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R.A. van Moerkerken

Abstract

Wind fields from an atmospheric fine-mesh Limited Area Model (LAM) and wave heights predicted by a shallow water, third generation wave model (NEDWAM) on the basis of those wind fields, have been compared with observations. The comparison is made for the following elements: wind direction, wind speed, wave height, low-frequency wave height and wave period for the period October 1990 until April 1991 inclusive for the following locations: EPF and K-13 in the southern North Sea, AUK in the central North Sea.

We made also a comparison between GONO (the operational wave model at KNMI) and LAM/NEDWAM.

Contents

1 Introduction

The NEDWAM model is a third-generation ocean wave prediction model. In its physics it is essentially identical to the WAM model, that was jointly developed by the Wave Model Development and Implementation group [4]. Its grid is identical to the GONO grid, a stereographic projection at 60°N. (see Fig. 1).
To explore its capabilities the NEDWAM model was coupled to an atmospheric limited-area model "fine-mesh LAM" (see Fig. 2). This model uses boundary conditions supplied by the ECMWF model; the initial conditions follow from an optimum interpolation analysis [1] and a bounded derivative method initialisation [3].

In this note we present a comparison of LAM and NEDWAM results with observations for three North Sea stations over the period October 1990 – April 1991. We make a similar comparison between GONO (the operational wave model at KNMI, for a description of which we refer to [2]) and observations, so that we are able to assess the quality of the predictions. In this comparison not only the differences between GONO and NEDWAM are considered, but also differences in predicted wind fields: fine-mesh LAM surface wind fields versus GONO winds; GONO winds are derived from the pressure fields of the fine-mesh model of the Meteorological Office of the United Kingdom.

2 The observations

In this report wind direction DD, wind speed FF, significant wave height H_S, the so called low-frequency wave height $H_{S,10}$ and wave period $T_{mo,-1}$ are considered, wave period from NEDWAM only. Stations to be discussed are given below (see fig. 3).

NAME	POSITION		Depth (in model)
EPF	52°00' N	3°16' E	25 m
K-13	53°13' N	3°13' E	25 m
AUK	56°24' N	2°04' E	80 m

- Wind speed has been reduced to the equivalent at 10 meter height.
- The significant wave height is defined as:

$$H_S = 4\sqrt{m_0} = 4\sqrt{\int_0^\infty E(f)df},$$

  where $E(f)$ is the one-dimensional frequency spectrum and m_0 the zero-th moment of the spectrum.

- The low-frequency wave height is defined as:

$$H_{S,10} = 4\sqrt{\int_0^{0.1} E(f)df}$$

- The wave period is defined as: $T_{mo,-1} = \frac{m_0}{m_{-1}}$, with

$$m_{-1} = \int_0^\infty E(f)f^{-1}df,$$

  the -1^{th} moment of the spectrum.

The observations were supplied by various sources. The wave data from EPF, K-13 and AUK were obtained from the Dutch North Sea network. The wind observations have been taken from the Global Telecommunication System (GTS).

3 Time series of LAM (winds) / NEDWAM (waves) and GONO (winds and waves) versus observations

The time series are presented in figures 4 to 45, showing every 6 hours the wind direction DD in degrees, the wind speed FF in metres/seconds, the wave height H_S in metres, the low-frequency wave height $H_{S,10}$ in metres and the wave period in seconds. The time series graphs in the NEDWAM model are labelled with the symbol fp = 0 and fp = +24, where fp denotes forecasting period in hours. So fp = 0 indicates the model analysis in which atmospheric synoptical observations have been assimilated. The fp = +24 model output was calculated 24 hours before. The time series graphs in the GONO model are labelled with fp = 0, 6, 0, 6. The 0.00 and 12.00 fields are based on analysed winds; the 6.00 and 18.00 fields are based on winds forecasted 6 hours ahead.

Some remarkable features in the time series:

- On November 3rd at AUK the NEDWAM wave height was better than the GONO one.
- On December 12th at EPF LAM produced a better wind forecast than GONO.
- On December 12th at K-13 both H_S and the $H_{S,10}$ are calculated too high by NEDWAM.
- The most remarkable extreme wave height (12 metres) in this verification period was on December 12th at station AUK. NEDWAM calculates both the analyses and the forecasts much better than GONO (see Fig. 20).
- On February 1st the wave period was generated too high by NEDWAM at all stations.
- On February 3rd and 4th at station AUK NEDWAM produces better wave heights than GONO.
- On February 22nd GONO calculates $H_{S,10}$ better than NEDWAM. The cause of this was an error in the extrapolation at the boundary of the NEDWAM grid [6]. The same happened during March 11th – 15th at AUK as may be seen from Fig. 38. The model has been corrected for this.

In our verification analysis we have also been looking for differences in wave height and the low-frequency wave height between the models and the observations, referred to as "outlyers" (see table 1). We define a prediction as an "outlyer" when the absolute value of the difference between observation and model is greater than 2 * standard deviation. The standard deviation is calculated over the full period considered for each model and each station. The resulting values are indicated.

4 Statistics

Tables

In this section we compare the model output with the observations by means of both summary table (table 2) and scatter diagrams (Fig. 46–60). Cases with wind speeds less than 5 m/s were excluded from the statistical analysis.
The statistics include:

- N, the number of the observation.
- AV.OBS, the average of the observations.
- BIAS, defined as $\bar{x} = \frac{1}{n}\sum x_i;\ x_i =$ model – observation.
  Note: the bias is negative when the model results are too low.
- SD, the standard deviation defined as

$$\sigma_d = \sqrt{\frac{\Sigma x^2 - \frac{1}{n}(\Sigma x)^2}{n}}.$$

- SI, the scatter index defined as 100 * (SD / AV.OBS).

Table 2 shows the statistics of wind direction, wind speed, wave height, low-frequency wave height and (for NEDWAM only) the wave period (+12 and +24 refer to forecasts). The bias and the standard deviation in the wind speeds are given in dm/s and the wave heights in cm, both in the summary table and in the scatter diagrams. The wave period in the summary table is expressed in deciseconds.

Scatter diagrams of forecasts, fp=+12

The average of the observations and the model output are marked by squares on the X- and Y-axis, respectively.

In general the statistics of LAM are better than those of GONO, except the bias in the sector 240–300 at EPF (see Fig. 47, 48). We also see this in the wave height calculation. NEDWAM statistics are mostly lower, except in the sector 240–300 at EPF. Remarkable is the bias in the wave height in the sectors 0–60, 60–120 and 300–360 (see Fig. 49, 50, 54, 55, 59 and 60). At all stations NEDWAM produces a lower bias than GONO.

Relation between wind speed error and wave height error

Table 3 gives a relation between the error in the wind speed $\Delta FF = FF_{model} - FF_{obs}$ and the error in the wave height $\Delta H_S = H_{S_{model}} - H_{S_{obs}}$. We have separated the wind speed in 6 classes. We only used cases with wind speeds > 10 m/sec. and forecasted fields, fp= +12.

Table 4 correlation coefficients for the correlation between wave height error and wind speed error. In general one expects only to find a correlation for wind sea, not for swell. The table gives an impression of the sensitivity for differences between the wind observations and the modelled wind speeds.

5 Conclusions and recommendations

Conclusions

1. Wind direction: LAM gives better analyses in terms of standard deviation than GONO, but this superiority disappears in the forecast (see table 2).

2. Wind speed: The standard deviation and the scatter index up to +12 hours forecast is smaller than GONO, but the advantage of LAM over GONO in the analyses (SD and SI) disappears in the +24 hours forecast (see table 2). In the scatter diagrams (fp=+12) LAM shows a better performance of the statistical parameters than GONO (see Fig. 47, 48, 52, 53, 57 and 58).

3. Wave height: for NEDWAM standard deviation and scatter index up to +12 forecast are smaller at EPF and K-13 than for GONO, at AUK even up to +24 forecast. (see table 2). In the scatter diagrams (Fp=+12) NEDWAM shows a better performance of the statistical parameters (see Fig. 49, 50, 54, 55, 59 and 60). The sensitivity of the wave field to errors in the wind field is rather weak in open sea (AUK) in NEDWAM. (see table 4).

4. Low-frequency wave height: NEDWAM gives a smaller standard deviation and scatter index than GONO. Especially the scatter index is remarkably less at all stations. (see table 2).

5. Wave period: the bias at all stations is less than 0.5 seconds. The scatter index at EPF and K-13 is about 20%; at AUK it is about 25% (see table 2). The forecasted values are not worse than the analyses.

6. Summarizing, we find that LAM/NEDWAM shows a better performance in wave forecasting than GONO.

Recommendations

1. Development of the GONO model has been terminated. In view of the better performance of NEDWAM/LAM the replacement of GONO by NEDWAM as the KNMI operational wave model is recommended.

2. Further development of NEDWAM should be considered. We expect that wave data assimilation will improve the performance of NEDWAM significantly.

Acknowledgments

I would like to thank Gerrit Burgers for providing the NEDWAM and LAM data, and thanks are due to Evert Bouws, Gerrit Burgers, Peter Janssen and Gerbrand Komen for helpful comments on the manuscript. Furthermore I am grateful to Hans de Vries and Greet de Graaf for preparing the layout of the report.

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List of tables

Figure Captions

WAVE HEIGHT

EPF: (total number 445)

	SD	model too high	model too low	total outlyers
NWAM fp=+12	51	8	28	36
GONO fp=+12	57	7	25	32

K-13: (total number 535)

	SD	model too high	model too low	total outlyers
NWAM fp=+12	57	12	19	31
GONO fp=+12	66	10	14	24

AUK: (total number 622)

	SD	model too high	model too low	total outlyers
NWAM fp=+12	74	17	19	36
GONO fp=+12	89	10	30	40

LOW-FREQUENCY WAVE HEIGHT

EPF: (total number 437)

	SD	model too high	model too low	total outlyers
NWAM fp=+12	16	8	16	24
GONO fp=+12	24	18	14	32

K-13: (total number 523)

	SD	model too high	model too low	total outlyers
NWAM fp=+12	31	9	20	29
GONO fp=+12	36	12	18	30

AUK: (total number 606)

	SD	model too high	model too low	total outlyers
NWAM fp=+12	65	18	19	37
GONO fp=+12	76	32	13	45

Table 1: SUMMARY OF THE NUMBERS OF "OUTLYERS" FOR FP=+12 AND $H_S > 100$ CM.

EPF	N	AV.OBS	BIAS			SD			SI		
			0	+12	+24	0	+12	+24	0	+12	+24
DD LAM	613		5	11	14	13	21	27			
DD GONO	613		13	12	12	21	22	24			
FF LAM	613	97	-9	-6	-8	16	20	25	16	21	26
FF GONO	613	97	-10	-7	-6	21	23	26	21	24	26
H_S NWAM	613	159	-27	-19	-19	40	51	58	25	32	36
H_S GONO	613	159	-28	-25	-23	54	57	59	34	36	37
$H_{S,10}$ NWAM	605	21	-6	-6	-5	14	16	20	66	77	87
$H_{S,10}$ GONO	605	21	-6	-6	-7	23	24	23	109	115	101
$T_{mo,-1}$ NWAM	613	53	-3	-2	-2	9	10	10	17	18	19

K-13	N	AV.OBS	BIAS			SD			SI		
			0	+12	+24	0	+12	+24	0	+12	+24
DD LAM	615		-1	1	2	10	16	26			
DD GONO	615		-2	-2	-3	16	18	22			
FF LAM	615	98	2	3	2	13	19	24	13	19	24
FF GONO	615	98	-7	-5	-4	22	24	28	22	25	28
H_S NWAM	610	187	-12	-2	-2	44	57	66	24	30	35
H_S GONO	610	187	-13	-9	-8	62	66	70	34	35	37
$H_{S,10}$ NWAM	599	38	-12	-11	-10	29	31	29	76	81	76
$H_{S,10}$ GONO	599	38	-13	-12	-11	34	36	33	90	95	85
$T_{mo,-1}$ NWAM	610	58	-4	-3	-2	12	12	12	20	21	21

AUK	N	AV.OBS	BIAS			SD			SI		
			0	+12	+24	0	+12	+24	0	+12	+24
DD LAM	609		-1	0	0	8	17	25			
DD GONO	609		-4	-3	-4	16	18	24			
FF LAM	609	100	6	5	4	13	20	26	13	21	26
FF GONO	609	100	-5	-3	-6	22	24	28	22	25	28
H_S NWAM	583	267	-14	-11	-18	64	74	90	24	27	33
H_S GONO	583	267	-38	-35	-38	83	89	100	31	33	38
$H_{S,10}$ NWAM	567	85	2	2	-2	57	65	76	70	77	86
$H_{S,10}$ GONO	567	85	-8	-5	-5	70	76	83	84	89	96
$T_{mo,-1}$ NWAM	580	67	1	1	1	16	17	17	24	25	25

Table 2: LAM AND GONO (*DD*, *FF*) AND NEDWAM AND GONO (H_S, $H_{S,10}, T_{mo,-1}$))

	K-13 (NEDWAM)		K-13 (GONO)	
ΔFF (dm/sec)	N	$<\Delta H_S>$ (cm)	N	$<\Delta H_S>$ (cm)
< -20	35	-66	72	-70
-20 – -10	30	-48	32	-31
-10 – 0	55	-35	31	-2
0 – 10	58	10	35	8
10 – 20	42	34	31	36
> 20	40	82	59	84

	AUK (NEDWAM)		AUK (GONO)	
ΔFF (dm/sec)	N	$<\Delta H_S>$ (cm)	N	$<\Delta H_S>$ (cm)
< -20	34	-72	59	-120
-20 – -10	28	-44	31	-68
-10 – 0	42	-42	33	-23
0 – 10	62	-28	33	-3
10 – 20	39	7	33	25
> 20	51	34	67	86

Table 3: $< H_S > (= H_{S_{model}} - H_{S_{obs}})$ for different classes of wind speed error for K-13 and AUK, where $<>$ denotes an average over a particular class.

NAME	NEDWAM	GONO
EPF	0.8	0.7
K-13	0.7	0.7
AUK	0.4	0.7

Table 4: Correlation between ΔFF and ΔH_S at 3 locations.

NEDWAM GRID

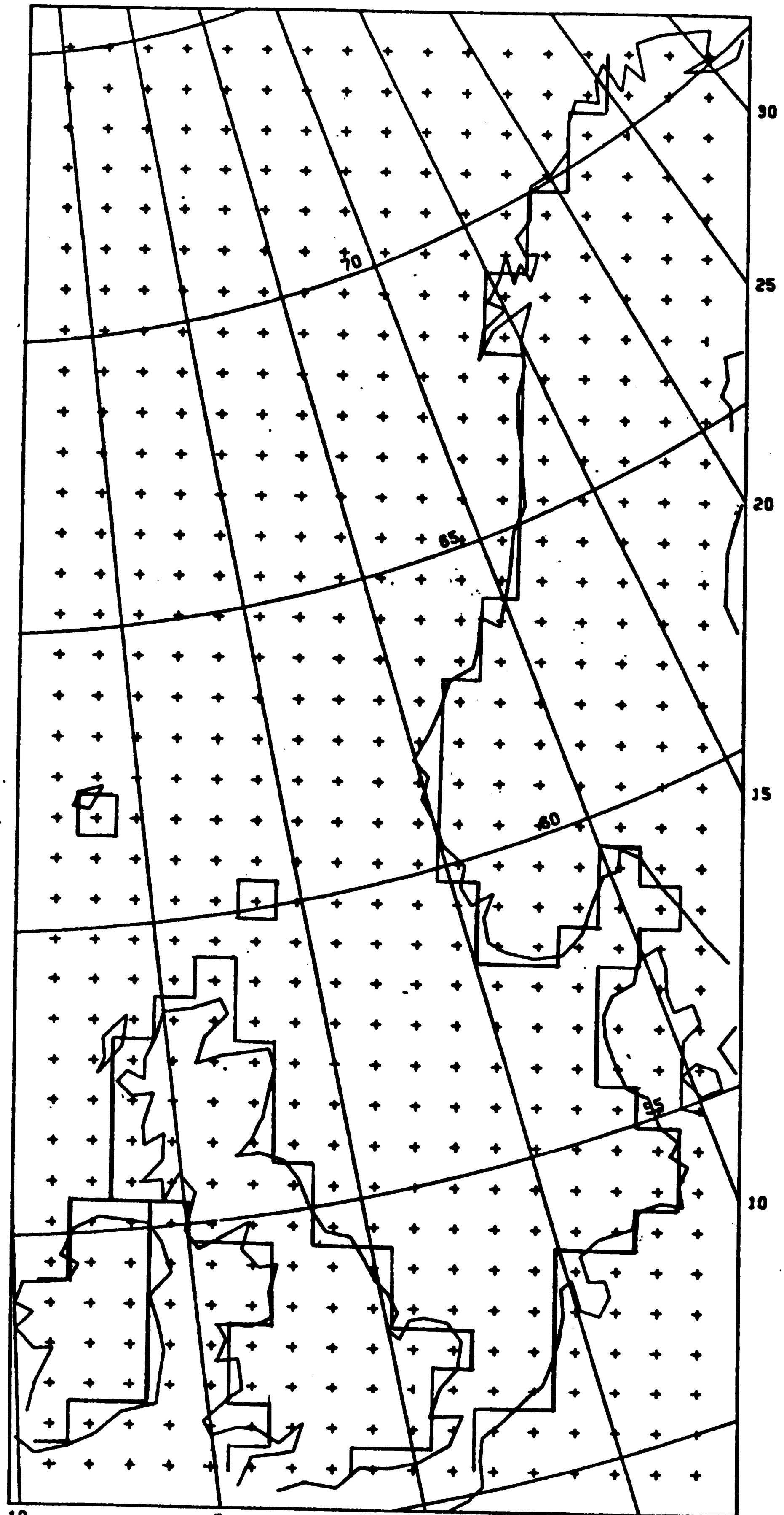


FIG. 1

LAM GRID

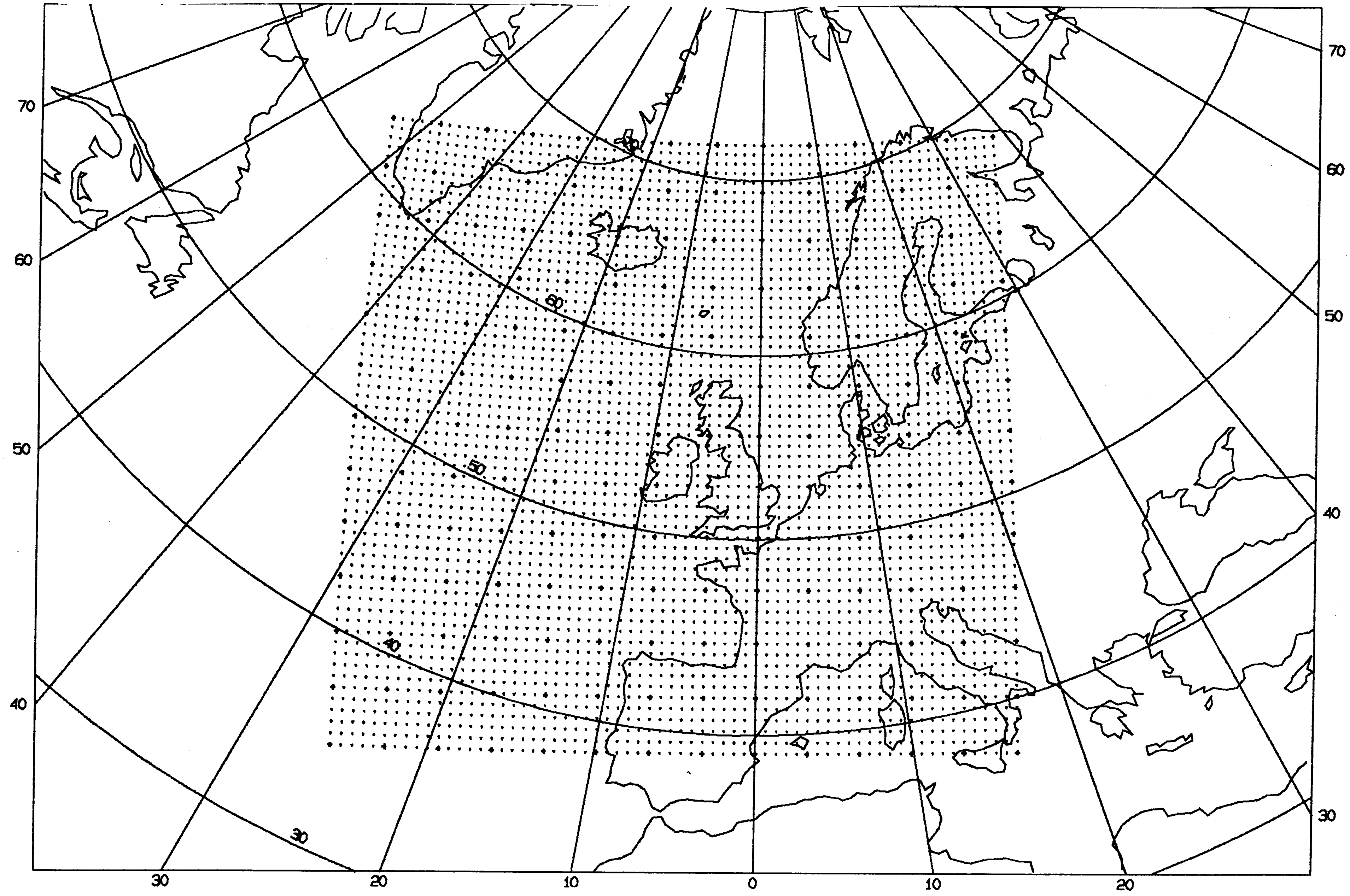
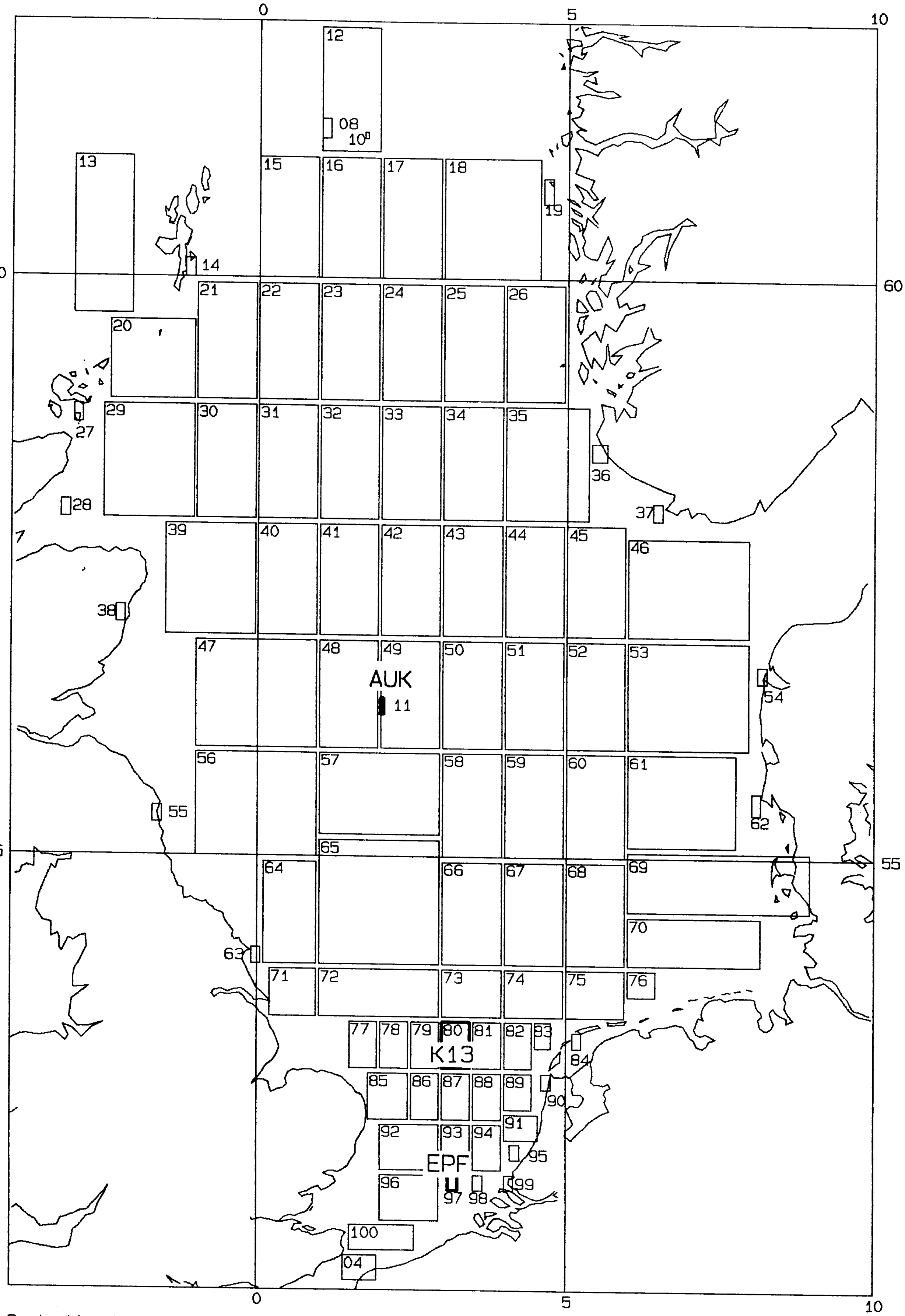


FIG. 2

Locations of the stations in the North Sea



Projection Mercator

FIG. 3

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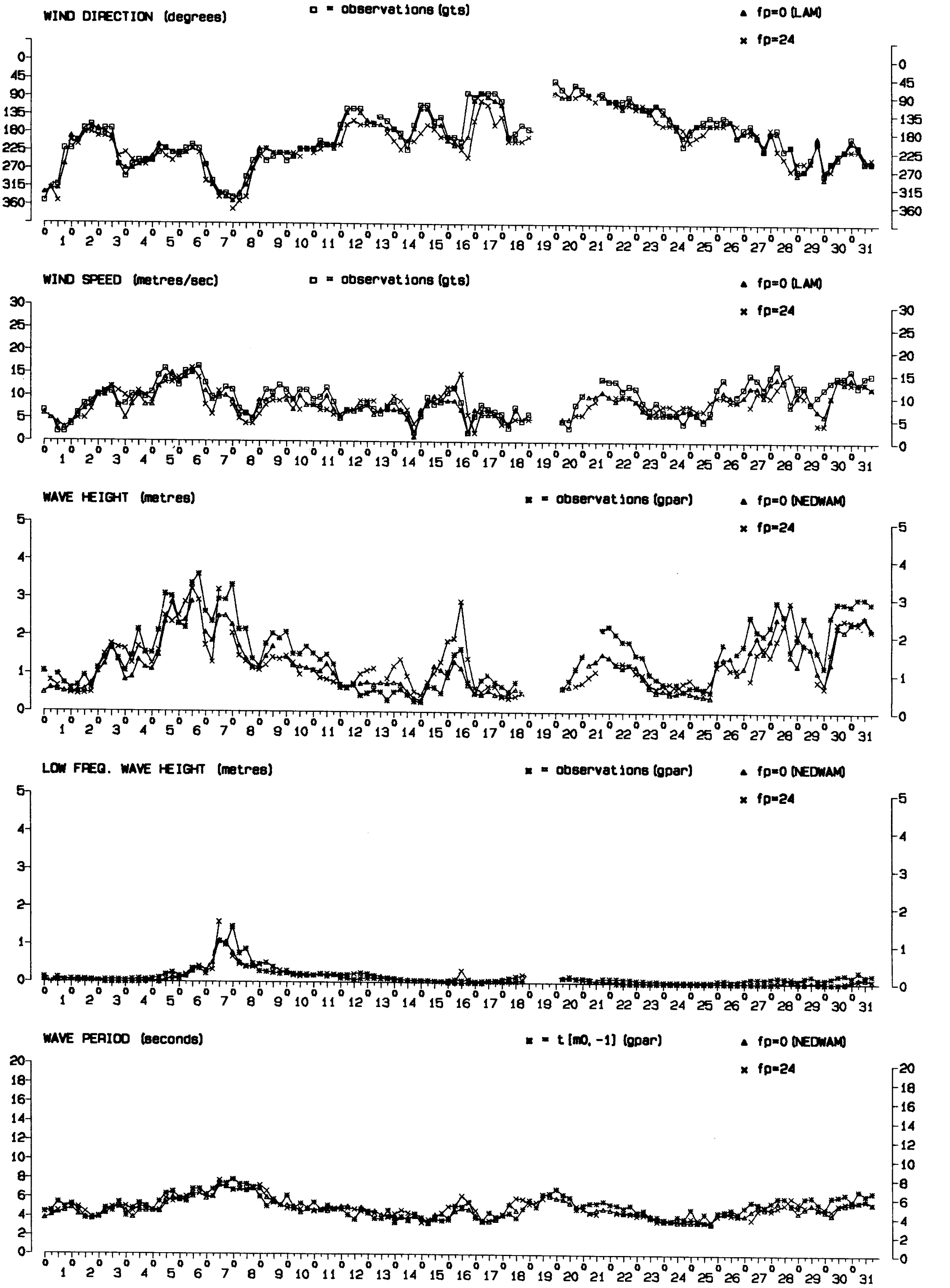

