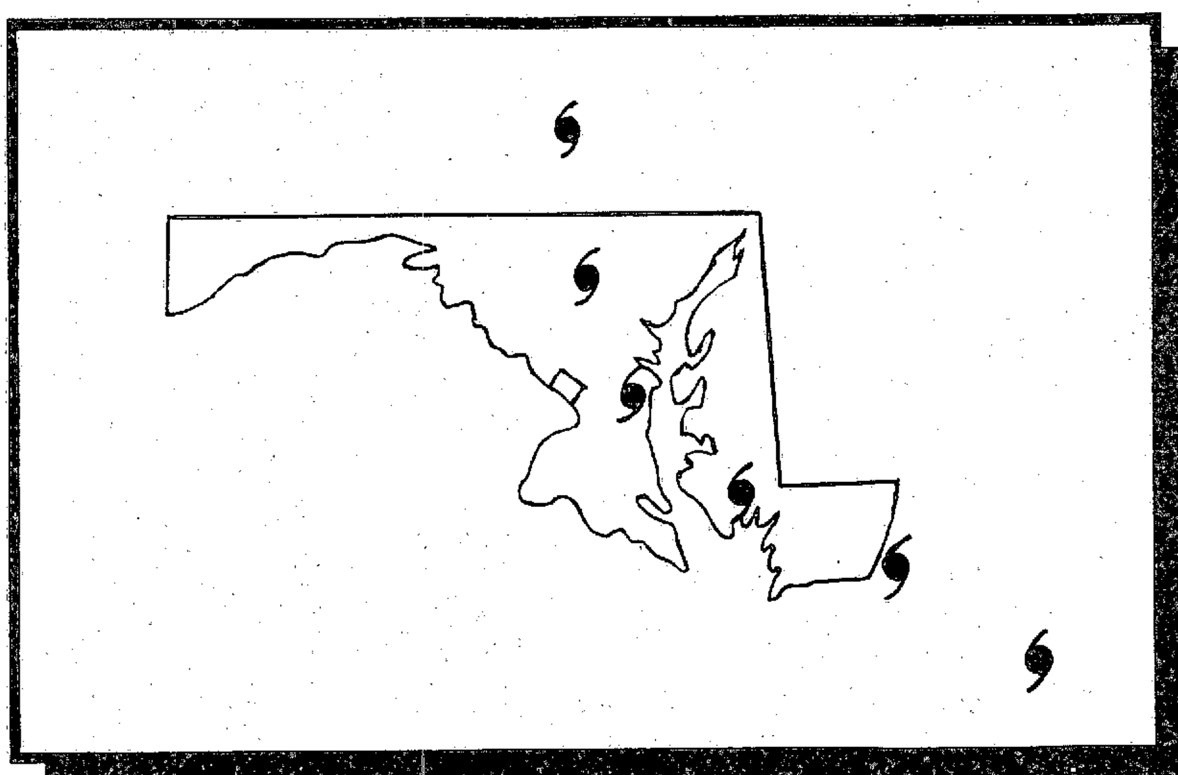
US Army Corps of Engineers
Baltimore District

December 1990

Maryland Hurricane Evacuation Study

Appendices A, B, C



Maryland Emergency Management Agency

Federal Emergency Management Agency, Region III

U.S. Army Corps of Engineers, Baltimore District

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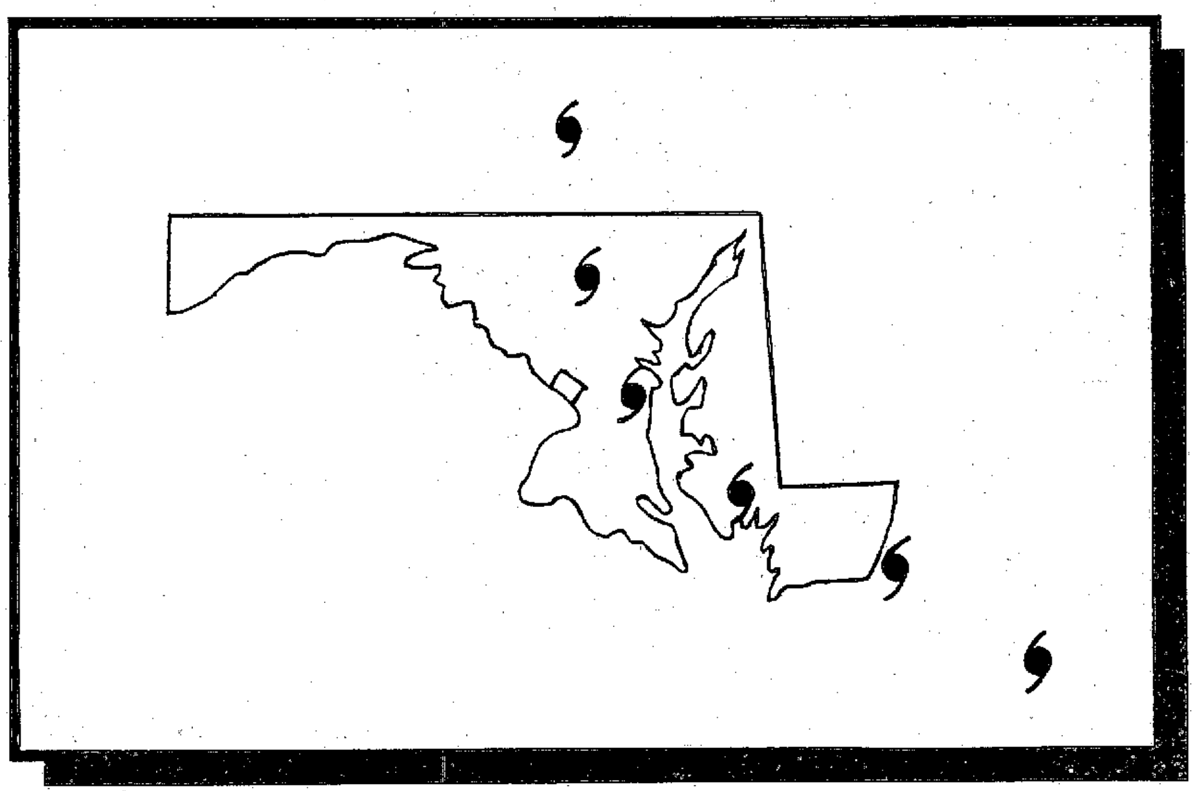

Maryland Emergency Management Agency

Federal Emergency Management Agency, Region III

U.S. Army Corps of Engineers, Baltimore District

MARYLAND HURRICANE EVACUATION STUDY

APPENDIX A - INUNDATION AND EVACUATION MAPS

APPENDIX B - HAZARDS ANALYSIS

APPENDIX C - BEHAVIORAL ANALYSIS

APPENDIX A

INUNDATION AND EVACUATION MAPS

THESE MAPS ARE PRESENTED TOGETHER IN A SEPARATE ENCLOSURE.

APPENDIX B

HAZARDS ANALYSIS

A STORM SURGE ATLAS FOR CHESAPEAKE BAY

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National Hurricane Center
National Oceanic and Atmospheric Administration
Coral Gables, Florida 33146

TABLE OF CONTENTS

1. INTRODUCTION

Storm surge is the abnormal rise in water level caused by wind and pressure forces of a hurricane. Storm surge produces most of the flood damage and drownings associated with tropical storms that make landfall or that closely approach a coastline (Anthes, 1982).

A numerical storm surge model developed by Jelesnianski (1967, 1972) and Jelesnianski and Taylor (1973) has been applied to the Chesapeake Bay region. The model, which calculates sea, lake and overland surges from hurricanes, and has the acronym "SLOSH," is a pairing of a model of a hurricane coupled to a model for storm surge. Crawford (1979) discussed some preliminary results using this model in the southeast Louisiana region.

The purpose of this atlas is to provide maps of SLOSH-modeled heights of storm surge and extent of flood inundation, for various combinations of hurricane strength, forward speed of storm and direction of storm motion. Strength is modeled by use of the central pressure and storm eye size, for the four weakest of the five categories of storm intensity that Saffir and Simpson have categorized (Simpson and Riehl, 1981). Six storm-track headings were selected, on the basis of observations by forecasters at the National Hurricane Center of the behavior of past storms.

The maps in this atlas summarize surge calculations made using the SLOSH model, when initialized with observed values (depths of water and heights of terrain and barriers) in the region centered on Chesapeake Bay.

2. THE GRID FOR THE "SLOSH" MODEL OF CHESAPEAKE BAY

Figure 1 illustrates the area covered by the grid for the Chesapeake Bay "SLOSH" model. The area covered by the grid is called a "basin"--the "Chesapeake Basin." The grid is a telescoping polar coordinate system with 79 arc lengths ($1 \leq I \leq 79$) and 84 radials ($1 \leq J \leq 84$). Unlike a true polar coordinate grid, which would have radial increment (ΔR) that was invariant with radius, this grid uses a ΔR that increases with increasing distance from the grid's pole. The result is that in each grid of the mesh, the increment of arc length (ΔS) of the side of a grid "square" is approximately equal to the radial increment of the "square," or $\Delta S \approx \Delta R$.

The telescoping grid is a compromise between conflicting needs. What is desired is that a large geographical area, but with small, detailed topography be modeled. Now, in a Cartesian coordinate system, this combination of big area, but spatially-small grid increment, requires that a computational mesh with many grid squares be used. A large mesh requires a computer with a large central processing unit (CPU) as well as more time to perform calculations in the more numerous grid squares. The telescoping grid, by comparison, permits a resolution of these conflicting needs: it has an acceptably small spatial resolution of 1 to 10 mi^2 per grid square over land, which is the area of greatest interest. Thus, topographic details, such as highway and railroad embankments, and dikes in harbors of cities are included in the model. However, the range increment contained in each grid square becomes progressively larger with increasing distance from the pole. As a result, a large geographic area is included in the model, so that the effects of the model's boundaries on the dynamics of the storm are diminished and the storm's physics are better emulated.

The grid is tangent to the earth at the basin center, Cape Henry, Virginia, at 36°55'N and 76°W. There, the grid increment is 2.7 statute miles. The pole (or origin) of the grid is located at 37°54'N and 78°04'W.

The telescoping grid has some disadvantages. Primarily, these stem from the distortion that occurs when the basin is remapped onto a display that has constant-sized increments in the vertical and horizontal, as happens when the basin is printed out by a conventional (computer) line printer. This distortion from remapping produces some difficulties in "reading" the results by the uninitiated. For example, neither latitude nor longitude lines remain uncurved and "parallels" become non-parallel. However, the projection is conformal. The projection scheme results in each grid square at I = 1, closest to the pole, representing an area of about 1.2 square miles. By contrast, at maximum distance from the pole, at I = 79, each grid square contains about 26 square miles. Thus, the distortions require that aids be provided to "read" and interpret the results.

3. "SLOSH" MODEL

A. Hurricane Model and Input

The hurricane model which drives the storm surge model was developed by Jelesnianski and Taylor (1973). It is a trajectory model of a stationary vortex and it balances the forces from pressure gradient, centrifugal, Coriolis and surface frictional effects. Adjustments are made to the computed vector wind to incorporate the hurricane's forward motion. The model's input includes the radius of maximum wind (RMW) and the difference (ΔP) in sea-level pressure between the ambient value and the minimum value in the storm's center. Directly measured wind vectors are not used. The model also requires input of the coordinates of the storm's center. Thus, input data include thirteen sets of latitude, longitude, ΔP and RMW, at six hour increments, beginning 48 hours before storm landfall and ending 24 hours after landfall. These 13 sets are then linearly interpolated into values/positions at hourly (or smaller) time increments. The model then generates the meteorological forces--surface stress and the gradient of atmospheric pressure--that drive the underlying ocean.

B. Storm Surge Model

Storm surge is the response by the ocean to meteorological forces. The model's governing equations are those given by Jelesnianski (1967), except now for the inclusion of the finite amplitude effect. Coefficients for surface drag, eddy viscosity and bottom slip are the same as those used in an earlier model (Jelesnianski, 1972). There is no calibration or tuning to force agreement between observed and computed surges; coefficients are fixed, and do not vary from one geographical region to another.

Special techniques are incorporated to model two-dimensional inland inundation, routing of surges inland when barriers are overtopped, the effect of trees, the movement of the surge up rivers, and flow through channels, cuts and over submerged sills. Besides surge, other processes affect water height (section 4B), but are not incorporated in the model.

Not surprisingly, the accuracy of modeled surge values increases as the accuracy of the input terrain and storm data improves.

4. OUTPUT AND INTERPRETATION OF THE MODEL RESULTS

A. Output from the "SLOSH" Model

The output for the Chesapeake "SLOSH" model consists of maps of water heights. At each grid point, the water height is the maximum value that was computed at that point during the 72 (maximum) hours of model time. Thus, the map displays the highest water levels and does not display events at any particular instant in time. The analyzed envelopes of high water show shaded areas that represent dry land which has been inundated and contours of high water relative to mean sea level (MSL). Height of water above terrain was not calculated because terrain height varies within a grid square. For example, the altitude of a 1-mile grid square may be assigned a value of 6-ft MSL, but this value represents an average of land heights that may include values ranging from 3 ft to 9 ft MSL. Thus, a surge value of 8 ft in this square, implying 2 ft average depth of water over the grid's terrain, would include some terrain without inundation and other parts with as much as 5 ft of overlying water. Therefore, the depth of surge flooding above terrain at a specific site in the grid square is deduced by subtracting the actual terrain height from the model-generated storm surge height in that square. Also supplied are printout lists of values of surge height, wind speed and wind direction for each of 100 sites. The values are ten-minute averages, every 30 minutes. These are useful for determining the time of onset of gale force winds and surge heights, for evacuation planning.

B. Interpretation of Results

Even if the model is supplied accurate data on storm positions, intensities and sizes, the computed surges may contain errors of +/- 20% of observed water levels. These primarily stem from:

1) Maps that are outdated: The maps which supplied heights of terrain and depths of water sometimes did not include changes, often man-made, that had been made to the heights and positions of barriers (e.g., highway and railway embankments) and depths and locations of channels. Inaccuracies of topography or bathymetry will contribute directly to errors in the modeling of all storm surges.
2) Anomalous water heights: Sea level can be at an altitude different from "mean sea level," days or even weeks before a storm is actually affecting a basin. The value of the actual, local sea level -- the "local datums" for pre-storm anomaly in the Atlantic Ocean and in Chesapeake Bay must be supplied to the model, before calculations are initiated.

3) Local processes, such as waves, astronomical tides, rainfall and flooding from overflowing rivers: These processes are usually included in "observations" of storm surge height, but are not surge and are not calculated by the SLOSH model.

Factors such as the foregoing must be considered when comparisons are made between modeled and observed values of storm surge.

5. HURRICANE CLIMATOLOGY

A. Tracks

Between 1886 and 1985, 18 tropical cyclones of hurricane intensity passed within 100 statute miles of Wallops Island, Virginia (Neumann et al., 1981), for an average of one hurricane within the 100-mile circle every 5.6 years.

Figures 2-4 show the tracks of storms with hurricane force winds that traversed the circle this century. Figure 2 shows the track for westbound Hurricane Doria, Figure 3 depicts the tracks for northbound (NNW-NNE) storms, and Figure 4 shows tracks for storms heading northeastward.

The tracks represent "best estimates" and are based on a variety of data sources. Historically, storm strength, location and motion were only inferred, from analyses of wind, pressure and cloud observations made at ships and land stations being influenced by the storm. In 1943, aircraft reconnaissance of hurricanes began. Not until 1959 were there land-based weather radars, as now at Cape Hatteras, Norfolk and Wallops Island, which could be used to observe and record structure, development and motion of precipitation fields, and help infer center location and radius of maximum winds. The 1960's saw the advent of photography from weather satellites of tropical storms. Observations by aircraft, radar and satellite have shown that the tracks of centers of hurricanes contain wobbles, gyrations and cycloidal motions (Lawrence and Mayfield, 1977) and that there often are rapid developments in size and intensity of rain bands, contractions of eyewall diameters and formation of concentric ("double") eyewalls. Every one of these factors indicates asymmetries in the storm's dynamical structure; every one of these dynamical asymmetries affects the storm's surge. But these factors were not documented in the earlier storms and remain beyond the reach of present-day forecasting skill.

The tracks in Figures 2-4 are labelled at 6-hour intervals with month/day/hour (GMT).

B. Intensities

Hurricane intensity is ususally defined by measurements at sea level of the maximum sustained wind speed and/or by minimum barometric pressure. Neither of these is easily obtained. Accurate estimates of these parameters at sea level were acquired only when a ship or land station was traversed by the storm's "eye." Minimum central pressure was gotten only when a barometer was in the precise path of the storm's center. Because the area covered by the strongest winds is much larger than that covered by the pressure minimum, strength of many older storms was deduced from measurements of wind speed. However, with the advent of aircraft reconnaissance, measurements made at flight level of meteorological parameters allow the calculation of barometric pressure at sea level. By comparison, winds at sea level are not so readily deduced from flight level data. For all the storm tracks in Figures 2-4, an estimate was made of the maximum wind speed at intervals of 6 hours. For some, only very indirect evidence exists of actual speeds. From the hourly values of the maximum wind speed inside the 100 mile circle, the largest value was selected. This maximum sustained wind speed for the hurricane is listed in Table 1 under the heading of "wind (in circle)." Storm heading and forward speed at hour of closest point of approach are listed in the last two columns.

The values listed in column 6 sometimes are poor estimates of the maximum wind speed; the following must be considered:

1) Actual wind speeds and directions exhibit gustiness.
2) The "average wind speed" has been calculated with a variety of time intervals over the years; thus, one can find historical wind records that have used time periods such as 1 hour, or 10 or 5 minutes or 1 minute as the "standard" period of measurement. Given the same record from a recording anemometer, the use of each of these measurement periods would likely yield a different average wind speed, with shorter periods probably giving higher average speeds.
3) The platforms for measuring maximum surface wind speed have changed over the years; data from ship and land stations now are supplemented by remotely-sensed data from aircraft, satellites and radar. However, the remote platforms, especially the last two, observe the motions of clouds or precipitation echoes, and these motions are not wind speed, nor are they at sea level.

Because of these limitations in determination of maximun wind speed, the SLOSH model uses storm-center sea-level pressure as a measure of storm intensity in modeling the Chesapeake Bay basin.

6. MAPS OF MAXIMUM ENVELOPE OF WATER ("MEOW") FROM SLOSH RUNS USING DATA FOR HYPOTHETICAL HURRICANES

A. Hypothetical Storm Tracks and Populations

The skill of the SLOSH model was evaluated by Jarvinen and Lawrence (1985), who compared modeled and observed surges at 523 sites during 10

Table 1. Hurricanes passing within 100 statute mile circle of Wallops Island, Virginia (37.84°N, 75.49°W), during 1886-1985.

			>>>At Closest Point of Approach: (@CPA) <<<				
Index (1)	Date (@CPA) (2)	Storm Name (3)	Range/Bearing (miles/degrees) (to CPA) (4)	(5)	Wind (in circle) (mph) (6)	Storm Motion (@CPA) (dir / mph) (7)	(8)
1	1893 Aug 24	Unnamed	81	082	98	N	24
2	1894 Sep 29	Unnamed	56	128	81	NE	7
3	1894 Oct 10	Unnamed	15	121	75	NNE	27
4	1899 Aug 19	Unnamed	82	145	90	NE	8
5	1903 Sep 16	Unnamed	93	080	84	NNW	24
6	1933 Aug 23	Unnamed	74	248	104	NNW	18
7	1933 Sep 16	Unnamed	83	123	86	NE	19
8	1935 Sep 6	Unnamed	62	160	78	ENE	32
9	1936 Sep 18	Unnamed	41	103	98	NNE	19
10	1944 Sep 14	Unnamed	58	108	99	NNE	35
11	1953 Aug 14	Barbara	56	123	81	NE	17
12	1954 Aug 31	Carol	79	118	98	NNE	38
13	1955 Aug 13	Connie	23	280	98	NNW	15
14	1955 Sep 20	Ione	93	156	79	ENE	9
15	1960 Sep 12	Donna	53	135	109	NNE	34
16	1967 Sep 16	Doria	33	137	77	SW	9
17	1976 Aug 9	Belle	82	096	101	N	26
18	1985 Sep 27	Gloria	30	112	104	NNE	30

Notes:

(1) Storm number for this list.

(2) Year, month and date that storm had maximum winds exceeding 74 mph and was closest to Wallops Island, Virginia.

(3) Storms were not formally named before 1950.

(4)-(5) Distance (statute miles) and direction (degrees) from Wallops Island to storm when it passed abeam.

(6) Maximum sustained wind speed near storm center while center was within 100 statute miles of Wallops Island. This is not necessarily the wind recorded at a given site.

(7)-(8) Storm heading and forward speed (mph) at hour of closest point of approach.

hurricanes. They found that the mean absolute error in surge height calculated by SLOSH was 1.4 ft. Although the error range was from -7.1 ft to +8.8 ft, the standard deviation was only 2.0 ft and 79% of the errors lay within one standard deviation of the mean error, -0.3 ft (on the average, modeled values were slightly less than those observed).

Because of this skill in calculating storm surge, the SLOSH model was used to create maps of surge flooding in the Chesapeake Bay basin for use in evacuation planning. The model was supplied with data from hypothetical storms and the resulting surge calculations were composited to produce maps of the maximum envelope of water. This section details why these calculations were made and how the compositing was done.

Storm surge height, at any particular location, partly depends on distance between that site and the storm's center. For a single storm, the model would produce a map of surge height for the modeled period of time (usually 72 hours), with values valid for only that particular storm track. If there were two storms, identicial in every respect except that one followed a track parallel to, but separated from the other by 50 miles,[†] and if the model was run with first one and then the other storm, and a comparison made of surge values, then very likely there would be geographical sites with surge values from one storm that differed markedly from those modeled for the other storm. When preparing plans for emergency evacuation, this dependency of

[†]A difference ("error") of 50 miles in storm track is not very large when compared to the vagaries of tracks of real hurricanes. The average error of 12-hour forecast landfall position, for U.S. Atlantic coast tropical cyclones, during 1970-1979, was about 59 statute miles, while for 24-hour forecasts, landfall position error was about 125 statute miles (Neumann and Pelissier, 1981). Thus, if a storm were forecast to make (eye) landfall at Cape Henry, Virginia, in 24 hours, and if, in fact, it made landfall anywhere between Ocracoke Inlet, North Carolina and Bethany Beach, Delaware, the error in forecast landfall position would be no worse than average.

surge height on storm track is not good. What was needed was a map of surge flooding potential for the entire basin, in which surge heights depended only on storm intensity (using the categories defined by Saffir and Simpson), and on storm speed and direction. To do this, we adopted a procedure that involved making surge calculations for each of an ensemble of 4 to 18 (depending on direction) identical storms, on parallel headings, separated (usually) by 20 miles. Then at each grid square, the maximum surge value that was calculated from any storm in the ensemble was extracted and saved. After this procedure was performed for all grid squares, the result was a basin map depicting the "maximum envelope of water," or MEOW, for the specified storm category, direction and speed. For the Chesapeake Bay basin, the hypothetical storms were specified to move in one of six directions, some at one and others at two constant speeds, as summarized in Table 2. There were 18 tracks for the west-northwest (WNW) moving storms (Figure 5), 13 tracks for the northwest-bound (NW) storms (Figure 6), 10 tracks for the north-northwestward (NNW) moving storms (Figure 7), 14 tracks for the northward moving storms (Figure 8), up to 11 tracks for the north-northeastward (NNE) storm headings (Figure 9) and up to 9 tracks for the northeast-bound (NE) storms (Figure 10). In total, 389 sets of data for hypothetical storms were run, using the SLOSH model, to create the results to be presented below. The selection of directions and speeds was based on advice of hurricane specialists at NOAA's National Hurricane Center.

B. <u>Intensities and Radii of Maximum Winds of Hypothetical Storms</u>

Most hurricanes weaken after making landfall because the central pressure increases (the storm "fills") and the RMW tends to increase. Table 3 summarizes pressure filling and RMW increases with time for 316 of the

Table 2. Chesapeake Basin's hypothetical storms: Directions, speeds, (Saffir/Simpson) intensities, number of tracks and the number of runs.

Direction	Speed (mph)	Intensities	Tracks	Runs
WNW	20	1 through 4	18	72
NW	20	1 through 4	13	52
NNW	20, 40	1 through 4	10	80
N	20, 40	1 through 4	14	112
NNE	20, 30	1, 2, 3, 4	11, 11, 5, 3	60
NE	20	1 and 2	9 and 4	13

Table 3. Time change of pressure difference and radius of maximum wind for hypothetical hurricanes having headings towards the north, north-northwest, northwest or west-northwest in Chesapeake Basin.

Values of pressure difference (ΔP, millibars) and radius of maximum wind (RMS, statute miles), beginning at time of landfall (LF) of center of storm and every six hours after LF.

	Landfall		LF + 6		LF + 12		LF + 18		LF + 24	
Category	ΔP	RMW	ΔP	RMW	ΔP	RMW	ΔP	RMW	ΔP	RMW
1	20	30	14	30	10	30	10	35	10	40
2	40	30	31	30	22	30	13	35	10	40
3	60	30	48	30	36	30	24	35	12	40
4	80	30	65	30	50	30	35	35	20	40

hypothetical storm runs. (Storms heading northeast or north-northeast were modeled to not undergo filling nor to change RMW.) These rates were based partly on the work of Schwerdt et al. (1979).

C. Initial Water Height

Based on observations from tide gages in the area of this basin, tidal anomalies of about +1 ft MSL before arrival of a hurricane are not uncommon. Thus, all SLOSH runs of hypothetical hurricanes were supplied with initial datums of +1 ft MSL. In an actual hurricane, if tide gage data in this basin indicate that there is no tide anomaly, then subtract 1 ft from the modeled values found in the maps (below).

D. The "MEOW" Figures

There are 34 MEOWS. They use the distorted geography mentioned in Section 2 and are presented in the Appendix. The contours represent the height of water above mean sea level, in 1-ft increments. The shaded areas indicate land areas that were modeled to have been inundated.

The MEOW figures are grouped by direction: west-northwestbound storms are in Figures A1-A4, northwestbound storms' MEOWS are in Figures A5-A8, north-northwestbound in Figures A9-A16, northbound in Figures A17-A24, north-northeastbound in Figures A25-A32 and northeastbound storms' MEOWS are in Figures A33 and A34. Figure A35 shows the locations of the major cities and bodies of water on the MEOW base map.

