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HURRICANE RISK ASSESSMENT TO ROLLBACK OR RIDE OUT
A COST VERSUS LOSS DECISION MAKING APPROACH

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To my fellow colleagues a special heartfelt thanks. Having been around you folks for the last couple of months has been a special treat. Good times, good memories, far too short. Farewell and best of luck in your endeavors.

RAW

ABSTRACT

The potential exists that a hurricane striking the Kennedy Space Center while a Space Shuttle is on the pad. Winds in excess of 74.5 knots could cause the failure of the holddown bolts bringing about the catastrophic loss of the entire vehicle. Current plans call for the rollback of the shuttle when winds of that magnitude are forecast to strike the center. As this is costly, a new objective method for making rollback/rideout decisions based upon Bayesian Analysis and economic cost versus loss is presented.

SUMMARY

There are an average of 8.4 tropical storms each year in the Atlantic Basin with 4.9 of these reaching hurricane strength. Should one of these make landfall at KSC while a shuttle were on the pad, the potential to seriously damage orbiter hardware exists. Protection of the shuttle from the heavy rain and hail is accomplished to a large extent with existing structures which surround the shuttle stack while on the pad, but strong winds are still a major consideration. Current wind limits stand at 74.5 knots sustained winds from any direction. At this point, wind loading on the shuttle stack can cause structural damage to the hold down skirts on the solid rocket boosters which attach the shuttle stack to the launch pad. The potential exists for loss of the vehicle should the attach points fail.

The current plan provides for rollback of the shuttle to the VAB in the event of a hurricane. This procedure requires at least 48 hours leadtime to the onset of 74.5 knot winds. Eight hours are actually required for the movement from the pad to the VAB.

Shuttle managers make the rollback/rideout decision based upon National Hurricane Center forecasts, with input from the Cape Canaveral Air Force Station weather support unit. Managers at present make subjective decisions based primarily on perceived risk of strike.

An analysis of risk based upon cost versus loss could provide managers an objective decision making tool. Using a Bayesian analysis with sequential events and their corresponding probabilities, along with the associated costs of performing each preparation/rollback operation, a decision making tree can be established for selected time critical milestones.

SECTION I INTRODUCTION

1.1 A HISTORY

Between the years of 1886 and 1991, 970 tropical storms spawned in the Atlantic Ocean basin with 614 of these reaching hurricane strength. At Kennedy Space Center, 64 of these tropical storms passed within 75 nautical miles; 26 which were of hurricane strength. Should a hurricane strike the cape while an orbiter were on the pad, damage to the space shuttle and associated hardware could occur. Protection of the Space Shuttle is of prime importance to management.

The Space Transportation System (STS) is made up of the orbiter, external tank and solid rocket boosters. It is stacked in the Vehicle Assembly Building (VAB) and moved to the launch pad some three to four weeks prior to launch where it is exposed to the elements. This exposure is mitigated somewhat by the protection afforded by the Rotating Service Structure (RSS) which encloses the upper surfaces of the orbiter, and the recently installed weather protection system. The weather protection system provides cover to the underside of the orbiter with huge movable panels which move into position from the RSS and block the bottom of the orbiter from exposure to the elements. Under most day to day thunderstorm and shower activity which is so prevalent in this part of the world, these precautions are sufficient to prevent damage to the stack.

Conditions which exist in a hurricane, however, could be beyond the protective capabilities afforded on the launch pad. Wind blown debris could cause damage to the exposed external tank or could damage the orbiter itself. Extreme winds and gusts might cause sufficient swaying in the stack bringing it into physical contact with support structures. In the worst case, the hold down attach points at the aft end of the SRB's could fail due to stack movement causing catastrophic loss of the vehicle.

1.2 HURRICANE PROTECTION PROCEDURES

Current plans provide for rollback from the launch pad of the stack in the event of a hurricane. However, the decision to roll the shuttle back to the VAB must be made long enough in advance for the stack to be secured prior to the onset of hurricane force winds. Signed limits are actually set at 74.5 knots, but for the purpose of this paper, hurricane force winds shall be examined. At present, the leadtime is 48 hours: 40 hours for preparation to rollback, and 8 hours moving to the VAB. A Space Shuttle Vehicle (SSV) Rollback Milestone Schedule is found in the Space Shuttle Hurricane Management Plan, and gives specific timeliness for operations which must be initiated and completed prior to rollback. The document also specifies the makeup and responsibilities of the Hurricane Management Team (HMT) headed by the Deputy Director of Space Shuttle Operations as the primary decision maker. Weather information is provided by a specific weather officer designated by the Cape Canaveral Air Force Station Forecast Facility. The weather officer is charged with providing the HMT all advisories, watches and warnings issued by the National Hurricane Center (NHC) along with rationale, track error analysis, and model confidence for each of these. The decision maker is faced with making a rollback/rideout choice based upon hurricane strike probabilities which are generally very low beyond the 48 hour point. The decision to rideout will eventually eliminate the possibility to rollback at some point in the decision making process because insufficient time for preparation remains to roll back. Consequently, the rollback decision is kept open until the threat safely passes or until the rollback occurs. Management must continually examine the threat and make decisions based at times upon somewhat subjective forecast information to keep those options open to preclude being overcome by events.

The economics of the situation provides another tool for determining whether to rollback or ride out by using a strict cost versus loss approach. While it is understood that the STS is a national resource whose loss or even damage could adversely affect future operations and public opinion, this study examines only the economics of the decisions involved. Loss costs include both orbiter and typical payload, which can be calculated for each mission. Costs associated with rollback begin when the decision maker halts processing and begins preparation for rollback, and mount with the execution of each rollback preparation procedure. Included in the cost part of the equation is the cost to return the SSV to the state of processing before protection measures were taken. Thus, costs and leadtimes are very dynamic figures. In fact, gathering cost data has proven to be one of the most challenging tasks of this research, and eluded efforts until the final week when a simplified cost figure was found. When the customer whose payload is aboard the Orbiter asks for a launch delay of one day (for example) he is required to pay for the delay. Payment is determined by dividing the yearly operating costs of shuttle operations and immediate support functions by 365. These numbers work out to approximately $1.68 million per day

SECTION II RESEARCH

Several areas required examination before a course of action could be taken. First was a review of previous studies. Next was a scheme which would generate probability changes to be incorporated into the analysis, and finally was the construction of a computer program to allow the weather expert to modify the forecast strike probabilities to reflect the historical data.

2.1 PREVIOUS WORK

2.1.1 STUDIES. In 1968 a study was conducted for the U.S. Department of Commerce titled 'Probability of Tropical Cyclone Induced Winds at Cape Kennedy' by Hope and Neumann which examined the tropical cyclone historical data through 1966. At the time, the critical windspeed was 35 knots which was dictated by safety concerns associated with the Saturn V/Apollo spacecraft. Using a statistical technique to examine storm tracks, Hope and Neumann found that there seemed to be two areas through which storms passed affected the Cape. One of these was in the Western Atlantic just north of the Lesser Antilles, and the other was in the western Caribbean/eastern Gulf of Mexico region. Indications were that the Atlantic storms hit the cape area from the south to south east, while the Caribbean storms arrived from the south to southwest. Storm data was limited to a large part to ship and aircraft reconnaissance reports as satellite data was nonexistent until the mid caribbean's. Conclusions reached were most useful for planning forecasts beyond the 72 hour point.

Neumann in 1975 conducted a study called 'A Statistical Study of Tropical Cyclone Positioning Errors with Economic Applications'. Inaccuracies in storm position and motions have a great affect upon its forecast position. Landfall forecasts are subsequently affected which lead to protection expenditures which were not required, or to damages which could have been avoided had protection measures been taken. Protection costs for the Gulf coast were typically $25.1 million for a 300 nautical mile stretch, and positioning errors of 10nm cost an additional $5 million in 1975 dollars. Building upon techniques used in the earlier paper, methods for storm position error correction and narrowing of landfall forecasts were developed.

A third technical memorandum titled 'The National Hurricane Center Risk Assessment Program (HURISK)' by Neumann consolidated progress made since the 1968 study and expanded upon it. It shall be discussed in some detail in this paper. A detailed description of the HURISK program and its output is discussed in detail in Neumanns paper.

2.2 THE HURRICANE RISK ASSESSMENT PROGRAM

HURISK was designed to be an analysis tool with some long range forecast applicability. The program selects hurricane and tropical storm data from a computer database which contains data back to 1886. Storms are selected which have passed at some time in their history through a circle with a radius of 75nm centered upon the site of interest. At this authors request, data for the Kennedy Space Center were generated using the HURISK computer program. Its results are described below. The data themselves, charts 1-12, make up Appendix A to this paper.

2.2.1 CHART DESCRIPTION. The first six charts are tabular and graphic data of those selected storms. Chart 1 is a tabular representation of data for each storm. Chart 2 and 3 are maps showing storm tracks for all tropical storms and hurricanes respectively. Chart 4 relates number of storms to the year in which they occurred, and shows some derived numbers: storms per year, hurricanes per year, mean interval, etc Later charts develop specific and detailed analysis of these preliminary data. Chart 5 plots number of occurrences to the date when the storm is nearest the site, and Chart 6 gives the direction from which those storms came. Of particular note here is the confirmation of Neumann's earlier observation of two directions from which storms move through prior to striking the cape area. While the mean direction is from almost due south there appear to be two local maxima, one from the southeast the other from the southwest.

In chart 7, the first of several mathematical models is constructed. Data is plotted for number of storms passing within a specified distance, and a quadratic equation is fitted. This quadratic equation is used in subsequent prediction models. One of these is the Radius of Maximum Wind (RMW) which for KSC is about 25nm for all storms. Again, this average is computed for all tropical storms and not just hurricanes. Chart 8 plots max wind vs. percent of cases and determines a Weibull distribution (an exponential curve) to fit the data. This curve is used in lieu of actual data to calculate the mean return period for a specific maximum wind in Chart 9 which provides perhaps one of the more useful pieces of information from the HURISK program. Since wind limits for STS are set at 74.5 knots, and since gusts (one second duration) are typically 1.25 times magnitude of the maximum sustained wind, enter the table with 60kts (74.5/1.25) and read off approximately 5.3 years for recurrence within the 75nm circle, and about 10 years within 50nm.

Charts 10 and 11 give the probability of x number of storms (1-5) occurring within the 75nm storm circle with respect to the number of years between those occurrences. The last hurricane to move through the 75nm site circle was hurricane David in 1979. To find the probability of having 13 years (1979 through 1992) without a hurricane, enter 13 on the x axis, and move to the right side y-axis and read off about 5%. Similarly, Chart 1 shows that the last tropical storm was in 1988. Using Chart 10, probability of not having a storm for 4 consecutive years is about 9%.

The last two charts 11 and 12 yield gamma distributions for tropical storm and hurricane forward speed respectively. The mean hurricane forward speed is 11.66kts with a standard deviation of 3.53kts. From this chart comes information for making decision circles, those distances at which a decision must be made concerning rollback or rideout preparations.

2.3 DECISION CIRCLES

Using the timeline from the SSV Rollback Milestone Schedule, a series of decision circles can be constructed. Attachment 1 is the timeline itself. Critical times are shown with their associated actions. These have been developed from a worst case situation (SSV on the pad with cargo aboard nearing the end of launch preparations) so there is some downward flexibility in the schedule. Using the timeline as shown the following table can be generated. The forward velocity of the storm is taken from chart 12 of the HURISK program. Values used are the mean velocity, 11.66kts, and 18.72kts which is the mean velocity plus twice the standard deviation. Note the variability of the first decision circle due to storm forward movement speed. Obviously, should a storm be moving at a much slower rate than the mean velocity, then the decision circles shrink accordingly. When plotted on a map of the region, these circles provide an area which can be used by the decision maker to gauge his time by graphically allowing him to see where he is in the decision making process. It should be noted, however, that quite often that cessation of forward movement signals a change in the intensity of the storm.