FIG. 4

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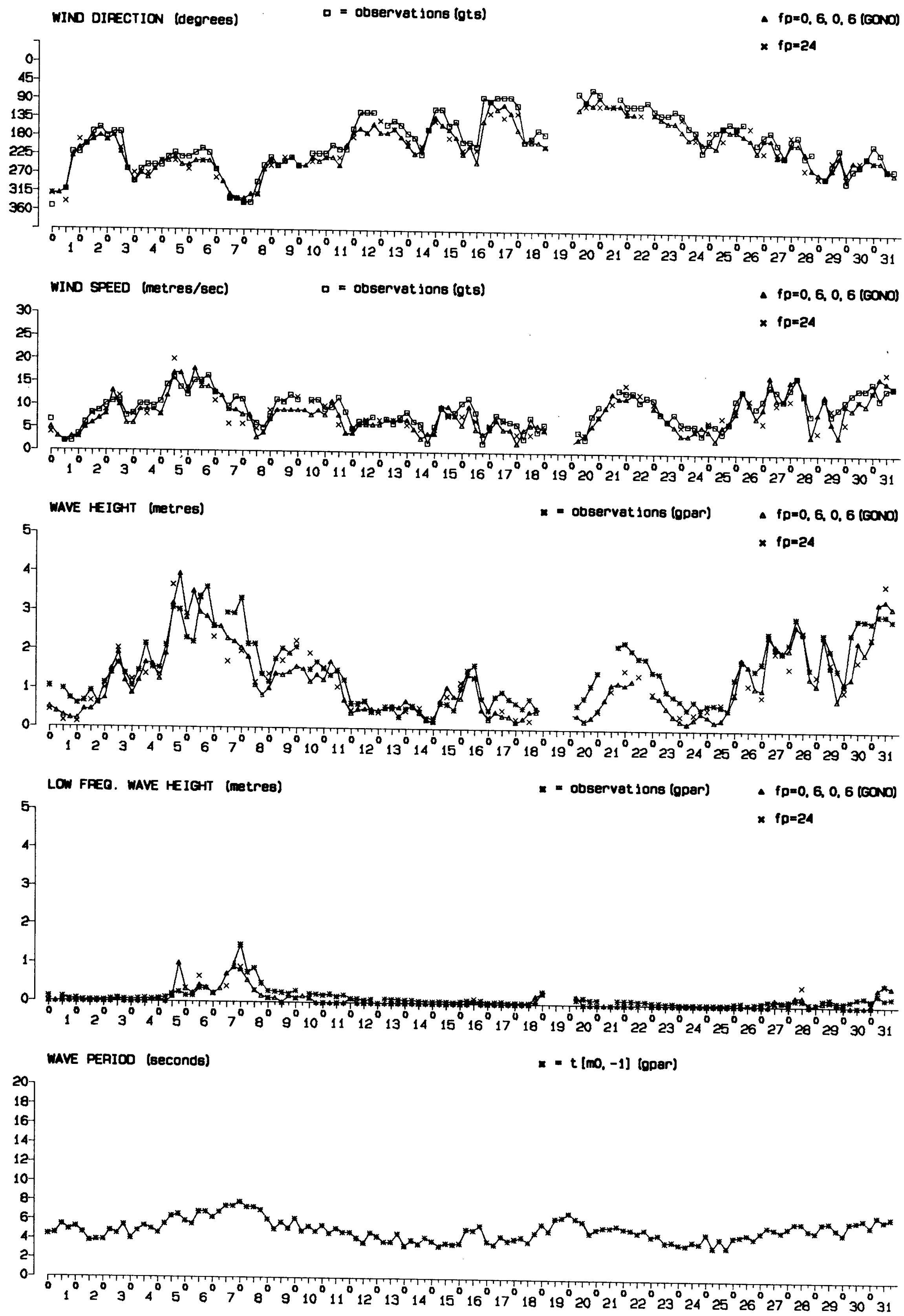
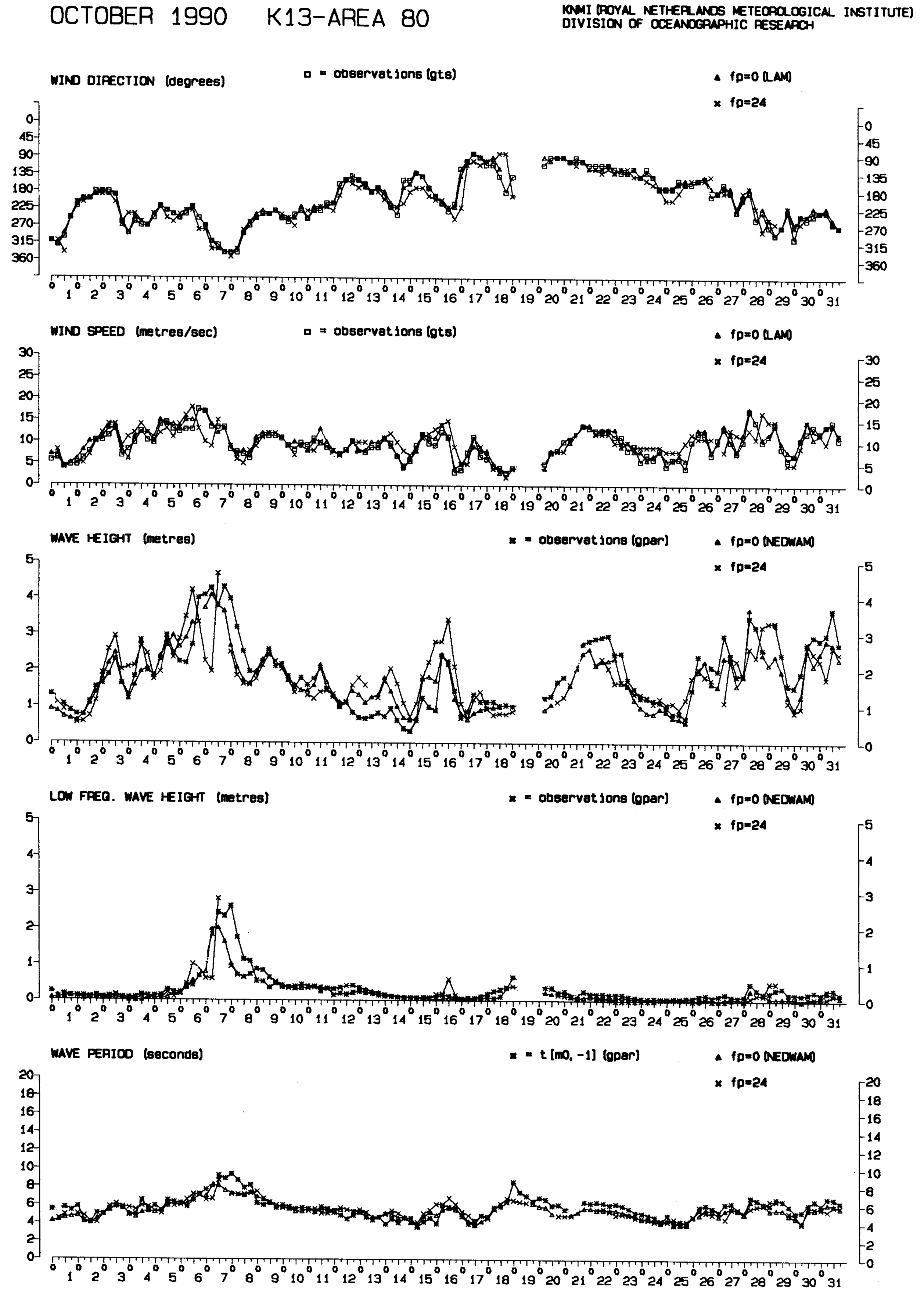


FIG.5



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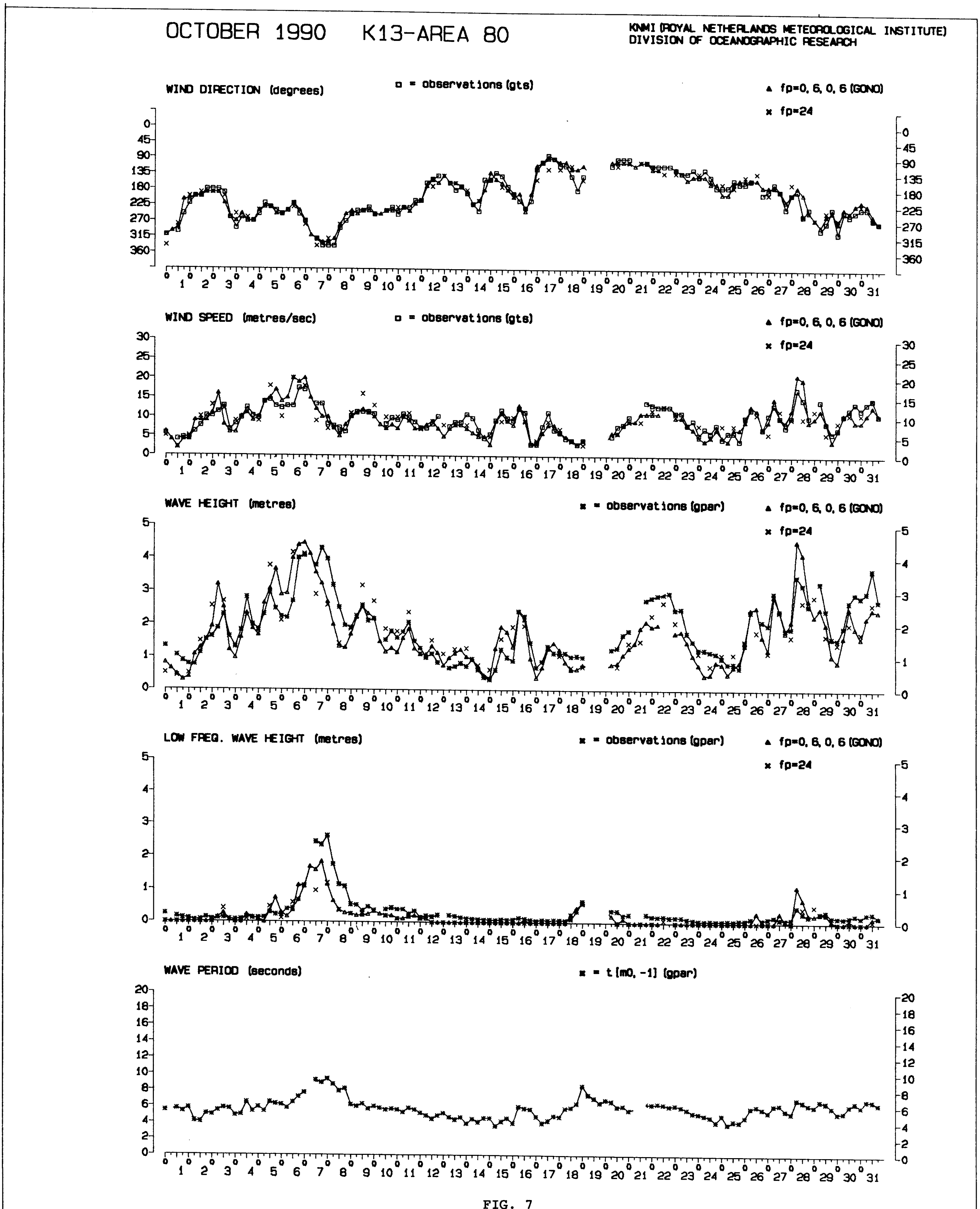
WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
WAVE PERIOD (seconds)
* = t [m0, -1] (gpar)
▲ fp=0 (NEDWAM)
× fp=24

FIG. 6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▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WAVE PERIOD (seconds)
✱ = t (m0, -1) (gpar)

FIG. 7

OCTOBER 1990 AUK-AREA 11

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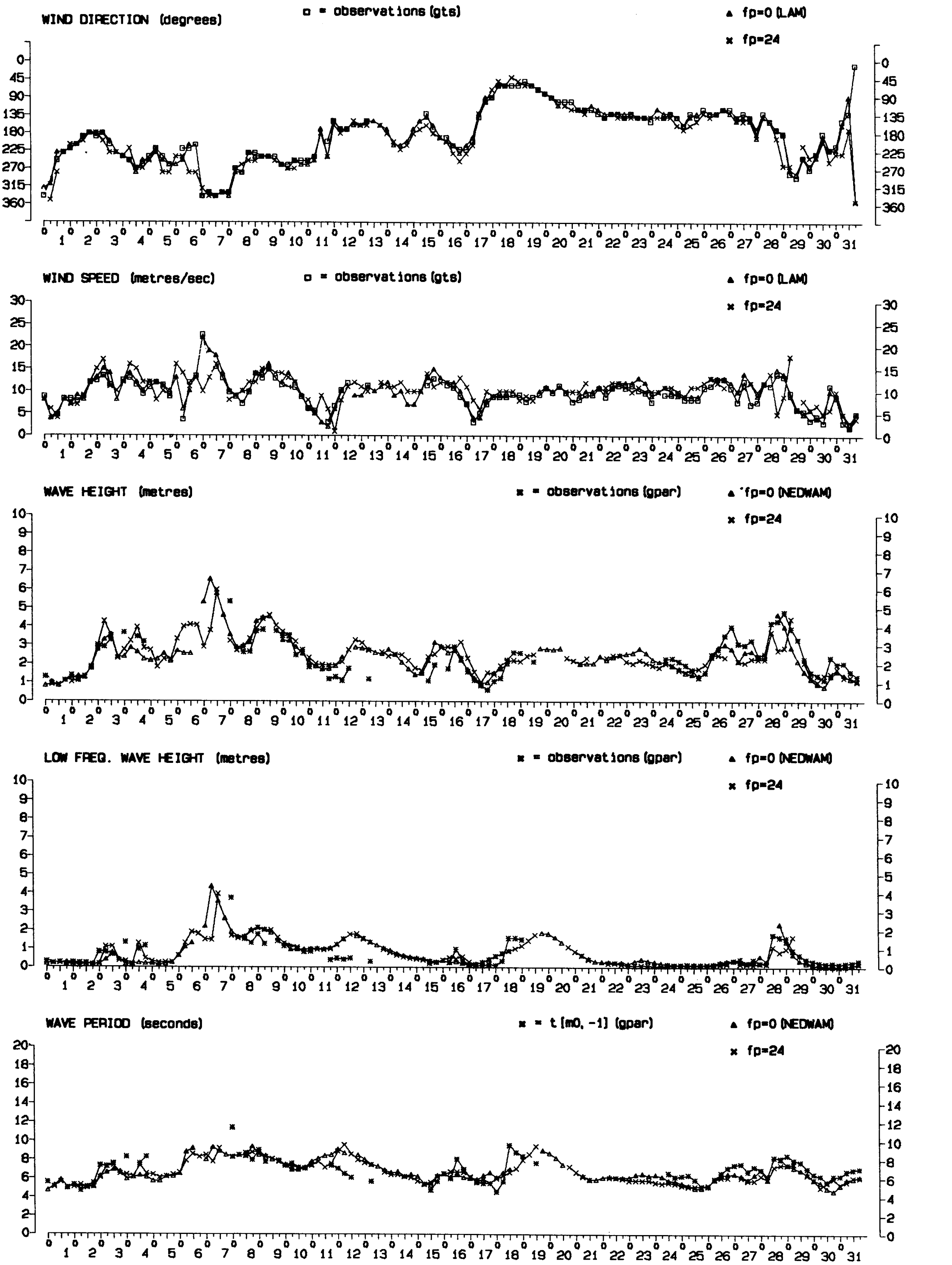

FIG. 8

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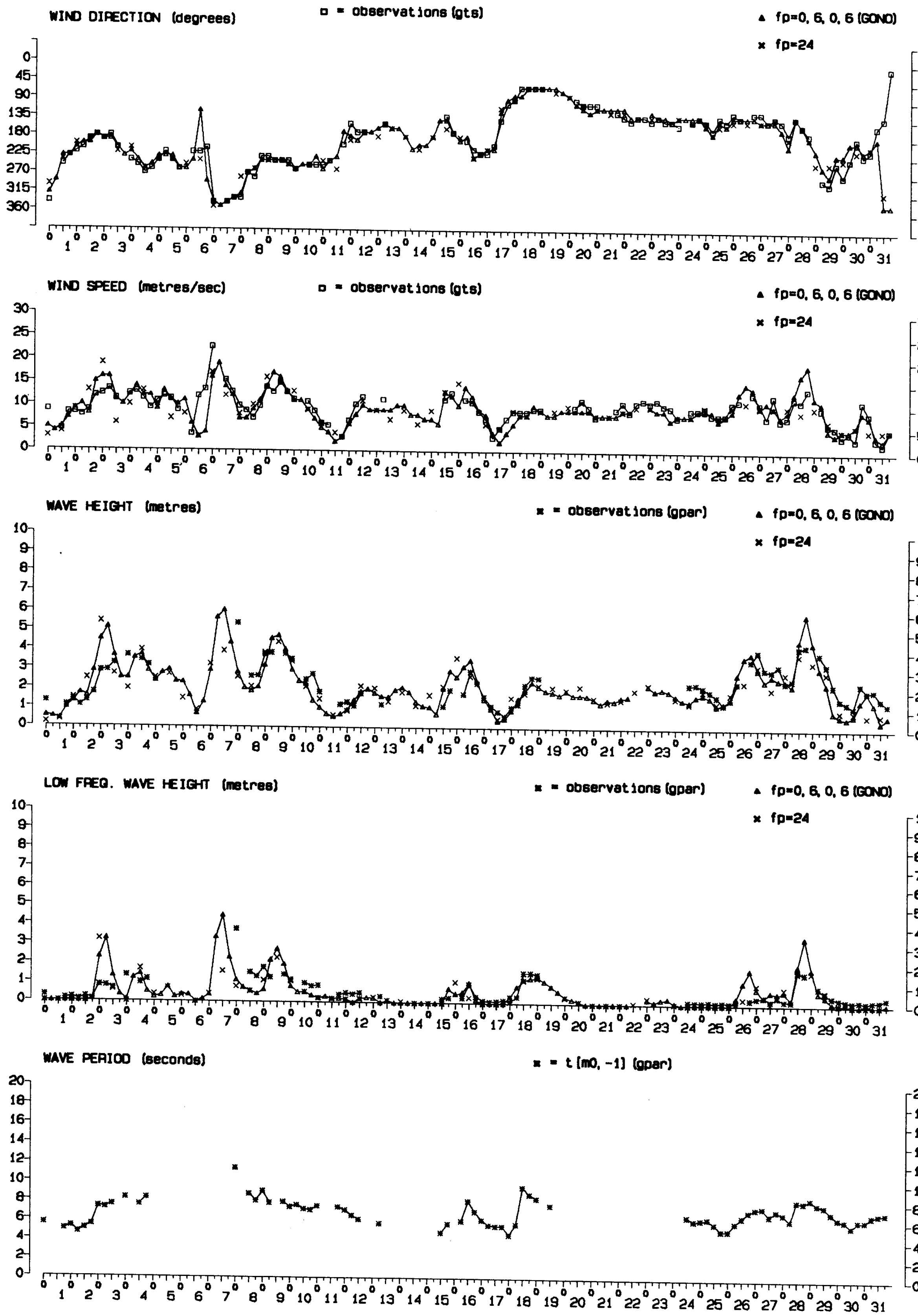
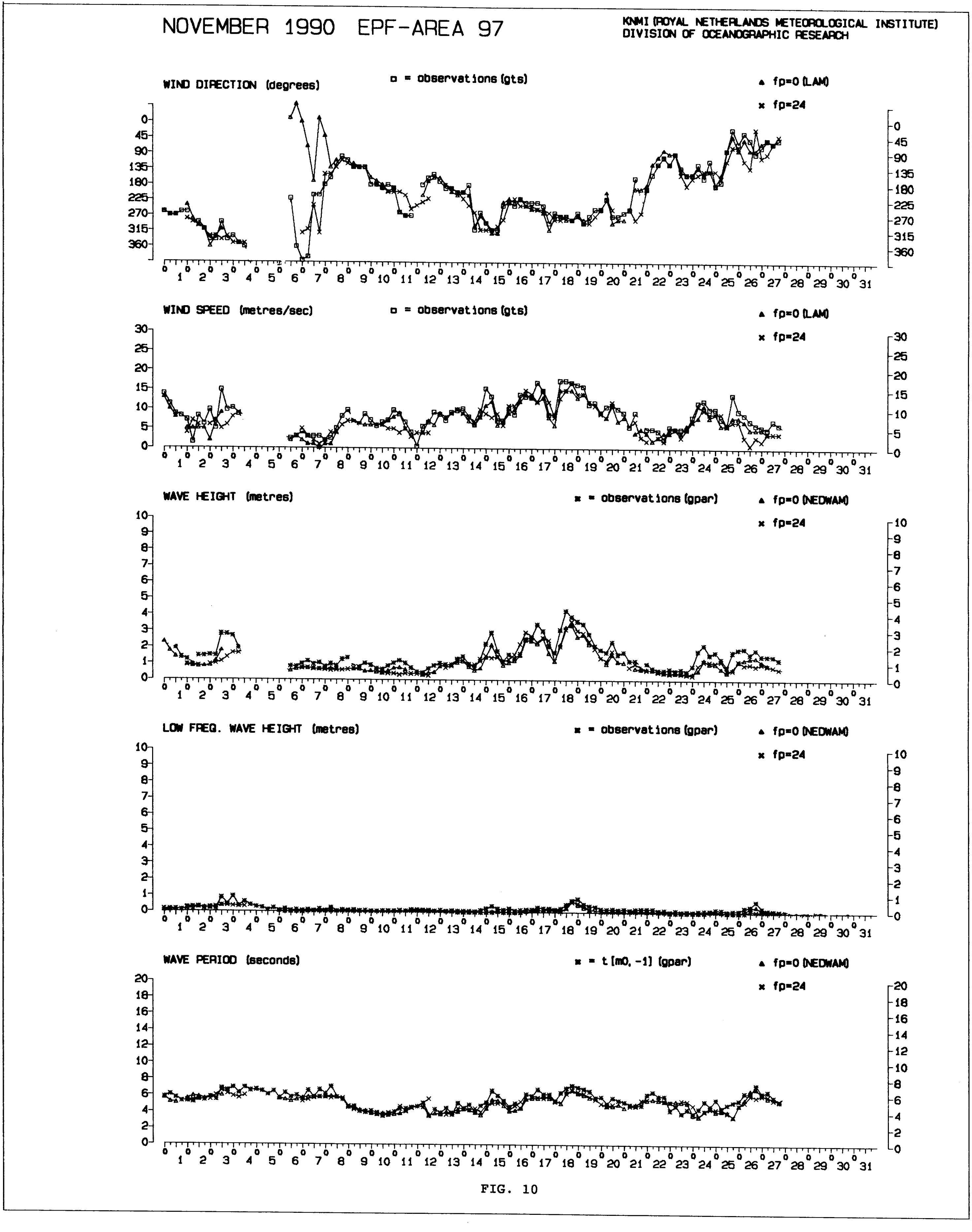


FIG. 9


NOVEMBER 1990 EPF-AREA 97
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▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
LOW FREQ. WAVE HEIGHT (metres)
WAVE PERIOD (seconds)
* = t [m0, -1] (gpar)

FIG. 10

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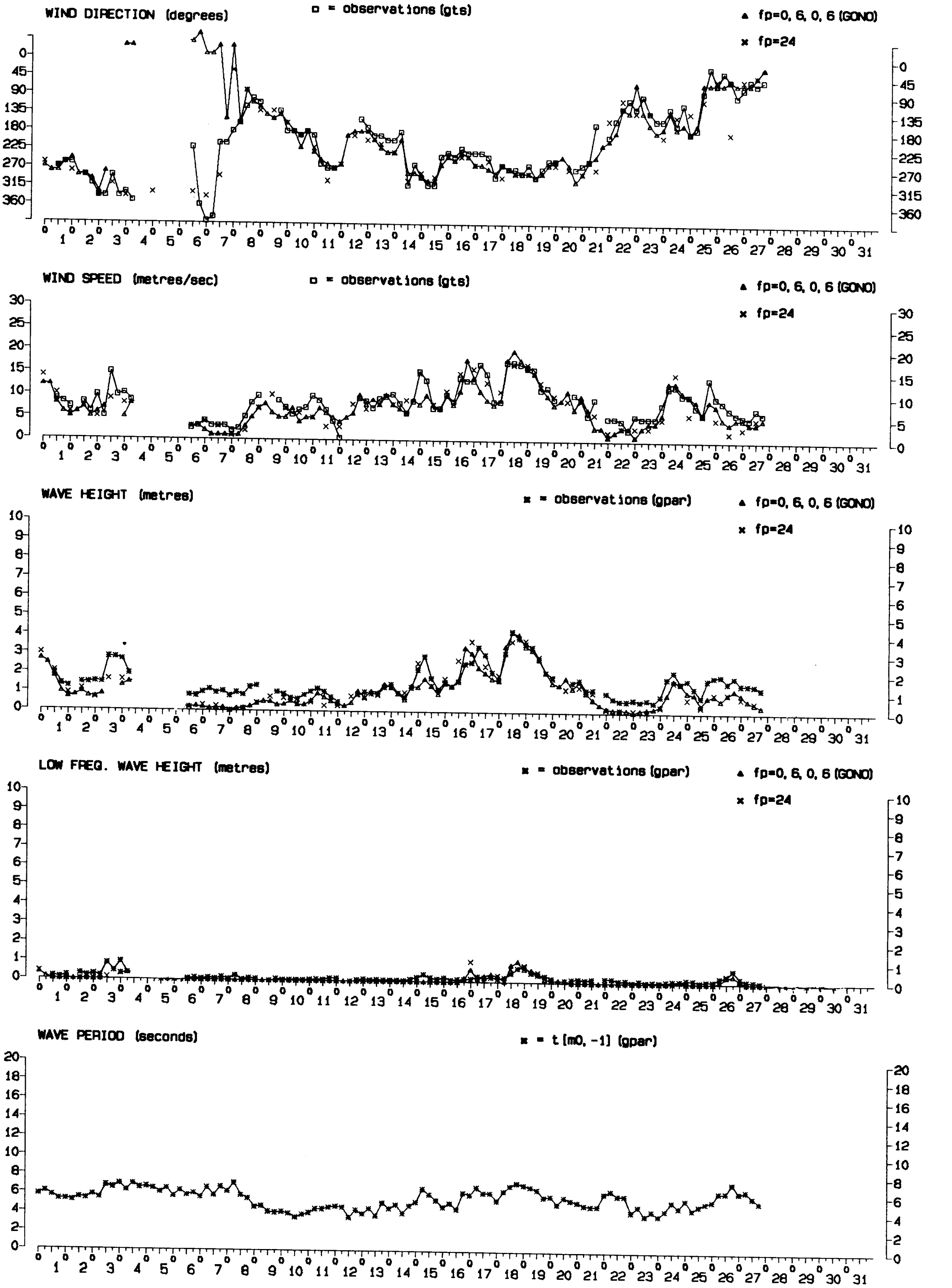
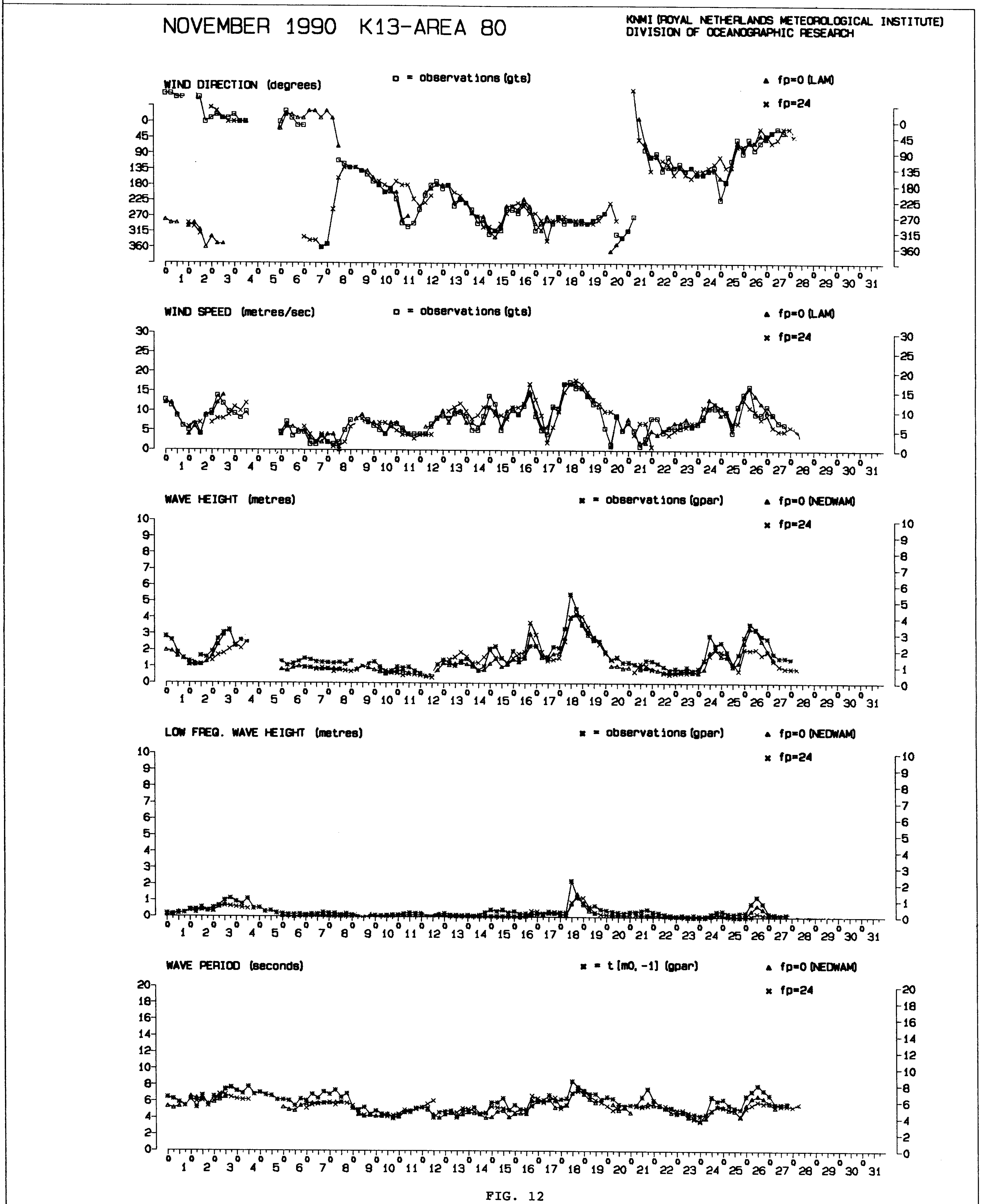


FIG. 11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WIND DIRECTION (degrees)
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▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
WAVE PERIOD (seconds)
✱ = t [m0, -1] (gpar)
▲ fp=0 (NEDWAM)
× fp=24

