Formulation of a Model for Ship Transit Risk

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Year 1 Progress Report

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Table of Contents

Figures and Tables

EXECUTIVE SUMMARY

The Transit Risk Project focuses on the development of models from historical casualty data to predict the risk of navigational vessel casualties during transits into and out of port. During the first year, the project has focused on a model of grounding risk at the port level, with special emphasis on the contribution of inaccuracies in navigation charts. In the second year, the project will continue this work and supplement the port-level analysis with a more detailed model at the waterway segment level. In the third year, it is expected that the focus will shift to other casualties, such as collisions.

Much of the first year's work centered on the collection, evaluation, and analysis of data available on groundings in five U.S. ports (Boston, New York/New Jersey, Tampa, Houston/Galveston, and San Francisco) between 1981 and 1995. U.S. Coast Guard casualty data and U.S. Army Corps of Engineers transit data were used to construct time series of grounding rates for the study ports. These grounding rates, and how they are affected by factors specific to each port, are the quantity to be predicted by the model. A set of parameters were examined to determine whether they are meaningful "contributing factors" to the risk of grounding, and therefore useful in the development of a port-level model of grounding risk.

Vessel type and size were found to be useful parameters; barge trains have higher historical grounding rates than self-propelled vessels, and large ships have higher rates than small ships. Uncertainty in hydrographic surveys, on which nautical charts are based, does not appear to be a useful parameter. Wind speed and visibility conditions were found to be useful parameters; historical groundings are associated with higher average wind speeds and lower average visibility than safe transits. Other parameters, such as operators' skill (as represented by proxies such as flag of registry) and complexity of the transit (using summary measures of channel complexity) are still being evaluated.

The results of the first year's work suggest that while the data available on historical groundings are far from complete or ideal for the construction of a model, there is sufficient information in the available data to construct a port-level model with some explanatory and predictive ability. Descriptions of the available data and specific recommendations for future data collection to improve the basis for modeling of this kind are included in the progress report. A separate model of economic risk has been developed, making use of a large body of previous work by the U.S. Coast Guard and others, to related physical grounding risk to expected economic losses.

In the second year, completion of work on the port-level risk model will proceed in parallel with development of a larger-scale model of risk within a segment of a single waterway. This model will incorporate results of the port-level analysis, and also capture features not included in the port-level model, such as specifics of the channel design, navigational aid configuration, currents, and water levels.

1. INTRODUCTION

A. Background and Objectives

Starting in the fall of 1995, researchers at the Massachusetts Institute of Technology (MIT) Ocean Engineering Department and the Marine Policy Center (MPC) of the Woods Hole Oceanographic Institution (WHOI) have collaborated on a project on Formulation of a Model for Ship Transit Risk. The project was developed by MIT, in collaboration with MPC staff, as a three-year research activity. The focus of the first year was on collection and assimilation of data to support an improved understanding of the factors contributing to vessel groundings. This report describes the research findings of the first year of the project.

Groundings of commercial ships account for about one third of all commercial maritime accidents, including some of the worst in the United States' history, such as the *Exxon Valdez*. Many factors contribute to vessel groundings. Some of these factors are of particular concern to federal agencies charged with responsibility for certain aspects of the nation's marine transit routes. For example, the National Oceanic and Atmospheric Administration (NOAA) is responsible for the survey of U.S. waters and for the publication of nautical charts. The U.S. Coast Guard (USCG) and the U.S. Army Corps of Engineers (ACE) are responsible for navigation aids and for channel design and maintenance, respectively. All of these factor may influence how likely groundings are to occur.

The main objective of the first year's work has been to investigate the relationship between various factors, such as environmental conditions and uncertainty in nautical chart depth data, and historical grounding incidents. This has been done with a view to the eventual development of a model of the probability of grounding (physical risk), with particular emphasis on aspects of such a model that might inform the prioritization of areas for re-survey. A secondary objective has been to develop a means of estimating the economic consequences of groundings (economic risk). Our work over the past year suggests that, while the historical data on circumstances surrounding groundings in U.S. waters are neither perfect nor complete, they contain information useful to understanding why groundings occur, and therefore justify further effort on the development of a physical risk model. The reasons for this conclusion are documented in this report. We also find that existing data and models support the development of an associated economic risk model. A simple version of this has been assembled and is also described in this report.

Following a decision reached with the project advisory group, the first year's work focused on five study areas: San Francisco Bay, Houston/Galveston, Tampa Bay, Port of New York/New Jersey, and Boston Harbor. Site visits and meetings with maritime safety organizations were held in San Francisco and Houston/Galveston. Data on historical groundings, transits, environmental conditions, and aspects of navigation infrastructure were collected for each study area for the period 1981 to 1995 from sources including national and local units of the U.S. Coast Guard and the U.S. Army Corps of Engineers; NOAA's National Ocean Service, National Climate Data Center, National Geophysical Data Center, and National Data Buoy Center; and local port authorities, marine exchanges, and pilots.

B. Physical Risk Model and Variable Selection

The general hypothesis behind the physical risk model is that the probability of grounding on a particular transit depends on a set of explanatory variables. Formally, the model can be described as follows: let G denote the event that a transit results in a grounding, and let $X = (X_1; X_2, X_3, \ldots, X_p)$ be the vector of explanatory variables. These variables may be categorical (including binary) or continuous. The model attempts to estimate the conditional probability of G given a specified value x of X. By Bayes' Theorem, this probability is given by:

$$p(G|x) = l(x|G)\, p \,/\, (l(x|G)\, p + l(x|S)\, (1-p))$$

where p is the unconditional probability of G and where $l(x|G)$ and $l(x|S)$ are the likelihoods of x given G and S, respectively, where S denotes the event that the transit is completed safely.

To implement this approach, it is necessary to select the set of explanatory variables that best discriminates between G and S (Hand, 1981) and to estimate the unconditional grounding probability p and the likelihoods $l(x|G)$ and $l(x|S)$. We have used USCG, NOAA, and ACE data to determine p for the study ports, and to construct samples representing transits G and S. The main challenge lies in the design of the vector of explanatory variables X, which must capture the attributes of the transit that can be expected reasonably to contribute to the likelihood of a grounding. This task occupied most of the analytical effort over the past year. The attributes were thought to include, among others:

a. skill, training, and experience of vessel operator(s)
b. topographic difficulty of the transit
c. environmental difficulty of the transit
d. quality of operator(s)' information about topography
e. quality of operator(s)' information about environmental conditions
f. vessel maneuverability

For each attribute, explanatory variables (x_i) must be extracted from historical data as numerical or categorical indicators. Existing data support the inclusion of these attributes in the analysis to varying degrees, as described in the sections that follow.

	Boston				New York/New Jersey				Tampa				Houston/Galveston				San Francisco			
	ships		barge trains		ships		barge trains		ships		barge trains		ships		barge trains		ships		barge trains	
	tank	dry	tank	dry	tank	dry	tank	dry	tank	dry	tank	dry	tank	dry	tank	dry	tank	dry	tank	dry
1981	0	2	1	0	7	5	3	0	1	4	5	5	9	4	37	5	1	1	1	0
1982	0	1	1	0	1	1	1	1	0	1	3	3	2	3	26	9	2	3	1	1
1983	0	0	1	0	1	2	2	0	2	0	1	1	8	10	13	3	3	4	0	0
1984	0	0	2	0	3	3	3	0	5	4	3	4	8	5	17	6	0	3	1	0
1985	0	0	1	0	8	9	6	1	4	4	6	6	2	1	4	1	3	2	1	0
1986	0	0	1	0	6	2	3	3	2	1	6	2	0	2	1	1	3	2	1	0
1987	0	0	0	0	4	3	2	4	3	3	2	2	6	3	6	0	2	5	1	0
1988	0	0	2	0	2	4	9	2	6	9	1	3	8	5	18	1	1	3	0	0
1989	1	1	0	0	14	2	9	3	5	3	1	1	6	1	5	3	4	3	2	1
1990	1	0	0	0	6	2	2	2	1	2	1	4	7	2	11	3	3	3	0	0
1991*	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	1	0	0
1992	0	1	0	0	5	4	5	0	2	4	4	1	8	2	16	2	1	3	0	0
1993	0	0	0	0	3	4	4	0	2	1	3	4	4	1	29	6	3	2	1	0
1994	1	0	0	1	2	1	6	1	2	2	3	4	9	6	49	4	3	6	1	0
1995	1	0	0	0	1	0	1	0	1	0	1	0	8	3	43	8	3	3	0	1
1981-95	4	5	9	1	63	44	56	17	36	38	40	41	86	48	275	52	32	44	10	3

*1991 data are clearly incomplete

Table 2-1: Groundings of Cargo Ships and Barge Trains, 1981-95

2. TRENDS IN GROUNDING RATES

A. Groundings

Grounding data are drawn from the USCG's CASMAIN (1981-90) and MSIS (1992-95) databases. Data for 1991 are sparse and obviously incomplete in each dataset; we replace the 1991 counts by averages of the four surrounding years for purposes of analysis. From the USCG data we selected for inclusion in this study only accidental, navigational groundings, and ignored those identified as intentional or due to mechanical failure or other, clearly non-navigational cause. We consider separately large (draft greater than 30 feet) and small tankers and dry cargo vessels, tank barge trains and dry cargo barge trains (a barge train is defined as a tug/towboat attached to one or more barges). Table 2-1 shows the number of groundings in the data for each study port and year.

Seasonal trends appear in the grounding counts of both ships (Figure 2-1) and barge trains (Figure 2-2), most significantly for the Port of Houston and, less strongly, the Port of New York. This may be due in part to seasonal environmental conditions (see Figures 5-1 and 6-1) and/or to seasonal fluctuations in traffic volumes. We will examine seasonal fluctuations in traffic volumes once more detailed transit data are obtained.

B. Transits

Transit data are based on ACE Waterborne Commerce Statistics annual summaries, 1981-1994. We have assumed that 1995 transits are the same as 1994, since 1995 data are not yet available. Monthly summaries are being obtained for 1992-94 to investigate seasonal fluctuations. To avoid double counting, we based our transit count for each study port on data for only one "waterway" in each port, as follows:

	waterways code
Port of Boston	0149
New York and New Jersey Channels	0388
Tampa Harbor	2021
Houston Ship Channel	2012
San Francisco Bay Entrance	4320

This procedure leads to underestimation of actual vessel movements, especially for Houston and New York. Unfortunately, there appears to be no simple way to build more accurate time series of transits for study port areas.

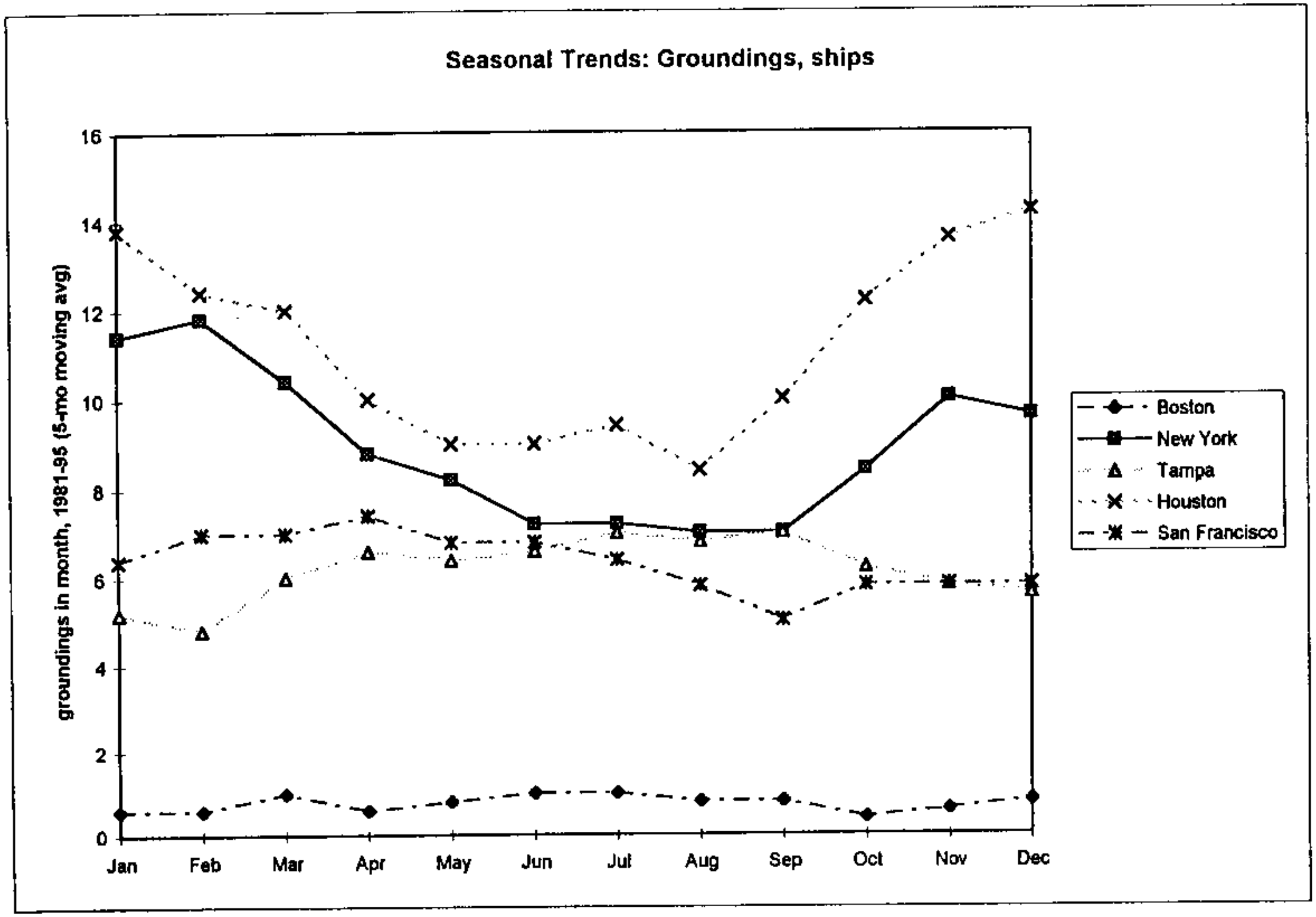

Seasonal Trends: Groundings, ships
groundings in month, 1981-95 (5-mo moving avg)
0
2
4
6
8
10
12
14
16
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Boston
New York
Tampa
Houston
San Francisco

Figure 2-1

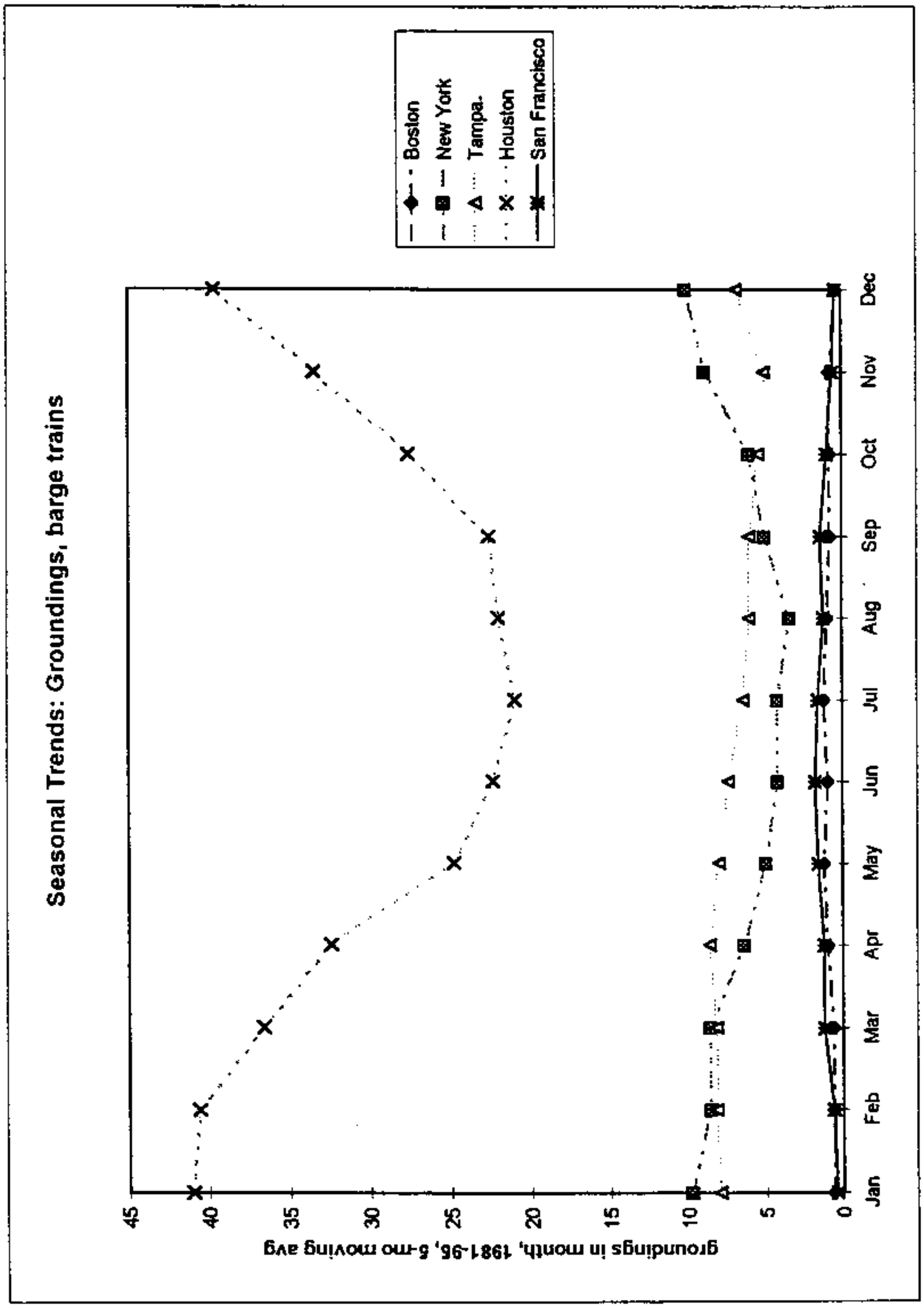

Seasonal Trends: Groundings, barge trains
groundings in month, 1981-95, 5-mo moving avg
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Boston
New York
Tampa.
Houston
San Francisco

Figure 2-2

We examine transit data using the same vessel type and size breakdown as for grounding data. Figures 2-3, 2-4, and 2-5 illustrate transits for ships and barge trains in each study port over the study period. The only explicit adjustment we made to ACE annual trip data is in the small dry cargo vessel category for the port of Boston, which included a large number of very small vessels (local passenger ferries). These have been removed from the data.

C. Grounding Rates

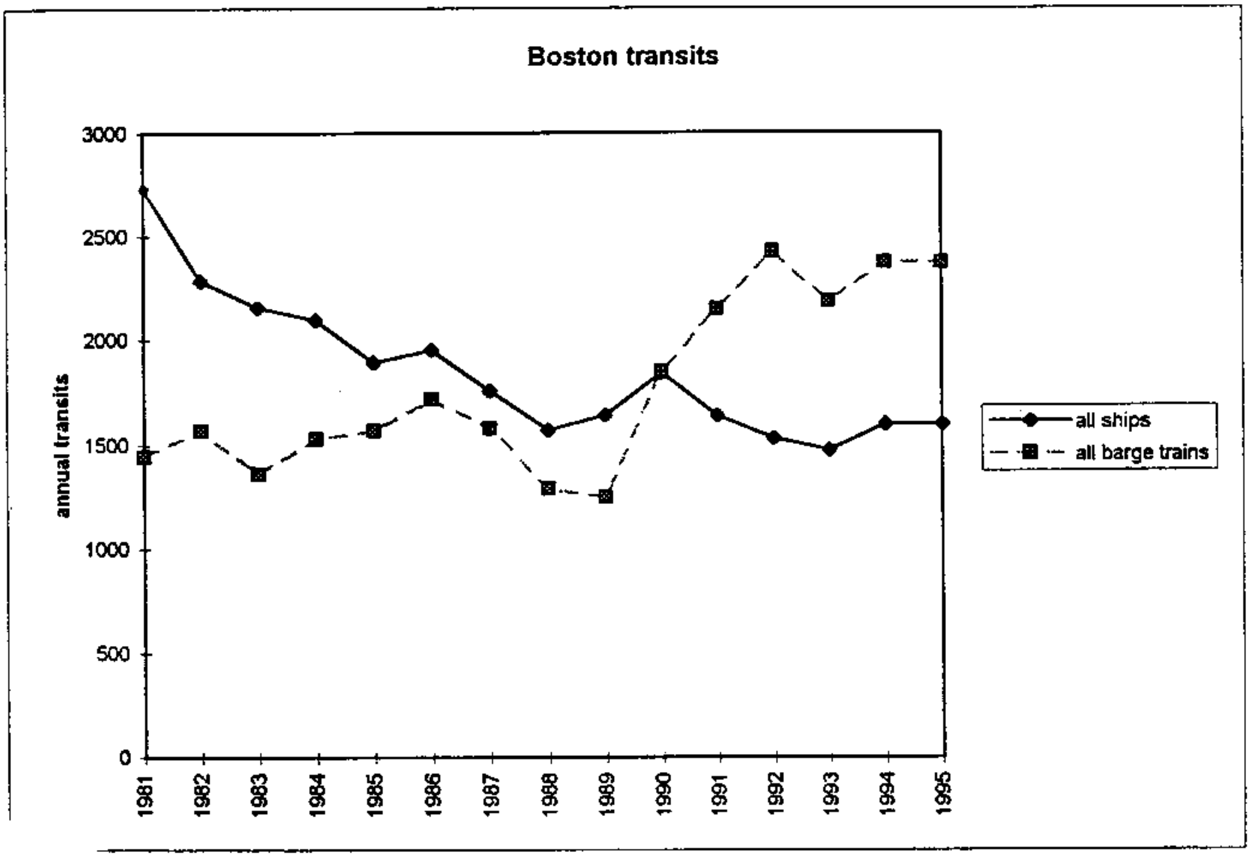
Grounding rates are calculated by dividing annual groundings by transits for each port. The raw grounding rate data are shown in Appendix 1. To clarify the trends, we show smoothed (five-point moving average) grounding rates for all ships in Figure 2-6 and all barge trains in Figure 2-7. Caution is in order when comparing these grounding rates across ports. Local USCG offices may employ different reporting criteria from one port to another (which could lead to apparent reductions in groundings), and our procedure for building transit counts may underestimate actual traffic densities to varying degrees in different ports (which would lead to inflated grounding rates).

Given these caveats, it appears that the time-averaged grounding rate for ships is highest in Tampa, lowest in Boston, and clustered in between around (0.75 groundings per 1000 transits, one grounding in 1300 transits) for New York, Houston, and San Francisco. The most obvious temporal change occurred in Tampa, where ship grounding rates rose significantly from 1986 to 1990 and then declined again to pre-1985 levels.

Grounding rates for barge trains appear to be lower in Boston and New York than in other ports. The Houston barge train rate declined during the early and mid 1980s but has risen again since then. In Tampa, the barge train grounding rate surged and then declined again, much like the ship grounding rate, but slightly earlier in time.

These underlying historical grounding rates form the basis for an estimate of p, the unconditional probability of grounding, in the physical risk model.

Figure 2-3


Boston transits

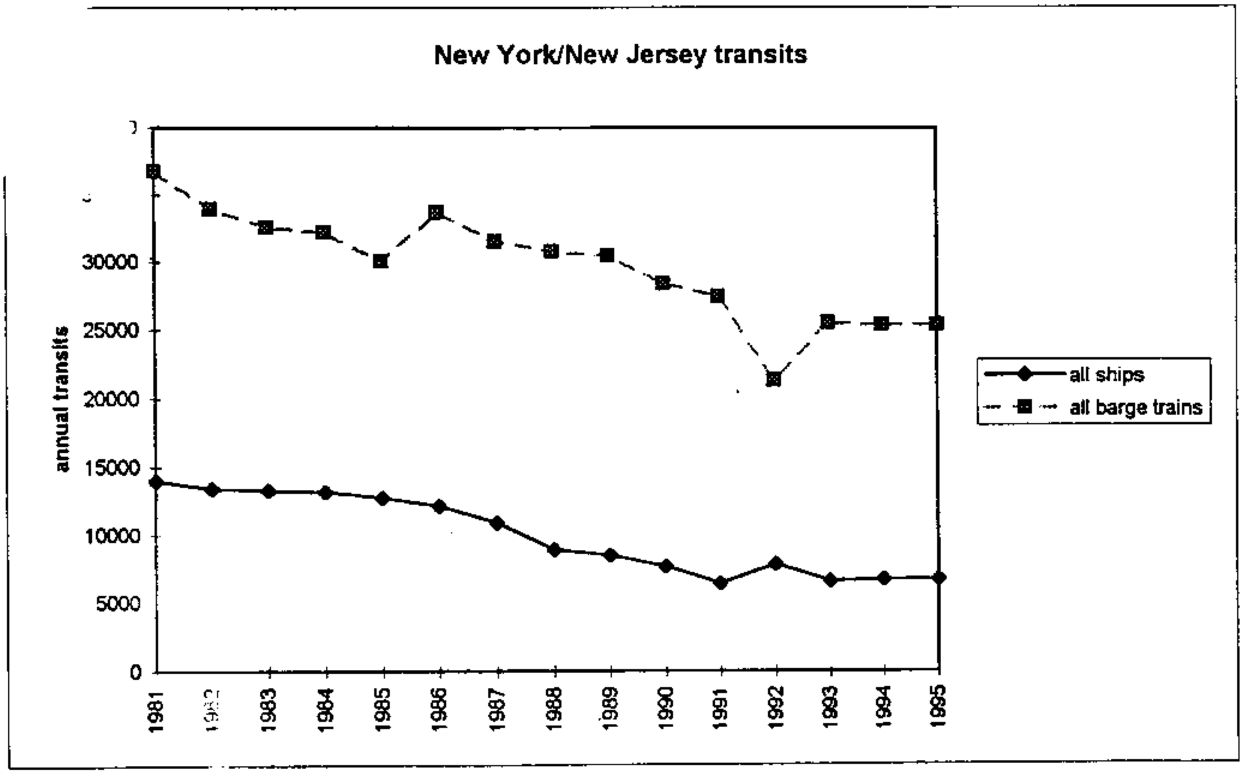
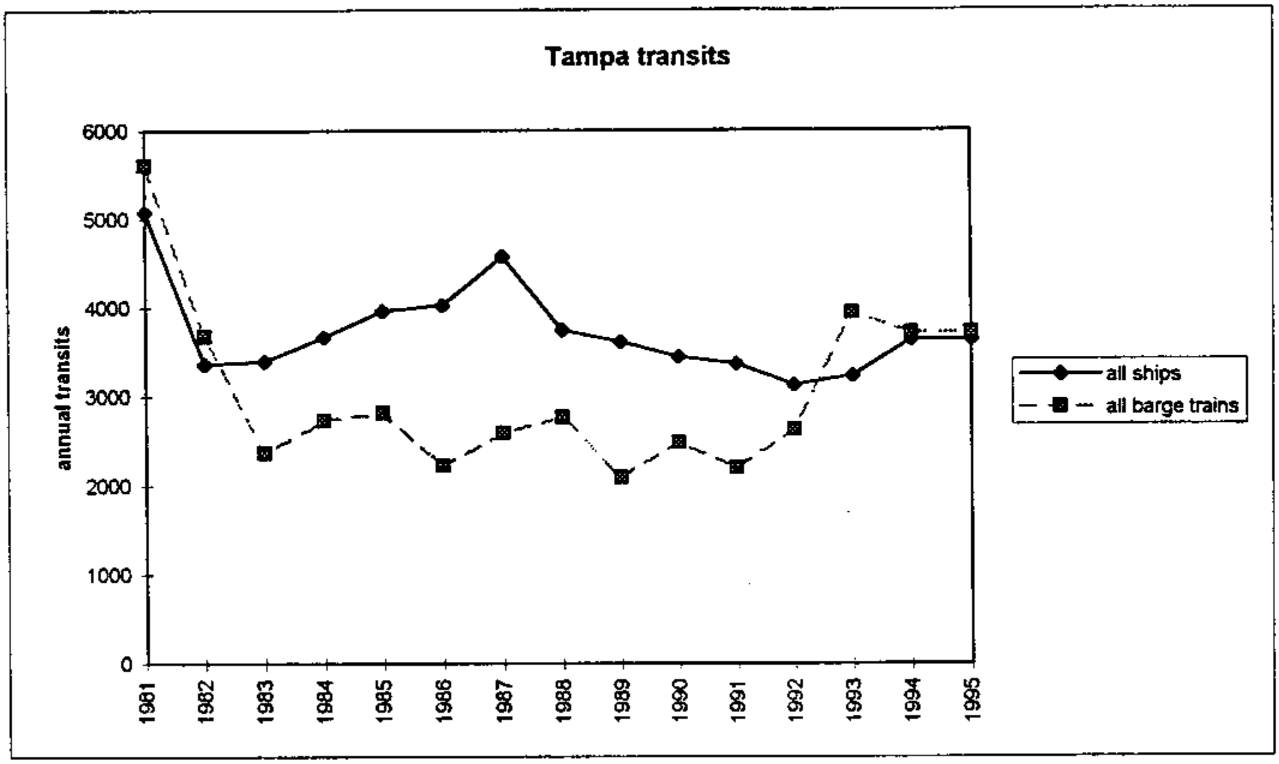

