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ABSTRACT

This document contains specific exercises designed to help secondary students understand the spatial and temporal characteristics of hurricanes that affect the eastern part of the United States. Selected exercises require students to: (1) use maps; (2) interpret statistics; and (3) perform mathematical calculations. Introductory material is presented for each topic or concept, followed by a set of questions and answers. Figures, tables, and maps, along with a 17-item bibliography, are included. (JHP)

UTILIZING HURRICANE DATA FOR CLASSROOM EXERCISES

Paper Presented

at

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UTILIZING HURRICANE DATA FOR CLASSROOM EXERCISES

Exercises were developed to provide a better understanding of the spatial and temporal characteristics of hurricanes that affect the eastern United States. Several different types of exercises were considered. Some required students to use maps, interpret statistics and even make mathematical calculations in answering questions about hurricanes. The answers to the questions have been included in each exercise. The questions that were developed served as examples of what can be accomplished with different types of data and hopefully they will encourage the user to expand on these exercises as well as develop new ones for the classroom.

It is recommended that before attempting the exercises a student should acquire the necessary background on hurricanes by consulting an introductory climate or weather textbook. The section on hurricanes which appears in Eagleman(see references) provides a thorough introduction to the subject. The discussions by Ahrens, Morgan and Ruffner provide a satisfactory discussion of hurricanes. The books by Riehl offer a detailed discussion for the student who wants to explore the topic more seriously.

Several terms require clarification that are related to hurricane development. A tropical cyclone is any nonfrontal low pressure synoptic-scale system that develops over tropical or subtropical waters and has a definite organized circulation. A tropical storm is defined as a tropical cyclone in which the maximum sustained surface winds(1-minute mean) range from 39 to 73 miles per hour. The maximum sustained surface wind associated with a hurricane equals or exceeds 74 miles per hour. The term tropical depression is applied to a developing or dissipating tropical cyclone with maximum sustained surface winds equal to or less than 38 miles per hour. Figure 1 reveals the location in the North Atlantic Ocean where tropical storms reached hurricane intensity over a 57 year period. Study this map and then answer the following questions.

<u>Question 1A</u>: What are two factors that hurricanes have in common regarding their origin in this part of the Atlantic Ocean?

<u>Answer</u>: They originate at low latitudes over very warm ocean waters north of the equator.

<u>Question 1B</u>: Why are the number of developing hurricanes restricted north of about 30 degrees north latitude?

<u>Answer</u>: Colder ocean waters and middle-latitude cyclones tend to discourage their development.

<u>Question 1C</u>: Why do hurricanes not originate much farther south of 10 degrees north latitude?

<u>Answer</u>: Due to the earth's rotation the Coriolis acceleration decreases to zero at the equator from a maximum at the poles. This lack of horizontal acceleration near the equator does not allow for the rotation required in a developing tropical cyclone.

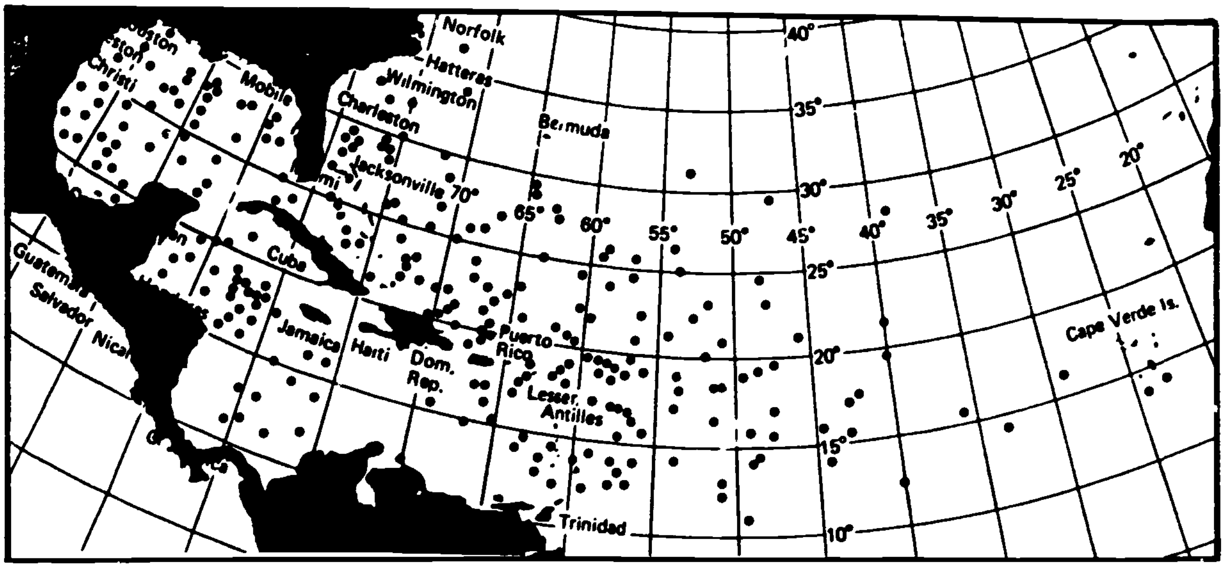
Consult one of the texts referred to earlier and then answer these sample questions regarding hurricane characteristics.

<u>Question 2A</u>: Describe the sequence of events associated with a developing hurricane.

<u>Answer</u>: Surface winds converge along the intertropical convergence zone(ITCZ) when it has been displaced north of the equator during summer and an atmospheric wave forms within this zone which can become an organized low pressure area where convection develops. When divergence aloft becomes superimposed over the area of surface convergence vertical circulation is established which enables hurricane force winds to develop and sustain itself through the release of latent heat associated with the rising, cooling air and associated condensation. Only a small fraction of all tropical cyclones ever become hurricanes.

FIGURE 1

LOCATION WHERE TROPICAL STORMS REACHED HURRICANE INTENSITY



Question 2B: Comment on the changes in wind direction and wind speed that are experienced moving from the western edge of a typical mature North Atlantic hurricane through the eye to the eastern edge.

Answer: Initially wind direction would be from the north and northwest becoming less defined within the eye and then would shift to the south and southeast as the eastern half of the hurricane is encountered. Wind speed would increase toward the center of the hurricane reaching maximum speed in the eye wall, which is a ring of intense thunderstorms adjacent to the eye.

Question 2C: Comment on the changes in cloud cover, rainfall, atmospheric pressure and temperature that are experienced moving from the western edge of a typical mature North Atlantic hurricane through the eye to the eastern edge.

Answer: Overcast conditions prevail along the periphery of the storm with cirrostratus clouds changing to a ring of intense thunderstorms adjacent to the eye. Within the eye the sky would brighten as middle altitude and high clouds appear. Rainfall would increase as the eye is approached with maximum intensity recorded in the eye wall with precipitation ceasing in the eye itself. Atmospheric pressure would be lowest in the eye and would increase quickly as the periphery of the storm is approached. The highest air temperature is found in the eye of the hurricane.