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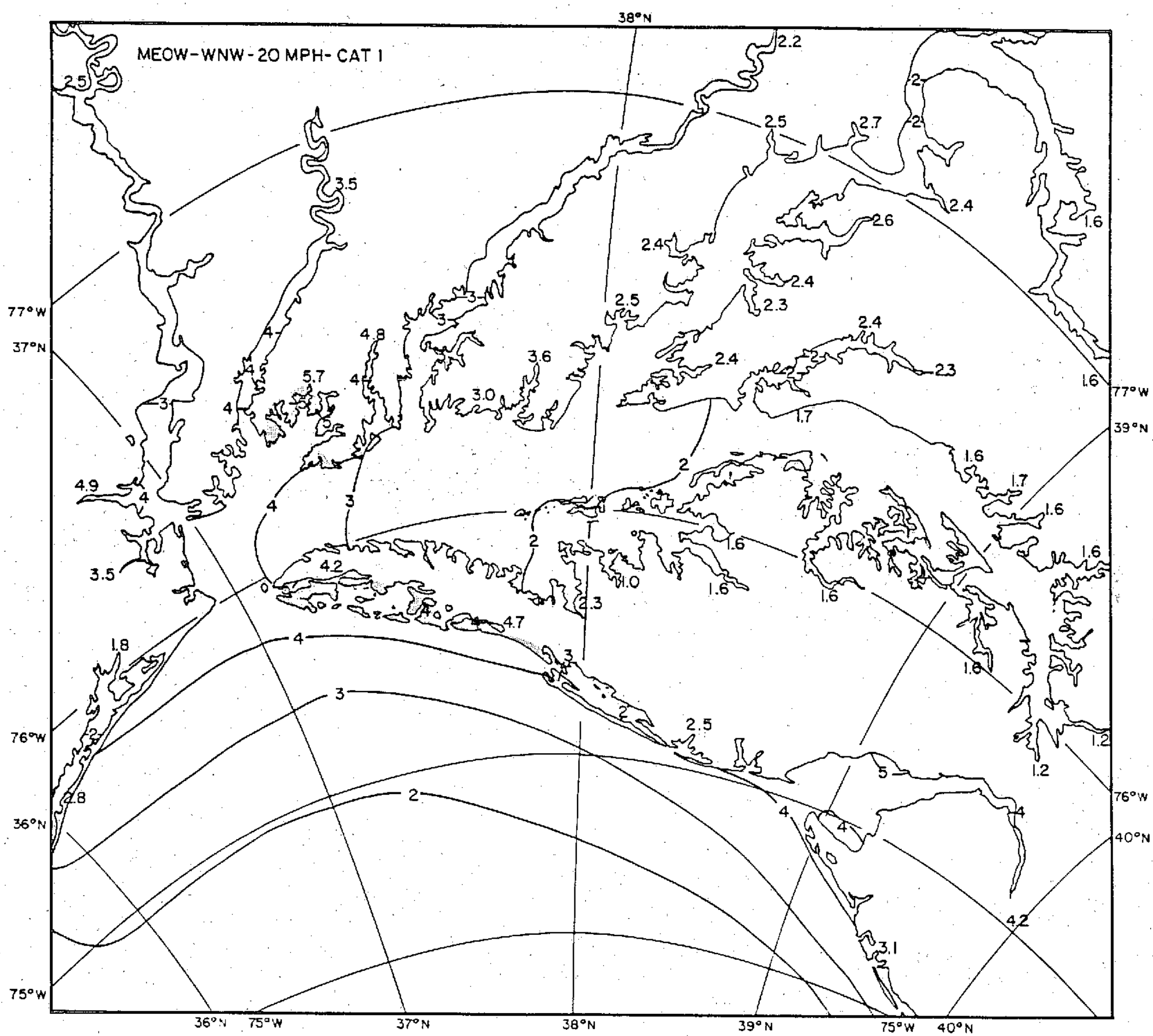
8. APPENDIX: MAXIMUM ENVELOPES OF WATER (MEOW); SERIES "A"

Figure	MEOW
A- 1	West-northwestbound, 20 mph, category 1 hurricane.
A- 2	West-northwestbound, 20 mph, category 2 hurricane.
A- 3	West-northwestbound, 20 mph, category 3 hurricane.
A- 4	West-northwestbound, 20 mph, category 4 hurricane.
A- 5	Northwestbound, 20 mph, category 1 hurricane.
A- 6	Northwestbound, 20 mph, category 2 hurricane.
A- 7	Northwestbound, 20 mph, category 3 hurricane.
A- 8	Northwestbound, 20 mph, category 4 hurricane.
A- 9	North-northwestbound, 20 mph, category 1 hurricane.
A-10	North-northwestbound, 20 mph, category 2 hurricane.
A-11	North-northwestbound, 20 mph, category 3 hurricane.
A-12	North-northwestbound, 20 mph, category 4 hurricane.
A-13	North-northwestbound, 40 mph, category 1 hurricane.
A-14	North-northwestbound, 40 mph, category 2 hurricane.
A-15	North-northwestbound, 40 mph, category 3 hurricane.
A-16	North-northwestbound, 40 mph, category 4 hurricane.
A-17	Northbound, 20 mph, category 1 hurricane.
A-18	Northbound, 20 mph, category 2 hurricane.
A-19	Northbound, 20 mph, category 3 hurricane.
A-20	Northbound, 20 mph, category 4 hurricane.
A-21	Northbound, 40 mph, category 1 hurricane.
A-22	Northbound, 40 mph, category 2 hurricane.
A-23	Northbound, 40 mph, category 3 hurricane.
A-24	Northbound, 40 mph, category 4 hurricane.
A-25	North-northeastbound, 20 mph, category 1 hurricane.


MEOW-WNW-20 MPH-CAT 1
38°N
77°W
37°N
76°W
36°N
75°W
39°N
40°N
36°N
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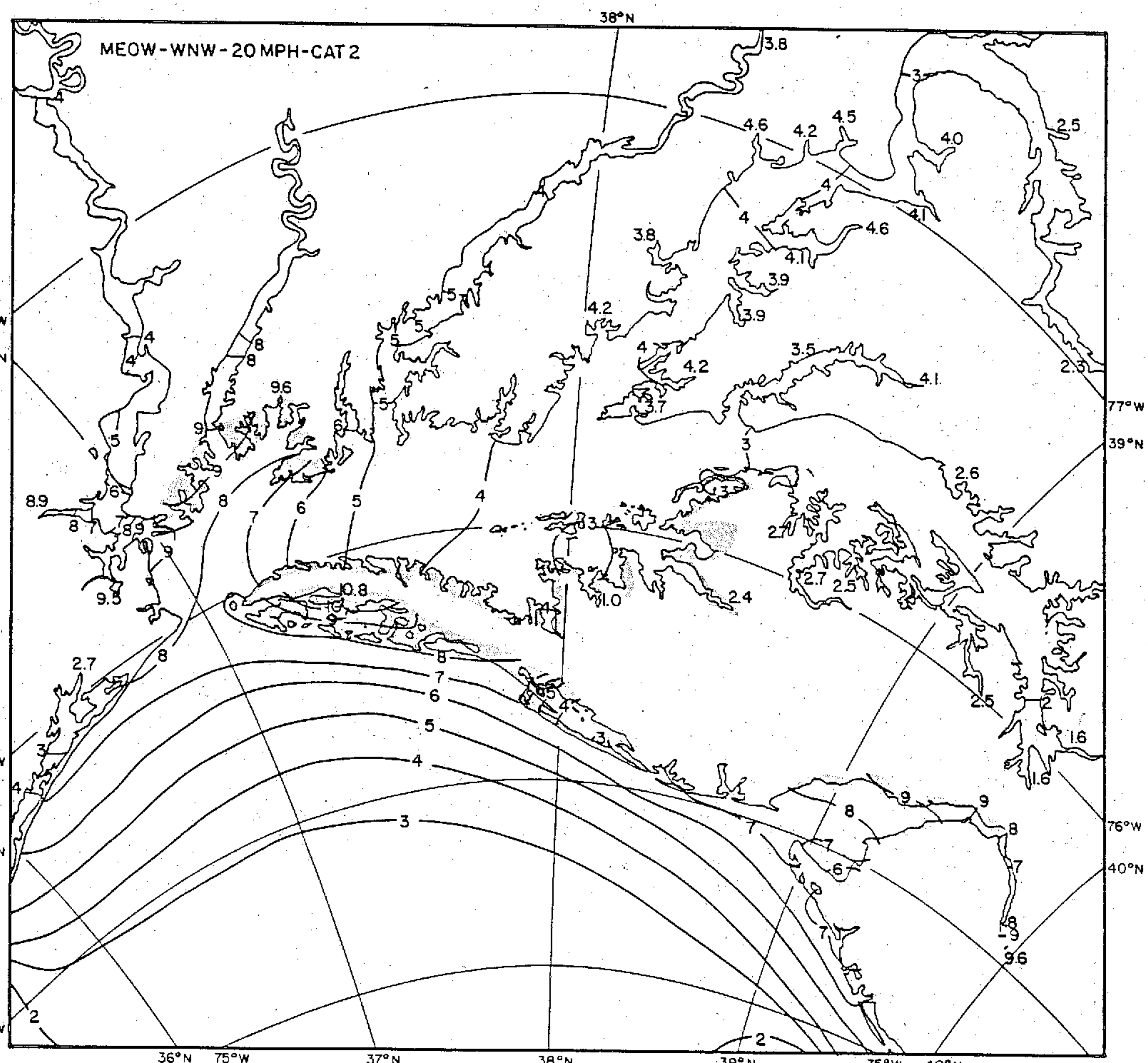
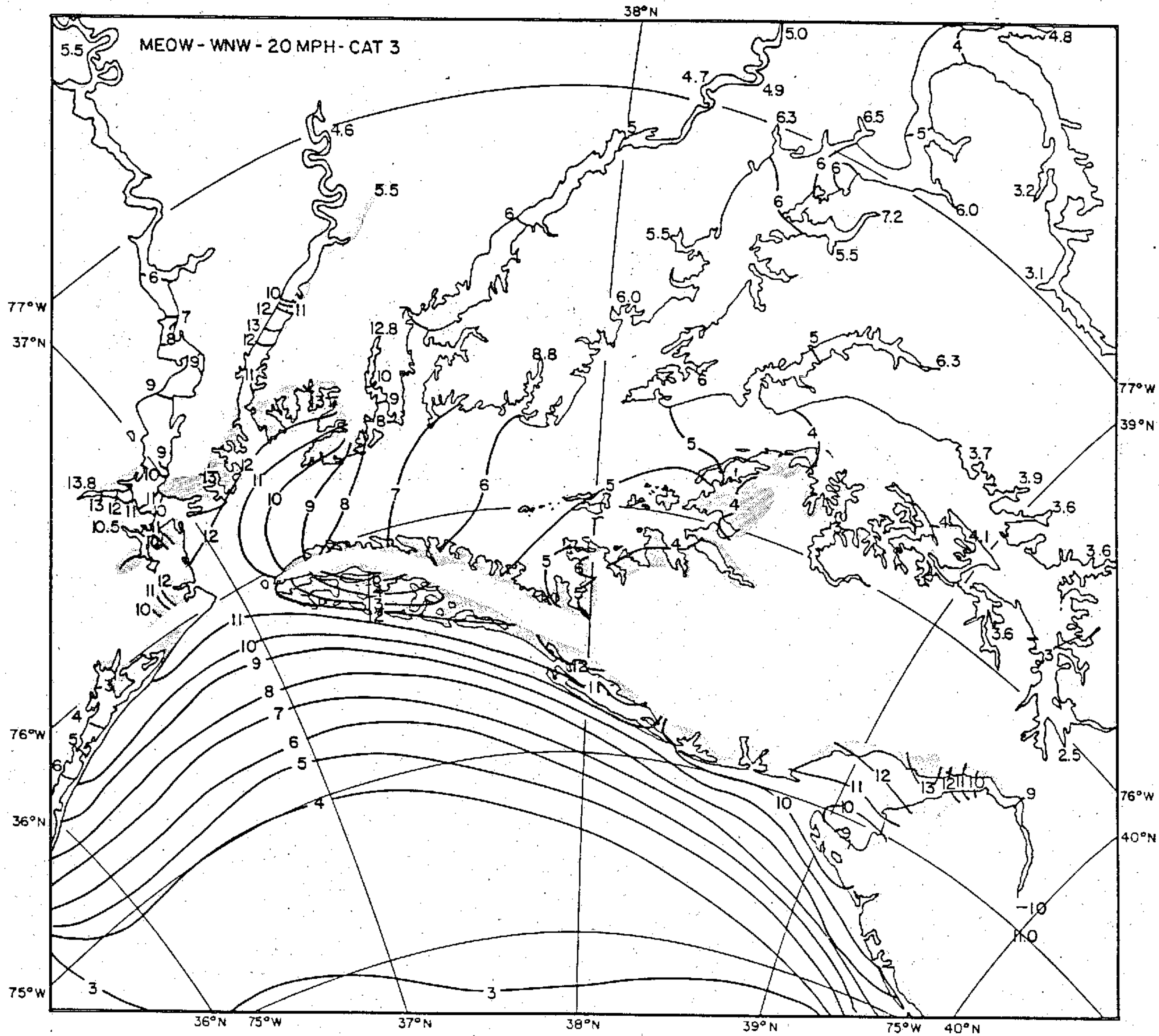
37°N
38°N
39°N
75°W
40°N

A-1


MEOW-WNW-20 MPH-CAT 2



MEOW - WNW - 20 MPH - CAT 3
38°N
37°N
36°N
39°N
40°N
77°W
76°W
75°W
5.5
4.6
5.0
4.7
4.9
4.8
6.3
6.5
6.0
7.2
5.5
3.2
3.1
12.8
8.8
6.3
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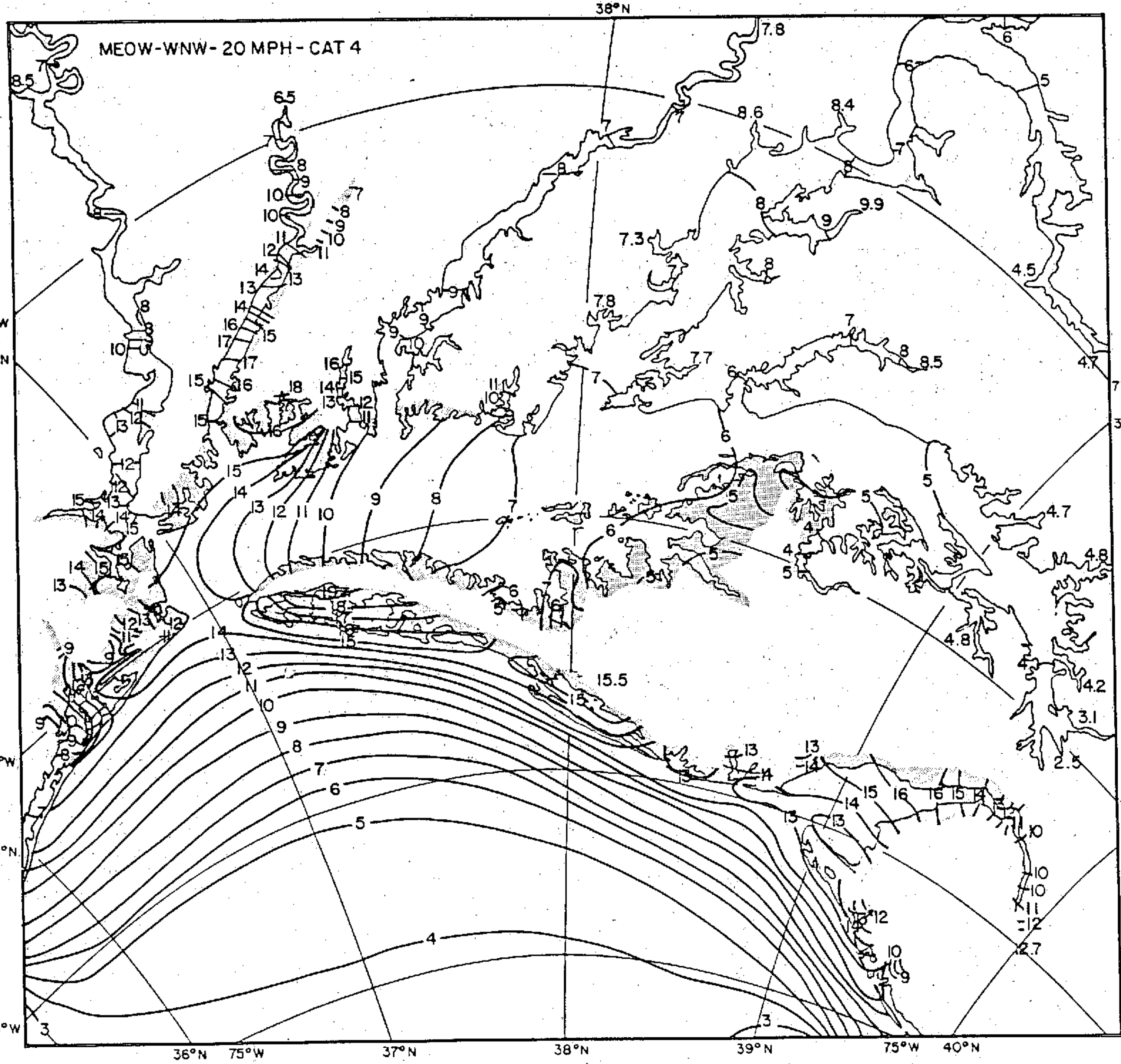
A-3


MEOW-WNW-20 MPH-CAT 4
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77°W
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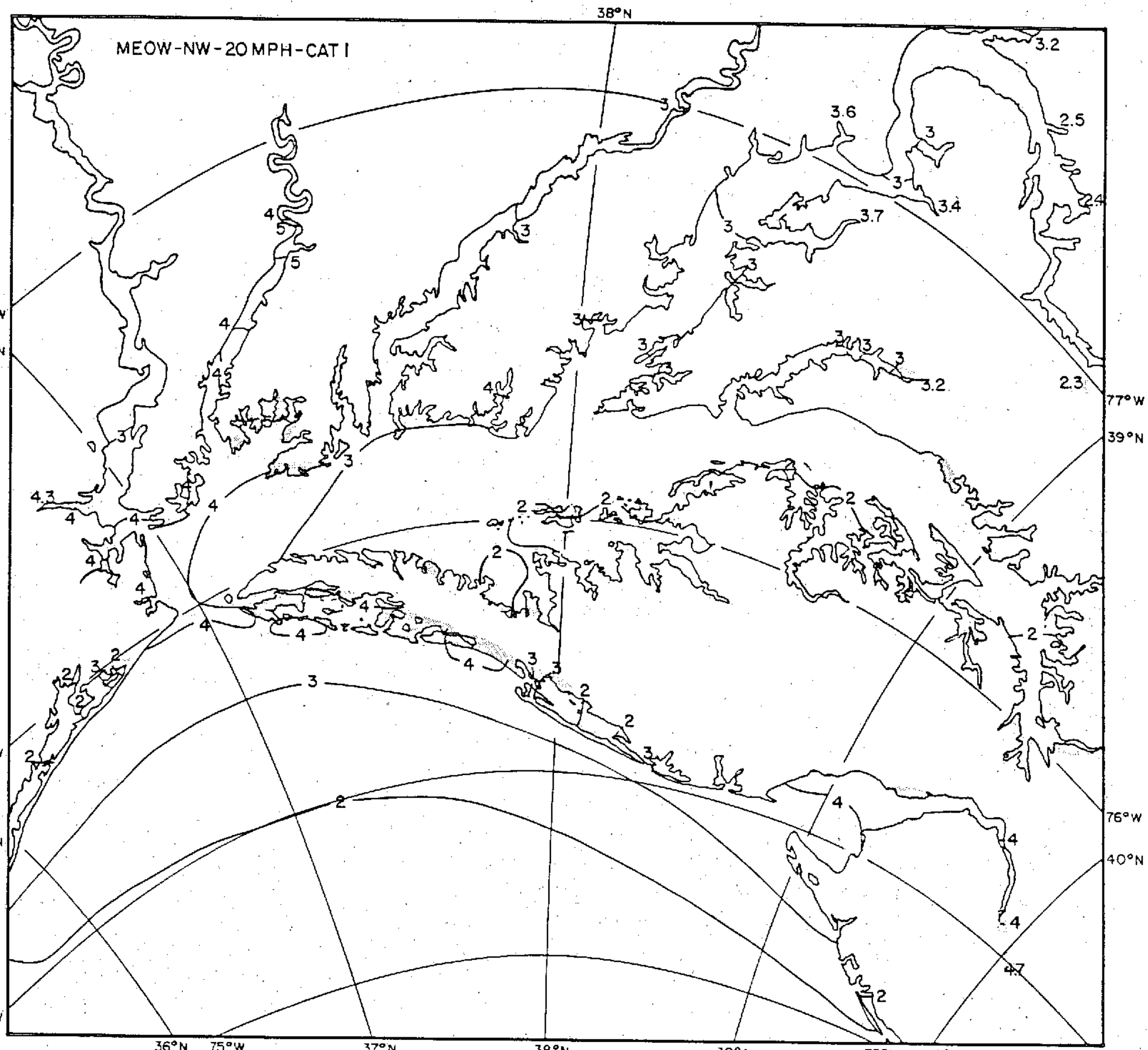
76°W
36°N
40°N
75°W
15.5