Hours to Strike	Diameter @ V=1.66 kts	Diameter @ V=18.72kts
48	560	899
44	513	824
40	466	749
36	420	674
28	326	254
22	257	412
20	233	374
12	140	225
8	93	150

Table I: Decision Circle Diameters

2.4 COST VERSUS LOSS

Decision making based upon probability forecasting is much like placing a bet. To make a good bet, payoffs need to be examined and risk assessment is required. With the STS, total risk avoidance would ground the fleet from June through October because there is a measurable chance a hurricane might hit the center. Acceptance of all risk, on the other hand would leave the STS on the pad during any weather and would ignore the chance of losing the vehicle to extreme hurricane winds. The ideal risk acceptance level lies somewhere between the two extremes. In the absence of a direct willingness or nonwillingness to take risk, this paper assumes that the decision maker is essentially risk neutral; that is, he will make his decision based upon the results of the cost versus loss scheme.

2.4.1 AN EXAMPLE. To help understand the cost versus loss scheme, examine the following example. Suppose that there is a 10% chance that today there will be a severe thunderstorm with damaging hail that will damage your car. Should your car be damaged, it will cost $1500 to repair. This is the loss value. A car cover which will totally protect the car costs $200. The decision is to protect and buy the car cover, or not protect and take the chance that the storm will not damage the car. As Figure 1 shows, there are several possible outcomes. First, if the choice is made to protect, the monetary consequence of that action is $200 regardless of the occurrence or non-occurrence of hail. If the choice is made not to protect, then there are two distinctly different outcomes. First, if there is no hail, the monetary consequence is $0. But, if there is hail, it will cause the loss of $1500. How to choose? Cost vs loss says that if the probability of the event occurring is less than the quotient of the cost divided by the loss then you do not protect. If it is greater, protect. So, based upon this information, the probability of hail (p) is .10, and cost/loss is .13333. Since p<(C/L), do not protect.

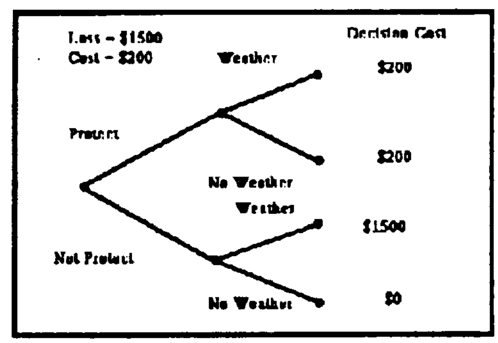


Figure 1. Cost vs. Loss Decision Tree

2.5 BAYES THEOREM

Bayes Theorem takes into account information received subsequent to the forecast being made to yield a new probability. The Theorem itself looks like:

$$(P|y) = \frac{P(E)\,P(y|E)}{P(E)\,P(Y|E) + P(\bar{E})\,P(y|\bar{E})}$$

where:

$P(E|y)=$ *probability of event E given event y*
$P(y|E)=$ *liklihood of E preceeded by y*
$P(\bar{E})=$ *probability of no E occurring*
$P(y|\bar{E})=$ *liklihood of y followed by no E*

2.5.1 AN EXAMPLE REVISITED Suppose that in the example above, we subsequently discover that there is a severe thunderstorm directly to our west 40 miles away. Historical records show that when our location received damaging hail, it was preceded by a severe thunderstorm 40 miles to the west. On the other hand, when there was a severe thunderstorm 40 miles to the west, in 10% of the cases our location did not receive damaging hail. Using Bayes theorem, we can examine the effect upon our probability:

$$P(E|y) = \frac{(.10)*(.30)}{(.10)*(.30)+(.90)*(.10)} = .25$$

The probability has changed and we can reenter the decision tree and determine whether protection is required or not. Since p = .25 and C/L = 1.3333, we should protect and buy the car cover.

2.6 DEVELOPMENT OF COMPUTER PROGRAMS

In order to generate probabilities for the Bayesian analysis, an examination of historical data had to be made. Storm data was obtained from the NHC and examined. This effort took considerable time as a computer program to make use of the data was not available and had to be written. The historical master data list itself is a huge ASCII file over 655K bytes long. Data for one storm on the master data list appears in Appendix B.

2.6.1 PROGRAM VECTOR. After running the program VECTOR, data is massaged into several files which are much more manageable. The first of the output files is called TKHDR.DATA. This file is comprised of all track header data from each of the storms as listed in the master data file. Output from one line of this file looks like:

```
62410 ALMA  5 17 1790 688 11 HR
```

The number 62140 is the sequence number of the entry in the master data file, ALMA is the storm name, 5/17/1970 is the start date of the storm, 688 is the sequential number of the storm in the data list, 11 is the number of days the storm lasted, and HR means that it reached hurricane strength at some point in its life. The second file that is created is called TRK.DATA, and an example of one storm is shown in Appendix C. The fortran program, VECTOR.FOR is Appendix D. The final output file is called VECTOR.DATA. Data in this file resemble the following:

```
62410  38
62410  16.80 315.59    0.00  25
62410  37.92 309.27   -6.32  25
62410  26.35 297.09  -12.18  25
```

These data represent the following. In the first line, 62410 is the sequence number from the master data list of the header data line in the master data list, and 38 is the number of pieces of data exist for the storm. This is also the number of data lines follows with data of storm 62410. Note that all data lines begin with the same sequence number to tie each to the other. In line 2, the number 16.80 is the distance traveled from the first coordinate given for the storm to the second coordinate. The equation used in the program is the Pythagorean Theorem with the convergence of the longitude lines taken into account for westward (or eastward, as the case might be) motion of the storm. Next is the direction of motion followed by the change in direction since the last position. Since this is the first motion detected, its change is set to zero. Finally is the data for the maximum wind in knots.

2.6.2 PROGRAM CHOOSE. The data is now in a very manageable format, and lends itself nicely to further selection. One selection program, CHOOSE, (Appendix E) allows the user to select storms between certain specified storm sequence numbers. For example, should the user wish to see only data from storms which occurred after 1980 and prior to 1990, by referencing the storm sequence numbers at the beginning and end of the time period (81000 to 90240) he can have those data put into a file named NEWVECT.DATA for further investigation.

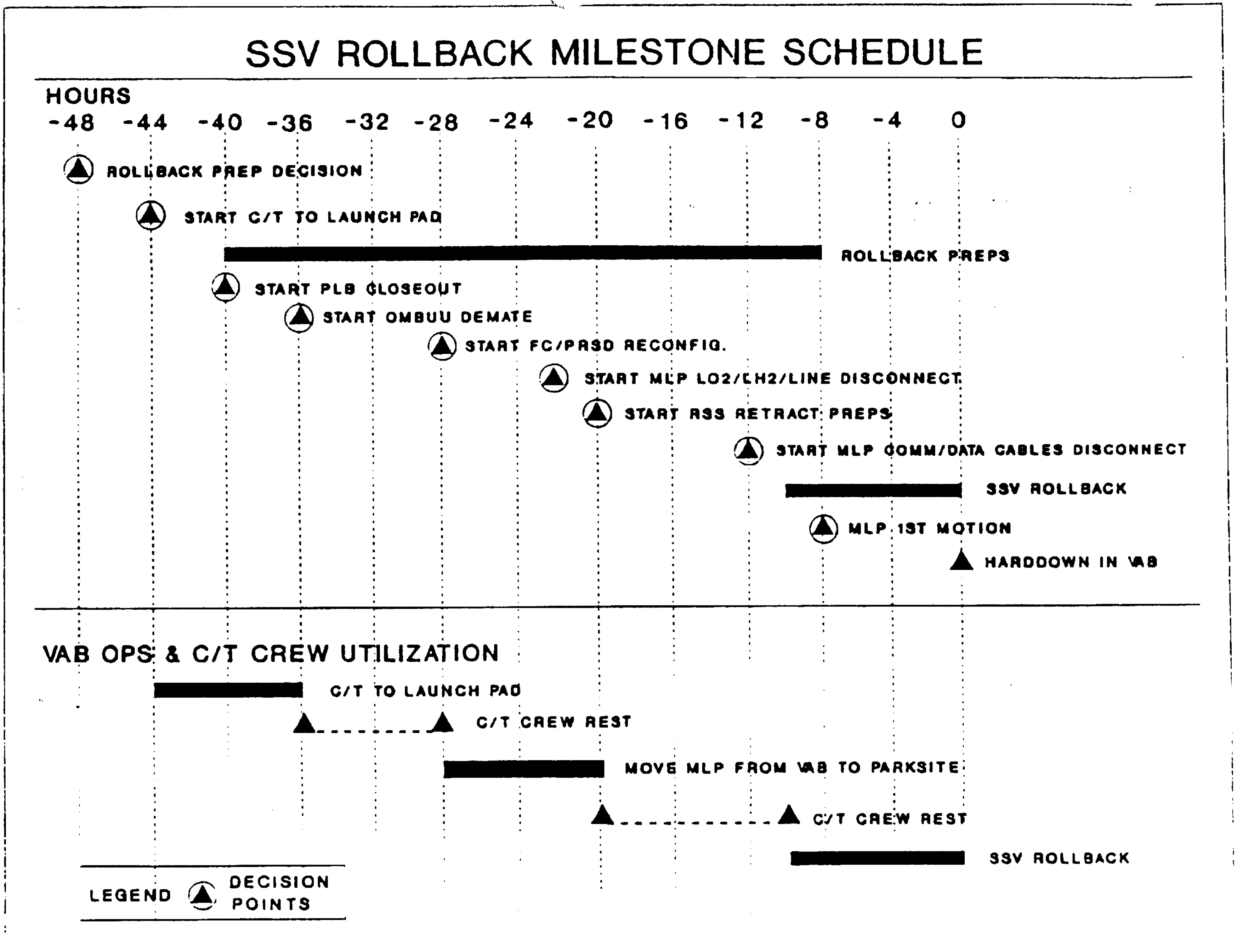
SECTION III DISCUSSION OF FUTURE INVESTIGATIONS

Now that the storm data is accessible, new selection programs can be written to allow the user to choose the storms which resemble the storm in progress. By analyzing the vector motion of the selected storms, both based upon time scales and upon distance scales, movement probabilities can be generated for use in the Bayesian analysis. Examination of the vector data yields the behavior of the storms. Questions to be answered could be of the form: given that my storm has turned right 10 degrees in both of the two most recent 6 hour periods, what is the probability that it will a) continue turning right, b) straighten out, or continue on its present heading or c) begin to turn left?

By selecting storms with similar characteristics in terms of windspeed, sea level pressure, forward movement, location and track, or any combination of these, reasonable probabilities can be found.

Once these programs and procedures are complete, they can be easily verified using the historical data. Since the user can de-select specific storms, that storm can be used to test the viability of the model. New insights to storm motion might be uncovered.

Ultimately, once these routines are incorporated into a single program, they should allow the user to gather, select and predict storm strike probabilities for the Center. Using NHC forecasts and analysis, a strike probability can be generated for use in the cost versus loss equation.