New York/New Jersey transits

Figure 2-4


Tampa transits
annual transits
6000
5000
4000
3000
2000
1000
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
all ships
all barge trains

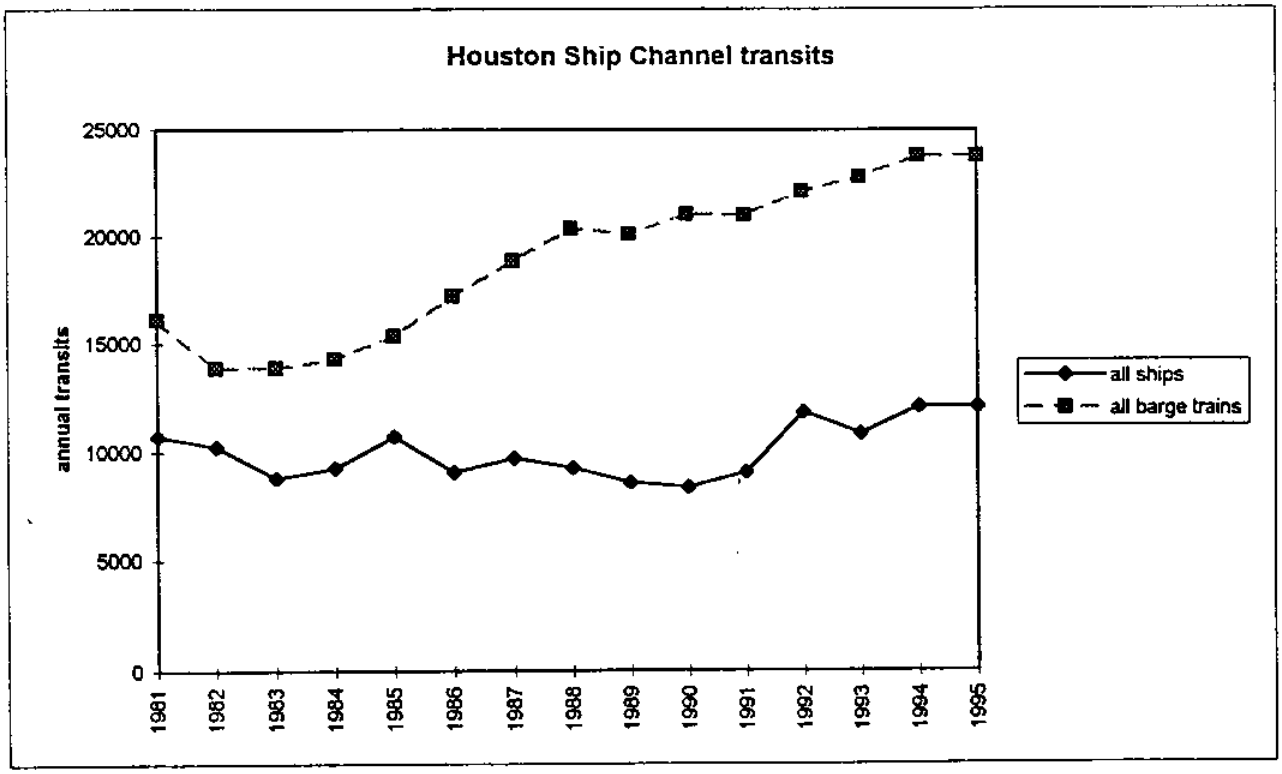
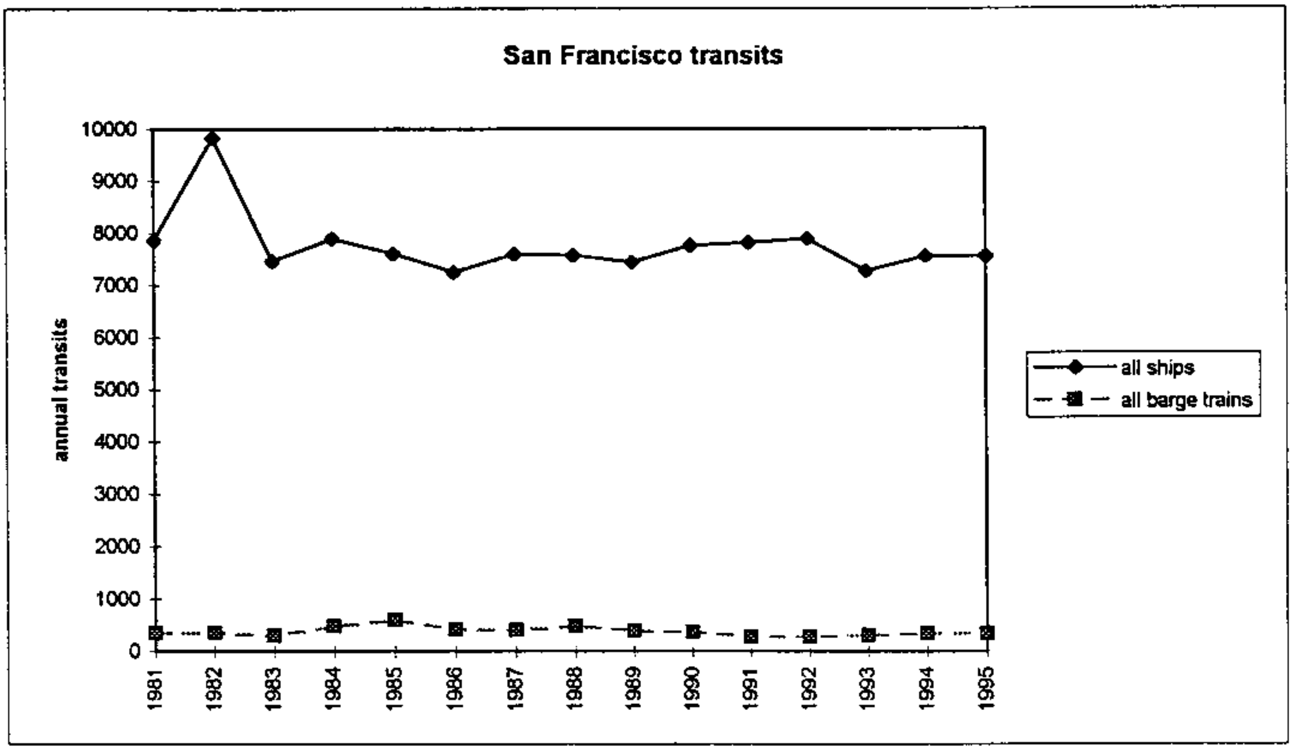

Houston Ship Channel transits
annual transits
25000
20000
15000
10000
5000
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
all ships
all barge trains

Figure 2-5


San Francisco transits
annual transits
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
all ships
all barge trains

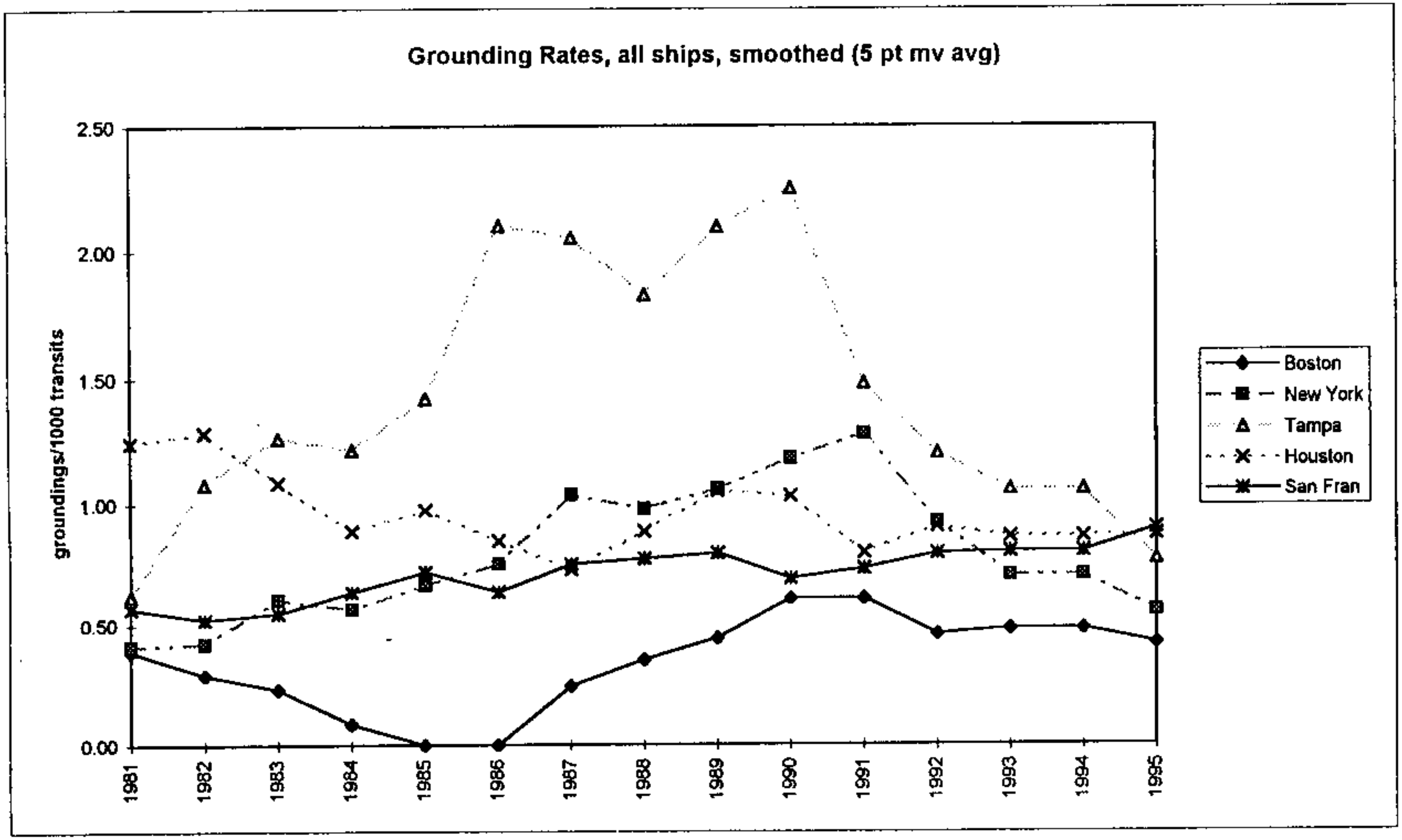

Grounding Rates, all ships, smoothed (5 pt mv avg)
groundings/1000 transits
2.50
2.00
1.50
1.00
0.50
0.00
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
Boston
New York
Tampa
Houston
San Fran

Figure 2-6

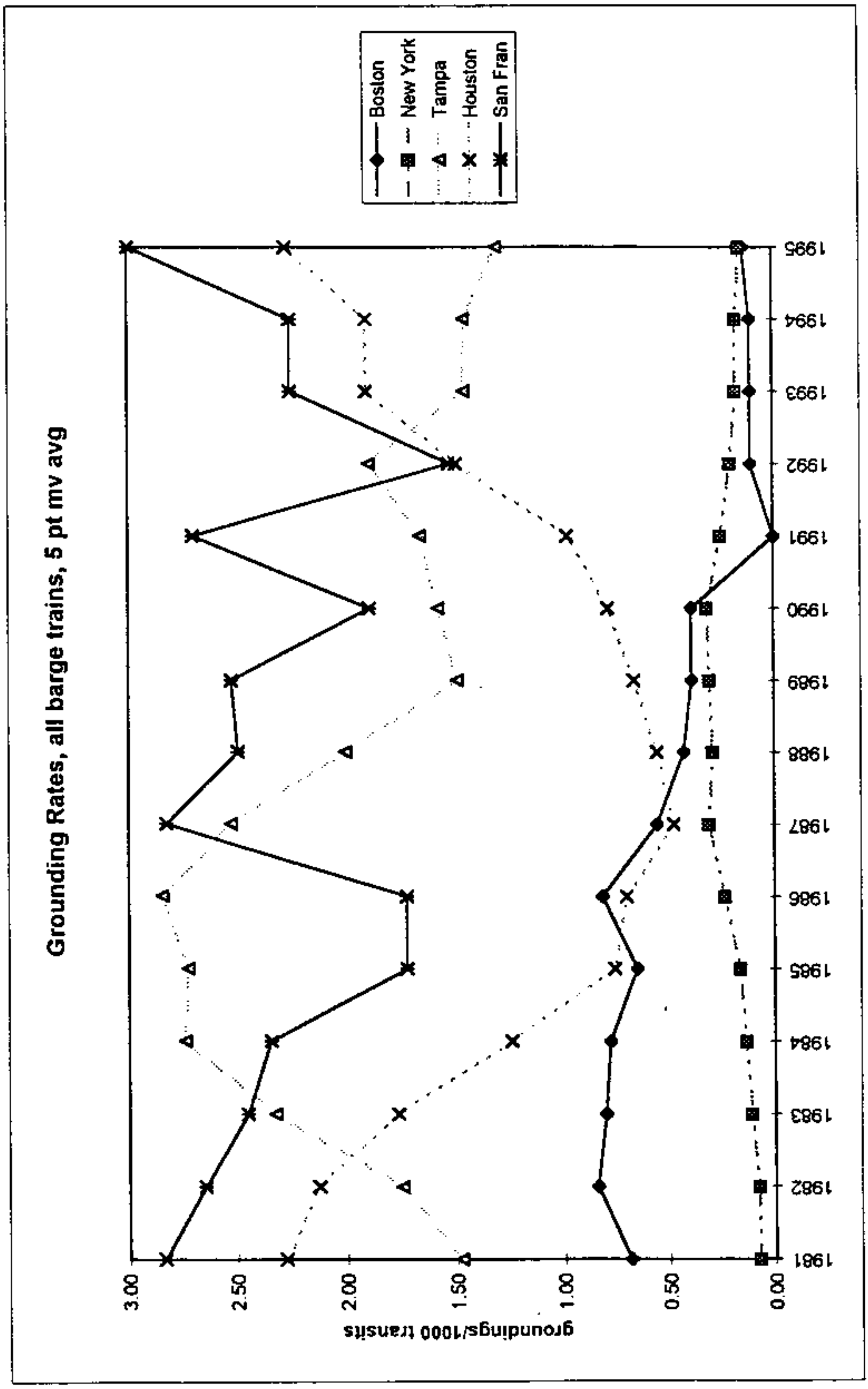

Grounding Rates, all barge trains, 5 pt mv avg
groundings/1000 transits
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
Boston
New York
Tampa
Houston
San Fran

Figure 2-7

3. FACTOR: VESSEL TYPE AND SIZE

Other things equal, a more maneuverable vessel may be expected to have a lower probability of grounding than a less maneuverable vessel. It is difficult to obtain meaningful summary measures of maneuverability. As a result, our analysis has to rely on proxies such as vessel type, vessel size, and whether tugs were present/used during the transit.

Our data suggest that barge trains are more likely to ground than ships, except in the port of New York. This is consistent with our expectations about maneuverability: barge trains are, in general, likely to be less maneuverable than ships. Table 3-1 shows 15-year average grounding rates for ships and barge trains, abstracting from the grounding rate data reported in Appendix 1.

Table 3-1: Average Grounding Rates, Ships and Barge Trains, 1981-95

	Boston	**New York**	**Tampa**	**Houston**	**San Francisco**
ships	0.32	0.72	1.32	0.89	0.65
barge trains	0.37	0.18	1.84	1.28	2.28

Our data also suggest that larger ships are consistently more likely to ground than small ships (draft less than 30 feet). Figure 3-1 shows time-averaged grounding rates for small and large ships in each study port. This result is also consistent with our expectations about maneuverability.

These findings suggest that factors such as vessel type and size can usefully be employed in developing the physical risk model. We are beginning to investigate related factors, such as the presence and use of tugs during vessel transits.

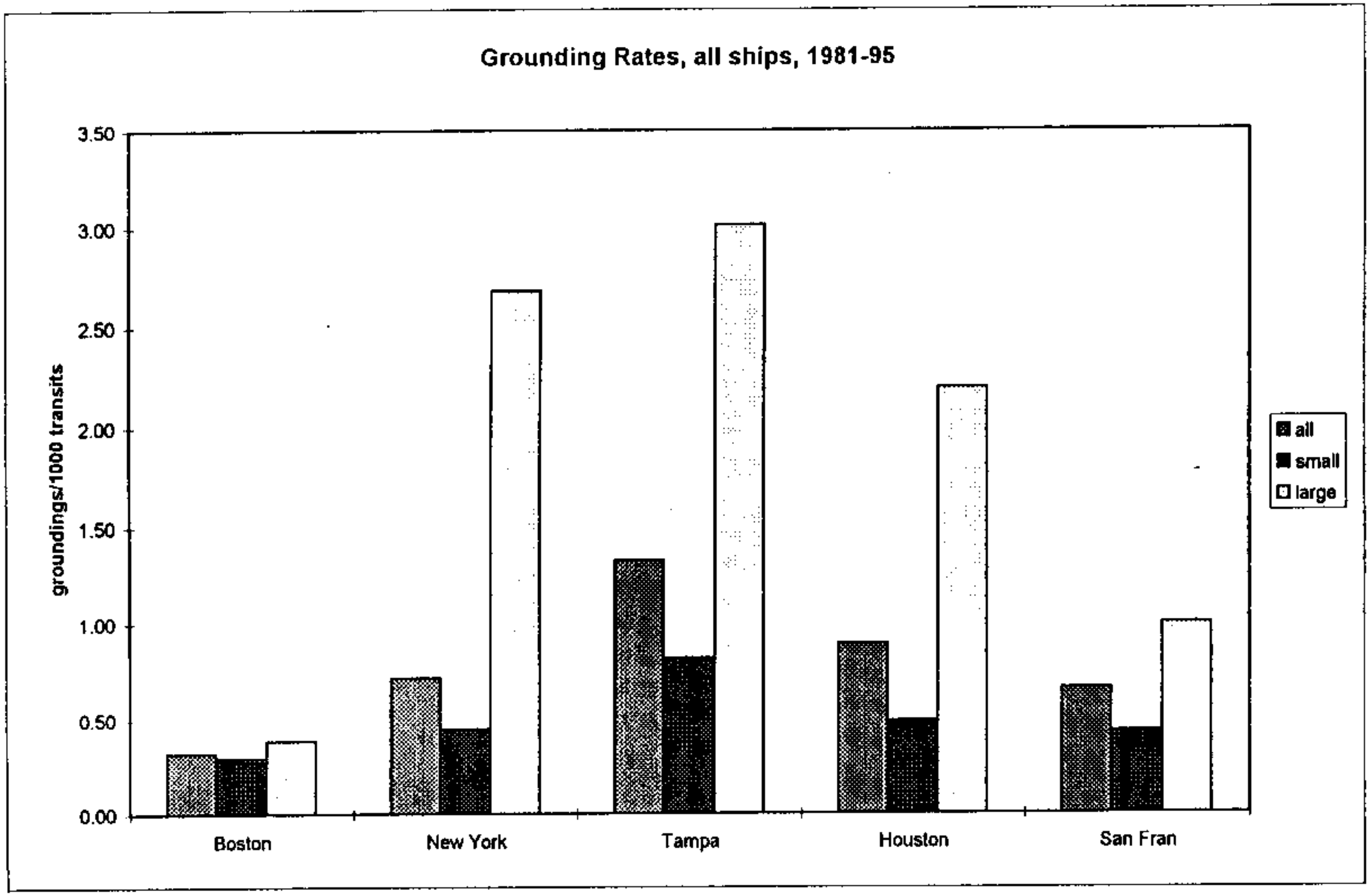

Grounding Rates, all ships, 1981-95
groundings/1000 transits
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Boston
New York
Tampa
Houston
San Fran
all
small
large

Figure 3-1

4. FACTOR: UNCERTAINTY IN SURVEYS/CHARTS

Other things equal, a transit through an area for which perfect charts are available may be expected to involve less risk of grounding than a transit through an uncharted or poorly charted region. Historically, navigators' knowledge of their own position was uncertain enough that they were very cautious of approaching charted hazards. The charts, and their underlying surveys, had generally far greater accuracy, and were constructed with much better instruments than those available to the average mariner. However, during the last 15 years we have experienced a shift in the technology available to navigators. Today, GPS users can position themselves with more accuracy than most of the surveyors were able to when they collected the data on which most charts navigators use today are based. This may have eroded some of the safety margin that was previously incorporated into the charts (Kielland and Tubman, 1994). Our objective has been to examine the possibility that the uncertainty in paper charts based on older surveys have made a contribution to the incidence of groundings in U.S. ports. To do so, we are analyzing hydrographic data for uncertainty using a program called Hydrostat and combining the results with grounding locations data to check for correlations between cartographic uncertainty and historical groundings.

A. Hydrostat Algorithm

The main function of the Hydrostat software is quality control of bathymetric data (Kielland et al, 1992). This hydrographic data processing program was developed by Geostat Systems International Inc. under contract with the Canadian Hydrographic Service (Dagbert, 1993). It is based on the requirement to make survey procedures more efficient, and the theory that survey errors no longer are negligible compared to other uncertainties facing navigators. By providing electronic chart users with statistically valid error estimates for the data they are using, for example, it is believed that this program will increase the utility and improve the safety of nautical chart data.

There are three main error sources when charts are designed from survey data: instrumental errors, interpolation errors, and design errors. Instrumental errors consist of positioning errors and depth measurements errors, and are assumed to be constant over the survey. The approximate size of these errors depends on the particular survey, but they are usually smaller than interpolation errors. Design errors are document handling errors and safety biased errors when data are transferred to navigational documents. Since both design errors and instrumental errors are well known and incorporated in the charts, they are of no particular interest to our investigation. Interpolation errors are bathymetric uncertainties that exist in the unsounded zones between measured soundings. They are the least controllable error for chart design and the focus of our investigation. If the surveyed depths are far apart then, depending on the topography of the sea floor, these interpolation errors can be much greater than the instrumental errors in the measurements themselves. They vary continuously and are unique to every location on a chart.

The Hydrostat software computes the depth in the unsounded zones between measured soundings using a geostatistical depth interpolation algorithm which also predicts the depth estimation errors inherent to each point on the interpolated bathymetric model. The results of the computation are two specific features: a bathymetric surface and a stochastic surface. The bathymetric surface is the digital terrain model interpolated from the observed sounding profiles, and is strictly a function of water depth. The stochastic surface is composed of the vertical error estimates for every point on the bathymetric surface. This surface is a function of both seabed texture and data sampling density. We are currently using the stochastic surface (the interpolated errors of the depth estimate) as a proxy to check for correlation between cartographic uncertainty and historical groundings. This is further described below.

B. Survey Data

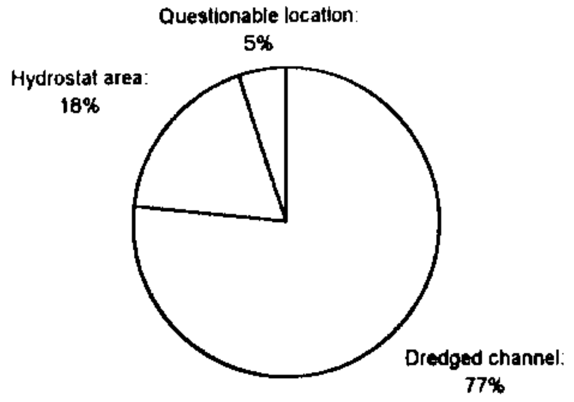
Within the five study areas, for the period 1981-90 and 1992-95, we found 886 groundings in the Coast Guard accident database of interest to this investigation. Of these 886 groundings, 125 accidents (14%), all from the CASMAIN database (1981-90), have no latitude/longitude location information. This leaves 761 accidents to evaluate (see Table 4-1). Based on plots of these remaining locations on nautical charts, 612 of these accidents happened around dredged channels or rivers, 109 accidents happened in areas amenable to investigation with Hydrostat, and the remaining 40 had an obviously faulty entry for location (they plotted within very shallow areas or on dry land). Groundings around dredged channels are not due to the sort of bathymetric uncertainty for which Hydrostat is designed (Hydrostat assumes the sea floor to be isotropic and the variation in depth variation to be normally distributed). Hence the basis for this part of our evaluation was reduced to 109 accidents, or 12% of the original number.

Unfortunately, not all of these 109 accidents are reported to sufficient accuracy to be useful for this analysis. In theory, the location of the accidents are given in the USCG database to an accuracy of +/-0.1 minutes latitude/longitude, or +/-150 to 200 meters in the areas we are examining. However, many of the accident locations are reported without the last decimal, which results in an accuracy of +/- 1500 to 2000 meters and makes them worthless to our study (see Table 4-3). This leaves us with between 58 and 83 useful groundings for this part of the evaluation. Although we would prefer to have more data available, this is still a statistically useful sample.

The hydrographic survey data were obtained from the National Geophysical Data Center (NGDC) of NOAA, and includes depth measurements and bottom features. These data are part of the base from which NOAA charts are designed. We analyzed the most recent surveys for the areas of interest. These surveys differed greatly in age, quality, and density of data.