MEOW-NW-20MPH-CAT I
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37°N
76°W
36°N
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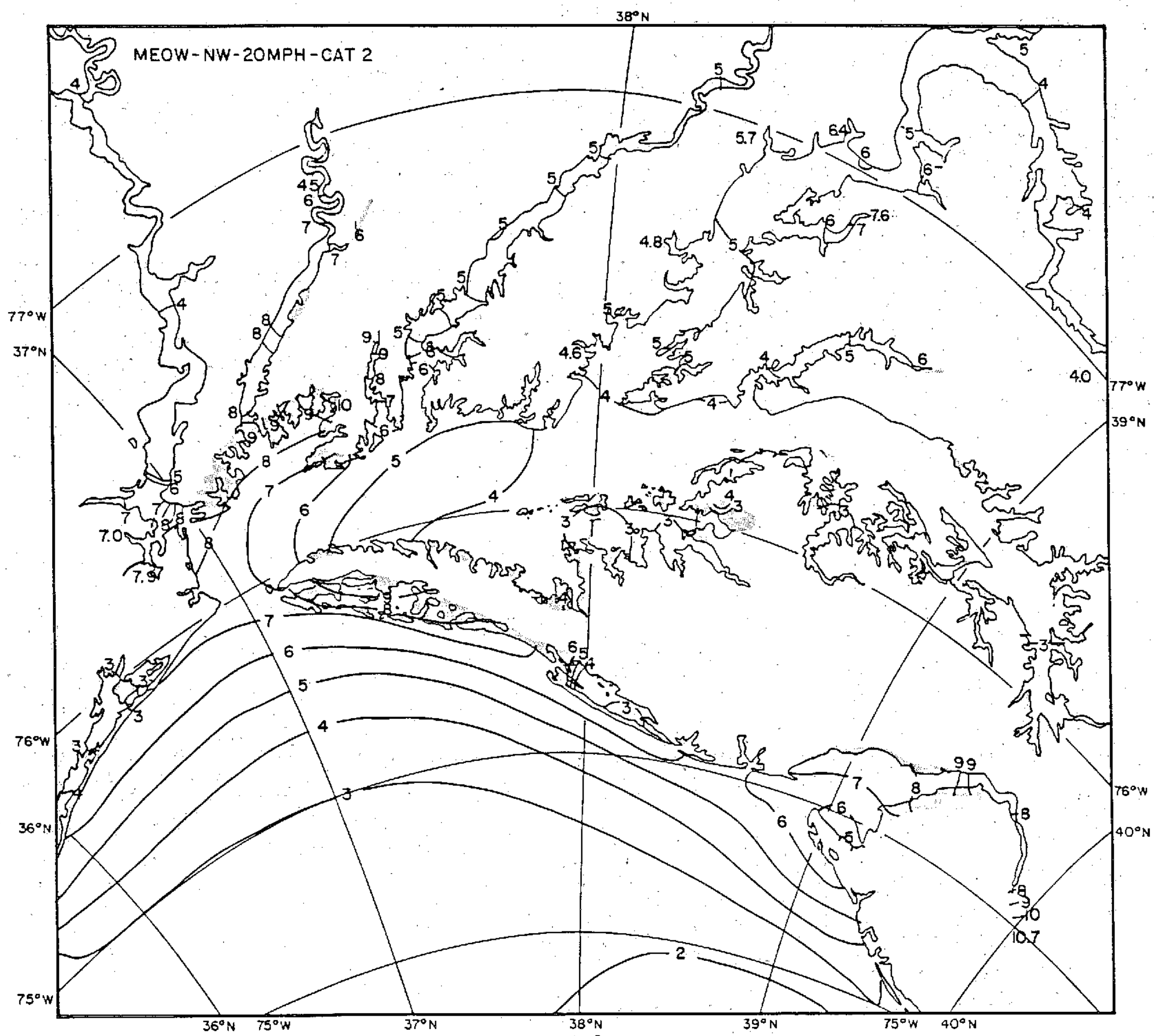
4.3
4.7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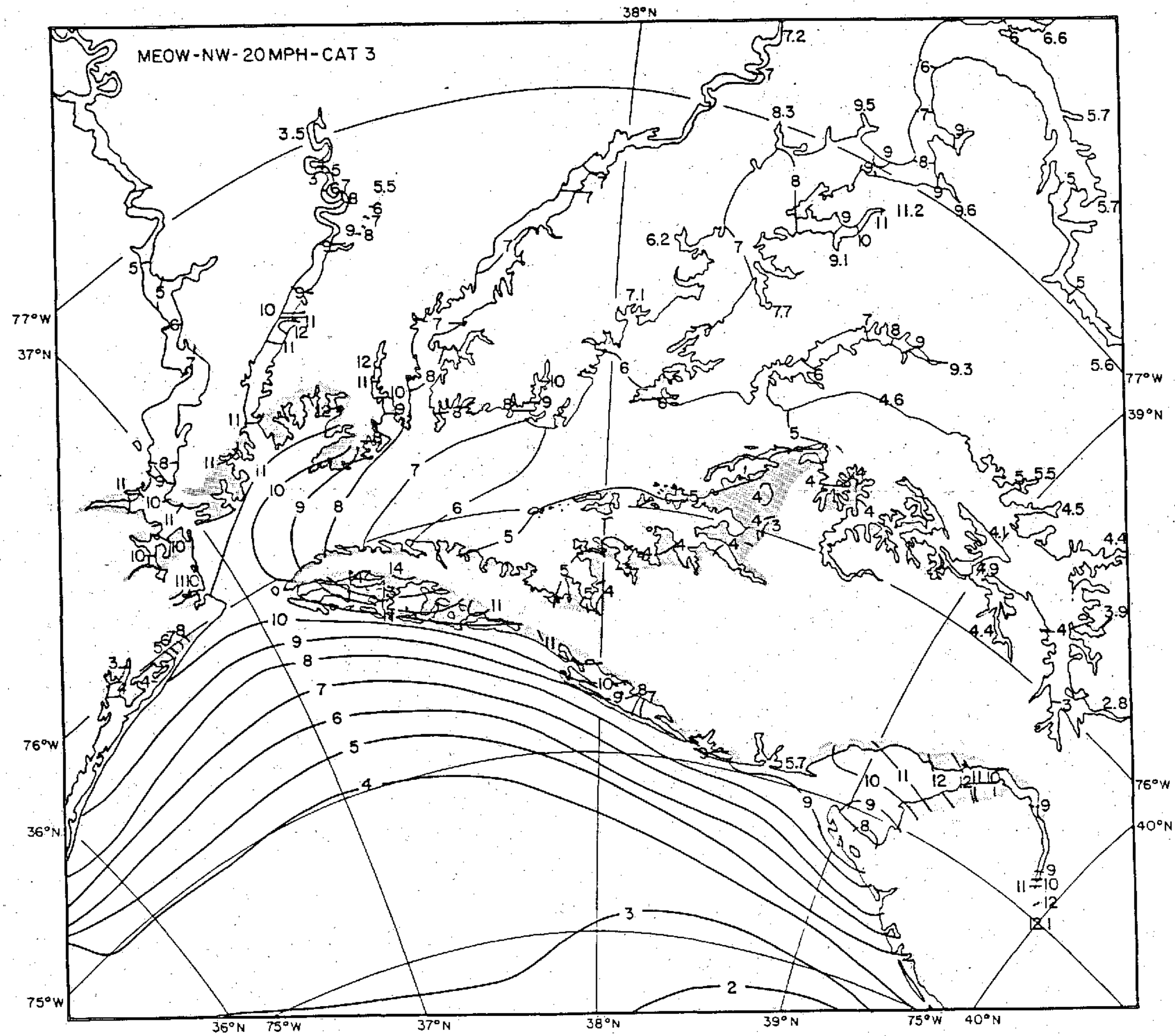
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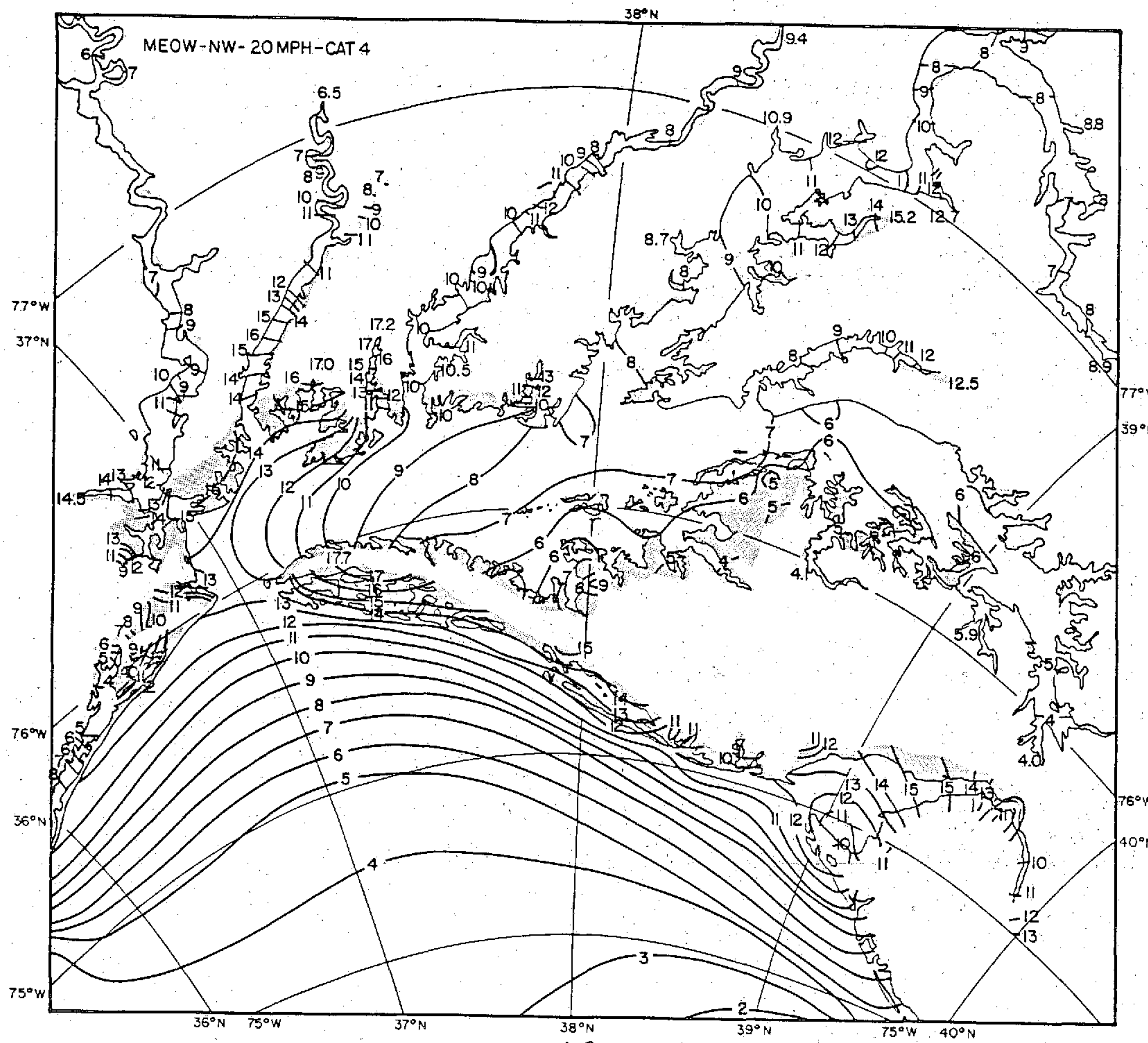
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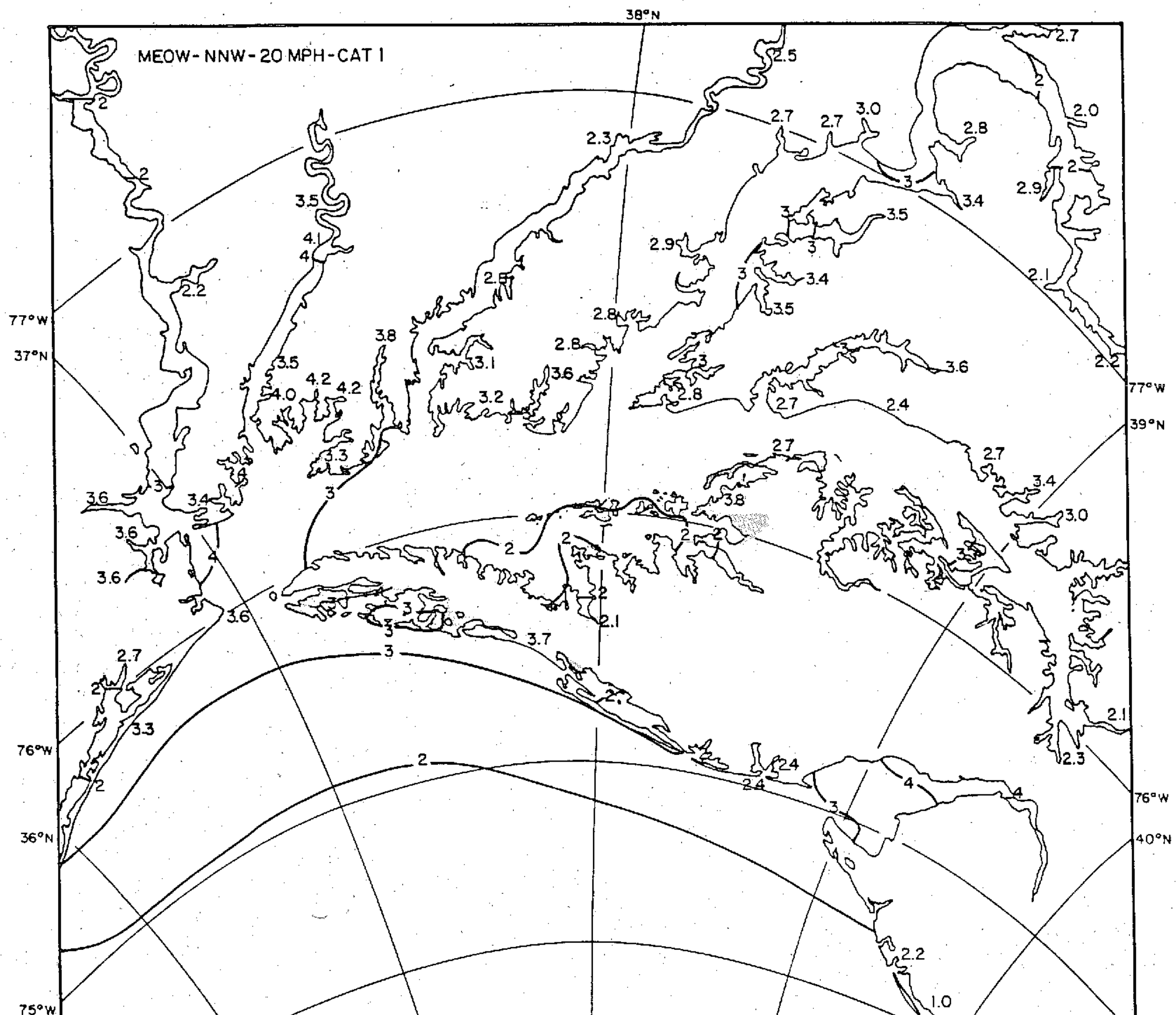
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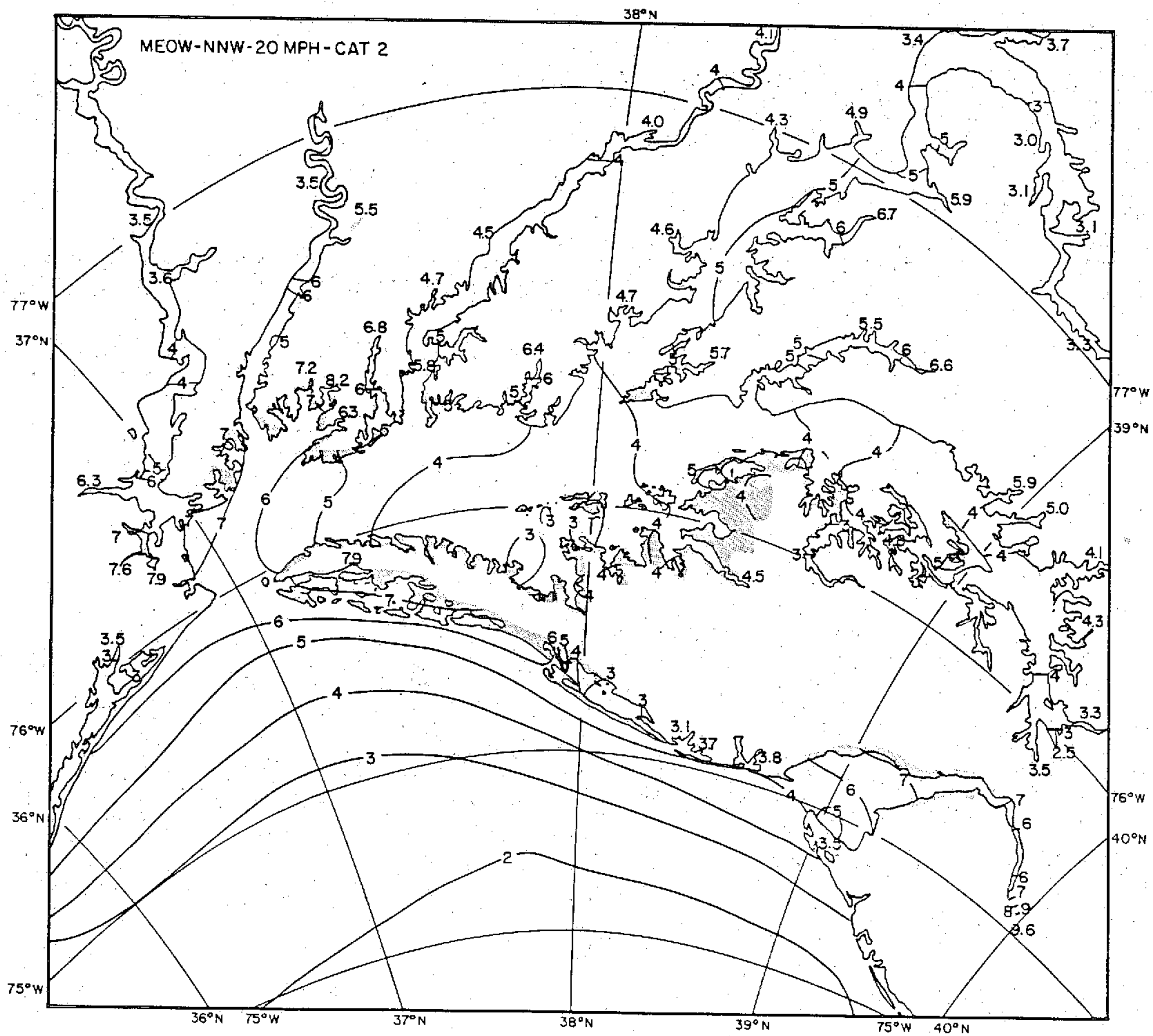
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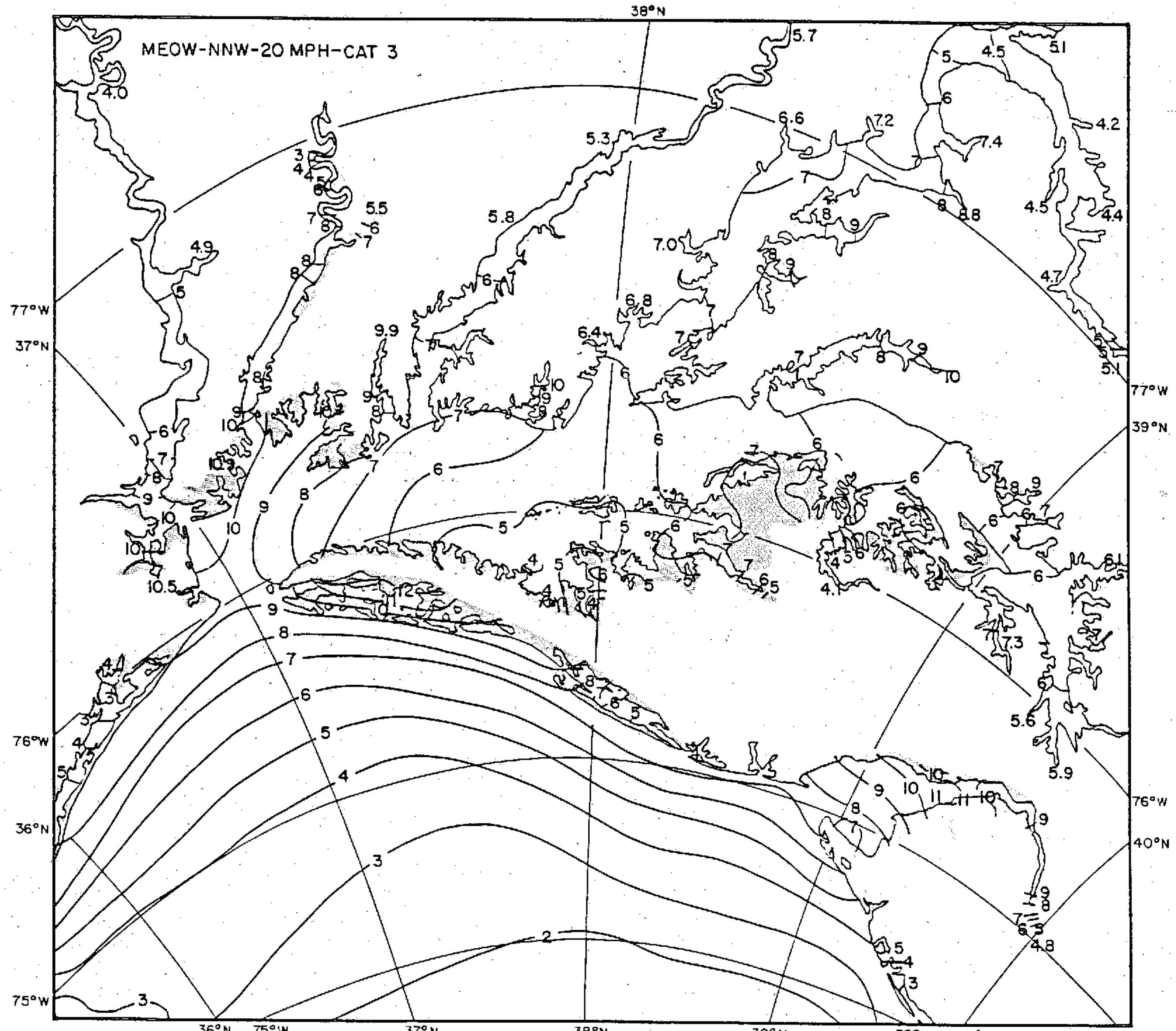
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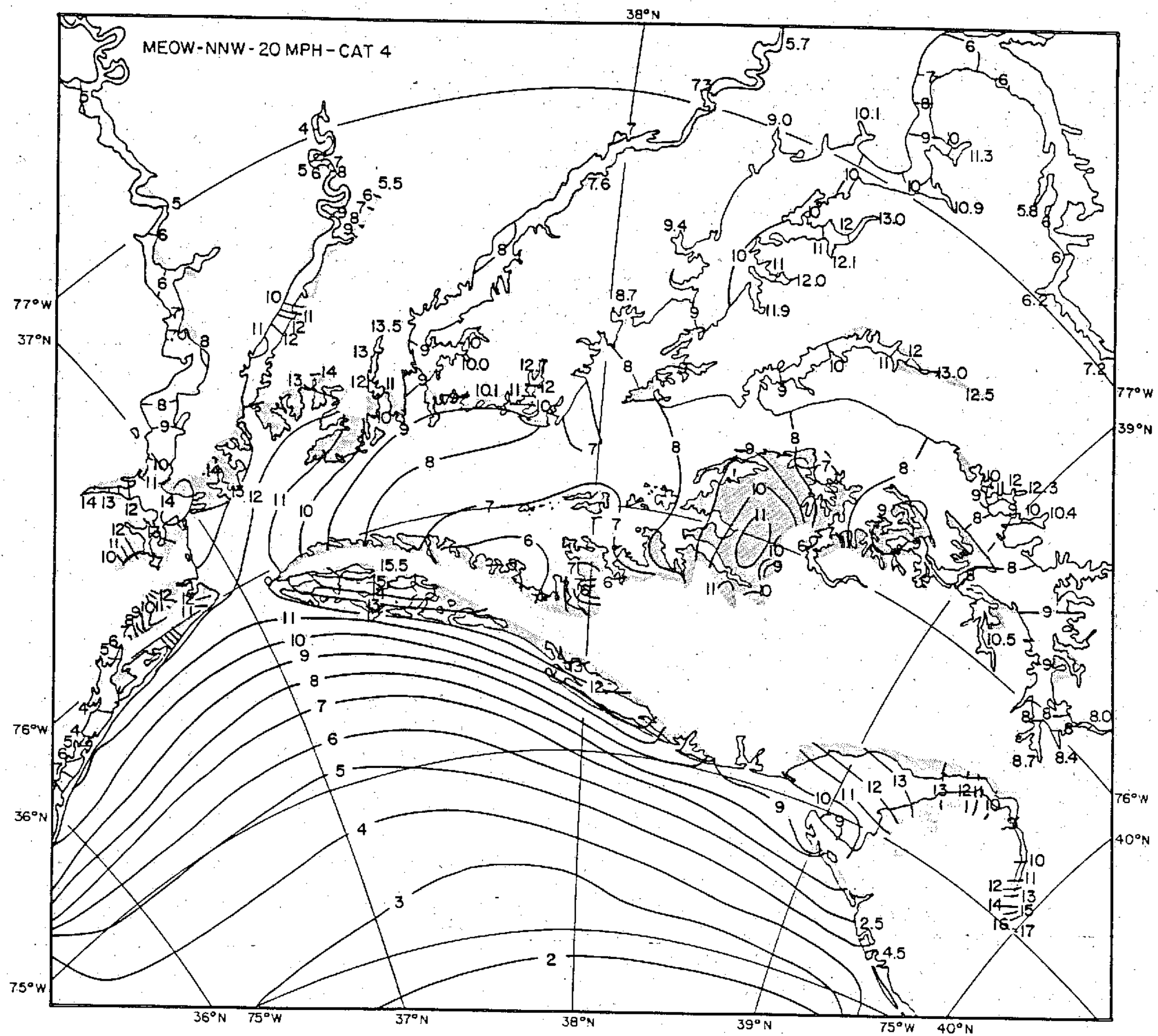
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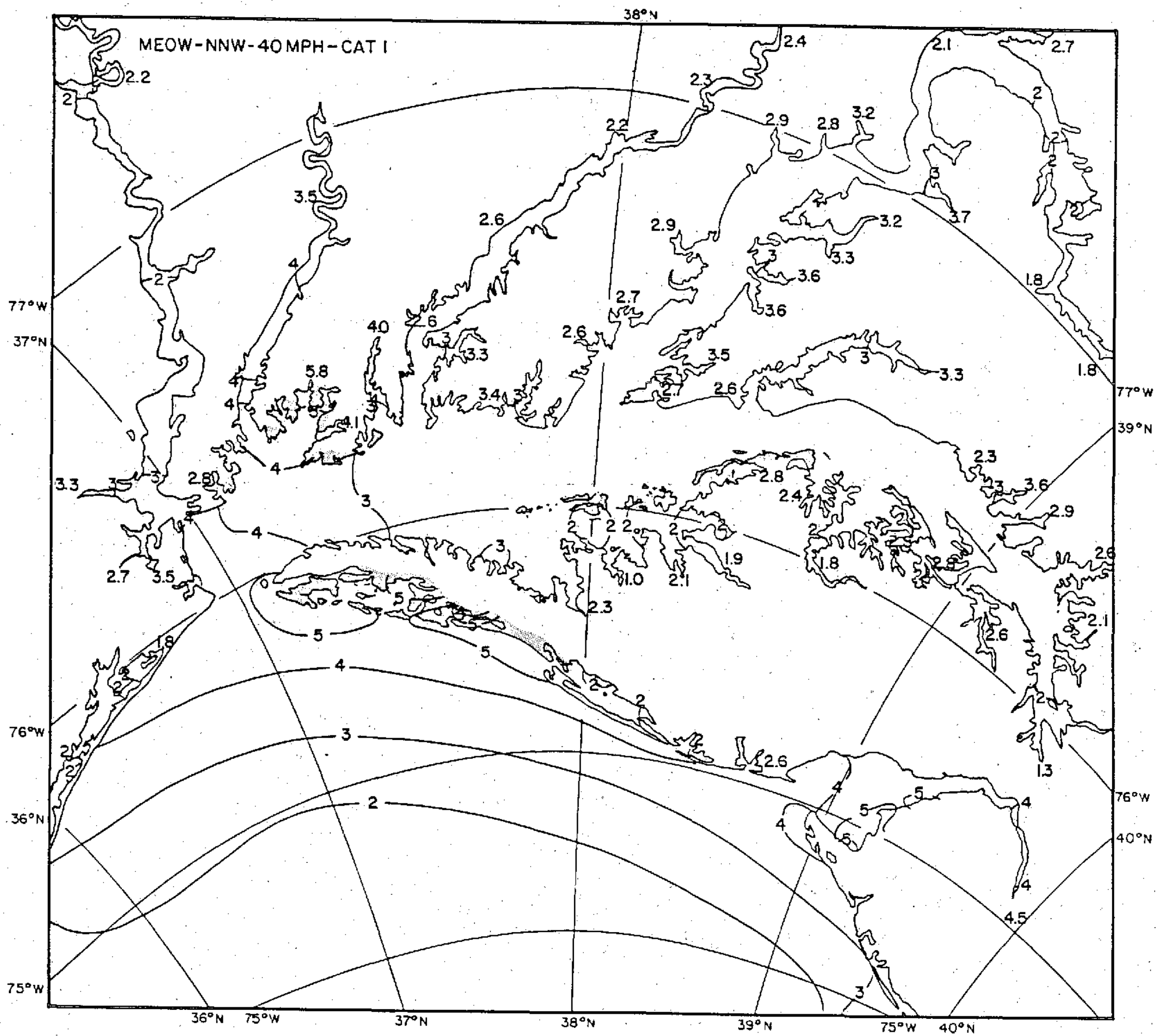