FIG. 12

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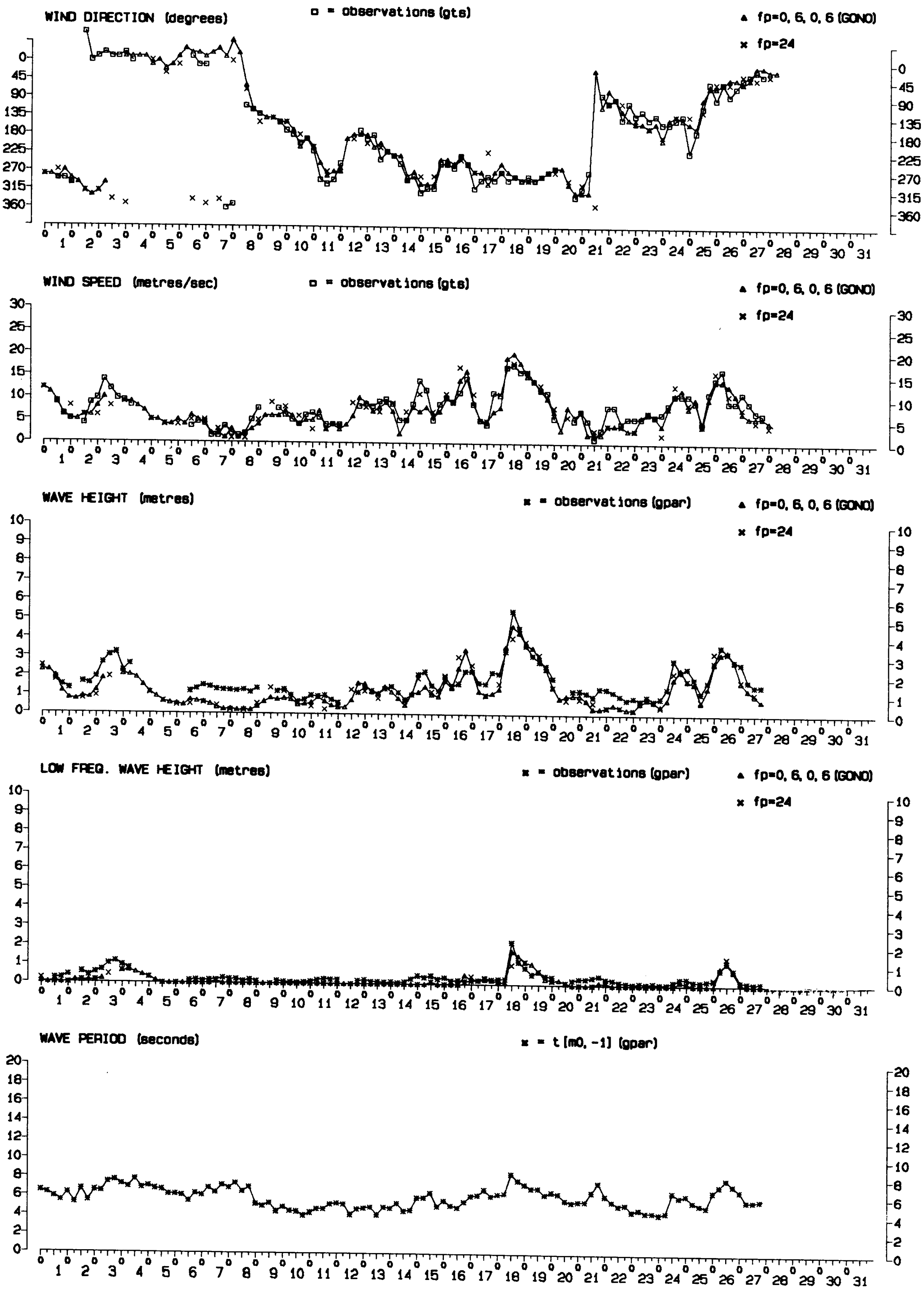
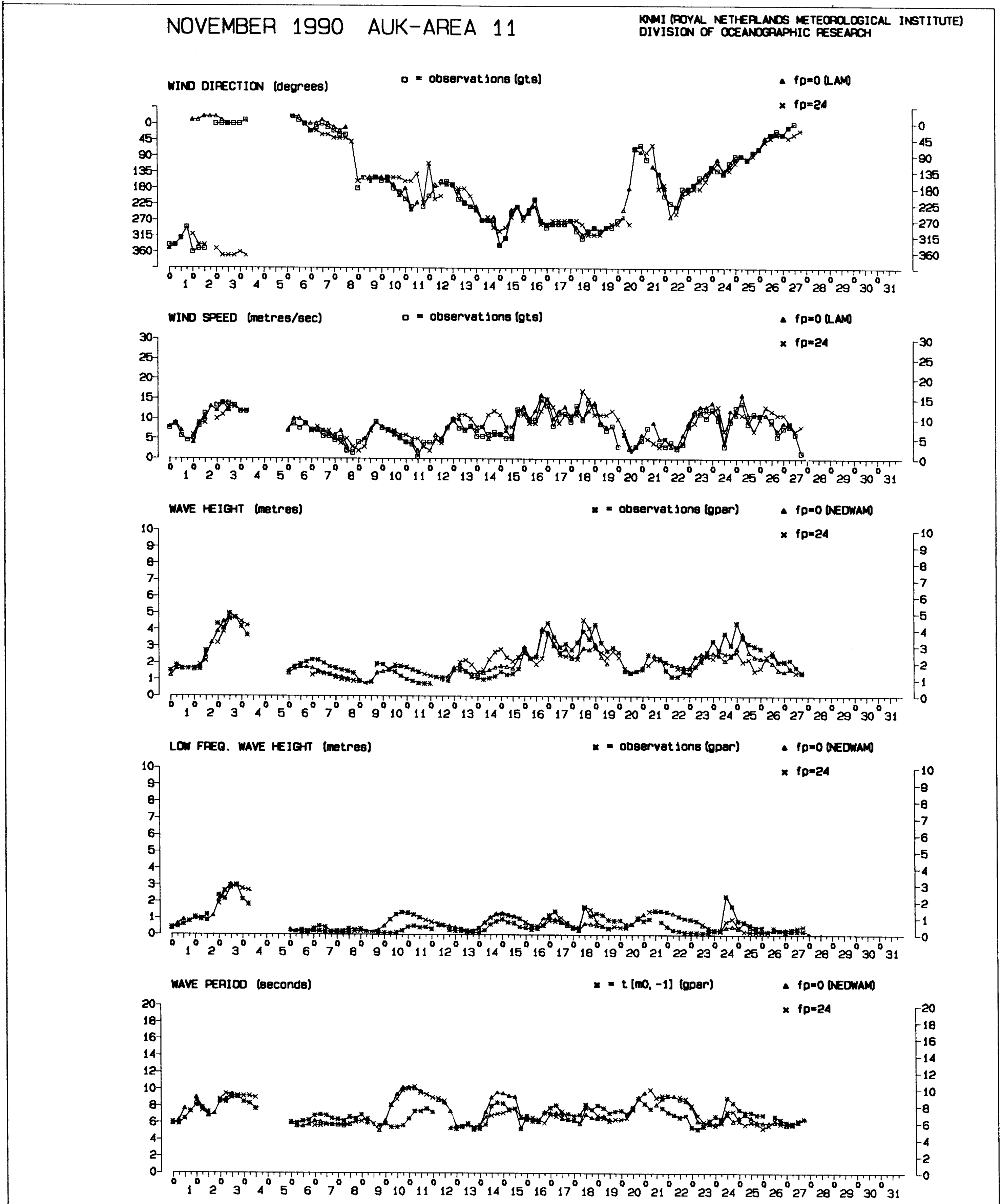


FIG. 13


NOVEMBER 1990 AUK-AREA 11
KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
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WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
WAVE PERIOD (seconds)
✱ = t (m0, -1) (gpar)
▲ fp=0 (NEDWAM)
× fp=24

FIG. 14

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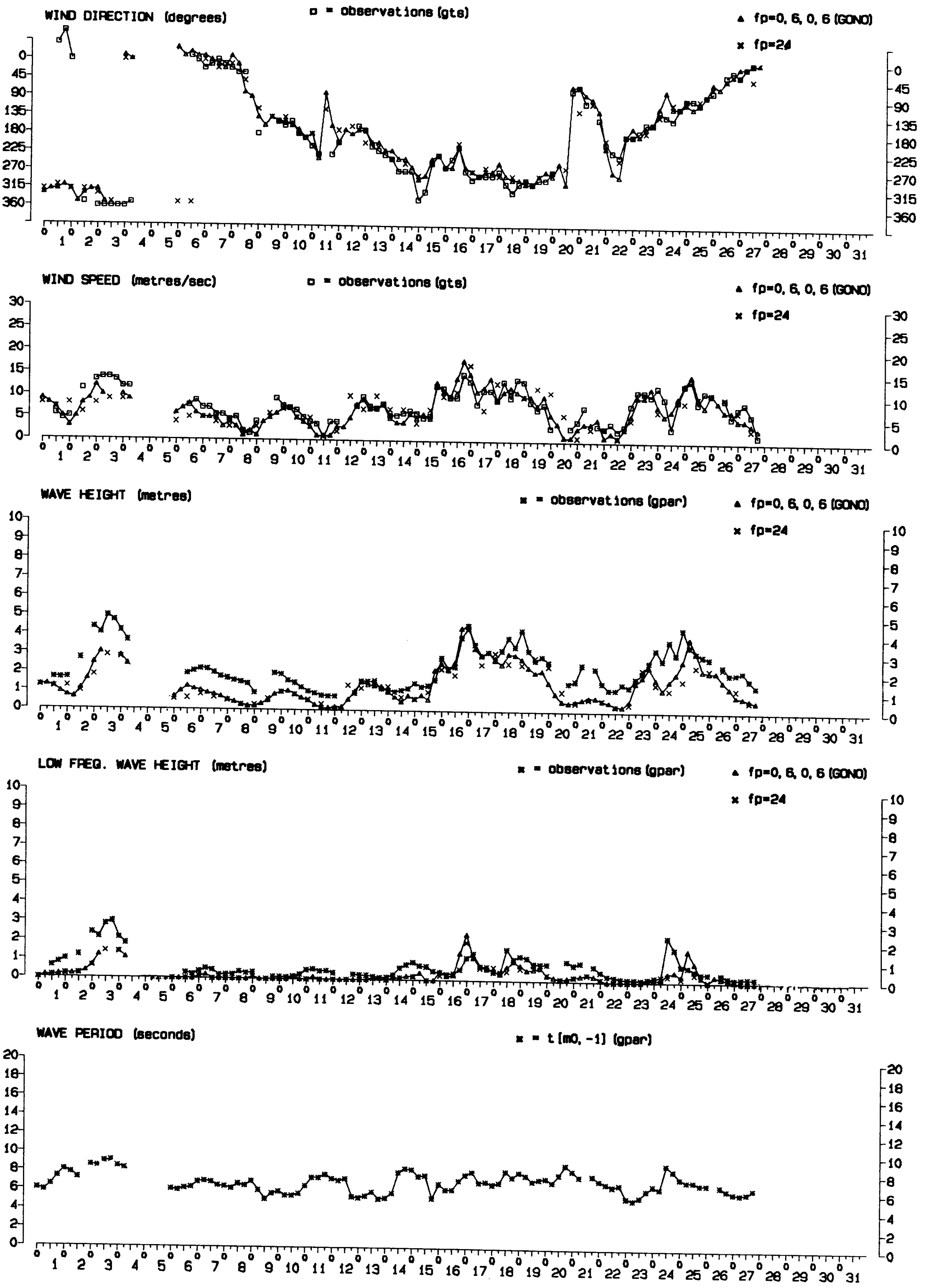

FIG. 15

DECEMBER 1990 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
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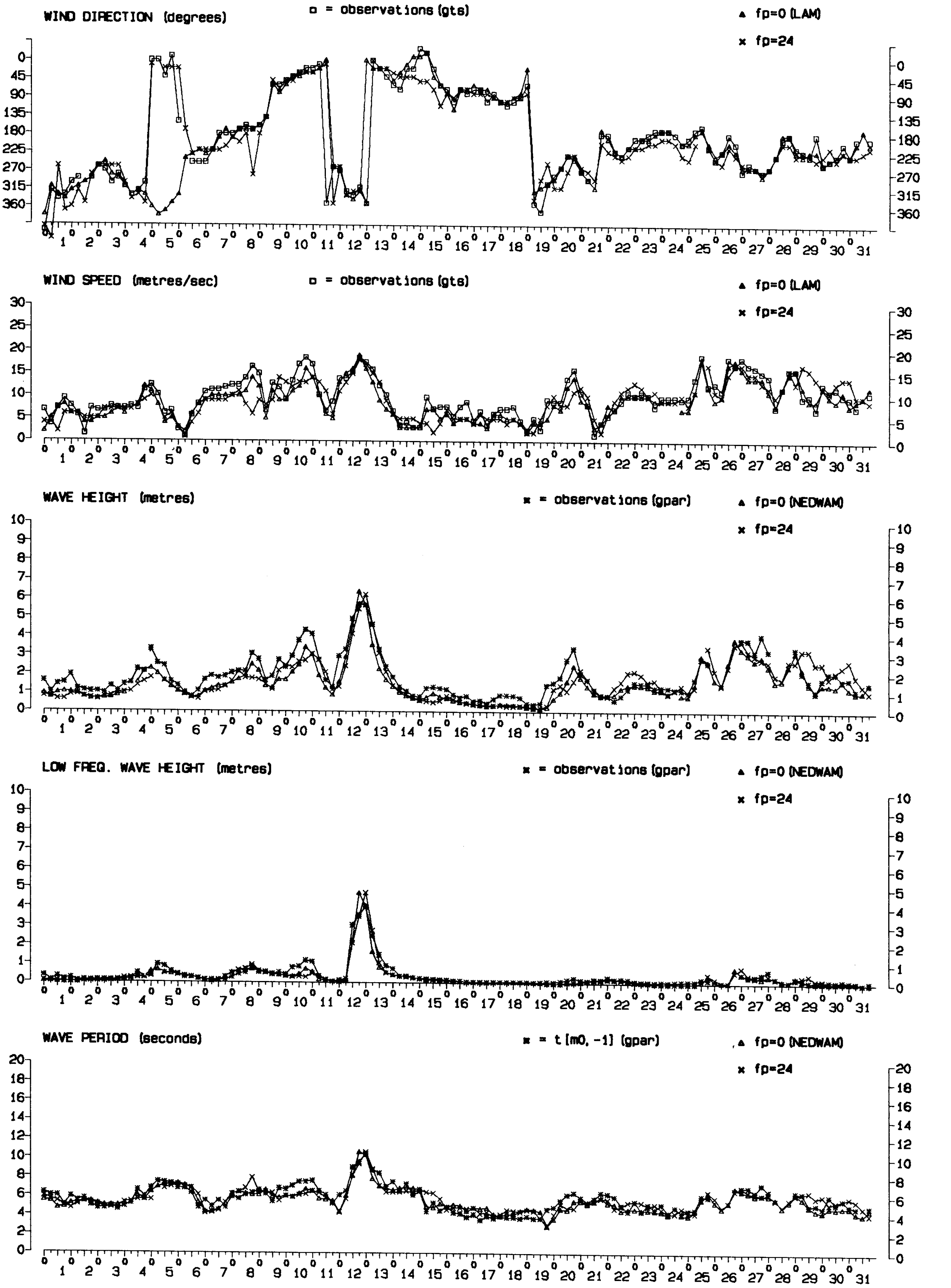


FIG. 16

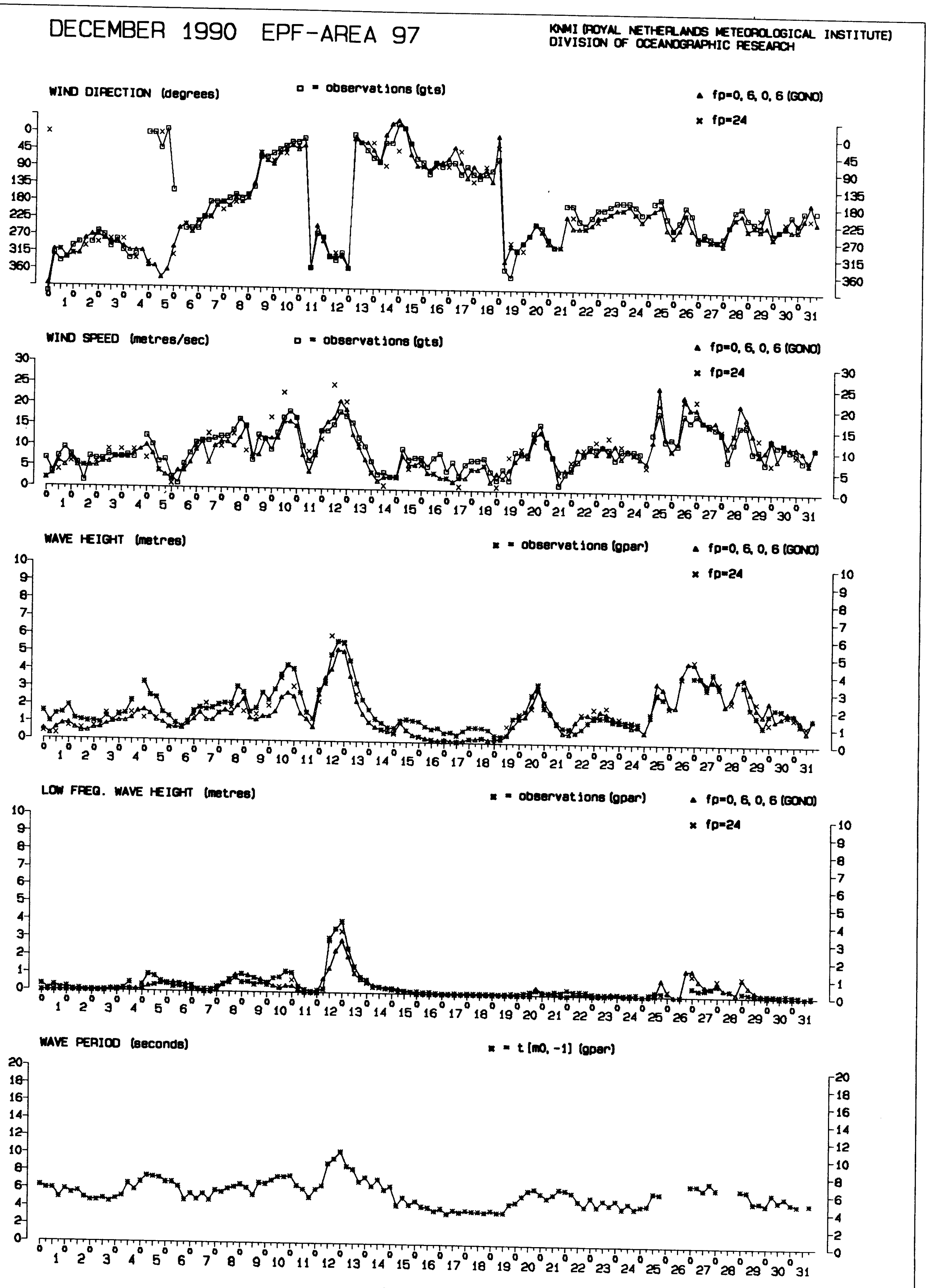

DECEMBER 1990 EPF-AREA 97
KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH
WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WIND SPEED (metres/sec)
WAVE HEIGHT (metres)
✱ = observations (gpar)
LOW FREQ. WAVE HEIGHT (metres)
WAVE PERIOD (seconds)
✱ = t [m0, -1] (gpar)

FIG. 17

DECEMBER 1990 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

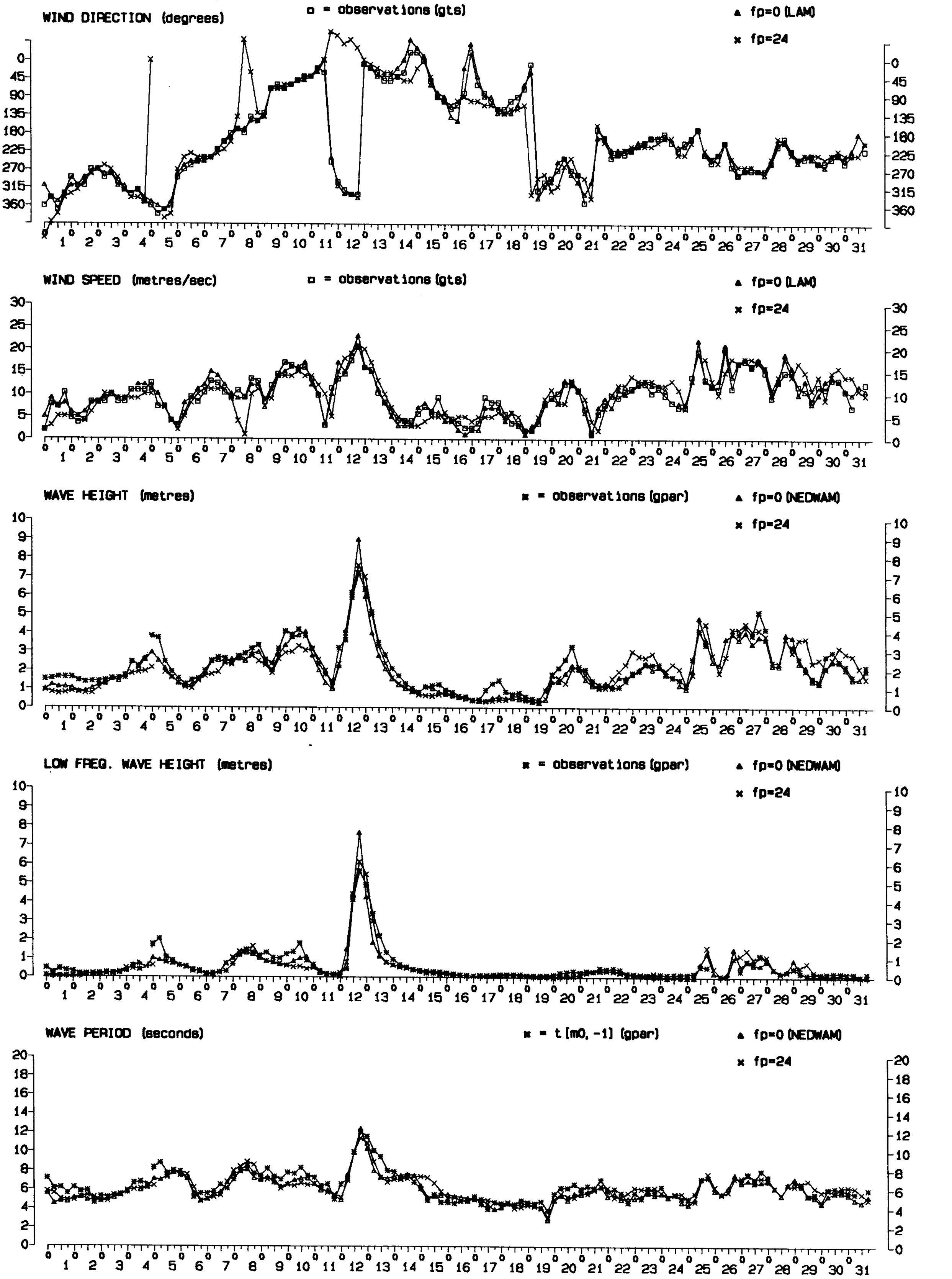
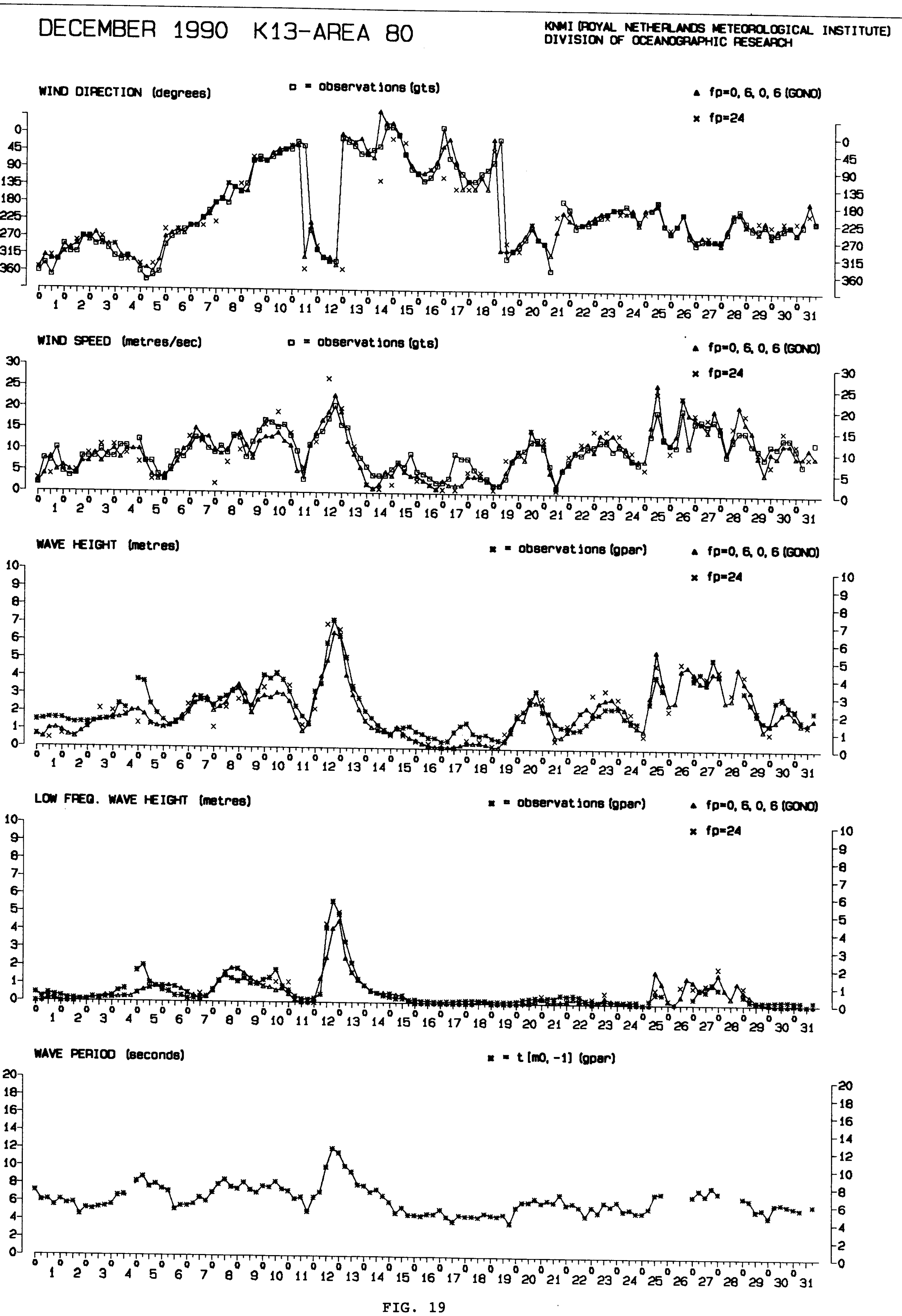


FIG. 18



DECEMBER 1990 K13-AREA 80
KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH
WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0, 6, 0, 6 (GONO)
× fp=24
WAVE PERIOD (seconds)
✱ = t (m0, -1) (gpar)

