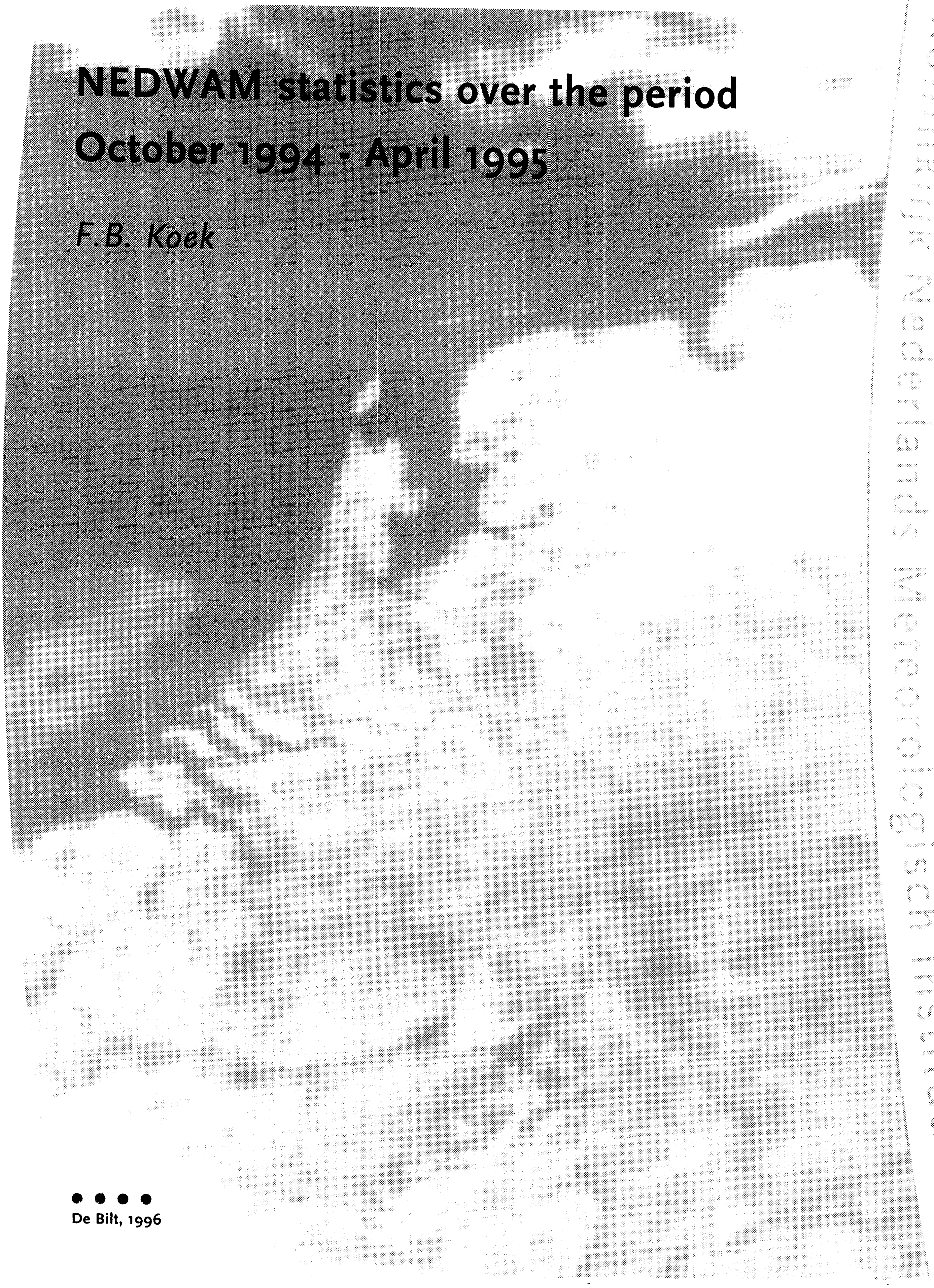
Technical report TR-190

KNMI

NEDWAM statistics over the period October 1994 - April 1995

F.B. Koek



Koninklijk Nederlands Meteorologisch Instituut

De Bilt, 1996

Technical report TR-190

De Bilt, 1996

Postbus 201
3730 AE De Bilt
The Netherlands

Telephone +31.30.220 69 11, telefax +31.30.221 04 07

UDC: 551.46.062.5
551.466.1
(261.26)
ISSN: 0169-1708
ISBN: 90-369-2102-3

NEDWAM statistics over the period October 1994 - April 1995

F.B. Koek

Contents

Abstract

In this paper a comparison is presented between NEDWAM wave forecasts and observations for three North Sea stations over the period October 1994 - April 1995 [5].

Wind fields from an atmospheric high resolution limited area model (HIRLAM) and wave heights predicted by a shallow water, third generation wave model (NEDWAM) on the basis of those wind fields, have been verified against GTS and buoy observations. The verification is carried out for the elements:

- wind direction,
- wind speed,
- significant wave height,
- low frequency wave height,
- significant wave period,
- mean wave direction.

The period during which these elements were verified was October 1994 - April 1995 for the locations: Euro Platform and K-13-Alpha in the southern North Sea and for AUK-Alpha in the central North Sea (see fig. 1).

In chapter 1 a short introduction is given to the NEDWAM model and the observations. Chapter 2 discusses the model's differences and similarities in relation to the observed values by means of time series. In these time series particularly the timing of the forecasts are shown clearly. In chapter 3 the results of the comparison are examined in a statistical way. This is done in tables with explicit figures, and in scatter diagrams, showing the relation between the model and the observations in an x-y (or scatter) plot. Chapter 4 deals with several special cases that were significant for this verification. Remarks, based on the findings in this verification, are briefly summarised in chapter 5. These remarks are for the author's responsibility only.

1. Introduction

In this chapter a brief description is given of the used NEDWAM model and the observations.

a. *NEDWAM*

The NEDWAM model is a third-generation ocean wave prediction model. In its physics it is essentially identical to the WAM model, which was jointly developed by the Wave Model Development and Implementation (WAMDI) group [1, 2]. It has a stereographic grid centred at 60°N (see fig. 2) [3].

NEDWAM is driven by winds from the atmospheric high resolution limited area model "HIRLAM" (see fig. 3) [4]. This model derives its boundary conditions from the ECMWF model.

The wind parameters of NEDWAM are derived from HIRLAM. Most of the grid values were interpolated, but, as the HIRLAM grid does not extend as far north as the NEDWAM grid, some values at the northern edge of the grid were extrapolated from HIRLAM grid values. NEDWAM makes a +36 hours forecast four times a day.

b. *The observations*

In this report wind direction *DD*, wind speed *FF*, significant wave height H_S, the so-called low-frequency wave height $H_{S,10}$, the significant wave period $T_{m0,-1}$ and the wave direction *DIR* are considered. Stations being discussed are given below, in table 1 (see also fig. 1).

Name	Position	Height wind measurement	Wind speed reduction factor	Water depth (model)
AUK-Alpha (AUK)	56°24'N 2°04'E	103.3 m	0.738	80 m
K-13-Alpha (K13)	53°13'N 3°13'E	73.8 m	0.770	25 m
Euro Platform (EPF)	52°00'N 3°16'E	29.1 m	0.871	25 m

Table 1 Characteristics of the used stations.

The observations were supplied by various sources. The wave data from AUK, K13 and EPF were obtained from the Dutch North Sea Network. The wind observations were derived from the Global Telecommunication System (GTS). Due to several computer problems during this season the number of observations is sometimes too low to make a good comparison with the forecasted values. If an observation of the selected station itself was missing, the surrounding area was inspected for an alternative (see fig. 1).

Wind speed was reduced with a fixed factor to the equivalent at 10 m above mean sea level (MSL). This reduction factor was established by the 'Meteorological Panel for the North Sea and Adjoining Waters' in 1977 [6]. The used reduction factors are given in table 1.

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 significant wave period is defined as:

$$T_{m0,-1} = \left(\frac{m_0}{m_{-1}}\right)^{-1},$$

with:

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

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

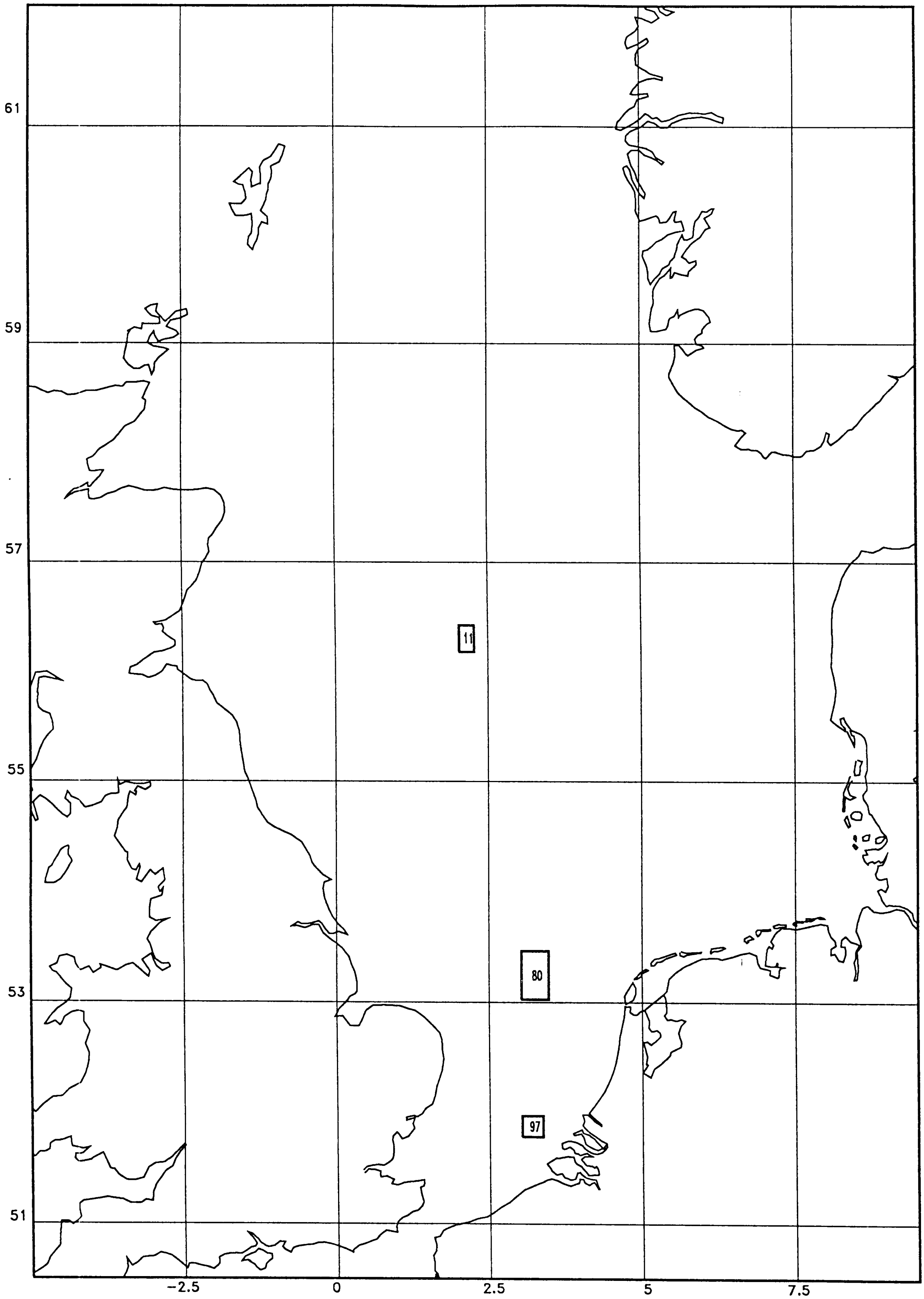


Figure 1 Areas around the presented stations

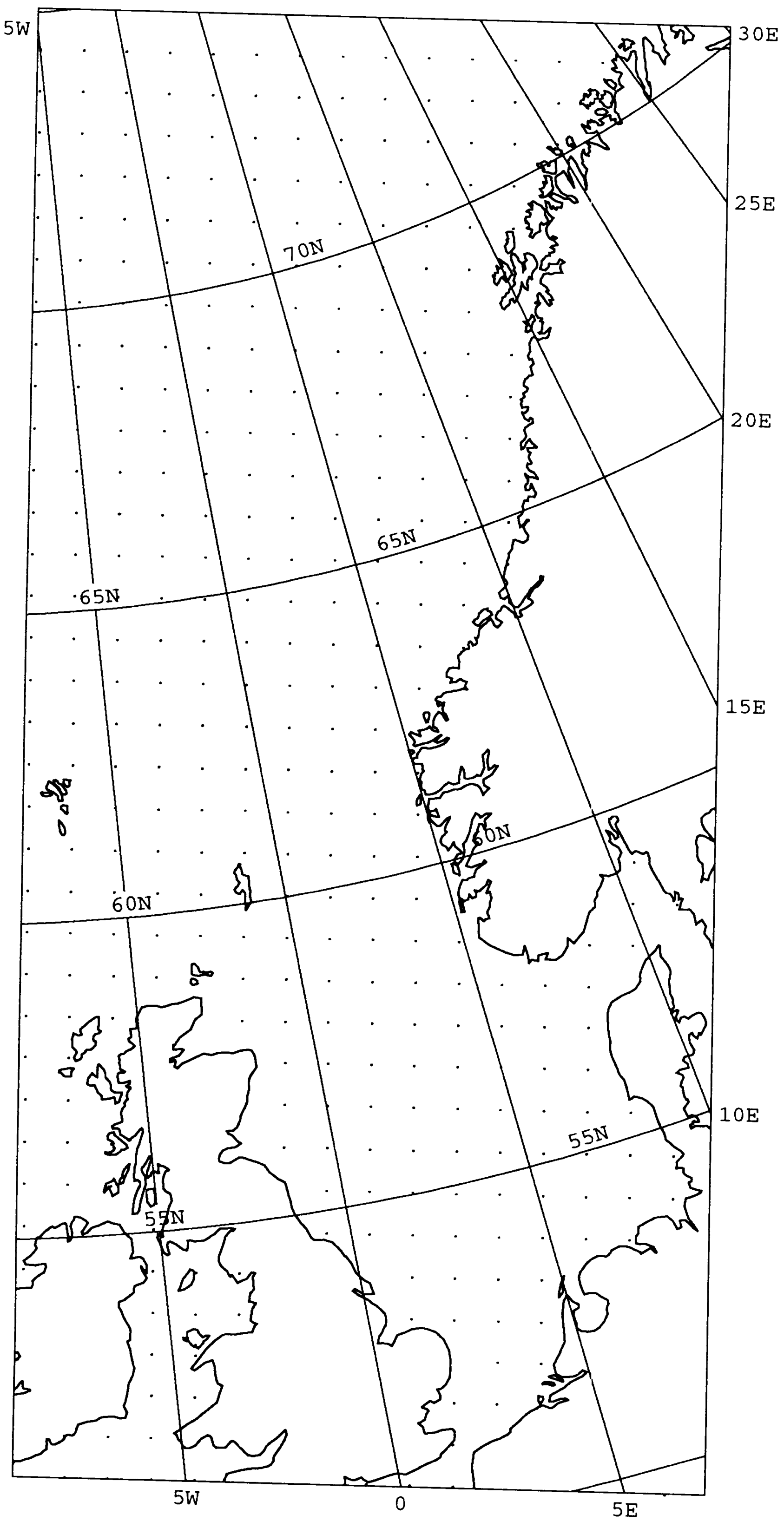


Figure 2 NEDWAM grid [3]

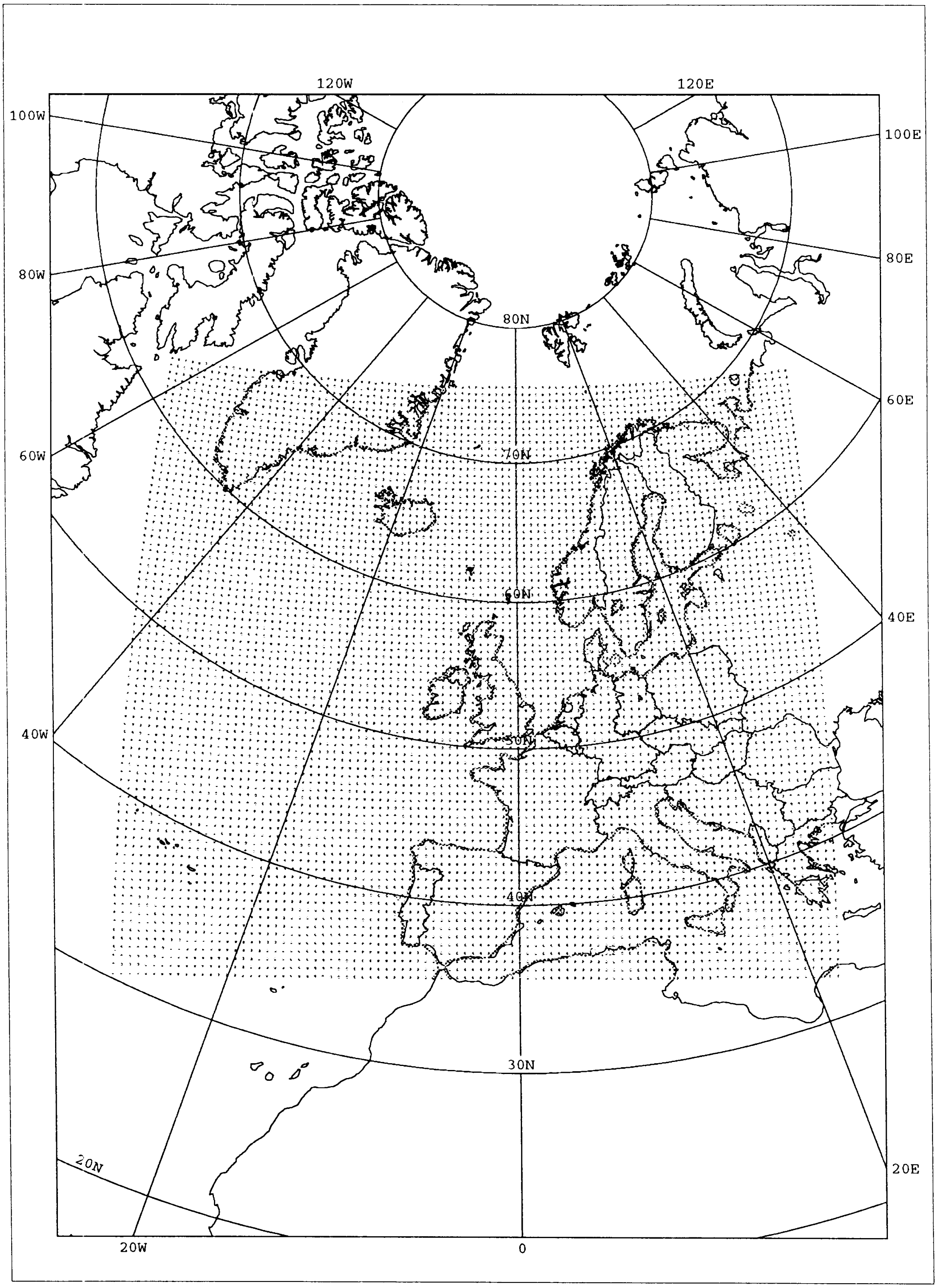


Figure 3 HIRLAM grid

2. Time series of observations and model data

Time series of observations and model forecasts for all stations and for all months are presented in figures 4-24. The time series may be used to track down time-differences between observed events and the model's forecasted events. The problem with this is that the model produces only four forecasts each day, while the observations are gathered here eight times per day (in three-hourly intervals). Consequently there may be differences in the synchronisation of the model, compared to the displayed observations. This difference in density between the number of observations and that of the model is also the cause that not all peaks are shown at the same height.

From the top to the bottom the following parameters, if available, are presented:

A. Temperatures of air (•), dew point (▵) and sea surface (□) in degrees (Celsius), derived from the GTS every three hours.

B. Wind directions (*DD*) in units of ten degrees, derived three-hourly from the GTS (•) and six-hourly in whole degrees from NEDWAM (originally from HIRLAM). Presented are the analysis (▵), the 12 hours forecast (□) and the 24 hours forecast (×).

C. Wind speed (*FF*) in m/s, derived every three hours from the GTS (•) and six-hourly from NEDWAM (originally from HIRLAM). Presented are the analysis (▵), the 12 hours forecast (□) and the 24 hours forecast (×).

D. Significant wave heights (H_s) in centimetres, derived three hourly from Dutch Measuring Network North Sea (•) and six-hourly from NEDWAM. Presented are the analysis (▵), the 12 hours forecast (□) and the 24 hours forecast (×).