Attachment 1

APPENDIX A

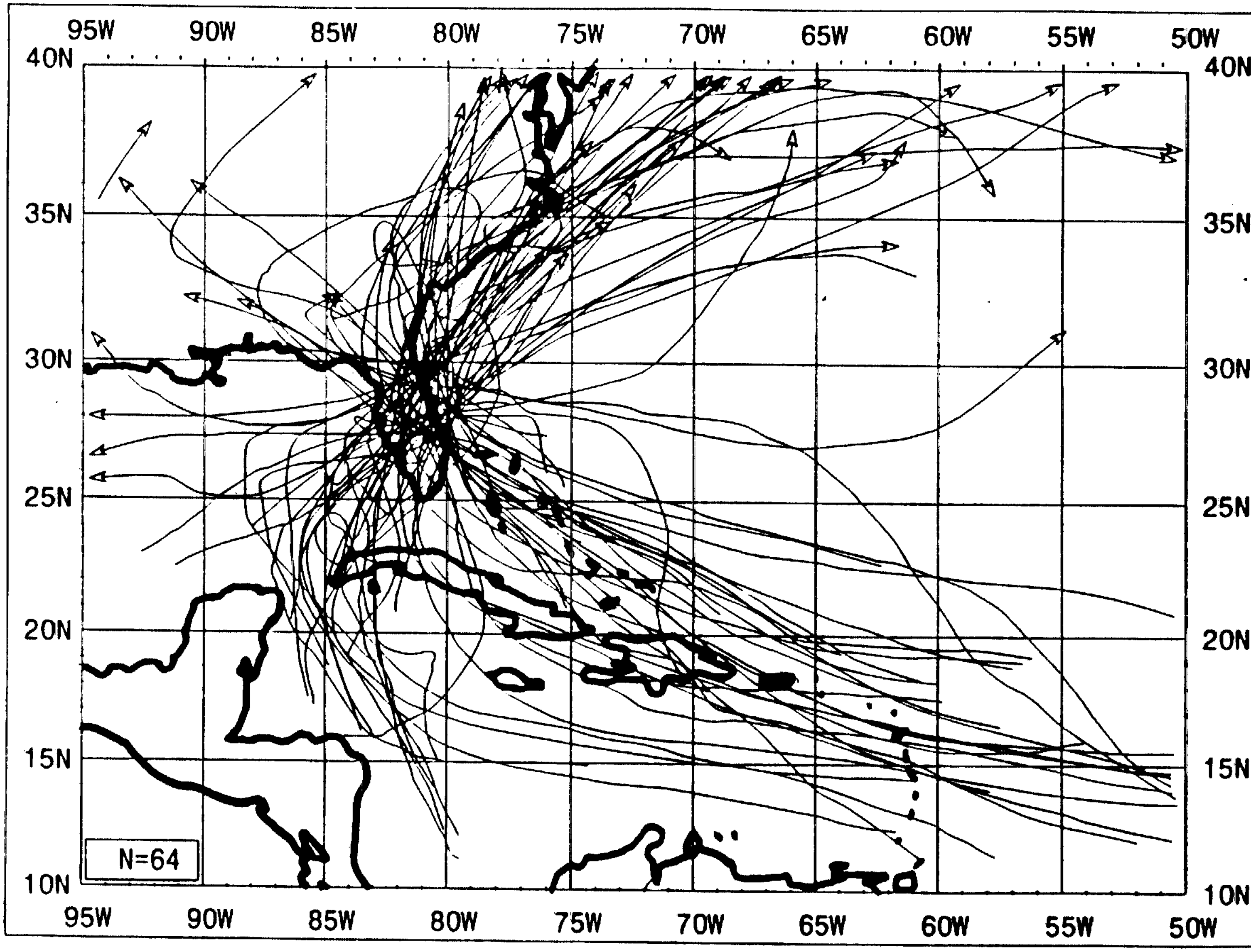
CHARTS 1-12
FROM

HURISK

TROPICAL CYCLONES (1886-1991) PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL

STORM INDEX NUMBER	STORM NAME	YEAR	MONTH	DAY (GMT)	STORM NUMBER FOR YEAR	MAXIMUM WIND (KTS) NEAR STORM CNTR AT CLOSEST PT. OF APPROACH	CLOSEST POINT OF APPROACH (CPA) N.MI.	STORM HEADING (DEGS) AT CPA	STORM FORWARD SPEED AT CPA(KTS)
1	NOT NAMED	1886	JUL	19	4	83	73	049	12.5
2	NOT NAMED	1887	AUG	20	4	105	68	356	12.8
3	NOT NAMED	1887	OCT	29	14	36	47	053	27.3
4	NOT NAMED	1889	OCT	5	9	45	68	015	18.8
5	NOT NAMED	1891	OCT	7	7	40	61	030	12.6
6	NOT NAMED	1891	OCT	10	8	35	9	037	8.8
7	NOT NAMED	1892	OCT	25	9	39	36	078	9.9
8	NOT NAMED	1893	AUG	27	6	105	39	332	12.6
9	NOT NAMED	1893	OCT	12	9	95	48	348	11.9
10	NOT NAMED	1894	SEP	26	3	78	31	015	9.4
11	NOT NAMED	1896	OCT	9	5	70	69	045	12.0
12	NOT NAMED	1897	SEP	21	3	35	15	028	11.3
13	NOT NAMED	1897	OCT	19	4	38	31	030	25.7
14	NOT NAMED	1898	AUG	2	1	69	72	290	15.4
15	NOT NAMED	1898	OCT	11	8	40	47	049	13.9
16	NOT NAMED	1899	AUG	14	2	105	47	360	7.0
17	NOT NAMED	1906	OCT	21	8	35	7	202	5.9
18	NOT NAMED	1906	OCT	17	9	35	64	246	15.2
19	NOT NAMED	1909	JUN	29	2	35	50	307	6.8
20	NOT NAMED	1909	AUG	30	6	35	2	345	5.3
21	NOT NAMED	1909	SEP	27	8	35	30	042	11.3
22	NOT NAMED	1910	OCT	18	4	60	55	354	9.0
23	NOT NAMED	1915	AUG	1	1	42	17	319	5.3
24	NOT NAMED	1916	SEP	13	8	35	16	304	18.8
25	NOT NAMED	1921	OCT	26	6	81	21	067	10.8
26	NOT NAMED	1925	DEC	1	2	63*	18	034	17.0
27	NOT NAMED	1926	JUL	28	1	68	3	324	7.4
28	NOT NAMED	1928	AUG	8	1	48*	30	312	6.0
29	NOT NAMED	1928	SEP	17	4	100	58	337	11.4
30	NOT NAMED	1930	SEP	10	2	35	37	058	4.0
31	NOT NAMED	1933	JUL	31	5	62	74	270	4.3
32	NOT NAMED	1933	SEP	4	12	55*	62	308	10.6
33	NOT NAMED	1934	MAY	28	1	39	49	027	15.7
34	NOT NAMED	1934	JUL	23	3	40	64	243	16.4
35	NOT NAMED	1936	AUG	21	9	44	45	299	15.7
36	NOT NAMED	1937	JUL	30	1	40	44	048	13.1
37	NOT NAMED	1937	AUG	30	3	49	17	291	11.3
38	NOT NAMED	1939	AUG	12	2	60*	52	300	12.2
39	NOT NAMED	1940	AUG	3	2	35	51	238	12.6
40	NOT NAMED	1944	OCT	19	11	63*	60	013	14.5
41	NOT NAMED	1945	JUN	24	1	65	66	048	12.6
42	NOT NAMED	1945	SEP	16	9	68	49	005	9.0
43	NOT NAMED	1949	AUG	27	2	88	59	308	11.3
44	EASY	1950	SEP	6	5	48*	27	028	7.5
45	KING	1950	OCT	18	11	67	32	339	17.2
46	HOW	1951	OCT	2	8	61	70	045	18.6
47	HAZEL	1953	OCT	9	12	55	51	054	24.0
48	DONNA	1960	SEP	11	5	97	37	027	16.2
49	CLEO	1964	AUG	28	5	59*	5	346	11.3
50	DORA	1964	SEP	10	8	100	70	279	6.2
51	ABBY	1968	JUN	6	1	50	17	313	6.7
52	GLADYS	1968	OCT	19	8	70	67	053	17.0
53	SUBTROP	1974	JUN	25	1	55	33	048	32.9
54	SUBTROP	1974	OCT	7	11	40	50	009	13.3
55	DOTTIE	1976	AUG	20	5	42	47	360	14.0
56	DAVID	1979	SEP	4	4	85	11	347	11.3
57	DENNIS	1981	AUG	19	4	35	6	002	10.6
58	BARRY	1983	AUG	25	2	34	45	260	10.0
59	DIANA	1984	SEP	9	5	55	58	338	4.4
60	ISIDORE	1984	SEP	28	10	45	60	307	10.3
61	BOB	1985	JUL	24	2	53	28	001	11.0
62	ISABEL	1985	OCT	10	9	41	64	307	11.0
63	CHRIS	1988	AUG	28	3	41	40	345	27.0
64	KEITH	1988	NOV	23	12	38	23	049	16.8

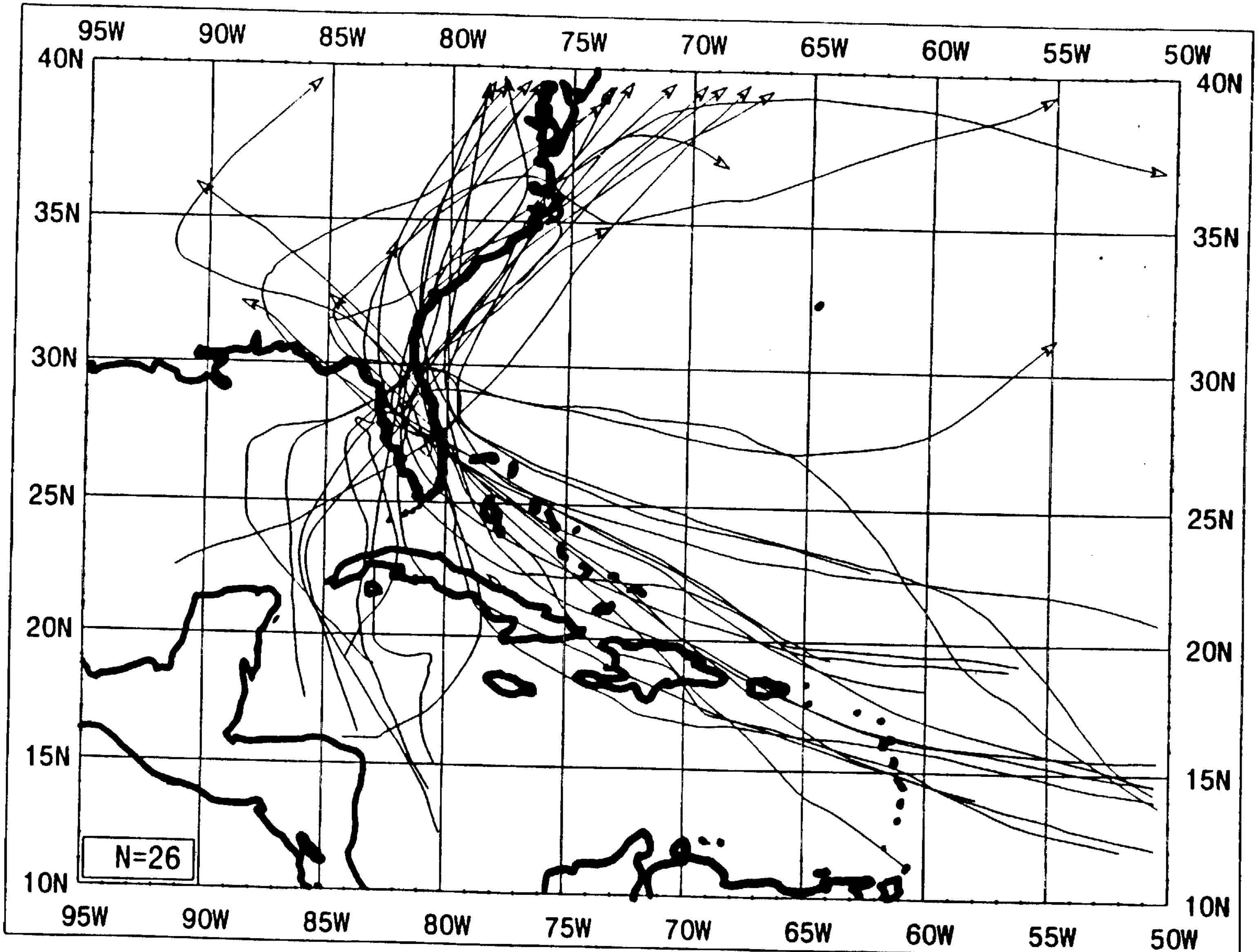
CHART 1



TROPICAL CYCLONES PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL 1886-1991