Table 4-1:
Accidents 1981-90

Port area:	Boston	Houston/Galveston	San Francisco	Tampa	New York	5 ports
Minimum latitude, (deg.min):	42.14	29.05	37.20	27.30	40.25	
Maximum latitude:	42.30	29.50	38.10	28.05	40.50	
Minimum longitude:	70.46	94.25	121.40	82.20	73.48	
Maximum longitude:	71.06	95.12	122.50	83.02	74.20	
Number of ships involved:	43	523	33	199	120	918
Number of accidents:	35	310	29	121	87	582
Out of range:	4	14	4	8	11	41
Number of accidents in area:	31	296	25	113	76	541
No location:	0	115	1	5	4	125
Valid accidents:	31	181	24	108	72	416
of which were located in:						
Dredged channel:	11	154	6	96	50	317
Hydrostat area:	19	19	15	12	11	76
Questionable location:	1	8	1		11	21
River:			2			2
	31	*181*	*24*	*108*	*72*	*416*



Accident Locations 1992 - 1995

Table 4-2

Port area:	Boston	Houston/Galveston	San Francisco	Tampa	New York	5 ports
Minimum latitude, (deg.min):	42.140	29.050	37.200	27.300	40.250	
Maximum latitude:	42.300	29.500	38.100	28.050	40.500	
Minimum longitude:	70.460	94.250	121.400	82.200	73.480	
Maximum longitude:	71.060	95.120	122.500	83.020	74.200	
Number of ships involved:	55	414	70	225	118	882
Number of accidents in the state:	55	407	69	222	118	871
Out of range:	43	184	45	178	76	526
Number of accidents in area:	12	223	24	44	42	345
No location:	0	0	0	0	0	0
Valid accidents:	12	223	24	44	42	345
of which were located in:	(12)	(223)	(24)	(44)	(42)	
Dredged channel:	4	203	13	38	35	293
Hydrostat area:	8	11	7	6	1	33
Questionable location:		9	4		6	19
	12	223	24	44	42	345

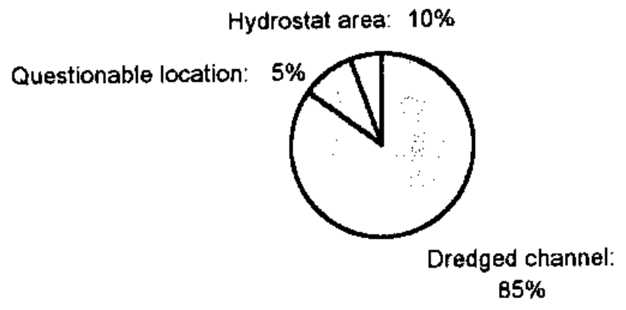


Table 4-3

Accidents 1981-90

Port area:	**Boston**	**Houston/Galveston**	**San Francisco**	**Tampa**	**New York**	**5 ports**
Number of accidents located within "Hydrostat" area:	19	19	15	12	11	76
of which has:						
both minute latitude and minute longitude decimal equal to zero:	7	4	5	2	3	21
only minute latitude decimal equal to zero:	2	1	4	1	0	8
only minute longitude decimal equal to zero:	4	3	1	0	3	11
Useful acidents:	**6**	**11**	**5**	**9**	**5**	**36**
Useful accidents and questionable accidents:	12	15	10	10	8	55

Accidents 1992-95

Port area:	**Boston**	**Houston/Galveston**	**San Francisco**	**Tampa**	**New York**	**5 ports**
Number of accidents located within "Hydrostat" area:	8	11	7	6	1	33
of which has:						
both minute latitude and minute longitude decimal equal to zero:	0	0	1	4	0	5
only minute latitude decimal equal to zero:	0	1	2	0	0	3
only minute longitude decimal equal to zero:	1	1	0	0	1	3
						0
Useful acidents:	**7**	**9**	**4**	**2**	**0**	**22**
Useful accidents and questionable accidents:	8	11	6	2	1	28

In Total:

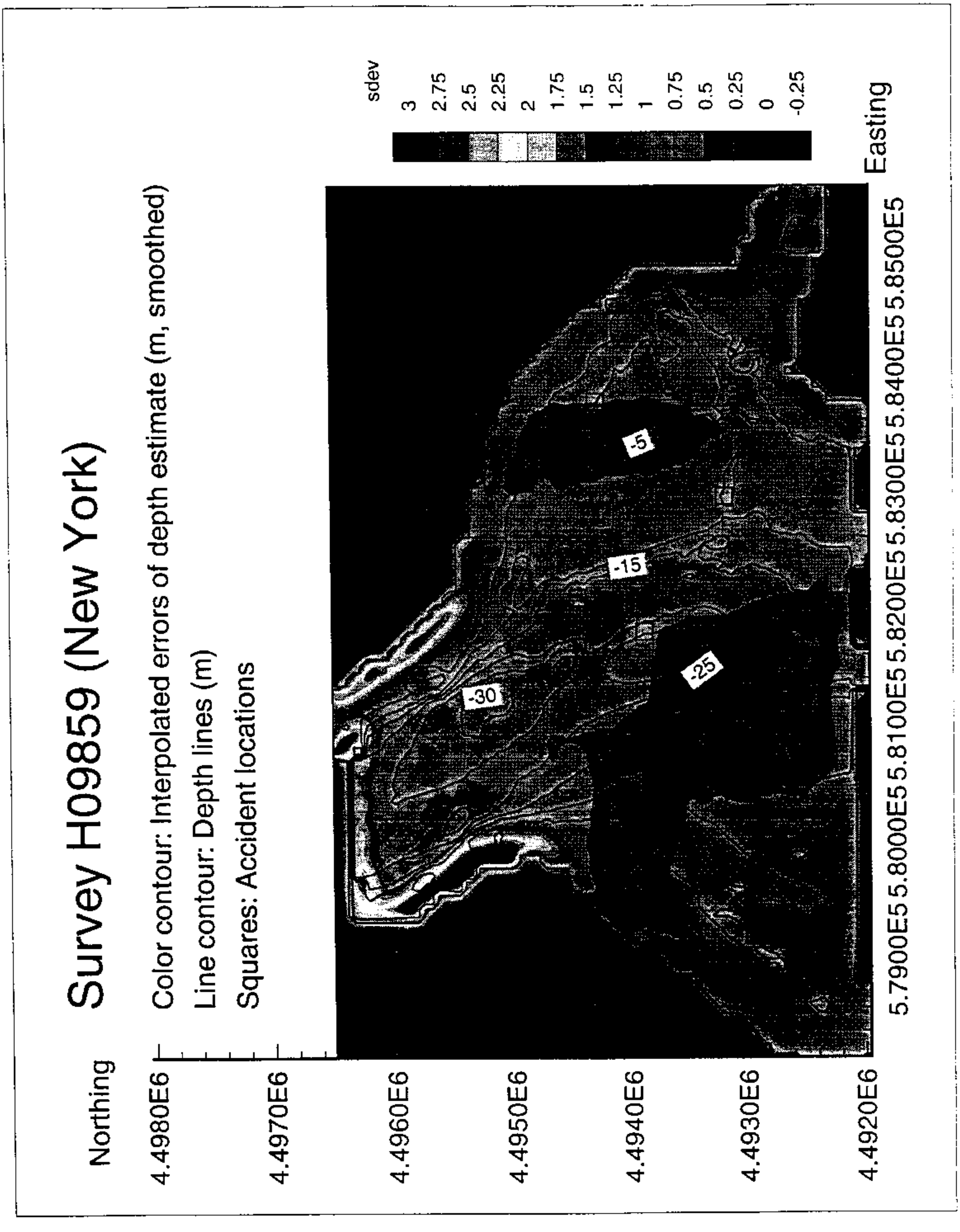
Port area:	**Boston**	**Houston/Galveston**	**San Francisco**	**Tampa**	**New York**	**5 ports**
Number of accidents located within "Hydrostat" area:	27	30	22	18	12	109
of which has:						
both minute latitude and minute longitude decimal equal to zero:	7	4	6	6	3	26
only minute latitude decimal equal to zero:	2	2	6	1	0	11
only minute longitude decimal equal to zero:	5	4	1	0	4	14
						0
Useful acidents:	**13**	**20**	**9**	**11**	**5**	**58**
Useful accidents and questionable accidents:	20	26	16	12	9	83

The analysis proceeds as follows: the locations of the accidents are plotted on a chart. The underlying hydrographic survey data are identified and reformatted and analyzed by Hydrostat to produce the interpolated error estimates. Both the interpolated errors at the location of the accidents and a general distribution of the errors are computed. These two results are compared to check for correlation between cartographic uncertainty and historical groundings. A correlation would be indicated by a concentration of the point-errors on the high side of the general error distribution.

C. Results to Date

To date, we have examined charted depth uncertainty for two of the five study ports in detail: New York and Houston/Galveston. Only 6 of the 114 New York accidents are located in the right kind of region and have good enough location accuracy to be evaluated by Hydrostat. Figure 4-1 shows depth error, depth curves, and accident locations for a sample New York survey area. Figure 4-2 shows the overall distribution of interpolated errors of estimated depth in the same survey, as well as the interpolated errors of the depth estimates at locations where the accidents occurred. Results are similar for other New York survey areas, and for survey areas in the Houston/Galveston region. There is no evidence that "open water" groundings tend to happen in high uncertainty areas. (In fact, 85 percent of groundings happens around dredged channels.)

Our analysis of uncertainty in charted depths and locations of historical groundings so far suggests that while it is in theory a compelling factor, operators' uncertainty about topography appears to have made a negligible contribution to the incidence of historical groundings in U.S. ports in recent decades.

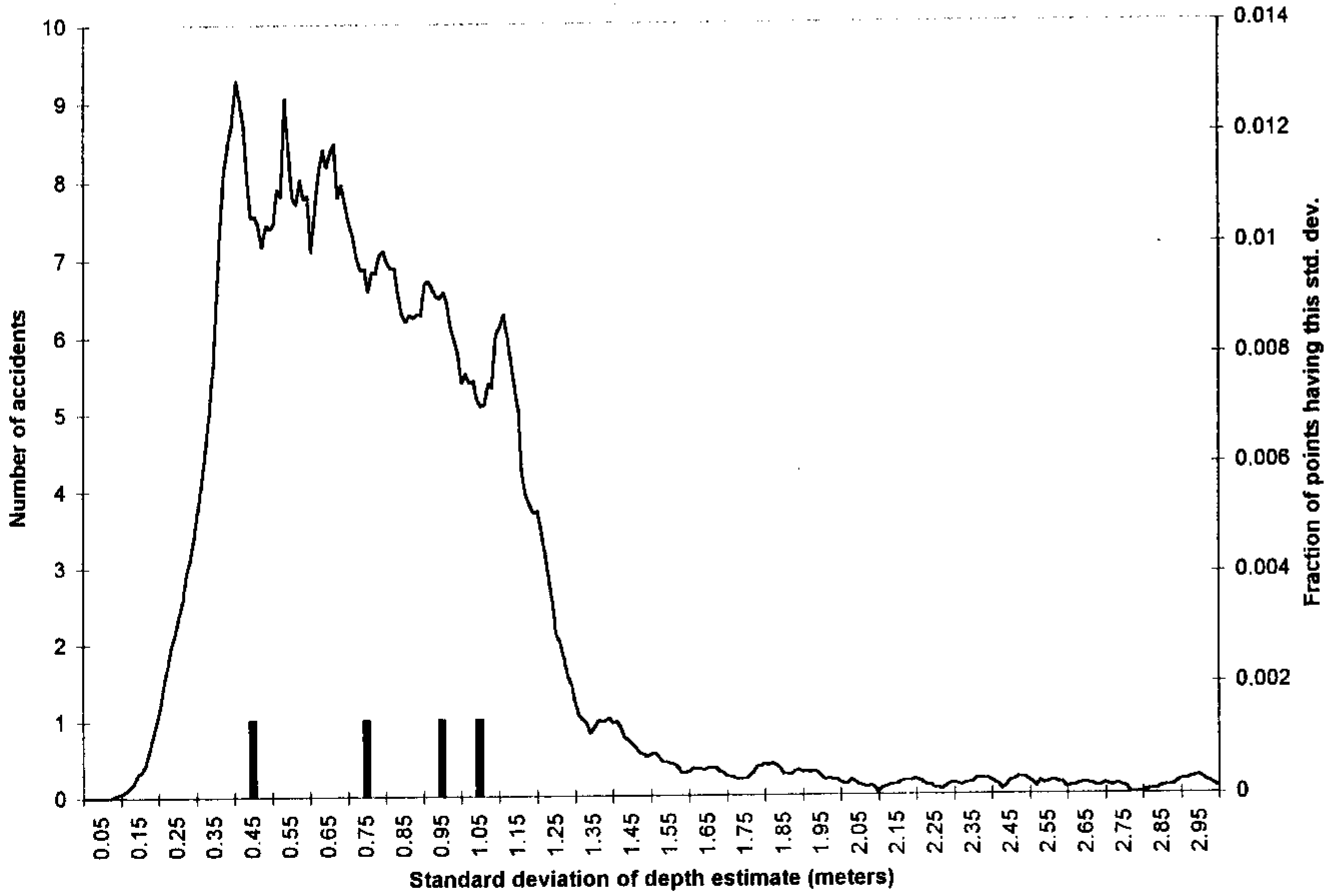

Survey H09859 (New York)

Color contour: Interpolated errors of depth estimate (m, smoothed)

Line contour: Depth lines (m)

Squares: Accident locations

Figure 4-1



Distribution of interpolated errors of estimated depth for survey H09859 (New York) and interpolated errors of depth estimate where groundings occured within this survey.

Figure 4-2

5. FACTOR: WIND SPEED

Other things equal, a transit through an area characterized by unfavorable environmental conditions, such as high wind, poor visibility, or strong currents, may be expected to involve a greater risk of grounding than a transit through the same area under more favorable conditions. We have tested two environmental variables: wind speed (discussed in this section) and visibility (see next section).

Two sources of wind speed data are used. The USCG casualty data provide reported wind speed at grounding incidents (these data are not complete). NOAA's National Climatic Data Center (NCDC) maintains hourly average wind speed data from sensors located at airports near the study ports, covering the entire study period. Seasonal fluctuations in mean wind speed are shown in Figure 5-1. Table 5-1 shows mean daily wind speeds for "grounding days" and "safe days" for the five study ports.

To characterize wind conditions on "safe" days, we can calculate the mean wind speed on all days during the study period when no groundings took place in the port. This is shown in first row of Table 5-1. Another characterization, shown in row 2 of Table 5-1, considers a smaller sample of "safe" days that coincide in month and date with grounding days for the port. The second approach reduces the influence of seasonal weather effects on the safe days mean. Note that the differences between means computed in these ways are small for ports with little seasonal wind speed fluctuation (Tampa) and larger for those (New York, San Francisco) with more significant seasonal wind speed effects (see Figure 5-1).

To analyze wind conditions when groundings took place, we first compute the mean daily wind speed from NOAA/NCDC data for grounding days (row 3, Table 5-1) and extract the average hourly wind speed from NOAA/NCDC data at the time of the groundings for those accidents (1992-95) for which time of day is known (row 4, Table 5-1). We also calculate the mean wind speed reported in the USCG data during grounding incidents (row 5, Table 5-1). USCG-reported wind speeds at grounding incidents are markedly higher than NOAA/NCDC average daily wind speeds for grounding days, probably because winds on the water tend to be higher than winds on land (where the airport sensors are located), and because the NOAA means are daily averages. We plan to refine the NOAA data analysis for grounding days by taking into account the time of day of each grounding, to the extent that this information is available in the USCG data.

Notably, the mean wind speed on safe days is less than the mean wind speed on grounding days for all ports, regardless of the analytical approach or data source. This

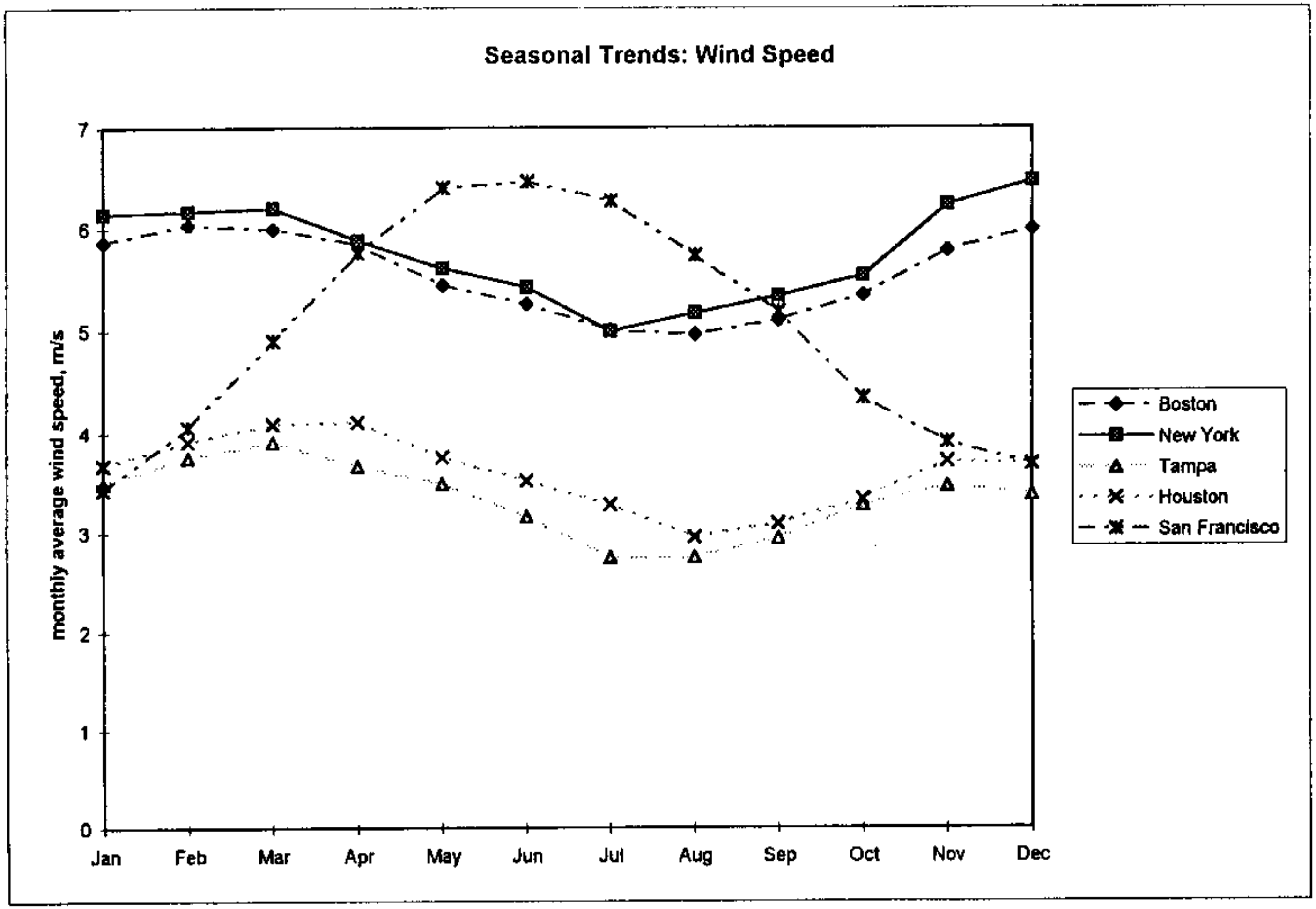

Seasonal Trends: Wind Speed
monthly average wind speed, m/s
7
6
5
4
3
2
1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Boston
New York
Tampa
Houston
San Francisco

Figure 5-1

Table 5-1

Mean Wind Speed (m/s), all vessels

(variance)(number of observations)

	Boston	New York	Tampa	Houston	San Francisco
Safe Days					
days	**5.54** (2.41)(5398)	**5.74** (3.91)(5243)	**3.32** (1.09)(5219)	**3.56** (1.31)(4879)	**5.00** (3.69)(5137)
dates	**5.41** (2.14)(874)	**5.90** (4.28)(2274)	**3.33** (1.04)(2019)	**3.60** (1.35)(3874)	**5.11** (3.52)(1435)
Grounding Days					
NOAA days	**5.83** (5.11)(71)	**6.08** (4.73)(224)	**3.52** (1.97)(189)	**3.80** (1.56)(595)	**5.18** (4.19)(121)
NOAA hours	**7.92** (13.38)(13)	**7.44** (14.04)(36)	**3.81** (7.79)(44)	**3.81** (4.60)(241)	**5.33** (7.58)(38)
USCG	**9.59** (48.48)(38)	**7.39** (41.11)(145)	**6.25** (36.34)(127)	**8.92** (55.79)(332)	**5.78** (53.14)(68)

suggests that wind speed is a significant contributing factor to groundings and can be used in the development of the physical risk model.

The distribution of mean wind speed on safe and grounding days is shown graphically for each port, and for ship and barge train groundings, in figures in Appendix 2. New York data are shown as an illustrative example in Figure 5-2. These plots show the cumulative distribution of mean wind speed w, p(w>x), given either grounding or safe days. A higher "tail" of this distribution in the higher wind speed range for grounding days, which is evident in many of the plots (see Figure 5-2), indicates that higher wind speeds are more commonly associated with groundings. The "all vessels" plots also show the distribution for the USCG wind speed data and the NOAA hourly data for comparison.

We have assumed here, in the absence of any but annual transit data, that safe traffic is uniformly distributed over the year. We are now obtaining some monthly transit statistics from ACE and will revise this assumption, and the associated distributions, if seasonal transit data suggest otherwise. We also plan to refine the analysis by truncating the safe distributions on the right to reflect port closures (no safe transits) at times when winds are very high. These truncations will be based on information supplied by port operations personnel in each study port. It may be appropriate to use different high-wind cutoffs for ships and for barges. This refinement will amplify existing differences in the safe and grounding wind speed distributions.

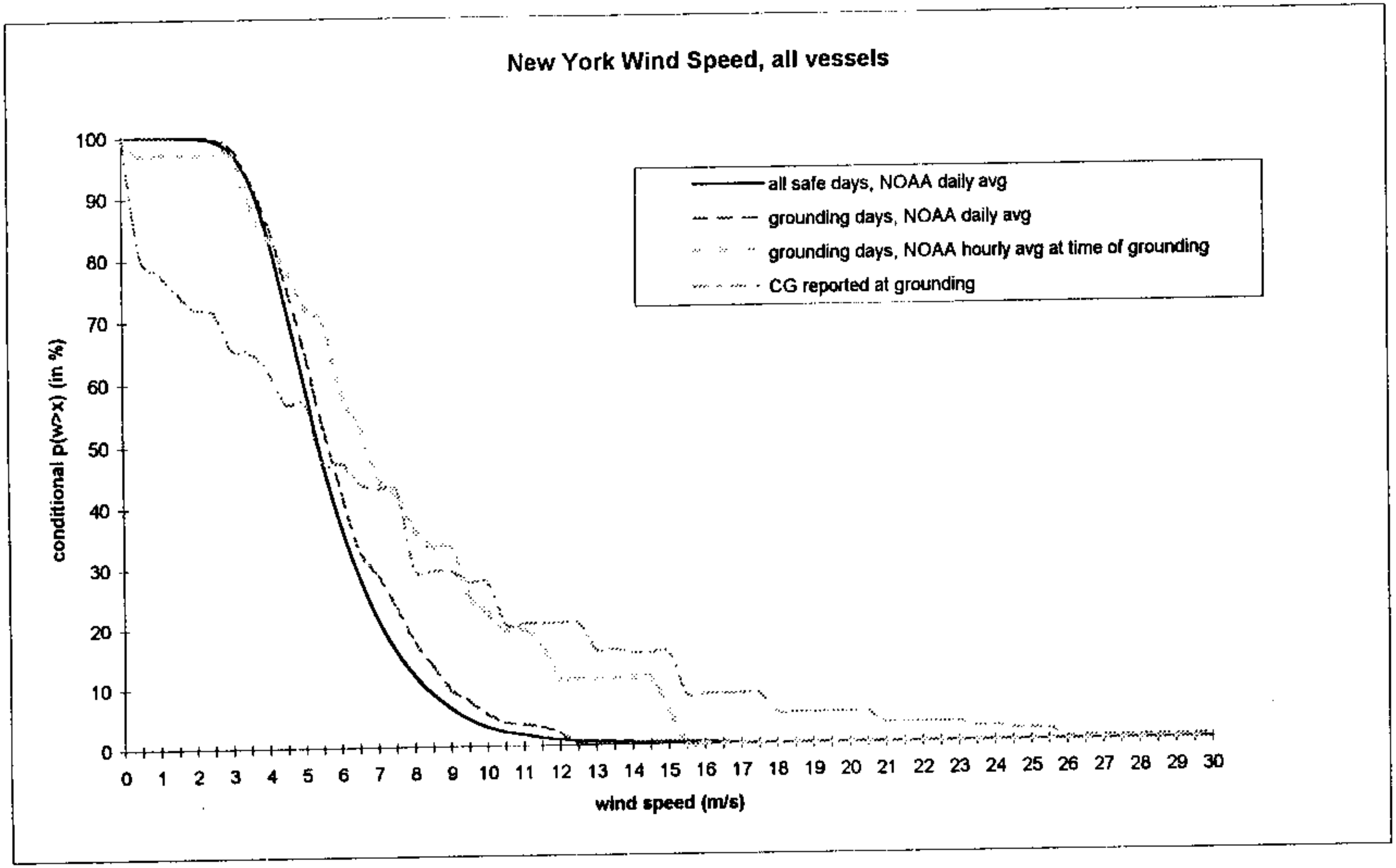

New York Wind Speed, all vessels
all safe days, NOAA daily avg
grounding days, NOAA daily avg
grounding days, NOAA hourly avg at time of grounding
CG reported at grounding
conditional p(w>x) (in %)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
wind speed (m/s)

Figure 5-2

6. FACTOR: VISIBILITY

The same two sources of data are used for visibility information. USCG casualty data include reported visibility at grounding incidents (again, the data are not complete). NOAA/NCDC hourly average horizontal visibility data are from sensors located at airports near the study ports. Seasonal fluctuations in mean visibility are shown in Figure 6-1. Table 6-1 shows daily mean visibility for "grounding days" and "safe days" for the five study ports.

The analysis of visibility data for "safe" and "grounding" days follows the approach described above for wind speed. Mean visibility for all days during the study period when no groundings took place in each port is shown in the first row of Table 6-1. Row 2 shows means of the sample of "safe" days that are anniversaries of grounding days. Here, also, the differences between means computed in these ways is largest for the port with the greatest seasonal fluctuation in visibility (San Francisco).

Visibility conditions on grounding days are characterized from NOAA/NCDC data as daily averages in row 3 and as hourly averages in row 4 of Table 6-1. USCG data on visibility during grounding incidents is shown in row 5. USCG-reported visibilities at grounding incidents are markedly lower than NOAA/NCDC average daily visibilities for grounding days, probably because visibility on the water tends to be worse than on land (San Francisco is a clear example), and because the NOAA means are daily averages. We plan to refine the NOAA data analysis for grounding days by taking into account the time of day of each grounding, to the extent that this information is available in the USCG data.

With the exception of Houston, the mean visibility on safe days is higher than the mean visibility on grounding days for all ports, regardless of the analytical approach or data source. This suggests that visibility is a significant contributing factor to groundings and can be used in the development of the physical risk model.

The distribution of mean visibility on safe and grounding days is shown graphically for each port, and for ship and barge train groundings, in figures in Appendix 3. Tampa data are shown as an illustrative example in Figure 6-2. These plots show the cumulative distribution of mean visibility v, p(v<x), given either grounding or safe days. A higher "tail" of this distribution in the lower visibility range for grounding days, which is evident in many of the plots (see Figure 6-2), indicates that lower visibilities are more commonly associated with groundings. The "all vessels" plots also show the distribution for the USCG visibility data and the NOAA hourly data for comparison.

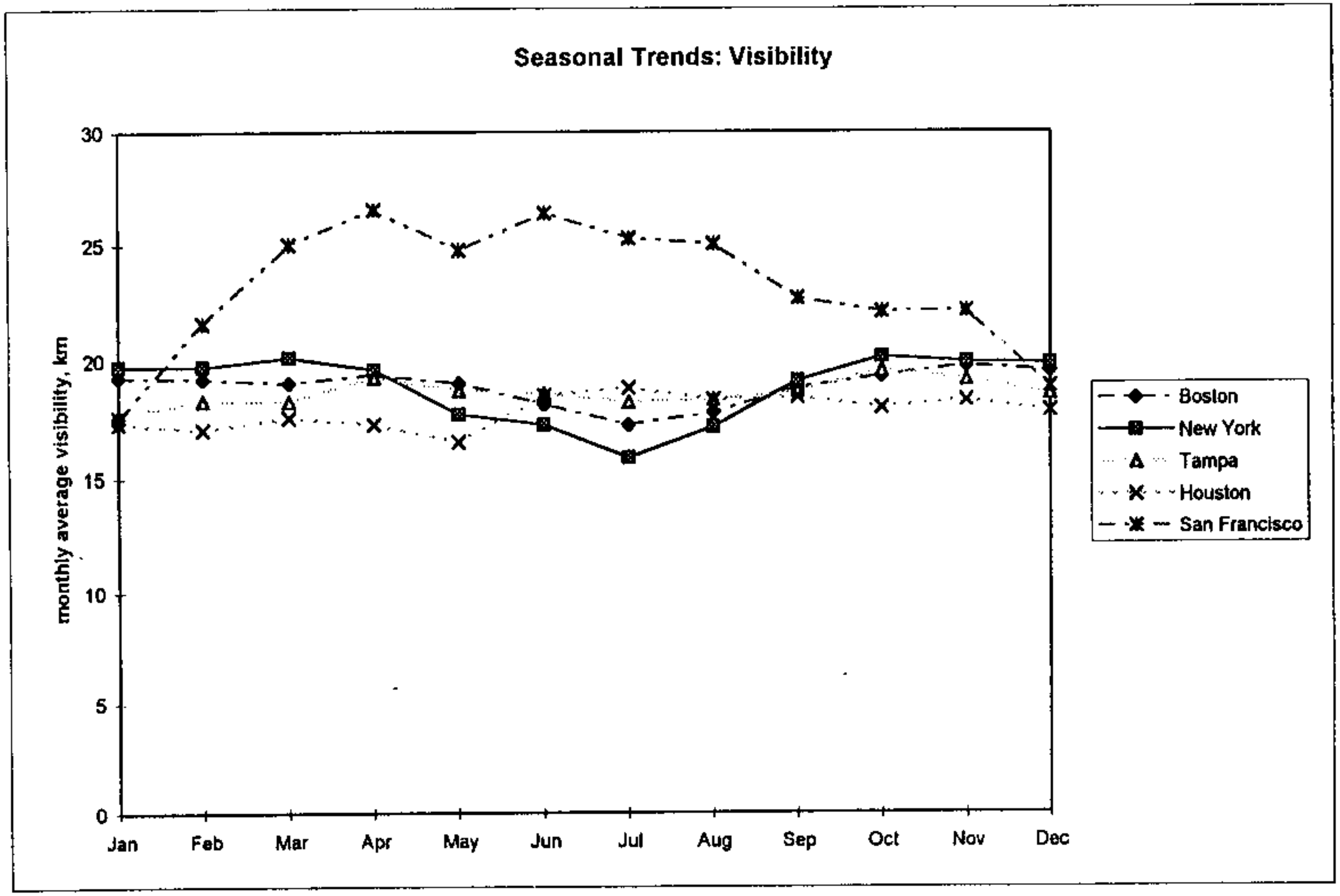

Seasonal Trends: Visibility
monthly average visibility, km
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Boston
New York
Tampa
Houston
San Francisco

Figure 6-1

Table 6-1

Mean Visibility (km), all vessels

(variance)(number of observations)

	Boston	New York	Tampa	Houston	San Francisco
Safe Days					
days	**18.88** (41.49)(5398)	**18.84** (62.04)(5243)	**18.62** (18.85)(5219)	**17.78** (27.44)(4879)	**23.13** (88.05)(5137)
dates	**18.80** (39.30)(874)	**19.09** (63.33)(2274)	**18.56** (19.56)(2019)	**17.72** (28.90)(3874)	**23.67** (87.57)(1435)
Grounding Days					
NOAA days	**18.64** (47.31)(71)	**18.70** (68.01)(224)	**18.04** (25.79)(189)	**18.14** (34.98)(595)	**23.45** (89.53)(121)
NOAA hours	**21.02** (58.72)(13)	**21.20** (128.34)(36)	**16.82** (63.08)(44)	**19.49** (60.21)(241)	**24.72** (284.51)(38)
USCG	**9.19** (59.27)(44)	**9.26** (86.96)(157)	**10.33** (43.09)(130)	**8.00** (50.90)(326)	**12.40** (88.41)(66)

As with the wind data, we have assumed that safe traffic is uniformly distributed over the year. We will revise our estimates appropriately if seasonal transit data suggest otherwise. Here, too, we expect to truncate the safe distributions on the left to reflect port closure on days when visibility is very low, possibly using different cutoffs for ships and for barges. Again, this refinement will amplify differences in the visibility distributions.

