NOAA TM ERL WMPO-6

A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

# NOAA Technical Memorandum ERL WMPO-6

**U.S. DEPARTMENT OF COMMERCE**
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

# Changes of the Maximum Winds in Atlantic Tropical Cyclones as Deduced From Central Pressure Changes

JOHN MICHAELS

Weather
Modification
Program Office
BOULDER,
COLORADO
August 1973

NHRL-105

# ENVIRONMENTAL RESEARCH LABORATORIES

## WEATHER MODIFICATION PROGRAM OFFICE

IMPORTANT NOTICE

Technical Memoranda are used to insure prompt dissemination of special studies which, though of interest to the scientific community, may not be ready for formal publication. Since these papers may later be published in a modified form to include more recent information or research results, abstracting, citing, or reproducing this paper in the open literature is not encouraged. Contact the author for additional information on the subject matter discussed in this Memorandum.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

NOAA Technical Memorandum ERL WMPO-6

# CHANGES OF THE MAXIMUM WINDS IN ATLANTIC TROPICAL CYCLONES AS DEDUCED FROM CENTRAL PRESSURE CHANGES

John Michaels

National Hurricane Research Laboratory

Weather Modification Program Office
Boulder, Colorado
August 1973

TABLE OF CONTENTS

LIST OF FIGURES

# CHANGES OF THE MAXIMUM WINDS IN ATLANTIC TROPICAL CYCLONES AS DEDUCED FROM CENTRAL PRESSURE CHANGES

John Michaels

*Changes of maximum winds for Atlantic tropical storms and hurricanes in the western Atlantic, Caribbean, and Gulf of Mexico have been studied to provide background for evaluating hurricane modification experiments. Mean values and standard deviations of these changes have been computed. Also, means and standard deviations have been computed for the same data stratified by direction of the storm's movement.*

*Charts show both the distribution of the maximum winds, and the means and standard deviations of the changes of the maximum wind speeds by 5 degree squares of latitude and longitude. The latter data are also presented stratified by direction of storm motion. The distributions are in terms of percentages of the total number of storms passing through each square. This investigation of tropical cyclones used 14 years of aircraft reconnaissance data. The study was confined to May through November. A discussion of some possible conclusions regarding regions of maximum intensification and come correlations between frequency and amount of change are given.*

## 1. INTRODUCTION

This study is analogous to a study done for the western north Pacific (Michaels, 1971) that obtained information for planning modification experiments proposed by Project STORMFURY.

Changes in the maximum wind speeds associated with tropical cyclones in the geographical area of the western north Atlantic, Caribbean Sea, and Gulf of Mexico show preferred variations by geographical location and directions of cyclone motion. Knowledge of the normal behavior of central pressure and maximum wind speeds associated with tropical cyclones is particularly important when analyzing results of hurricane modification experiments. It permits the researcher to determine whether intensity changes observed in modified storms are different from those normally observed in unmodified storms; furthermore, it assists in determining if the changes were caused by the experiment or by natural forces.

Storms were selected to study what occurred during May to November inclusively in the area bounded by 45° and 100° W longitude and 10° and 45° N latitude (fig. 1). The study was limited to the ocean areas where the surface conditions remain nearly the same from storm to storm.

Earlier studies in the Atlantic provided background that could be used in evaluating the results of these data. Climatological studies done by Thom (1971) of the NOAA Environmental Data Service were extremely helpful in comparing the distribution of storms by intensity with the distribution

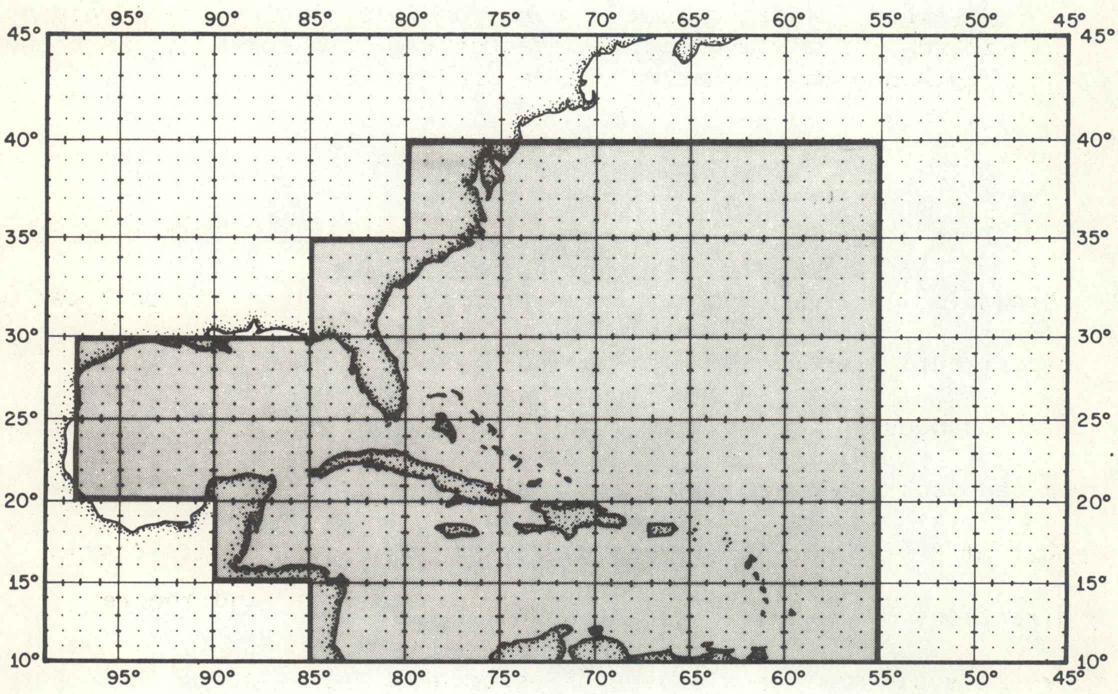



*Figure 1. Area considered for this study.*

of intensity changes. Kraft (1961) suggested a means of computing the maximum winds given the central pressure and Colon (1953) examined the tracks of hurricanes through the area of concern to Project STORMFURY. Hope and Neumann (1971) digitized most of the tropical cyclone tracks in the Atlantic.

## 2. DATA

Since 1957, the quantity of reconnaissance data has increased appreciably along with the quality. The accuracy of these data becomes an important factor when evaluating intensity changes. With improved instrumentation and data recording facilities, this accuracy is constantly being improved.

One-thousand four-hundred eighty-three (1,483) eye penetrations of 104 tropical cyclones giving position time, minimum sea level pressure, and various other parameters from tabulated U.S. Navy, Air Force, and NOAA's Research Flight Facility reconnaissance reports were used. Additional information available to the forecasters and analysts has made possible the development of best track information that is increasingly more accurate. For the more recent years, some of this information was used to supplement the reconnaissance observations. Figure 2 shows the frequency distribution of the observations.

These data were analyzed by 5-degree squares, and the results of the analysis are given in two forms: (1) histograms of maximum wind speed changes by 10-knot classes for each square (appendix A); and (2) tabulations of mean changes of the maximum wind speeds (and standard deviations from

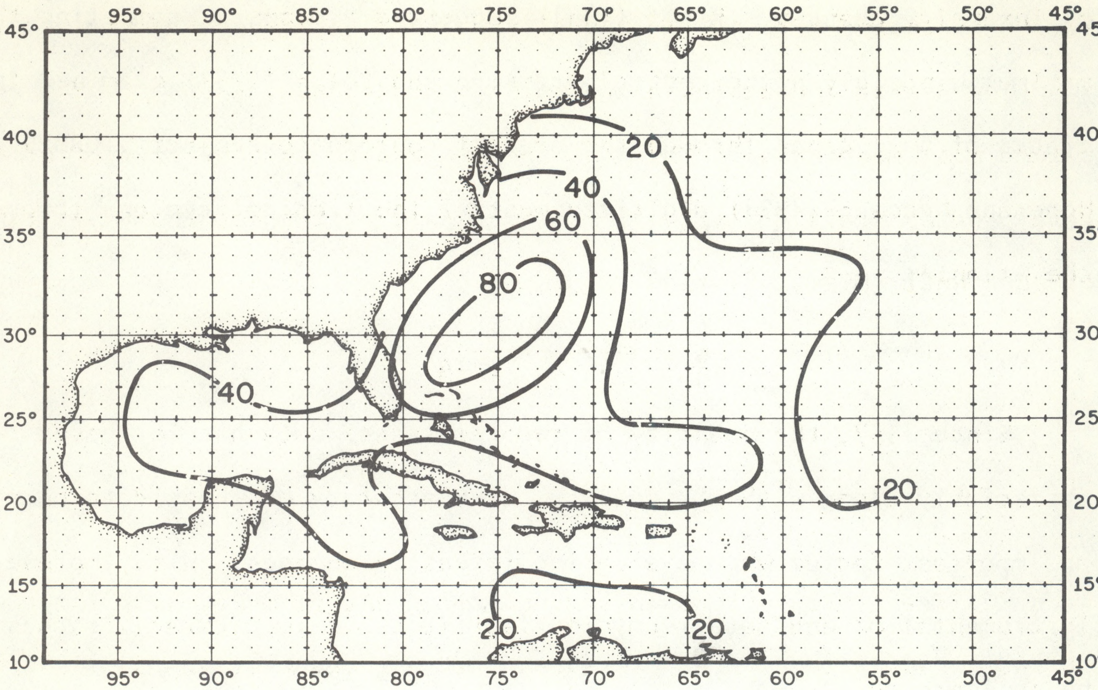



*Figure 2. Distribution of the observations used.*

these means) for the same 5-degree squares plotted in sectors of a circle which characterized the direction of movement out of each square (appendix B). Maximum surface winds were computed from central pressures to eliminate any discrepancies between estimates of surface winds by different observers. (In many cases, measurements of the maximum winds were not available.) Observation times did not always come at regular 6 or 12 hour intervals. In such cases, surface pressures as a function of time were linearly interpolated when an observation was within 2 hours of the projected time. Where the central pressure was unavailable, a nomograph developed by Dr. C.L. Jordan (1957) was used to estimate the central pressure from flight level information. If two observations from the same storm fell in the same square, each was treated individually. Since we are looking for areas favoring either increasing or decreasing wind speed, this approach was deemed most meaningful. The wind speeds were calculated from a formula developed by Kraft (1961) that is now in use by the National Hurricane Center (NHC), Miami, Florida,

$$V_{(max)} = 14 \sqrt{1013 - P_c} \tag{1}$$

where $P_c$ = minimum central pressure in millibars and $V_{(max)}$ is the maximum wind speed in knots.

Holliday (1969) compared several different formulas used for computing surface winds from central pressures that assumed a standard pressure gradient from the outermost closed isobar about the storm to the center. To obtain the most reliable observations, he examined 66 years of data and determined that coastal stations that recorded the minimum central pressure and maximum sustained wind should be best suited for this study. In comparing the different formulas, he found that the probable error in Kraft's equation was 5.9 knots. Table 1 gives the results of Holliday's findings.

Figure 3 shows how the histograms are to be interpreted. They show the percentage of storms having maximum winds that increased or decreased by categories: -5 to +5, 5-15, 15-25, 25-35 knots, etc. Only observations that had succeeding 12, 24, and 48 hour observations have been used in this study. If the storm moved out of the square during the period in question, its changes were tabulated in the original square.

Table 1. Statistics on Equations Used to Determine Maximum Winds in Hurricanes When Checked With Data Sample

| Equation | | Standard Deviation (mps) | Average Error (mph) | Probable Error (mph) |
|---|---|---|---|---|
| $V_{(max)}$ (kts) = | | | | |
| Fletcher's (1955) | $18\sqrt{1010-P_c}$ | 14.0 | 11.6 | 9.4 |
| Takahashi | $13.4\sqrt{1010-P_c}$ | 15.5 | 10.6 | 10.5 |
| JTWC (1952) | $(20-\frac{\phi}{5})\sqrt{1010-P_c}$ | 9.6 | 7.3 | 6.5 |
| Myers (1957) | $11\sqrt{1010-P_c}$ | 27.4 | 24.5 | 18.5 |
| Kraft (1961)[1] | $14\sqrt{1013-P_c}$ | 8.8 | 6.7 | 5.9 |

[1] Histograms of changes in the maximum winds (computed using Kraft's formula) by 5 degree squares are presented in appendix A.

The means for each 5 degree square were computed from

$$\overline{\Delta V} = \sum_{i=1}^{n} \frac{\Delta V_{(max)i}}{n} \qquad (2)$$

where $\Delta V_{(max)}$ is the change in maximum wind speed in knots, and $\overline{\Delta V}$ is the mean change in the maximum winds. The standard deviations were computed from

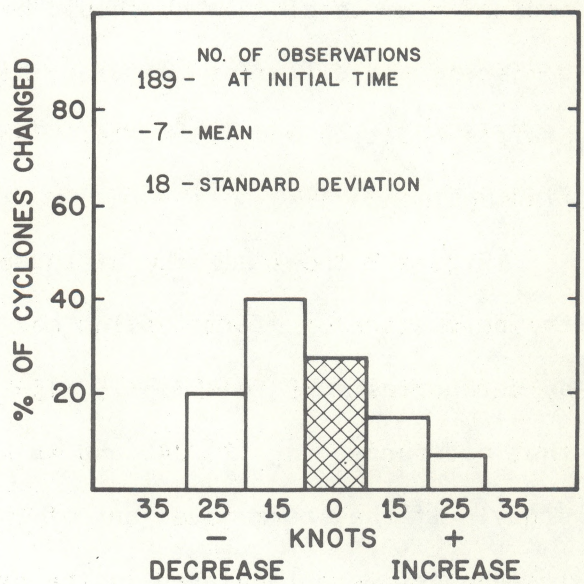



*Figure 3. Key to histograms.*

$$\Delta V_{(max)} = \sqrt{\frac{\sum_{i=1}^{n} (\Delta V_i - \overline{\Delta V})^2}{n}}, \; n < 30 \qquad (3)$$

and

$$V_{(max)} = \sqrt{\frac{\sum_{i=1}^{n} (\Delta V_i - \overline{\Delta V})^2}{n-1}}, \; n < 30 \qquad (4)$$

where $\overline{\Delta V}$ is the mean change in the maximum wind speed, and $\Delta V$ is the change in these winds. In squares that had more than 30 observations, the standard deviations were computed with (3), and where the number of observations in the sample was less than 30, (n-1) was used in the denominator of (3) to compensate for population size. The mean values and standard deviations were thus computed for each square, and these values are in the upper left corner on each histogram along with the number of cases. The data were next stratified into four categories, according to the storm's direction of movement from each square. The number of cases, mean changes in knots, and standard deviations were plotted on pie graphs for each square. Figure 4 shows how the pie graphs are interpreted.

All the histograms and graphs were prepared using a digital incremental plotter at the National Hurricane Research Laboratory (NHRL) in Miami, Florida, with data received from NOAA's Suitland Computer Center on the remote terminal.