E. Low frequency wave height ($H_{S,10}$) in centimetres, derived three hourly from Dutch Measuring Network North Sea (•) and six-hourly from NEDWAM. Presented are the analysis (▵), the 12 hours forecast (□) and the 24 hours forecast (×). Please note that in the right Y-axes the E_{10} is displayed. E_{10} is defined as the energy of the low frequency waves:

$$E_{10} = \left(\frac{1}{4} H_{S,10}\right)^2$$

F. Wave period ($T_{m0,-1}$) in seconds, derived three hourly from Dutch Measuring Network North Sea (•) and six-hourly from NEDWAM. Presented are the analysis (▵), the 12 hours forecast (□) and the 24 hours forecast (×).

In the legend of the time series the NEDWAM model is abbreviated as *WAM* and the Dutch Measuring Network North Sea as *CIC*.

On the different pages the scales of the Y-axes may vary. This in order to show as much detail as possible.

Except in the plots of the wind direction, the observations are inter-connected if they were available every three hours.

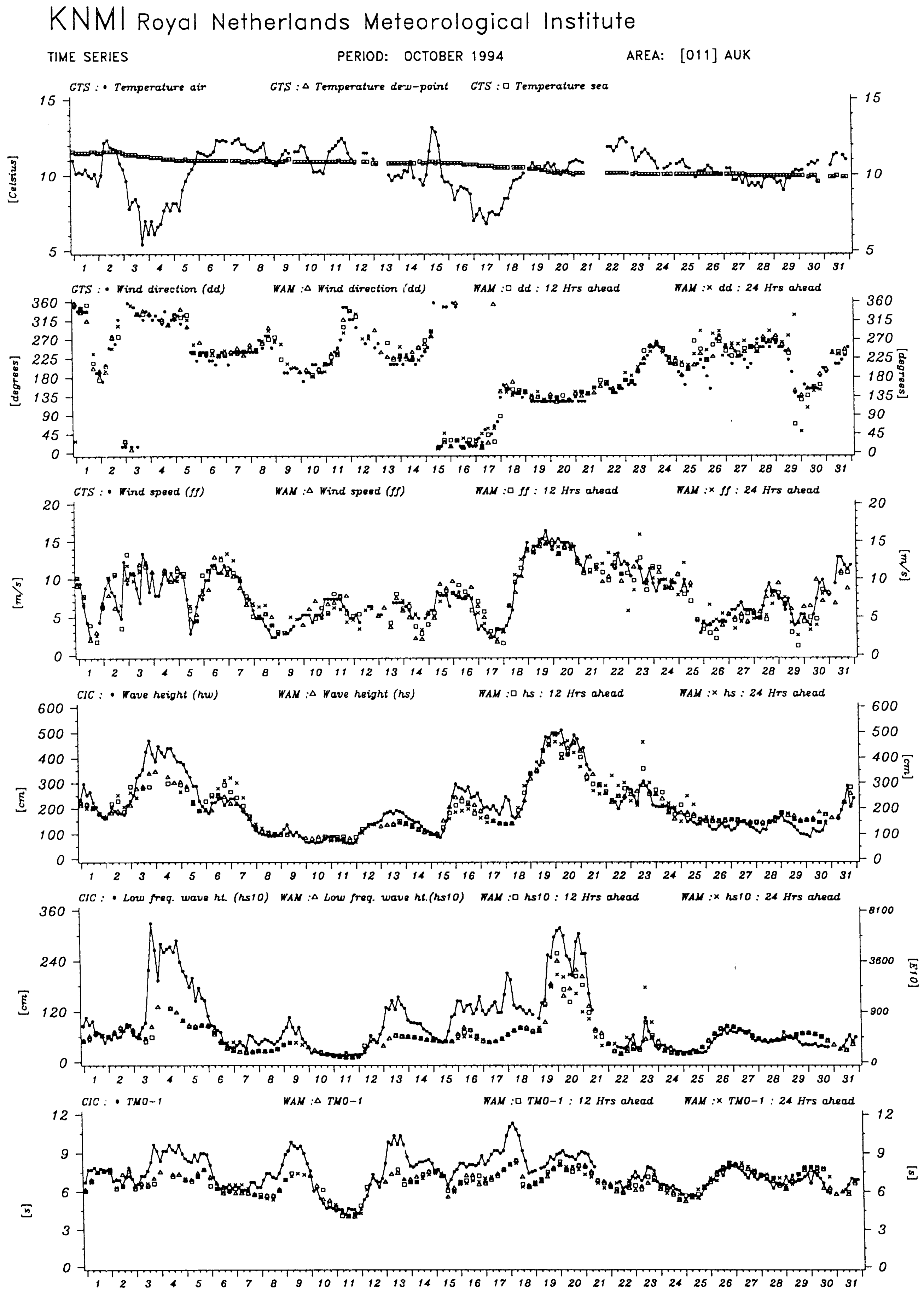


Figure 4 AUK October 1994

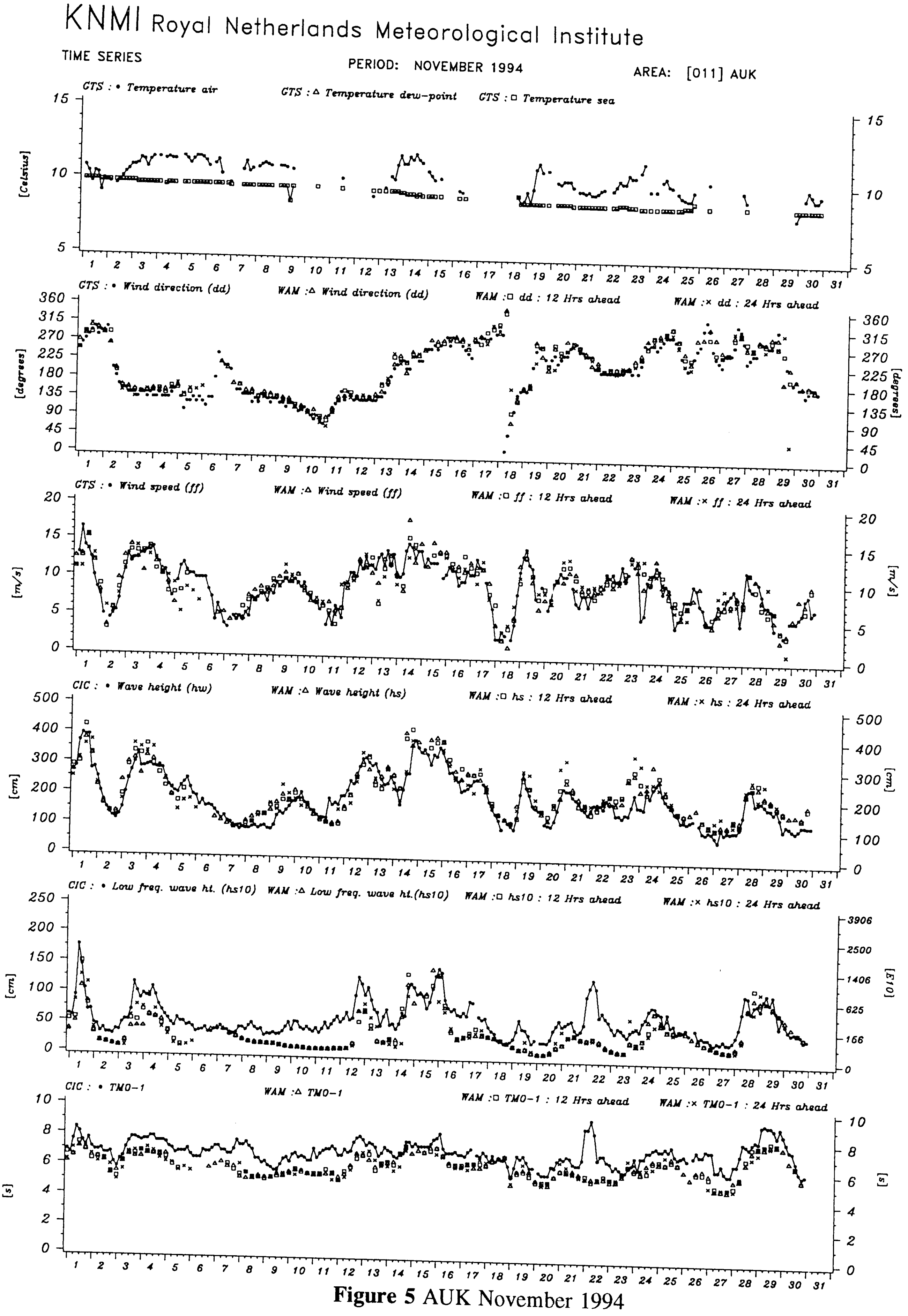


Figure 5 AUK November 1994

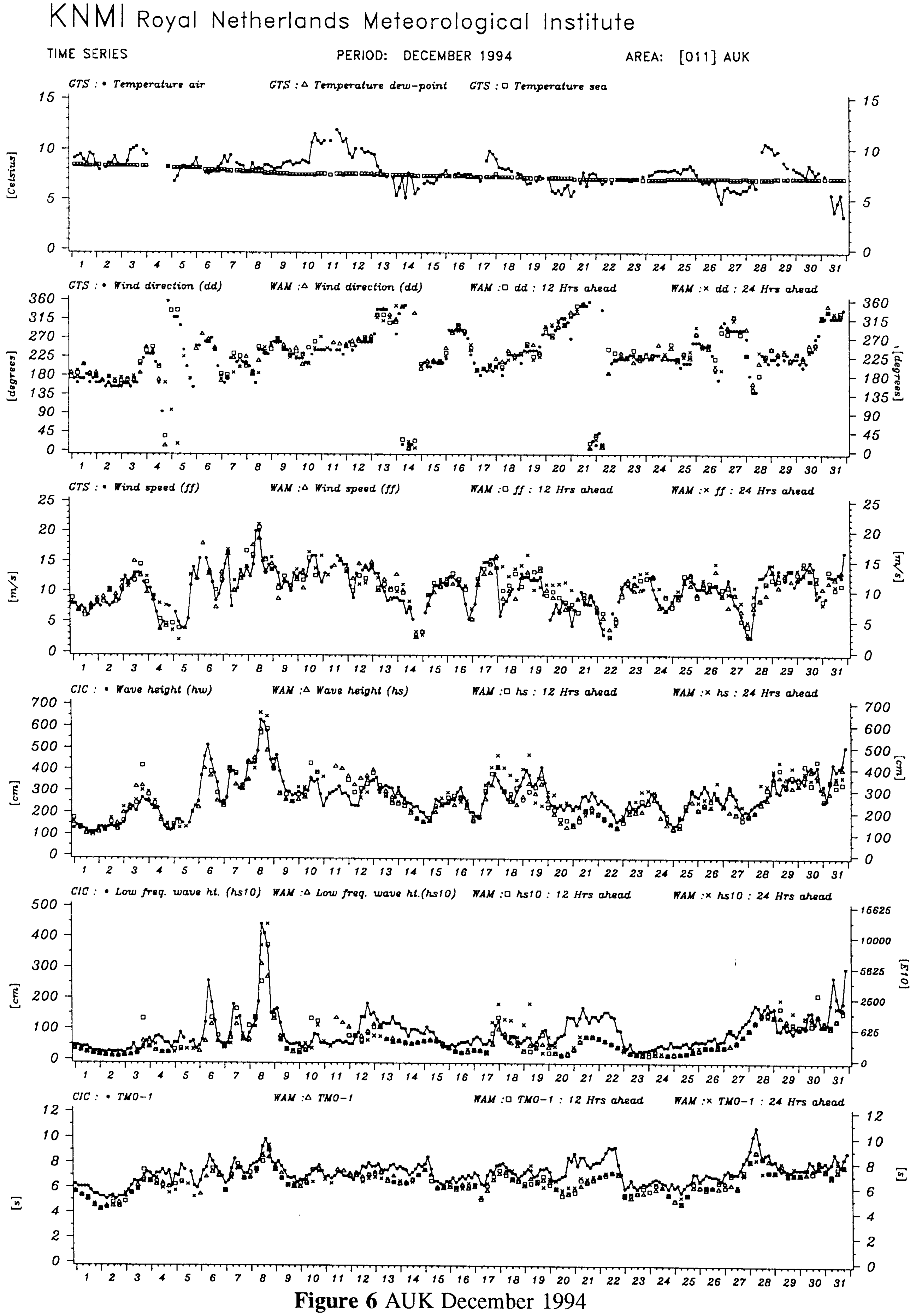


Figure 6 AUK December 1994

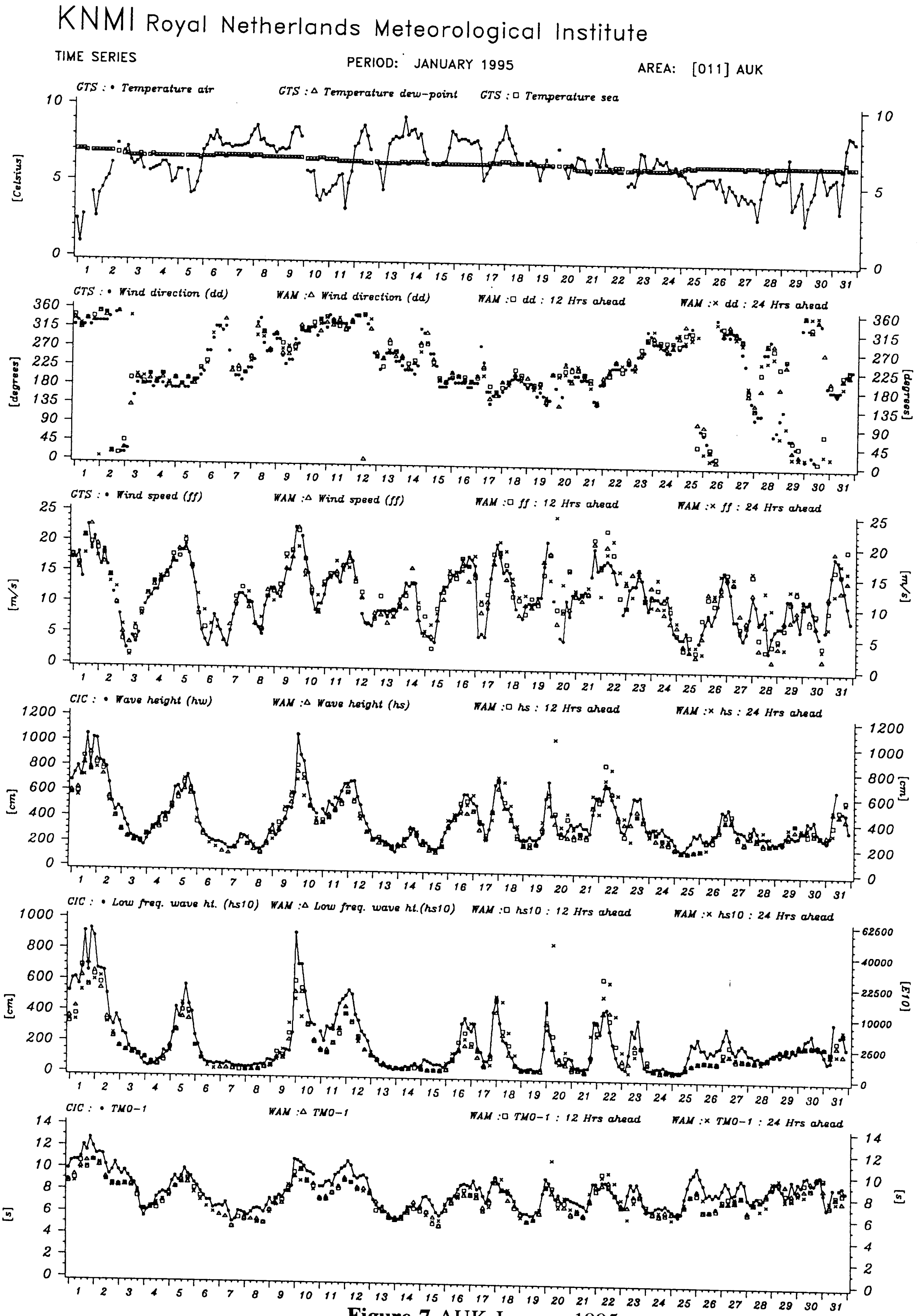


Figure 7 AUK January 1995

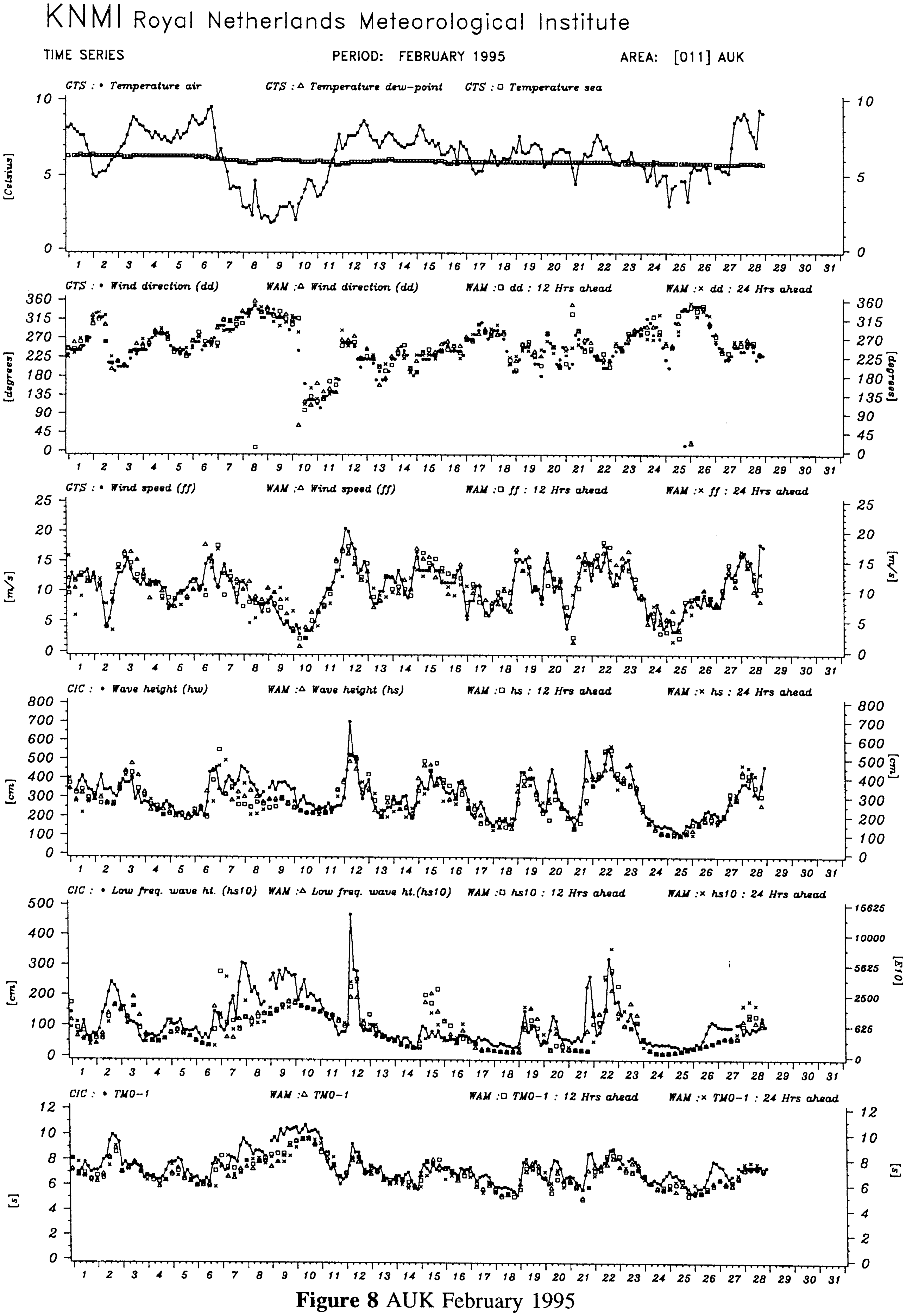


Figure 8 AUK February 1995

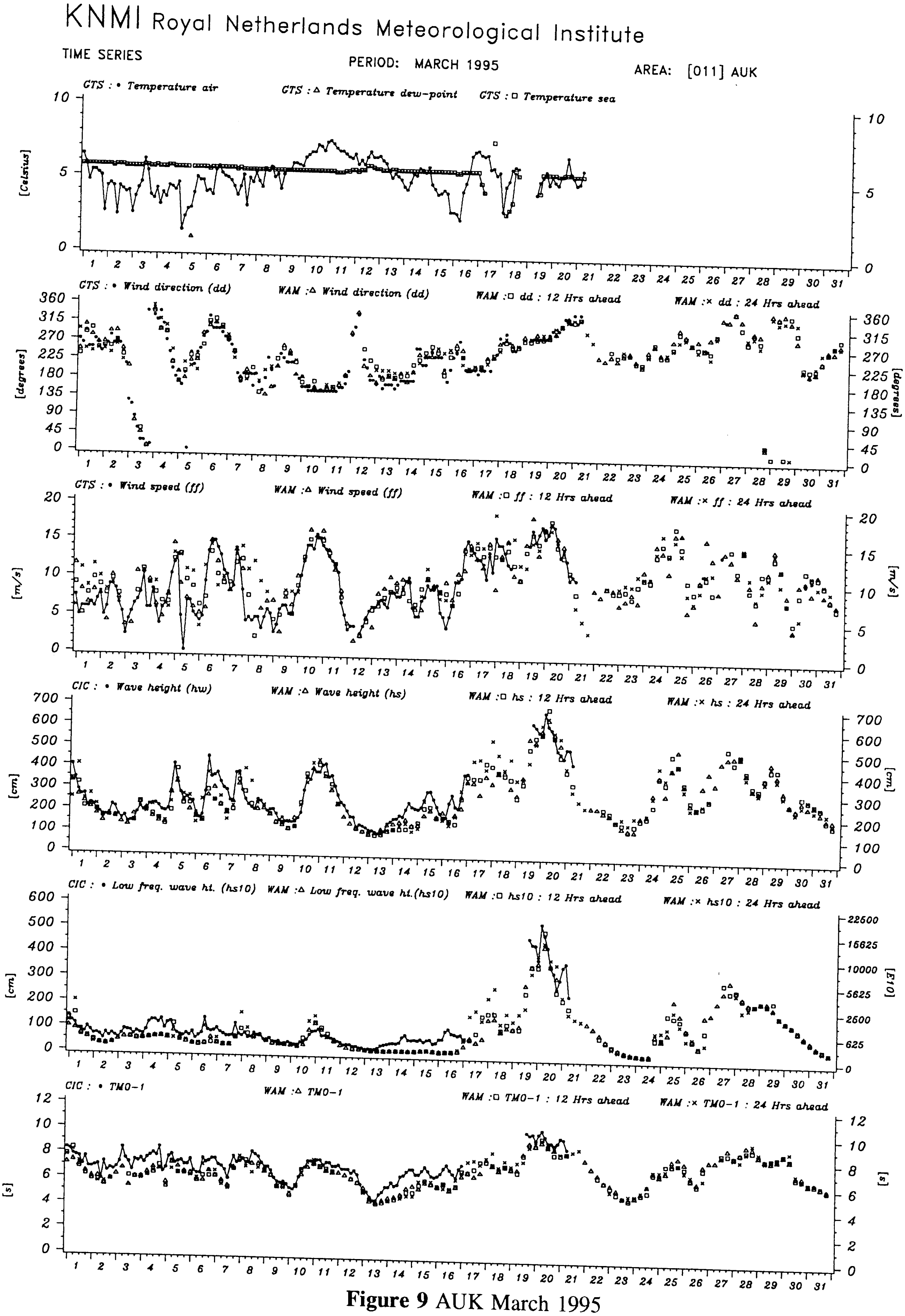


Figure 9 AUK March 1995

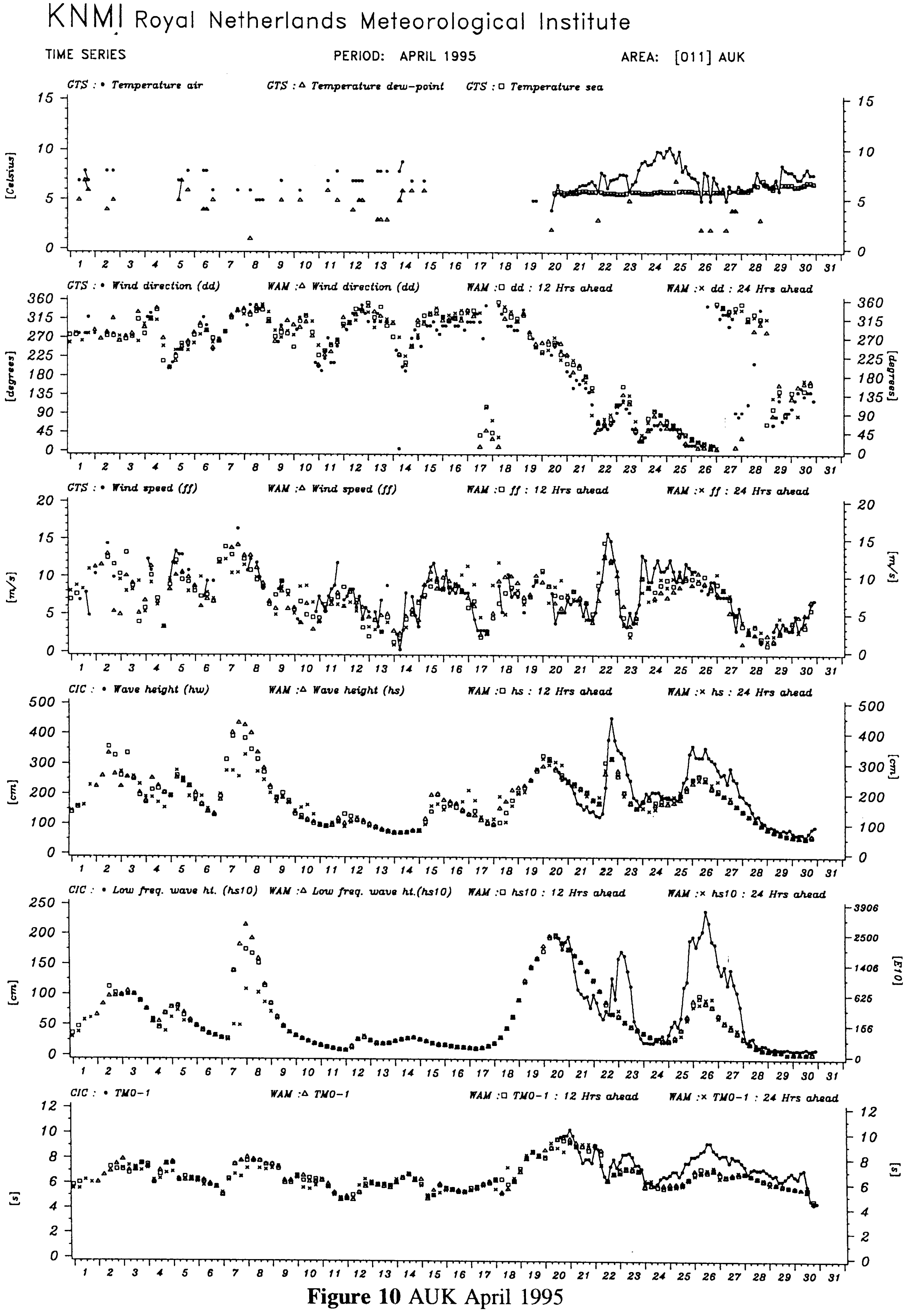


Figure 10 AUK April 1995

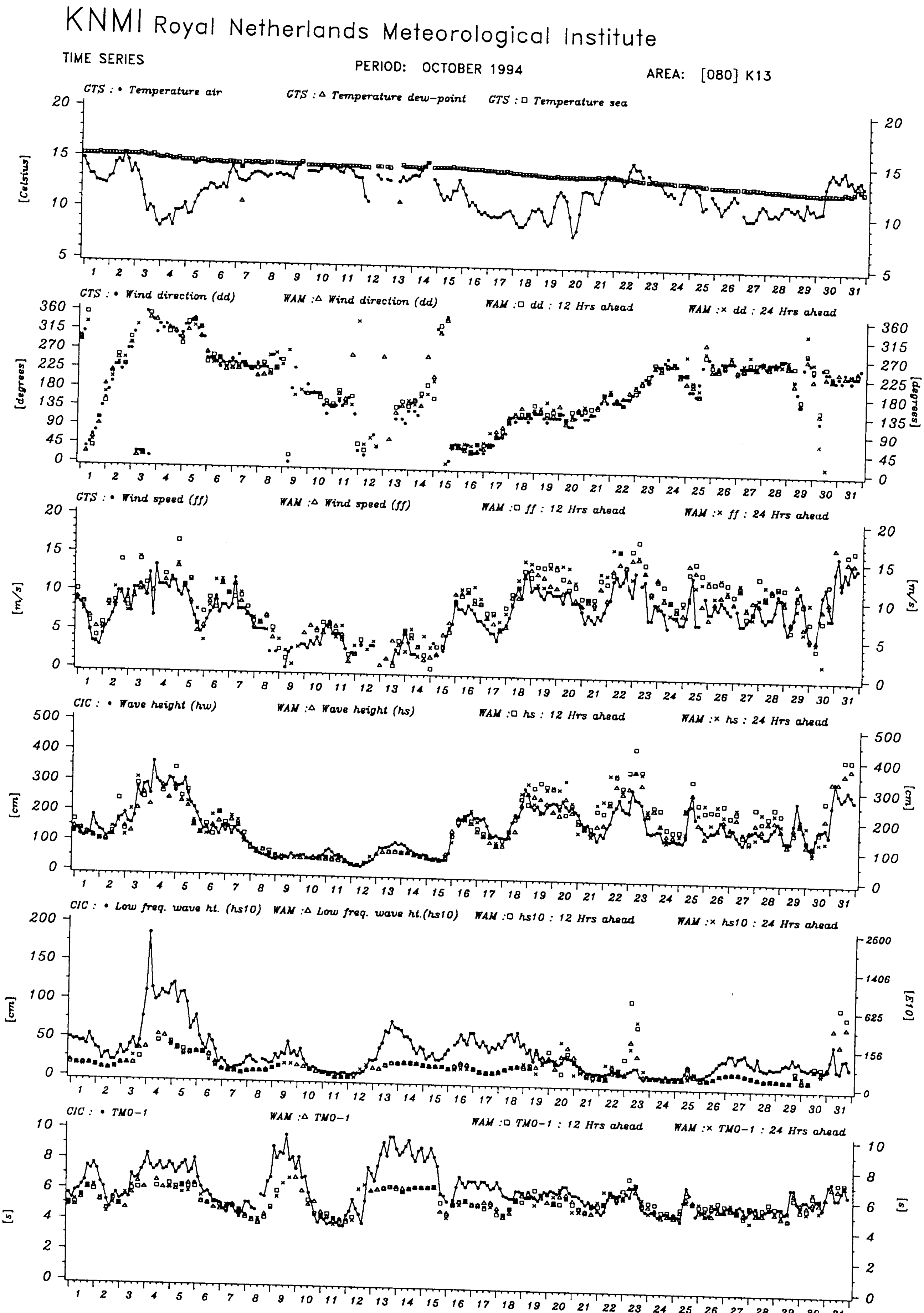


Figure 11 K13 October 1994

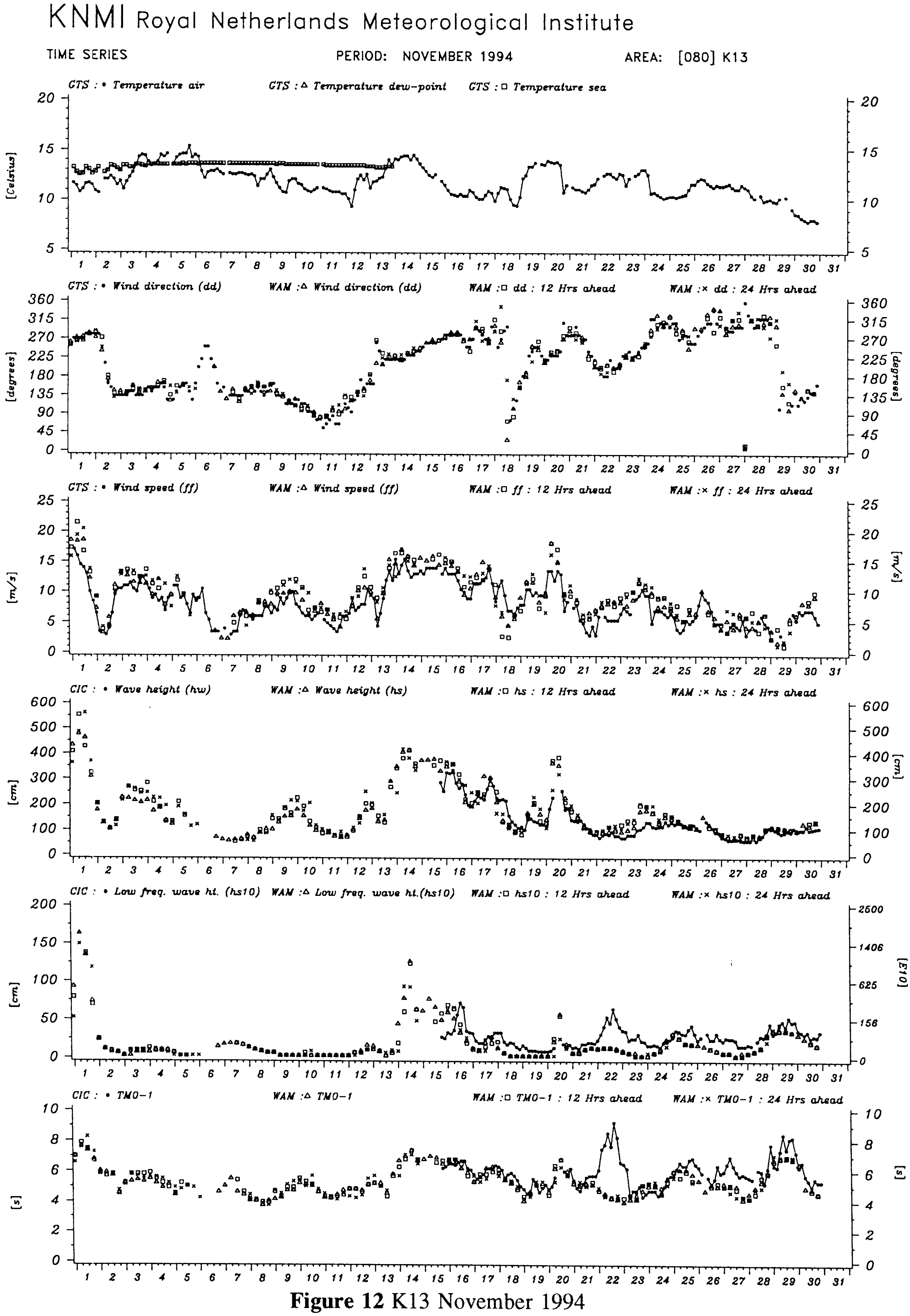


Figure 12 K13 November 1994

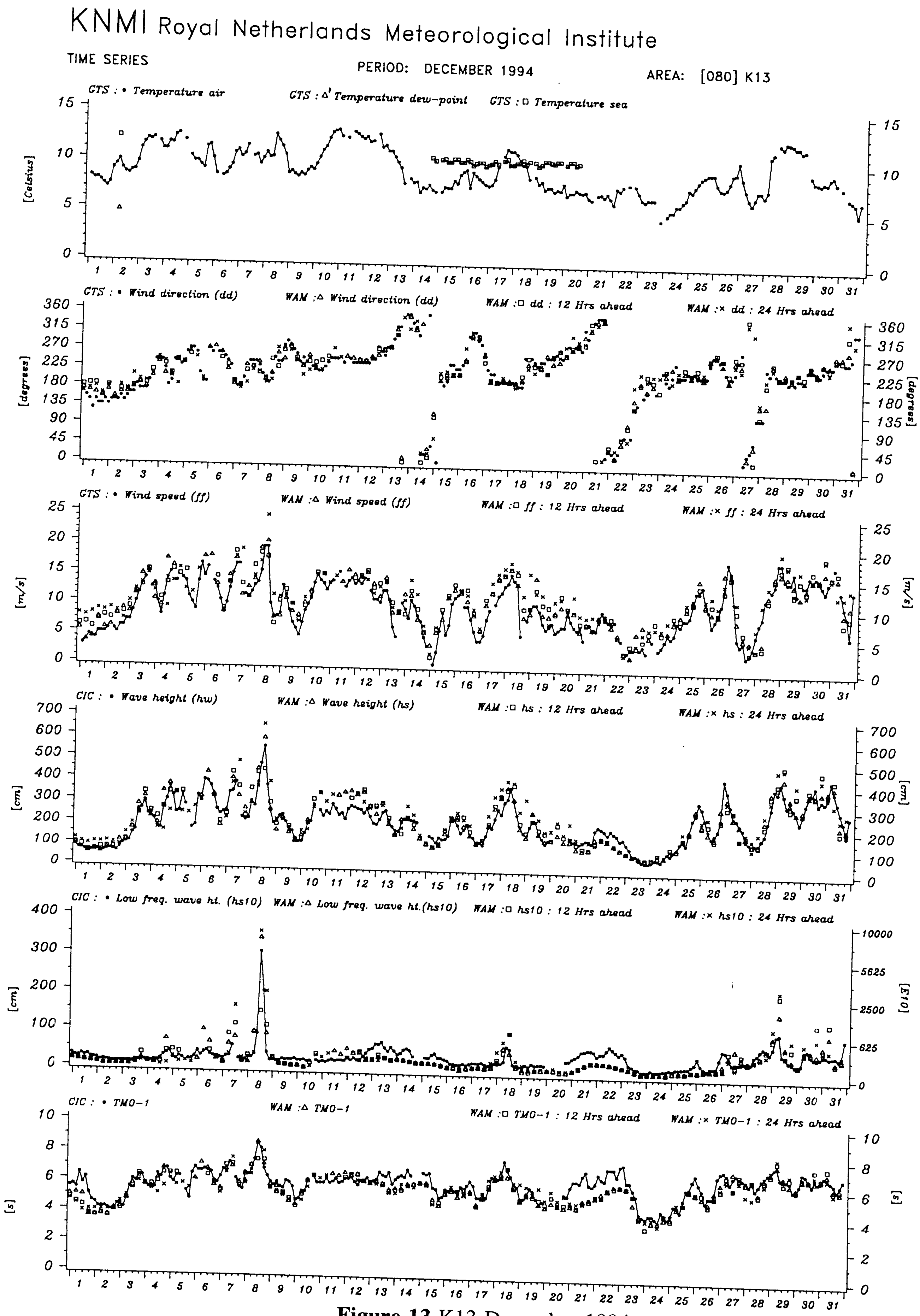


Figure 13 K13 December 1994

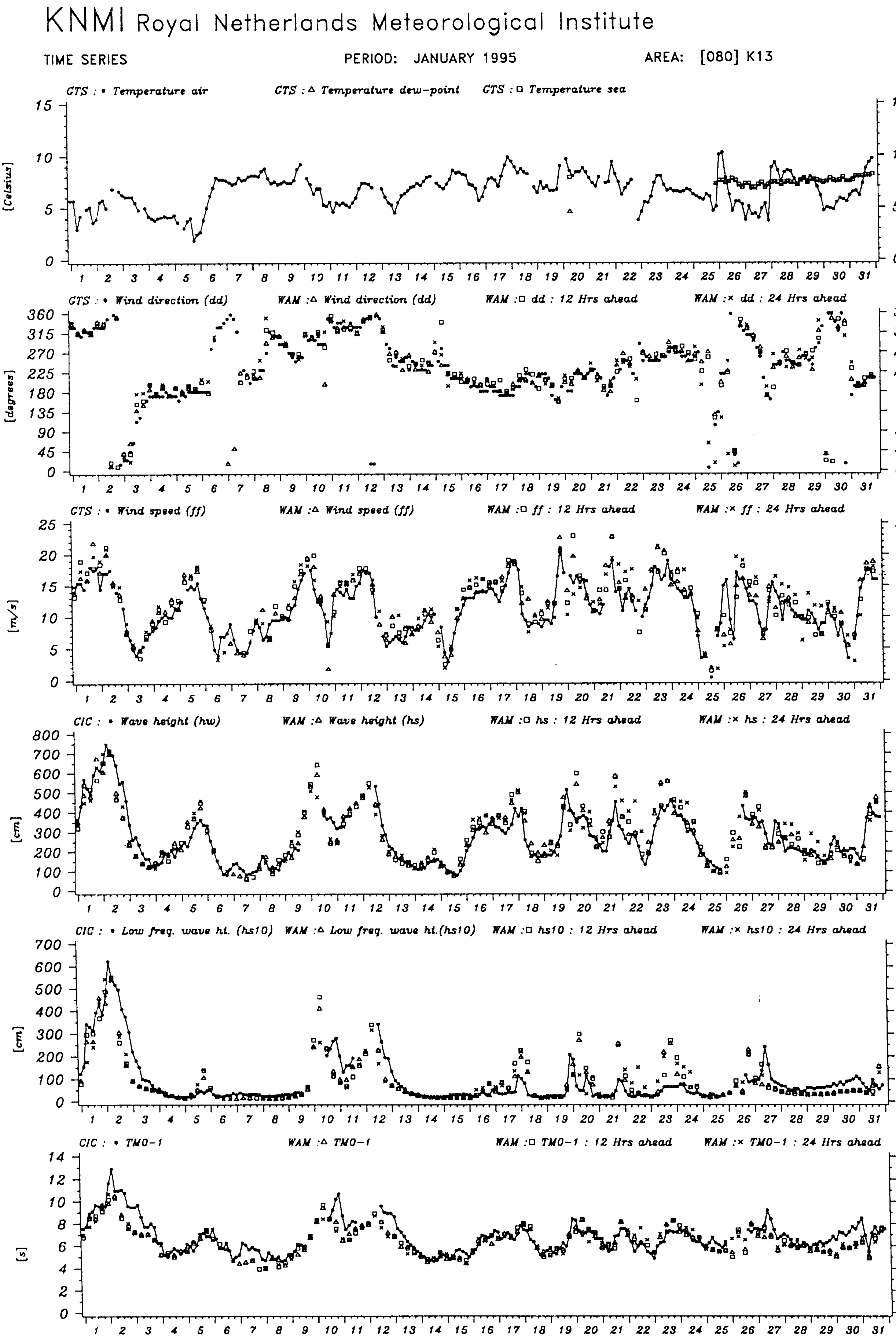


Figure 14 K13 January 1995

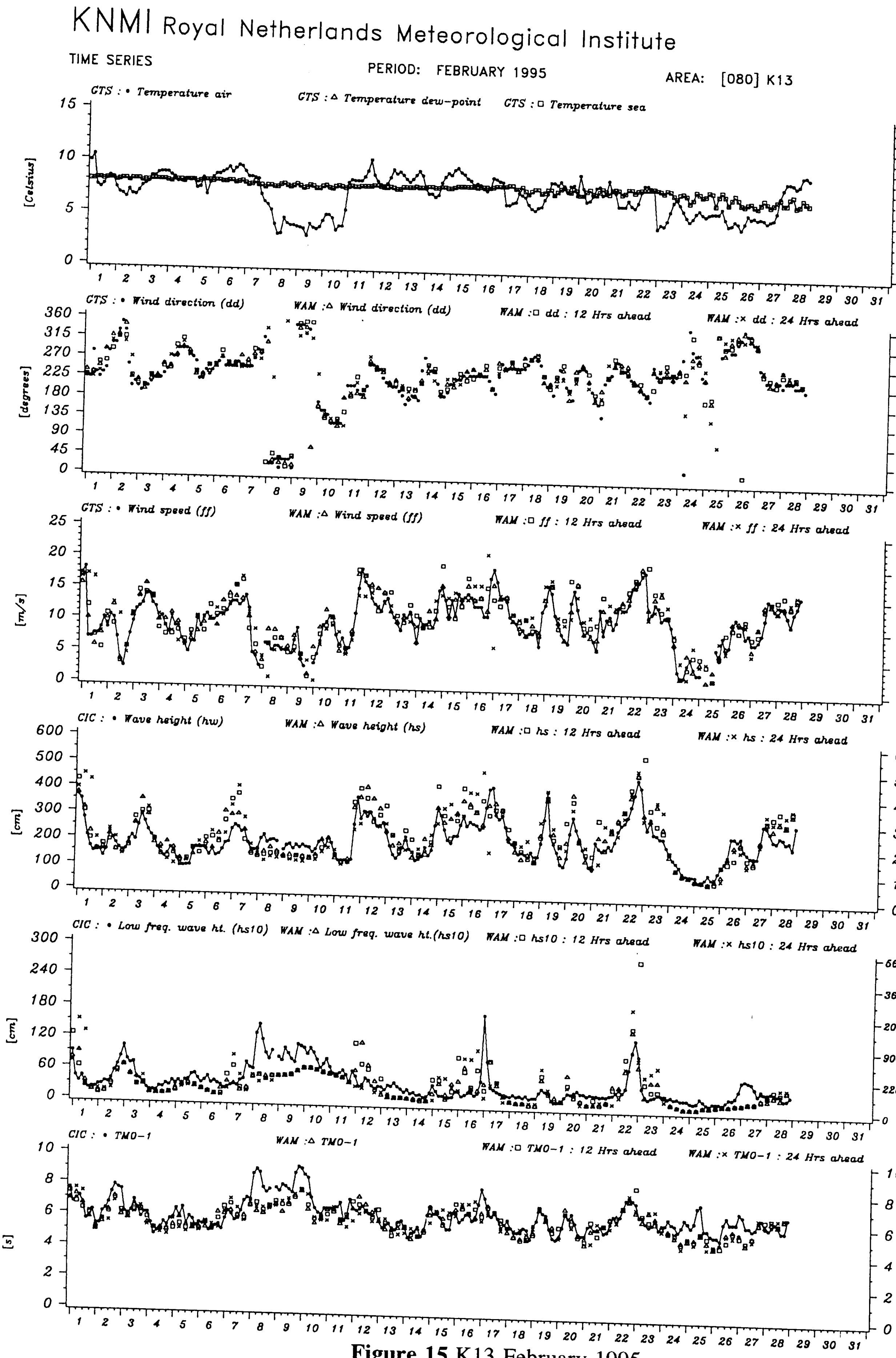


Figure 15 K13 February 1995

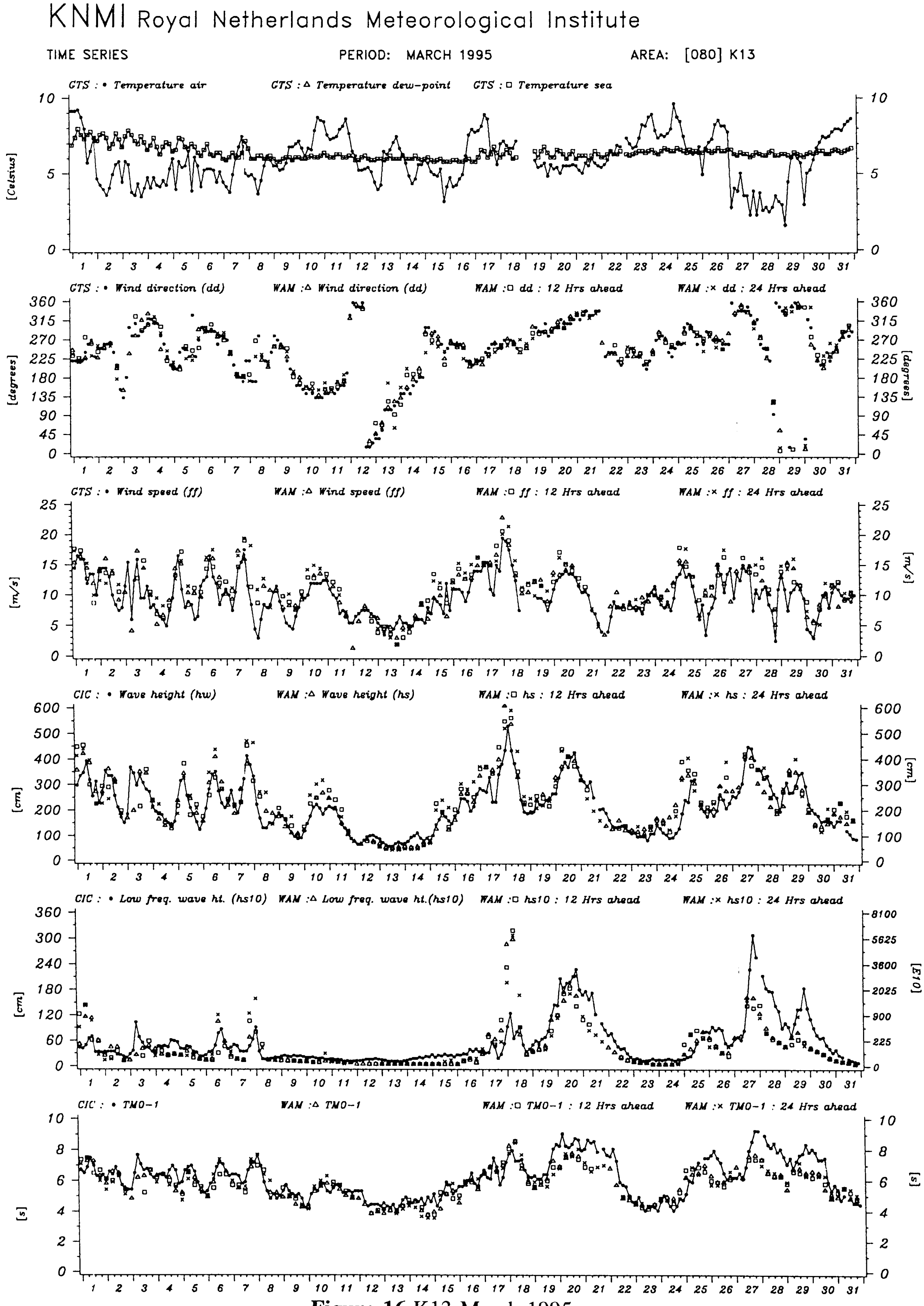


Figure 16 K13 March 1995

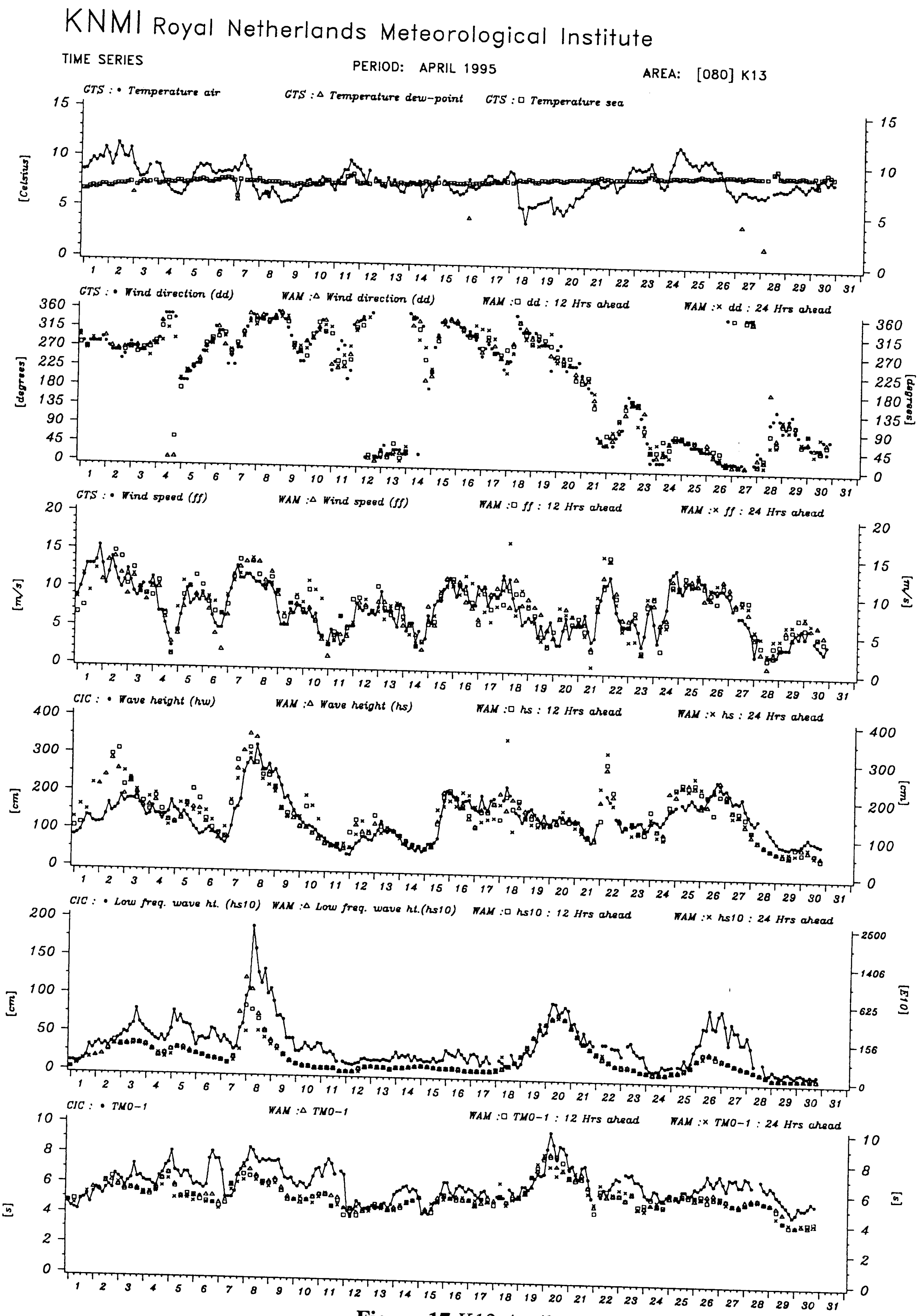


Figure 17 K13 April 1995

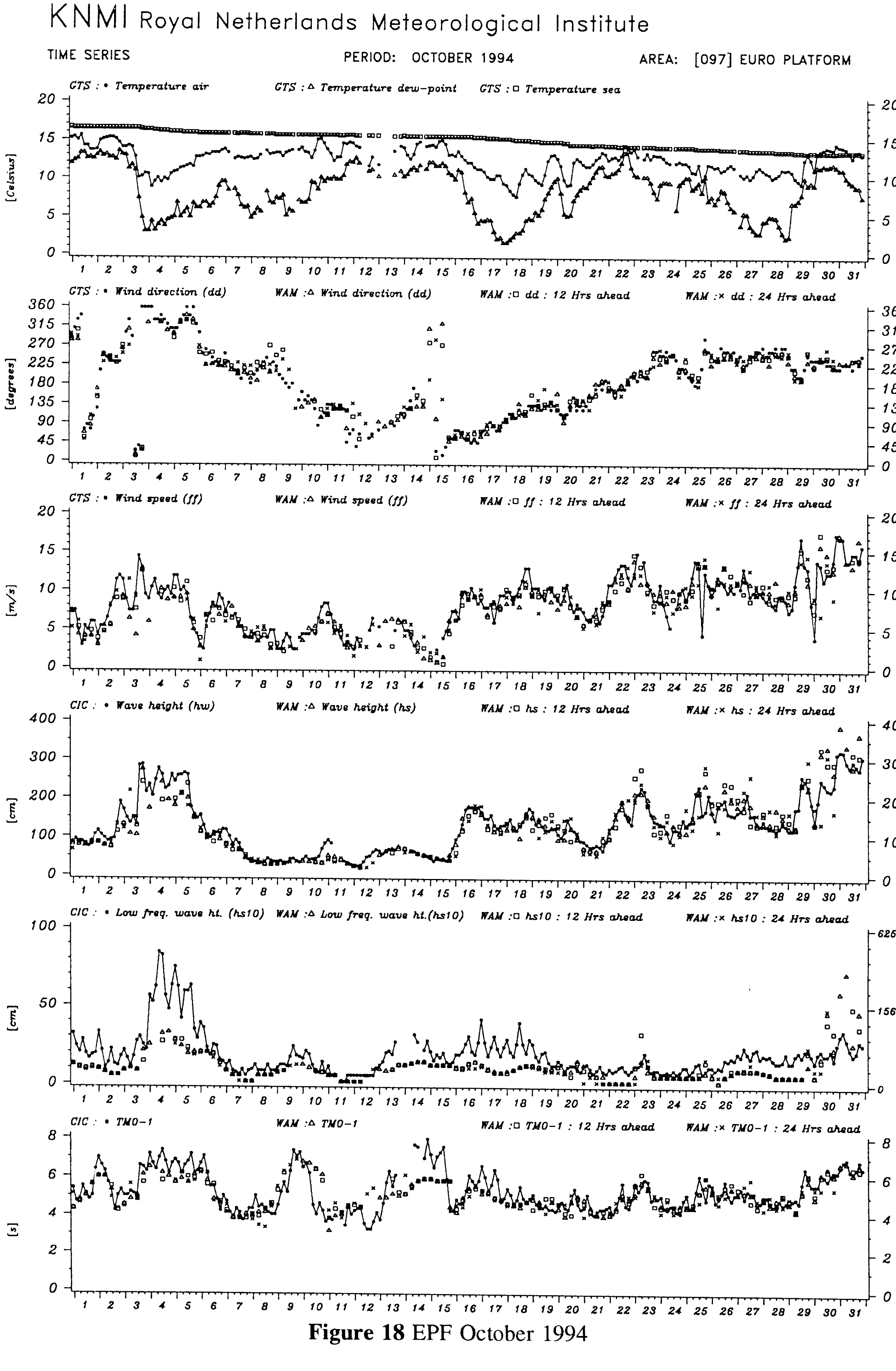


