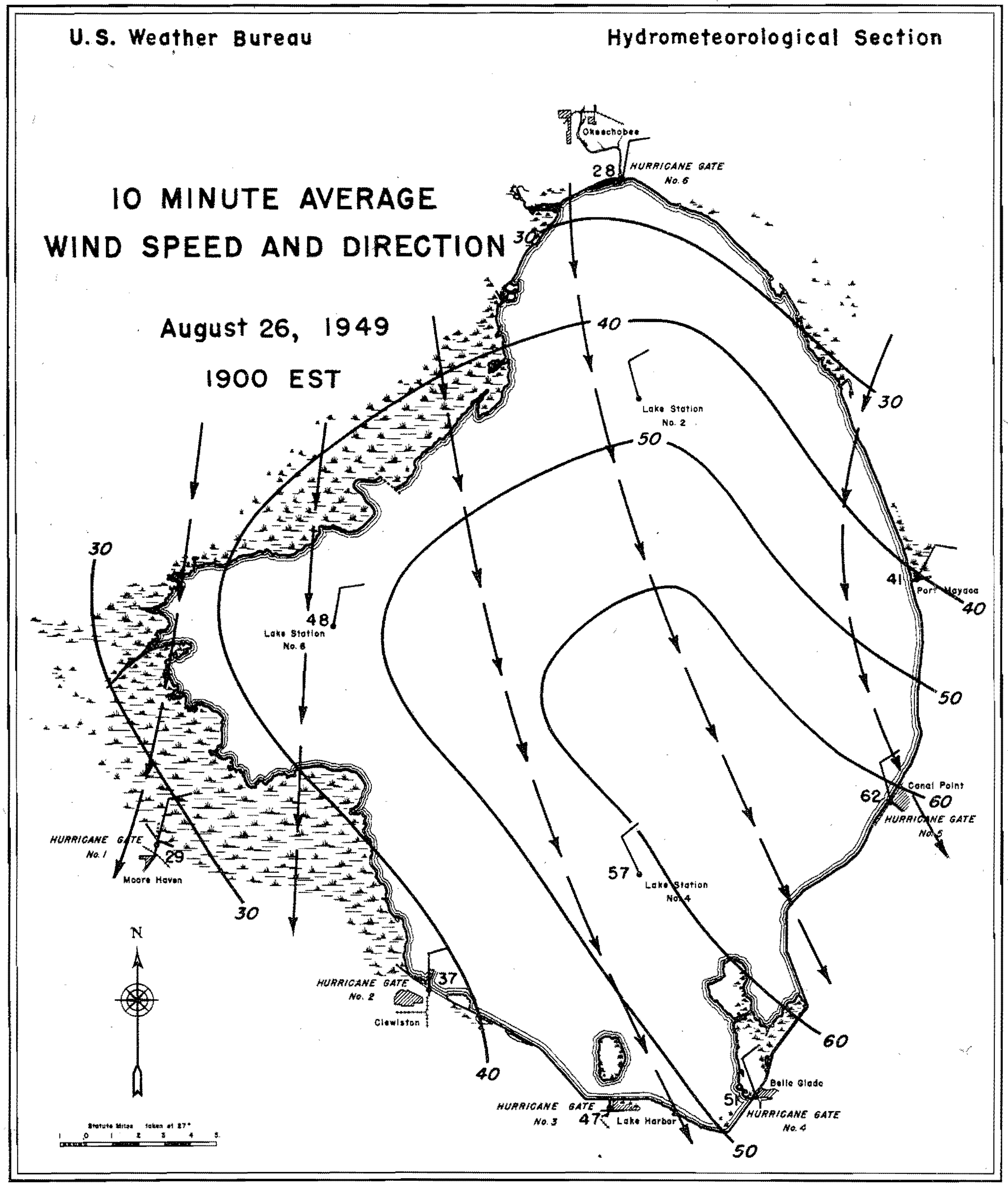

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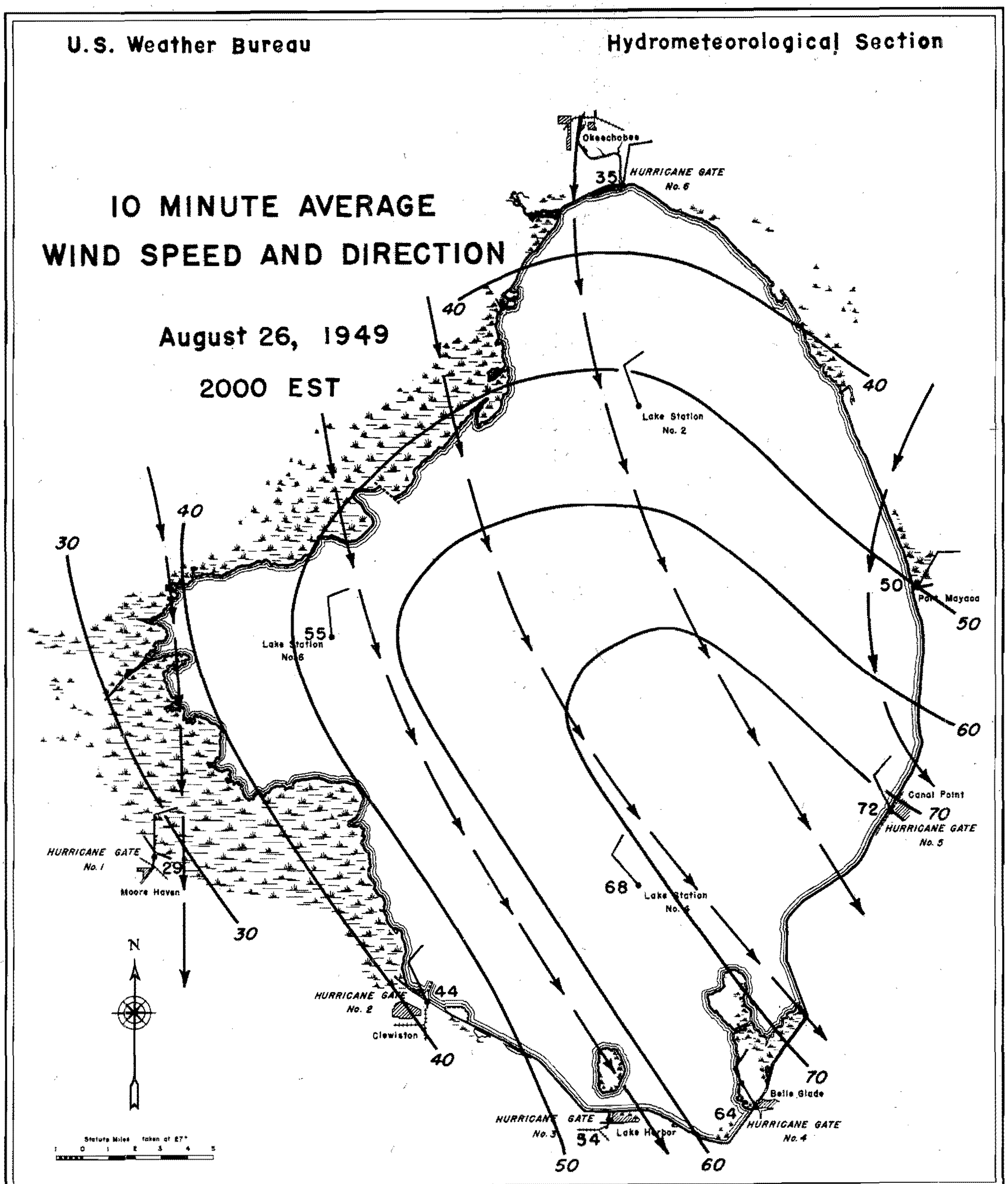

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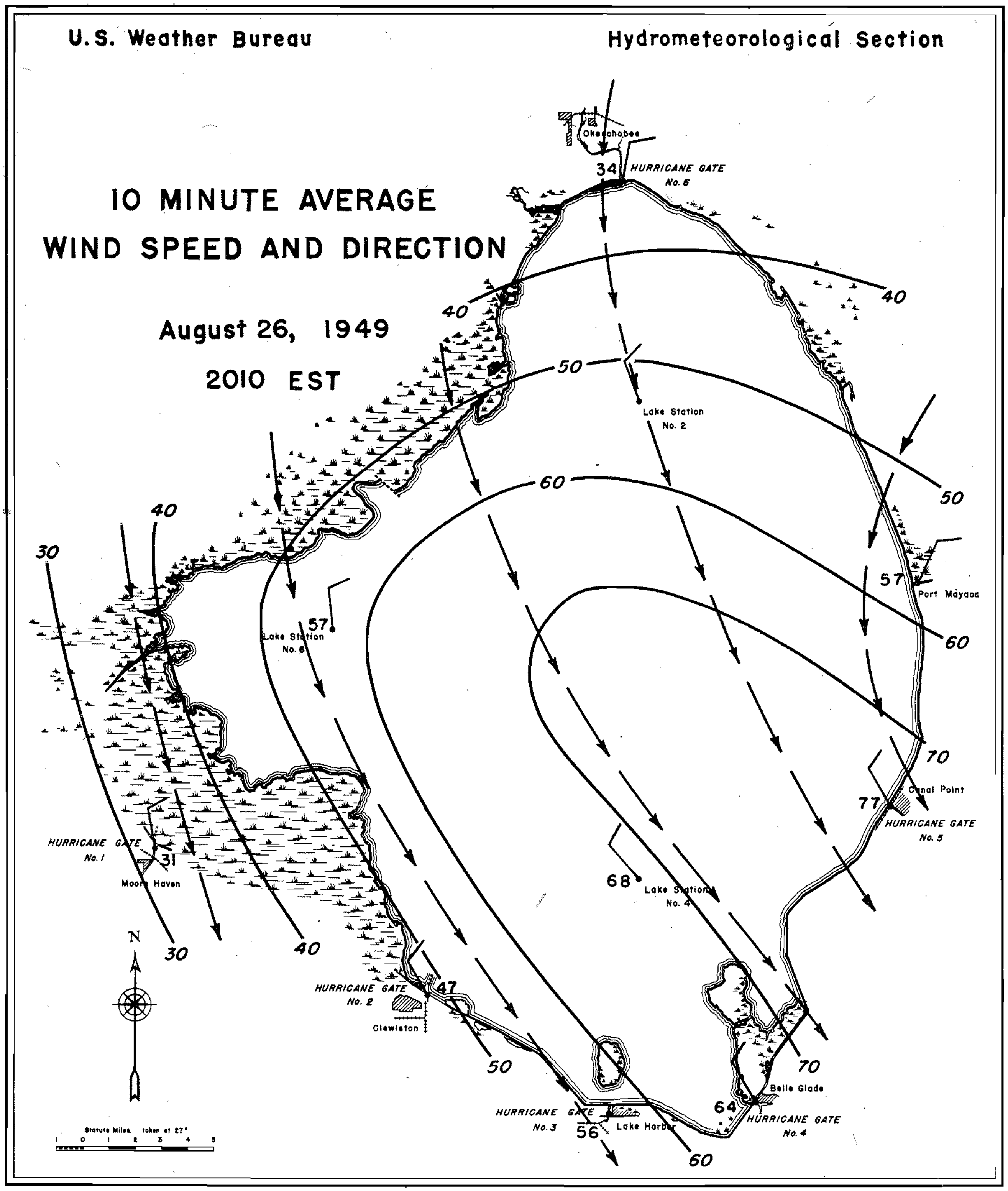

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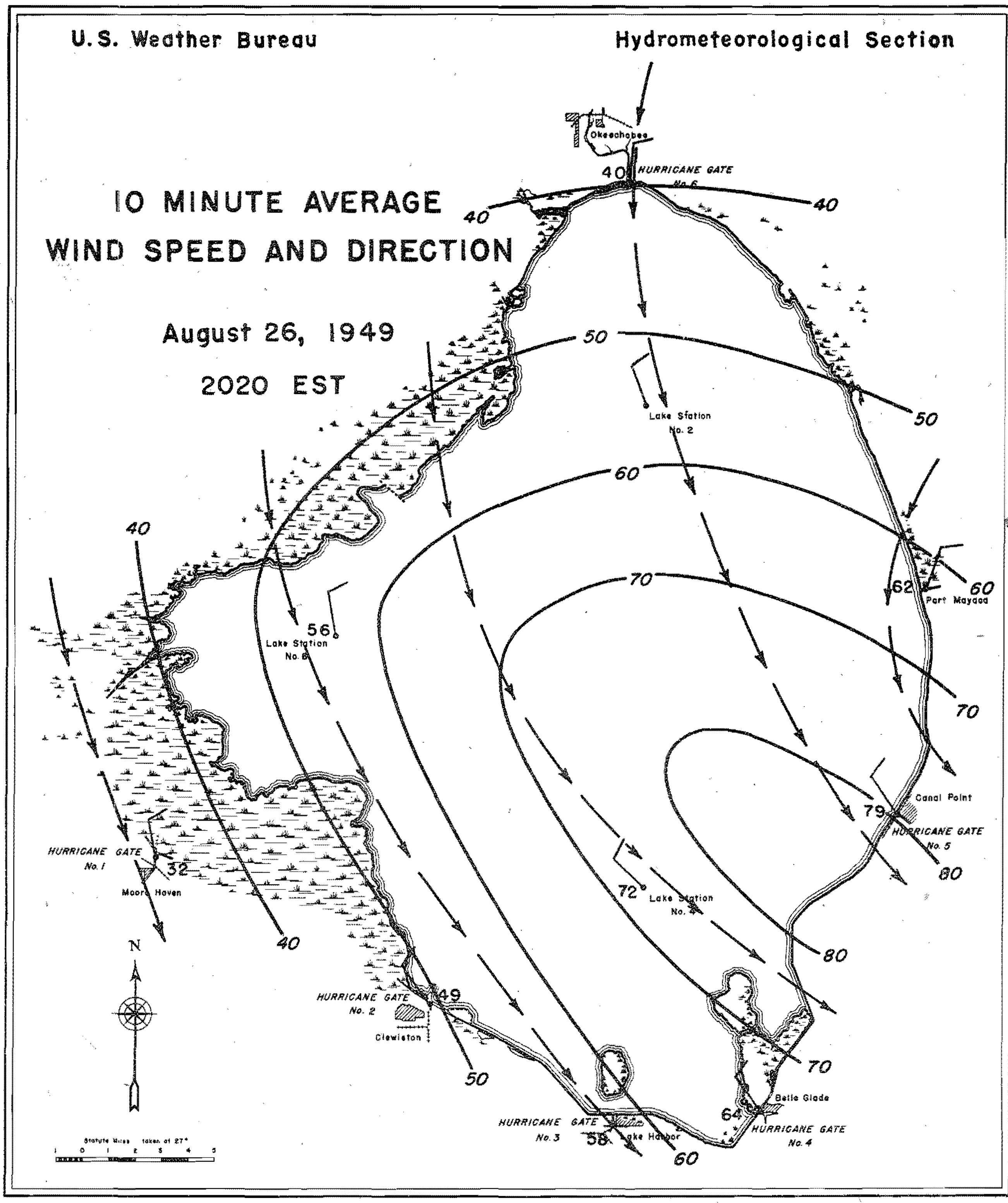

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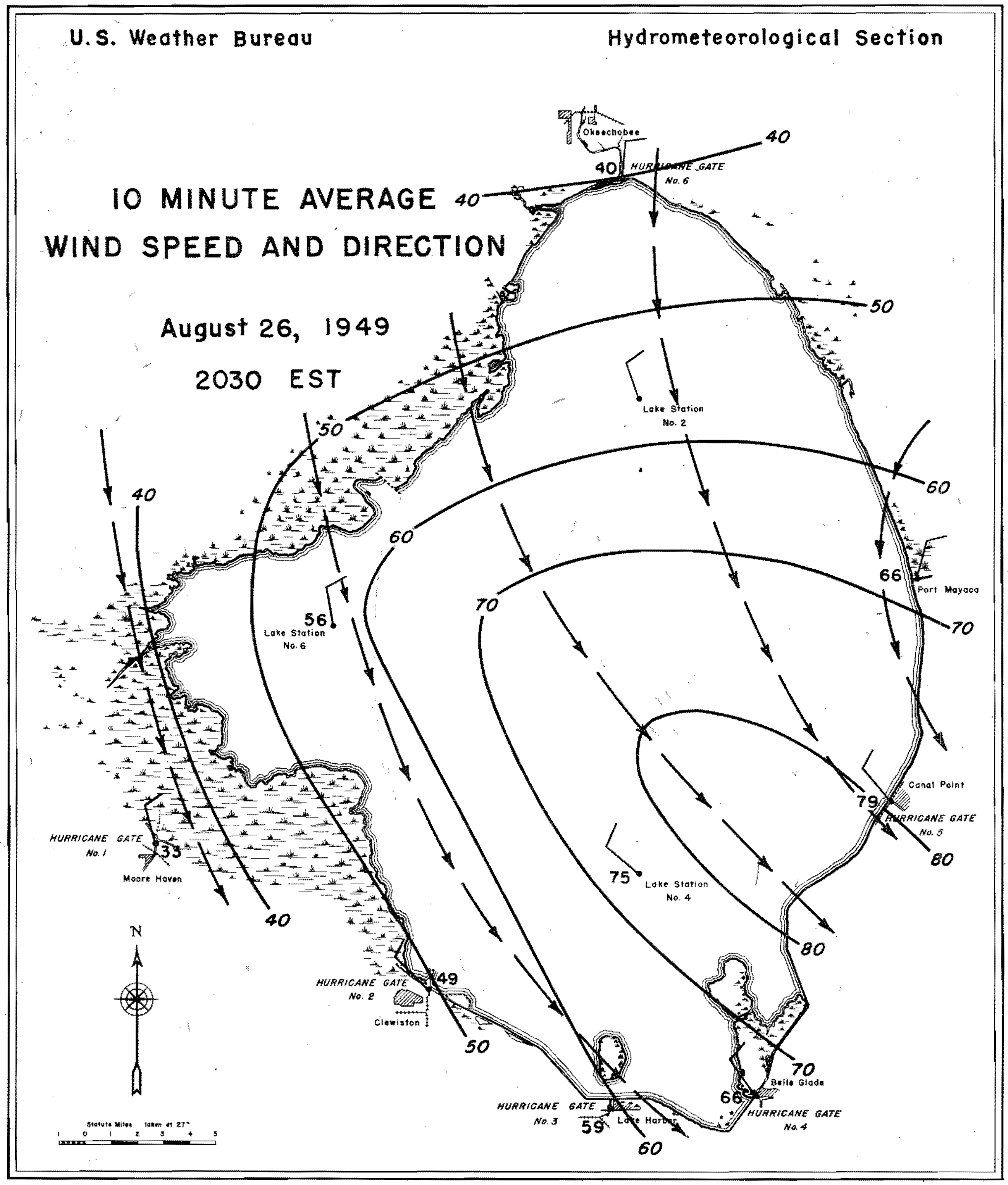

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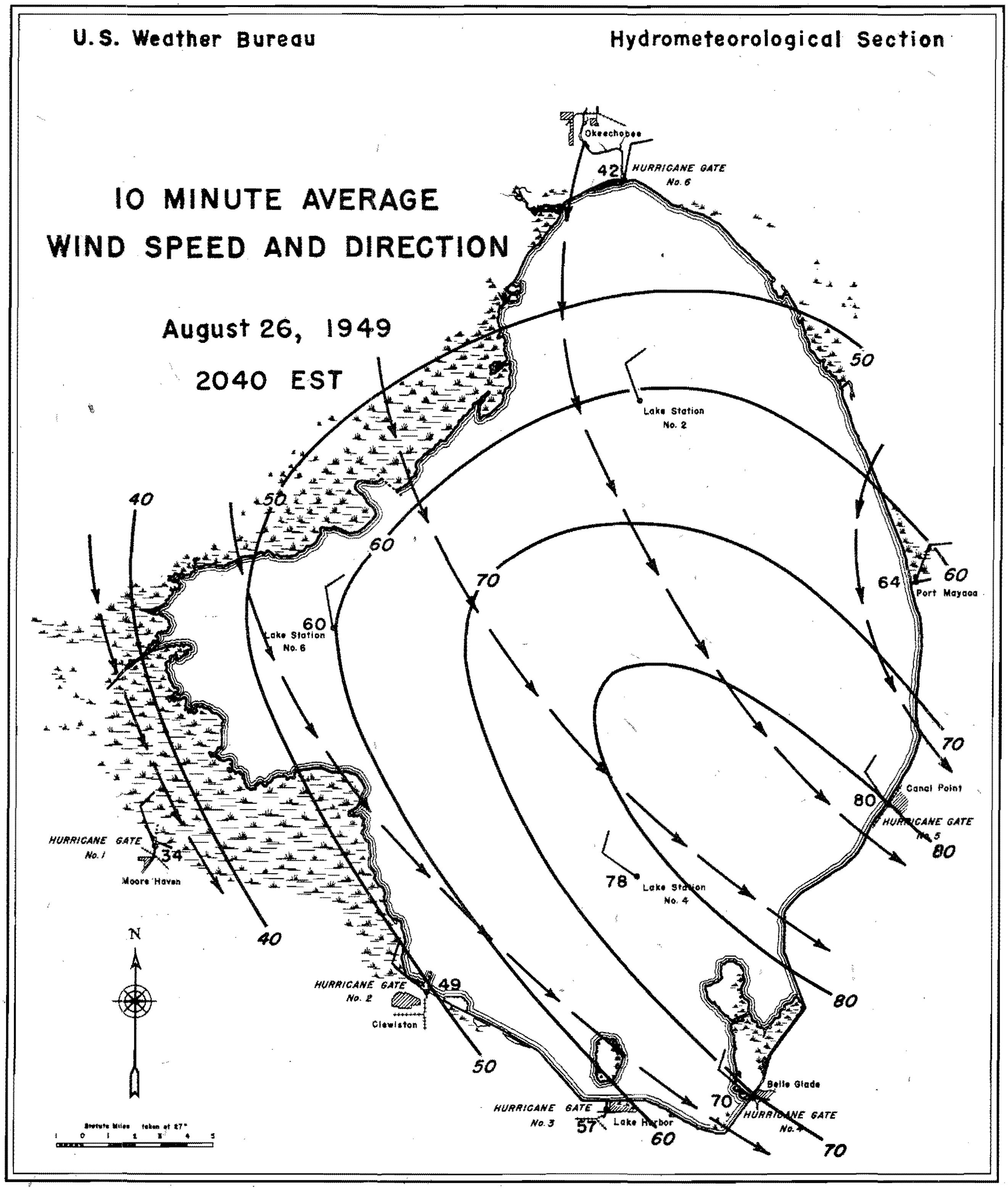

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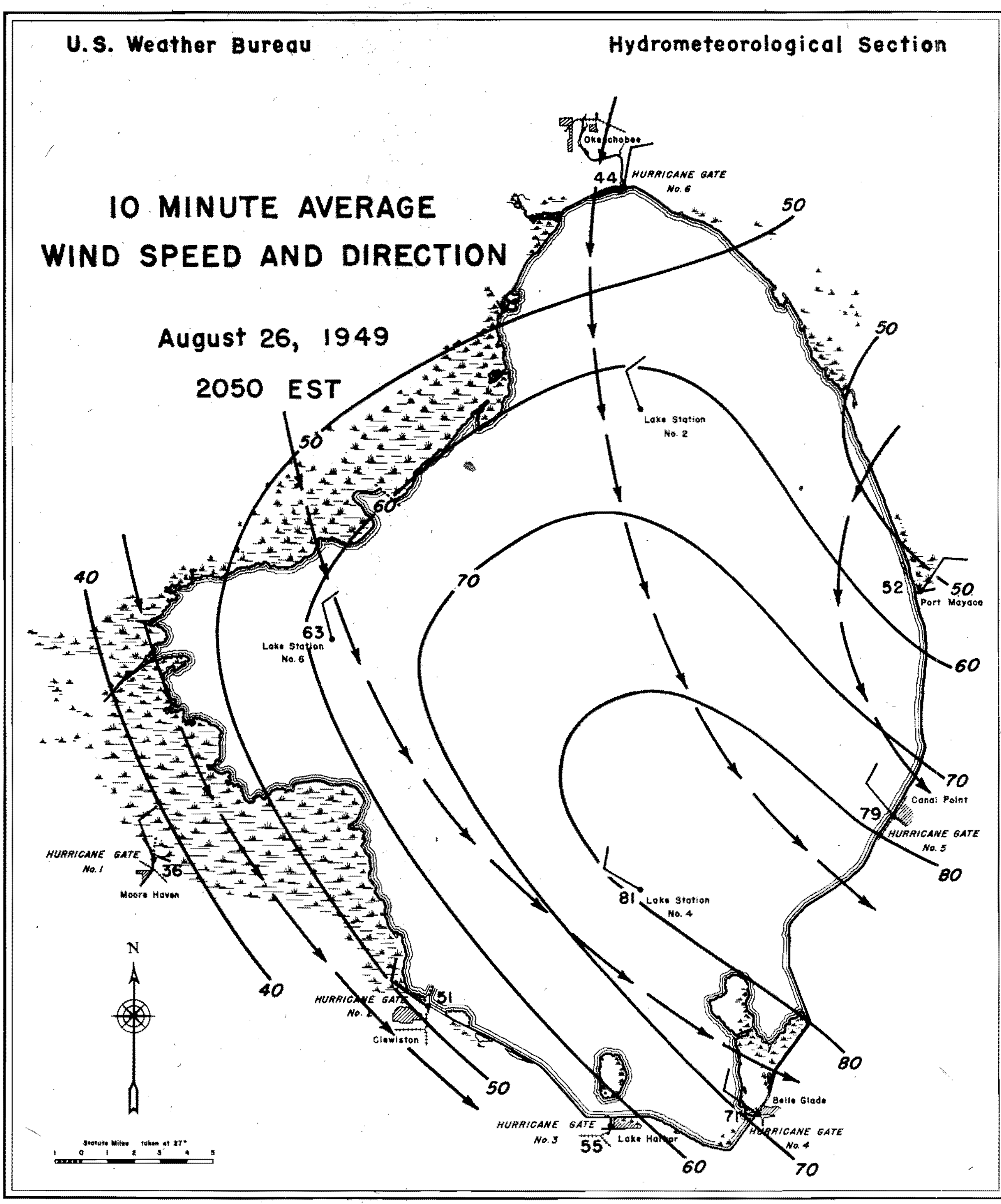