Question 2D: In what ways are middle-latitude cyclones and hurricanes that affect the United States similar to one another?

Answer: Both are low pressure systems, rotate counterclockwise and depend on the energy associated with the release of latent heat to sustain them.

Question 2E: List three major ways in which hurricanes differ from middle-latitude cyclones.

Answer: In contrast to middle-latitude cyclones, hurricanes usually develop over very warm ocean waters mainly during the late summer and early fall. They do not have fronts associated with them, are larger in size, have higher sustained maximum wind speeds, are longer-lived, have a central eye, cause more property damage and are easier to track.

Table 1 contains 56 years of average monthly data on tropical cyclones and hurricanes that developed in the North Atlantic Ocean. Most hurricanes occur during the official hurricane season which runs from June 1 through November 30 with a very few occurring in May and December. Only two tropical cyclones were recorded in the months of January and February during this period, neither of which became hurricanes.

<u>Question 3A</u>: Based on the data in Table 1 are hurricanes more common in the warmer part of the year?

<u>Answer</u>: Yes. More than 98 percent of all hurricanes in Table 1 occurred between June 1 and November 30.

<u>Question 3B</u>: In which two months were the most hurricanes recorded and what were these percentages for each month?

<u>Answer</u>: The figure for August was 29% and for September it was 39%.

<u>Question 3C</u>: Why does the month of September experience the greatest number of tropical cyclones and hurricanes of any month?

<u>Answer</u>: Ocean water heating lags behind maximum summer temperature by several months which means the warmest waters occur in late summer or early fall rather than in June during the summer solstice.

<u>Question 3D</u>: Calculate the percentage of all tropical cyclones(542) that became hurricanes(311). Do the same for each month and place the figures in the column on the right in Table 1.

<u>Answer</u>: The yearly value is 57%. See Table 1 for monthly values.

<u>Question 3E</u>: Which months exceeded the average figure in 3D? What were these values?

<u>Answer</u>: August was 64% and September was 63%.

<u>Question 3F</u>: What is the average yearly number of tropical cyclones and hurricanes during the period 1931-1986?(to nearest whole number)

<u>Answer</u>: Tropical cyclones averaged almost 10 per year and hurricanes averaged almost 6 per year.

TABLE 1

NORTH ATLANTIC TROPICAL CYCLONE AND HURRICANE FREQUENCY BY MONTH

(1931-1986)

Month	Tropical Cyclones	Hurricanes	Percentage Tropical Cyclones to Hurricanes
May	12	2	17
June	31	13	—
July	43	20	—
August	140	90	—
September	191	120	—
October	98	51	—
November	23	13	—
December	4	2	50
Total	542	311	—

This exercise provides the opportunity to learn about the paths that Atlantic hurricanes frequently follow that affect the United States. In Table 2 are listed the latitude and longitude for selected positions associated with four major hurricanes that were each responsible for millions of dollars of property damage along the coast. The path of each hurricane can be plotted by placing a dot at the intersection of each grid coordinate on Figure 2. The dots should then be connected with a smooth curve to approximate the changes in direction of the hurricane. Outline each hurricane track with a different colored pencil. Write the name start where you began plotting and place an arrow with the last set of coordinates to indicate the direction of each hurricane. Also label each hurricane by name, as well as the dates that it existed. Some sample questions and answers follow using this data.

<u>Question 4A</u>: Based on your completed tracking chart, hurricanes move in approximately which direction when they first develop?

<u>Answer</u>: They moved toward the northwest.

<u>Question 4B</u>: What major surface wind belt guides these four hurricanes during their initial movement?

<u>Answer</u>: The northeast trade winds.

<u>Question 4C</u>: What is the name of the semi-permanent high pressure system located over the Atlantic Ocean that is responsible for the steady northeast trade winds? Describe the pattern of surface and vertical winds around this high pressure area.

<u>Answer</u>: The Bermuda or Azores high pressure system. The air descends and rotates outward from the center of the high in a clockwise fashion.

<u>Question 4D</u>: At approximately what latitude do these hurricanes change course and move toward the northeast?

<u>Answer</u>: Approximately 30 degrees north latitude.

<u>Question 4E</u>: What causes this eventual shift in hurricane direction toward the northeast?

<u>Answer</u>: The southwest westerlies are encountered at more northerly latitudes which direct the hurricanes toward the northeast.

<u>Question 4F</u>: Which of the four hurricanes exhibited the most erratic path?

<u>Answer</u>: Betsy. This hurricane moved along the east coast and then abruptly assumed a track toward the western Gulf of Mexico.