## 3. STRATIFICATION BY INTENSITY

The data were stratified by intensities into four groups according to whether the maximum winds were greater than 20 knots, 40 knots, 64 knots,

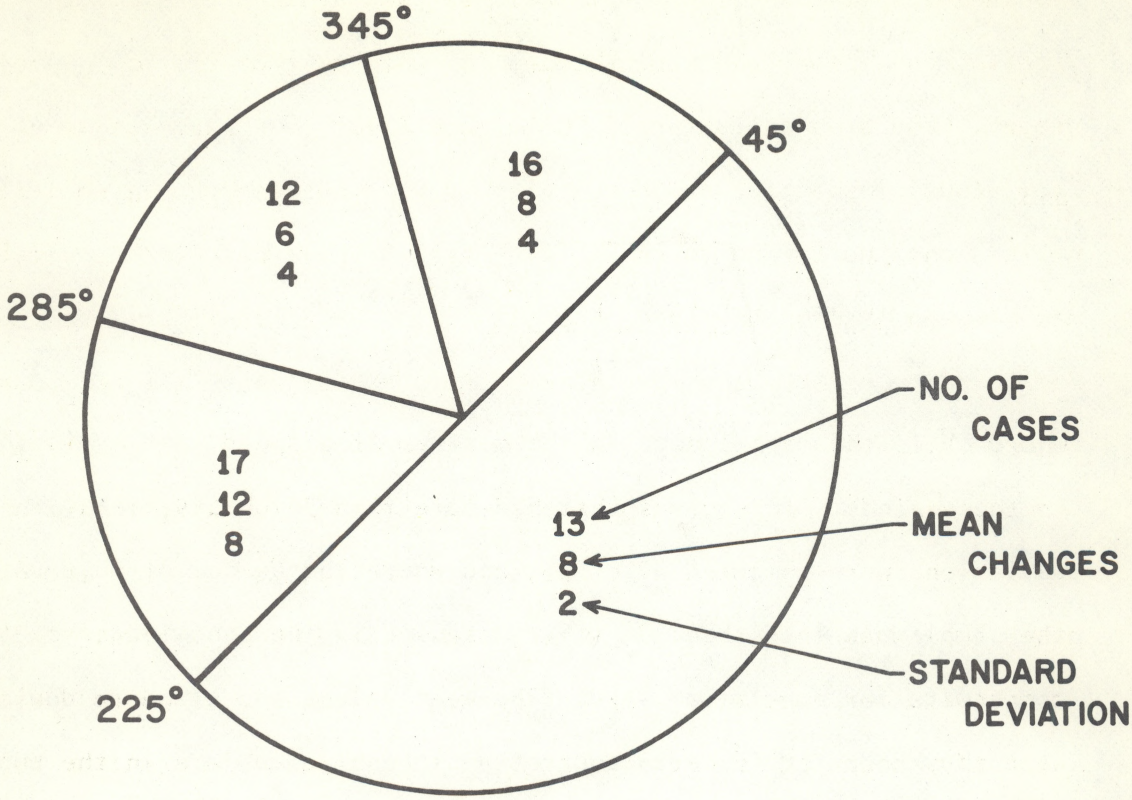



*Figure 4. Key to pie graphs.*

or 80 knots. These storm data were than tabulated by the changes in maximum wind speeds and displayed in histograms. A change of ± 5 knots in the initial wind speed was considered little or no change. If an increasing or decreasing change occurred it was put in categories of ± 5-15, 15-25, 25-35, and >35 knots, as appropriate.

Further, the data were stratified by direction of movement out of the respective square by using the pie diagrams (fig. 4).

## 4. CONCLUSIONS

The most striking feature of this study is that Atlantic tropical cyclones do not have the same explosive quality as their Pacific counterparts

(Michaels, 1971). However, some well-defined areas of preferred intensification do appear, and storms traveling through them are most likely to deepen. The area that we call "Hurricane Alley" has been justly named. From visual inspection of this region, extending from the Lesser Antilles north along the Caribbean chain, a general trend toward intensification can be seen (see appendices), especially in the 24 to 48 hour periods. The majority of storms moving through this region reach the northern Bahamas and start recurving to the north and northeast and apparently intensifying. A small portion of these storms approaching the Bahamas from the east cross the Florida Keys into the Gulf of Mexico, and in many cases they then intensify. However, this change is not large. Tropical storms with maximum winds $\geq$ 40 knots and hurricanes with winds $\geq$ 64 knots intensify about 5 to 10 knots; however, the changes deviate from this as much as 10 knots in a 24-hour period. These same storms can grow at a substantial rate in 48 hours if their tracks put them into the central Gulf of Mexico rather than curving to the north.

Tropical storms with wind speeds greater than 80 knots tend to intensify when approaching the Bahamas and then curve northward (app. B, fig. B-11). This is seemingly realistic, for if these cyclones continue west rather than assuming a northerly component, the islands in the Bahamas as well as the coasts of Cuba and Florida influence the circulation about these systems of intensity, causing them to hold steady and even decrease.

The most pronounced changes in the storms along "Hurricane Alley" occur when they move from the area just to the north of Puerto Rico. This area is climatologically favorable to storm development and intensification. Seventy percent of all tropical cyclones with winds $\geq$ 40 knots that passed through this area did intensify, some by more than 35 knots in 12 hours (figs. A-4, A-5, A-6). The mean increase of maximum wind speeds was about 10 knots with a standard deviation of about the same amount. This is a favored area for change in some very large and intense hurricanes; this shows in the large increases for the 24 and 48 hour periods (figs. A-5, A-6, B-5, and B-6). In 24 hours, we have a mean intensification of 15 knots with a standard deviation of 21 knots (fig. A-5). Storms moving from this region with a westerly component have the greatest increase in intensity. In the 24-hour change group, the mean change increases to 19 knots with the standard deviation remaining at 21 knots (fig. A-6). This indicates that a high percentage of systems leaving this area have grown to hurricane intensity. Out of the 28 observations in this region, 78 percent intensified, with 30 percent intensifying greater than 35 knots, and only 10 percent showed a decrease from 1 to 25 knots.

East of Florida the area bounded by 75° to 80° W longitude and 25° to 30° N latitude is where an increase in the maximum winds of cyclones moving through this area is not confined to direction of motion (figs. A-4 to A-6 and B-4 to B-6) except in the 12-hour change group of tropical cyclones $\geq$ 40 knots. There is a slight decrease in the mean change with storms having an eastward component. The slight increase occurring in the westward moving storms in 12 hours may be the influence of the warm Gulf Stream (fig. A-4). In the 24 and 48 hour groups, the increase is apparent in all quadrants of storm motion. The largest change occurs in 48 hours where

70 percent of the 59 observations showed an increase, 20 percent keep the same wind speed, and 10 percent or less decrease (fig. A-6).

In trying to understand what area this sort of change can affect, we assumed an average movement of 10 to 15 knots per hour. Using this particular square east of Florida as an example, we constructed figure 5 to show what these 12, 24, and 36 hour changes mean in terms of distance the storm can travel in these times. Also, note how much area can be affected in the same time when only one direction of movement increases (fig. 6).

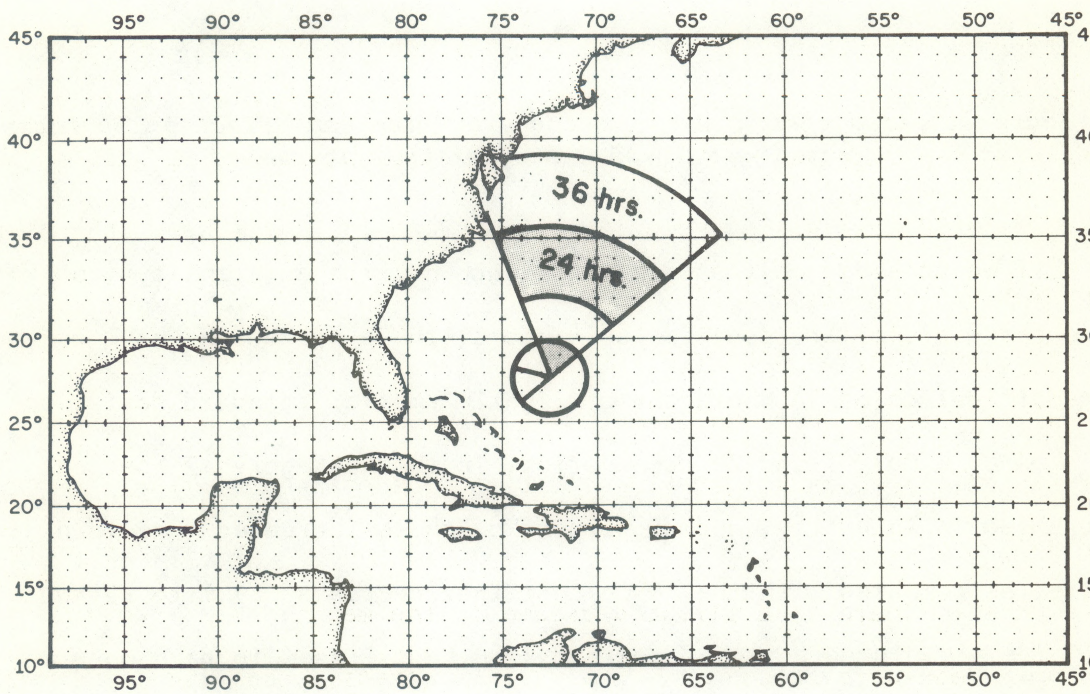



*Figure 5. Area that a storm moving away from a designated sector can affect in 36 hours.*

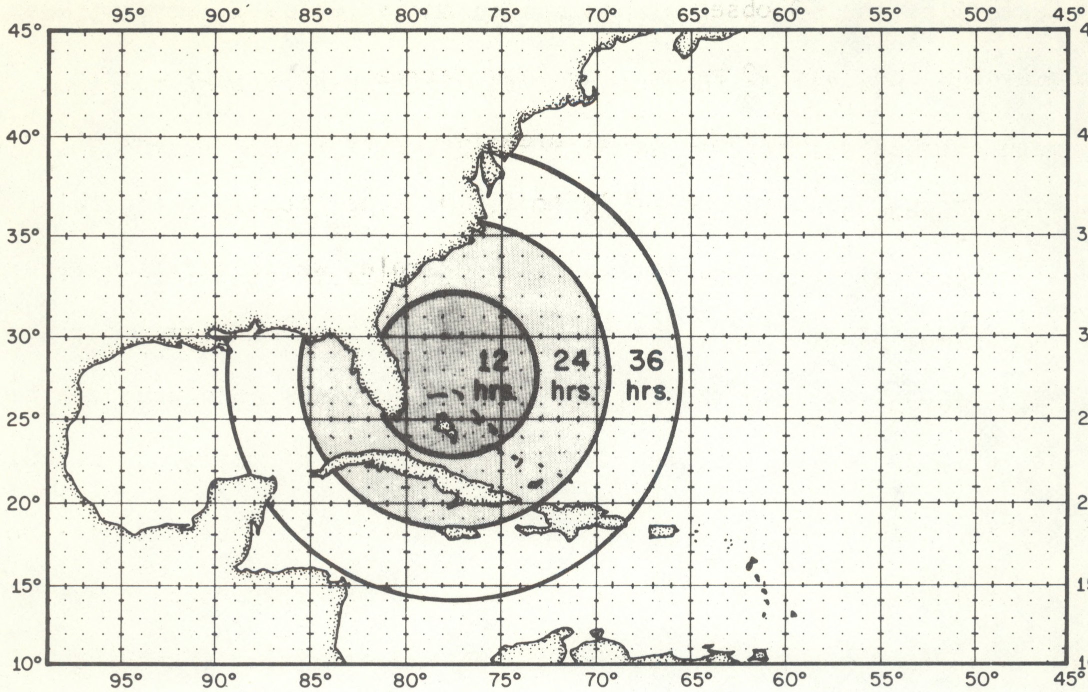



*Figure 6. Area that a storm moving away from can affect in 36 hours assuming a 10-15 knots per hour movement.*

If we consider only storms that reach hurricane intensity (>64 knots), we observe a similar result. In 24 hours, these hurricanes have a mean intensification of 24 knots and a slightly smaller standard deviation (fig. A-8). Out of the 20 observations in this category, 75 percent increased in intensity, and 35 percent of these increased more than 35 knots, as compared with the 10 percent that decreased by 1 to 25 knots.

The very intense storms (already >80 knots) seem to take on a more normal distribution, but still 10 percent manage to show a 35-knot increase. This increase is evident just north of Puerto Rico (fig. A-11) and in storms having a northeasterly track east of the Florida peninsula (figs.

A-10 and B-10). If their 48-hour changes are noted more closely, we see that most of the intensifications occur with north-to-northeast movement, and the mean changes decrease to as much as 10 knots if the storm moves into the lower Bahamas or just north of Cuba.

This statistical technique of geographically stratifying intensity changes in maximum winds brings up the practical problem of trying to relate the preferred area of intensification with large-scale climatologically preferred circulation patterns, ocean temperatures, and orographic features. The "preferred" area for intensification is on the western side of the climatological location of the 200 mb mid-Atlantic trough. This trough orients itself northeast-southwest over the Atlantic, extending from over Puerto Rico to Europe during June, July, August, and September. Whether this means that storms surviving the trough transit are likely to deepen or whether the deepening occurs when the trough is temporarily displaced is still unclear. One must conclude that storms seeded in this region will present difficulty to understanding the effects of the modification experiment. It should be an area closely watched by the hurricane forecaster for rapid growth and intensification.

The region west of the Isle of Pines, through the Yucatan Straits, and into the Gulf of Mexico is also favorable for hurricane intensification.

First, looking at the 48-hour categories (figs. A-6 and B-6), we see that 75 percent of all of the storms with wind speeds $\leq$ 40 knots have a mean increase of 25 knots in 48 hours; most of this takes place late in this period. This can be seen by the large standard deviations in the western Gulf of Mexico.

The only cases where we encounter a decrease in intensity are those storms passing over the Yucatan Peninsula. This decrease shows in the 24 and 48 hour groups because there is insufficient time for the storms to enter the Gulf of Mexico and increase in intensity once more. Such was the case with some very severe storms as Hurricane Edith (1971) which filled rapidly as it crossed the Yucatan.

It is easy to associate this area with storm development, since it has warm sea-surface temperatures, well separated from the mid-Atlantic trough, and thus is a favorite site for storms developing late in the season.

In the midst of the predominant areas of intensification, there occurs an area with which we associate reduction in intensification and a slowing down in forward momentum. This may be best explained by the effects of the mountains of Hispanola and Cuba.

Storms moving near these rugged topographic features show a definite decrease in intensity. The high values in the standard deviation show that the change is rapid. The land masses also slow forward motion. If we look at the square south of Puerto Rico, we see that storms moving northwest from this square (fig. B-3) show a mean decrease of 2 knots. This is definite evidence of the influence the land plays on the storm. Also, note that the decrease of 2 knots for the group moving southwest was biased by Hurricane Beulah (1967), which passed out of this region while still being influenced by a very unusual synoptic situation. As Hurricane Beulah was moving northwest, it intensified rapidly and on September 10, 1967, had deepened to 947 mb with winds exceeding 130 knots. At the same time, a strong anticyclone developed over the Bahamas in association with a strong ridge over the eastern United States. A well-marked 200 mb jet stream from the north-northeast extended over Haiti to within 2 degrees of Beulah's eyewall. Beulah began a recurvature to the southwest, and interaction with the upper level wind maxima is believed to have caused the sharp decrease in wind speed and rapid rise of the central pressure. On September 12, Beulah had filled to 1006 mb with the wind decreasing to 40 knots as it moved southwest. The rapid change in its intensity biases the results for this area.

The overall pattern of changes in hurricane intensity be area and direction of storm movement, which emerges from this study of the Atlantic and Gulf of Mexico, helps verify some of our impressions about preferred regions of intensification. The areas appear reasonably well defined, and the study provides a background that will hopefully allow us to better understand the climatology of influences on hurricanes and to better evaluate any seeding experiments carried out in these areas.

## 5. REFERENCES


Colon, J.A. (1953). A Study of Hurricane Tracks for Forecasting Purposes. *Monthly Weather Review, 81,* No. 3, 53-66.

Fletcher, R. (1955). Computation of Maximum Surface Winds in Hurricanes. *Bulletin AMS, 36,* June 1955, 247-250.

Holliday, C. (1969). On Maximum Sustained Winds Occuring in Atlantic Hurricanes. *Weather Bureau Technical Memorandum, NWS SR-63,* Miami, Florida.

Hope, J.R. and C.J. Neumann (1971). Digitized Atlantic Tropical Cyclone Tracks. *NOAA Technical Memorandum, NWS SR-55,* Miami, Florida.

Jordan, C.L. (1957). Estimating Central Pressure of Tropical Cyclones From Aircraft Data. *National Hurricane Research Project Report, No. 10,* U.S. Weather Bureau.

Kraft, R. (1961). The Hurricane's Central Pressure and Highest Winds. *Mariners Weather Log, 5,* No. 5, 157.

Michaels, J. (1971). Intensity Changes of the Maximum Winds in Tropical Cyclones in the Western North Pacific. (National Hurricane Research Laboratory unpublished report).

Mcknowan, R., and Collaborators (1952). *Fifth Annual Report of the Typhoon Post Analysis Board,* Anderson Air Force Base, Guam, M.I., 52 pp.

