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A Study of Increased Flow Off the Eastern Seaboard of the United States Within Four Synoptic Flow Patterns During the Winter Months

John Dale Liechty
Old Dominion University

A STUDY OF INCREASED FLOW OFF THE EASTERN SEABOARD
OF THE UNITED STATES WITHIN FOUR SYNOPTIC FLOW PATTERNS
DURING THE WINTER MONTHS

by

John Dale Liechty
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James E. Smith (Director)

ABSTRACT

A STUDY OF INCREASED WIND FLOW
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DURING THE WINTER MONTHS

John Dale Liechty
Old Dominion University, 1983
Director: James E. Smith

A study of increased winds during the winter season off the United States Eastern Seaboard was made in each of four synoptic flow patterns: prefrontal; postfrontal; northeast; and southerly. Eight years of synoptic data for the months October through March from two pairs of stations were utilized. Each pair consisted of one land and one sea station; of the sea stations, Frying Pan Light was located in or near the warmer water of the Gulf Stream while Chesapeake Light was situated in colder, coastal water. Both land stations were situated in the vicinity of the coast.

A statistical analysis was made of the following data: mean monthly frequency of occurrences; mean monthly duration of occurrences; mean monthly sea surface temperatures; mean monthly air-sea temperature differences; mean monthly maximum wind speeds; mean monthly sea-land wind

speed differences; percentage breakdown in categories of the mean monthly maximum wind speeds; and the absolute maximum and mean monthly durations of mean maximum wind speed categories.

The results of the data analysis indicated that, in general, wind speeds and the durations of the occurrences were greater at Wilmington/Frying Pan Light, where the water temperature was warmer, than at Norfolk/Chesapeake Light.

ACKNOWLEDGEMENTS

I would like to expess my appreciation to the members of my committee, Col. James Smith, Director, Dr. Earl Kindle, and Dr. John Zack for their support during the writing of this paper. During the previous three and a half years, Dr. Earl Kindle, has been my faculty advisor, and without his help, faith, and guidence, the successful completion of this degree would not have been a reality.

I would like to acknowledge the efforts of the many previous, unnamed students who compiled the data which I used in this thesis, and to Mr. Herman Wobus, through whose technical expertise, massaged the data into a meaningful and useful format.

Without the help of the following officers at the Naval Eastern Oceanography Center, Norfolk, Va., I would not have been able to attend the classes necessary for the completion of this degree: Cdr. Thomas Fraim; Cdr. Thomas Upton; Lcdr. Gordon Bellemer; and Lcdr. John Hughes; thank you, gentlemen. A special thank you is for Mrs. Patti Moisant, for instructing me on the use of the command's word processor, without which this thesis could not have been typed.

To the memory of my father, Dr. John D. Liechty, I express my deepest appreciation for the inspiration he provided to me throughout my life.

Finally, and certainly most important, to my wife, Nancy, and daughter, Lora, for their ultimate understanding, love, devotion, and encouragement. I can say that without you both, I could not have done it. Thank you.

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I. INTRODUCTION

During the autumn and winter months along the east coast of the United States, observed wind speeds offshore are generally greater than those over land. This has been observed for many years, however very few, if any, statistical, climatological studies of this phenomenon exist.

A. Background

A majority of investigators concerned themselves with measurements in the transfer of energy and mass during air-sea interaction. Henry and Thompson (1978) examined the heat flux density in return flow from a cold core high pressure system over the warmer water of the East China Sea. Kondo (1976) also studied transfers of heat and momentum for the East China Sea and adjacent waters during the winter. Agee and Howley (1977) calculated latent and sensible heat fluxes at the air-sea interface.

Some work has been done to examine coastal and offshore flow, but on a smaller scale. SethuRaman and Raynor (1980) conducted observations over coastal Long Island out to five kilometers in the Atlantic Ocean to study the effects of roughness and fetch on wind speeds over the water as compared to over the beach. They found that winds were 15-100% stronger over the water. Raynor (et. al., 1979) examined the coastal internal boundary layer, again over Long Island, measuring turbulence and temperature during onshore flow. The results showed that the wind speeds within the air mass over land were approximately 70% of those at the coast with turbulence levels being several times greater near the surface and above.

Lenschow (1973) conducted two experiments over the Great Lakes in late autumn while the water temperature was still relatively warm. His goal was to determine the amount of air mass modification by comparing upwind station measurements with those downwind. The comparisons included observations of vertical velocities, sensible and latent heat fluxes, and the amount of liquid water in the cloud layer just below the top of the mixed layer. His results showed that considerable modification to the air mass took place as seen by the increases in upward fluxes of heat, moisture, and momentum.

Sweet (et. al., 1981) observed significant changes in low-level wind speeds, sea state (roughness), and the distribution of low-level air temperature and moisture on on either side of the north wall (or edge) of the Gulf Stream. From the data collected, these changes appeared to be the result of differences in atmospheric turbulence caused by the increased air-sea temperature differences on the Gulf Stream side of the boundary.

Smith and Kindle (1976) developed a statistical approach in classifying increased wind speed occurrences off the eastern seaboard of the United States but were primarily concerned with cold, postfrontal flow patterns.

Numerous attempts at modeling this phenomenon have been undertaken, i.e., Taylor (1970), Pond (1972), Kindle (et. al., 1976), and Piccolo (1981) with varying, but generally good results. These results are beyond the scope of this paper as the goal here is to present a climatological base in studying increased wind flow off the east coast of the United States.

B. Purpose

The objective of this thesis is to examine increased wind speed occurrences within four distinct synoptic flow patterns: prefrontal; postfrontal; northeast; and southerly. A determination will be made as to which area or flow pattern experiences greater increases in occurrences, occurrence durations, and wind speeds.

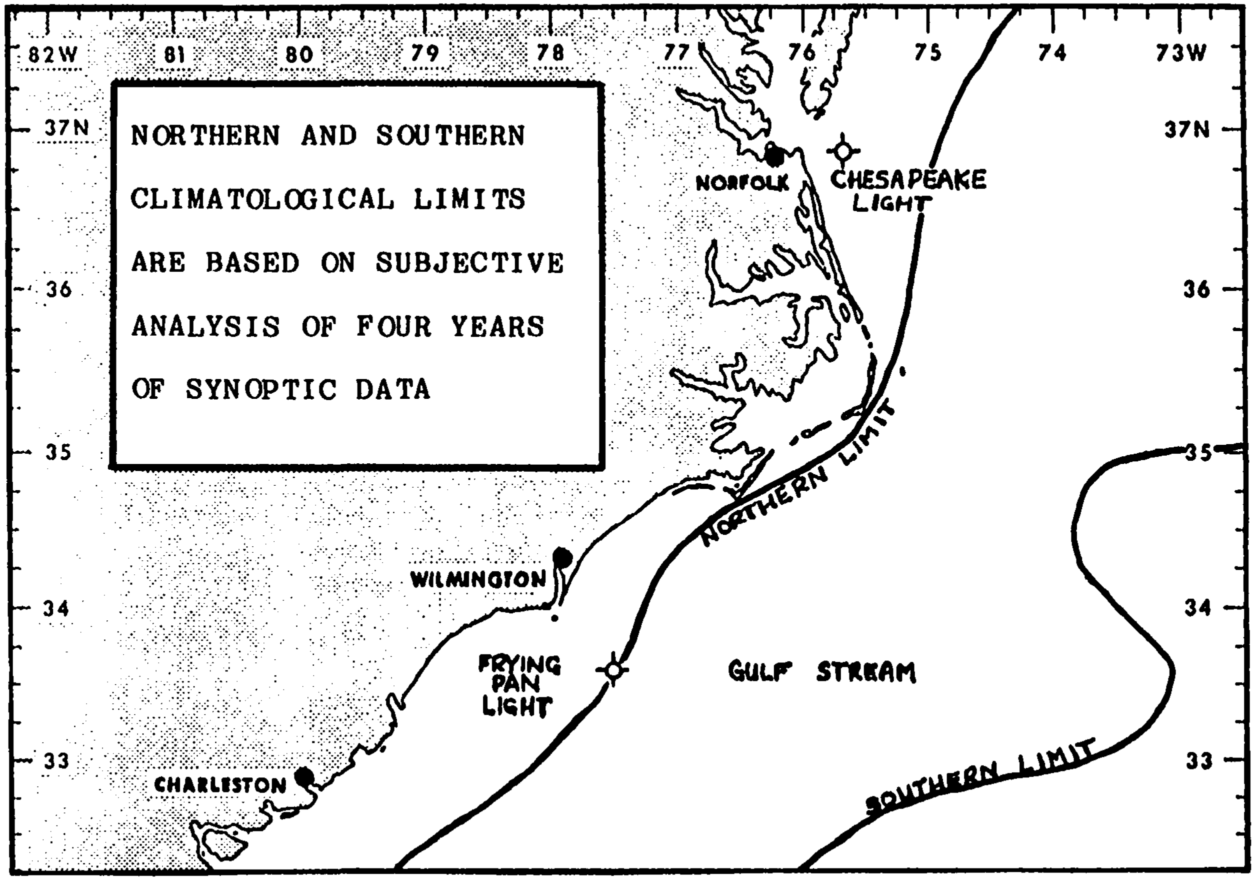
Eight years of synoptic data (1965-1972) for the months October through March were used for two pairs of reporting stations: Wilmington, N. C./Frying Pan Light (ILM); and Norfolk, Va./Chesapeake Light (ORF).

Wilmington is located on the Cape Fear River near the Atlantic Ocean in southeastern North Carolina (Figure 1). Due to the shape of the coastline, the ocean is approximately five miles east and 20 miles south of the city. The surrounding terrain averages less than 40 feet above sea level in gentle rolling land in which cultivated fields alternate with large wooded areas. Frying Pan Light is situated 54.7 miles south-southeast of Wilmington in 55 feet of water.

Norfolk is located in the tidewater area of southeast Virginia (Figure 1) and is nearly surrounded by water, with the Chesapeake Bay to the north, Hampton Roads to the west and the Atlantic Ocean to the east. The average elevation is only 13 feet above sea level. Chesapeake Light is situated 32.8 miles slightly north of east from Norfolk in 36 feet of water.

These pairs were selected primarily for the location of the sea stations, Frying Pan Light being in or near the northern limits of the warmer Gulf Stream year-round, and Chesapeake Light being situated in the relatively colder, coastal water (Figure 1).

Wind direction was used to classify occurrences into each of four synoptic patterns with corresponding air temperature, trends in surface pressure (steady, rising or falling), and humidity values.



VIRGINIA AND NORTH CAROLINA COASTAL REGIONS
INDICATING THE NORTHERN AND SOUTHERN CLIMATOLOGICAL
LIMITS OF THE GULF STREAM

FIGURE 1

C. Four Synoptic Flow Patterns

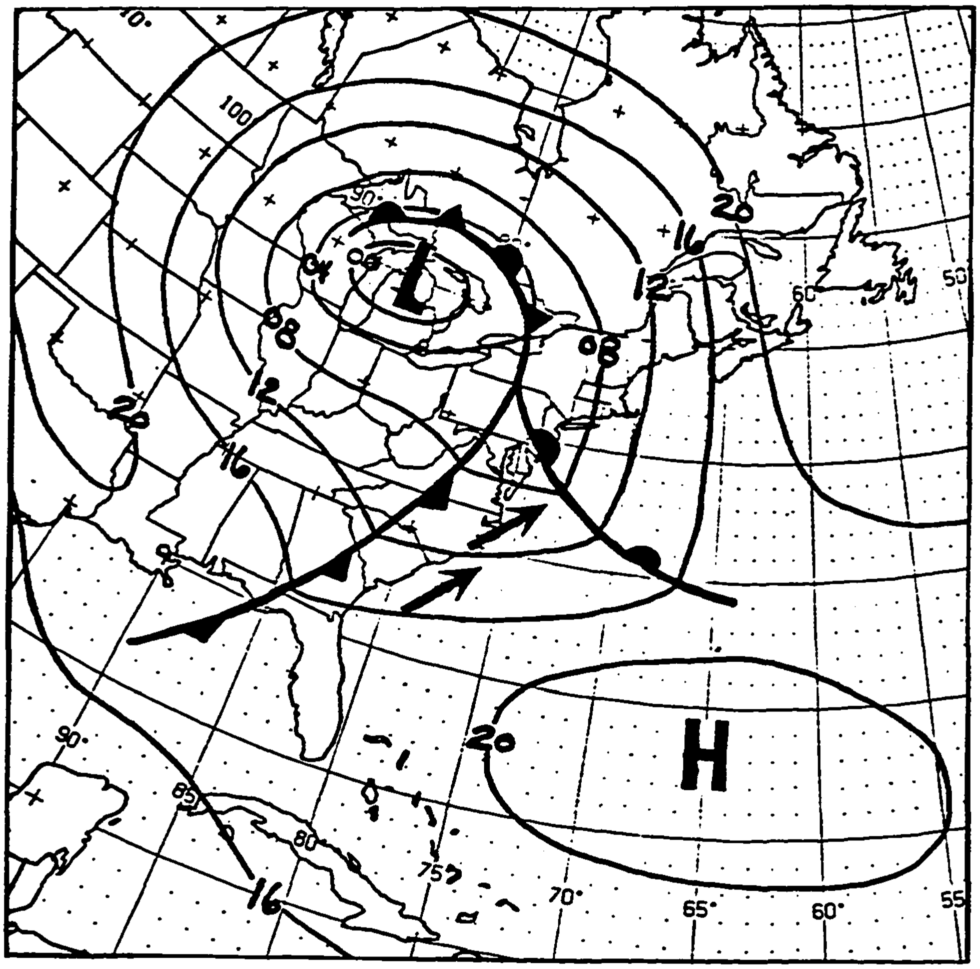
The four synoptic flow patterns were subjectively defined as follows:

1. Prefrontal Pattern

With the approach of a cold front from the west, surface winds increase most frequently from the southwest, but on occasion, can be from the south or southeast. The parent low pressure system is normally located north or northwest of the coastal areas (Figure 2). The air mass is usually modified continental or modified maritime in nature. Warm air advection is typical in this flow pattern (Figure 3) with the increased surface winds resulting from the cyclonic circulation around the low. Air temperature and humidity are, as expected, generally higher than postfrontal cases with trends in the surface pressure showing steady falls until frontal passage.

2. Postfrontal Pattern

After a cold frontal passage, strong pressure gradients can exist between the relatively deep low located to the north or northeast and the strong, cold high pressure system centered to the northwest, usually over the Great Lakes (Figure 4). The air mass is dry, polar or Arctic in origin. Winds are generally from the northwest, but may vary from westerly to northerly. Cold air advection

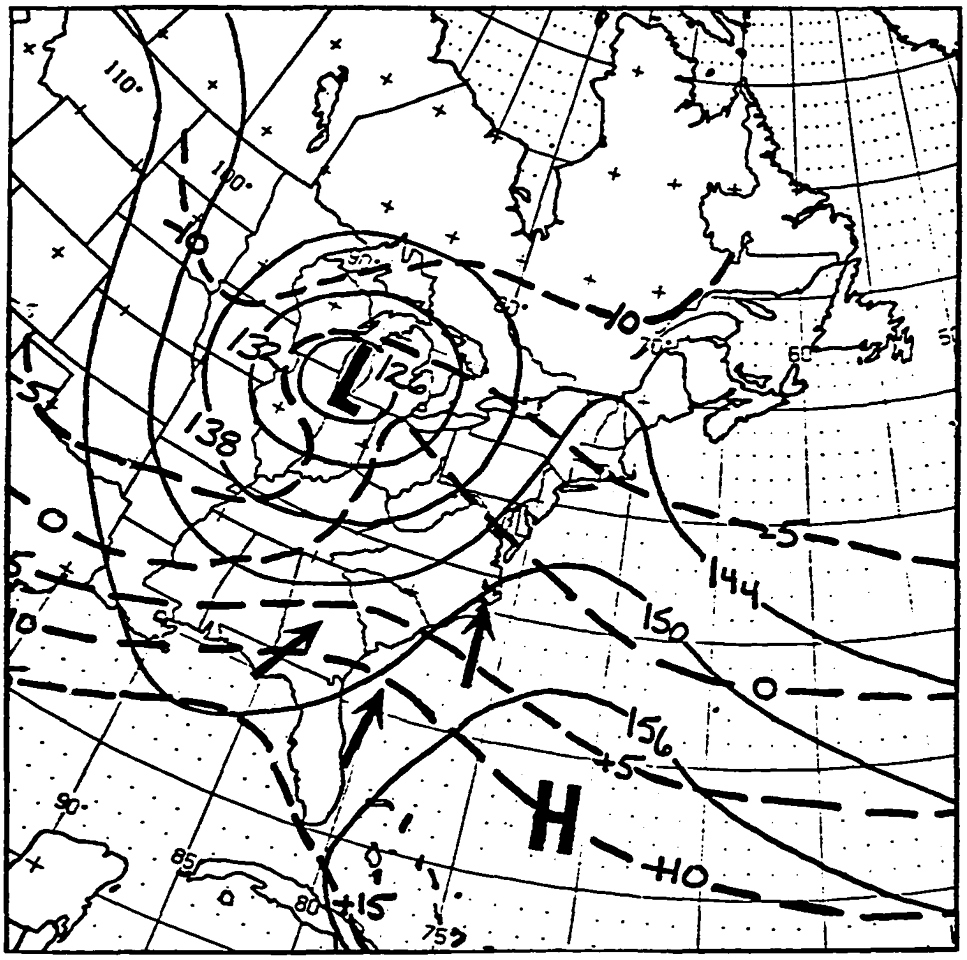


SCHEMATIC OF TYPICAL PREFRONTAL SURFACE PATTERN

ARROWS INDICATE DIRECTION OF SURFACE FLOW

(PRESSURE CONTOURS IN MILLIBARS)

FIGURE 2

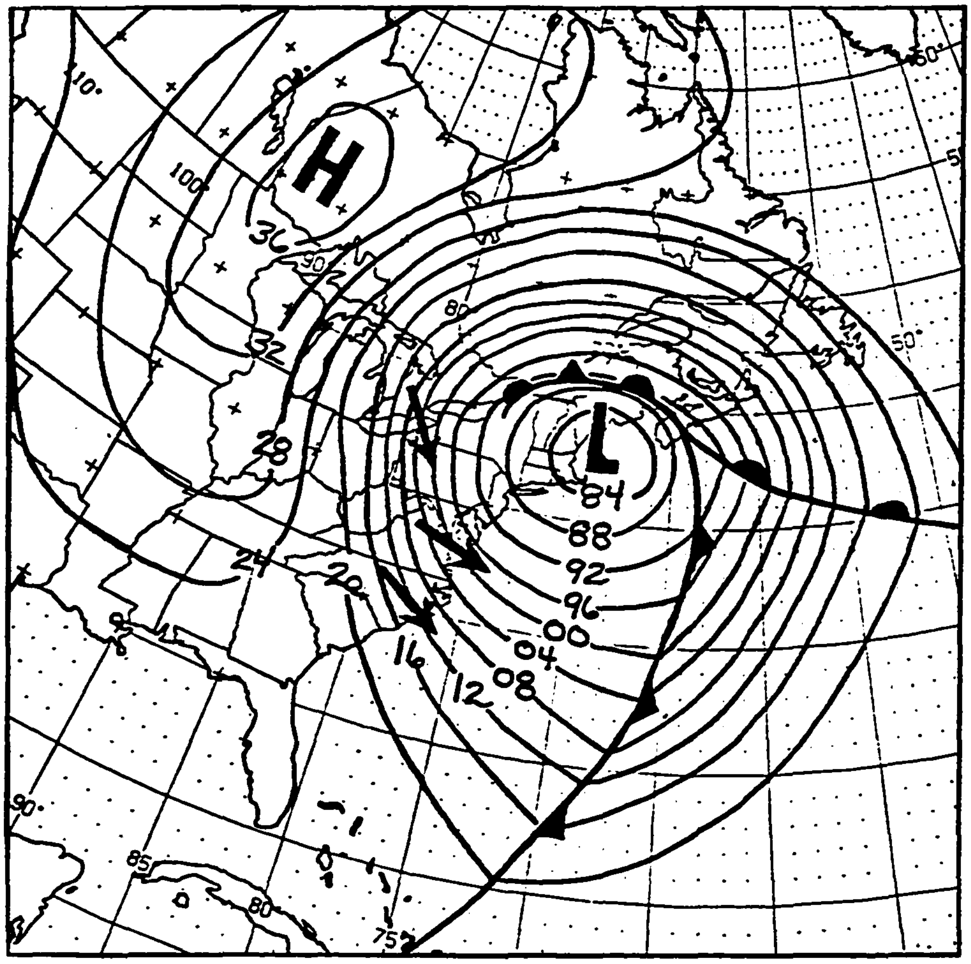


SCHEMATIC OF TYPICAL 850 MB LEVEL PREFRONTAL PATTERN

ARROWS INDICATE DIRECTION OF FLOW/WARM ADVECTION

(HEIGHT CONTOURS IN TENS OF METERS;
ISOTHERMS IN DEGREES CELSIUS, °C)

FIGURE 3

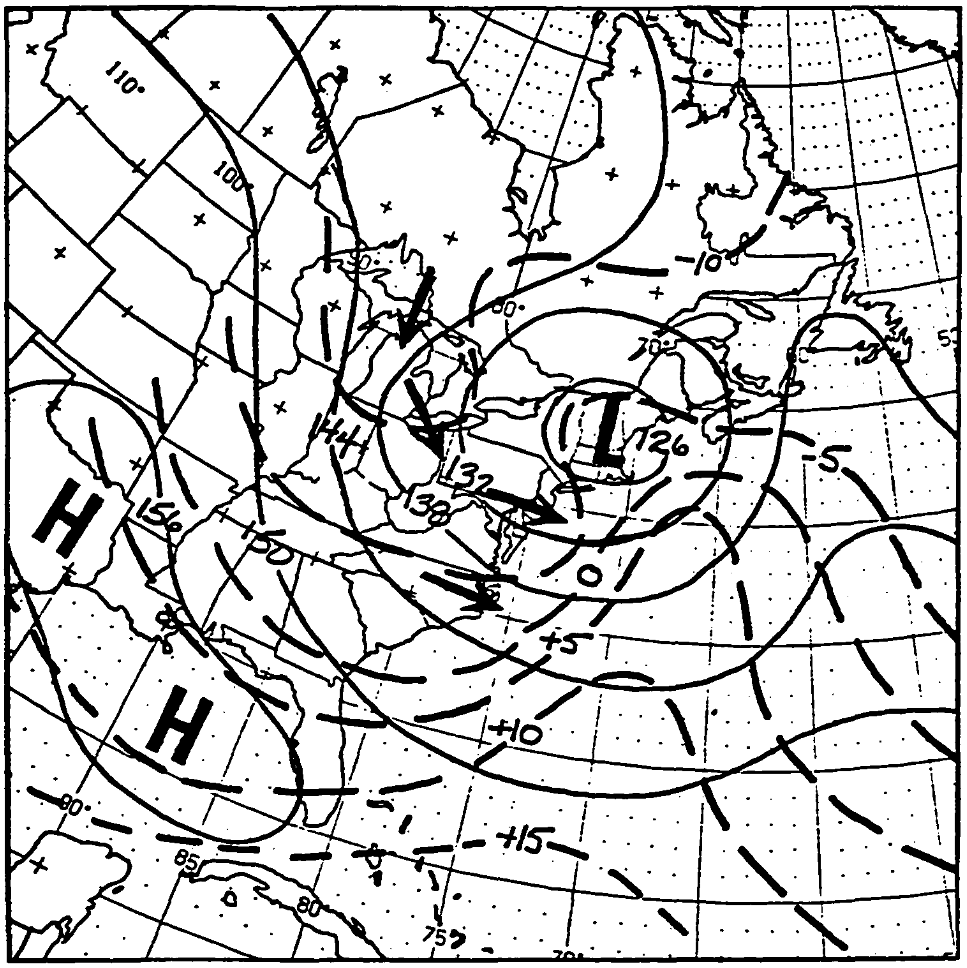


SCHEMATIC OF TYPICAL POSTFRONTAL SURFACE PATTERN

ARROWS INDICATE DIRECTION OF SURFACE FLOW

(PRESSURE CONTOURS IN MILLIBARS)

FIGURE 4



SCHEMATIC OF TYPICAL 850 MB LEVEL POSTFRONTAL PATTERN

ARROWS INDICATE DIRECTION OF FLOW/COLD ADVECTION

(HEIGHT CONTOURS IN TENS OF METERS;
ISOTHERMS IN DEGREES CELSIUS, °C)

FIGURE 5

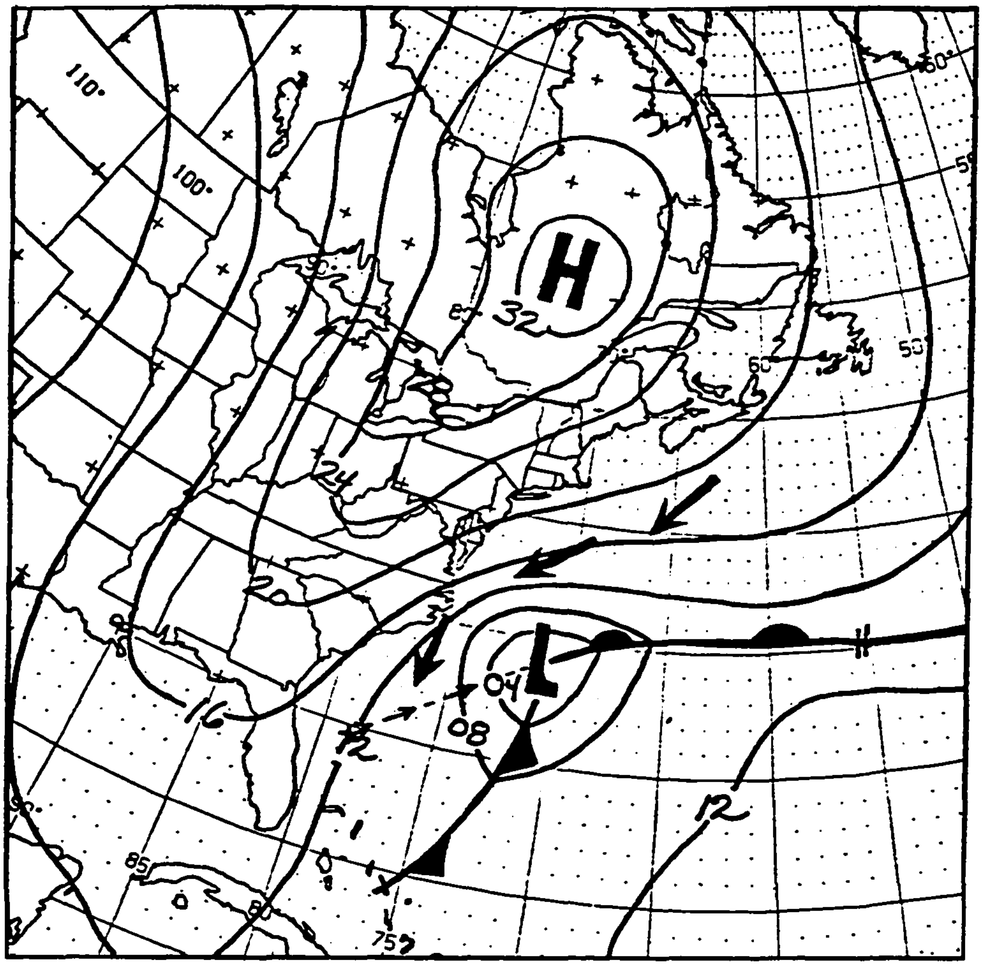
is generally strong and offshore (Figure 5). Surface pressures rise with an accompanying decrease in humidity and air temperature.