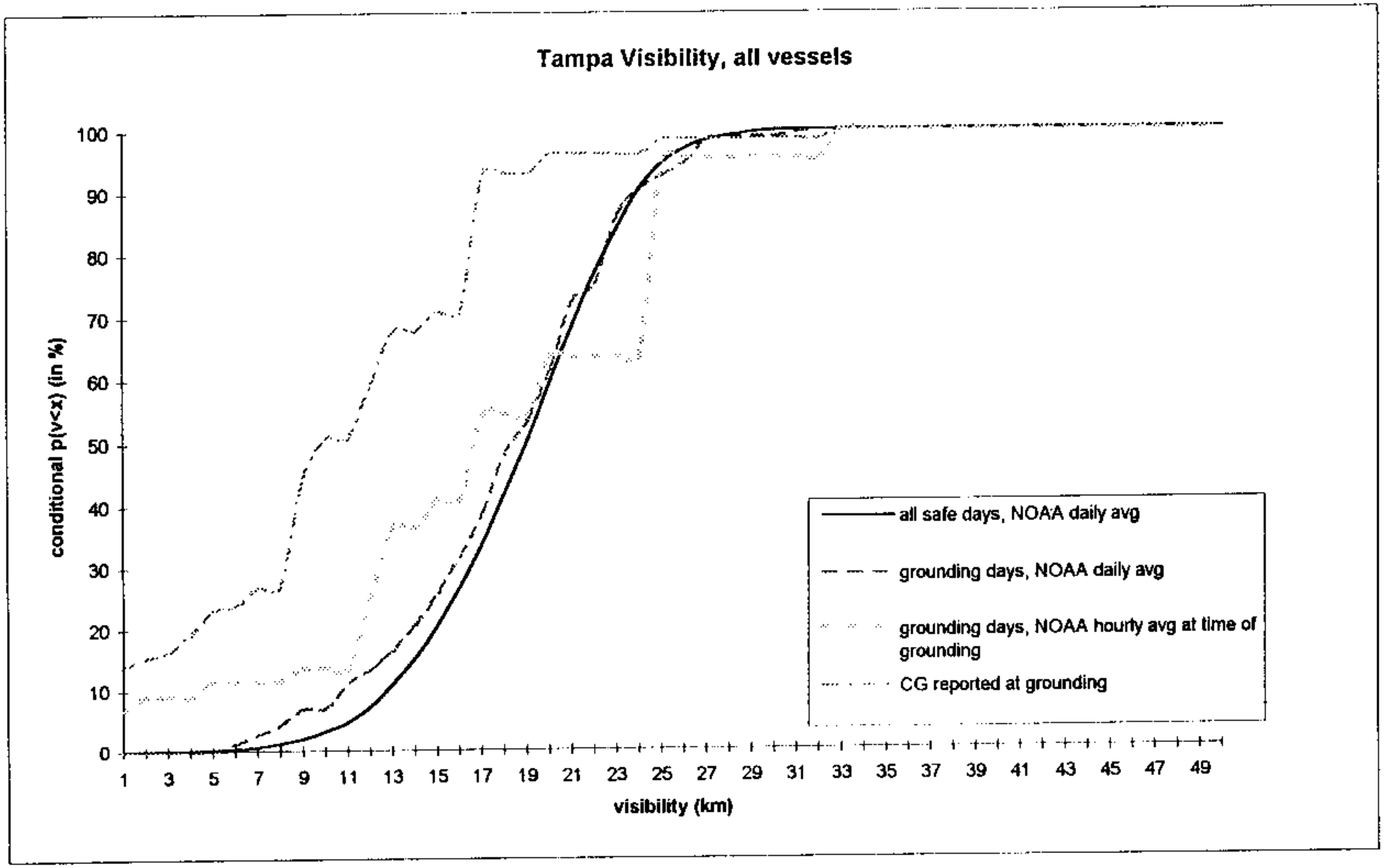

Tampa Visibility, all vessels
conditional p(v<x) (in %)
100
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
visibility (km)
all safe days, NOAA daily avg
grounding days, NOAA daily avg
grounding days, NOAA hourly avg at time of grounding
CG reported at grounding

Figure 6-2

7. FACTOR: PERSONNEL

Other things equal, more highly skilled or seasoned operators, and those with better local knowledge, may be expected to experience a lower risk of grounding. The only proxies for this factor that can be readily constructed from historical data are the flag of the vessel and, possibly, the use of pilots in the transit.

The USCG casualty data include information about the registry of each vessel involved in a grounding. To date, we have obtained data from local marine exchanges and port authorities for three of the study ports on the overall distribution of registries of vessels calling on the ports. This analysis is relevant only to ships; tugs/tows and barges in U.S. waters are almost without exception U.S.-registered.

Table 7-1 shows the number of U.S.- and foreign-registered ships using the two ports for which more or less complete data have been obtained to date. U.S.-registered ships account for 16 percent of transits but 36 percent of groundings in Tampa; and the relationship is reversed in San Francisco, where U.S. ships account for 67 percent of transits but only 29 percent of groundings. In the other port for which partial transits data are available, Houston, U.S. ships account for 13 percent of transits and 43 percent of groundings. In the two remaining ports, for which we do not yet have transit distributions, U.S. registered ships account for 11 percent of groundings in Boston and 52 percent of groundings in New York.

While there appears to be a distinct signal in the data for Tampa and San Francisco (and possibly Houston), this factor requires further exploration before it can be endorsed as useful in the development of the physical risk model. size distribution of U.S. vs. non-U.S. ships in general not known from available data.

A separate factor related to personnel issues is the presence of a pilot on board each vessel. The USCG data contain information about the presence of state or federally licensed pilots on board vessels involved in groundings (only through 1990). We will obtain similar information from the study ports for overall transits, and conduct a similar comparison.

	Tampa						San Francisco					
	all ship transits			ship groundings			all ship transits			ship groundings		
	US flag	other flag	% US	US flag	other flag	% US	US flag	other flag	% US	US flag	other flag	% US
1981				2	3	**40**	2184	1597	**58**	2	0	**100**
1982	289	1421	**17**	0	1	**0**	2077	1361	**60**	3	2	**60**
1983	267	1411	**16**	2	0	**100**	2356	1265	**65**	1	6	**14**
1984	287	1458	**16**	3	6	**33**	2644	1135	**70**	0	3	**0**
1985	263	1650	**14**	4	4	**50**	2557	1129	**69**	2	3	**40**
1986	203	1596	**11**	1	2	**33**	2549	1120	**69**	1	4	**20**
1987	332	1781	**16**	3	3	**50**	2591	1071	**71**	2	5	**29**
1988	333	1597	**17**	4	11	**27**	2551	1120	**69**	1	3	**25**
1989	345	1486	**19**	4	4	**50**	2490	1144	**69**	1	6	**14**
1990	328	1311	**20**	1	2	**33**	2531	1130	**69**	2	4	**33**
1991	276	1313	**17**	0	0		2449	1222	**67**	0	1	**0**
1992	259	1282	**17**	1	5	**17**	2375	1269	**65**	0	4	**0**
1993	242	1296	**16**	1	2	**33**	2293	1191	**66**	4	1	**80**
1994	241	1461	**14**	1	3	**25**	2375	1127	**68**	1	8	**11**
1995	350	1257	**22**	0	1	**0**	2200	977	**69**	2	4	**33**
1981-95	4015	20320	**16**	27	47	**36**	36222	17858	**67**	22	54	**29**

Table 7-1: Ships' Registry and Groundings, Tampa and San Francisco

8. FACTOR: CHANNEL COMPLEXITY

Other things equal, a transit through a region that is relatively shallow, or via a channel that is relatively narrow and/or requires sharper turns, may be expected to involve a greater risk of grounding. Unfortunately, we have no good data on water depth relative to vessel draft. Reconstructing water (tidal) levels during grounding incidents is difficult because water level models and historical data are incomplete, and the USCG casualty data do not include information about vessel draft and trim. The best we can do is to rely on general indicators of relative depth, such as vessel type and size, described above.

We are investigating the use of other indicators to capture aspects of channel complexity. Measures of effective channel width and characterizations of the number and severity of channel bends were developed for the Port Needs Study (USCG, 1991). Some possible measures of this kind are shown in Table 8-1.

The inclusion of channel complexity factors in the physical risk model will allow comparisons across different ports and waterways, as well as the evaluation of design changes for a given waterway. This work will receive priority during the second year of the project.

	length (nm)	min. width (meters)	avg. width (meters)	# of turns	avg. head change/turn (degrees)
Boston					
approaches	9.5	400	6684	2	29.8
convergence	4.5	600	5745	2	27.2
open harbor/bay	4.0	400	5266	2	23.2
enclosed harbor	4.5	200	329	3	23.5
constricted	2.9	75	125	6	32.6
New York					
open approach	25.7	266	402	1	4.1
convergence	7.3	266	266	2	30.4
open harbor/bay	3.2	266	952	1	90.7
open harbor/bay	2.9	266	1656	3	37.2
constricted	15.3	75	517	13	30.1
Tampa					
open approach	28.0	233	1431	4	8.7
open harbor/bay	31.5	130	212	11	24.5
enclosed harbor	10.9	100	149	6	43.9
Houston					
open approach	27.3	275	7711	1	9.5
constricted	11.2	275	282	4	25.4
enclosed harbor	2.7	350	350	3	19.2
San Francisco					
open approach	29.8	666	666	0	0.0
convergence	22.0	666	749	2	5.6
open harbor/bay	32.2	200	962	11	24.9
enclosed harbor	4.6	116	145	2	24.3
river	68.0	66	359	55	13.5

Table 8-1: Channel Complexity Measures. Source: PNS (USCG, 1991).

9. OBSERVATIONS ABOUT GROUNDING RATES AND FACTORS

As mentioned above, it is important to use caution when comparing grounding rates across ports because of possible differences in reporting criteria and because of distortions in transit counts.

Promising explanatory risk factors identified by our research to date include vessel type, vessel size, wind speed, visibility, and (possibly) ship registry. We expect to refine our understanding of these factors, and examine others, during the second year of the project, leading up to the development of a physical risk model.

One factor we have not explicitly analyzed, but about which the present data from Tampa may suggest interesting results, is operators' quality of information about environmental conditions. Other things equal, better information about currents, tide levels, and winds may be expected to reduce the likelihood of grounding. This factor can be tested by distinguishing between study areas and time periods for which information from real-time monitoring systems was available to vessel operators (such as Tampa Bay in the 1990s) and those for which it is not. Our data show that grounding rates in Tampa have indeed declined dramatically, for both ships and barge trains, in the 1990s. Further analysis is required to determine how much of this decline is attributable to the availability of real-time environmental information.

10. ECONOMIC LOSSES

The economic loss associated with a grounding can be calculated as the sum of all costs associated with the grounding. Costs are classified as either internal or external. Internal costs are those arising from the vessel involved in the grounding and other parts of the marine transportation system; they include damage to the vessel, loss of cargo, injury or death of crew members, cleanup costs, and delays due to blockage of the route, among others. External costs are those incurred outside the transportation system, including environmental degradation, human health risks, lost fishery revenues, and lost recreational benefits, among others. Both external and internal costs will vary with the severity of the grounding; the size of the vessel, its construction, and its cargo; and other factors. External costs will also vary greatly with the environmental and human health sensitivity of the location.

An algorithm has been developed to estimate the cost of groundings as a function of relevant parameters such as vessel size, nature of cargo, and nature of the transit area, following the approach taken in the Port Needs Study (PNS) (USCG, 1991). PNS provides information about the number and nature of groundings that can be avoided in each PNS port (including the five study areas of this project) with certain vessel traffic service (VTS) systems, and the associated (avoided) losses. The PNS study included in its loss estimation each of the following categories of losses (see Schwenk, 1991):

- loss of human life and personal injuries,
- vessel hull damage,
- cargo loss and damage,
- economic cost of the vessel being out of service,
- spill clean up costs,
- losses in tourism and recreation,
- losses in commercial fish species,
- impacts on marine birds and mammals,
- losses due to LPG/LNG fires and explosions, and
- bridge and navigational aids damage.

Not included in the estimation procedure are damages to on-shore facilities and water supplies, legal fees for litigation over vessel casualties, cumulative effects of consecutive spills, effects of chemical releases into the air, and non-use values.

A summary of the PNS loss estimation procedure is provided by Schwenk (1991). In addition to its own procedures, PNS draws on several sources for damage estimation models. These include the Natural Resource Damage Assessment Model (see below);

several models developed by A.T. Kearney (1990) for losses in tourism, property values, and subsistence households; and models by ERG (1990) for losses due to cleanup costs and to vessel damage and repair. The PNS data, which reflect inputs from all of these models, are used to estimate the losses associated with one grounding involving various vessel types (tanker, dry cargo, tug/barge) and sizes in each transit risk project study area.

Perhaps the most volatile element in the PNS loss estimation procedure is the model used to calculate natural resource damages. These damages -- loss of fish, birds, marine plants, and other species -- account for between 10 and 40 percent of total damages, depending on the location and nature of the accident. The PNS results are based on a version of the Department of the Interior's Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) which is in the process of being replaced by a new version of NRDAM/CME (see Federal Register 59(5):1062-1189). The new version includes a new model of restoration costs and makes use of updated biological, chemical, and economic data. Preliminary analysis of the new model's parameters suggests that there is no consistent way to scale results from the previous version to reflect the likely new model results. Present cost estimation algorithms therefore include natural resource damage estimates based on an "old" version of the NRDAM/CME.

Table 10-1 shows the total average economic losses estimated by these models for tanker and dry cargo ship groundings in the five study ports. These averages take into account the distribution of vessel size and cargo for each port, and also reflect seasonal averages for environmental losses.

Table 10-1: Average Economic Losses Associated with Ship Groundings
Numbers in millions of 1993$. Based on PNS (USCG, 1991).

	tanker grounding	**dry cargo ship grounding**
Boston	10.7	0.3
New York	1.7	0.5
Tampa	1.0	0.4
Houston	2.4	0.5
San Francisco	1.3	0.4

11. DATA ISSUES

In the course of our evaluation to date, some deficiencies and limitations have been identified in the available historical data. We describe these briefly for each major data source.

A. USCG Vessel Casualty Data

The USCG vessel casualty databases, CASMAIN and MSIS, are the most comprehensive source of commercial vessel casualty information for U.S. waters available. However, these databases (particularly the older CASMAIN data) are occasionally difficult to work with because of missing data, duplicate entries, and inaccuracies. Also, some useful information for the analysis of casualties is not collected in these datasets at all.

The locations of groundings (and other accidents) are reported in theory to tenths of minutes latitude/longitude. As discussed above, this level of accuracy is not met for many entries; 18 percent of CASMAIN grounding records have no latitude/longitude information at all; and several groundings have erroneous location information (they plot on dry land). In several cases, a single casualty is described by two (slightly different) entries, one of which is probably erroneous and should have been removed from the database.

No data are presently collected on the actual draft or trim of vessels at the time they were involved in groundings; and it is difficult to reconstruct actual water depth at the time of the accident from the environmental data. Further, the presence and use of escort tugs is not quantified in the data, and the new MSIS data no longer include information about the presence of pilots on board vessels. These data could be usefully included in future USCG casualty data.

The USCG casualty dataset could be further improved by the adoption of a consistent set of criteria to govern what incidents are included in the dataset and how the information is to be obtained (i.e. wind speed, visibility, water level at time of the accident, etc.).

B. ACE Transit Data

The ACE Waterborne Commerce transit data annual summaries are useful but suffer from several limitations for the purposes of our analysis. Dry cargo and passenger vessels are mixed in a single reporting category, requiring adjustments based on approximations (see discussion above). The breakdown of transits by specific waterways is useful, but makes the compilation of a composite "port region" transit history difficult because of potential double counting. Finally, barge movements are reported for individual barges, and there is no completely accurate way to determine the number of barge train movements.

Monthly statistics are said to be available for recent years; these will be obtained for ongoing work on this project.

C. NOAA Environmental Data

NOAA wind and visibility are available as hourly averages, allowing for fairly detailed time-analysis. However, they are general to each port area, and measured at an airport location that does not necessarily reflect conditions on the water. We will investigate the possibility of using these data together with data from nearby buoys to establish on-water baselines.

Historical water level (tidal and meteorological forcing) and current information is not available with the same detail and consistency as wind and visibility, and water level and current conditions during historical groundings therefore cannot be reconstructed. This will change as real-time oceanographic data systems, such as PORTS in Tampa, become more common in U.S. ports.

D. Port-Specific Traffic Data

More detailed information about safe transits would be useful for several aspects of our investigation. Ideally, monthly (or even daily) counts by flag, vessel type, vessel size, with tug escort and piloting information could be used.

REFERENCES

A.T. Kearney, 1990. Methodology for estimating the environmental costs of OCS oil and gas exploration, development, production, and transportation. Kearney Centaur Division.

Dagbert, M., 1993. Kriging of sea bottom elevation with uncertain data. Geostat Systems International Inc.

Eastern Research Group (ERG), Inc., 1990. Estimates of costs associated with oil and hazardous chemical spills and costs of idle resources during vessel repairs. Prepared for the John A. Volpe National Transportation Systems Center as part of the Port Needs Study (see USCG, 1991).

Hand, D.J., 1981. *Discrimination and classification*. John Wiley & Sons, New York.

Kielland, P., K. Burrows, B. Ward, M. Dagbert, and R. Velberg, 1992. Toward "IHOstat": IHO approved software which evaluates the quality of bathymetric data. Hydro '92 Conference, Copenhagen, December 1992.

Kielland, P., Tubman, T., 1994. On estimating map model errors and GPS position errors.

Schwenk, J.C., 1991. Unit costs of vessel casualty consequences. Prepared for the John A. Volpe National Transportation Systems Center as part of the Port Needs Study (see USCG, 1991).

United States Coast Guard (USCG), 1991. Port Needs Study (Vessel Traffic Services Benefits). DOT-CG-N-01-91. National Technical Information Service, document PB92-107697.

APPENDIX 1: GROUNDING RATES

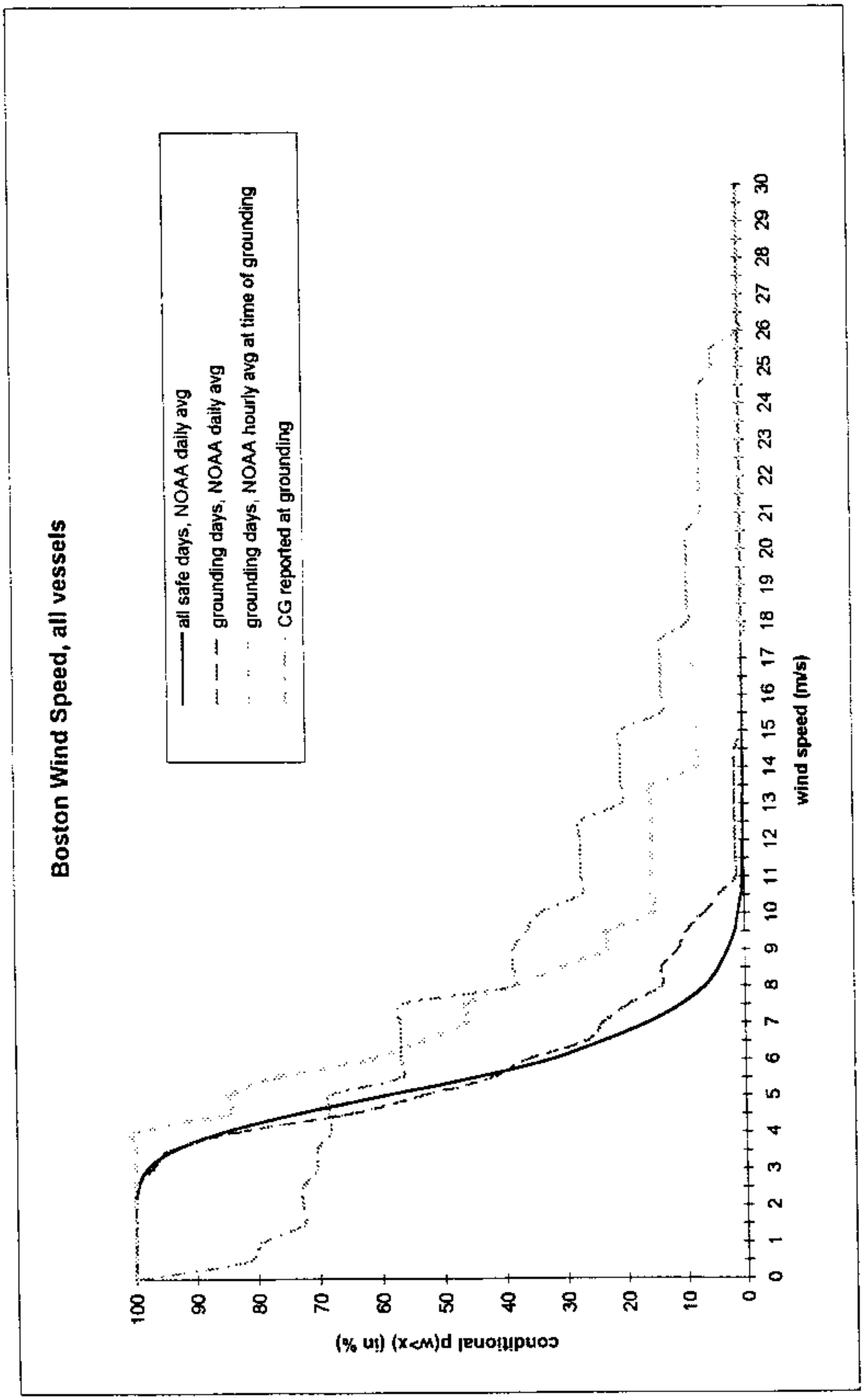
	ships			tankers			dry cargo			barge trains		
	all	small	large	all	small	large	all	small	large	all	tank	dry cargo
Boston												
1981	0.73	0.91	0.00	0.00	0.00	0.00	2.00	2.35	0.00	0.69	0.79	0.00
1982	0.44	0.54	0.00	0.00	0.00	0.00	0.99	1.18	0.00	0.64	0.67	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.79	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.31	1.43	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.67	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.69	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.55	1.61	0.00
1989	1.22	0.90	1.90	1.22	0.00	2.85	1.21	1.54	0.00	0.00	0.00	0.00
1990	0.54	0.00	1.81	1.03	0.00	2.75	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.65	0.99	0.00	0.00	0.00	0.00	1.29	1.80	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.63	1.15	0.00	1.40	2.39	0.00	0.00	0.00	0.00	0.42	0.00	2.36
1995	0.63	0.00	1.37	1.40	0.00	3.38	0.00	0.00	0.00	0.00	0.00	0.00
15 years	0.32	0.30	0.39	0.27	0.10	0.66	0.39	0.52	0.00	0.37	0.39	0.26
New York												
1981	0.86	0.48	3.88	0.62	0.29	3.55	1.85	1.32	4.75	0.11	0.13	0.00
1982	0.15	0.00	1.36	0.09	0.00	0.93	0.43	0.00	2.52	0.06	0.05	0.08
1983	0.23	0.08	1.35	0.09	0.00	0.90	0.82	0.49	2.70	0.06	0.09	0.00
1984	0.45	0.17	2.99	0.27	0.00	2.89	1.38	1.07	3.33	0.09	0.15	0.00
1985	1.33	0.80	5.48	0.73	0.40	3.72	5.07	3.59	10.39	0.23	0.31	0.09
1986	0.66	0.57	1.16	0.56	0.54	0.72	1.30	0.83	3.03	0.24	0.15	0.22
1987	0.64	0.52	1.52	0.42	0.49	0.00	2.01	0.72	21.28	0.19	0.11	0.30
1988	0.67	0.26	2.99	0.27	0.32	0.00	2.61	0.00	28.57	0.42	0.55	0.14
1989	1.88	1.38	4.73	1.92	1.30	5.34	1.62	1.84	0.00	0.46	0.52	0.23
1990	1.04	1.05	0.96	0.89	0.86	1.10	2.01	2.32	0.00	0.14	0.12	0.17
1991	0.31	0.36	0.00	0.00	0.00	0.00	2.56	2.95	0.00	0.00	0.00	0.00
1992	1.14	0.57	5.79	0.82	0.57	2.52	2.26	0.59	44.12	0.23	0.36	0.00
1993	1.06	0.34	7.19	0.50	0.19	3.06	6.58	1.77	71.43	0.16	0.31	0.00
1994	0.44	0.33	1.38	0.34	0.19	1.52	1.14	1.23	0.00	0.28	0.47	0.08
1995	0.15	0.17	0.00	0.17	0.19	0.00	0.00	0.00	0.00	0.04	0.08	0.00
15 years	0.72	0.45	2.68	0.50	0.33	1.75	1.90	1.10	7.20	0.18	0.21	0.09

Tampa											
1981	0.98	1.22	0.00	0.89	1.39	0.00	1.01	1.18	0.00	1.96	3.88	1.16
1982	0.30	0.00	1.33	0.00	0.00	0.00	0.40	0.00	2.07	1.63	2.43	1.23
1983	0.59	0.39	1.22	2.59	1.96	3.83	0.00	0.00	0.00	0.85	0.83	0.87
1984	2.45	2.16	3.38	5.59	4.71	7.78	1.44	1.40	1.59	2.56	2.66	2.49
1985	2.02	0.95	6.21	5.64	2.10	12.88	1.23	0.74	3.50	4.62	6.17	3.26
1986	0.74	0.60	1.43	2.79	2.10	4.17	0.30	0.35	0.00	4.05	6.99	1.46
1987	1.31	0.82	3.29	3.21	1.64	6.15	0.82	0.65	1.70	1.55	2.40	1.14
1988	4.00	3.23	6.21	5.96	4.92	7.58	3.28	2.76	5.26	1.45	0.96	1.74
1989	2.21	0.38	7.29	4.81	1.49	10.78	1.16	0.00	5.09	0.96	0.98	0.93
1990	0.87	0.41	1.96	0.97	0.00	2.54	0.83	0.56	1.60	2.02	0.87	2.99
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.79
1992	1.92	0.87	4.84	1.78	0.00	5.25	2.00	1.28	4.48	1.90	3.13	0.74
1993	0.93	0.83	1.19	1.77	1.45	2.27	0.47	0.58	0.00	1.77	1.54	2.00
1994	1.10	0.00	4.90	1.76	0.00	4.93	0.80	0.00	4.87	1.88	1.59	2.18
1995	0.27	0.00	1.22	0.88	0.00	2.46	0.00	0.00	0.00	0.27	0.53	0.00
15 years	1.32	0.81	3.01	2.45	1.36	4.46	0.92	0.66	2.05	1.84	2.14	1.52
Houston											
1981	1.21	0.85	2.41	2.70	1.95	3.91	0.54	0.49	0.82	2.73	3.26	1.04
1982	0.49	0.39	0.81	0.56	0.00	1.36	0.45	0.53	0.00	2.74	2.49	2.65
1983	2.04	1.19	4.78	2.46	1.54	3.84	1.80	1.05	6.34	1.37	1.15	1.16
1984	1.40	0.42	4.73	2.43	0.00	6.19	0.84	0.58	2.44	1.68	1.53	1.87
1985	0.28	0.11	1.01	0.63	0.50	0.84	0.13	0.00	1.25	0.33	0.32	0.33
1986	0.22	0.15	0.43	0.00	0.00	0.00	0.36	0.21	1.26	0.12	0.07	0.38
1987	0.93	0.41	2.43	1.63	0.51	2.88	0.50	0.38	1.35	0.32	0.37	0.00
1988	1.40	0.28	4.99	2.33	1.04	3.97	0.85	0.00	7.25	1.08	1.02	0.37
1989	0.81	0.30	2.48	1.70	0.98	2.70	0.20	0.00	1.87	0.55	0.29	1.10
1990	1.07	0.33	3.08	1.85	0.45	3.77	0.43	0.25	1.46	0.71	0.60	1.16
1991	0.11	0.00	0.45	0.24	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.84	0.52	2.09	1.85	1.14	2.94	0.26	0.29	0.00	0.81	0.80	0.93
1993	0.46	0.24	1.22	0.92	0.38	1.76	0.15	0.17	0.00	1.84	1.42	2.47
1994	1.23	0.98	2.00	1.94	1.46	2.64	0.80	0.78	0.90	2.61	2.28	1.78
1995	0.90	0.87	1.00	1.73	1.83	1.58	0.40	0.47	0.00	2.36	2.00	3.57
15 years	0.89	0.48	2.20	1.52	0.81	2.55	0.51	0.35	1.54	1.28	1.13	1.24

San Fran												
1981	0.25	0.00	0.76	0.42	0.00	0.96	0.18	0.00	0.63	2.92	9.52	0.00
1982	0.51	0.55	0.39	0.93	1.82	0.00	0.39	0.32	0.67	5.59	7.52	4.44
1983	0.94	0.81	1.18	1.47	1.92	1.01	0.74	0.52	1.29	0.00	0.00	0.00
1984	0.38	0.57	0.00	0.00	0.00	0.00	0.51	0.71	0.00	2.08	6.62	0.00
1985	0.66	0.38	1.27	1.78	1.07	2.64	0.34	0.23	0.63	1.67	7.87	0.00
1986	0.69	0.43	1.15	1.68	1.04	2.41	0.37	0.27	0.56	2.38	7.19	0.00
1987	0.92	0.22	1.98	0.96	0.00	1.95	0.91	0.29	1.99	2.51	6.94	0.00
1988	0.53	0.00	1.22	0.50	0.00	0.96	0.54	0.00	1.34	0.00	0.00	0.00
1989	0.94	0.49	1.49	1.96	0.93	3.12	0.56	0.33	0.84	7.58	9.85	5.18
1990	0.77	0.92	0.59	1.34	0.90	1.77	0.54	0.93	0.00	0.00	0.00	0.00
1991	0.13	0.00	0.27	0.00	0.00	0.00	0.18	0.00	0.38	0.00	0.00	0.00
1992	0.51	0.49	0.53	0.40	0.77	0.00	0.55	0.36	0.77	0.00	0.00	0.00
1993	0.69	0,26	1.18	1.32	0.86	1.80	0.40	0.00	0.88	3.23	4.00	0.00
1994	1.19	1.02	1.38	1.43	0.92	1.98	1.10	1.06	1.15	2.88	3.39	0.00
1995	0.79	0.25	1.38	1.43	0.92	1.98	0.55	0.00	1.15	2.88	0.00	19.23
15 years	0.65	0.43	0.99	1.01	0.73	1.32	0.52	0.34	0.83	2.28	3.54	1.04

APPENDIX 2: WIND SPEED DISTRIBUTION PLOTS

(See discussion in section 5.)