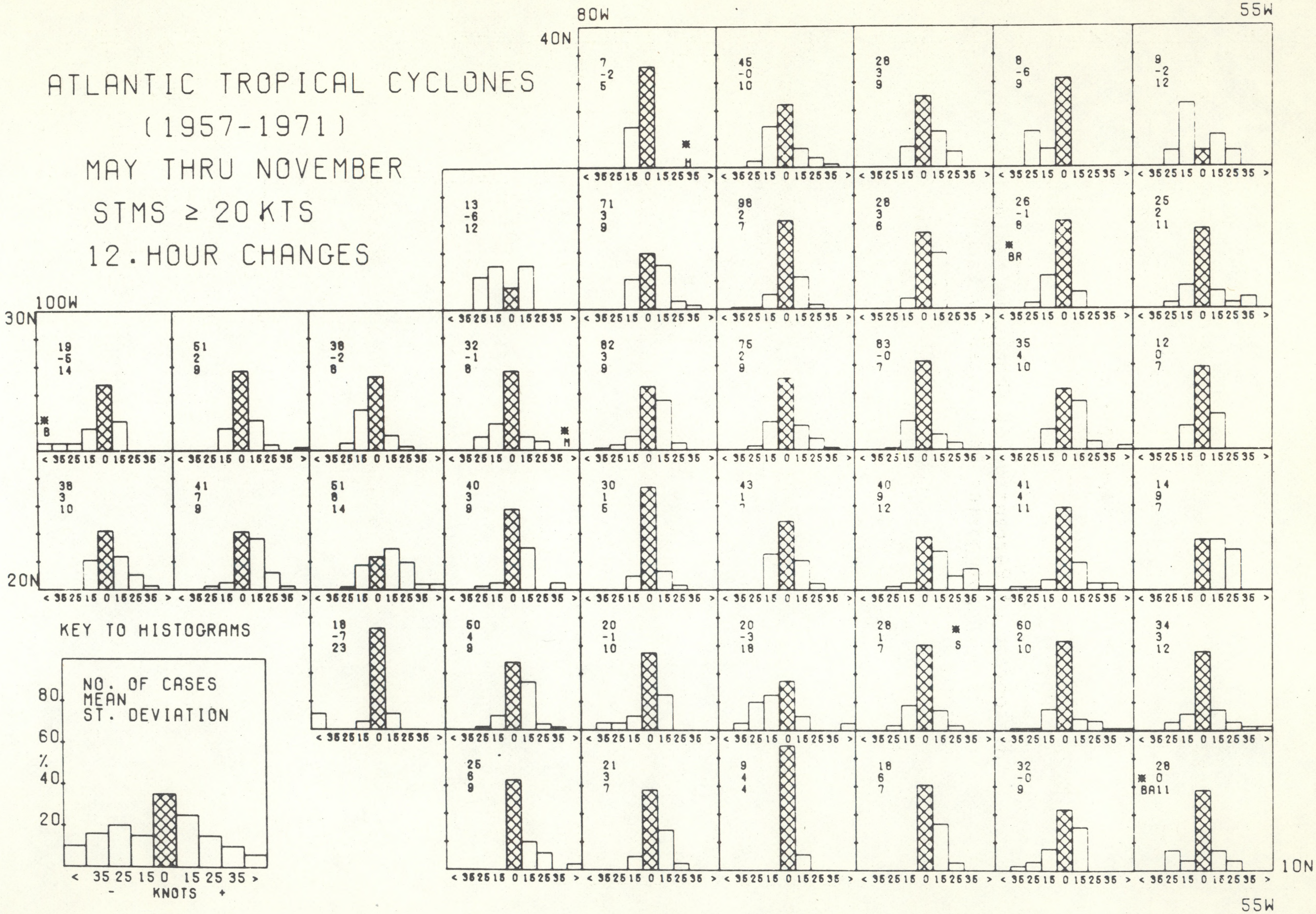
Myers, V. (1957). Maximum Hurricane Winds. *Bulletin AMS, 38,* No. 4, April 1957, 227-228.

Takahashi equation for maximum winds in hurricanes--from files at Weather Bureau Forecast Center, Suitland, Maryland.

Thom, H.C.S. (1971). Tropical Cyclone Crossing Frequencies for the World and Their Applications. NOAA Environmental Data Service, presented at the Seventh Conference on Hurricane and Tropical Meteorology, December 1971, Barbados (unpublished).

# APPENDIX A

Histograms of Percentage of Change in Maximum Winds
in Categories Designated by Each



ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 20 KTS
12.HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +


Figure A1

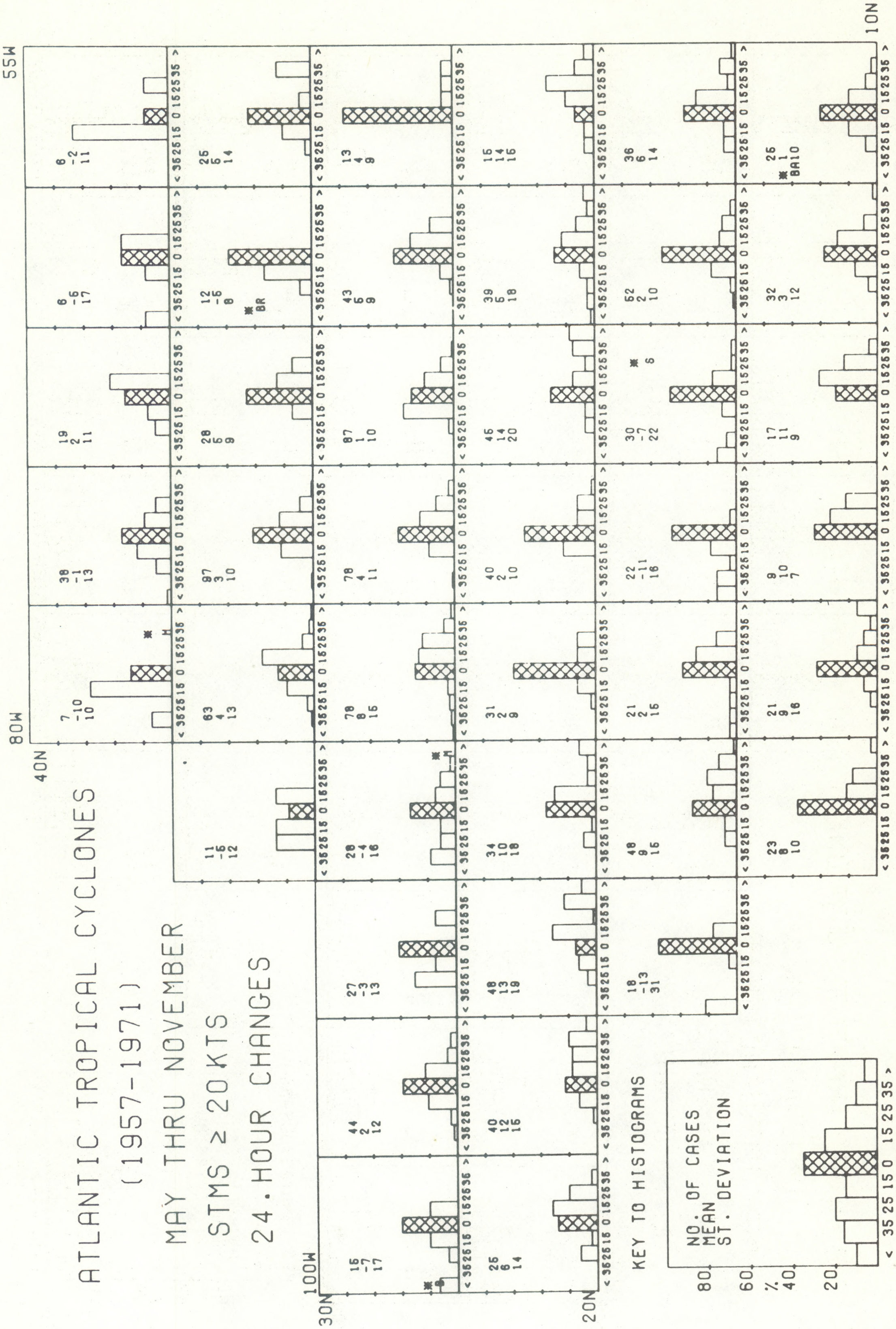

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 20 KTS
24. HOUR CHANGES
100W
80W
55W
30N
40N
20N
10N
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
%
80
60
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A2

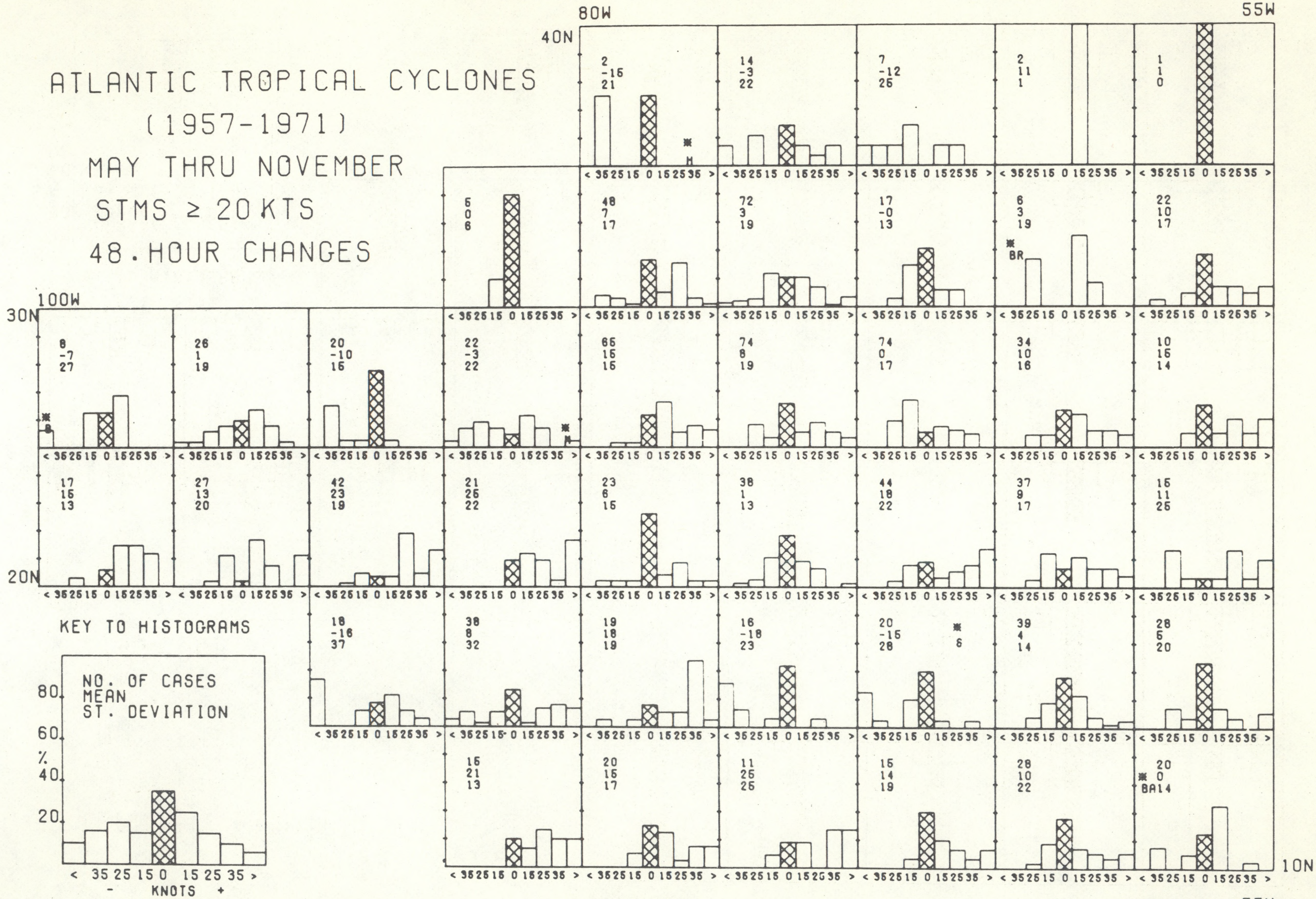

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 20 KTS
48. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
2 -15 21
14 -3 22
7 -12 25
2 11 1
1 1 0
5 0 6
48 7 17
72 3 19
17 -0 13
6 3 19
22 10 17
8 -7 27
26 1 19
20 -10 15
22 -3 22
65 15 15
74 8 19
74 0 17
34 10 16
10 15 14
17 15 13
27 13 20
42 23 19
21 25 22
23 6 15
38 1 13
44 18 22
37 9 17
15 11 25
18 -16 37
38 8 32
19 18 19
16 -18 23
20 -15 28
39 4 14
28 5 20
15 21 13
20 15 17
11 25 25
15 14 19
28 10 22
20 0 BA14
< 352515 0 152535 >
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A3