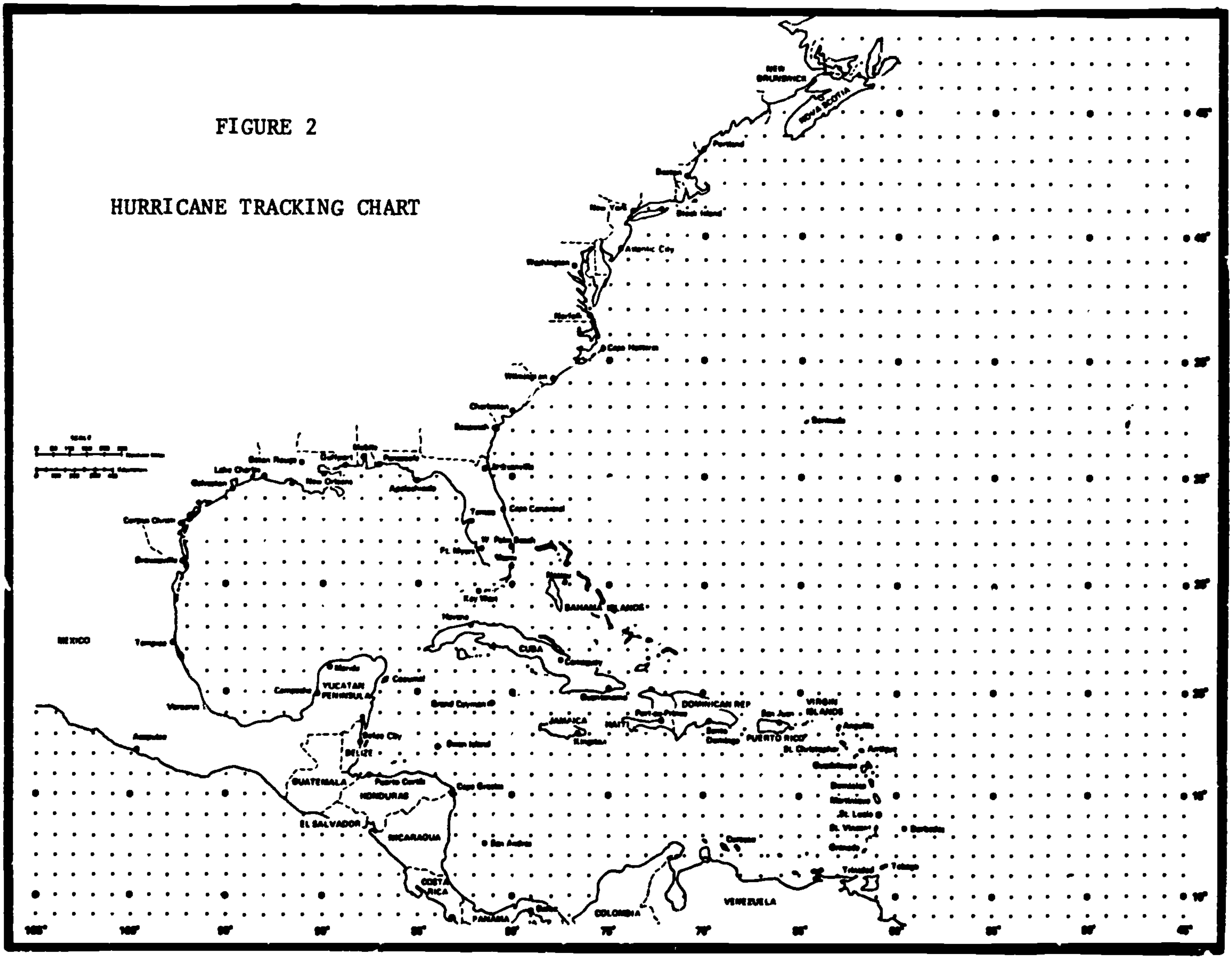
TABLE 2

HURRICANE GRID COORDINATES

Name	Dates	Latitude	Longitude
Agnes	June 14-22, 1972	20 N(start)	88 W
		21 N	86 W
		30 N	86 W
		33 N	82 W
		37 N	78 W
		39 N	75 W
Camille	August 14-22, 1969	19 N(start)	82 W
		23 N	85 W
		25 N	87 W
		32 N	89 W
		34 N	90 W
		35 N	89 W
		38 N	86 W
Betsy	August 26-Sept. 12, 1965	21 N(start)	65 W
		22 N	66 W
		22 N	70 W
		28 N	75 W
		26 N	77 W
		25 N	80 W
		26 N	85 W
		29 N	90 W
		32 N	92 W
		35 N	90 W
		38 N	87 W
New England	September 10-22, 1938	23 N(start)	70 W
		28 N	75 W
		31 N	75 W
		35 N	73 W
		30 N	73 W

FIGURE 2

HURRICANE TRACKING CHART



Question 4G: List at least three different ways that hurricanes can cause major destruction and fatalities as they approach the coast and then move inland.

Answer: Flooding along the coast from the storm surge usually accounts for the greatest destruction and loss of life. Boaters and even oil rig personnel caught unaware are frequently claimed as victims. Considerable damage and numerous fatalities can also result from heavy rains which generate flash floods as the storm moves inland. Strong winds can blow down buildings and homes and can create flying debris that acts as a battering ram against anything in its path. Tornadoes spawned around the storm are especially deadly because they cannot be easily detected when embedded in heavy rains. In September 1957 Hurricane Beulah generated a record 115 tornadoes as it struck the Texas coast.

The Saffir/Simpson Hurricane Scale displayed in Table 3 provides a convenient means of classifying hurricanes by assigning a number from one through five based on a combination of central pressure, wind speed and height of the storm surge. Note that as the number increases so does the intensity of the hurricane and its associated damage. The central pressure of a hurricane is an important characteristic because it is closely related to the maximum winds generated by the storm. The maximum winds can be approximated by the following formula(see Dunn and Miller 1964, p. 159).

$$\text{Max. Wind Speed} = 16\sqrt{P_n - P_o}$$

Where: Max. Wind Speed = speed in knots(1 knot=1.15 statute miles)

P_n = pressure in millibars along the periphery of the storm

P_o = pressure in millibars at the center of the storm

The pressure along the periphery of a storm can be selected from a surface chart that displays hurricane isobars by adding 2 or 3 millibars to the value of the last closed isobar around the storm, or in most cases a constant P_n value of 1010 millibars can be substituted usually with good results. This formula produces as accurate an estimate of maximum winds as can be obtained by any other means, although some scientists feel it is a better estimate of gusts rather than sustained winds.

TABLE 3

SAFFIR/SIMPSON HURRICANE INTENSITY SCALE

Scale Number (category)	Central Pressure(mb)	Wind Speed (mph)	Storm Surge (ft)	Damage
1	$\geq$ 980	74-95	4-5	Minimal
2	965-979	96-110	6-8	Moderate
3	945-964	111-130	9-12	Extensive
4	920-944	131-155	13-18	Extreme
5	$<$ 920	$>$ 155	$>$ 18	Catastrophic

Question 5A: Use the formula for maximum wind speed and calculate the maximum wind speed in milesper hour(mph) for categories 1 and 5 in Table 3. Use a P_n value of 1010 millibars. How do the values compare to those in Table 3?

Answer: For category 1 the maximum value $= 16\sqrt{1010-980}$

$= 16\sqrt{30}$

$= 16 \times 5.477$

$= 87.632$ knots

$= 87.632 \times 1.15$

$= 100.78$ mph

For category 5 the maximum value $= 16\sqrt{1010-920}$

$= 16\sqrt{90}$

$= 16 \times 9.487$

$= 151.792$ knots

$= 151.792 \times 1.15$

$= 174.56$ mph

The category 1 answer is closer to the maximum of 95 mph in the table than the category 5 answer of 155 mph. Since the formula overestimates wind speeds compared to Table 3 this may support some scientists' contention that the formula is a better estimate of wind gusts than sustained winds. Do note, however, that the value of 1010 millibars is not an actual pressure but only an estimate. Use of the actual pressure along the periphery of a hurricane might provide values that correspond more closely to the tabled values.

Question 5B: The maximum wind speed associated with a hurricane was 138 mph. Estimate the central pressure in millibars(mb). Use a value of 1010 mb for P_n. How does your answer compare to those in the table?

<u>Answer</u>: The maximum value $= 16\sqrt{1010-P_o}$

$$138/1.15 = 120 \text{ knots}$$

$$120 = 16\sqrt{1010-P_o}$$

$$120/16 = \sqrt{1010-P_o} = (1010-P_o)^{1/2}$$

$$7.5 = (1010-P_o)^{1/2}$$

$$(56.25)^{1/2} = 7.5 = (1010-P_o)^{1/2}$$

$$(56.25)^{1/2} = (1010-P_o)^{1/2}$$

$$56.25 = 1010-P_o$$

$$P_o = 1010-56.25 = 953.75 \text{ mb}$$

The estimated pressure of 953.75 mb corresponds to a category 3 hurricane in Table 3 when in fact it should be a category 4 hurricane based on a maximum wind speed of 138 mph. See the discussion in 5A for some reasons for this discrepancy.

If the isobars around a stationary hurricane are symmetrical the wind speeds would be equal on all sides of the eye of the storm. If, however, a hurricane is moving the surface winds would exhibit different velocities around the storm. As a general rule the highest wind speeds are experienced to the right of the path of a moving hurricane in the northern hemisphere as a result of a combination of rotating winds and the forward motion of the storm. The lowest wind speeds are found directly opposite the area of maximum winds. The intermediate areas usually have a wind speed which is approximately the average of the highest and lowest sides of the moving hurricane.