Figure 18 EPF October 1994

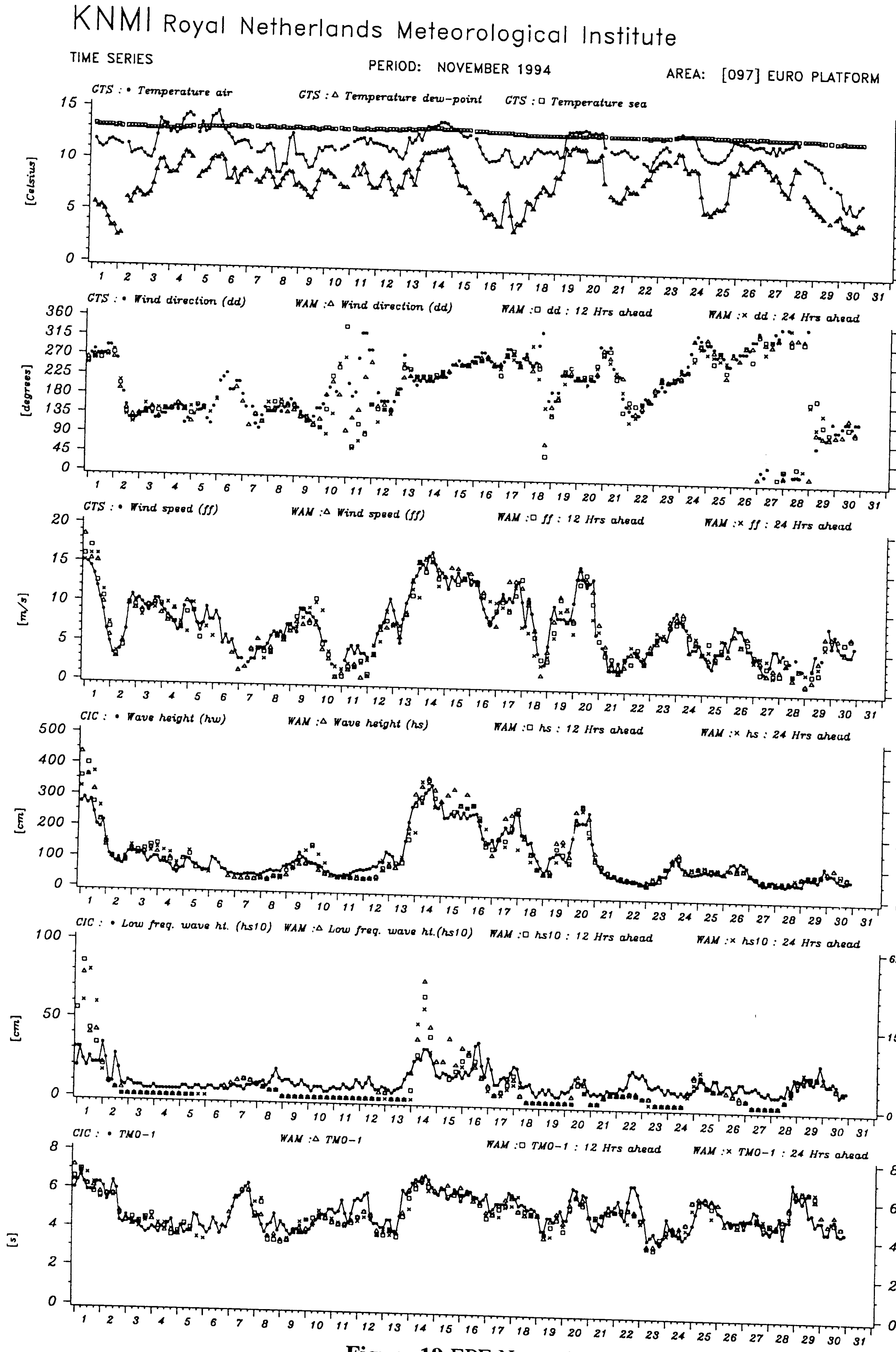


Figure 19 EPF November 1994

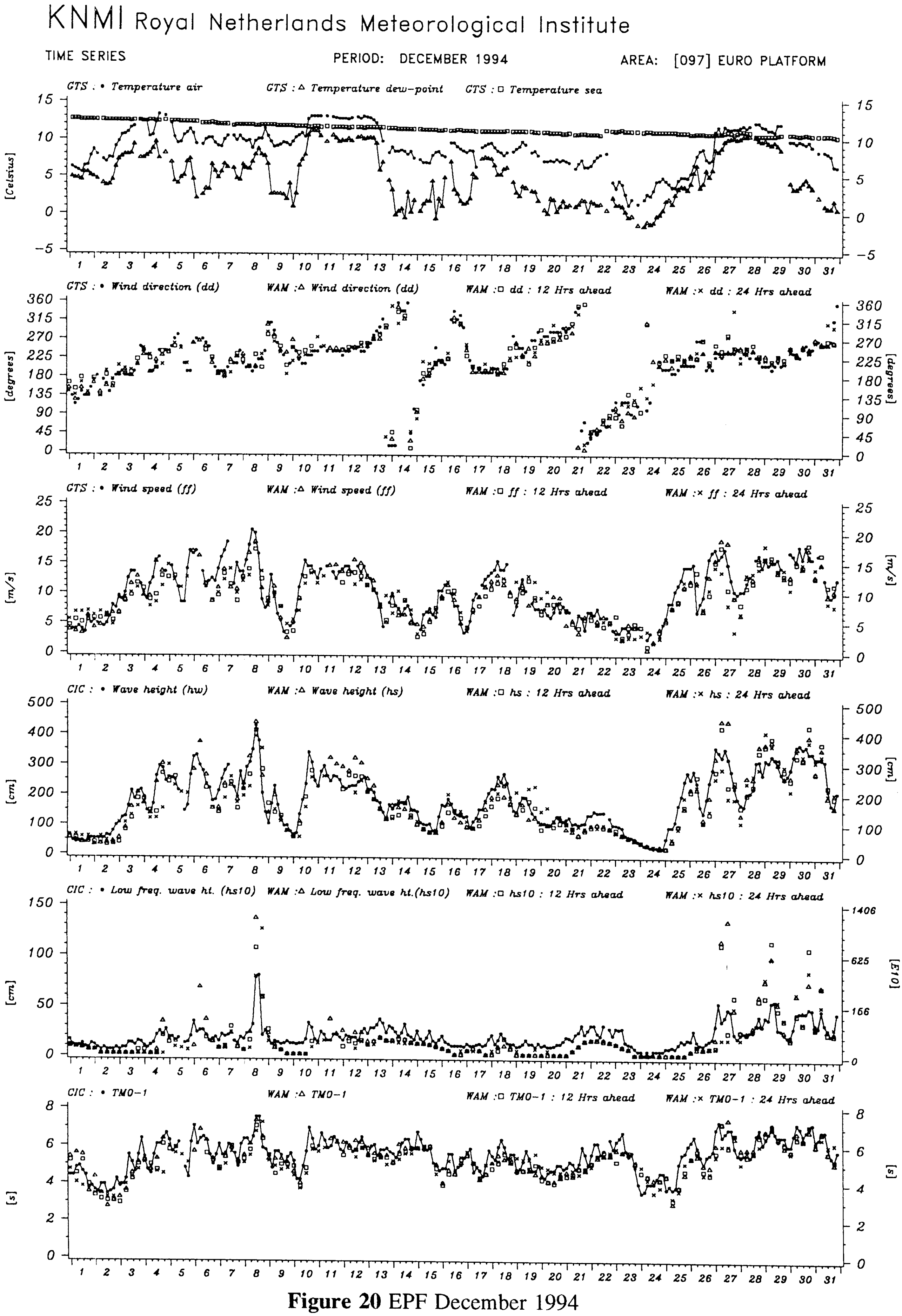


Figure 20 EPF December 1994

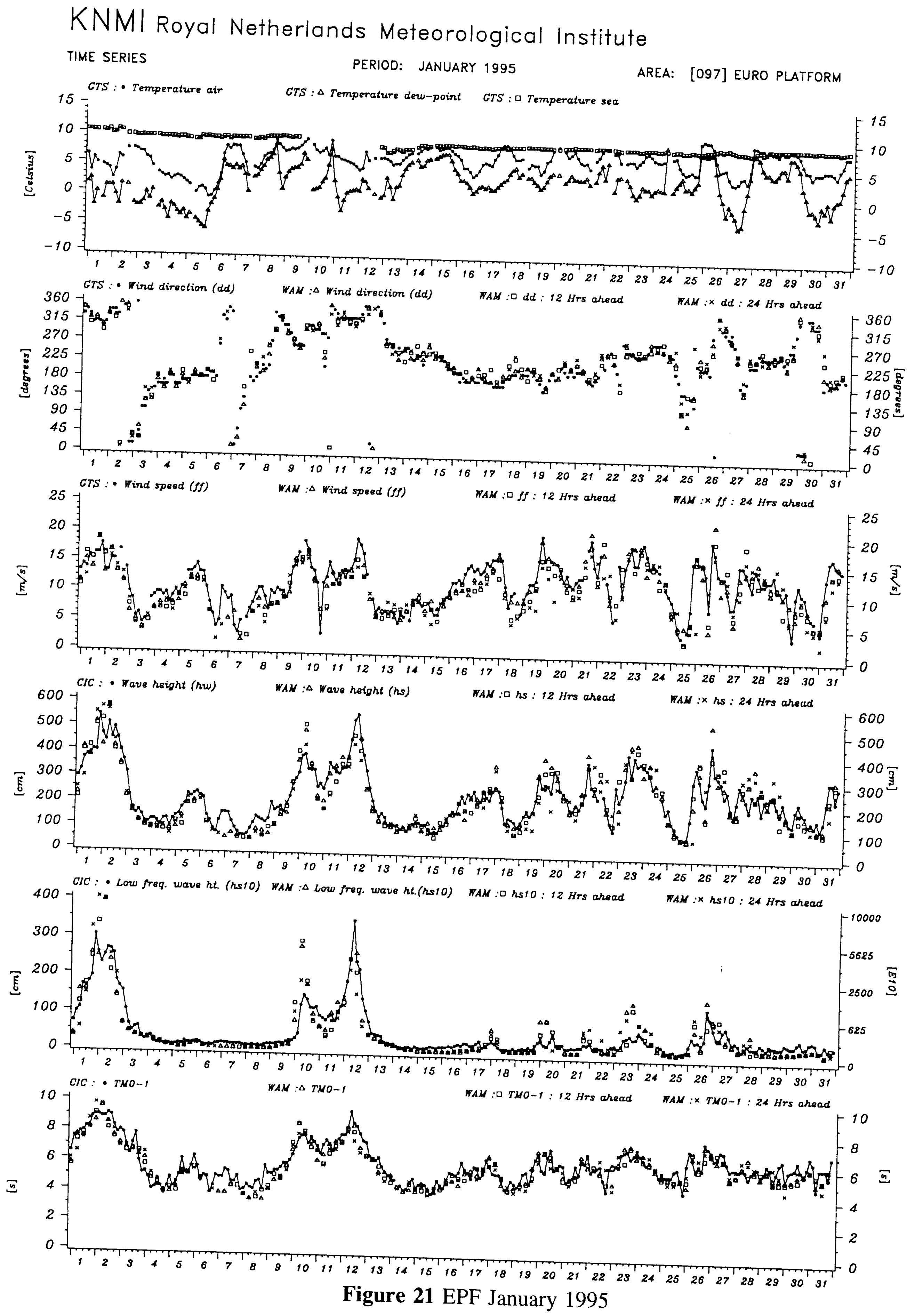


Figure 21 EPF January 1995

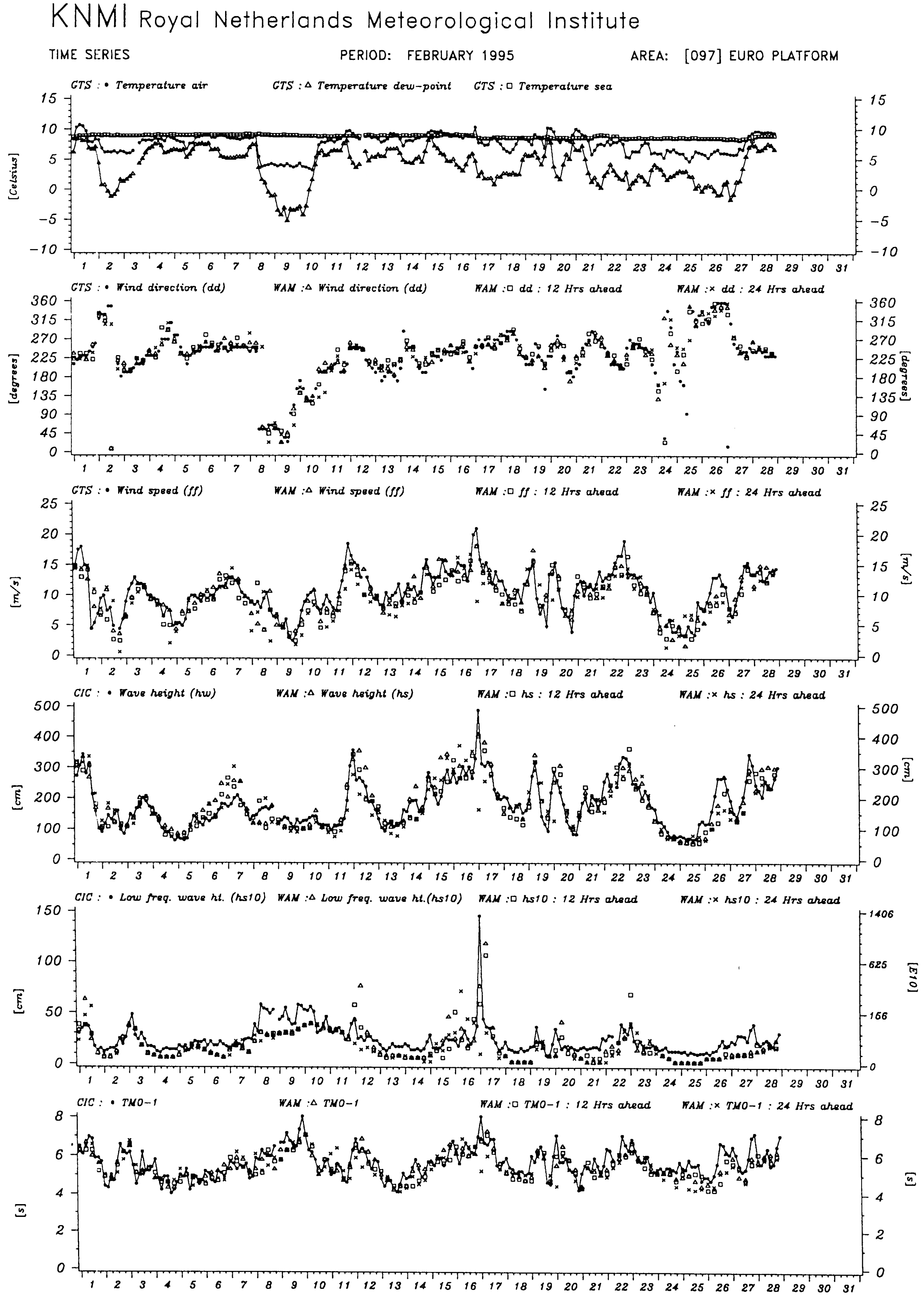


Figure 22 EPF February 1995

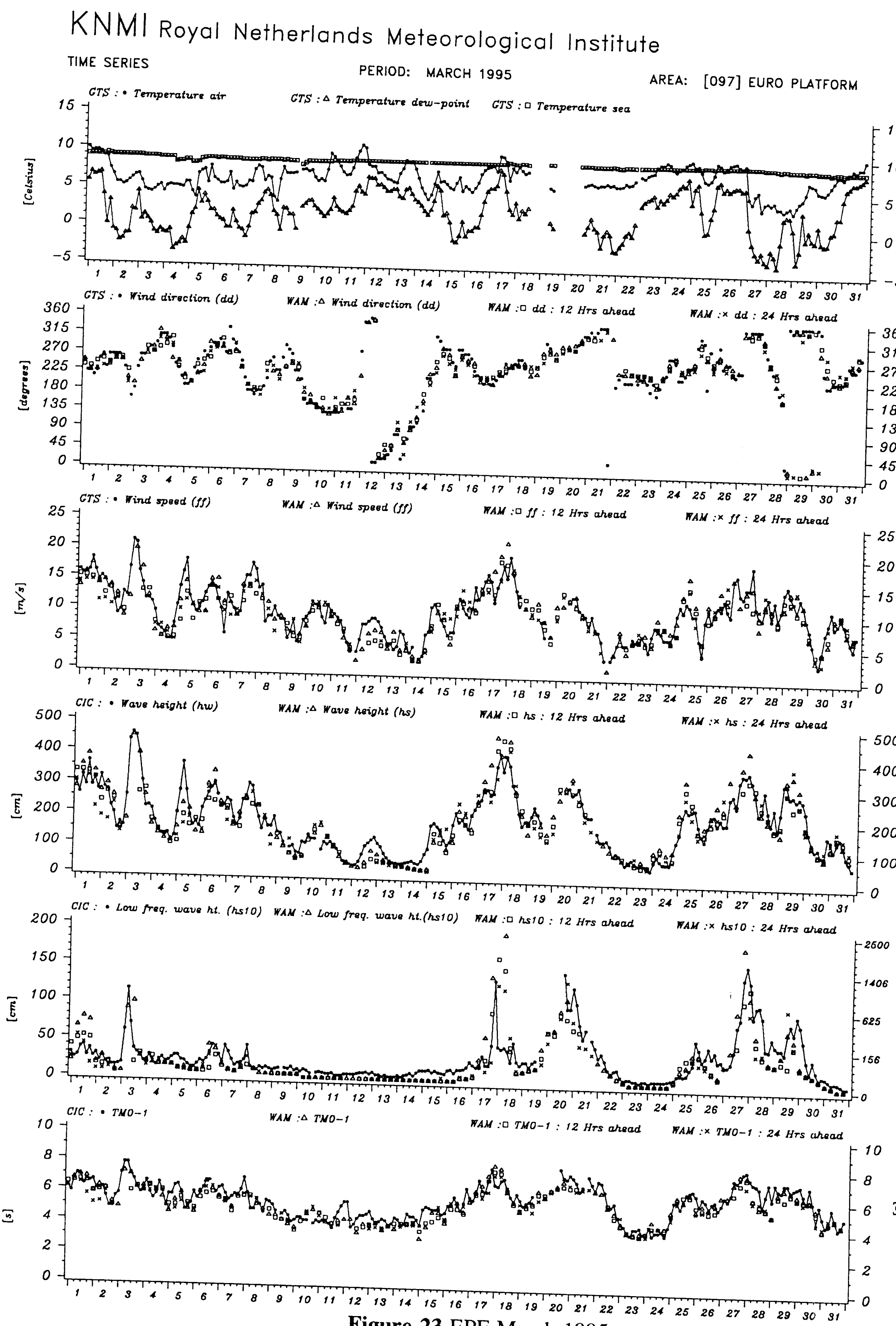


Figure 23 EPF March 1995

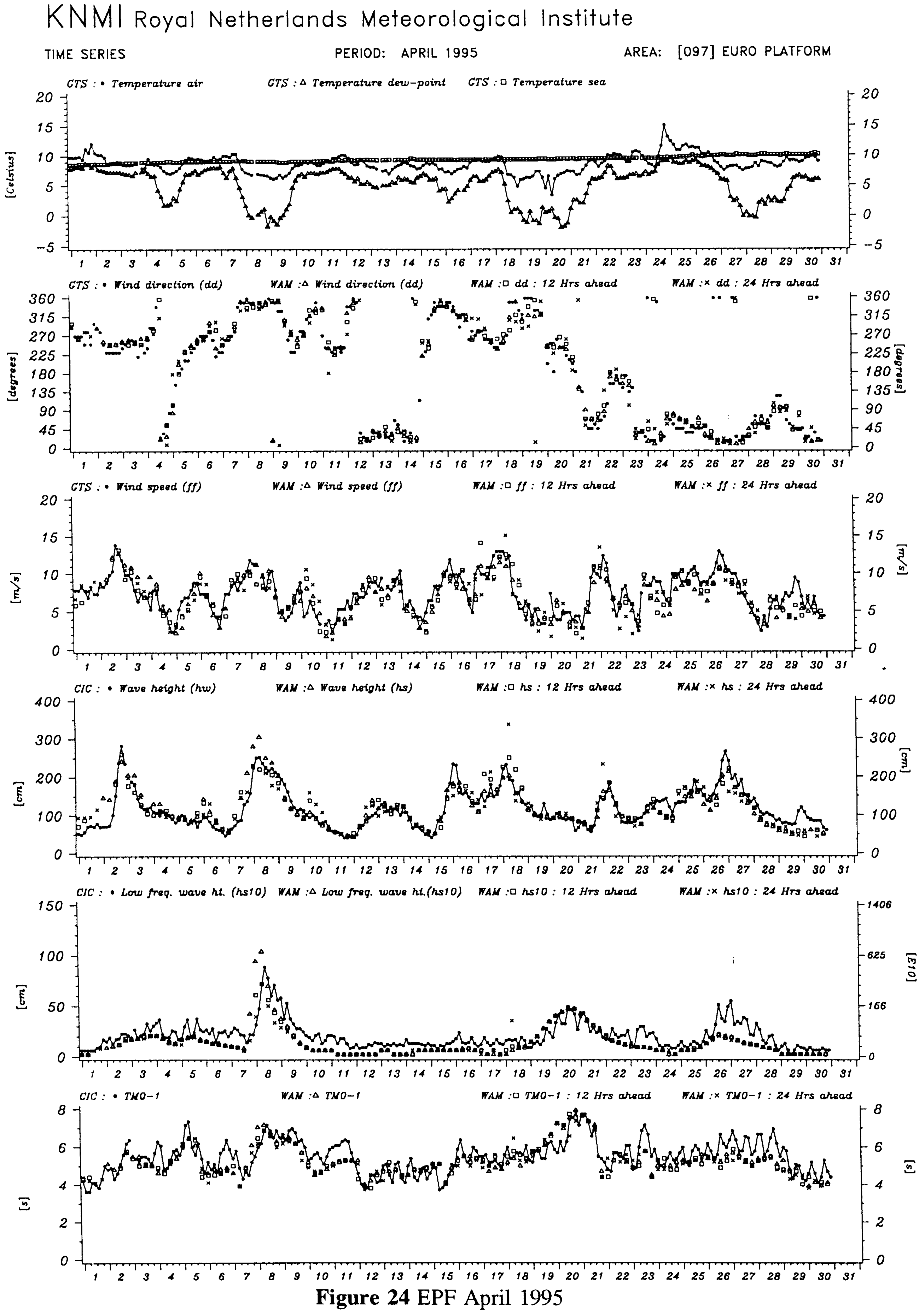


Figure 24 EPF April 1995

3. Statistics

In this chapter the quality of the model forecasts is evaluated in a statistical way. This evaluation is displayed in a tabular form (see chapter 4.a) and in scatter plots (see chapter 4.b). Most of the used formulas are described in chapter 4.a, but some additional formulas may be found in chapter 2.

a. Tables

Some statistical results are displayed in tabular form, one table for each station covering the whole period October 1994 - April 1995 (see tables 2-4). To examine the variation of some individual statistical parameters during this period, tables 5 and 6 are added.

To obtain a result that is not biased too much, low frequency wave heights ≤ 10 cm were excluded from the set of observations and observations in this part.

Used abbreviations and formulas:

BIAS The bias is defined as:

$$\bar{x} = \frac{1}{n}\sum x_i$$

where x_i = model - observation
Note: the bias is negative when the model results are too low. The bias is the so-called mean difference (mean error) between the model values and the observational values.

DD Wind direction

DD_06 Forecasted wind direction for +06 hours

DIR Mean wave direction

DIR_06 Forecasted wave direction for +06 hours

FF Wind speed

FF_06 Forecasted wind speed for +06 hours

HS Significant wave height, 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.

HS_06 Forecasted wave height for +06 hours

HS10 Low frequency wave height, defined as:

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

HS10_06 Forecasted low frequency wave height for +06 hours

N Number of data points plotted.