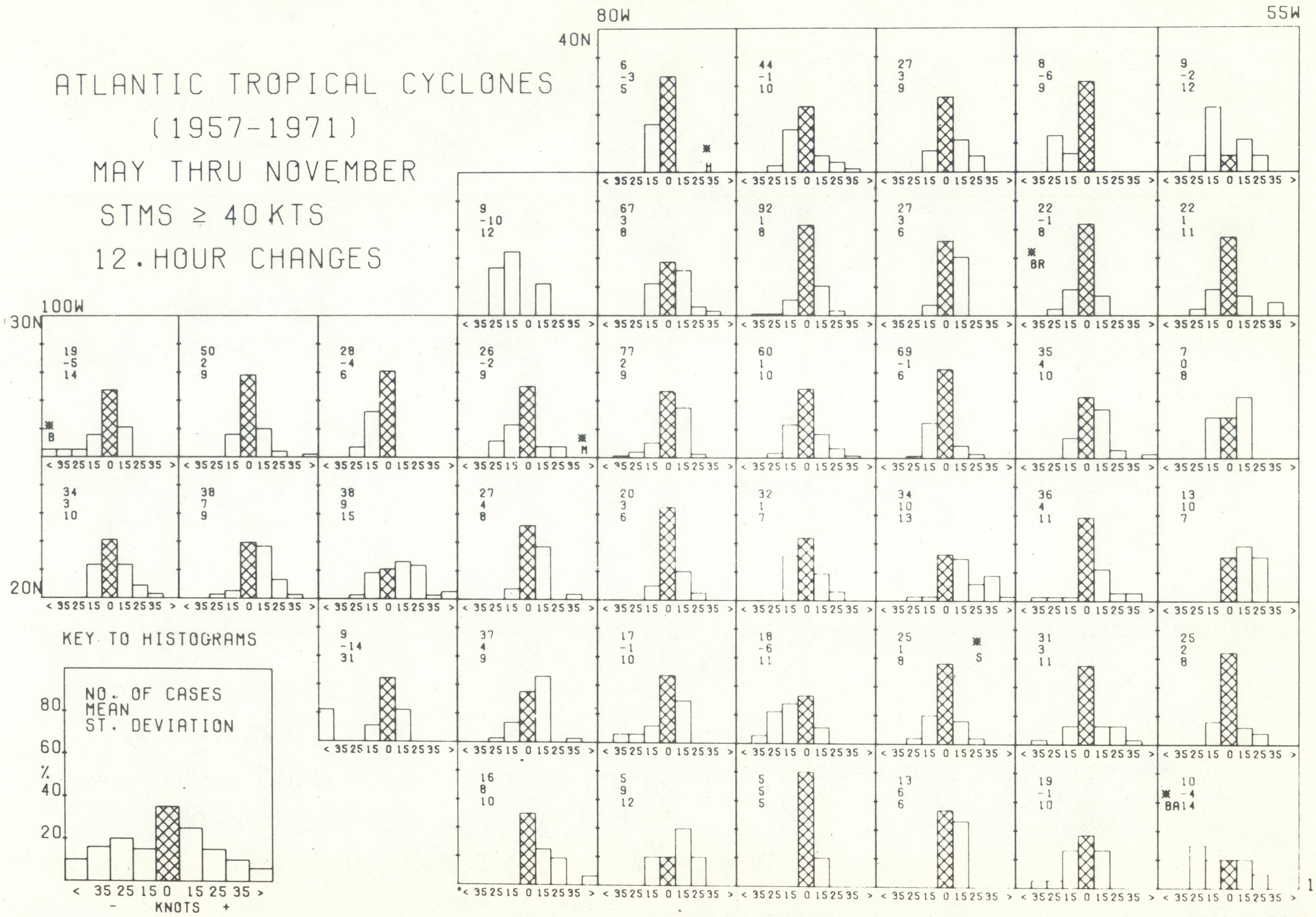
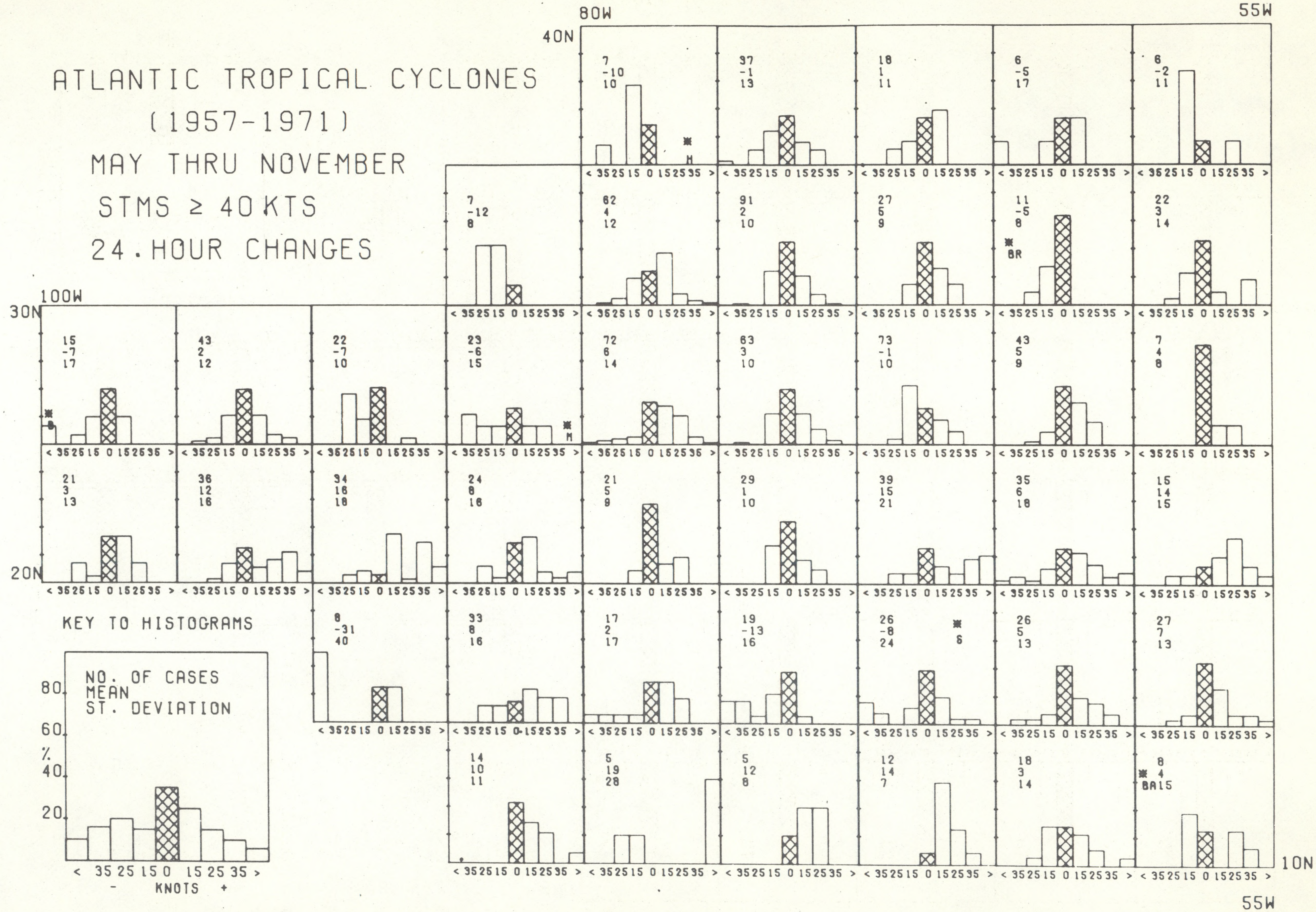

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 40 KTS
12. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A4



ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 40 KTS
24. HOUR CHANGES
80W
55W
40N
30N
100W
20N
10N
55W
7 -10 10 * M
37 -1 13
18 1 11
6 -5 17
6 -2 11
7 -12 8
62 4 12
91 2 10
27 5 9
11 -5 8 * BR
22 3 14
15 -7 17 * B
43 2 12
22 -7 10
23 -6 15 * M
72 6 14
63 3 10
73 -1 10
43 5 9
7 4 8
21 3 13
36 12 16
34 16 18
24 8 16
21 5 9
29 1 10
39 15 21
35 6 18
15 14 15
8 -31 40
33 8 16
17 2 17
19 -13 16
26 -8 24 * S
26 5 13
27 7 13
14 10 11
5 19 28
5 12 8
12 14 7
18 3 14
8 4 * BA15
< 35 25 15 0 15 25 35 >
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +


Figure A5

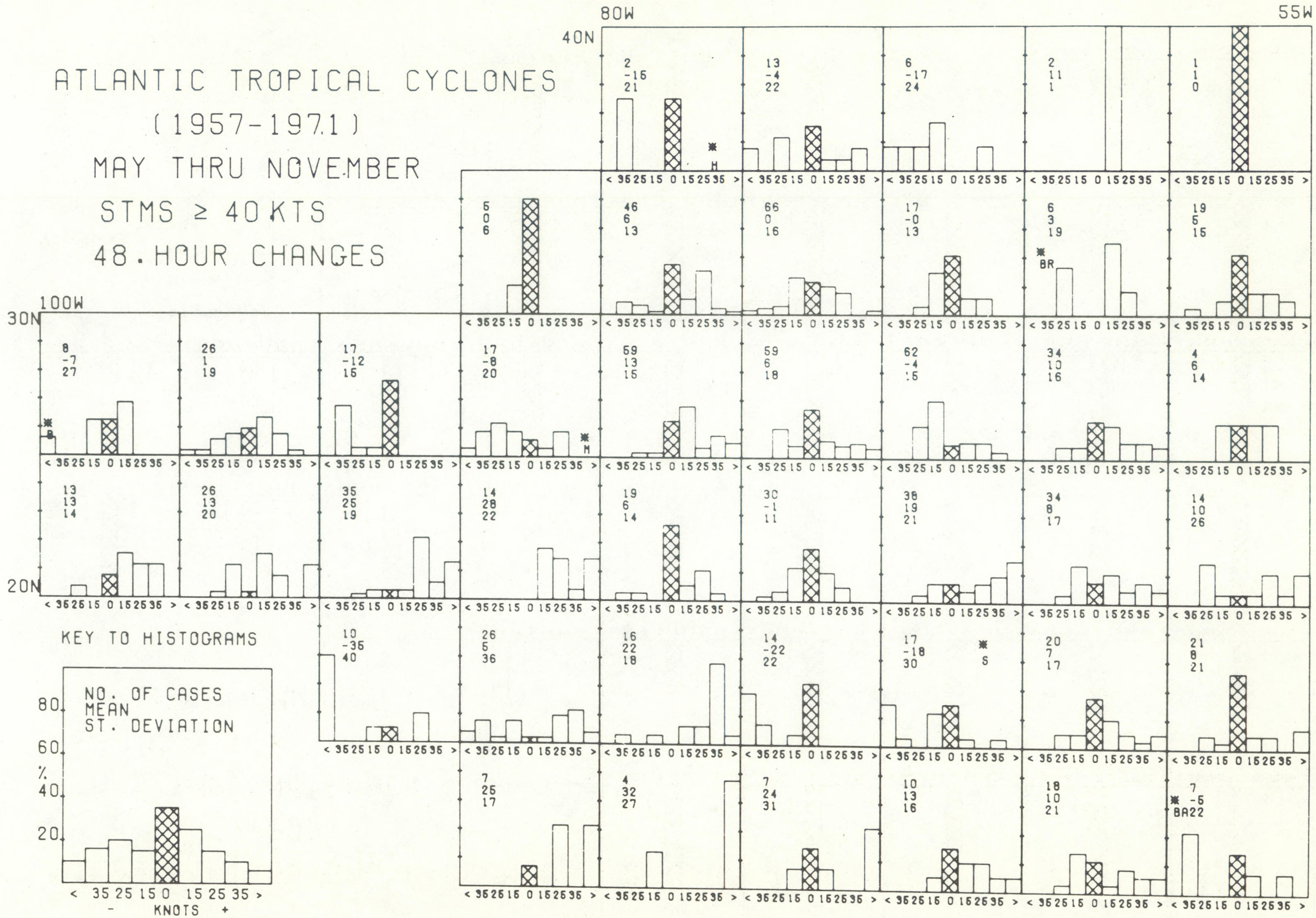

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 40 KTS
48.HOUR CHANGES
80W
55W
40N
30N
100W
20N
10N
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
%
KNOTS

Figure A6

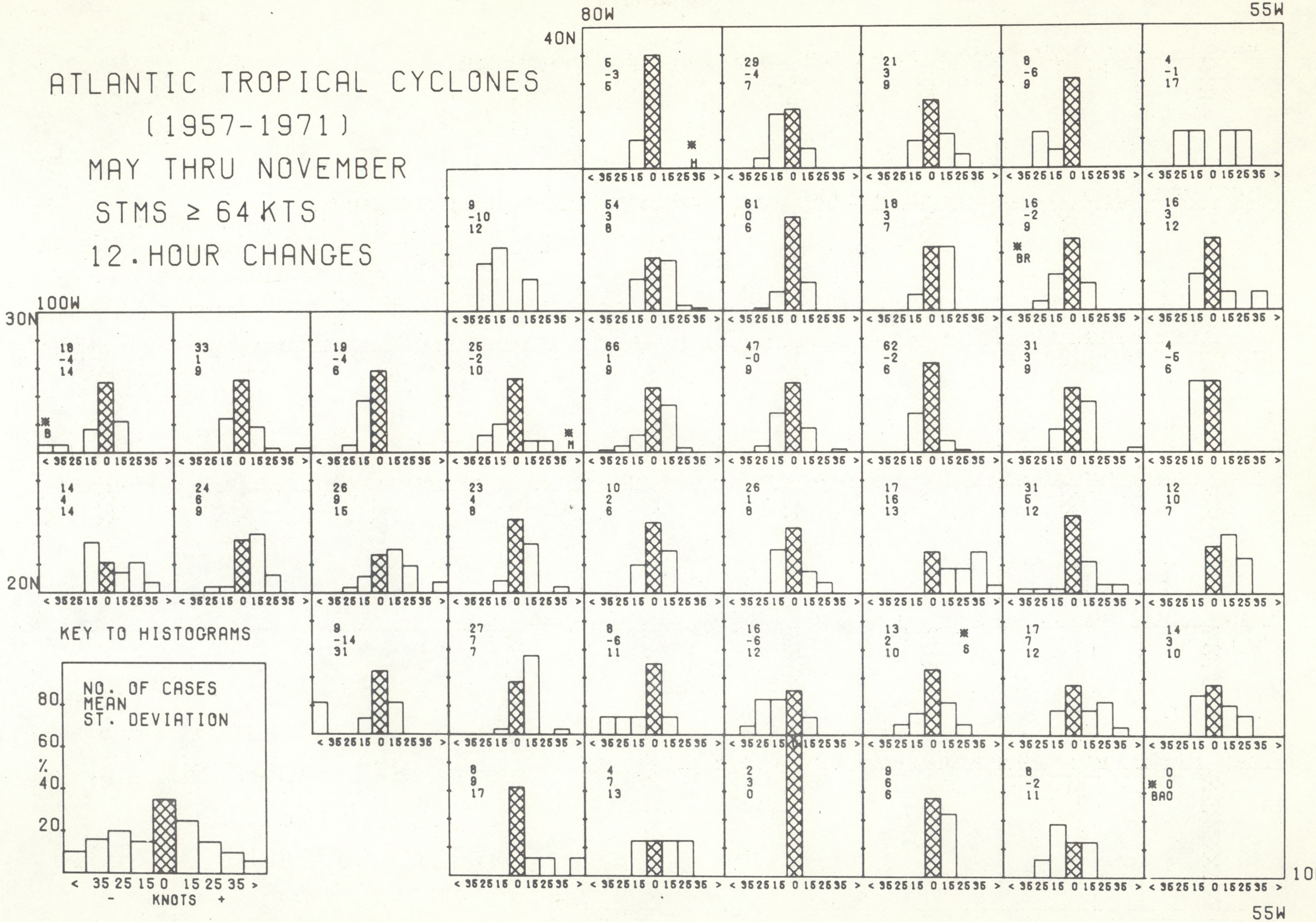

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 64 KTS
12. HOUR CHANGES
80W
55W
40N
30N
100W
20N
10N
55W
5 -3 5 * M
29 -4 7
21 3 9
8 -6 9
4 -1 17
9 -10 12
54 3 8
61 0 6
18 3 7
16 -2 9 * BR
16 3 12
18 -4 14 * B
33 1 9
19 -4 6
25 -2 10 * M
66 1 9
47 -0 9
62 -2 6
31 3 9
4 -5 6
14 4 14
24 6 9
26 9 15
23 4 8
10 2 6
26 1 8
17 16 13
31 5 12
12 10 7
9 -14 31
27 7 7
8 -6 11
16 -6 12
13 2 10 * 6
17 7 12
14 3 10
8 9 17
4 7 13
2 3 0
9 6 6
8 -2 11
0 0 BAO *
< 35 25 15 0 15 25 35 >
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A7