For example, if a stationary hurricane with 110 mph winds was to move due west at 20 mph the highest wind speeds of 130 mph would be located toward the north with the lowest speeds of 90 mph located south of the eye. Speeds of 110 mph would be found due west and east of the storm's center. The difference between a wind of 130 and 90 mph is considerable in terms of its destructive power.

<u>Question 6A</u>: In which quadrant would the winds be strongest for a hurricane moving northwest in the Gulf of Mexico? The weakest?

<u>Answer</u>: The strongest winds would be found to the northeast of the storm's eye and the weakest winds toward the southwest.

Question 6B: In which quadrants would the strongest and weakest winds be found around a hurricane moving due southwest in the southern hemisphere?

Answer: The strongest winds are in the southeast quadrant and the weakest to the northwest of the storm's center. In this case the rotation is clockwise and the strongest winds are located to the left of the hurricane's path of motion.

It was established in the answer to question 4G that a majority of hurricane deaths result from drowning caused by the rapid rise of water from the storm surge generated along the coast as a hurricane approaches. Table 4 contains the lowest pressure recorded and the associated storm surge height for various hurricanes in the Gulf of Mexico. A cursory examination of this data seems to support the conclusion that higher pressures are associated with lower surge heights and lower pressures are generally associated with higher surge heights. That is, an indirect relationship exists similar to the one portrayed in Table 3. To confirm this relationship the data was subjected to a Spearman rank correlation. This technique requires that ranked data be used and has the advantage that since it is a non-parametric statistic it does not have to meet the requirement that the data be randomly selected and normally distributed. It is also less tedious than other methods and yet provides accurate results. As you complete this exercise be aware that no causal relationship can be inferred from a correlation coefficient alone. Cause and effect can only be confirmed by additional evidence and the judgement of the investigator. For a more detailed discussion of this technique consult Hammond and McCullagh pages 223-228.

The two sets of data in Table 4 were ranked with the number one being assigned to the highest rank and were then placed in Table 5. Whenever ties occurred the mid-rank method was used to assign ranks according to the procedure outlined by Arkin and Cotton pages 85-87. Next, the differences for each set of data were squared and then summed for all 22 cases.

Question 7A: Use the information in Table 5 to calculate the Spearman rank correlation(R_s):

$$R_s = 1- 6 \sum D^2/N^3 - N$$

where: D^2 = difference in ranks squared

N = number of observations(22 in this case)

Answer: The calculated R_s value is -.75.

TABLE 4

LOWEST PRESSURE AND MAXIMUM STORM SURGE BY GULF OF MEXICO HURRICANES

Lowest Pressure(mb)	Maximum Surge Heights(ft)
993	4.4
992	3.6
987	5.6
981	8.0
980	7.8
979	5.5
975	5.0
974	4.8
973	7.4
968	11.1
965	10.8
964	6.5
961	4.7
959	10.0
958	7.8
956	8.4
953	13.9
951	14.8
949	13.0
948	11.1
944	9.0
936	14.5

TABLE 5

SPEARMAN RANK CORRELATION OF HURRICANE DATA

Lowest Pressure(mb) ranked	Maximum Surge Height(ft) ranked	Difference Squared(D^2)
1	21	400
2	22	400
3	16	169
4	11	49
5	12.5	56.25
6	17	121
7	18	121
8	19	121
9	14	25
10	5.5	20.25
11	7	16
12	15	9
13	20	49
14	8	36
15	12.5	6.25
16	10	36
17	3	196
18	1	289
19	4	225
20	5.5	210.25
21	9	144
22	2	400
		$\Sigma D^2 = 3099$

Question 7B: The R_s value can range from plus one to minus one. The closer R_s is to either extreme the better the overall match. Usually a strong direct relationship can be inferred for values greater than .70. A strong indirect relationship can be inferred with values less than minus .70. What does your answer to 7A reveal about the nature and strength of the relationship?

Answer: A strong indirect relationship is evident between lowest pressure and maximum surge height.

A best-fit trend line has been derived mathematically using the data in Table 4. Many hand calculators have the capability of finding the equation of a straight line or it can be computed by hand using the method described by Hammond and McCullagh on pages 253-260. The equation for the best-fit trend line was $Y = -.1673X + 170.1$. The Y value is the maximum surge height and the X value is the lowest barometric pressure. The number -.1673 is the slope of the line which indicated an indirect relationship because of the negative sign. The number 170.1 is the Y intercept. The equation represents a line which fits the data so that, overall, it minimizes the distances of the 22 paired observations to the line. The values in Table 4 are close to the line because the R_s value of -.75 is close to -1.0. This means you can place considerable confidence in using the equation to calculate one value such as surge height when the lowest pressure is known. It is now possible to use the equation to confirm how well it estimates individual values in Table 4. It should also be possible to forecast for values not found in Table 4. For example, if the lowest pressure was 965 mb(X) then what is the corresponding maximum surge height(Y)? The answer is: $Y = -.1673(965) + 170.1 = 8.66$ feet.

Question 8A: Use the equation to find the maximum surge height(Y value) when the lowest pressure is 993 mb(X value). Why is your answer not exactly equal to the corresponding value of 4.4 feet in Table 4?

Answer: $Y = -.1673(993) + 170.1 = 3.97$ feet

The equation represents an average derived from all the observations, most of which are not located exactly on the best-fit trend line.

Question 8B: If the surge height is 7 feet use the equation to find the corresponding lowest pressure.

Answer: $7 = -.1673(X) + 170.1$

$X = 975$ mb

Table 6 contains statistics on hurricanes which made direct hits on coastal states. Approximately 42 percent of all hurricanes during this 86 year period were classified as major ones(categories 3-5). The last column on the right needs to be completed by the student. The value for major hurricanes for a given state should be divided by the corresponding value in the all categories column and then multiplied by 100 to obtain a percentage. For example, the value for Texas(45%) has been provided to serve as a guide.

Question 9A: Consult Figure 3 and then offer several reasons why more than one-quarter of all hurricanes making landfall in Table 6 struck the State of Florida.

Answer: Florida is a peninsula and has more of its coastline exposed to hurricanes generated in the warm waters surrounding it. The state's configuration makes it vulnerable since storm paths frequently are split with one following the western shore adjacent to the Gulf of Mexico and the other following the eastern shore north along the Atlantic coast.

Question 9B: Transfer the percentages in Table 6 to the corresponding state in Figure 3. Based on this pattern what two areas of the United States have experienced major hurricanes at least 50 percent of the time?

Answer: The western half of the Gulf of Mexico coast including the States of Louisiana and Mississippi plus the northeastern United States including New York, Connecticut and Rhode Island.

Question 9C: Why are the hurricane figures for the State of Georgia so low in Table 6 compared to surrounding states which have much higher values?