3. Northeast Pattern

A "nor'easter" normally occurs after the formation of a low pressure system off the southeast coast of the United States. In conjunction with a strong, cold continental high centered over eastern Canada or New England, the wind flow increases from the northeast (Figure 6). The air mass is polar in nature but has undergone modification over water with cold air advection being from the northeast, also (Figure 7). Surface pressures are fairly steady during the occurrences with the temperatures remaining nearly constant and somewhat colder than the underlying water.

4. Southerly Pattern

A high pressure system, generally continental in origin, moves offshore and modifies over the western Atlantic with a low pressure system or major trough in the midwest. The position of the high pressure center is to the east or east-southeast of the coastal areas (Figure 8). Winds are from a southeasterly to southwesterly direction on the return flow side of the anticyclone with the gradient being generated by the outflow from the high pressure system. The temperature advection pattern is

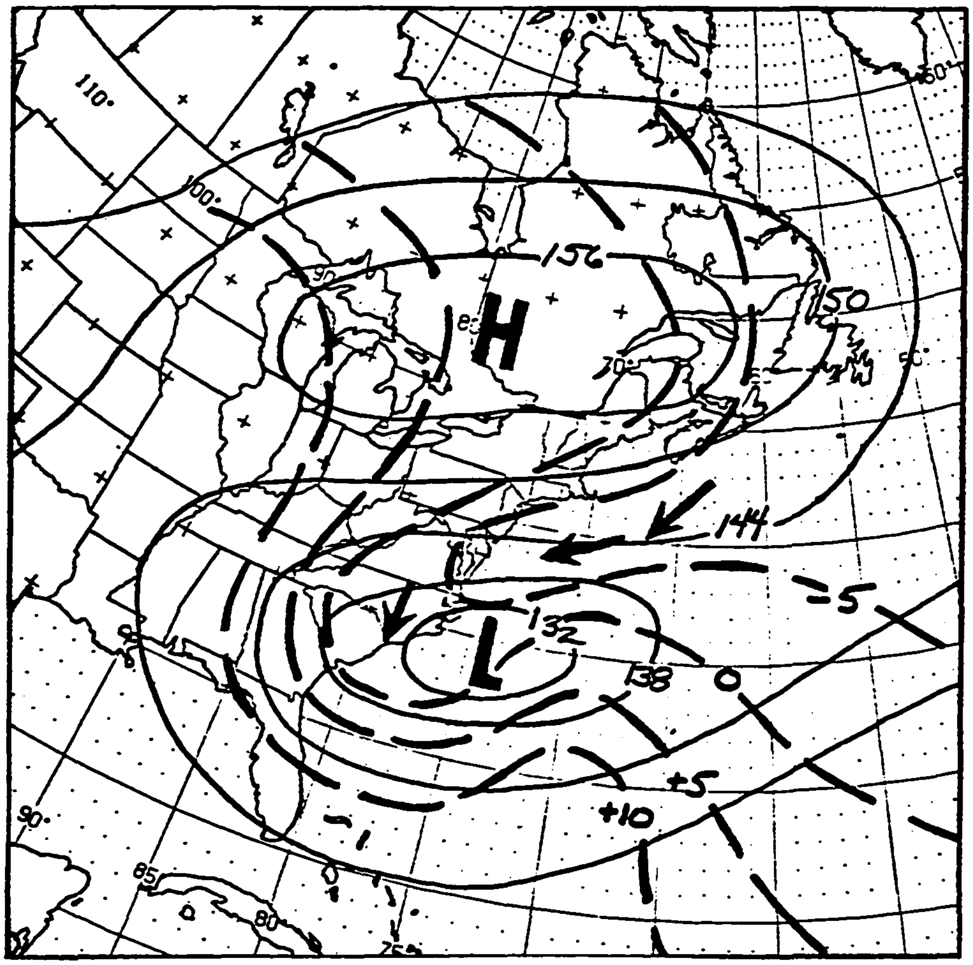


SCHEMATIC OF TYPICAL NORTHEAST SURFACE PATTERN

ARROWS INDICATE DIRECTION OF SURFACE FLOW

(PRESSURE CONTOURS IN MILLIBARS)

FIGURE 6

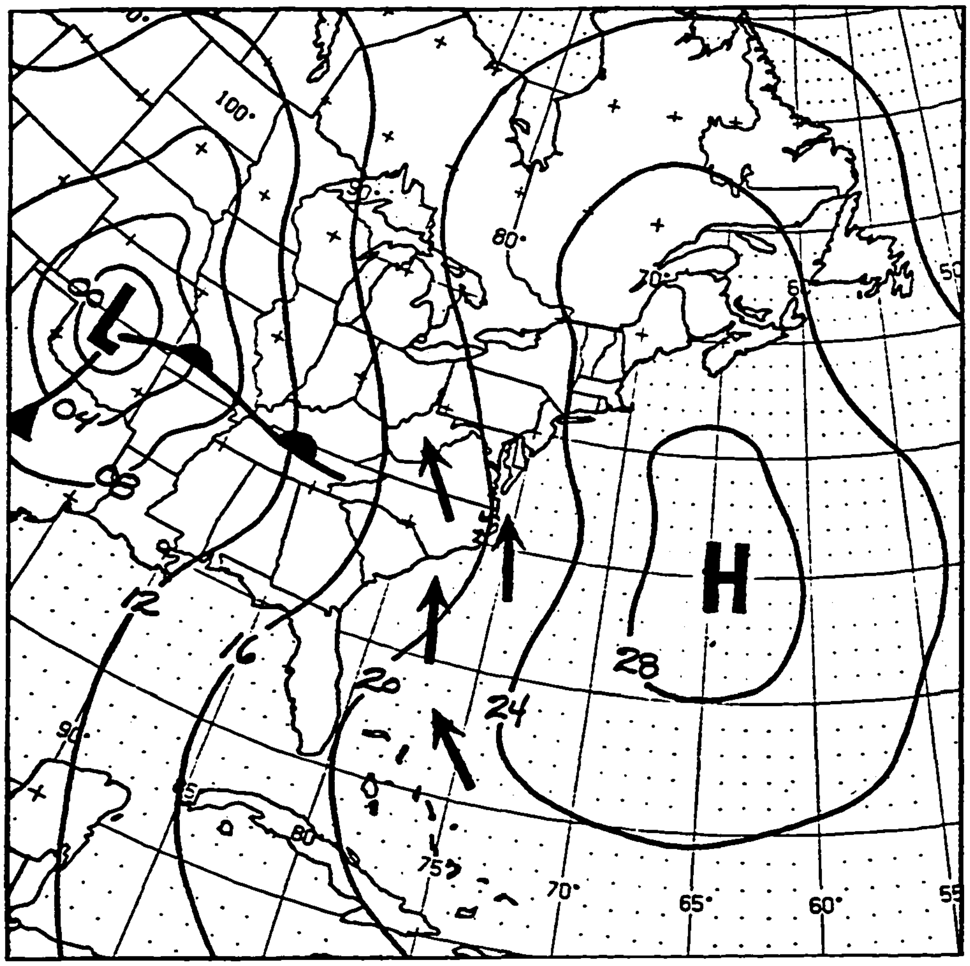


SCHEMATIC OF TYPICAL 850 MB LEVEL NORTHEAST PATTERN

ARROWS INDICATE DIRECTION OF FLOW/COLD ADVECTION

(HEIGHT CONTOURS IN TENS OF METERS;
ISOTHERMS IN DEGREES CELSIUS, °C)

FIGURE 7

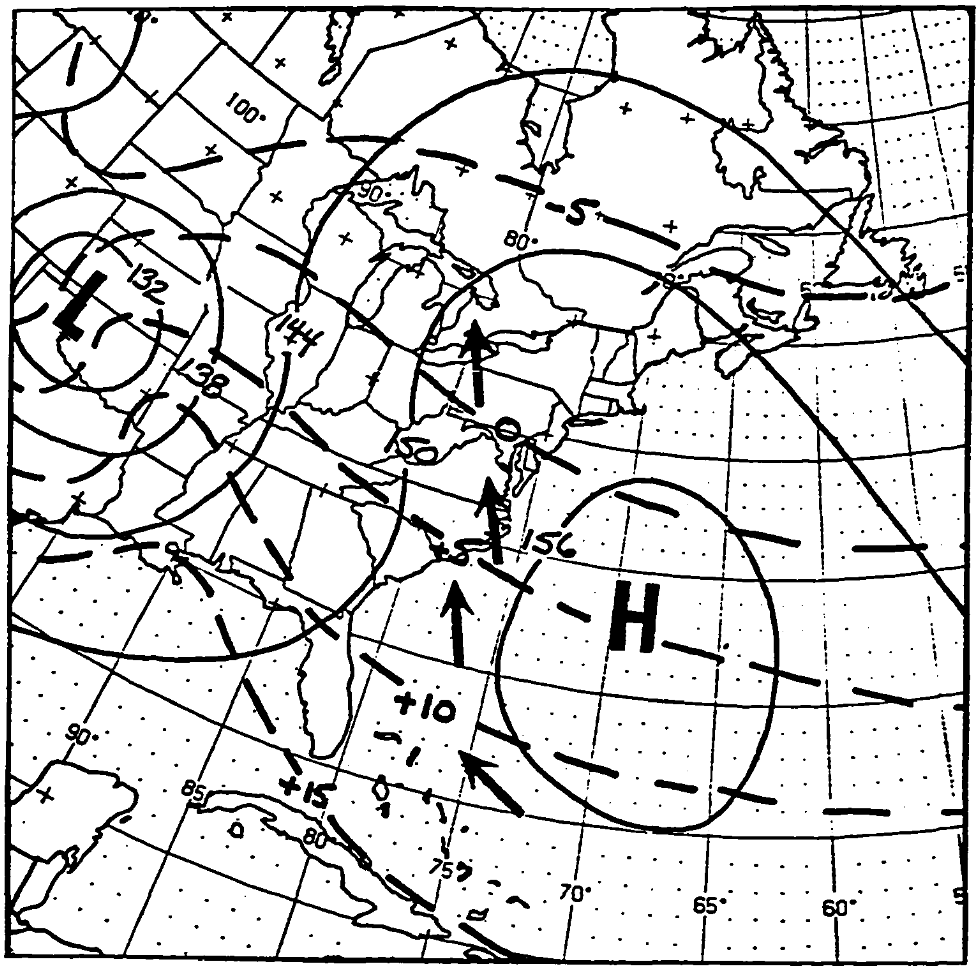


SCHEMATIC OF TYPICAL SOUTHERLY SURFACE PATTERN

ARROWS INDICATE DIRECTION OF SURFACE FLOW

(PRESSURE CONTOURS IN MILLIBARS)

FIGURE 8



SCHEMATIC OF TYPICAL 850 MB LEVEL SOUTHERLY PATTERN

ARROWS INDICATE DIRECTION OF FLOW/WARM ADVECTION

(HEIGHT CONTOURS IN TENS OF METERS;
ISOTHERMS IN DEGREES CELSIUS, °C)

FIGURE 9

relatively weak, warm air (Figure 9) with the winds being onshore. Surface pressures are normally steady with air temperatures changing little or increasing slightly. This pattern is relatively stable due to subsidence from the high pressure system and the relatively high moisture content of the air mass.

II. PARAMETERS

Two criteria were used to classify an increased off-shore wind condition. First and primary was that in a series of observations, the difference between the wind speed at the sea station was at least eight knots greater than that at the land station. This value is somewhat arbitrary but it was found during data analysis, prolonged increased flow occurrences generally included wind speed differences of eight knots or more. The duration of an occurrence was based upon how long this increased flow persisted. Second, the type flow pattern was based upon wind direction, air temperature, surface pressure, and humidity.

The number of occurrences for each synoptic pattern were tallied by month (October through March) with the duration being measured in number of synoptic observations or periods (one synoptic period equals six hours). A mean monthly frequency of distinct occurrences was computed in conjunction with a mean monthly duration of occurrences.

Since the water temperature contributes significantly to the development of increased offshore winds, values for the mean monthly sea surface temperatures, and the mean monthly air-sea temperature differences were tabulated for each flow pattern. The air-sea temperature difference was defined as the value in degrees Fahrenheit (°F) between the air temperature and the water temperature, both of which were measured at the sea station.

For each occurrence, a maximum wind speed over water was observed and recorded. The duration of the maximum wind speed was based upon the number of consecutive observations within three knots of this maximum wind value. Mean monthly maximum wind speeds and mean monthly durations of the mean maximum wind speeds were then calculated for each flow pattern.

Four categories of winds were arbitrarily selected. From the total occurrences observed in each flow pattern, percentages were calculated for each of the following categories:

Category I	$<$ 20 knots
Category II	20 - 29 knots
Category III	30 - 39 knots
Category IV	$\geq$ 40 knots

Finally, the longest monthly observed duration period for each wind speed category during the eight year period was noted. A mean monthly duration for each wind speed category was also computed. These two values were then recorded, both in number of synoptic observations.

III. EVALUATION AND COMPARISON OF DATA

A. Prefrontal Pattern

1. Wilmington/Frying Pan Light (ILM)

There were 137 occurrences in the prefrontal condition for the eight year period. October and November displayed extremes in the mean monthly frequency of occurrences (Figure 10). For the remainder of the season, values were steady between three and four per month. Mean monthly durations of occurrences were fairly uniform for the entire six months (Figure 11), at nearly three synoptic periods.

Mean monthly sea surface temperatures at ILM steadily declined through the season from 77.9°F in October to 58.8°F in March (Figure 12). Mean monthly air-sea temperature differences remained less than zero (air colder than water) for the entire season though a gradual increase was indicated after November (Figure 13) as the sea water temperature continued to decrease.

Mean monthly maximum wind speeds showed nearly a six knot range between the high and low values (Figure 14). The highest mean values of 32.0 knots and 30.9 knots occurred in December and February, respectively. Mean monthly sea-land wind speed differences were quite high, ranging from 17.3 to 22.9 knots (Figure 15) with the highest differences centered in the mid-winter months, December and January.

The greatest percentages of occurrences of mean maximum wind speeds were in Categories II and III (Figure 16). Maximum winds in Category I were virtually nonexistent with only three occurrences observed for the eight year period. Mean durations of mean maximum wind speeds (Figure 18) were between one and two and a half observation periods. The longest occurrence duration for maximum winds was eight periods (48 hours) which occurred only once, in December, 1971, in Category II. The remaining absolute maximums were between two and four periods in length.

2. Norfolk/Chesapeake Light (ORF)

Mean monthly frequency of occurrences spanned a narrow range from 0.875 to 1.875 per month (Figure 10) with only 68 prefrontal condition occurrences documented. Mean monthly durations of occurrences were short, between one and three observation periods (Figure 11); the values showed increasing length into January with a gradual decrease in the late winter months, February and March.

Mean monthly sea surface temperatures at ORF (Figure 12) showed a steady decrease from October through February with a slight warming trend appearing in March. This was probably due to the fact that the coldest portion of the winter was over and the air temperature was beginning to moderate thereby resulting in an increase in water temperature. With the exception of October and November, mean monthly air-sea temperature differences (Figure 13) indicated that the air was slightly warmer than the water. In this situation, a downward flux of sensible heat would be expected.

Mean monthly maximum wind speeds (Figure 14) indicated a four knot range between the high and low values with no preference shown for any significantly stronger or weaker month. The mean monthly sea-land wind speed differences (Figure 15) did show an upward turn in March, from the relatively constant 10.5 to 13.8 knot range for the other five months.

The greatest portion of mean maximum wind speeds were in Categories I and II (Figure 17) with the total percentages in these categories at or above 69% for all six months. Only four occurrences out of 68 had winds in Category IV.

Mean occurrence durations for mean maximum wind speeds (Figure 19) were steady in October and November, at one period or less, but increased to one to two periods for the remainder of the winter. A one time maximum observed duration of three periods (18 hours) occurred in March.

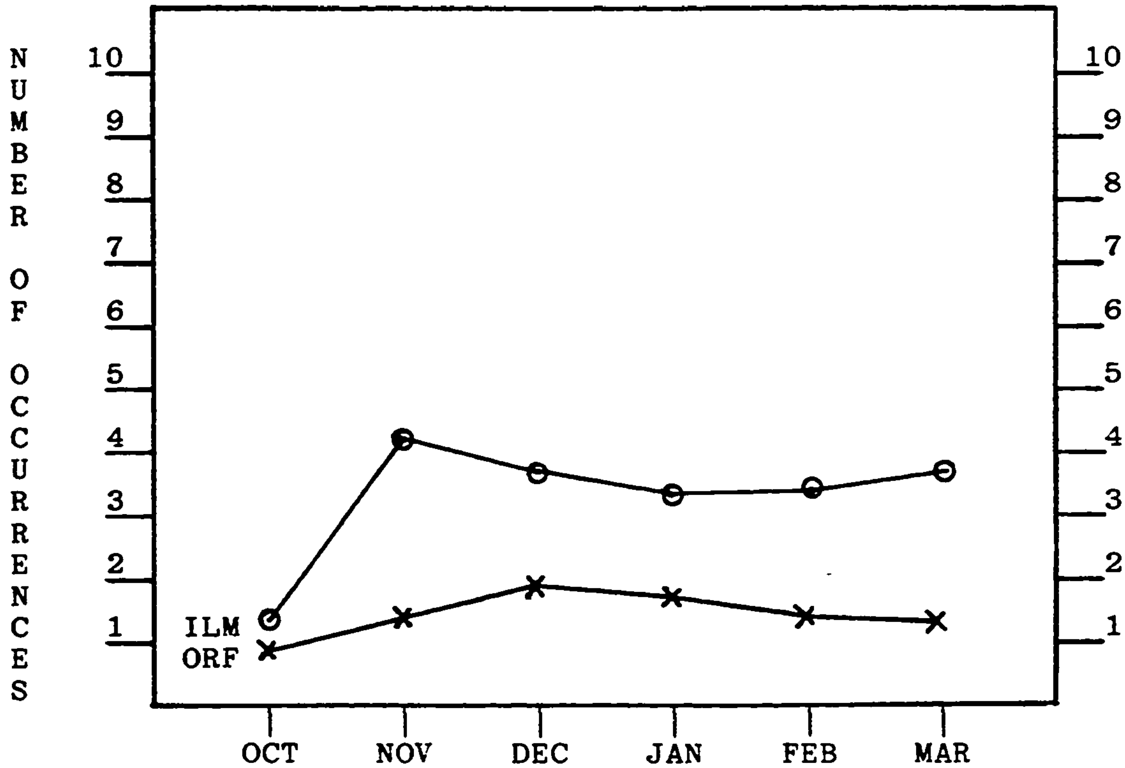
3. Comparison

In the prefrontal condition, there were twice as many total occurrences at Wilmington (ILM) than Norfolk (ORF), 137 versus 68, with mean monthly durations of occurrences being two to three times greater.

Differences in mean monthly sea surface temperatures showed that ILM was considerably warmer than ORF due to the proximity of the Gulf Stream. The greatest difference in sea surface temperature between the two stations was 19.0°F in February. In March, the difference decreased to 14.9°F as the water at ORF began to warm and ambient air temperatures moderated. With the exception of October and November, when air-sea temperature differences were nearly the same at both stations, ILM maintained a negative temperature difference due to the relative warmth of the water. ORF showed positive differences, and therefore relatively more stable conditions, for the mid- and late winter months due to the relative warmth of the air.

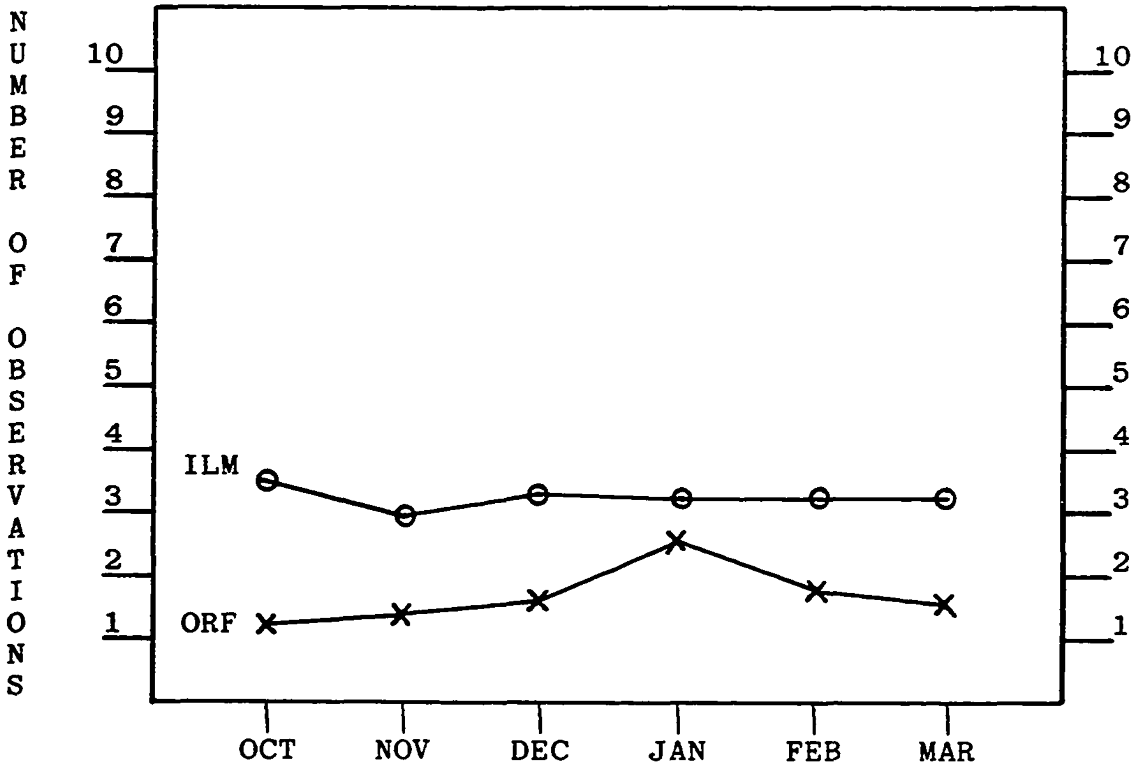
Values for the mean monthly maximum wind speeds were five to seven knots higher at ILM than ORF. At the same time, mean monthly sea-land wind speed differences were up to 11 knots greater at ILM.

In the prefrontal pattern, mean maximum wind speeds and mean durations for all wind speed categories, tended to be greater at ILM; this was also the case for absolute maximum durations of the wind speed categories. This tendency could be attributed to two factors. The first was an instability resulting from an upward flux of sensible heat from the warmer water below. The second was the longer distance, or fetch, over which the air stream must travel. With longer distances over water, less surface friction was encountered which provided a longer period of time for the effects of friction to adjust between the land and ocean surfaces; this resulted in an increase in the surface winds. (See Table 1 for a summary of data for the Prefrontal Pattern.)



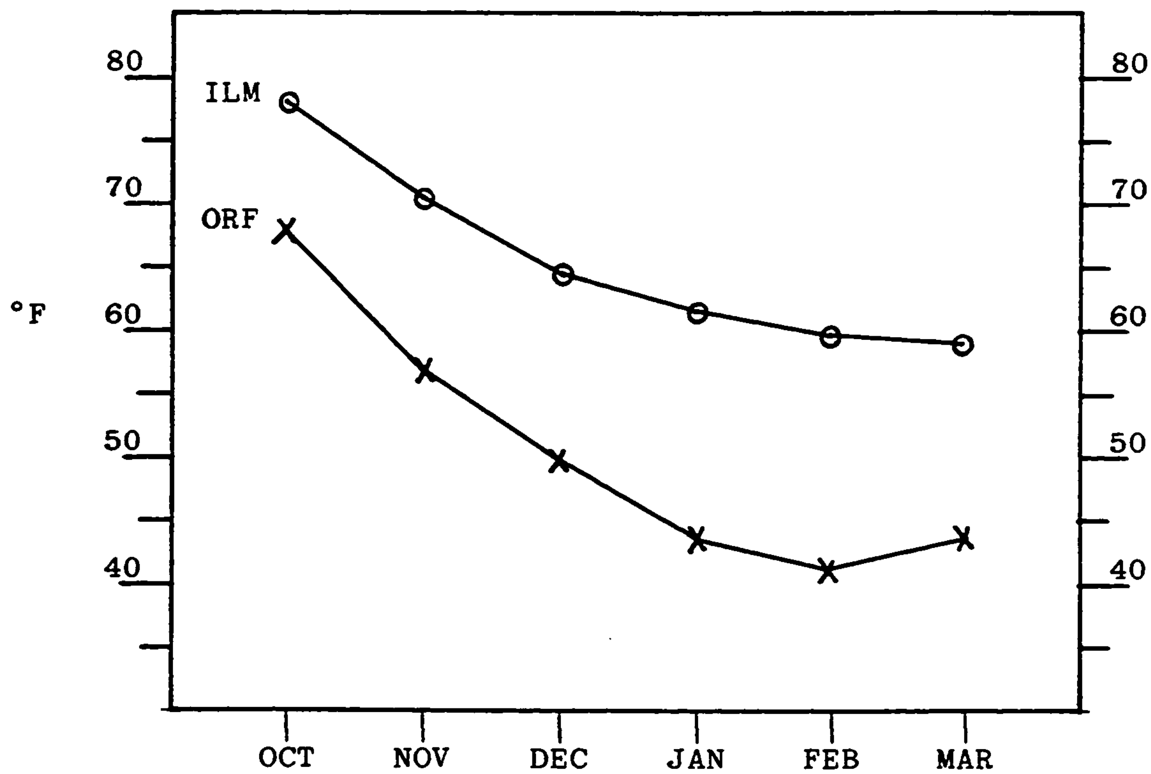
MEAN MONTHLY FREQUENCY OF OCCURRENCES (PREFRONTAL)

FIGURE 10



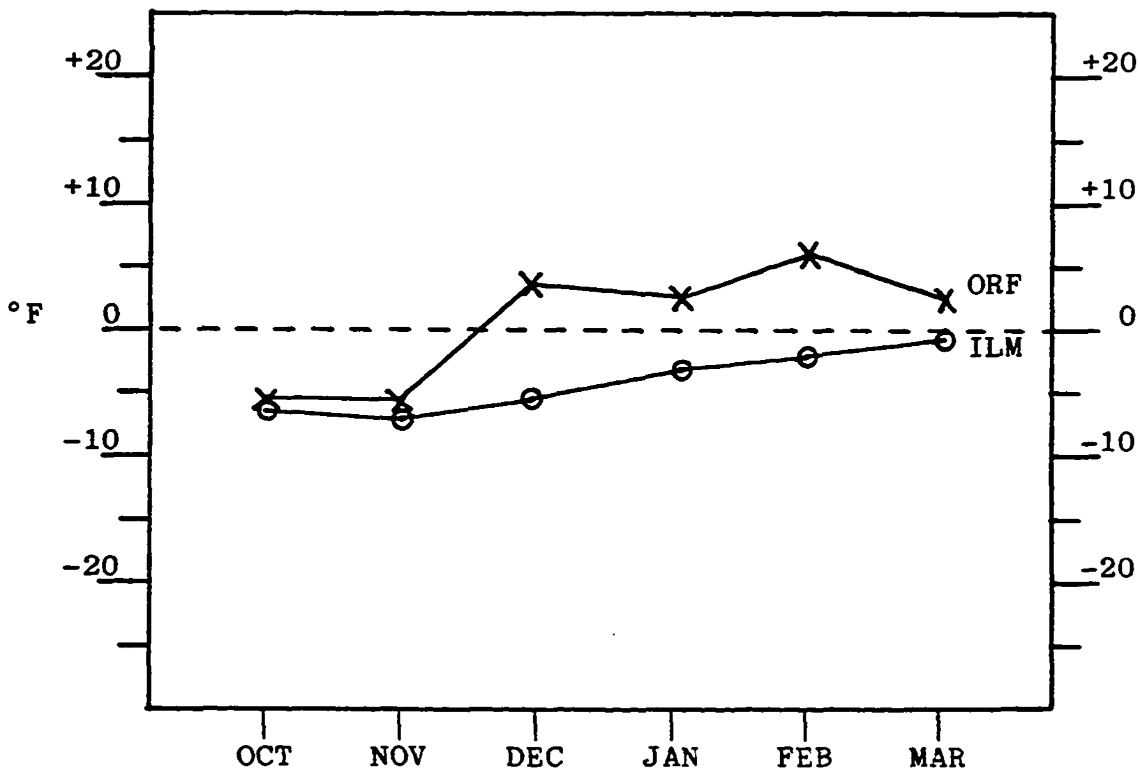
MEAN MONTHLY DURATION OF OCCURRENCES (PREFRONTAL)