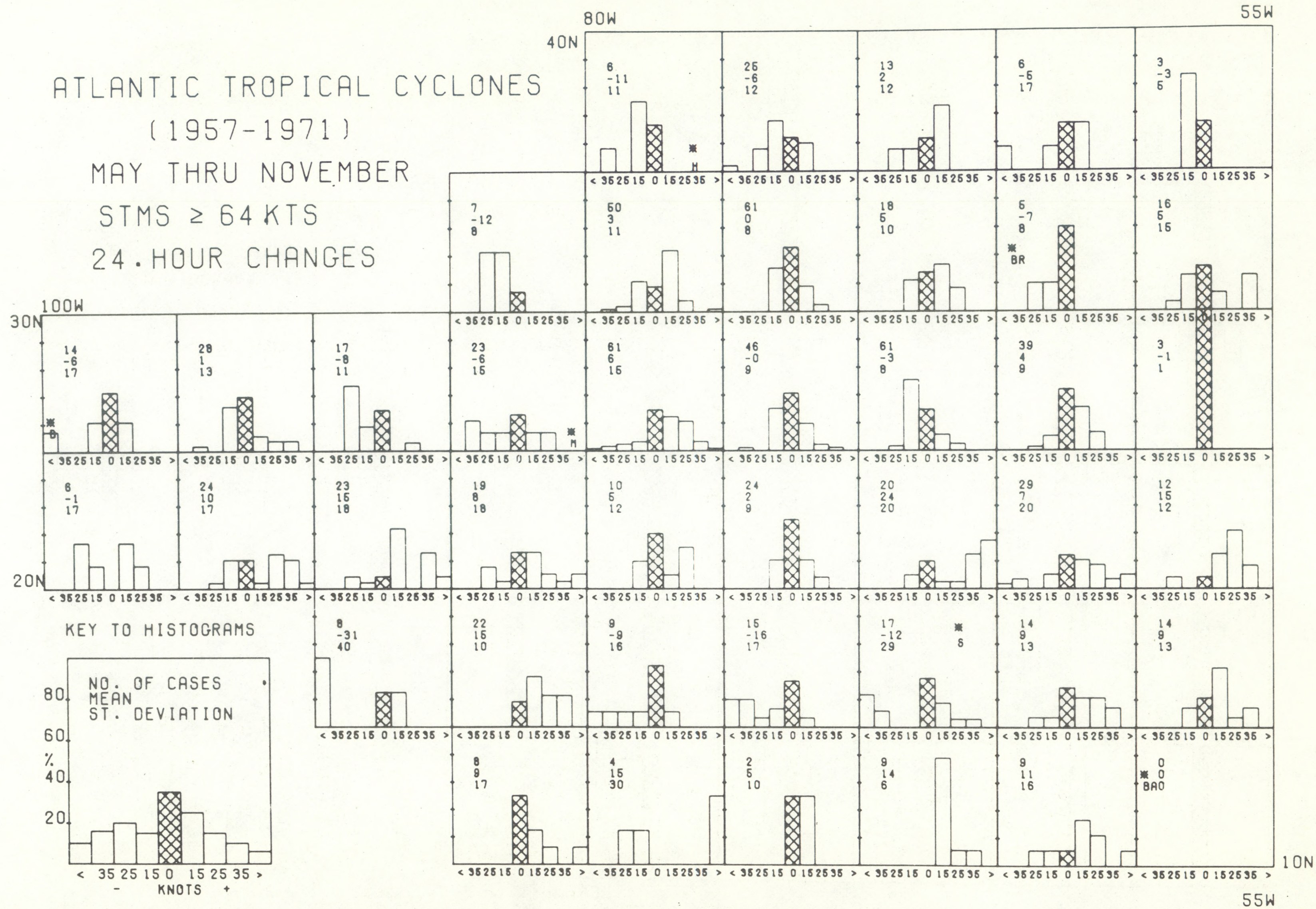
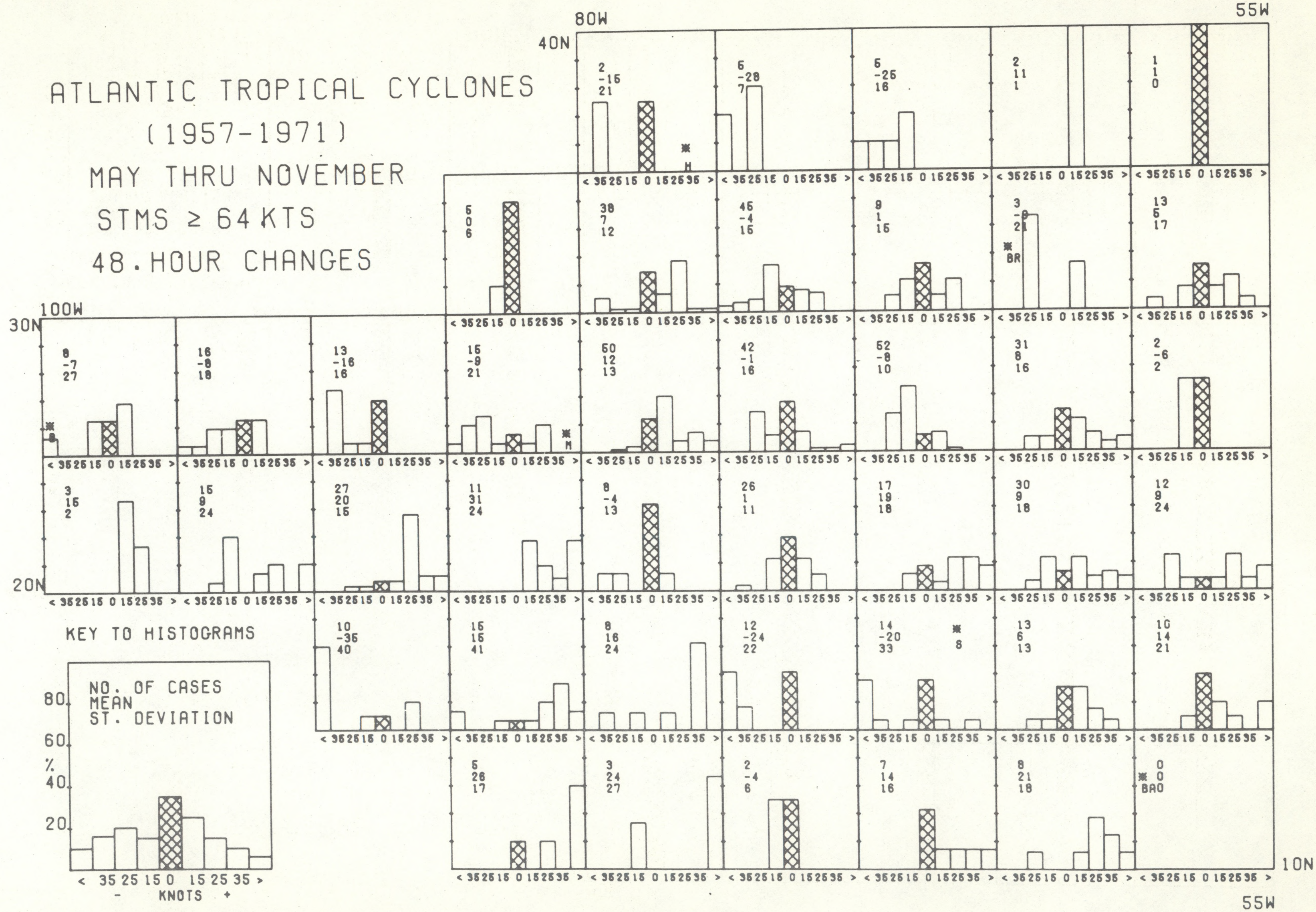

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 64 KTS
24.HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A8



ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 64 KTS
48. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +


Figure A9

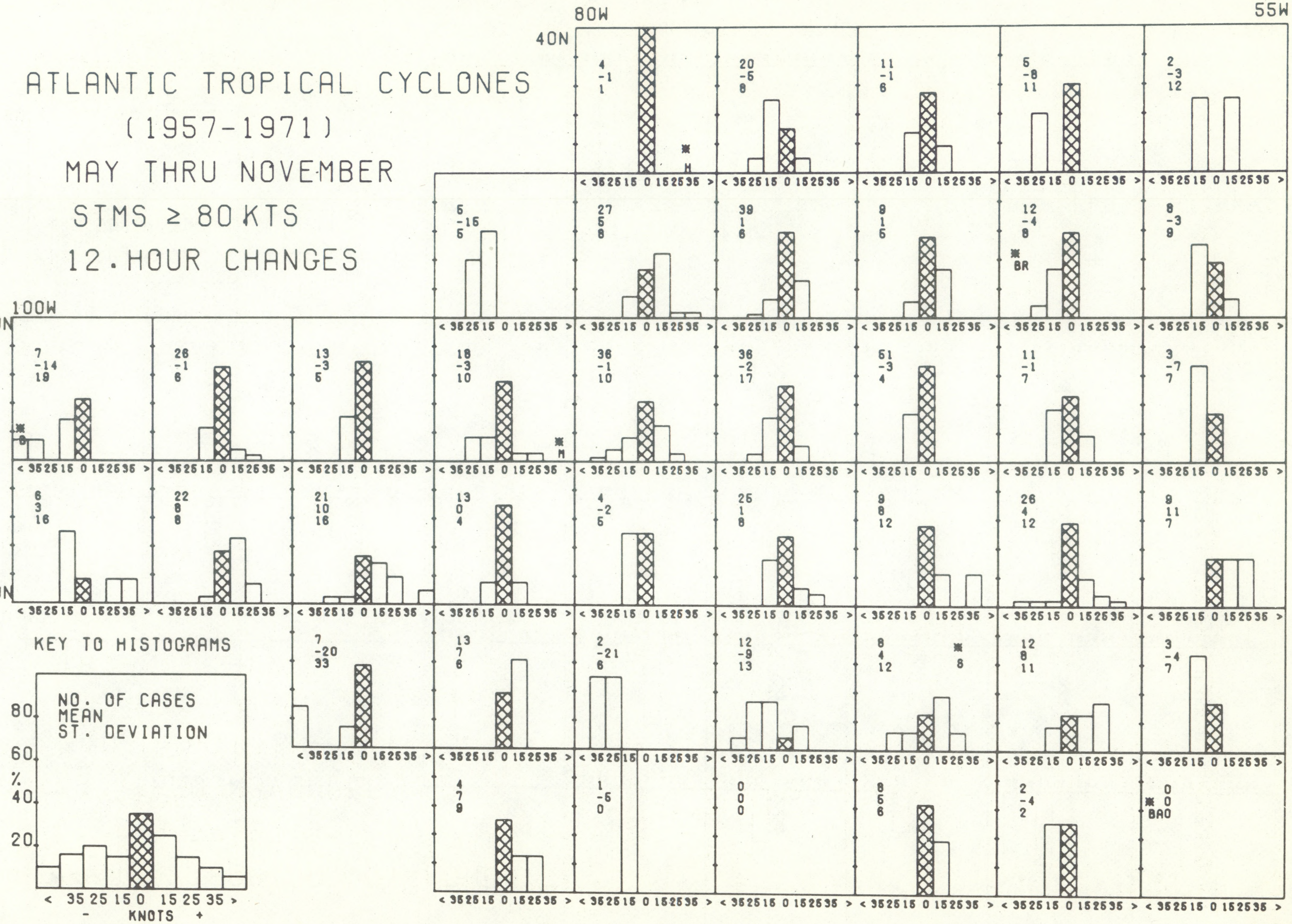

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 80 KTS
12. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A10

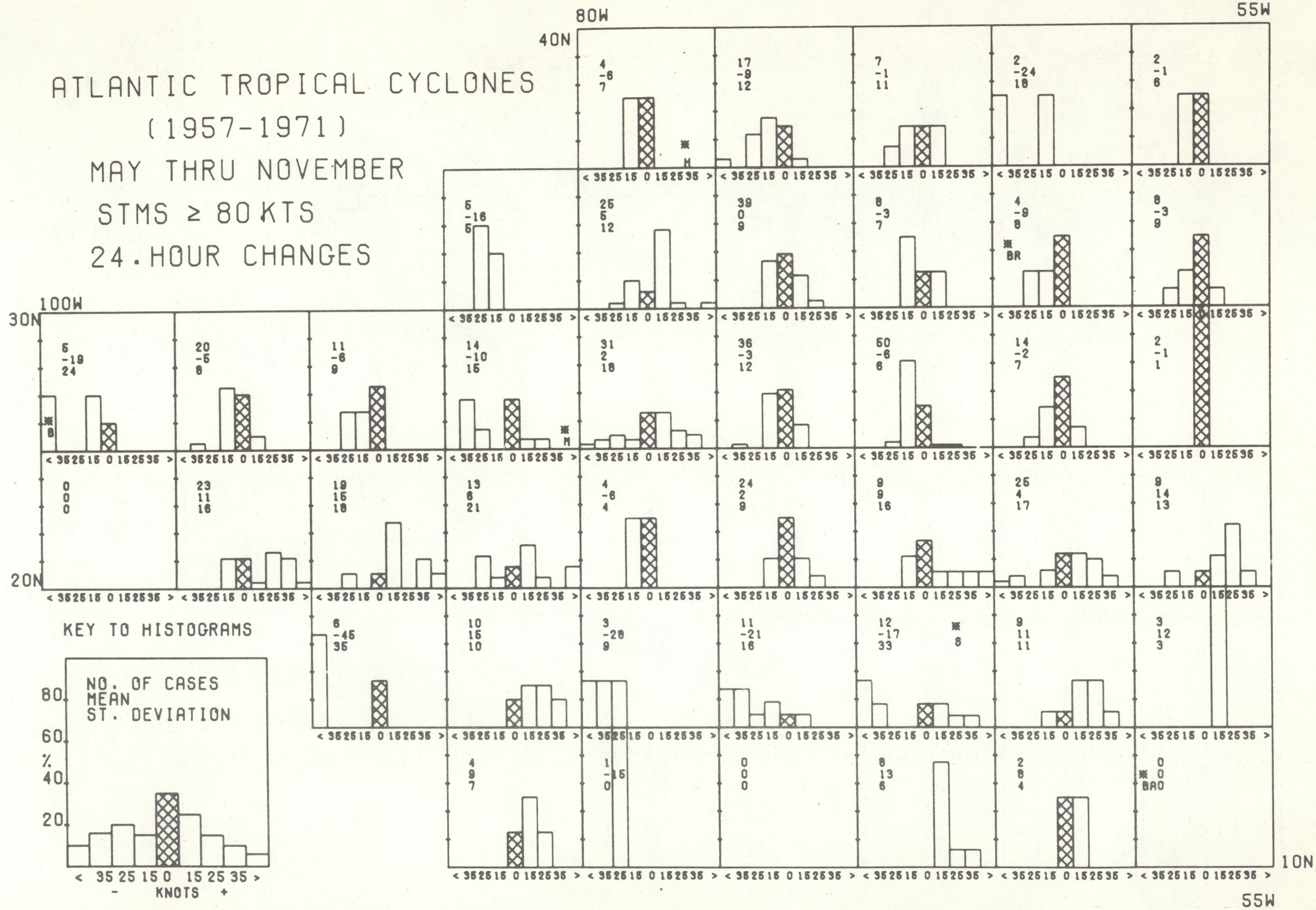

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 80 KTS
24.HOUR CHANGES
100W
80W
55W
40N
30N
20N
10N
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A11

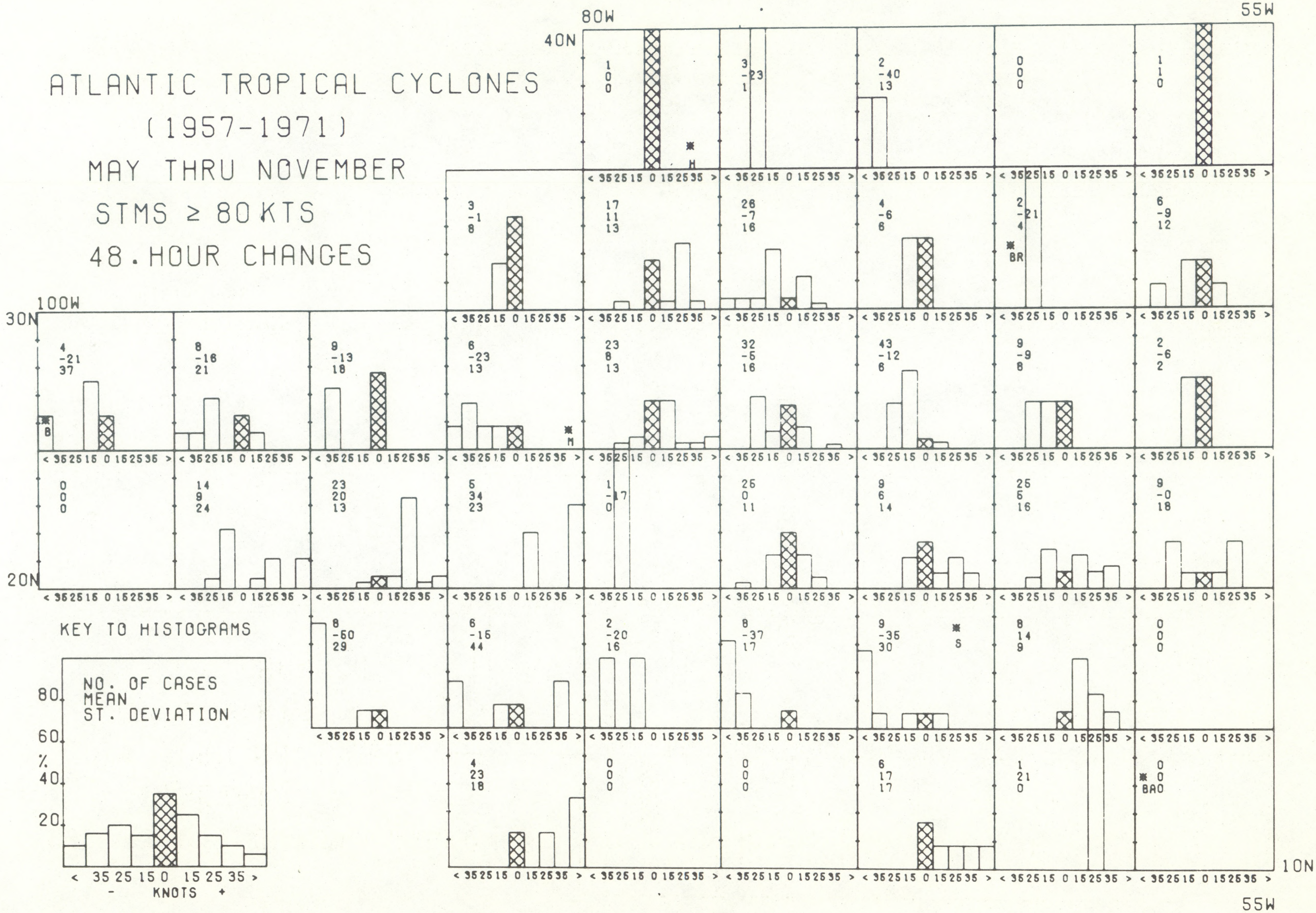

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 80 KTS
48. HOUR CHANGES
80W
55W
40N
30N
100W
20N
10N
55W
1 0 0 M
3 -23 1
2 -40 13
0 0 0
1 1 0
3 -1 8
17 11 13
26 -7 16
4 -6 6
2 -21 4 BR
6 -9 12
4 -21 37 B
8 -16 21
9 -13 18
6 -23 13 M
23 8 13
32 -5 16
43 -12 6
9 -9 8
2 -6 2
0 0 0
14 9 24
23 20 13
5 34 23
1 -17 0
25 0 11
9 6 14
25 5 16
9 -0 18
8 -50 29
6 -16 44
2 -20 16
8 -37 17
9 -35 30 S
8 14 9
0 0 0
4 23 18
0 0 0
0 0 0
6 17 17
1 21 0
0 0 BAO
< 35 25 15 0 15 25 35 >
KEY TO HISTOGRAMS
NO. OF CASES
MEAN
ST. DEVIATION
80
60
%
40
20
< 35 25 15 0 15 25 35 >
- KNOTS +