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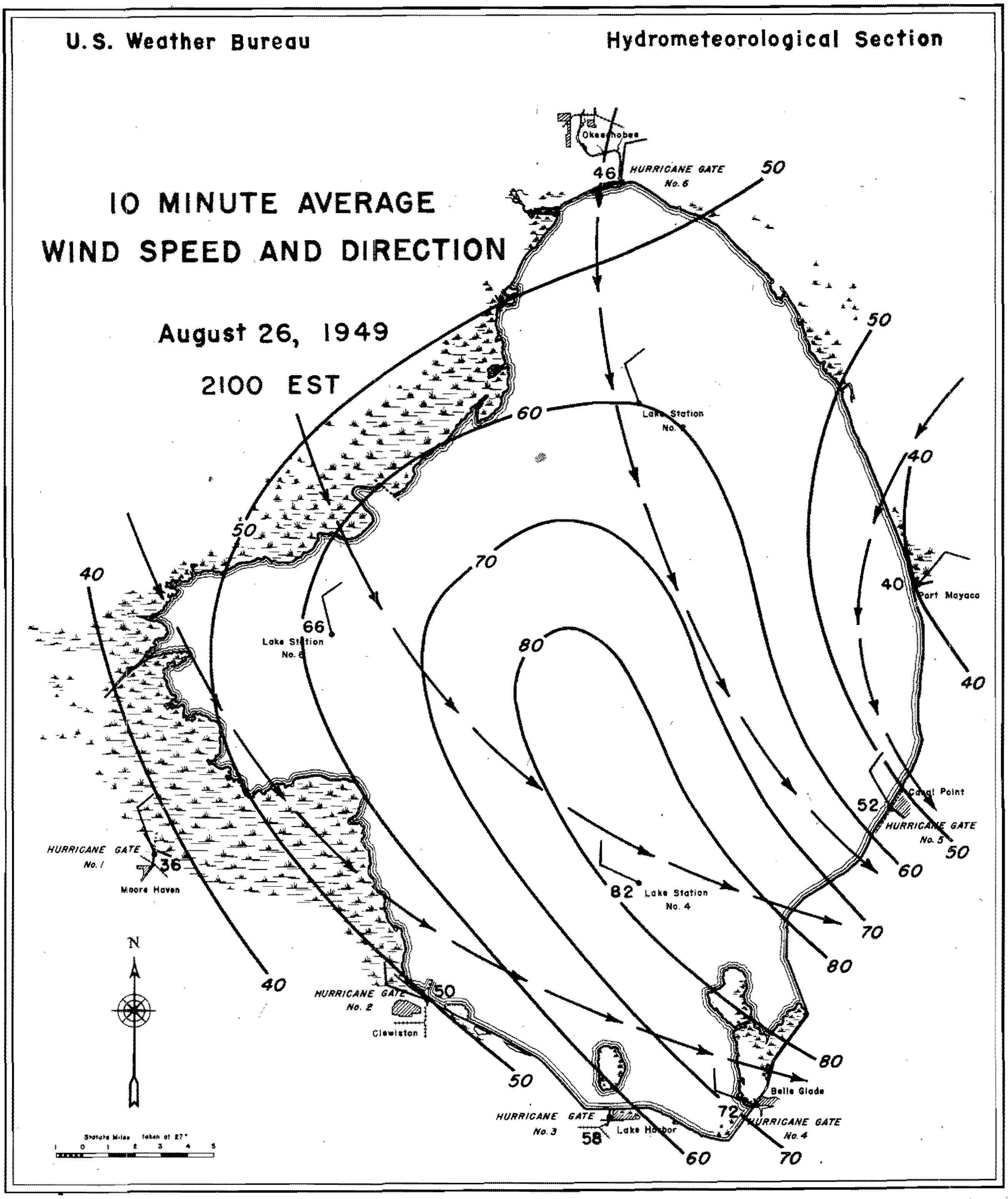

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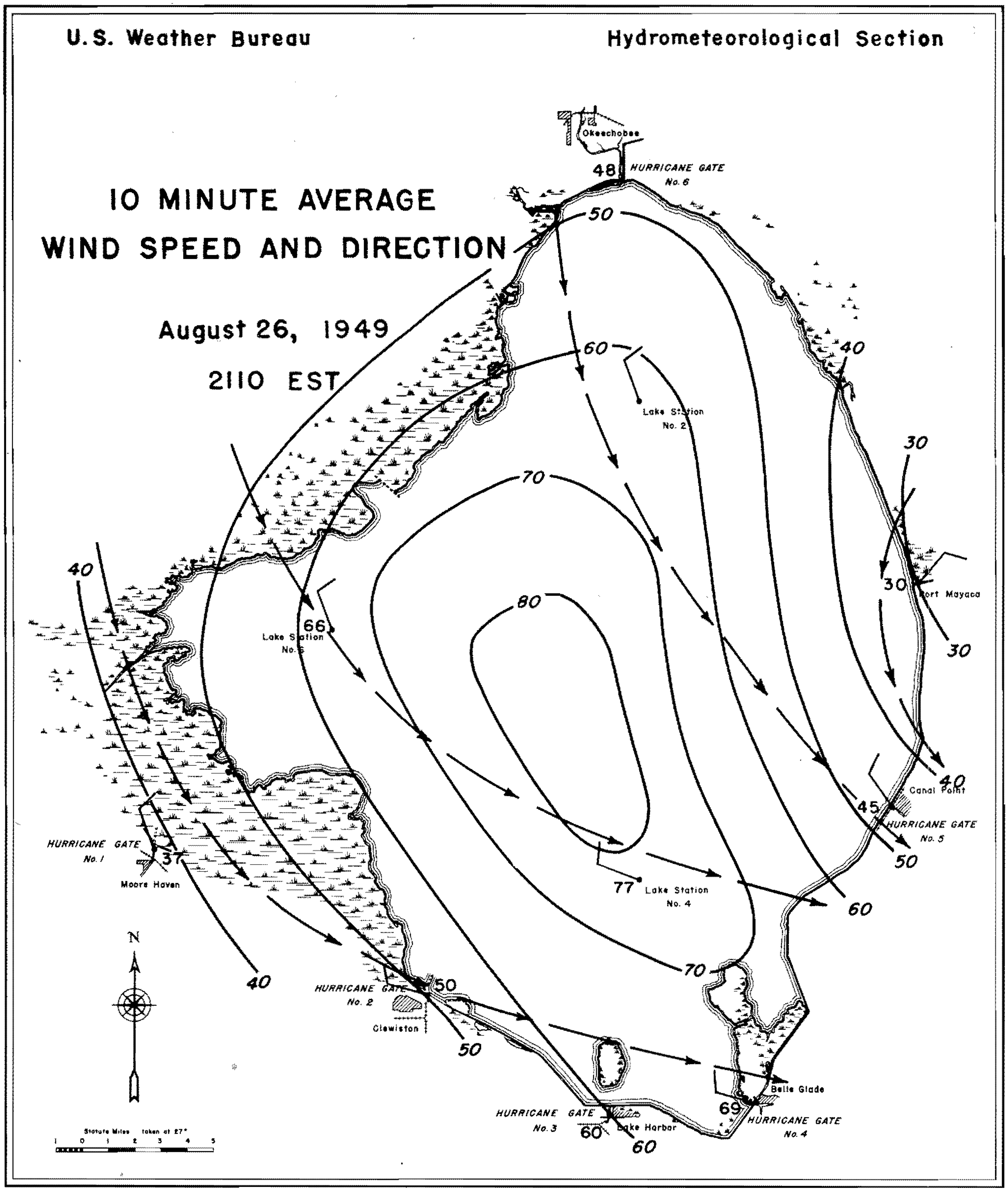

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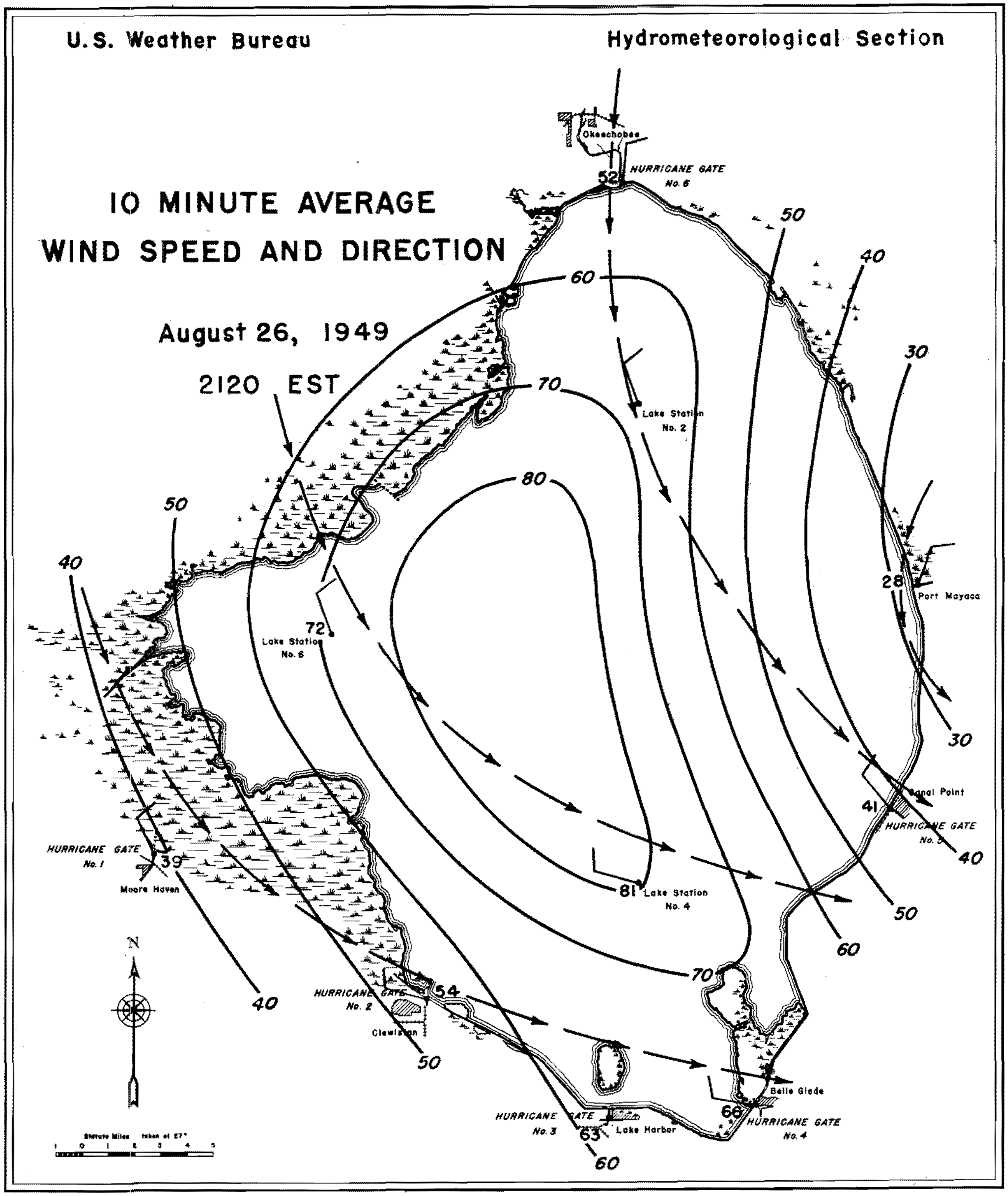

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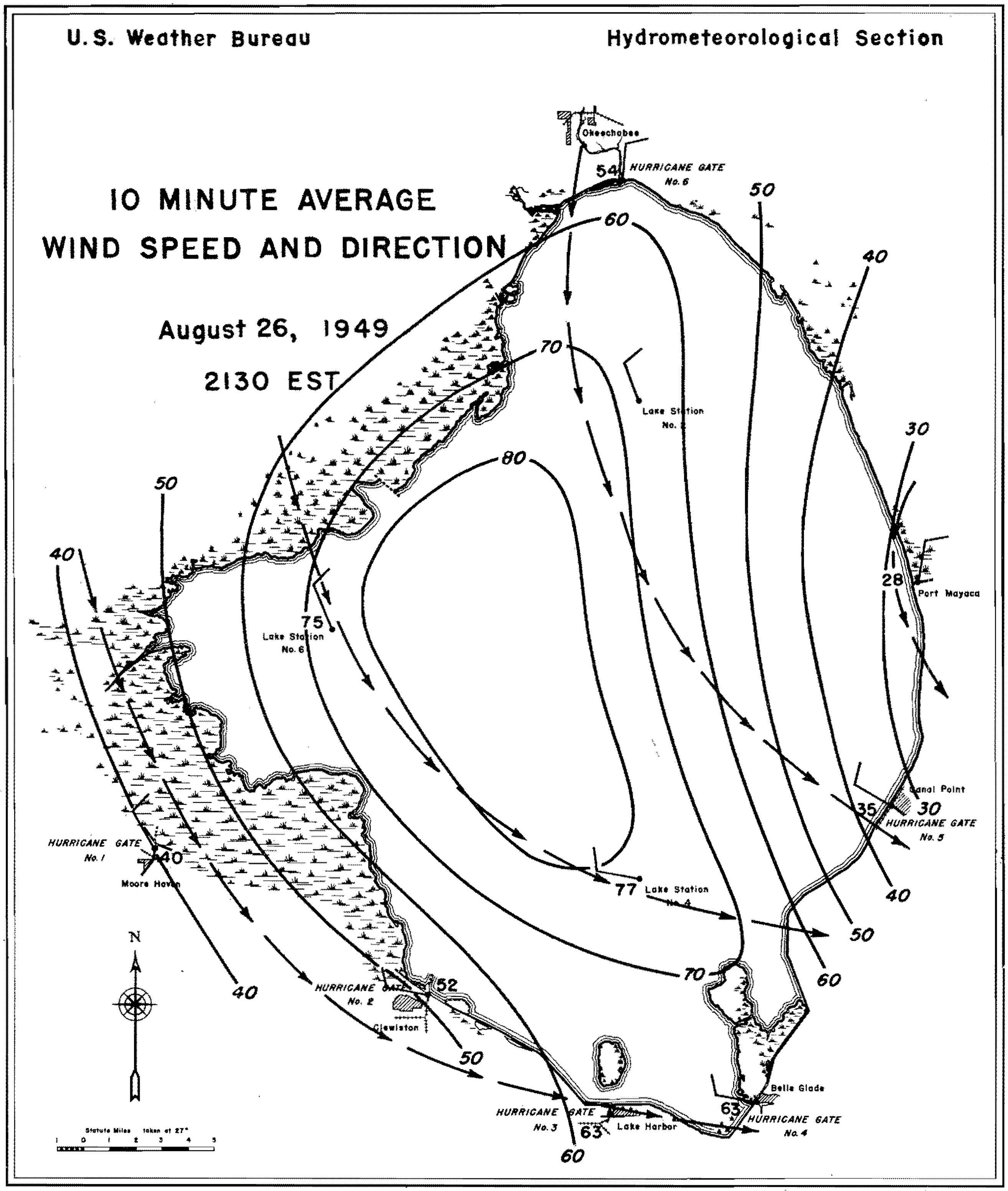

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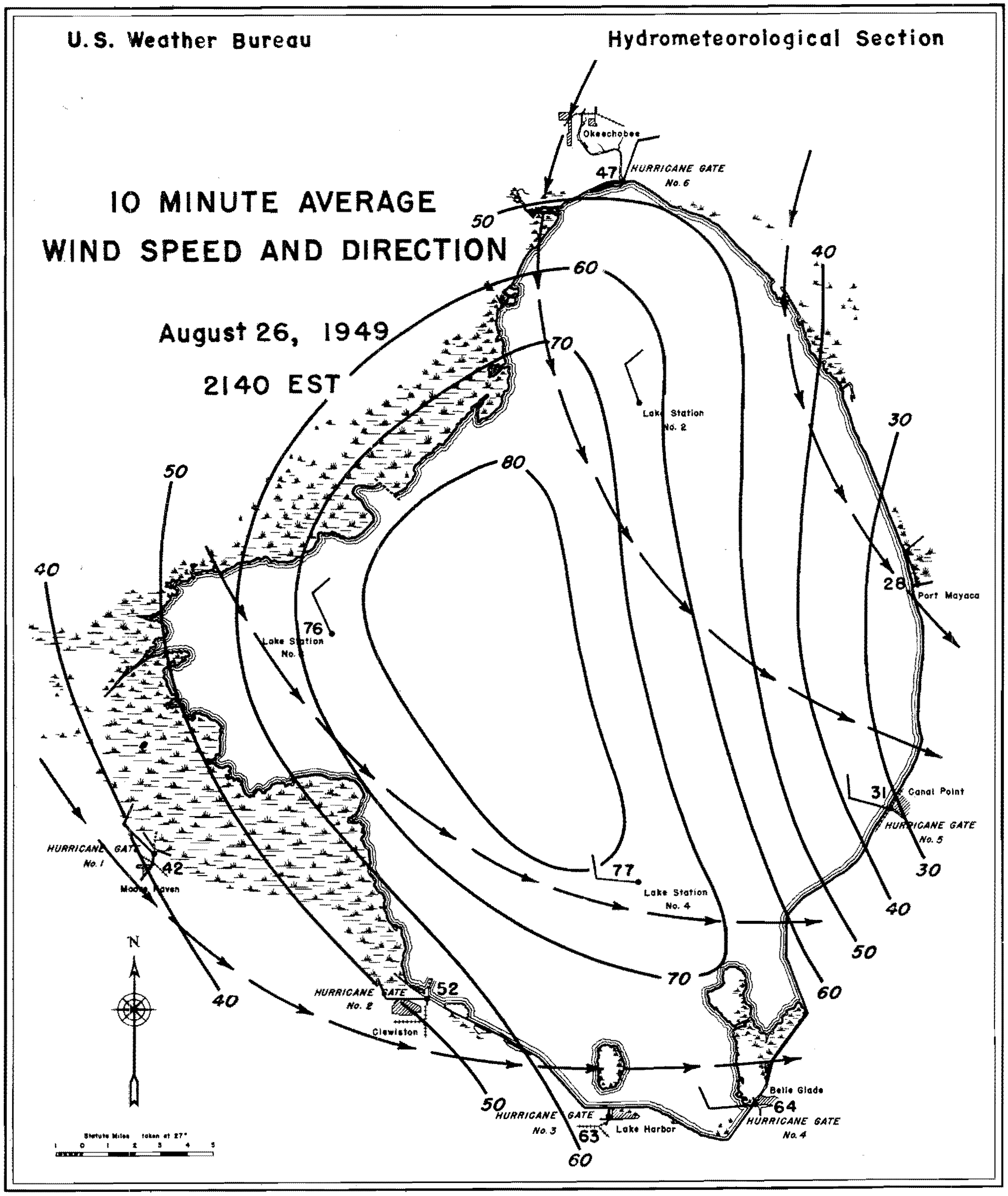

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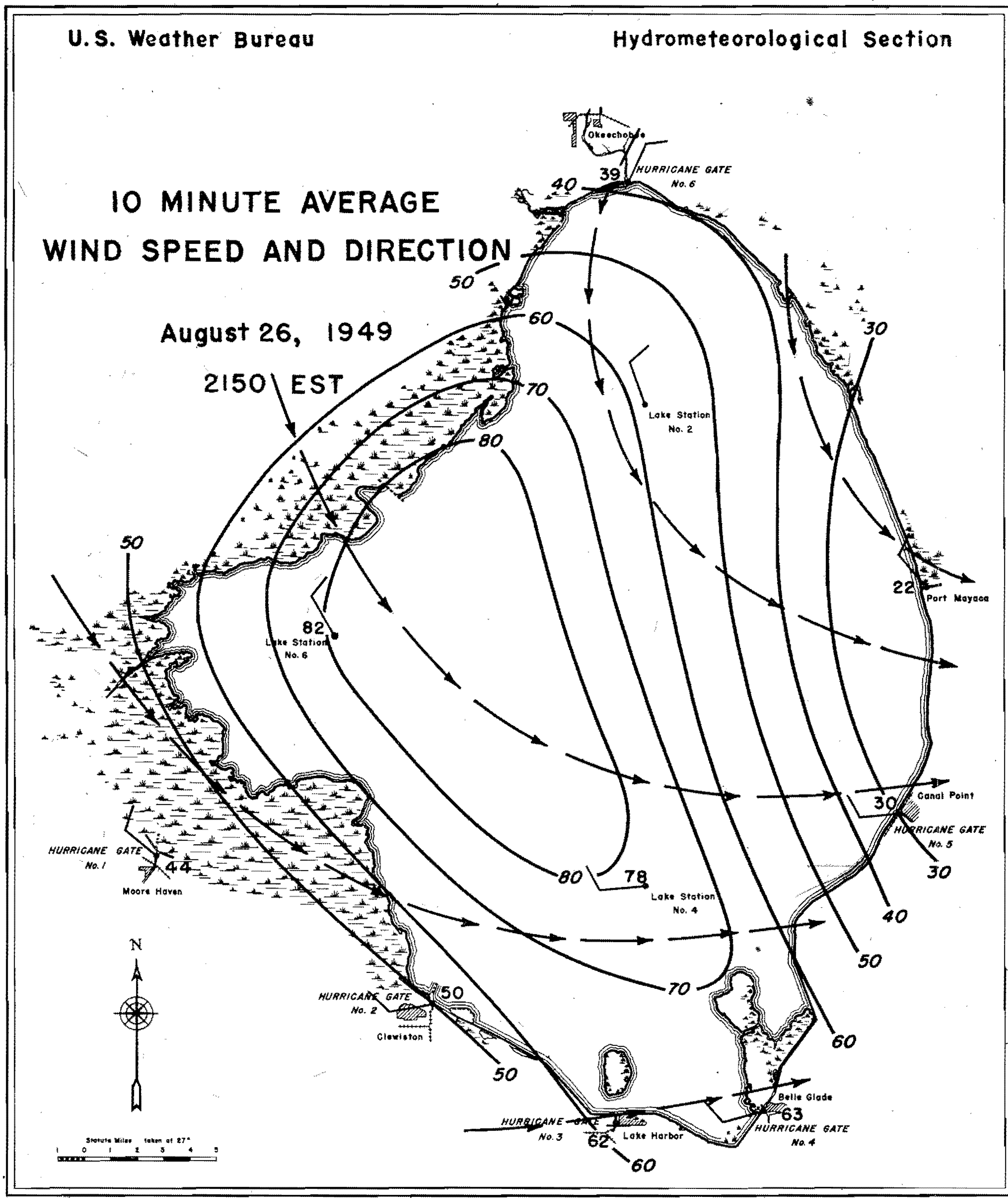
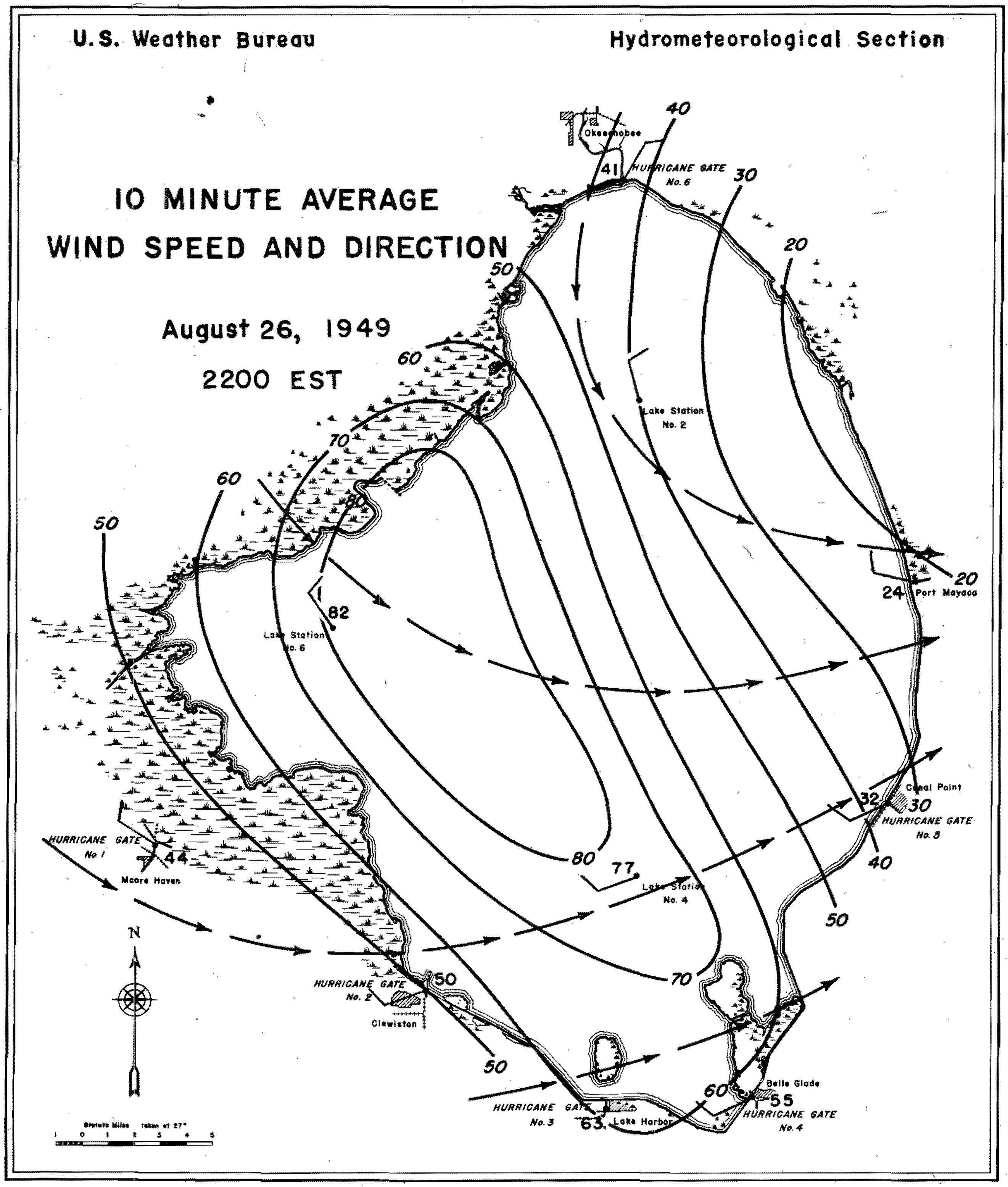
Figure 28