FIG. 19

DECEMBER 1990 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

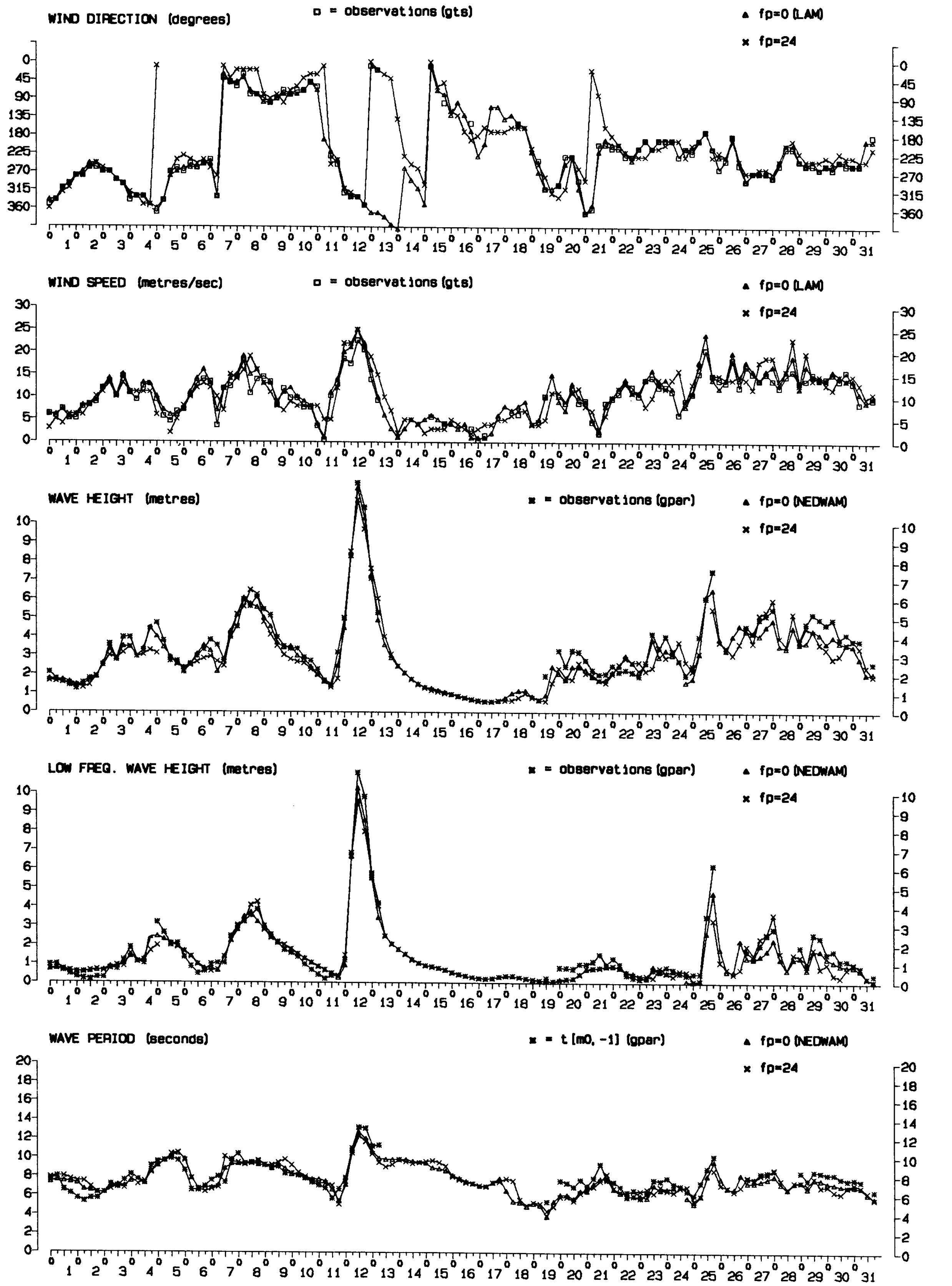


FIG. 20

DECEMBER 1990 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

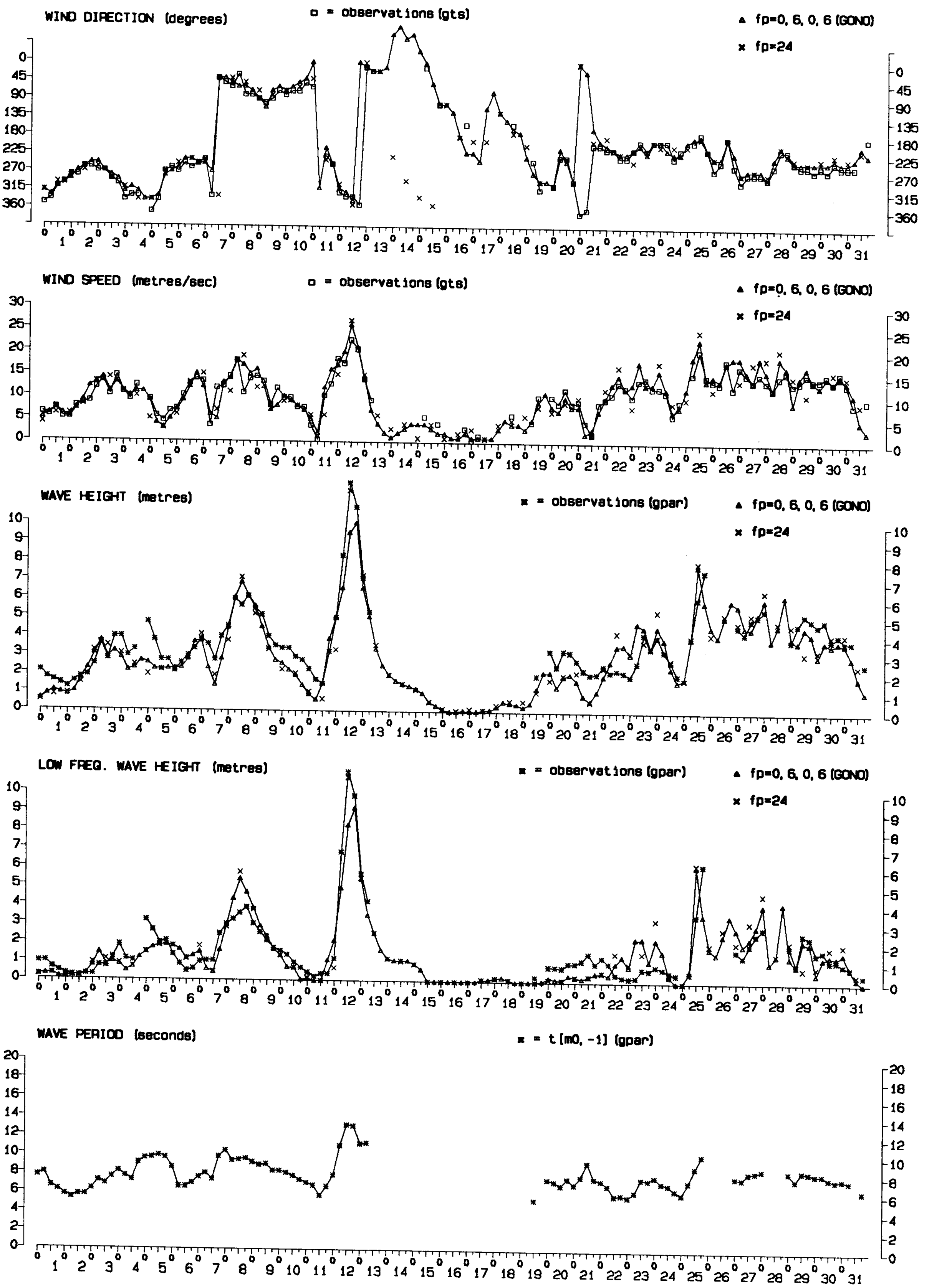


FIG. 21

JANUARY 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

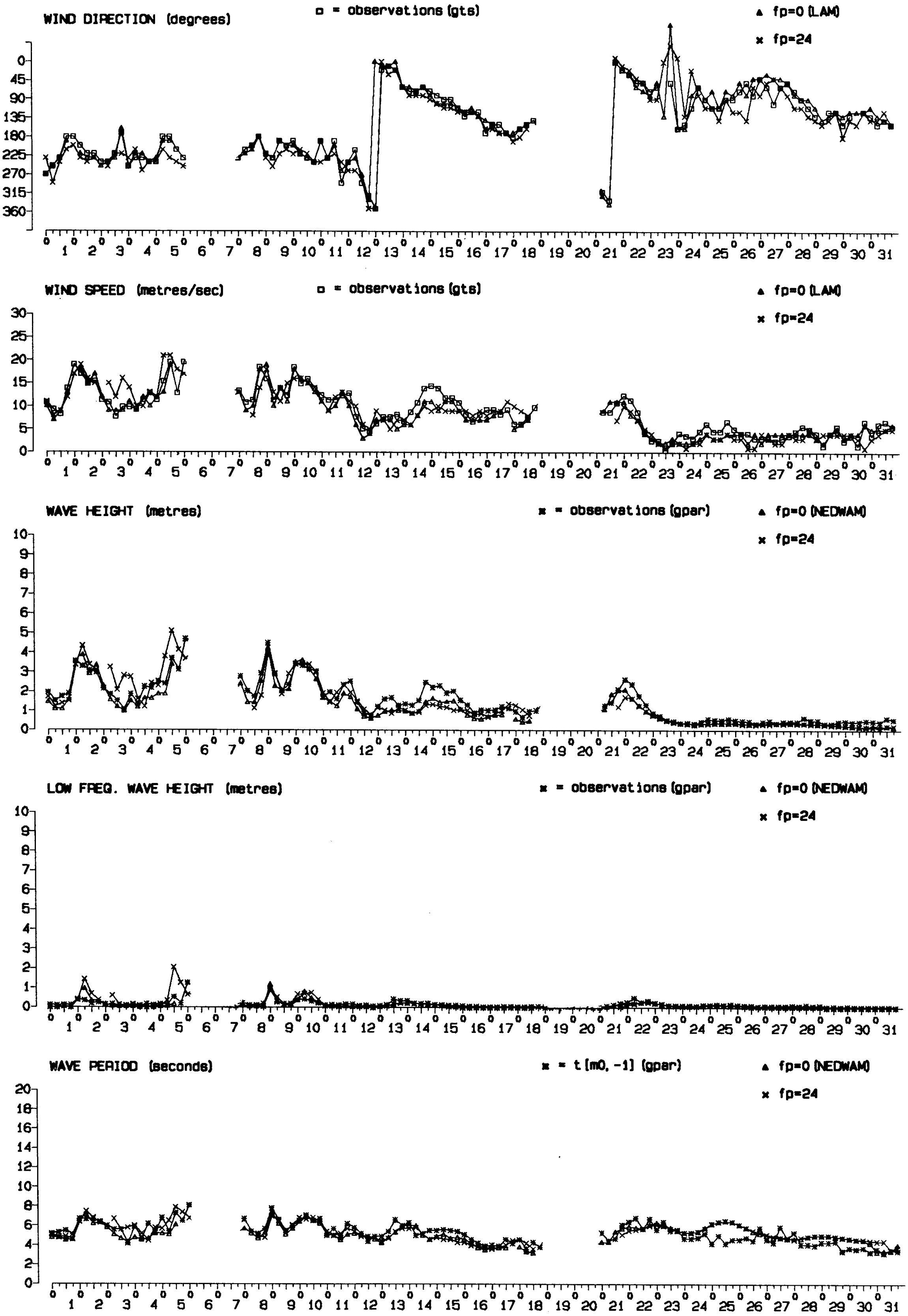


FIG. 22

JANUARY 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

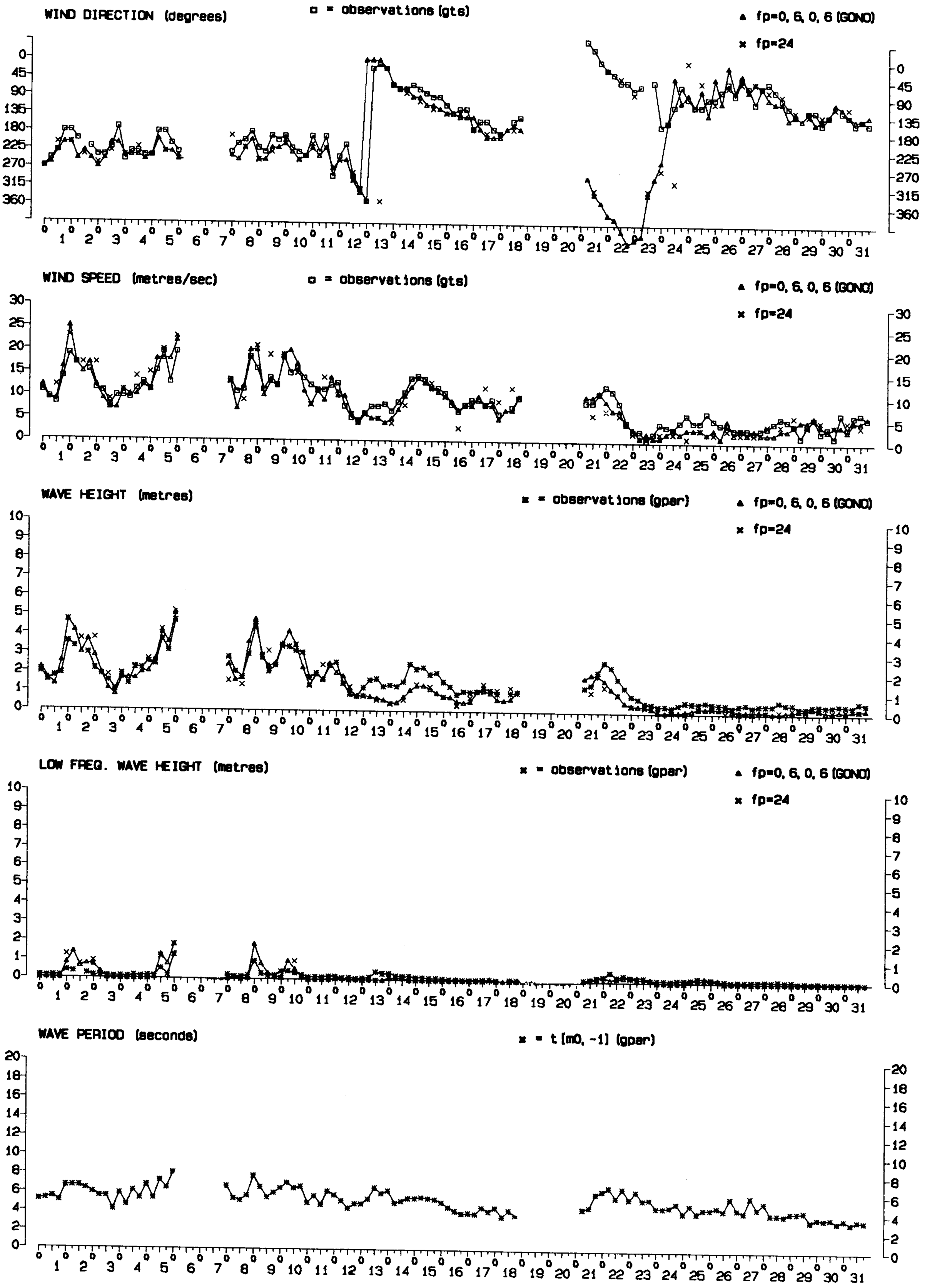


FIG. 23

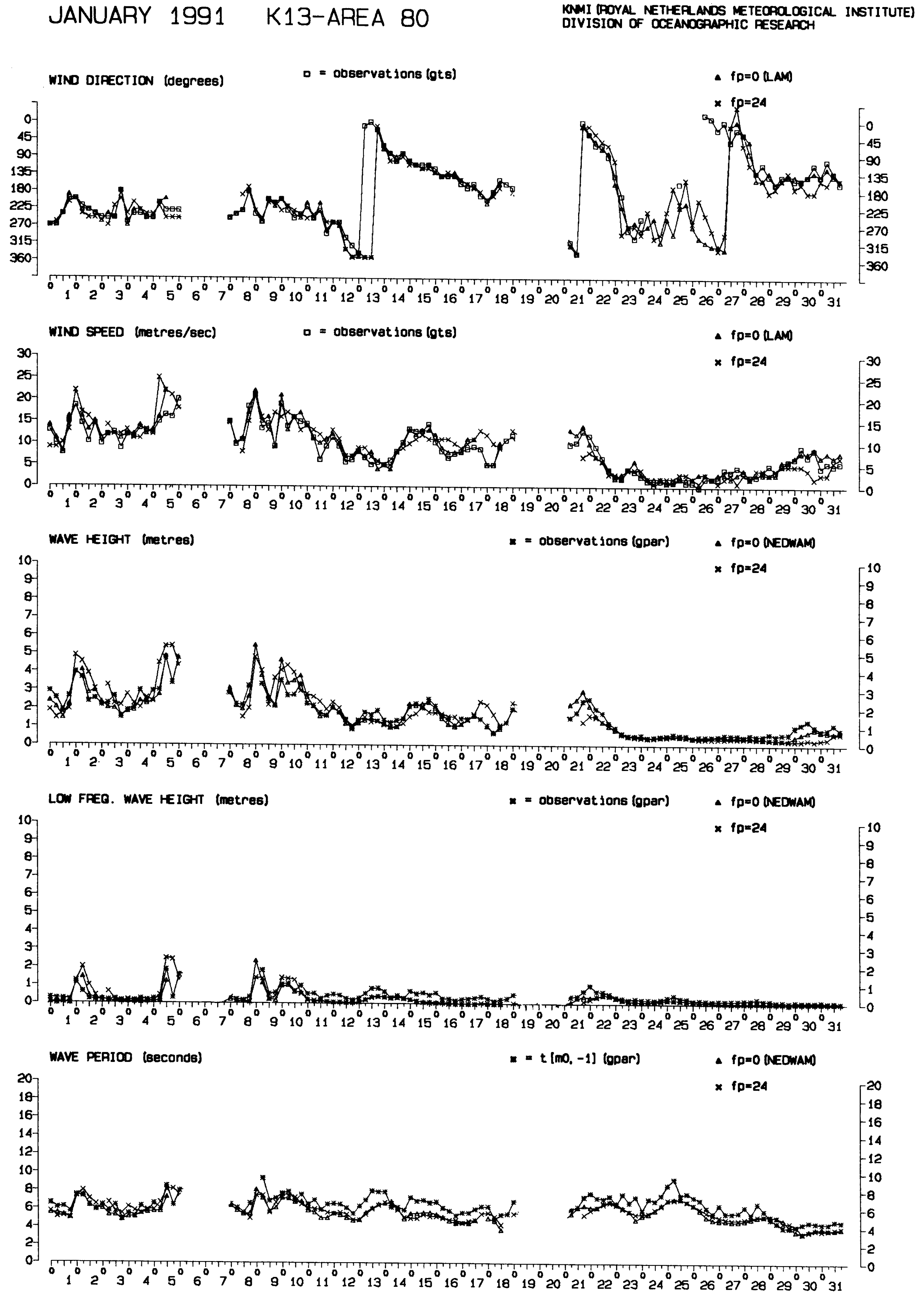

JANUARY 1991 K13-AREA 80
KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH
WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
WAVE PERIOD (seconds)
* = t [m0, -1] (gpar)
▲ fp=0 (NEDWAM)
× fp=24