Boston Wind Speed, all vessels
all safe days, NOAA daily avg
grounding days, NOAA daily avg
grounding days, NOAA hourly avg at time of grounding
CG reported at grounding
conditional p(w>x) (in %)
100
90
80
70
60
50
40
30
20
10
0
wind speed (m/s)
0
1
2
3
4
5
6
7
8
9
10
11
12
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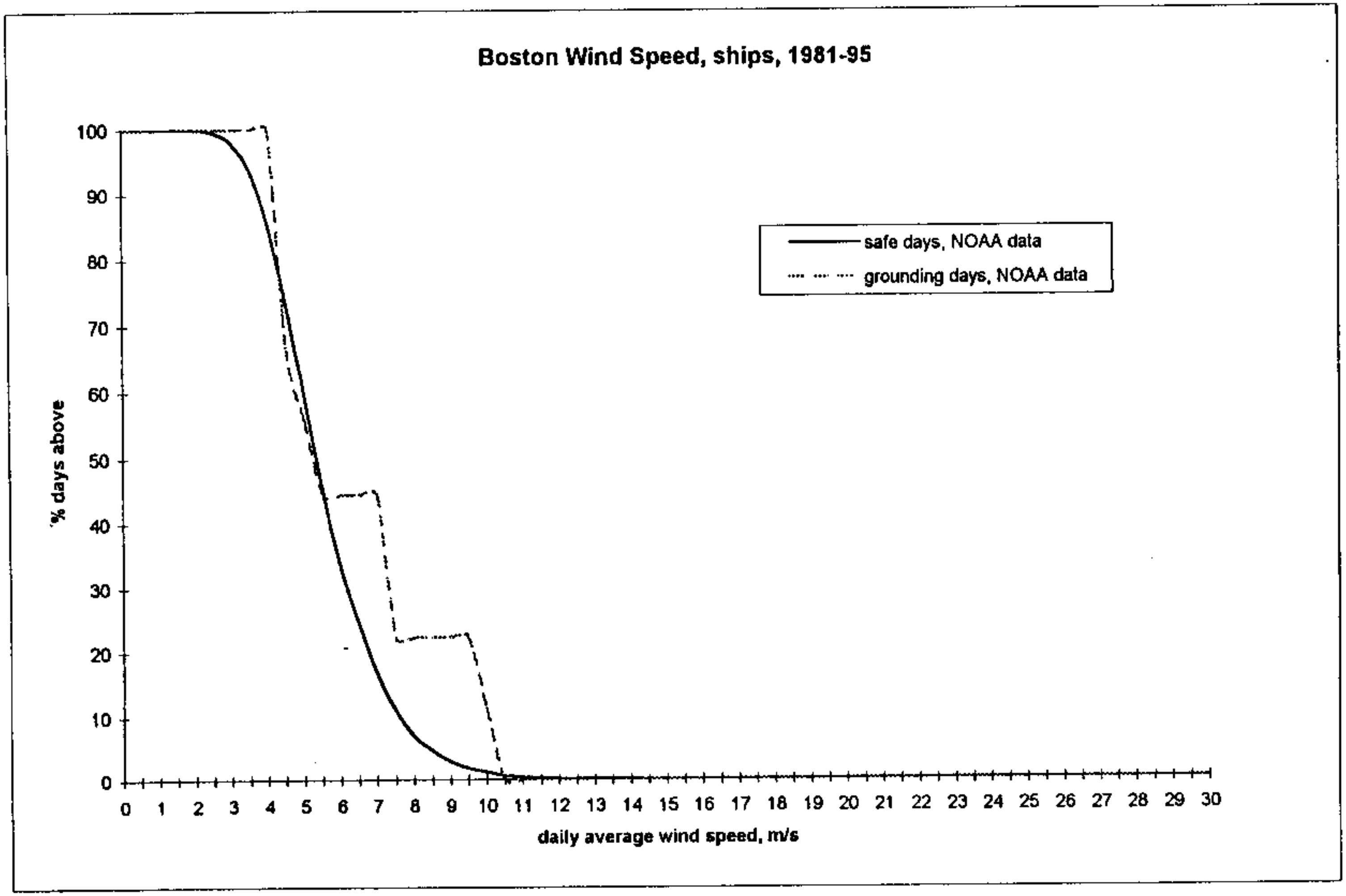
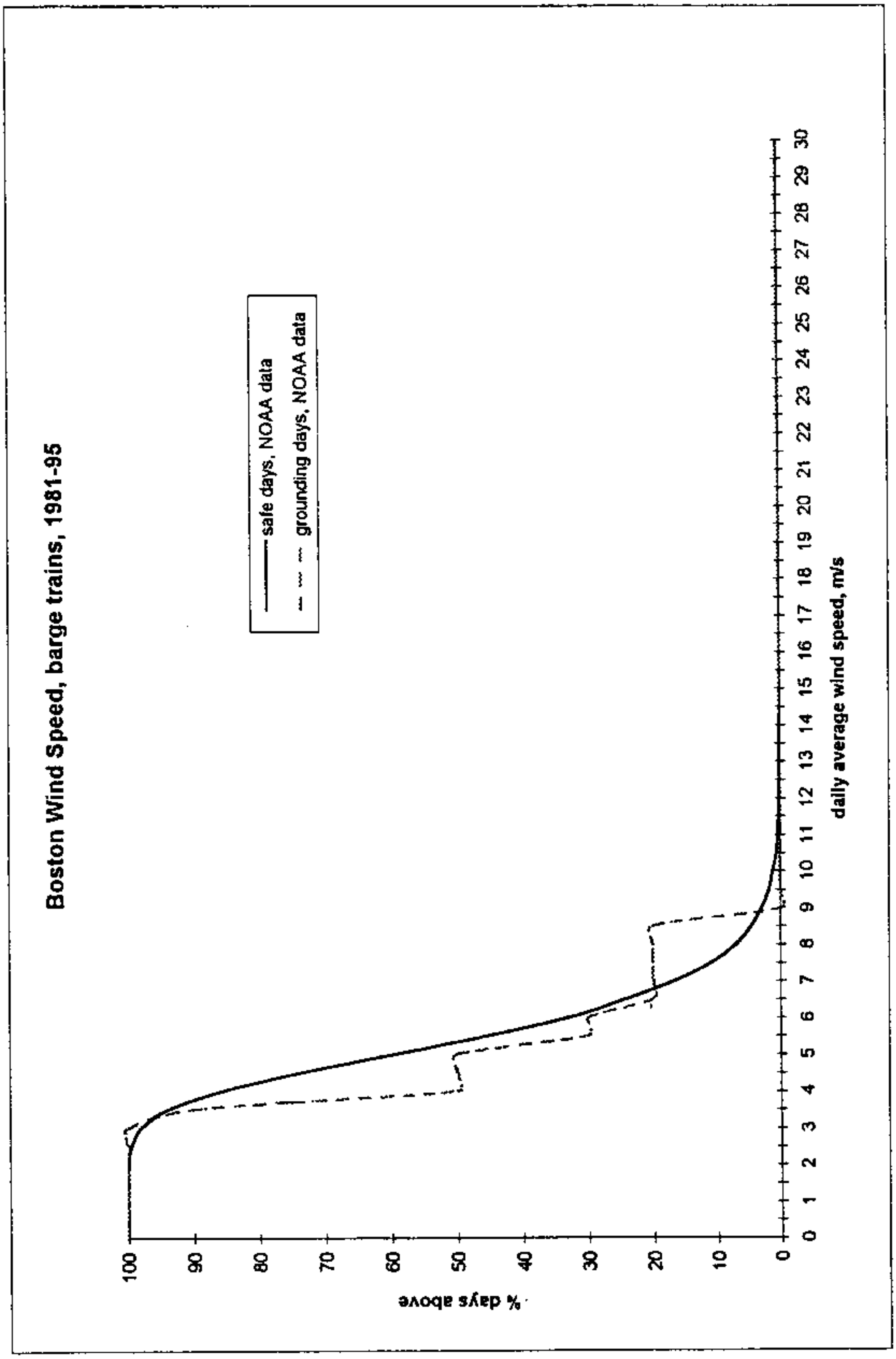
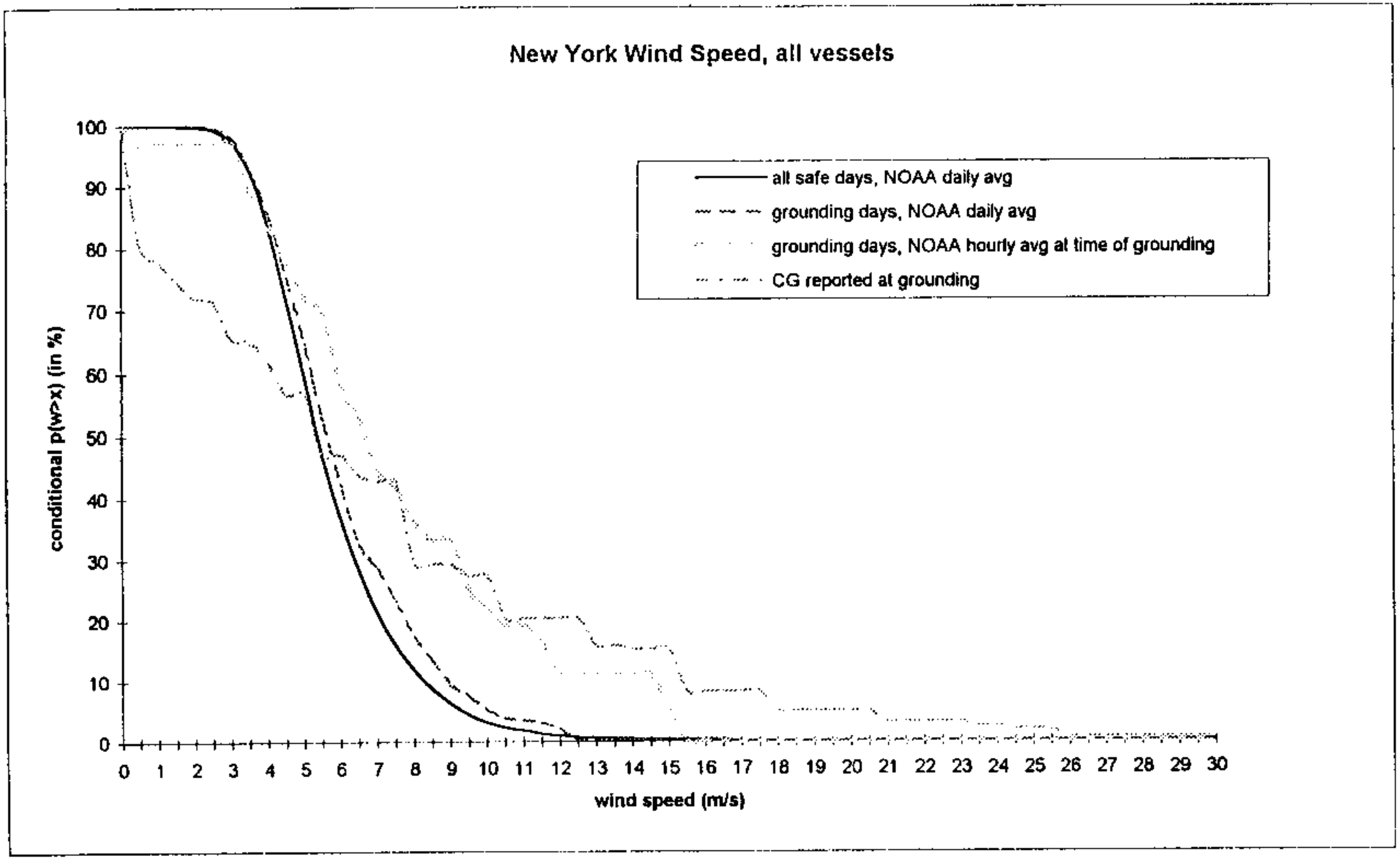

Boston Wind Speed, ships, 1981-95
safe days, NOAA data
grounding days, NOAA data
% days above
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
daily average wind speed, m/s

WINCUTS.XLS



Boston Wind Speed, barge trains, 1981-95

WINCUTS.XLS



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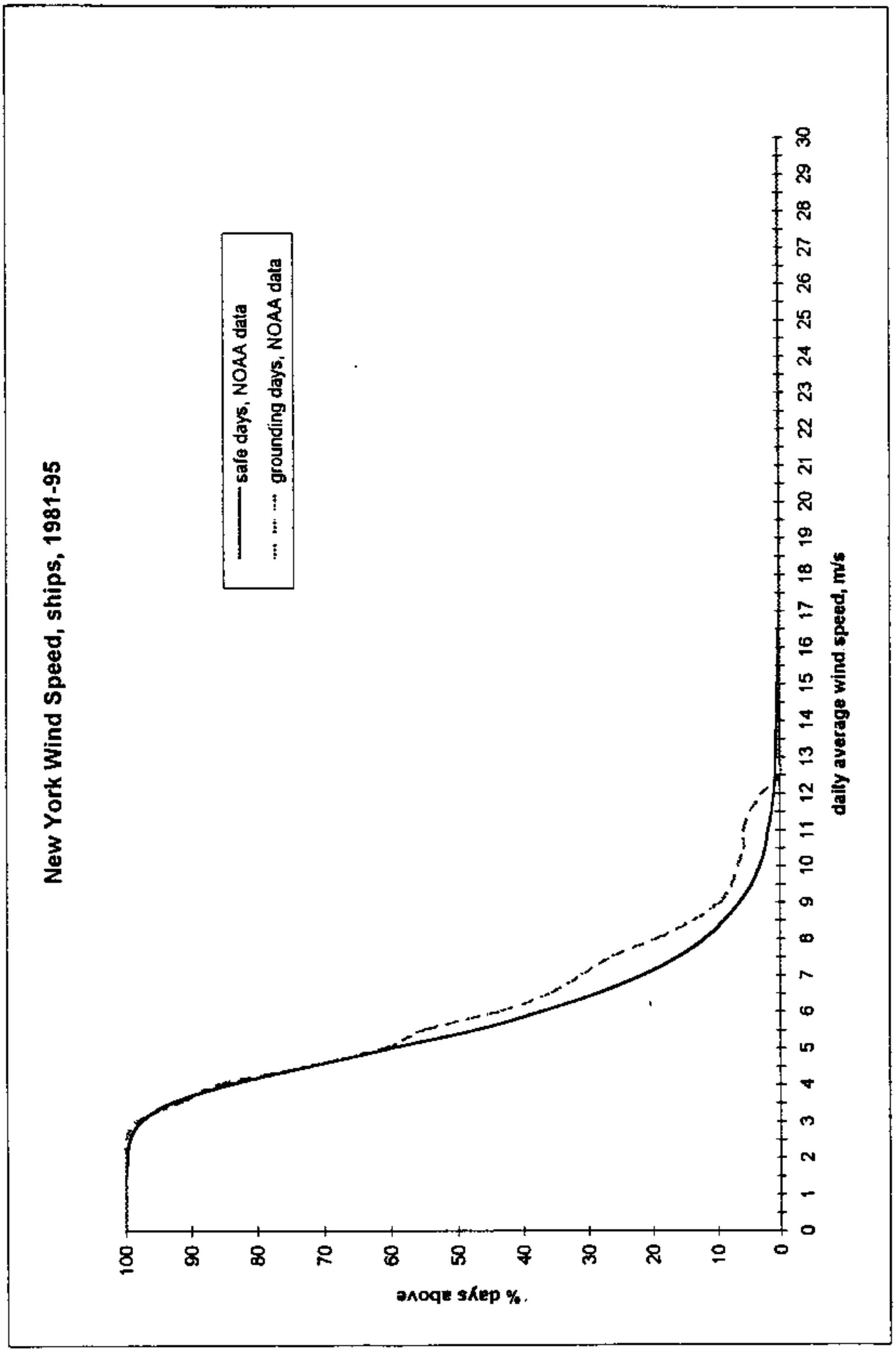
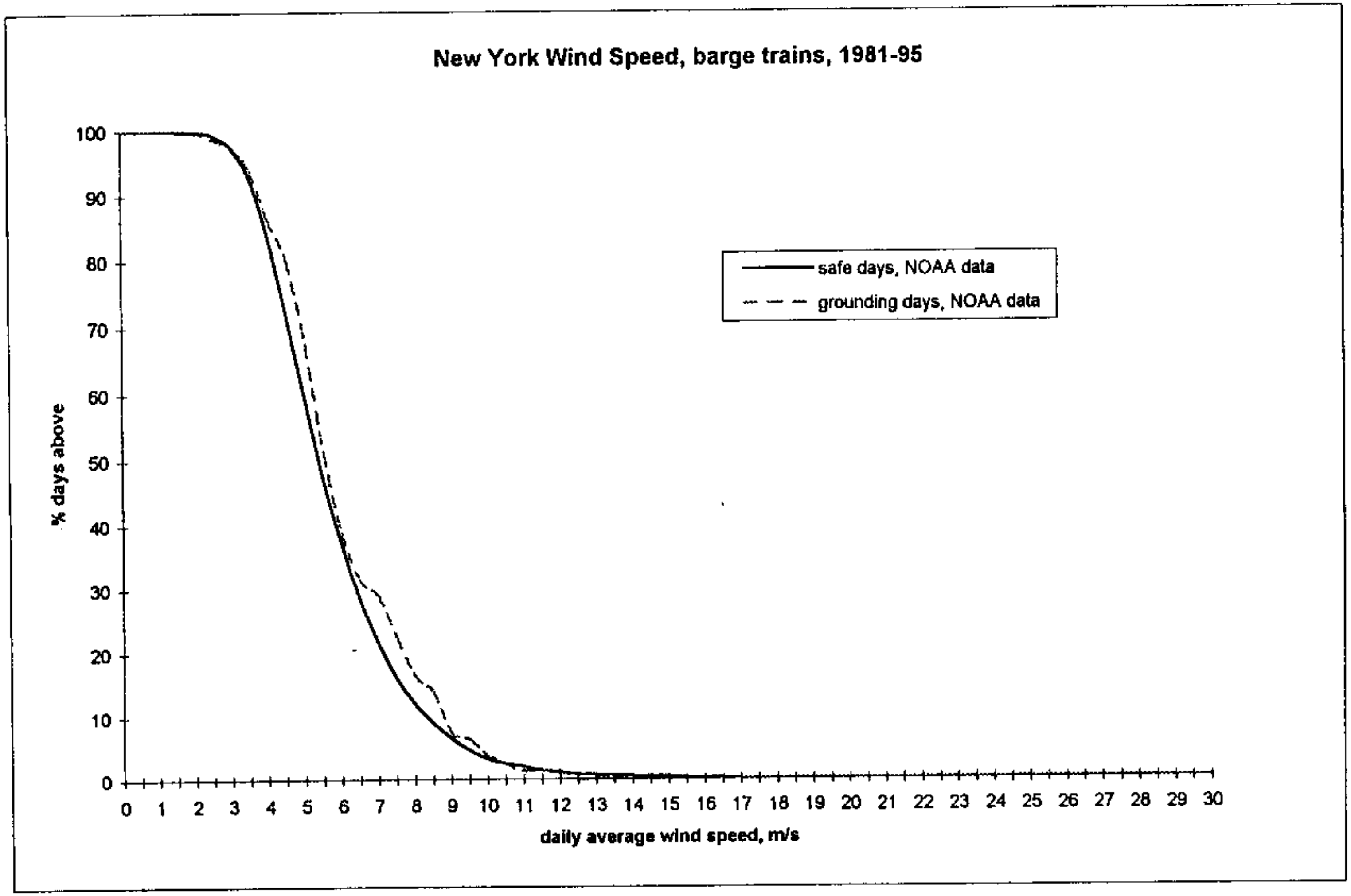

New York Wind Speed, ships, 1981-95
safe days, NOAA data
grounding days, NOAA data
% days above
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
daily average wind speed, m/s

WINCUTS.XLS


New York Wind Speed, barge trains, 1981-95
safe days, NOAA data
grounding days, NOAA data
% days above
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
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23
24
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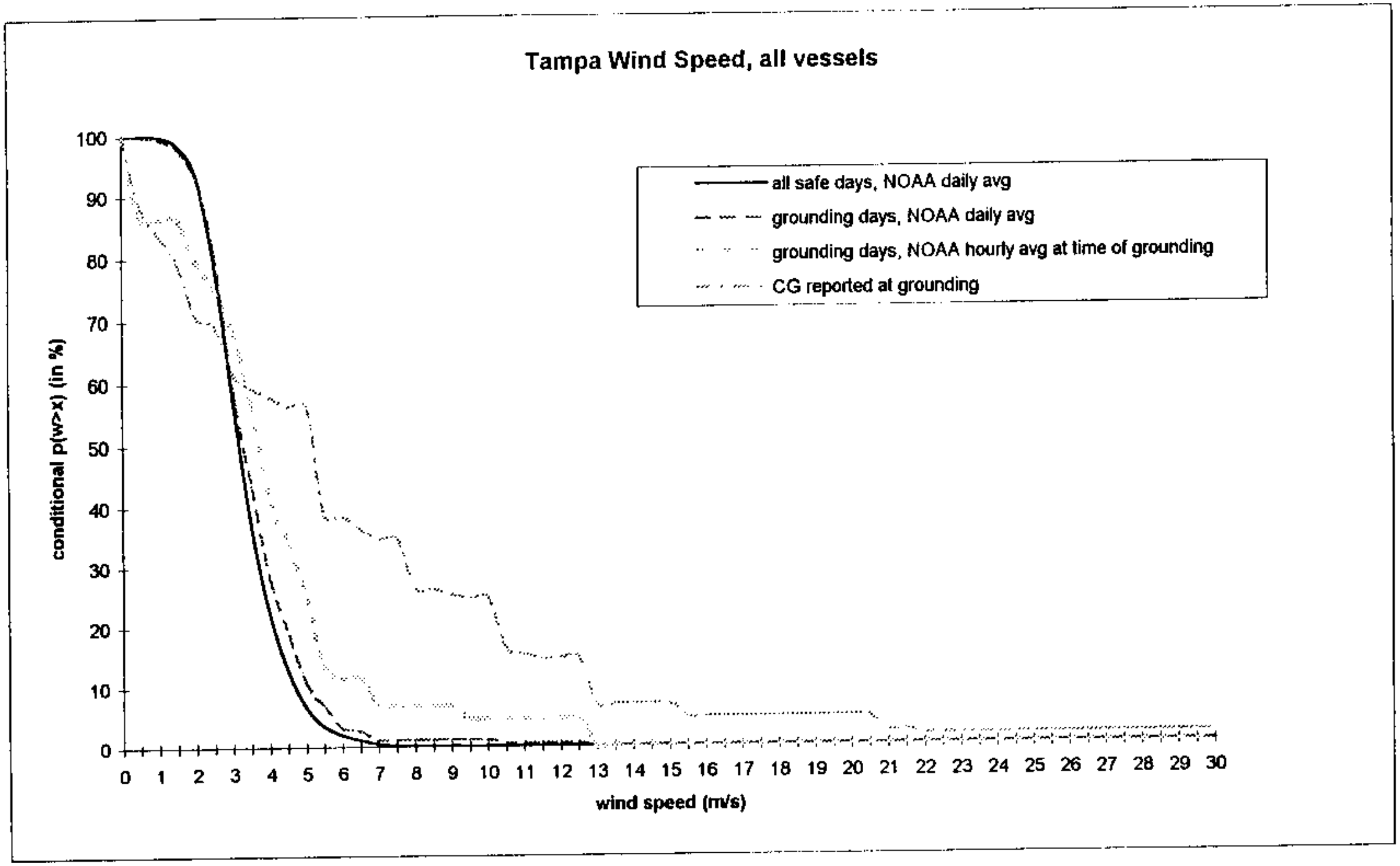
27
28
29
30
daily average wind speed, m/s