(SITE LOCATION MOVED TO 28.6N, 80.9W)

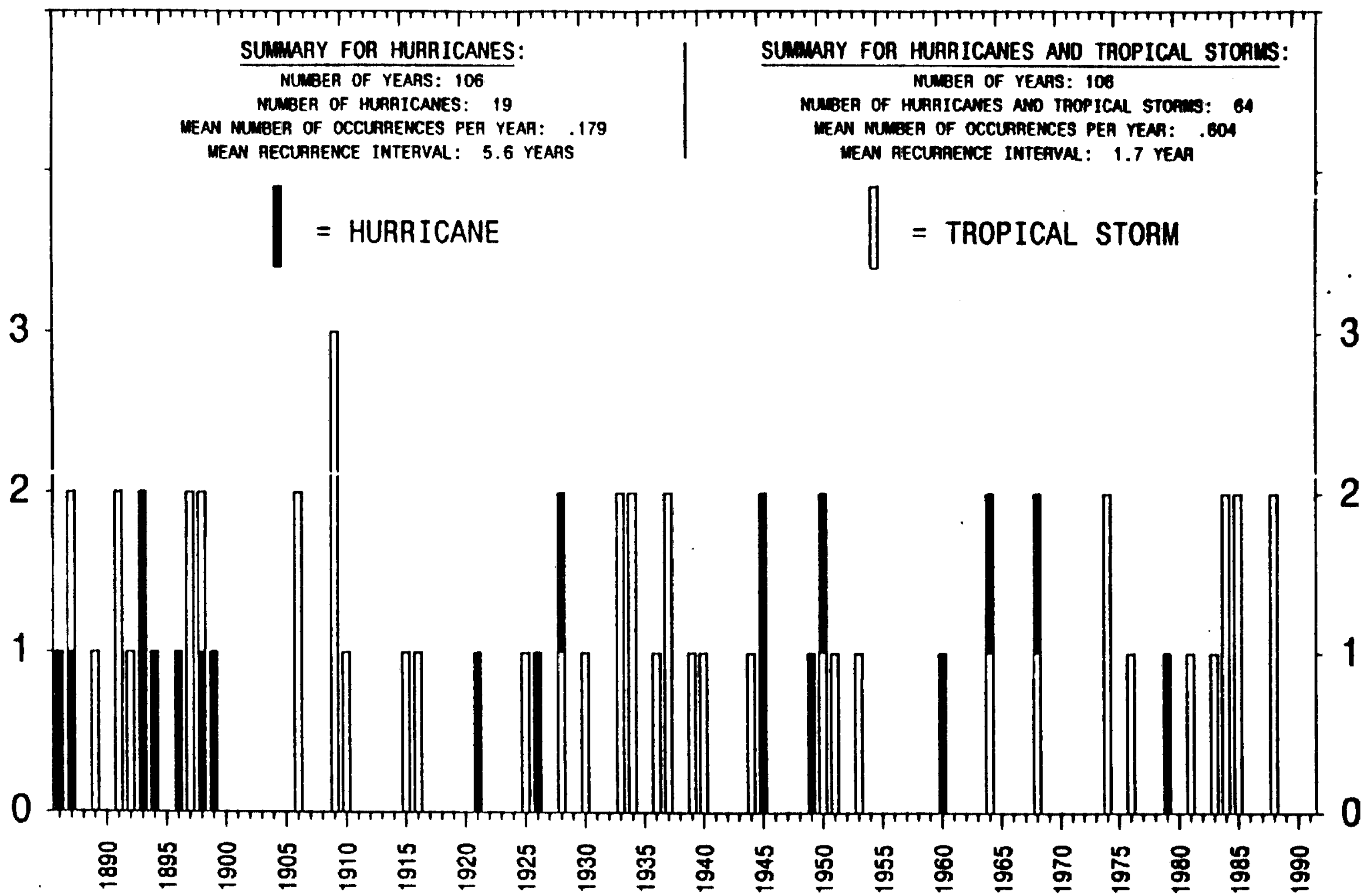
CHART 2



HURRICANES PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL 1886-1991

(SITE LOCATION MOVED TO 28.6N, 80.9W)

CHART 3



TROPICAL CYCLONES PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL 1886-1991

(Note: Storm intensity is determined at time of closest approach to site)

CHART 4

TROPICAL CYCLONES PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL

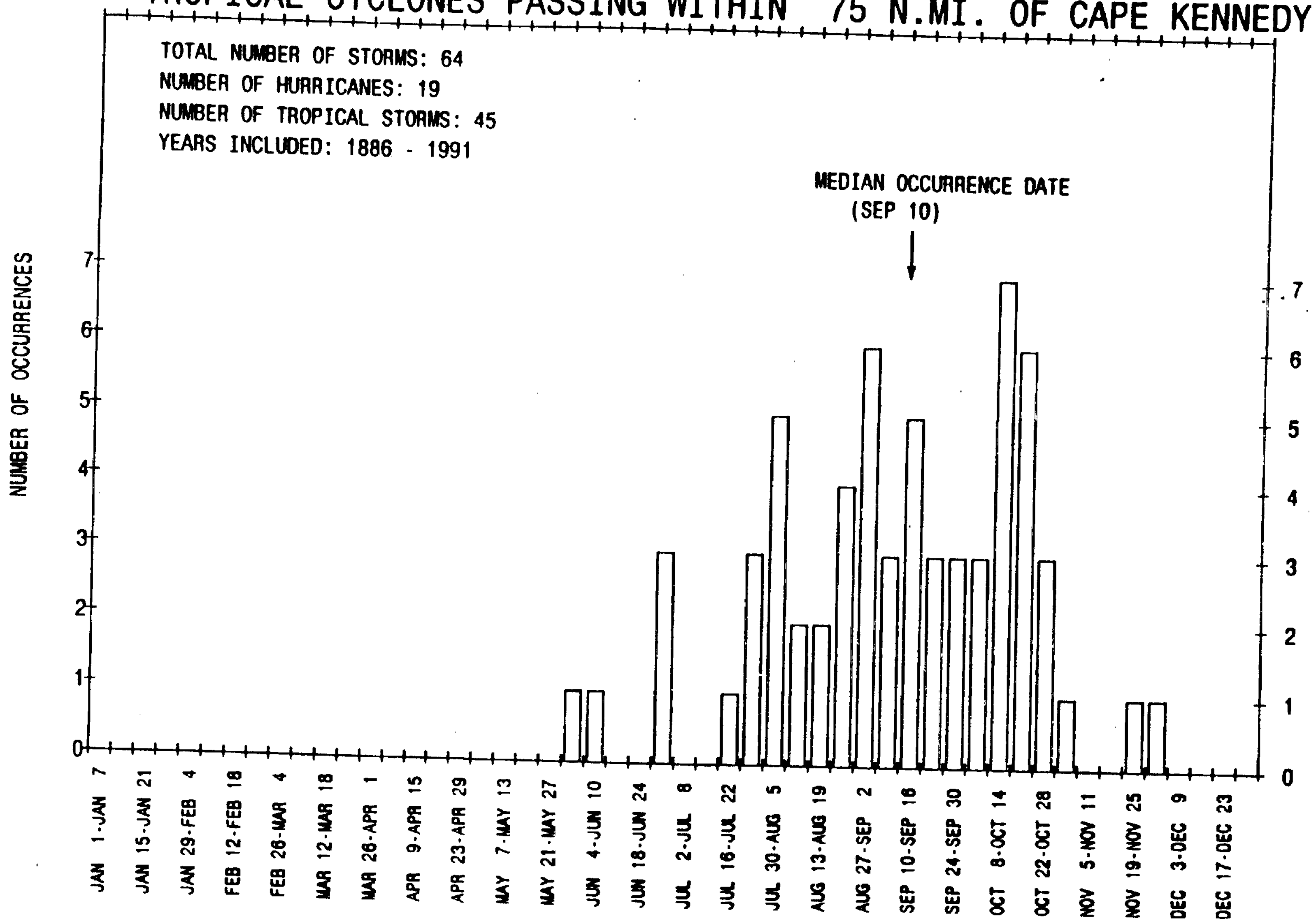


CHART 5

DIRECTION DISTRIBUTION FOR STORMS PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL