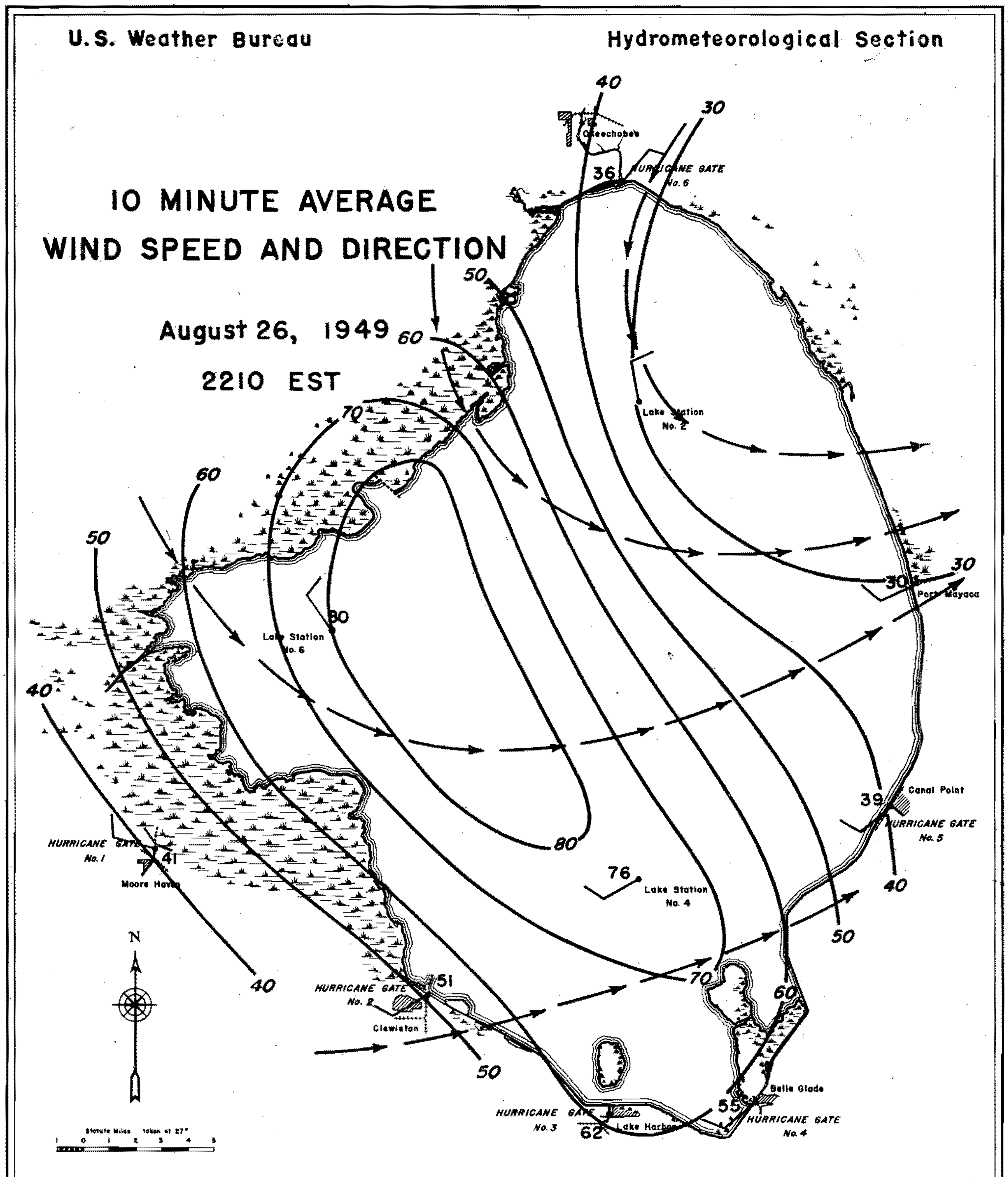
File 5011

Figure 29



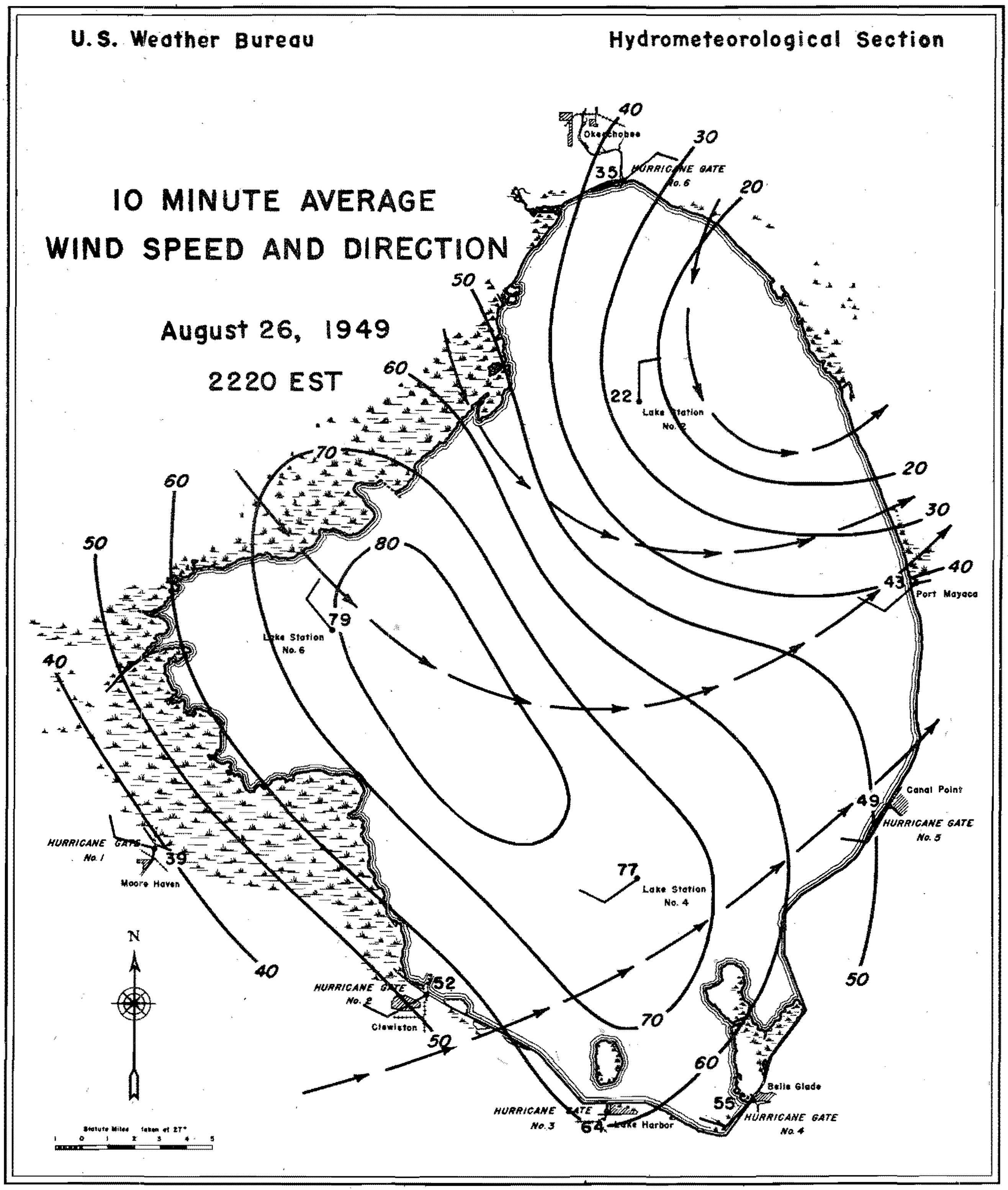
File 5011

Figure 30



File 5011

Figure 31



File 5011

Figure 32

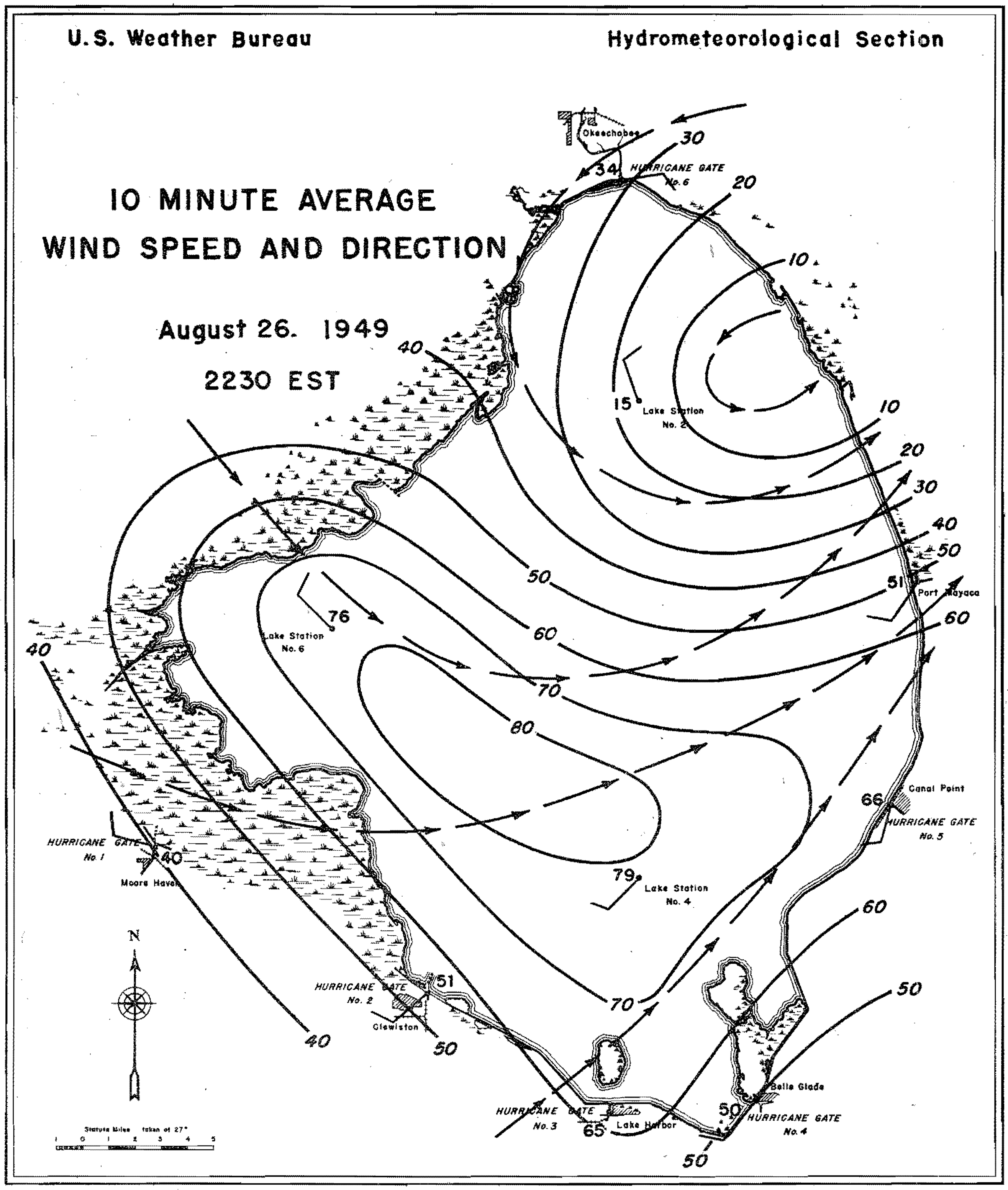


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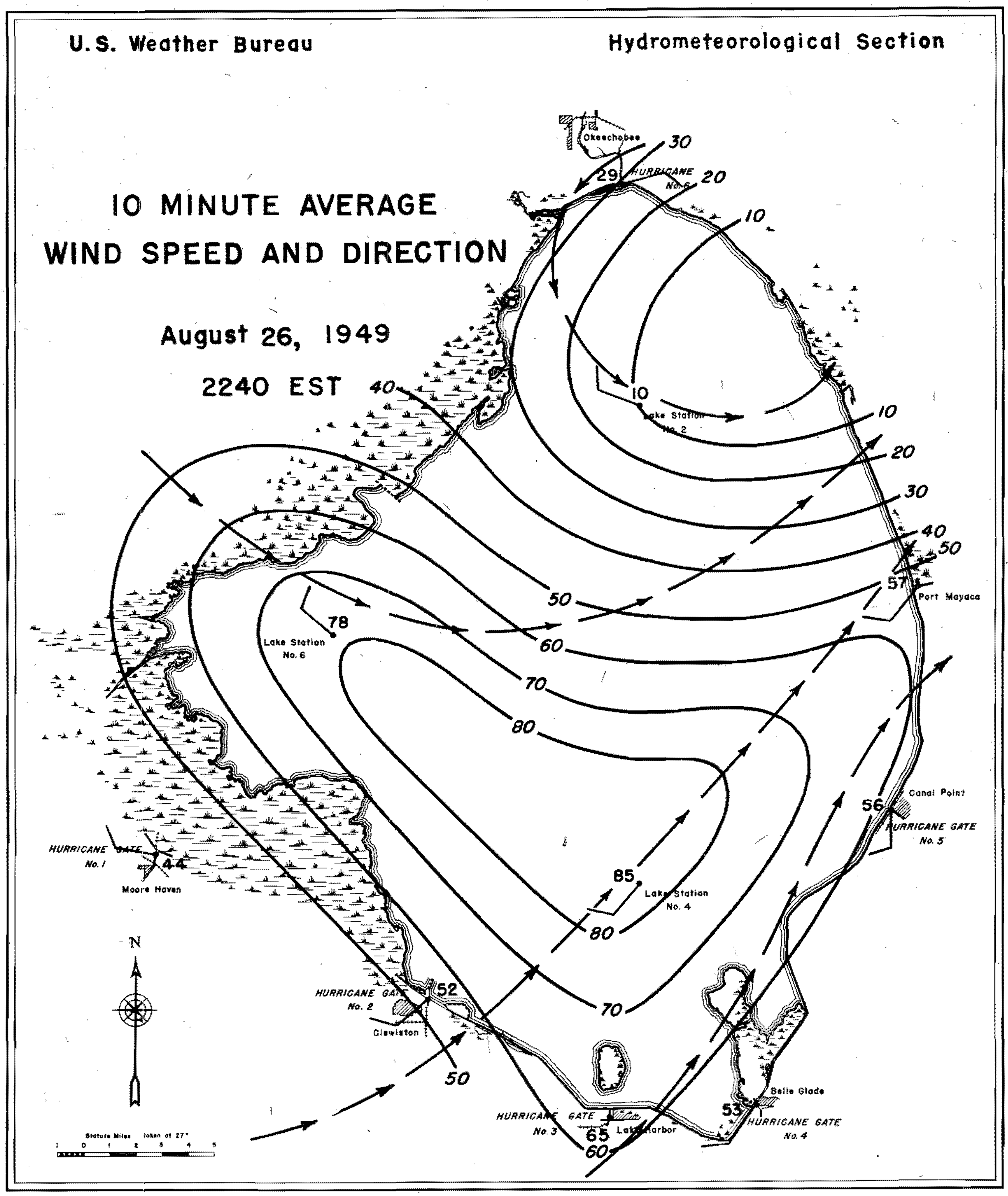
Figure 33



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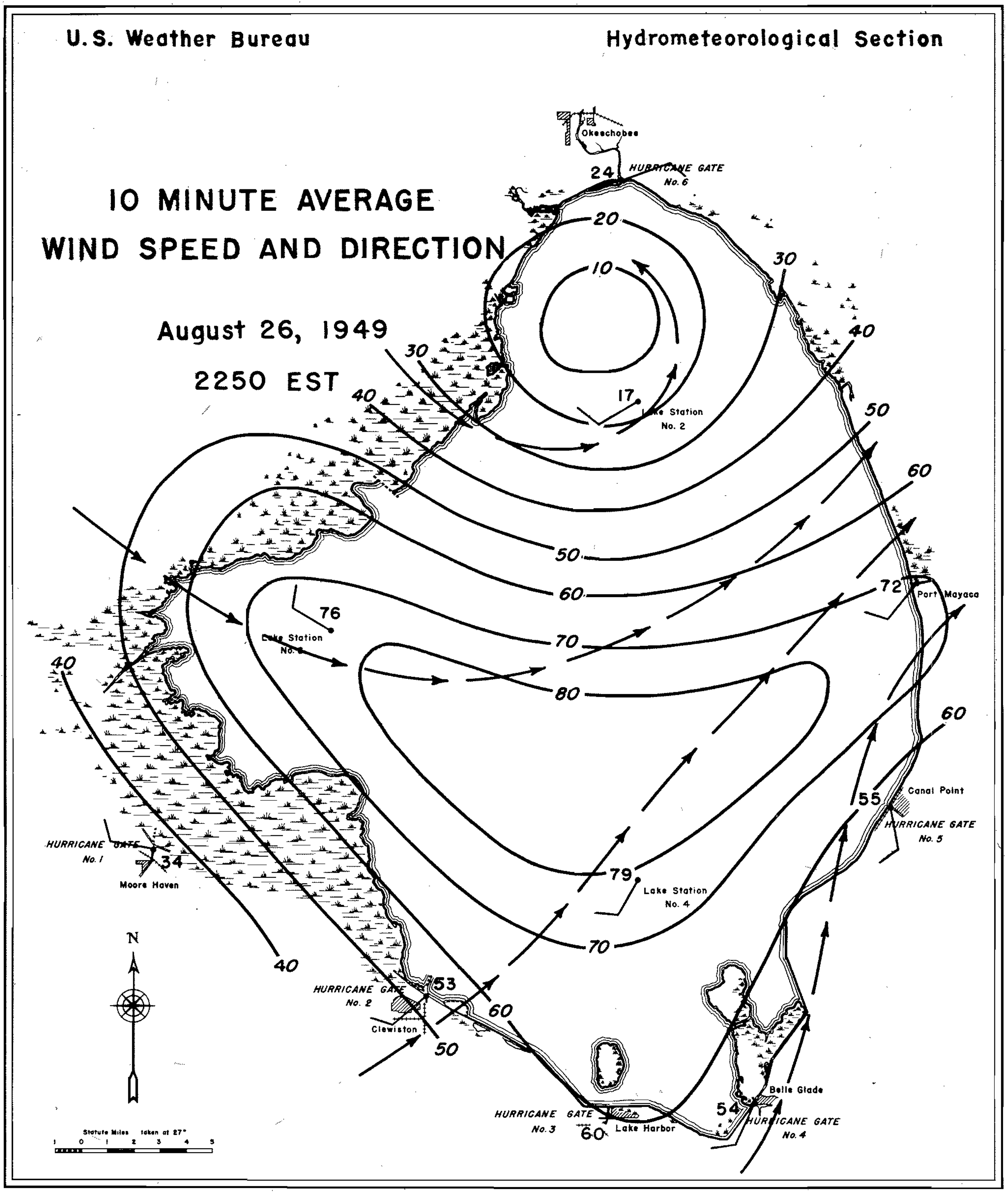

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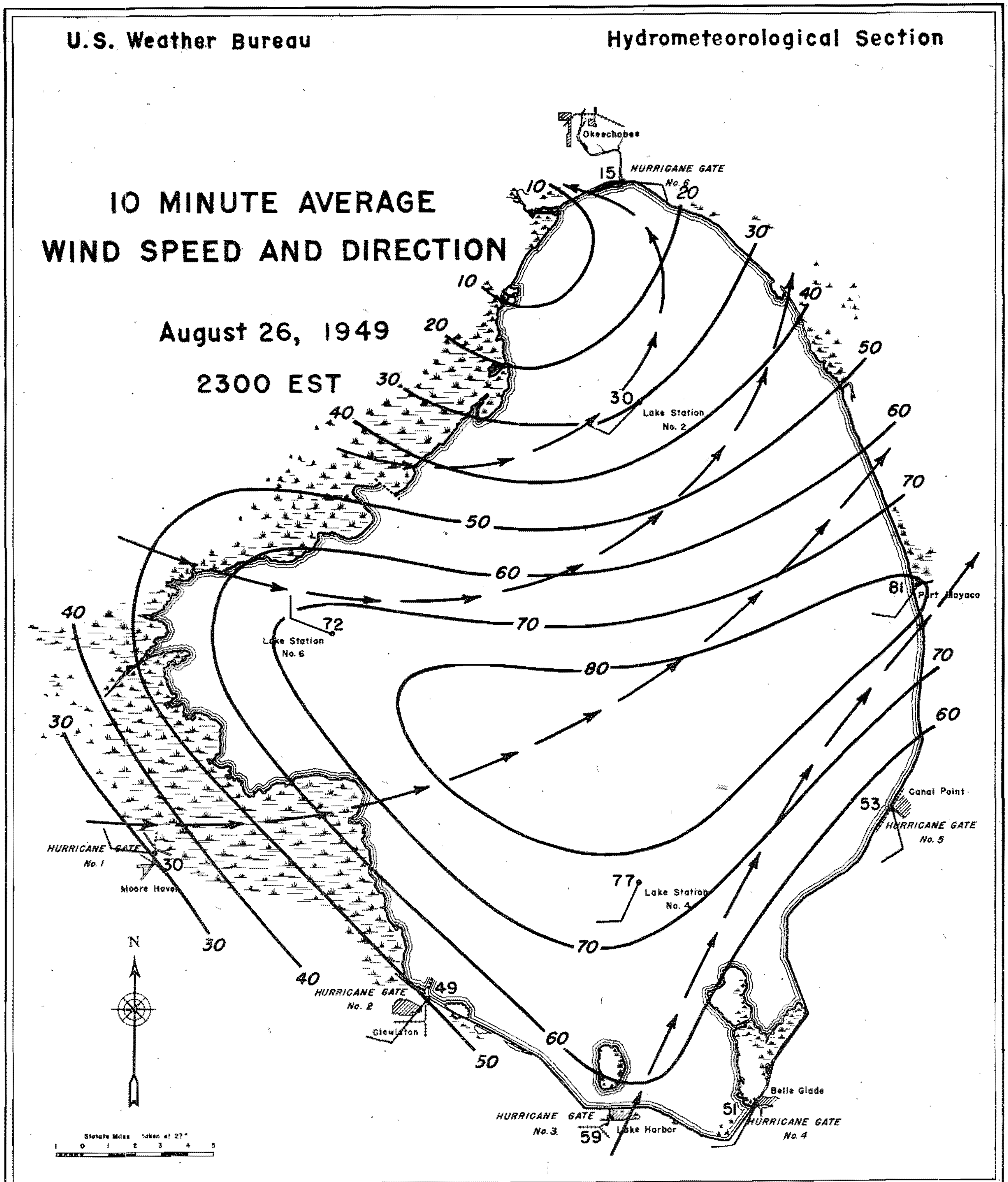
Figure 35