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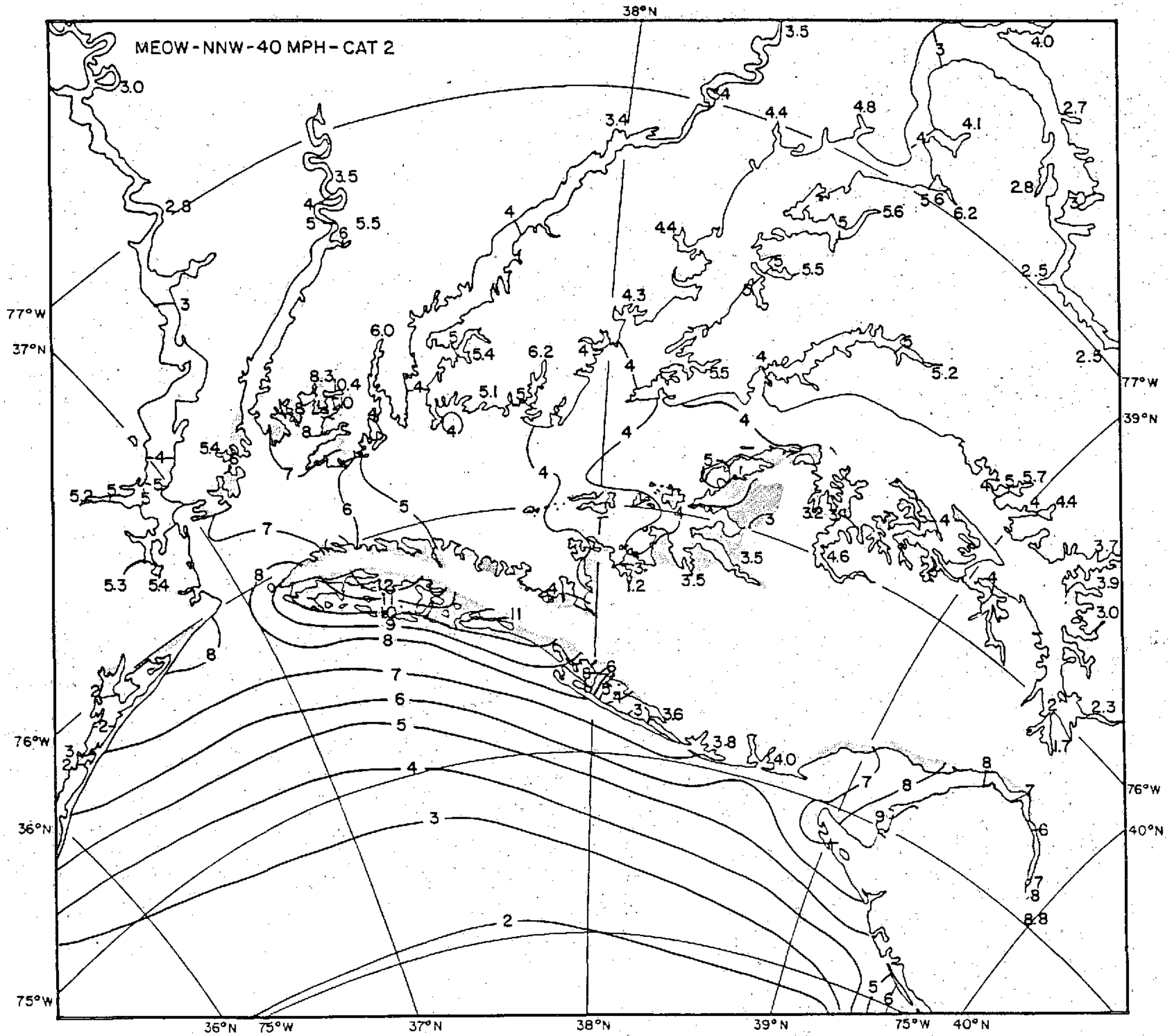
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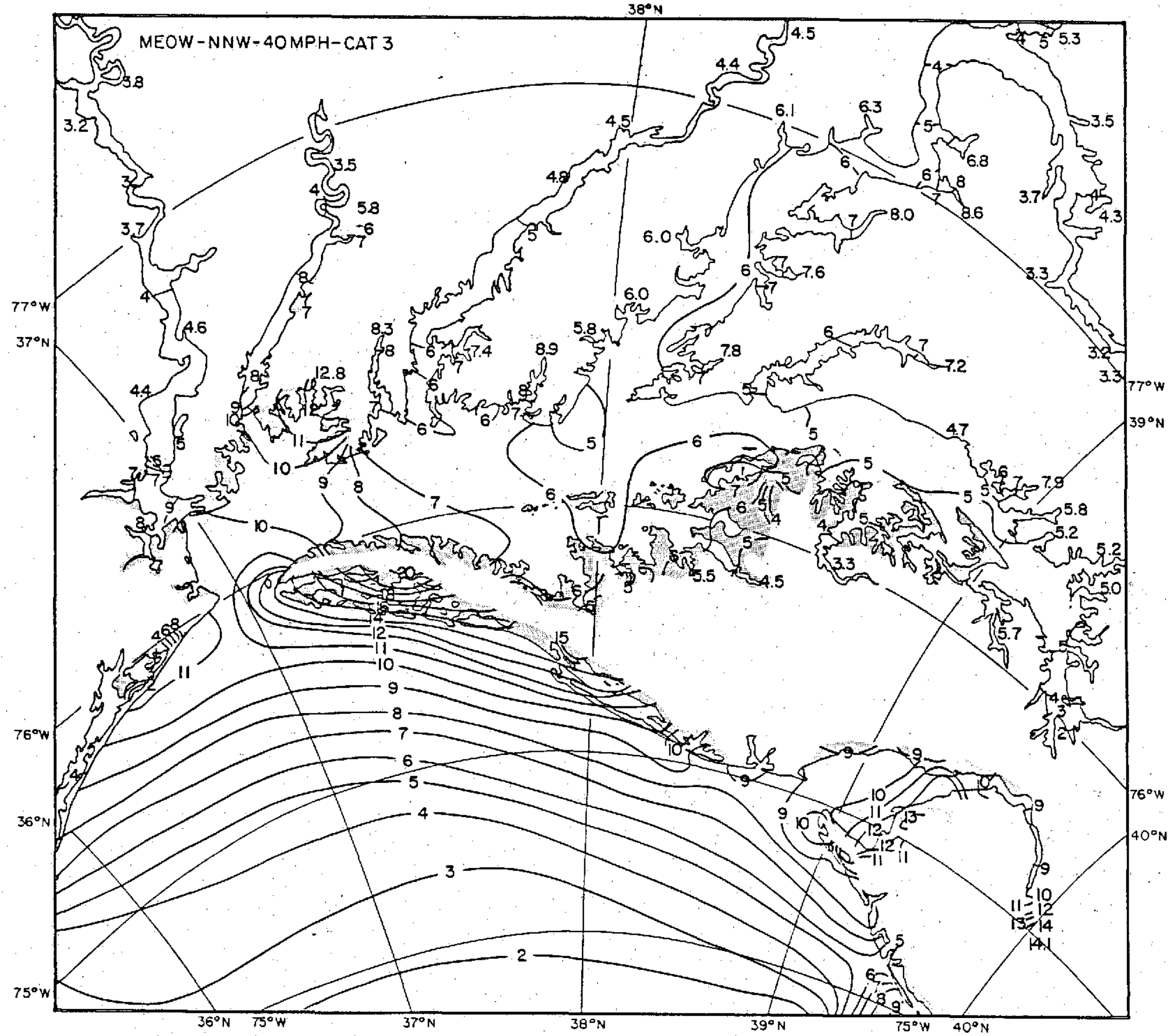
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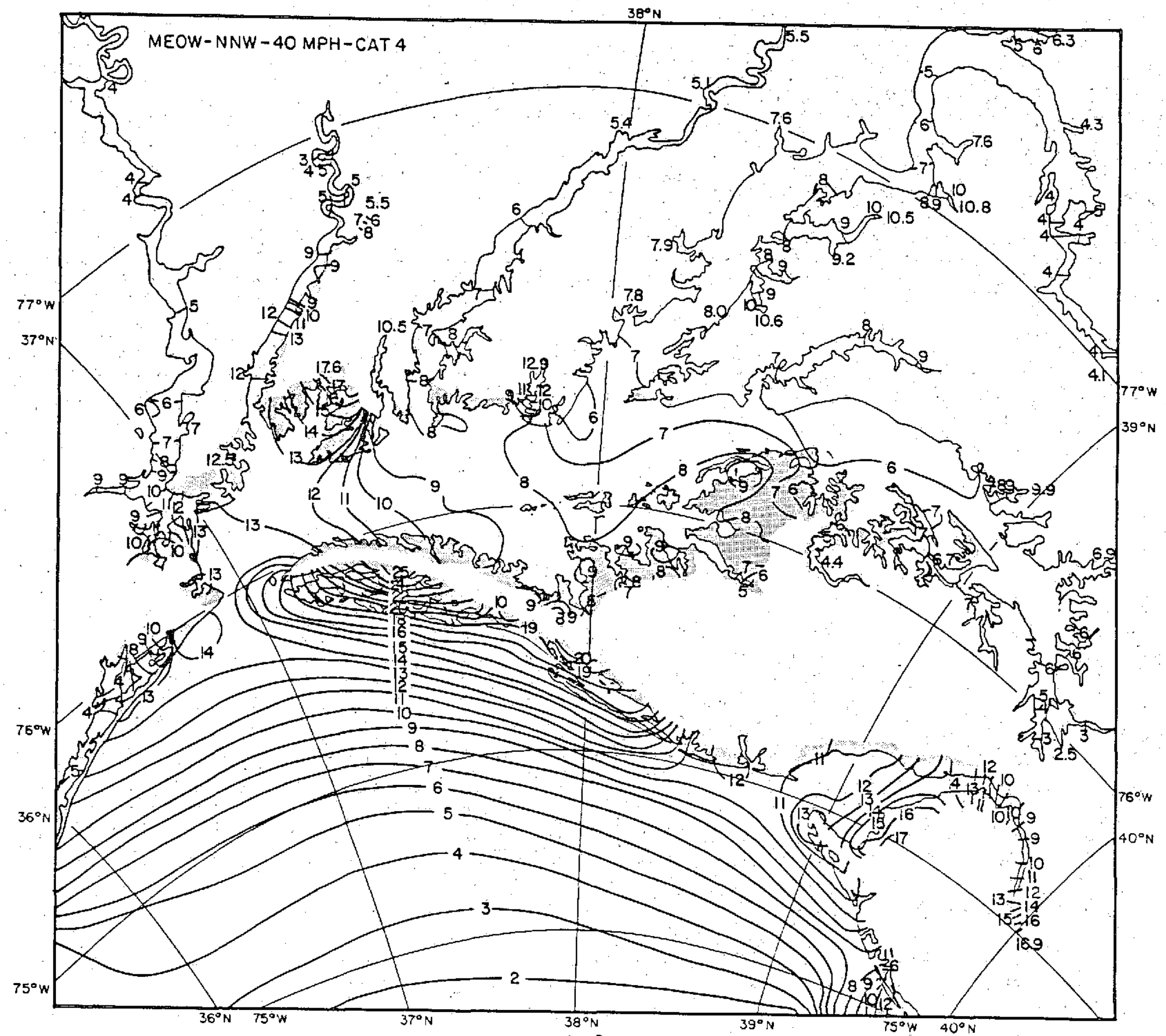
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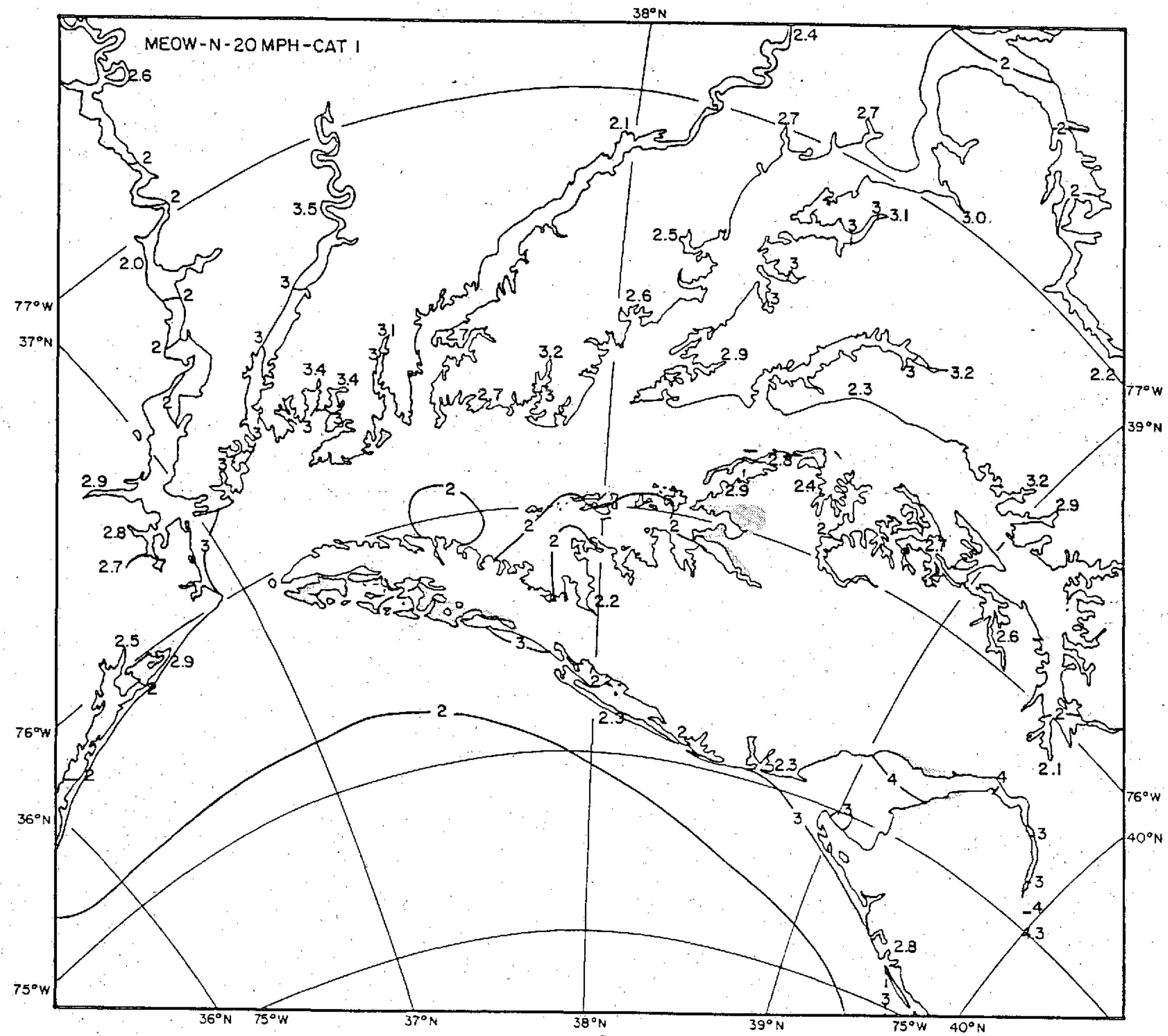
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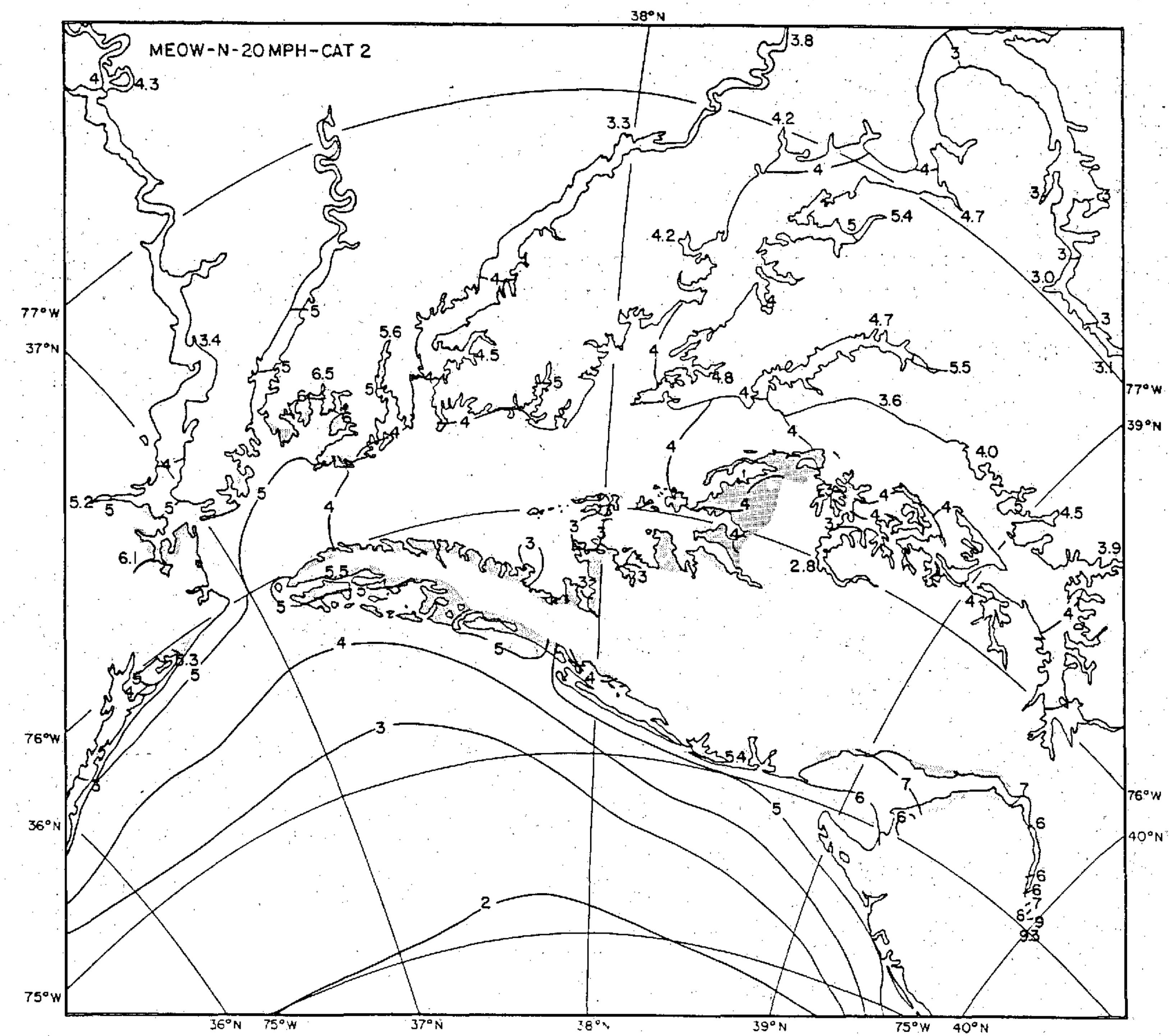
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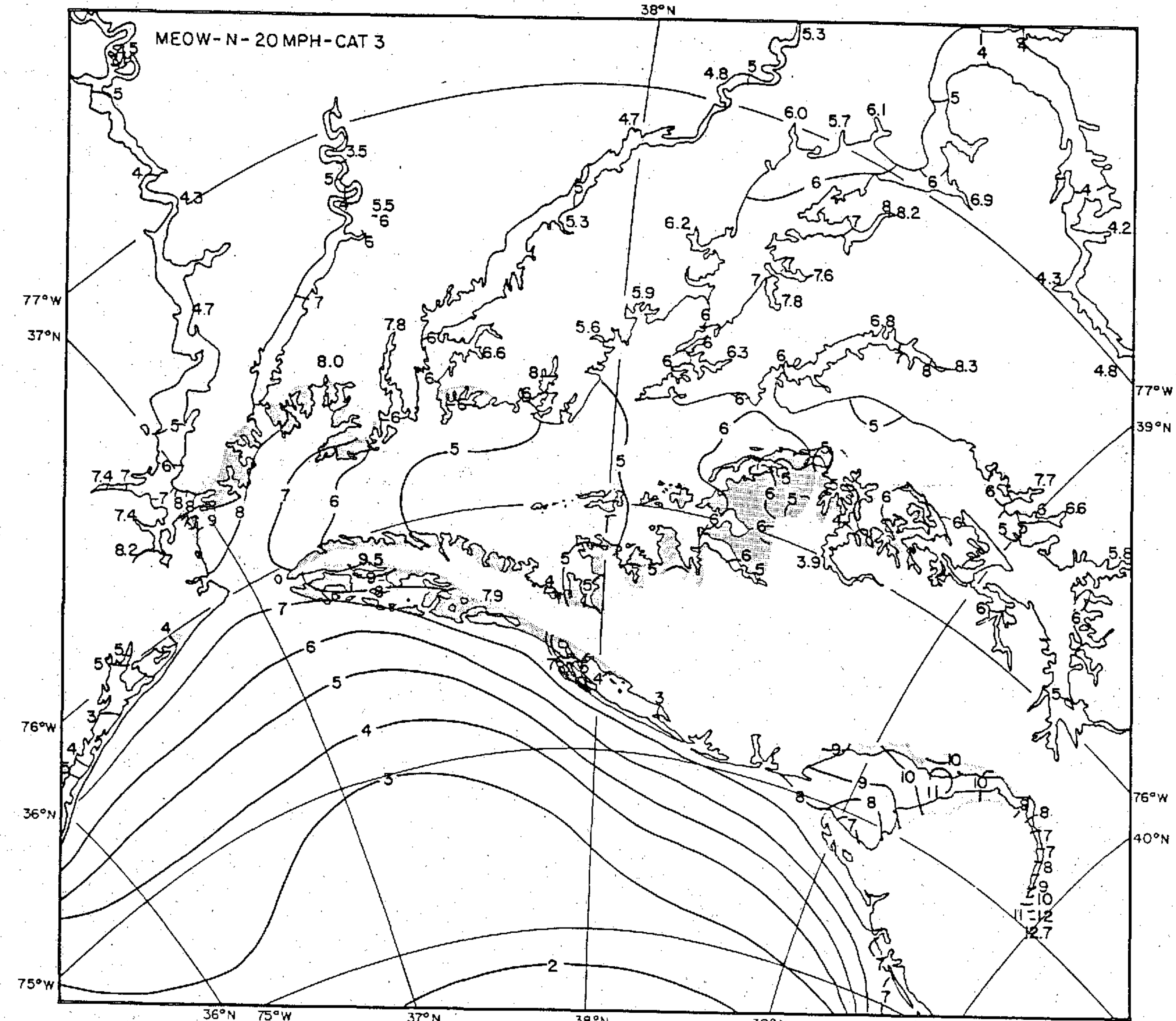
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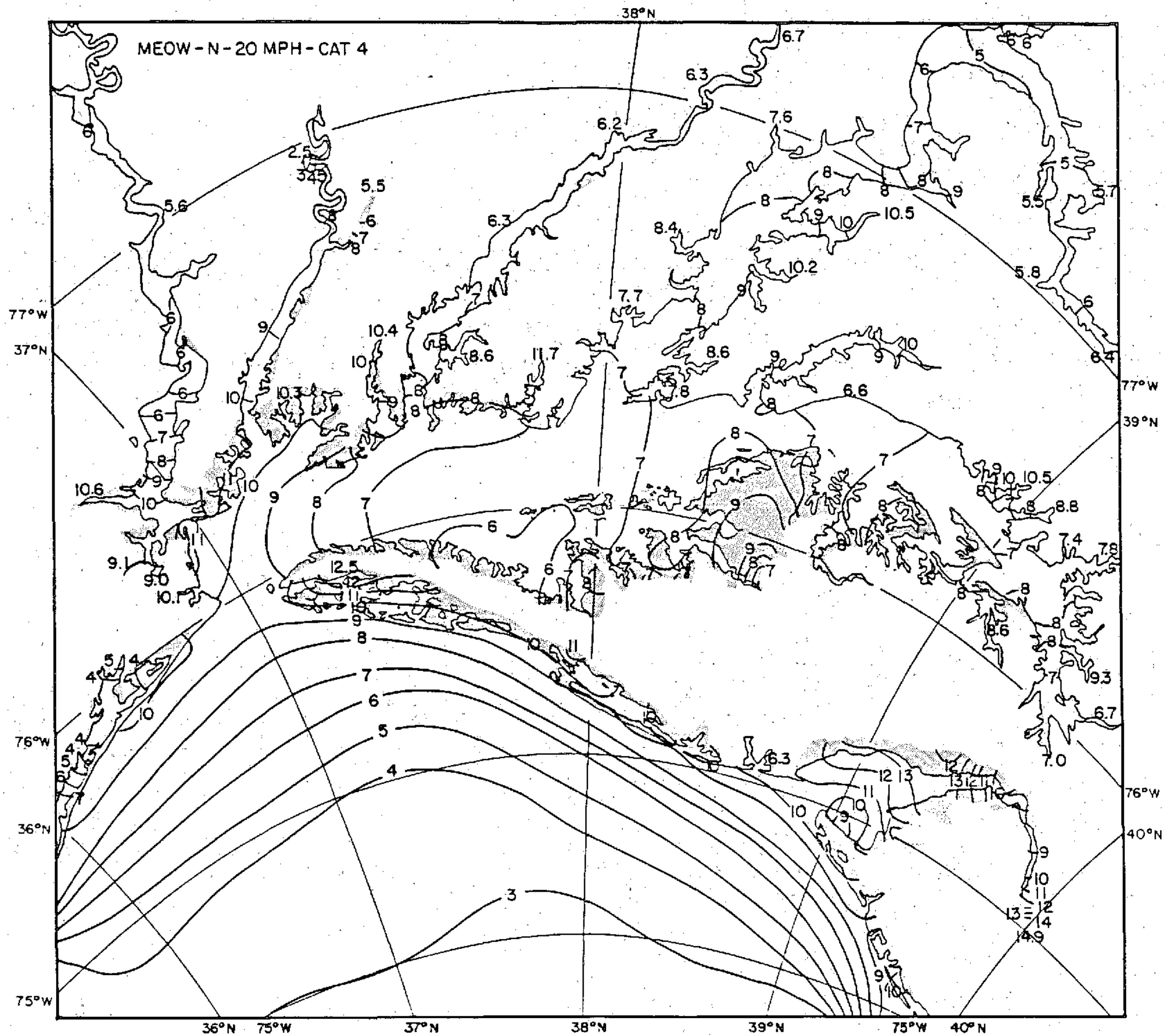
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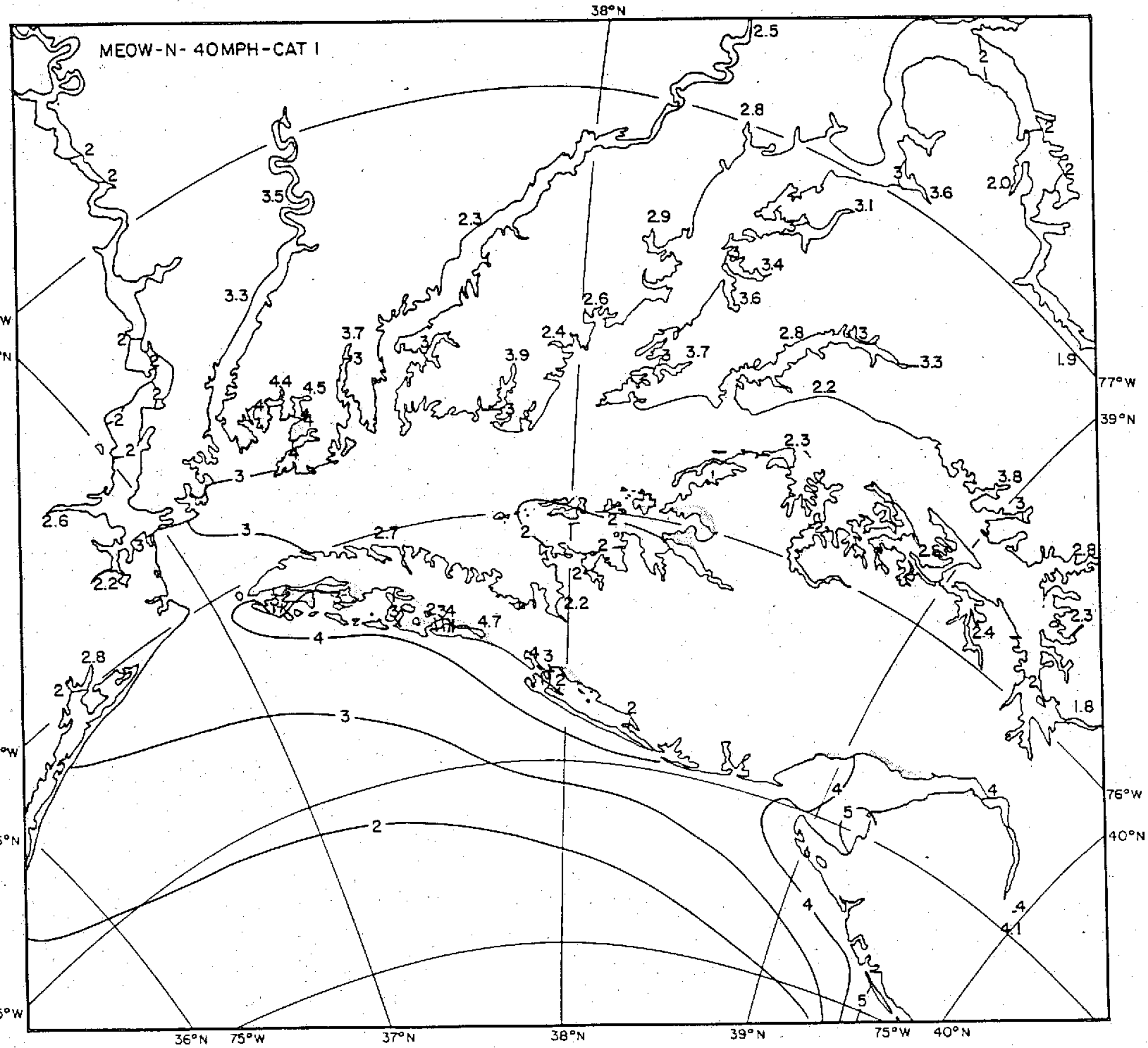
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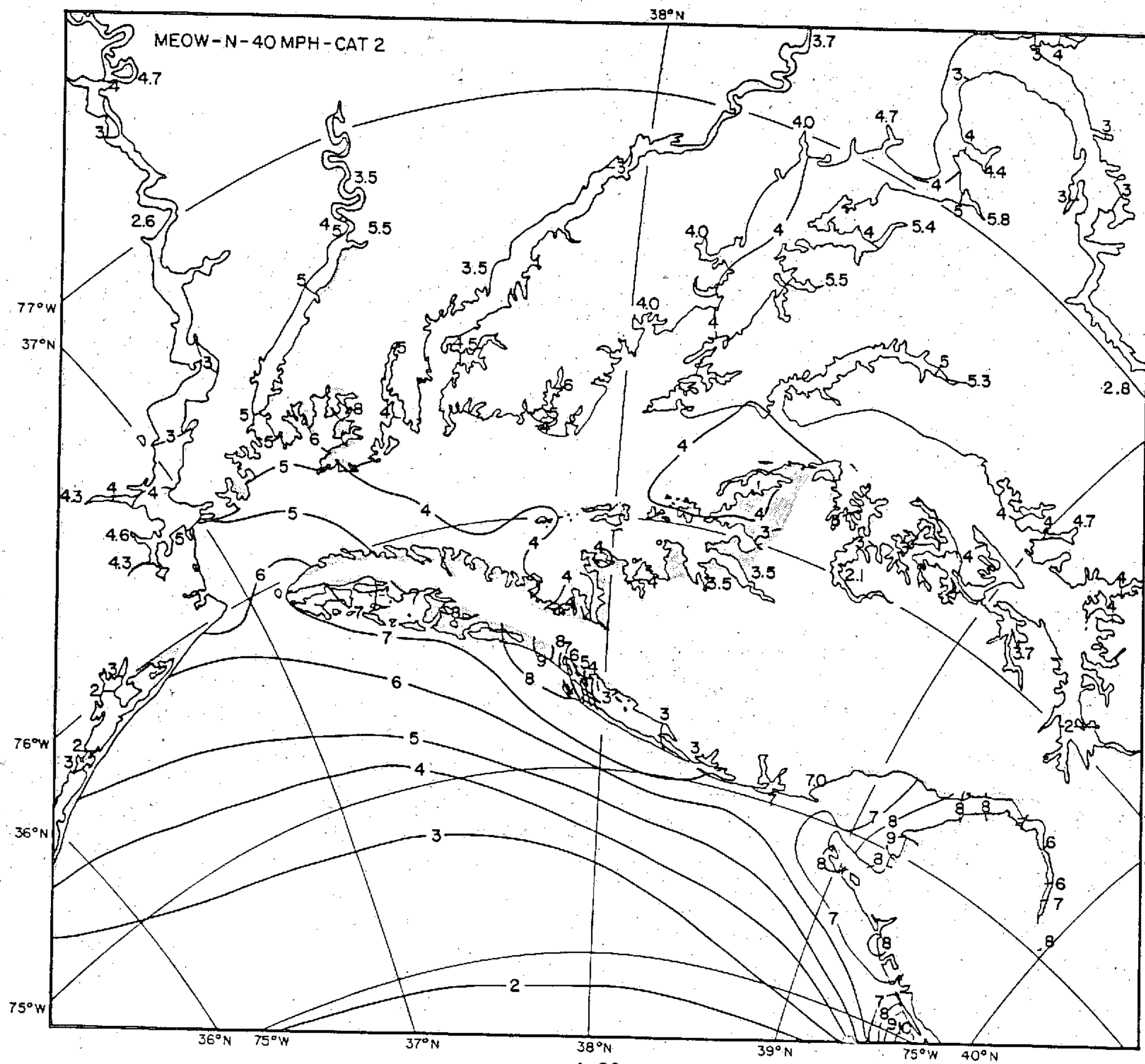
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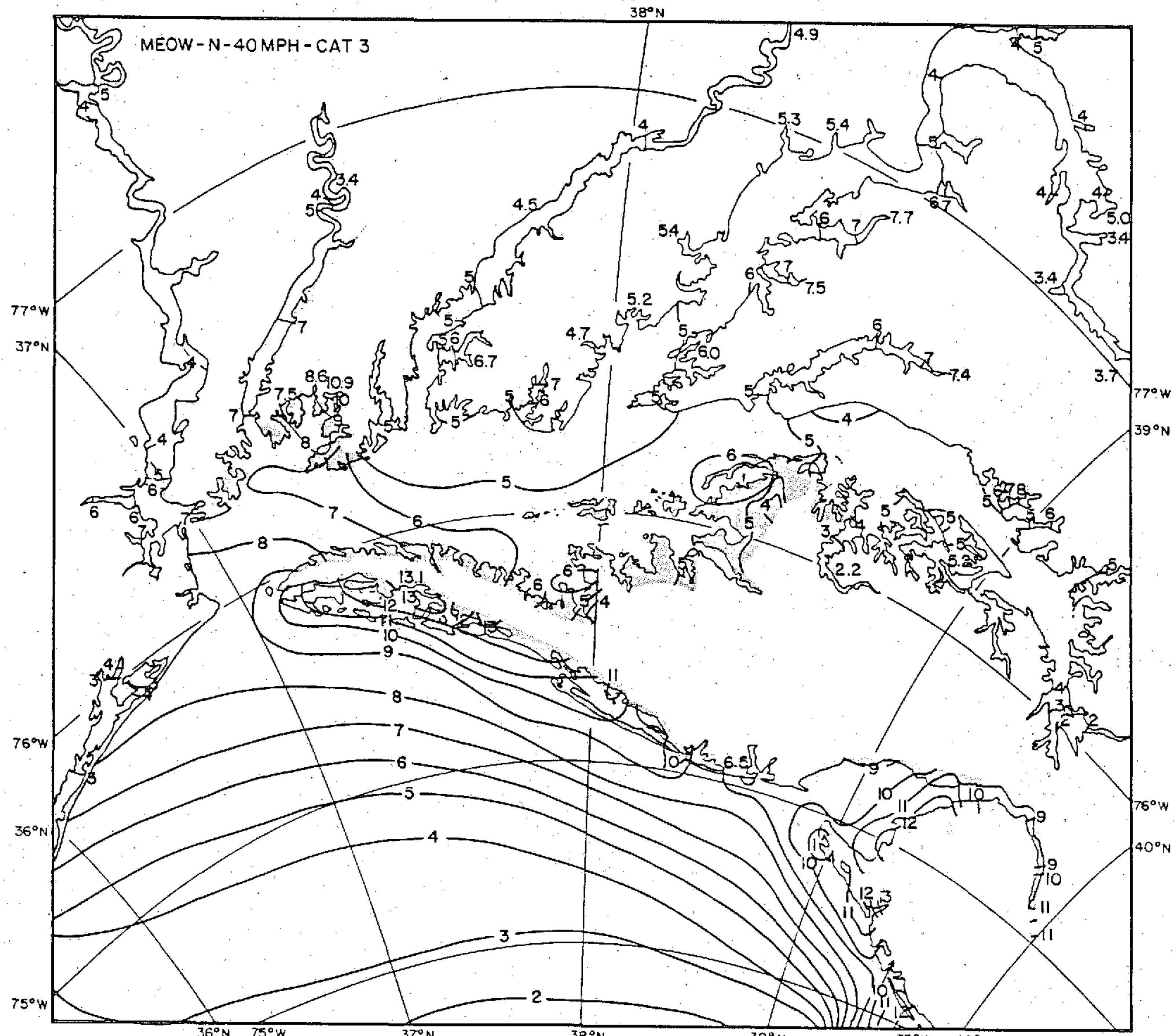