R The correlation coefficient. One interprets this parameter as the fraction of the variation of the y's that is accounted by the relationship with x.

$$R = \sqrt{\frac{S_{xy}.S_{xy}}{S_{xx}.S_{yy}}}$$

with

$$S_{ij} = \sum i\,j - \frac{1}{N}\left(\sum i\right)\left(\sum j\right) \quad with\ i,j = x,y$$

RMS Root Mean Squared

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} (y_i - x_i)^2}{N}}$$

SD, σ_d Standard deviation in both directions. It is computed as follows:

$$\sigma_d = \sqrt{\frac{\sum_{i=1}^{N}(y_i-x_i)^2 - \frac{1}{N}(\sum_{i=1}^{N}(y_i-x_i))^2}{N}}$$

SI The scatter index. This is the spread of the distribution of *y-x*, computed as a fraction of the mean x value. It is calculated as percentage. The mathematical formula used is:

$$SI = \frac{100}{\bar{x}}\sqrt{\frac{\sum(y_i-x_i)^2 - \frac{(\sum(y_i-x_i))^2}{N}}{N}}$$

TM0-1_06 Forecasted wave period for +06 hours

Xmean, $\bar{x}$ The weighted mean in x is defined as:

$$\bar{x} = \frac{\sum_{i=1}^{N}(\frac{1}{\Delta x_i})^2 x_i}{\sum_{i=1}^{N}(\frac{1}{\Delta x_i})^2}$$

where x_i are the measurements and Δx_i are the standard deviations in the measurements, $\bar{x}$ is the mean value.

Ymean, $\bar{y}$ The weighted mean in y.

KNMI Royal Netherlands Meteorological Institute

Tables with statistics for MOERAV areas

Period: 94100100-95043018 6

AREA: [011] AUK

X: cic	Y: wam	N	Xmean	Ymean	BIAS	SD	RMS	SI (%)	R
DD [degrees]	DD [degrees]	660			7.1	22.0	23.1		
DD [degrees]	DD_06 [degrees]	655			7.0	20.1	21.2		
DD [degrees]	DD_12 [degrees]	652			7.5	21.7	23.0		
DD [degrees]	DD_24 [degrees]	637			4.7	30.0	30.4		
DD [degrees]	DD_36 [degrees]	628			6.3	36.5	37.1		
FF [m/s]	FF [m/s]	664	9.4	9.6	0.1	1.7	1.8	19	0.91
FF [m/s]	FF_06 [m/s]	658	9.5	9.7	0.2	1.7	1.7	18	0.91
FF [m/s]	FF_12 [m/s]	653	9.5	9.7	0.2	1.9	1.9	20	0.89
FF [m/s]	FF_24 [m/s]	638	9.5	9.9	0.4	2.4	2.4	25	0.83
FF [m/s]	FF_36 [m/s]	629	9.5	9.9	0.5	2.7	2.7	29	0.77
DIR [degrees]	DIR [degrees]	332			−1.9	24.3	24.4		
DIR [degrees]	DIR_06 [degrees]	331			−1.5	23.3	23.4		
DIR [degrees]	DIR_12 [degrees]	329			−1.2	22.9	22.9		
DIR [degrees]	DIR_24 [degrees]	325			−0.3	23.5	23.5		
DIR [degrees]	DIR_36 [degrees]	323			0.8	31.3	31.3		
HS [cm]	HS [cm]	665	268.0	249.0	−19.0	50.5	53.9	19	0.93
HS [cm]	HS_06 [cm]	659	269.4	251.5	−17.9	51.5	54.5	19	0.93
HS [cm]	HS_12 [cm]	654	270.1	255.0	−15.1	55.2	57.2	20	0.92
HS [cm]	HS_24 [cm]	639	271.5	262.1	−9.4	69.8	70.5	26	0.87
HS [cm]	HS_36 [cm]	630	273.1	264.5	−8.6	77.8	78.3	28	0.84
HS10 [cm]	HS10 [cm]	609	113.3	82.4	−30.9	49.6	58.5	44	0.91
HS10 [cm]	HS10_06 [cm]	601	115.1	84.2	−30.9	51.1	59.8	44	0.90
HS10 [cm]	HS10_12 [cm]	598	115.2	87.3	−27.8	53.3	60.1	46	0.89
HS10 [cm]	HS10_24 [cm]	587	115.3	90.4	−24.9	68.2	72.6	59	0.81
HS10 [cm]	HS10_36 [cm]	589	114.7	90.4	−24.2	74.1	77.9	65	0.77
TM0−1 [s]	TM0−1 [s]	665	7.4	6.7	−0.8	0.6	1.0	9	0.85
TM0−1 [s]	TM0−1_06[s]	659	7.5	6.7	−0.8	0.7	1.0	9	0.85
TM0−1 [s]	TM0−1_12[s]	654	7.5	6.7	−0.7	0.7	1.0	9	0.84
TM0−1 [s]	TM0−1_24[s]	639	7.5	6.8	−0.7	0.8	1.0	10	0.80
TM0−1 [s]	TM0−1_36[s]	630	7.5	6.8	−0.7	0.8	1.1	11	0.76

Table 2 Statistics for AUK October 1994 - April 1995

KNMI Royal Netherlands Meteorological Institute

Tables with statistics for MOERAV areas

Period: 94100100–95043018 6

AREA: [080] K13

X: cic	Y: wam	N	Xmean	Ymean	BIAS	SD	RMS	SI (%)	R
DD [cegrees]	DD [degrees]	723			1.7	21.8	21.9		
DD [degrees]	DD_06 [degrees]	715			2.0	22.2	22.3		
DD [degrees]	DD_12 [degrees]	706			3.7	23.6	23.9		
DD [degrees]	DD_24 [degrees]	692			3.4	28.8	29.0		
DD [degrees]	DD_36 [degrees]	685			2.2	35.2	35.3		
FF [m/s]	FF [m/s]	722	9.0	9.9	0.9	1.7	1.9	19	0.91
FF [m/s]	FF_06 [m/s]	714	9.0	10.3	1.2	1.8	2.2	20	0.91
FF [m/s]	FF_12 [m/s]	708	9.0	10.2	1.2	2.0	2.4	23	0.88
FF [m/s]	FF_24 [m/s]	692	9.0	10.3	1.3	2.4	2.7	26	0.84
FF [m/s]	FF_36 [m/s]	684	9.0	10.3	1.3	2.6	2.9	29	0.81
DIR [degrees]	DIR [degrees]	461			−1.1	23.4	23.5		
DIR [degrees]	DIR_06 [degrees]	455			−0.7	24.2	24.2		
DIR [degrees]	DIR_12 [degrees]	452			1.6	24.4	24.5		
DIR [degrees]	DIR_24 [degrees]	441			0.2	25.2	25.2		
DIR [degrees]	DIR_36 [degrees]	437			0.2	29.2	29.2		
HS [cm]	HS [cm]	723	193.3	202.3	9.0	43.9	44.8	23	0.92
HS [cm]	HS_06 [cm]	715	193.5	207.4	13.9	47.5	49.5	25	0.91
HS [cm]	HS_12 [cm]	709	193.3	208.4	15.1	50.9	53.0	26	0.90
HS [cm]	HS_24 [cm]	693	191.9	209.7	17.8	56.0	58.8	29	0.87
HS [cm]	HS_36 [cm]	685	192.1	211.1	19.0	62.2	65.1	32	0.85
HS10 [cm]	HS10 [cm]	469	59.4	48.2	−11.2	43.3	44.7	73	0.75
HS10 [cm]	HS10_06 [cm]	466	59.0	50.0	−9.0	45.2	46.1	77	0.74
HS10 [cm]	HS10_12 [cm]	456	59.5	50.2	−9.3	49.3	50.2	83	0.69
HS10 [cm]	HS10_24 [cm]	444	58.9	49.5	−9.4	47.1	48.1	80	0.72
HS10 [cm]	HS10_36 [cm]	447	57.9	50.2	−7.7	48.9	49.5	85	0.69
TM0−1 [s]	TM0−1 [s]	723	6.3	5.7	−0.5	0.7	0.9	12	0.77
TM0−1 [s]	TM0−1_06[s]	715	6.3	5.7	−0.5	0.8	0.9	12	0.76
TM0−1 [s]	TM0−1_12[s]	709	6.2	5.8	−0.5	0.8	0.9	13	0.74
TM0−1 [s]	TM0−1_24[s]	693	6.2	5.8	−0.5	0.8	1.0	13	0.72
TM0−1 [s]	TM0−1_36[s]	685	6.2	5.8	−0.4	0.9	1.0	14	0.69

Table 3 Statistics for K13 October 1994 - April 1995

KNMI Royal Netherlands Meteorological Institute

Tables with statistics for MOERAV areas

Period: 94100100–95043018 6

AREA: [097] EURO PLATFORM

X: cic	Y: wam	N	Xmean	Ymean	BIAS	SD	RMS	SI (%)	R
DD [degrees]	DD [degrees]	787			−1.6	22.5	22.6		
DD [degrees]	DD_06 [degrees]	778			−0.6	24.1	24.1		
DD [degrees]	DD_12 [degrees]	770			2.3	25.8	25.9		
DD [degrees]	DD_24 [degrees]	754			1.8	31.4	31.4		
DD [degrees]	DD_36 [degrees]	746			1.1	41.3	41.3		
FF [m/s]	FF [m/s]	787	9.2	8.8	−0.4	1.7	1.7	19	0.91
FF [m/s]	FF_06 [m/s]	778	9.2	8.5	−0.6	1.7	1.8	18	0.91
FF [m/s]	FF_12 [m/s]	770	9.2	8.6	−0.6	1.8	1.9	20	0.89
FF [m/s]	FF_24 [m/s]	754	9.1	8.5	−0.6	2.3	2.3	25	0.83
FF [m/s]	FF_36 [m/s]	748	9.1	8.4	−0.7	2.6	2.7	29	0.78
DIR [degrees]	DIR [degrees]	778			−2.1	31.3	31.3		
DIR [degrees]	DIR_06 [degrees]	772			−1.1	32.3	32.3		
DIR [degrees]	DIR_12 [degrees]	765			0.2	32.1	32.1		
DIR [degrees]	DIR_24 [degrees]	752			0.7	34.3	34.3		
DIR [degrees]	DIR_36 [degrees]	748			0.7	36.9	37.0		
HS [cm]	HS [cm]	789	161.5	160.1	−1.4	37.5	37.6	23	0.93
HS [cm]	HS_06 [cm]	780	161.5	152.7	−8.8	34.9	36.0	22	0.93
HS [cm]	HS_12 [cm]	772	161.2	153.9	−7.3	36.4	37.1	23	0.93
HS [cm]	HS_24 [cm]	756	159.7	152.8	−6.9	45.8	46.3	29	0.88
HS [cm]	HS_36 [cm]	750	158.9	151.4	−7.4	50.6	51.2	32	0.85
HS10 [cm]	HS10 [cm]	369	37.4	39.0	1.6	29.1	29.1	78	0.78
HS10 [cm]	HS10_06 [cm]	359	38.1	35.6	−2.5	25.1	25.2	66	0.81
HS10 [cm]	HS10_12 [cm]	345	38.9	36.7	−2.2	27.0	27.1	69	0.81
HS10 [cm]	HS10_24 [cm]	327	38.9	36.2	−2.7	26.7	26.9	69	0.82
HS10 [cm]	HS10_36 [cm]	320	38.9	35.9	−3.0	27.6	27.7	71	0.78
TM0−1 [s]	TM0−1 [s]	789	5.6	5.3	−0.2	0.6	0.6	10	0.85
TM0−1 [s]	TM0−1_06[s]	780	5.5	5.3	−0.3	0.6	0.6	10	0.84
TM0−1 [s]	TM0−1_12[s]	772	5.5	5.3	−0.3	0.6	0.6	10	0.84
TM0−1 [s]	TM0−1_24[s]	756	5.5	5.3	−0.3	0.6	0.7	11	0.81
TM0−1 [s]	TM0−1_36[s]	750	5.5	5.3	−0.2	0.7	0.7	12	0.78

Table 4 Statistics for EPF October 1994 - April 1995

		Oct '94	Nov '94	Dec '94	Jan '95	Feb '95	Mar '95	Apr '95
AUK(H_S)	SD(00)	40.0	34.2	46.5	57.5	52.6	39.7	49.5
	SD(12)	44.3	36.5	45.1	65.4	66.2	44.6	51.6
	BIAS(00)	-10.0	17.7	-21.2	-44.2	-22.0	-33.1	-33.0
	BIAS(12)	-4.1	17.7	-13.6	-34.1	-22.4	-33.1	-29.4
K13(H_S)	SD(00)	35.4	32.1	36.7	61.4	41.7	48.2	37.2
	SD(12)	46.7	35.4	43.9	66.4	53.9	53.1	40.7
	BIAS(00)	2.2	15.0	7.3	6.4	16.4	14.9	2.9
	BIAS(12)	20.2	19.8	10.4	9.8	22.1	20.9	4.5
EPF(H_S)	SD(00)	27.3	31.1	38.6	49.1	37.8	44.3	25.6
	SD(12)	29.2	27.1	38.0	47.7	37.6	39.1	25.4
	BIAS(00)	-3.7	5.1	-7.9	-6.8	4.7	0.1	-1.4
	BIAS(12)	-2.3	1.6	-18.3	-10.5	-6.4	-13.1	-1.4

Table 5 SD and BIAS (00, +12) per month, for H_S in cm. Small print when number of useful obs. < 80% of the max. possible number.

		Oct '94	Nov '94	Dec '94	Jan '95	Feb '95	Mar '95	Apr '95
AUK(FF)	SD(00)	1.4	1.5	1.6	1.8	2.0	2.0	1.7
	SD(12)	1.5	1.8	1.6	2.2	2.2	1.9	1.5
	BIAS(00)	-0.1	0.3	0.0	0.1	0.2	0.7	-0.6
	BIAS(12)	0.0	0.3	0.2	0.5	0.0	0.7	-0.4
K13(FF)	SD(00)	1.6	1.8	1.7	1.7	1.4	2.2	1.6
	SD(12)	1.9	2.3	1.9	1.8	2.0	2.3	1.8
	BIAS(00)	1.2	1.0	1.0	0.8	0.8	1.1	0.4
	BIAS(12)	1.8	1.1	1.2	0.9	1.0	1.6	0.6
EPF(FF)	SD(00)	1.6	1.4	1.8	1.8	1.8	2.0	1.4
	SD(12)	1.5	1.5	2.2	2.0	1.7	1.9	1.6
	BIAS(00)	-0.4	-0.2	-0.6	-0.7	-0.3	-0.1	-0.4
	BIAS(12)	-0.3	-0.2	-0.9	-1.0	-0.8	-0.6	-0.3
AUK($T_{M0,-1}$)	SD(00)	0.8	0.6	0.5	0.6	0.6	0.5	0.8
	SD(12)	0.9	0.6	0.6	0.7	0.6	0.5	0.7
	BIAS(00)	-0.7	-1.0	-0.8	-0.7	-0.5	-0.9	-0.7
	BIAS(12)	-0.7	-1.0	-0.8	-0.7	-0.5	-0.8	-0.7
K13($T_{M0,-1}$)	SD(00)	0.8	1.0	0.5	0.8	0.7	0.7	0.7
	SD(12)	0.9	1.0	0.5	0.8	0.7	0.7	0.8
	BIAS(00)	-0.7	-0.6	-0.4	-0.5	-0.4	-0.4	-0.8
	BIAS(12)	-0.6	-0.6	-0.4	-0.5	-0.3	-0.4	-0.8
EPF($T_{M0,-1}$)	SD(00)	0.6	0.5	0.5	0.6	0.5	0.5	0.6
	SD(12)	0.7	0.6	0.5	0.5	0.5	0.5	0.6
	BIAS(00)	-0.2	-0.1	-0.2	-0.3	-0.2	-0.2	-0.3
	BIAS(12)	-0.2	-0.1	-0.3	-0.3	-0.2	-0.3	-0.3

Table 6 SD and BIAS (00, +12) per month, for *FF* in m/s and for $T_{M0,-1}$ in s. Small print when number of useful obs. < 80% of the max. possible number.

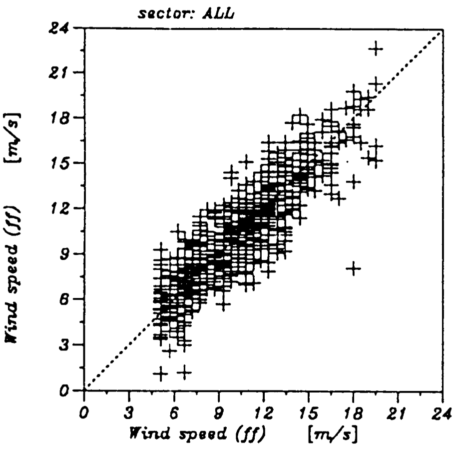
b. Scatter diagrams

In this part the model output and the actual observations are displayed in so-called scatter diagrams (or x-y plots / scatter plots). Together with each diagram a small summary of the relevant statistical parameters and their values is given. The formulas used to obtain these results are shown in chapter 2 and 4.a.

To get a result that is not biased too much, wind speed ≤ 5 m/s were excluded from the set of observations in this part. Due this restriction for the wind speed the values of the statistical parameters is not always the same as displayed in the tables (see chapter 4.a.).

KNMI Royal Netherlands Meteorological Institute

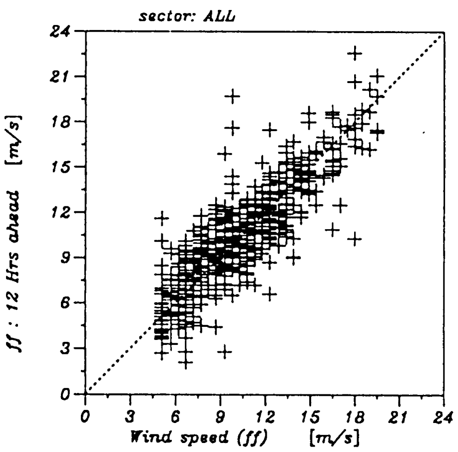
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [011] AUK



$\bar{x}$	10.3
$\bar{y}$	10.3
σ_d	1.7
RMS	1.7
BIAS	0.0
SI (%)	17
R	0.87
N	577

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [011] AUK

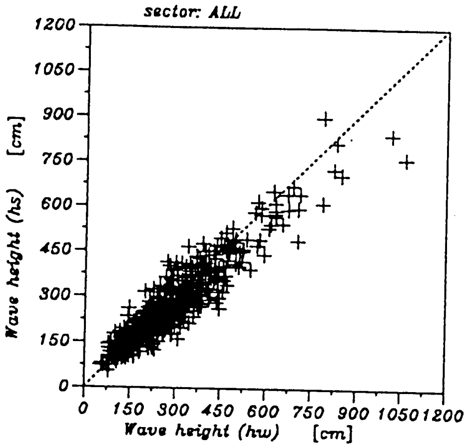


$\bar{x}$	10.3
$\bar{y}$	10.5
σ_d	1.8
RMS	1.9
BIAS	0.1
SI (%)	18
R	0.85
N	569

Figure 25 AUK *FF* +00, +12

KNMI Royal Netherlands Meteorological Institute

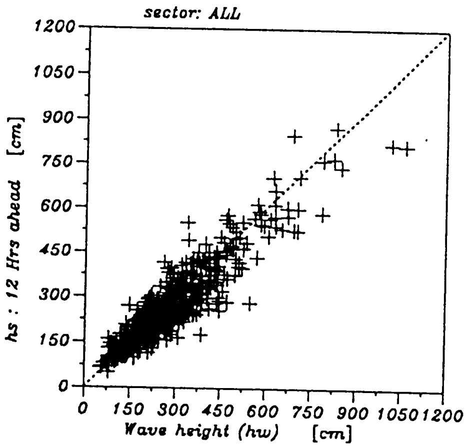
SCATTER PLOTS: X: clc Y: wam PERIOD: 94100100–95043018 6 AREA: [011] AUK



$\bar{x}$	281.4
$\bar{y}$	263.2
σ_d	51.7
RMS	54.8
BIAS	−18.2
SI (%)	18
R	0.93
N	579

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: clc Y: wam PERIOD: 94100100–95043018 6 AREA: [011] AUK

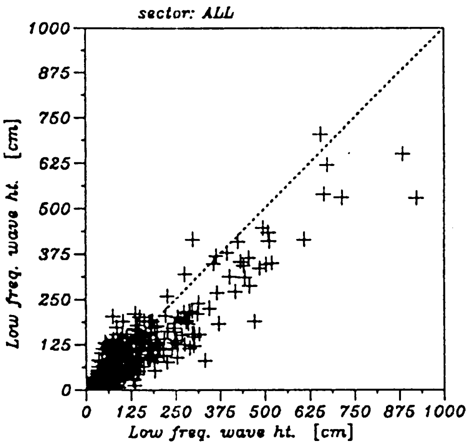


$\bar{x}$	283.8
$\bar{y}$	269.5
σ_d	56.9
RMS	58.7
BIAS	−14.3
SI (%)	20
R	0.92
N	571