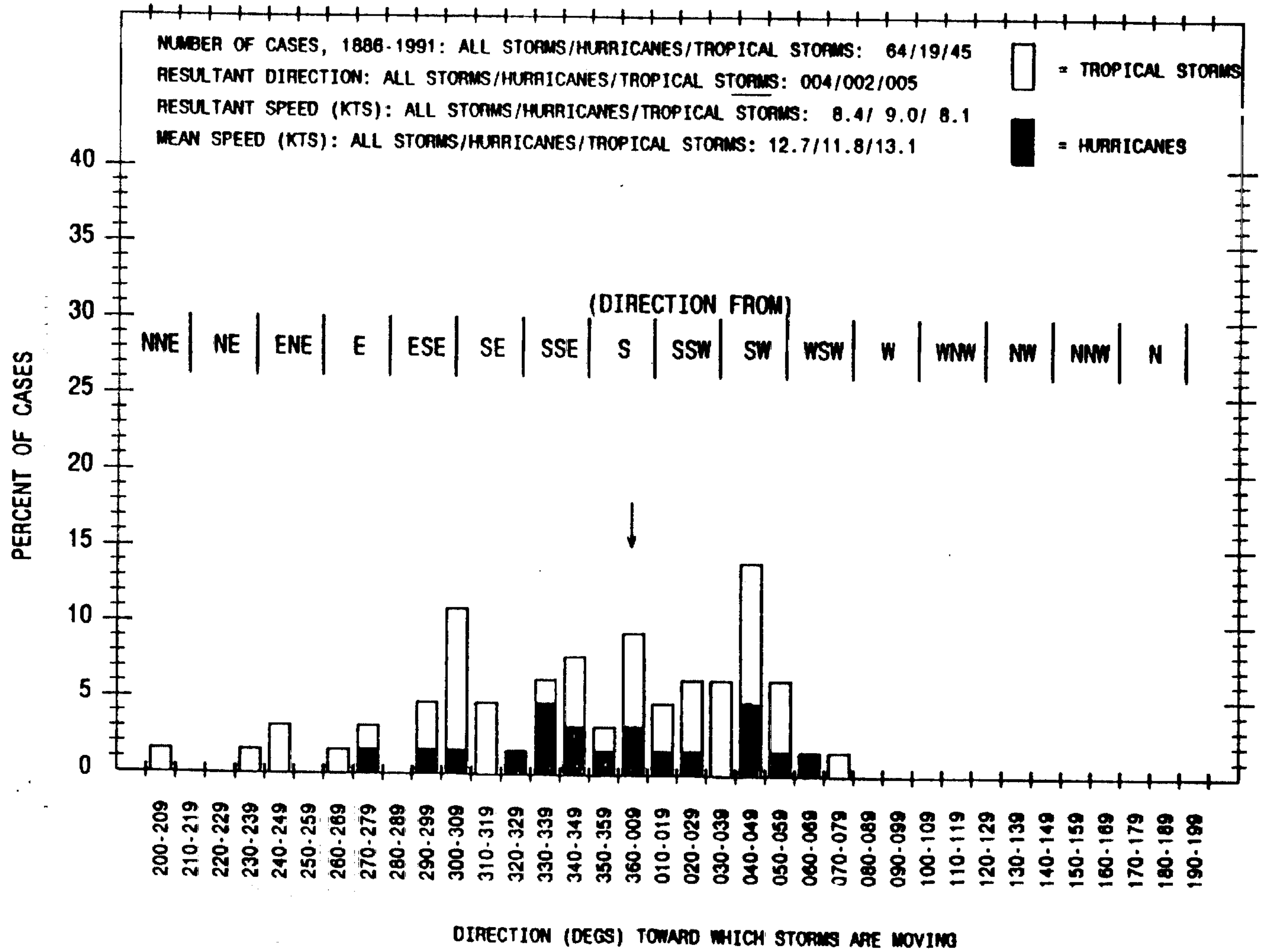


CHART 6

NUMBER OF STORMS (1886-1991) PASSING WITHIN SPECIFIED DISTANCES FROM CAPE KENNEDY, FL

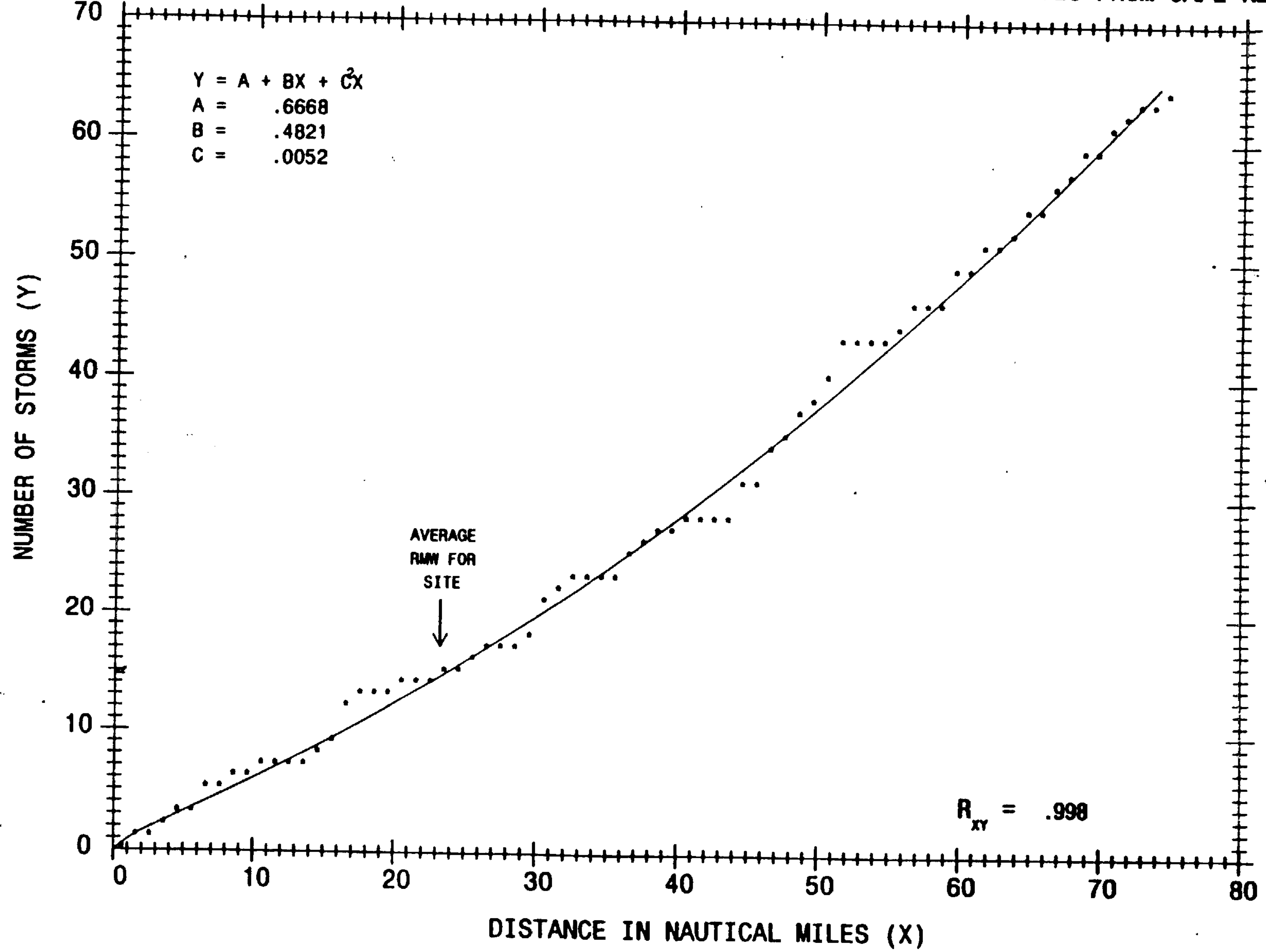


CHART 7

WEIBULL DISTRIBUTION FITTED TO HISTOGRAM OF OBSERVED MAXIMUM WINDS

FOR TROPICAL CYCLONES PASSING WITHIN 75 N.MI. OF CAPE KENNEDY, FL

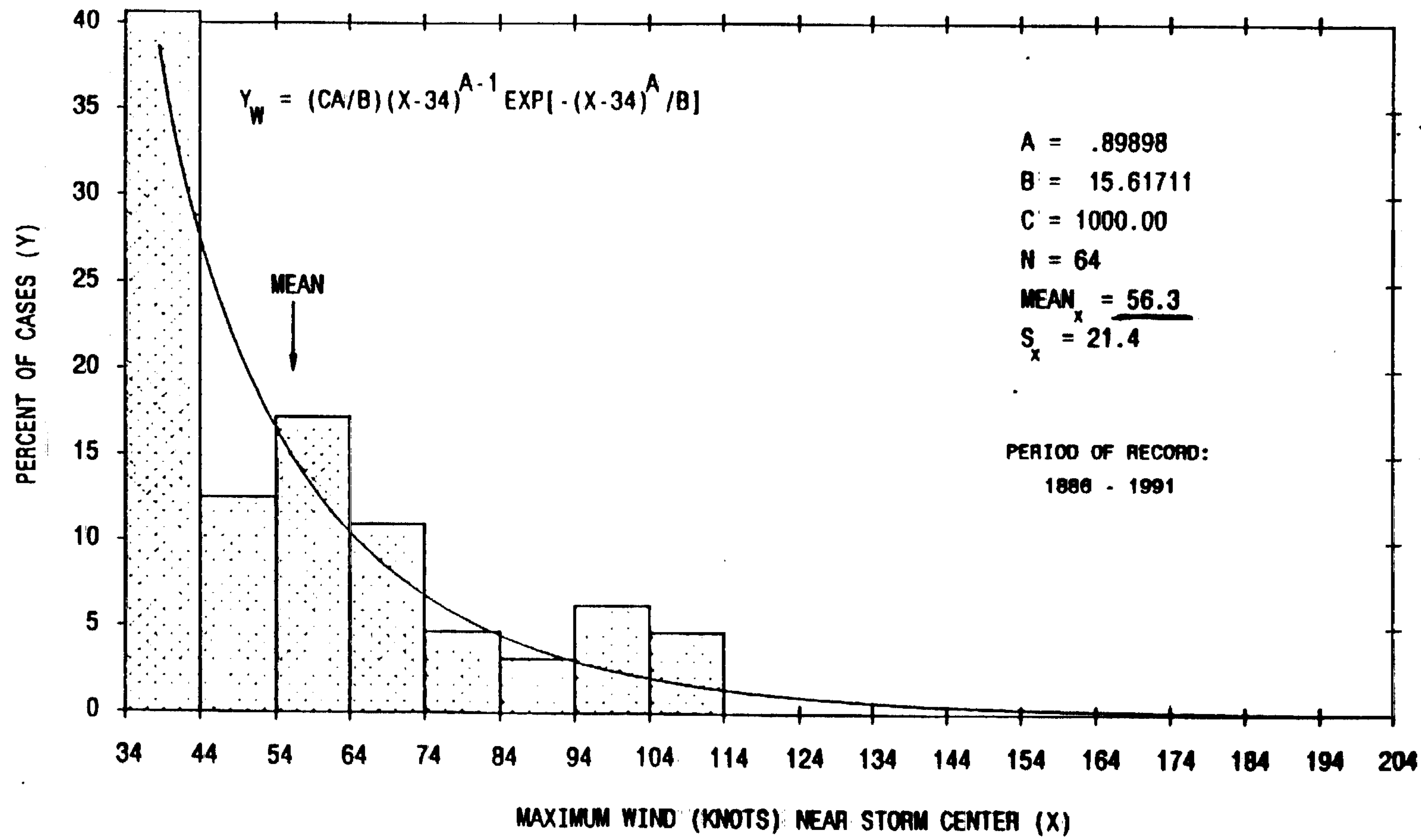


CHART 8

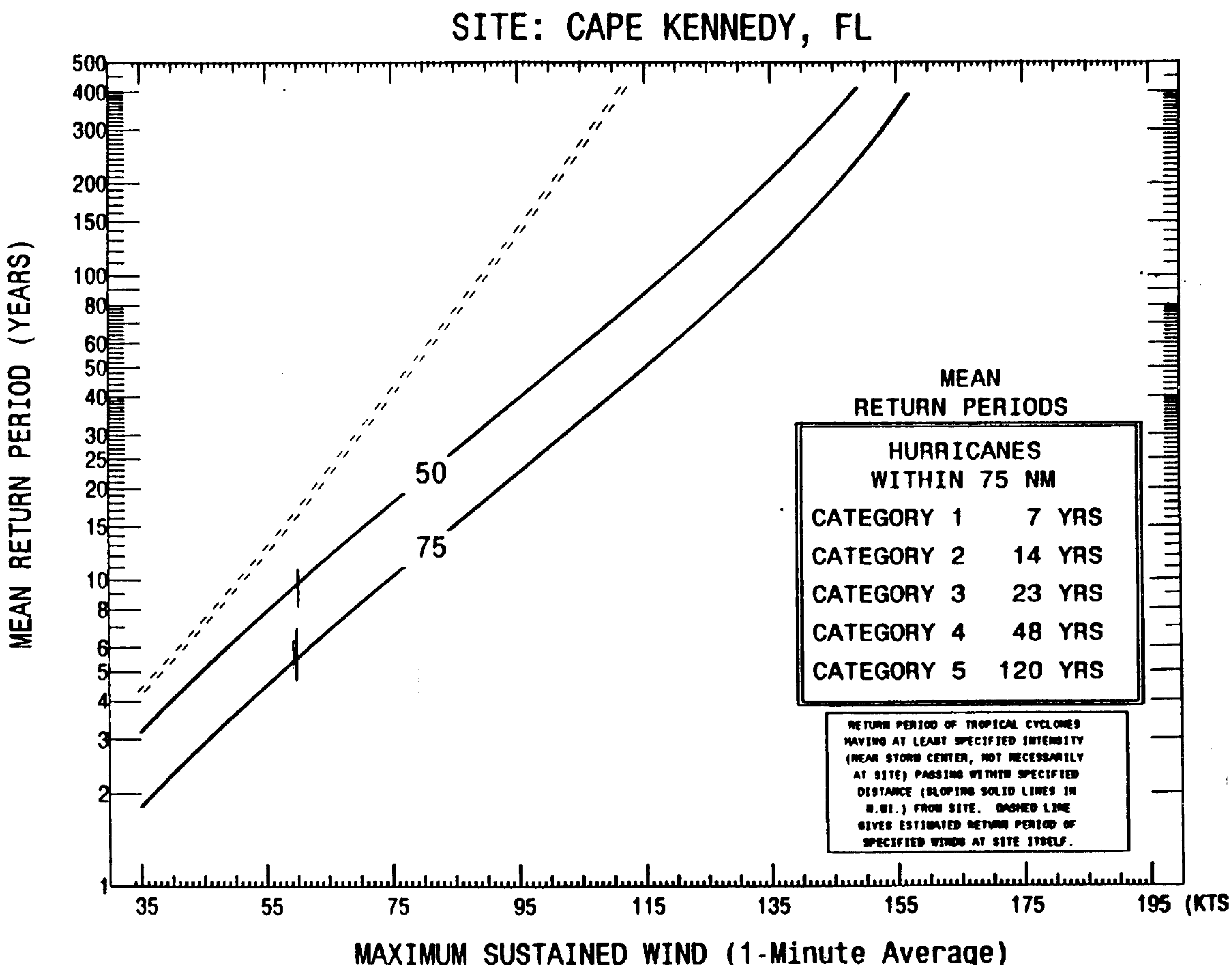

SITE: CAPE KENNEDY, FL
MEAN RETURN PERIOD (YEARS)
500
400
300
200
150
100
80
60
50
40
30
25
20
15
10
8
6
5
4
3
2
1
35
55
75
95
115
135
155
175
195 (KTS)
MAXIMUM SUSTAINED WIND (1-Minute Average)
50
75
MEAN
RETURN PERIODS
HURRICANES
WITHIN 75 NM
CATEGORY 1 7 YRS
CATEGORY 2 14 YRS
CATEGORY 3 23 YRS
CATEGORY 4 48 YRS