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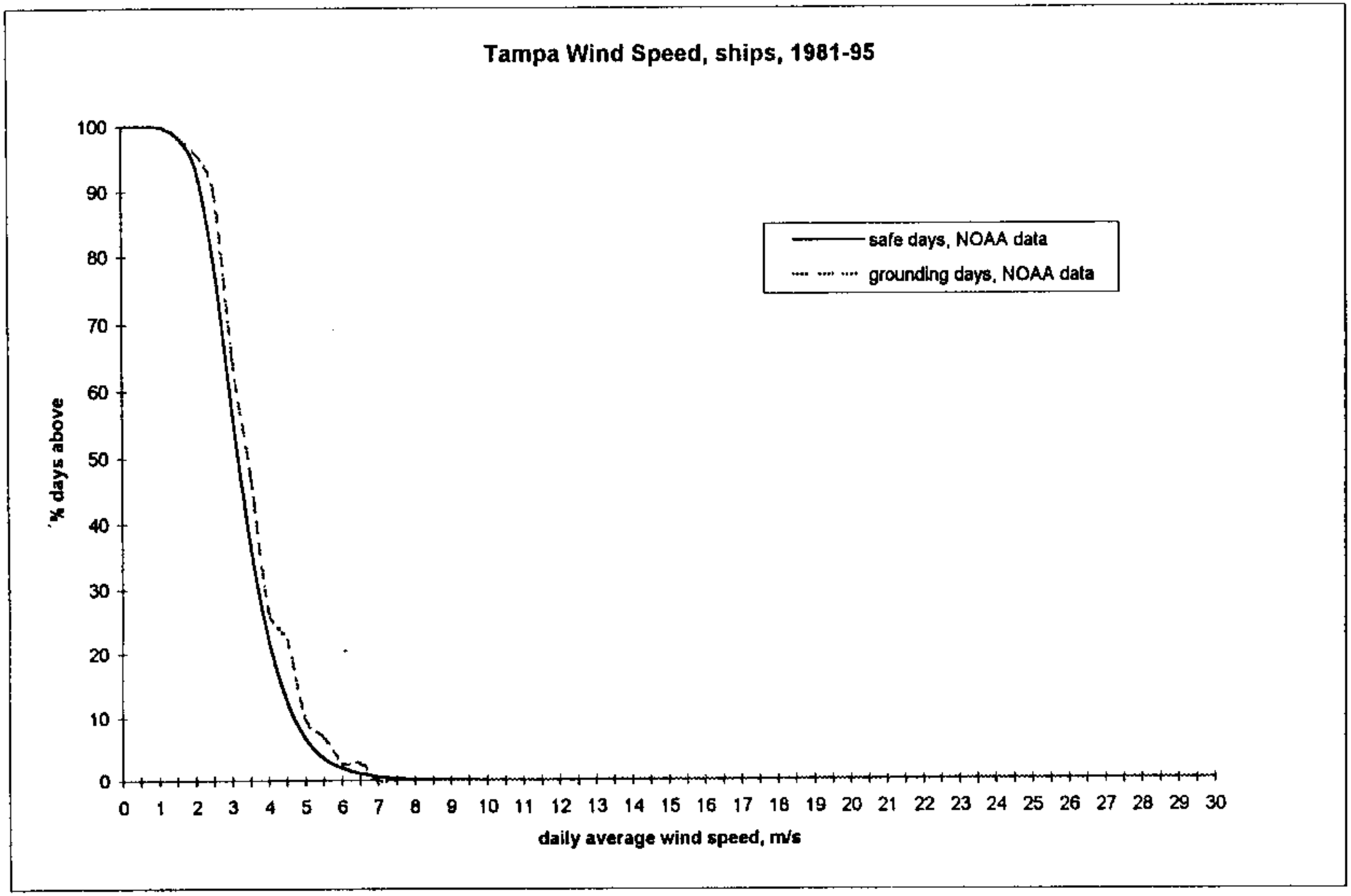
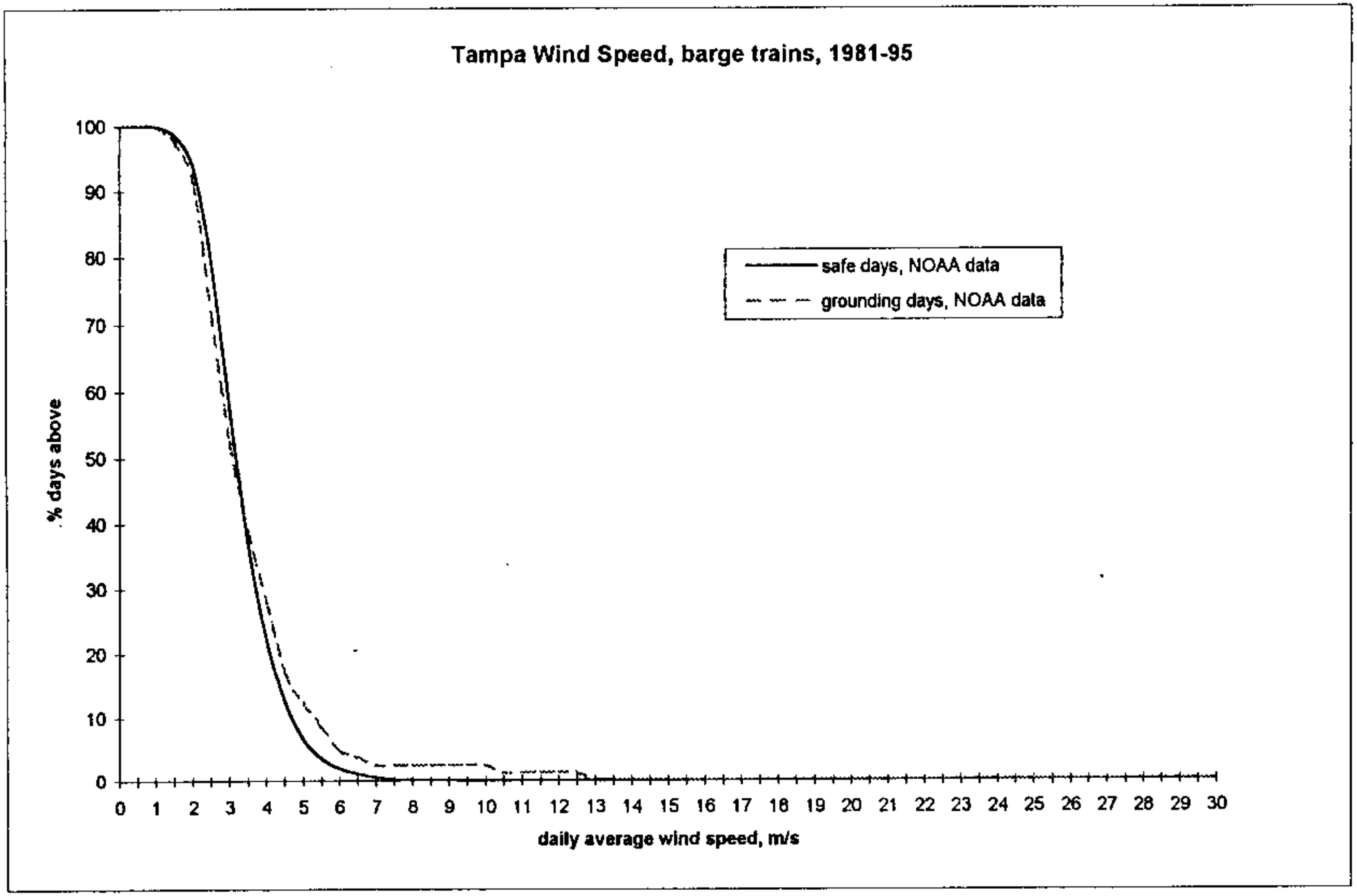
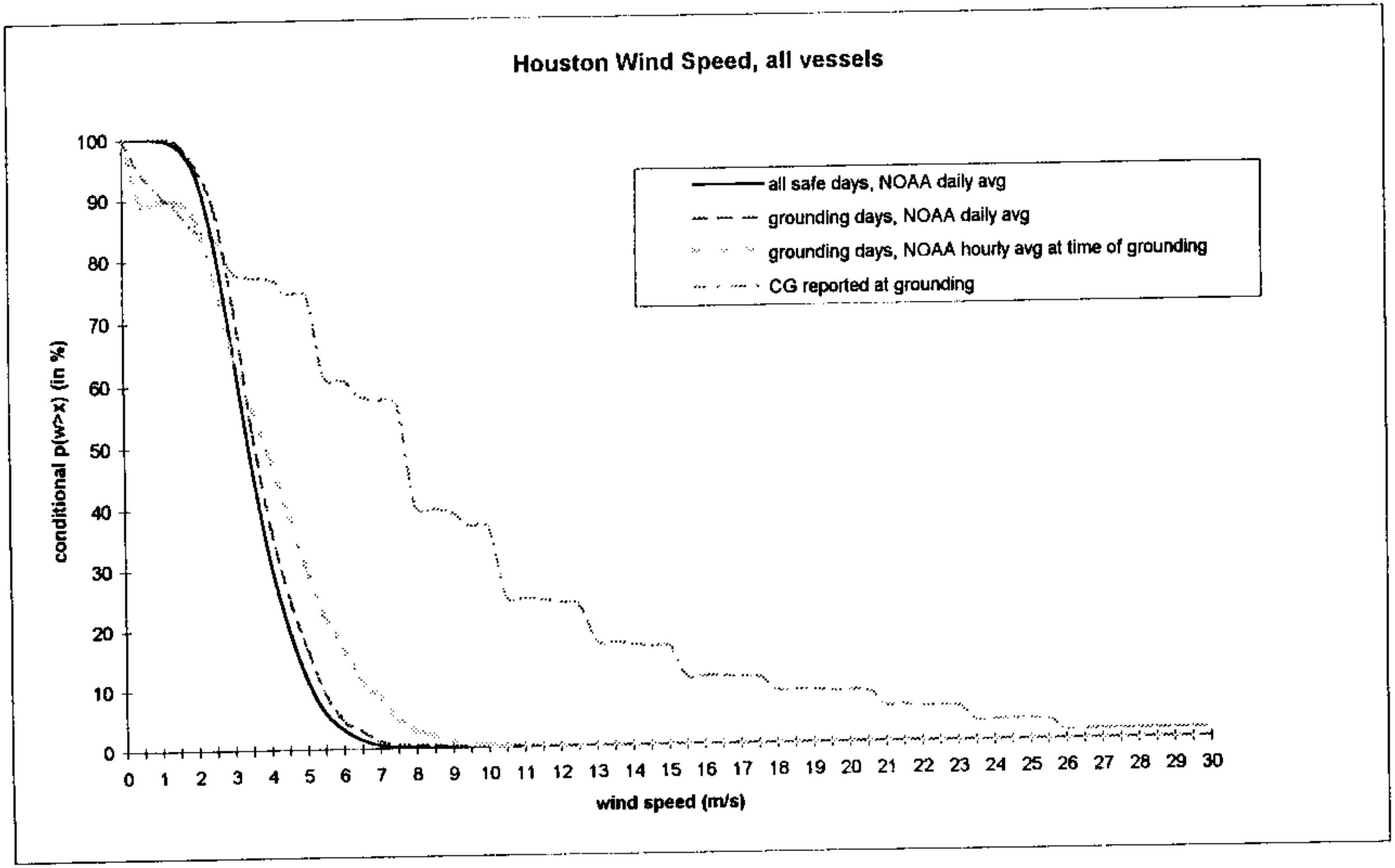

Tampa Wind Speed, ships, 1981-95
safe days, NOAA data
grounding days, NOAA data
% days above
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
daily average wind speed, m/s

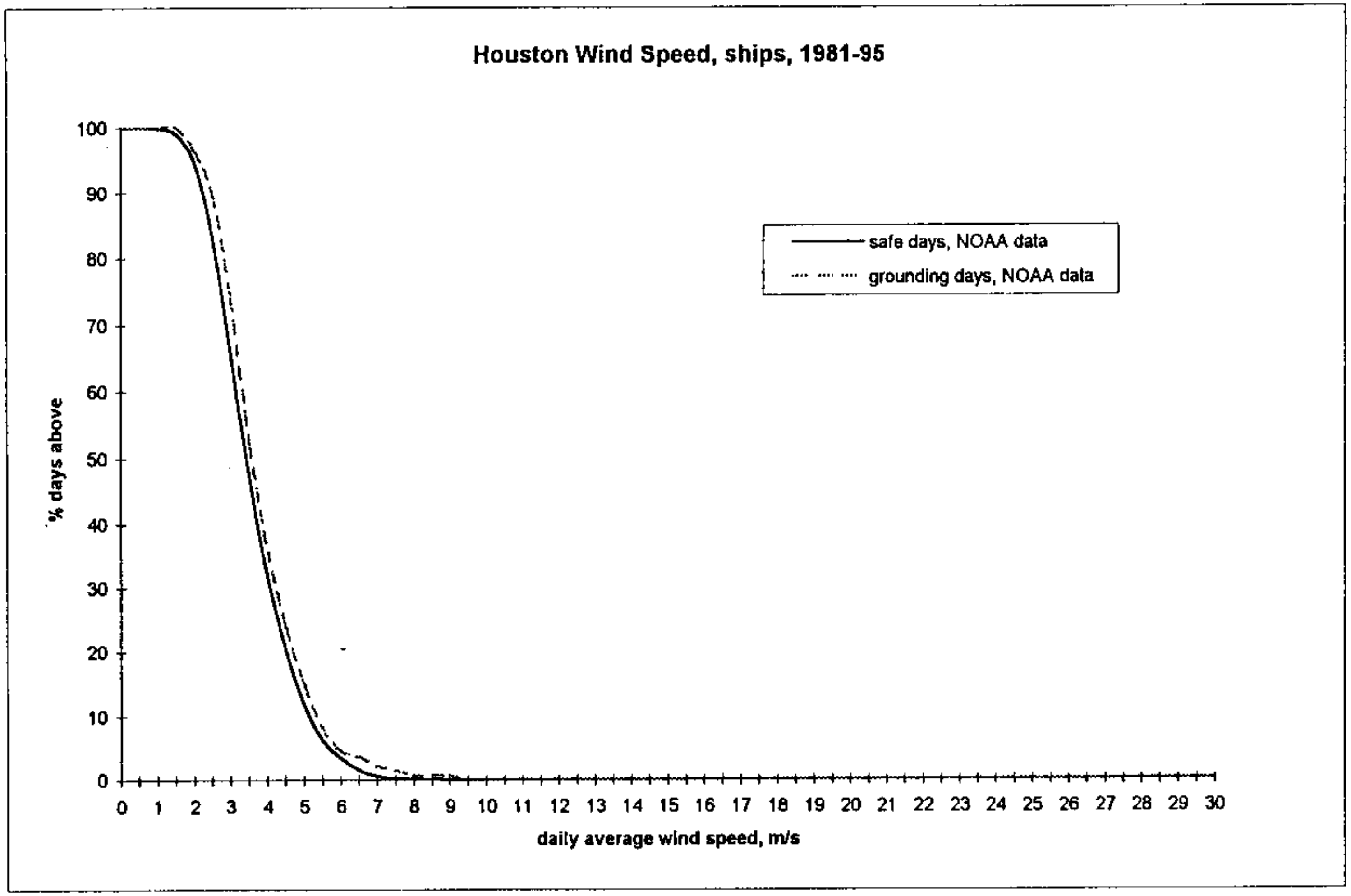
WINCUTS.XLS


Tampa Wind Speed, barge trains, 1981-95

WINCUTS.XLS

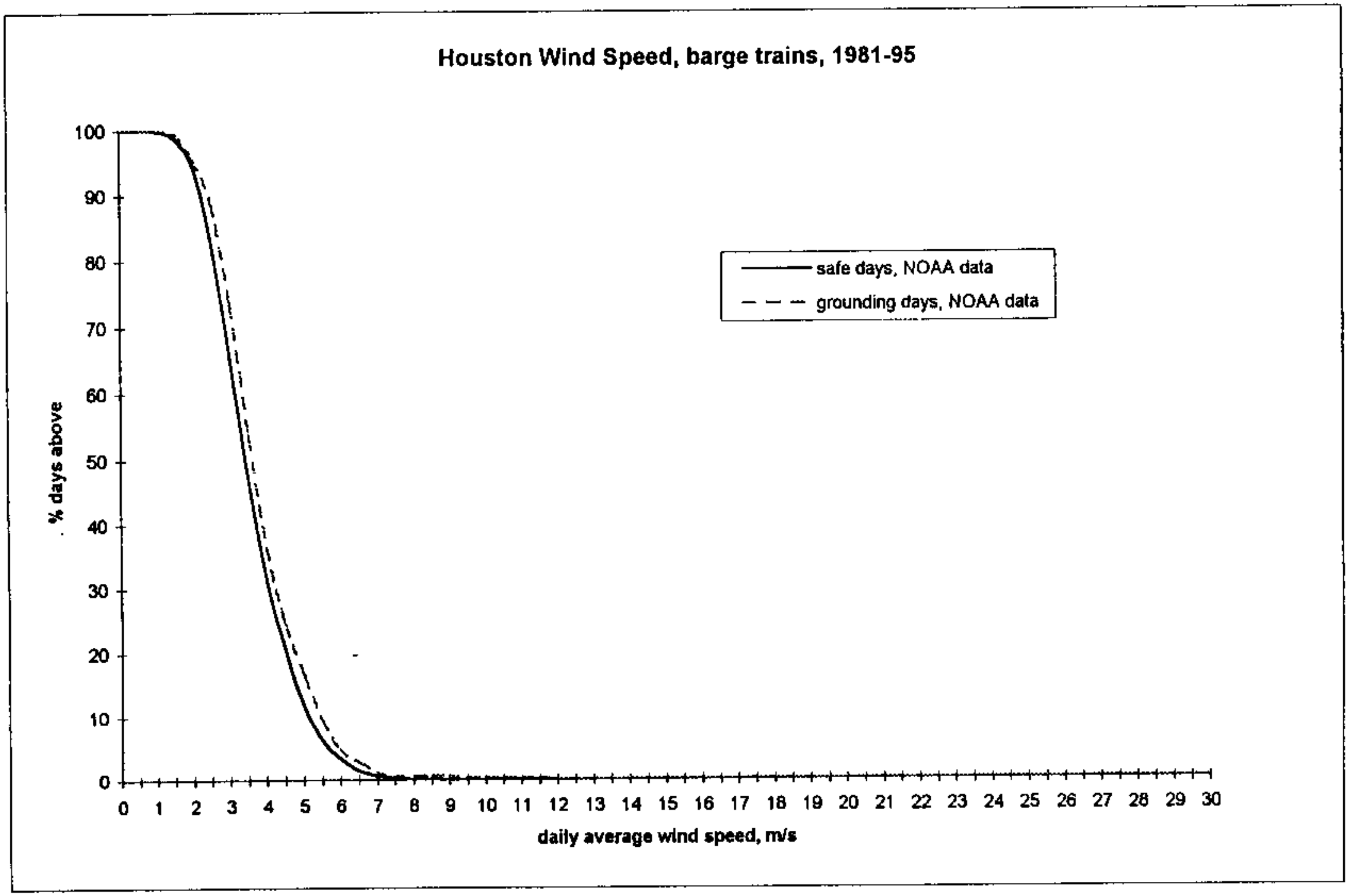


WINCUTSZ.XLS



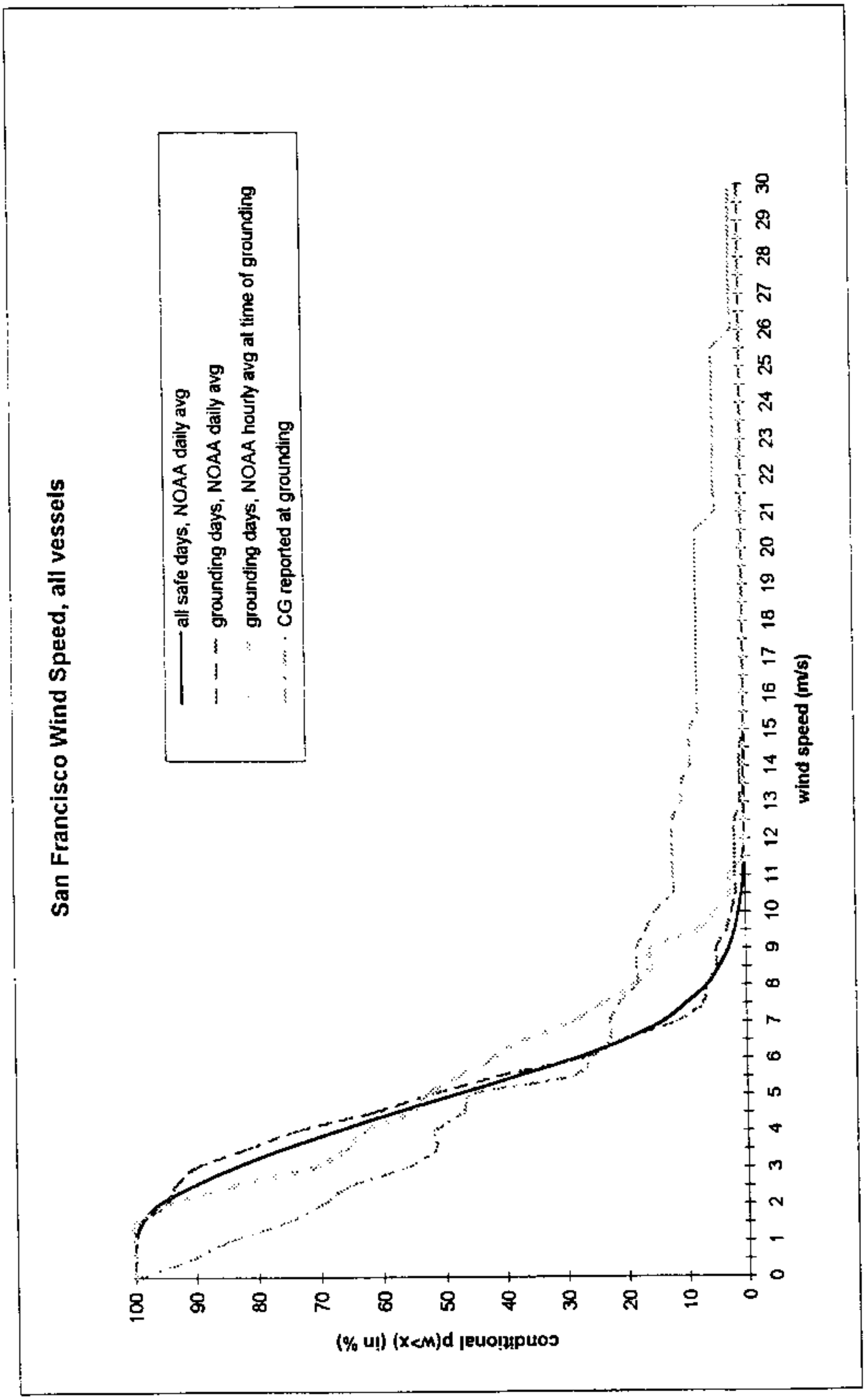
Houston Wind Speed, ships, 1981-95

WINCUTS.XLS

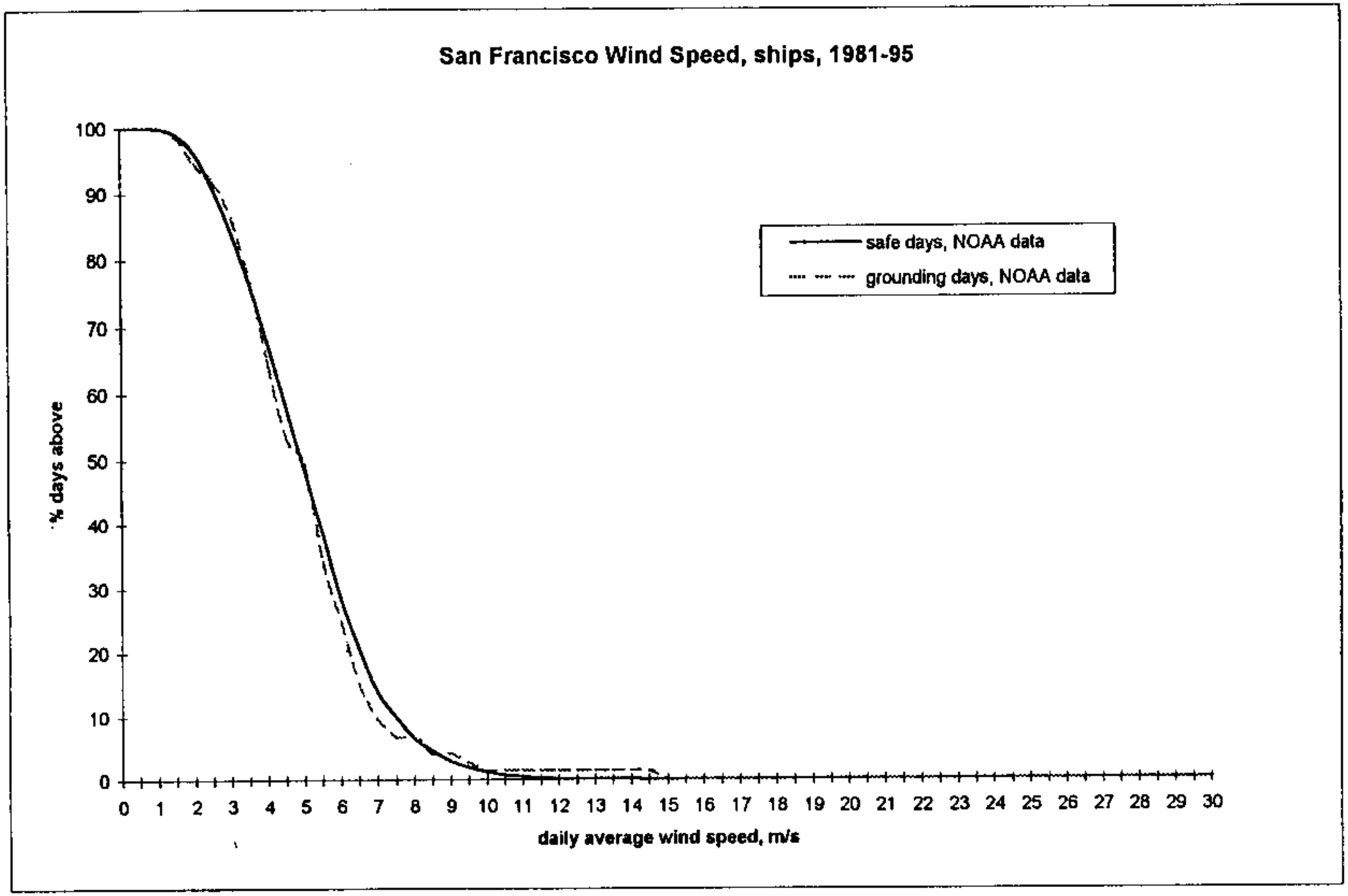


Houston Wind Speed, barge trains, 1981-95

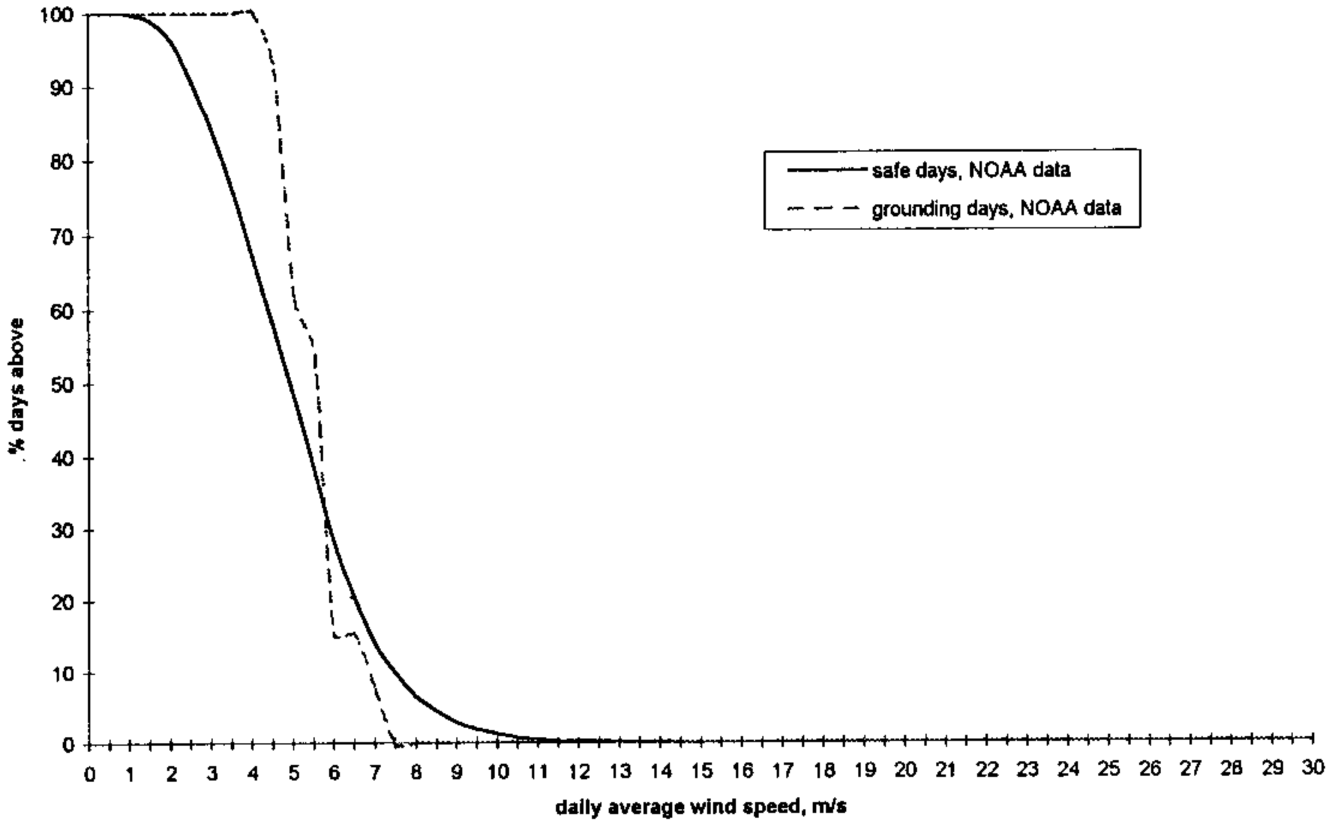
WINCUTS.XLS



WINCUTSZ.XLS


San Francisco Wind Speed, ships, 1981-95

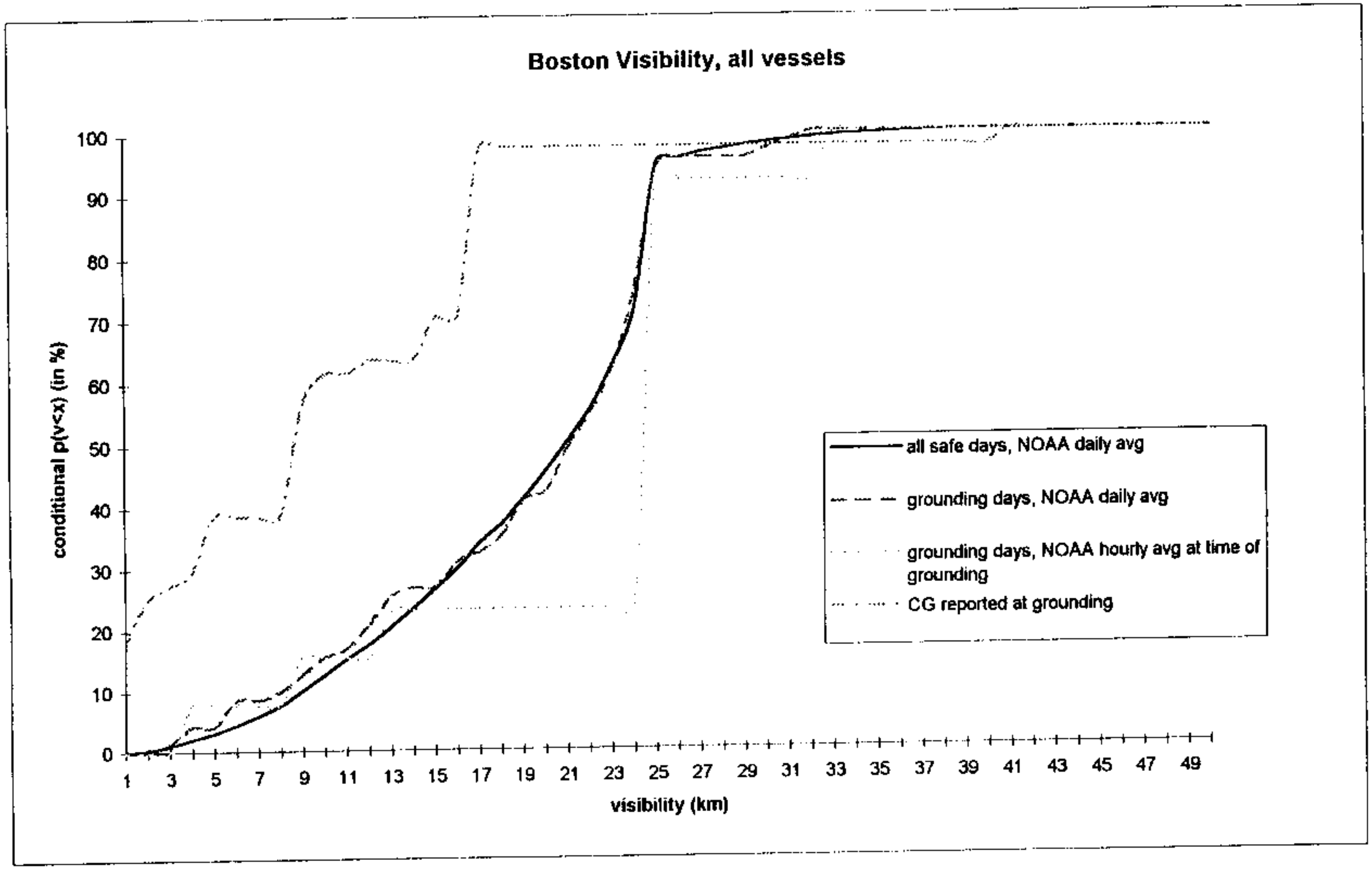
San Francisco Wind Speed, barge trains, 1981-95