Figure A12

# APPENDIX B

## Pie Graphs Stratifying Storms by Direction of Movement in Categories Designated by Each

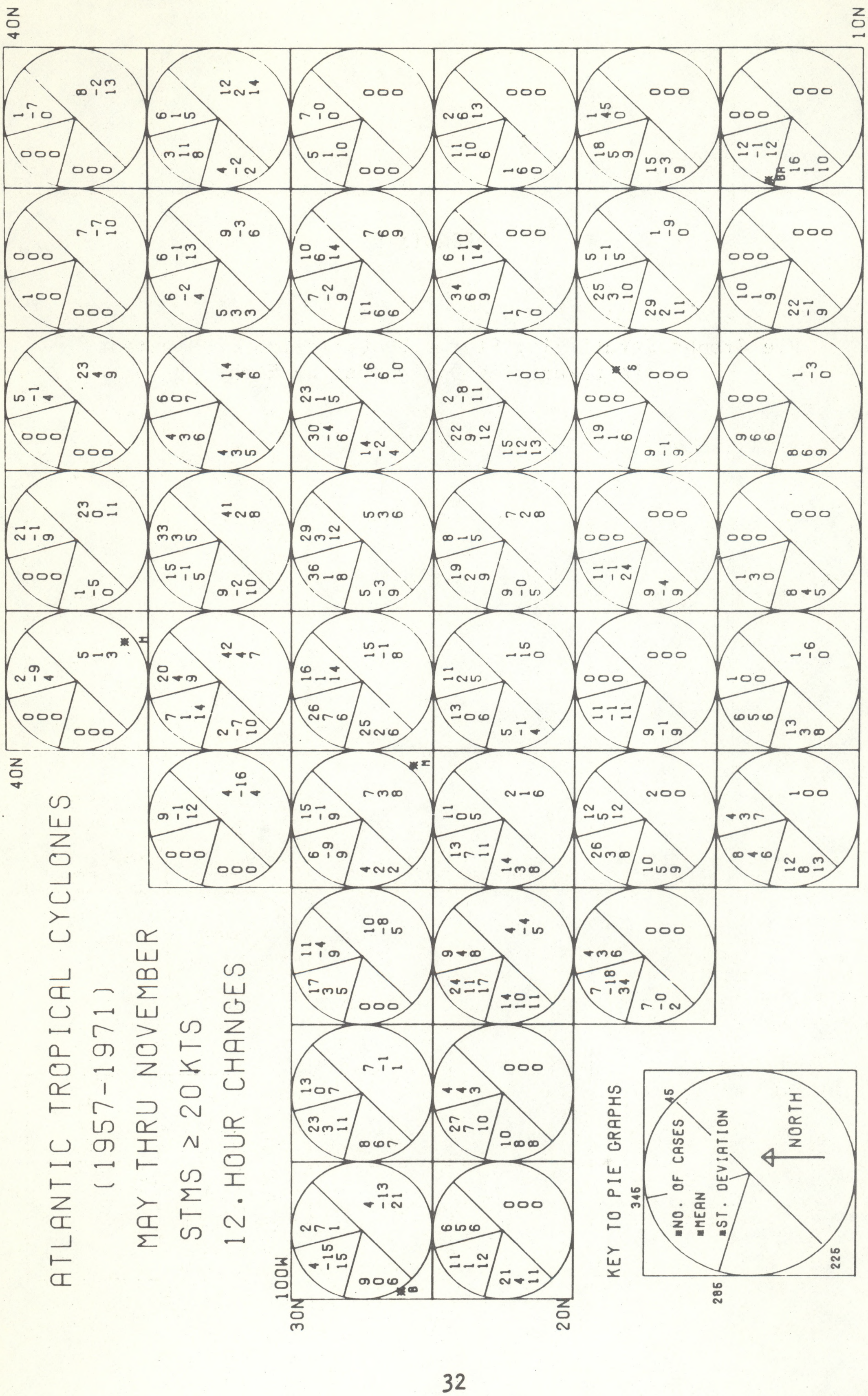

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 20 KTS
12. HOUR CHANGES
KEY TO PIE GRAPHS
NO. OF CASES
MEAN
ST. DEVIATION
NORTH
100W
80W
55W
40N
30N
20N
10N

Figure B1

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 20 KTS
24.HOUR CHANGES

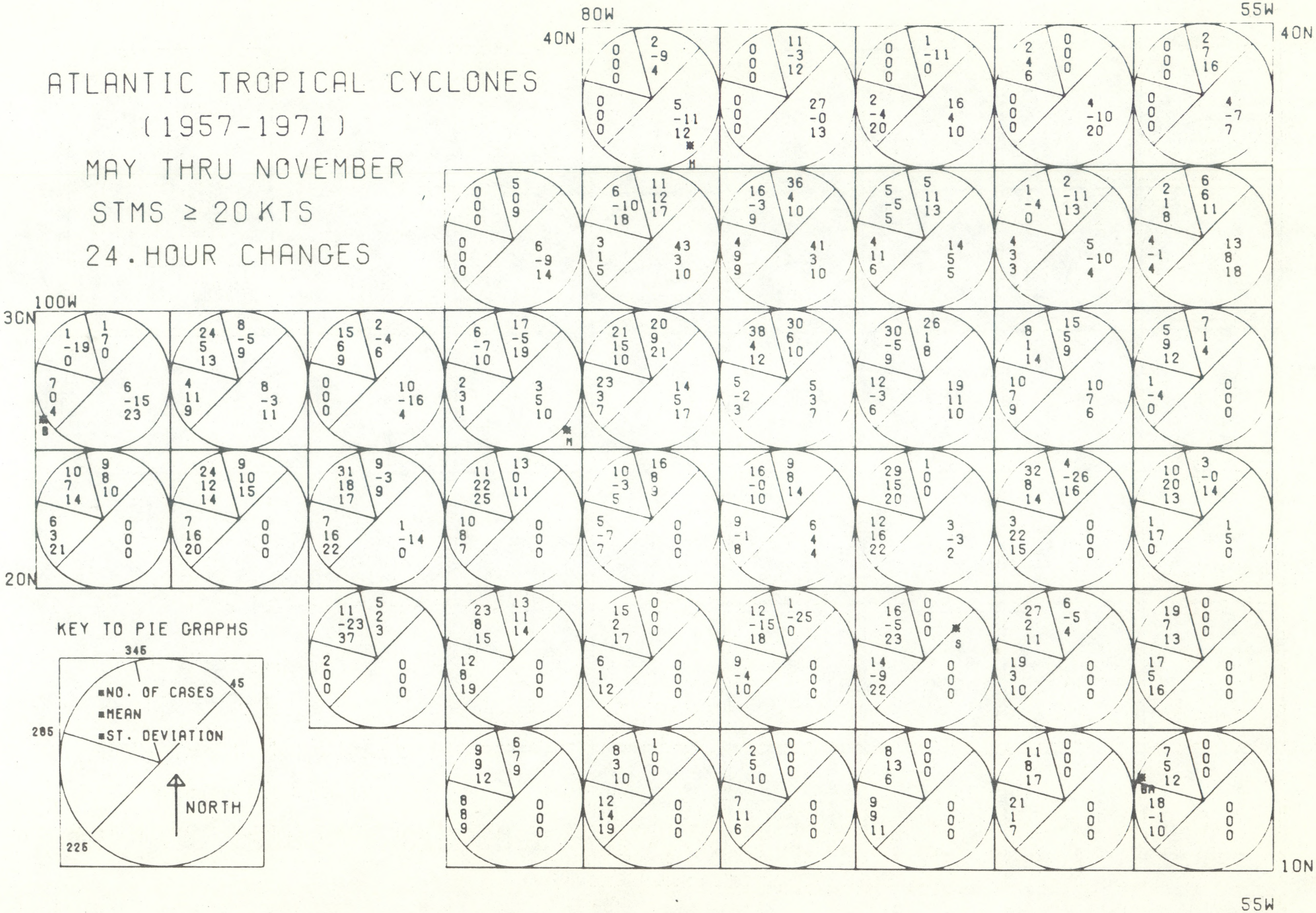



Figure B2

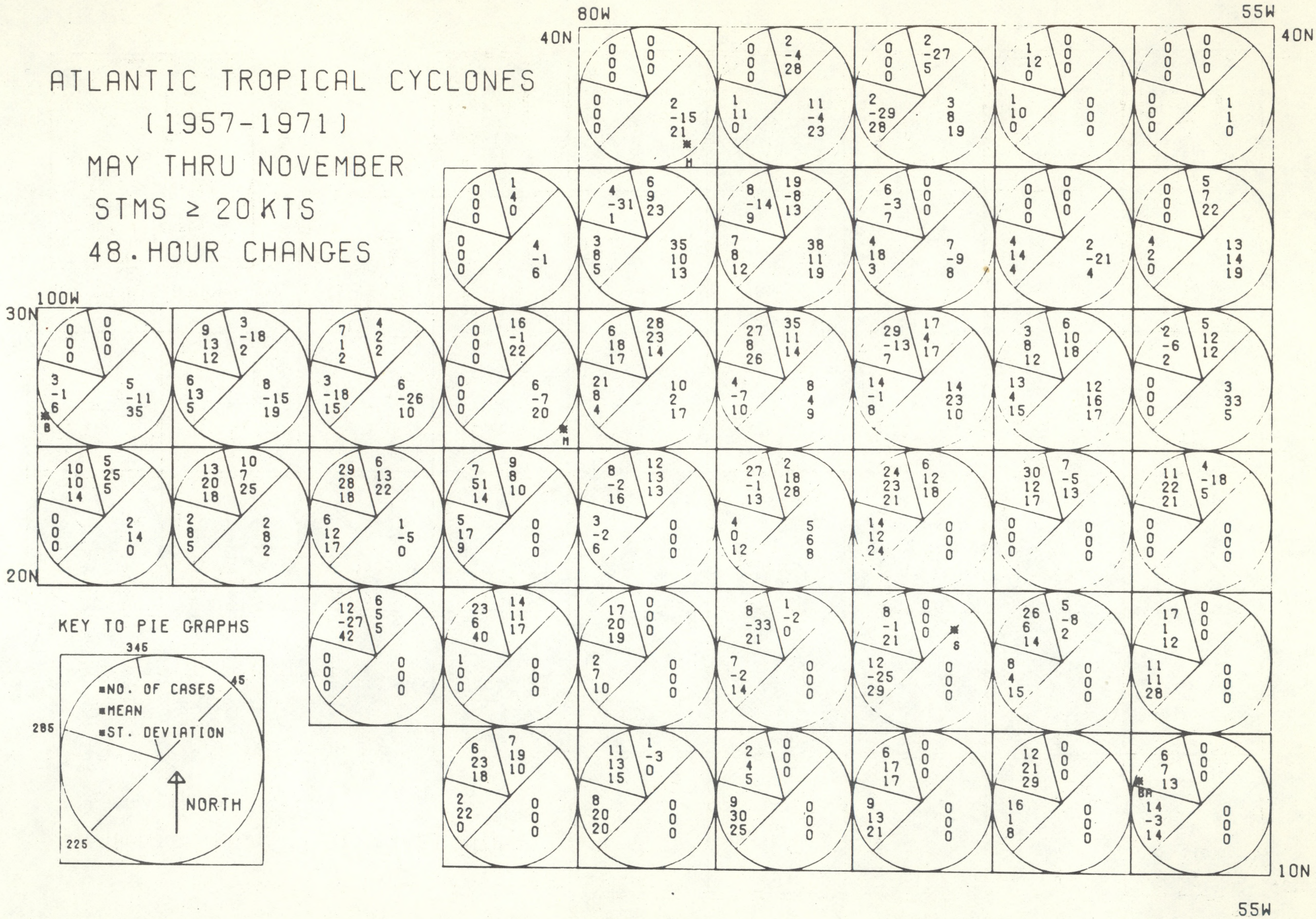

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 20 KTS
48.HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO PIE GRAPHS
346
45
285
225
▪NO. OF CASES
▪MEAN
▪ST. DEVIATION
NORTH

Figure B3

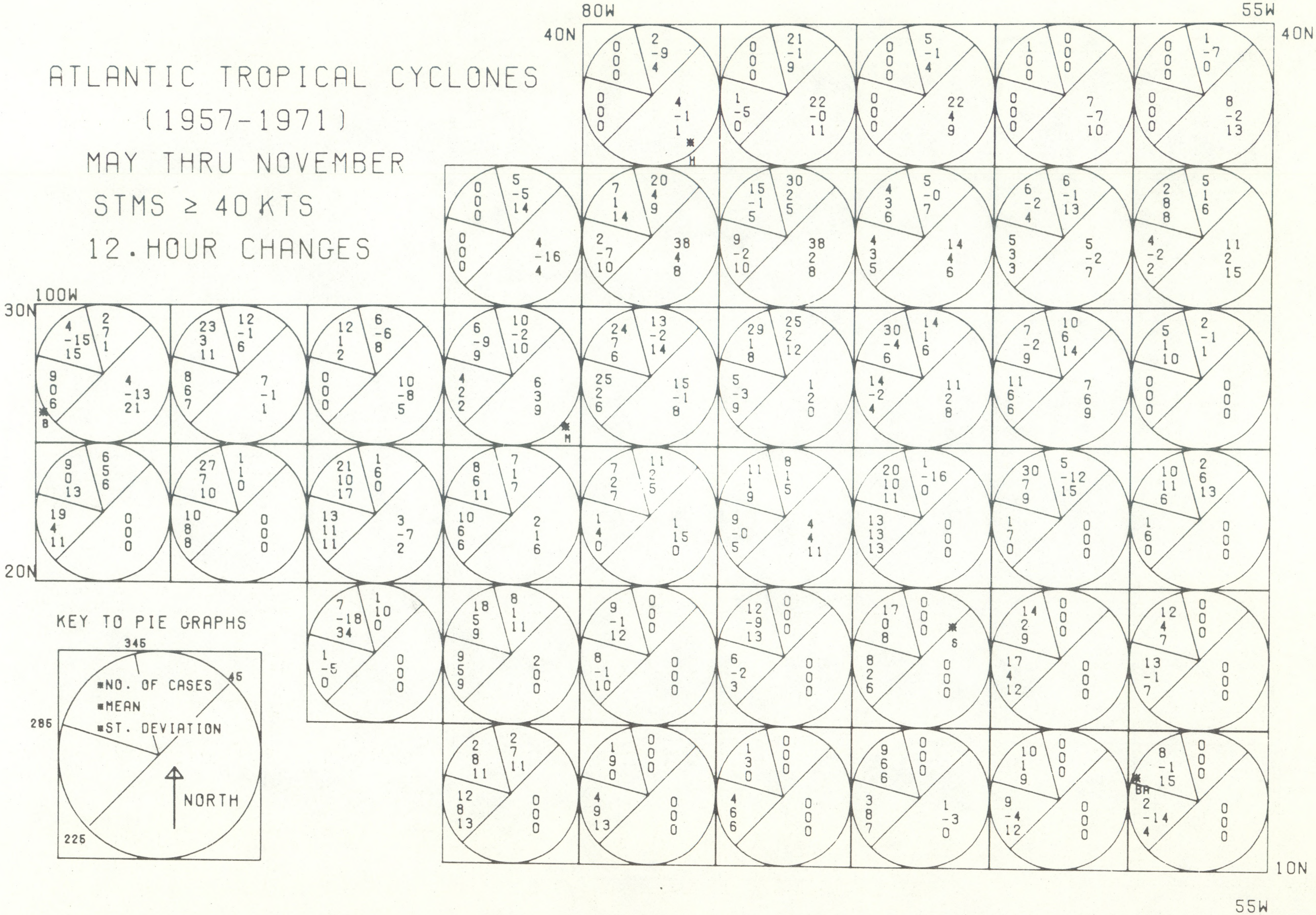

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 40 KTS
12.HOUR CHANGES
KEY TO PIE GRAPHS
345
45
285
225
NO. OF CASES
MEAN
ST. DEVIATION
NORTH
80W
55W
40N
100W
30N
20N
10N