CATEGORY 5 120 YRS
RETURN PERIOD OF TROPICAL CYCLONES HAVING AT LEAST SPECIFIED INTENSITY (NEAR STORM CENTER, NOT NECESSARILY AT SITE) PASSING WITHIN SPECIFIED DISTANCE (SLOPING SOLID LINES IN N.MI.) FROM SITE. DASHED LINE GIVES ESTIMATED RETURN PERIOD OF SPECIFIED WINDS AT SITE ITSELF.

CHART 9

PROBABILITY OF AT LEAST X TROPICAL CYCLONES (≥34 KNOTS) PASSING
WITHIN 75 N.MI. OF SPECIFIED SITE OVER N CONSECUTIVE YEARS

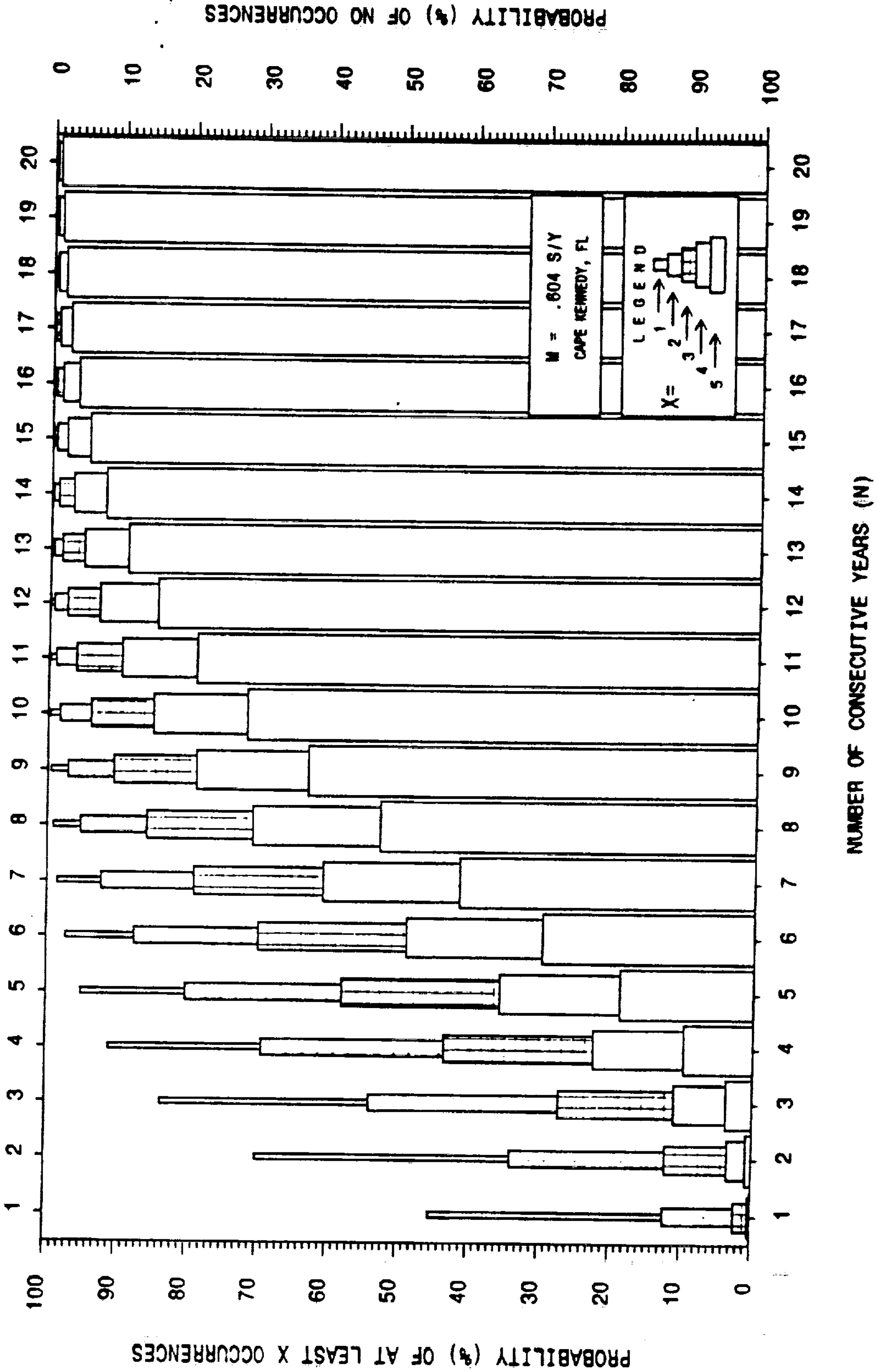


CHART 10

PROBABILITY OF AT LEAST X TROPICAL CYCLONES (≥64 KNOTS) PASSING
WITHIN 75 N.MI. OF SPECIFIED SITE OVER N CONSECUTIVE YEARS

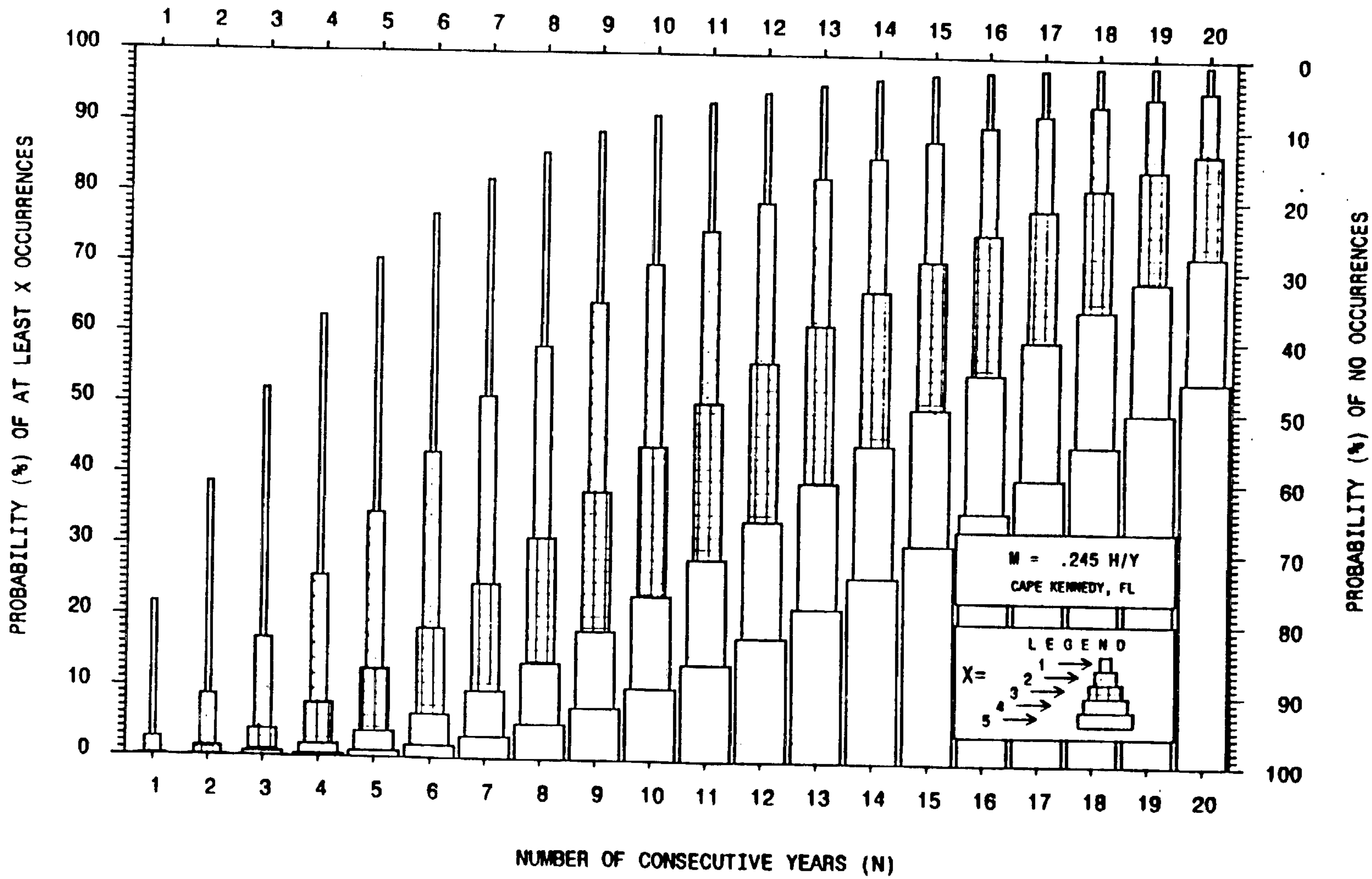


CHART 11

GAMMA DISTRIBUTION OF STORM TRANSLATIONAL SPEEDS

(STORM INTENSITY ≧ 34 KTS)