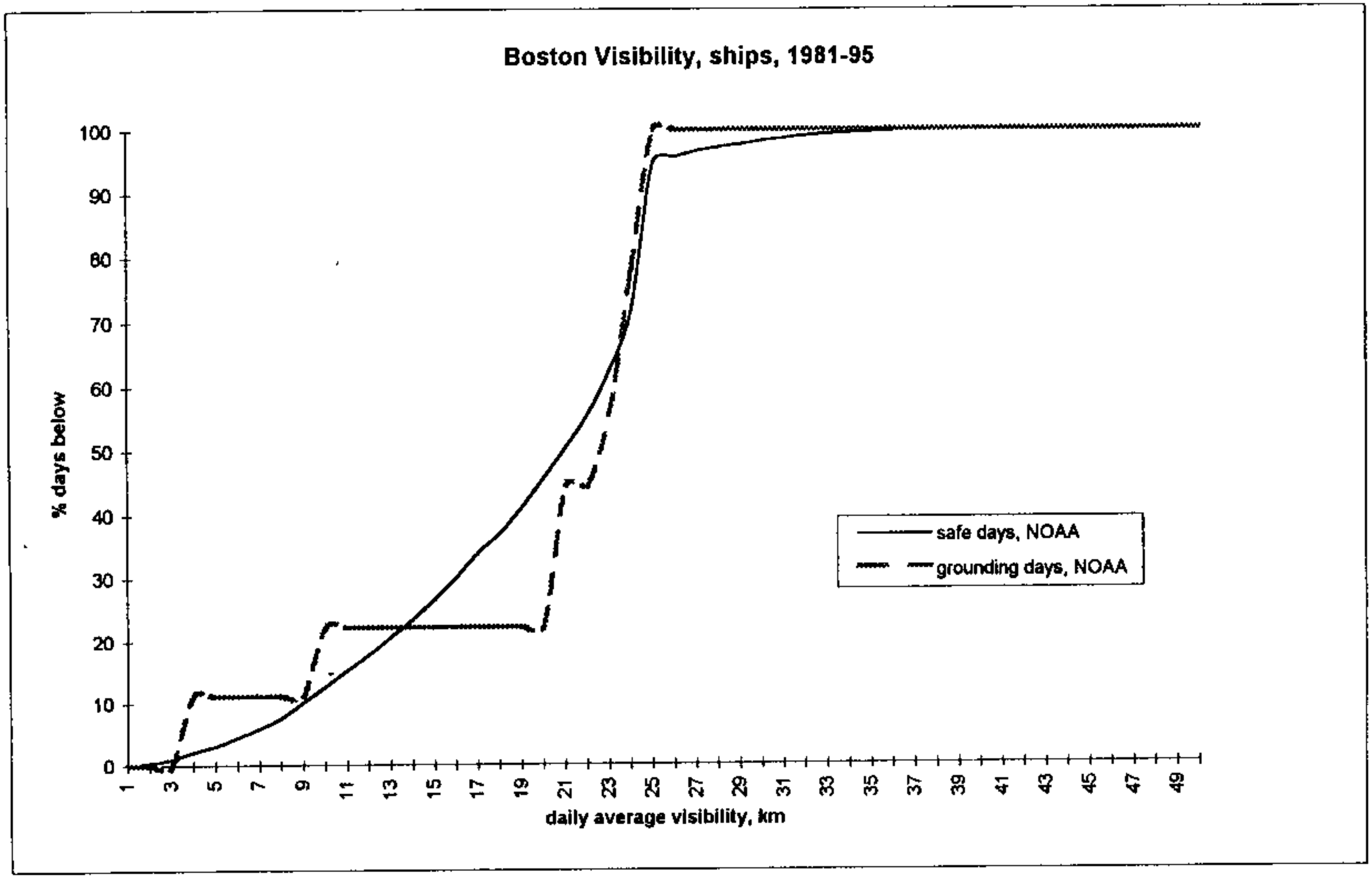
WINCUTS.XLS

APPENDIX 3: VISIBILITY DISTRIBUTION PLOTS

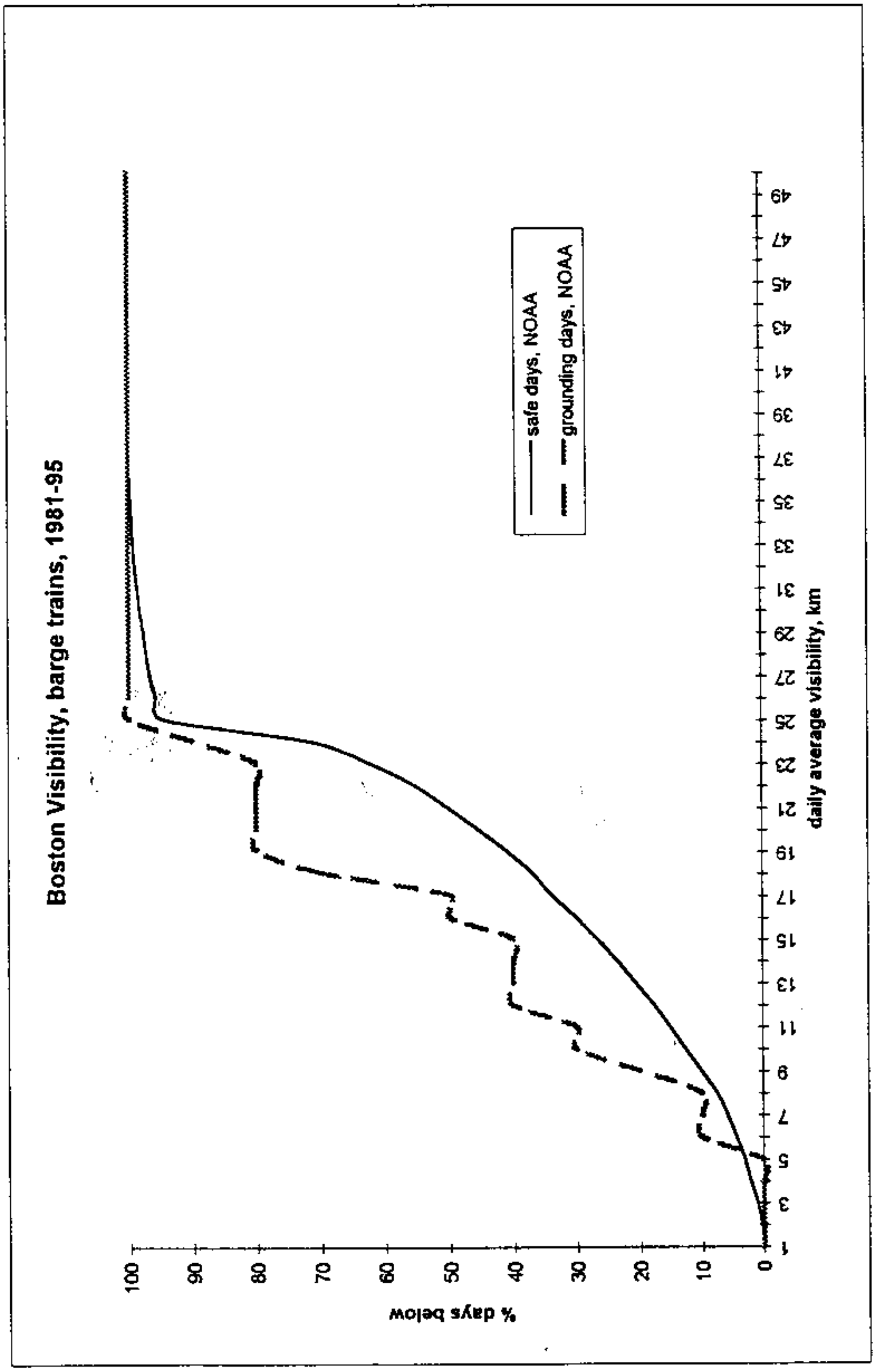
(See discussion in section 6.)

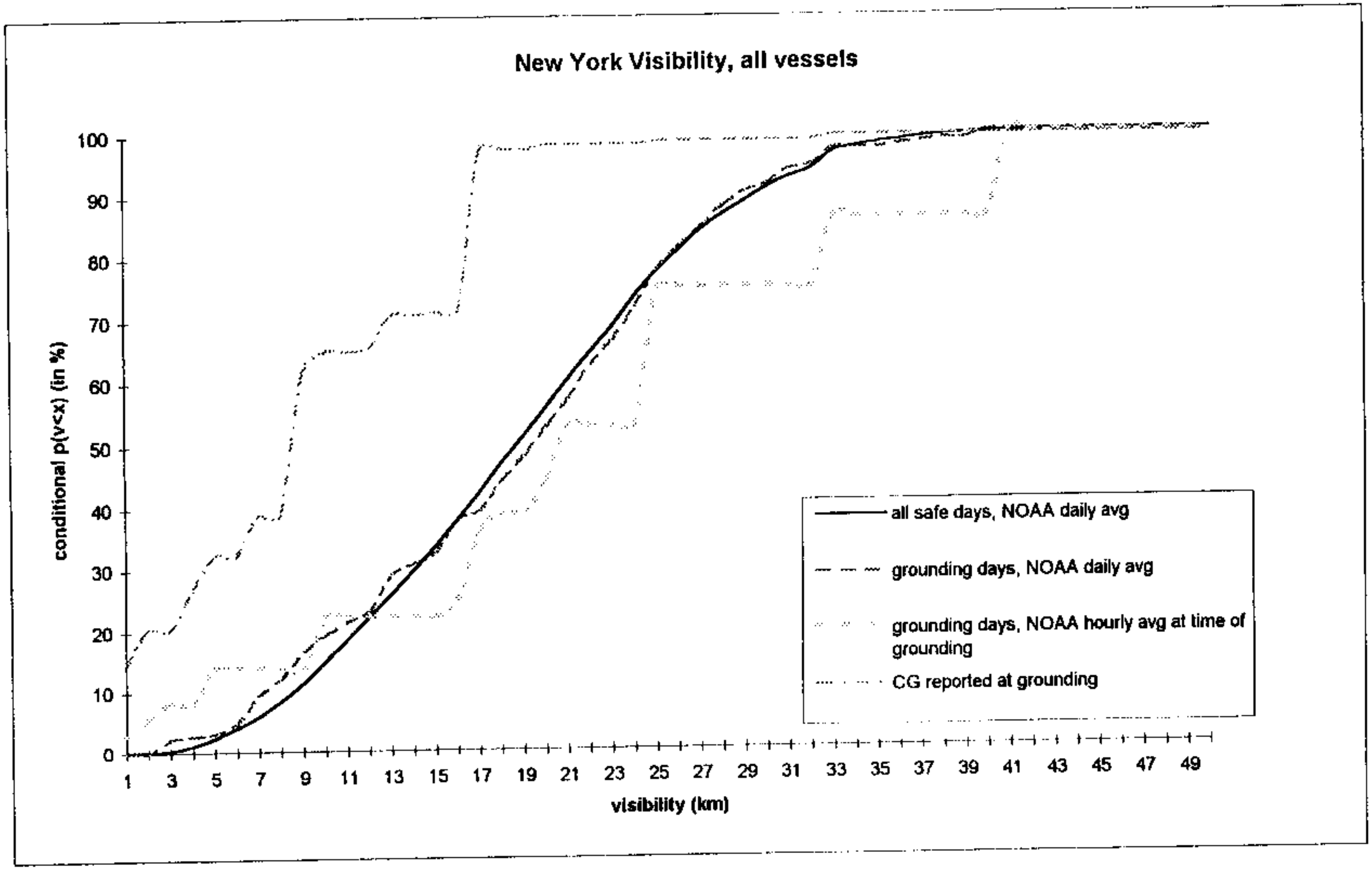


VISCUTSZ.XLS

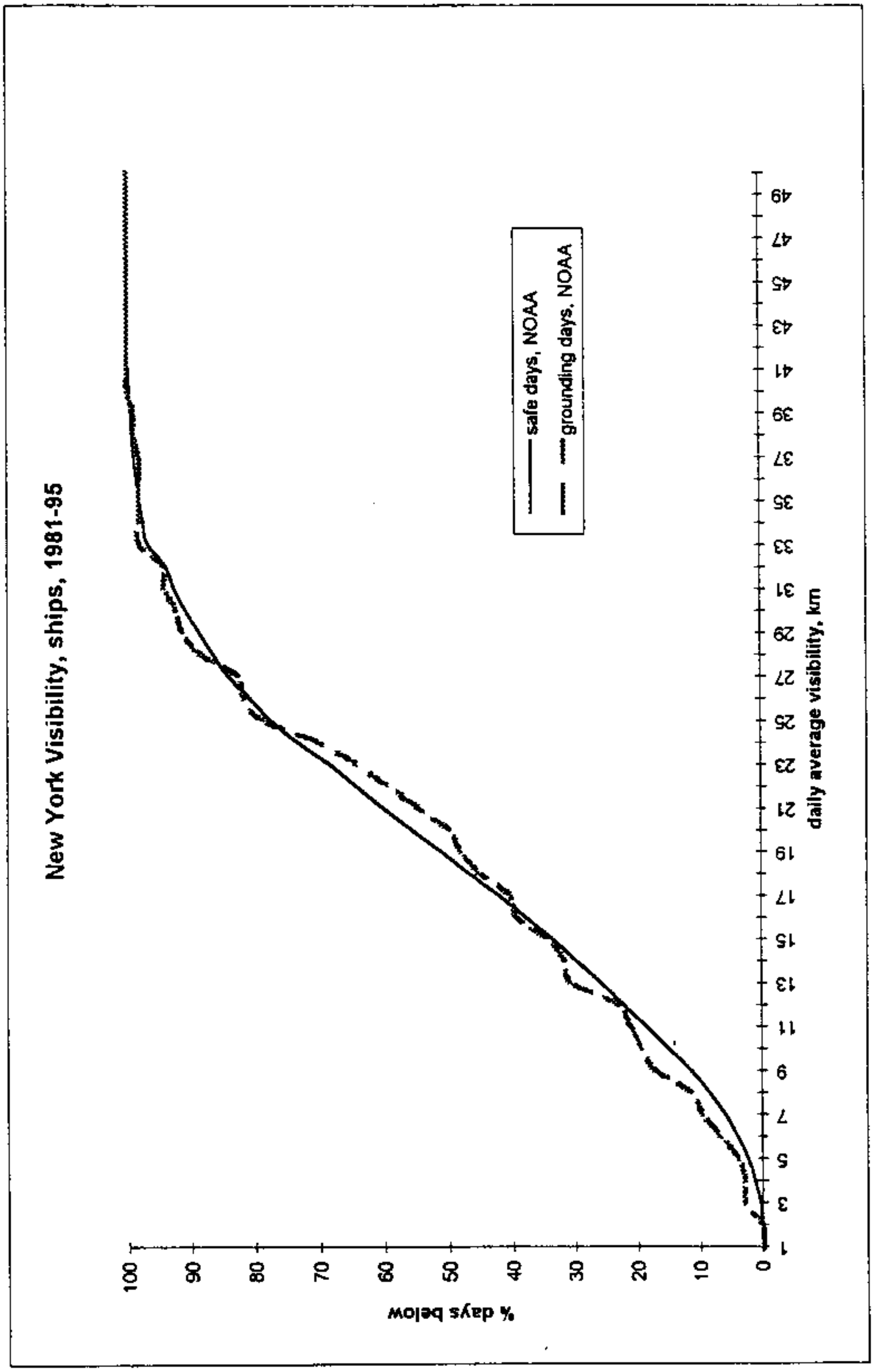


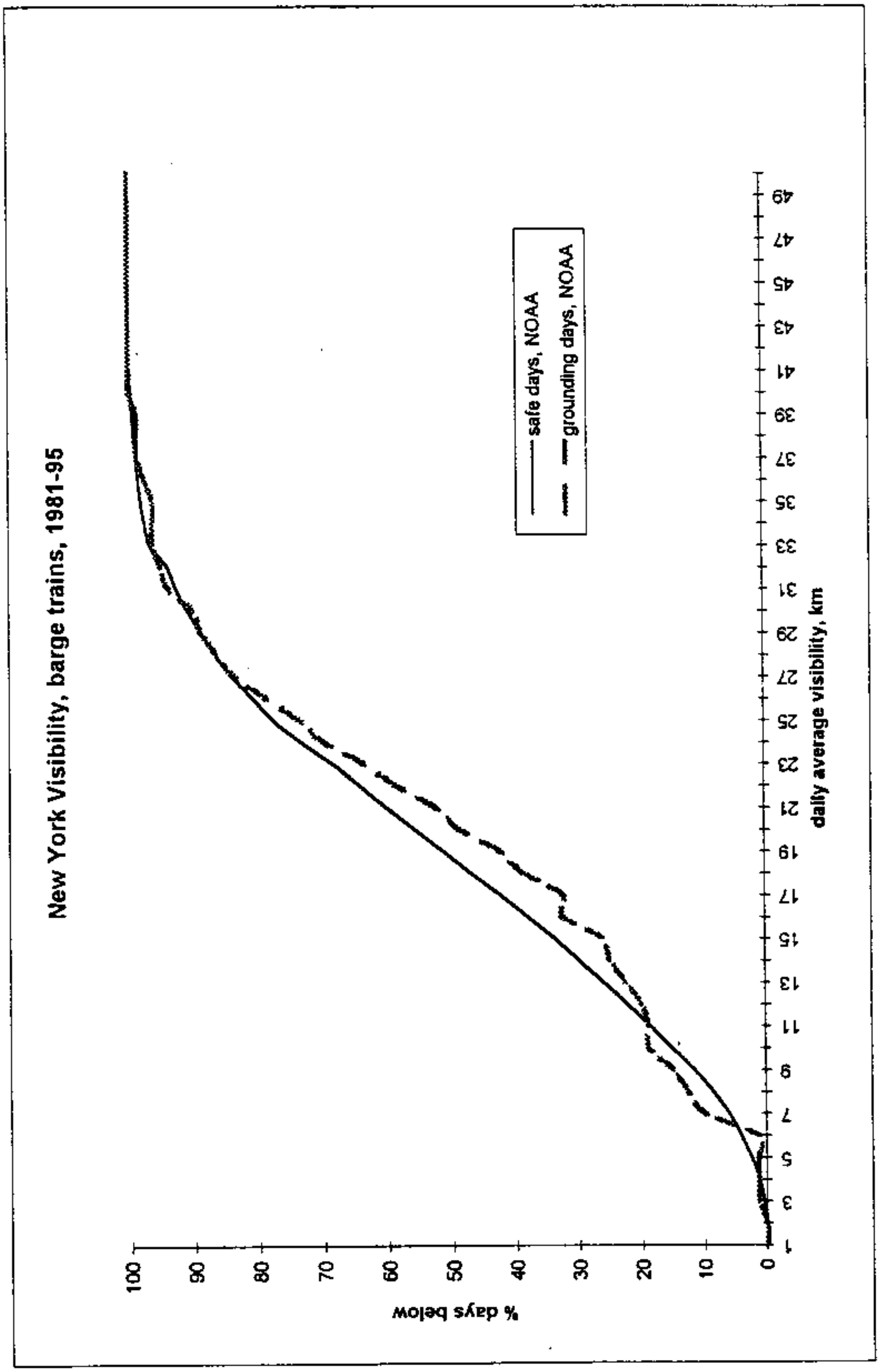
Boston Visibility, ships, 1981-95

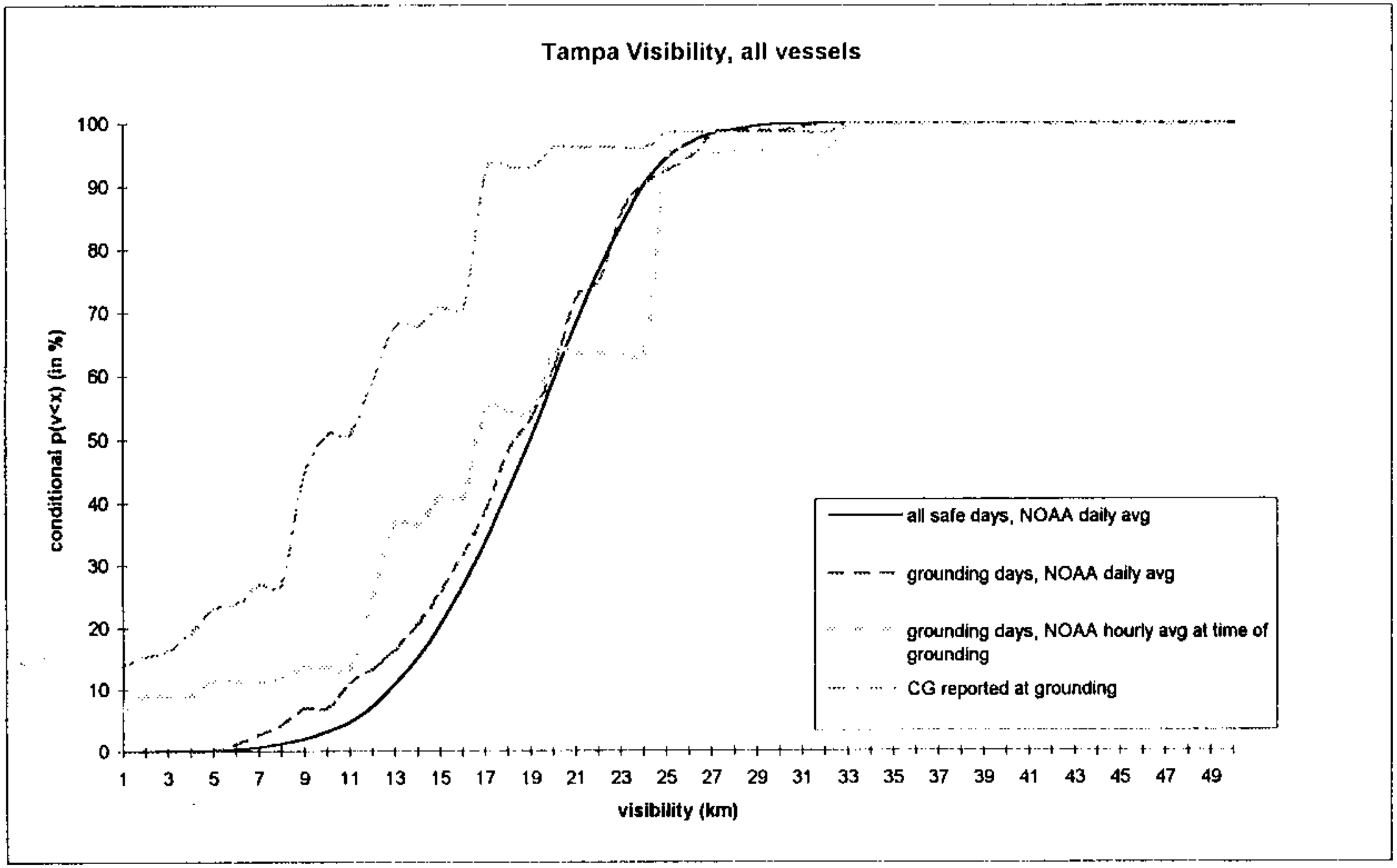

Boston Visibility, barge trains, 1981-95
% days below
0
10
20
30
40
50
60
70
80
90
100
daily average visibility, km
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
safe days, NOAA
grounding days, NOAA