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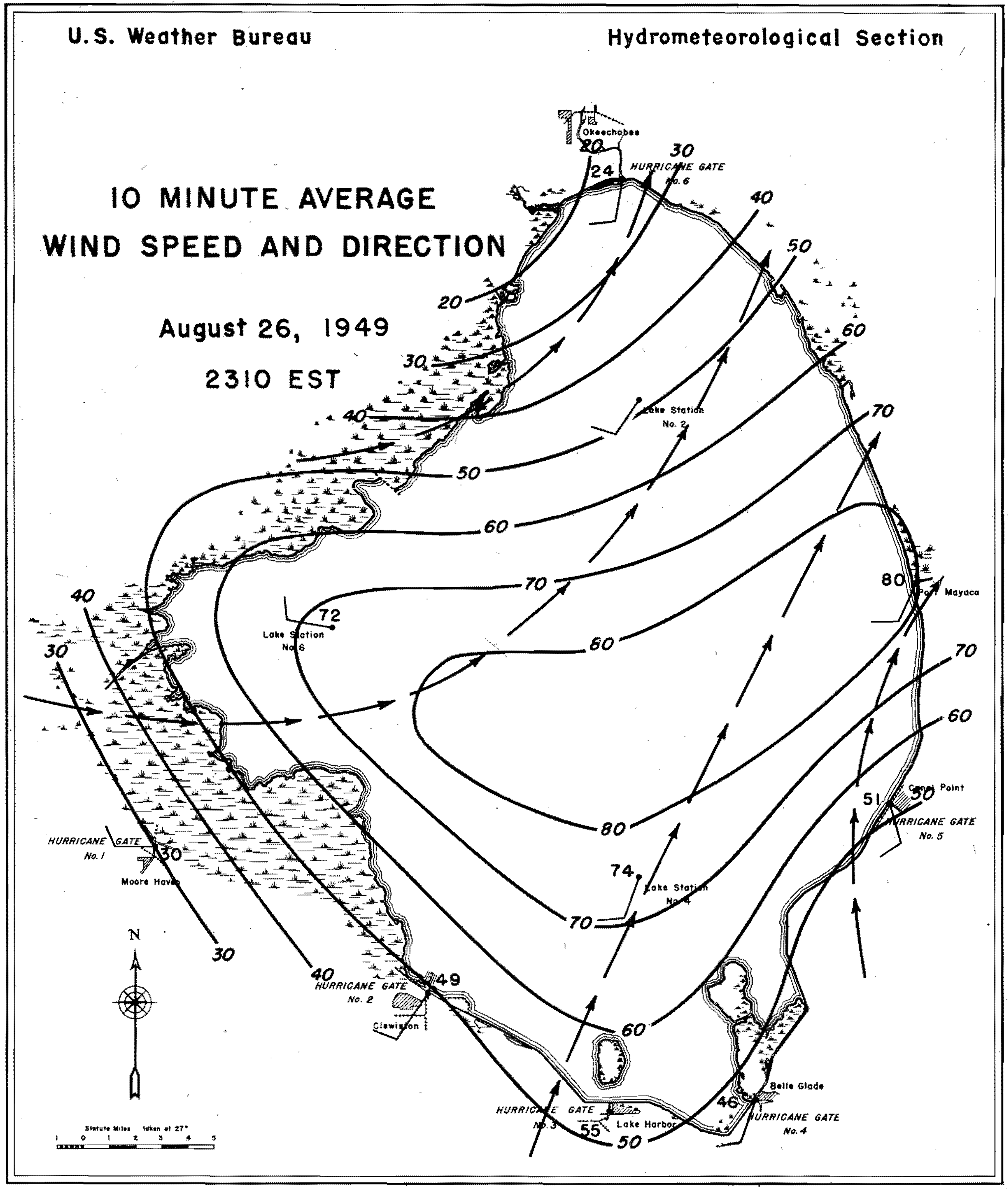

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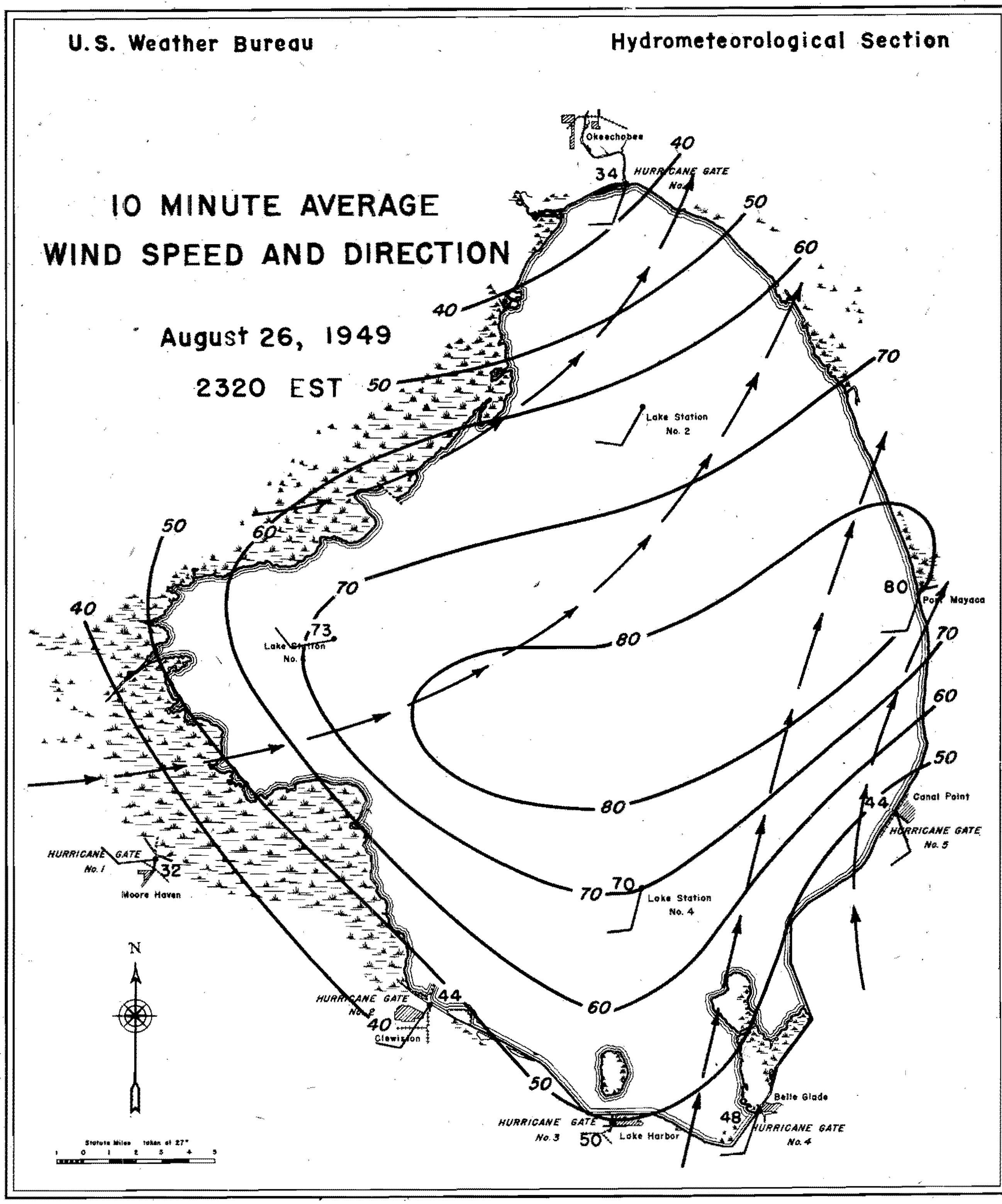

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Figure 38

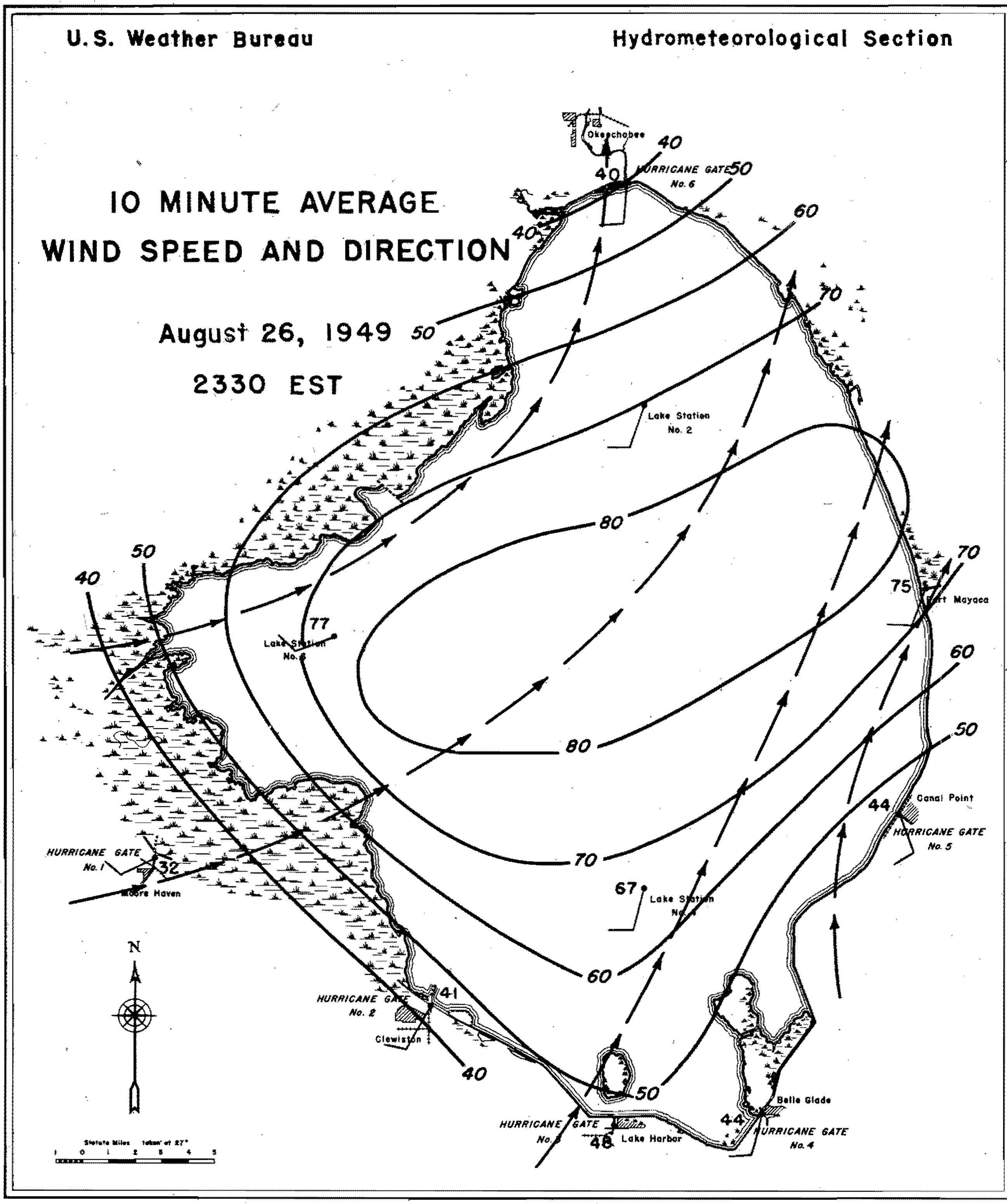

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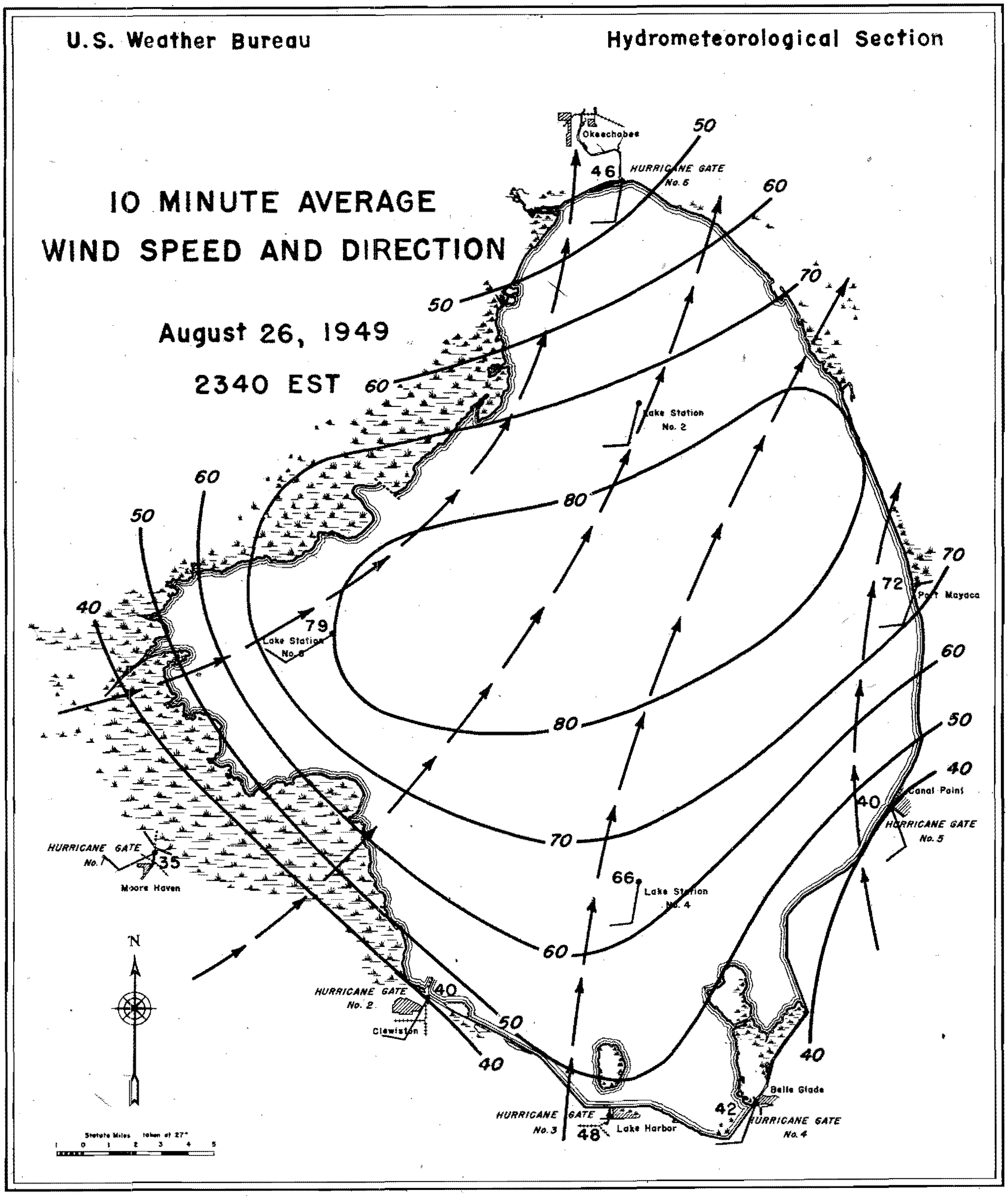
Figure 39



File 5011

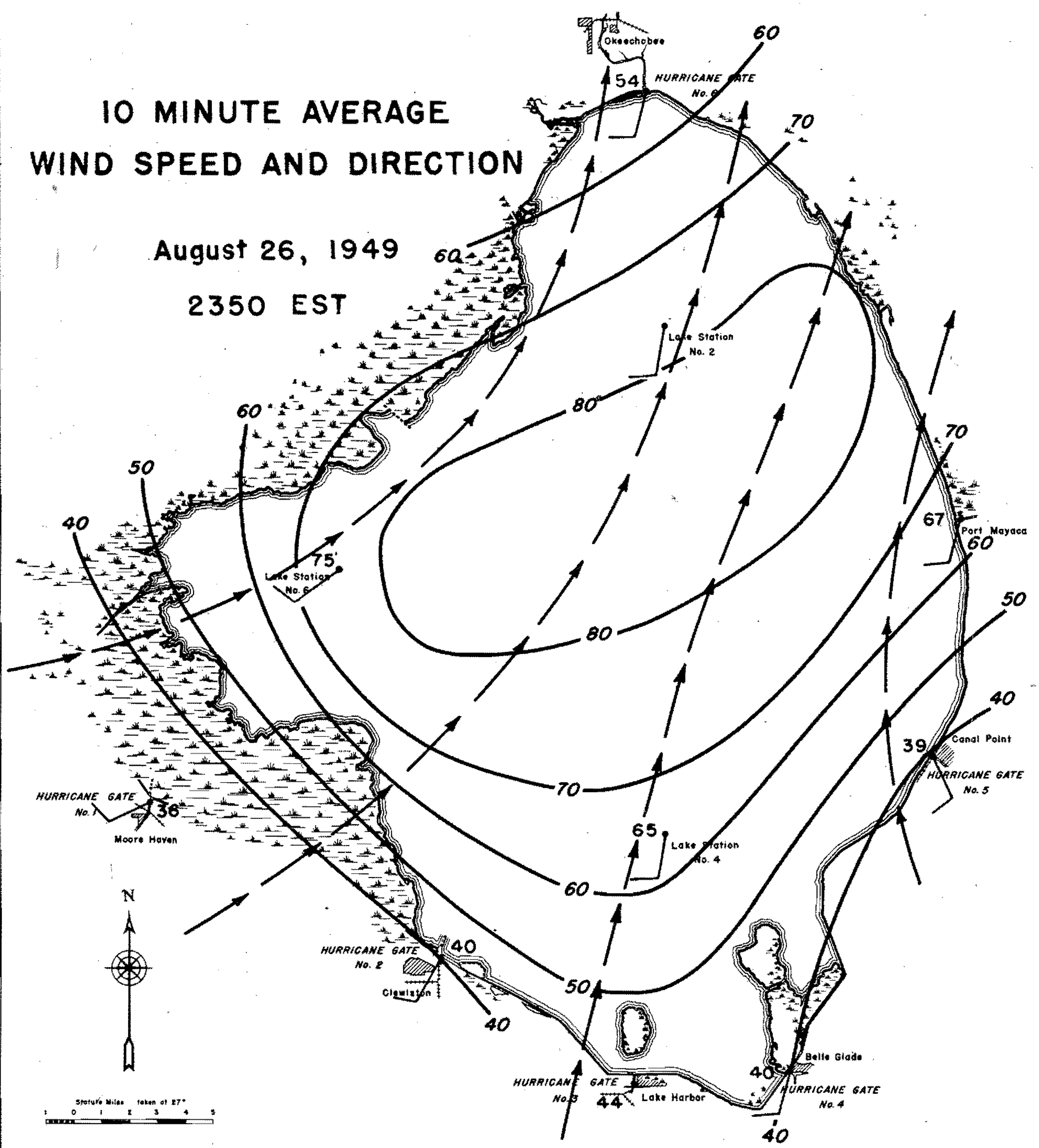
Figure 40

U.S. Weather Bureau　　　　Hydrometeorological Section

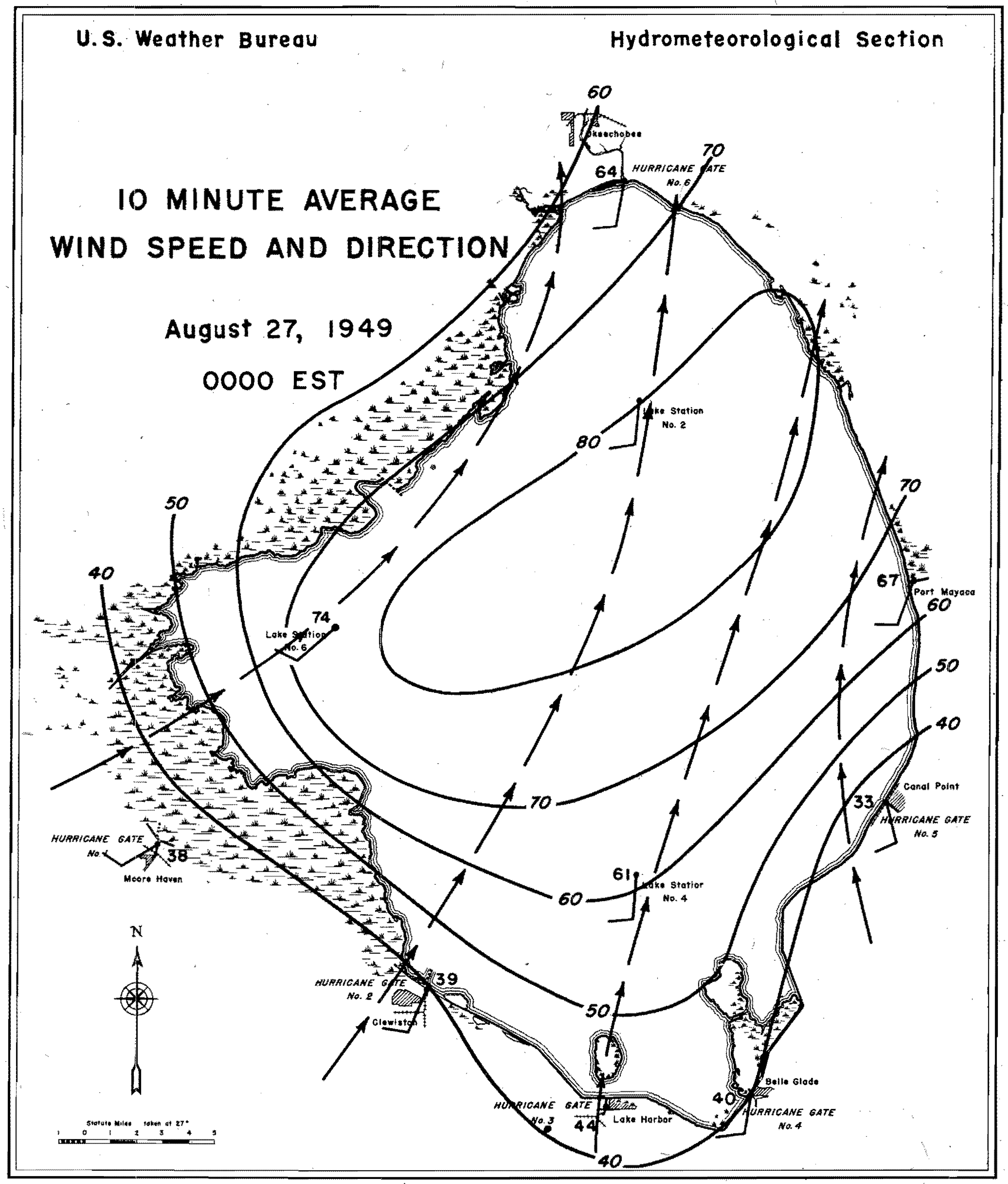
10 MINUTE AVERAGE WIND SPEED AND DIRECTION