Figure B4

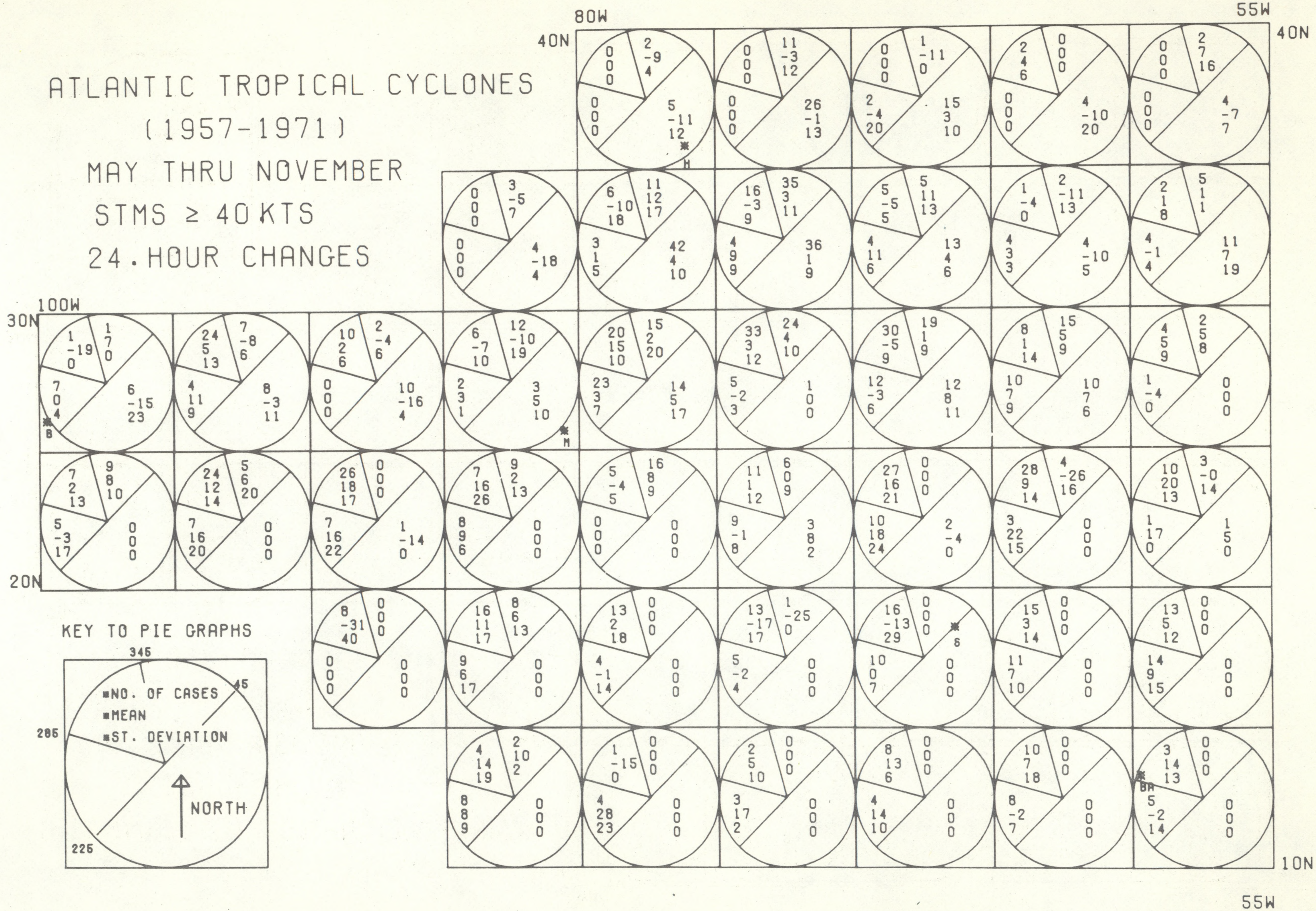

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 40 KTS
24.HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
KEY TO PIE GRAPHS
345
45
285
225
▪NO. OF CASES
▪MEAN
▪ST. DEVIATION
NORTH

Figure B5

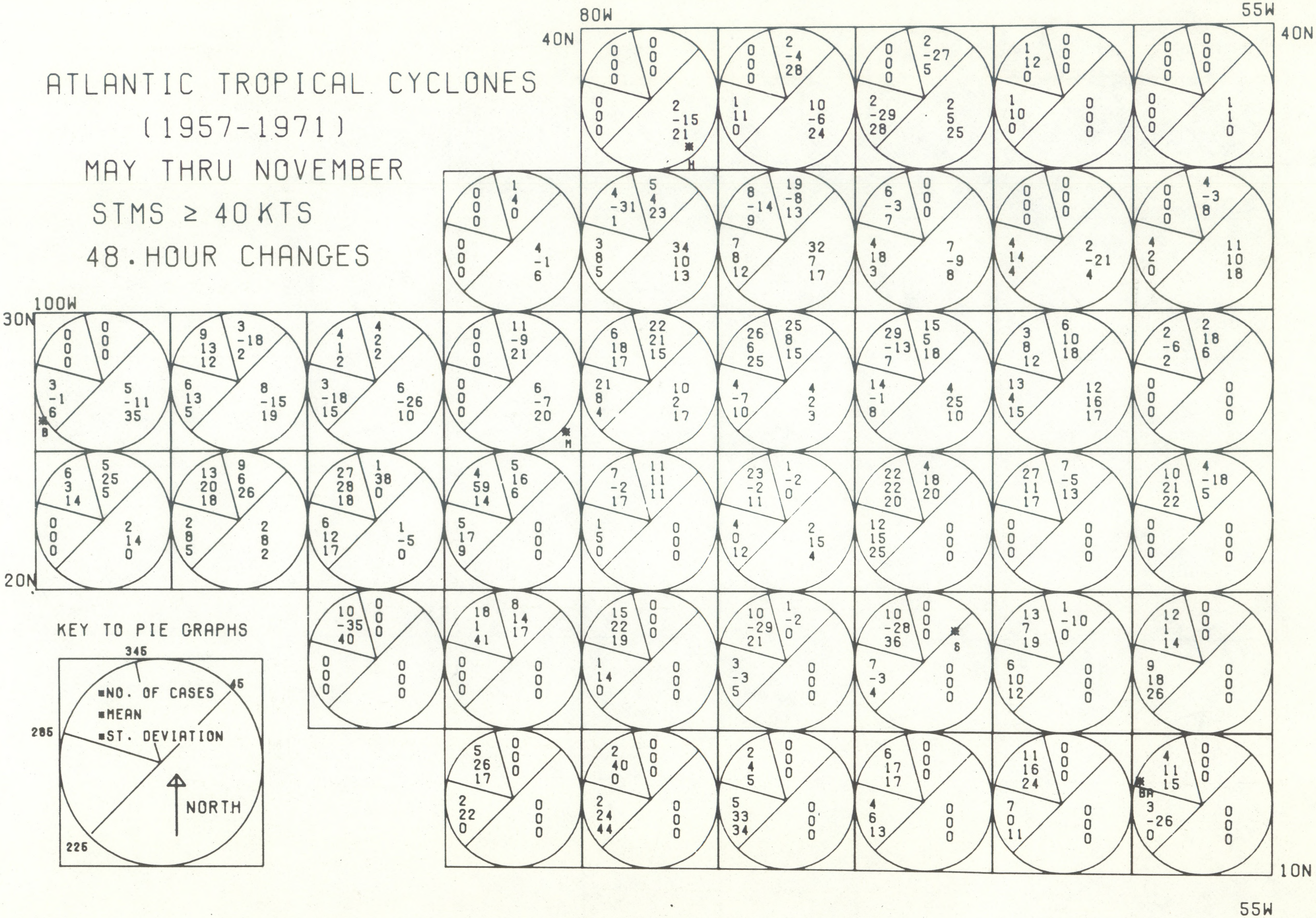
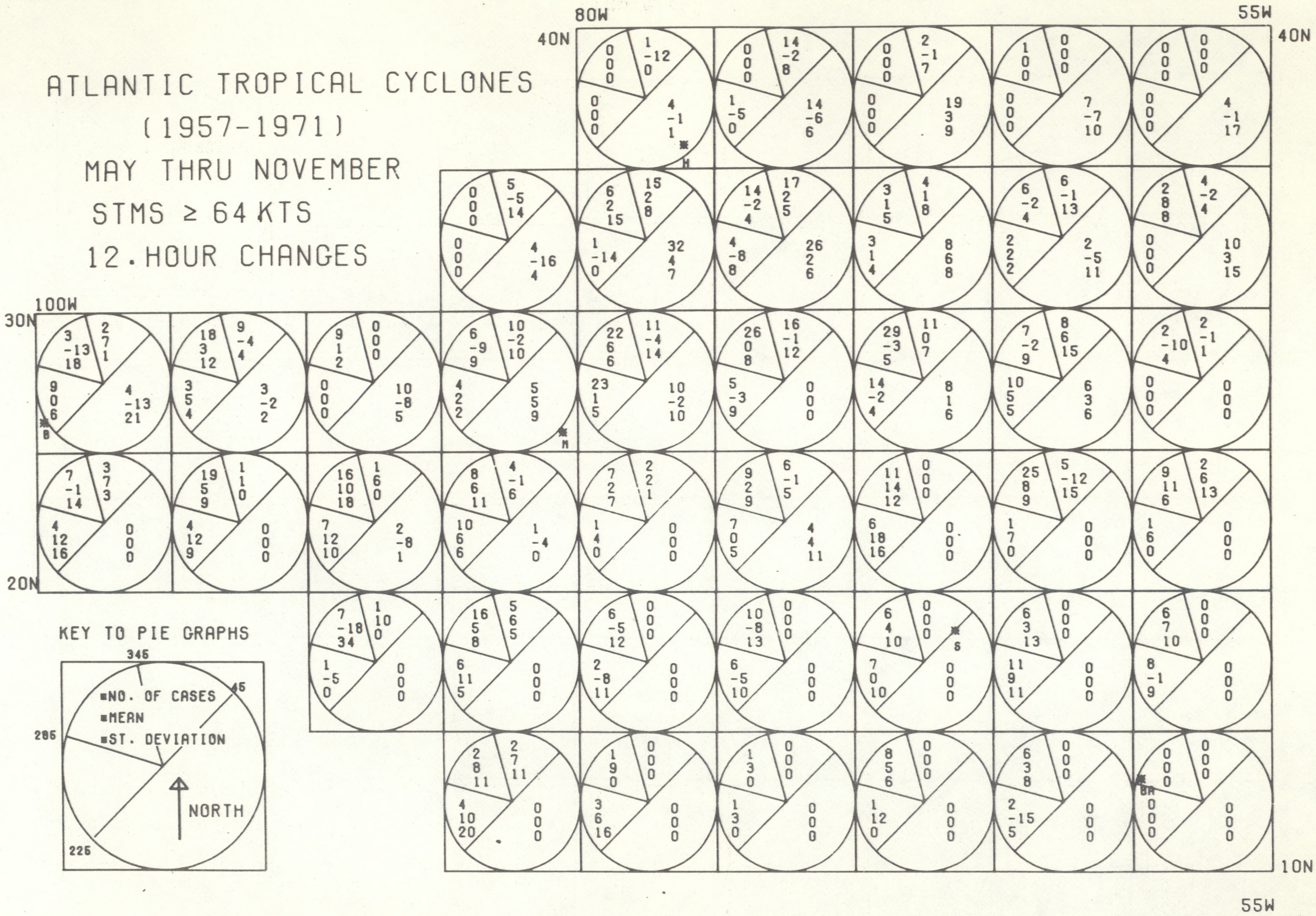

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 40 KTS
48. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
KEY TO PIE GRAPHS
345
45
285
225
NO. OF CASES
MEAN
ST. DEVIATION
NORTH

Figure B6



ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 64 KTS
12.HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
KEY TO PIE GRAPHS
NO. OF CASES
MEAN
ST. DEVIATION
NORTH
345
45
285
225


Figure B7

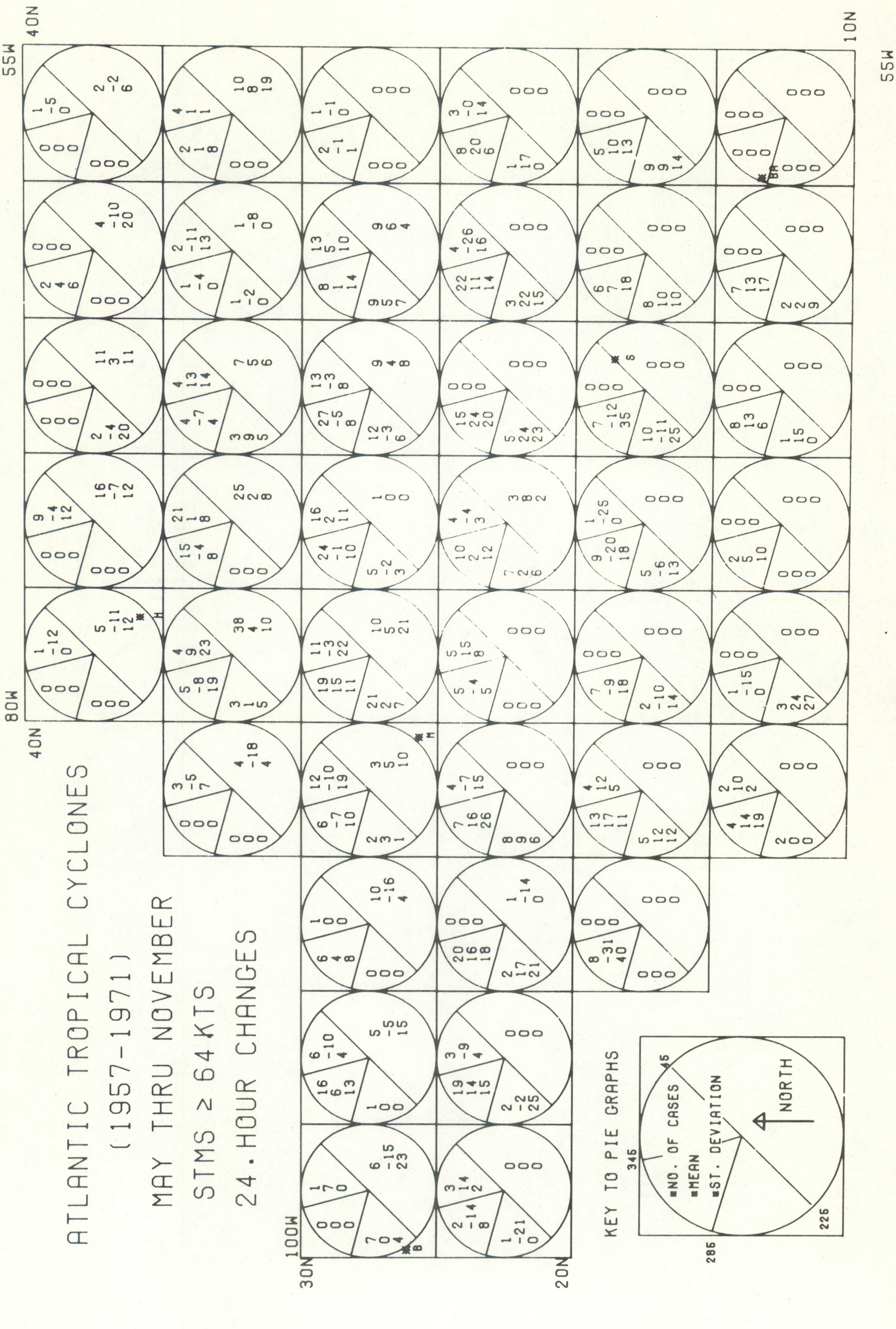

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 64 KTS
24.HOUR CHANGES
KEY TO PIE GRAPHS
NO. OF CASES
MEAN
ST. DEVIATION
NORTH
346
45
286
226
100W
80W
55W
40N
30N
20N
10N