FIGURE 11



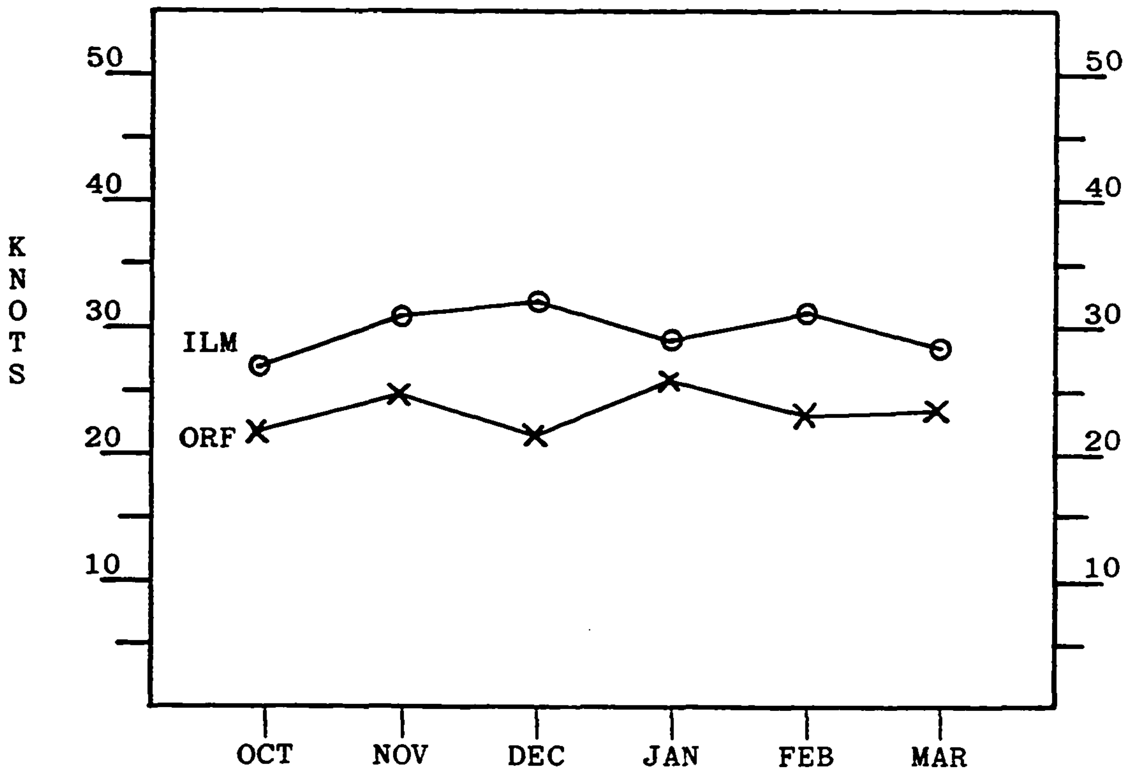
MEAN MONTHLY SEA SURFACE TEMPERATURE (PREFRONTAL)

FIGURE 12



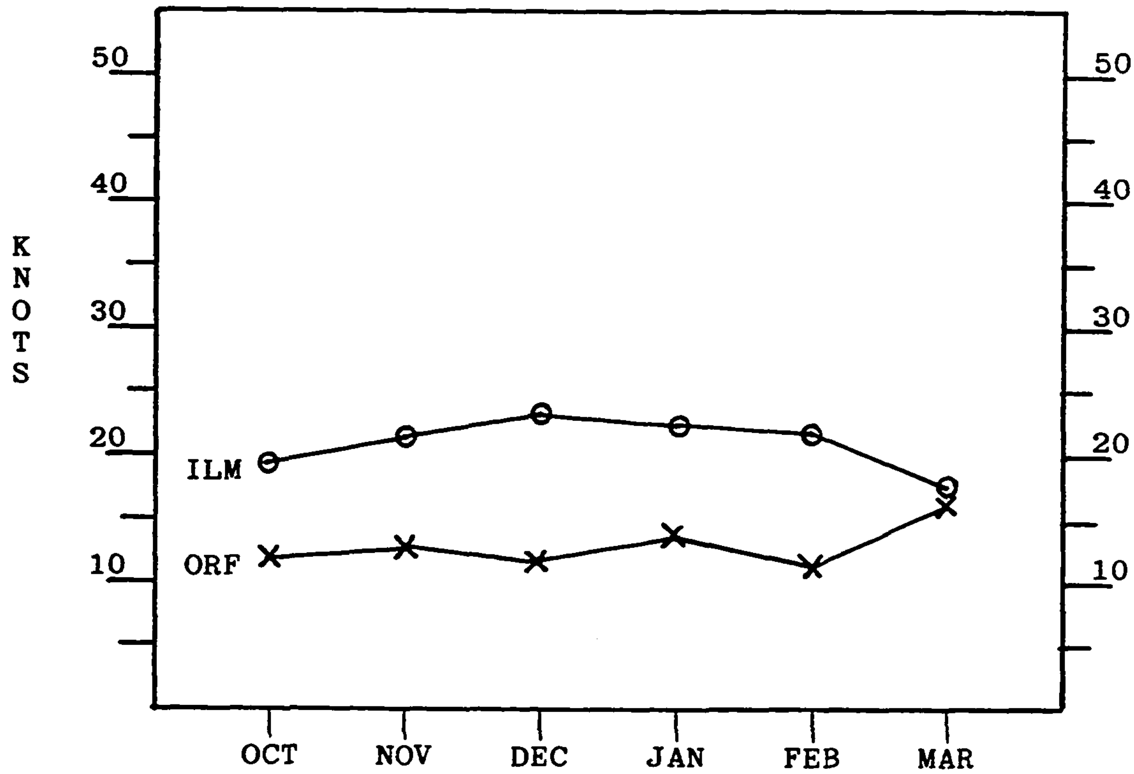
MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE
(PREFRONTAL)

FIGURE 13



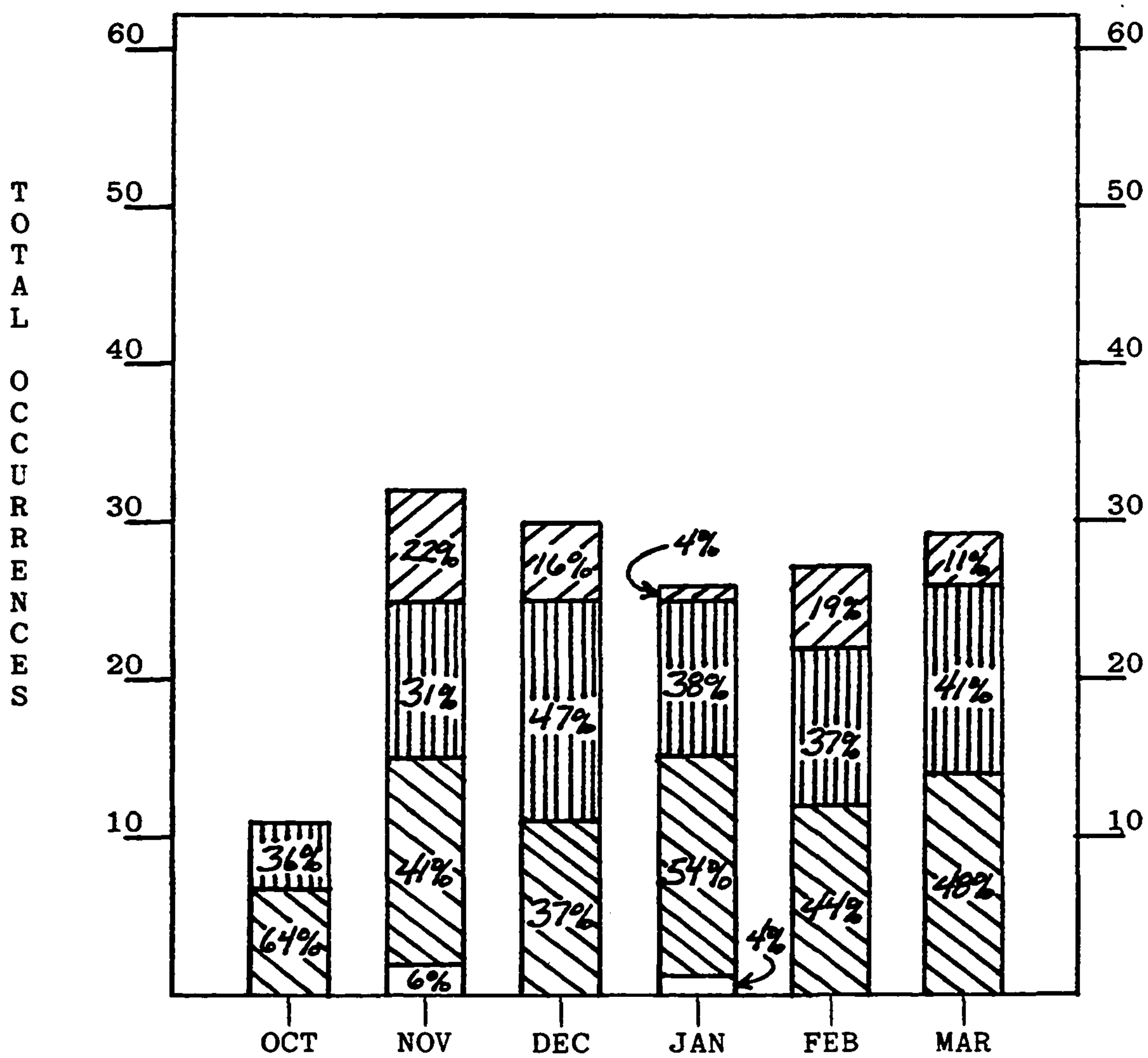
MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER
(PREFRONTAL)

FIGURE 14



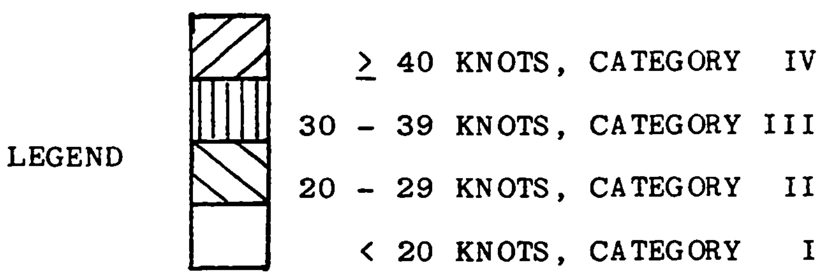
MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE
(PREFRONTAL)

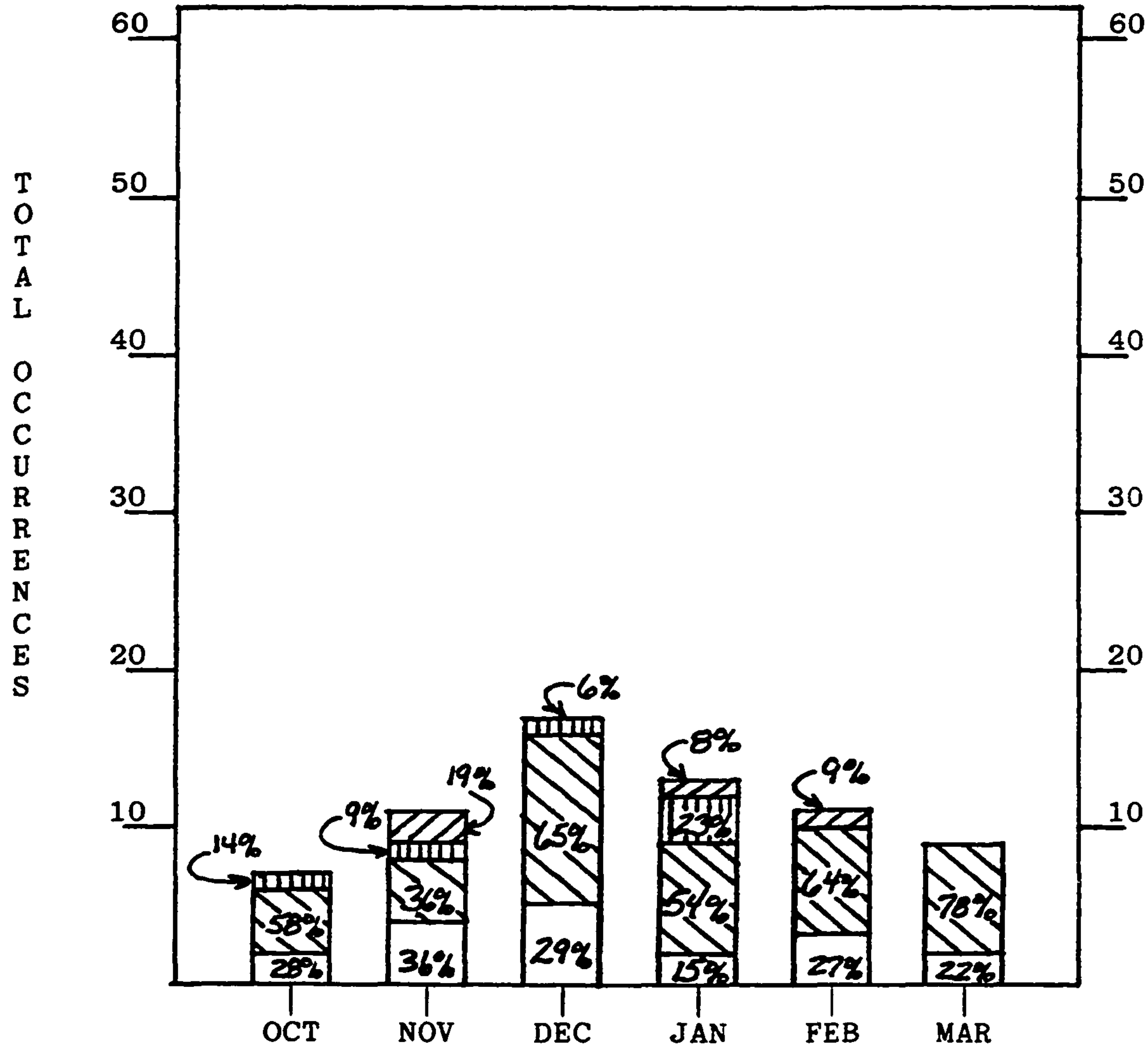
FIGURE 15



PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ILM (PREFRONTAL)

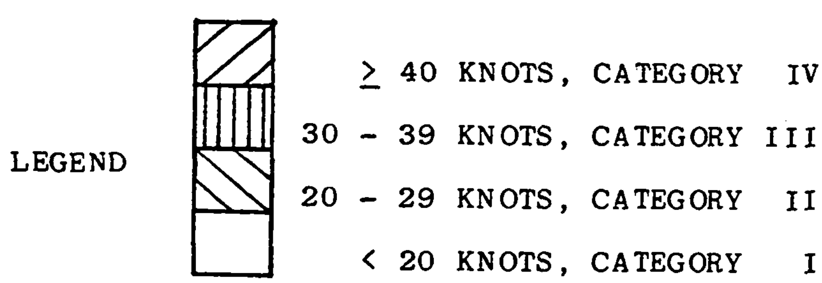
FIGURE 16

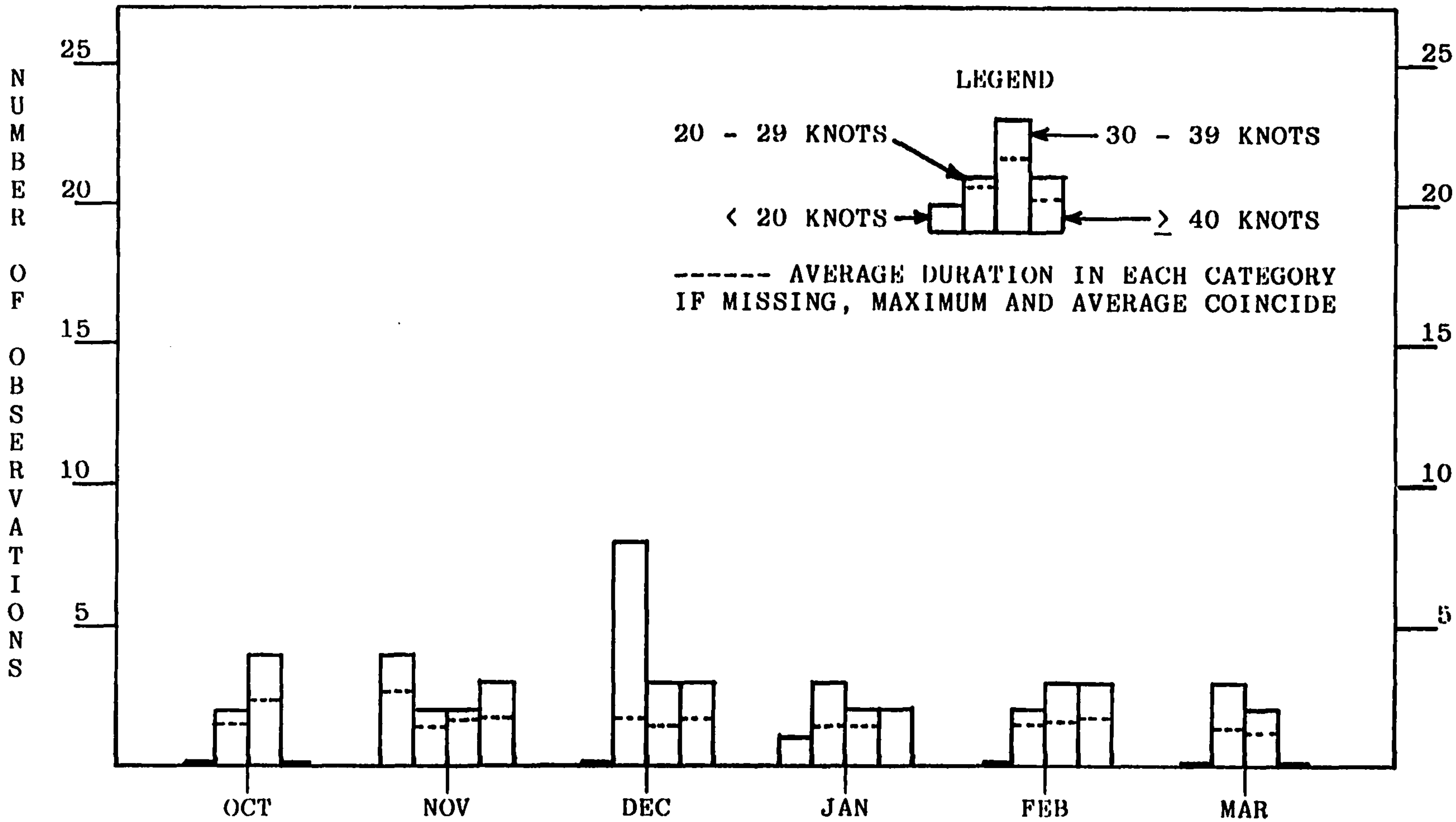




PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ORF (PREFRONTAL)

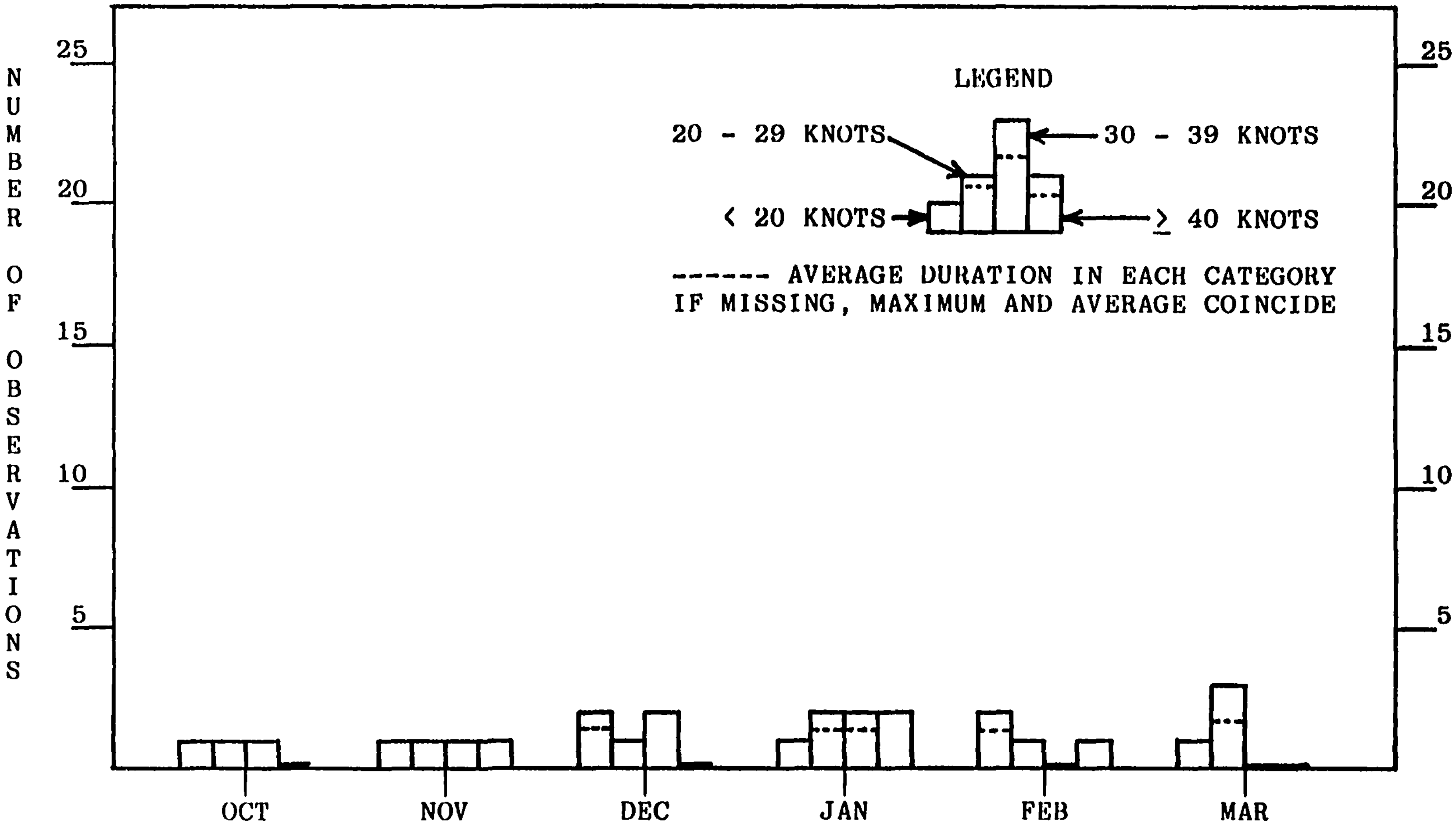
FIGURE 17





ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ILM (PREFRONTAL)

FIGURE 18



ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ORF (PREFRONTAL)

FIGURE 19

TABLE 1: SUMMARY OF DATA FOR THE PREFRONTAL PATTERN

A. MEAN MONTHLY FREQUENCY OF OCCURRENCES (FIGURE 10)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	1.375	4.125	3.750	3.250	3.375	3.750
ORF	.875	1.375	1.875	1.625	1.375	1.125

B. MEAN MONTHLY DURATION OF OCCURRENCES IN NUMBER OF SYNOPTIC OBSERVATIONS (FIGURE 11) (ONE SYNOPTIC OBSERVATION PERIOD = SIX HOURS)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	3.45	2.97	3.20	3.15	3.15	3.14
ORF	1.14	1.36	1.59	2.54	1.82	1.44

C. MEAN MONTHLY SEA SURFACE TEMPERATURE (°F) (FIGURE 12)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	77.8	70.1	64.6	61.3	59.5	58.8
ORF	67.6	56.5	49.9	43.5	40.5	43.9

D. MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE (°F) (AIR TEMP - SEA TEMP) (FIGURE 13)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	-6.1	-7.3	-5.5	-3.8	-2.4	-0.5
ORF	-5.7	-6.3	2.9	2.2	5.3	2.0

E. MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER (KNOTS) (FIGURE 14)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	26.3	30.4	32.0	28.7	30.9	28.0
ORF	21.7	24.4	21.2	25.4	22.9	23.1

TABLE 1 (CONTINUED)

F. MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE (KNOTS) (FIGURE 15)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	19.0	20.9	22.9	22.2	21.3	17.3
ORF	11.6	12.9	10.7	13.8	10.5	15.6

G. TOTAL NUMBER OF INCREASED WIND SPEED OCCURRENCES WITH PERCENTAGE BREAKDOWN OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (FIGURES 16 AND 17)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM # OF EVENTS	11	32	30	26	27	29
< 20	-	6%	-	4%	-	-
20 - 29	64%	41%	37%	54%	44%	48%
30 - 39	36%	31%	47%	38%	37%	41%
≥ 40	-	22%	16%	4%	19%	11%
ORF # OF EVENTS	7	11	17	13	11	9
< 20	28%	36%	29%	15%	27%	22%
20 - 29	58%	36%	65%	54%	64%	78%
30 - 39	14%	9%	6%	23%	-	-
≥ 40	-	19%	-	8%	9%	-

H. ABSOLUTE MAXIMUM DURATION OF MEAN MAXIMUM WIND SPEEDS AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (SYNOPTIC OBSERVATIONS) (FIGURES 18 AND 19)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
< 20	-	4/2.50	-	1/1.00	-	-
20 - 29	2/1.14	2/1.08	8/1.82	3/1.29	2/1.50	3/1.50
30 - 39	4/2.25	2/1.20	3/1.36	2/1.30	3/1.70	2/1.25
≥ 40	-	3/1.43	3/1.80	2/2.00	3/1.80	-
ORF						
< 20	1/1.00	1/1.00	2/1.20	1/1.00	2/1.30	1/1.00
20 - 29	1/1.00	1/1.00	1/1.00	2/1.29	1/1.00	3/1.43
30 - 39	1/1.00	1/1.00	2/2.00	2/1.30	-	-
≥ 40	-	1/1.00	-	2/2.00	1/1.00	-

B. Postfrontal Pattern

1. Wilmington/Frying Pan Light (ILM)

Two hundred twenty four postfrontal occurrences were observed in the eight year period. Mean monthly frequency of occurrences (Figure 20) ranged from 4.625 to 6.125 per month with the exception of October being 2.125. A peak occurred in January with a secondary high in November. Mean monthly durations of occurrences (Figure 21) were not significantly greater than those of the prefrontal pattern.

Except for October, mean monthly sea surface temperatures were within one to two degrees of prefrontal values, steadily decreasing from 72.2°F to 57.5°F (Figure 22). Mean monthly air-sea temperature differences (Figure 23) were significantly lower than the prefrontal condition which was to be expected during cold air outbreaks in a postfrontal situation.