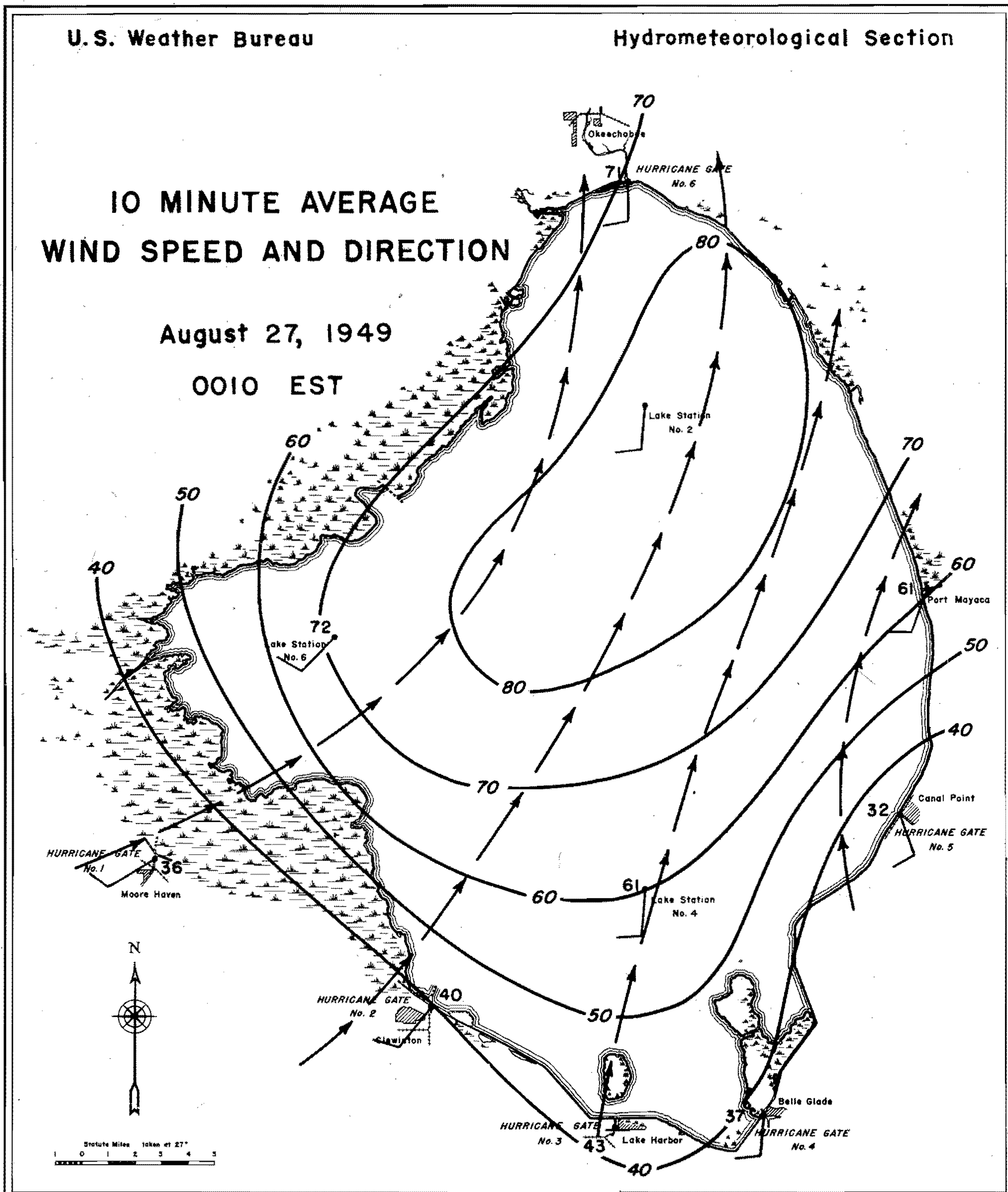
August 26, 1949

2350 EST



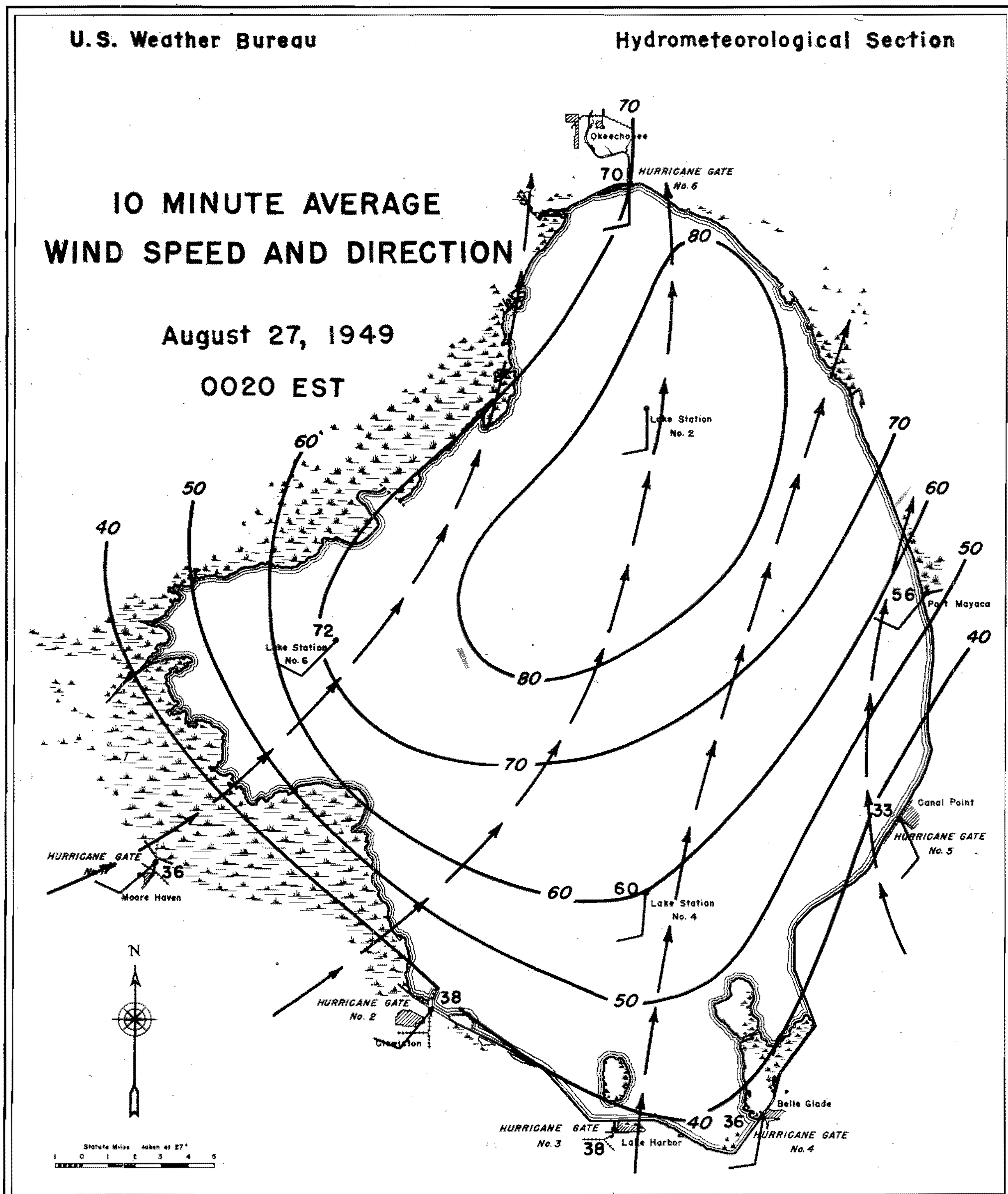
File 5011　　　　Figure 41


U.S. Weather Bureau
Hydrometeorological Section
10 MINUTE AVERAGE
WIND SPEED AND DIRECTION
August 27, 1949
0000 EST
Okeechobee
HURRICANE GATE No. 6
64
Lake Station No. 2
80
70
Lake Station No. 6
74
50
40
67
Port Mayaca
60
HURRICANE GATE No. 1
38
Moore Haven
Canal Point
33
HURRICANE GATE No. 5
61
Lake Station No. 4
N
HURRICANE GATE No. 2
39
Clewiston
HURRICANE GATE No. 3
44
Lake Harbor
40
Belle Glade
HURRICANE GATE No. 4
Statute Miles taken at 27°



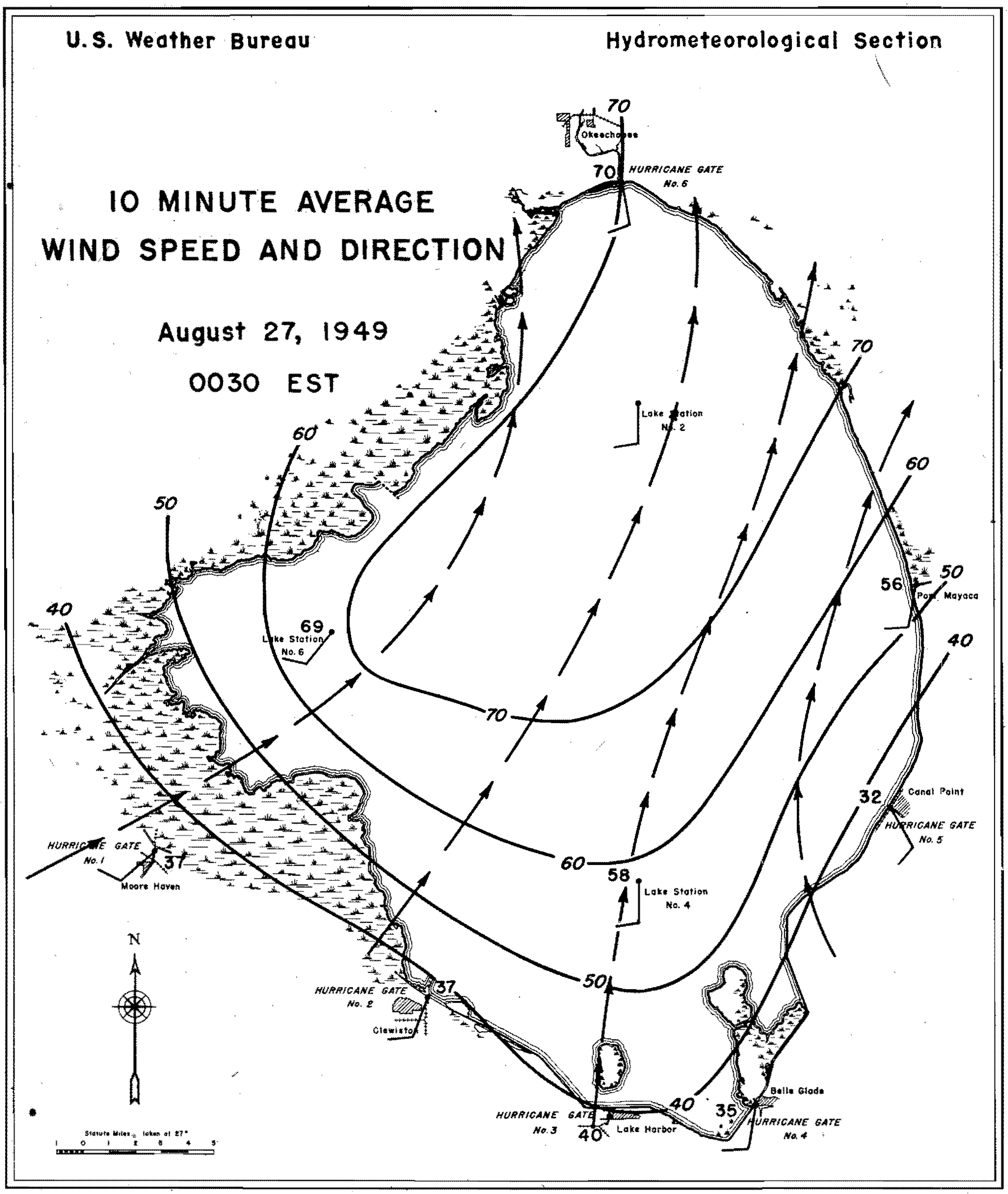
File 5011

Figure 43



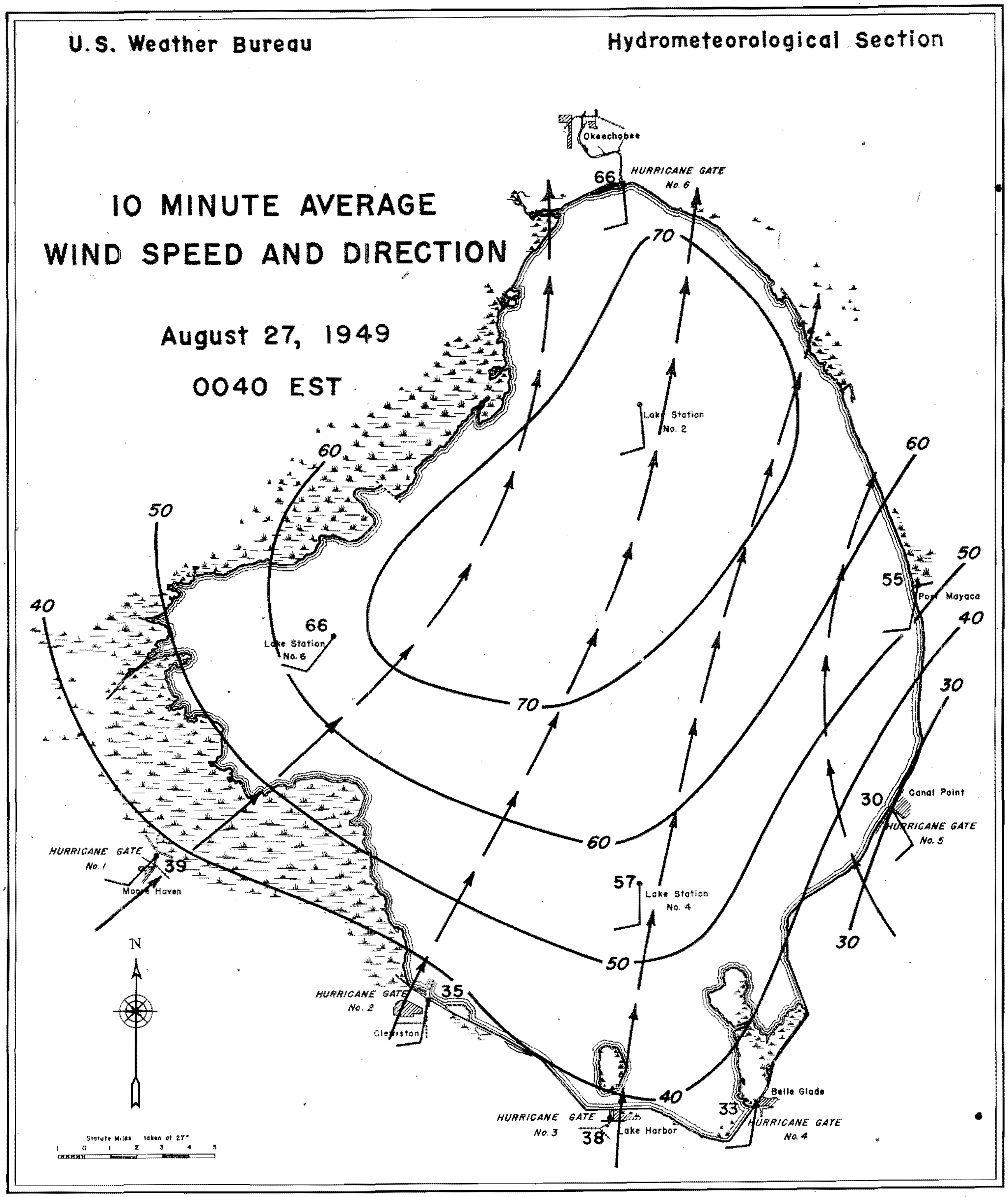
File 5011

Figure 44



File 5011

Figure 45



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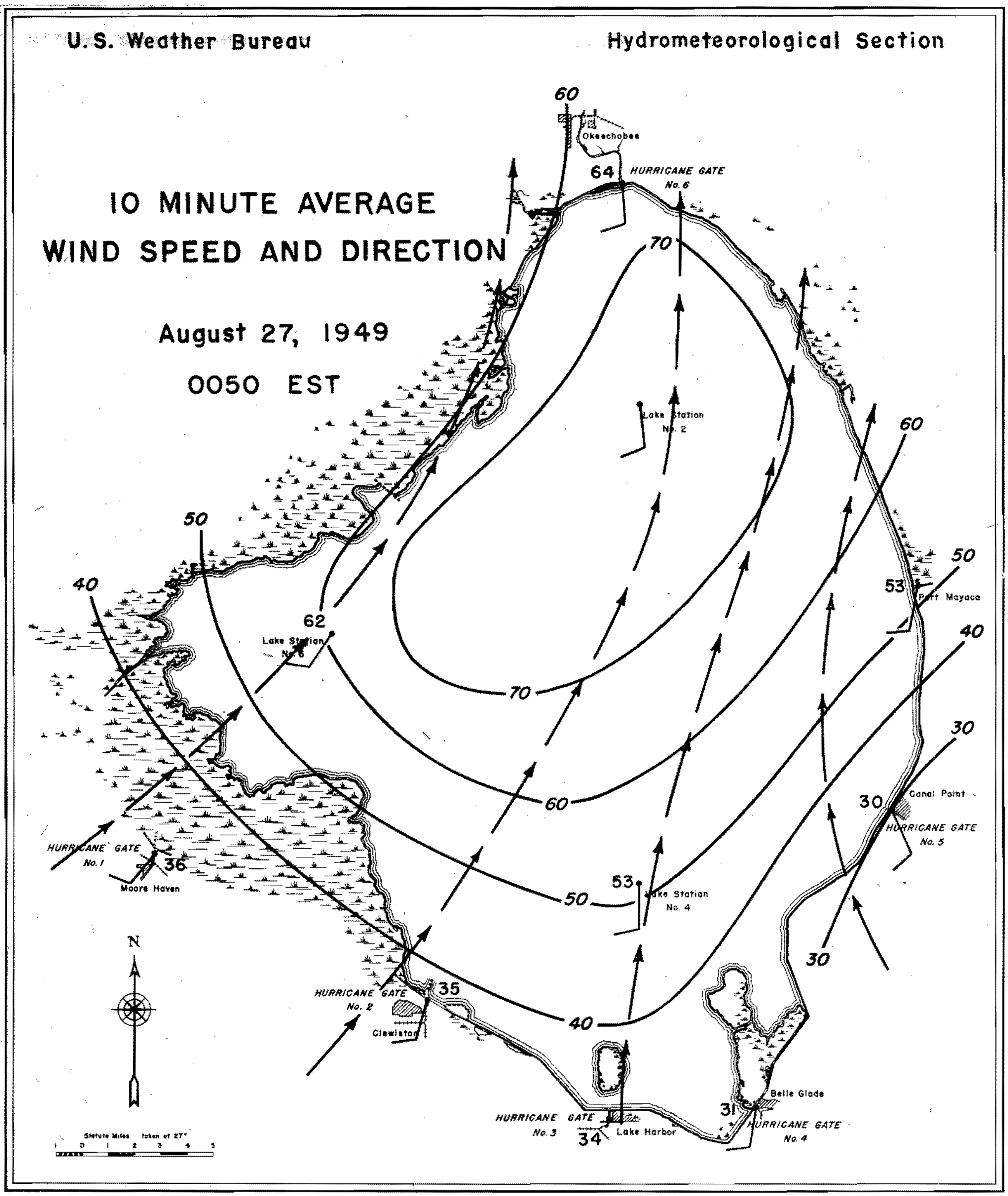

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Figure 47

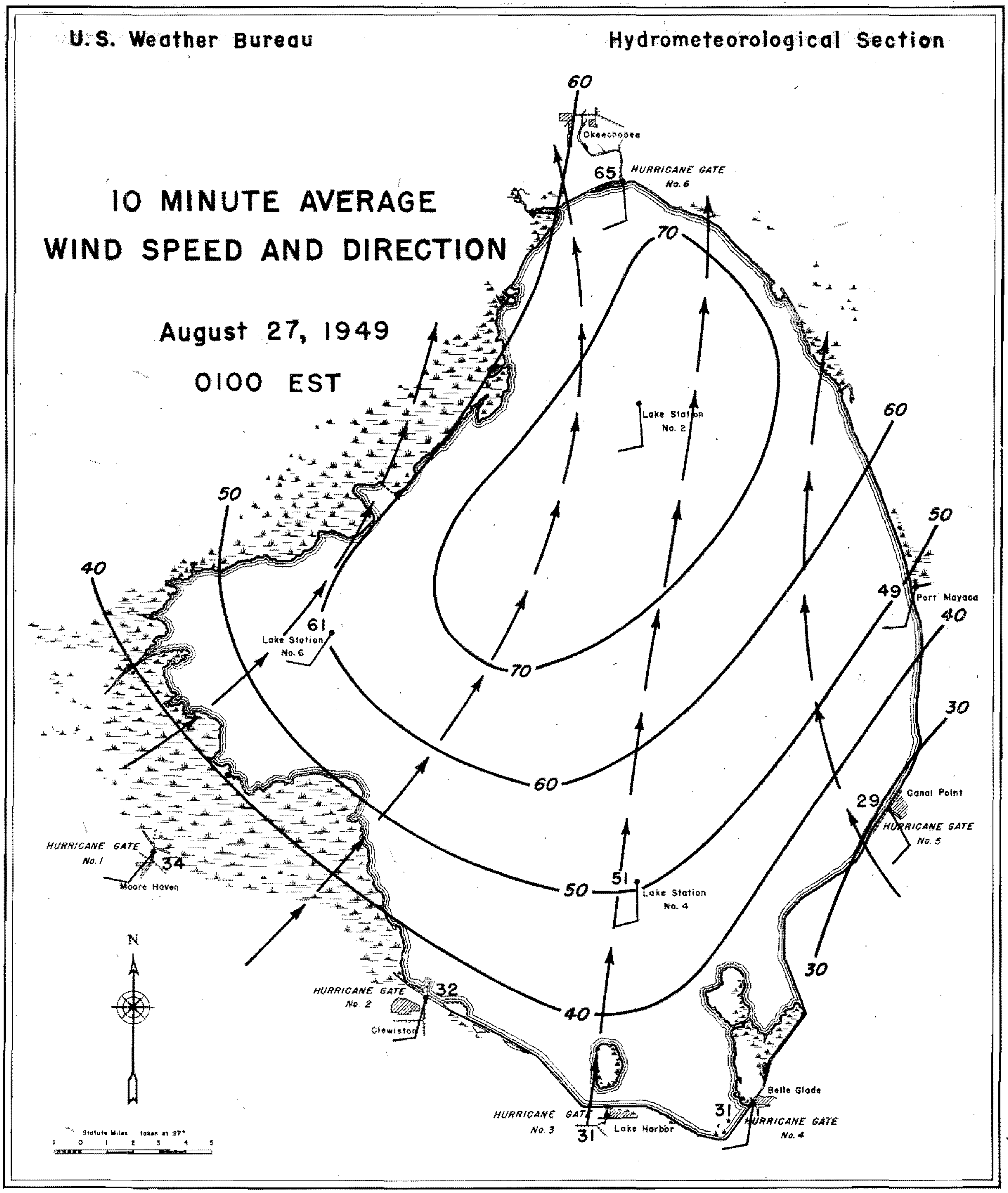

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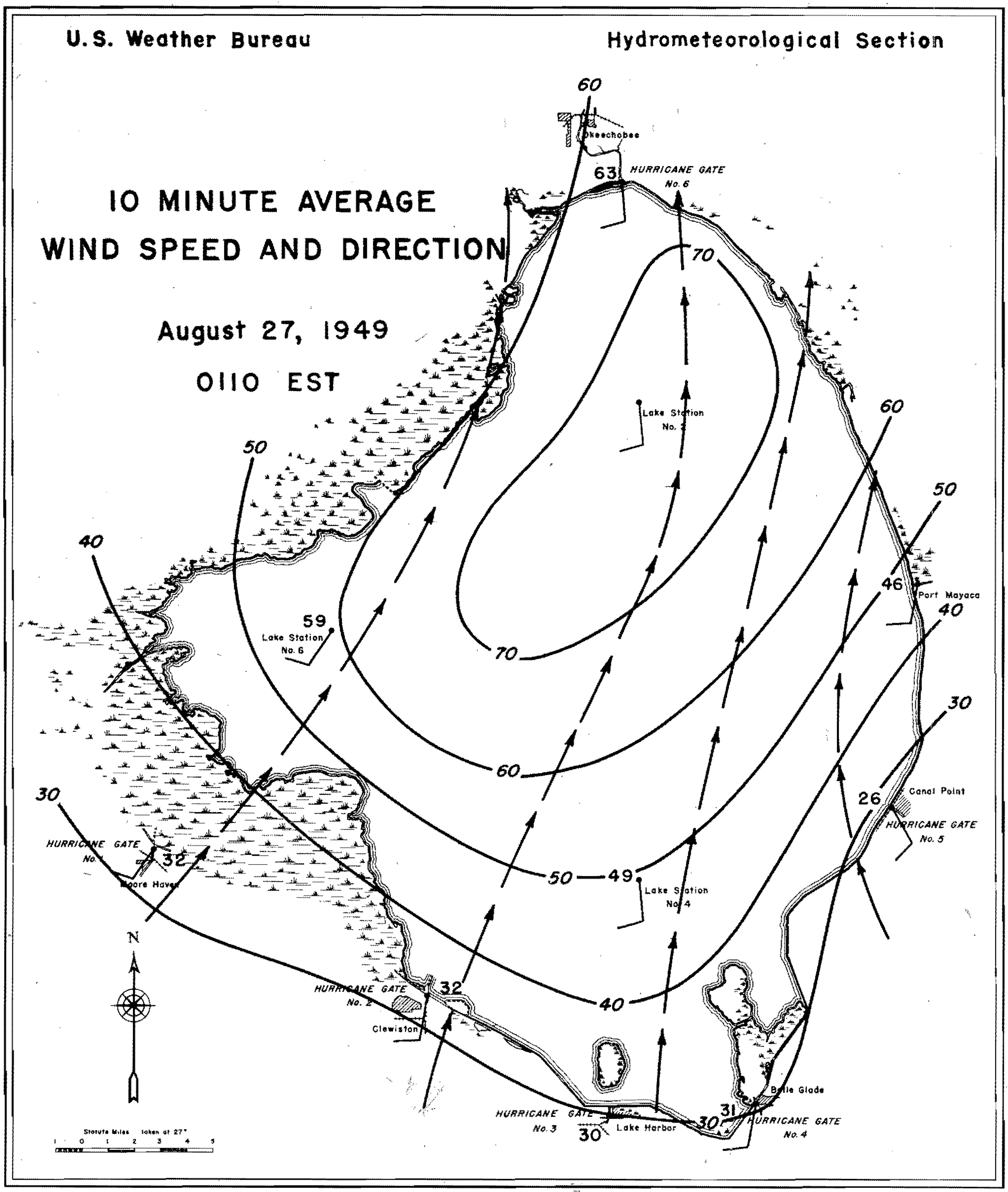
Figure 48