Figure B8

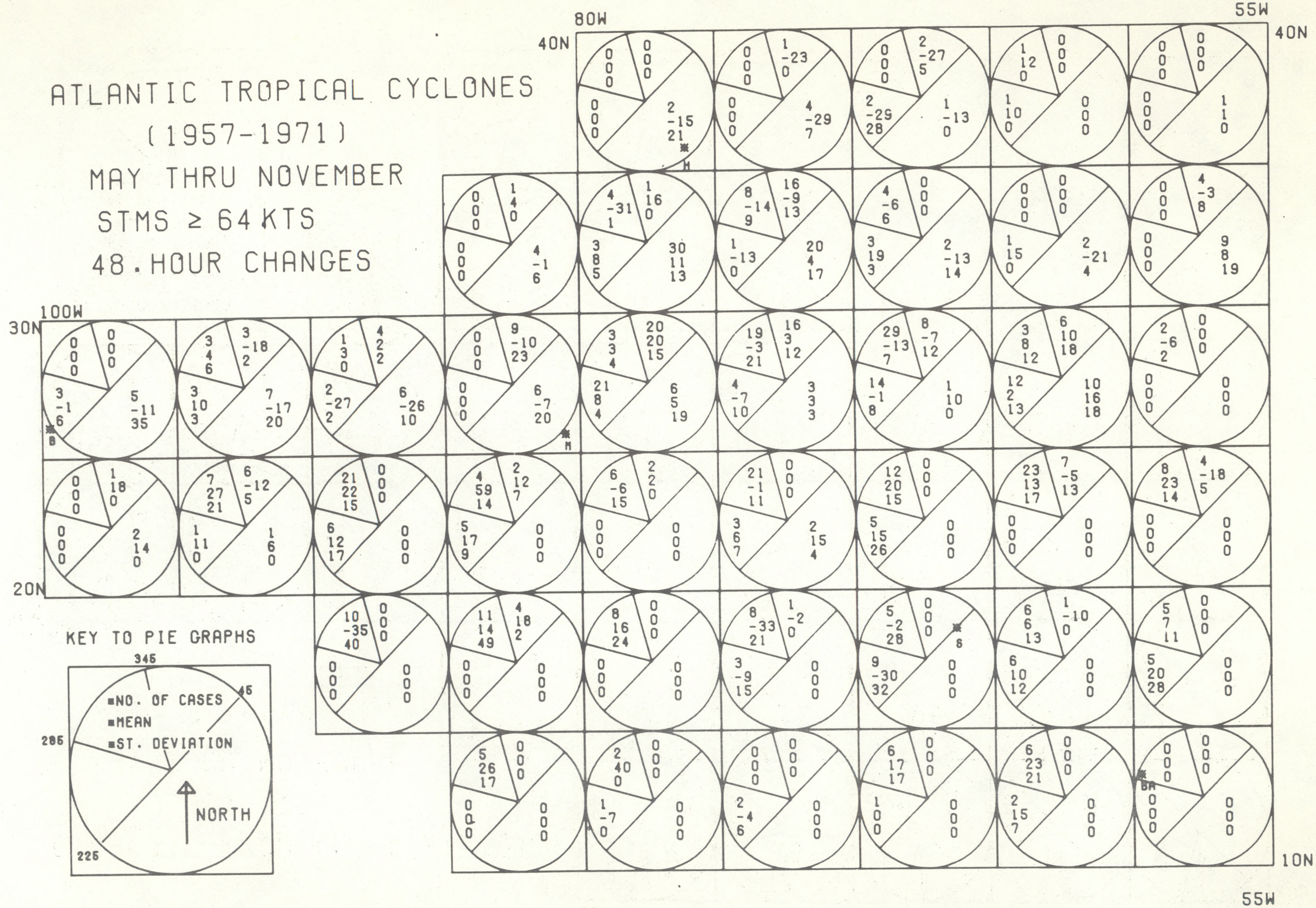

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 64 KTS
48. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO PIE GRAPHS
345
45
285
225
NO. OF CASES
MEAN
ST. DEVIATION
NORTH

Figure B9

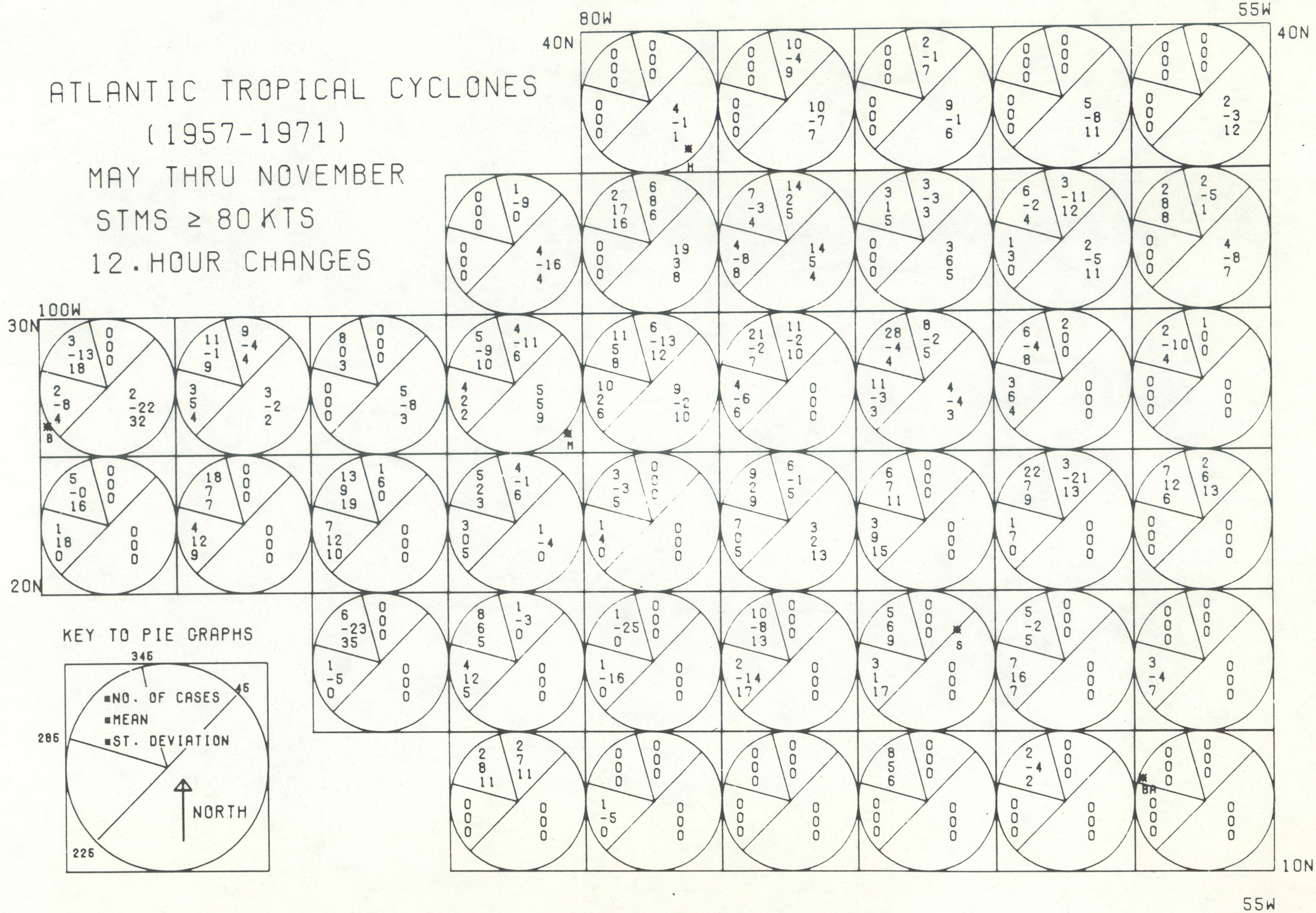

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 80 KTS
12. HOUR CHANGES
80W
55W
40N
100W
30N
20N
10N
55W
KEY TO PIE GRAPHS
346
45
286
225
NO. OF CASES
MEAN
ST. DEVIATION
NORTH

Figure B10

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 80 KTS
24.HOUR CHANGES

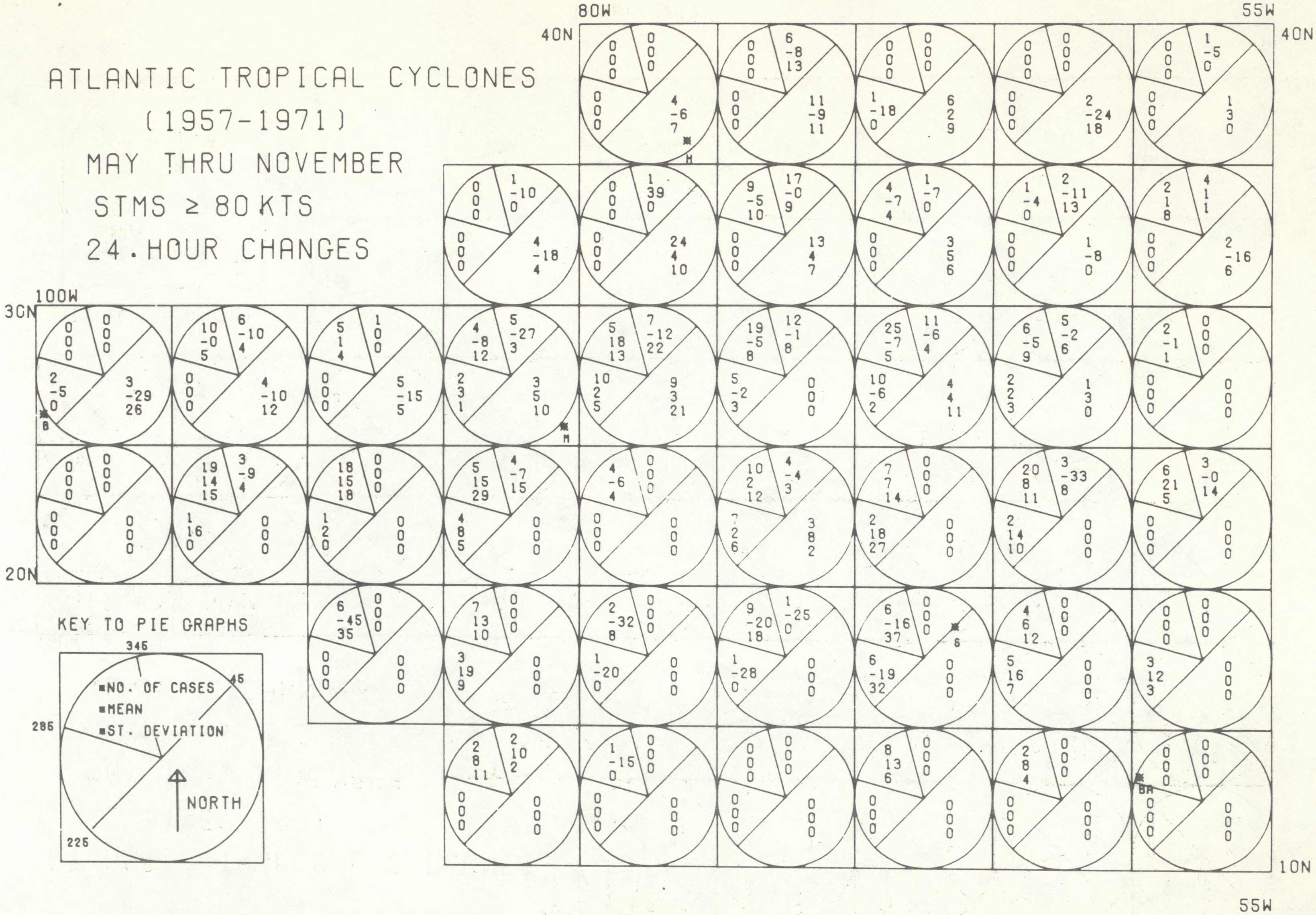



Figure B11

ATLANTIC TROPICAL CYCLONES
(1957-1971)
MAY THRU NOVEMBER
STMS ≥ 80 KTS
48. HOUR CHANGES

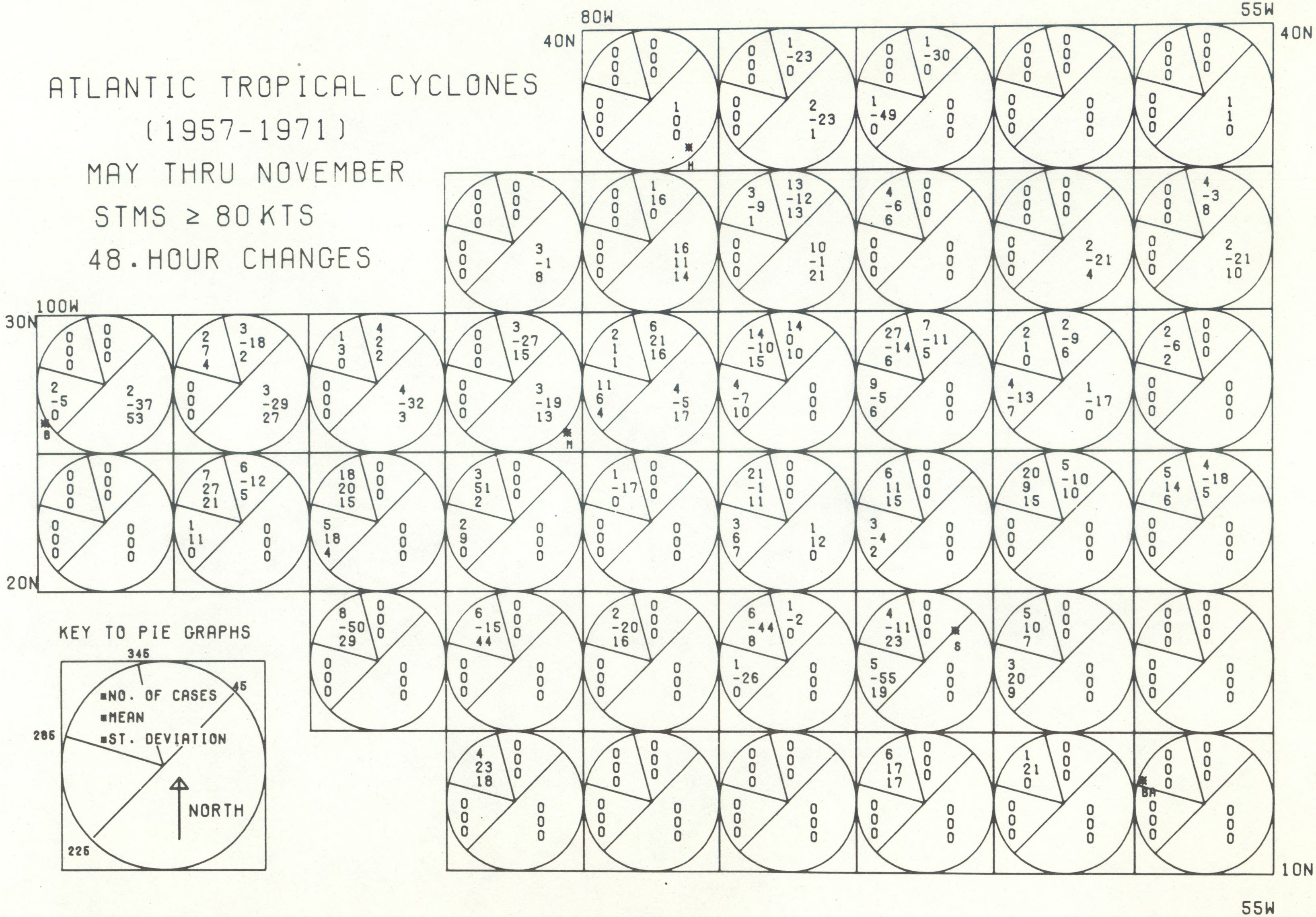



Figure B12