Answer: The tracks of most hurricanes miss Georgia because they either move inland after striking the western Gulf or are deflected eastward from the Atlantic coast by the configuration of the Florida coastline. The warm waters of the Gulf Stream located offshore may in addition attract potential hurricanes away from the Georgia coast.

Question 9D: Examine the figures for the States of New York, Connecticut, Rhode Island and Massachusetts in Table 6. Notice that the number of hurricanes is small compared to the Gulf States yet the percentage of major hurricanes is higher than most of these states. What does this relationship reveal about hurricane frequency and intensity in the northeastern United States?

Answer: Hurricanes occur much less frequently than in the Gulf of Mexico but when they do occur they have a greater chance of becoming major hurricanes than farther south.

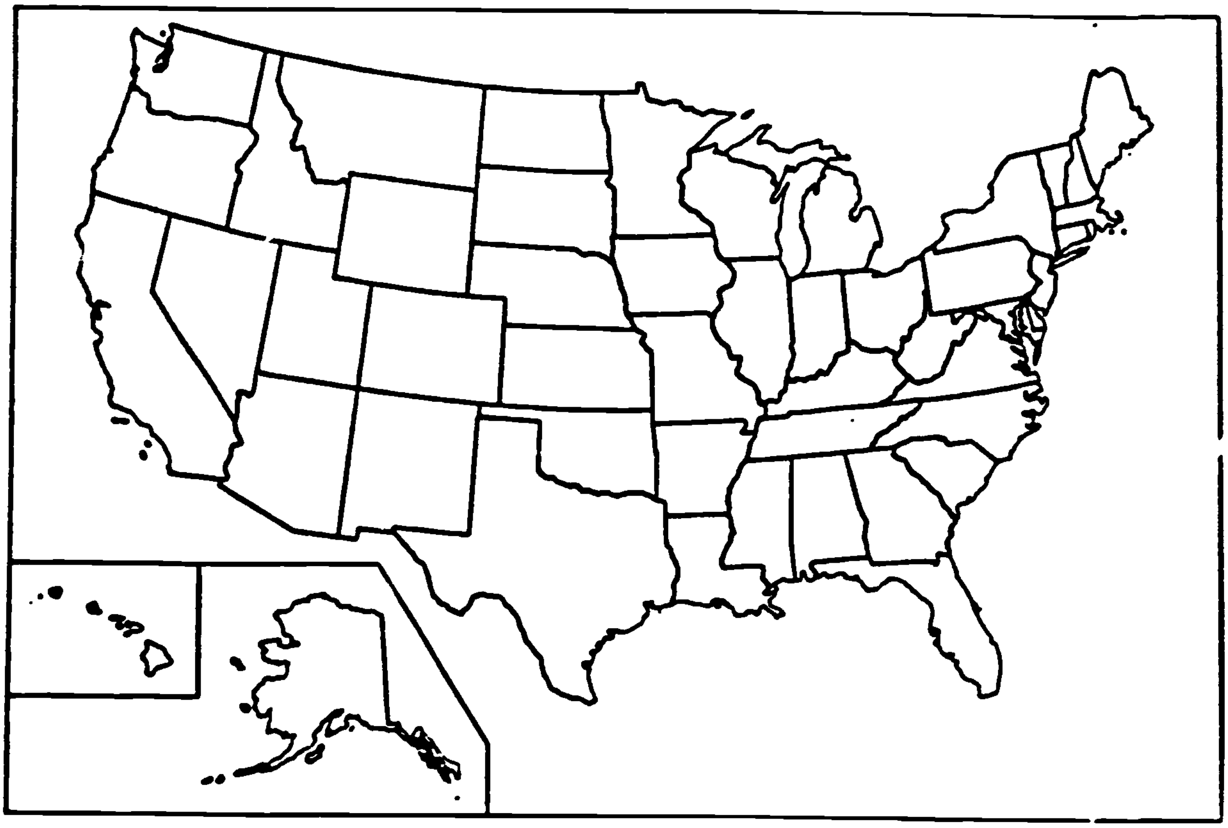
TABLE 6

UNITED STATES DIRECT HITS BY HURRICANES 1900-1985

State	All Categories (1-5)	Major Hurricanes (categories 3-5)	Percent Major Hurricanes
Texas	33	15	45
Louisiana	23	10	—
Mississippi	6	4	—
Alabama	8	4	—
Florida	52	21	—
Georgia	4	0	—
South Carolina	11	3	—
North Carolina	20	8	—
Virginia	3	1	—
Maryland	1	0	—
Delaware	0	0	—
New York	8	5	—
Connecticut	6	3	—
Rhode Island	4	3	—
Massachusetts	5	2	—
New Hamshire	1	0	—
Maine	4	0	—
Total	189	79	

FIGURE 3

MAP LOCATION FOR DATA FROM TABLE 6



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Examine the 30 years of data for North Atlantic hurricanes in Table 7. Some sample questions follow using the data.

Question 10A: On the average what percentage of the total hurricanes originating in the North Atlantic Ocean strike the coast of the United States?

Answer: Twenty-six percent(41/159)

Question 10B: During any given year are hurricanes more likely to strike the United States when the total number of hurricanes is greater or less than the average of almost six per year?

Answer: No clear pattern emerges to support a direct or indirect relationship between the number of total hurricanes and those that strike the United States.

Question 10C: Calculate the average number of hurricanes that struck the United States each year for the 30 year period.

Answer: The average is 1.4 per year(41/30)

Question 10D: Calculate the average number of hurricanes that struck the United States for the periods 1956-1970 and for 1971-1985. What conclusions can you make from these figures?

Answer: The figures are 1.4(21/15) and 1.3(20/15) per year, respectively. The average annual number of hurricanes striking the United States during the last 30 years has remained nearly constant for the two time periods.

Question 10E: What is your forecast for the number of hurricanes that would strike the United States during 1986?

Answer: It is unlikely that the much greater than average number of hurricanes experienced in 1985 would occur again in 1986 since such a pattern is not evident in the past. It is more likely that 1986 could be slightly above the 30 year average but any forecast, even for the next year, is risky when weather related phenomena are concerned especially when only 30 years of data are involved.

Question 10F: What is the average annual loss of life from hurricanes in the United States?

Answer: About 44 deaths per year(1318/30)

Question 10G: How many of the 30 years of recorded deaths exceed the average calculated in 10F?

TABLE 7

NORTH ATLANTIC HURRICANES 1956-1985

Year	Total Hurricanes	Reaching U.S. Coast	U.S. Loss of Life
1956	4	1	21
1957	3	1	395
1958	7	0	2
1959	7	3	24
1960	4	2	65
1961	8	1	46
1962	3	0	4
1963	7	1	11
1964	6	4	49
1965	4	1	75
1966	7	2	54
1967	6	1	18
1968	4	1	9
1969	10	2	256
1970	3	1	11
1971	5	3	8
1972	3	1	121
1973	4	0	5
1974	4	1	1
1975	6	1	21
1976	6	1	9
1977	5	1	0
1978	5	0	35
1979	5	3	22
1980	9	1	2
1981	7	0	0
1982	2	0	0
1983	3	1	21
1984	5	1	3
1985	7	6	30
Total	159	41	1318

Answer: Eight years which corresponds to an above average number of deaths about once every four years.