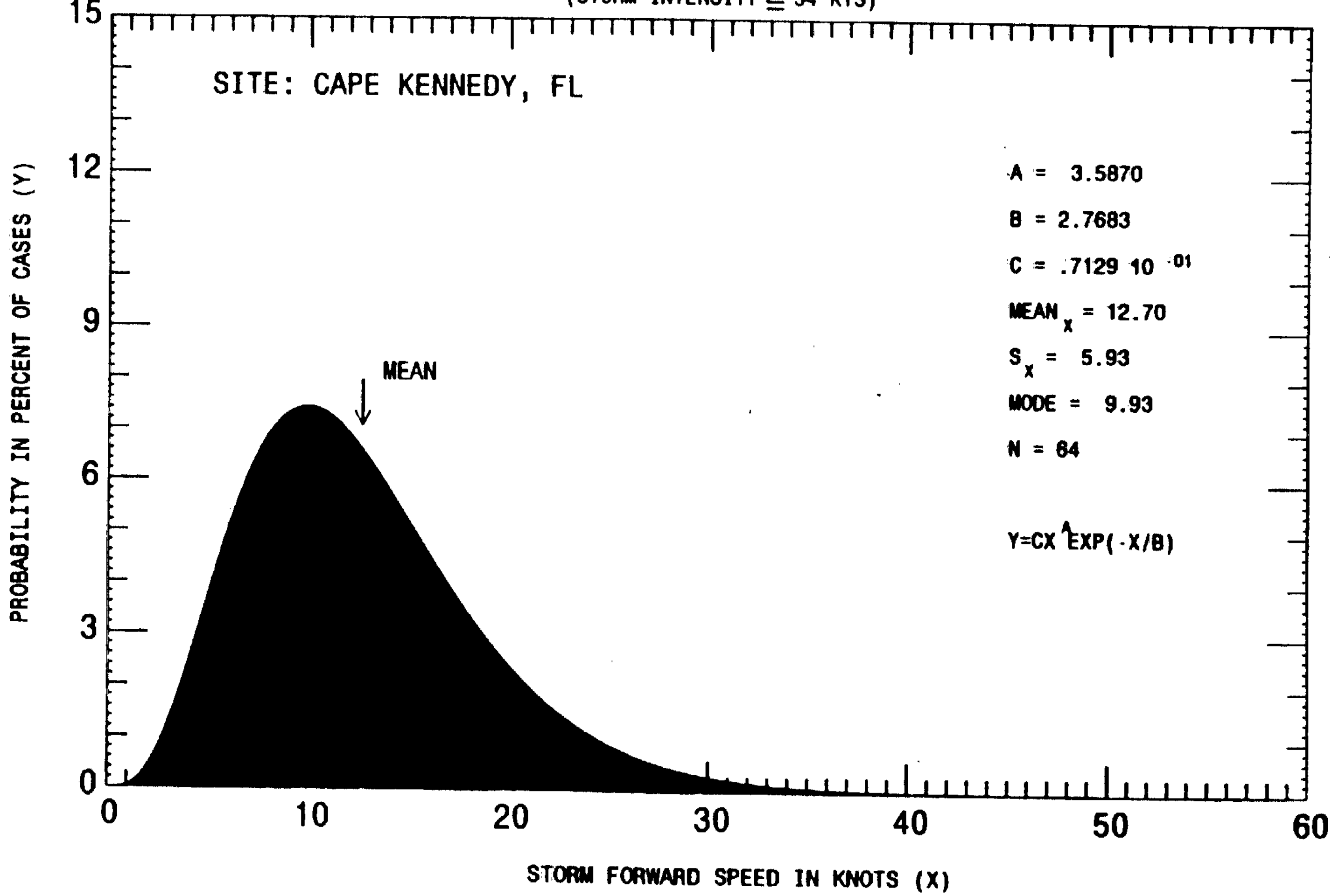


CHART 11

GAMMA DISTRIBUTION OF STORM TRANSLATIONAL SPEEDS

(STORM INTENSITY ≥ 64 KTS)

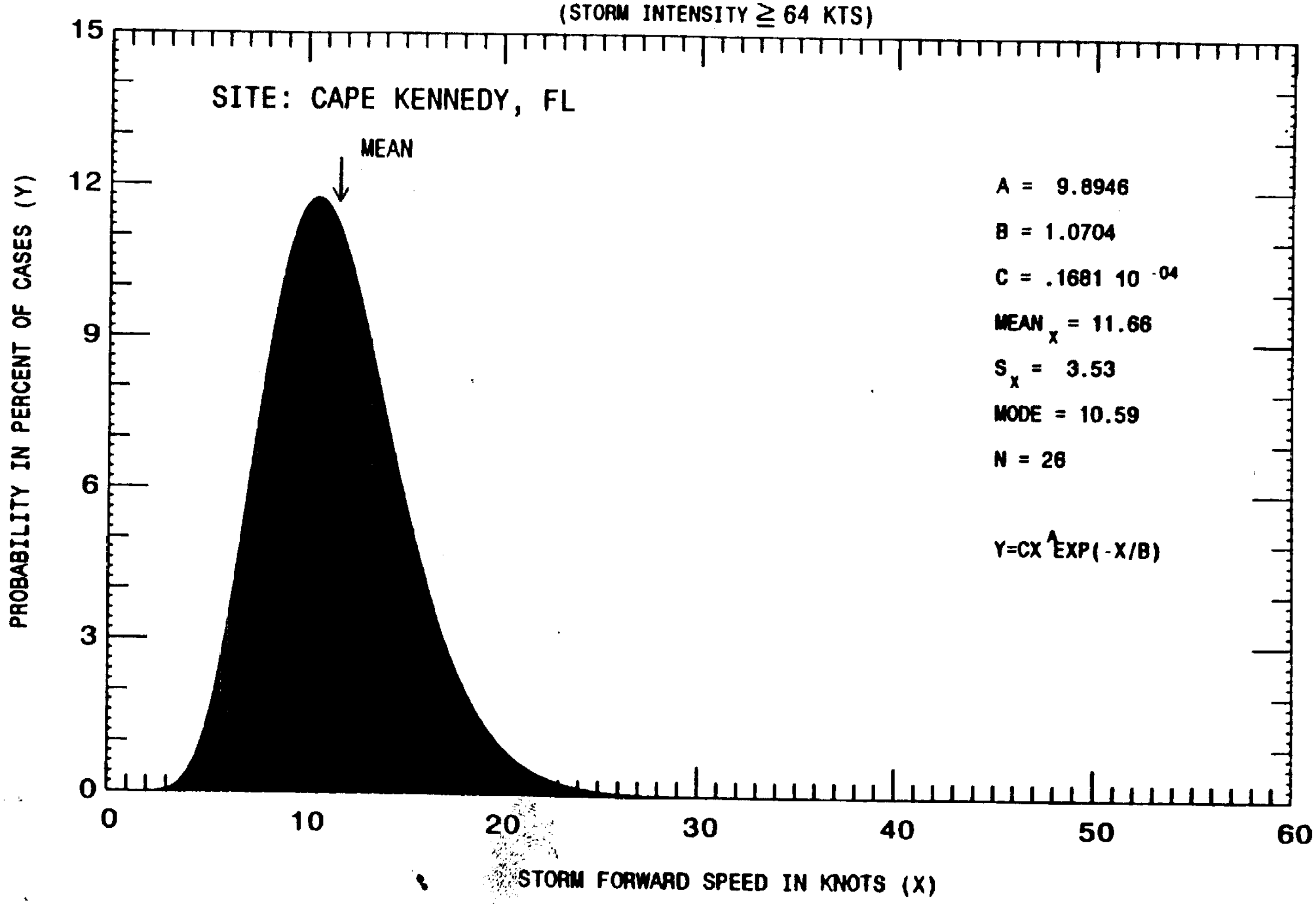


CHART 12

APPENDIX B

MASTER DATA LIST

```
62410 05/17/1970 M=11  1 SNBR= 688 ALMA        XING=0
62420 05/17*  0   0   0     0*  0   0   0     0*  0   0   0     0*115 790  25    0*
62430 05/18*117 792  25     0*121 797  25     0*123 801  25 1007*125 805  25    0*
62440 05/19*130 810  25     0*135 815  25     0*140 820  25 1005*145 825  25    0*
62450 05/20*155 825  35     0*162 823  35     0*168 819  65     0*172 816  70  993*
62460 05/21*180 810  55     0*182 803  50     0*185 802  45     0*190 800  40  998*
62470 05/22*196 801  35 1004*193 806  30     0*191 811  30     0*190 818  30 1007*
62480 05/23*192 827  30     0*198 835  25     0*210 839  25     0*219 840  25    0*
62490 05/24*230 840  25     0*240 840  25     0*252 840  25 1008*268 839  25    0*
62500 05/25*283 836  25     0*295 829  25     0*306 822  25     0*318 816  25    0*
62510 05/26*326 812  25 1005*333 807  25     0*348 799  25     0*357 787  25    0*
62520 05/27E365 770  25 1003E370 755  25     0*  0   0   0     0*  0   0   0    0*
62530 HR
```

APPENDIX C

LISTING OF TRK.DAT OUTPUT

62410	38			
62410	16.80	315.59	0.00	25
62410	37.92	309.27	-6.32	25
62410	26.35	297.09	-12.18	25
62410	26.33	297.11	0.02	25
62410	41.91	315.72	18.61	25
62410	41.87	315.77	0.06	25
62410	41.82	315.83	0.06	25
62410	41.78	315.90	0.06	25
62410	60.00	360.00	44.10	25
62410	43.56	15.37	15.37	35
62410	42.73	32.59	17.22	35
62410	29.53	35.65	3.06	65
62410	59.00	35.56	-0.09	70
62410	41.69	73.27	37.71	55
62410	18.88	17.56	-55.71	50
62410	32.08	20.75	3.19	45
62410	36.44	351.06	-29.68	40
62410	33.53	237.53	-113.53	35
62410	30.77	247.04	9.51	30
62410	40.15	261.41	14.36	30
62410	52.42	283.23	21.83	30
62410	57.82	308.51	25.27	30
62410	75.43	342.65	34.14	25
62410	54.29	354.10	11.45	25
62410	66.00	360.00	5.90	25
62410	60.00	360.00	0.00	25
62410	72.00	360.00	0.00	25
62410	96.15	3.22	3.22	25
62410	91.40	10.06	6.84	25
62410	80.85	27.05	17.00	25
62410	75.35	28.85	1.79	25
62410	78.31	23.16	-5.69	25
62410	52.12	22.93	-0.22	25
62410	48.97	30.94	8.01	25
62410	98.40	23.84	-7.10	25
62410	79.83	47.44	23.60	25
62410	95.37	59.78	12.35	25
62410	78.10	67.41	7.63	25