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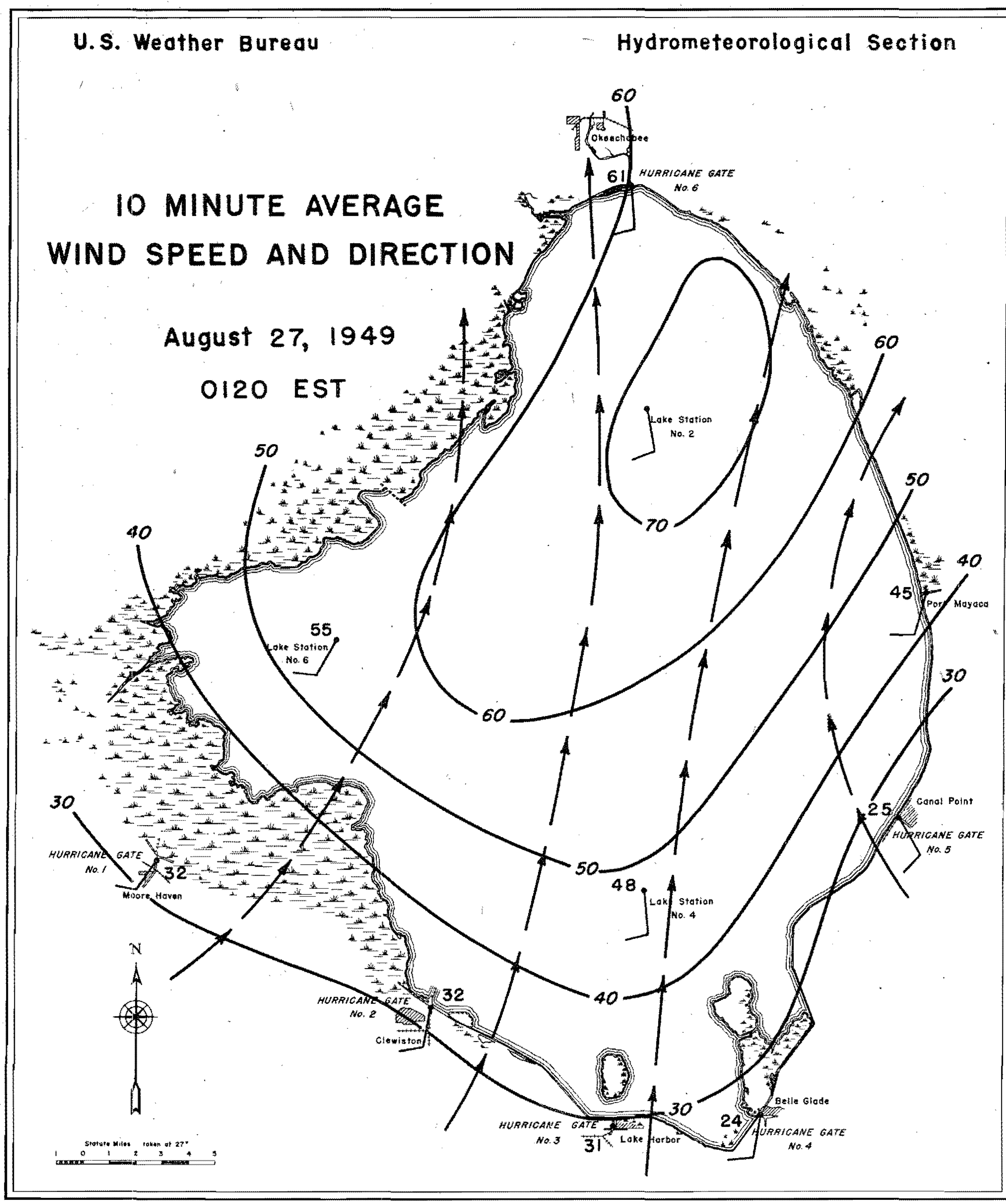