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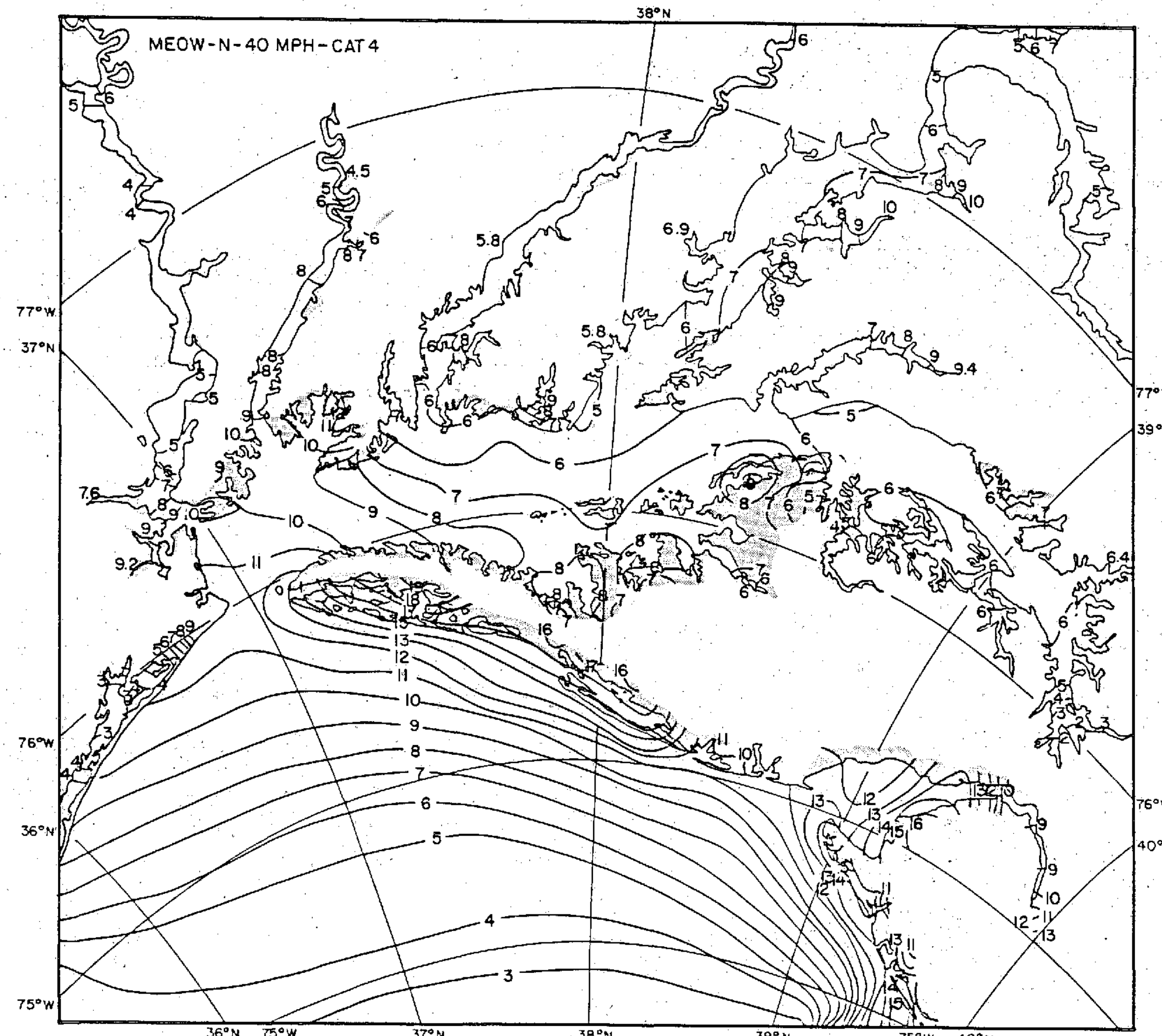
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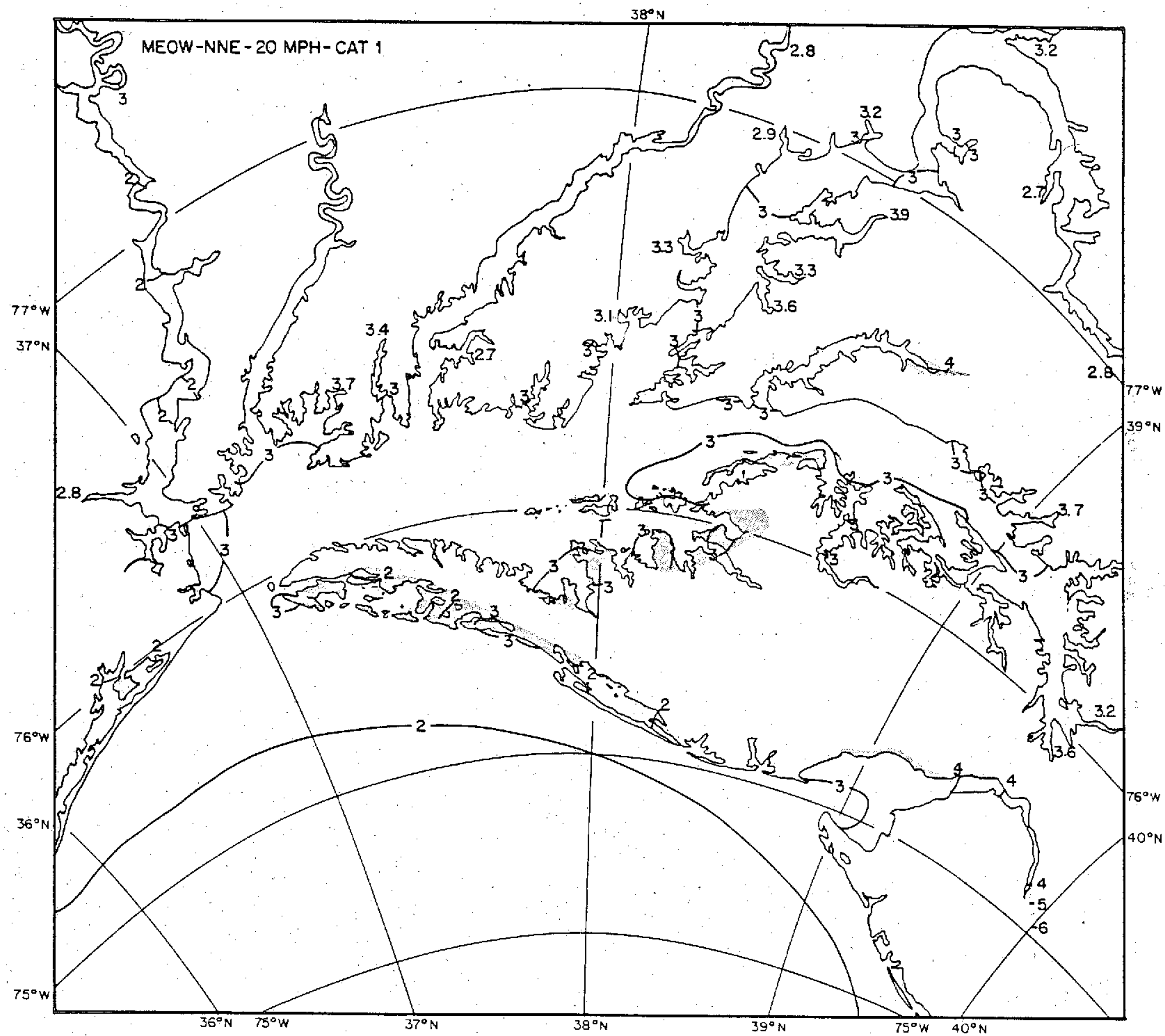
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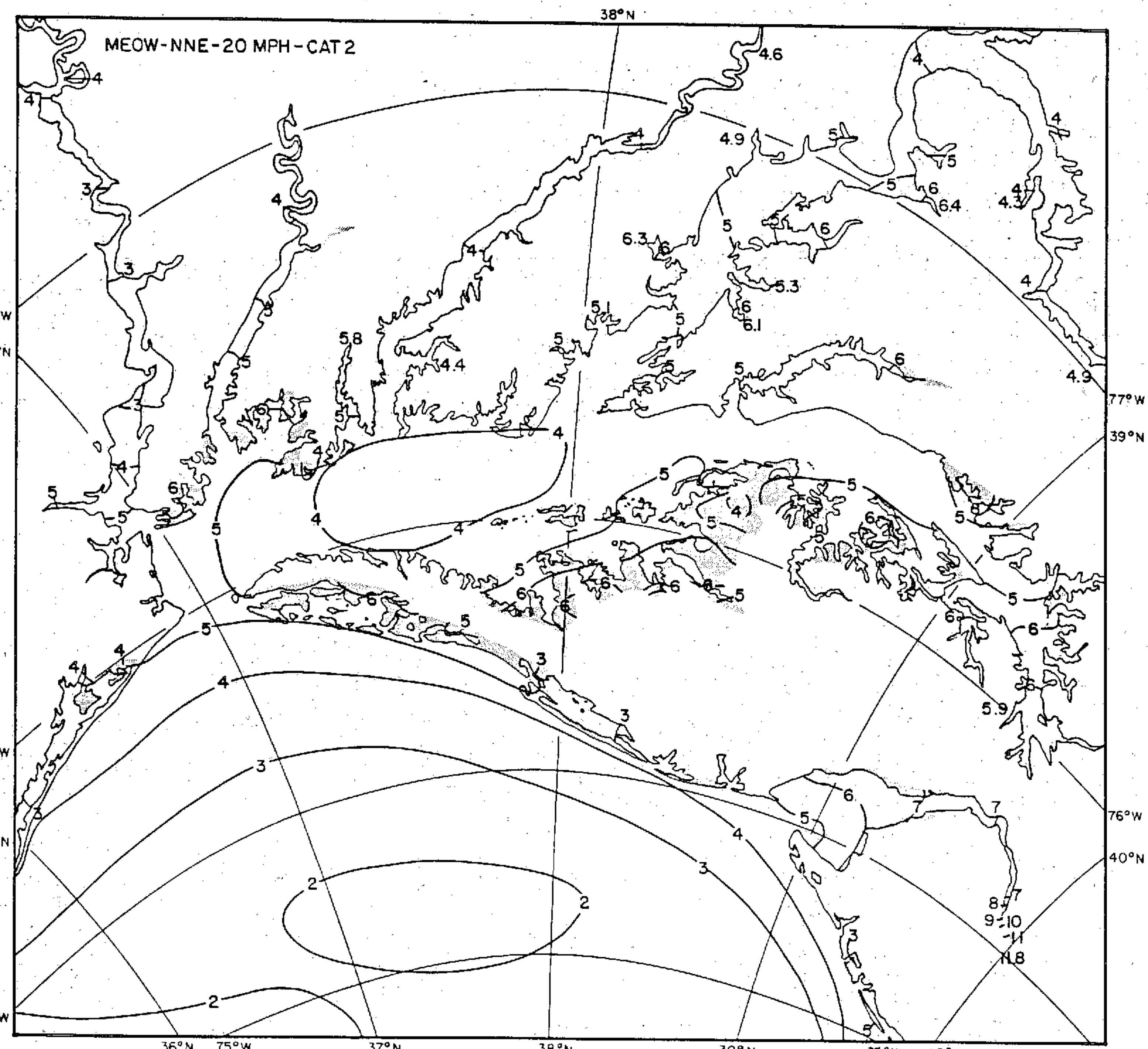
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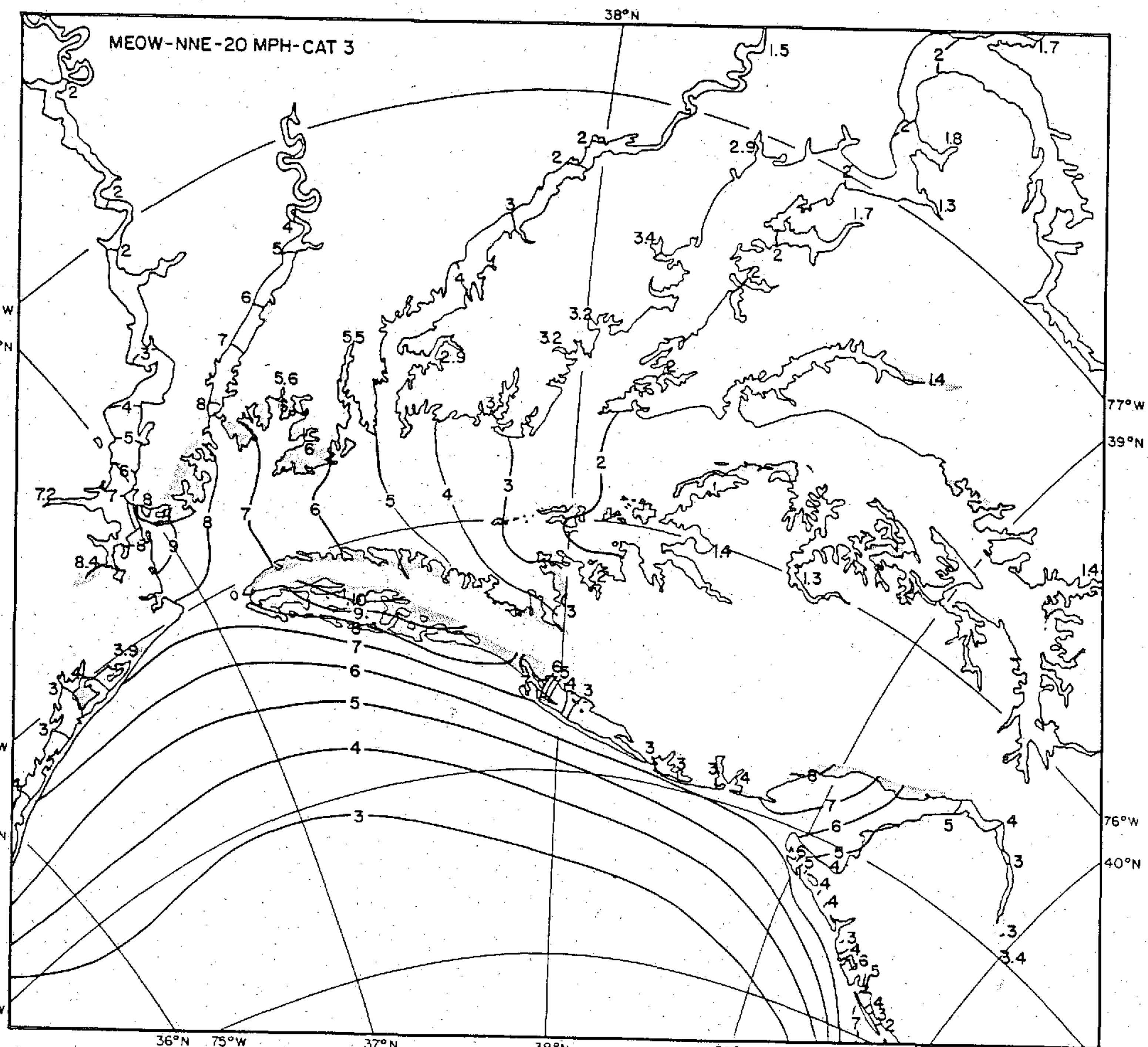
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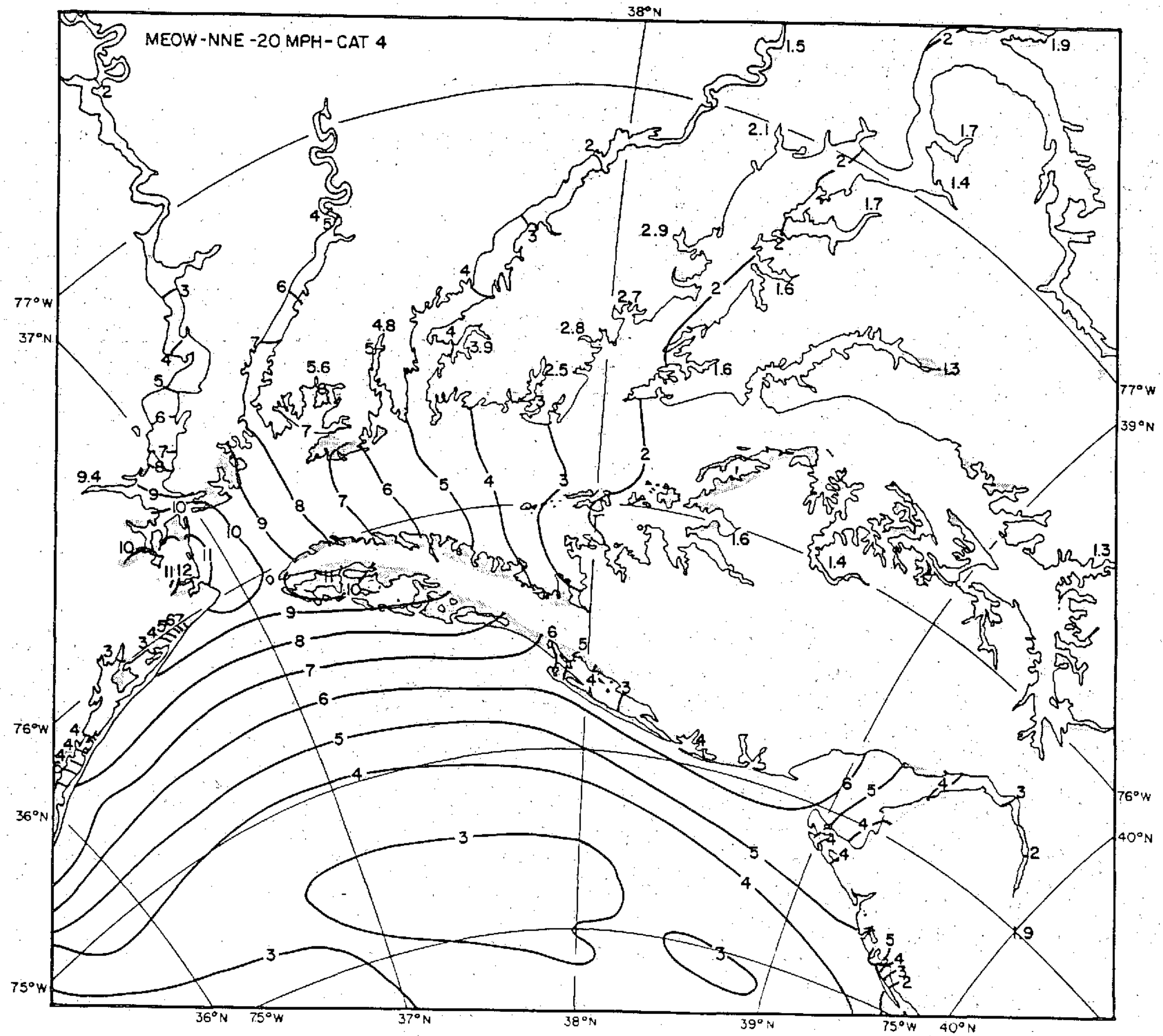
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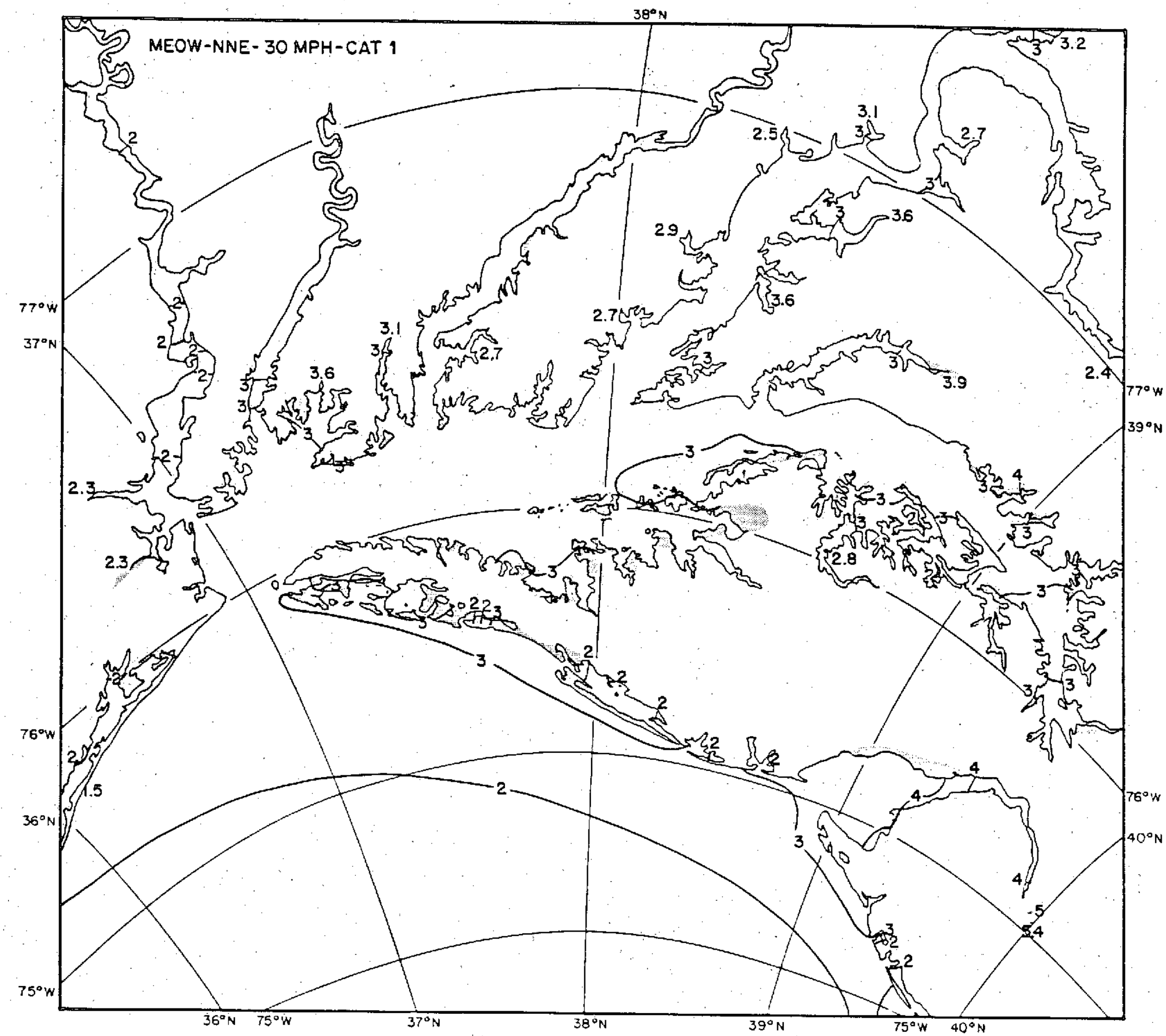