The range between the highest and lowest mean monthly maximum wind speeds (Figure 24) increased to nearly eight knots, two knots above that in the prefrontal pattern. Except for October, mean monthly maximum wind speeds were much like those of the prefrontal condition, with December and February having the highest values. Mean monthly sea-land wind speed differences (Figure 25) in five of the six months were nearly the same as the prefrontal pattern.

Percentages of mean maximum wind speeds in Categories I and IV (Figure 26) were greater than those in the pre-frontal pattern but the majority of maximum wind speeds remained in Categories II and III. Mean durations of mean maximum wind speeds (Figure 28) increased slightly to between one and just over three observation periods. Absolute maximum periods observed increased significantly with the longest of 13 periods (78 hours) in January, 1970, in Category III. A second maximum of 12 periods (72 hours) occurred in February, 1969.

2. Norfolk/Chesapeake Light (ORF)

A marked increase was indicated in mean monthly frequency of occurrences (Figure 20) and mean monthly durations of occurrences (Figure 21) as compared to the prefrontal pattern. With the exceptions of October (4.250) and March (5.625), the mean frequency of occurrences remained consistently above six per month. Mean durations assumed a bell shaped curve with low values in October and March, and the highest value in January.

Mean monthly sea surface temperatures (Figure 22) were nearly unchanged from those of the prefrontal case, however, mean monthly air-sea temperature differences (Figure 23) were larger. The values remained negative for all months indicating the air was colder than the water all season.

Mean monthly maximum wind speeds (Figure 24) were relatively consistent throughout the season with less than a three knot range among all months. Mean monthly sea-land wind speed differences (Figure 25) were nearly constant with less than two knots separating high and low values.

Percentages of mean maximum wind speeds (Figure 27) were nearly constant in all catagories. A slight increase in Category IV was seen during the last three months, but overall, little change in the proportions was evident for the entire season. This could be attributed, in part, to the greater decrease in the sea surface temperature at ORF than ILM, which suggests that the amount of instability generated by the warmer water would be not be as great.

Mean durations of mean maximum wind speeds (Figure 29) increased from October to a peak in December, remained relatively constant through February, then declined in March. Absolute maximum durations of mean maximum wind speed categories occurred in December with seven periods (42 hours) in Category II; January and February had five periods (30 hours) each in Category III. Maximum winds in Category IV peaked during November (two periods), March (two periods), and February (three periods).

3. Comparison

Since ORF was located 178 miles farther north than ILM, there was a greater probability of encountering cold air outbreaks earlier in the season. Thus, postfrontal activity occurred more frequently at ORF than at ILM, 285 occurrences versus 224. The consistency in mean monthly frequency of occurrences at ORF for the months November through February revealed that cold air outbreaks reached the area sooner; mean monthly durations of occurrences at ORF showed a steady value of nearly five observation periods for the same four months. This indicated that the postfrontal occurrence persisted for a longer period of time at ORF than at ILM.

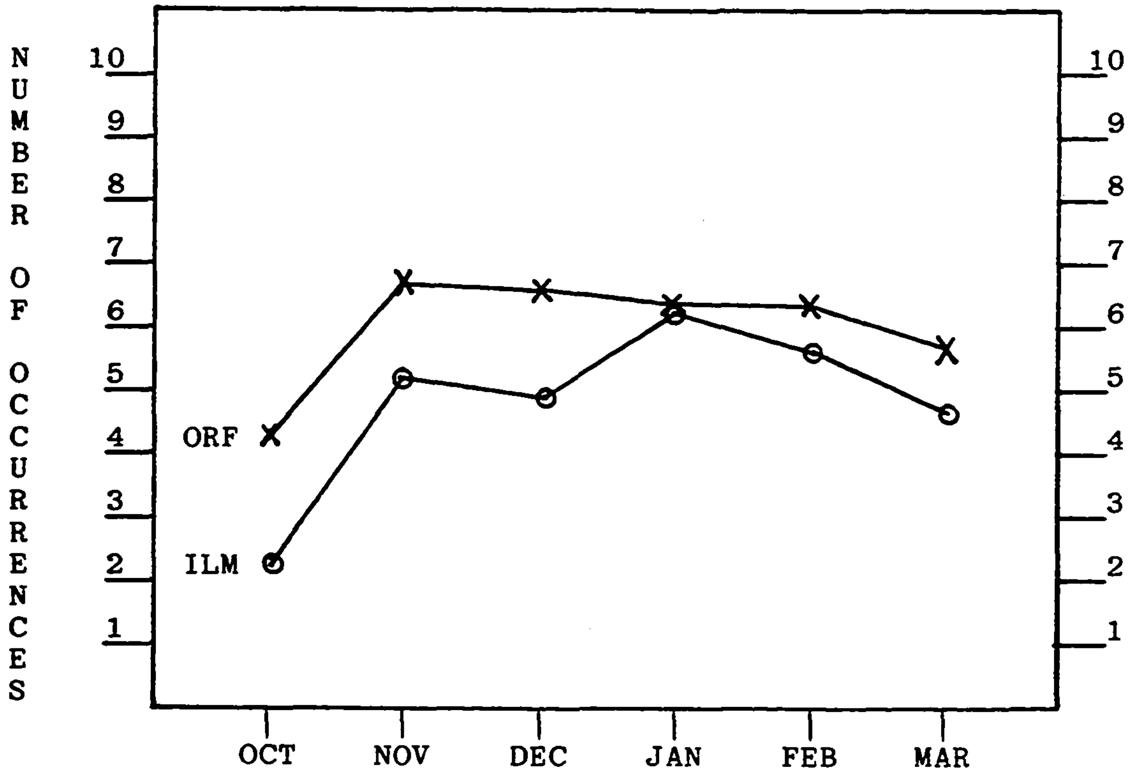
Compared to the prefrontal pattern, mean monthly sea surface temperatures were nearly unchanged for ILM and ORF, with one exception. In October the mean sea surface temperature at ILM was up to five degrees colder (72.2°F) than during the other three synoptic patterns. This was probably due to the combination of three factors: first, strong offshore flow forced warmer surface water seaward with cooler water upwelling from beneath. Second, the Gulf Stream migrates seaward during the winter months. Third, the air temperature contributed to the cooling of the surface water.

Mean monthly air-sea temperature differences at both stations indicated negative values which showed that the air remained relatively colder than the water. The temperature differences were greater at ILM, as expected, due to the warmer water offshore.

Mean monthly maximum wind speeds were nearly the same at both stations. Relative high speeds were in December and February at ILM while at ORF mean maximum wind speeds were nearly constant for the entire six month period. Mean monthly sea-land wind speed differences were more uniform at ORF with values within one knot of 15 knots all season. At ILM, mean sea-land wind speed differences were generally higher.

In analyzing percentages of mean maximum wind speeds, one point was evident. In all wind speed categories at ORF, values remained relatively uniform all season. At ILM, however, a definite increase was noted in mid-winter with December and February reflecting peaks for winds in Category IV, while at the same time showing the lowest values for winds in Category I in January and February.

Mean durations of mean maximum wind speeds peaked from December through February for both stations. However, mean durations were, overall, more than three hours longer at ILM (10.14 hours) than at ORF (7.08 hours). The longest absolute maximum durations occurred at ILM with 13 periods in January and 12 periods in February. At ORF, an absolute maximum of seven periods occurred in December. (See Table 2 for a summary of data for the Postfrontal Pattern.)



MEAN MONTHLY FREQUENCY OF OCCURRENCES (POSTFRONTAL)

FIGURE 20

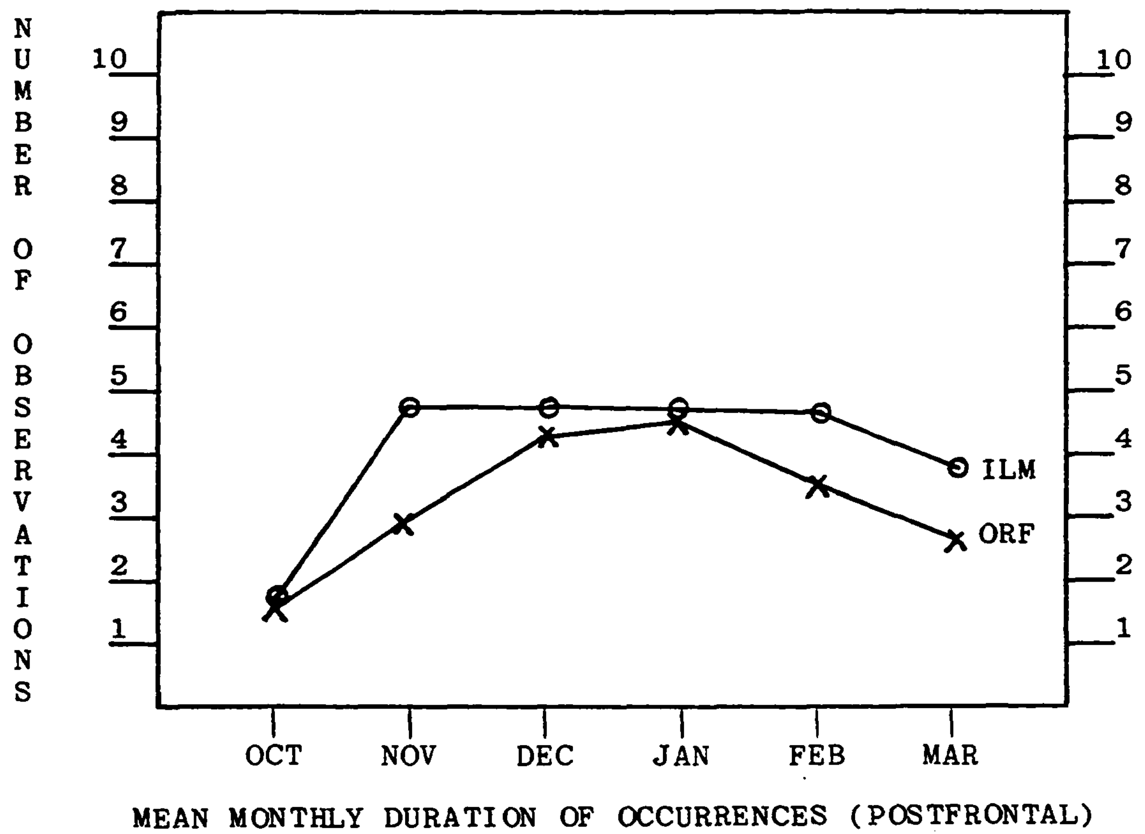
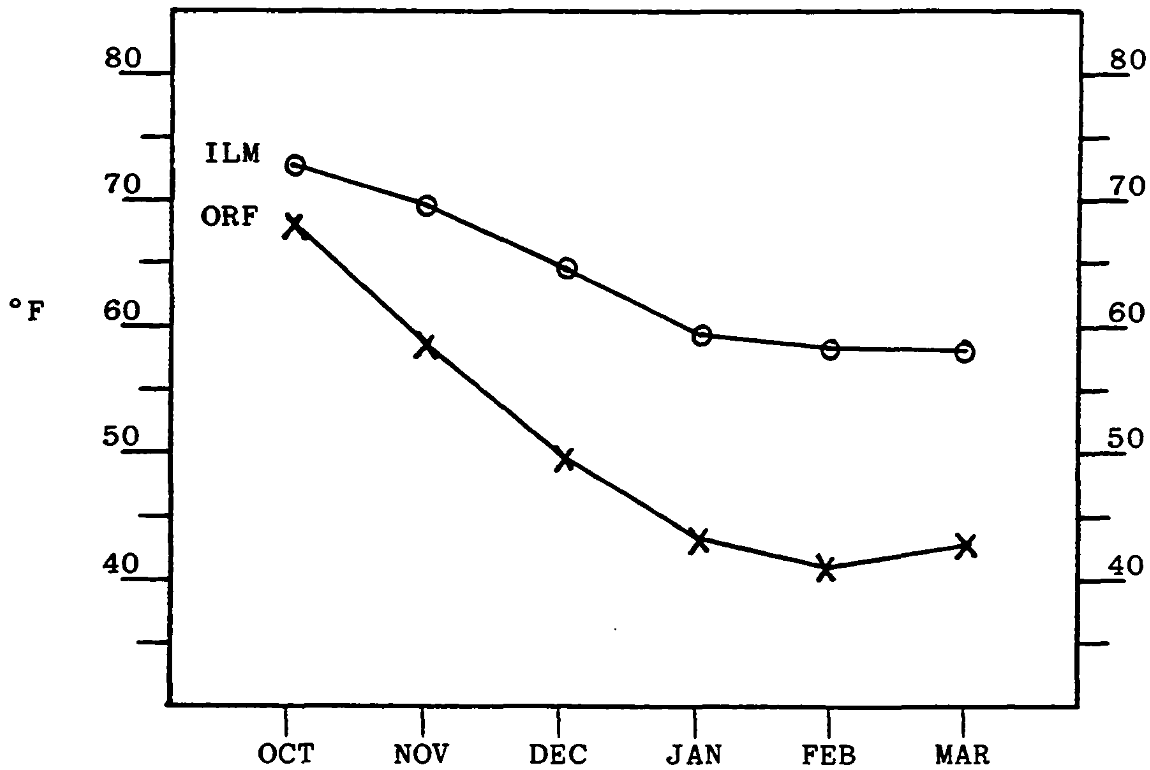
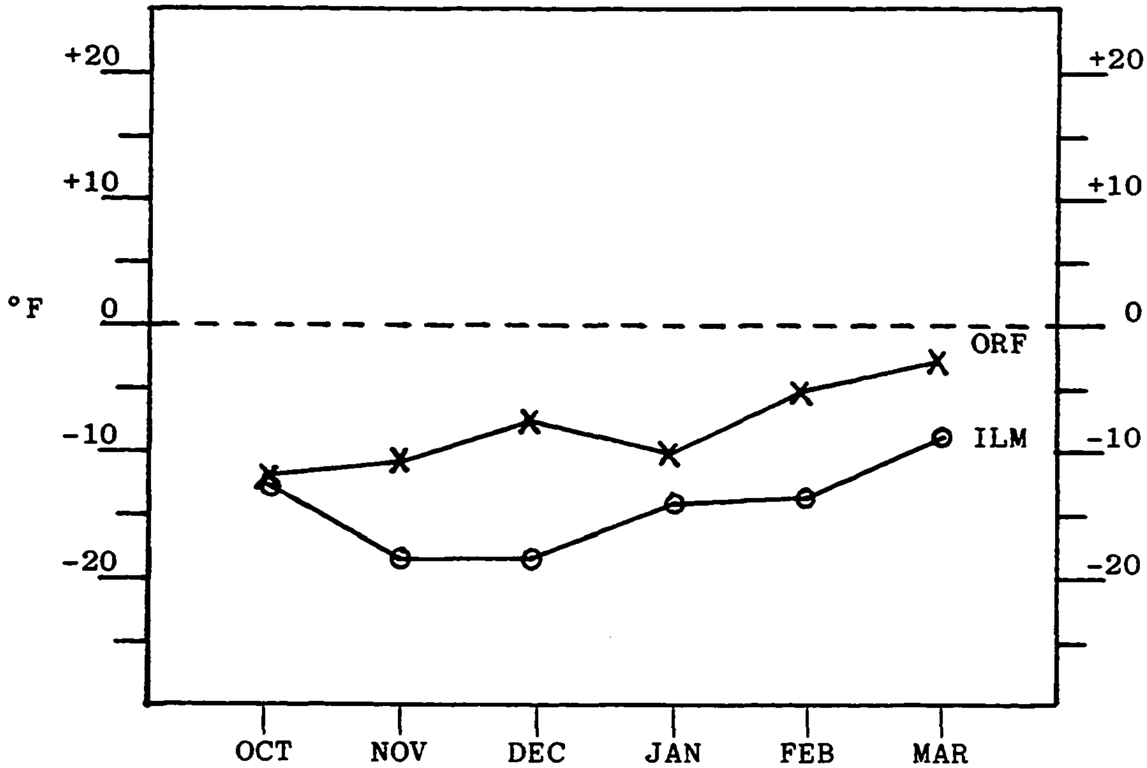

NUMBER OF OBSERVATIONS
10
9
8
7
6
5
4
3
2
1
ILM
ORF
OCT
NOV
DEC
JAN
FEB
MAR
MEAN MONTHLY DURATION OF OCCURRENCES (POSTFRONTAL)

FIGURE 21



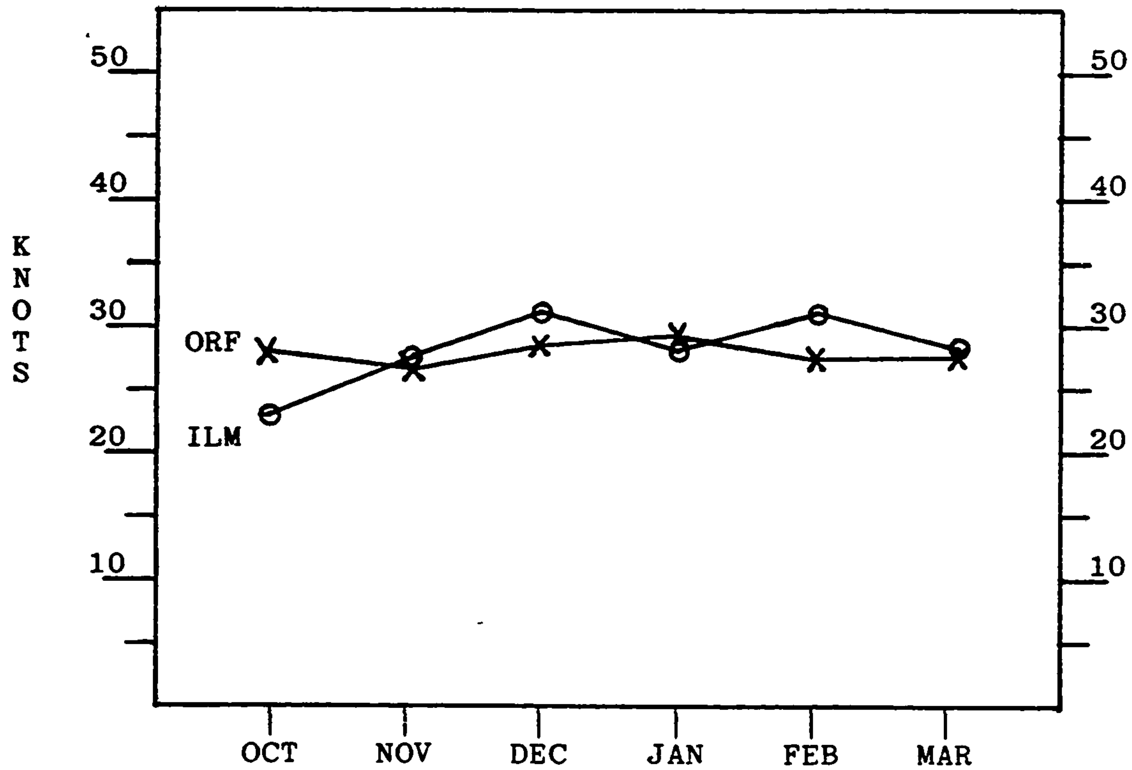
MEAN MONTHLY SEA SURFACE TEMPERATURE (POSTFRONTAL)

FIGURE 22



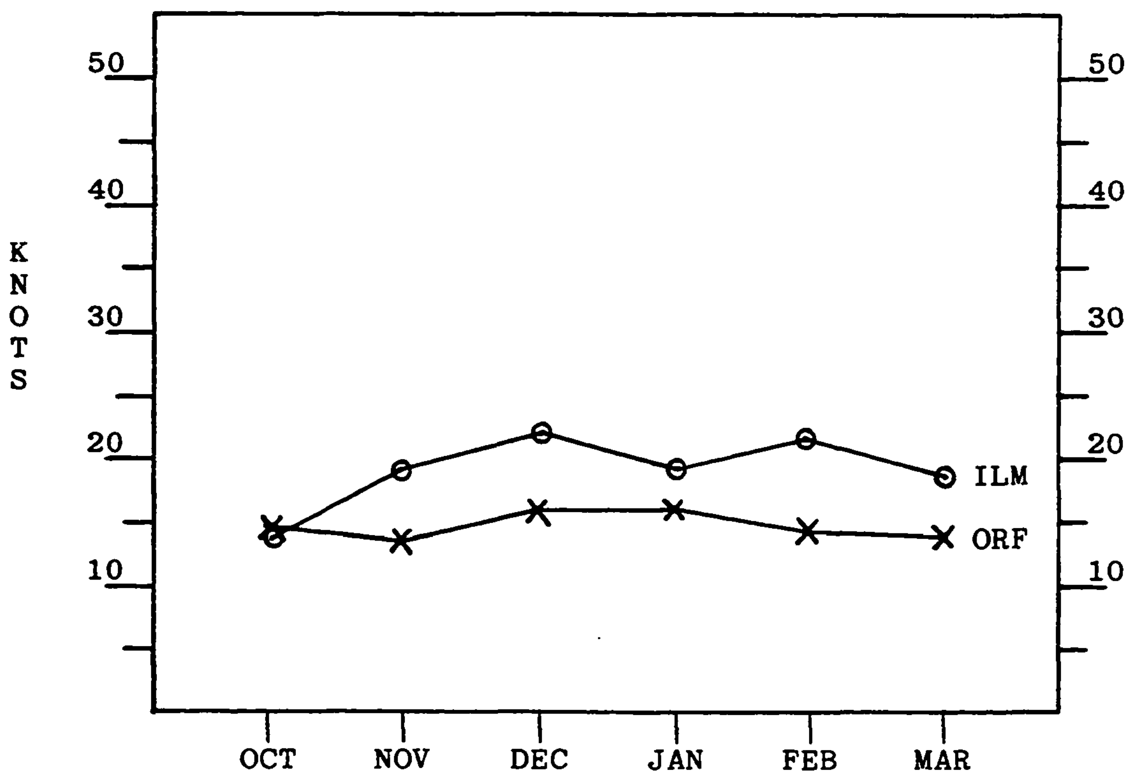
MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE
(POSTFRONTAL)

FIGURE 23



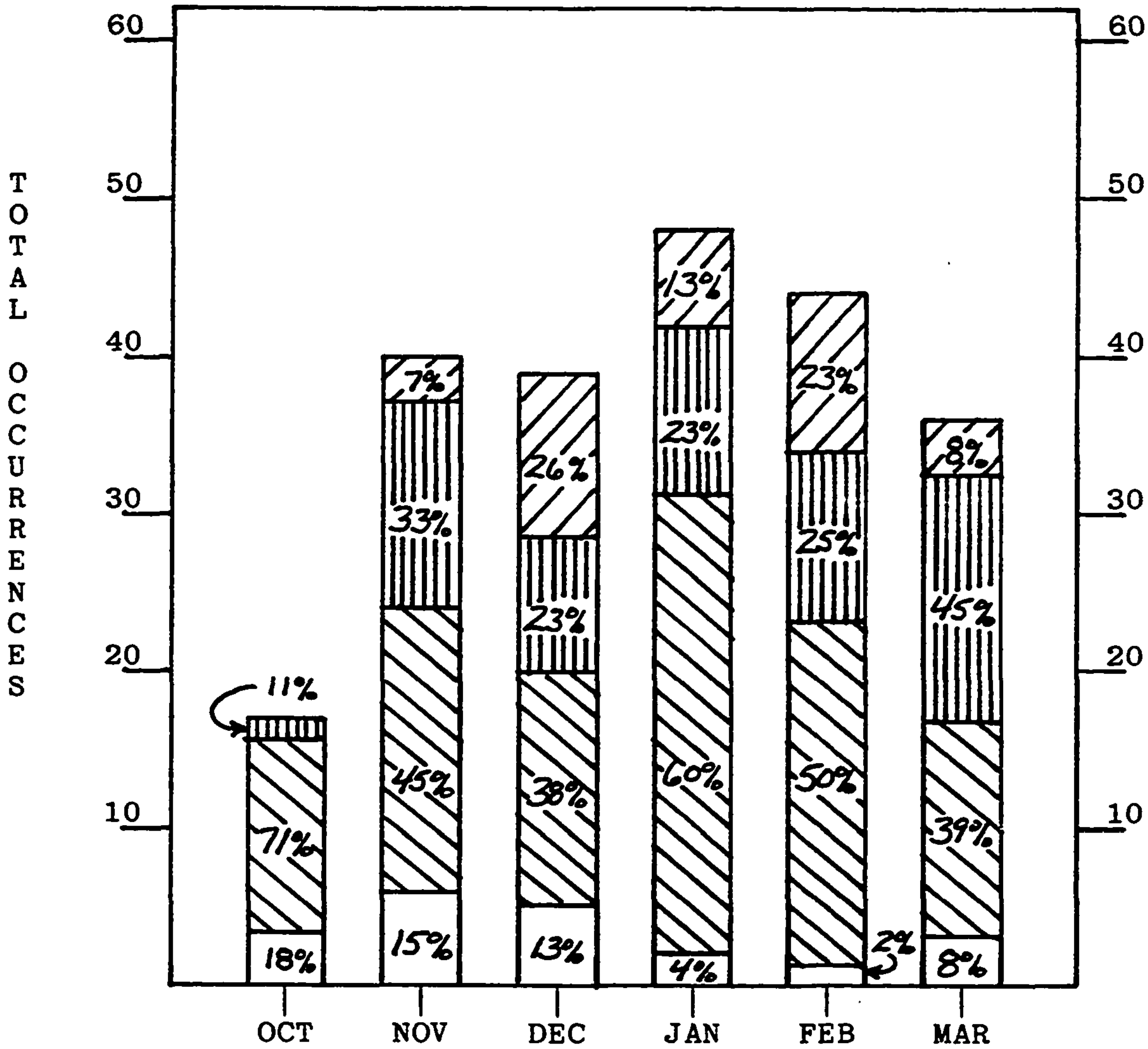
MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER
(POSTFRONTAL)

FIGURE 24



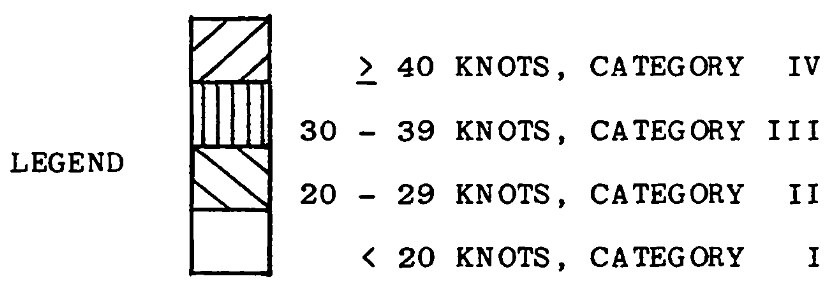
MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE
(POSTFRONTAL)