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Figure 50

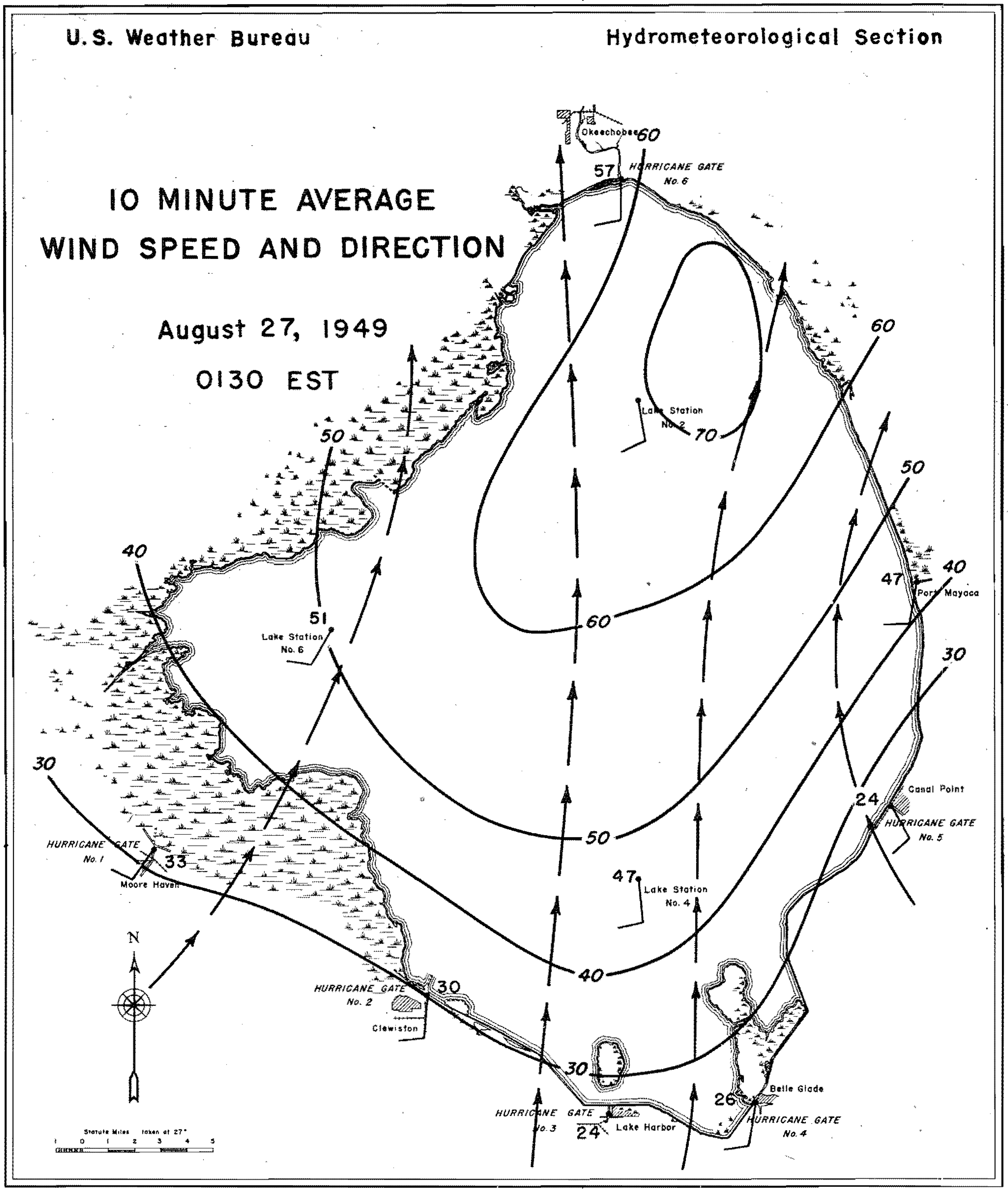

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Figure 51

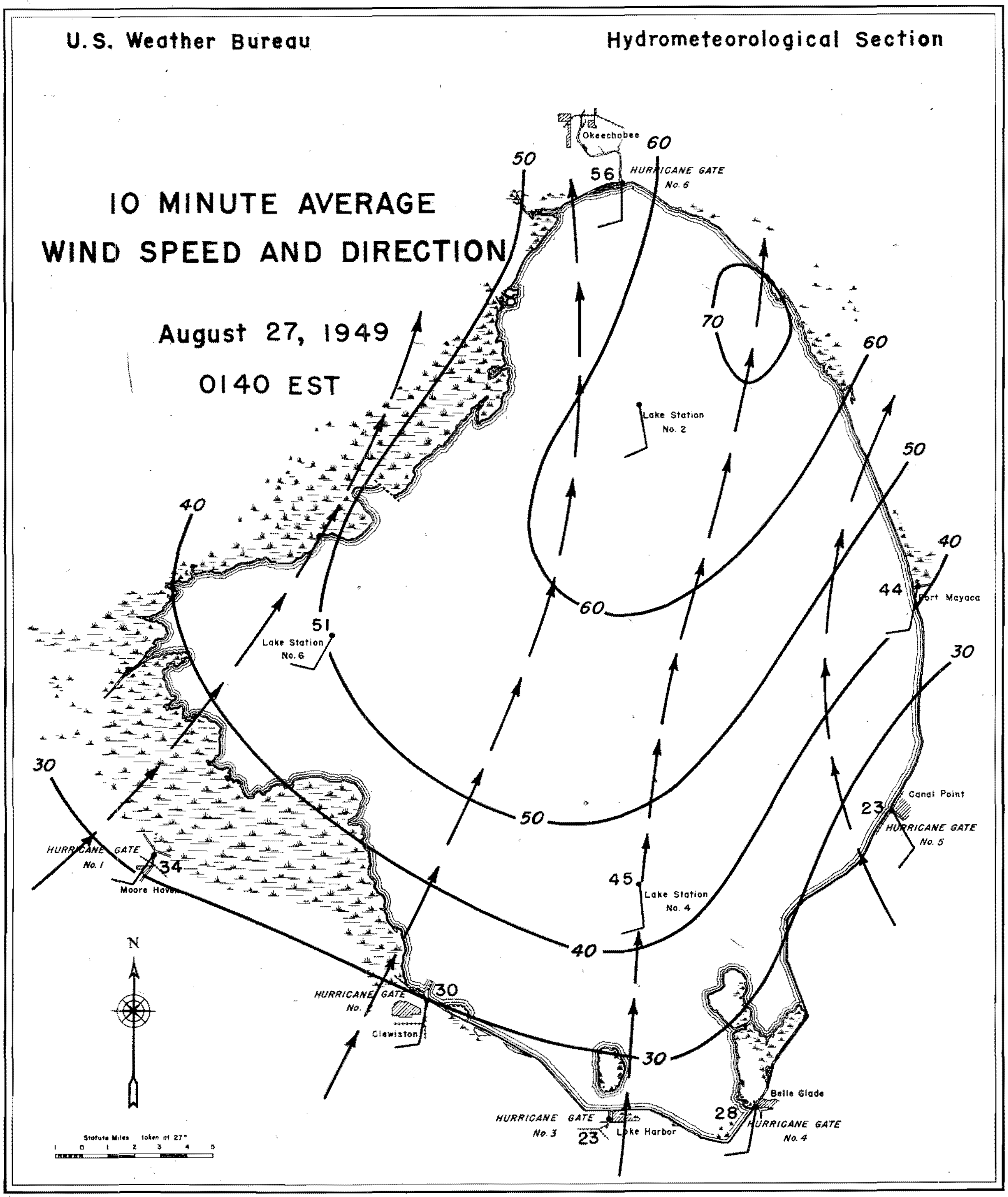

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Figure 52

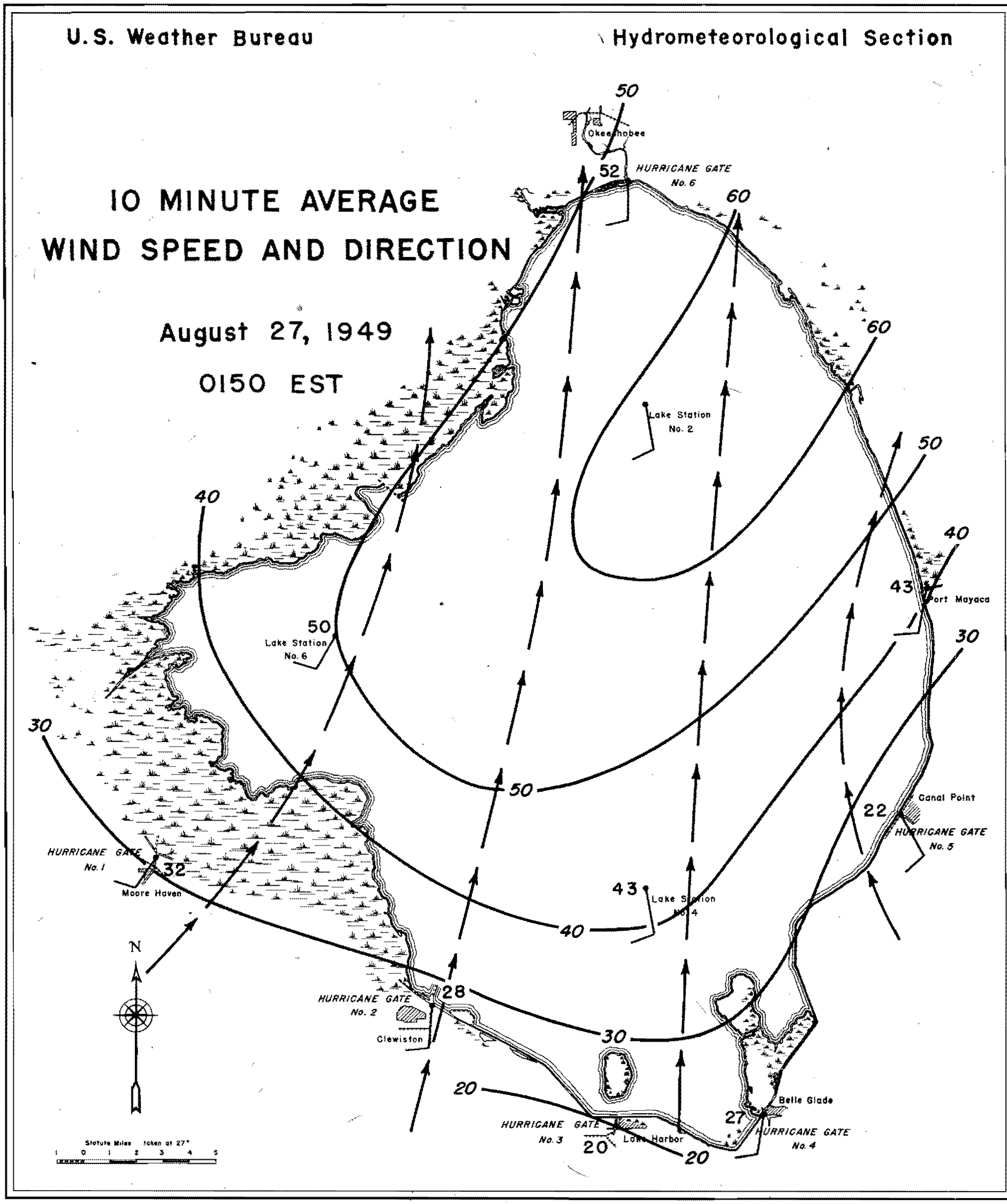

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Figure 53

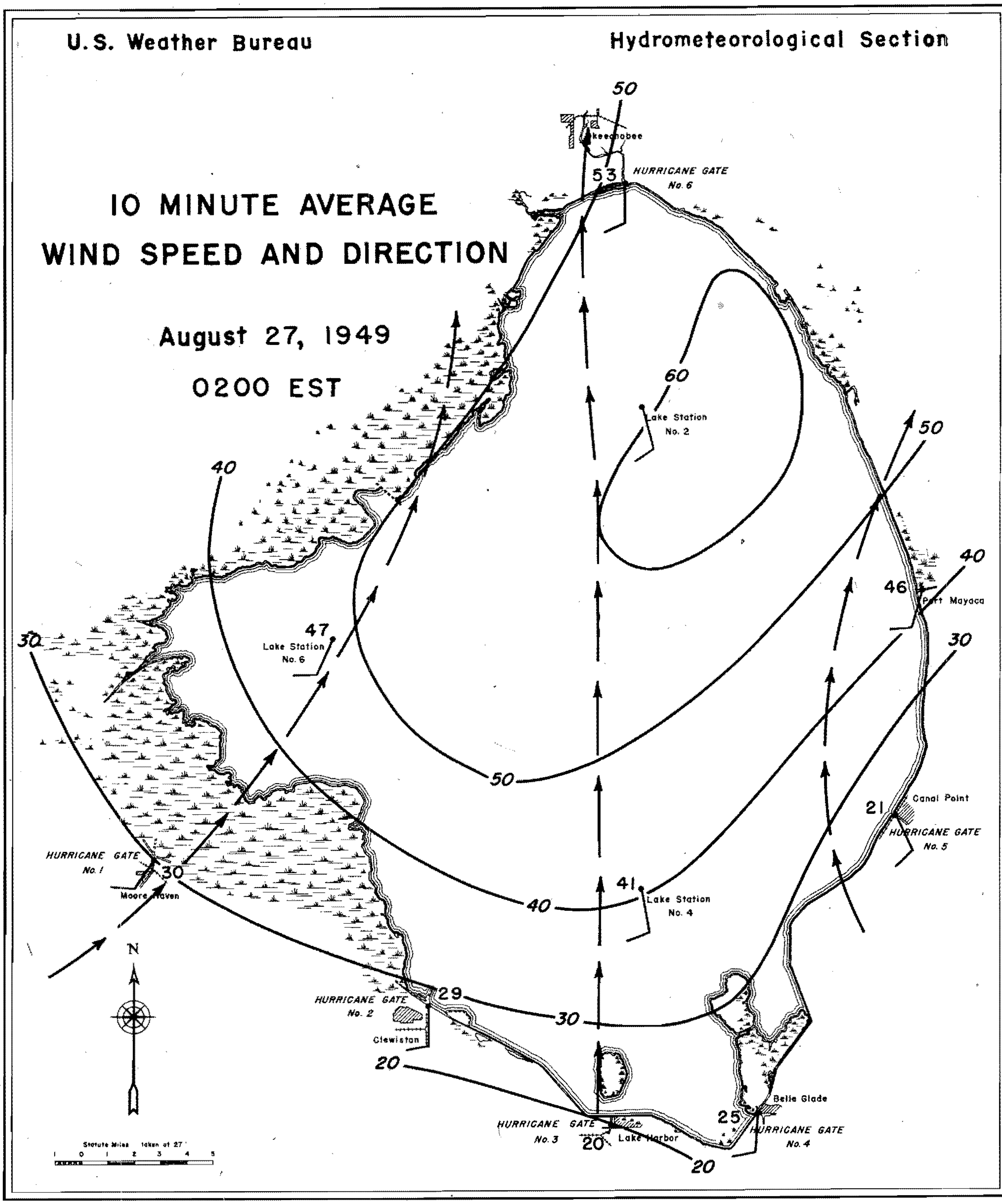

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Figure 54

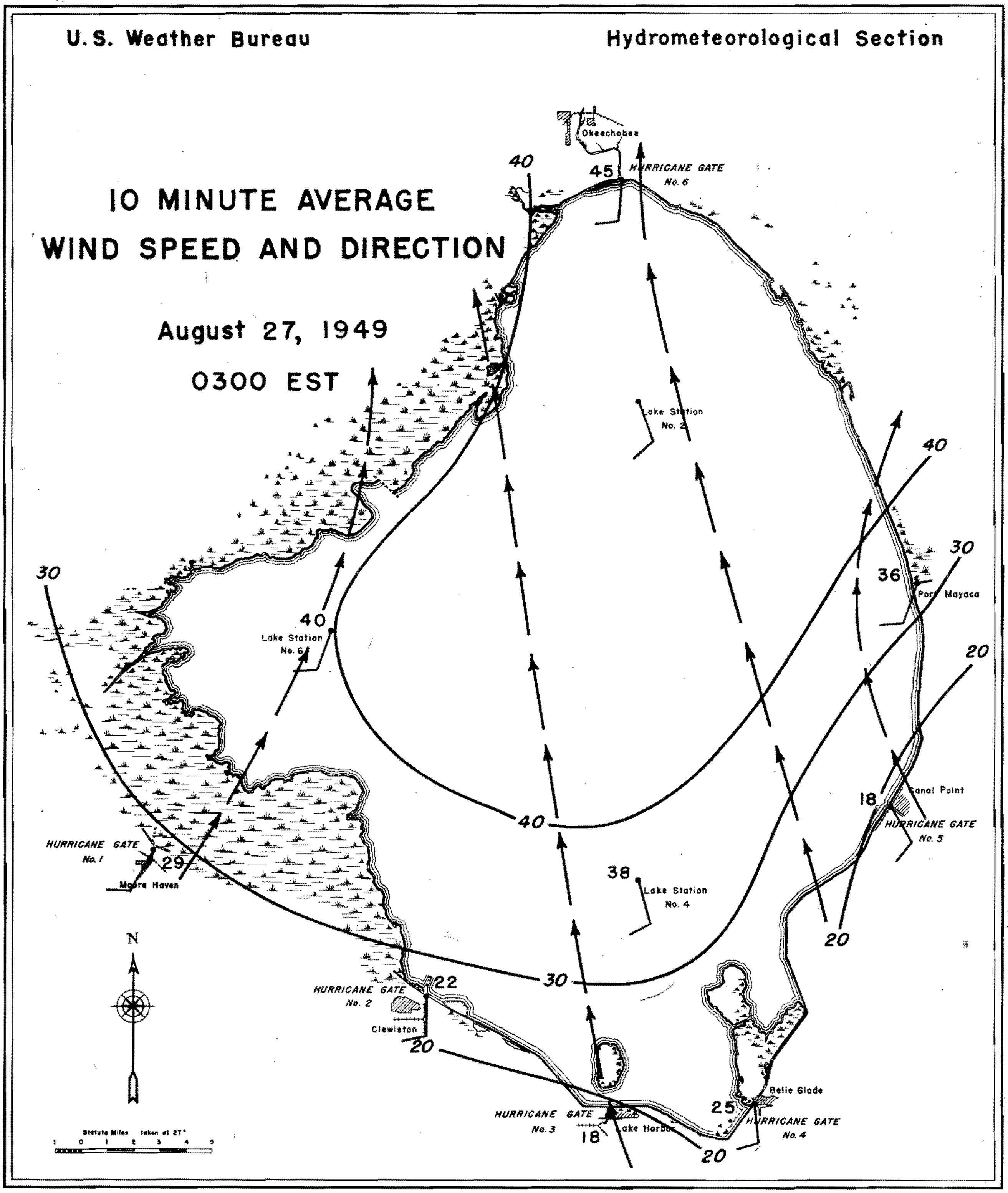

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Figure 55

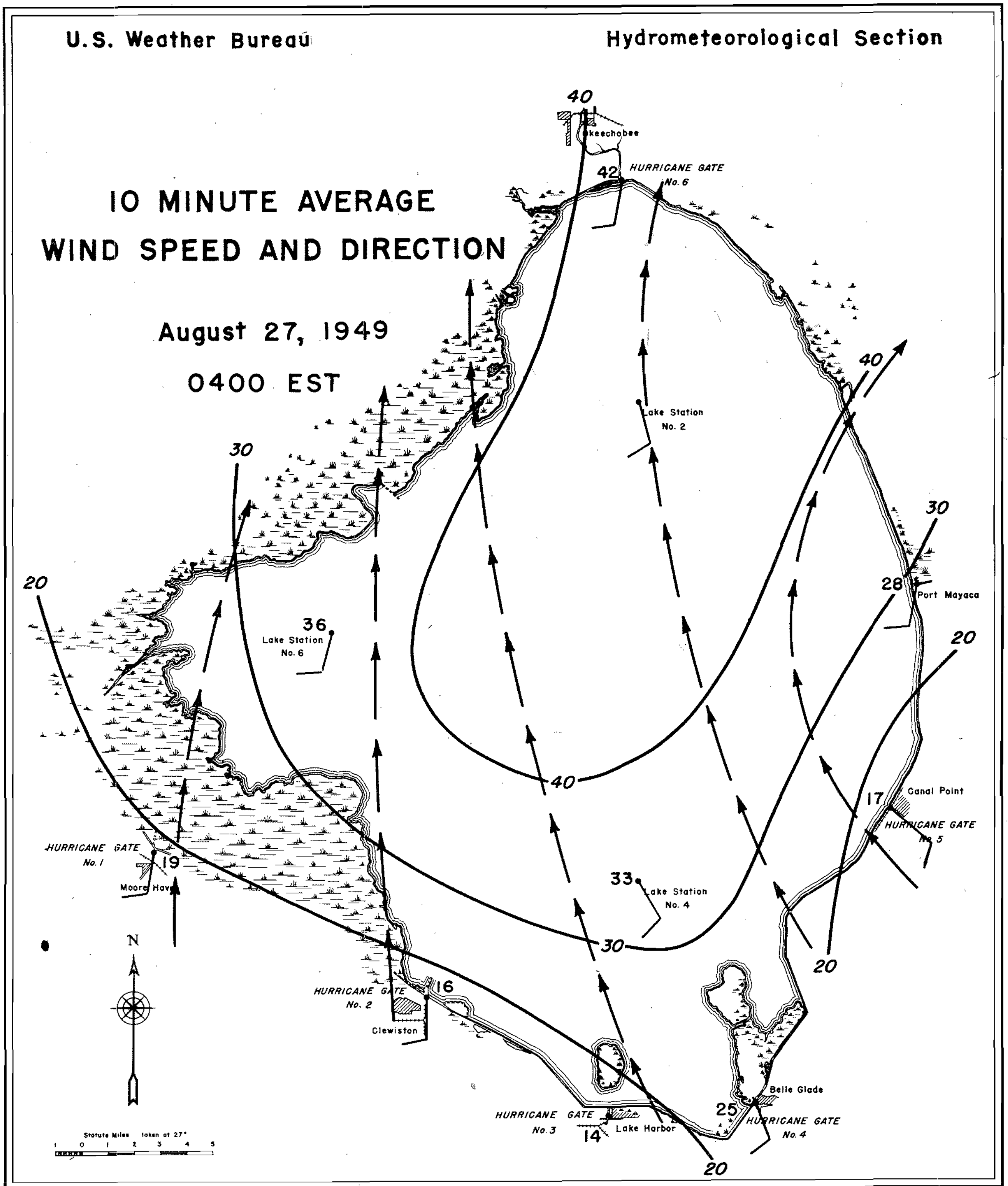

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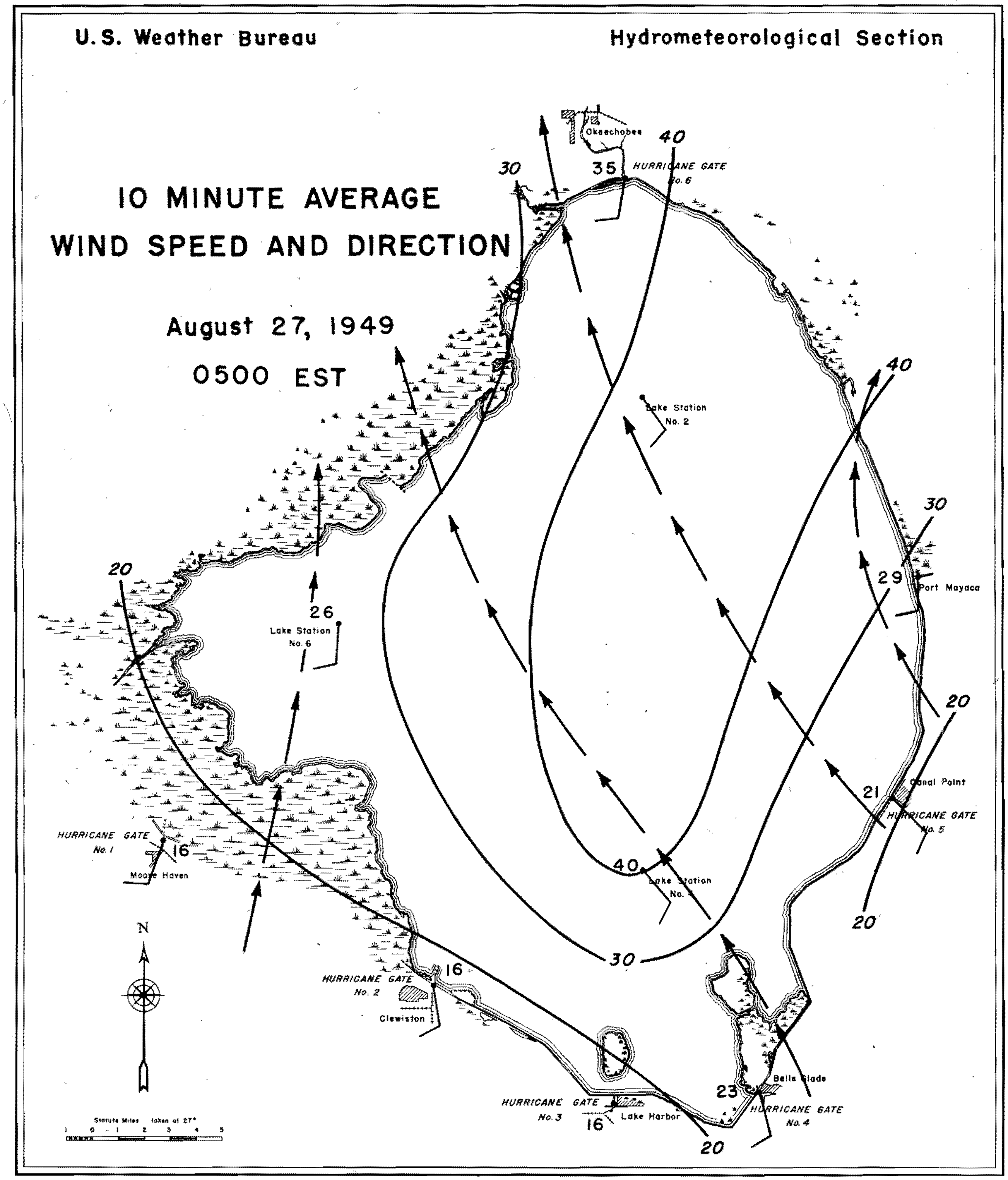
Figure 56



File 5011 Figure 57

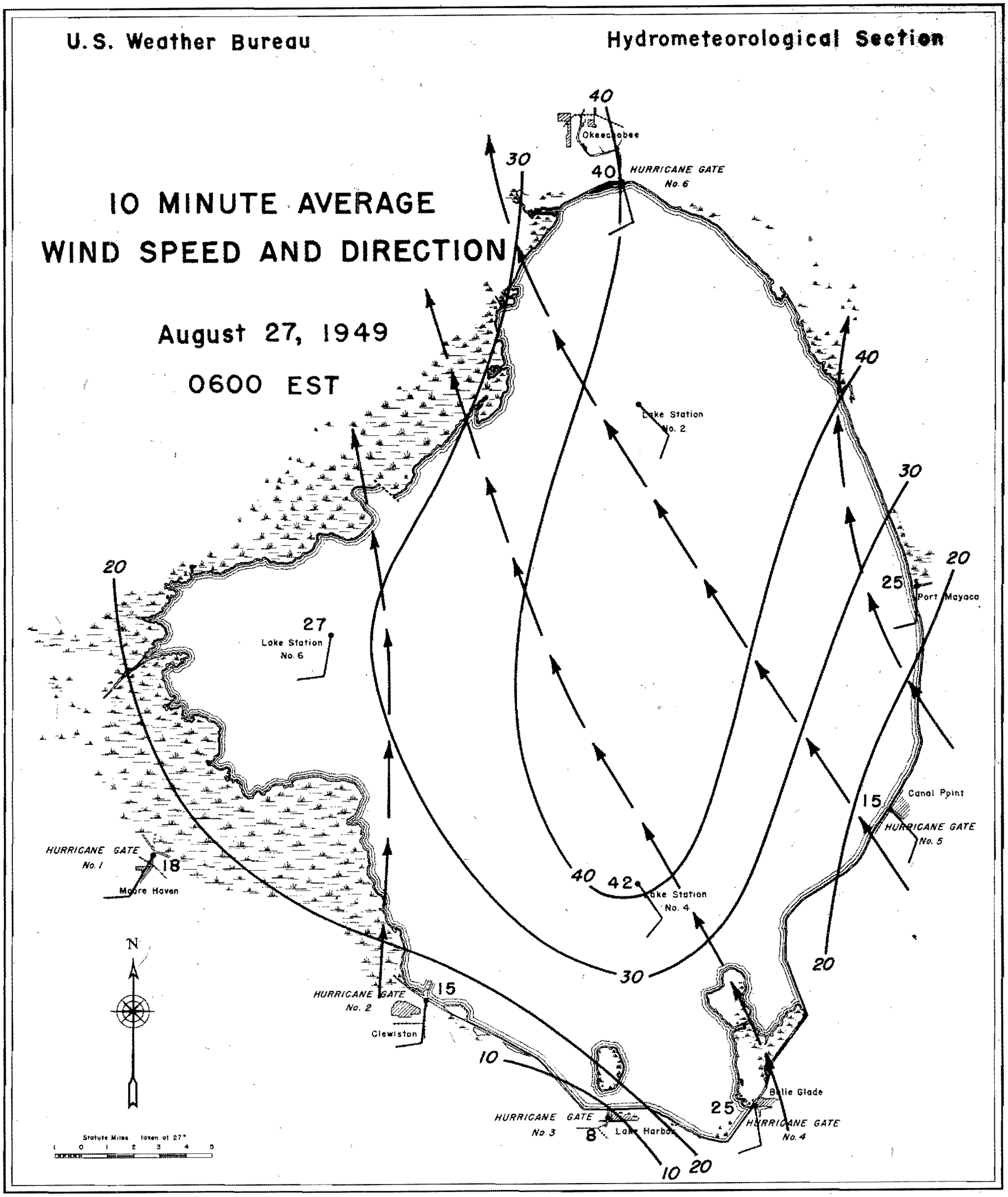


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Figure 58

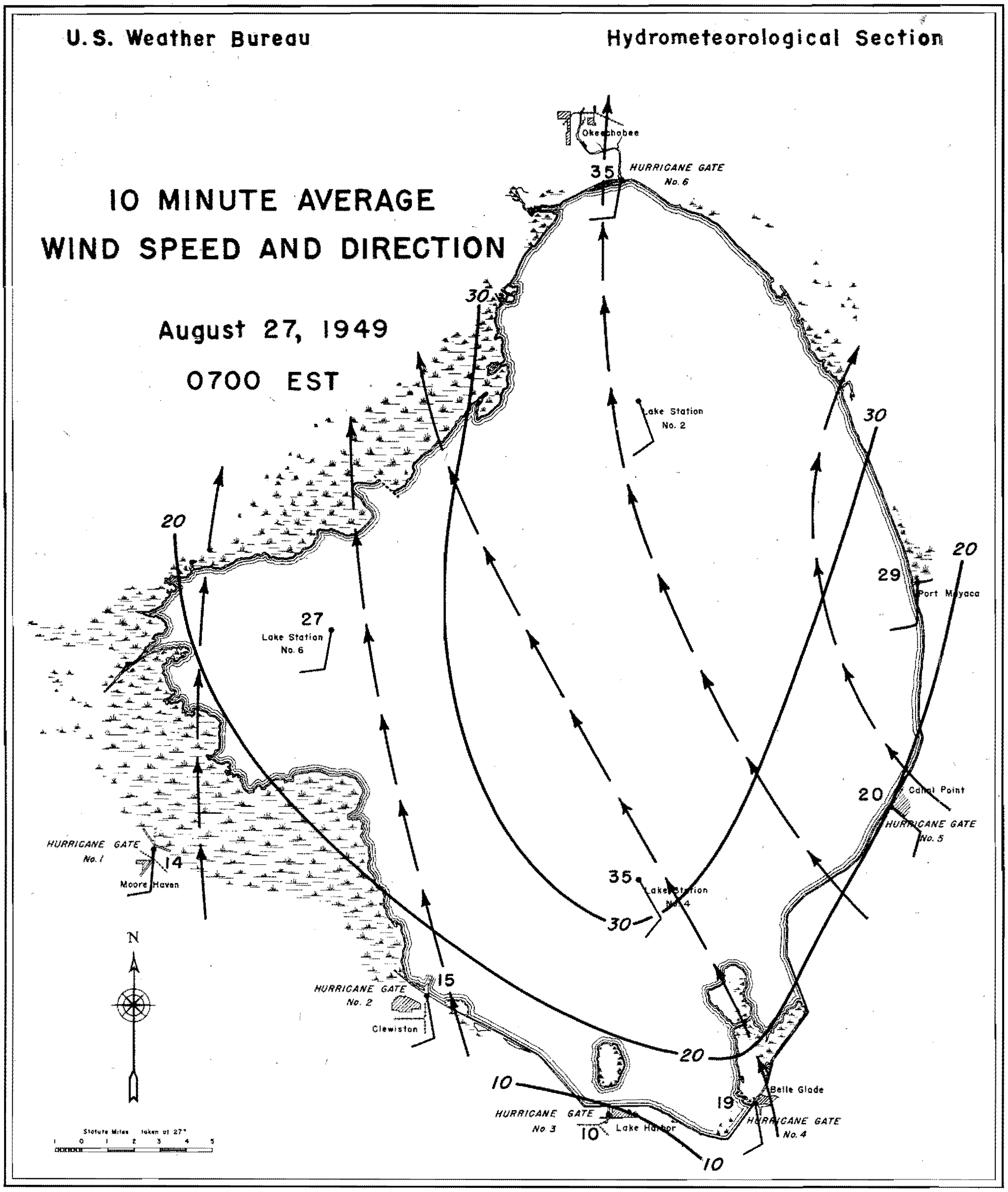

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Figure 59

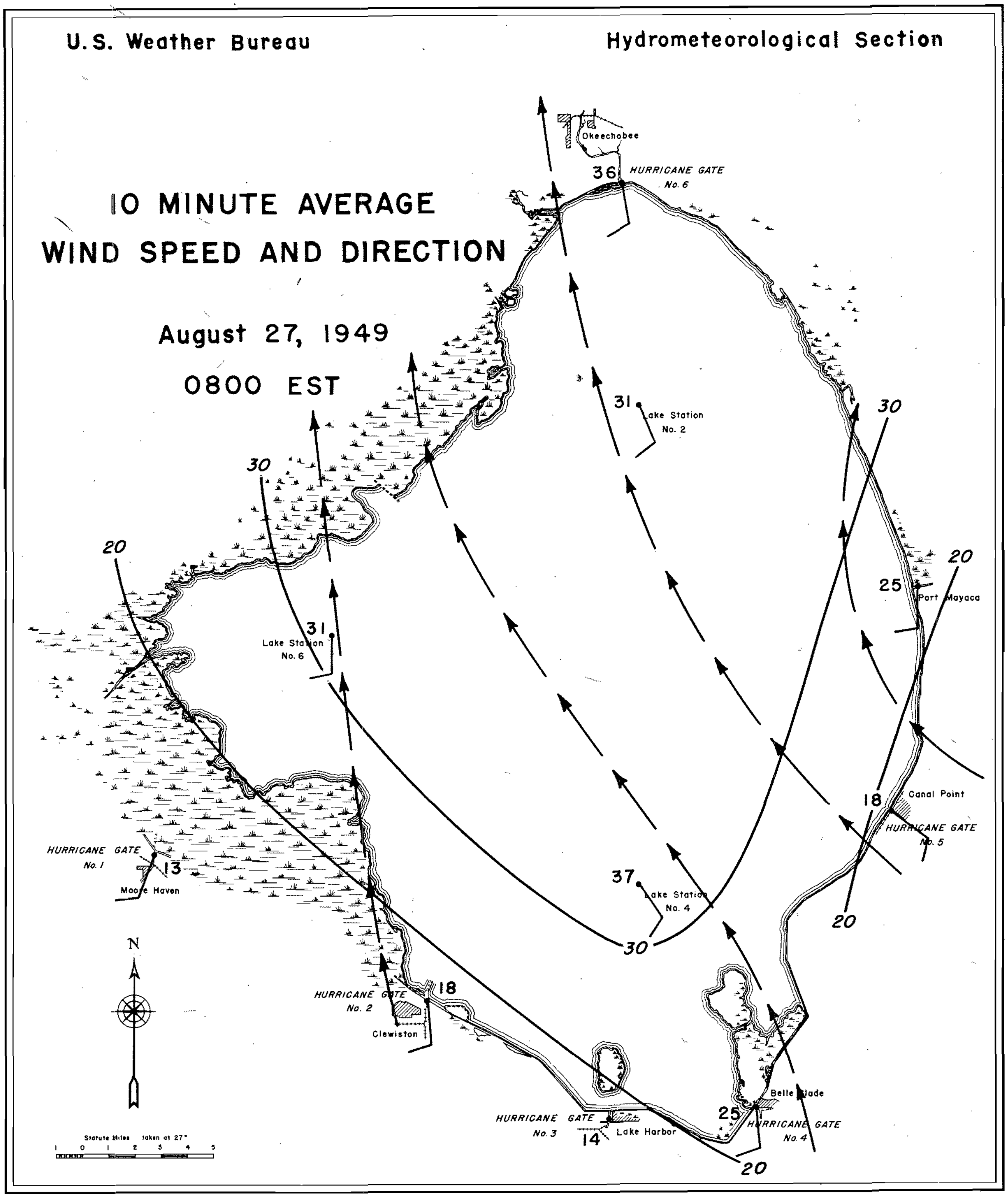
U.S. Weather Bureau
Hydrometeorological Section
10 MINUTE AVERAGE
WIND SPEED AND DIRECTION
August 27, 1949
0800 EST
Okeechobee
HURRICANE GATE No. 6
36
31
Lake Station No. 2
30
20
31
Lake Station No. 6
25
Port Mayaca
Canal Point
18
HURRICANE GATE No. 5
HURRICANE GATE No. 1
13
Moore Haven
37
Lake Station No. 4
N
HURRICANE GATE No. 2
18
Clewiston
Belle Glade
25
HURRICANE GATE No. 4
HURRICANE GATE No. 3
14
Lake Harbor
Statute Miles taken at 27°

Figure 60

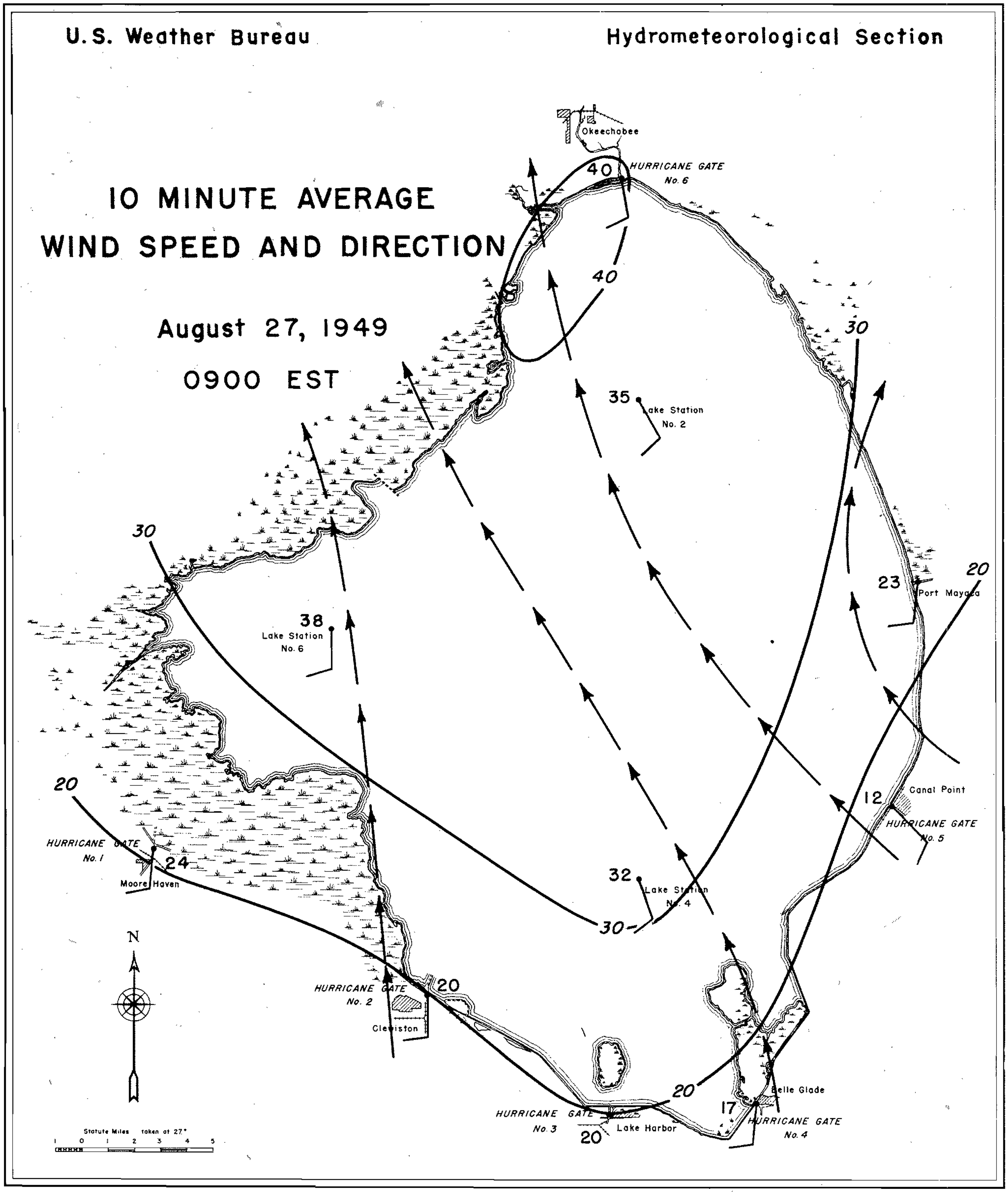

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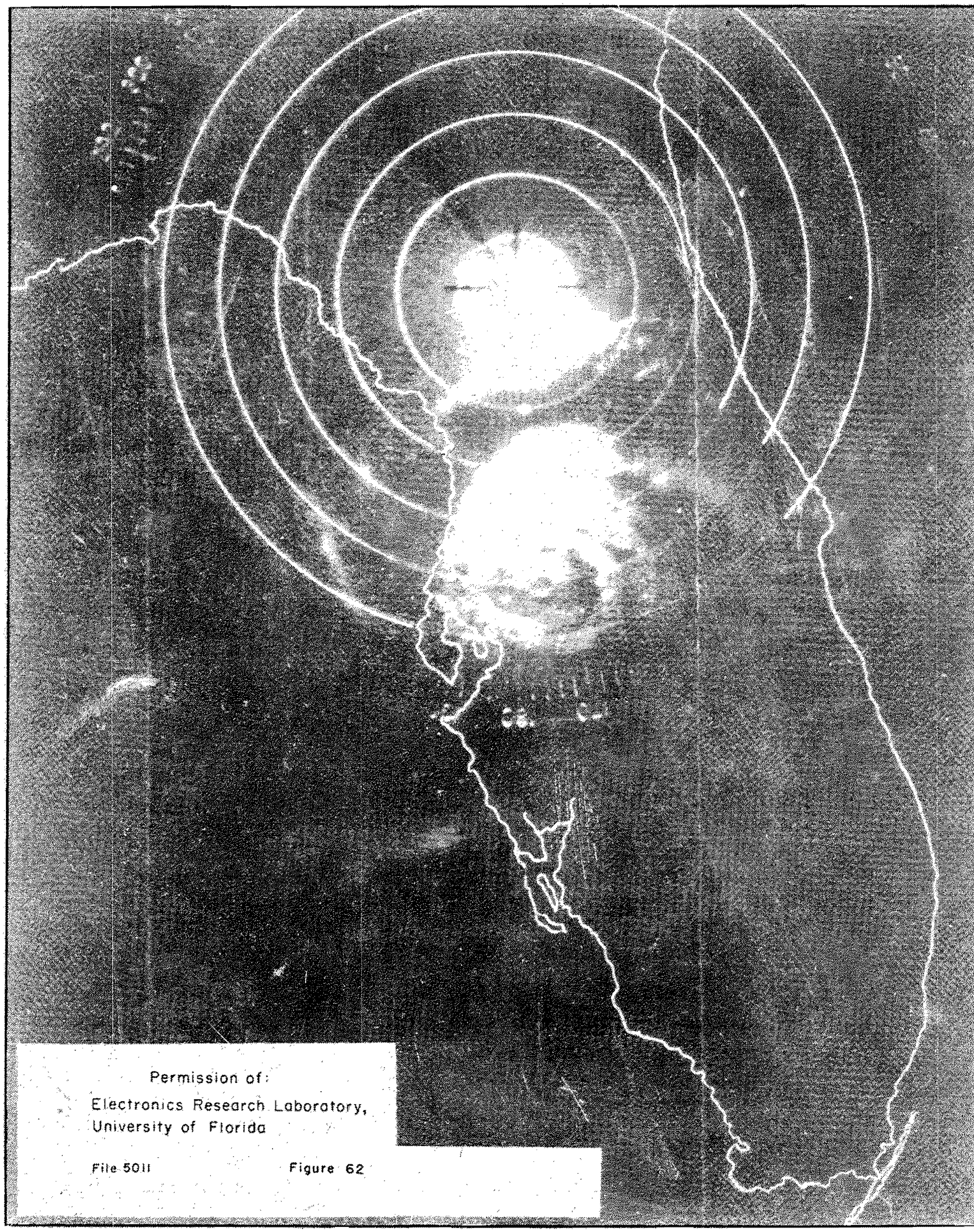
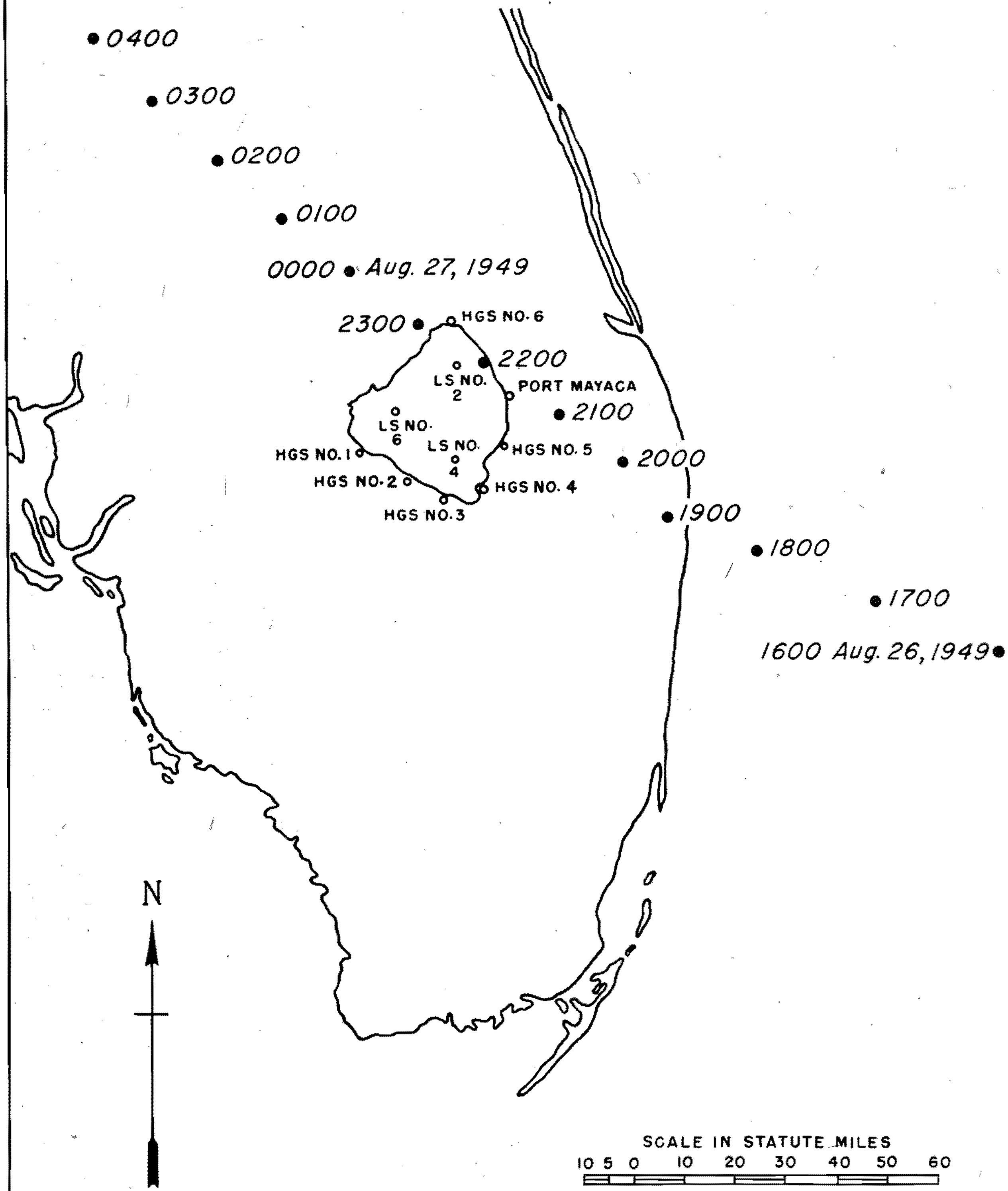
Figure 61