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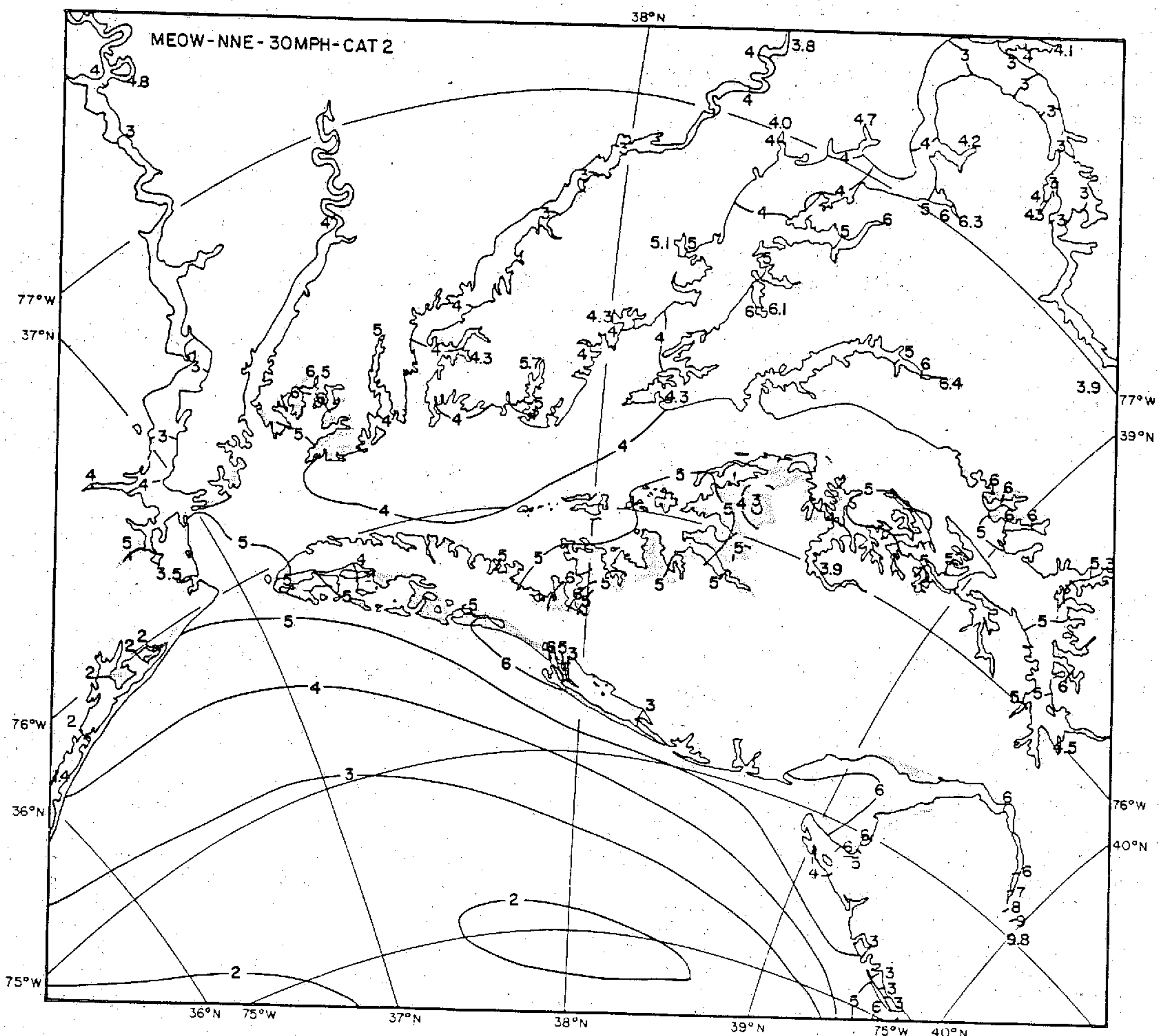
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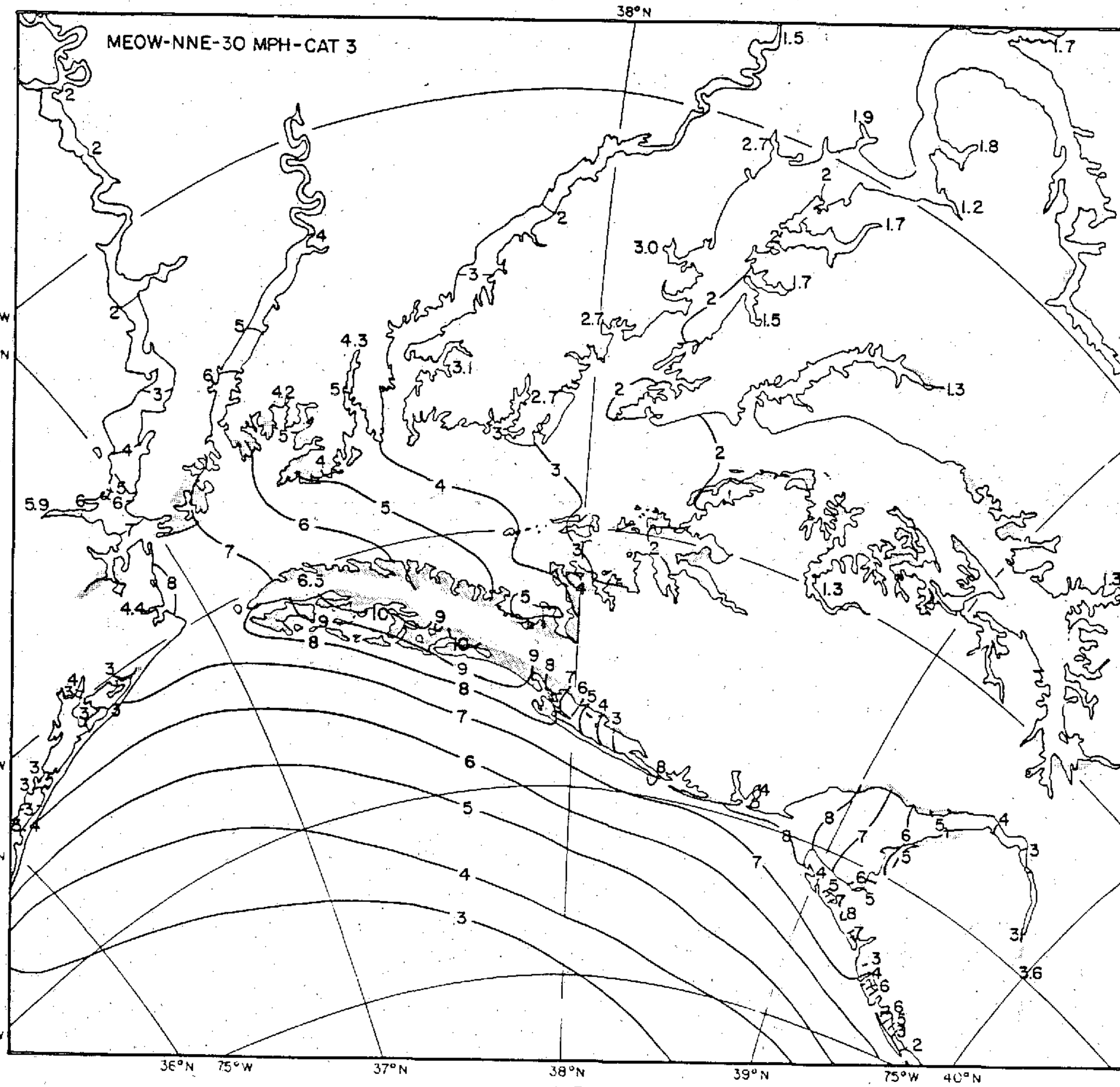
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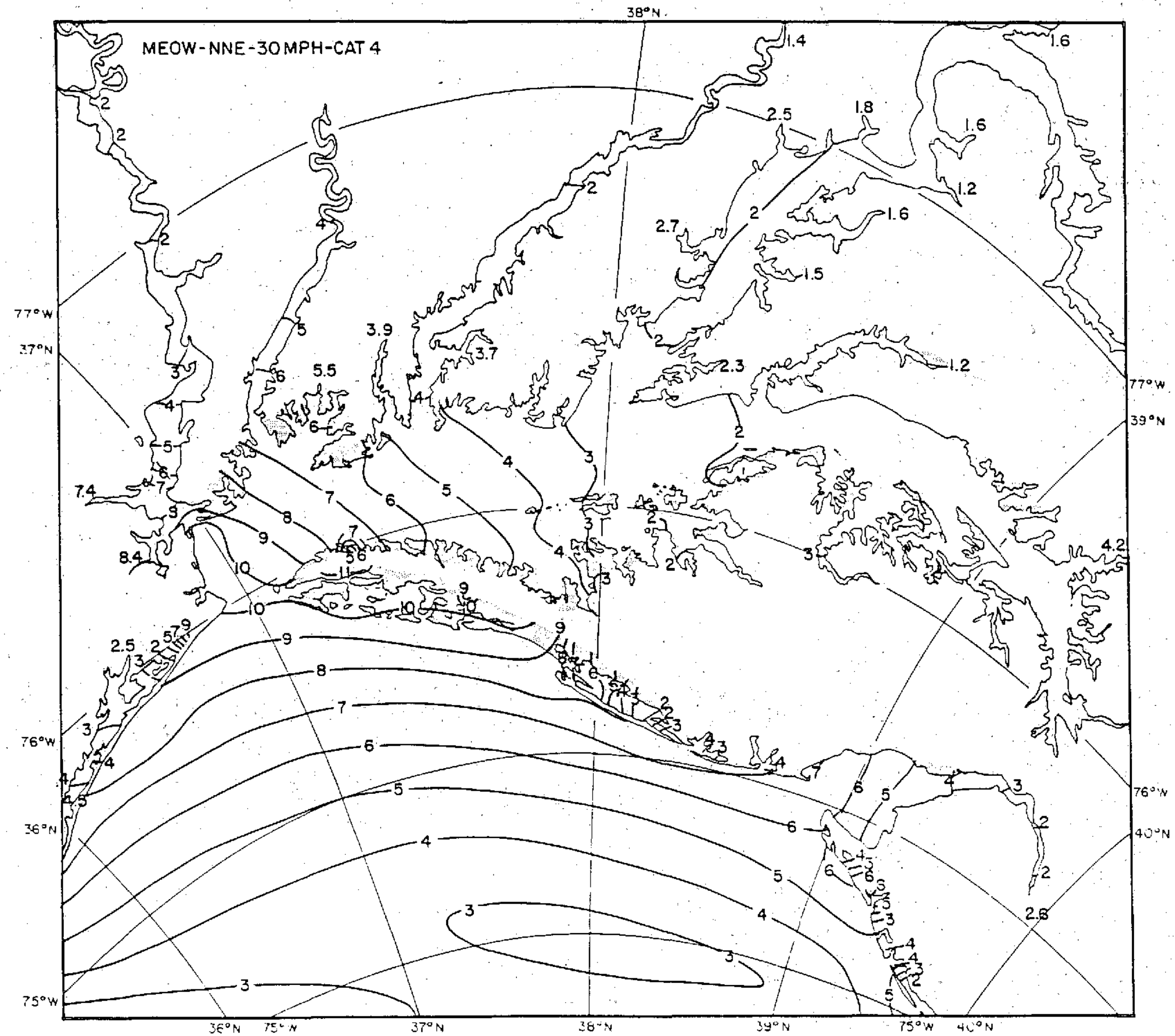
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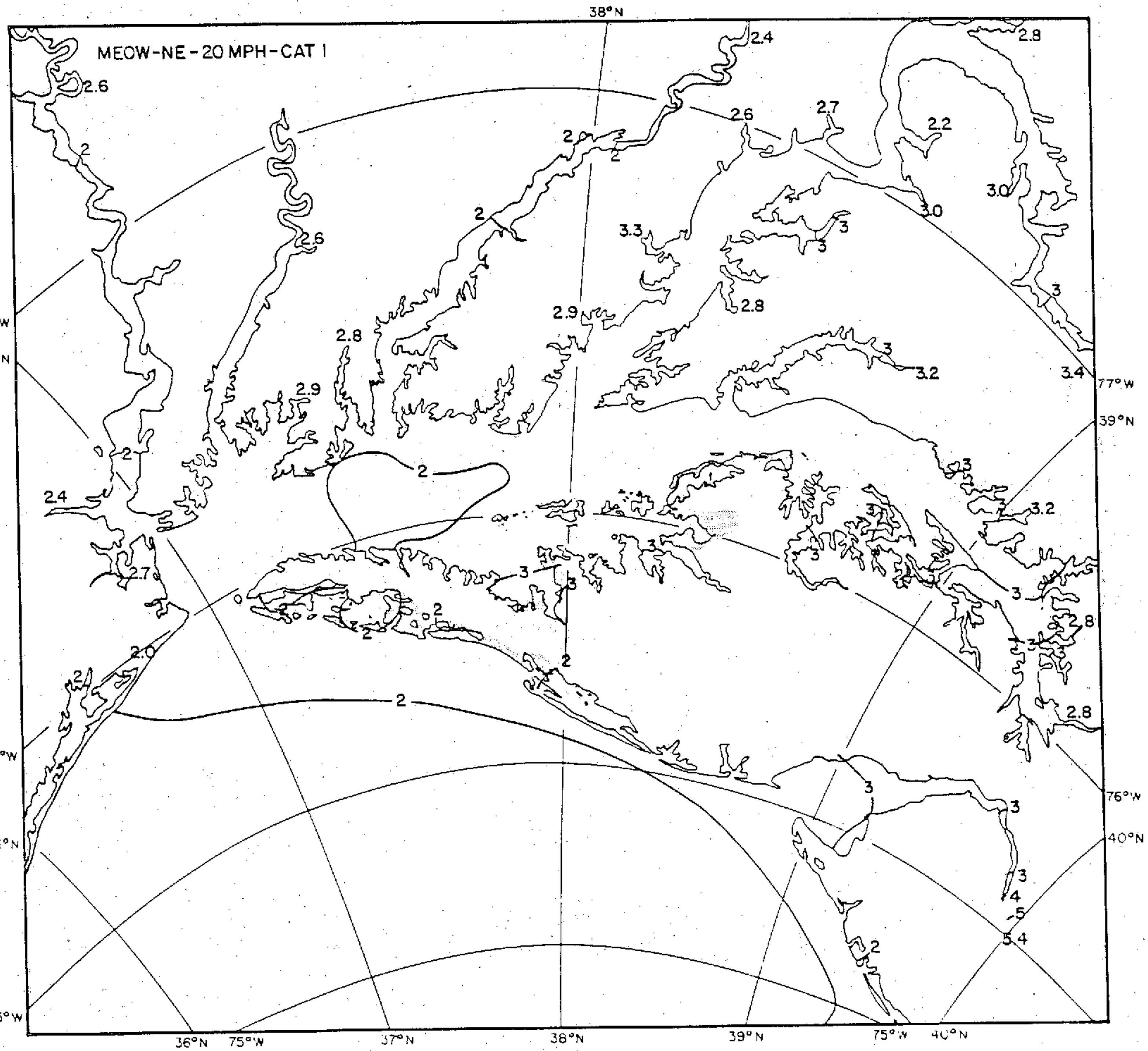
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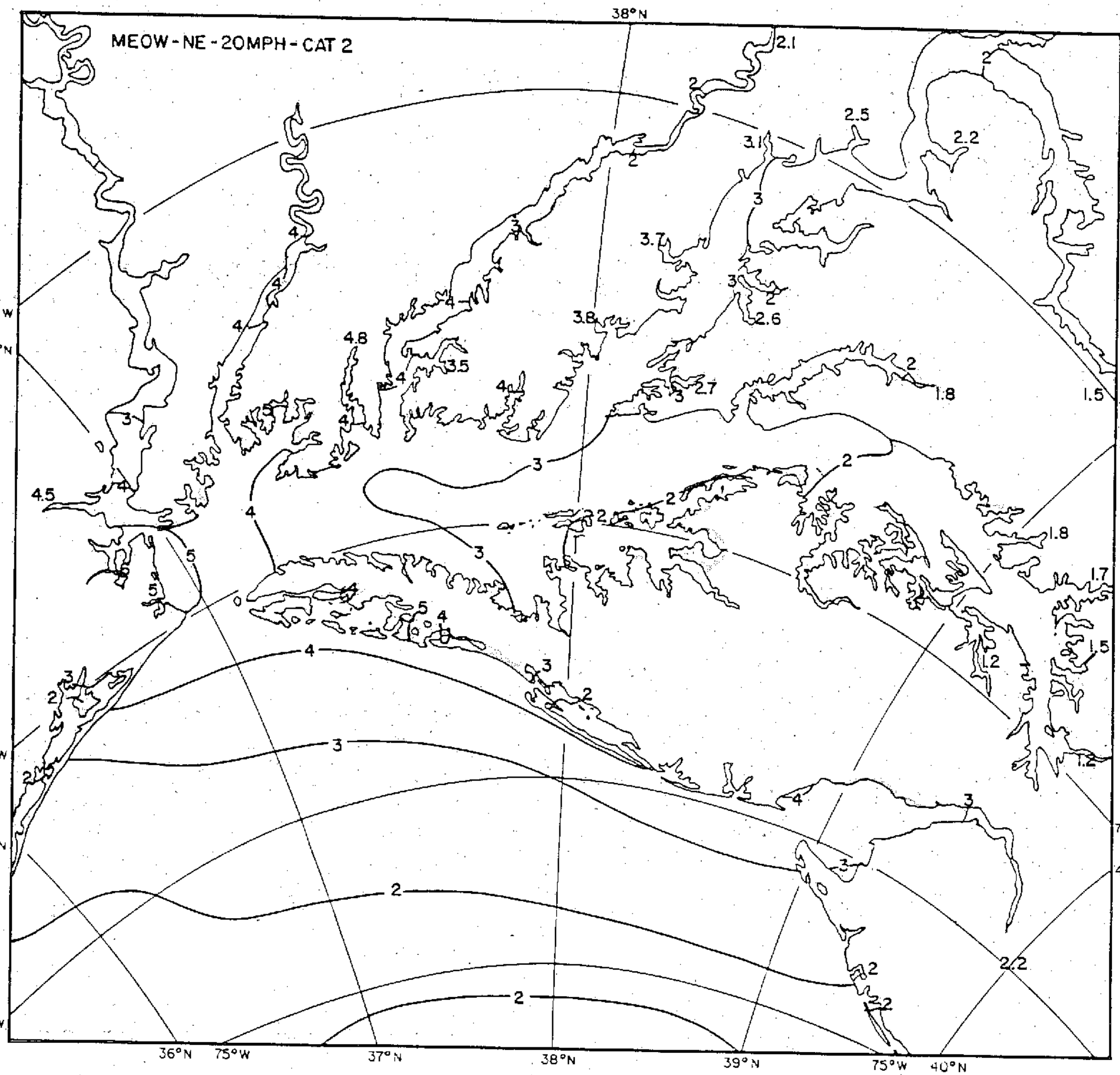
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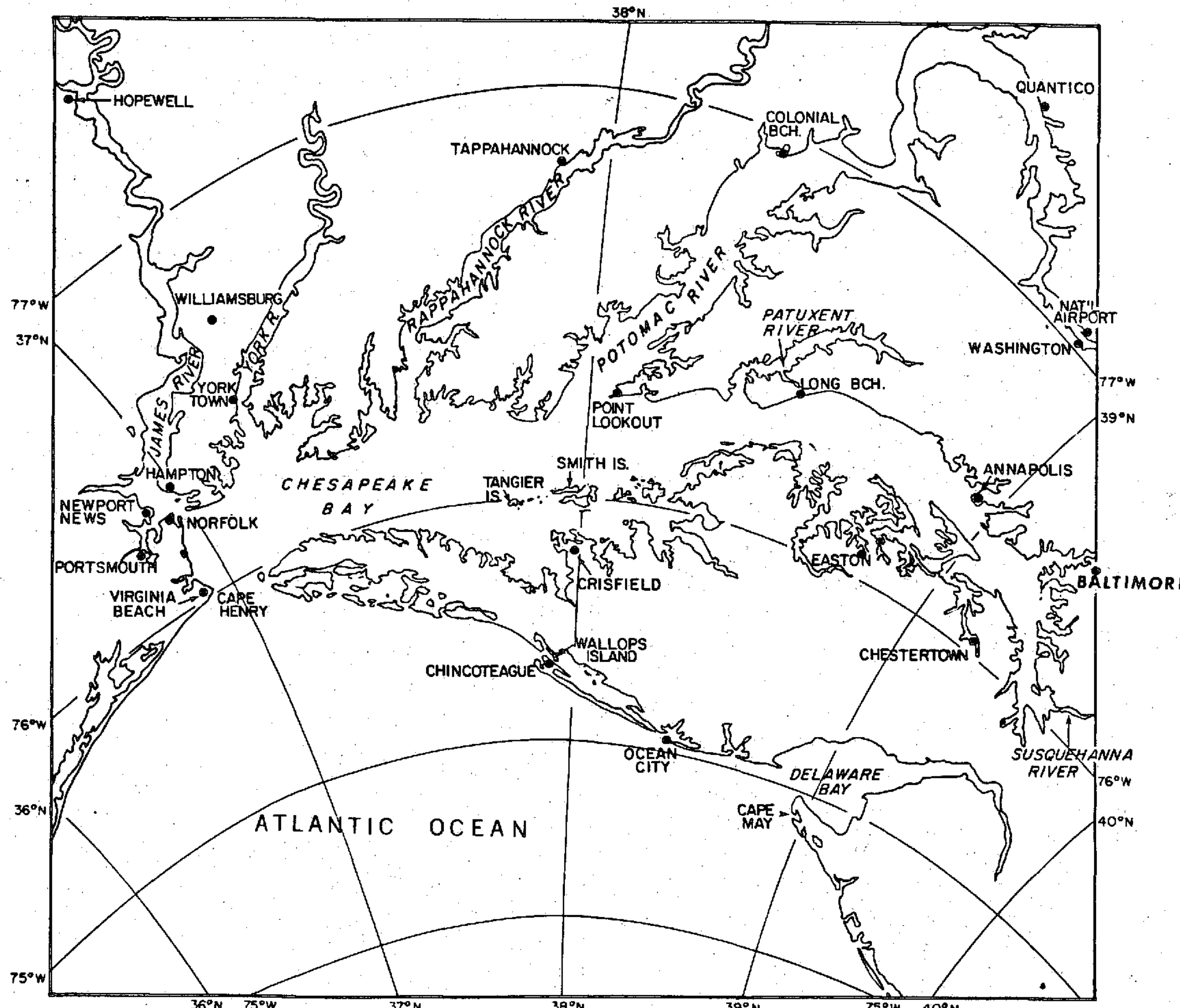
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9. FIGURE CAPTIONS