FIG. 24

JANUARY 1991 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

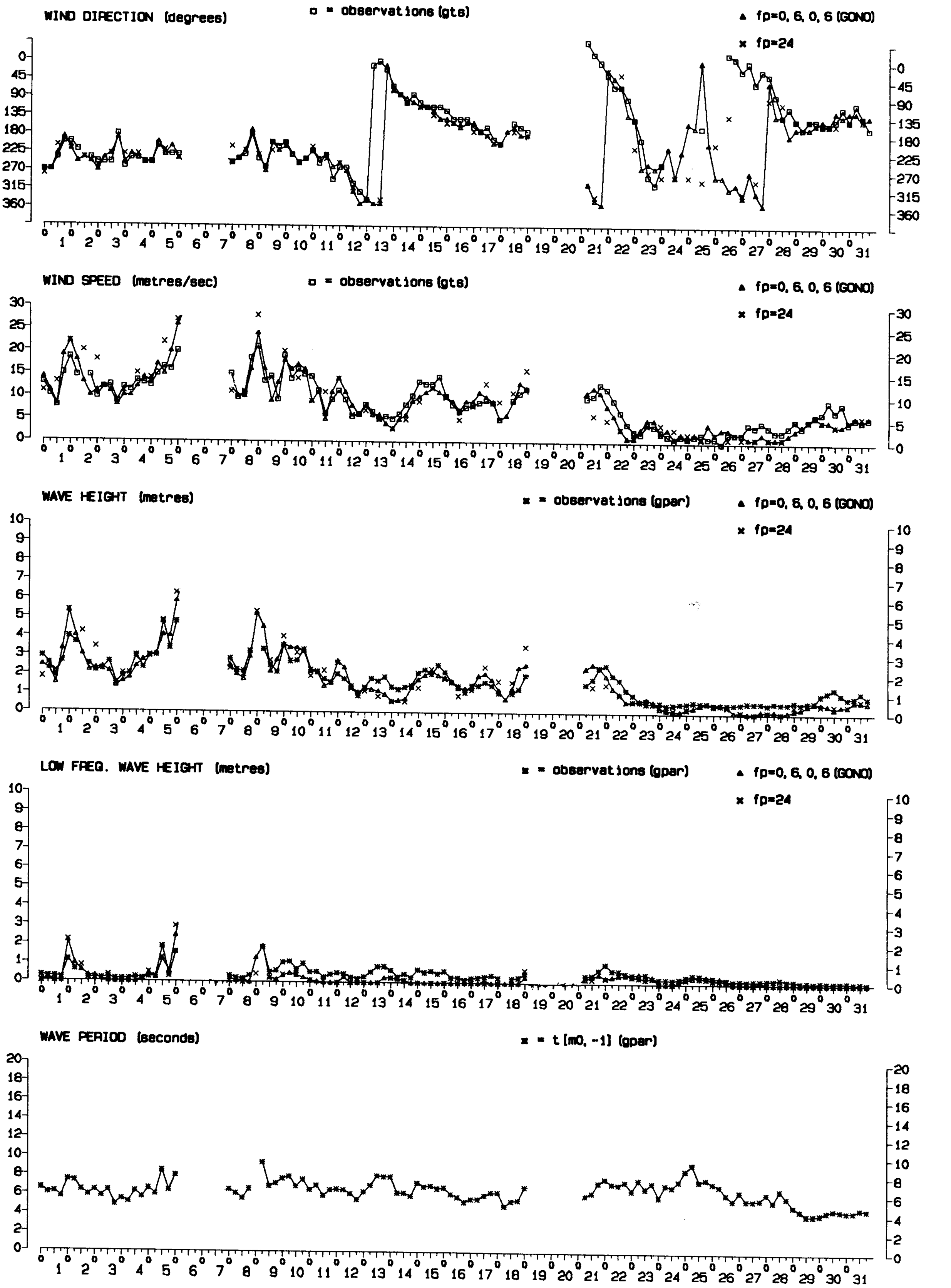


FIG. 25

JANUARY 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

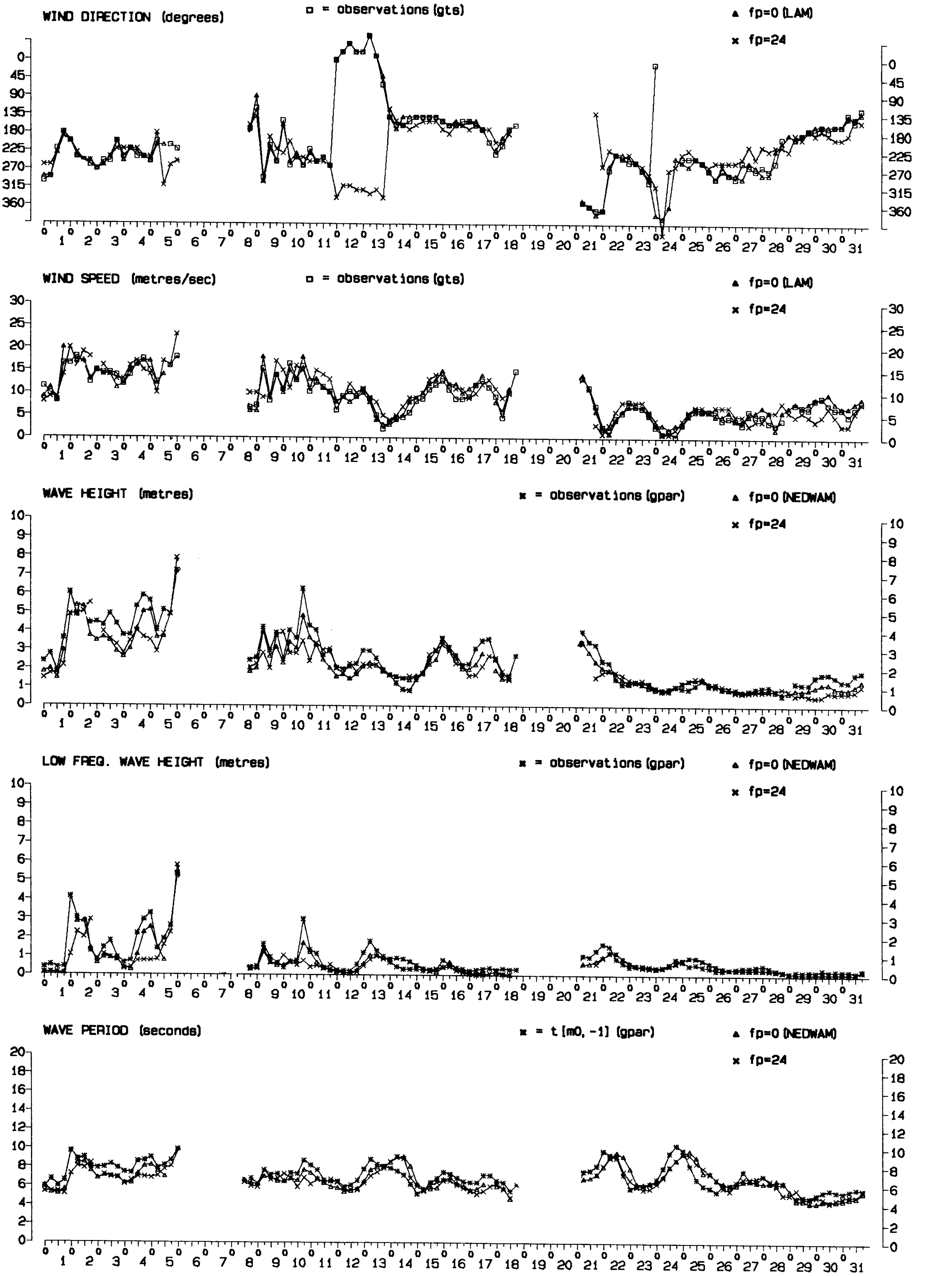


FIG. 26

JANUARY 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

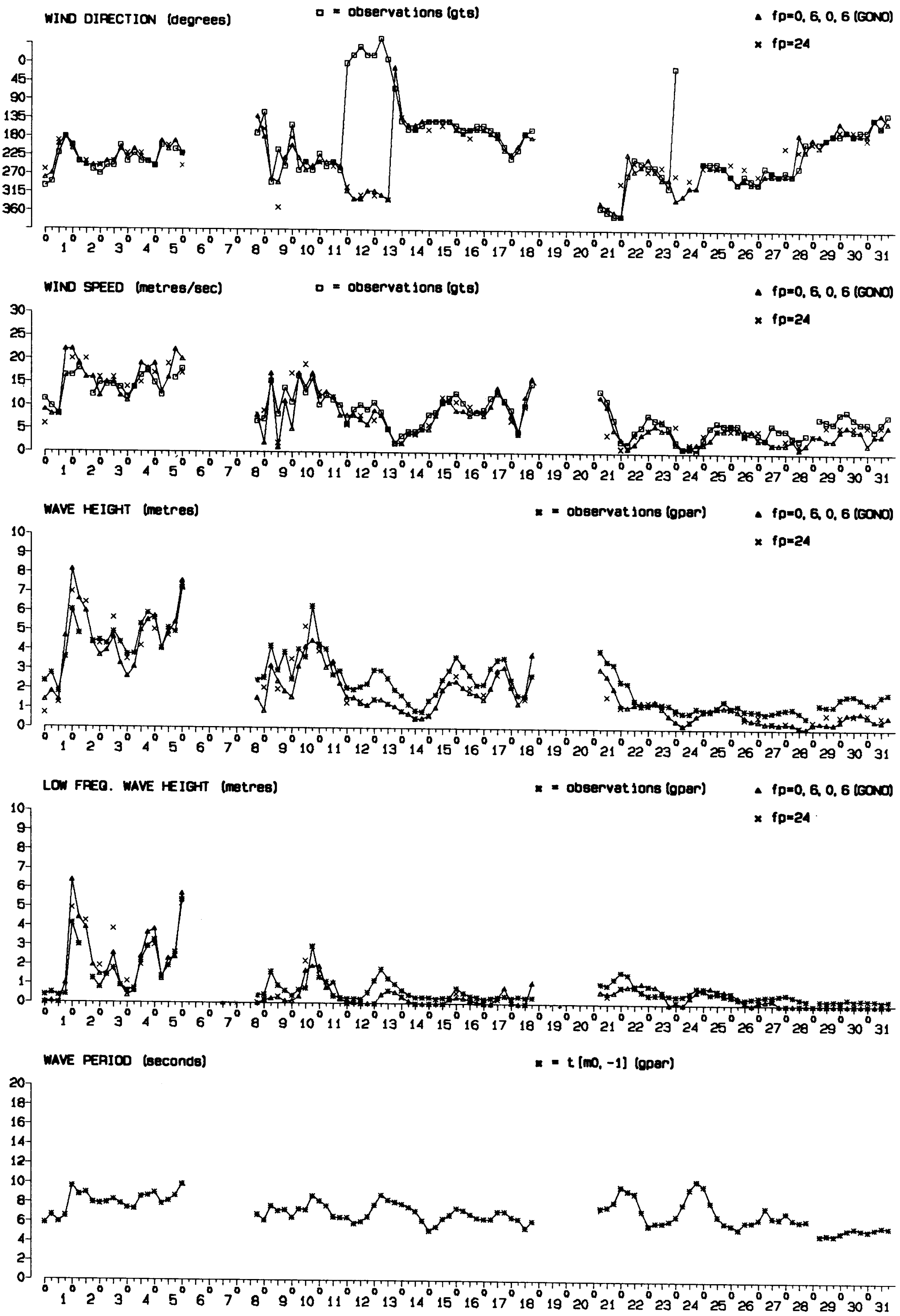


FIG. 27

FEBRUARY 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

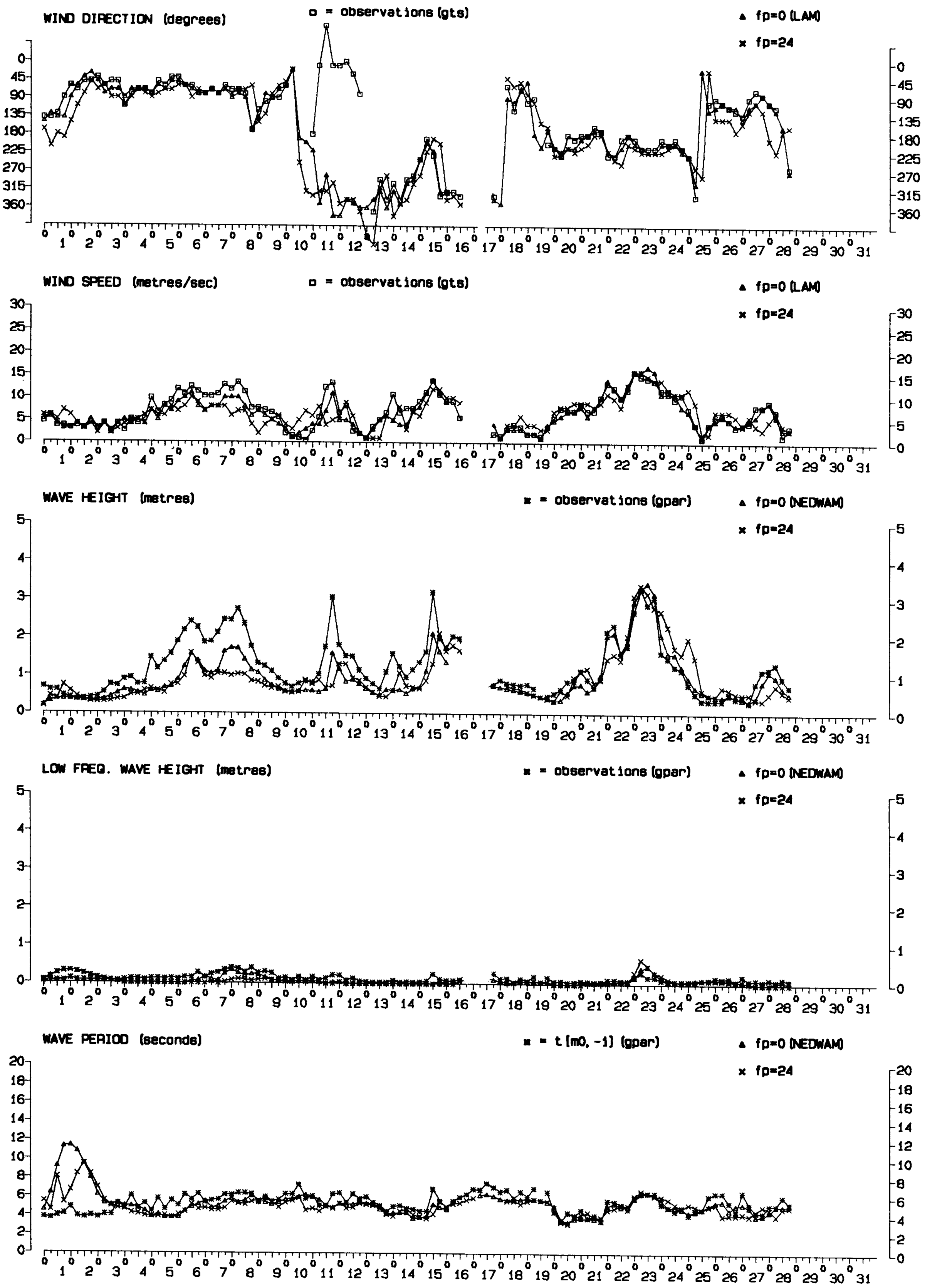


FIG. 28

FEBRUARY 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

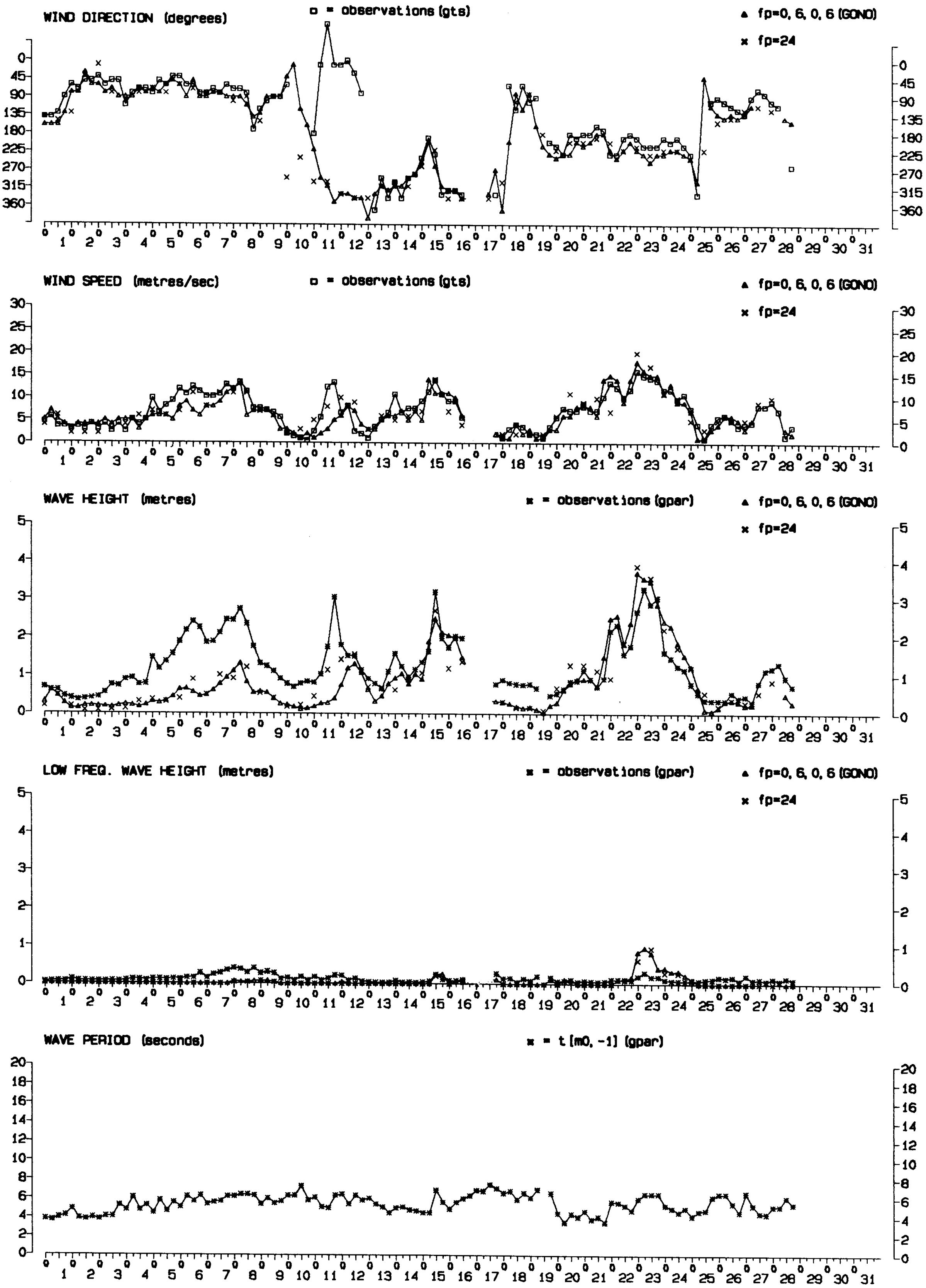


FIG. 29

FEBRUARY 1991 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

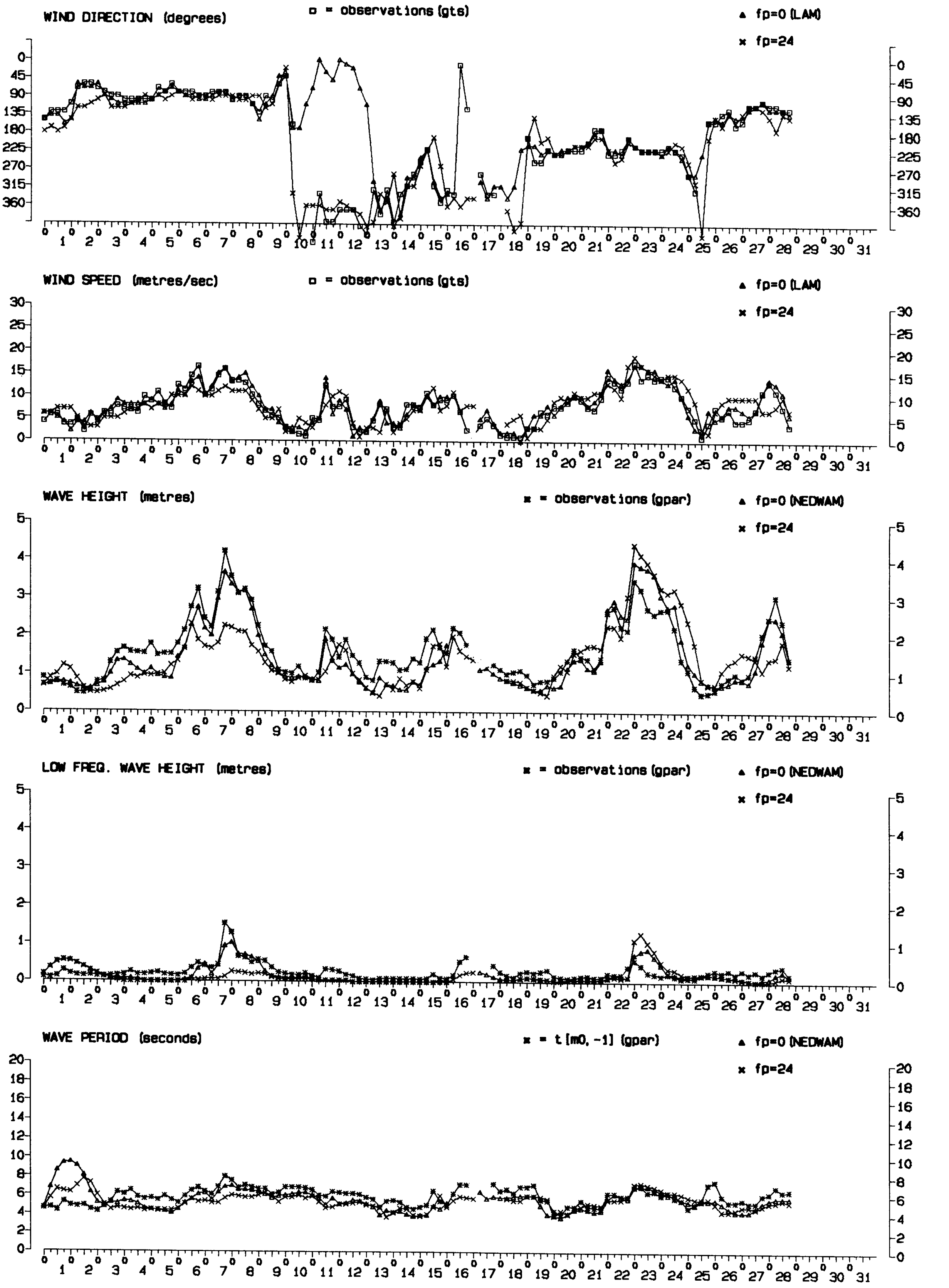


FIG. 30

FEBRUARY 1991 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

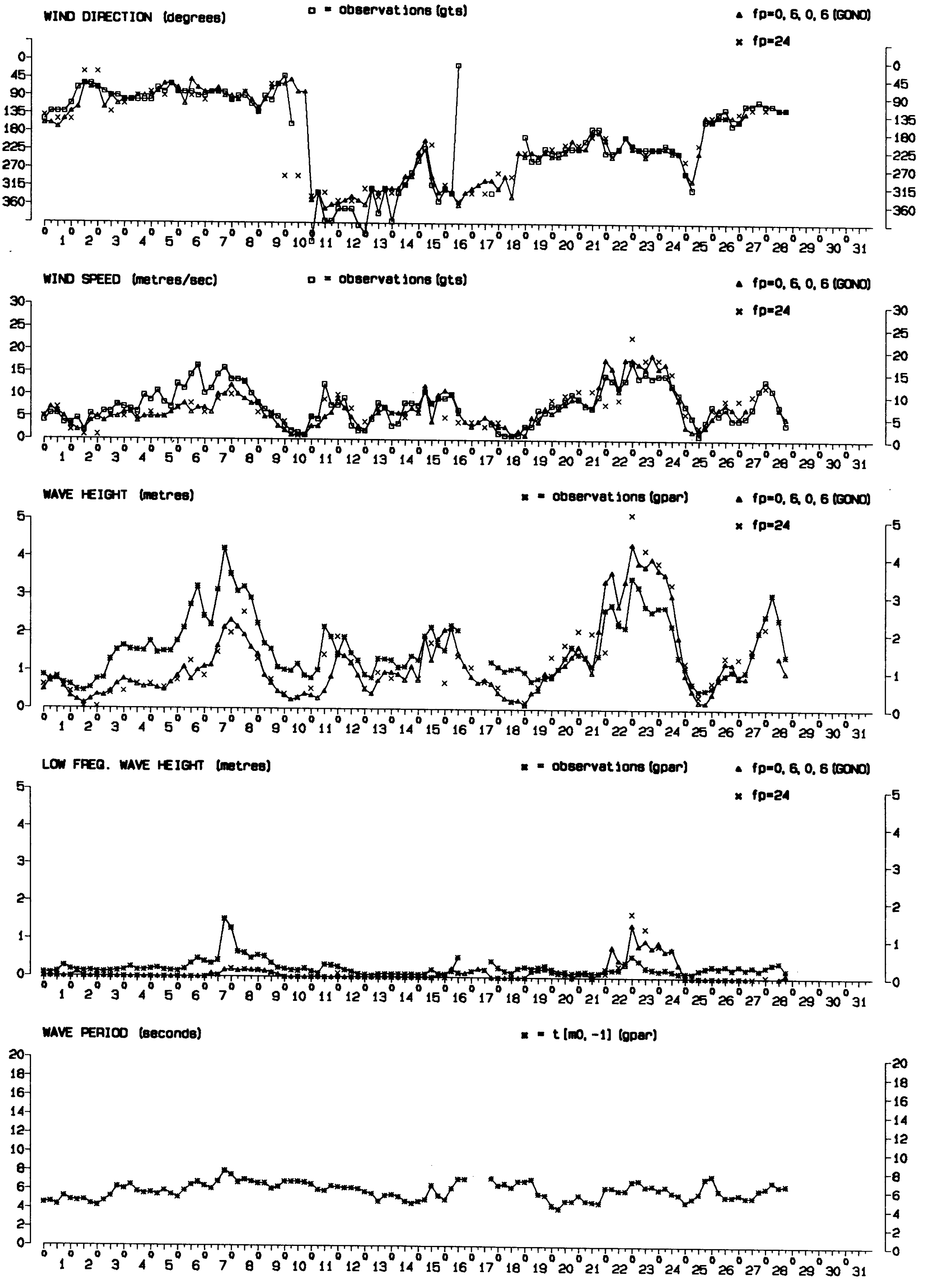


FIG. 31

FEBRUARY 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

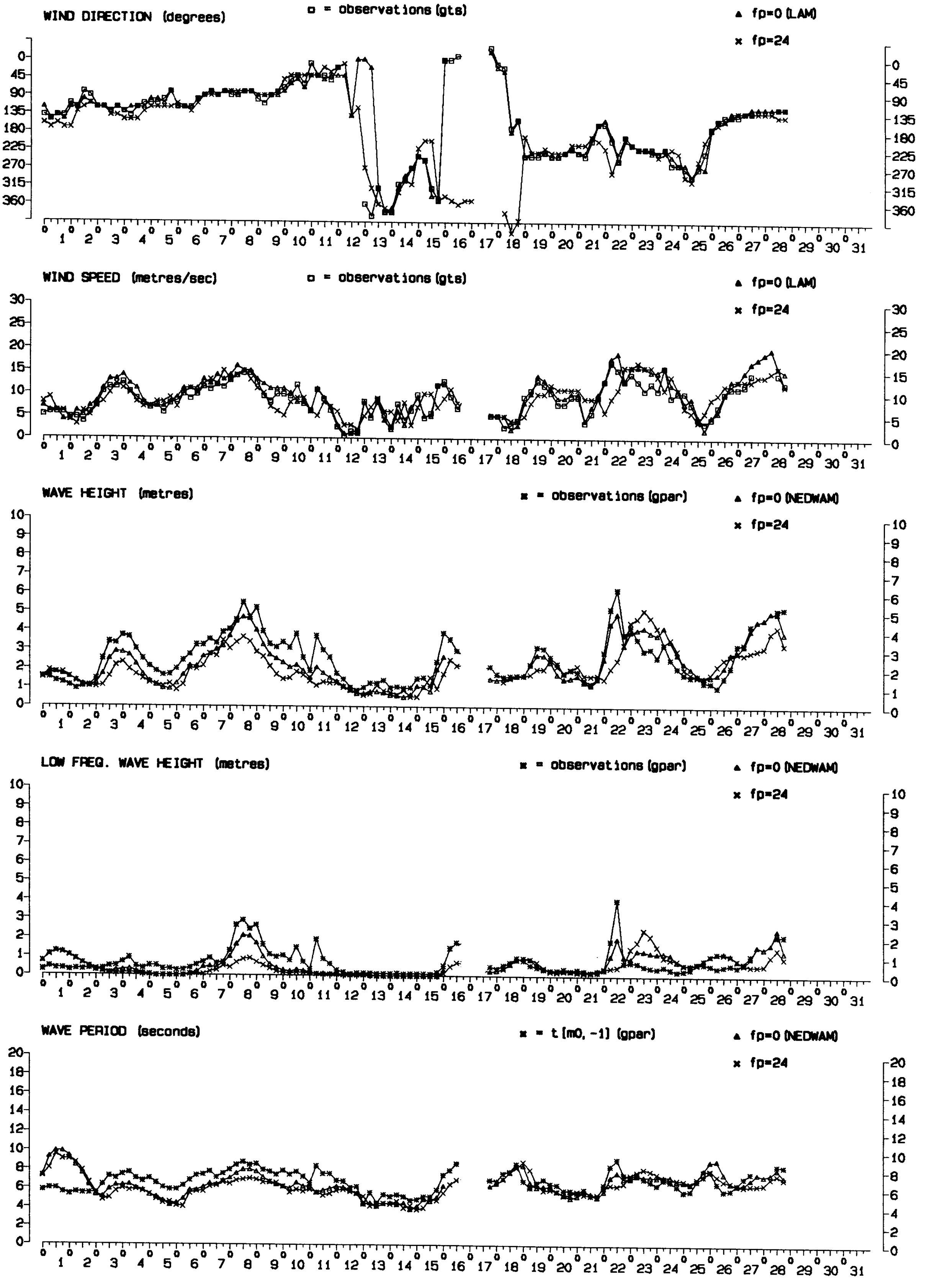


FIG. 32

FEBRUARY 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

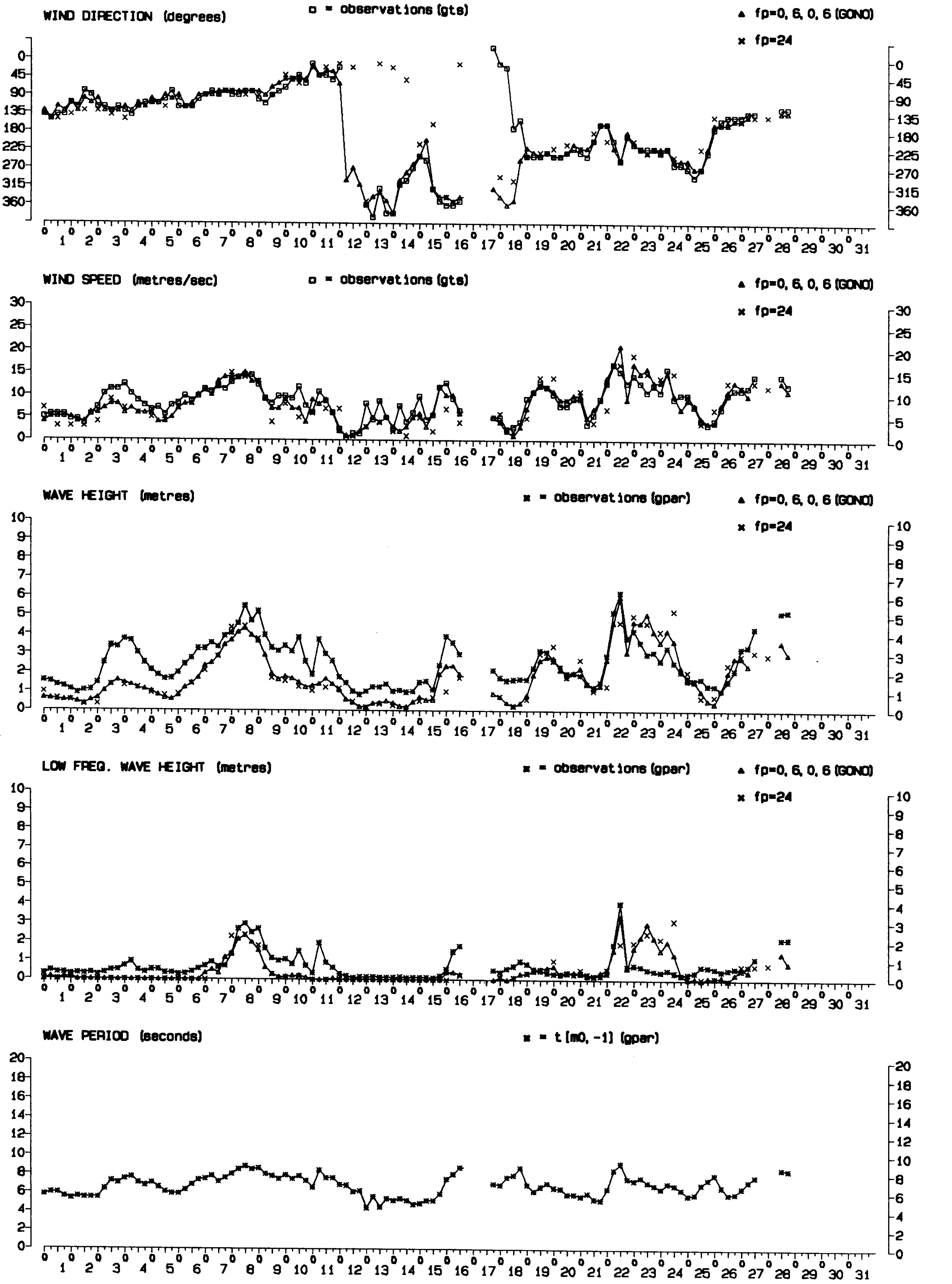


FIG. 33

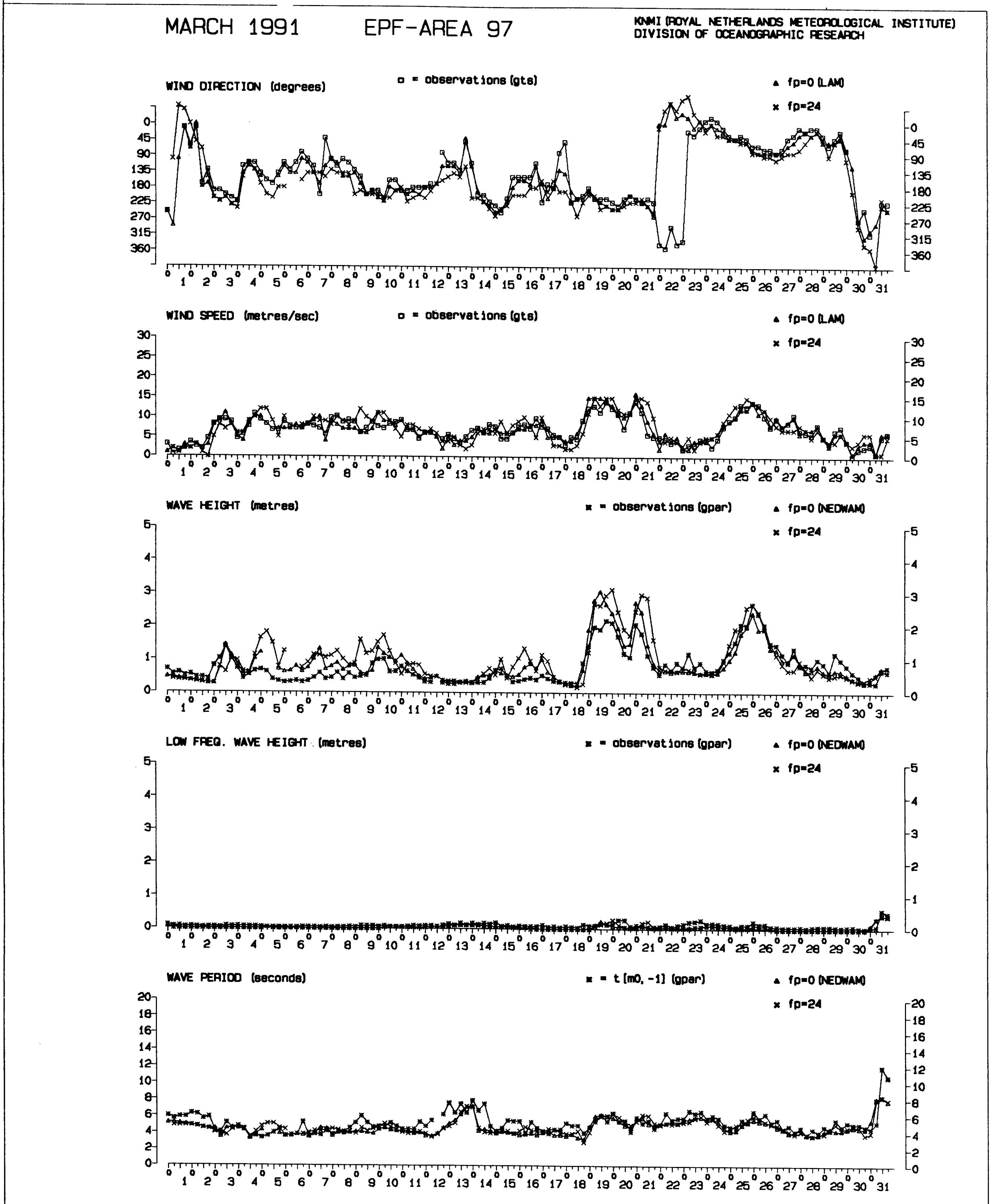

MARCH 1991
EPF-AREA 97
KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH
WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
✱ = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
WAVE PERIOD (seconds)
✱ = t [m0, -1] (gpar)
▲ fp=0 (NEDWAM)
× fp=24

FIG. 34

MARCH 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

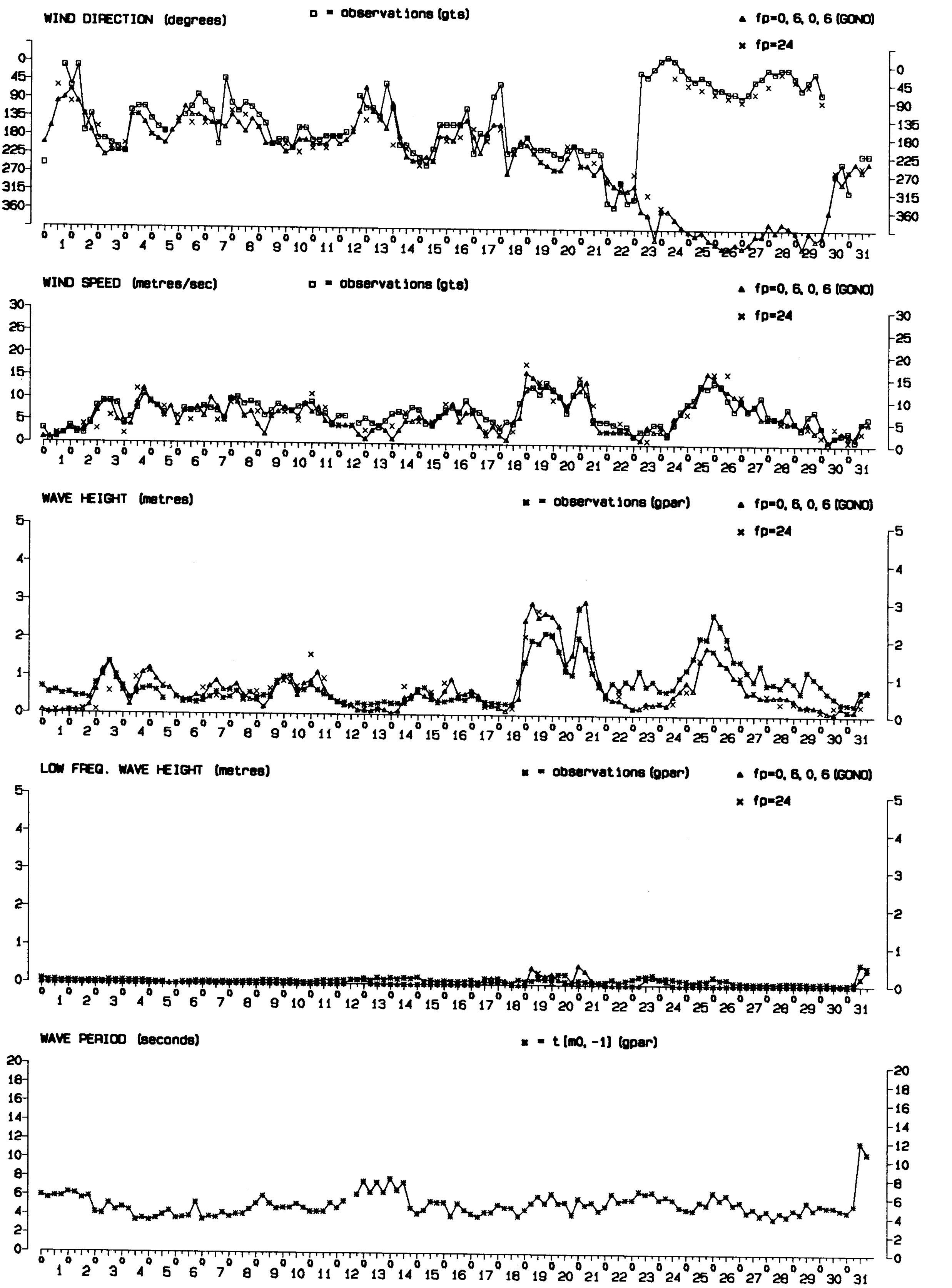


FIG. 35

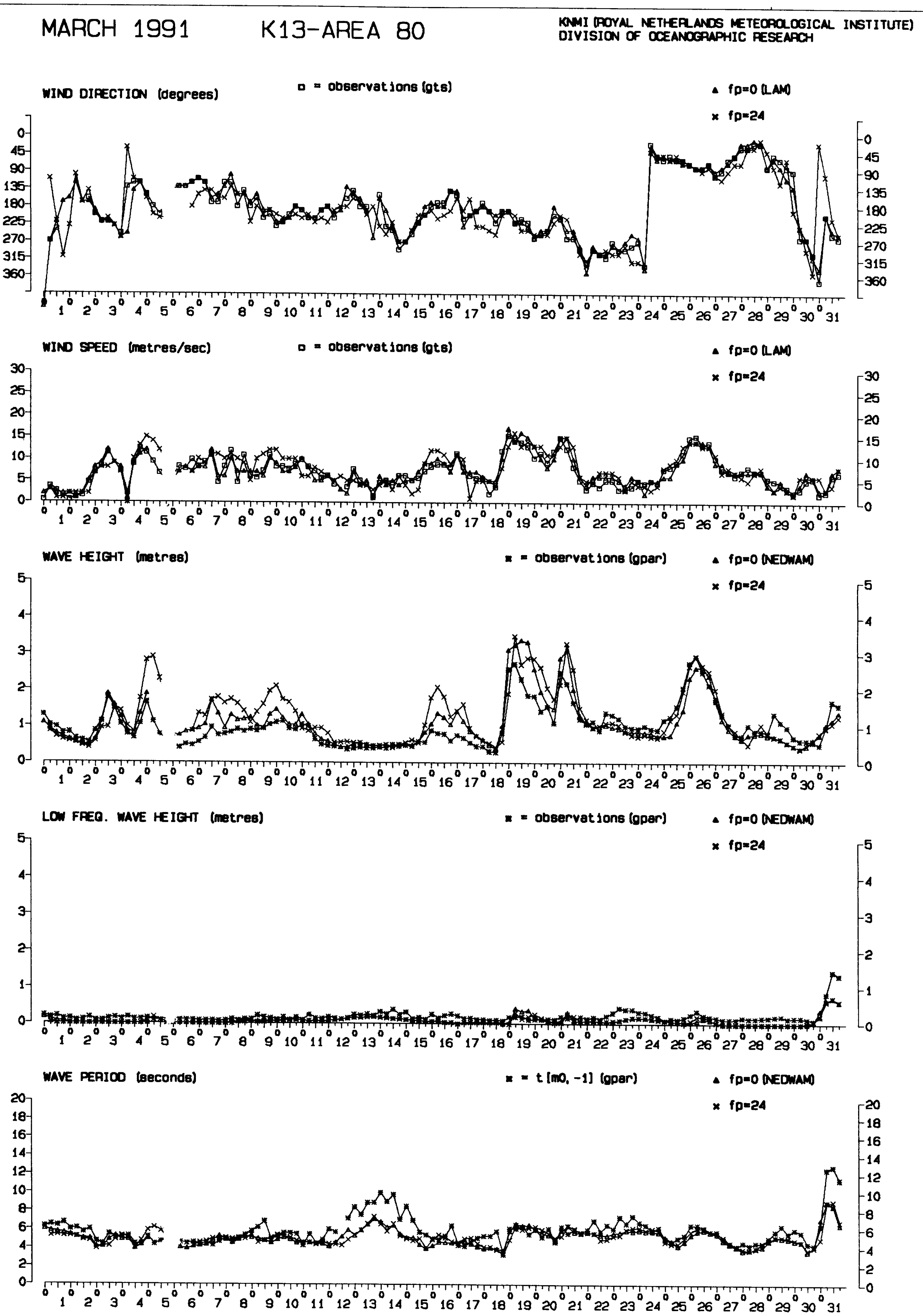

MARCH 1991
K13-AREA 80
KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH
WIND DIRECTION (degrees)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WIND SPEED (metres/sec)
□ = observations (gts)
▲ fp=0 (LAM)
× fp=24
WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
LOW FREQ. WAVE HEIGHT (metres)
* = observations (gpar)
▲ fp=0 (NEDWAM)
× fp=24
WAVE PERIOD (seconds)
* = t [m0, -1] (gpar)
▲ fp=0 (NEDWAM)
× fp=24