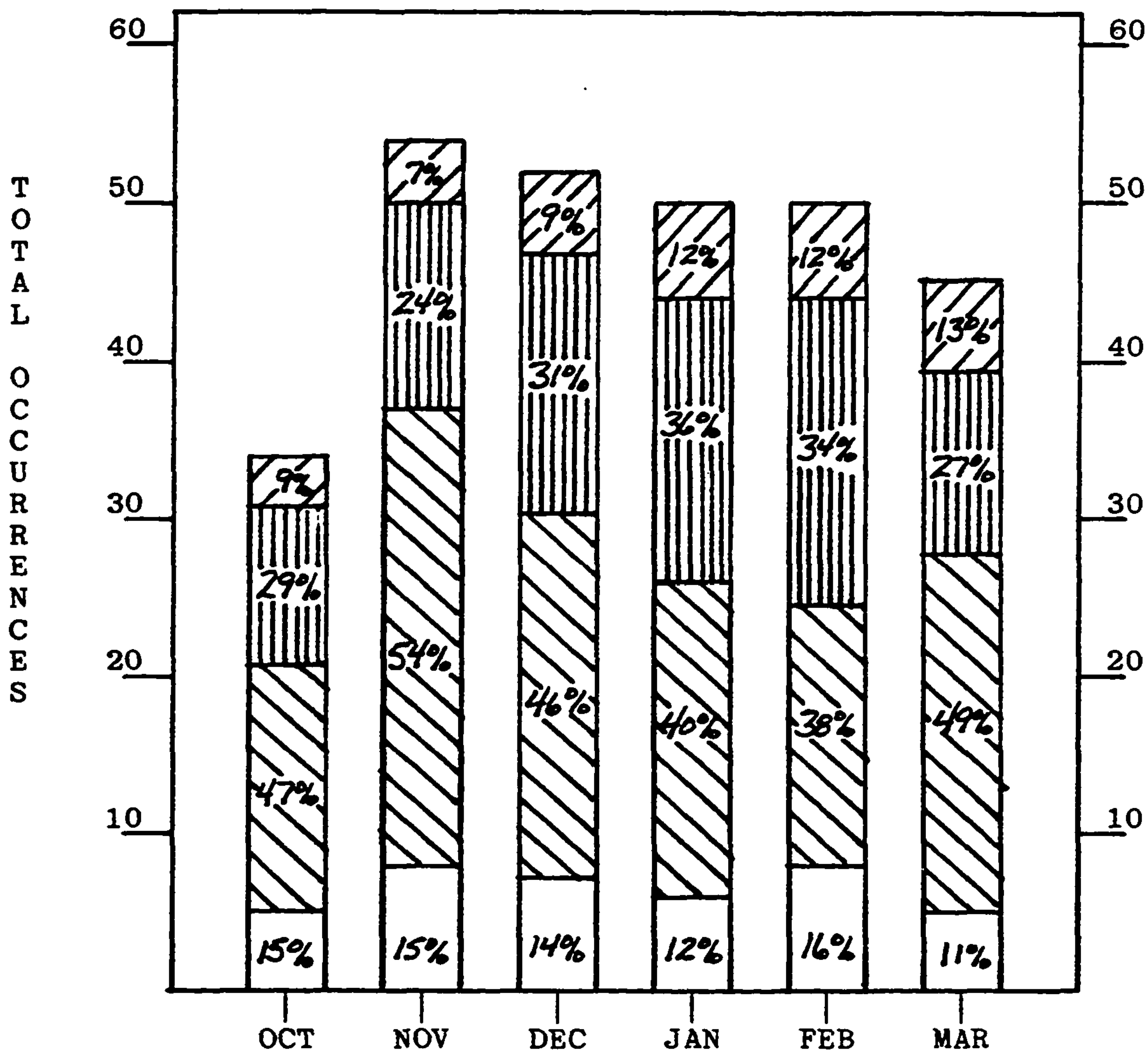
FIGURE 25



PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ILM (POSTFRONTAL)

FIGURE 26





PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ORF (POSTFRONTAL)

FIGURE 27

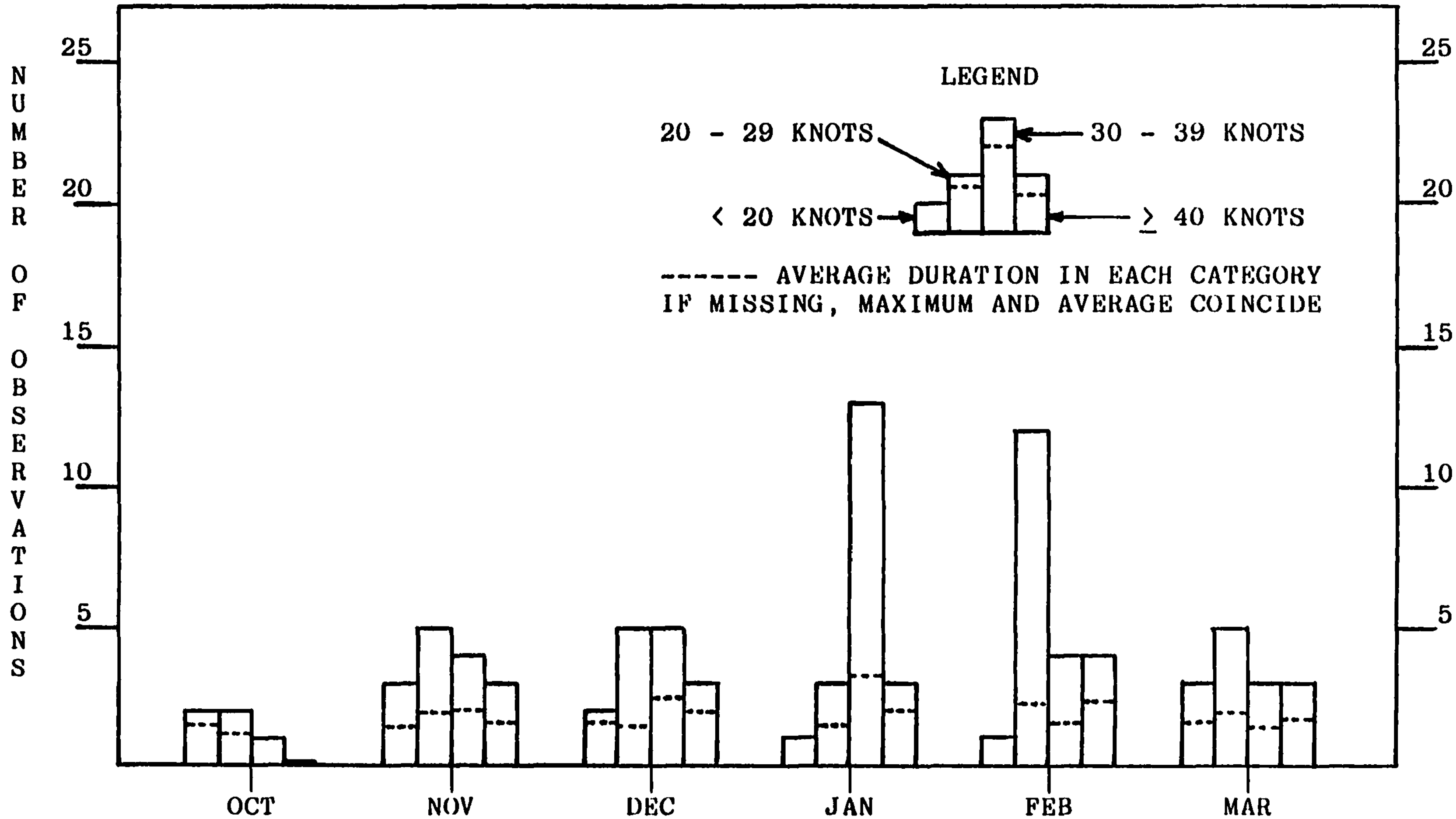
LEGEND

≥ 40 KNOTS, CATEGORY IV

30 - 39 KNOTS, CATEGORY III

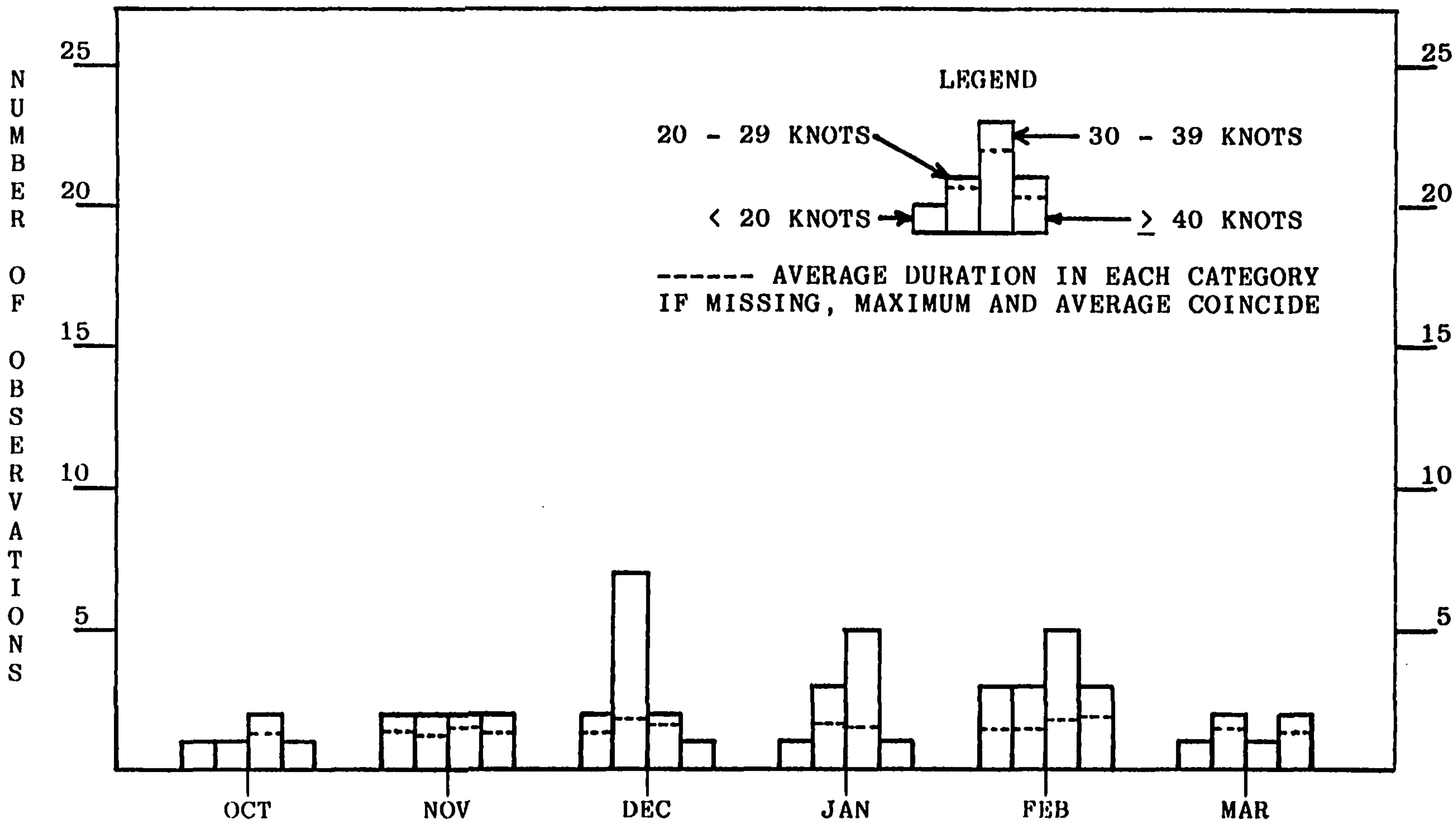
20 - 29 KNOTS, CATEGORY II

< 20 KNOTS, CATEGORY I



ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ILM (POSTFRONTAL)

FIGURE 28



ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ORF (POSTFRONTAL)

FIGURE 29

TABLE 2: SUMMARY OF DATA FOR THE POSTFRONTAL PATTERN

A. MEAN MONTHLY FREQUENCY OF OCCURRENCES (FIGURE 20)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	2.125	5.125	4.875	6.125	5.625	4.625
ORF	4.250	6.750	6.500	6.250	6.250	5.625

B. MEAN MONTHLY DURATION OF OCCURRENCES IN NUMBER OF SYNOPTIC OBSERVATIONS (FIGURE 21) (ONE SYNOPTIC OBSERVATION PERIOD = SIX HOURS)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	2.82	4.85	4.82	4.77	4.75	3.78
ORF	2.79	2.96	4.17	4.66	3.44	2.53

C. MEAN MONTHLY SEA SURFACE TEMPERATURE (°F) (FIGURE 22)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	72.2	69.7	64.3	59.1	58.1	57.5
ORF	67.3	57.7	49.5	42.9	40.2	42.5

D. MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE (°F) (AIR TEMP - SEA TEMP) (FIGURE 23)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	-12.8	-18.4	-18.3	-14.8	-14.6	-9.1
ORF	-12.6	-10.9	-8.2	-10.5	-5.4	-3.1

E. MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER (KNOTS) (FIGURE 24)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	22.7	27.3	30.6	27.9	30.5	28.4
ORF	27.3	26.4	28.1	29.1	27.3	28.1

TABLE 2 (CONTINUED)

F. MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE (KNOTS) (FIGURE 25)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	14.7	19.3	22.2	19.5	21.2	18.5
ORF	14.9	14.1	15.4	15.7	14.2	14.7

G. TOTAL NUMBER OF INCREASED WIND SPEED OCCURRENCES WITH PERCENTAGE BREAKDOWN OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (FIGURES 26 AND 27)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
# OF EVENTS	17	40	39	48	44	36
< 20	18%	15%	13%	4%	2%	8%
20 - 29	71%	45%	38%	60%	50%	39%
30 - 39	11%	33%	23%	23%	25%	45%
≥ 40	-	7%	26%	13%	23%	8%
ORF						
# OF EVENTS	34	54	52	50	50	45
< 20	15%	15%	14%	12%	16%	11%
20 - 29	47%	54%	46%	40%	38%	49%
30 - 39	29%	24%	31%	36%	34%	27%
≥ 40	9%	7%	9%	12%	12%	13%

H. ABSOLUTE MAXIMUM DURATION OF MEAN MAXIMUM WIND SPEEDS AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (IN SYNOPTIC PERIODS) (FIGURES 28 AND 29)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
< 20	2/1.67	3/1.33	2/1.60	1/1.00	1/1.00	3/1.67
20 - 29	2/1.08	5/1.94	5/1.53	3/1.28	12/2.14	5/1.93
30 - 39	1/1.00	4/2.00	5/2.33	13/3.09	4/1.36	3/1.38
≥ 40	-	3/1.67	3/2.00	3/2.00	4/2.20	3/1.67
ORF						
< 20	1/1.00	2/1.25	2/1.14	1/1.00	3/1.25	1/1.00
20 - 29	1/1.00	2/1.21	7/1.67	3/1.45	3/1.26	2/1.23
30 - 39	2/1.10	2/1.31	2/1.50	5/1.33	5/1.59	1/1.00
≥ 40	1/1.00	2/1.25	1/1.00	1/1.00	3/1.83	2/1.17

C. Northeast Pattern

1. Wilmington/Frying Pan Light (ILM)

In the 210 observed occurrences of the northeast condition, mean monthly frequencies of occurrences existed between 3.500 and 5.250 with relative highs in October and January (Figure 30). Mean monthly durations of occurrences (Figure 31) became more erratic from a 3.80 period low in March to significant highs of 9.41 in October and 6.11 periods in February. A possible explanation for this longer duration was the synoptic pattern itself, which will be presented in detail in the conclusions.

Mean monthly sea surface temperatures (Figure 32) remained within two and a half degrees of the observed means in the pre- and postfrontal patterns. With a cold, northeasterly flow, mean monthly air-sea temperature differences (Figure 33) were predictably negative (air colder than water). This pattern produced the widest temperature differences with minimums of -14.6°F and -12.9°F in October and March and a maximum of -24.9°F in December.

Mean monthly maximum wind speeds (Figure 34) remained fairly constant while mean monthly sea-land wind speed differences (Figure 35) were unusually consistent, between

17.3 and 19.6 knots.

Despite having the greatest mean air-sea temperature differences of the four synoptic patterns, mean monthly maximum wind speeds and mean monthly sea-land wind speed differences remained extraordinarily steady. This consistency probably resulted, in part, from two factors acting in concert: the air mass was at, or near, saturation which aided in limiting any further substantial latent heat transfer; and subsidence, from the high pressure system located to the north, which provided a stabilizing effect due to the downward motion in the air itself.

Percentages of mean maximum wind speeds (Figure 36) shifted toward Categories II and III at the expense of winds in Category IV. Percentages in Category I remained nearly unchanged all season from the postfrontal pattern.

Mean durations of mean maximum wind speeds (Figure 38) were slightly longer than in the postfrontal case, between one and a half and four observation periods. Absolute maximums occurred between one and nine periods but lengths of 12, 13 and 22 were also observed. The 22 period event (132 hours) occurred in October within Category II, with wind speeds maintaining nearly 22 knots throughout the occurrence.

2. Norfolk/Chesapeake Light (ORF)

As at ILM, a distinct increase in October of mean monthly frequency of occurrences (Figure 30) and mean monthly durations of occurrences (Figure 31) was noted. The remaining five months showed relatively even values.

Mean monthly sea surface temperatures (Figure 32) were nearly unchanged from previous synoptic cases. Mean air-sea temperature differences (Figure 33) remained negative from October to January but made a change in February increasing to +1.8°F (air warmer than water). In March, the mean air-sea temperature difference had a value of zero which indicated that the air and water temperatures were virtually the same.

Mean monthly maximum wind speeds (Figure 34) were very constant through the season as were the mean monthly sea-land wind speed differences (Figure 35).

Of the 106 total northeast occurrences, percentages of the mean maximum wind speeds (Figure 37) showed a decrease in Category I through the winter months with Categories II and III maintaining the greatest portion. January and March were months with the greatest number of Category IV winds, up to two and a half times the number of occurrences of the other four months.

The absolute maximum durations of mean maximum wind speeds (Figure 39) indicated an anomaly in October of five periods (30 hours) in Category II. This was the longest duration for the entire eight years at ORF.

3. Comparison

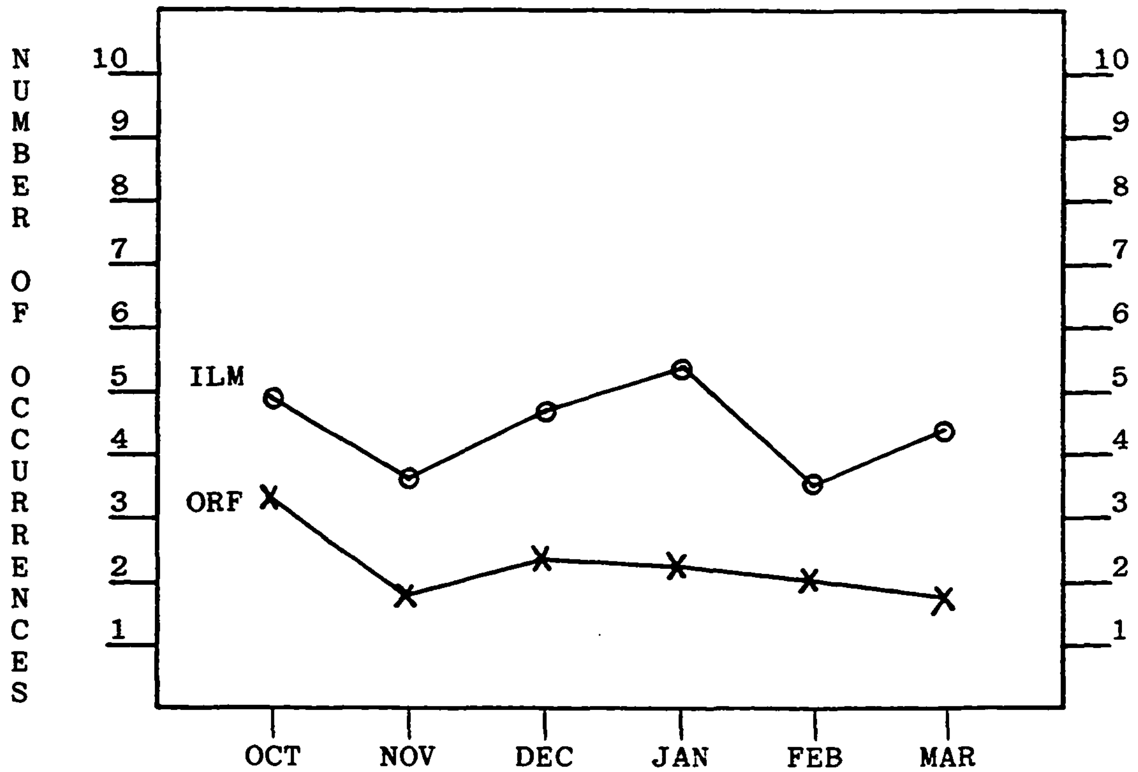
Even though the total number of occurrences was almost twice as many at ILM than ORF, 210 versus 106, mean durations of occurrences at both stations showed one particular anomaly. In October, mean durations of occurrences were far above those for the remaining five months, 9.41 periods at ILM, 6.62 periods at ORF. For the remainder of the season, ORF displayed a bell shaped curve for mean durations of occurrences, while at ILM, a random pattern existed.

Mean monthly sea surface temperatures at both stations decreased steadily through February with a slight increase noted in March. The mean monthly air-sea temperature differences were significantly less at ORF than ILM, up to 22.2°F less in December due to the relatively colder water located at Chesapeake Light.

Mean monthly maximum wind speeds varied little between the two stations. The primary difference in the wind data was at ILM in the mean monthly sea-land wind speed differences; these were three to five knots higher at ILM.

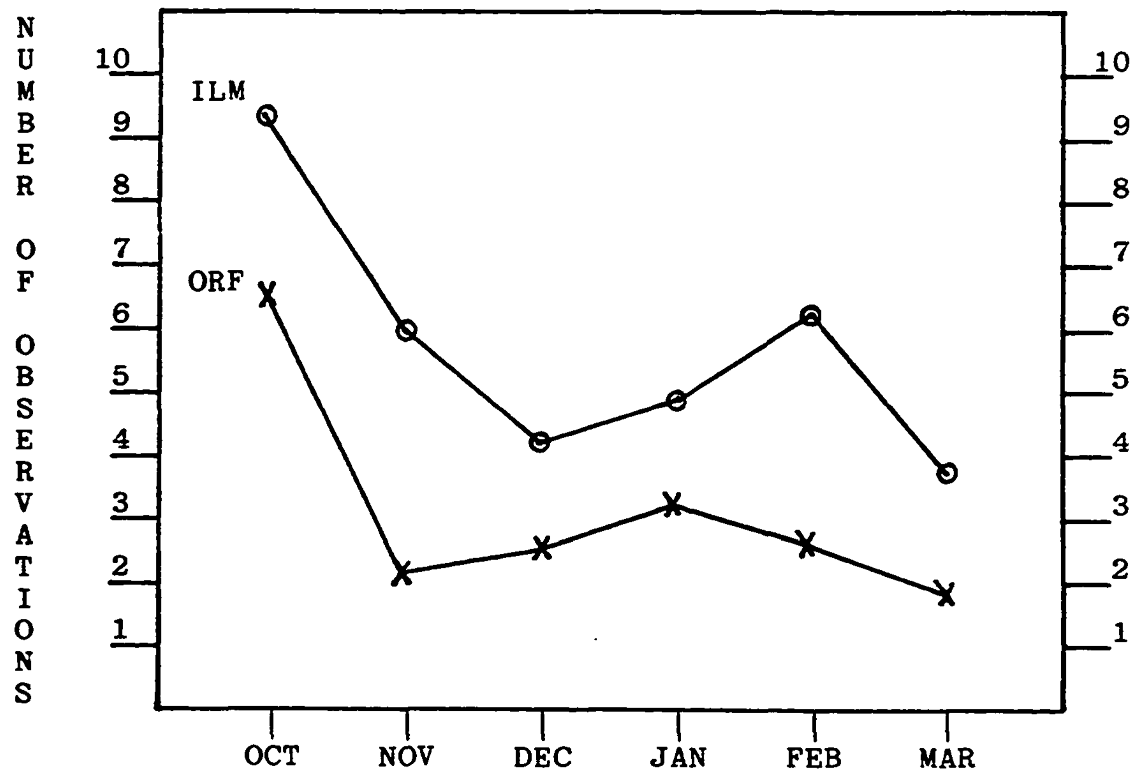
Percentages of mean maximum wind speeds showed ORF having the majority in Categories I and II while at ILM, Categories II and III possessed the largest portions; these values suggested that in a northeasterly flow pattern, wind speeds can be expected to be stronger over areas where the sea surface temperature is warmer.

Anomalies in absolute maximum wind speed durations were observed in October for both stations, ILM for 22 periods (132 hours) in Category II, and ORF 12 periods (72 hours) in Category II. Other absolute maximums also observed at ILM were 13 in November (Category II), and 12 (Category III) and nine (Category IV) in October. For the remainder of the season, ILM showed absolute maximum durations of mean maximum wind speeds between one and eight periods, while at ORF, absolute maximum values stayed in the one to three period range. Mean durations of mean maximum wind speeds overall were significantly longer at ILM (2.15 periods), nearly twice that of ORF (1.19 periods). (See Table 3 for a summary of data for the Northeast Pattern.)