Figure 26 AUK H_S +00, +12

KNMI Royal Netherlands Meteorological Institute

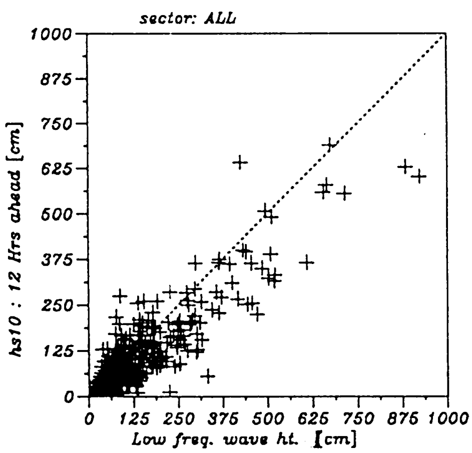
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [011] AUK



$\bar{x}$	109.9
$\bar{y}$	79.5
σ_d	48.8
RMS	57.5
BIAS	-30.4
SI (%)	44
R	0.91
N	579

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [011] AUK

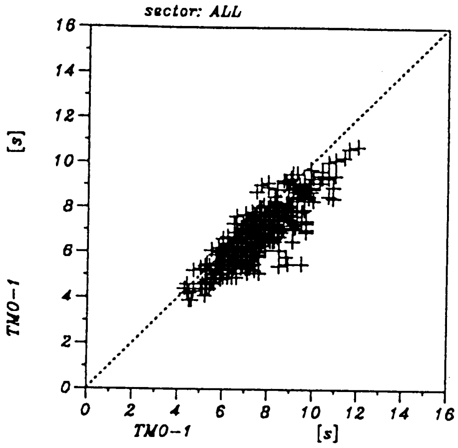


$\bar{x}$	111.8
$\bar{y}$	84.3
σ_d	52.5
RMS	59.2
BIAS	-27.4
SI (%)	47
R	0.90
N	571

Figure 27 AUK $H_{S,10}$ +00, +12

KNMI Royal Netherlands Meteorological Institute

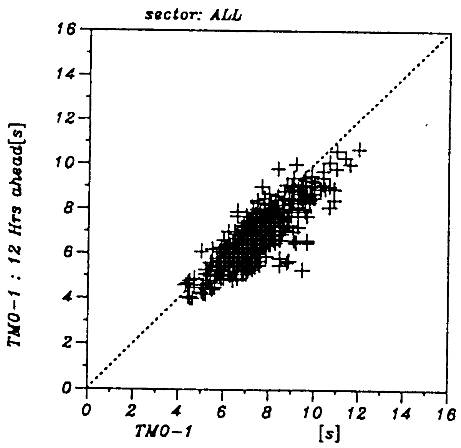
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [011] AUK



$\bar{x}$	7.4
$\bar{y}$	6.6
σ_d	0.6
RMS	1.0
BIAS	−0.7
SI (%)	9
R	0.85
N	579

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [011] AUK

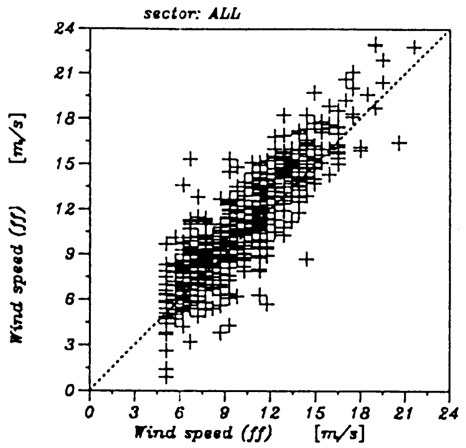


$\bar{x}$	7.4
$\bar{y}$	6.7
σ_d	0.7
RMS	1.0
BIAS	−0.7
SI (%)	9
R	0.84
N	571

Figure 28 AUK $T_{M0,-1}$ +00, +12

KNMI Royal Netherlands Meteorological Institute

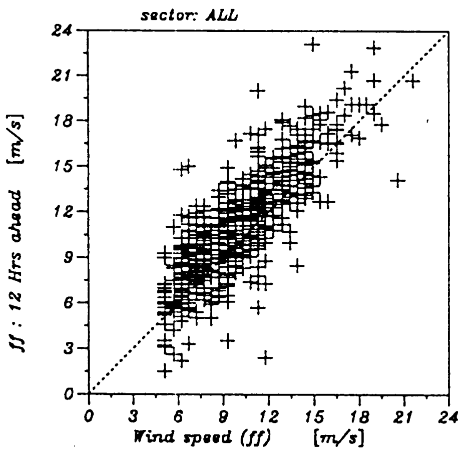
SCATTER PLOTS: X: clc Y: wam PERIOD: 94100100–95043018 6 AREA: [080] K13



$\bar{x}$	10.1
$\bar{y}$	10.9
σ_d	1.8
RMS	1.9
BIAS	0.8
SI (%)	17
R	0.88
N	609

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: clc Y: wam PERIOD: 94100100–95043018 6 AREA: [080] K13

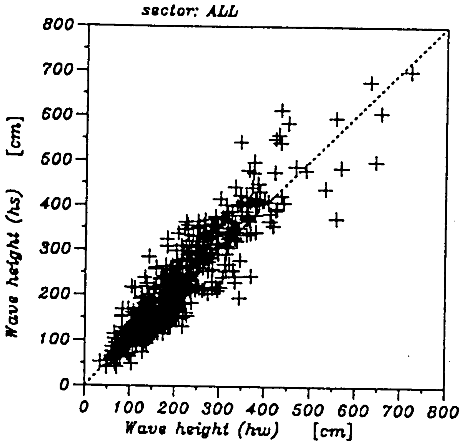


$\bar{x}$	10.1
$\bar{y}$	11.3
σ_d	2.1
RMS	2.4
BIAS	1.1
SI (%)	21
R	0.82
N	593

Figure 29 K13 *FF* +00, +12

KNMI Royal Netherlands Meteorological Institute

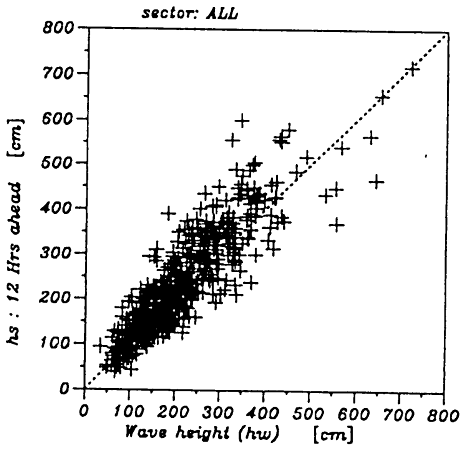
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [080] K13



$\bar{x}$	209.6
$\bar{y}$	222.9
σ_d	45.6
RMS	47.5
BIAS	13.3
SI (%)	22
R	0.91
N	610

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [080] K13

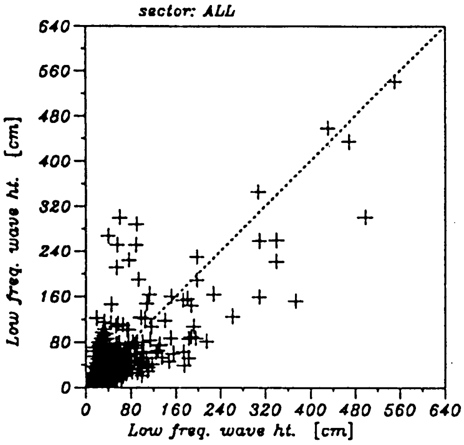


$\bar{x}$	210.7
$\bar{y}$	230.5
σ_d	53.1
RMS	56.7
BIAS	19.8
SI (%)	25
R	0.88
N	594

Figure 30 K13 H_S +00, +12

KNMI Royal Netherlands Meteorological Institute

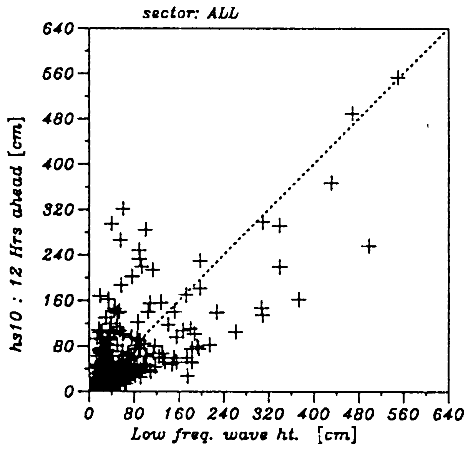
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [080] K13



$\bar{x}$	46.1
$\bar{y}$	35.9
σ_d	37.4
RMS	38.8
BIAS	-10.2
SI (%)	81
R	0.79
N	610

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [080] K13

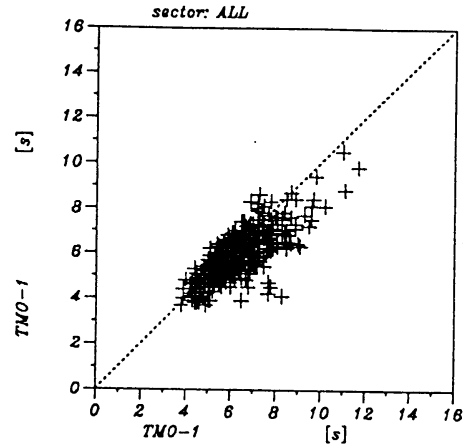


$\bar{x}$	46.4
$\bar{y}$	37.4
σ_d	42.7
RMS	43.6
BIAS	-9.0
SI (%)	92
R	0.73
N	594

Figure 31 K13 $H_{S,10}$ +00, +12

KNMI Royal Netherlands Meteorological Institute

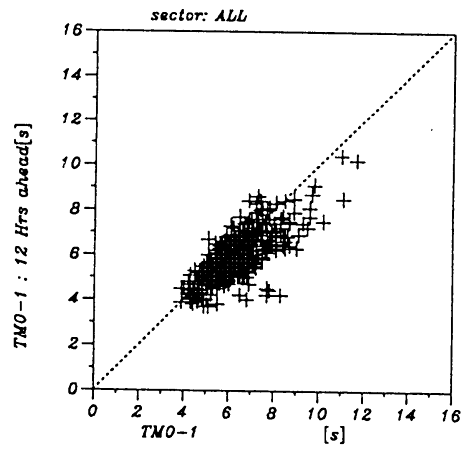
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [080] K13



$\bar{x}$	6.2
$\bar{y}$	5.8
σ_d	0.7
RMS	0.8
BIAS	-0.4
SI (%)	11
R	0.78
N	610

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [080] K13

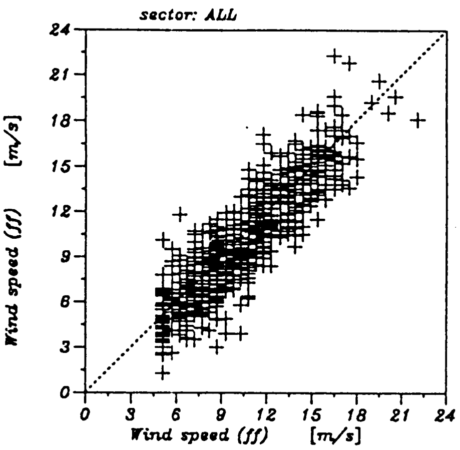


$\bar{x}$	6.2
$\bar{y}$	5.8
σ_d	0.7
RMS	0.8
BIAS	-0.4
SI (%)	12
R	0.76
N	594

Figure 32 K13 $T_{M0,-1}$ +00, +12

KNMI Royal Netherlands Meteorological Institute

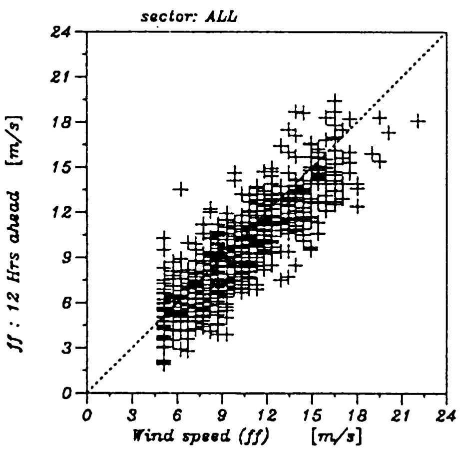
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [097] EURO PLATFORM



$\bar{x}$	10.2
$\bar{y}$	9.7
σ_d	1.7
RMS	1.8
BIAS	-0.6
SI (%)	17
R	0.89
N	665

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100-95043018 6 AREA: [097] EURO PLATFORM

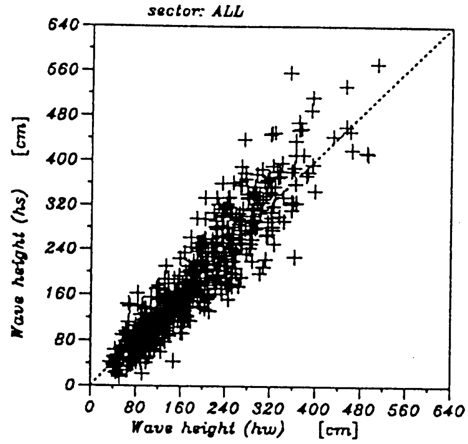


$\bar{x}$	10.2
$\bar{y}$	9.5
σ_d	1.8
RMS	2.0
BIAS	-0.7
SI (%)	18
R	0.85
N	652

Figure 33 EPF *FF* +00, +12

KNMI Royal Netherlands Meteorological Institute

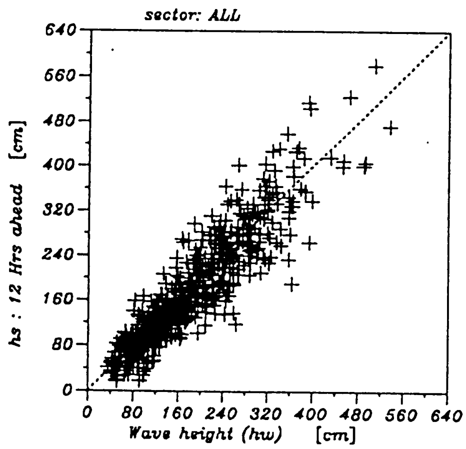
SCATTER PLOTS: X: clc Y: wam PERIOD: 94100100-95043018 6 AREA: [097] EURO PLATFORM



$\bar{x}$	177.3
$\bar{y}$	177.3
σ_d	40.1
RMS	40.1
BIAS	-0.1
SI (%)	23
R	0.92
N	665

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: clc Y: wam PERIOD: 94100100-95043018 6 AREA: [097] EURO PLATFORM

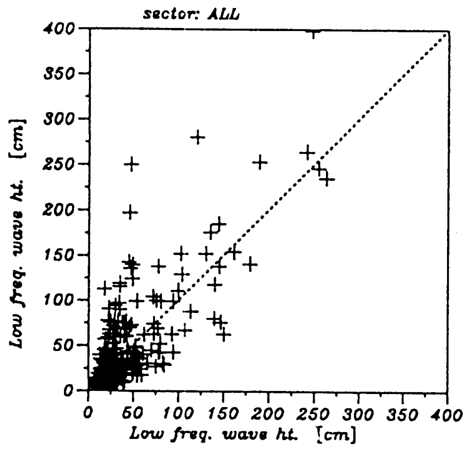


$\bar{x}$	176.9
$\bar{y}$	169.6
σ_d	38.9
RMS	39.6
BIAS	-7.3
SI (%)	22
R	0.91
N	652

Figure 34 EPF H_S +00, +12

KNMI Royal Netherlands Meteorological Institute

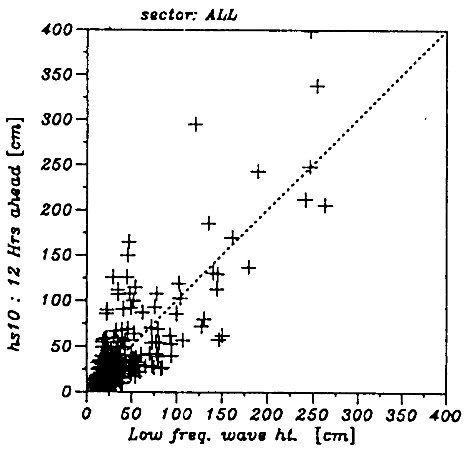
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [097] EURO PLATFORM



$\bar{x}$	26.1
$\bar{y}$	21.9
σ_d	22.4
RMS	22.7
BIAS	-3.2
SI (%)	89
R	0.82
N	665

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [097] EURO PLATFORM

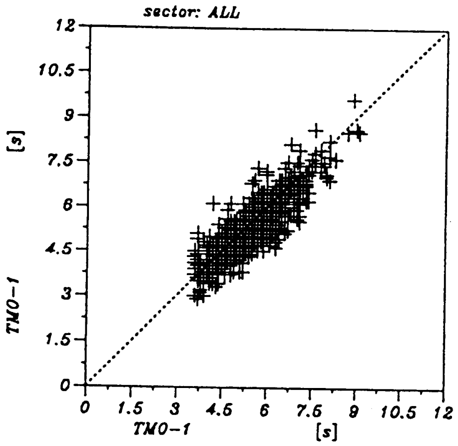


$\bar{x}$	25.3
$\bar{y}$	19.9
σ_d	20.0
RMS	20.8
BIAS	-6.4
SI (%)	79
R	0.84
N	652

Figure 35 EPF $H_{S,10}$ +00, +12

KNMI Royal Netherlands Meteorological Institute

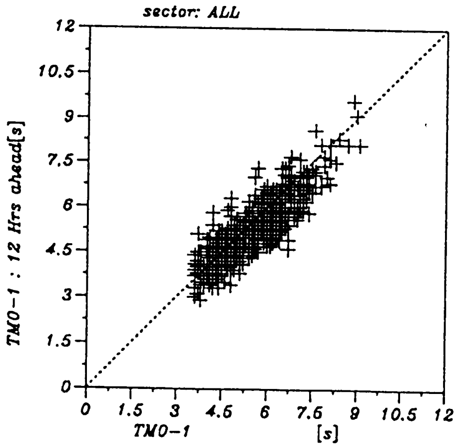
SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [097] EURO PLATFORM



$\bar{x}$	6.5
$\bar{y}$	6.3
σ_d	0.5
RMS	0.6
BIAS	−0.2
SI (%)	10
R	0.86
N	665

KNMI Royal Netherlands Meteorological Institute

SCATTER PLOTS: X: cic Y: wam PERIOD: 94100100–95043018 6 AREA: [097] EURO PLATFORM



$\bar{x}$	6.5
$\bar{y}$	6.3
σ_d	0.5
RMS	0.6
BIAS	−0.3
SI (%)	10
R	0.85
N	652

Figure 36 EPF $T_{M0,-1}$ +00, +12

4. Special cases

In this chapter some special cases are described. We can separate special cases in severe weather (wind speed ≥ 19.3m/s) and in extreme deviations (≥ 3 x standard deviation) between the observations and the model. In chapter 5.a a brief summary is given of some storms during the period between October 1994 and April 1995. In chapter 5.b some extreme differences between the observations and the model are described.

a. Storms

Storms is just a phrase to capture all winds speeds ≥ 19.3m/s. In fact this contains strong gale, storm, violent storm and hurricane. The value of 19.3m/s is used as the lower limit, which corresponds with the lower boundary of strong gale, 9 Beaufort in the scientific Beaufortscale, proposed by the Commission of Maritime Meteorology of WMO (CMM-IV scale), taken from WMO (1970).

In this section several days are considered. During these days the observed wind speed reached at least 9 Beaufort.

8 DECEMBER 1994
A deep low (< 950 hPa) over Iceland, a low (980 hPa) southwest of Ireland and high pressure over central Europe was the cause of an strong, initially southwesterly flow over the North Sea. The low near Ireland passed the North Sea during this day and arrived in the Norwegian Sea at midnight. The accompanying passage of the frontal system caused a short windshift to southerly directions and back to southwest.

AUK: The *FF*, H_S and $T_{m0,-1}$ were performing well. The $H_{S,10}$, with a peak at 445cm (observed at 12:00), was underestimated and too late by the +12 forecast (375cm at 18:00) and too late by the +24 forecast (445cm at 18:00) as well.

K13: The observed *FF* was at its highest at 09:00 and 12:00 with values around 19.5m/s. The increase in *FF* was expected sooner but the peak was good (18.4m/s at 06:00) in the +12 forecast but too high (24.8m/s at 12:00) in the +24 forecast. The decreasing of the *FF* was expected sooner in the +12 forecast.
The observed H_S peaked at 556cm (12:00). The H_S started to increase too early in the model. The +12 forecast peak was too low (448cm at 12:00) and the +24 forecasted peak was too high (662cm at 12:00).
The observed $H_{S,10}$ had a peak of 308cm (12:00). This was not picked up very good in the forecasts (147cm in the +12 and 363cm in the +24 forecast).
The $T_{m0,-1}$ of the model was following the reality well.