FIG. 36

MARCH 1991 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

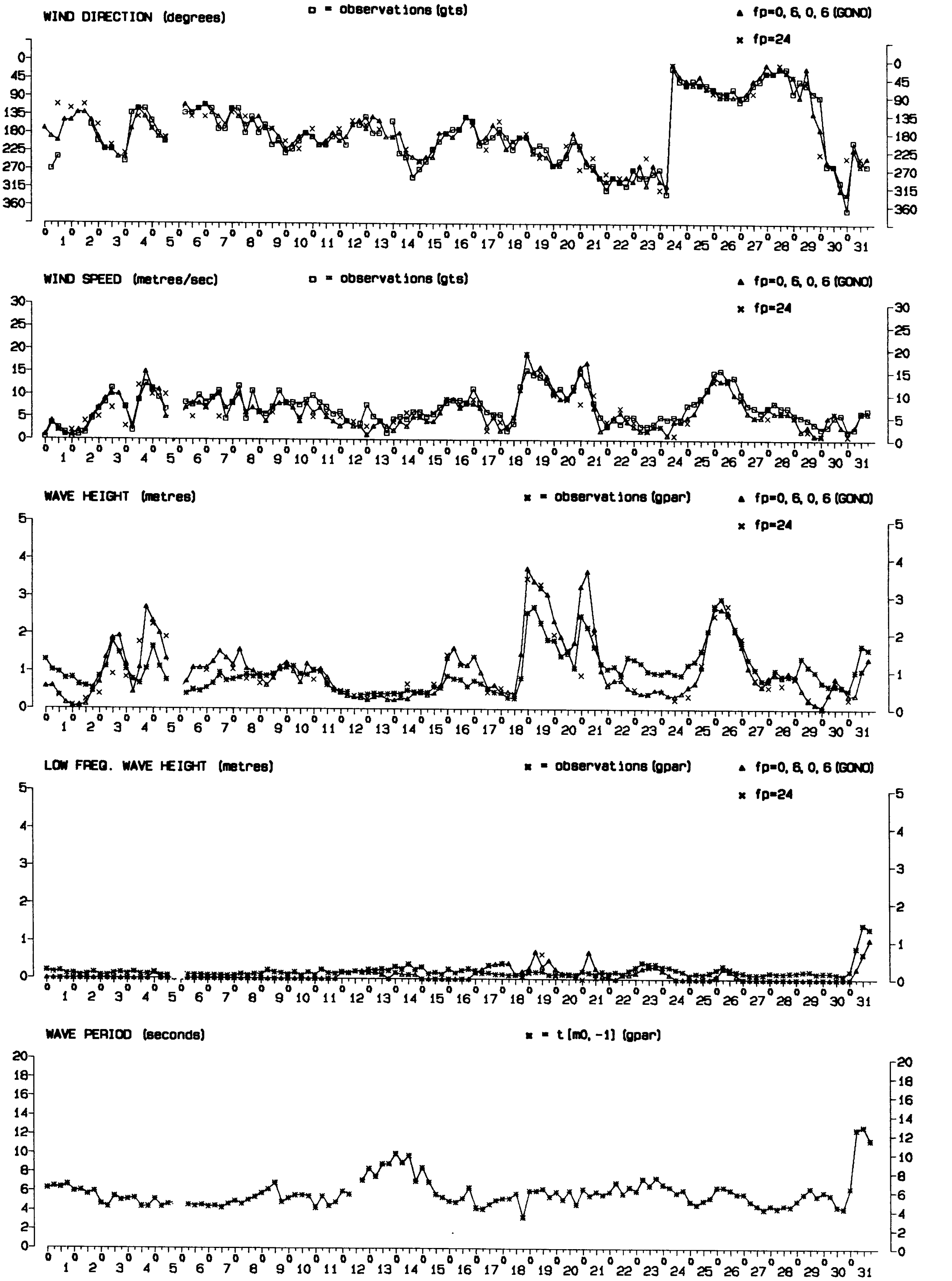


FIG. 37

MARCH 1991   AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

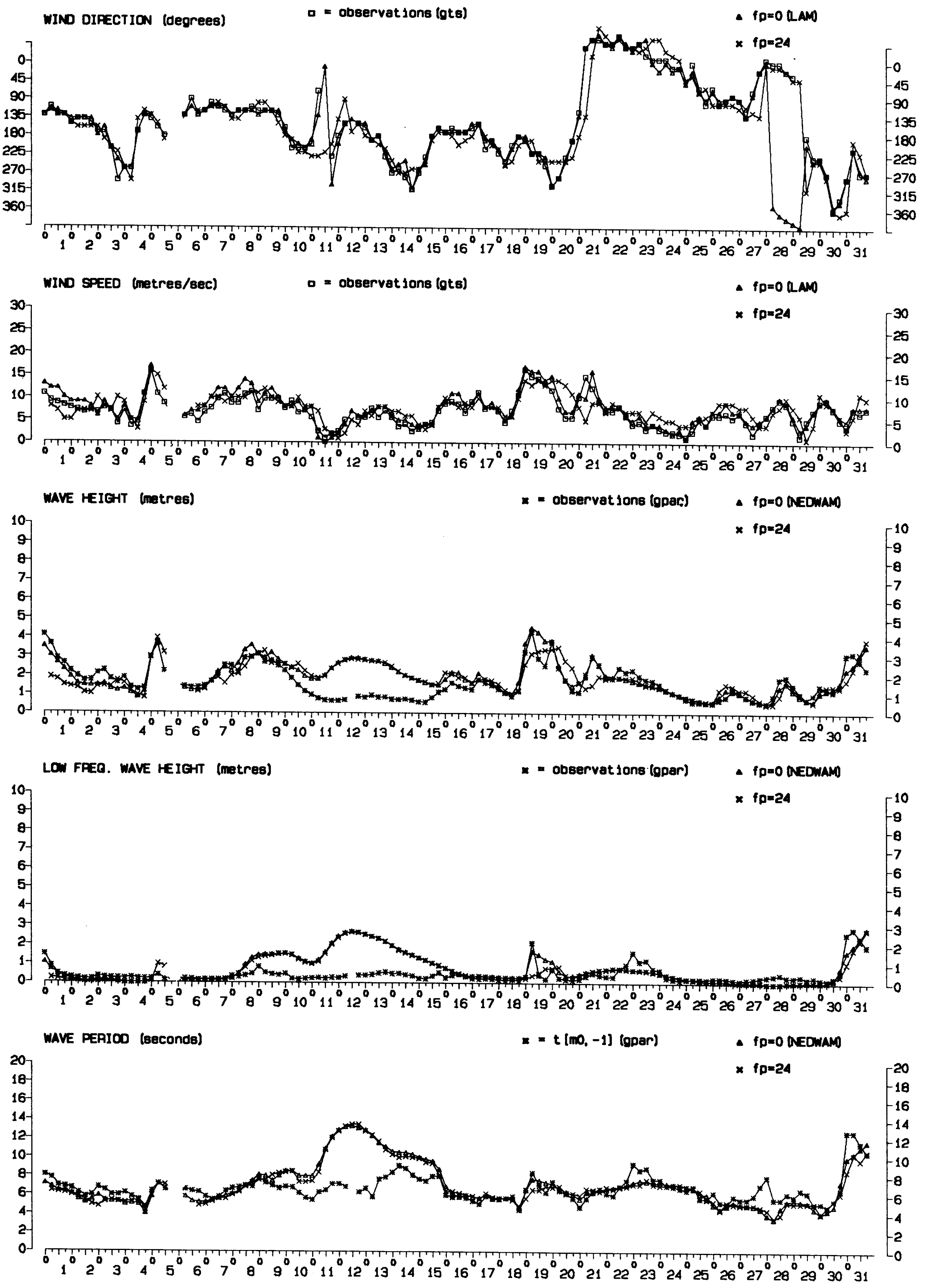


FIG. 38

MARCH 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

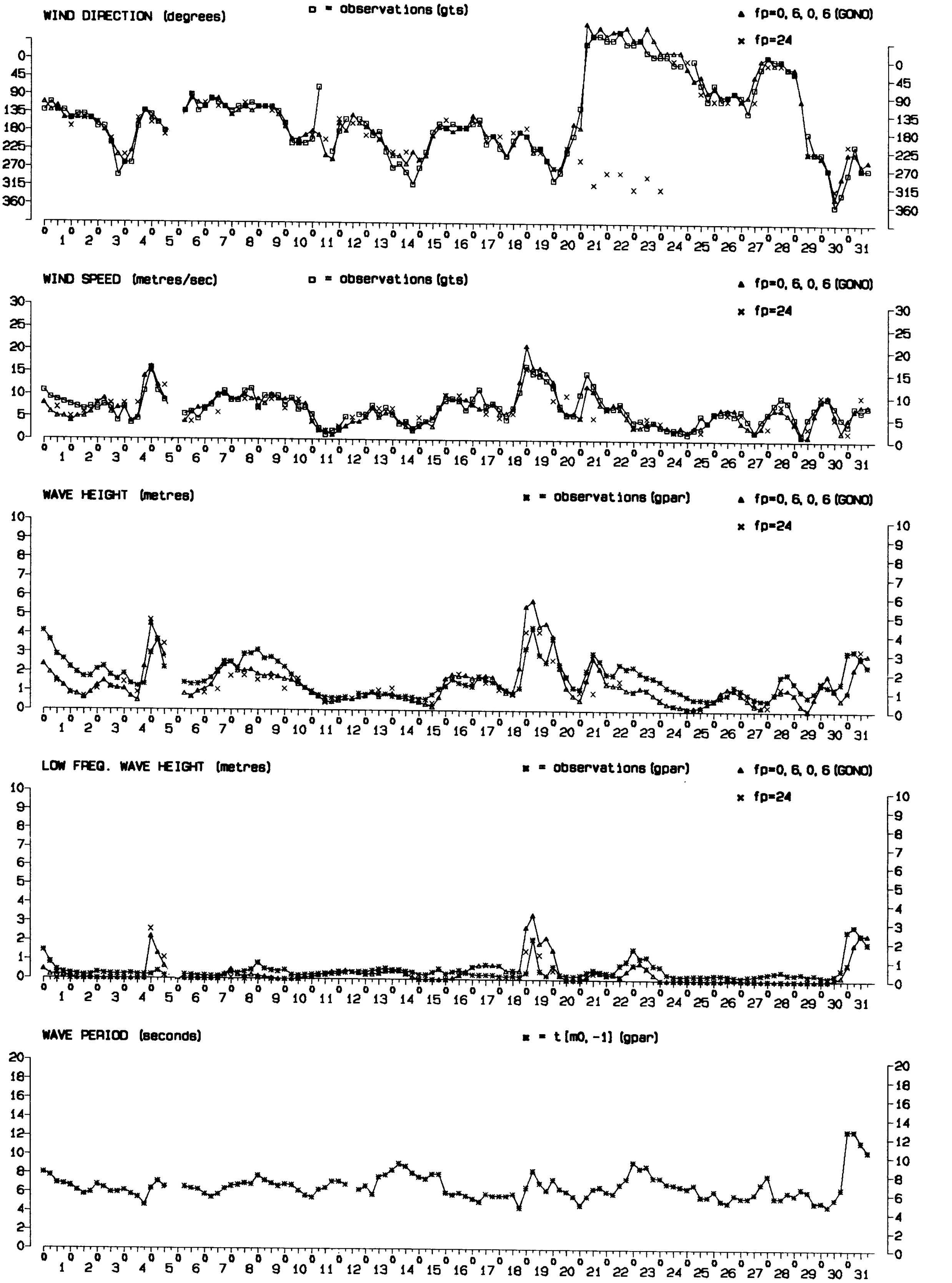


FIG. 39

APRIL 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

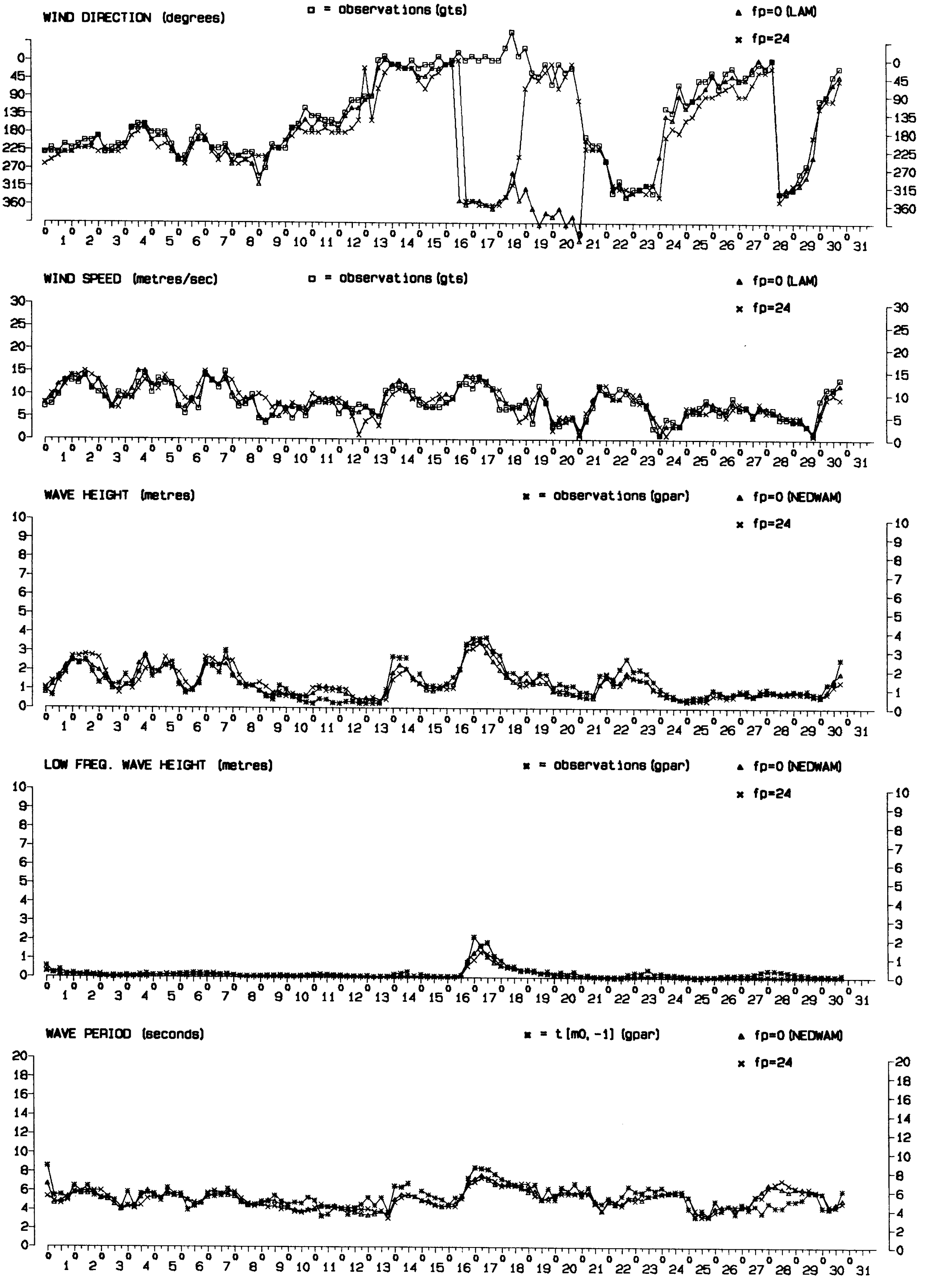


FIG. 40

APRIL 1991 EPF-AREA 97

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

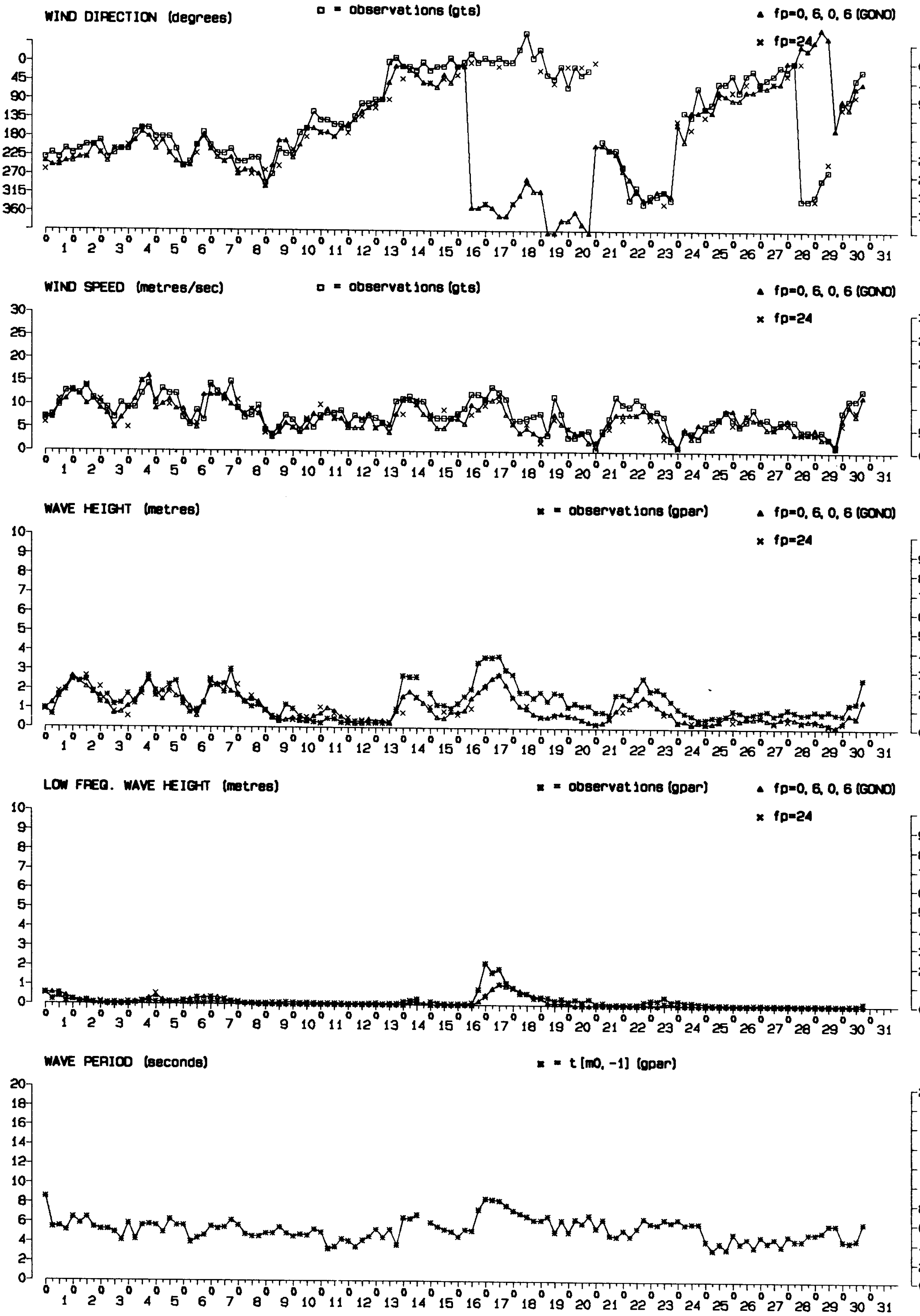


FIG. 41

APRIL 1991 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

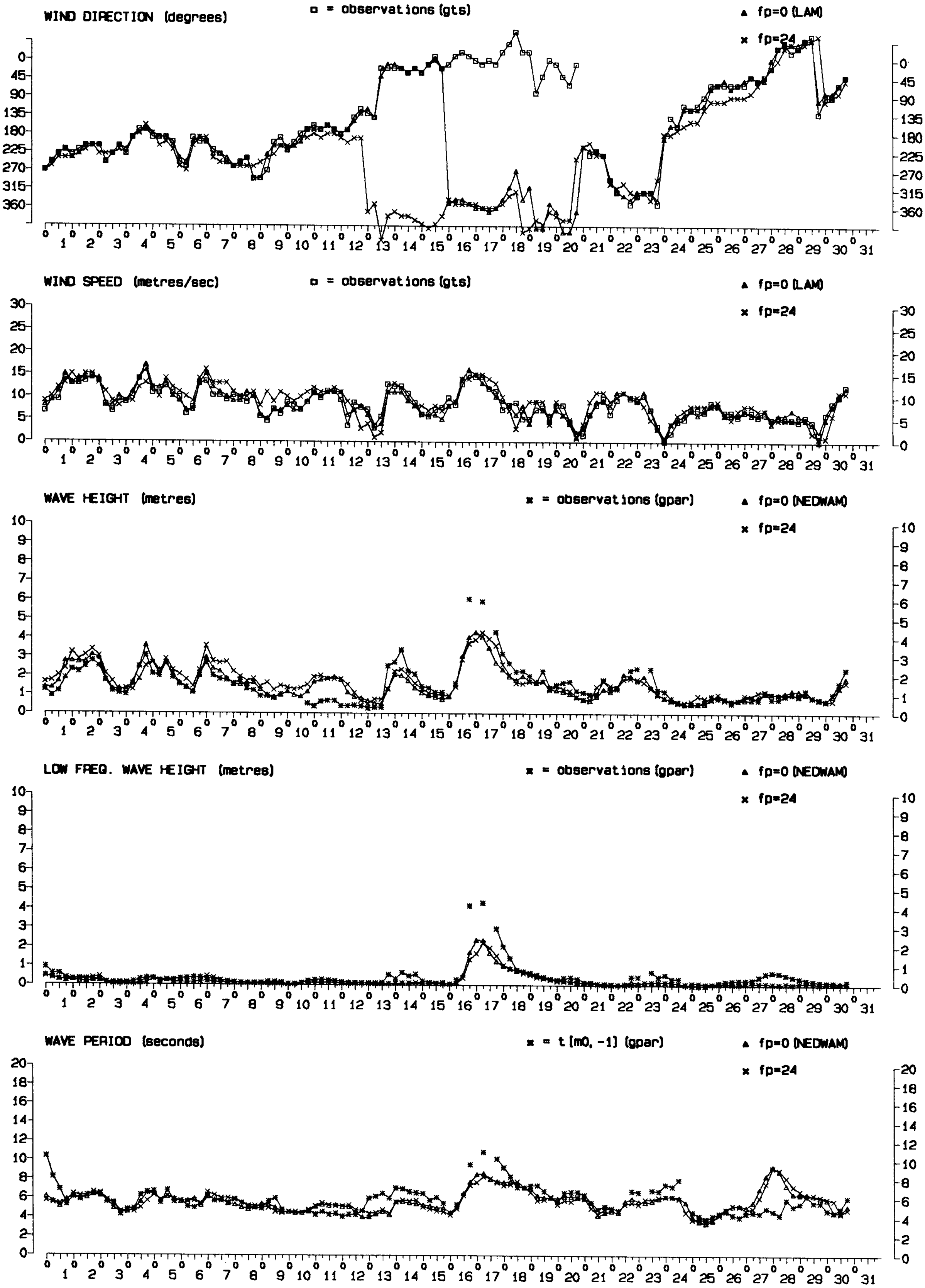


FIG. 42

APRIL 1991 K13-AREA 80

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

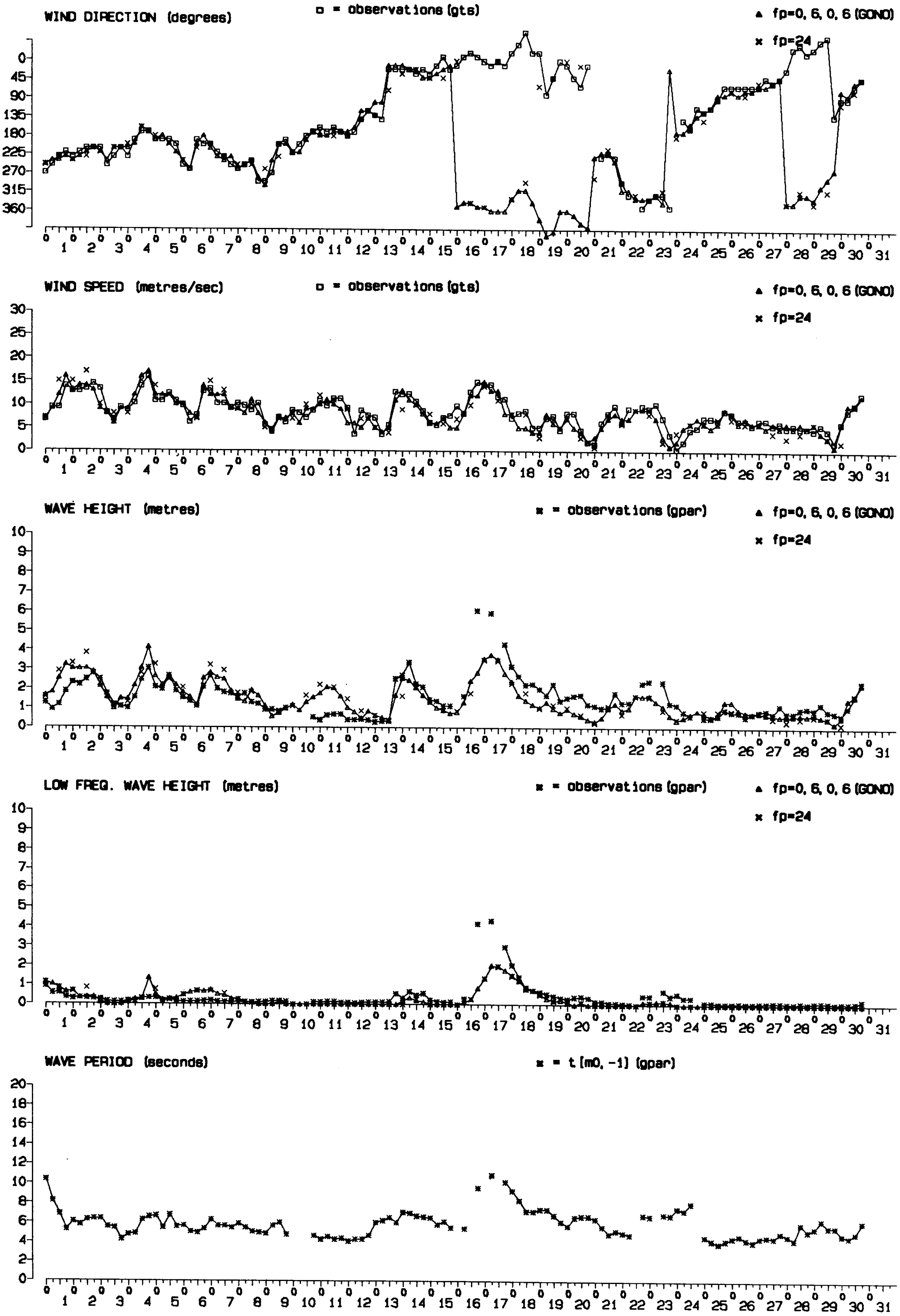


FIG. 43

APRIL 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

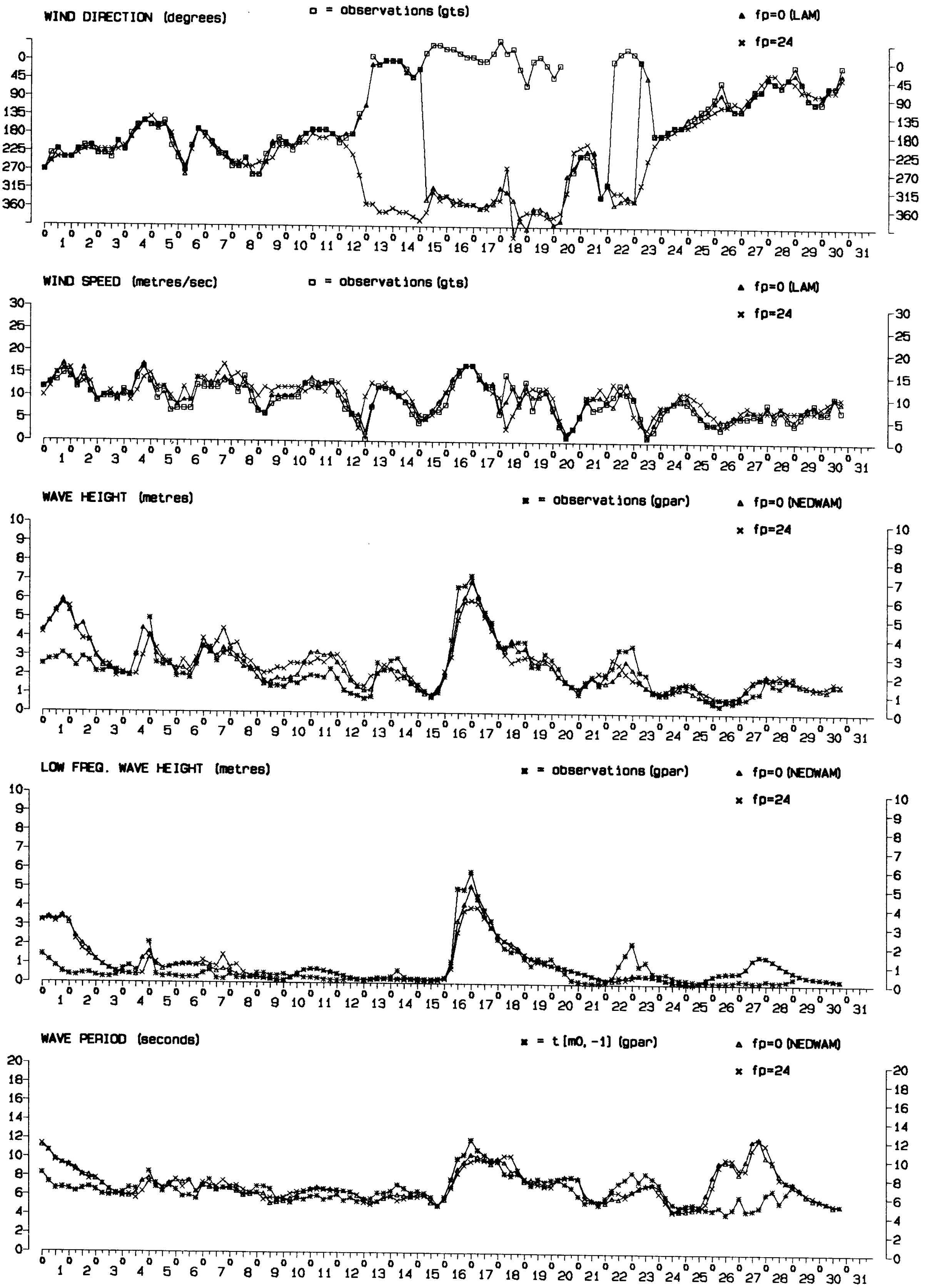


FIG. 44

APRIL 1991 AUK-AREA 11

KNMI (ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE)
DIVISION OF OCEANOGRAPHIC RESEARCH

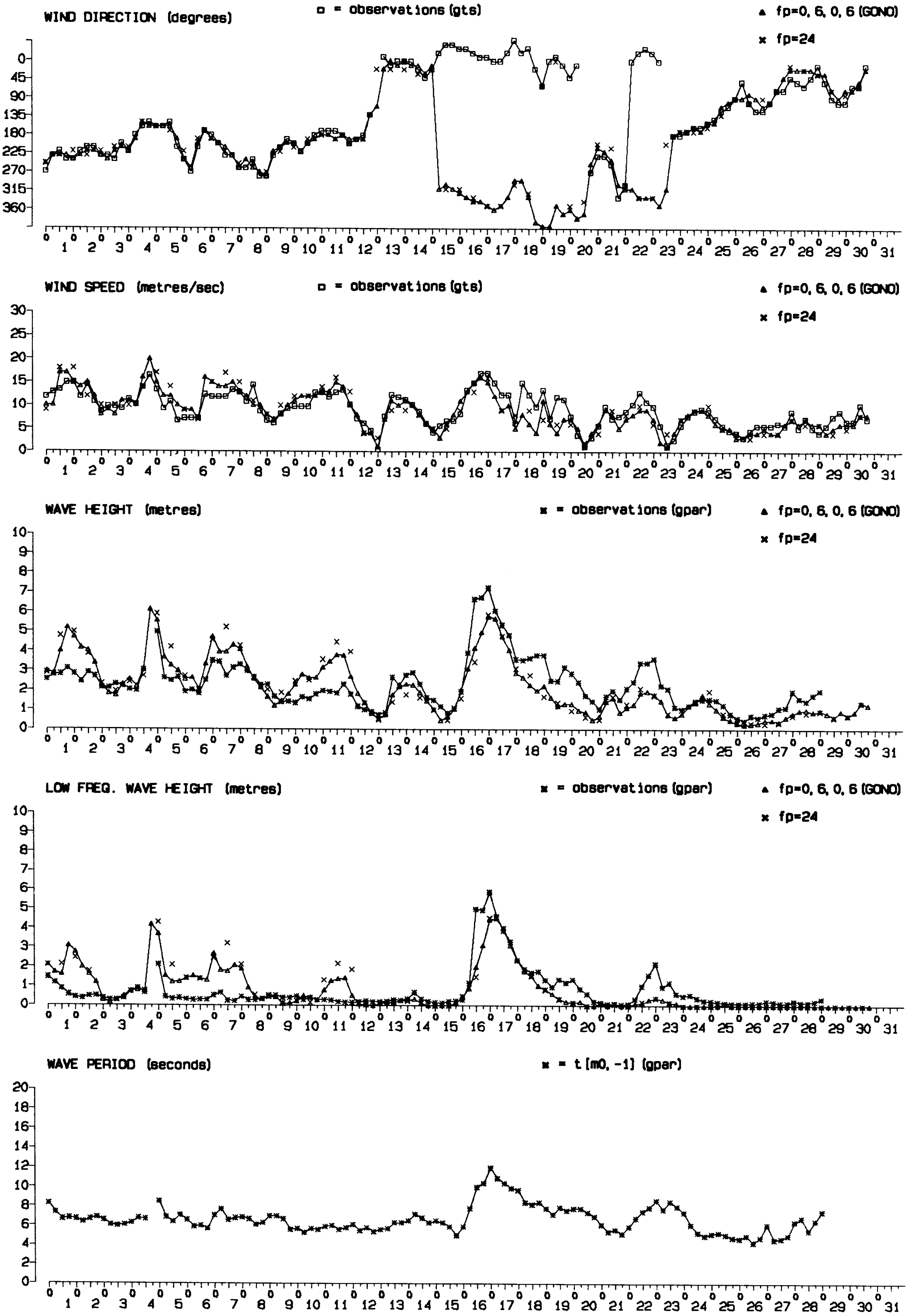
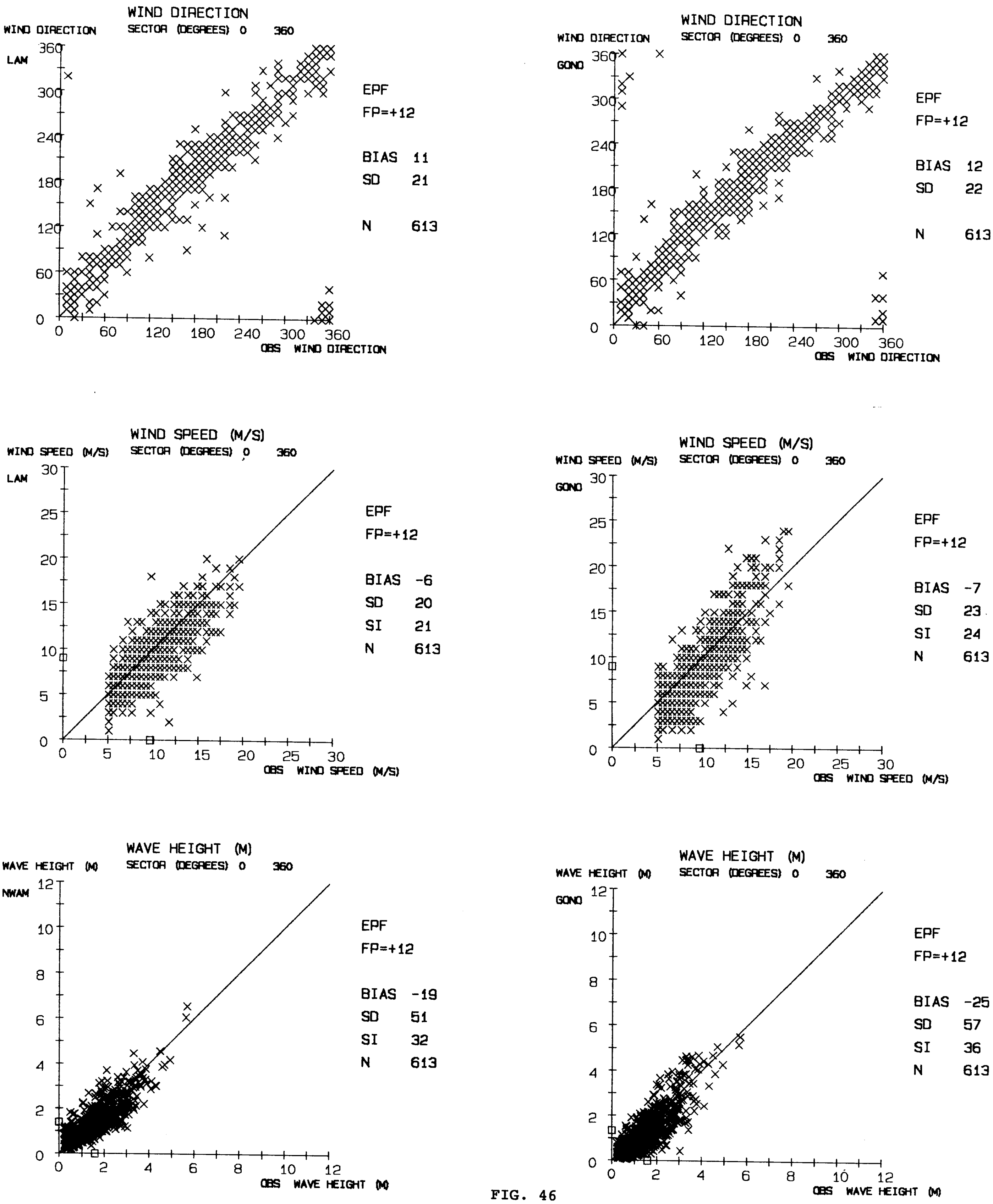
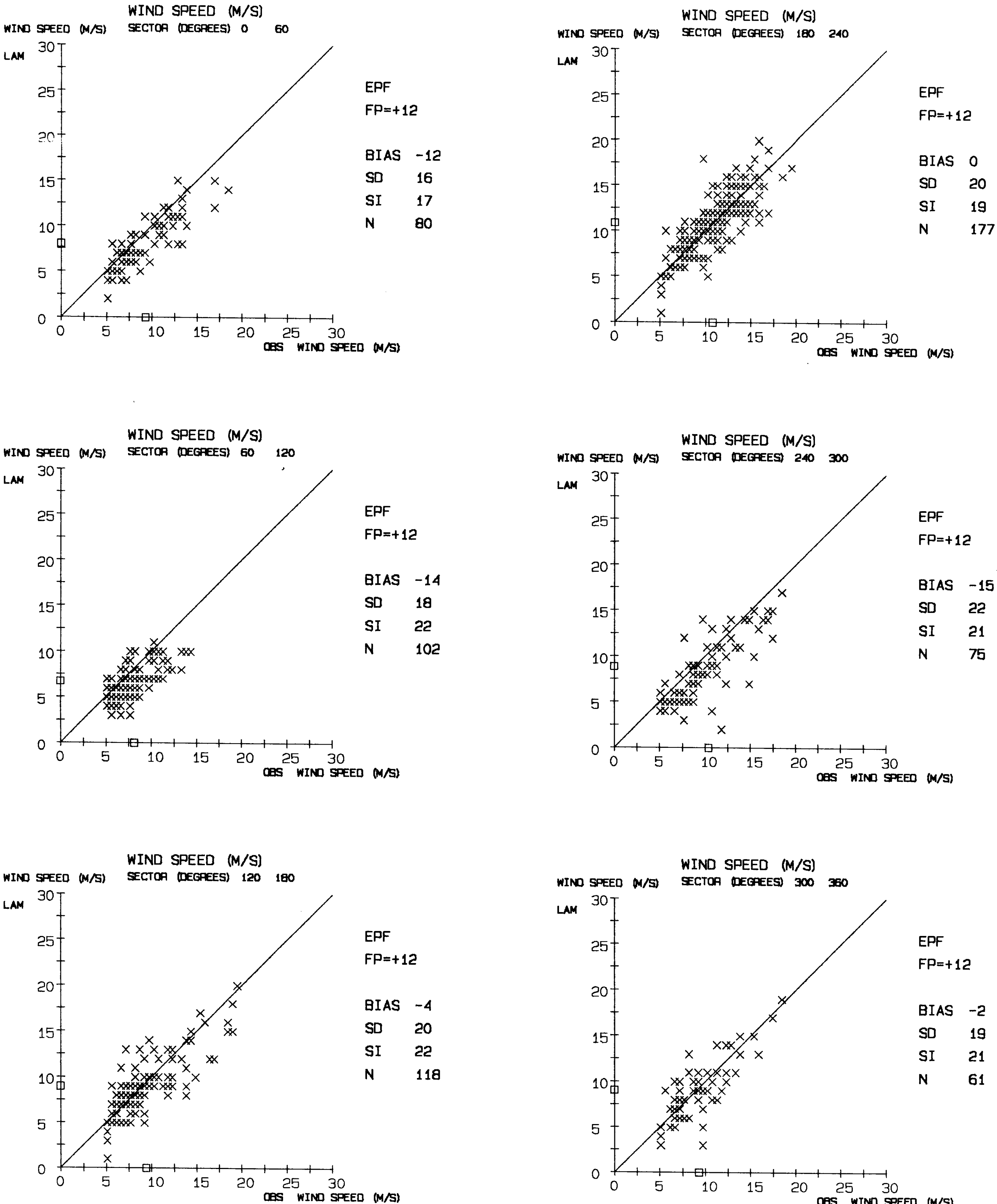


FIG. 45



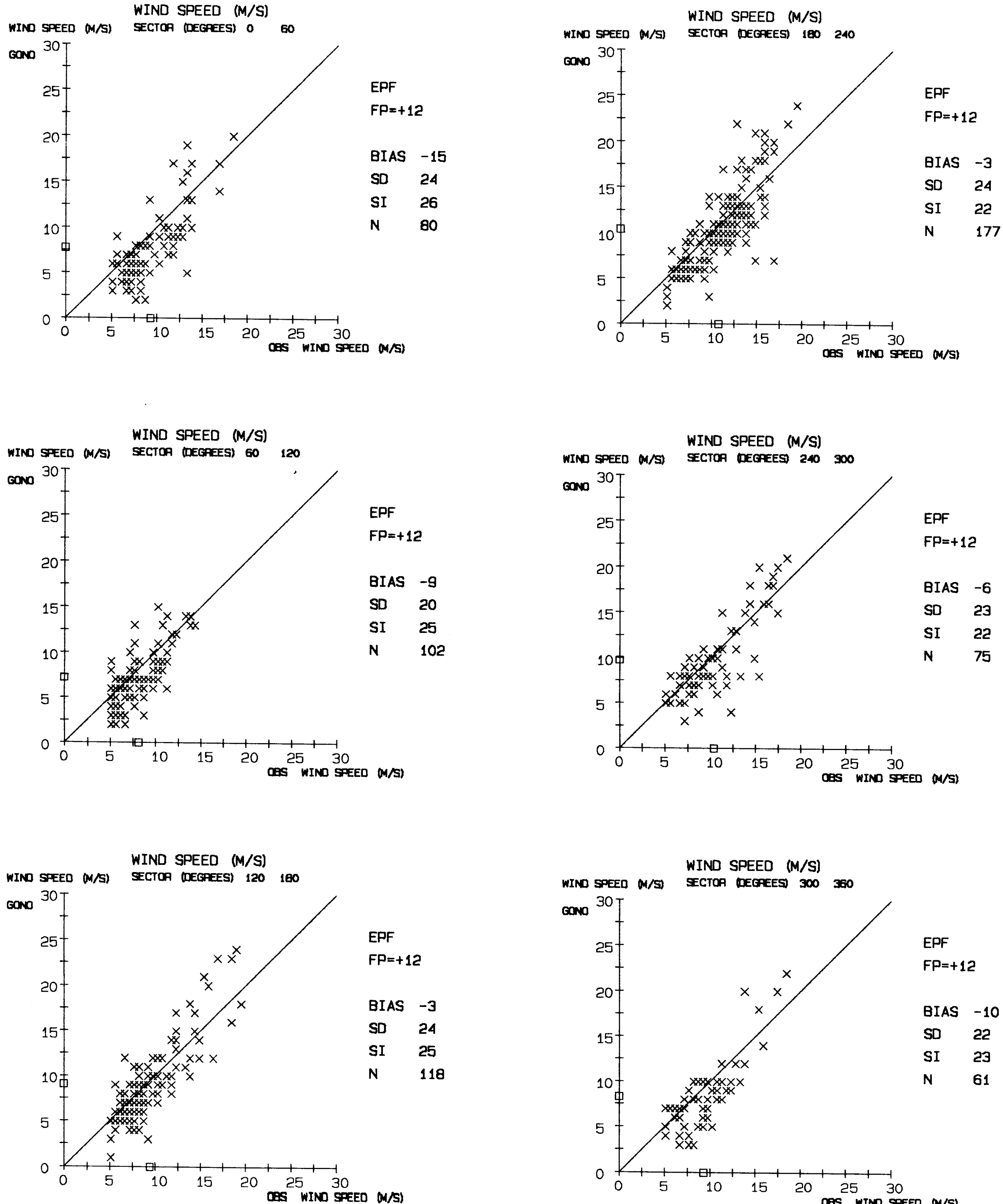
WIND DIRECTION
WIND DIRECTION
SECTOR (DEGREES) 0 360
LAM
OBS WIND DIRECTION
EPF
FP=+12
BIAS 11
SD 21
N 613
WIND DIRECTION
WIND DIRECTION
SECTOR (DEGREES) 0 360
GONO
OBS WIND DIRECTION
EPF
FP=+12
BIAS 12
SD 22
N 613
WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 360