Question 10H: When was the last time that an above average number of deaths occurred in the United States? What does this indicate about the pattern of hurricane deaths for the future?

Answer: The most recent year was 1972. Since then deaths from hurricanes have remained much below normal. Hopefully, this pattern will continue as long as people remember to take the necessary precautions when hurricanes threaten.

Question 10I: Examine Table 7 again. Under what circumstances could just one hurricane reaching the coast in 1957 claim 395 lives and yet six hurricanes in 1985 claimed "only" 30 lives?

Answer: The number of hurricanes occurring in any year is not directly related to the potential loss of life. The single hurricane of 1957 was intensely developed(category 4), had strong winds which generated a substantial flood surge along the densely populated coastal area which could account for the above normal fatalities especially if evacuation efforts were hampered or people delayed too long before responding to local warnings to leave. An intense hurricane could survive longer after landfall creating heavy rainfall inland with resulting flash floods that could easily catch people unprepared to cope with the unexpected threat.

The ten deadliest and costliest hurricanes affecting the United States are ranked in Tables 8 and 9, respectively. Use these tables to answer the following questions.

Question 11A: Notice that all of the locations affected in Tables 8 and 9 were either along the Gulf of Mexico or the east coast. What factors tend to discourage hurricane activity off the west coast of the United States?

Answer: Even during summer the temperature of the ocean surface along the west coast is colder than the critical value of 80°F required for hurricane formation because of upwelling along the coast. In addition, the Pacific high pressure system during the summer is capable of deflecting any hurricane that might develop to the southwest away from the coast because of the clockwise rotation.

Question 11B: Which area has received the most visits from deadly hurricanes?

Answer: The Gulf of Mexico including the States of Florida, Louisiana and Texas.

TABLE 8

TEN DEADLIEST HURRICANES TO STRIKE THE UNITED STATES 1900-1986

Hurricane	Year	Deaths	Saffir/Simpson Category
Galveston, Texas	1900	6000	4
Lake Okeechobee, Fl.	1928	1836	4
Florida Keys/S. Tx.	1919	600-900	4
New England	1938	600	3
Florida Keys	1935	408	5
Audrey(La./Tx.)*	1957	395	4
Northeast U.S.	1944	390	3
Grand Isle, La.	1909	350	4
New Orleans, La.	1915	275	4
Galveston, Tx.	1915	275	4

* Names were not assigned to hurricanes prior to 1950

TABLE 9

TEN COSTLIEST HURRICANES TO STRIKE THE UNITED STATES 1900-1986

Hurricane	Year	Damage (billions $)	Saffir/Simpson Category
Frederic(Al./Ms.)	1979	2.3	3
Agnes(Fl./NE USA)	1972	2.1	1
Alicia(Tx.)	1983	2.0	3
Juan(La.)	1985	1.5	2
Camille(Ms./La.)	1969	1.42	5
Betsy(Fl./La.)	1965	1.42	3
Elena(Fl./Ms.)	1985	1.0	3
Gloria(E/NE coast)	1985	.9	4
Diane(NE USA)	1955	.83	1
Eloise(NW Fl.)	1975	.55	3

Question 11C: Offer several reasons why no additions to Table 8 have been made since 1957.

Answer: Recent hurricanes may have been less intense, missed major populated areas along the Gulf and residents may have responded more quickly because of more accurate warnings to recent threats.

Question 11D: The Florida Keys hurricane of 1935 was the only 5 category found in Table 8. Why was it probably ranked only fifth in total deaths when it was ranked first in intensity?

Answer: The area was sparsely settled at the time compared to the rapid growth in population during the last several decades.

Question 11E: In contrast to Table 8 the most costly hurricanes to strike the United States in Table 9 are much more recent occurrences. The four top ranked hurricanes in terms of damages have all occurred since 1972 with destruction of property exceeding over a billion dollars in each case. How do you explain the fact that deaths are down in recent years but damages are increasing from hurricanes?

Answer: Population growth during the last several decades along the coasts of the southeastern United States has resulted in substantial increases in residential and commercial structures. This property is subject to destruction when hurricanes occur but fortunately local residents have been responsive to warnings and cooperated during large-scale evacuation efforts which has helped keep fatalities to a mimimum.

In Table 9 Hurricane Agnes ranked second as the most costly hurricane every to strike the United States yet it was assigned to category 1 on the Saffir/Simpson Hurricane Scale which normally indicates minimal damage(Table 3). In fact, Hurricane Agnes only qualified as a hurricane for a few hours and spent the rest of its life as a tropical storm. Figure 4 provides a detailed look at the path that Agnes took during its lifetime and will help to explain why such a weak storm could generate record property damage.

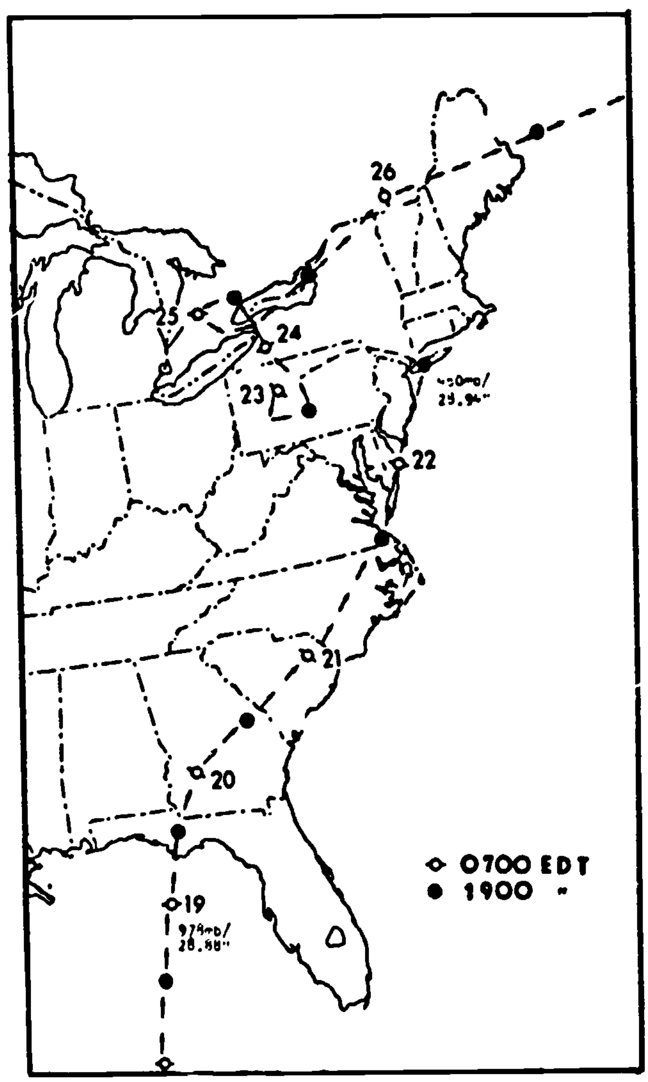
A total of nine persons died along the Florida Panhandle as Hurricane Agnes made landfall. High tides and 15 tornadoes caused most of the damage in this state. By the time tropical storm Agnes reached Georgia the eastern half of the United States was dominated by very warm unstable air which prolonged Agnes' life as it skirted along the east coast. Heavy flooding was recorded in South Carolina north to the Chesapeake Bay where Agnes was responsible for record floods and 19 dead in Maryland.