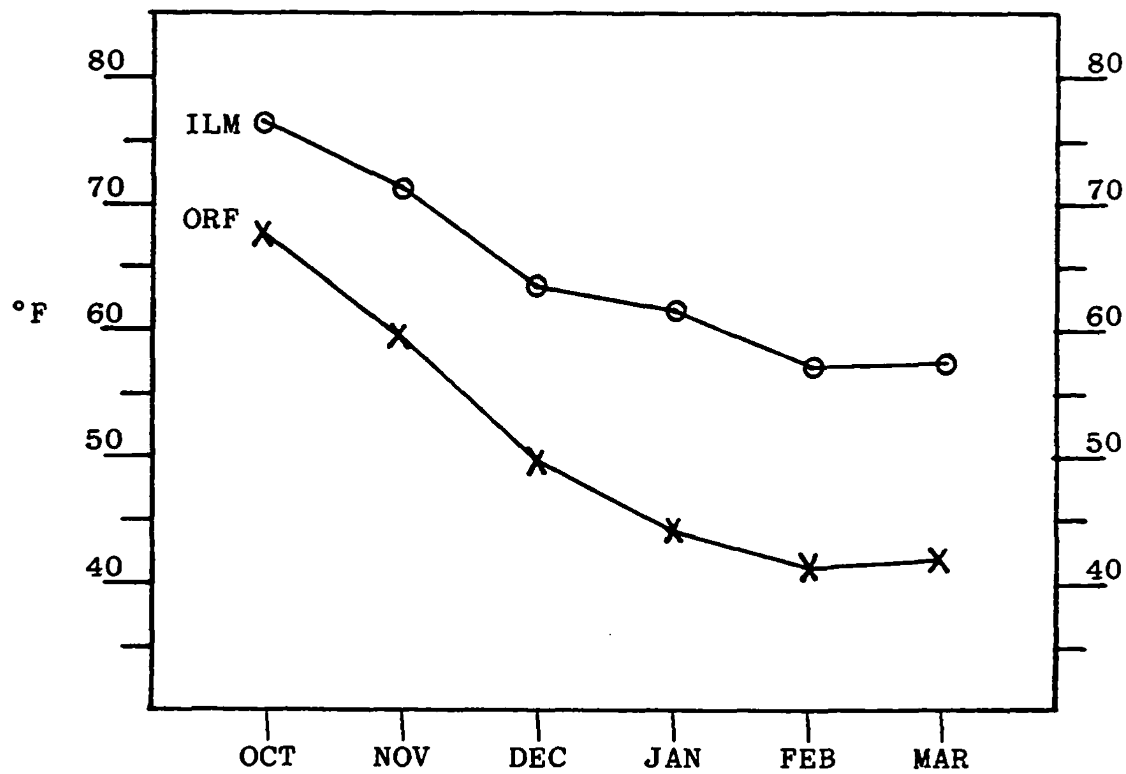
MEAN MONTHLY FREQUENCY OF OCCURRENCES (NORTHEAST)

FIGURE 30



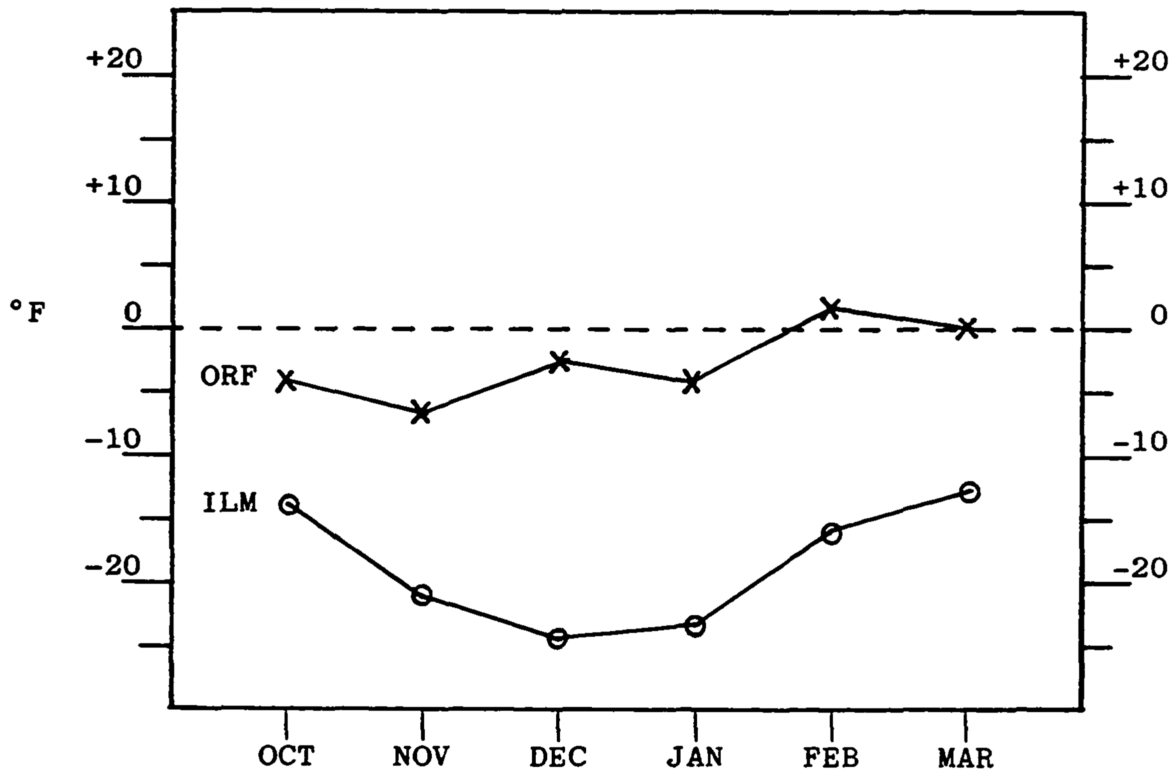
MEAN MONTHLY DURATION OF OCCURRENCES (NORTHEAST)

FIGURE 31



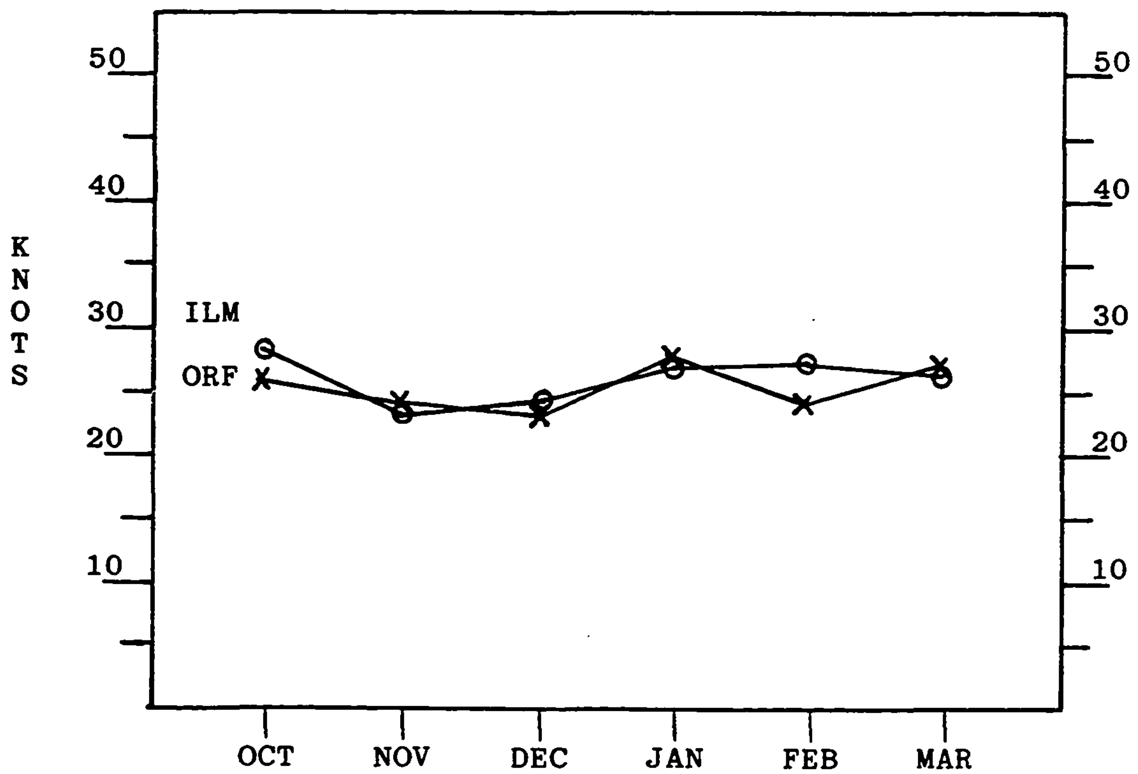
MEAN MONTHLY SEA SURFACE TEMPERATURE (NORTHEAST)

FIGURE 32



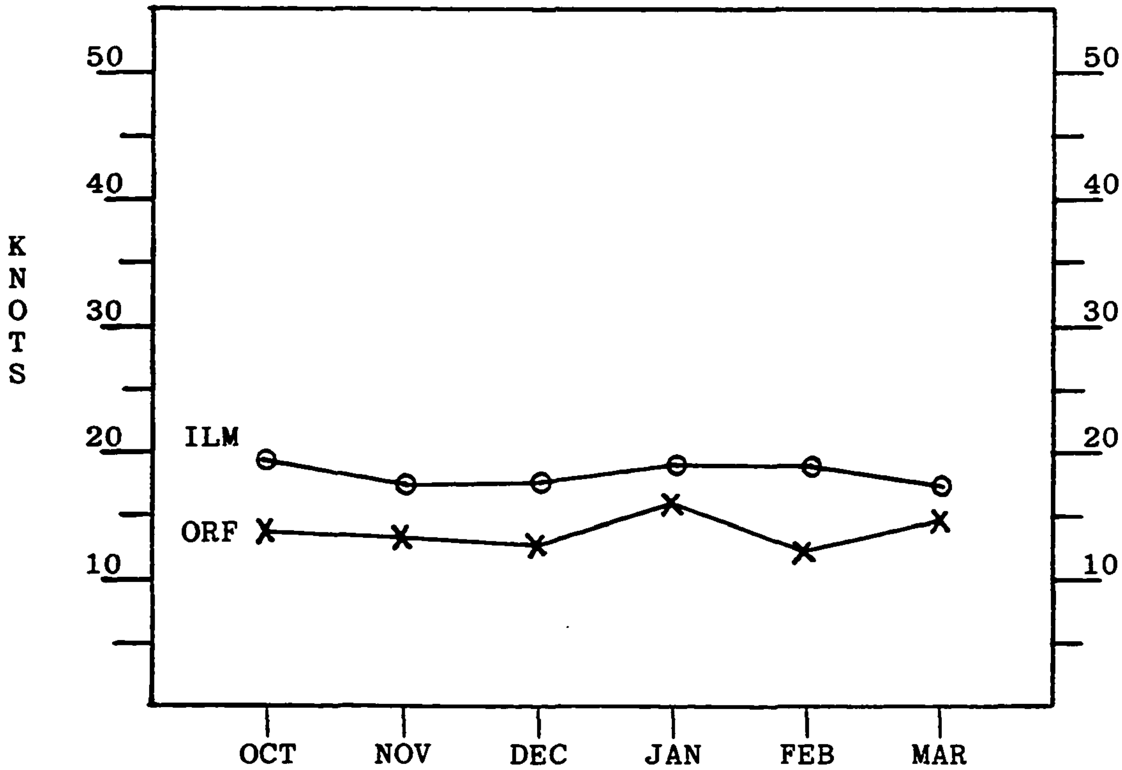
MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE
(NORTHEAST)

FIGURE 33



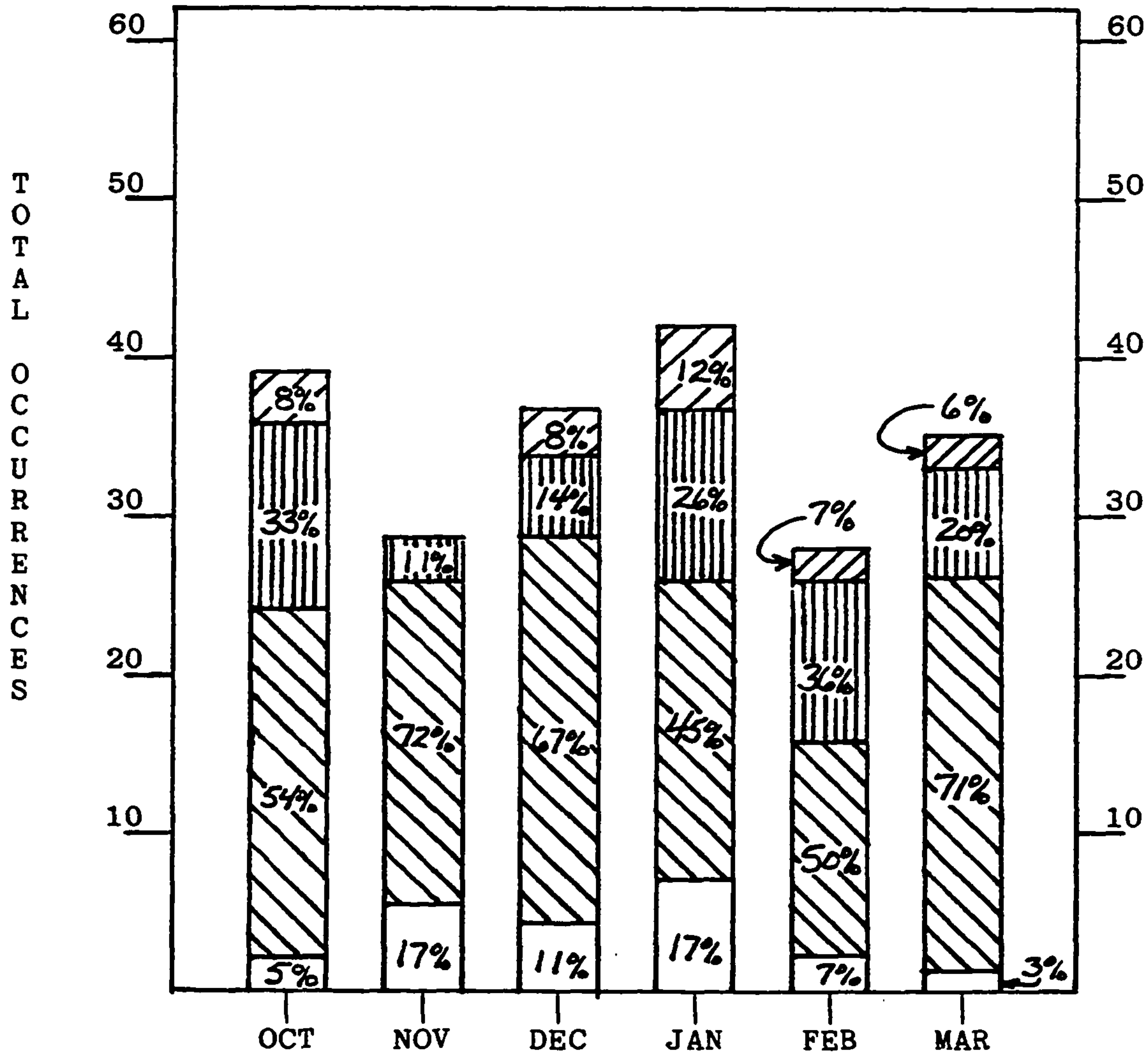
MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER
(NORTHEAST)

FIGURE 34



MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE
(NORTHEAST)

FIGURE 35

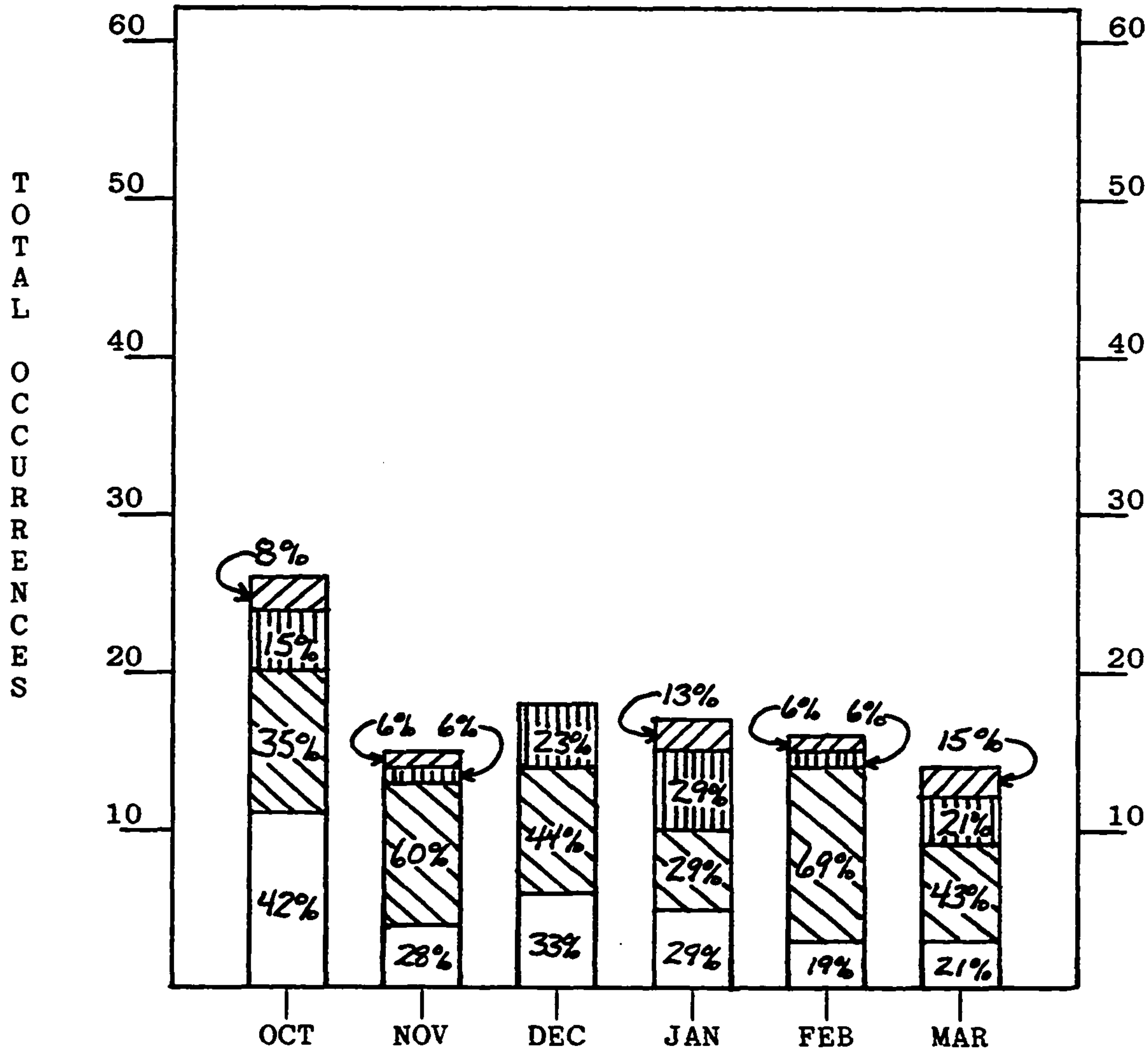


PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ILM (NORTHEAST)

FIGURE 36

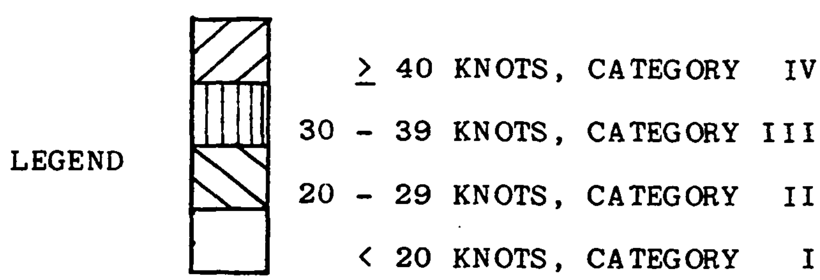
LEGEND

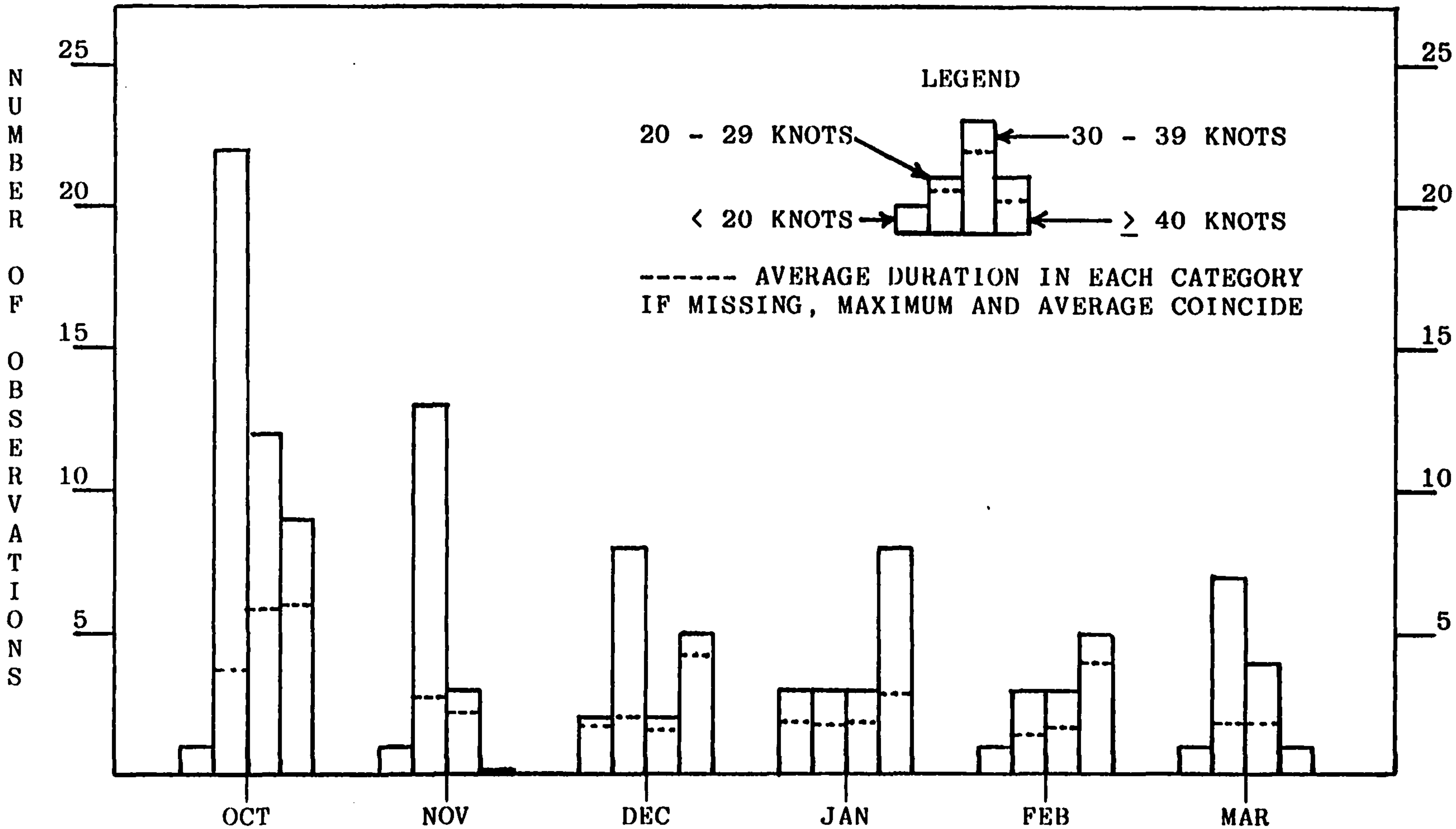
- ≥ 40 KNOTS, CATEGORY IV
- 30 - 39 KNOTS, CATEGORY III
- 20 - 29 KNOTS, CATEGORY II
- < 20 KNOTS, CATEGORY I



PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ORF (NORTHEAST)

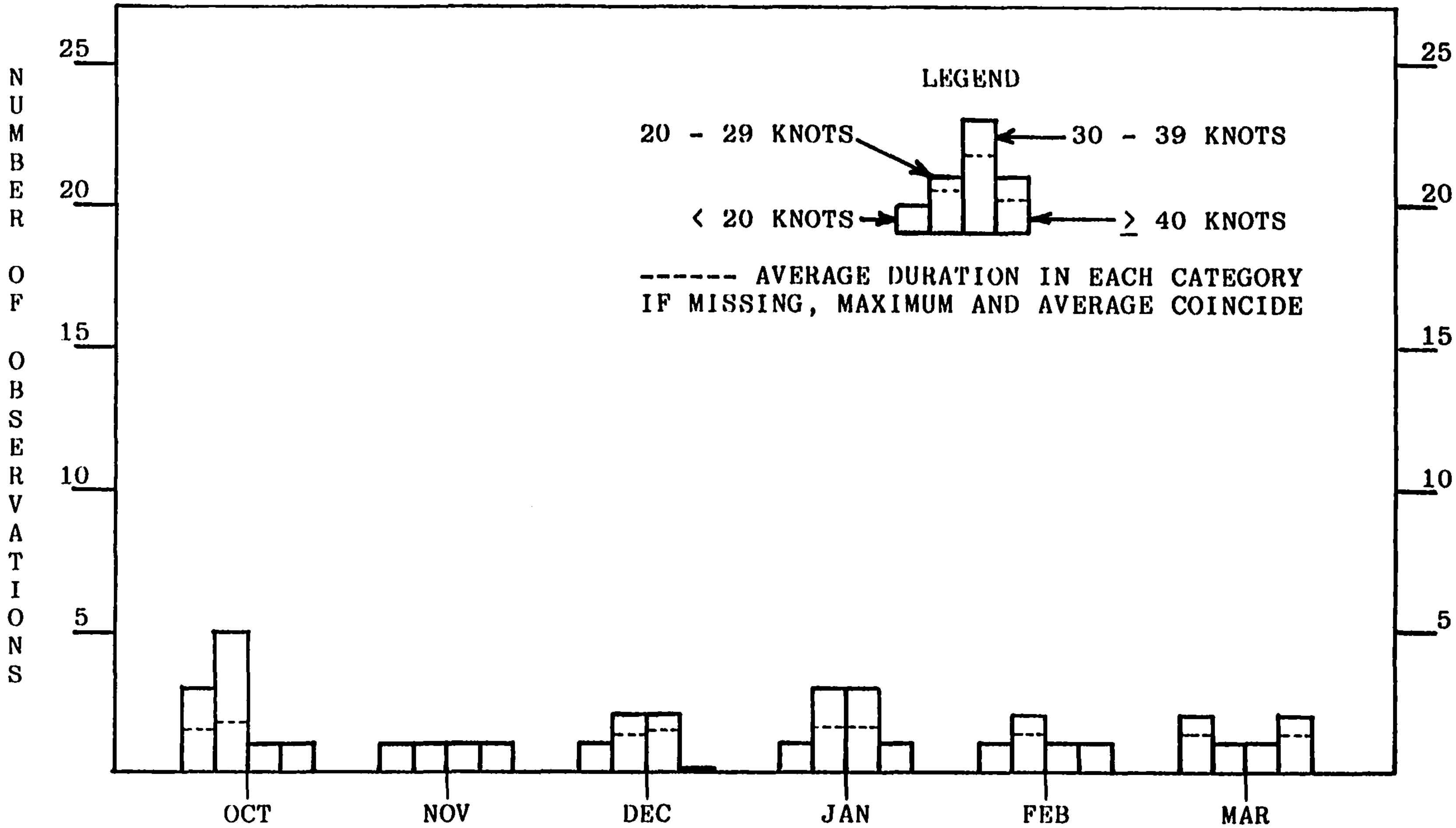
FIGURE 37





ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ILM (NORTHEAST)

FIGURE 38



ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ORF (NORTHEAST)

FIGURE 39

TABLE 3: SUMMARY OF DATA FOR THE NORTHEAST PATTERN

A. MEAN MONTHLY FREQUENCY OF OCCURRENCES (FIGURE 30)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	4.875	3.625	4.625	5.250	3.500	4.250
ORF	3.250	1.875	2.250	2.125	2.000	1.750

B. MEAN MONTHLY DURATION OF OCCURRENCES IN NUMBER OF SYNOPTIC OBSERVATIONS (FIGURE 31) (ONE SYNOPTIC OBSERVATION PERIOD = SIX HOURS)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	9.41	6.00	4.11	4.90	6.11	3.80
ORF	6.62	2.07	2.50	3.06	2.62	1.93

C. MEAN MONTHLY SEA SURFACE TEMPERATURE (°F) (FIGURE 32)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	76.1	71.4	63.7	61.7	57.1	57.3
ORF	67.6	59.1	49.3	43.9	40.9	41.4

D. MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE (°F) (AIR TEMP - SEA TEMP) (FIGURE 33)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	-14.6	-21.2	-24.9	-23.6	-16.6	-12.9
ORF	-4.9	-7.0	-2.7	-4.6	1.8	0.0

E. MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER (KNOTS) (FIGURE 34)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	28.2	23.1	24.7	26.4	27.2	25.9
ORF	25.2	23.4	23.3	27.2	24.0	26.1

TABLE 3 (CONTINUED)

F. MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE (KNOTS) (FIGURE 35)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	19.6	17.6	17.7	18.9	18.6	17.3
ORF	13.9	13.1	12.5	15.4	12.3	14.6

G. TOTAL NUMBER OF INCREASED WIND SPEED OCCURRENCES WITH PERCENTAGE BREAKDOWN OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (FIGURES 36 AND 37)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
# OF EVENTS	39	29	37	42	28	35
< 20	5%	17%	11%	17%	7%	3%
20 - 29	54%	72%	67%	45%	50%	71%
30 - 39	33%	11%	14%	26%	36%	20%
≥ 40	8%	-	8%	12%	7%	6%
ORF						
# OF EVENTS	26	15	18	17	16	14
< 20	42%	28%	33%	29%	19%	21%
20 - 29	35%	60%	44%	29%	69%	43%
30 - 39	15%	6%	23%	29%	6%	21%
≥ 40	8%	6%	-	13%	6%	15%

H. ABSOLUTE MAXIMUM DURATION OF MEAN MAXIMUM WIND SPEEDS AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (SYNOPTIC OBSERVATIONS) (FIGURES 38 AND 39)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
< 20	1/1.00	1/1.00	2/1.50	3/1.57	1/1.00	1/1.00
20 - 29	22/3.14	13/2.67	8/2.00	3/1.32	3/1.50	7/1.72
30 - 39	12/5.54	3/2.00	2/1.40	3/1.45	3/1.60	4/1.71
≥ 40	9/5.67	-	5/4.00	8/2.80	5/4.00	1/1.00
ORF						
< 20	3/1.36	1/1.00	1/1.00	1/1.00	1/1.00	2/1.33
20 - 29	5/1.44	1/1.00	2/1.13	3/1.60	2/1.09	1/1.00
30 - 39	1/1.00	1/1.00	2/1.25	3/1.60	1/1.00	1/1.00
≥ 40	1/1.00	1/1.00	-	1/1.00	1/1.00	2/1.50

D. Southerly Pattern

1. Wilmington/Frying Pan Light (ILM)

Mean monthly frequency of occurrences (Figure 40) was computed from a total of 93 cases with slightly fewer numbers observed in the late winter months. Mean monthly durations of occurrences (Figure 41) were relatively long, near four periods per month.