EPF: The peak of the observations of *FF* was at 09:00 (20.6m/s). The increase in *FF* was set in too late. The +12 forecast gave a peak of 17.3m/s and the +24 forecast one of 18.3m/s, both at 12:00. The decrease in *FF*, shown by the model, was again too late compared with the observations.
The H_S showed the same characteristics as the *FF*. The peaks were nearly the same height, but both the increase and the decrease in the forecasted H_S set in too late. The $H_{S,10}$ was not very high, therefore the difference is not really meaningful. The $T_{m0,-1}$ in both the observations and the model were of similar accuracy.

1-2 JANUARY 1995

On 1 and 2 January 1995 a low over Scandinavia-Baltic and an area with high pressure over the North Atlantic caused a strong north to northwesterly flow across the North Sea.

AUK: The *FF* was well represented by the model.
The observed H_S had a maximum (1052cm at 15:00) and was not represented that high in both the +12 forecast (872cm at 12:00) and the +24 forecast (717cm at 12:00). A second observed peak (1022cm at 21:00) again was estimated too low in the +12 forecast (817cm at 00:00 on 2 January) and in the +24 forecast (802cm at 06:00 on 2 January).
The first observed peak of $H_{S,10}$ was 917cm (at 15:00). The forecasted $H_{S,10}$ started off too low. The +12 forecast gave the first peak of 690cm at 12:00, while the +24 forecast did not show a peak around this time at all. The second observed peak was 935cm at 21:00. The +12 forecast showed the second peak of 629cm (at 00:00 on 2 January) and the +24 forecast gave a corresponding peak of 618cm at 06:00 on 2 January.
During the two days of this storm the $T_{m0,-1}$ was approximately 1.5s too low.

K13: During these two days the *FF* of the model appeared to be on the high side. In the time series (see fig. 14) you can observe that the observations did not get higher than 18.0m/s, while the model's analysis (Δ) had a peak of 21.9m/s. On the other hand the forecasted H_S, $H_{S,10}$ and $T_{m0,-1}$ showed the increase in wave height on the right time. The decrease of the values of these three parameters after the peak however, was forecasted 6-9 hours too early by the model.

EPF: The *FF* was forecasted rather well by the model. It had peaks at approximately the same times and heights.
The observed H_S and the $H_{S,10}$ developed slower than forecasted. A peak of 509cm in the observations was 580cm in the +12 forecasted H_S at 06:00 (on 2 January). The decrease in H_S set in 3-6 hours too early by the model.
For the $H_{S,10}$ the highest value in the observations was 303cm on 1 January at 21:00. The +12 forecasted $H_{S,10}$ showed 338cm and the +24 forecast 405cm, both at 00:00 (on 2 January). At 06:00 the +12 and +24 forecasts of $H_{S,10}$ showed 399cm. The observations already were back to 248cm. From this time the decrease of the $H_{S,10}$ was set in by the model, while the observations did not decrease until 12:00.

9-12 JANUARY 1995

An area with high pressure (± 1045 hPa) near the Azores was steady during the whole period. A low (985 hPa) near the Norwegian coast developed quickly and moved in southeasterly direction. Wind speeds in the North Sea region increased rapidly resulting in a strong north to northwesterly flow.

AUK: The peak in both the observed *FF* and the model's *FF* was at the same height and nearly at the same time. The increase and decrease of the *FF* of the model was forecasted too early.
The actual peak height of the H_S (1064cm at 00:00 on 10 January) was not reached by the model. The +12 forecasted H_S came closest with 813cm.
The peak of the observed $H_{S,10}$ was at the same time (923cm). Again the model was too low with 602cm in the +12 forecast and 483cm in the +24 forecast.
The sudden increase (from 8.5s to 11s) in the $T_{m0,-1}$ was not forecasted properly by the model. The model also was too low.

K13: The peak in the observed *FF* was at 00:00 on 10 January and reached 19.4m/s. At the same time the +24 forecast showed a peak at approximately the same height. The +12 forecast gave 19.9m/s, but 6 hours later. The increase of the *FF* was forecasted too early. The decrease in *FF* was somewhat later in the model compared to the observations.
Unfortunately no wave observations of K13 were available for this period.

EPF: The *FF* was forecasted rather well. The peak in the model was a bit lower than in reality.
The observed H_S had a peak of 392cm while the +12 forecast was 514cm and the +24 forecast was 430cm.
The observed $H_{S,10}$ showed a height of 148cm, while the +12 forecast gave 295cm and the +24 forecast 187cm. Both the H_S and the $H_{S,10}$ decreased too soon and too much. A second peak on 12 January was not picked up properly by the model. Observed H_S gave 558cm, the +12 forecast gave 472cm and the +24 forecast showed 435cm. The $H_{S,10}$ was observed to be 353cm, but the +12 forecast was 100cm lower.

17-23 JANUARY 1995

During this whole period a low (minimum pressure 950 hPa) was moving very slowly from Iceland towards the North Sea. On some days it formed a larger area with low pressure together with a second low near the British Islands. In the same period an area with high pressure (maximum pressure 1045 hPa) was located over Russia. This situation was the cause of a strong, mainly southerly flow over the North Sea.

AUK: The first peak in the observed *FF* reached 20.1m/s at 21:00 on the 17th. The +12 and +24 forecast had their peaks at 00:00 (on the 18th) with respectively 18.8m/s and 20.5m/s.

The peak in the observed H_S was 712cm at 00:00 on the 18th. The +12 and the +24 forecasts showed 706cm and 737cm at the same time. Also the observed, as well as the forecasted $H_{S,10}$ had a peak at that same time. The observed $H_{S,10}$ reached 512cm, while the +12 and +24 forecasts showed 491cm and 518cm respectively. The observed and forecasted $T_{mO,-1}$ matched well during this event.

A second peak in de observed *FF* reached 20.6m/s at 21:00 on the 19th. Unfortunately there were no observations available at 00:00 and 06:00 of the 20th. The model's +12 forecast showed 18.5m/s at 00:00 on the 20th, while the +24 forecast gave 24.8m/s at 06:00 on the 20th. The observed H_S had a peak of 706cm at 00:00 on the 20th. The +12 forecast gave a peak of 599cm at the same time, but the +24 forecast showed 1051cm six hours later.

Together with the H_S the $H_{S,10}$ also showed a peak at 00:00 on the 20th. The observed $H_{S,10}$ showed 486cm while the +12 forecast showed 351cm at this time. The +24 forecast showed 869cm at 06:00.

A third peak of strong gale force (19.5m/s) was observed at 18:00 on January 21st. Both the +12 and the +24 forecasts showed the peak at the same time and with almost the same value.

The observed H_S had a peak of 688cm at 06:00 on the 22nd. The +12 outlook was forecasted at the right time, but too high with 847cm. The peak in the +24 forecast was predicted six hours later and with a height of 812cm.

K13: An observed peak in the *FF* at 18:00 on January 19th showed 21.1m/s. The peaks in both the +12 and the +24 forecasts were predicted at the same time and showed a height of 20.7m/s and 21.1m/s respectively. Remarkable was that on the 20th at 06:00 the observations showed only 15.4m/s (7 Beaufort), while the +12 forecast showed 23.1m/s (10 Beaufort!) on that moment. Also the observed H_S (346cm) was much lower than the +12 forecast with 600cm. Another peak in H_S was observed to be 450cm at 18:00 on the 21st. The +12 and +24 forecasts showed a peak of 580cm and 531cm respectively at the same time.

EPF: On 19 January, at 18:00 the observed *FF* had a peak of 20.1m/s. The forecasted *FF* showed a peak at the same time, but lower. The +12 and +24 forecasts showed 15.9m/s and 14.8m/s respectively. After this peak the +24 forecast decreased too soon.
A peak in the observed H_S showed 326cm at 18:00 on the 19th. The +12 and +24 forecasts did not predict this peak.
A second peak in the *FF* was reported at 18:00 on 21 January. The observations showed 19.5m/s, while the +12 forecast showed 18.3m/s and the +24 forecast gave 17.0m/s.

11-12 FEBRUARY 1995

A small area of low pressure, moving from western Scotland to Norway, had a through over the North Sea. This through influenced mainly the northern part of the North Sea.

AUK: The observed *FF* had a peak of 20.6m/s at 03:00 on February 12th. The +12 and the +24 forecasts were slightly later (at 06:00), but lower (17.5m/s and 16.8m/s respectively).
Together with this wind was an observed H_S of 705cm at 06:00, while about 524cm was forecasted in both +12 and +24 outlooks.
A peak in the observed $H_{S,10}$ of 472cm at that same time was not found that high in the forecasts. The +12 forecast showed a peak of 251cm at 12:00, while the +24 forecast showed a peak around 242cm at 06:00 and at 12:00.

16-17 FEBRUARY 1995

A small depression (995 hPa) moved quickly from southern Ireland to eastern Germany, causing a short increase in the windspeed in the southern North Sea.

EPF: A peak of 21.1m/s was observed at 00:00 on the 17th. This peak was predicted in the +12 forecast at the same time but lower (18.1m/s). The +24 forecast showed this peak at 18:00 on the 16th with 16.8m/s.
An observed peak in H_S of 493cm at 00:00 (17 February) was found back in the +12 forecast with 406cm on the same time, and in the +24 forecast at 18:00 of the 16th with 354cm.
The $H_{S,10}$ showed an explicit peak of 147cm in the observation of 00:00 of the 17th. This peak was shown in the +12 forecast of 06:00, with a height of 107cm. The +24 forecast did not show this peak at all.

3 MARCH 1995

A depression (990 hPa) moved from south of Ireland towards the North Sea. This caused a short increase in wind speed from the south west in the southern part of the North Sea.

EPF: A peak of 21.1m/s was observed at 03:00. Unfortunately, due to archiving problems, the model's forecasts valid for 00:00 and 06:00 were not retained.

b. Extreme deviations

In table 7 a summary is given of the differences of the H_S and $H_{S,10}$ for the +12 forecast for all three stations during the whole verifacation period. When the absolute difference between an observation and a model value is ≥ 3 x standard deviation (standard deviation of the whole period), I consider this difference as extreme. In former publications [5] a similar investigation was done. The differences ≥ 2 x standard deviation were referred to then as 'outlyers'. Table 7 also displays these 'outlyers'. In this section I will discuss the extreme differences between the observations and the +12 hours forecasts of H_S and $H_{S,10}$ only. To produce a number of serious occasions, an arbitrary lower boundary of 100cm for the H_S and 10cm for $H_{S,10}$ was applied.
Some of the described occasions were previously treated in chapter 4.a. In those cases only a short note is given.

Parameter	Number of Observations	Standard Deviation	Model			
			number too high		number too low	
			2xSD	3xSD	2xSD	3xSD
AUK H_S (+12)	546	58cm	6	1	23	8
K13 H_S (+12)	526	54cm	25	2	5	4
EPF H_S (+12)	528	55cm	4	3	33	1
AUK $H_{S,10}$ (+12)	395	52cm	13	14	11	2
K13 $H_{S,10}$ (+12)	460	43cm	17	4	12	5
EPF $H_{S,10}$ (+12)	305	28cm	5	2	13	5

Table 7 Summary of numbers of extreme deviations and 'outlyers' for H_S (+12) and $H_{S,10}$ (+12) (observed H_S > 100cm and observed $H_{S,10}$ > 10cm).

3 OCTOBER 1994

AUK: Remarkable in this situation was that the air temperature dropped 6-7 degrees within 30 hours. This caused an atmospheric instability. The model did not react well to this new situation. Particularly the H_S and $H_{S,10}$ were far too low, compared with the observations.

23 OCTOBER 1994

K13: The *FF* was forecasted too high for this day. This and the absence of an observation at 06:00 was the cause of a +12 forecast of H_S that was too high. Also $H_{S,10}$ was forecasted too high, but not ≥ 2 x standard deviation.

1 NOVEMBER 1994

EPF: The passage of two small disturbances across the southern part of the North Sea between 29 and 31 October was not caught very well by the model. This caused the H_S and $H_{S,10}$ to run out of range. On 1 November the differences between observed H_S and the +12 forecast were extreme.

8 DECEMBER 1994

Extremes were found in $H_{S,10}$ at AUK and K13. These are already discussed in chapter 5.a.

1-3 JANUARY 1995

A general picture was given in chapter 5.a.

AUK: Extremes were discovered in H_S and $H_{S,10}$ at AUK on 1 and 2 January. Both were forecasted too low.

K13: Also here both H_S and $H_{S,10}$ were predicted too low on January 2nd. At EPF on January 2nd the model showed a $H_{S,10}$ that was too high at first, but too low later.

10-12 JANUARY 1995

This period was already discussed in the previous chapter.

AUK: The +12 forecasts of H_S and $H_{S,10}$ both were too low on all three days.

EPF: The forecasted $H_{S,10}$ was too high on January 10th only.

20-23 JANUARY 1995

This period was already discussed in chapter 5.a.

AUK: $H_{S,10}$ was forecasted too high on January 22nd.

K13: Both H_S and $H_{S,10}$ were predicted too high on 20 January. $H_{S,10}$ was also forecasted too high on the 21st and 23rd.

26 JANUARY 1995

AUK: The $H_{S,10}$ was forecasted too low on this day. The observed wave heights were increasing but the model neglected that. Maybe the absence of an observed wind speed and direction at AUK disturbed the model slightly.

7-8 FEBRUARY 1995

AUK: A peak in the observed *FF* on February 6th was predicted too late and slightly too high. Therefore the +12 forecasts of H_S and $H_{S,10}$ were too late and too high as well. The air temperature dropped 6-7 degrees causing an instable atmosphere. Again the model's wave parameters stayed too low.

12 FEBRUARY 1995

See chapter 5.a for more details.

AUK: On this day both H_S and $H_{S,10}$ were predicted too low.

17 FEBRUARY 1995

A summary for this day is given in chapter 5.a.

EPF: The $H_{S,10}$ was forecasted too low. The sharp peak in the observed $H_{S,10}$ was predicted 6 hours too late (see fig. 22).

20-21 FEBRUARY 1995

AUK: A peak in H_S on 19 February predicted to decrease more than observed on the 20th. When the waves started to grow, again the predicted H_S was too low. On February 21st both H_S and $H_{S,10}$ were forecasted too low. The observed wave heights were already increasing while the model stayed behind.

23 FEBRUARY 1995

On 22 and 23 February a significant frontal system passed the southern North Sea, causing the wind to shift and decrease within a short period.

K13: The model's forecasted H_S and $H_{S,10}$ did not follow this change smoothly, resulting in an considerable overestimation.

26 FEBRUARY 1995

EPF: The +12 forecasted H_S was estimated too low and peaked too late.

3 MARCH 1995

EPF: The decrease of the wave height of the observed H_S was estimated too fast by the model. This resulted in un underestimation of the +12 forecasted H_S. See also the description in chapter 5.a.

5 MARCH 1995

On this day again a frontal system crossed the southern North Sea.

EPF: The accompanying incrementation of *FF*, and resulting H_S, were predicted too late and too low by the model.

18 MARCH 1995

The $H_{S,10}$ at K13 and EPF were both estimated much too high.

25 MARCH 1995

K13: Although the observed H_S increased on 24 and 25 March, the +12 forecast of this parameter started to increase approximately 6 hours earlier. The difference in height between the peaks was with 2 x standard deviation.

27 MARCH 1995

K13: The peak in the observed $H_{S,10}$ (310cm) was not forecasted that high (135cm) by the model. The only remarkable fact this day was the instable atmosphere.

5. Remarks

Since this report covers the period October 1994 - April 1995, the observant reader may have noticed that there is a gap between the last verification report [5] and this one. Although a verification report in this form is a time-consuming job, I will try to fill this gap with the two missing reports in the near future.

The following remarks are made on basis of what I encountered during the whole verification process. Some of them are personal opinions, others more common.

A. In general one of the main problems I encountered, was the high percentage of absence of observed wind data. This resulted primarily in a less accurate wind model and consequently in less accurate NEDWAM results. In the second place, the absence of wave data had, in some cases, its repercussions in the validation of NEDWAM.

One of the reasons for this low number of wind observations is the collection of data via the Message Switching System (MSS). This MSS is programmed with constrictions that are too secure sometimes. E.g. if a message with an observation has an unexpected character at the end of the message, the complete message is rejected. This results in the loss of valuable information. Occasionally up to 20% (!) of the ships' observations have been rejected by these constraints. Actions have already been taken to improve the correctness of the messages before they enter the MSS. It is very important that in the future more attention is paid to the timely availability of marine data of good quality. Programs such as TURBO-1, developed at KNMI [8], will help to improve the quality of the observations.

B. Apart from the absence of observations there is also a problem with the observed wind speeds at the stations of the Dutch North Sea Network (North Cormorant, Auk, K13, Measuring Platform Noordwijk, IJmuiden, Euro Platform, Light Platform Goeree and Hook of Holland). At these stations the wind speed was reduced with a fixed factor to the equivalent wind speed at 10 m above mean sea level (MSL). This reduction factor was established by the 'Meteorological Panel for the North Sea and Adjoining Waters' in 1977 [6]. The used reduction factors are given in table 1. It is generally known that these factors reduce the wind too much. Fortunately these factors were reviewed and changed in the summer of 1995. The verification of the next winter season (95-96) will certainly show this improvement.

C. It was remarkable this period that in unstable situations (air temperature is lower than the sea surface temperature) the model was underestimating the wave heights at AUK and K13. This divergence was less explicit at EPF.

D. The BIAS of H_S of the model acted abnormal in November 1994 at AUK and at EPF (see table 5). Normally the BIAS is negative and in November 1994 it was positive. One of the main causes is the input of HIRLAM, because the BIAS of *FF* at AUK is also showing a sudden increase this month. Due to some events that were not picked up good by the wind model, the results in NEDWAM were also biased. The resulting BIAS during the whole verification period of H_S at AUK has the same accuracy as the same parameter in the last verification report ('Winter' 1990-1991) [2, 5].

E. At K13 the BIAS of H_S was -12cm in the 'winter' 1990-1991 [2, 5]. During the verification period in the present report this BIAS was positive every month and the resulting overall BIAS was +9cm. In January the BIAS of H_S at K13 was high, compared to the other months. In some occasions the wind model was overestimating the reality, which is clearly visible in the time series (see fig. 14). Due to this overestimated wind input the wave heights are also exaggerated. These special events influence statistical values, such as the bias, very direct.
At EPF the H_S was affected by individual events with a high $H_{S,10}$. In the time series (see fig. 18-24) this is clearly discernible at occurrences such as on 14 November 1994, 8 December 1994 and 10 January 1995.

F. Overall the $H_{S,10}$ was forecasted too low at all stations, especially at AUK. Here the BIAS for the whole period was -30cm for the analysis. Compared to the 'winter' of 1990-1991 [5], with +2cm, this is a decrease in accuracy.
Evaluating the $H_{S,10}$ for a period of a month is not very reliable. The $H_{S,10}$ is usually low. A few events with higher $H_{S,10}$ cause the statistics to be amplified abnormally.

G. Also the $T_{m0,-1}$ was too low at all stations. Nevertheless the BIAS was not more than -1.0s.

6. Acknowledgements

I would like to thank Roel van Moerkerken for his determination in developing MOERAV. MOERAV produces different views of both the observed and the model's data. With MOERAV it is possible to find structural errors in the model. Before retiring, Roel was spending all (and more) of his time in finishing his MOERAV-system. This system is the foundation for future development of verifying models.

For me this was the first *magnum opus* in the field of verification. Without the comment, help, material and vision of Gerbrand Komen, Jeanette Onvlee and Evert Bouws this would be a much more difficult task. I would like to thank them for what they did. Also thanks to Toon Moene, who supplied figure 3, the HIRLAM grid.

7. References

[1] WAMDI Group: S. Hasselman, K. Hasselman, E. Bauer, P.A.E.M. Janssen, G.J. Komen, L. Bertotti, P. Lionello, A. Guillaume, V.C. Cardone, J.A. Greenwood, M. Reistad, L. Zambresky and J.A. Ewing, 1988. The WAM model - A third generation ocean wave model. *J. Phys. Oceanogr.* **18**, 1775-1810.

[2] Komen, G.J., L. Cavaleri, K. Hasselman, S. Hasselman, P.A.E.M. Janssen, 1994. Dynamics and Modelling of Ocean Waves; University Press, Cambridge, 532p,

[3] Burgers, G., 1990. A guide to the Nedwam wave model. KNMI scientific report, WR-90-04, De Bilt, 81p.

[4] Gustafsson, N., (ed.), 1993. HIRLAM 2 Final Report; Technical Report No. 9., SMHI, Norrköping.

[5] Moerkerken, R.A. van, 1991. LAM and NEDWAM statistics over the period October 1990 - April 1991. KNMI technical report TR-137, De Bilt.

[6] Report of the first meeting Meteorological Panel for the North Sea and Adjoining Waters, De Bilt 20-22 September 1977.

[7] Moene, A.R., 1994. HIRLAM Documentatie (unpubl. manuscript).

[8] Stam, M., 1995. Turbo Observations with New Efficiency, Manual for the use of Turbo1 , Version 3.x