Figure 1. Grid mesh for SLOSH model for Chesapeake Bay basin.

Figure 2. Tracks of hurricanes passing within 100 miles of Wallops Island, Virginia, since 1900: westbound Hurricane Doria.

Figure 3. Same as Figure 2, except for northbound storms.

Figure 4. Same as Figure 2, except for northeastward moving storms.

Figure 5. Tracks of the hypothetical hurricanes that were used for calculating the maximum envelope of water (MEOW). Hurricane symbol is at point of landfall of eye of storm, and dots are eye positions at 6 hour increments. Tracks are identified by the distance (in miles) of their landfall point to the left side (LS) or right side (RS) of Cape Henry; west-northwestward (WNW) moving storms only.

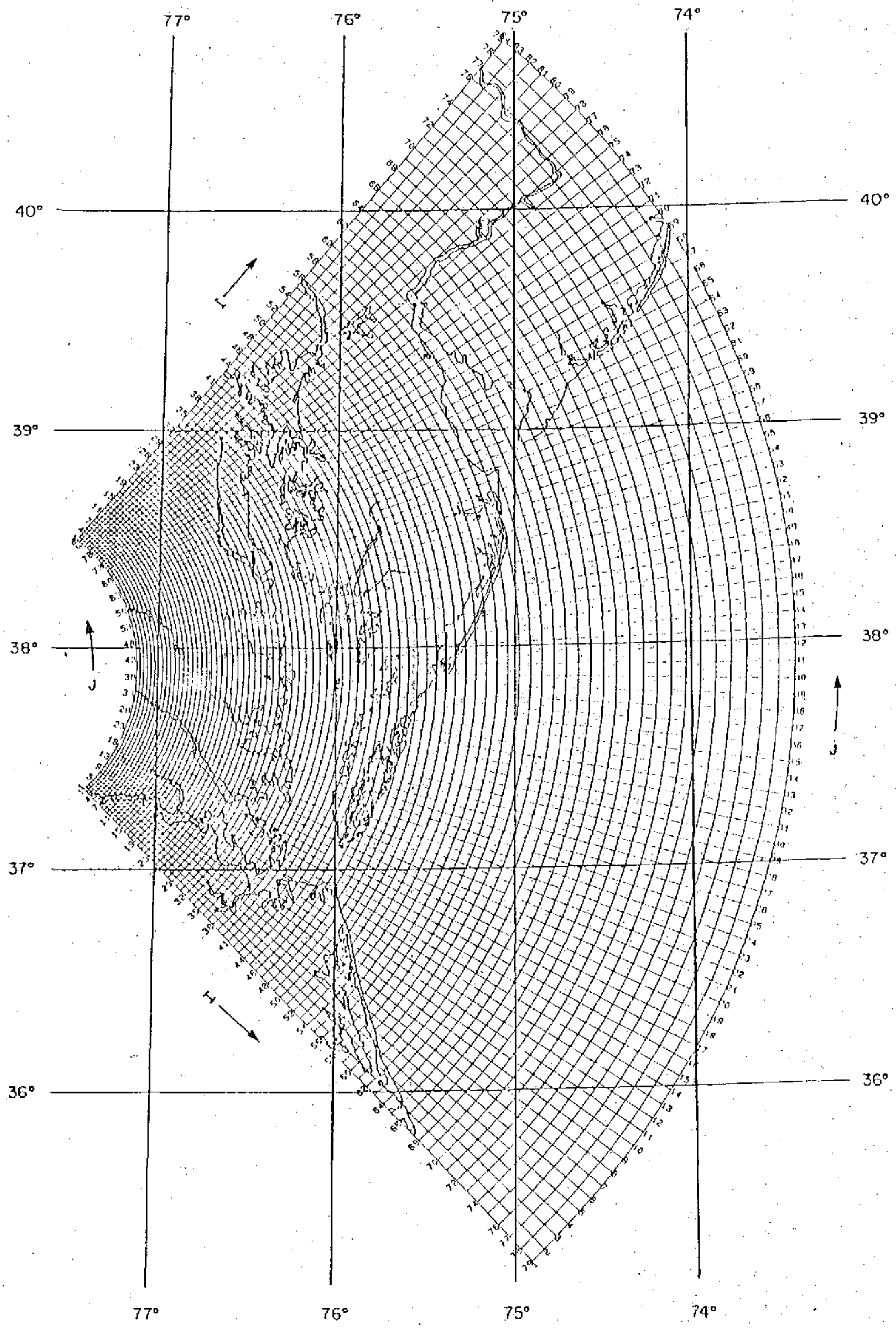
Figure 6. Same as Figure 5, except for northwestbound (NW) storms only.

Figure 7. Same as Figure 5, except for north-northwestbound (NNW) storms only.

Figure 8. Same as Figure 5, except for northbound (N) storms only. Tracks lying to the right of track through Cape Henry have their "landfall point" on a perpendicular through Cape Henry.

Figure 9. Same as Figure 8, except for north-northeastbound (NNE) storms only.

Figure 10. Same as Figure 5, except for northeastbound (NE) storms only.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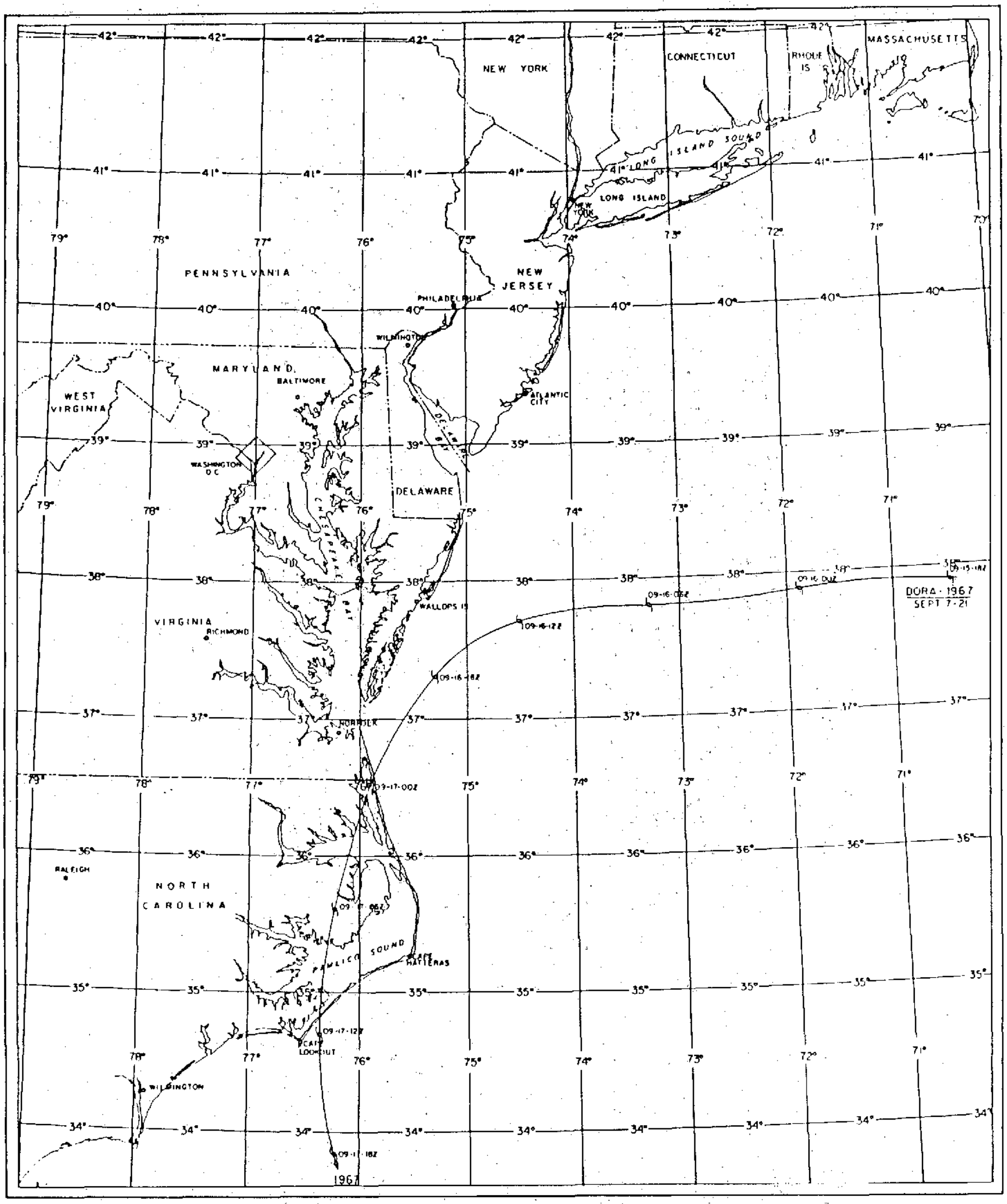

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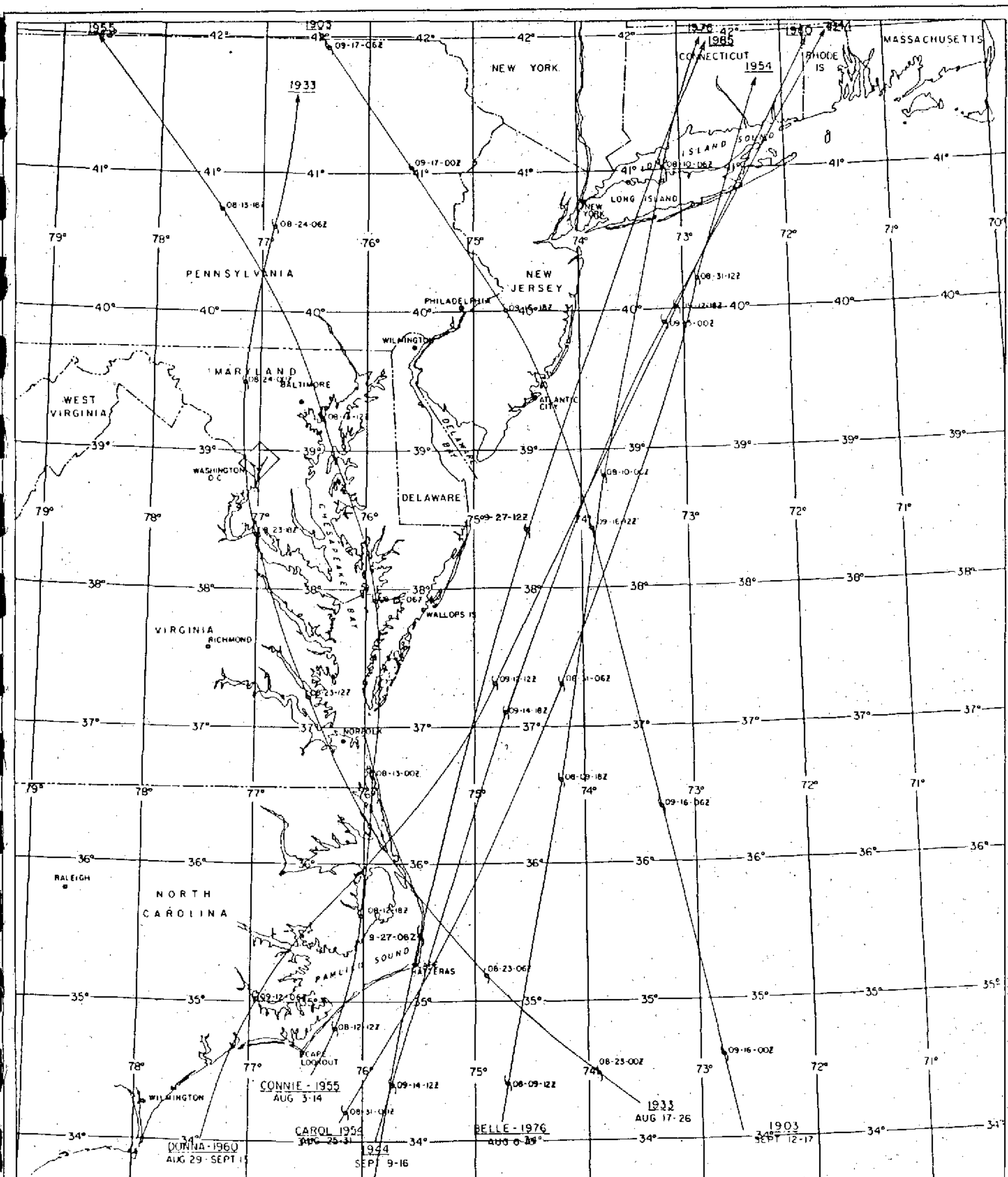
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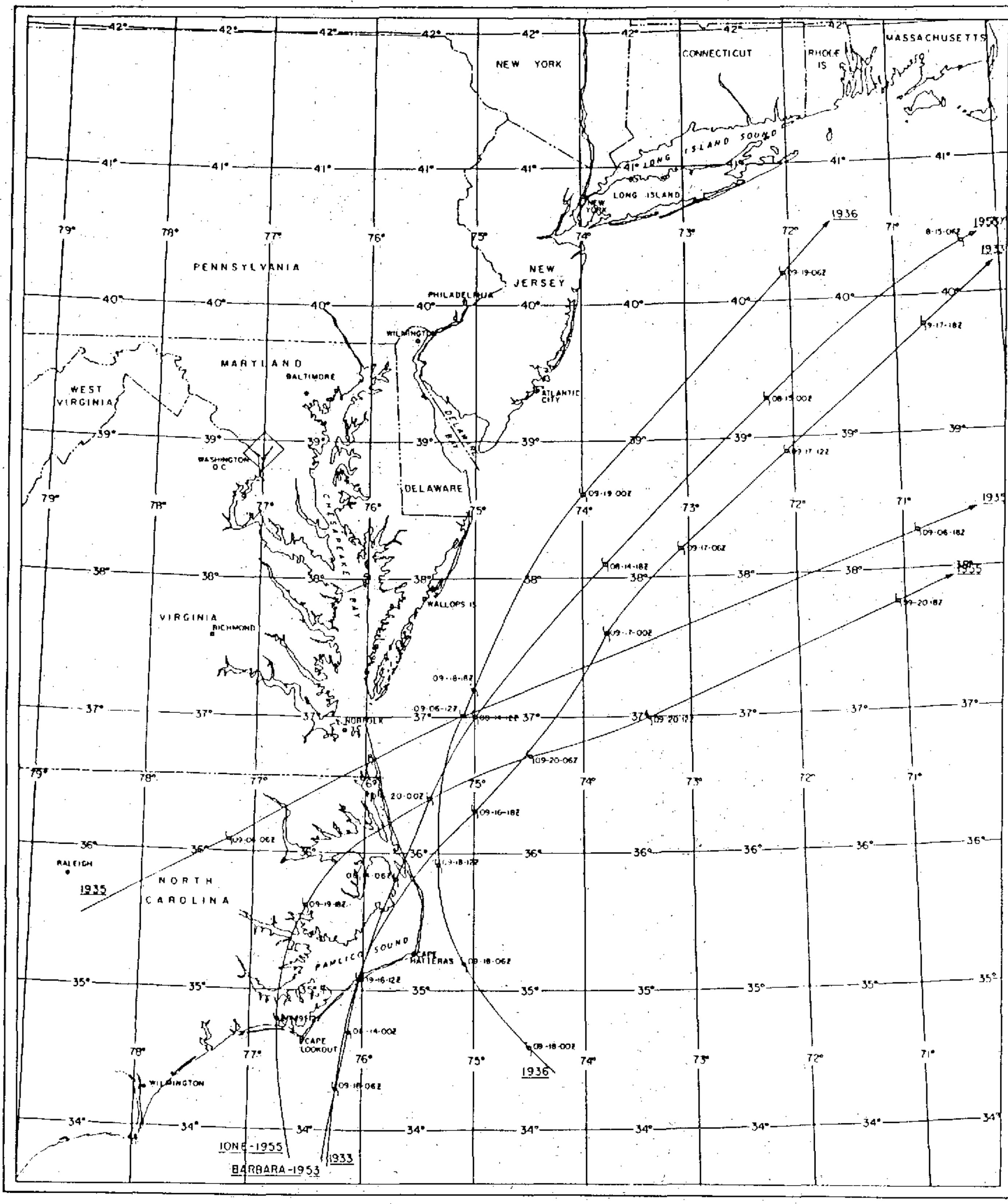

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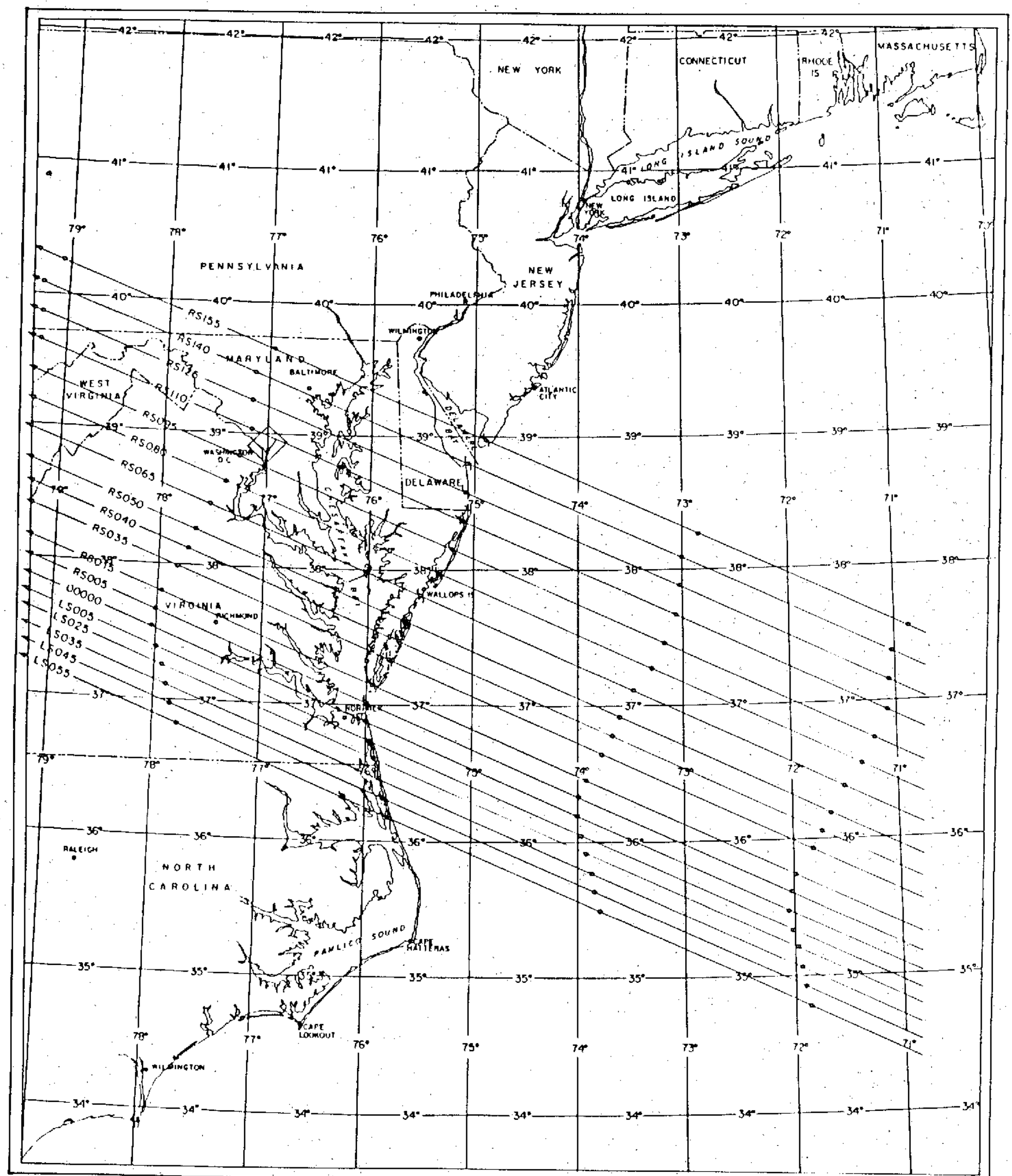

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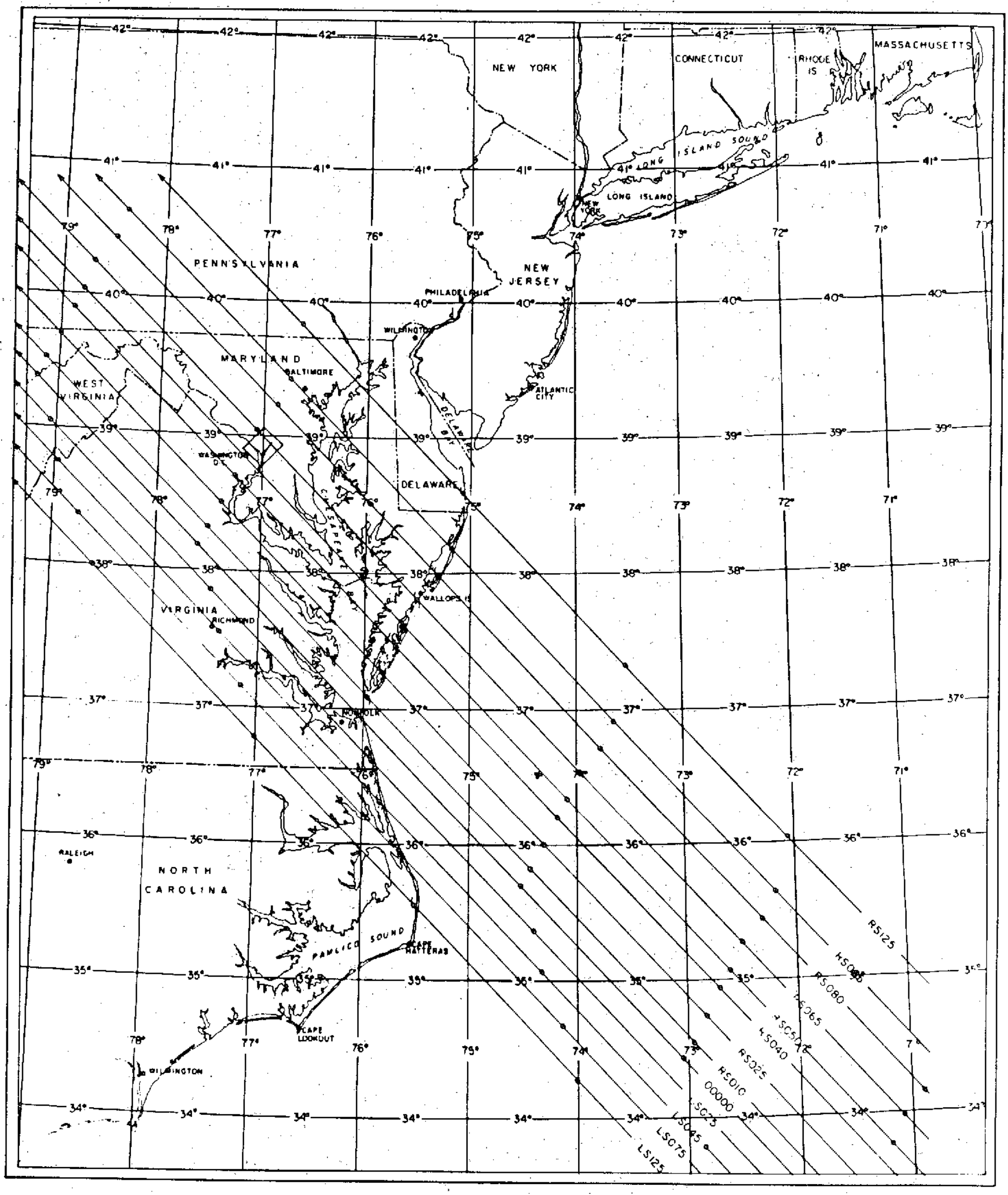

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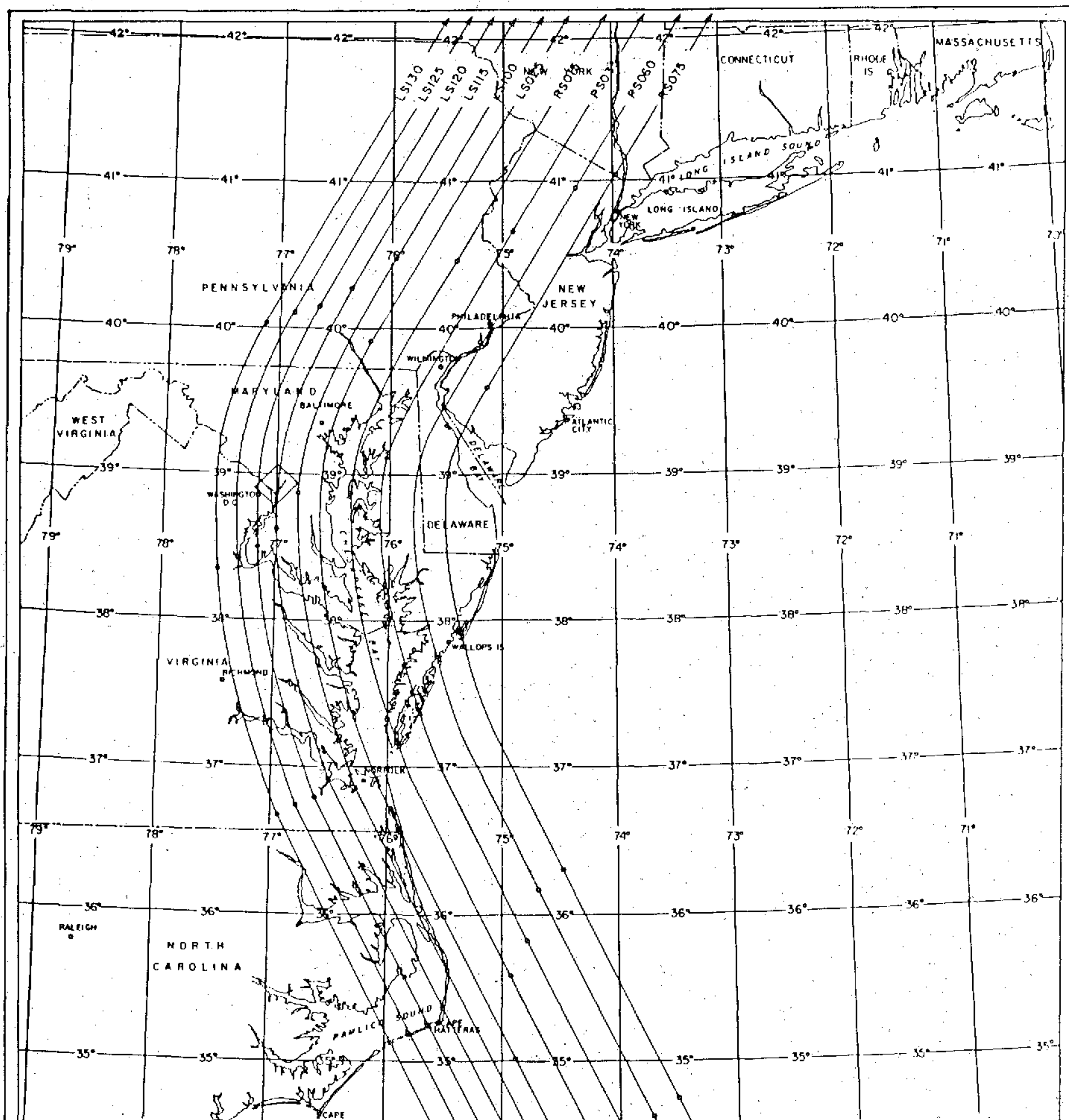