Question 12A: Hurricane Agnes will probably rank as Maryland's greatest natural disaster because of the damage created by torrential rain and devastating floods. Why did Agnes intensify as it approached the Chesapeake Bay area?

FIGURE 4

PATH OF HURRICANE AGNES

June 18-26, 1972



Answer: The warm waters of the bay rejuvenated the storm by permitting more evaporation and ultimately the release of latent heat of condensation.

Question 12B: Pennsylvania and New York suffered the greatest damage and fatalities of any states affected by Hurricane Agnes. Pennsylvania recorded damages in excess of two billion dollars and 50 deaths. The entire state was declared a federal disaster area. New York experienced the greatest flash flooding in its history with damages of 300 million dollars and 24 deaths. This occurred even as Agnes was losing momentum and turning abruptly westward leaving behind its energy source over the Atlantic Ocean. What climatological conditions could explain this seemingly unexpected turn of events?

Answer: On June 23 the remnant of tropical storm Agnes was absorbed into the center of a middle-latitude cyclone located over western Pennsylvania. The two storms combined into a broad center of low pressure which drifted westward for awhile causing record rainfall and then moved northeast through the State of New York.

Question 12C: Figure 5 reveals the total amount of precipitation from Hurricane Agnes that fell in Pennsylvania in less than a week. Are there any physical features that may have accounted for the unusually heavy rainfall (14-16 inches) in the east-central part of the state? (check an atlas if available)

Answer: The low mountains in this part of Pennsylvania could easily have caused additional uplifting of the moisture laden air triggering torrential rainfall locally.

Question 12D: Provide an estimate of what percentage of the annual average precipitation you think fell in east-central Pennsylvania during Agnes' visit of just a few days. Find the highest value on the map and use it to estimate your answer.

Answer: Approximately 40 percent(18/44) to 45 percent(18/40).

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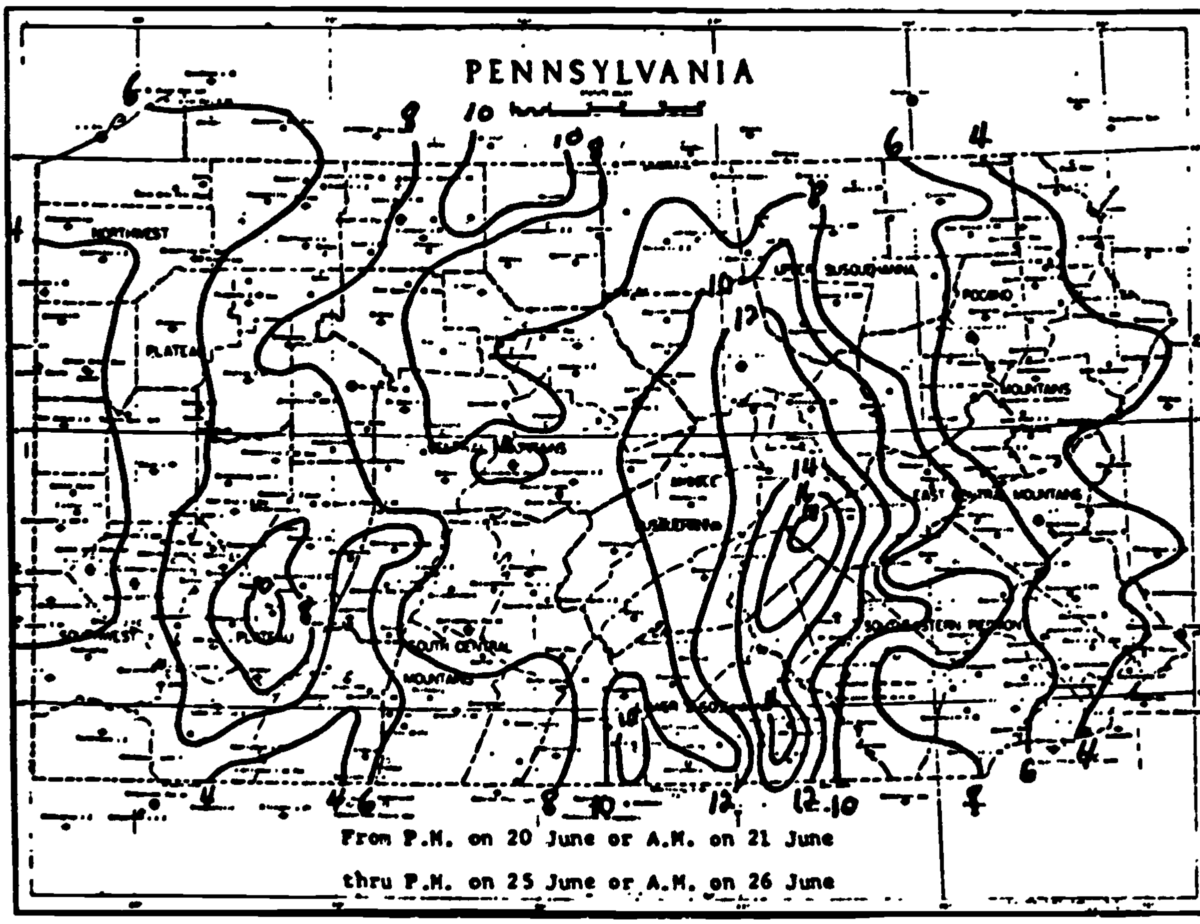
FIGURE 5

RAINFALL FROM TROPICAL STORM AGNES IN PENNSYLVANIA

June 20-26, 1972



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During the first two decades of this century major hurricanes most often affected the western Gulf States of Texas and Louisiana. From 1920 until about 1940 major hurricane activity shifted to the eastern Gulf coastal states and Florida. During the 1940s and 1950s major hurricanes were prevalent in Florida and along the Atlantic coast. During the 1950s to 1970s major hurricanes shifted back to the western Gulf coast.

Question 13: What advantages and/or disadvantages arise from forecasting that certain portions of the United States will periodically be more likely to experience major hurricanes than other portions?

Answer: Weather forecasters could watch more closely for landfalls in these areas and concentrate on informing coastal residents of any potential threats. Local residents could prepare in advance for the likely hurricane.

The areas supposedly not affected during this period might become too complacent and ignore early warnings about an unexpected major hurricane that is moving their way. There are no absolute certainties when hurricane forecasting is concerned and all portions of the coast must be alert since not all major hurricanes have conformed to the patterns of the past.