LAM
OBS WIND SPEED (M/S)
EPF
FP=+12
BIAS -6
SD 20
SI 21
N 613
WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 360
GONO
OBS WIND SPEED (M/S)
EPF
FP=+12
BIAS -7
SD 23
SI 24
N 613
WAVE HEIGHT (M)
WAVE HEIGHT (M)
SECTOR (DEGREES) 0 360
NWAM
OBS WAVE HEIGHT (M)
EPF
FP=+12
BIAS -19
SD 51
SI 32
N 613
WAVE HEIGHT (M)
WAVE HEIGHT (M)
SECTOR (DEGREES) 0 360
GONO
OBS WAVE HEIGHT (M)
EPF
FP=+12
BIAS -25
SD 57
SI 36
N 613

FIG. 46



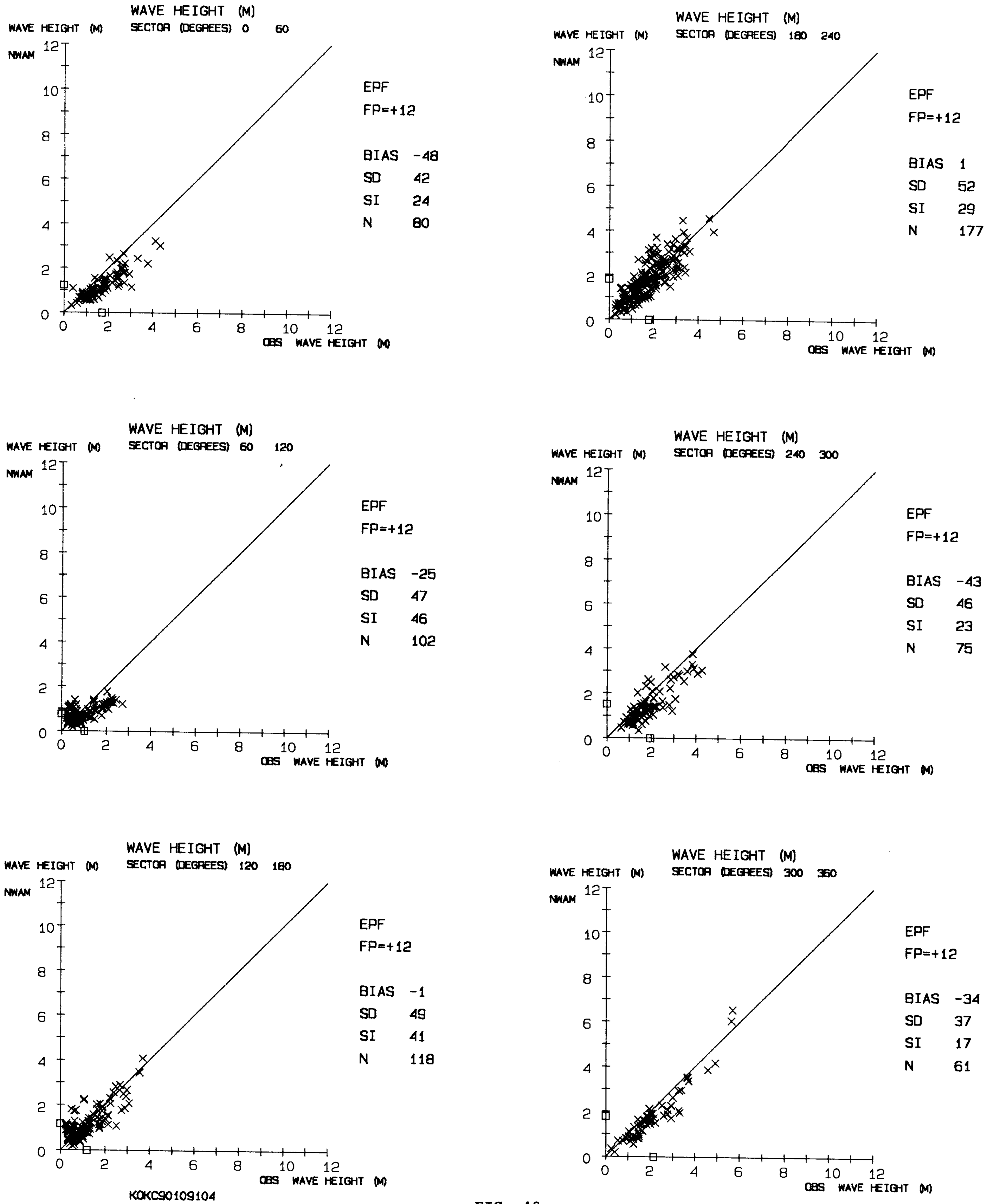
KOKC90109104

FIG. 47



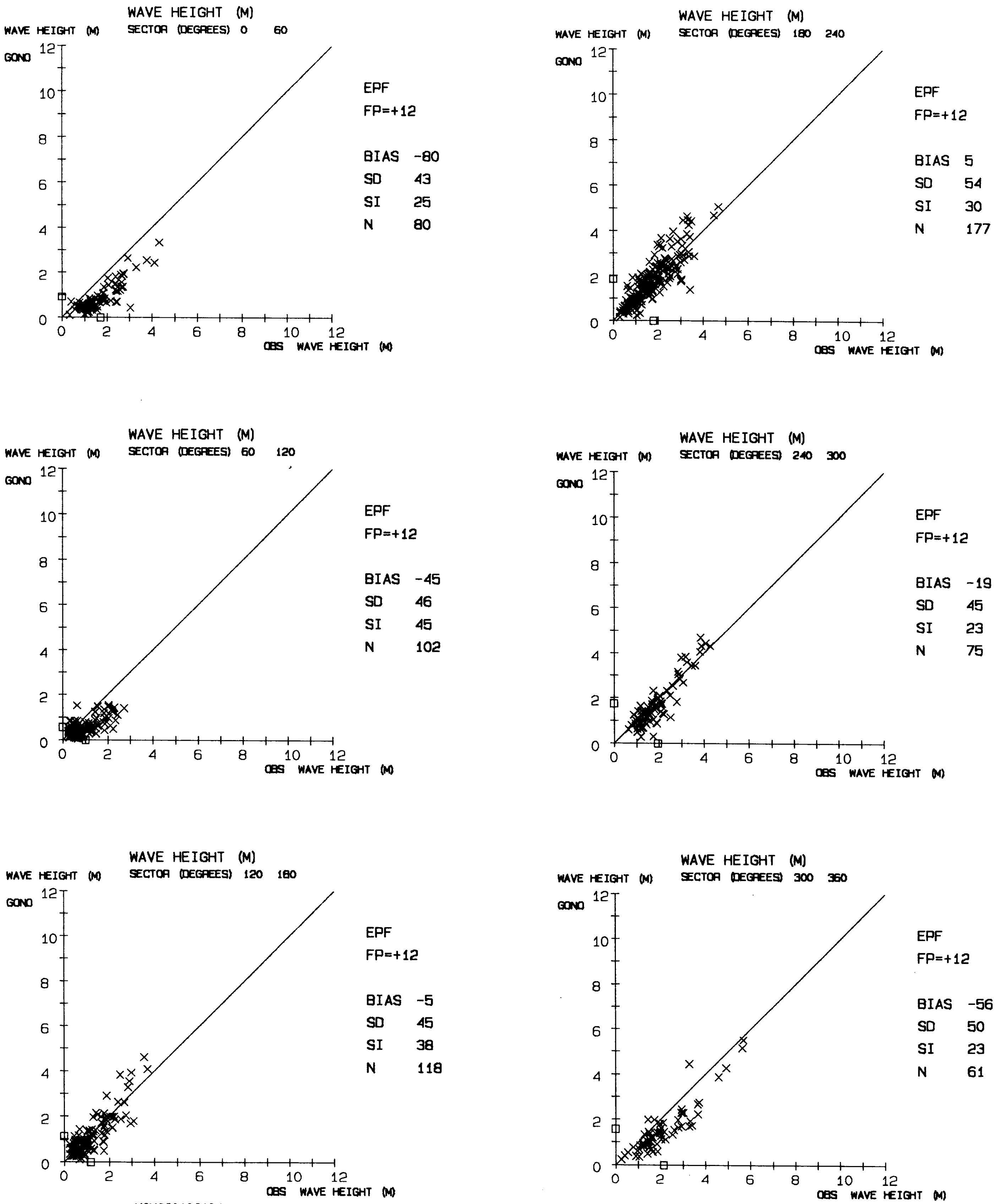
KOKC90109104

FIG. 48



KOKC90109104

FIG. 49



KOKC90109104

FIG. 50

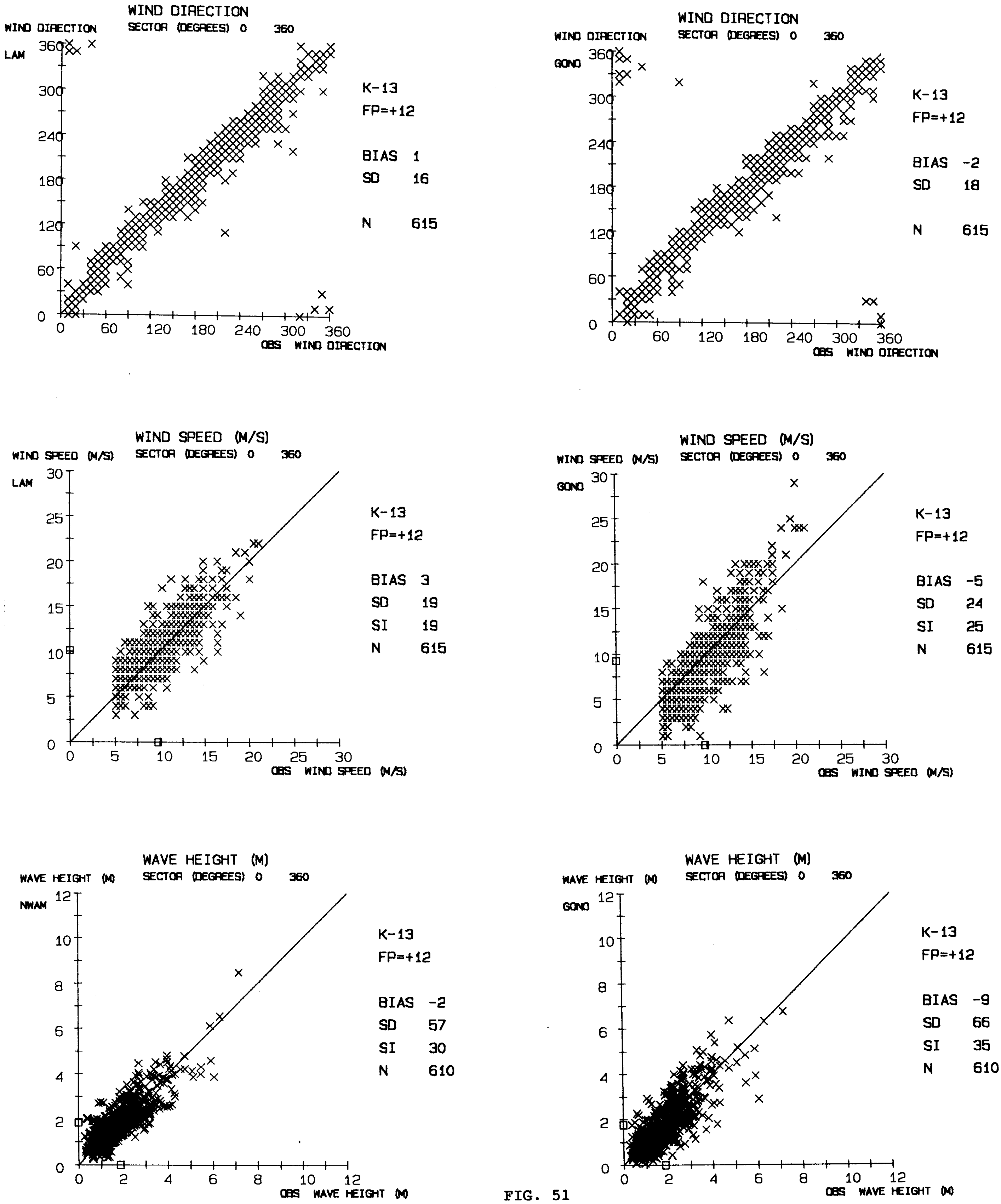

WIND DIRECTION
WIND DIRECTION
SECTOR (DEGREES) 0 360
LAM
OBS WIND DIRECTION
K-13
FP=+12
BIAS 1
SD 16
N 615
WIND DIRECTION
WIND DIRECTION
SECTOR (DEGREES) 0 360
GONO
OBS WIND DIRECTION
K-13
FP=+12
BIAS -2
SD 18
N 615
WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 360
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS 3
SD 19
SI 19
N 615
WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 360
GONO
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS -5
SD 24
SI 25
N 615
WAVE HEIGHT (M)
WAVE HEIGHT (M)
SECTOR (DEGREES) 0 360
NWAM
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS -2
SD 57
SI 30
N 610
WAVE HEIGHT (M)
WAVE HEIGHT (M)
SECTOR (DEGREES) 0 360
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS -9
SD 66
SI 35
N 610

FIG. 51

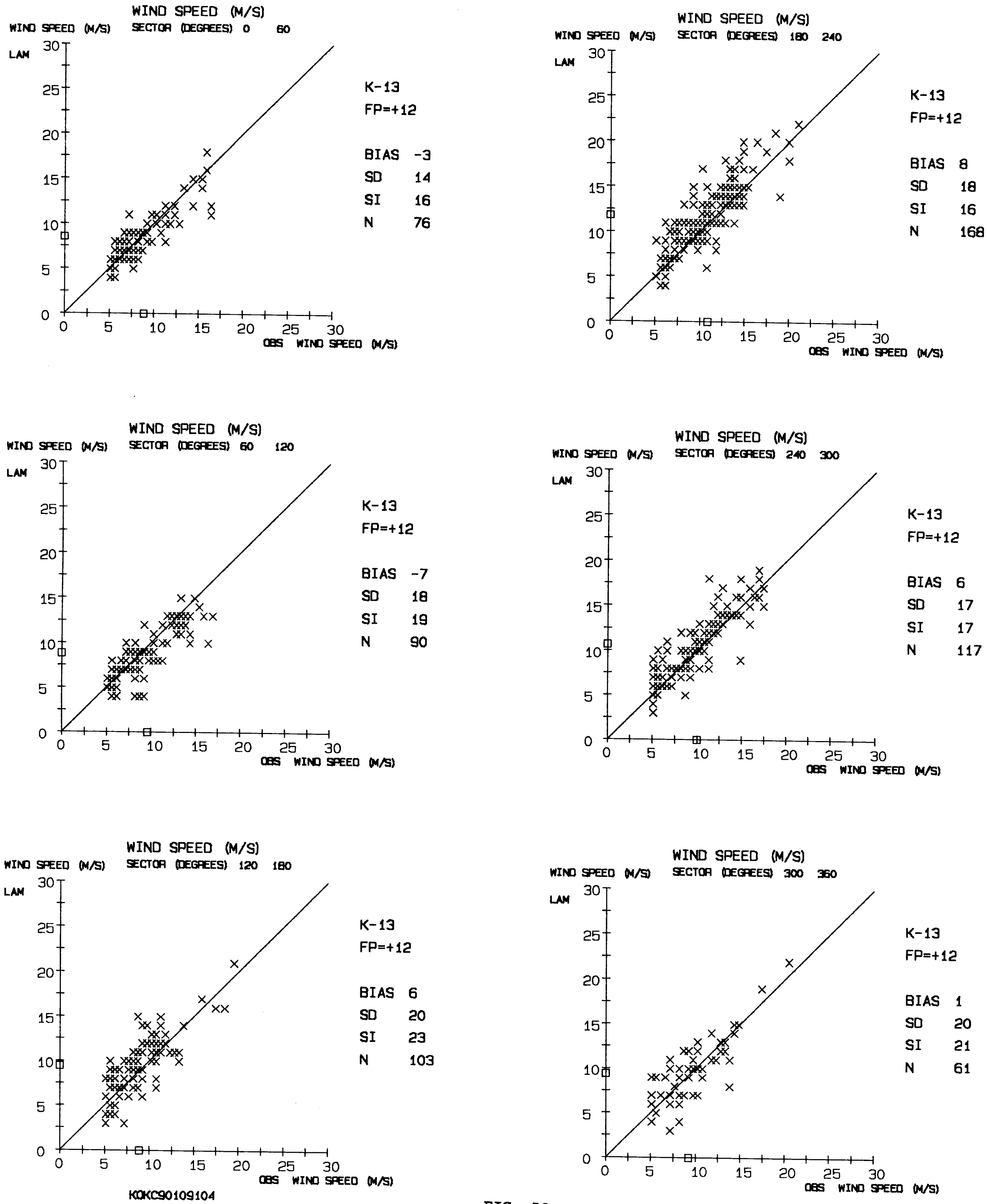
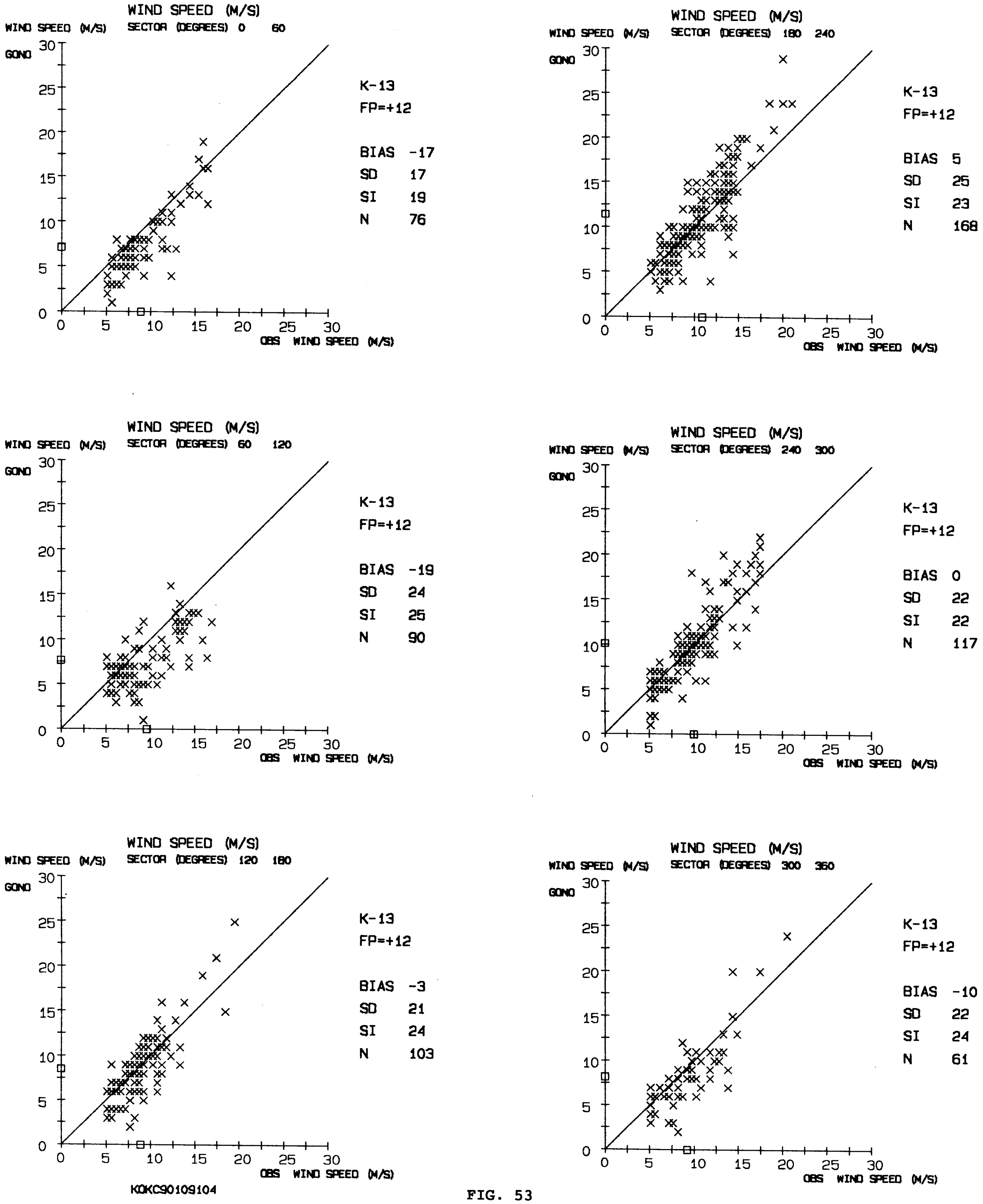

WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 0 60
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS -3
SD 14
SI 16
N 76
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 180 240
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS 8
SD 18
SI 16
N 168
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 60 120
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS -7
SD 18
SI 19
N 90
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 240 300
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS 6
SD 17
SI 17
N 117
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 120 180
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS 6
SD 20
SI 23
N 103
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 300 360
LAM
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS 1
SD 20
SI 21
N 61
KOKC90109104

FIG. 52



WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 60
GONO
OBS WIND SPEED (M/S)
K-13
FP=+12
BIAS -17
SD 17
SI 19
N 76
WIND SPEED (M/S)
SECTOR (DEGREES) 180 240
K-13
FP=+12
BIAS 5
SD 25
SI 23
N 168
WIND SPEED (M/S)
SECTOR (DEGREES) 60 120
K-13
FP=+12
BIAS -19
SD 24
SI 25
N 90
WIND SPEED (M/S)
SECTOR (DEGREES) 240 300
K-13
FP=+12
BIAS 0
SD 22
SI 22
N 117
WIND SPEED (M/S)
SECTOR (DEGREES) 120 180
K-13
FP=+12
BIAS -3
SD 21
SI 24
N 103
WIND SPEED (M/S)
SECTOR (DEGREES) 300 360
K-13
FP=+12
BIAS -10
SD 22
SI 24
N 61
KOKC90109104

FIG. 53

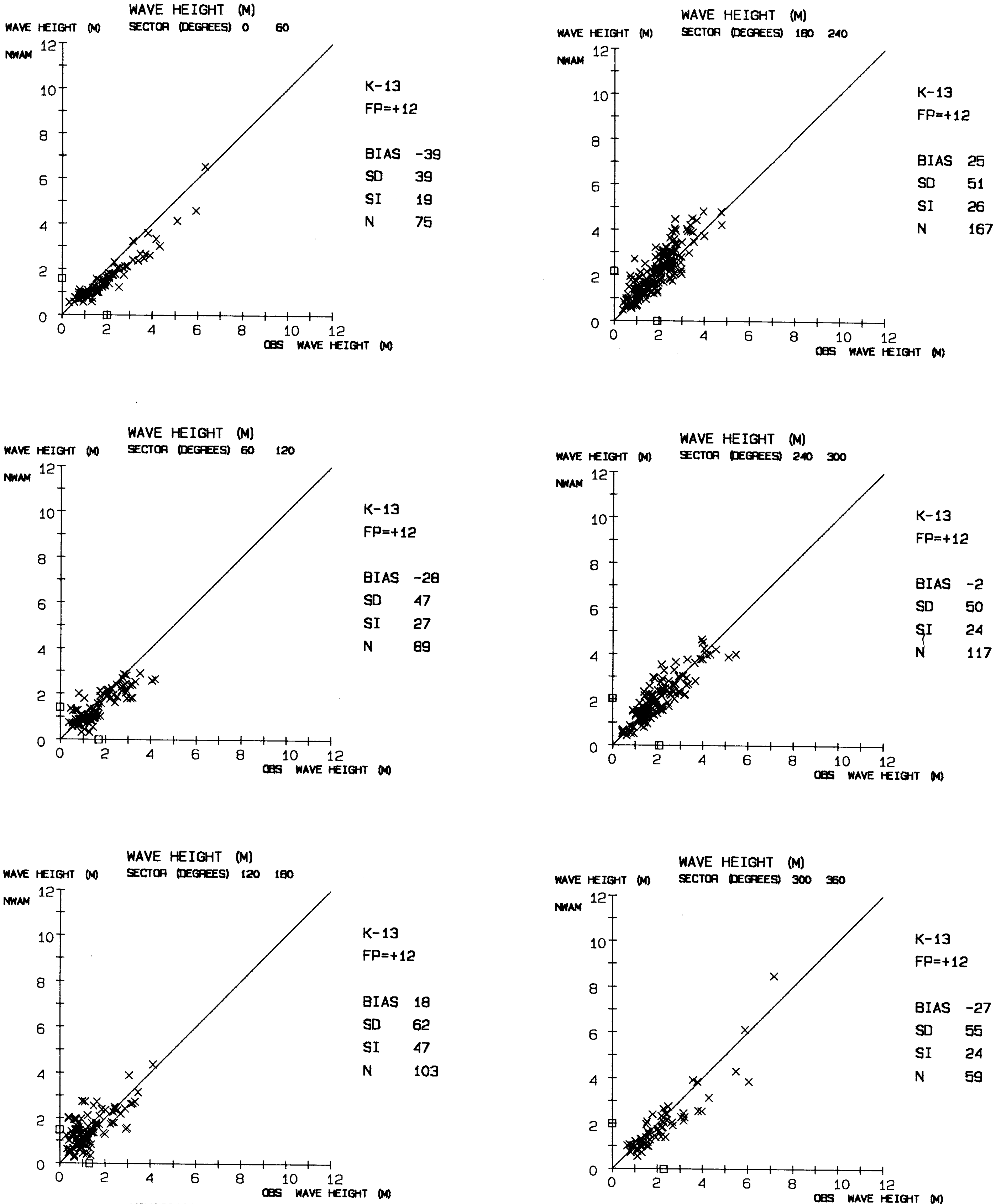


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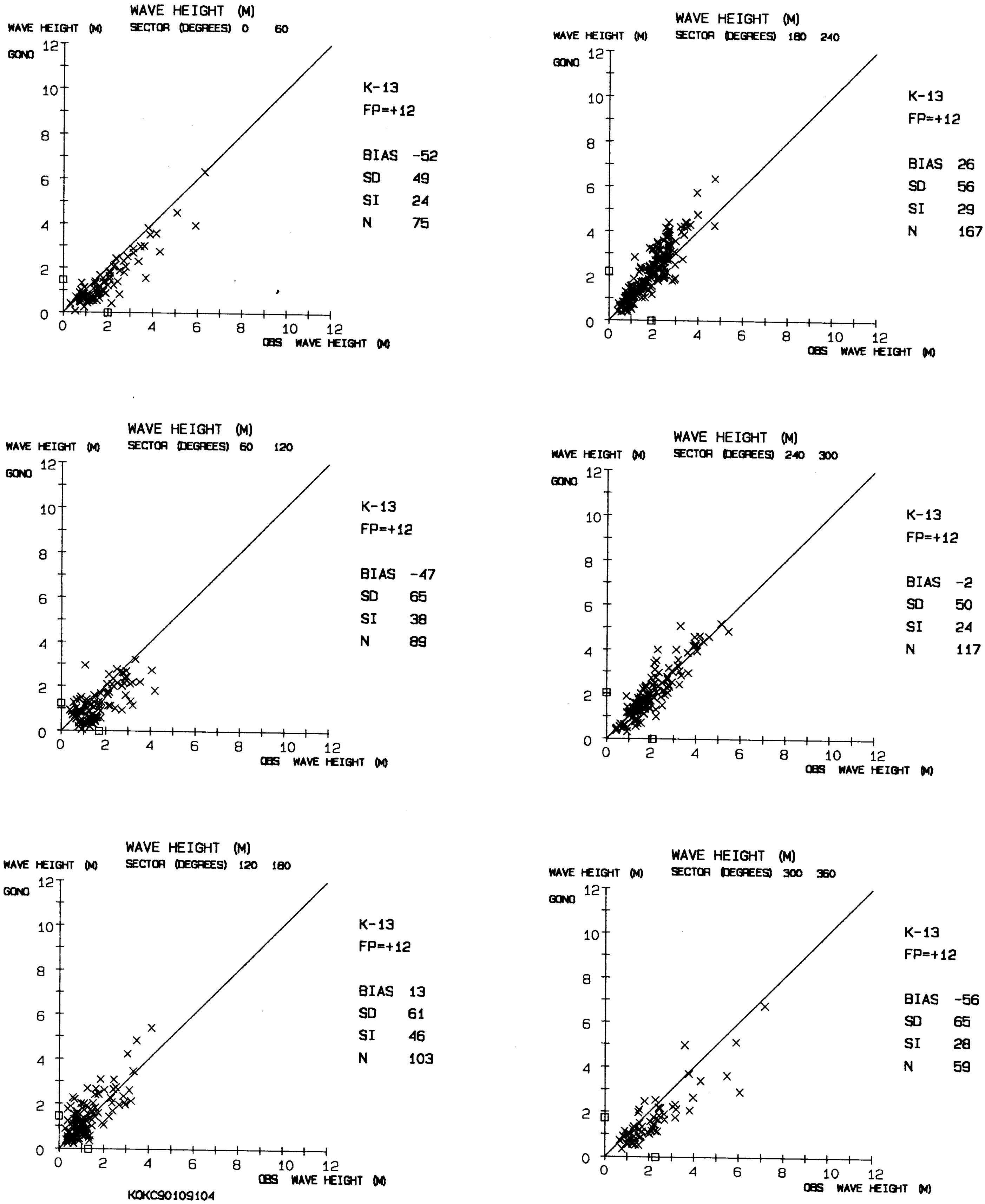
FIG. 54



WAVE HEIGHT (M)
WAVE HEIGHT (M) SECTOR (DEGREES) 0 60
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS -52
SD 49
SI 24
N 75
WAVE HEIGHT (M)
WAVE HEIGHT (M) SECTOR (DEGREES) 180 240
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS 26
SD 56
SI 29
N 167
WAVE HEIGHT (M)
WAVE HEIGHT (M) SECTOR (DEGREES) 60 120
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS -47
SD 65
SI 38
N 89
WAVE HEIGHT (M)
WAVE HEIGHT (M) SECTOR (DEGREES) 240 300
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS -2
SD 50
SI 24
N 117
WAVE HEIGHT (M)
WAVE HEIGHT (M) SECTOR (DEGREES) 120 180
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS 13
SD 61
SI 46
N 103
WAVE HEIGHT (M)
WAVE HEIGHT (M) SECTOR (DEGREES) 300 360
GONO
OBS WAVE HEIGHT (M)
K-13
FP=+12
BIAS -56
SD 65
SI 28
N 59
KOKC90109104

FIG. 55

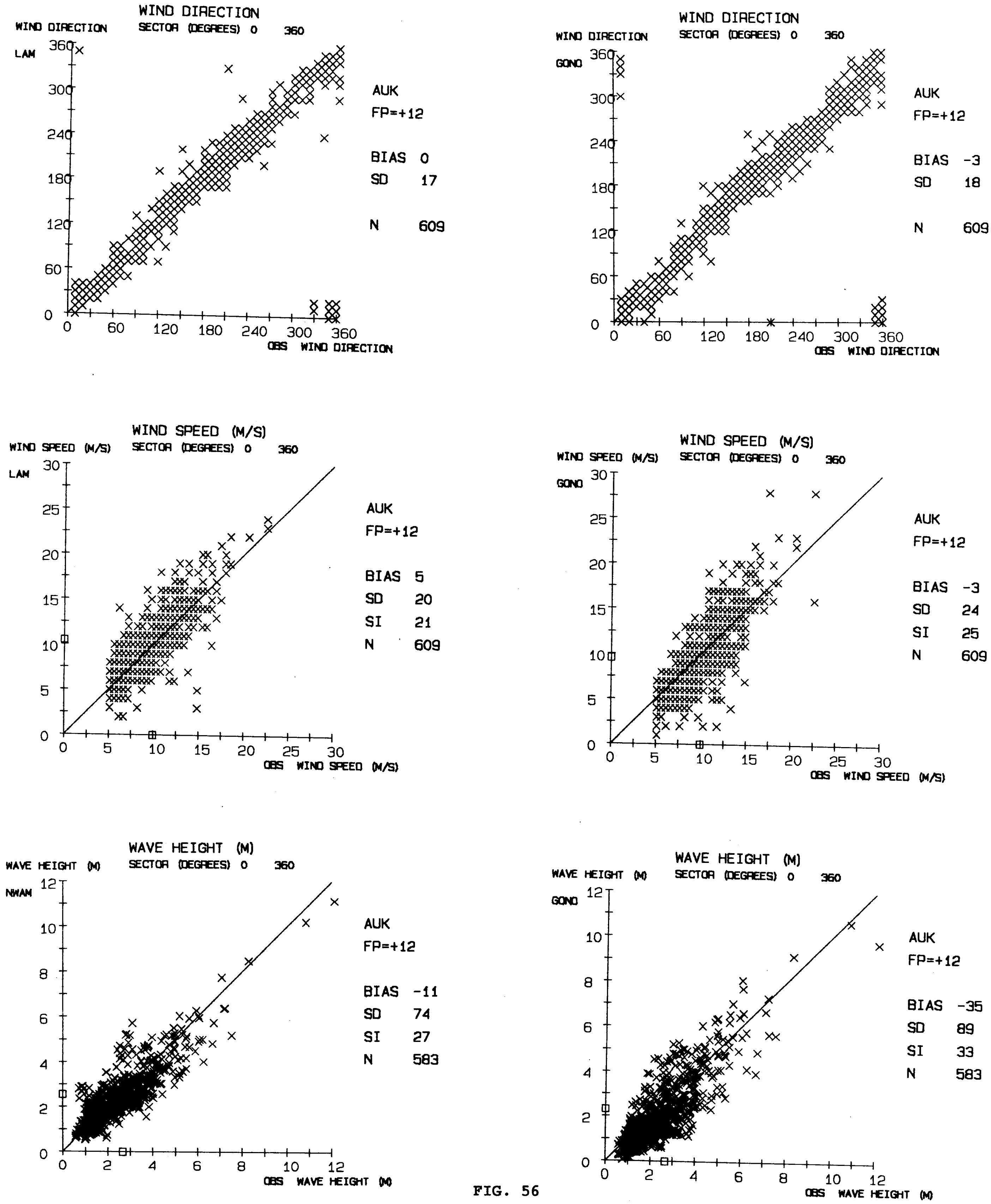

WIND DIRECTION
WIND DIRECTION
SECTOR (DEGREES) 0 360
LAM
OBS WIND DIRECTION
AUK
FP=+12
BIAS 0
SD 17
N 609
WIND DIRECTION
WIND DIRECTION
SECTOR (DEGREES) 0 360
GONO
OBS WIND DIRECTION
AUK
FP=+12
BIAS -3
SD 18
N 609
WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 360
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS 5
SD 20
SI 21
N 609
WIND SPEED (M/S)
WIND SPEED (M/S)
SECTOR (DEGREES) 0 360
GONO
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS -3
SD 24
SI 25
N 609
WAVE HEIGHT (M)
WAVE HEIGHT (M)
SECTOR (DEGREES) 0 360
NWAM
OBS WAVE HEIGHT (M)
AUK
FP=+12
BIAS -11
SD 74
SI 27
N 583
WAVE HEIGHT (M)
WAVE HEIGHT (M)
SECTOR (DEGREES) 0 360
GONO
OBS WAVE HEIGHT (M)
AUK
FP=+12
BIAS -35
SD 89
SI 33
N 583

FIG. 56

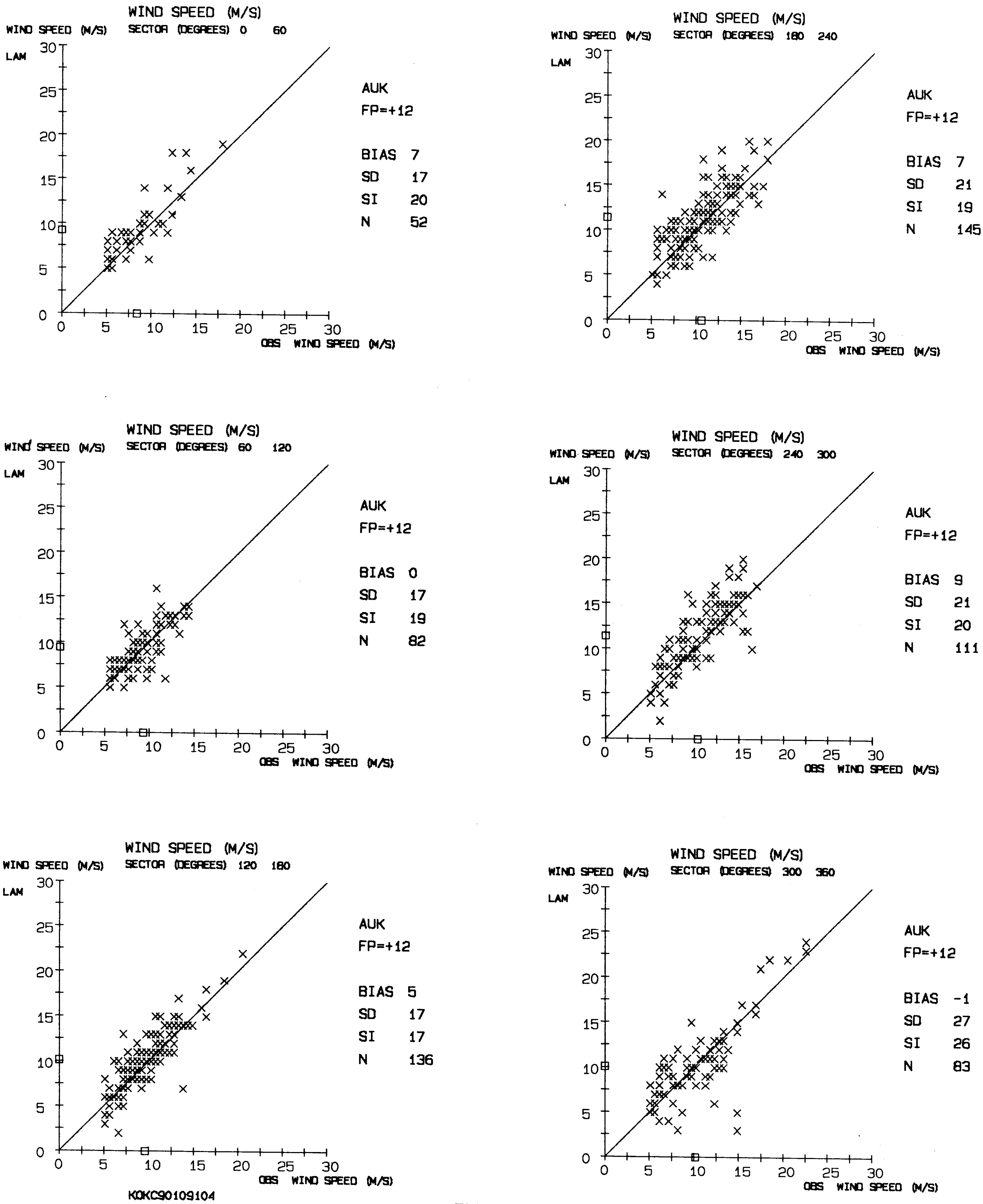

WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 0 60
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS 7
SD 17
SI 20
N 52
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 180 240
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS 7
SD 21
SI 19
N 145
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 60 120
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS 0
SD 17
SI 19
N 82
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 240 300
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS 9
SD 21
SI 20
N 111
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 120 180
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS 5
SD 17
SI 17
N 136
WIND SPEED (M/S)
WIND SPEED (M/S) SECTOR (DEGREES) 300 360
LAM
OBS WIND SPEED (M/S)
AUK
FP=+12
BIAS -1
SD 27
SI 26
N 83
KOKC90109104

FIG. 57

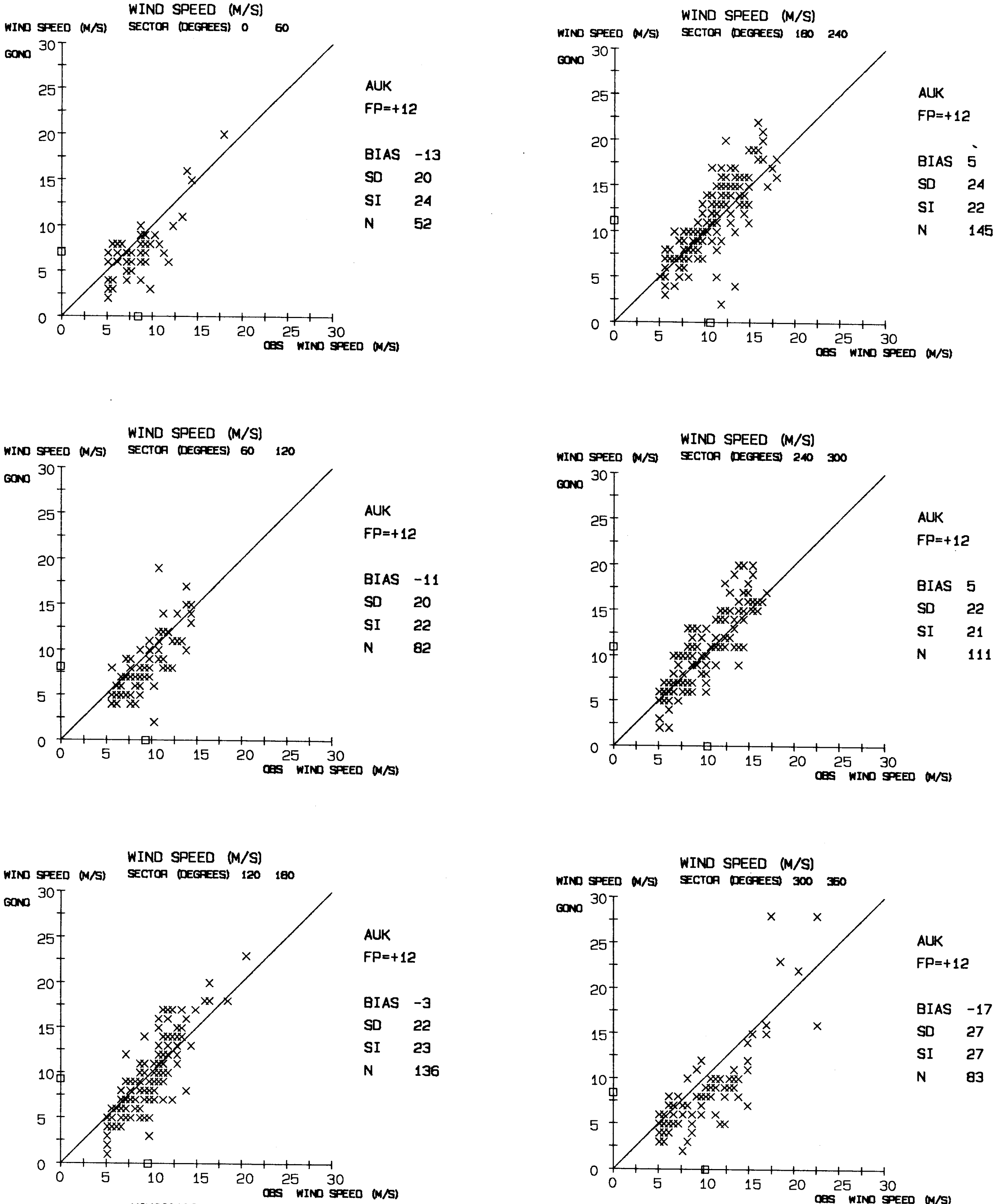


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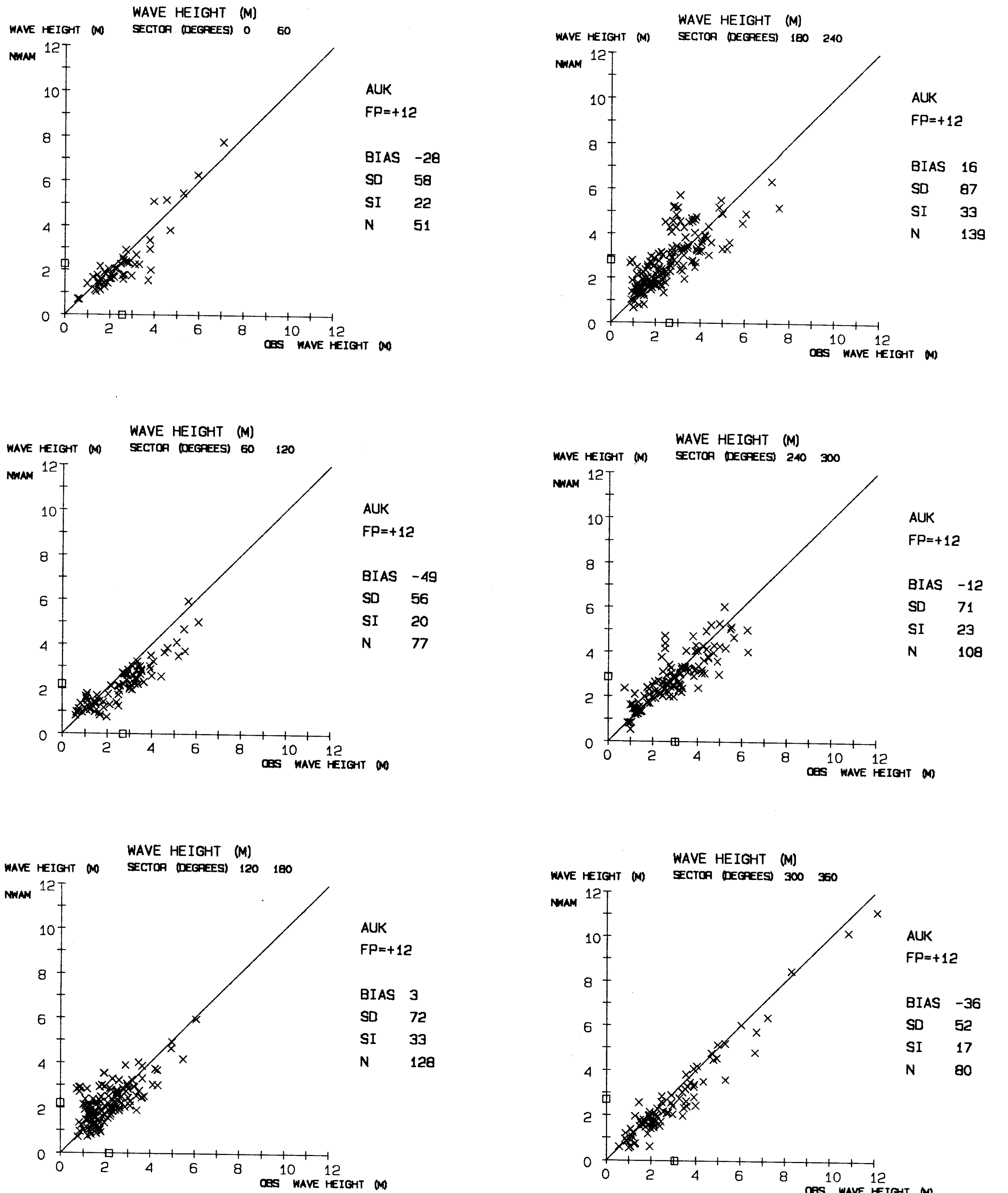
FIG. 58



KOKC90109104

FIG. 59

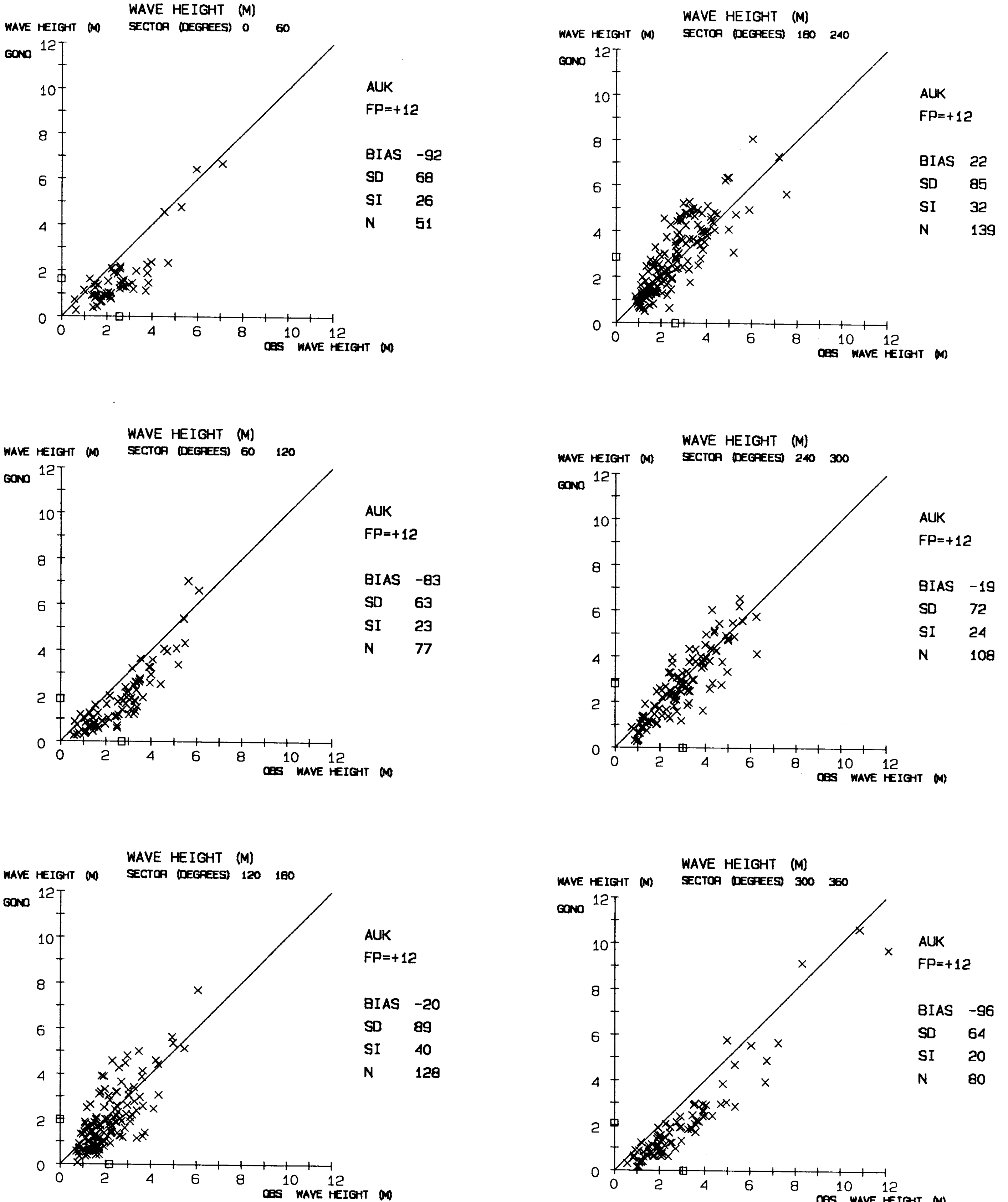


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FIG. 60