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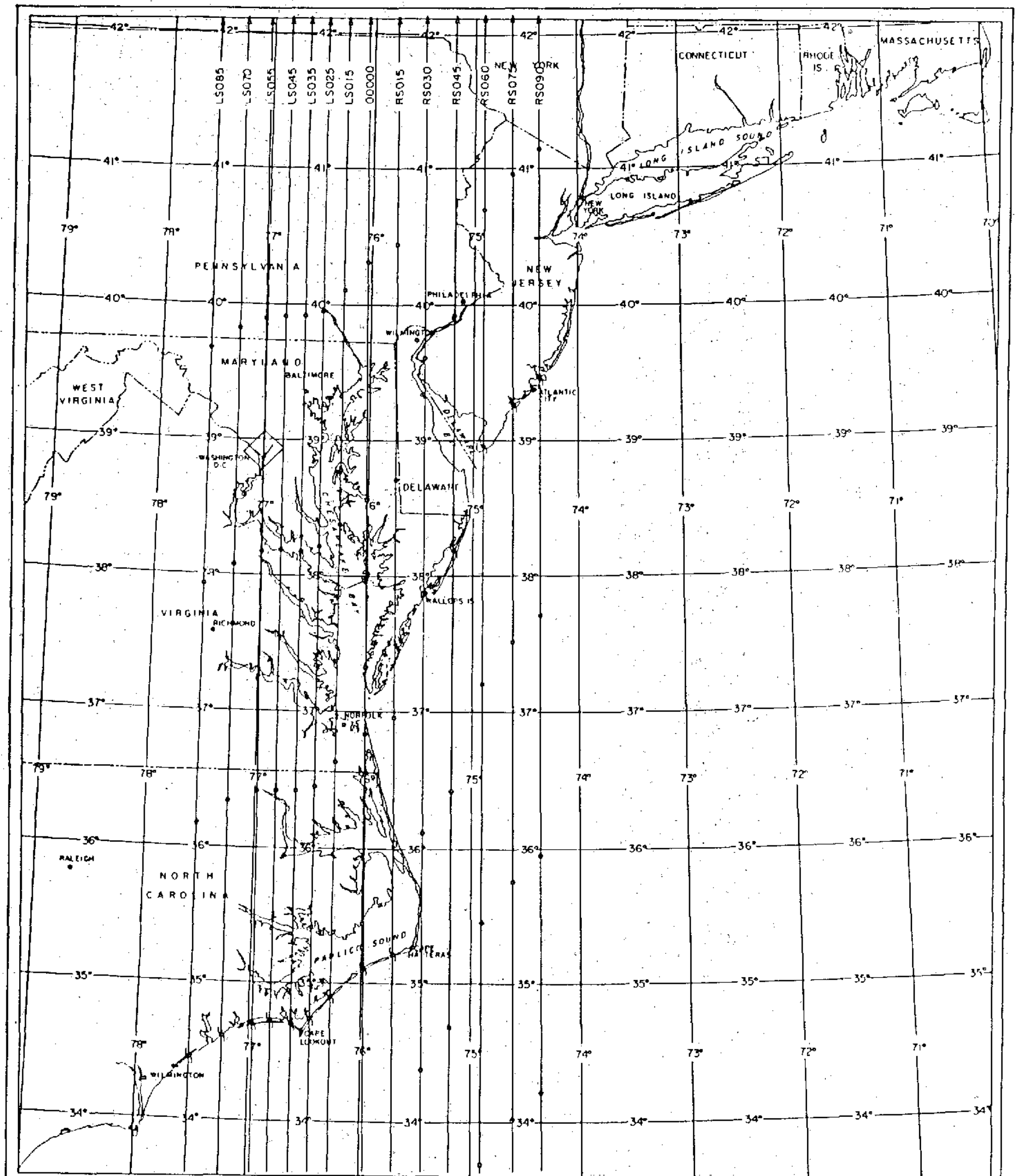
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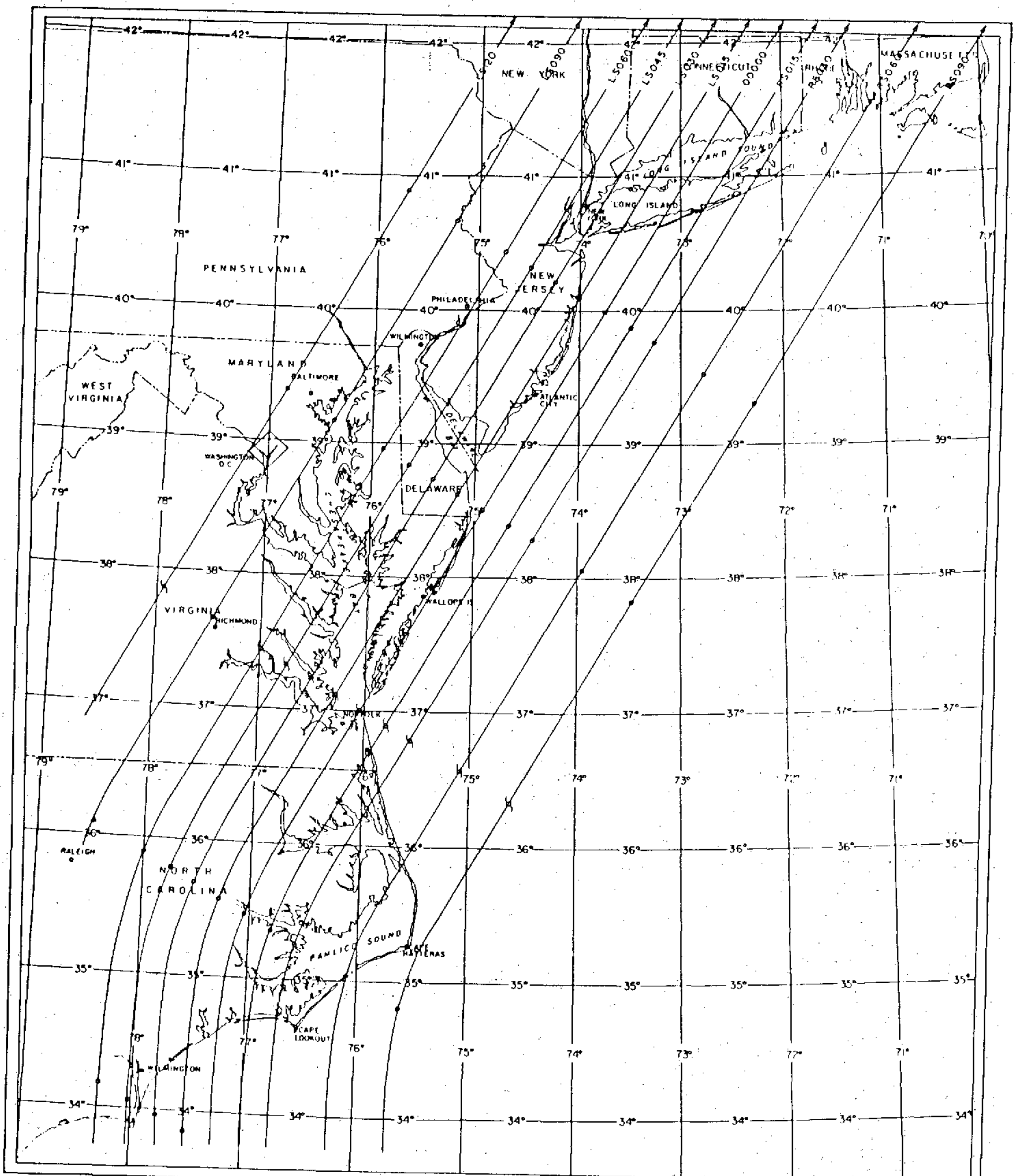

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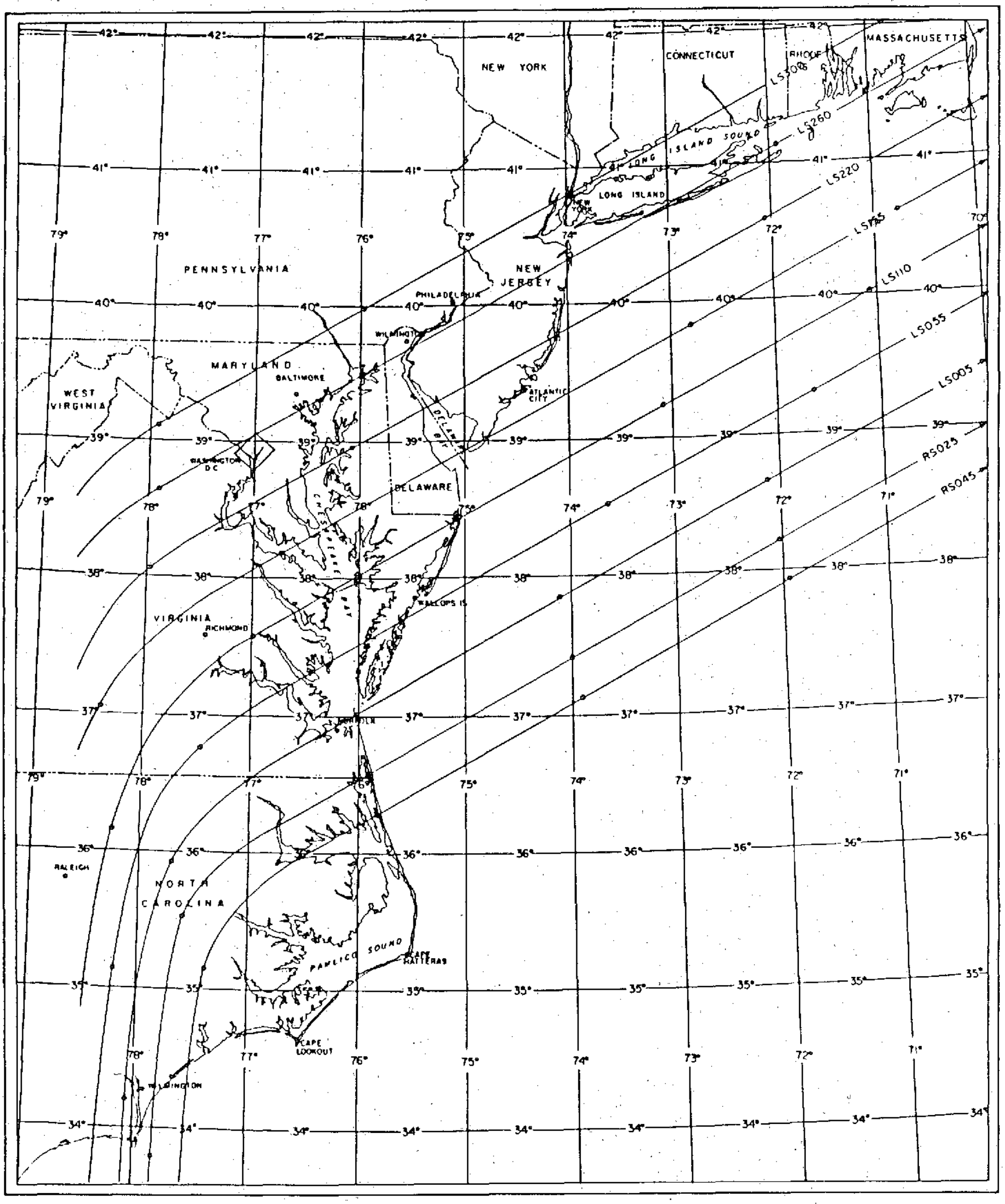
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APPENDIX C

BEHAVIORAL ANALYSIS

Hurricane Evacuation Behavioral Assumptions for Maryland

Appendix to
Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States

Prepared by

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For

U.S. Army Corps of Engineers

1989

Preface

This document is accompanied by a lengthier report titled *Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States*, referred to hereafter as the "Main Report". That volume provides background information relevant to understanding the following discussion. In particular the Main Report describes methodology and data which form the basis for many of the recommendations included in this volume. On occasion this report will make reference to MR-Fig. *x*, meaning a particular figure in the Main Report.

Sample survey results for four Maryland locations are reported in this document, but the reader should be aware that they are included as "tests" of the general response model's applicability to Maryland rather than to provide actual figures for evacuation planning. Even for the four sites themselves response in future hurricanes could be considerably different than that observed in Gloria.

Evacuation Rates Among Residents

The percentage of respondents in our sample who evacuated in Gloria varied greatly among interview sites. Sixty-three percent left from Ocean City, 32% from Anne Arundel and Crisfield, and only 8% from Denton (MR-Fig. 8). This does not necessarily mean, however, that more should have left from those areas. Gloria did not actually "hit" Maryland, and had the storm's course changed to cause more severe conditions in our sample locations, the eventual evacuation rates would have been higher.

Only in Anne Arundel county did more than half the sample say they were told by officials to evacuate, and in Denton only 4% said officials told them to leave (MR-Fig. 10). In every location (too few left Denton to say) people hearing that they should leave were more likely to do so (MR-Fig. 11). In Crisfield and Anne Arundel the differences were more dramatic than in Ocean City where even people who didn't hear officials tell them to leave tended to do so. In all locations people perceived the evacuation notice to be advisory rather than mandatory (MR-Fig. 12).

In all four locations a majority of those who didn't leave said they felt safe staying where they were (MR-Fig. 18). Twenty-two percent of the stayers in Denton said they did so because officials told them there was no need to leave (4%) or didn't tell them they should (18%) (MR-Fig. 19).

Response in Gloria in all four interview locations conforms to patterns predicted by the general response model. Table 1 summarizes the general guidelines for use in assigning evacuation rates to specific locations elsewhere in Maryland. The table varies response on the basis of four variables.

Severe Storm Evacuation Ordered in High/Mod. Risk Areas, and Mobile Homes			Weak Storm Evacuation Ordered in High Risk Areas Only, and Mobile Homes		
Risk Area					
High	*Mod*	*Low*	*High*	*Mod*	*Low*
Housing Other Than Mobile Homes					
90%+	80%	30%	85%	40%	20%
Mobile Homes					
95%	95%	85%	90%	75%	65%

Table 1. Evacuation rates to be used for planning in Maryland.

Storm Severity

The table addresses two storm scenarios. The first is a strong storm, a category 3 or worse. The second storm is weaker. The difference obviously is that more people are at risk in the more severe storm, and evacuation will be greater from moderate-risk and low-risk locations.

Action by Officials

It is assumed that officials will tell people to leave from high-risk and moderate-risk locations and tell all mobile home dwellers in coastal counties to evacuate in the severe storm. In the weaker storm only mobile home residents and people who live in high-risk locations are told to leave.

It is also assumed that officials are successful at communicating the evacuation notices to residents. The Gloria data attests to the greater likelihood of people leaving if they believe officials have told them to. The only way to ensure that everyone will hear the notice is to have it disseminated door-to-door. If that is not possible, vehicles with loudspeakers are the second best method. If officials cannot disseminate the evacuation notices in either of those manners, evacuation rates will be 25% lower in high-risk areas and 50% lower in moderate-risk and low-risk areas.

Risk Area

High-risk areas refer primarily to barrier islands and other land areas exposed to the open ocean where wave battering and scour are major hazards in addition to flooding. Moderate-risk areas are subject to flooding in moderate to strong storms but do not experience significant battering and scour. Low-risk areas are subject only to wind and are adjacent to moderate-risk locations.

Housing

Table 1 distinguishes between mobile homes and other housing. None of the four survey locations contained a large percentage of mobile homes, but they should be considered separately for planning. Evacuation will be greater from mobile homes than from other housing, all other factors being the same.

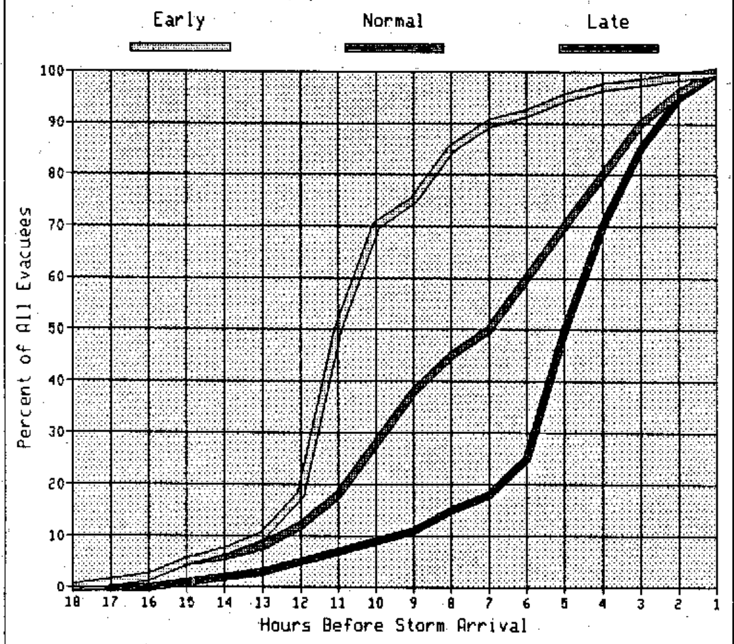
Evacuation Timing By Residents

With so few people evacuating from Crisfield and Anne Arundel county, it's difficult to make very confident statements about the exact time evacuees left. The matter is further complicated by the fact that interviewees were being asked to recall fairly precise information from something that occurred two years previously. It's clear, however, that evacuees left earlier from Ocean City and Crisfield than from Anne Arundel (MR-Fig. 23). In fact, of the 26 Anne Arundel residents who indicated the time they left their homes, 65% said they left after 9 pm on the 26th, and 42% said they left at midnight or later. By contrast, in Ocean City only 23% left after 9 pm and only 11% left after midnight. This reflects the greater risk perceived by residents in the first two sites (being closer to the storm) and differences in the timing of actions taken by local officials.

Evacuation timing, however, will vary greatly from storm to storm, and little can be generalized from Gloria. For planning purposes three different sets of assumptions depicted in Figure 1 should be analyzed. The three curves in Figure 1 reflect three different rates at which evacuees leave, reflecting in turn three different levels of urgency.

The left-most curve represents response when forecasts are early and residents are told to evacuate with plenty of warning. That scenario should probably be called optimistic. The middle curve is probably more typical. Warning is not quite so early in relation to landfall. Finally, the right-hand curve will pertain when a storm accelerates, intensifies, or changes course unexpectedly. People will leave very promptly if it is made clear to them that they must. All three curves should be used for planning because all three will occur eventually.

Fig. 1. Cumulative Response Curves for Planning



Fewer than 20% of eventual evacuees will leave before being told to leave. When told, however, people will leave as promptly as they believe they must. Given the luxury of time, most people will not evacuate late at night and will wait until morning if they haven't left by 11 pm or midnight. People will leave in the middle of the night if officials make it clear that circumstances make it imperative that they do so. People from high-risk locations (barrier islands) tend to leave earlier than other evacuees.

Demand for Public Shelters by Residents

Far more evacuees used public shelters in Crisfield (32%) and Anne Arundel (49%) than in Ocean City (14%) (MR-Fig. 25), and both instances demonstrate important influences on shelter use. Low income residents tend to use public shelters more than other groups, and 34% of the Crisfield sample indicated having household incomes below $10,000 and 65% below $25,000.

Income certainly can't explain the high shelter use in Anne Arundel, because this was one of the most affluent of the 19 sample locations in the overall study. The earlier evacuees leave, however, the less likely they are to use public shelters, probably because they are more likely to leave the local area when evacuating early and because they have made arrangements with friends, relatives, or motels. Recall that the Anne Arundel evacuees left much later than others in the Maryland samples (65% after 9 pm and 42% at midnight or later). Such late night evacuation tends to maximize shelter use, primarily because it is occurring with a sense of urgency, leaving no time to make alternative arrangements with friends, relatives, and motels or leaving too little time to travel the distance necessary to go out-of-town, particularly at night.

Ocean City exemplifies the opposite extreme. Residents of high-risk locations such as Ocean City tend to leave earlier and travel greater distances, therefore relying less upon public shelters. Residents of beach communities usually have higher incomes and choose not to stay at public shelters and can afford motels if arrangements can't be made with friends and relatives.

Table 2, showing guidelines for projecting normal shelter demand, reflects these patterns. Late, urgent evacuations, which will roughly double normal shelter

	Risk Area		
	High	*Mod*	*Low*
Income			
High	5%	10%	10%
Med.	15%	20%	25%
Low	-	40%	40%

Note:

Figures will be higher if officials encourage use of public shelters.

Figures will be higher for retirees.

Figures will be lower for developments with on-site shelters (e.g., clubhouses).

Figures will be lower where churches and other organizations shelter members.

Table 2. Evacuees going to public shelters: planning assumptions for Maryland.

demand, are not a function of location. Shelter demand (as a percent of all evacuees) in Anne Arundel county, for example, will usually be less than half the level observed in Gloria. It should also be noted that emergency management officials in some communities encourage shelter use more than others, and such policies should be taken into account in planning, because officials can take actions which either increase or decrease shelter use. Other factors to note are that retirees living in "retirement areas" are more likely to use public shelters than other groups, some communities have churches and other organizations which reduce "public" shelter use by being more active than normal in providing their own shelters, and some housing developments and mobile home parks provide onsite shelter which will alleviate demand for public shelter.

Evacuation Out-of-Town by Residents

Very few people evacuating from Crisfield went out-of-town (30%), compared to Ocean City (83%) and Anne Arundel (67%) (MR-Fig. 30). The Anne Arundel rate is somewhat misleading, however. Recall that the sample was drawn from several towns spread over a fairly large reach of coastline, and although evacuees may have been leaving their own "town" they didn't go very far. Seventy-six percent reached their destination in 30 minutes or less, and all the evacuees in our sample took less than an hour (MR-Fig. 31). In contrast, in Ocean City less than half took 30 minutes or less to reach their destinations, and 25% said they took more than two hours.

The differences are accounted for primarily by income (low income residents don't go as far), evacuation timing (late night, urgent evacuees don't go as far), and risk area (evacuees from high-risk beach areas go farther). Table 3 reflects these generalizations. Note too, that emergency management officials can influence this response. In some locations agencies have policies to discourage evacuees from staying in the local area. Communities which aggressively provide and publicize public shelters will have fewer evacuees leaving the local area.

Very Strong Storm, Early Evacuation			Weak Storm Typical Timing		
Risk Area			Risk Area		
High	*Mod*	*Low*	*High*	*Mod*	*Low*
50%	35%	25%	40%	25%	20%

Note:

Figures will be lower for low income and elderly retired evacuees.

Figures will be lower for last minute evacuations.

Figures will be higher if officials encourage evacuees to leave area.

Table 3. Percent of evacuees leaving local area: planning assumptions for Maryland.

Vehicle Use by Residents

The average number of vehicles used per evacuating household in Gloria was about the same for Ocean City (1.2), Crisfield (1.1), and Anne Arundel (1.0) (MR-Fig.'s 36-37). More people in the latter two locations used no vehicles at all, probably walking short distances to friends or to shelters or riding with someone else.

Normally 65% to 75% of the vehicles available to a household are used in evacuations, and Crisfield and Ocean City each used 71% in Gloria. Evacuees from Anne Arundel, however, indicated that only 49% of the available vehicles there were used. This reflects the fact that more vehicles were available in that area to begin with, and because of the timing and urgency of the evacuation fewer of them were taken, not wanting to separate family members at night with a storm imminent. For planning purposes it would be prudent and reasonable to assume that approximately 70% of available vehicles will be used in most evacuations, however.

No one in Ocean City said they required assistance from public agencies in evacuating, but 11% of the Crisfield evacuees and 3% of the Anne Arundel evacuees (1 person out of 32 interviewed) did (MR-Fig. 41). Of those respondents who did not evacuate in Gloria, some (including 17% in Ocean City) said they would have needed assistance if they had evacuated (MR Fig. 42). They were not asked whether they would require agency assistance or could rely upon friends and relatives. Even in communities where agencies prepare lists of people and addresses needing evacuation assistance, it is common to find that those people have already been provided for by friends and relatives when public vehicles arrive to collect them.

Planning Assumptions for Ocean City Vacationers

Visitor Characteristics

Based upon the best available, but rough, information, 42% of the visitors to Ocean City reside elsewhere in Maryland (18% in the Baltimore area, 18% in the Prince Georges area, 3% in the Frederick area, 3% on the Eastern shore), 22% come from Pennsylvania, 8% from Virginia (4% from northern Virginia, 2.4% from the Winchester area), 6% from New Jersey, 5% from New York, 3% from Ohio, 2% from West Virginia, 2% from D.C., 2% from Connecticut, and 1% from Delaware (Wilmington). Thus three-fourths of the vacationers could easily return home in a few hours if a hurricane were to threaten. The vast majority of visitors arrive via their own cars and stay for less than a week. All these factors are relevant to how vacationers to the area will respond to a hurricane threat. A summary of response assumption recommendations appears in Table 4.

Evacuation Rates

Vacationers are not usually reluctant to evacuate their lodging or campground when advised. In many instances vacationers, especially RV operators, depend very heavily upon the accommodation management for guidance. Having prepaid for lodging has not been a deterrent to vacationer evacuation in the past. Up to half the vacationers can be expected to leave, but possibly return after the threat, without hearing an official evacuation notice for their location. This occurs largely because they are seeking to avoid cloudy, rainy weather, even if it is not life-threatening.

Evacuation Rates:	95% in severe storms 85% in weaker storms 50% in absence of evacuation notice if weather deteriorates
Evacuation Timing:	Generally same as for residents, but earlier if weather deteriorates.
Leaving County:	90% in severe storms (except in last minute evacuations) 70% in weak storms, *if* space is available locally
Public Shelters:	< 5% in severe storms (except in last minute evacuations) >15% in weak storms

Note:

Vacationers are frequently influenced by information received from hotel/motel management. This is particularly true of RV parks.

Table 4. Planning assumptions for Ocean City vacationers.

Evacuation Timing

Vacationers leave about the same time as other evacuees, and the same response curves should be applied. If weather conditions are unpleasant, however, vacationers will leave earlier.

Public Shelters

Few people look forward to spending even part of their vacation in a public shelter. If they don't know friends or relatives to stay with in the area, they will return home or relocate to motels farther inland. In a weak storm, with the threat less certain, a few more evacuating vacationers will go to local shelters, hoping to avoid an unnecessary trip outside the area.

Leaving the Local Area

For reasons already mentioned, when vacationers evacuate they are most likely to leave the area entirely to escape not only the hurricane but deteriorating weather. If more than a few days remain of their planned stay, they will probably return if the storm misses the area.

Vehicle Use

Vacationers will take their own cars when evacuating. RV operators will probably wish to relocate their vehicles to safer locations inland but usually depend upon campground or park management for advice in this regard. When Diana threatened the Myrtle Beach, South Carolina area in 1984, some campgrounds were almost completely evacuated, including RV's, whereas in others only half the vehicles were removed. The variation was almost entirely a function of guidance offered by management.