As recently as 1985, according to an article in the Chicago Tribune, many weather forecasters admitted that they are no better at warning residents where and when hurricanes will make landfall than they were 20 years ago. During this period more construction has occurred along coastlines most vulnerable to hurricanes. Some beachfront areas have become so densely populated that an evacuation would take much longer now than when warnings were first issued for hurricanes. For example, the evacuation-time estimated for the Tampa Bay area has increased from 12 to 18 hours in 1980 to 18 to 24 hours in 1985. Many new residents, who have never experienced a hurricane, are complacent about such threats because they feel modern technology will protect them. Table 10 lists eight coastal cities that would be vulnerable to a major hurricane because of the low elevation above sea level. The coast of Mississippi has been selected for a detailed discussion of a worst-scenario situation that might occur in spite of all the efforts of modern technology to reduce damages and fatalities.

Question 14: List several conditions that would slow evacuation efforts along the Mississippi coast, especially from the major cities of Gulfport, Biloxi and Pascagoula(Figure 6).

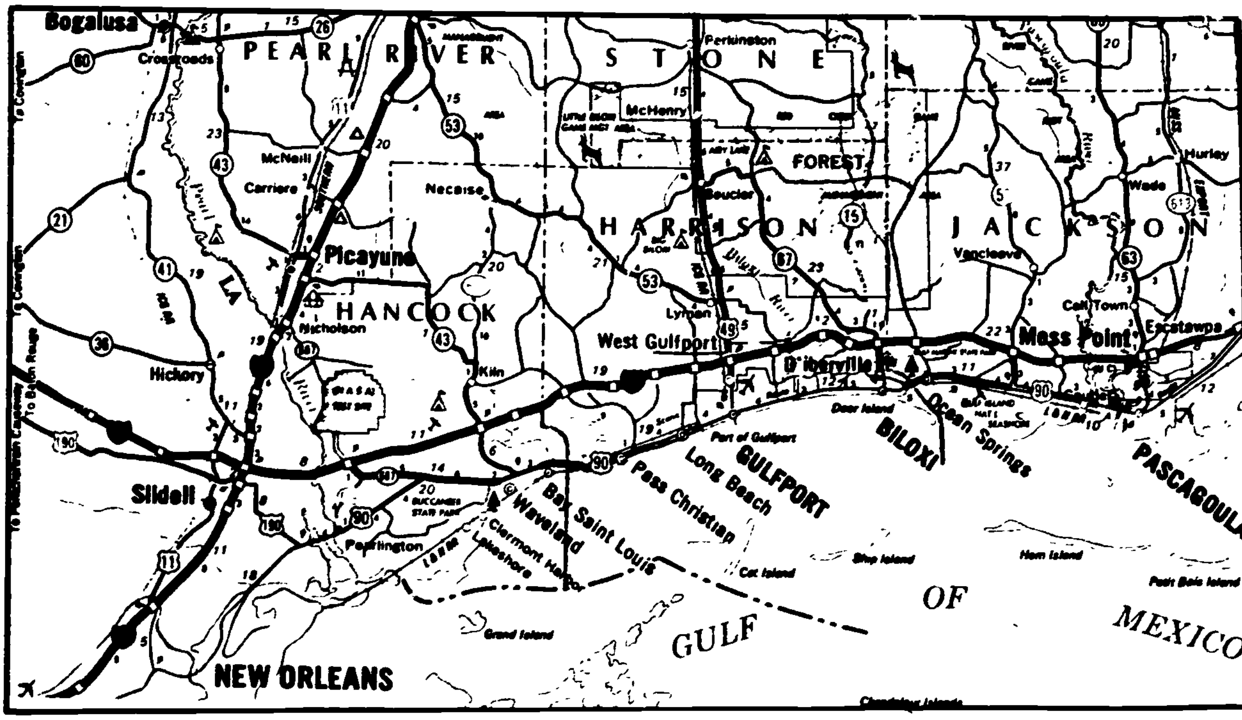
TABLE 10

UNITED STATES COASTAL CITIES

Name	Population(1980)	Elevation Above Sea Level(ft)
New Orleans, Louisiana	557,927	5
Biloxi, Mississippi	49,311	20
Gulfport, Mississippi	39,676	20
Pascagoula, Mississippi	29,318	20
Miami, Florida	346,931	10
West Palm Beach, Florida	62,530	15
Savannah, Georgia	141,654	20
Atlantic City, New Jersey	40,199	10

FIGURE 6

THE COASTLINE OF THE STATE OF MISSISSIPPI



Answer: A major hurricane deviates from its expected path shortly before landfall and quickly gains strength as it approaches this coastal area. Evacuation efforts have been slowed because of large numbers of tourists, as well as many local residents who began to evacuate at the same time because of so little warning and jammed major highways leading north. Some people take too long to evacuate their homes while others do not take the hurricane warnings seriously. In both cases the storm surge washes out or covers the major highways making retreat impossible for the procastinators. Finally, numerous tornadoes developed around the hurricane causing major damage and higher than expected fatalities.

There are numerous precautions that residents of coastal areas threatened by hurricanes can take. First, stay tuned to your local radio station and pay attention to all information issued about the storm's development. Small-craft warnings should be taken seriously and boats should not venture into the open sea.

Question 15A: What is the difference between a hurricane watch and warning?

Answer: A hurricane watch means that hurricane conditions are a real possibility for a specified area and duration. Residents should listen for advisories and be prepared to act quickly.

A hurricane warning means hurricane conditions are expected within 24 hours and identifies the coastal areas expected to receive high winds and high water. All precautions should be taken as soon as the warning is issued.

Question 15B: What precautions should be taken before leaving if you are told to evacuate your home?

Answer: Moor your boat if you have one. Board up windows, secure all outdoor objects that would be blown away and keep your car fueled because gas stations may not be functioning when you leave.

Question 15C: What precautions should be taken if you are not requested to evacuate your home but expect near hurricane conditions?

Answer: Follow the same precautions mentioned in the answer to 15B plus store drinking water, check your battery-operated equipment such as flashlights, radios, remain indoors and stay tuned to weather advisories for important updates. If you are located along a stream or low lying area flash flooding could occur and you should probably move to a structure located on higher ground.

Question 15D: What should you do after the passage of a hurricane?

Answer: Check food for spoilage if power is off, watch for loose or hanging electrical wires outside, avoid standing water in your house until electrical equipment is checked, remain out of hardest hit areas so your presence does not hamper first-aid and rescue efforts. Drive carefully along roads that could collapse because they have been undermined by flood waters. Avoid crossing roads under several feet of water especially when strong currents are evident.

Suggested Activities: Use the data in Table 10 and compare state highway maps for each of these cities. Then provide a short narrative about how evacuation efforts would be hampered or facilitated because of the coastal orientation, road patterns, location of population centers, etc., as a major hurricane approached the coast.

Finally, follow newspaper reports the next time a hurricane develops that threatens the United States. Compare and contrast its characteristics with those of hurricanes discussed in this paper.

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