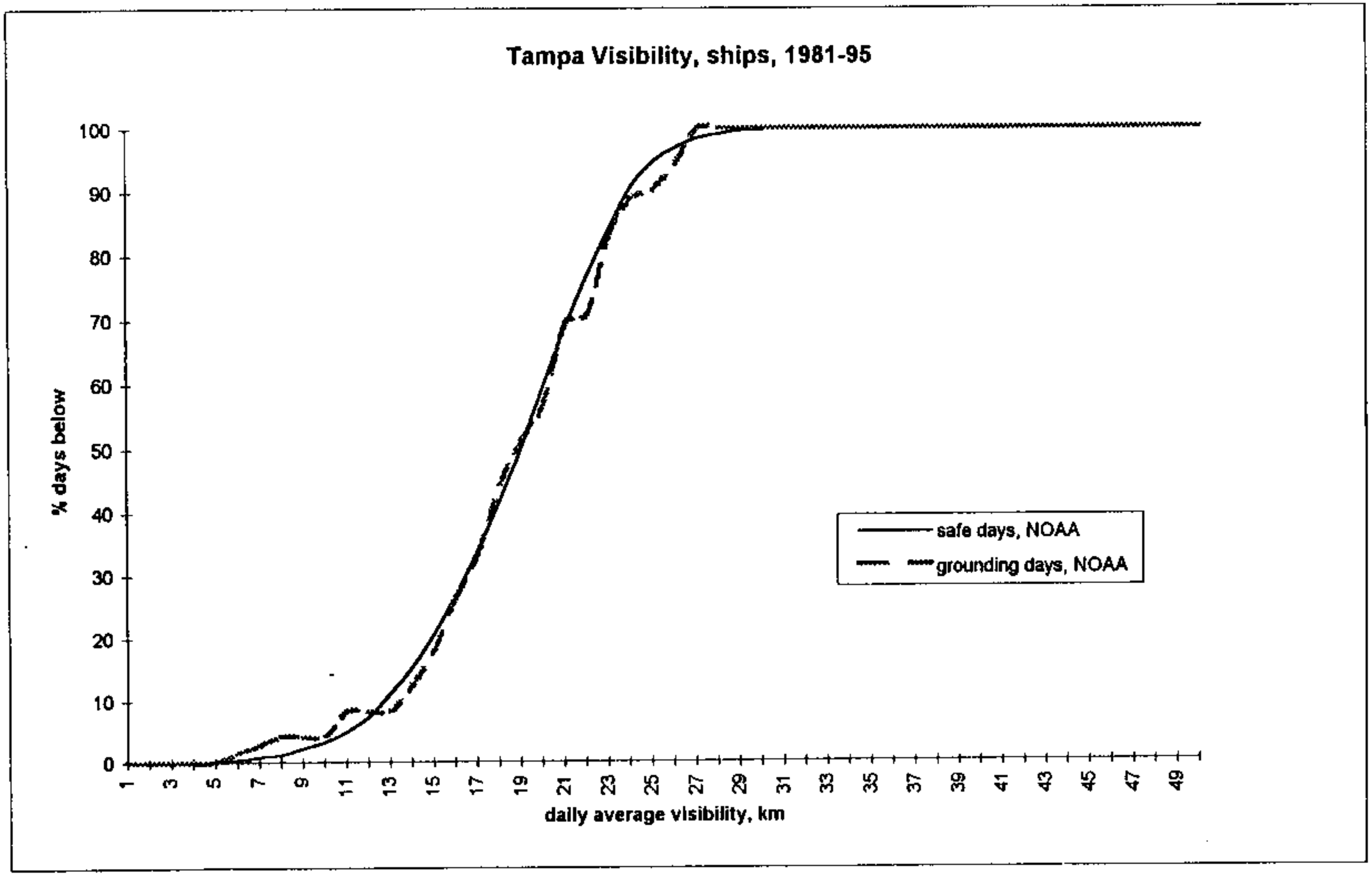
VISCUTSZ.XLS


New York Visibility, ships, 1981-95

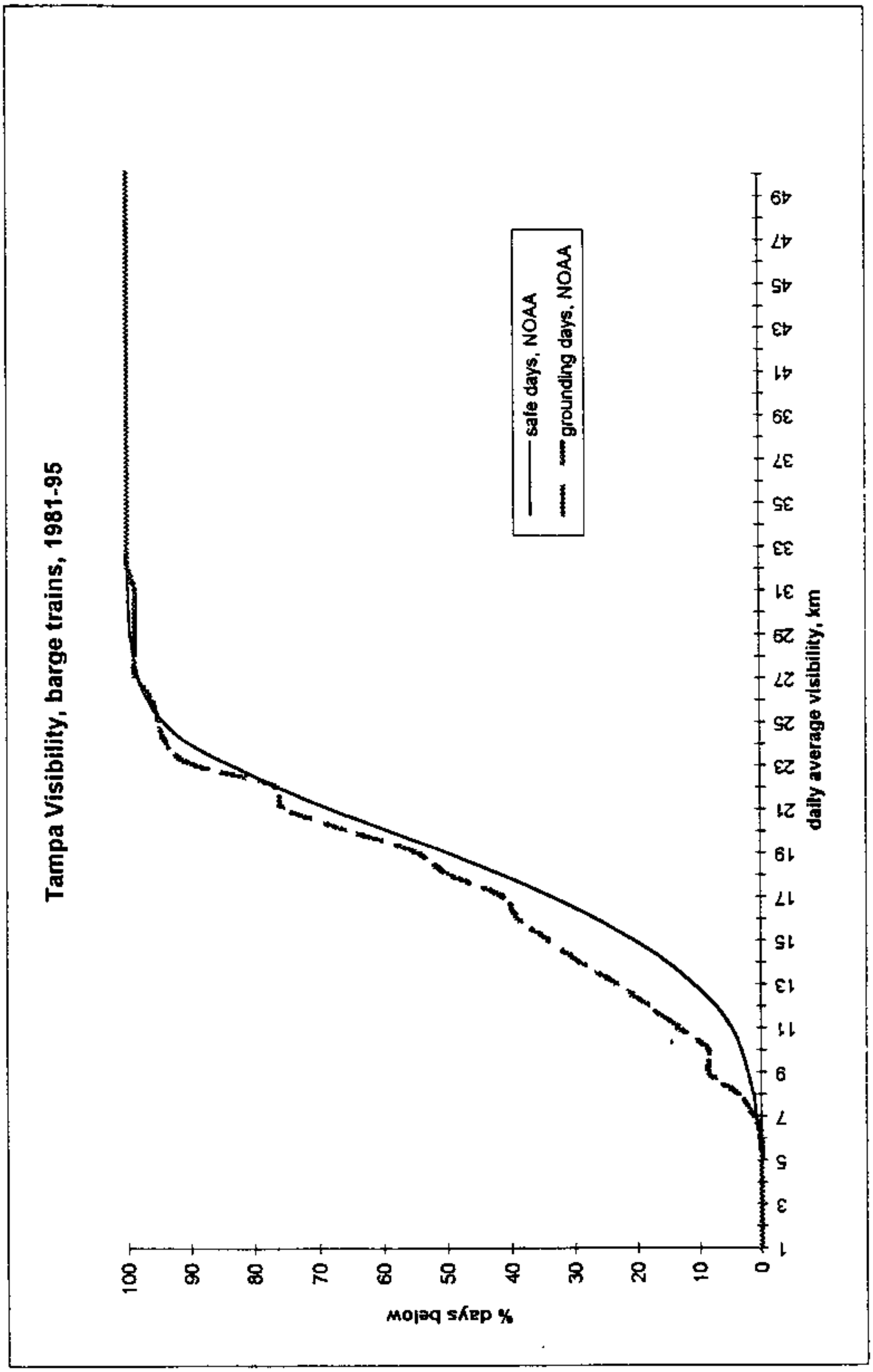

New York Visibility, barge trains, 1981-95
% days below
100
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
daily average visibility, km
safe days, NOAA
grounding days, NOAA

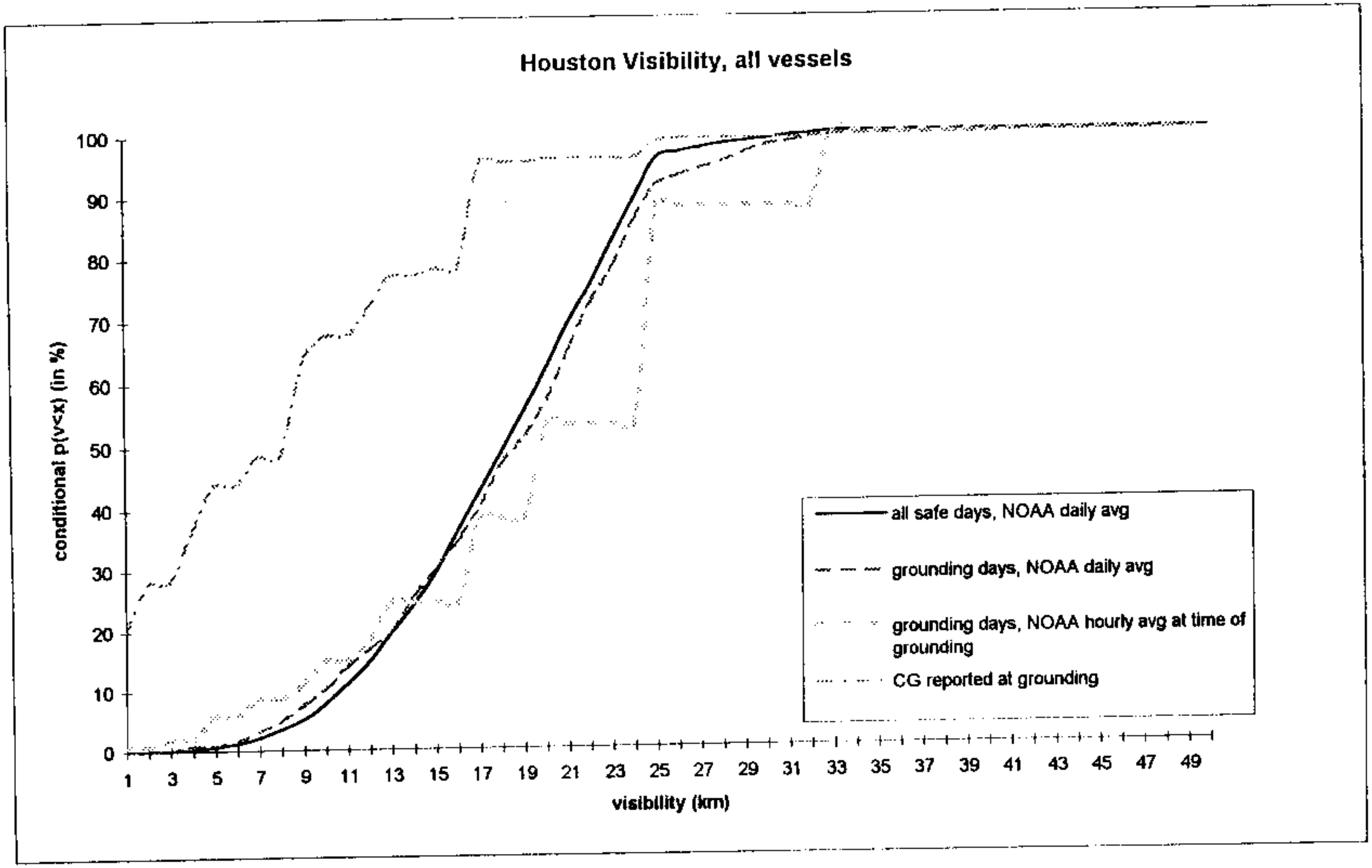

Tampa Visibility, all vessels

VISCUTSZ.XLS

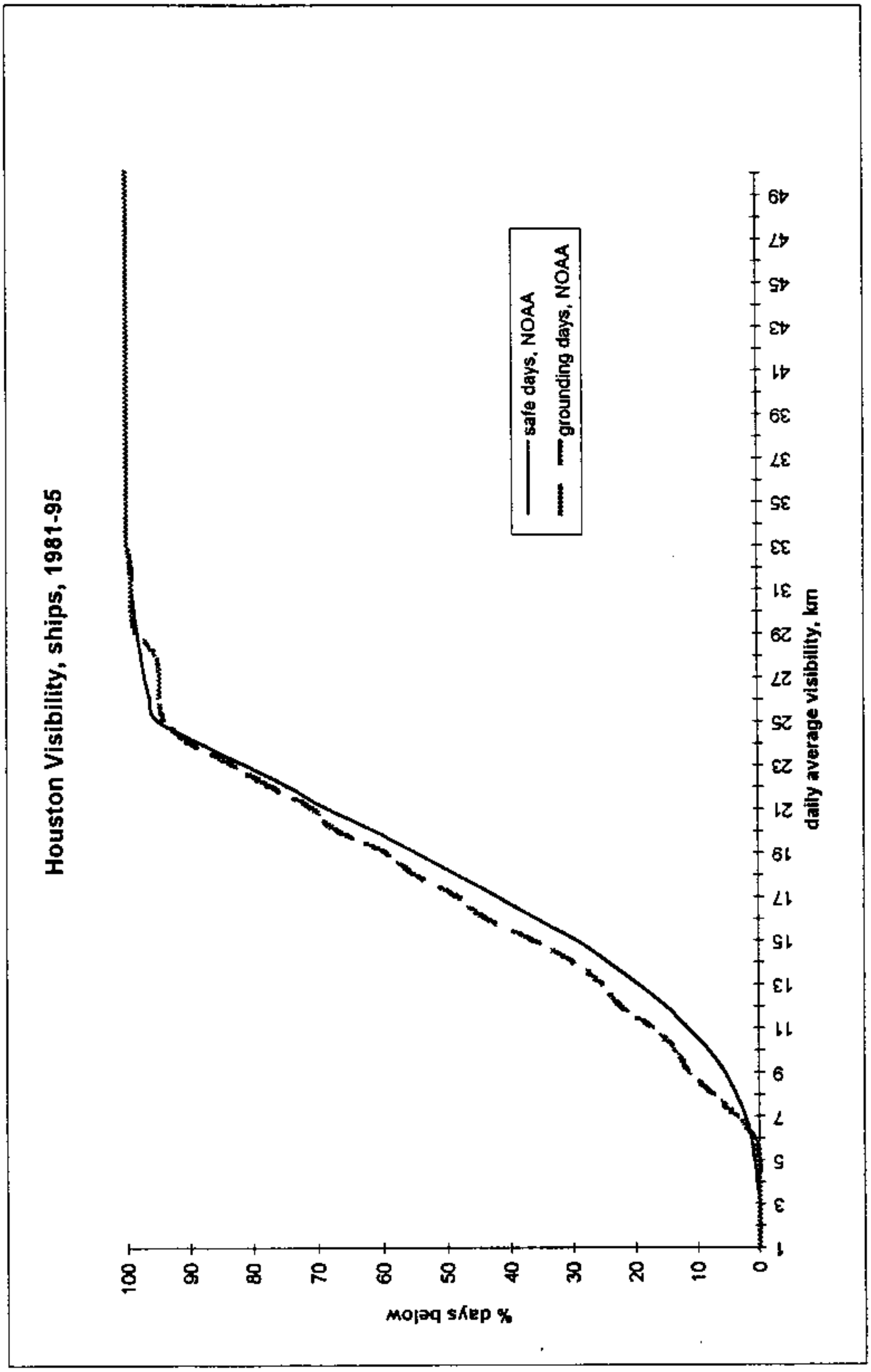


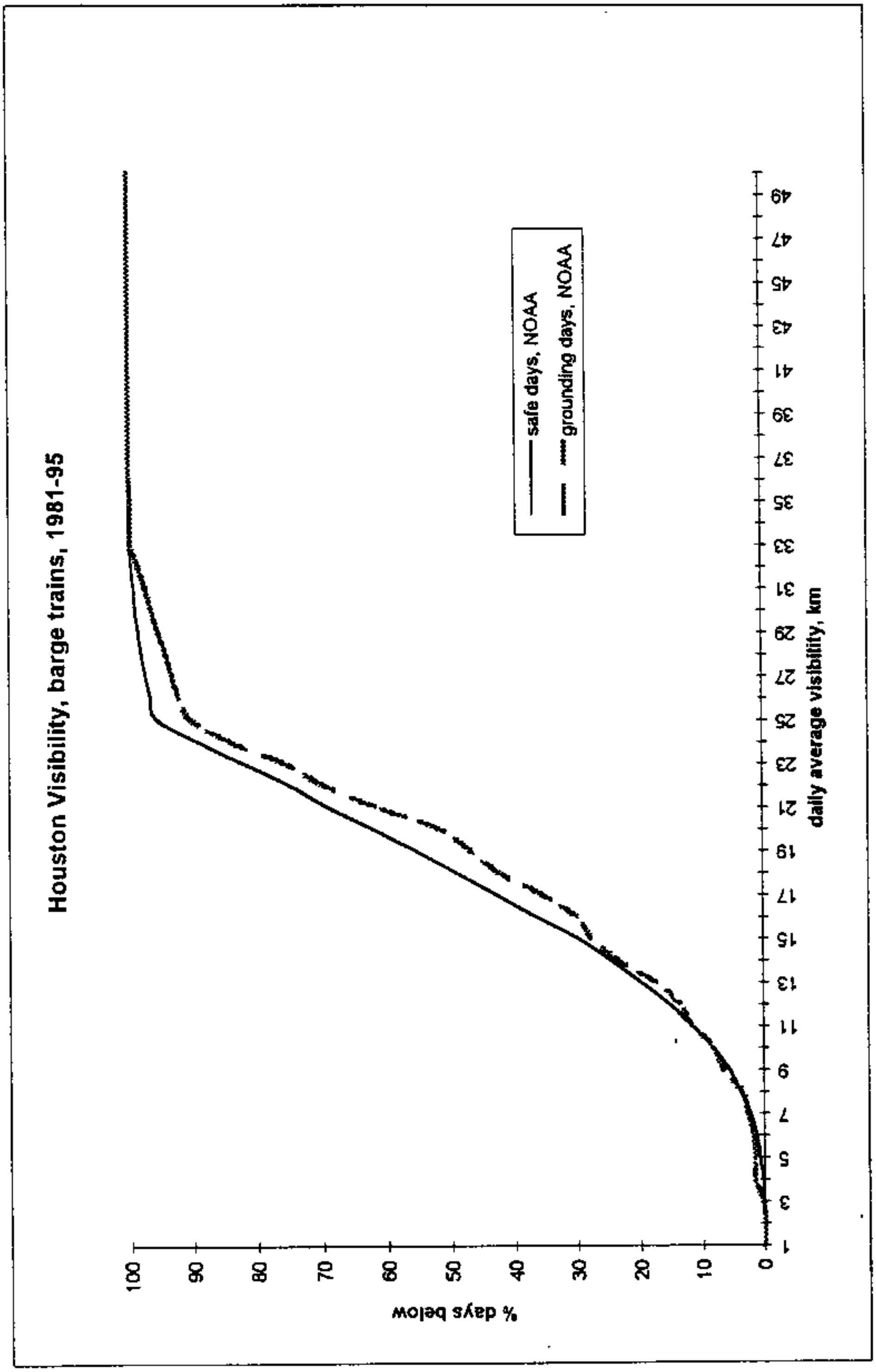
Tampa Visibility, ships, 1981-95


Tampa Visibility, barge trains, 1981-95
safe days, NOAA
grounding days, NOAA
% days below
100
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
daily average visibility, km



VISCUTSZ.XLS


Houston Visibility, ships, 1981-95
safe days, NOAA
grounding days, NOAA
% days below
100
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
daily average visibility, km


Houston Visibility, barge trains, 1981-95
% days below
100
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
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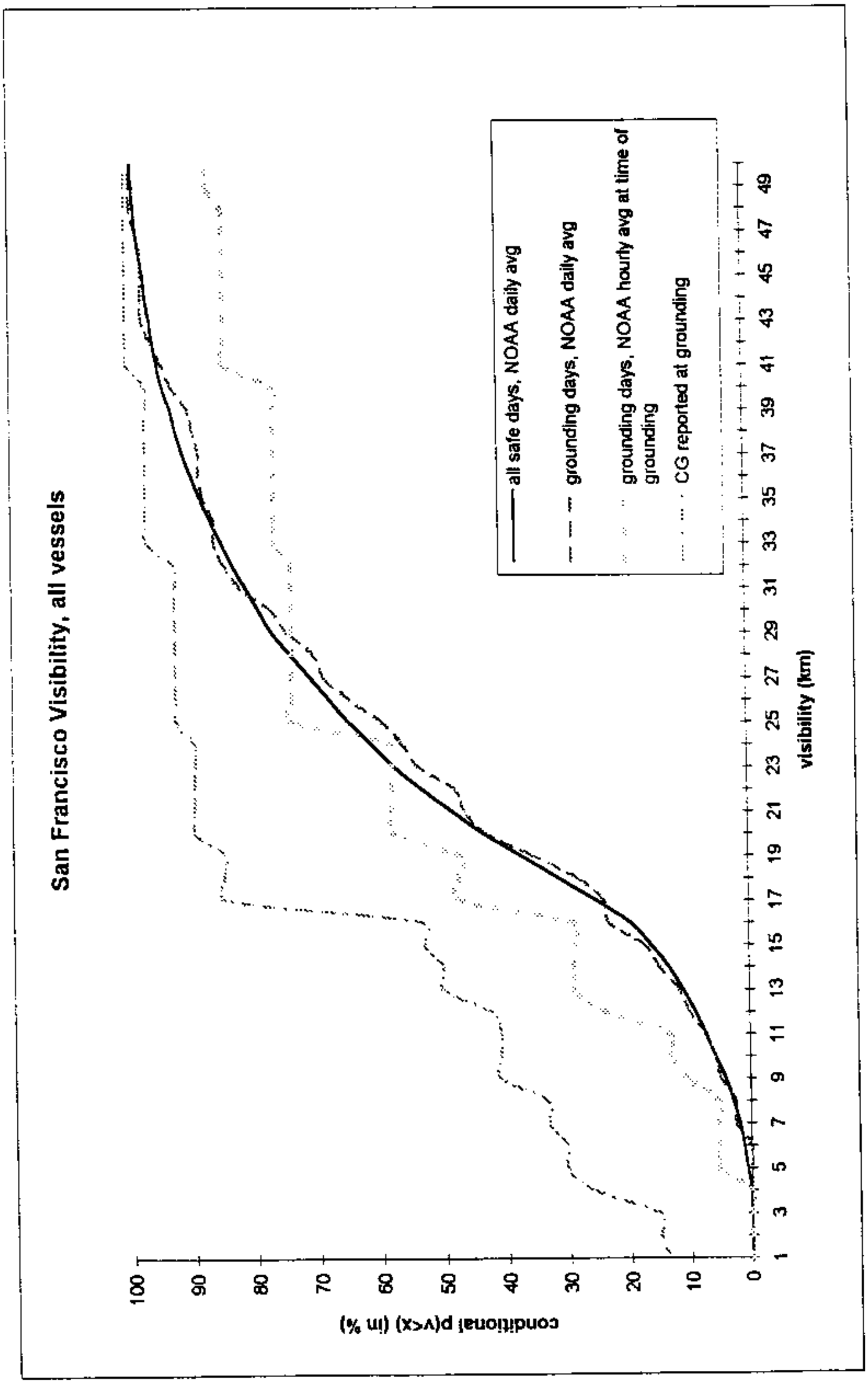
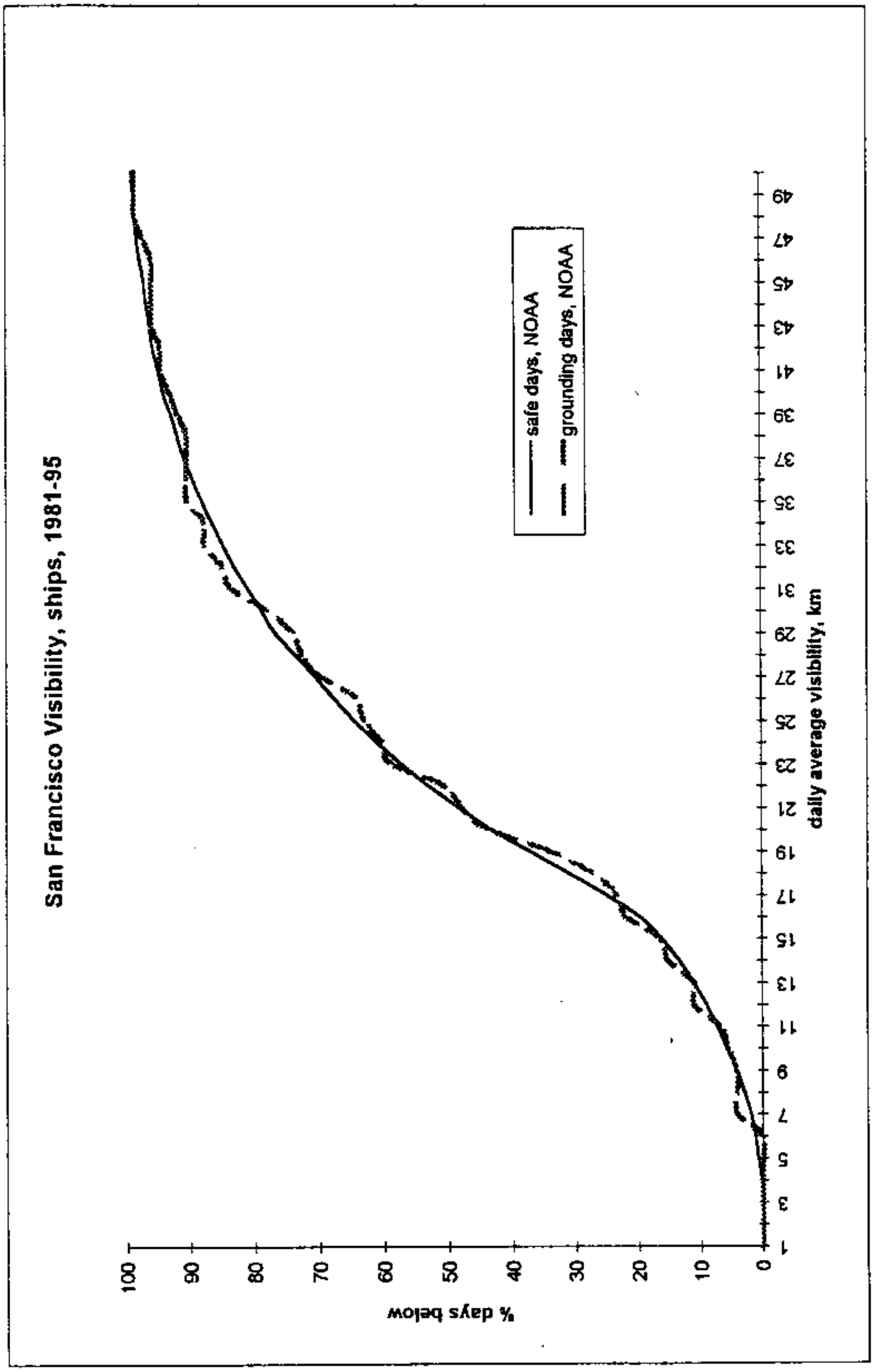
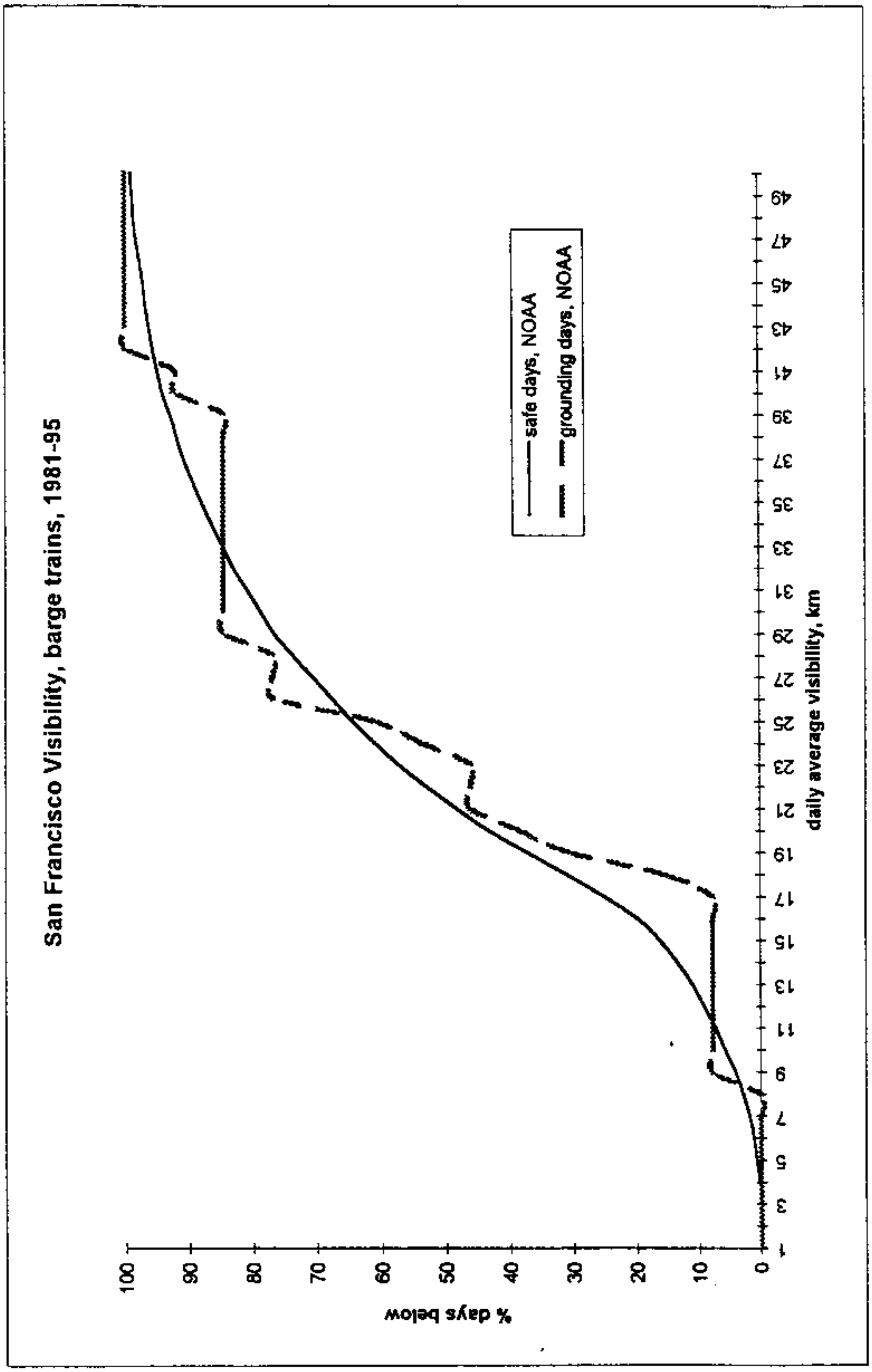
37
39
41
43
45
47
49
daily average visibility, km
safe days, NOAA
grounding days, NOAA



VISCUTSZ.XLS



San Francisco Visibility, ships, 1981-95



San Francisco Visibility, barge trains, 1981-95