Permission of:
Electronics Research Laboratory,
University of Florida
File 5011
Figure 62

U.S. Weather Bureau

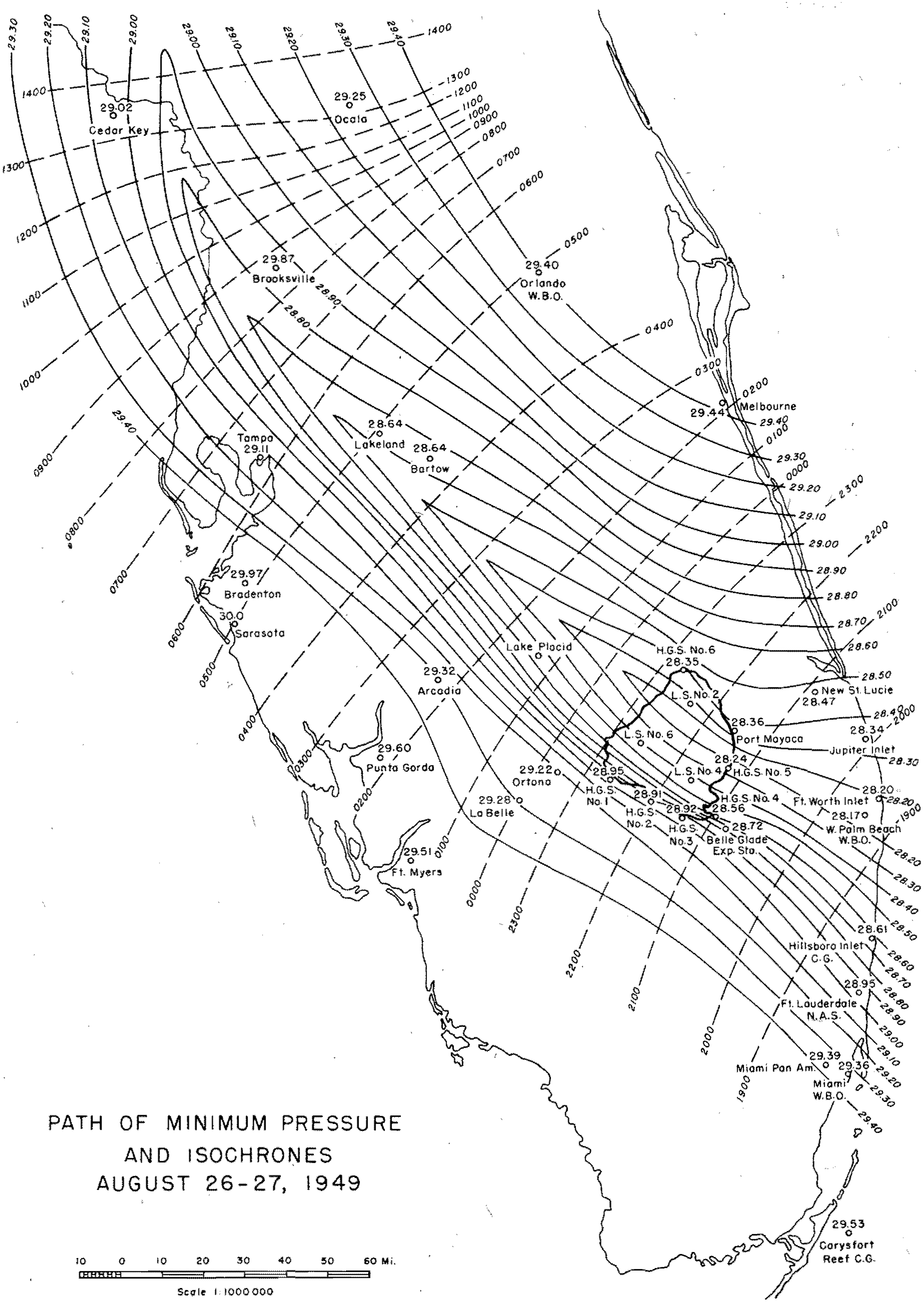
Hydrometeorological Section

PATH OF PRESSURE SYMMETRY
HURRICANE OF AUGUST 26-27, 1949



FILE 5011

FIGURE 63

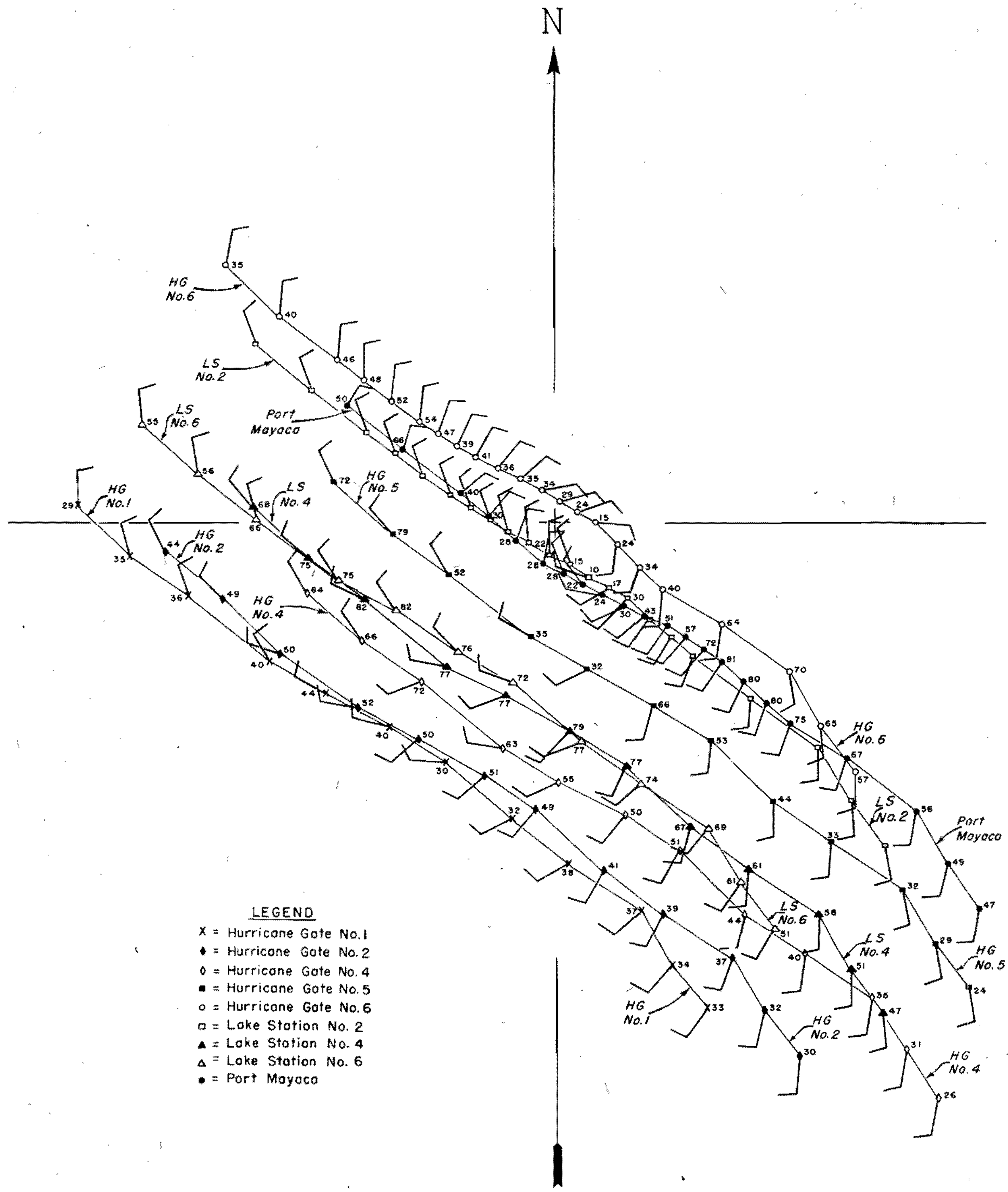


PATH OF MINIMUM PRESSURE
AND ISOCHRONES
AUGUST 26-27, 1949

RELATION OF WINDS TO CENTER OF PRESSURE SYMMETRY

AT HALF HOURLY INTERVALS (Except 10 Minute Intervals near the Center)

2000 AUGUST 26 — 0130 AUGUST 27, 1949



WIND DIRECTION FIELD

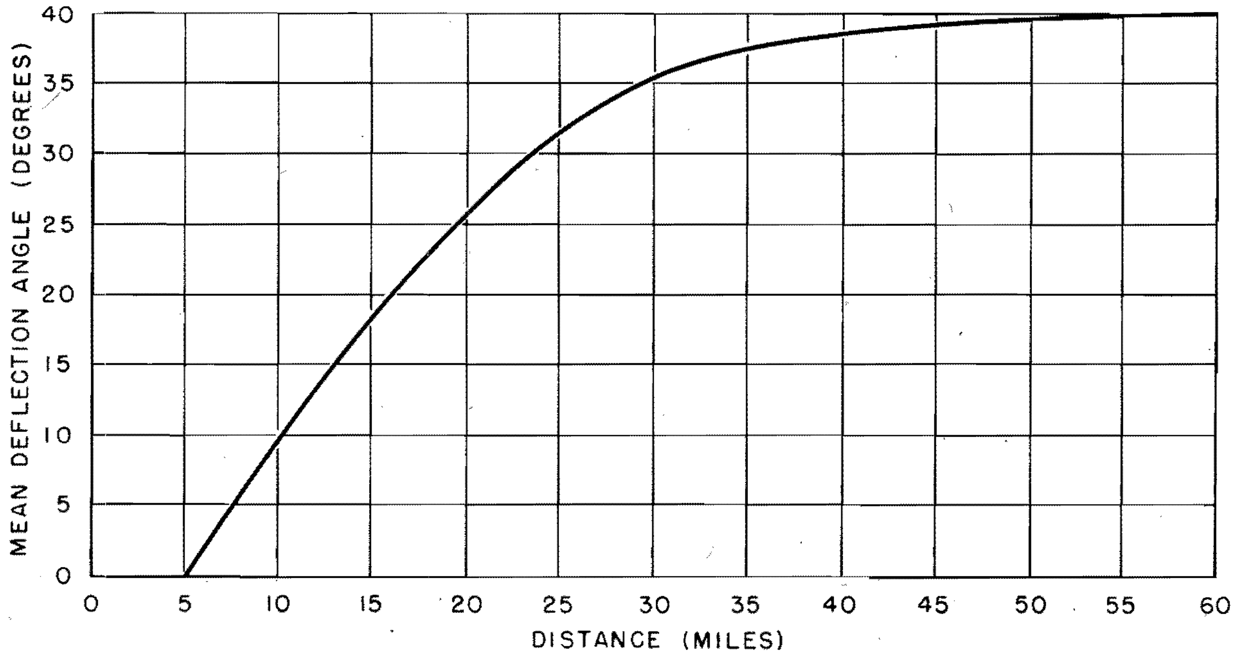


Fig. 66 A

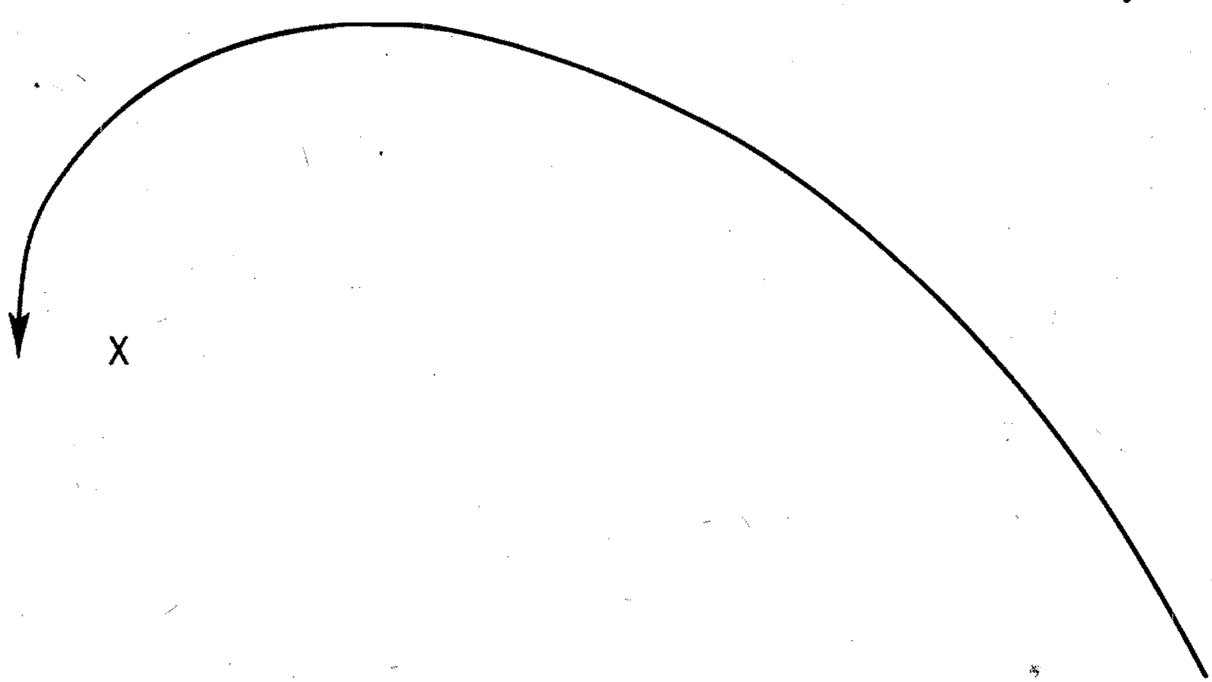


Fig. 66 B

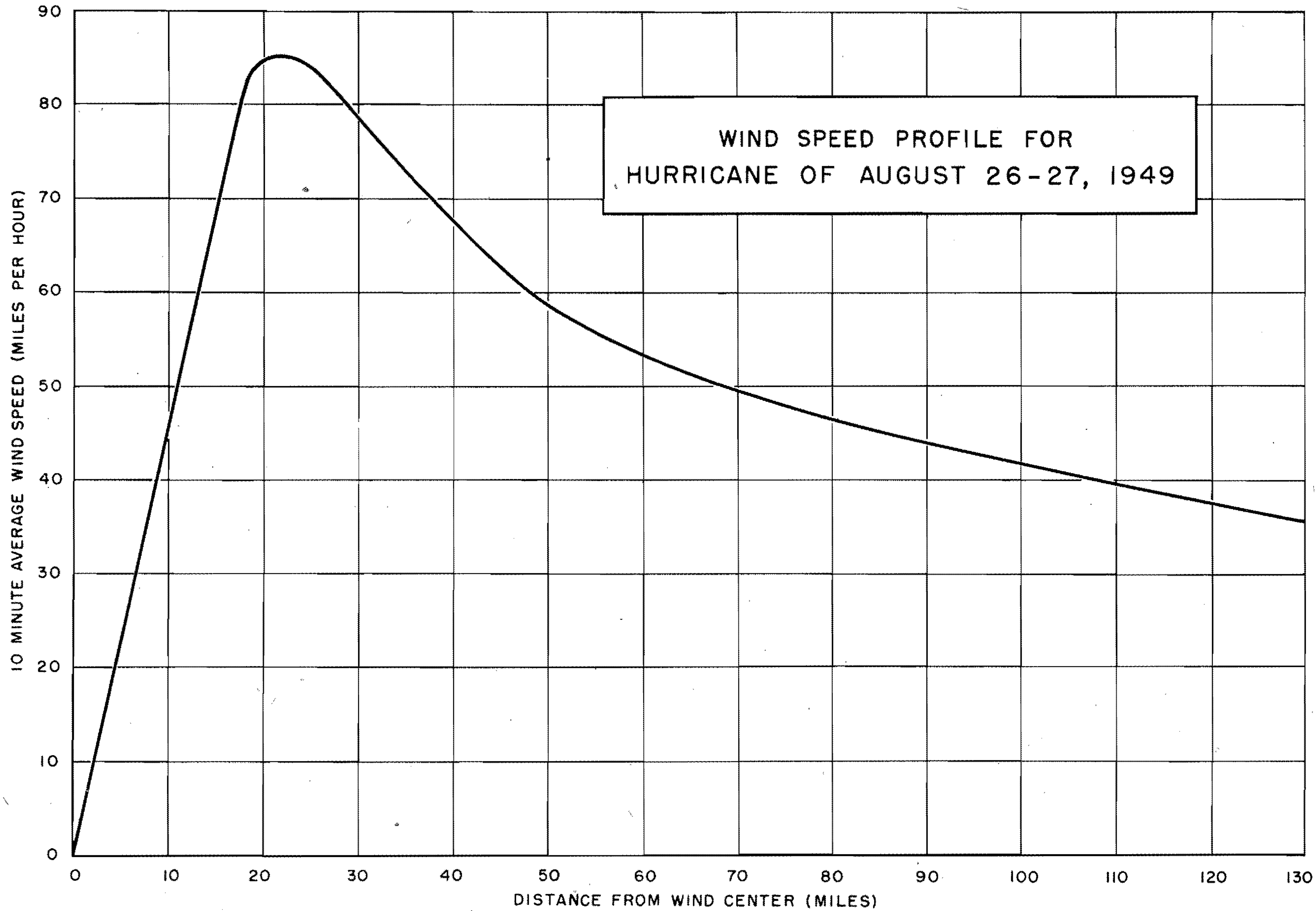
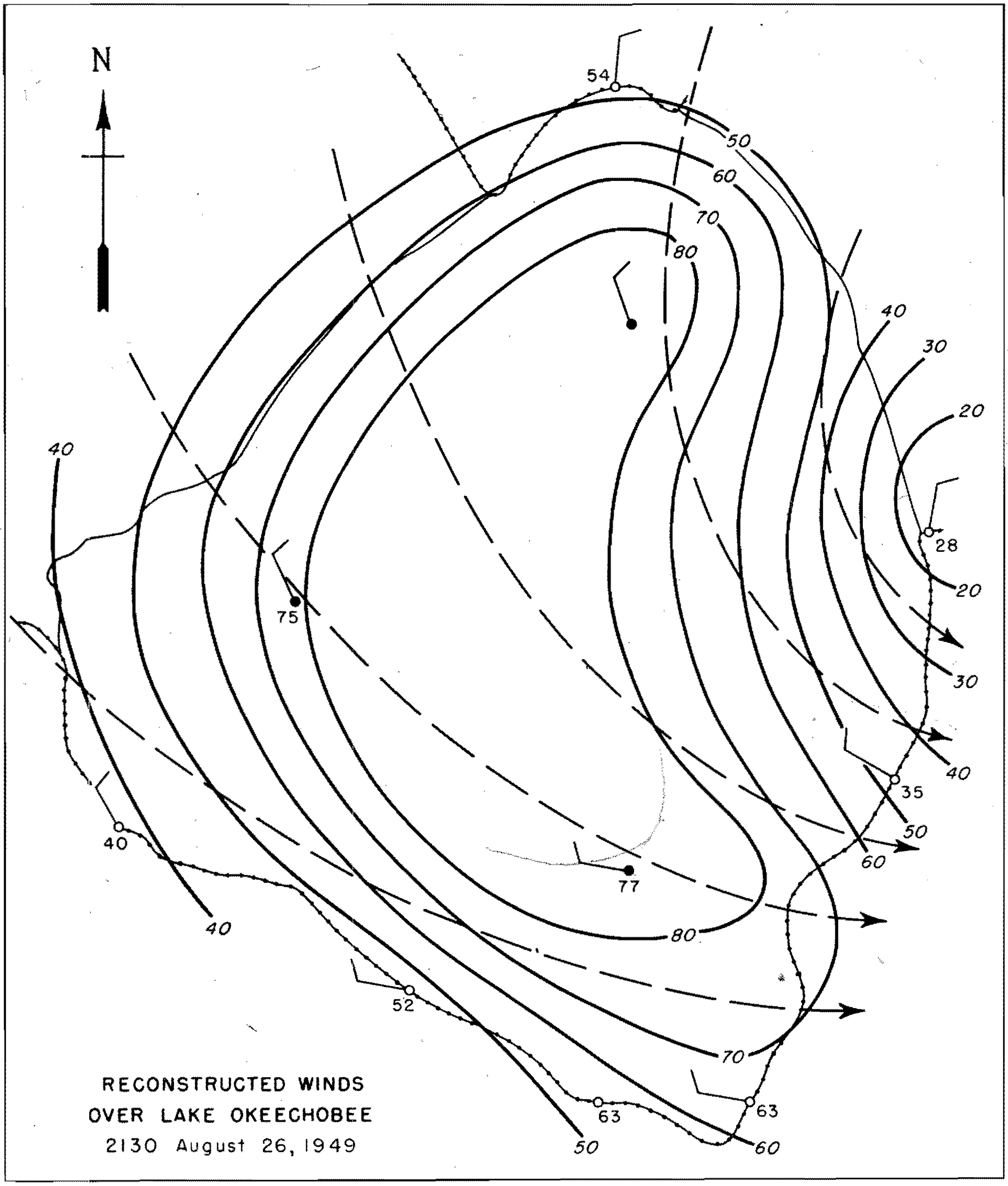

WIND SPEED PROFILE FOR
HURRICANE OF AUGUST 26-27, 1949
10 MINUTE AVERAGE WIND SPEED (MILES PER HOUR)
0
10
20
30
40
50
60
70
80
90
0
10
20
30
40
50
60
70
80
90
100
110
120
130
DISTANCE FROM WIND CENTER (MILES)

FIGURE 67



RECONSTRUCTED WINDS
OVER LAKE OKEECHOBEE
2130 August 26, 1949

U. S. GOVERNMENT PRINTING OFFICE : O—1950