Mean monthly sea surface temperatures (Figure 42) were aligned more to those in the prefrontal case with temperatures on the whole being the warmest observed. A gradual decrease in temperatures from 75.9°F in October to 59.6°F in February was observed with a warming trend indicated thereafter. These slightly warmer mean temperatures were possibly caused by two factors: the forcing of warmer surface water closer to the coast by onshore flow; and the warming of the water surface by the air itself. Mean monthly air-sea temperature differences (Figure 43) were significantly smaller than in the postfrontal or northeast patterns, and continued to decrease through the season.

Mean monthly maximum wind speeds (Figure 44) were reasonably steady during the last half of the winter. However, the first half showed the greatest fluctuations from a smooth curve. Mean monthly sea-land wind speed differences were unusually high for a stable flow pattern, 16.7 to 23.4 knots, which were comparable to those differences in the postfrontal pattern.

A larger percentage of mean maximum wind speeds occurred in Categories II and III (Figure 46). Only 12 of the 93 total occurrences consisted of winds in Category IV. The only significant anomaly was in October with three occurrences observed in Category IV. Southerly flow produced a rather uniform appearance in the mean durations of mean maximum wind speeds (Figure 48), with values only between one and two periods.

Absolute maximum durations of mean maximum wind speeds, five and six periods in length, occurred in all months except January and March. The slow movement of the the high pressure cell located offshore likely produced these longer duration periods.

2. Norfolk/Chesapeake Light (ORF)

An increase in mean monthly frequency of occurrences (Figure 40) was noted beginning in December. Mean monthly durations of occurrences were fairly constant between 1.88 2.47 periods for all six months (Figure 41).

Mean monthly sea surface temperatures (Figure 42) were nearly unchanged from previous flow patterns with a trend toward warming temperatures in March. The significant point was that five of the six months showed mean monthly air-sea temperature differences (Figure 43) that were positive and continued to increase through the season. This was indicative of warm air flow over a cooling water surface.

Mean monthly maximum wind speeds (Figure 44) were significantly lower and relatively constant, near 21 knots. Little importance was drawn from mean monthly sea-land wind speed differences (Figure 45) except that this type flow pattern at ORF was relatively stable as shown by the narrow range of values, between 10.6 and 12.0 knots.

Percentages of mean maximum wind speeds (Figure 47) revealed that winds in Category IV were noticeably missing. Speeds in Categories I and II had the majority portion in all months. This also appears to verify the fact that southerly flow was generally stable and not as turbulent in nature as the postfrontal or northeast patterns.

Mean durations of mean maximum wind speeds (Figure 49) were between one and one and a half periods with the overall trend of the absolute maximum durations being between two and three periods. Winds in Categories I and II were generally of longer duration than those few (ten of 151) in Category III.

3. Comparison

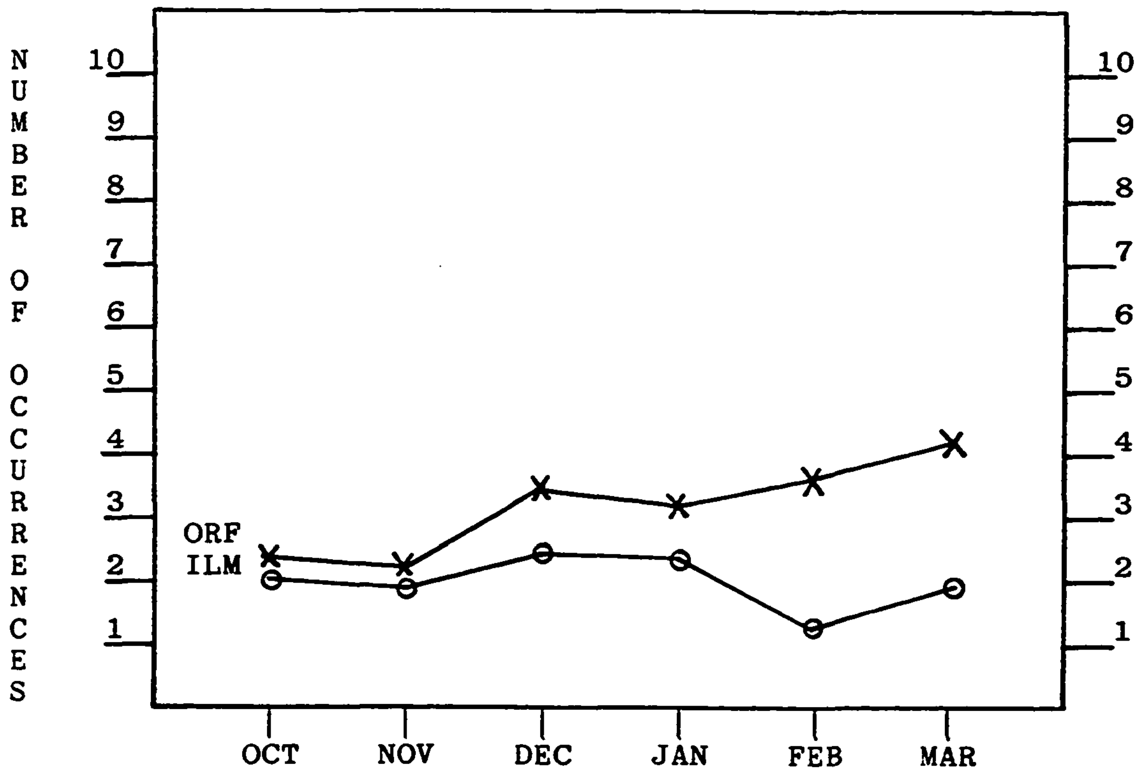
There were nearly one and a half times the number of occurrences at ORF than ILM, 151 and 93, respectively. The general trend was toward increasing mean monthly frequency of occurrences through the season at ORF. At ILM, however, mean monthly frequency of occurrences for the entire season remained nearly constant except for a slight decrease in February. The opposite was evident for the mean monthly duration of occurrences; ILM showed an erratic curve with up to twice the duration lengths as ORF. ORF, on the other hand, showed a level, nearly constant duration curve for the entire six months.

Trends in mean monthly sea surface temperatures changed little from the previous three synoptic patterns. However, mean monthly air-sea temperature differences were quite different. As would be expected, these temperature differences were positive at ORF (except for October), maintaining a steady increase through March as the air remained relatively warmer and the water temperature decreased. At ILM, all mean air-sea temperature differences were negative except for March, which was slightly positive, +1.3°F. Temperature differences revealed steady increases at ILM, also, but not as quickly as at ORF.

Mean monthly maximum wind speeds were dramatically different. ILM showed values between 24.5 and 29.9 knots while ORF remained near 20 knots. Mean monthly sea-land wind speed differences were also significantly different, ranging from 16.7 to 23.4 knots at ILM, while at ORF, differences were much lower, in the 10.9 to 12.0 knot range. These results revealed that even though there were fewer total occurrences at ILM, the mean duration of occurrences tended to be longer and the mean maximum wind speeds stronger.

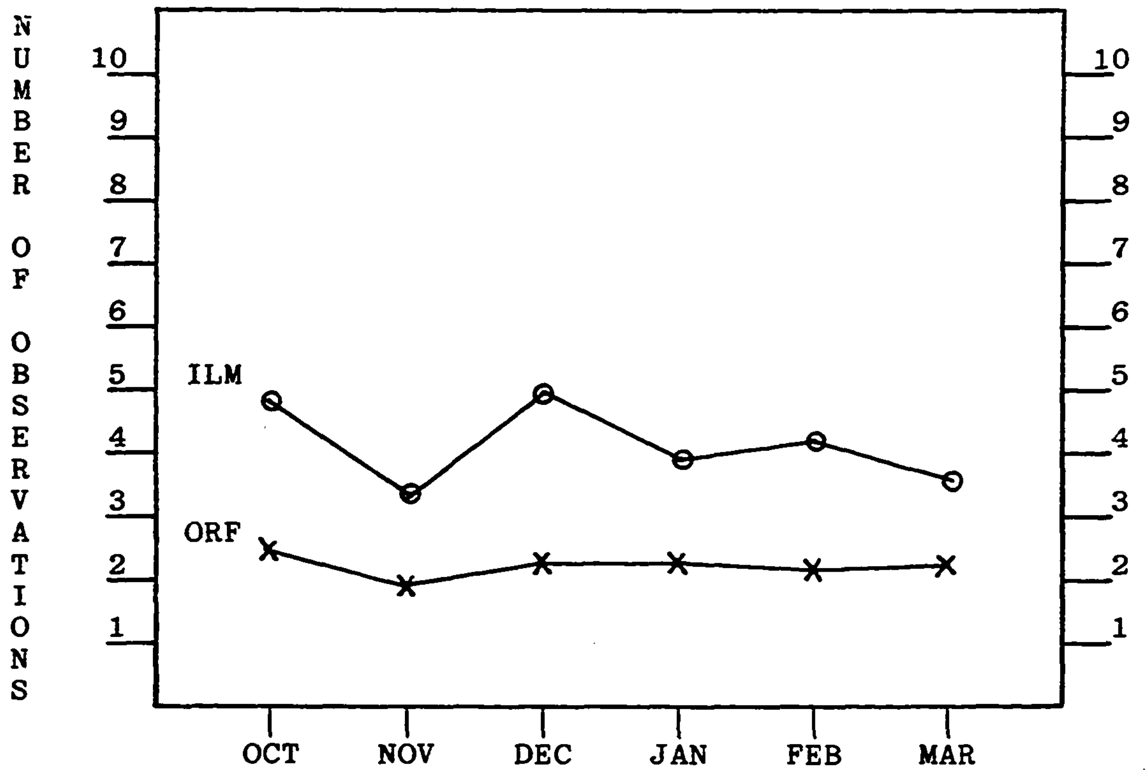
In the percentage breakdown of mean maximum wind speeds, the significant feature noted was the lack of Category IV winds at ORF, while at ILM, Category IV winds were indicated in all months but January. The majority of the winds at ORF were in Categories I and II. At ILM, however, a steady decrease in Category I continued into February with Categories II and III becoming the majority.

Mean durations of mean maximum wind speeds were only slightly longer at ILM with absolute maximum durations being nearly twice as long than at ORF. Absolute maximum durations were in the five and six observation period range at ILM, while two and three periods were the rule at ORF. (See Table 4 for a summary of data for the Southerly Pattern.)



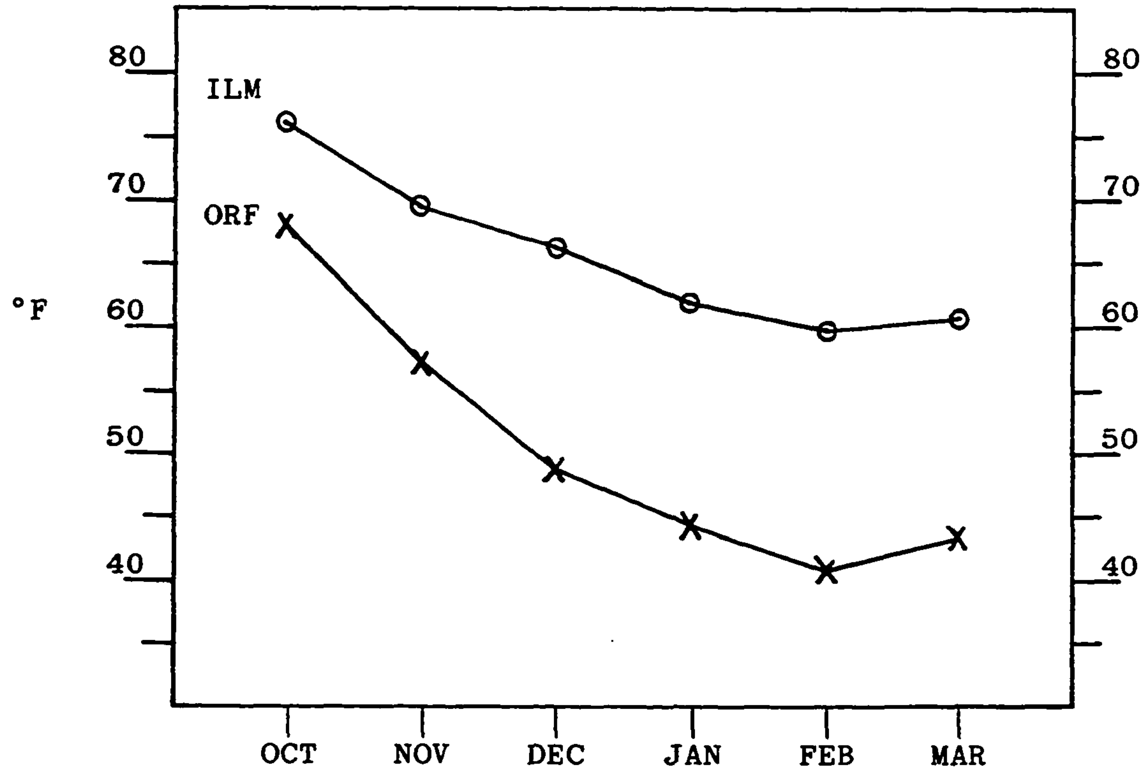
MEAN MONTHLY FREQUENCY OF OCCURRENCES (SOUTHERLY)

FIGURE 40



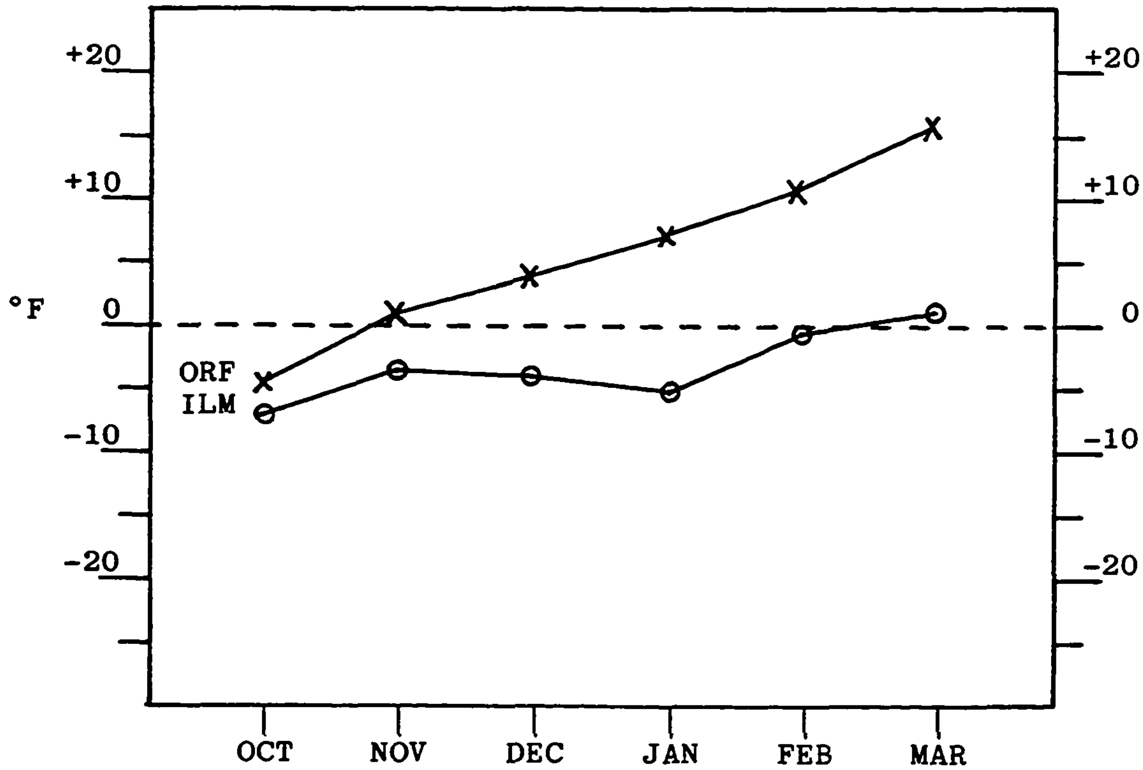
MEAN MONTHLY DURATION OF OCCURRENCES (SOUTHERLY)

FIGURE 41



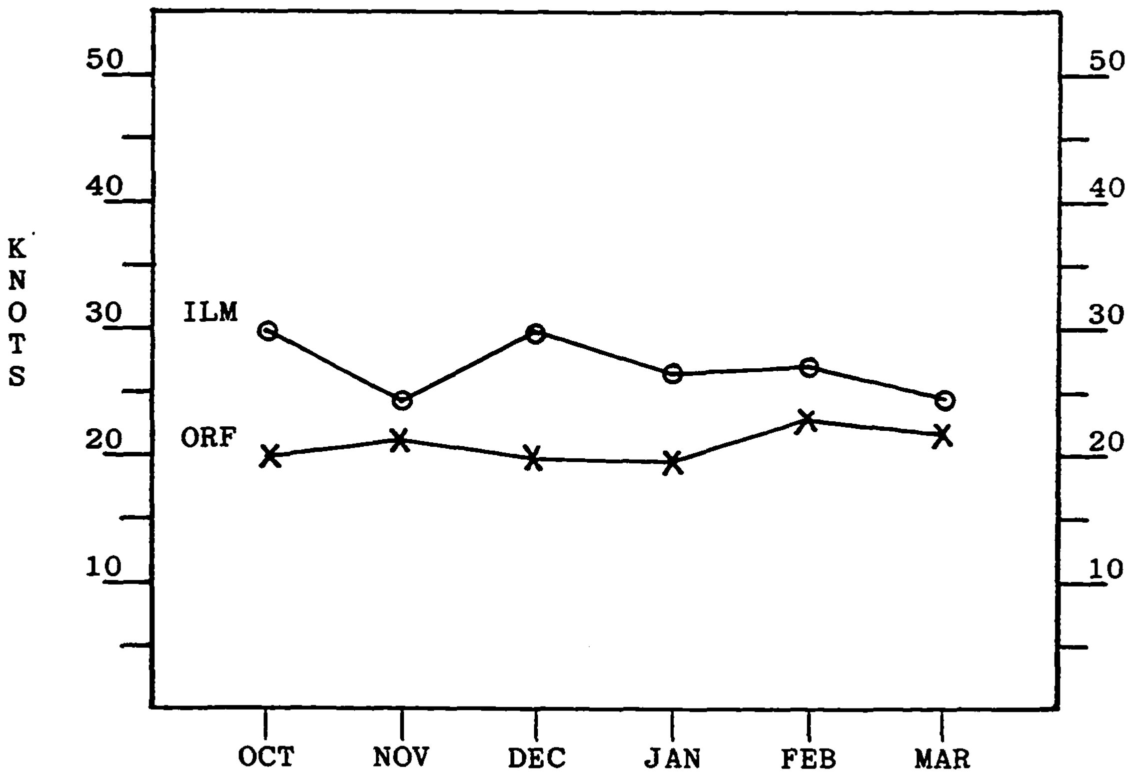
MEAN MONTHLY SEA SURFACE TEMPERATURE (SOUTHERLY)

FIGURE 42



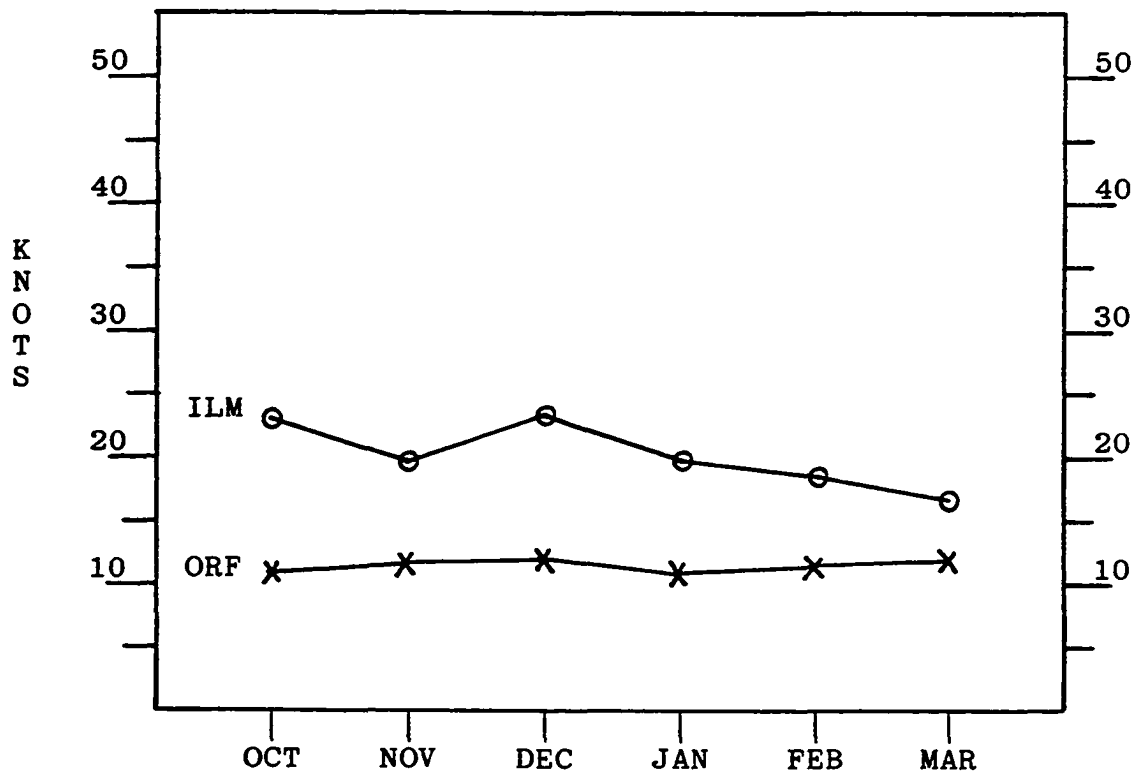
MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE
(SOUTHERLY)

FIGURE 43



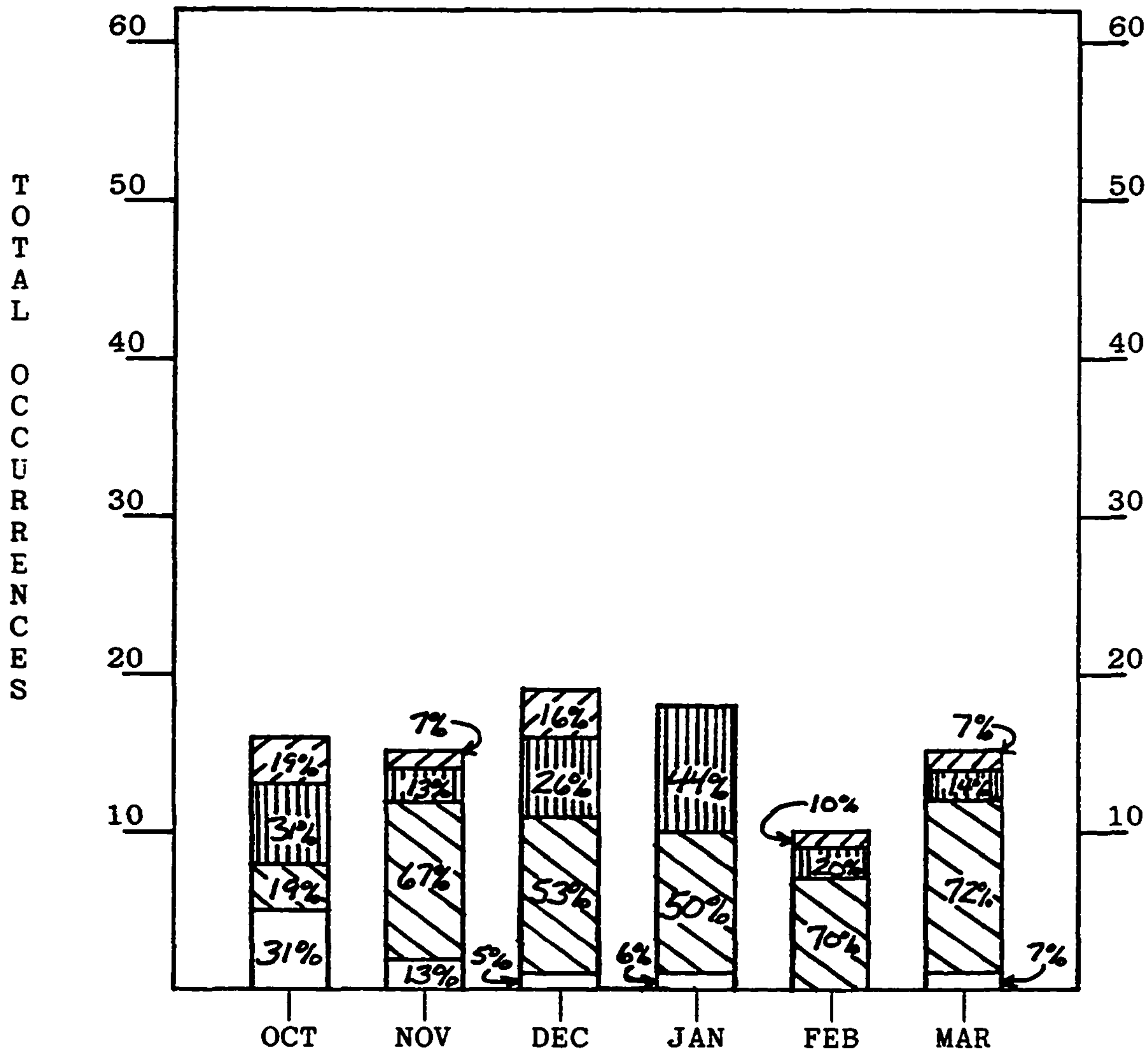
MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER
(SOUTHERLY)

FIGURE 44



MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE
(SOUTHERLY)

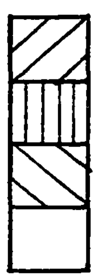
FIGURE 45



PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ILM (SOUTHERLY)