APPENDIX D

LISTING OF PROGRAM VECTOR.FOR

```
C----------------------------7/22/92-----------------------------------
         PROGRAM VECTOR
C
         INTEGER DATLIN, DATLIN2,DAY,MO,YR,M,SNBR,XING
         INTEGER DLIN(30),MN(30),DY(30)
         INTEGER LAT(30,4),LON(30,4),MAX(30,4),SLP(30,4),MX(120),SP(120)
C
         CHARACTER*1 J1
         CHARACTER*2 J2
         CHARACTER*5 J5
         CHARACTER*6 J6
         CHARACTER*9 NAME,TYPE
         CHARACTER*12 FILENAME
C
         REAL LT(120),LN(120),DIS(120),DIR(120),ADIR(120),PI,DR,XDIS,YDIS
C
         PI=3.141592654
C
C        OPEN (UNIT=10,FILE='NEWTEST.TRK', STATUS= 'OLD',FORM='FORMATTED')
         OPEN (UNIT=11,FILE='TKHDR.DAT',STATUS='NEW',FORM='FORMATTED')
         OPEN (UNIT=12,FILE='TRK.DAT',STATUS='NEW',FORM='FORMATTED')
         OPEN (UNIT=13,FILE='VECTOR.DAT',STATUS='NEW',FORM='FORMATTED')
C
5        WRITE (6,*) 'PLEASE TYPE IN THE NAME OF YOUR STORM FILE.'
         READ (6,10) FILENAME
10       FORMAT (A12)
         OPEN (UNIT=10,FILE=FILENAME,STATUS='OLD',FORM='FORMATTED',ERR=20)
         GOTO 100
20       WRITE (6,25)FILENAME
25       FORMAT (1X,'OOPS, THE DATA FILE ',A12,' DOES NOT EXIST.'
     &   '  TRY AGAIN.',//)
         GOTO 5
100      CONTINUE
C        ---------CLEARS DATA FROM ARRAYS----
C
         DO 150 I=1,30
                 DO 160 J=1,4
                 LAT(I,J)=0
                 LON(I,J)=0
                 MAX(I,J)=0
                 SLP(I,J)=0
160              CONTINUE
150      CONTINUE
         DO 170 I=1,120
                 LT(I)=0
                 LN(I)=0
                 MX(I)=0
                 SP(I)=0
170      CONTINUE
C
C        ---------READING HEADER DATA-----
         READ (10,1000,END=3000) DATLIN,MO,J1,DAY,J1,YR,J2,M,K,J5,SNBR,NAME
1000     FORMAT (I5,1X,I2,A1,I2,A1,I4,1X,A2,I2,I4,A5,I4,1X,A9)
C        ---------READS STORM DATA---------
         DO 2000 I=1,M
                 READ (10,1010)DLIN(I),MN(I),J1,DY(I),J1,
     &           LAT(I,1),LON(I,1),MAX(I,1),SLP(I,1),J1,
     &           LAT(I,2),LON(I,2),MAX(I,2),SLP(I,2),J1,
     &           LAT(I,3),LON(I,3),MAX(I,3),SLP(I,3),J1,
     &           LAT(I,4),LON(I,4),MAX(I,4),SLP(I,4)
C
1010             FORMAT (I5,1X,I2,A1,I2,A1,I3,I4,1X,I3,1X,I4,A1,
     &           I3,I4,1X,I3,1X,I4,A1,I3,I4,1X,I3,1X,I4,A1,
     &           I3,I4,1X,I3,1X,I4)
C LN59
```

```
C WHEW! LN129
C       ---------SAVES TO VECTOR.DAT FILE-----
C
                ADIR(1)=0.0
                IF((I-1).EQ.1) GOTO 4740
                ADIR(I-1)=DIR(I-1)-DIR(I-2)
                IF (ADIR(I-1).LT.-270) THEN
                        ADIR(I-1)=ADIR(I-1)+360
                ELSEIF (ADIR(I-1).GT.270) THEN
                        ADIR(I-1)=ADIR(I-1)-360
                ENDIF
4740            WRITE (13,4750)DATLIN,DIS(I-1),DIR(I-1),ADIR(I-1),MX(I-1)
4750            FORMAT (1X,I5,1X,F6.2,1X,F6.2,1X,F7.2,1X,I3)
4700    CONTINUE
C
C       ---------READS STORM MAX INTENSITY---------
        READ (10,1050)DATLIN2,TYPE
1050    FORMAT (I5,1X,A2)
C 140      ---------WRITING DATA TO SCREEN AND FILE---------
C       WRITE (6,1100)DATLIN,NAME,MO,DAY,YR,SNBR,M,TYPE
C       WRITE (6,*)NFIX
1100    FORMAT (1X,I5,1X,A9,1X,I2,1X,I2,1X,I4,1X,I3,1X,I3,1X,A2)
        DO 2500 I=1,M
                WRITE (12,1200)DLIN(I),LAT(I,1),LON(I,1),MAX(I,1),SLP(I,1),
     &                  LAT(I,2),LON(I,2),MAX(I,2),SLP(I,2),
     &                  LAT(I,3),LON(I,3),MAX(I,3),SLP(I,3),
     &                  LAT(I,4),LON(I,4),MAX(I,4),SLP(I,4)
1200            FORMAT(1X,I5,1X,I3,1X,I4,1X,I3,1X,I4,
     &                  1X,I3,1X,I4,1X,I3,1X,I4,
     &                  1X,I3,1X,I4,1X,I3,1X,I4,
     &                  1X,I3,1X,I4,1X,I3,1X,I4)
2500    CONTINUE
        WRITE (11,1100)DATLIN,NAME,MO,DAY,YR,SNBR,M,TYPE
        GOTO 100
C       ---------LOOPS BACK TO BEGINNING OF PROGRAM TO READ NEXT------
C       ---------JUMPS HERE IF READ ENCOUNTERS EOF MARKER IN DATA-----
CLN145
3000    WRITE (6,6000)
6000    FORMAT (1X,/,' ALL DONE!',//,' HEADER DATA IN FILE NAMED ',
     &  'TKHDR.DAT,',/,' STORM DATA IN TRK.DAT,',/,' AND VECTOR DATA',
     &  ' IS IN A FILE NAMED VECTOR DAT.')
        CLOSE (UNIT=10)
        CLOSE (UNIT=11)
        CLOSE (UNIT=12)
        CLOSE (UNIT=13)
        END
```

```
2000    CONTINUE
C
C       ---------STORES STORM DATA IN WORKING FILES-----
C
        DO 4100 I=1,M
                DO 4200 J-1,4
                                LT(4*I-4+J)=LAT(I,J)*.1
                                LN(4*I-4+J)=LON(I,J)*.1
                                MX(4*I-4+J)=MAX(I,J)
                                SP(4*I-4+J)=SLP(I,J)
4200            CONTINUE
4100    CONTINUE
C
C       ---------GETS RID OF ZERO VALUES AT BEGINNING OF ARRAYS-----
C LN78
4500    IF (LT(1).LT.1) THEN
                DO 4550 J=1,(M*4)
                        LT(J)=LT(J+1)
                        LN(J)=LN(J+1)
                        MX(J)=MX(J+1)
                        SP(J)=SP(J+1)
4550                    CONTINUE
                GOTO 4500
        ENDIF
C
C       ---------COUNTS NUMBER OF FIXES-----
C
        NFIX=1
4560    IF (LT(NFIX+1).NE.0.0) THEN
                NFIX=NFIX+1
                IF (NFIX+1.GT.M*4)GOTO 4570
                GOTO 4560
4570            CONTINUE
        ENDIF
C
C       ---------COMPUTES DISTANCE TRAVELED EACH 6HR PERIOD-----
C  LN100
        K=NFIX-1
        WRITE (13,4600)DATLIN,K
4600    FORMAT(1X,I5,1X,I3)
        DO 4700 I=2,NFIX
                XDIS=(LN(I-1)-LN(I))*
     &                  COS(((LT(I-1)+LT(I))/2)*PI/180)*60
                YDIS=(LT(I)-LT(I-1))*60
C
                DIS(I-1)=SQRT((XDIS)**2+(YDIS**2))
C
C110    ---------COMPUTES HEADING TRAVELED FOR EACH 6HR PERIOD-----
C
                IF ((XDIS.GT.0).AND.(YDIS.GT.0)) THEN
                        DIR(I-1)=ATAN(XDIS/YDIS)*180/PI
                ELSEIF ((XDIS.GT.0).AND.(YDIS.LT.0)) THEN
                        DIR(I-1)=ATAN(XDIS/YDIS)*180/PI+180
                ELSEIF ((XDIS.LT.0).AND.(YDIS.GT.0)) THEN
                        DIR(I-1)=ATAN(XDIS/YDIS)*180/PI+360
                ELSEIF ((XDIS.LT.0).AND.(YDIS.LT.0)) THEN
                        DIR(I-1)=ATAN(XDIS/YDIS)*180/PI+180
                ELSEIF ((XDIS.EQ.0).AND.(YDIS.GT.0)) THEN
                        DIR(I-1)=360.0
                ELSEIF (XDIS.EQ.0) THEN
                        DIR(I-1)=180.0
                ELSEIF ((YDIS.EQ.0).AND.(XDIS.GE.0)) THEN
                        DIR(I-1)=90.0
                ELSE
                        DIR(I-1)=270.0
                ENDIF
```

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OF POOR QUALITY

APPENDIX E

LISTING OF PROGRAM CHOOSE.FOR

```
C       -------CHOOSE.FOR------
C       THIS PROGRAM ALLOWS THE USER TO SELECT SPECIFIC STORM OR STORM
C       DATA FROM THE VECTOR.DAT FILE.
C
        PROGRAM CHOOSE
C
        REAL DIS(120),DIR(120),ADIR(120)
        INTEGER MAX(120),N,DATLIN
C
        OPEN (UNIT=10,FILE='VECTOR.DAT',STATUS='OLD',ERR=50)
        OPEN (UNIT=11,FILE='NEWVECT.DAT',STATUS='NEW',FORM='FORMATTED')
        GOTO 80
C
50      WRITE (6,*) ' CANNOT OPEN VECTOR.DAT FILE.  RUN VECTOR FIRST'
        GOTO 5000
80      WRITE (6,*) ' WHAT IS THE FIRST SEQUENCE NUMBER OF DATA?'
        READ (6,*,ERR=70) ISTART
        WRITE (6,*) ' WHAT IS THE LAST SEQUENCE NUMBER? (MAY BE THE SAME)'
        READ (6,*,ERR=70) IFIN
        GOTO 90
70      IF (ISTART.LT.IFIN) THEN
                WRITE (6,*) ' GOT A PROBLEM.  WE SHALL TRY AGAIN.'
                GOTO 80
        ENDIF
90      READ (10,100,END=3000)DATLIN,N
100     FORMAT (1X,I5,1X,I3)
C
C       -----GETS RID OF DATA BEFORE TIME OF INTEREST-----
C
        IF (DATLIN.LT.ISTART) THEN
                DO 500 I=1,N
                        READ (10,150)JUNK1,R1,R2,R3,JUNK2
150                     FORMAT (I5,1X,F6.2,1X,F6.2,1X,F7.2,1X,I3)
500             CONTINUE
                GOTO 90
C
C       -----SAVES DATA OF INTEREST IN NEW DATA FILE-----
C
        ELSEIF ((DATLIN.GE.ISTART).AND.(DATLIN.LE.IFIN)) THEN
                FLAG=1
                WRITE (11,100)DATLIN,N
                DO 1000 I=1,N
                        READ (10,250)JUNK,DIS(I),DIR(I),ADIR(I),MAX(I)
250                     FORMAT (1X,I5,1X,F6.2,1X,F6.2,1X,F7.2,1X,I3)
                        WRITE (11,250)DATLIN,DIS(I),DIR(I),ADIR(I),MAX(I)
1000            CONTINUE
                GOTO 90
C
C       -----GIVES ERROR MESSAGE FOR DATA NOT FOUND.
C
        ELSE
        IF (FLAG.EQ.1) GOTO 3000
        WRITE (6,4000)
4000    FORMAT (/,' COULD NOT FIND ANY OF THOSE IN THE VECTOR.DAT',
     &  ' FILE.',/,' YOU MIGHT WANT TO RERUN "VECTOR" AND MAKE SURE ',
     &  ' OF YOUR NUMBERS.',/,' THEN YOU COULD RERUN THIS PROGRAM. ',
     &  ' BYE!')
        GOTO 5000
        ENDIF
        GOTO 90
3000    WRITE (6,*)
        WRITE (6,*)
        WRITE (6,3500) ISTART,IFIN
3500    FORMAT (//,' GOT IT.  YOUR NEW FILE IS NEWVECT.DAT, AND IT',
     &  ' CONTAINS DATA FROM',/,1X,I5,' TO ',I5,'.')
5000    END
```

REFERENCES

Etter, D. M.; Structured Fortran 77 for Engineers and Scientists; 3rd ed.; The Benjamin/Cummings Publishing Co. Inc., 1990.

Hope, John R., Charles J. Neumann; Probability of Tropical Cyclone Induced Winds at Capt Kennedy; ESSA Techical Memorandum WBTM SOS-1, Silver Spring, MD., 1968.

Martin, J. J.; Bayesian Decision Problems and Markov Chains; John Wiley & Sons, 1967.

McCracken, Daniel D.; A Guide to Fortran Programming; Wiley, 1961.

Murphy, Allan M and Richard Katz editors; Probability, Statistics and Decision Making in the Atmospheric Sciences; Westview Press, 1985.

Neumann, Charles J.; A Statistical Study of Tropical Cyclone Positioning Errors With Economic Applications; NOAA Technical Memorandum NWS SR-82, Springfield, VA., 1975.

Neumann, Charles J.; The National Hurricane Center Risk Analysis Program (HURISK); NOAA Technical Memorandum NWS NHC 38, Springfield, VA., 1987.