FIGURE 46

LEGEND

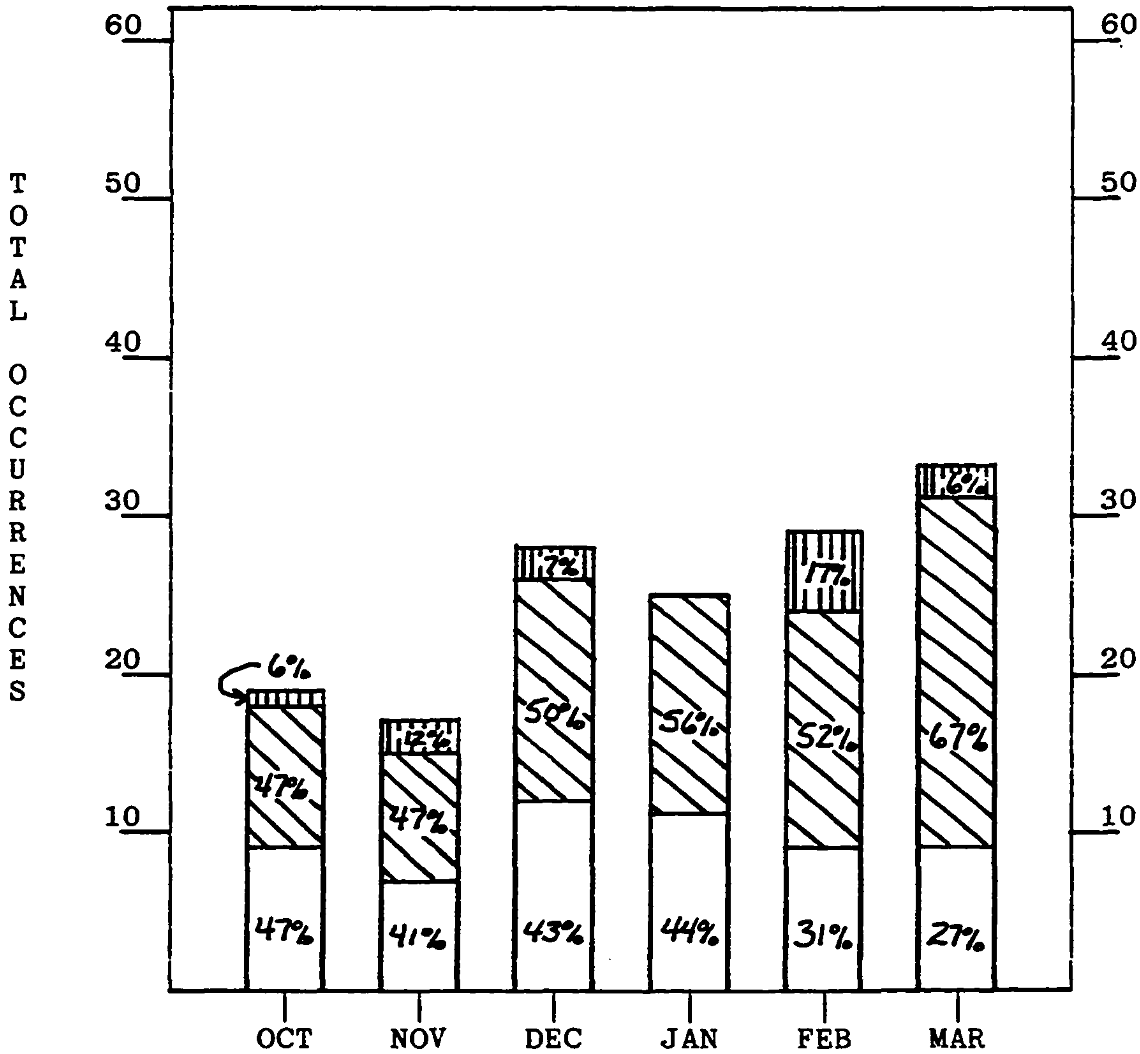


≥ 40 KNOTS, CATEGORY IV

30 - 39 KNOTS, CATEGORY III

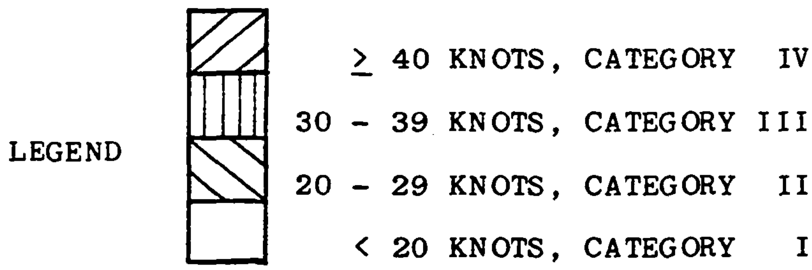
20 - 29 KNOTS, CATEGORY II

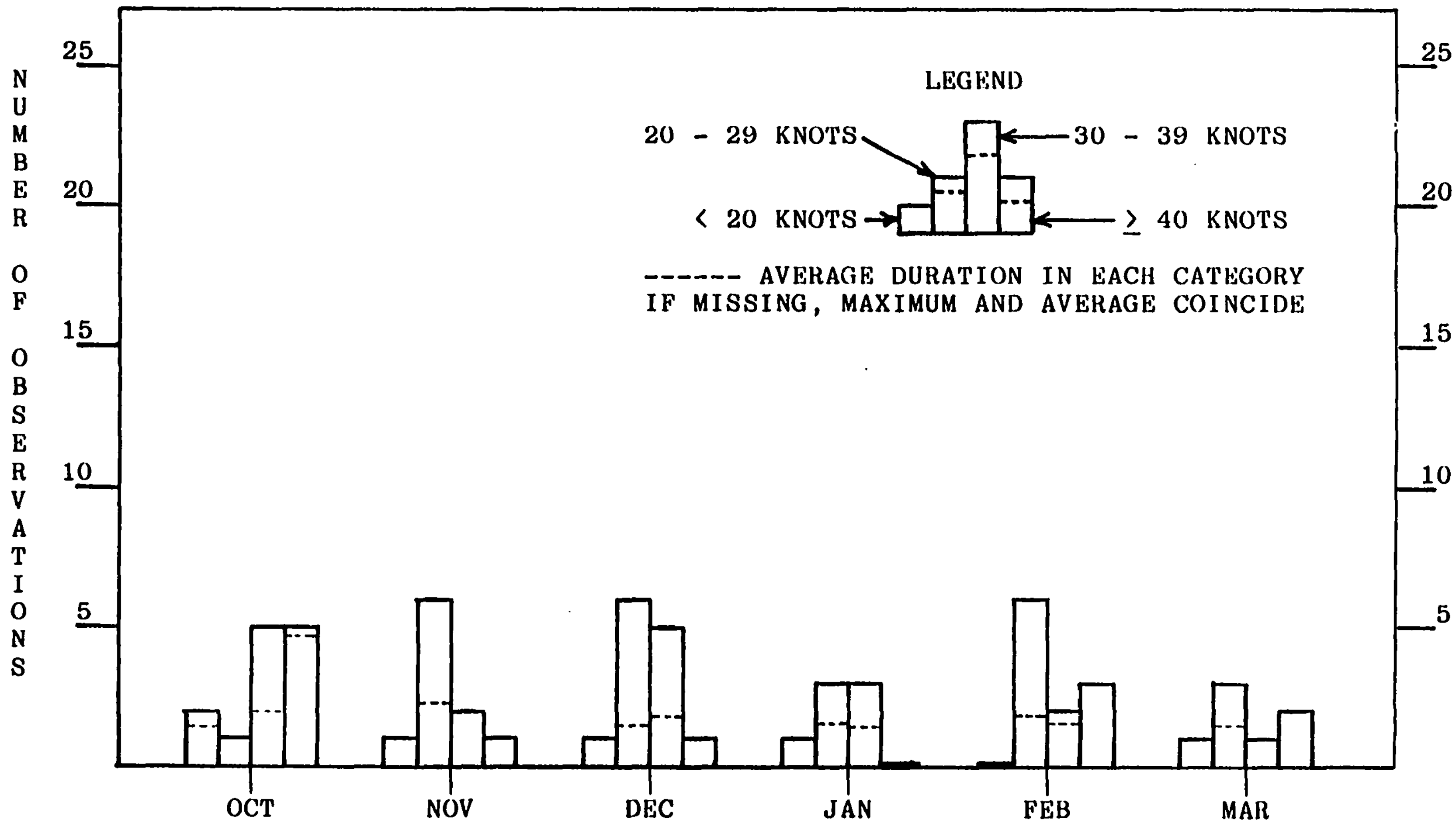
< 20 KNOTS, CATEGORY I



PERCENTAGE BREAKDOWN OF MEAN MAXIMUM
WIND SPEEDS AT ORF (SOUTHERLY)

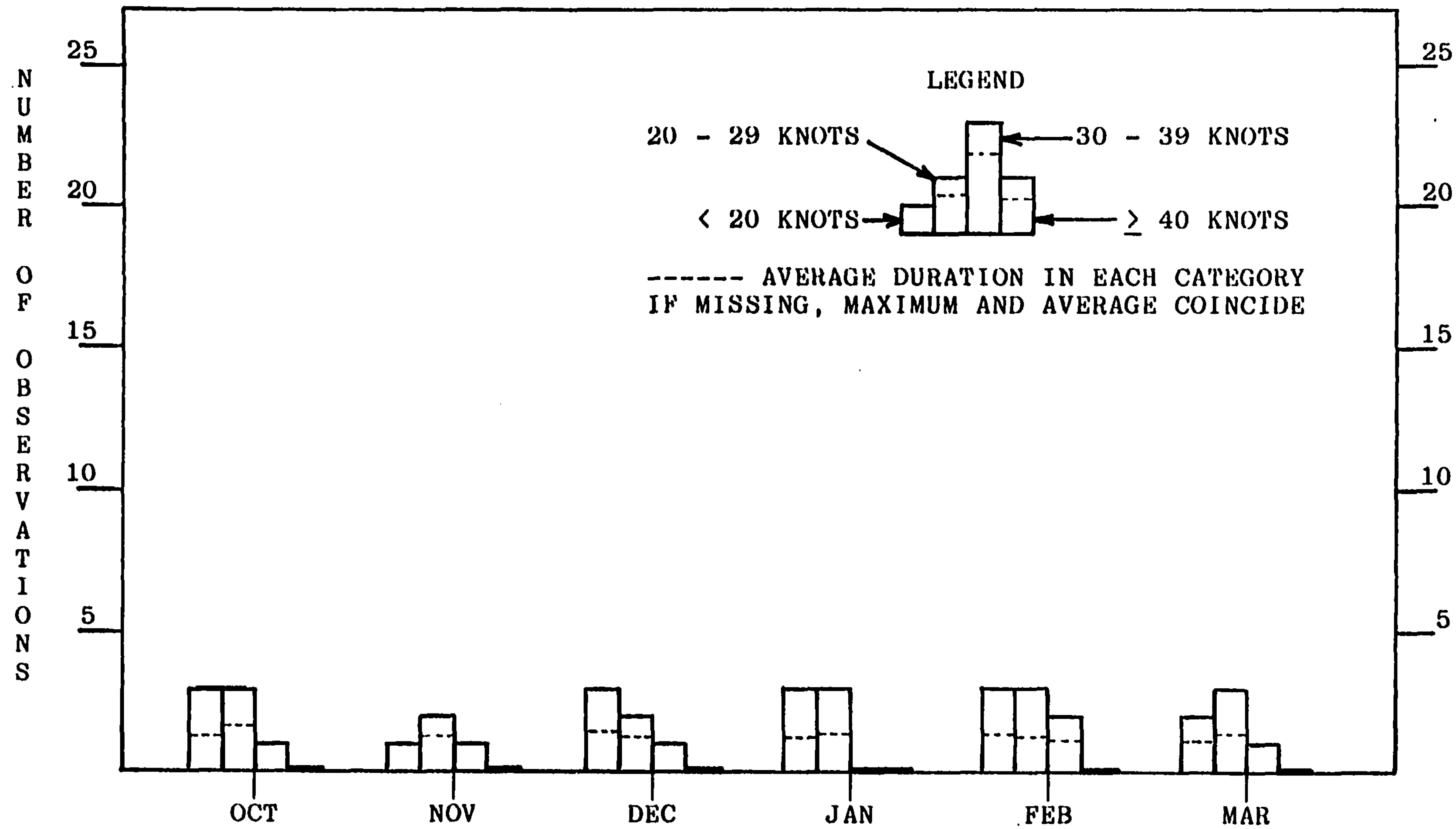
FIGURE 47





ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ILM (SOUTHERLY)

FIGURE 48



ABSOLUTE MAXIMUM DURATION AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS AT ORF (SOUTHERLY)

FIGURE 49

TABLE 4: SUMMARY OF DATA FOR THE SOUTHERLY PATTERN

A. MEAN MONTHLY FREQUENCY OF OCCURRENCES (FIGURE 40)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	2.000	1.875	2.375	2.250	1.250	1.875
ORF	2.375	2.125	3.500	3.125	3.625	4.125

B. MEAN MONTHLY DURATION OF OCCURRENCES IN NUMBER OF SYNOPTIC OBSERVATIONS (FIGURE 41) (ONE SYNOPTIC OBSERVATION PERIOD = SIX HOURS)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	4.81	3.33	4.95	3.94	4.10	3.60
ORF	2.47	1.88	2.21	2.20	2.07	2.18

C. MEAN MONTHLY SEA SURFACE TEMPERATURE (°F) (FIGURE 42)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	75.9	69.5	66.6	62.0	59.6	60.3
ORF	67.8	56.9	48.4	44.0	40.6	43.3

D. MEAN MONTHLY AIR-SEA TEMPERATURE DIFFERENCE (°F) (AIR TEMP - SEA TEMP) FIGURE 43)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	-7.1	-3.9	-4.3	-5.2	-0.6	1.3
ORF	-4.9	0.7	3.5	7.4	10.2	15.9

E. MEAN MONTHLY MAXIMUM WIND SPEED OVER WATER (KNOTS) (FIGURE 44)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	29.9	24.2	29.8	26.3	27.1	24.5
ORF	19.9	21.5	19.9	19.3	22.7	21.9

TABLE 4 (CONTINUED)

F. MEAN MONTHLY SEA-LAND WIND SPEED DIFFERENCE (KNOTS)
(FIGURE 45)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM	23.0	19.3	23.4	19.6	18.5	16.7
ORF	10.9	11.7	12.0	10.8	11.4	12.0

G. TOTAL NUMBER OF INCREASED WIND SPEED OCCURRENCES WITH PERCENTAGE BREAKDOWN OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (FIGURES 46 AND 47)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
# OF EVENTS	16	15	19	18	10	15
< 20	31%	13%	5%	6%	-	7%
20 - 29	19%	67%	53%	50%	70%	72%
30 - 39	31%	13%	26%	44%	20%	14%
≥ 40	19%	7%	16%	-	10%	7%
ORF						
# OF EVENTS	19	17	28	25	29	33
< 20	47%	41%	43%	44%	31%	27%
20 - 29	47%	47%	50%	56%	52%	67%
30 - 39	6%	12%	7%	-	17%	6%
≥ 40	-	-	-	-	-	-

H. ABSOLUTE MAXIMUM DURATION OF MEAN MAXIMUM WIND SPEEDS AND MEAN DURATION OF MEAN MAXIMUM WIND SPEEDS BY WIND SPEED CATEGORY (SYNOPTIC OBSERVATIONS)
(FIGURES 48 AND 49)

	OCT	NOV	DEC	JAN	FEB	MAR
ILM						
< 20	2/1.20	1/1.00	1/1.00	1/1.00	-	1/1.00
20 - 29	1/1.00	6/2.20	6/1.60	3/1.56	6/1.86	3/1.45
30 - 39	5/2.00	2/2.00	5/1.80	3/1.50	2/1.50	1/1.00
≥ 40	5/4.67	1/1.00	1/1.00	-	3/3.00	2/2.00
ORF						
< 20	3/1.33	1/1.00	3/1.33	3/1.18	3/1.44	2/1.11
20 - 29	3/1.67	2/1.13	2/1.14	3/1.29	3/1.27	3/1.36
30 - 39	1/1.00	1/1.00	1/1.00	-	2/1.20	1/1.00
≥ 40	-	-	-	-	-	-

IV. CONCLUSIONS

In the prefrontal and northeast flow patterns, a greater frequency of occurrences existed at ILM. Topography appeared to play a part in increased values for the prefrontal pattern in that the coast was oriented northeast/southwest which generally paralleled the flow. At ORF, however, the coast was oriented nearly north/south, thereby sheltering the sea station somewhat. Since Frying Pan Light was more open to the southwest, a longer fetch area existed than at Chesapeake Light. It follows then that greater frequencies of occurrences and longer duration periods would occur at ILM in the prefrontal condition. The greatest frequency of occurrences for the postfrontal and southerly patterns, however, occurred at ORF.

The longest mean monthly durations of occurrences of the four flow patterns in all months were observed at ILM. An anomaly existed in October during the northeast flow pattern in which a significant increase in the mean monthly duration of occurrences was evident. A possible explanation for this anomaly follows.

October is considered a transition month between summer and winter. A typical summertime synoptic feature over the western Atlantic is the quasistationary Bermuda high. The first outbreaks of cold, dry air make their way out of Canada, over the Appalachians to collide with the relatively warm, moist air mass along the coast. Historically, these Canadian high pressure cells become nearly stationary over New England. A surface convergence zone (or stationary front) forms between the two air masses. An inverted trough develops just off the southeast coast due to the temperature and moisture contrasts across the zone. (Cyclogenesis could also occur if sufficient upper air support is available.) This pattern will persist for long periods of time due to the slow movements of both high pressure systems. Once the colder, continental air mass moves offshore, usually east of Newfoundland, the pattern will dissipate.

Minor fluctuations in the mean sea surface temperatures occurred at both stations. The most significant factor observed was that the sea surface temperatures at ILM were significantly warmer than at ORF in all cases during all months of the season.

The mean air-sea temperature differences revealed that the air temperature was always less than that of the sea surface at ILM in all four patterns, except for one month in southerly flow, March; with the air colder than the water, an upward flux of sensible heat would occur which could likely add to the instability of the boundary layer.

During the northest pattern at ILM, the greatest air-sea temperature differences were noted. At ORF in the prefrontal and southerly flow, the air temperature was warmer than the water for a majority of the season which indicated a downward flux of sensible heat and a possible stabilizing effect on the boundary layer. Except during the northeast pattern at ILM, the general trend was for decreases in the temperature differences resulting from the respective decreases in the sea surface temperatures throughout the season.

Mean maximum wind speeds were in the 20 to 30 knot range at both stations during the prefrontal and southerly patterns, with wind speeds ranging from three to ten knots greater at ILM than at ORF. Surprisingly, there were practically no differences between both stations in the postfrontal and northeast pattern wind speeds. Since the greatest air-sea temperature differences occurred at ILM in the northeast pattern, one would expect the strongest wind speeds there; this was not the case.

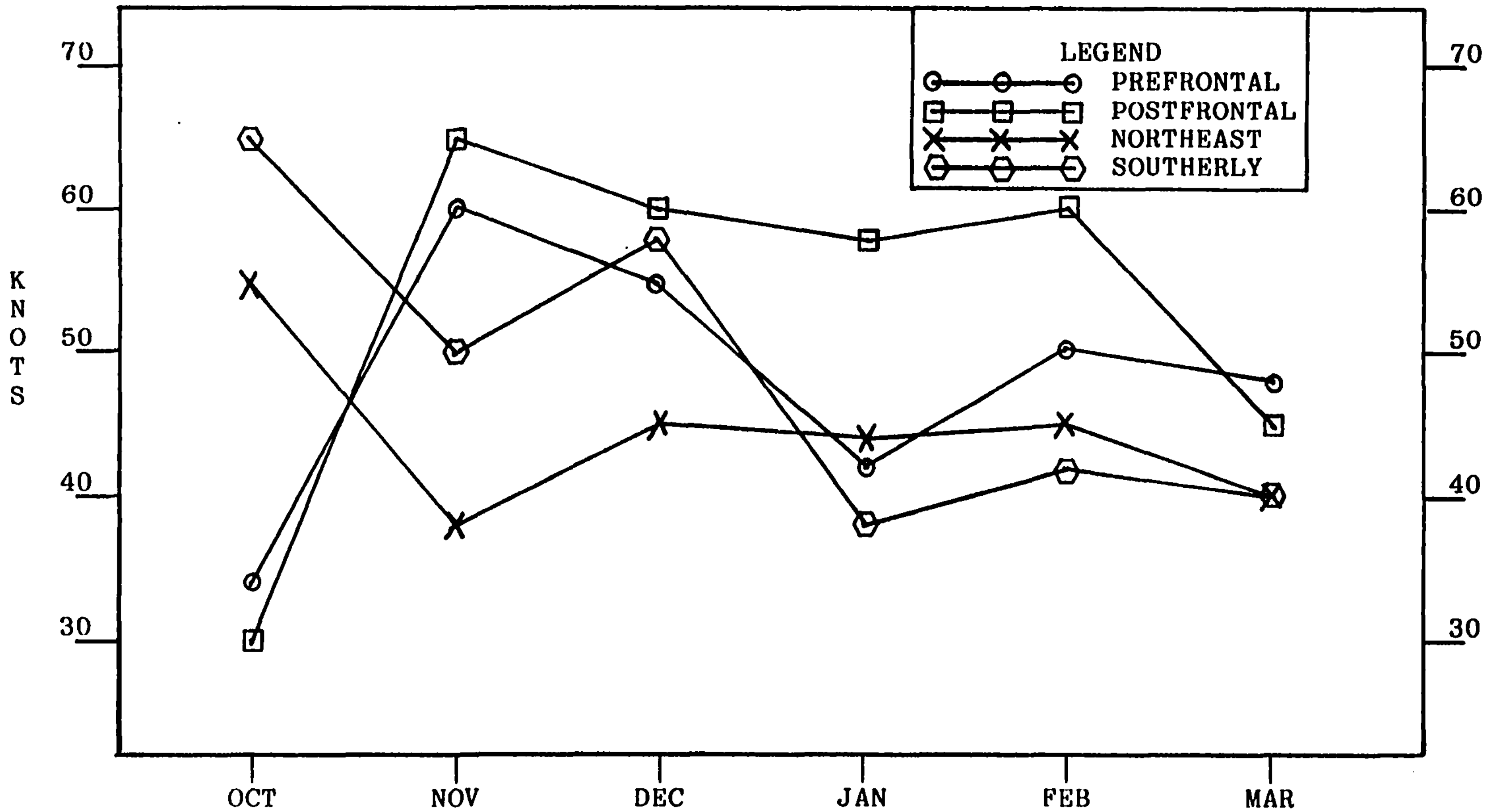
In all four patterns, ILM had mean sea-land wind speed differences greater than those at ORF. The most pronounced differences were during the prefrontal and southerly flow which were characterized by warm air advection; these differences were up to 12 knots greater at ILM. In the postfrontal and northeast patterns, the wind speed differences were between three and eight knots. The fact that Frying Pan Light is located farther offshore than Chesapeake Light, would likely contribute to the greater wind speed differences since the air stream would have more time to adjust to the reduced frictional effects over the water.

The significant point that stands out in analyzing the percentages of mean maximum wind speed categories, (except in the postfrontal pattern), is the relative scarcity of winds $\geq$ 40 knots (Category IV) at ORF. At ILM, the relative lack of winds $<$ 20 knots (Category I) is noticible. On the whole, the increased wind speed occurrences at ILM tended to have maximum winds in Categories II through IV, while at ORF, they were in Categories I through III.

Absolute maximum durations of mean maximum wind speed categories revealed that at ILM, occurrences were significantly longer in most all cases with mean durations being up to three times longer than at ORF.

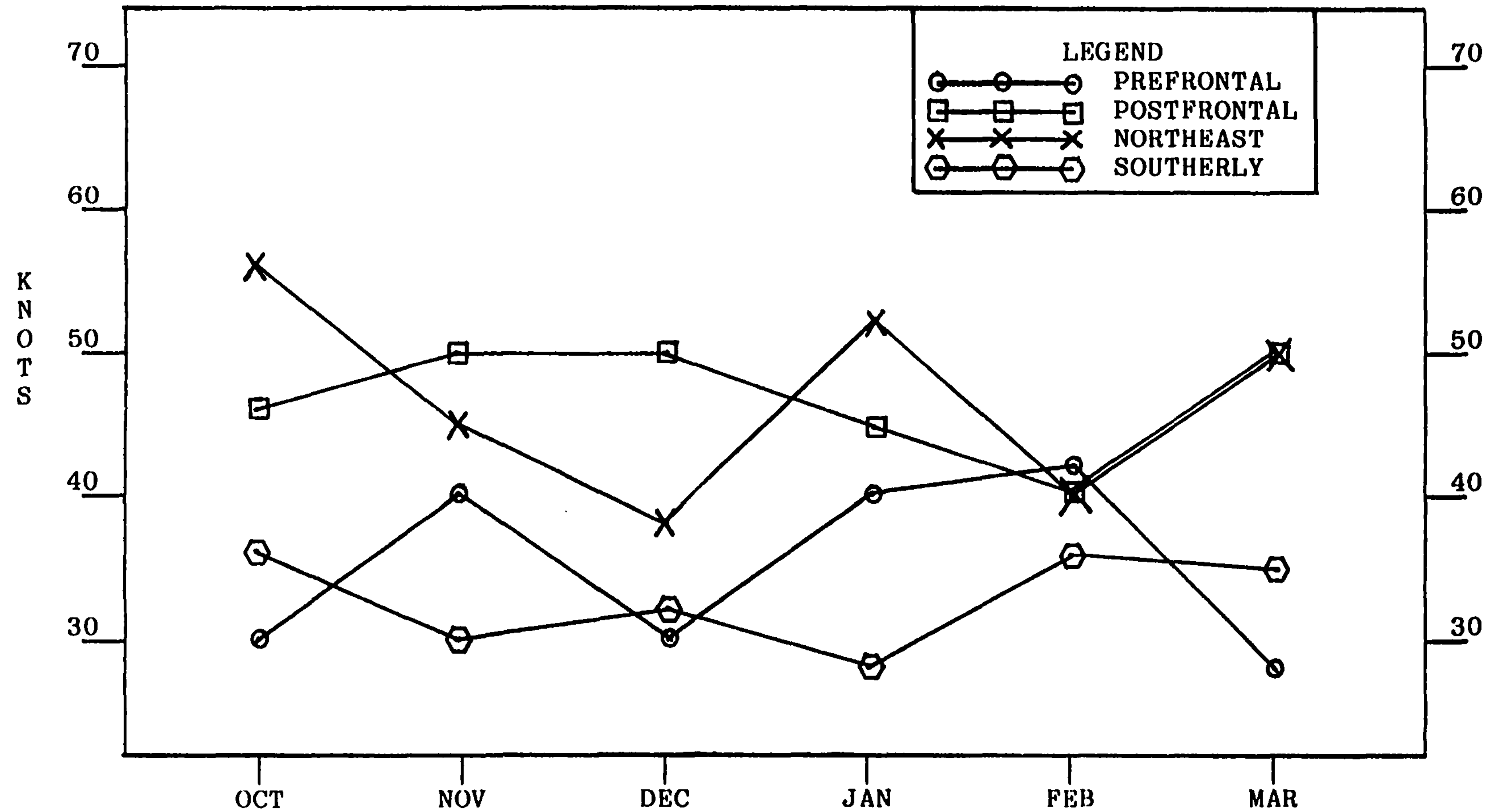
V. Summary

It can be seen from the absolute maximum wind speeds observed for all four patterns (Figures 50 and 51), that overall, ILM appears to have the most severe high wind conditions of the the two stations; it is also evident in other data presented. This fact can be attributed to numerous factors working in concert to produce a more unstable flow pattern. Among them is the sea surface temperature which can provide significant amounts of sensible heat to the boundary layer. Other parameters that must also be considered are topography, terrain roughness (or wave height), water vapor and heat fluxes, and air mass stability. Without the understanding and incorporation of all these factors, increased winds occurring offshore cannot be realistically modeled. (See Table 5 for a summary of absolute maximum wind speeds observed.)



ABSOLUTE MAXIMUM WINDS OBSERVED AT ILM FOR ALL FLOW PATTERNS

FIGURE 50



ABSOLUTE MAXIMUM WINDS OBSERVED AT ORF FOR ALL FLOW PATTERNS

FIGURE 51

TABLE 5: ABSOLUTE MAXIMUM WIND SPEEDS OBSERVED OVER WATER (KNOTS) (FIGURES 50 AND 51)

	OCT	NOV	DEC	JAN	FEB	MAR
PREFRONTAL						
ILM	34	60	55	42	50	48
ORF	30	40	30	40	42	28
POSTFRONTAL						
ILM	30	65	60	58	60	45
ORF	46	50	50	45	40	50
NORTHEAST						
ILM	55	38	45	44	45	40
ORF	56	45	38	52	40	50
SOUTHERLY						
ILM	65	50	58	38	42	40
ORF	36	30	32	28	36	35

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